Tennessee Water Resources Research Center

Annual Technical Report

FY 2000

Introduction

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Water Resources Issues and Problems of Tennessee

Tennessee is fortunate to have what many consider to be an abundant and good quality water supply. Historically, federal government agencies, such as the Tennessee Valley Authority (TVA), Corps of Engineers, Soil Conservation Service, U.S. Geological Survey and others, have been the primary contributors to the management and monitoring of water resources. In recent years, however, the State, through the Tennessee departments of Environment and Conservation, Wildlife Resources, Agriculture and others, have @begun to develop a more active and aggressive role in the management and protection of these resources. The State has moved to establish an integrated and coordinated policy and administrative system for the management of water resources in Tennessee.

While the situation is improving, there remain many of the additional types of water problems. Although the overall supply of water is adequate, the distribution is still not optimal. Local shortages occur during dry periods. The summer of 1980 was a particularly hot and dry one. During this period over 35 water districts out of a total of 671 public systems in Tennessee experienced lesser degrees of difficulty in supply water. The situation continued to worsen in the late 1980's. Beginning in 1985 and continuing on through the summer of 1988, Tennessee experienced another major drought period which severely strained the water supplies of many communities across the state. In recent years, many of the small municipal water suppliers and utility districts that rely on wells, springs, or minor tributaries for their water sources continue to face severe water shortage problems. All across the state many private, domestic, and commercial use wells have become severely strained, forcing users to seek alternative sources of water. Providing an adequate supply of water for industrial, commercial, and domestic uses and the protection of these surface and groundwater resources are of major concern in all regions of the state and vital to the economic development and growth of the state.

Groundwater presents a particular challenge in Tennessee. Over 50% of the population of Tennessee depends on groundwater for drinking water supply. In West Tennessee, nearly all public suppliers, industries, and rural residents use groundwater. However, not enough is known about the quality and quantity of groundwater in the state, and consequently, maximum benefit from and protection of this resource cannot be easily accomplished. More information about the quality of the state's groundwater, particularly about the potential impact of recharge areas, is needed in order to develop an effective management and protection program for this valuable resource.

There is also the problem of potential contamination of groundwater from agricultural and urban non-point sources. The "fate and transport" of agricultural chemicals (herbicides and pesticides) and toxic substances in groundwater is a problem area that must be addressed if the state's groundwater protection strategy is to be effective in protecting this vital resource.

Although the danger of large-scale, main-stem flooding is controlled by mainstream and tributary dams that have been constructed by TVA and the Army Corps of Engineers, localized flooding and even general flooding in unregulated watersheds remain substantial problems across the state. A lack of effective local floodplain management land-use controls is apparent in West Tennessee, where related problems of excessive erosion, sedimentation, drainage, and the loss of wetlands constitutes what many consider to be the greatest single water resource issue in the state from an economic and environmental point of view. Effective regulation of private levee design, construction, maintenance, and safety is needed.

Water quality problems continue to persist from past industrial practices, from the surface mining of coal and other minerals (especially from abandoned mines), from agricultural and urban nonpoint sources and from improperly planned, designed and operated waste disposal sites. As has been the situation in the past, the state program for the construction of municipal wastewater treatment facilities and improved operation and management of the facilities have experienced numerous set-backs due to shortfalls in funding and administrative delays. In major urban areas that have combined storm and sanitary sewers, urban storm water runoff causes increased pollution and, during periods of wet weather, bypasses treatment facilities, which allows raw sewage to enter receiving waters untreated. Tennessee cities, both large and small, are concerned about current (and future) impacts of the new NPDES storm water discharge permit requirements on clean up needs and costs. In certain regions of the state, failing septic fields and the practice of blasting bedrock for new septic fields are serious threats to surface and groundwater resources.

There are existing programs which can address many of these problems. However, some problems do not have easy solutions. Additional research can also play a role in understanding and solving these problems, but the greatest impediments are the lack of agreement between competing interests and a shortage of financial support for existing programs. From the viewpoint of the State government, the legal, institutional, and administrative aspects of water management are major concerns. The state is still working to develop new policy and to refine administrative structure for the effective management of its water resources.

To address the problems and issues of effective water resources management in the state of Tennessee, a truly interdisciplinary and well-coordinated effort is necessary. The Tennes5ee Water Resources Research Center has the capability and organization that can call upon the diverse set of disciplinary expertise necessary to address the key water issues of the state and region.

The Tennessee Water Resources Research Center: Overview of Program Objectives and Goals:

The Tennessee Water Resources Research Center serves as a link between the academic community and water-related organizations and people in federal and state government and in the private sector, for purpose of mobilizing university research expertise in identifying and addressing high-priority water problems and issues and in each of the respective state regions.

The Tennessee Water Resources Research Center, located at the University of Tennessee, is a federally-designated state research institute. It is supported in part by the U.S. Geological Survey of the U.S. Department of Interior under the provisions of the Water Resources Research Act of 1984, as amended by P.L. 101-397 and 10 I - 1 47. The Act states that each institute shall:

1. plan, conduct or otherwise arrange for competent research that fosters the entry of new research scientists into the water resources fields; the training and education of future water scientists, engineers and technicians; the preliminary exploration of new ideas that address water problems or expand understanding of water and water-related phenomena, and the dissemination of research results of water managers and the public.

2. cooperate closely with other colleges and universities in the state that have demonstrated capabilities for research, information dissemination, and graduate training, in order to develop a statewide program designed to resolve state and regional water and related land problems.

In supporting the federal institute mandate, the TWRRC is committed to emphasizing these major goals:

1. To assist and support all the academic institutions of the state, public and private, in pursuing water resources research programs for addressing problem areas of concern to the state and region.

2. To provide information dissemination and technology transfer services to state and local governmental bodies, academic institutions, professional groups, businesses and industries, environmental organizations and others, including the general public, who have an interest in water resources matters.

3. To promote professional training and education in fields relating to water resources and to encourage the entry of promising students into careers in these fields.

4. To represent Tennessee in the Universities Council on Water Resources, the American Water Resources Association (including Tennessee Section), the Ohio River Basin Consortium for Research and Education, the Clinch-Powell River Basin Consortia, the South Atlantic-Gulf regional grouping of state water resources research institutes, the ORNL-TVA-UT Research Consortium and the National Institutes for Water Resources (NIWR) Directors. To work with these and other associations and with state, local and federal government agencies dealing with watt resources in identifying problems amenable to a research approach and in developing coherent programs to address them. Particularly, to cooperate with the other state institutes and their regional groupings for assisting the U.S. Geological Survey in developing a national water resources strategy.

In fulfilling the Center’s major goals indicated previously, TWRRC emphasizes the application of Section 104 grant and required matching funds for primarily supporting the research and training/education needs of the state. While the information dissemination and technology transfer portion of the Center’s overall program does not receive direct or significant section 104 funding, this is accomplished primarily from the research and training activities of the Center from other funding sources--state, private, or non-profit. The Center recognizes that education and training, research, and information transfer are not independent objectives or are not mutually exclusive. Instead these goals are achieved through the administration of a coordinated, fully- integrated program within the limitations of the resources available to the Center.

Research Program

Basic Information

Title:	An Investigation to Identify Sources and Quantities of Modern Recharge to the Memphis Aquifer in the Sheahan Well Field in Shelby County, Tennessee
Project Number:	B-03
Start Date:	3/1/2000
End Date:	2/28/2001
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Hydrology, Non Point Pollution
Descriptors:	groundwater hydrology, groundwater movement, age dating, groundwater recharge, groundwater modeling, groundwater quality
Lead Institute:	The University of Memphis
Principal Investigators:	Randall Wilson Gentry, James Harris, Kip Solomon, Daniel Larsen, Jerry Anderson

Publication

1. Larsen, D., R. W. Gentry, B. Waldron, S. Ivey, S. Hudgins and M. Salyers, 2000. Variations in Water Quality and Tritium in the Sheahan and Morton Well Fields in Memphis, Tennessee, 11th Tennessee Water Resources Symposium, Nashville, TN. April 4-6, 2001.
2. Larsen, D., R. W. Gentry, and S. Ivey, 2000. Water Quality Impact A Distribution of Modern Recharge on Municipal Pumpage in the Sheahan Well Field, Memphis, Tennessee. GSA December, 2000.
3. Gentry, R.W. 2000. The Use of Environmental Tracers to Better Understand Inter-aquifer Hydraulics in Shelby County, Tennessee,AwwaRF Technology Transfer Conference, Miami, Fl. January 25, 2001.
4. Gentry, R.W. 2000. Current Research to Better Understand the Flow Dyamics of the Memphis Aquifer. MLGW Vice-Presidents and Mangers Meeting, April 23, 2001, Memphis, Tennessee.

1. **<u>Problem and Research Objectives:</u>**

The Memphis aquifer is part of the much larger Northern Mississippi Embayment aquifer system composed of tertiary and cretaceous-age unconsolidated sand aquifers alternating with sand, silt, and clay confining units (Grubb and Carillo, 1988), see ***Figure 1***. The Memphis aquifer is utilized as the primary drinking water source in the Memphis area and in practically all smaller urban areas in western Tennessee. ***Figure 2*** shows the distribution of production wellfields within Shelby County, Tennessee. The clay layers within the overlying upper Claiborne confining unit are known to be thin or absent in several areas of Shelby County, see ***Figure 2***. Absence of the clay and downward flux of surface waters and shallow groundwater impacted by non-point source pollution are believed to contribute to water quality changes and potential contamination of the Memphis aquifer (Graham and Parks, 1986; Richardson, 1989; Parks, 1990; Parks and Mirecki, 1992; and Parks et al, 1995). The Memphis aquifer or similar unconsolidated sand aquifers are used throughout the Mississippi Embayment region for agricultural, domestic, and municipal water supplies. Lateral heterogeneities in regional confining layers, such as those observed in the Memphis area, may provide avenues for local and regional contamination, especially in areas where high groundwater use has substantially lowered potentiometric surfaces.

The research proposed herein addresses identification of the geologic mechanism providing the interaquifer flux in and near the Sheahan well field in Shelby County, Tennessee (see ***Figure 2***). Previous research indicates that a window in the confining aquitard of the Memphis aquifer may be present in this area (Kingsbury and Parks, 1993).

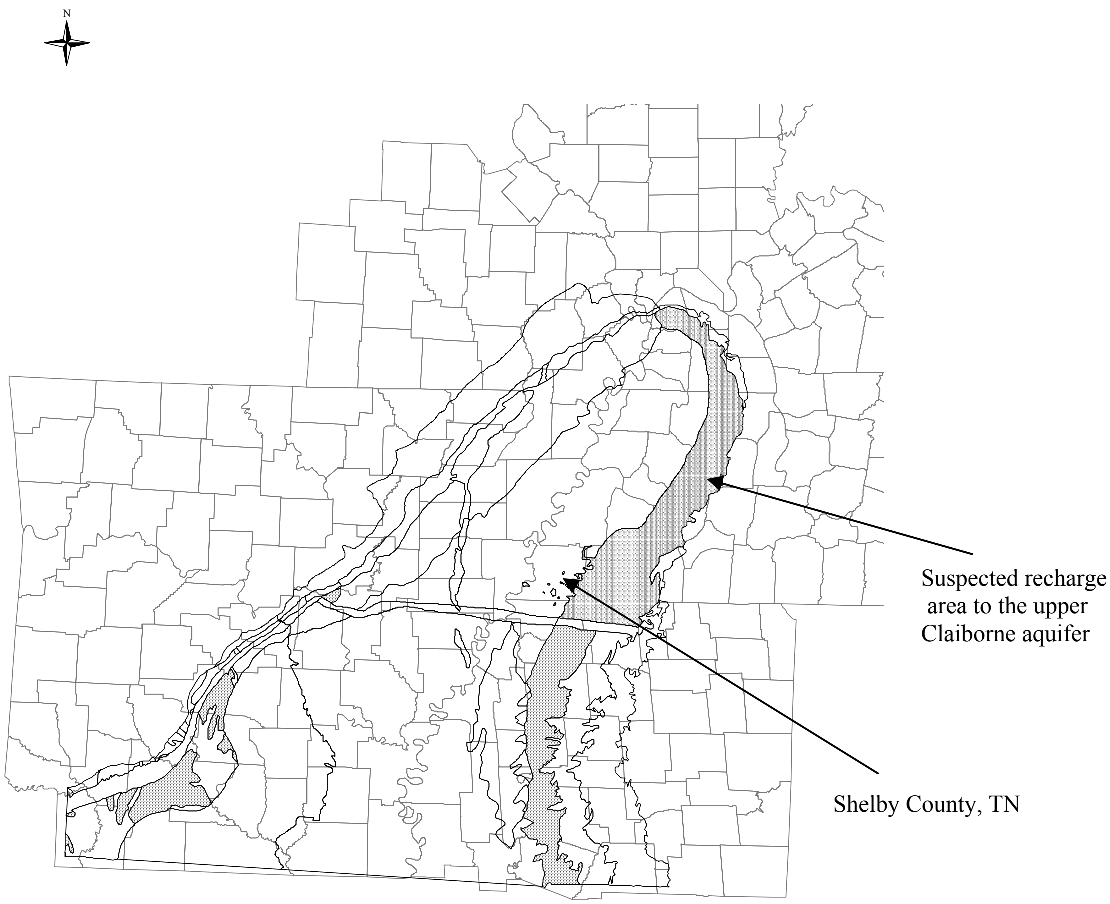

Figure 1. Geographical extent of the northern Mississippi Embayment.

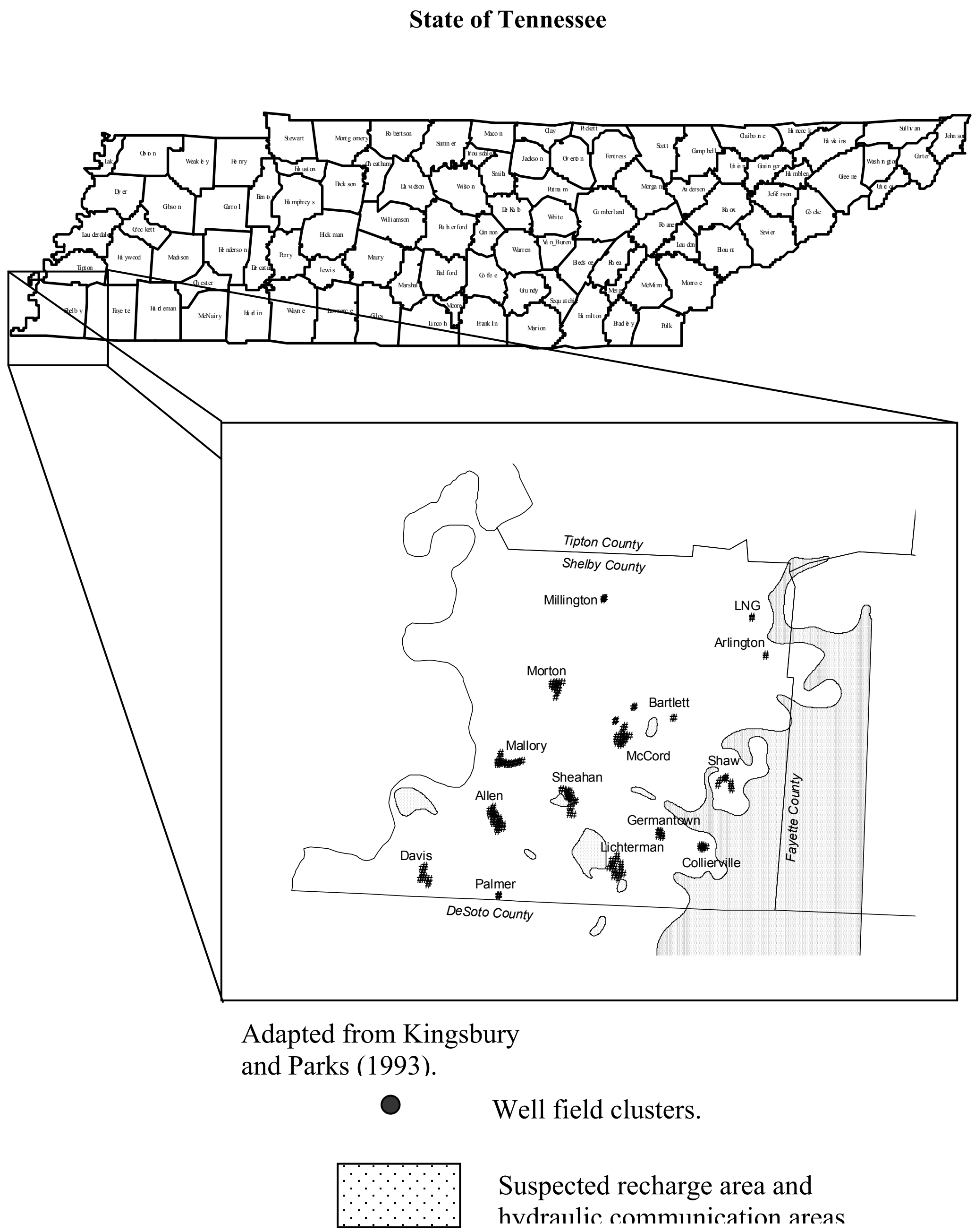

Figure 2. Geographical extent of Shelby County Tennessee with suspected areas of recharge and hydraulic communication windows in the confining clay layer of the Memphis aquifer.

The Sheahan wellfield provides an opportunity to study the mechanisms of interaquifer leakage by utilizing tritium/^{3}Helium (^{3}H/^{3}He) coupled with a detailed seismic investigation of the area to determine possible lateral heterogeneities of the Upper Claiborne confining layer. This information is needed by municipal water suppliers in the Memphis area (Memphis Light, Gas, and Water, etc.) to assess vulnerability of well fields to contamination. The results should provide a conceptual model for the mechanism of interaquifer leakage that will be useful to the region.

Objectives:

The specific objectives of the research are focused toward achieving the following goals:

1. To develop methods to better understand aquifer recharge and potential for downward migration of non-point source pollution to the Memphis Sand aquifer and to determine the nature of the hydraulic connection between the shallow aquifer and Memphis Sand aquifer ;

2. To prove the utility of environmental tracers (^{3}H/^{3}He and ^{85}Kr) for model calibration; and
3. To foster development of a long-term collaborative effort between the United States Geological Survey (USGS), the Ground Water Institute (GWI) and Department of Geological Sciences at the University of Memphis, the Department of Geological Sciences and the Institute for Rare Isotope Measurements (IRIM) at the University of Tennessee and The University of Utah Department of Geology and Geophysics for the purpose of better understanding non-point-source pollution flux and groundwater recharge to sand aquifer systems.

Methodology:

The various methodologies to be utilized for each component of the study are described in the sections below.

Water sampling—Water from production wells will be obtained from a sampling port located on the discharge main of a production well pump. For monitoring wells, standard low-flow groundwater sampling protocols will be used to obtain samples for conventional water chemistry and tritium analyses. Both filtered and unfiltered samples will be collected for major ions; the filtered samples will be preserved with concentrated nitric acid. ^{3}He is a dissolved gas which can easily be exchanged in a groundwater sample by exposure to the atmosphere or by diffusion through the walls of a plastic sample bottle. To control losses, the groundwater sample must be isolated from the atmosphere in a tightly-sealed glass container, or the dissolved gases can be stripped from the groundwater either as it is sampled or through an in-situ diffusion sampler. The researchers will coordinate with Dr. Kip Solomon to determine the needs and requirements for sampling from the Sheahan production wells. The methodology will include either an in-situ diffusion sampler or gas stripping of the water sample as it is collected. The observation wells will be sampled utilizing an in-situ diffusion sampler. The proposed program will use both the conventional water sampling and gas-stripping techniques to provide a quantitative comparison of values derived from the methods.

Chemical analyses – On-site chemical data determined by probes in a multiport sampling chamber will include pH, Eh, dissolved oxygen, and conductivity. In addition, on-site titrations for alkalinity and dissolved oxygen, and spectrophotometric analysis of nitrate, dissolved oxygen and sulfide will be conducted. Major anion and cation analyses will be conducted by ion chromatography and flame atomic absorption spectroscopy. Trace metal analysis will be performed using flame or graphite furnace atomic absorption spectroscopy, depending on the sensitivity required.

Standard ^{3}H measurement -- Tritium activity will be determined at the Center for Applied Isotopes Study, University of Georgia. Tritium enrichment will be utilized to obtain a detection limit of 0.1 tritium units (TU).

Enriched ^{3}H and ^{3}He -- Low-level ^{3}H measurements will be made at the University of Utah by Dr. Kip Solomon using the ^{3}He ingrowth method (Clarke et al., 1976). The practical detection limit for this method is approximately 0.05 TU when 250 ml samples are sealed for four months. Helium-3 will be measured using a combination of a quadrupole and sector-magnet mass spectrometers after cryogenic separation of non-reactive gases. The analytical precision is approximately ± 0.5% for He isotopes. The combined $^{3}H/^{3}He$ method has great advantages over conventional ^{3}H age dating methods. By measuring both ^{3}H and its daughter product ^{3}He, the ambiguity inherent in conventional ^{3}H age determinations (*e.g.* does a low ^{3}H level indicate pre-bomb or recent post-bomb water) may be removed.

S-wave Seismic Profiles -- The proposed S-wave reflection investigation (performed by personnel in the Department of Geology, Millsaps College) is a high-resolution, six-fold common-depth-point (CDP) survey. The recording system will be a 12-channel Bison 5012 signal enhancement seismograph. The 5012 has instantaneous floating point gain and records digital data on an internal storage board. Based on preliminary reflection tests in the area, the probable shotpoint and receiver spacings will be 3 m for the S-wave data collection. The available receivers include 4.5 Hz and 30 Hz horizontal geophones. In order to generate S-waves, a 10 kg steel I-beam will be oriented perpendicular to the geophone spread and impacted horizontally with a 4.5 kg sledge hammer. In our experience, 5-10 hammer blows are usually required to image the upper 100 m of the section. Because they are low-cost, durable, and portable, we have had good success with hammer and mass shear wave sources. Data processing will follow a standard sequence for shallow CDP reflection data, including trace editing, bandpass filtering, and automatic gain control.

Preliminary Results:

Twenty-one production wells in the Sheahan well field were sampled during September through December of 1999. Samples were collected again during May through July of 2000. A limited number of wells were sampled in October 2000 for $^{3}H/^{3}He$ and ^{85}Kr analysis. Summary tables of all sampling events are provided in the ***Appendix*** of this report. The tritium and selected water-chemistry results from the 1999 sampling event are shown in ***Figure 3***. Tritium activities above the detectable limit are observed in all but seven of the wells. No clear spatial trends in the tritium values are observed, aside from the generally higher values observed in the north-central part of the well field. In general, the tritium values decrease with increasing depth (***Figure 3***). Many dissolved constituents also decrease or increase in concentration with increasing depth, often following non-linear trends, as demonstrated in ***Figure 3***. Linear trends in water chemistry are shown on the Piper diagram (***Figure 3***); water compositions range from calcium-, magnesium-, and bicarbonate-rich waters at depth to compositions with substantially greater proportions of sodium, chloride, and sulfate in shallower wells. Similar trends are noted in the data from the year 2000 sampling event and are shown in ***Figure 4***.

The tritium and water chemistry data are interpreted to reflect changes associated with vertical recharge of modern water into the upper part of the Memphis aquifer. Tritium acts as a conservative tracer of modern water and provides a qualitative indicator of proportion of modern water mixed with older sub-modern water. The increased sodium, chloride, and sulfate in water from the upper part of the aquifer are interpreted to reflect chemical contributions from shallow aquifer water and chemicals released from the confining unit.

The $^{3}H/^{3}He$ provide quantitative information regarding the timing of infiltration. The $^{3}H/^{3}He$ provides an apparent age of the system and is strongly coupled to the youngest water in the system for a binary mixing relationship. The $^{3}H/^{3}He$ apparent ages range from 16 to 52 and indicate that vertical leakage is occurring by relatively fast recharge pathways.

The results of our analyses of tritium confirm the presence of modern water in the Memphis aquifer within the Sheahan well field that was initially identified by Graham and Parks (1986). They sampled only two wells in the southern part of the well field and found tritium activities of 18.6 and 11.9 T.U. Those wells have since been shut down and sealed, and were not available for our sampling. The measured tritium activities in the Sheahan well field during this study are substantially less than those determined in the south Sheahan wells. Even considering radioactive decay of the tritium, our results indicate that a much smaller component of modern water is present in the aquifer in the northern part of the Sheahan well field than was observed by Graham and Parks in the southern part.

It is clear from the changes in water chemistry and tritium values with increasing depth that a component of modern water is entering the Memphis aquifer in the Sheahan well field area. The complexity of lateral patterns in tritium values suggests that vertical recharge is occurring at multiple locations in the well field and not through a single window through the confining unit. Sheahan well field data indicate that the thickness of clay in the confining layer ranges from 24 to 171 feet thick (Parks, 1990). Furthermore, analysis of geophysical logs indicates that the thickness of clay is particularly thin where a Pleistocene paleovalley has carved through the upper part of the confining unit. As a part of this research, S-wave reflection geophysical techniques were utilized to examine the top of the upper Claiborne aquitard in this area. The data from the S-wave reflection survey is shown in ***Figure 5***. Even though the data was collected in an area rampant with cultural noise, a paleochannel feature is clearly identified in the seismic cross-section. The inverted cone responses shown in ***Figure 5*** also indicate buried anomalies within the survey area (i.e. concrete culvert and water distribution main). Thus, our initial results indicate that the S-wave reflection survey is a powerful and useful tool for identifying potential pathways of recharge through the confining layer.

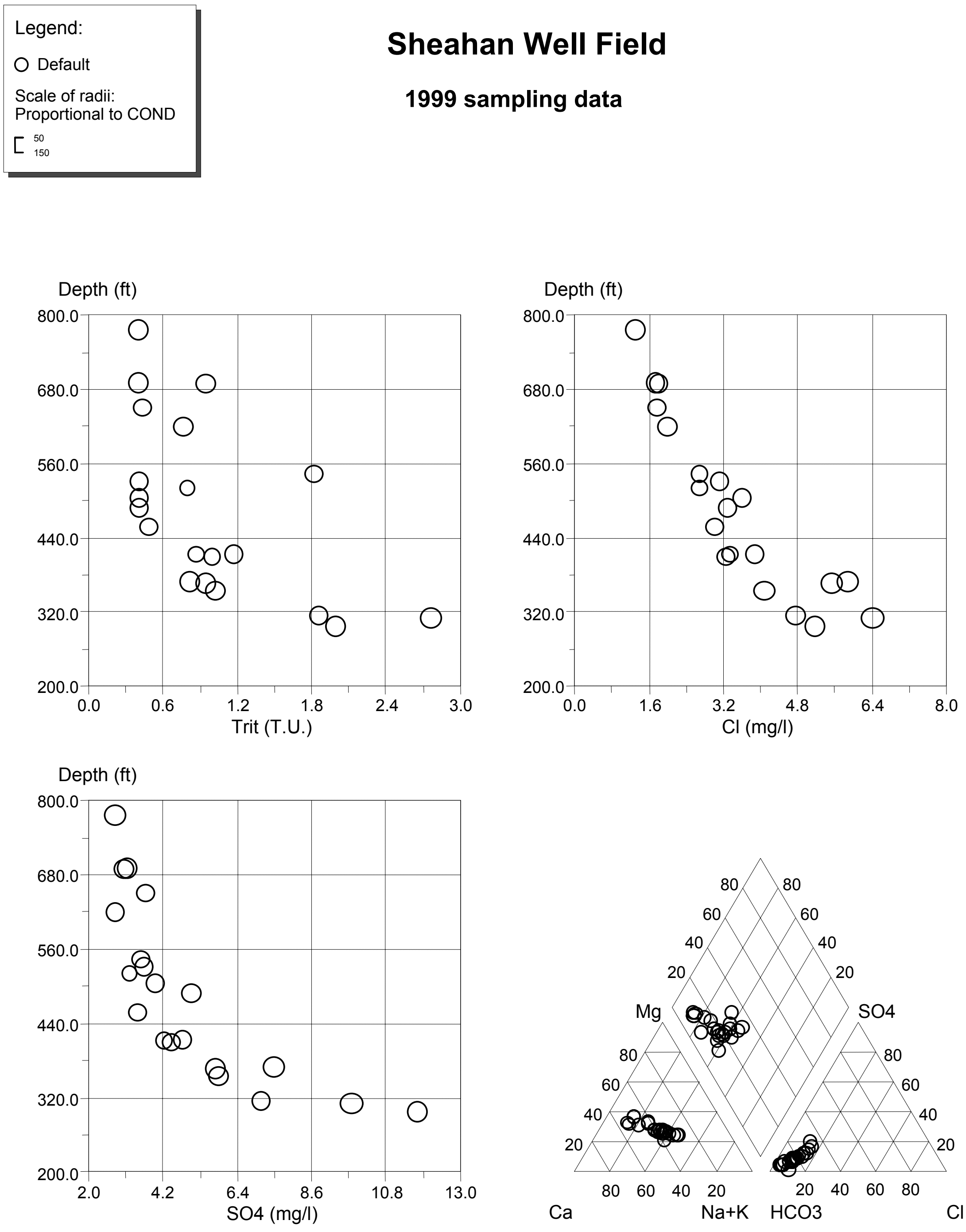

Figure 3. Plots of tritium and dissolved constituents versus depth and Piper plot for production wells in the Sheahan well field and University of Memphis well sampled in 1999.

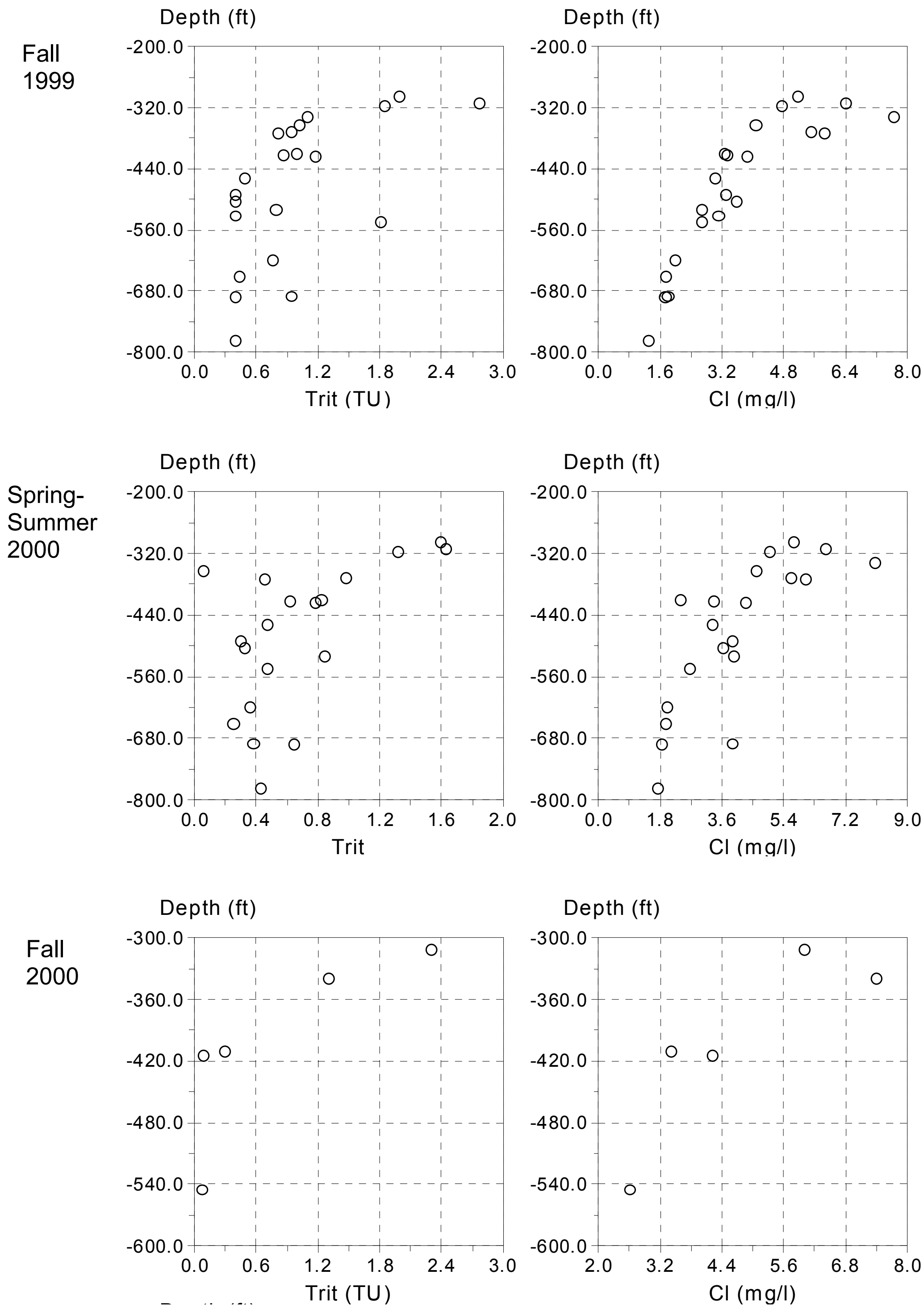

Figure 4. Comparison of data from 1999 and 2000 sampling events.

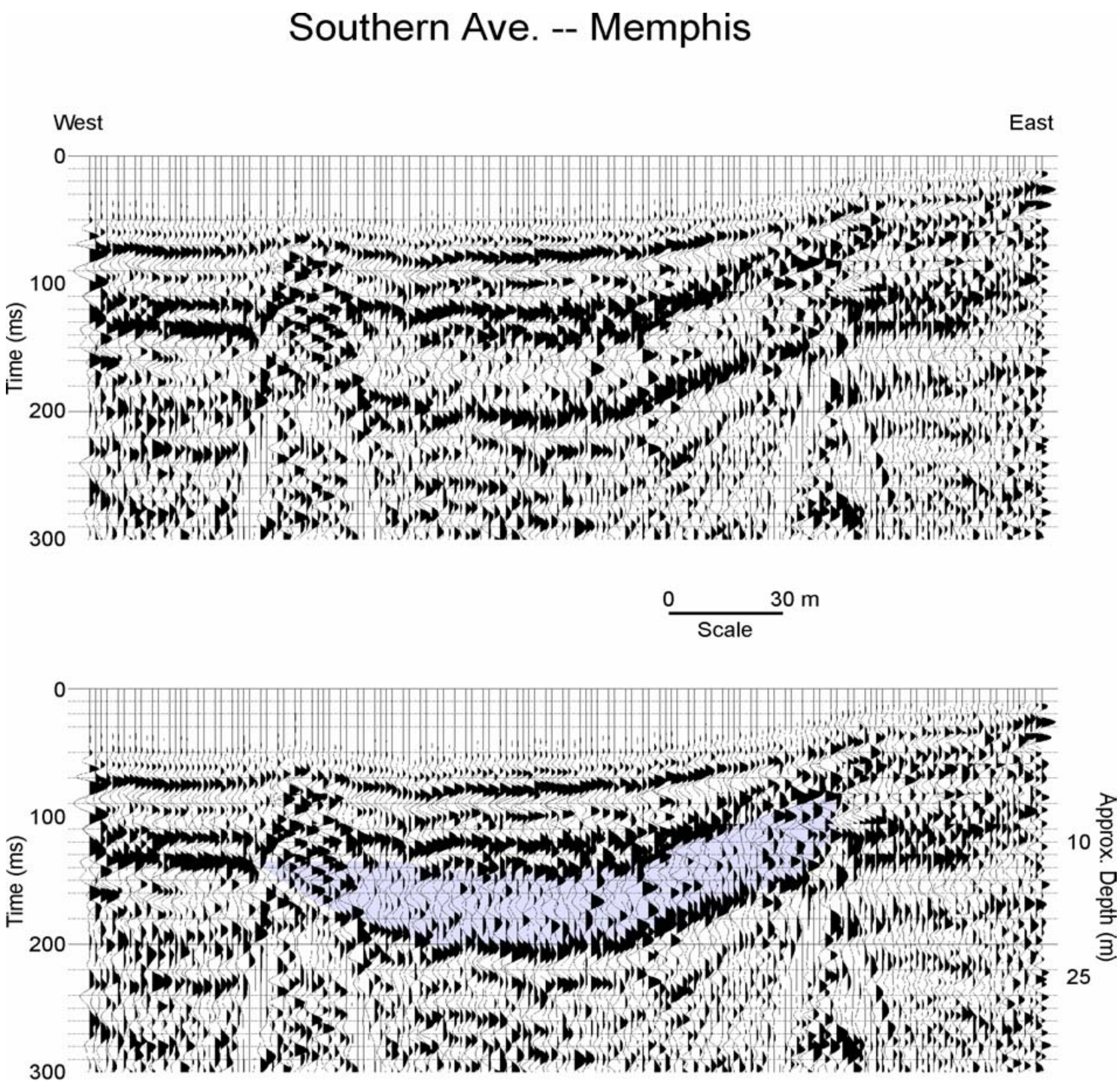

Figure 5. S-wave reflection profile along Southern Avenue near the Sheahan wellfield.

Future Research and Funding:

Although this study has clarified many aspects of how vertical leakage affects groundwater at the Sheahan well field, several questions remain.

(1) Where does the leakage water come from? The shallow aquifer is dry throughout most of the well field and the thin upper Claiborne confining unit has little storage. However, subsurface lateral migration of water from a surface water source, such as nearby Nonconnah Creek, may provide a continuous supply of water.
(2) How do pumping stresses affect the amount of vertical leakage? Initial tests suggest that the proportion of modern and old water change systematically during an individual pumping cycle at a production well. The effects of pumping patterns in the well field on degree and distribution of leakage is currently not known.
(3) What are the key geologic features that transport the majority of leakage to the Sheahan well field? Review of geophysical logs and acquisition of seismic data have clarified the types of features responsible of much of the leakage. However, the location of the key features in the Sheahan well field still remains illusive.

These questions can be partially addressed through groundwater modeling efforts that are currently underway at the Ground Water Institute. However, additional field studies are also necessary to identify the source of leakage water and the key geologic structures.

Publications and Presentations:

Gentry, R.W., *The use of environmental tracers to better understand inter-aquifer hydraulics in Shelby County, Tennessee*, AwwaRF Technology Transfer Conference, Miami, January 25, 2001.

Larsen, D., Gentry, R.W., Waldron, B., Ivey, S., Hudgins, S., and Salyers, M., Variations in water quality and tritium in the Sheahan and Morton well fields, Memphis, Tennessee, USA., 11th Tennessee Water Resources Symposium, Nashville, April 4-6, 2001.

Larsen, D., Gentry, R., Ivey, S., *Water quality impact and distribution of modern recharge on municipal pumpage in the Sheahan well field, Memphis, TN, USA*, GSA December, 2000.

Gentry, R. W., *Current Research to Better Understand the Flow Dynamics of the Memphis Aquifer*, MLGW Vice-Presidents and Managers Meeting, April 23, 2001.

The data and research performed for this study is being used to prepare other manuscripts and presentations for future publication.

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Robinson, J.L., Carmichael, J.K., Halford, K.J., and Ladd, D.E., 1997, Hydrogeologic framework and simulation of ground-water flow and travel time in the shallow aquifer system in the area of Naval Support Activity Memphis, Millington, Tennessee: U.S. Geological Survey Water Resources Investigations Report 97-4228, 56p.

Smith, D.M., 1997, Physical and chemical interactions between trichloroethelene and undisturbed loess: unpubl. Doctoral dissertation, Memphis, University of Memphis, 167p.

Basic Information

Title:	Spherical Cavity Ring-down Spectroscopy of Water
Project Number:	B-02
Start Date:	3/1/2000
End Date:	2/28/2001
Research Category:	Water Quality
Focus Category:	Methods, Water Quality, None
Descriptors:	ring-down spectroscopy, whispering gallery mode, water quality control
Lead Institute:	University of Tennessee
Principal Investigators:	Ling-Jun Wang

Publication

1. Jackson, C., L.J. Wang and R.W. Shaw. 2000. Spherical Cavity Ringdown Spectroscopy of Water. In: Proceedings of Tennessee Academy of Science, Nashville, Tennessee.
2. Shaw, R.W., W.B. Whitten, M.D. Barnes, J.M. Ramsey, and L.J. Wang. 2000. Spherical Cavity Ringdown Spectroscopy Experiments. In: Proceedings of Conference of Laser Applications in Chemical and Environmental Analysis, pages unknown. Santa Fe, New Mexico

1. **Problem and Research Objectives:**

Chemical measurement techniques are central to water quality control. The ability to sensitively, accurately, precisely, rapidly, and conveniently determine the presence of foreign species in natural waters allows for potential control of pollution sources and the verification of regulations. The goal of this research project is to develop a highly sensitive spectroscopy using an ultrafast pulsed laser and the spherical cavity-ringdown technique for fast and sensitive detection of pollutants in water. The method will be especially useful in dealing with radioactive pollutants in the Watts Bar lake and the Clinch River area, where the pollutants are low in concentration but highly hazardous. The technique should be beneficial to water quality control agencies.

Two scenarios are envisioned. In the first, our measurement sensitivity would exceed the best current methods. Thus, earlier detection of problems (e.g., industrial effluent) could be achieved or more stringent regulation compliance could be validated. Current sensitive methods are laboratory-based, and collected samples must be returned to some facility for analysis. In the second scenario, the use of cavity ringdown in spheres might only result in sensitivity comparable to laboratory-based methods, but might be amenable to field use. Our ultrafast pulse lasers are currently far from field-deployable, but new developments in laser technology are occurring at a rapid rate. Fiber optic lasers capable of generating ultrafast light pulses are currently commercially available and might be useful for these measurements. A strong driving force for further laser improvements is that the same parameters important for our needs apply to optical communications needs, as well. Thus, a consumer, rather than a scientific, market will set the development pace.

2. **Methodology:**

The experimental set-up is shown in Figure 1. Two-picosecond duration pulses near 795 nm at 76 MHz are generated using a Kerr lens mode-locked titanium:sapphire laser with an average power of approximately 1 watt. The laser beam is coupled into a liquid sphere through a glass prism with an index of refraction of 1.722. The laser beam is incident into the prism at a certain angle so that complete internal reflection is achieved and a whispering-gallery mode is established in the sphere. Each laser pulse thus generates a train of pulses. The intensity of these pulses decay exponentially as a result of the leakage at the coupling spot and absorption by the liquid. The decay time constant depends on the leakage and the absorption of the liquid, but does not depend on the intensity of the incident laser pulse. Part of the laser pulse circulating around the sphere is coupled out through the prism and imaged onto a fast photodiode (14 ps risetime) and processed with a digital oscilloscope. The digital oscilloscope is interfaced to a PC computer and the data is transferred into the computer for analysis. The pulse width is accurately measured with an autocorrelator. A He-Ne laser is integrated into the system to aid the alignment.

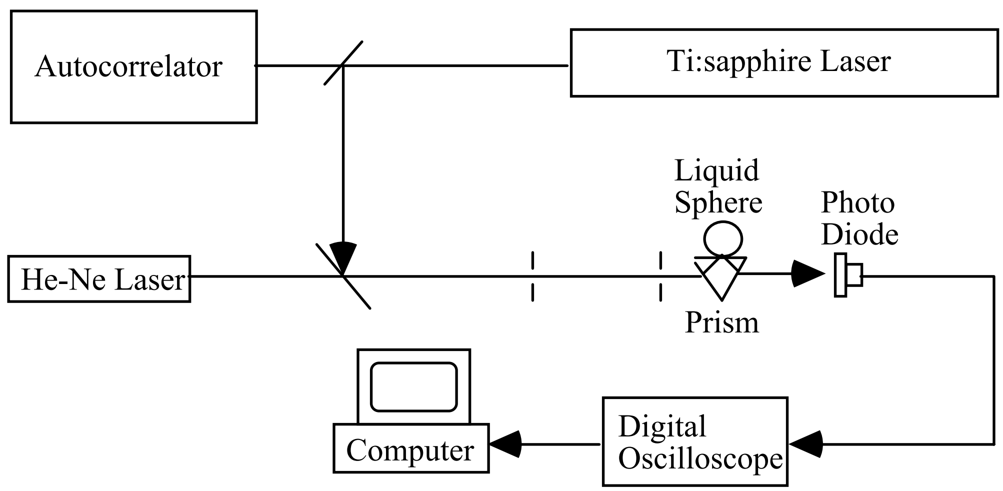

Figure 1. Experimental Set-up

From March 2000 to February 2001, we have carried out an experiment on spherical cavity ring-down spectroscopy of water in the Chemical and Analytical Sciences Division at Oak Ridge National Laboratory. Chemical measurement techniques are central to water quality control. The ability to sensitively, accurately, precisely, rapidly, and conveniently determine the presence of foreign species in natural waters allows for potential control of pollution sources and the verification of regulations. Our goal is to develop an optical absorption technique for the sensitive measurement of chemicals in water, the universal agent of many pollutants.

We have studied the propagation of ultra short light pulses with a duration as short as 2 picoseconds in spherical dielectric cavities. The cavity modes in these devices are analogous to the whispering gallery modes (WGM) of acoustics. The light travels around the sphere circumference, just at the interface between the sphere and its surroundings. While the pulse is totally internally reflected at each reflection apex, leakage of a small fraction of the light can be detected using a properly oriented, fast photodiode.

3. **<u>Principle Findings and Significance:</u>**

1) Experiments with carbon disulfide

We extended these experiments to liquid CS_2 contained in a hollow glass sphere, wherein the light was slightly absorbed on each transit around the liquid sphere that contained a weak absorber. The index of refraction of the liquid must be greater than that of the glass vessel in order for whispering gallery modes to propagate. CS_2 is such an easily accessible liquid that satisfies these conditions. We improved the spherical bottle - prism method to achieve stable whispering-gallery modes in liquid carbon disulfide and achieved a whispering gallery mode with 9 ring-down peaks. The envelope of the ringing signal follows an exponential decay curve, with very little background. This ring down pattern was quantified by fitting the amplitudes to an exponential. By comparison of the time constants in each solution to that in the pure solvent, we were able to calculate the solution absorbency. The decay constants of the different solutions were deduced and related to the corresponding concentrations of the dye absorbent Exiton 800. The results show that the decay time of the cavity ring down signal is linearly affected by the solution absorbency.

2) Cavity ringdown in water.

The index of refraction of water is only 1.33, much less than that of any glass. Although the beam can enter the water and emerging at a glancing angle tangent to the glass-water surface, we suffer heavy energy loss since the internal reflection is not perfect. Exactly for the same reason, the laser beam would stay within the thin glass wall due to total internal reflection at both the glass-water and glass-air interfaces.

The second method we tried to achieve cavity ring down in a water sphere (or ellipsoid) was to form a spherical water drop on a horizontal surface of a prism, much like a water drop on a lotus leaf. However, it is extremely difficult to make the surface hydrophobic to make a sizable water sphere. When the diameter of the water drop is as large as a few millimeters, it started to form a hemisphere with a 90 degree cusp angle to the prism surface. This technique should be very attractive if we know how to make a highly hydrophobic surface on glass.

The most direct technique was to employ a water drop. Unfortunately, coupling light into a free water drop results in extremely leaky whispering gallery modes, and the propagating pulse decays away too rapidly. Touching the drop to a coupling prism solves this problem by changing the WGM orders achievable, but so severely distorts the drop from sphericity that it will not support whispering gallery modes.

3) Reversible adsorption method

We also tried to study reversible adsorption of chemicals into selective sphere coatings(a polymer doped with a calorimetric reagent). In this embodiment, an optical whispering gallery mode would hopefully be launched in the thin sphere coating; pollutants adsorbed from dilute water solutions would be concentrated in the coating, and their absorption spectrum can be studied by cavity ringdown measurement. It proved quite a challenge to coat a glass sphere with a layer of coating and preserve the optical sphericity. Since the coating was microscopically porous (It had to be porous to adsorb water solutions), the laser beam suffered too heavy a loss to sustain a cavity ring down for a sensible measurement. The hope is in the chemical technique of coating a glass sphere uniformly with certain non porous reversible adsorbing chemicals.

4. **Future Research and Funding:**

We have studies cavity-ringdown spectroscopy in liquid spheres. The experimental data show that the technique promises a highly sensitive spectroscopy for weak absorbents, due to the long absorption length and the fact that it is based on the time domain measurement using ultra fast laser pulses. The experiments with carbon disulfide solutions of Exciton 800 dye demonstrate that the absorption and optical density are indeed linearly proportional to the density of the solution.

Our ultimate goal is to achieve cavity ringdown in a water sphere or ellipsoid. Since the index of refraction of water is only 1.33, it will not realize internal reflection at the inner surface of a glass bottle. A way of providing a reflective surface is to coat the inside surface with a highly reflective layer of metal film by ion sputtering in vacuum.

The method of making a water drop on a hydrophobic glass surface remains a very attractive possibility. We hope to be able in the near future to learn a way to make hydrophobic surfaces.

Finally, the linear cavity version of cavity ring down offers another alternative.. The advantage of this method is that we can use high quality mirrors that are easily adaptable to water. This method is highly attractive because all the key equipment are commercially available. However, significant funding has to be secured to support further research, as our collaborator at Oak Ridge is not able to support the equipment due to conflict with other on-going projects.

10. **Publications and Presentations:**

(Presentation and Paper)

Shaw, R.W., W.B. Whitten, M.D. Barnes, J.M. Ramsey, and L.J. Wang. 2000. Spherical Cavity Ringdown Spectroscopy Experiments. In: *Proceedings of Conference of Laser Applications in Chemical and Environmental Analysis,* pages unknown. Santa Fe, New Mexico.

Jackson, C., L.J. Wang and R.W. Shaw. 2000. Spherical Cavity Ringdown Spectroscopy of Water. In: *Proceedings of Tennessee Academy of Science,* Nashville, Tennessee.

Information Transfer Program

The major emphasis of the information transfer program during the FY 2000 grant period focused on technical publication support, conference planning/development, and improvement in the information transfer network. The primary purpose of the program was to support the objectives of the technical research performed under the FY 2000 Water Resources Research Institute Program.

The primary objectives, as in previous years, of the Information Transfer Activities are:

To provide technical and structural support to water researchers performing research under the WRRIP.

To deliver timely water-resources related information to water researchers, agency administrators, government officials, students and the general public.

To coordinate with various federal, state, and local agencies and other academic institutions on program objectives and research opportunities.

To increase the general public’s awareness and appreciation of the water resources problems in the state.

To promote and develop conferences, seminars and workshops for local and state officials and the general public which address a wide range of issues relating to the protection and management of the state’s water resources.

During the FY 2000 grant period, a major focus of the information transfer activities was on the participation of the Center staff in the planning and implementation of several statewide conferences and workshop.

As co-sponsor, the Center was involved in the planning and implementation of the Tenth Tennessee Water Resources Symposium, which was held on April 10-12, 2000 in Nashville, Tennessee. The purposes of the symposium are: (1) to promote communication on water resources research and management, and (2) to encourage cooperation among the diverse range of water professionals in the state. As with previous symposia, the tenth symposium was very successful with over 250 attendees and approximately 70 papers being presented in the two-day period. The event received a good deal of publicity across the state.

The Center also participated in several meetings and workshops across the state that were held to address water related problems and issues such as stormwater management, water quality monitoring, non-point source pollution, water supply planning, multiobjective river basin management and lake management issues in Tennessee.

The following is a brief listing of formal meetings, seminars and workshops that the Center actively hosted, supported and participated in during FY 2000:

Tennessee Clean Water Network Conference, March 17-19, 2000, Nashville, TN.

Tennessee Water Resources Research Center Statewide Advisory Committee annual meeting, interaction among researchers and researcher users, March 21, 2000, Knoxville, TN.

Sustainable Watersheds ? Balancing Multiple Needs: 10th Annual Southeastern Lakes Conference, North American Lake Management Society, March 21-23, 2000, Knoxville, TN.

Using the Clean Water Act to Protect Your Watershed: A Concentrated Course, River Network and Tennessee Clean Water Network, April 7-9, 2000, Nashville, Tn.

Tennessee Wetlands Technical Advisory Task Force meeting, April 25-26, 2000, Nashville, Tennessee. Meeting of government agency staff and technical experts to advise to the State on issues related to the Tennessee Wetlands Management Plan.

WaterFest, May 5, 2000, Knoxville, TN. An annual community-wide event sponsored by the Water Quality Forum that highlights the importance of our water resources and the activities of the WQF partners to protect and manage those resources. Adopt-A-Watershed Teacher Training Workshop, June 19-22, 2000, Knoxville, TN. A workshop to train high school and middle school teachers the AAW science based curriculum program that utilizes the local watershed as a living laboratory. The Southeast Watershed Roundtable, August 23-25, 2000, Birmingham, AL. The Roundtable was sponsored by the Southeast Watershed Forum and TNWRRC. It is an annual regional Roundtable convened to assess watershed restoration progress in the Southeast. It is a key element of the President Clinton?s Clean Water Action Plan. Watershed Monitoring Workshop, September 16, 2000, Brookhaven Farms Knoxville, TN. A workshop sponsored by Tennessee Valley Authority and TNWRRC. The objective of the workshop was to train members of local watershed associations in monitoring and assessment techniques. Urban Runoff Working Group, September 22, 2000, Nashville, TN.

Kids-In the-Creek, September 26, 2000, Holston Middle School, Knoxville, TN. A watershed experience sponsored by Tennessee Valley Authority, TNWRRC and the CAC AmeriCorps Water Quality Team. An all day event for 100 7th grade students introducing them to watershed science including biological and chemical monitoring and land use impacts on water quality. Knox County Soil Conservation District BMP Tour, October 19, 2000, Knoxville, TN. TNWRRC staff made presentations on streambank restoration demonstration projects in Knox County. Tennessee Nonpoint Source Partnership Conference, October 26-27, 2000, Nashville, TN. TNWRRC cosponsored the conference and staff made several presentations.

Eleventh Annual SAMAB Conference, November 1-3, 2000, Gatlinburg, TN. Sponsored by the Southern Appalachian Man and the Biosphere. TNWRRC staff made several presentations on watershed assessment projects. Erosion Control BMP Workshop. December 5, 2000, Ijams Nature Center, Knoxville, TN. Knoxville Water Quality Forum, Quarterly meetings, May, July and October 2000 and January 2001. Meeting of government agencies and other organizations to share information and discuss water quality issues in the Tennessee River and it?s tributaries in Knox county. Little River , French Broad and Emory Watershed Associations, monthly meetings. Agency staff and community leaders working towards protection of the Little River, lower French Broad and the Emory/Obed watersheds. Joint UT-TVA-ORNL Water resources Consortium Seminar Series on timely water resources topics, issues and projects of common interest to the three organizations.

Other principal information transfer activities which were carried out during the FY 2000 grant period focused on the dissemination of technical reports and other water resources related reports published by the Center as well as other types of information concerning water resources issues and problems. A majority of the requests for reports and information have come from federal and state government agencies, university faculty and students, and private citizens within the state. The Center also responded to numerous requests from across the nation and around the world.

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	0	3	0	0	3
Masters	1	3	0	0	4
Ph.D.	0	2	0	0	2
Post-Doc.	0	0	0	0	0
Total	1	8	0	0	9

Notable Awards and Achievements

None resulting from work supported by Section 104 awards.

Publications from Prior Projects

1. There were no publications from prior projects for FY 2000.