New Waves
The Research Newsletter of the Texas Water Resources Institute
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TWRI "Water for Texas Conference" January 26-27 in Austin: Focuses on New Findings from Research

The Texas Water Resources Institute (TWRI) is sponsoring a major conference that will present results of water and environmental research from universities and agencies throughout Texas. The meeting, "Water for Texas: Research Leads the Way," will be Jan. 26-27 at the Driskill Hotel in Austin. The Conference is sponsored by TWRI, the Texas Water Development Board, the Texas Water Conservation Association, and many other institutions and agencies.

"Researchers at universities and state and federal agencies are now investigating a wider range of water related problems. These studies focus on such issues as environmental policy, pollution, water use and conservation, lake and river quality, and many others," said TWRI Director Wayne Jordan. "The goal of this meeting is to provide researchers with an opportunity to discuss current research and to provide citizens and decision makers with an opportunity to become familiar with recent discoveries at one place and one time."

So far, 120 researchers have indicated they will present their research findings at the meeting. The conference is organized so that representatives from state agencies will provide keynote speeches beginning at 8:30 on Thursday morning, when they will describe research opportunities and programs. Concurrent technical sessions will begin Thursday afternoon and run until 5 PM Friday. Technical session topics include the following: water supply and management, water conservation and reuse, aquatic biology, instream flows, coastal studies, water quality, socioeconomic and policy issues, watershed management, and groundwater.

People can still register for the meeting for a cost of $50, which includes a copy of the Proceedings. To get more information about this meeting, please call TWRI at (409) 845-1851 or Fax (409) 845-8554.

Texas A&M Biologists Study Brazos River Oxbow Lakes

If you were to raft or canoe down the middle and lower reaches of the Brazos River, you might notice the many small and shallow lakes that are found in the "oxbows" where the river snakes and meanders.

These oxbow lakes are unique because this part of the Brazos River (Brazos, Burleson, Waller, Washington, Austin, Brazoria, and Fort Bend counties) is one of the few areas in Texas where a major river has not been dammed, channeled or levied. Now, Texas A&M University scientists are undertaking a major effort to learn more about the ecosystem dynamics in these lakes.

Texas A&M students push this boat into Brazos River oxbows to obtain water quality samples.

Two studies are being conducted simultaneously by Kirk Winemiller, Jim Cotner, and Brian Murphy of the Wildlife and Fisheries Sciences Department. One study focuses on how intermittent floods and droughts affect the species that live in the lakes and the river. The other project is investigating environmental features that influence the amount and types of fish that live in the river. It involves building a geographic information system (GIS) to examine relationships between the morphology and gradient of the river, aquatic species and their needs, hydrology, and contaminants.

The project began in July 1992 and will run through August, 1995. So far, the researchers have taken as many as 18 students out to the river and its oxbow lakes to gather samples and collect data on water levels, water chemistry, sediments, fish, zooplankton and phytoplankton. The research will lead to two Ph.D. dissertations and provides many undergraduates with hands-on experience in aquatic research.

Winemiller says the studies are needed because there are few undisturbed rivers left in Texas and because oxbow lakes have rarely been studied. He believes that oxbow lakes increase biodiversity in rivers because they nourish many species that could not normally live in nearby rivers. When floods occur, there is often an exchange of species between the oxbow lakes and the main river channel. The researchers found bluegill sunfish, white crappie and bullhead catfish were all more abundant in the oxbow lakes, while long-nose gar and flathead catfish were more common in the river.

For details, call Winemiller at (409) 862-4020. His e-mail address is kow1956@zeus.tamu.edu. Murphy can be contacted at (409) 845-5785, and Cotner's phone number is (409) 845-1068.

Incorporating Salinity into Reservoir System Modeling

Authors: Ralph Wurbs, Gerardo Sanchez Torres, and David Dunn, Civil Engineering Department, Texas A&M University.

Problem: Effective management of multiple reservoir systems within large watersheds requires that water rights and salinity and other water quality criteria also be considered. This is particularly true in Texas where many rivers are fully allocated and where natural salt loads limit the usable amount of water.

Objectives: 1) To develop a model that can simulate reservoir system reliability while considering water rights and salinity; 2) to improve operating strategies that can increase yields from multi-reservoir systems; 3) to examine the impact of natural salt loads on water supplies; and 4) to perform a comprehensive reliability study for reservoirs in the Brazos River Basin.

Background Information: This research is one component of a series of studies by Wurbs that examine reservoir system operation. For example, Wurbs previously developed the Texas A&M University Water Rights Analysis Program (TAMUWRAP), which examines how water rights affect reservoir yields.

Methodology: This report presents a detailed overview of Texas' surface water allocation and permitting system, describes the use of TAMUWRAP, and summarizes the rivers, dams, and reservoirs of the Brazos River system. Development of basic data sets that provided input to TAMUWRAP are documented, as are simulation test runs of how TAMUWRAP was used to assess reservoir reliability in the basin. The development and use of two new simulation packages, WRAP3 (which provides additional water rights capabilities) and WRAPSALT (which considers salinity problems) are documented. The basic concept behind WRAPSALT is that water will not be widely used when salinity is high. The report identifies key water management strategies and modeling assumptions that could increase yields, based on the test runs.

Results: The 12 major reservoirs in the Brazos River basin can supply water to rights holders with a 98% reliability, when salinity constraints are not considered. Incorporating salinity constraints reduces the reliability considerably. Similarly, the Brazos River Authority system could supply additional reservoirs with 200,000 acre feet (AF) annually with a 99% reliability and little negative impact on existing water rights, if salinity was not considered. When salinity is considered, reliability declines considerably. For example, providing water with less than 500 mg/L of total dissolved solids (TDS) lowers reliability to 66% and for 1,000 mg/L TDS it is only 74%. The report also suggests that salt water diversion dams may only marginally improve system yields, even though they improve water quality. Developing the basic data needed to simulate a river basin requires considerable time and expense. More research needs to be done so that existing data can be automatically translated into a form TAMUWRAP can use, with little need for conversion.

Reference: Wurbs, Ralph, G. Sanchez Torres, and David Dunn, *Reservoir and River System Reliability Considering Water Rights and Water Quality* (TR 165), TWRI, College Station, TX.

NOTE: This report is available free by calling TWRI at (409) 845-1851.

Using GIS to Classify Playa Lake Ecosystems

Authors: Tony Mollhagen, Civil Engineering Department, and Ernest Fish, Range and Wildlife Management Department, both Texas Tech University, Lubbock, TX.

Problem: There are roughly 20,000 playa lakes basins in Llano Estacado and the southern High Plains south of the Canadian River. Playa lakes have not yet been classified or inventoried. Compiling information on playa lakes will improve our understanding of the role of playa lakes in agriculture, biology, nonpoint source pollution, stormwater management and many other issues.

Objectives: 1) To digitize the location of every playa basin in the Llano Estacado of Texas and New Mexico; 2) to estimate the amount of Randall clay in each playa lake bed, 3) to assign a unique catalog number to each playa lake, and 4) to review the literature to discover information from previous studies that can be added to the playa lake geographic information system (GIS).

Methodology: Maps (7.5 minute quadrangles) were obtained from the U.S. Geological Survey and were digitized using ERDAS software. Data were fed into a GIS using ARC/Info software. Data were also converted to a d-Base file format so that they could be sorted and summarized. Photocopies of county soil maps were obtained from the U.S. Soil Conservation Service and were used to digitize areas where Randall clay is dominant in playa lake beds. Soon, information about the topography and drainage area of each playa lake will be added.

Results: The locations of all identifiable playa lakes were digitized from 450 quadrangle maps. A system to catalog the location of each lake and other information was developed. Theoretically, this information can be used along with a global positioning system to locate the site of any individual playa lake in the region. Determining the area where Randall Clay is widespread is the most time-consuming activity, but has been completed for 10 Texas counties (work still needs to be done for 12 counties). A library with more than 12,000 references to Texas playa lakes has been developed and is being indexed in a computerized database. A first draft of the list of the plants and animals that use playa lakes has been developed. Ultimately, the GIS should be a tool that researchers in many disciplines can use to analyze water quality and water supply issues that affect playa lakes.

Reference: Mollhagen, T., and E. Fish, "Playa Basin Classification Using Geographic Information Systems," in *Playa Basin Symposium*, 1994. **NOTE**: This proceedings can be purchased from the Texas Tech Water Resources Center at (806) 742-3597.

Using the Estuarine Clam to Biomonitor Dioxins and Furans in the Neches River

Authors: Richard Harrel and Marc McConnell, Biology Department, Lamar University, Beaumont, TX.

Problem: The goal of the study was to use the estuarine clam *(Rangea cuneata)* to determine the distribution of dioxin and furans in the river and at two remote sites. Dioxins and furans are part of a group of highly toxic chemicals called polychlorinated dibenzo-para-dioxins (PCDDs) and dibenzofurans (PCDFs).

Objectives: 1) To assess if the estuarine clam can be used as a biomonitor of dioxins and furans, and 2) to determine the distribution of these chemicals in the river and at remote sites.

Background Information: Dioxins and furans are by-products of chlorine bleaching at pulp and paper mills, processes that manufacture chlorinated phenol compounds, and incineration operations. One dioxin isomer (2,3,7,8-TCDD) is the most potent carcinogen and teratogen known to exist. In a national EPA study of kraft paper mills that use chlorine bleaching, PCDDs and PCDFs were found in sludge and wastewater from a paper mill that was permitted to release 53 million gallons per day of effluents into the Neches River. TCDD levels of up to 9 parts per million were reported in fish tissue samples collected below the paper mill's discharge point. The Texas Department of Health issued a dioxin advisory warning, urging people to limit or avoid eating fish taken from the Neches River between Highway 96 and Highway 10. This section of the river, which is above the paper mill's outfall, is used heavily for contact recreation and fishing. Estuarine clams were chosen as a biomonitor because they are resident and immobile, and they let scientists determine the level and distribution of pollutants at a site.

Methodology: In November 1990, estuarine clams were collected from four sites in the Neches River that were within the dioxin advisory zone. Three sites were above the paper mill's discharge, and one site was below the outfall. Size of the clams was measured, ages were estimated, and reproductive condition was assessed. Clam tissues were removed from the shell, wrapped in foil, placed in sterile glass jars, stored on ice, frozen and shipped to California for laboratory analyses . Tissue lipid contents were determined by EPA method 8290 and levels of 10 PCDFs and 7 PCDDs were measured by EPA method 1613. In August 1993, two years after dioxin control measures began, tissue samples were collected at the four river sites, and at two remote sites in the Neches-Trinity Coastal Basin that do not receive the paper mill's discharges.

Results: Measurable levels of PCDDs and PCDFs were present in *R. cuneata* tissues at all sites, but higher levels were found in the sections of the Neches River that received paper mill effluent. Highest levels of PCDDs occurred at sites 5 miles and 10 miles upriver from the paper mill outfall. This may indicate that these pollutants were transported upriver by saltwater intrusion or that nonpoint sources exist upstream. The presence of PCDDs and PCDFs in clam tissues at remote sites indicates that other pollutant sources may also exist. Other sources of PCDDs and PCDFs in the river could

include runoff containing PCBs used as wood preservatives or runoff from the use of herbicides like 2,4-D. Possible sources of PCDDs and PCDFs at remote sites include air emissions from a hazardous waste incinerator and herbicides used to control aquatic vegetation. Whole tissue levels of 2,3,7,8-TCDD and all PCDD cogeners were not statistically different, but lipid-normalized concentrations were significantly different. Even under extreme physiological conditions, the estuarine clam was an effective biomonitor. Because it is tolerant of many environmental conditions and is easily maintained in the laboratory, this species could be used *in situ* or in Texas estuaries as a sentinel organism for hazardous substances.

Reference: Harrel, R.C., and M.A. McConnell "The Estuarine Clam Rangea Cuneata as a Biomonitor of Dioxins and Furans in the Neches River, Taylor Bayou, and Fence Lake, TX, *Estuaries*, Vol. 18 (1995), No. 1B (in press).

Changes in Wetland and Aquatic Habitats in Galveston Bay

Authors: William White, Thomas Tremblay, and Jerry Wermund, Bureau of Economic Geology, University of Texas, Austin, and Lawrence Handley, National Biological Survey, Lafayette, LA.

Problem: Wetland and aquatic habitats are essential biological components of the Galveston Bay ecosystem. Understanding the spatial and temporal trends of these habitats is critical, if they are to be managed and protected.

Objectives: 1) To determine the trends and status of wetlands in the Galveston Bay system using aerial photographic analyses and field surveys, 2) to determine the probable causes of these trends, and 3) to characterize wetland plant communities.

Methodology: The distribution of wetlands was determined by examining aerial photographs that were taken in the 1950s, 1979, and 1989. Wetlands were interpreted and delineated on aerial photographic stereo pairs using a stereoscope with magnification of approximately 6X. Wetlands were classified by system (marine, estuarine, riverine, palustrine and lacustrine), subsystem (based on hydrologic conditions) and class (based on the type of vegetation and soil substrate). Maps for 1979 and 1989 were classified by subclass, based on vegetation types, and by upland land use. Field investigations at more than 180 sites confirmed information on the aerial photos. There is an explainable margin of error when aerial photos are used to delineate wetlands and quantify habitat changes.

Results: Wetlands and aquatic habitats are dominated by Galveston Bay and an extensive estuarine system. Major habitats include salt, brackish and fresh marshes, forested and scrub-shrub wetlands, subtidal aquatic beds, intertidal flats, and open water. Vegetated wetlands represent 13% of all habitats (including areas of open water and uplands). Nearly all (94%) vegetated wetlands are marshes. Vegetated wetland acreage has declined from 171,000 acres in the 1950s to only 138,600 acres in 1989. The rate of loss decreased during that time and was less than 700 acres per year from 1979 to 1989. Marshes (emergent wetlands) suffered a net loss from 165,500 acres in the 1950s to 130,400 acres in 1989. The gross loss of this habitat was much greater (88,500 acres), but

was offset somewhat by the spread of emergent vegetation into new areas. Major losses in interior and freshwater marshes occurred as large areas (36,000 acres) were transformed to uplands. Man-made factors that affected changes in marsh habitats include draining and filling of wetlands for urban and agricultural uses, subsidence, and sea-level rise. Major losses in submerged aquatic vegetation occurred as approximately 1,800 acres (more than 70% of this resource) disappeared between the 1950s and 1989. Hurricanes and subsidence may have added to losses of this habitat.

Reference: White, W.A., T.A. Tremblay, E.G. Wermund, and L.R. Handley, *Trends and Status of Wetland and Aquatic Habitats in the Galveston Bay System*, 1993, published by the Galveston Bay National Estuary Program (GBNEP). For details, call GBNEP at (713) 332-9937.

Managing Non-Point Source Pollutants in the North Bosque River Watershed

Authors: Ron Jones, Jack Nelson, Dahna Branyan, Edward Dittfurth, Joan Flowers, Tim Jones, Heather Jones, and Tina Coan, Texas Institute for Applied Environmental Research, Tarleton State University, Stephenville, TX.

Problem Statement and Background Information: Because a number of large dairies have moved into North Central Texas, there are concerns that surface and ground waters in the Upper North Bosque River watershed may be suffering from non-point source pollution. As a result, a comprehensive study was conducted under Section 319 of the Clean Water Act to implement, educate and demonstrate aspects of dairy management in efforts to improve water quality. This abstract summarizes research efforts at Tarleton State University to address these concerns. Generally, most of this research began in 1990 and continued through 1992.

Objectives: 1) To educate and demonstrate how new dairies can be sited to minimize the risk of surface and ground water pollution; 2) to monitor compliance with dairy waste management permits and provide guidelines to dairy operators on proper waste management practices to prevent water pollution; 3) to demonstrate to dairy operators how best management practices (BMPs) can be used to meet Texas Natural Resource Conservation Commission (TNRCC) water quality criteria; 4) to educate dairy operators about alternative solid waste disposal options; 5) to demonstrate the use of alternative wastewater treatment practices; 6) to evaluate and compare lagoon lining criteria and determine if improved liners are appropriate for use in the watershed.

Methodology: For task 1, types of land were identified that are vulnerable to pollution if improper management practices are utilized. Environmental criteria for siting dairies were examined and assessed. For task 2, TIAER developed a compliance monitoring program to evaluate dairy management practices. Monitoring criteria included compliance with TNRCC requirements to contain wastewater and to apply and dispose of liquids and solids. A waste disposal record keeping system was developed and made available in paper and computer formats. For task 3, TIAER monitored 24 stream and reservoir sites in the watershed to gather data on non-point source pollution from storms,

and used simulation models to assess if the use of BMPs would improve water quality. Educational seminars and field days were conducted to encourage dairy operators to adopt BMPs. For Task 4, TIAER evaluated the economics of composting and contacted firms to determine the feasibility of developing a regional composting facility for dairy and municipal wastes. For task 5, cropping patterns, application methods and rates, and management procedures were evaluated to determine if pollution risks could be lessened. Demonstration projects and field days were used to educate operators. For task 6, the effectiveness of *in-situ* lagoon liners comprised of local soils were evaluated based on permeability, seepage and sealing properties of dairy waste.

Results: For task 1, a siting guide was developed that can be used to evaluate the environmental suitability of potential sites for new dairies. It was hard to tell if the site information helped dairy operators locate facilities outside of "critical" areas, because few new dairies were built during the study period. Results from task 2 indicate that 94% of the permitted dairies had constructed wastewater lagoons to collect runoff from confined areas and that 70% installed structural BMPs required by TNRCC waste management permits. Simulation modeling conducted for task 3 suggested that the widespread use of BMPs could lower total nitrogen loadings by 98% and total phosphorus loads by 91%. Surface water quality in the watershed was characterized based on chemical and biological criteria. Degraded water quality, evidenced by elevated pollutant concentrations and low benthic diversity, was observed at several monitoring stations. Non-point source nutrient loads, monitored during storm runoff events, were much higher than base flow conditions. Results from task 4 activities suggest that composting may be a viable alternative to applying solid wastes to agricultural fields. The feasibility of establishing a regional compost facility is marginal without supplemental funding. Results from task 5 suggest that dairy operators are often willing to adopt innovative technologies to lower pollutant loads, but are hampered by the lack of cost-share incentives and institutional factors. Results from task 6 show that adding manure to local soils decreased the permeability of lagoon liners, but local soils still did not typically meet TNRCC permeability standards. Vadose zone monitoring identified potential seepage problems associated with *in-situ* dairy lagoon liners.

Reference: Jones, R., J. Nelson, D. Branyan, E. Dittfurth, J. Flowers, T. Jones, H. Jones, and T. Coan, *Final Report on Section 319 Nonpoint Source Pollution Management Program for the North Bosque Watershed*, 1992, TIAER, Tarleton State University, Stephenville, TX.

Pasadena Uses New Technology to Save Time, Money, on Sewer Main Repair

When a concrete sewer main burst and caved in on a busy street in the winter of 1993, officials with the City of Pasadena (south of Houston) felt that a long and expensive repair job may be needed. The use of an innovative method that places a new replacement pipe inside existing mains saved time and money.

Pasadena had to replace more than a mile of a 36-inch sanitary sewer line. Typically, that would involve removing the existing line and replacing it at a cost of as much as $4

million. In addition, this type of job would often take as long as 3 months to complete. Instead, Pasadena utilized a "trenchless" system that installs a new pipe inside the existing pipe and mechanically locks it into place. As a result, the job was completed in only two weeks and the cost was a relatively inexpensive $1.3 million.

The trenchless technology is manufactured by Insituform Gulf South, which has installed more than 1 million feet of replacement pipe. More details can be obtained by calling Insituform at (713) 643-9990.

Workers install a new pipe inside of an existing water main in Pasadena, TX, in late 1993. City officials say this use of "trenchless technology" may have saved them time and money.

Results from TAES, SCS Studies Suggest that Removing Young Cedars May Boost Recharge to Edwards Aquifer

Results of recent field experiments near Uvalde suggest that clearing young cedar trees may increase the amount of water yield from rangeland in the area by as much as 65,000 gallons per acre annually. If brush clearing were implemented throughout the area, it could enhance recharge to the Edwards Aquifer.

Two experiments are being conducted by research teams led by Bill Dugas of the Texas Agricultural Experiment Station and Phillip Wright of the U.S. Department of Agriculture Soil Conservation Service.

Dugas' studies, which began in 1990, involved clearing 10 to 15 foot cedar trees from rocky, sloping rangeland in northern Uvalde County. Tall metal frames that look like oversized coat racks were instrumented to measure rainfall, evapotranspiration, humidity, temperature and other factors. On the ground, some of the trees were fitted with stem gauges to measure water flows and water use. Results were compared to sites where the cedars were left in place.

Wright's studies were conducted two miles away. They cleared eight acres of cedars to measure the impact of brush clearing on flows to a nearby spring. Since the trees were cleared more than 2 years ago, the amount of water flowing to the springs has increased 28%, despite a 14% drop in rainfall during that time.

For more information, call Dugas at (817) 968-4147 or Wright at (210) 426-3198.

Shiner May be Endangered

The U.S. Fish and Wildlife Service (USFWS) has proposed that the Arkansas River Shiner (a two-inch fish found in the Texas High Plains) be declared an endangered species. If that occurs, water managers in the region say it could impact on surface and groundwater management in the region. In Texas, the Shiner is found along the Canadian River. USFWS says the action is needed because, in the last 20 years, the shiner's range has shrunk by 80%. An article describing the issue was published in the *Cross Section* newsletter. Copies can be obtained by calling (806) 762-0181.

Texas Tech Helps Develop Ogallala Water Plan

Researchers from Texas Tech University are cooperating with the High Plains Underground Water Conservation District No. 1, other local water districts, and other groups to develop a regional Ogallala water management plan for the Texas High Plains. This effort expands on planning work done by the Texas Water Development Board.

This fall, 40 water professionals from the region met in Lubbock to begin working on the plan. James Jonish of the Texas Tech Economics Department spoke about environmental needs, ways to increase participation, water supply and demand management. Lloyd Urban of the Texas Tech Water Resources Center identified topics that may need to be addressed including planning, water availability, and economic conditions.

Committees were formed to gather information on such topics as current and historic water use, the impact of conservation on groundwater depletion, and options to enhance water supplies. In December, committees reported on progress, and the group discussed a mission statement. Work on the mission statement will occur at the next meeting in late March in Amarillo.

For details, call Urban at (806) 742-3597 or the District at (806) 762-0181. Urban can also be reached with e-mail to lurban@coe2.coe.ttu.edu.

Texas A&M-Corpus Christi Researchers to Assist in Evaluating Environmental Impact of Laguna Madre Dredging

Scientists with the Conrad Blucher Institute for Surveying at Texas A&M University-Corpus Christi (TAMU-CC) will play a key role in monitoring the environmental impact of dredging the Lower Laguna Madre. The U.S. Army Corps of Engineers recently awarded a contract to dredge the southern section of the Gulf Intracoastal Waterway (GIWW) from Port Isabel to the Arroyo Colorado.

Texas A&M-CC scientists taking part in the project include Nick Kraus, Cheryl Brown and Chris Faucette. They mounted six data platforms along the Laguna Madre (three in the lower Laguna Madre, one where the upper Laguna Madre opens into Corpus Christi Bay, and two in Baffin Bay). The stations will automatically monitor water quality parameters including 3-dimensional currents, turbidity, salinity, temperature, dissolved oxygen, and chlorophyll. Data will be transmitted to the Institute. Goals are to monitor

the effects of dredging on the environment and to make recommendations that may reduce the cost of dredging. Other TAMU-CC scientists are investigating how the dredging may affect sea grass health, light attenuation, and the release of nutrients to the water. Much of the work will be done in cooperation with the National Marine Fisheries Service.

The maintenance dredging will help keep the GIWW open to shipping and is now being carried out. This dredging operation involves many environmental considerations including planting of seagrasses, environmental and sediment monitoring, and studies of the impact of the dredging on turbidity and water quality. Environmental groups including the Lower Laguna Madre Foundation and the Texas Center for Policy Studies protested the dredging. In 1994, the Center published a report that argued that maintaining this section of the GIWW was not economical and could pose environmental risks.

For details, call the Corps of Engineers Galveston office at (409) 766-3004, Kraus at (512) 994-2646, or the Center for Policy Studies at (512) 474-0811.

1950s Battle Over Comanche Springs is Focus of A&M Study

A Texas A&M University graduate student has published a paper that suggests a 1954 conflict between surface and groundwater users in the Fort Stockton area may provide some valuable insights into current water controversies. Laura Wimberley of the History Department, worked with researchers Tom Dunlap and Bob Calvert to produce a paper titled "The Battle for Comanche Springs."

This photo from the 1930s shows a healthy Comanche Springs with plenty of water. The springs are now dry.

In her study, Wimberley found that the Comanche Springs case was complex, and involved conflicts over agricultural practices, surface and groundwater rights, legal systems, and hydrology. The Pecos County Water Control and Improvement District and farmers they served believed that an "underground stream" flowed to the area and provided water for Comanche Springs and Leon Springs. This could make the waters subject to Texas surface water law. Other farmers in the area

(including the father of prominent future Texas A&M University graduate and gubernatorial candidate Clayton Williams) thought otherwise. They held that groundwater in the area was percolating and belonged to those who owned the land above it. A series of lawsuits was filed. The District sued groundwater pumpers in 1952, claiming that excessive groundwater use was cutting supplies to the springs.

As the lawsuit dragged on during the 1950s drought, the flow at Comanche Springs dipped to dangerously low levels. In 1954, a Civil appeals court ruled in favor of rights of landowners who pumped groundwater. The Texas Supreme Court twice refused to hear the case. The ultimate result was that the water district ceased to exist by 1955, because groundwater pumping had reduced spring and creek flows to only a slow trickle. Many farms in the area that were watered by the springs returned to a desert-like condition.

Wimberley's paper was ranked as one of the top articles at a recent symposium. For more information, contact her or Dunlap at the History Department at (409) 845-7151.

Dallas Aquarium Breeds Endangered Edwards Species

Rare and endangered species from the Edwards Aquifer are now being bred and reproduced at the Dallas Aquarium.

So far, zoo aquatic biologist David Schleser and his staff have cooperated with the San Diego Zoo to successfully breed the Comal Springs salamander (they're the only group in the world that has done so). The aquarium obtained some of the salamanders from Glenn Longley at Southwest Texas State University in 1990. At first, they could get the females to develop eggs, but not reproduce. After diving into the springs to observe the salamanders, the biologists discovered that although they couldn't observe any salamanders laying eggs, young salamanders always appeared in the vents near the spring openings. This suggested that salamanders travel downward into the spring upwellings to lay their eggs. As a result, the Aquarium developed a device consists of a 5-gallon fish tank that sits on top of a 4-foot plexiglass tube. The tube is filled with rocks and water is pumped through it. So far, the salamanders have used it to reproduce on five occasions.

Dallas Aquarium staff also helped breed the Texas blind salamander and the fountain darter and are now working to breed the threatened San Marcos salamander. The aquarium is fortunate that its groundwater supply is very similar to that of the Edwards Aquifer in terms of temperature, pH, and levels of dissolved minerals. For details, call the Dallas Aquarium at (214) 670-8453.

New TWRI Technical Reports Focus on Water Marketing, Border Environmental Issues

The Texas Water Resources Institute (TWRI) has recently published the following technical reports.

Legal and Institutional Barriers to Water Marketing in Texas (TR 167) was written by Ron Kaiser of the Texas A&M University Recreation, Parks, and Tourism Sciences

Department, with assistance from Fred Boadu of the Texas A&M Agricultural Economics Department and James Mertes of the Texas Tech University Landscape Architecture Department. The report presents and overview of Texas water law and water rights, explains how water needs can be met by reallocating existing supplies, analyzes public interest and legal issues that may affect water marketing, and assesses how Texas water law may impact water transfers and markets. The report also includes 11 recommended policy changes that Kaiser believes may make it easier to foster the growth and success of water markets.

Environmental Issues of the U.S.-Mexico Border region (TR 166) was edited by Howard Malstrom the Texas Agricultural Experiment Station at El Paso and TWRI Director Wayne Jordan. The report contains abstracts of presentations made by university researchers, and agency personnel at a workshop that TWRI held in June 1994 at Texas A&M University. The report identifies issues and recommended solutions to enhance data availability and information exchange in the border region.

Other recent TWRI technical reports include the following: *Reservoir Reliability Considering Water Rights and Quality* (TR 165) by Ralph Wurbs of the Texas A&M Civil Engineering Department, *Farmers, Lenders and Water Districts Response to Texas' Low Interest Loan Program for Water Conservation in Agriculture* (TR 164) by Ron Lacewell of the Texas A&M Agricultural Economics Department and Eduardo Segarra of Texas Tech University, *A Model for the Edwards Aquifer* by Nisai Wanakule of the Edwards Aquifer Research and Data Center at Southwest Texas State University (TR 163), and *Water and Solute Flow in A Highly Structured Soil* by Kevin McInnes and Willem Heuvelman of the Texas A&M Soil and Crop Sciences Department (TR 161).

TWRI also publishes three other newsletters: *Texas Water Resources*, *Texas On-Site Insights*, and *Texas Water Savers*. To receive a free copy of any newsletter, call TWRI at (409) 845-1851 or FAX us at (409) 845-8554. The e-mail address is twri@tamu.edu.

USGS Reports Deal with El Paso Recharge Project, Water Quality at Big Bend National Park

New reports published by the U.S. Geological Survey include the following: *Hydrogeology and Selected Water Quality Aspects of the Hueco Bolson Aquifer at the Hueco Bolson Recharge Project Area in El Paso* (WRI 94-4092) by Paul Buszka, Robert Brock and Richard Hooper; and *Hydrogeologic and Water Quality Data from Wells Near the Hueco Bolson Recharge Project Area in El Paso* by Robert Brock, Paul Buszka, and Edward Godsy (Open File Report 94-329). Other new USGS reports include: *Simulation of Ground-Water Flow and the Movement of Saline Water in the Hueco Bolson Aquifer and Adjacent Areas* (OFR 92-171) by George Groschen; *Hydrogeology, Geochemistry, and Quality of Water of the Basin and Oak Spring Areas of the Chisos Mountains, Big Bend National Park* (WRI 93-4112) by E.T. Baker and Paul Buszka; and *Organic Compounds from a Treated Wastewater Discharge Near Dallas* (WRI 93-4194) by Paul Buszka, Larry Barber, Michael Schroeder, and Larry Becker.

To order any of these reports or other USGS publications, call the library at the USGS Austin office at (512) 873-3020.

Report Summarizes Work of National Water Institutes

Recent accomplishments of the National Institutes for Water Research, including TWRI, have been published in a new report.

The report, *Research Program of the Water Resources Research Institutes* (1993-94), was prepared by Paul Godfrey of the Massachusetts Water Resources Research Center. It summarizes current research, lists projects by state and by research categories, and contains ways to contact all 54 institutes. The report shows that the majority of the projects carried out by Institutes focus on water quality, toxic substances, non-point pollution, and hydrology. Even though the program is allocated only $6 million annually by the Federal government, it generates $41 million in non-federal funds and $19 million in other federal funds.

Limited copies of the report are available by calling TWRI at (409) 845-1851.

Supercritical Water Oxidation is Focus of UT Reports

Technical reports dealing with supercritical water oxidation (SCWO) have been published recently by the Center for Research in Water Resources at the University of Texas at Austin.

Reports focusing on SCWO include the following: *SCWO and Hydrolysis Kinetics of Pyridine and 2,4-Dichlorophenol* (CRWR 241) by Neil Crain and Earnest Gloyna; *SCWO of Four Selected Priority Pollutants* (CRWR 242) by Anusuya Kanthasamy and Gloyna; *Separation of Inorganic Salts and Metal Oxides from SCWO by Cross-Flow Microfiltration* (CRWR 248) by Marcel Goemans, Gloyna, and Lixiong Li, *Reactions of Inorganic Nitrogen Species in Supercritical Water* (CRWR 250) by Phillip Dell'Orco and Gloyna; *Destruction of Toxic Organic Materials by SCW* (CRWR 251) by James Griffith and Gloyna, *Effect of Additives on the Oxidation of Dimethyl Methylphosphonate in SCW* (CRWR 252) by Jacqueline McKendry and Gloyna, and *SCWO of Dimethyl Methylphosphonate and Thiodiglycol* (CRWR 254) by Michael Turner. Another report, *Porous Medium Advection-Dispersing Modeling in a Geographic Information System* (CRWR 253) was written by John Tauxe. To order any report, call the CRWR at (512) 471-3131.

Computerized Bulletin Board from Gulf Coast Hazards Center Contains Information on Pollution, Cleanup Technologies

The Gulf Coast Hazardous Substance Research Center at Lamar University has recently made information on many of its programs available electronically.

Information can be obtained through the Center's Environmental Library Bulletin Board System (BBS). The system first brings users into a menu with nine choices. From there they can choose information on Center funded projects, researchers affiliated with the

Center, and publications that resulted from Center research. The BBS also provides access to the U.S. Environmental Protection Agency. Users are also able to request on-line searches of the Center's CD-ROM collection or to correspond with the Center.

The library can be accessed by modem by calling (409) 880-8709. Users can also reach the BBS by using telnet software and accessing the site at "lub002.lamar.edu" For more information, call (409) 880-8897.

Rice University and UT Researchers Write Books on Groundwater Contamination, Protection

Researchers at Rice University and the University of Texas at Austin have recently contributed to two books that deal with groundwater pollution.

Groundwater Contamination: Transport and Remediation was co-authored by Hanadi Rifai of the Rice U. Environmental and Energy Systems Institute, Philip Bedient the Rice U. Environmental Science and Engineering Department, and Charles Newell of Groundwater Services, Inc. of Houston. The book contains sections focusing on groundwater hydrology, groundwater flow and well mechanics, sources and types of contamination, data collection methods, mechanisms for contaminant transport, sorption and other chemical reactions, biodegradation kinetics, flow and transport through the unsaturated zone, hydrogeologic site investigations, legal protection of groundwater, and groundwater remediation and design. The book was published by Prentice Hall and can be ordered by calling 1 (800) 922-0579.

Groundwater Remediation was written by Randall Charbeneau of the Center for Research in Water Resources of the University of Texas at Austin (UT), Bedient, and Raymond Loehr of the UT Civil Engineering Department. The book contains chapters dealing with subsurface flow, subsurface contaminant transport, bioremediation of contaminated soils and sludges, pump and treat systems for groundwater contamination, bioremediation, and multiphase contamination and free product recovery. This book is published by Technomics and can be ordered by calling 1 (800) 233-9936.

TNRCC Reports Describe Water Quality in Neches River, Macrobenthos in Houston Ship Channel, Wellhead Protection

The Texas Natural Resource Conservation Commission (TNRCC) has recently produced many new reports including the following: *Intensive Survey of the Neches River Segment 0604* (AS-23/ IS) by David Petrick, and *Evaluation of Macrobenthic Community Trends in Relation to Water and Sediment Quality in the Houston Ship Channel from Historical Monitoring Data* (AS-33/ SR) by Leann Marks. Other new TNRCC reports include *Analysis of Fish Kills and Associated Water Quality Conditions in the Trinity River* (AS-24) by Jack Davis, and *A Public Water Supply Protection Strategy for the City of Claude* (AS-39) by Brad Cross, David Terry, and David Prescott.

To order any of these reports, call the TNRCC Publications Office at (512) 239-0028.

UT LBJ School Study Deals with Impact of NAFTA on the Environment

A new report that describes how the North American Free Trade Agreement (NAFTA) may affect Texas laws and the environment has been published by the Lyndon B. Johnson School for Public Affairs at the University of Texas at Austin.

The report, *The Evolving Protection of State Laws and the Environment: NAFTA from a Texas Perspective*, was prepared with assistance from the Texas Attorney General's office. Sections of the report deal with such issues as resolving environmental disputes, environmental provisions of NAFTA, environmental organizations that will work to implement and administer NAFTA, and the impact of NAFTA on the Texas legislative process.

The report was developed as part of the LBJ School's U.S.-Mexico Studies Program, and can be ordered from the LBJ School by calling (512) 471-8951.

Tarleton State U. Software Helps Manage Dairy Wastes

Researchers with the Texas Institute for Applied Environmental Research at Tarleton State University recently developed a computer software program to help dairy operators effectively manage their wastes.

The program, *Waste Disposal Management System* (version 2.0), was developed by Paul McKee and Joan Flowers in 1993. The software can be used to determine application rates for dairy manure. It also helps dairy operators maintain records of waste applications to agricultural fields and to record information from soil tests. The program allows users to keep separate records for harvests of each crop grown with dairy wastes, rainfall data, the location and acreage of disposal fields, and waste applications for each disposal field. The software can be obtained by contacting TIAER at Tarleton State University at (817) 968-9567.

Texas A&M-Kingsville Assesses if Saline Water Can Supplement Irrigation in Semi-Arid Areas

Can saline water be used to supplement rainfall in arid and semi-arid areas? That was the focus of a recent project conducted by Duane Gardiner and graduate student Gopikrishna Malladi of the Agronomy Department at Texas A&M University-Kingsville.

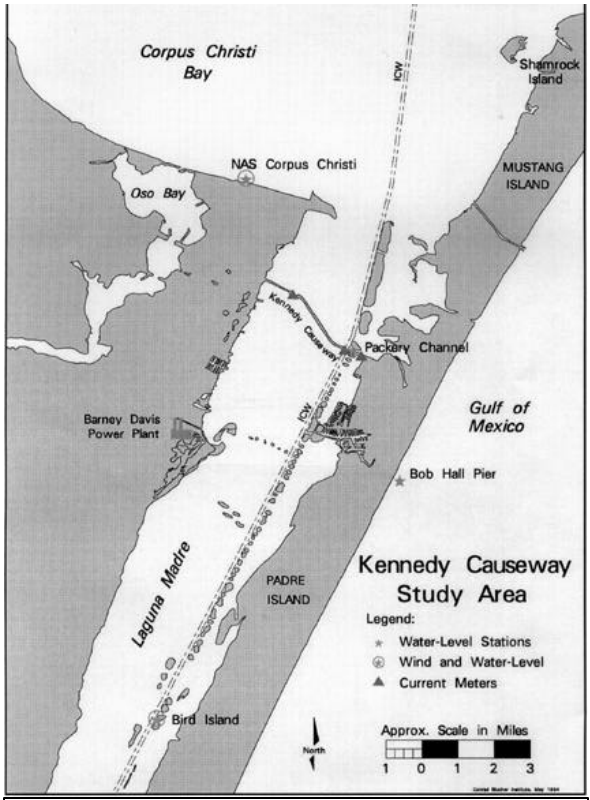
In the study, industrial saline wastewater was applied at three different levels of salinity ranging from 7,000 to 2,000 parts per million. The researchers applied the saline and rain water to cotton, grain sorghum and Bermuda grass that were grown in a laboratory. When crops received two-thirds of their water needs from rainfall and the rest from irrigation with the saline water, there was no adverse effect from irrigating with the salty water on any crop, but beans. In fact, cotton actually grew better when some saline water was applied.

Gardiner says the project is unique because saline water was applied intermittently along with simulated rainfall. As a result, the project is representative of "real world" conditions that receive sporadic amounts of rainfall. "This project shows that water supplies in the arid and semi-arid parts of south Texas could be supplemented by irrigation with saline water without reducing yields," Gardiner said. "This may be another asset farmers want to consider."

For details, call Gardiner at (512) 595-3719.

Texas A&M Corpus Christi Scientists Monitor Water Currents Along JFK Causeway

Scientists at Texas A&M University-Corpus Christi (TAMU-CC) have deployed solar-powered current meters at three openings in the John F. Kennedy (JFK) Causeway to measure horizontal and vertical water flow. TAMU-CC researchers participating in the project include Nick Kraus, Cheryl Brown, and Patrick Michaud of the Conrad Blucher Institute for Surveying and Science.



This map shows the sites along the JFK Causeway in Corpus Christi that are now being monitored by the Blucher Institute.

The first current meter was installed in the Humble Channel on June 6, 1994. Two other meters were installed about 10 days later in the Intracoastal Waterway and in the relief canal that runs into Packery Channel. The meters will be serviced monthly to remove biological organisms, mussels, and benthic organisms that can clog the system.

The current meters are state-of-the art instruments and are based on acoustic signal processing. Acoustic technology has many advantages over standard current meters. Acoustic instruments are more accurate, use less power, and can be operated for long periods without calibration. The current meters have backup batteries.

Measurements from the system are transmitted regularly by radio to the Blucher Institute, where they are quality checked, plotted, and stored for analyses. Blucher Institute researchers designed and built special computer hardware and software needed to run the current meters and transmit the data. Mounts for the meters were developed by the Institute's field operations group, with the cooperation of the Texas Department of Transportation. "Measurements so far have shown the flow in the Humble Channel and Intracoastal Waterway to be much stronger than in the Relief Canal," says

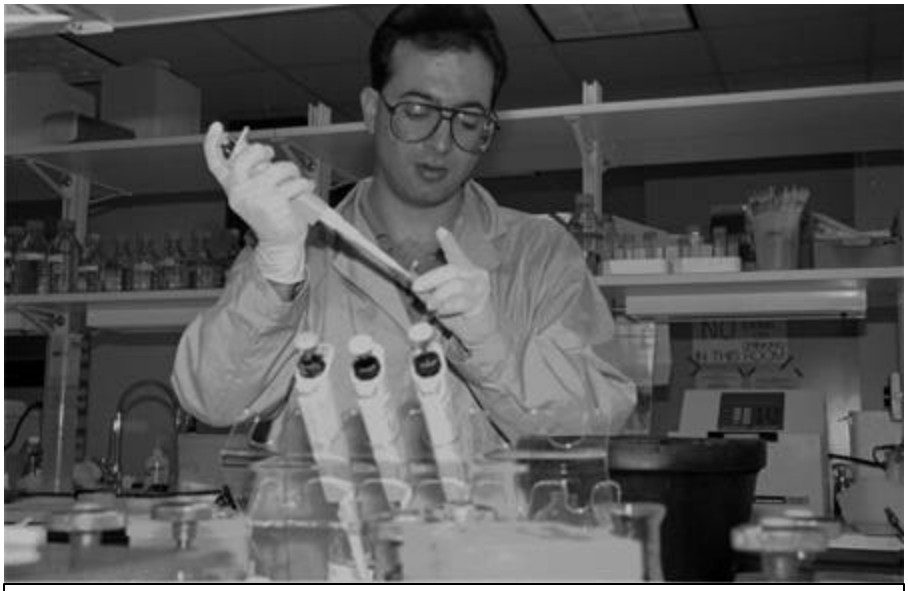
Blucher Institute Director Nick Kraus. "Typically, when the southeast winds blow, the current is strongest at Humble Channel."

When combined with simultaneous tide and wind measurements made by the Institute at nearby Bird Island and the Naval Air Station, the current meters will give unprecedented information on the flow patterns of water in the Upper Laguna Madre and Corpus Christi Bay. Information from this project will be useful in studies dealing with the environment, oil spill prevention and surveillance, and navigation. Data on these currents is now being entered in the Institute's computer models of water flow and water quality for the Laguna Madre.

For details, call Kraus at (512) 994-2715. His e-mail address is Kraus@cbi.tamucc.edu.

Texas A&M and Rice U. Researchers Investigate How Plant Roots React to Environmental Stress

A research project has been awarded to Texas A&M University scientists to study how the roots of maize plants react to environmental stresses. The goal is to identify genetic factors that could be used to modify the root systems of many crops so that they can more easily access the water they need to avoid the negative effects of drought and heat stress. Lead scientists in the study are Page Morgan, Rod Wing, and Wayne Jordan of the Soil and Crop Sciences Department (Jordan is also Director of TWRI). Janet Braam of the Rice University Biochemistry and Cell Biology Department will collaborate in the study.



Graduate student (above) David Finklestein isolates genetic material from corn roots to identify genes that enable roots to penetrate through high strength soils to extract water.

The project focuses on genetic factors that limit or enhance the ability of plant roots to penetrate into the soil to extract water. Specific environmental factors make it difficult for roots to grow and may limit plant growth. Much of the research by Jordan and Morgan will investigate the role of a chemical, ethylene, that provides early signals about when maize roots are stressed. They will also utilize a cDNA library to identify genes that are transformed when root growth is impeded. Braam will identify similar processes in a

mustard plant, *Aridopis*, that has less DNA than other plants and can be easily manipulated.

The study may provide new insights about the cues that crop roots use to signal that they are under stress and the genetic programs plants use to overcome stress. This could be critical in developing new crop strains and tillage practices. For details, call Jordan at (409) 845-1851 or Morgan at (409) 845-8274.

Playa Lakes Are Rich in History, Texas Tech Researcher Says

To many people today, the playa lakes in the Texas High Plains are only regarded as a source of irrigation water or maybe as a habitat for migrating birds. However, a recent paper by a researcher at the Texas Tech University Library reminds us that these lakes are also rich in historical significance.

David Murrah is the Associate Director of Libraries for Special Collections at Texas Tech. He recently presented a paper, "Round as Plates: Playas and the Exploration and Settlement of the Llano Estacado," at the Playa Basin Symposium at the University. Murrah's paper confirms that mankind has used the playa lakes almost continuously (except during droughts) for 12,000 years. He cites archeological evidence that Native Americans used the playas as a water source and as sites that could be used to hunt mammoths, buffaloes, and other animals.

When Spanish explorers, under the lead of Francisco de Coronado, arrived in 1541, they named the lakes playas because they were "round as plates." The Spaniards located and named virtually every river and spring-fed lake in the region including Punte de Agua ("point of water") which is now known as Lubbock Lake; Laguna Sabinas ("Cedar Lake" in Gaines County), Laguna Salada ("Salt Lake" in Bailey County), and many others.

Even relatively modern history influences how we perceive playa lakes, Murrah said. A myth that the region was the "Great American Desert" was popular in the 1860s. To counter that idea, land promoters of the early 1900s chose names like Roaring Springs, Running Water, Shallowater, and Oasis for new settlements. Many farm tracts were laid out so a playa lake was part of each parcel.

Proceedings of the Conference can be obtained from the Texas Tech Water Resources Center at (806) 742-3597. Murrah can be contacted at (806) 742-3749.

University of North Texas Researchers Develop System That Uses GIS to Site Monitoring Wells

Researchers at the University of North Texas are investigating whether geographic information systems (GIS) can be used to design groundwater monitoring networks.

Paul Hudak and Andrew Schoolmaster of UNT's Geography Department and Hugo Loaciga of the University of California at Santa Barbara cooperated on the project, which was featured in the June 1993 issue of *Water Resources Bulletin.* The goal of the study

was to develop a process that would use GIS and computer simulation models to more easily and accurately locate sites for groundwater monitoring wells that may be vulnerable to contamination from nearby waste facilities.

The process works like this. Sampling sites are determined by hydrogeologic conditions near the contaminant source. Potential sites are ranked according to geographic and hydrogeologic factors. The GIS is used to register the location of potential wells sites, to calculate the distance between those sites and a waste disposal facility, and to store data about groundwater conditions.

The researchers assessed the use of this type of system to design a network of groundwater monitoring wells near a landfill. A raster-based GIS was used to map the landfill and to evaluate different locations for monitoring wells. GWPATH software was utilized to track pollutant flow in the groundwater system. The result was the development of a monitoring system in which wells are strategically placed between the contaminant source and water supply wells.

For details, call Hudak at (817) 565-4312 or Schoolmaster at (817) 565-2452.

Texas A&M-Galveston Scientists Assess Stratification of Houston Ship Channel Waters

Researchers at Texas A&M University-Galveston (TAMU-G) recently conducted field studies of the Houston Ship Channel (HSC) to determine how much stratification was occurring in those waters.

The research was conducted during the fall of 1992 and spring 1993 by Fred Schlemmer, Ted Engelhardt and Susan Anderson of the TAMU-G Marine Sciences Department. The overall goal of the study was to determine how water quality characteristics like temperature and salinity vary or stratify with depth in the water.

In the project, the scientists used a SeaBird SEACAT Profiler and a 17-foot boat to sample water quality during 4 surveys of 17 stations. The surveys covered the HSC from its intersection with the Galveston Ship Channel to Redfish Island. Samples were collected for such parameters as salinity, temperature and water depth.

The results of the sampling suggest that stratification in the HSC is dominated by salinity levels, not temperature changes. A strong interface of saline water from the Gulf of Mexico was observed in the HSC. A distinct freshwater/saltwater wedge was observed that penetrated to the bottom of the HSC and extended well into Galveston Bay. Schlemmer said that it was surprising that waters in the HSC are stratified, because they are subject to strong mixing generated by ship traffic. For details, call Schlemmer at (409) 740-4518.

Rainulator May Be A Better Way to Study Infiltration, TAES Blackland, Baylor Researchers Say

Often, researchers need to control rainfall and other factors in field studies of soils. To respond to this need, researchers with the Texas Agricultural Experiment Station (TAES) and Baylor University are cooperating to develop and test a rainfall simulator that may be a more accurate method to determine infiltration rates.

Lead investigators of the study are Ranjan Muttiah of the TAES Blackland Research Center in Temple, and Bruce Byars and Peter Allen of the Baylor University Geology Department. Their work involves designing and testing of a device they call the "rainulator." The rainulator consists of eight sprinkler heads that are mounted on a frame that is 6-feet high and 4.5 feet square. The speed and intensity of different rainfall events can be simulated, ranging from drizzle to intense thunderstorms.

Muttiah and Byars used the rainulator to determine infiltration rates for two types of clay soils (Fairlie and Stephen) that are commonly found in Central Texas. Field studies were performed near Bullhide Creek, nine miles south of Waco. The researchers said that the rainulator performed effectively in the estimation of soil hydraulic properties. A major advantage over previous methods is that the rainulator accounts for areas where large cracks and fissures called macropores are located.

An article about the research was published in the 1994 proceedings from the American Institute of Hydrology meetings that were held in Austin in April. For details, call Muttiah at (817) 770-6659 or Byars or Allen at (817) 755-2361. Muttiah's e-mail is muttiah@brcsun0.tamu.edu.

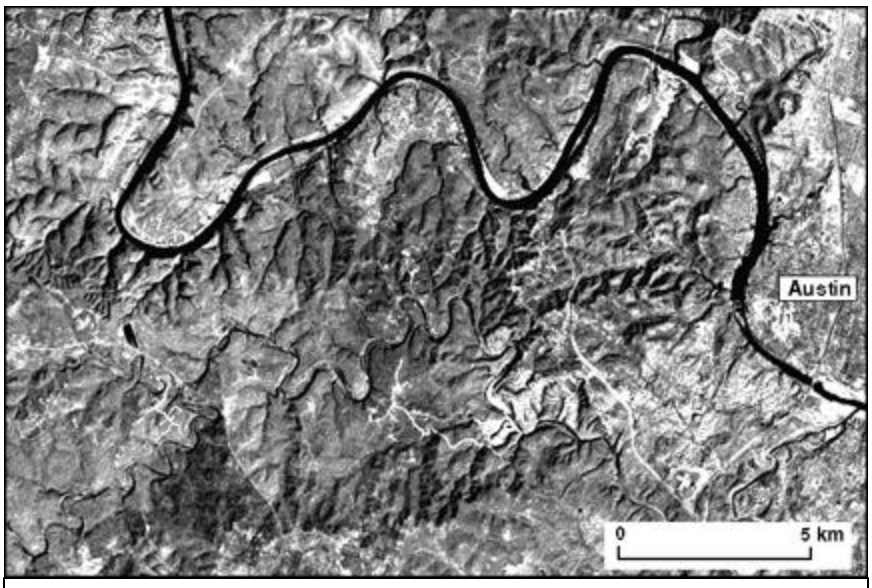
TCU Scientists Use Remotely Sensed Images, Computer Analyses, to Trace Karst Aquifer Flow Patterns

Sophisticated computer analyses of remotely sensed images are being used by Texas Christian University scientists to determine flow patterns in the Barton Springs portion of the Edwards Aquifer.

The studies are being conducted by Neven Kresic, Art Busbey, and Ken Morgan of the TCU Geology Department. The overall goal of the research was to determine whether the location of faults, fractures, and other karst surfaces could be detected from remotely sensed images and used to assess groundwater flow paths.

In the research, the scientists first created a digital elevation model by merging nine U.S. Geological Survey (USGS) digital elevation maps into a computer file. A relief energy surface map was created using in-house software, while Spyglass Transform software was used to analyze energy trends on the map. The final map was then neotectonically interpreted and the active zones were compared to information on faults from previously published USGS paper maps. A result of the analysis is that strong agreement between neotectonically active zones and fault lines was apparent.

The research also involved identifying naturally occurring lineaments like stream valleys, faults and fractures. A Landsat multi-spectral image of the Barton Springs area was analyzed using Adobe Photoshop software filters. Potential lineaments were divided into those that were naturally occurring fault and fracture lines and those that were really man-made structures like roads and power lines.



This Landsat image shows Barton Springs, west of Austin. The image was analyzed with computer software to show groundwater flow patterns.

The TCU researchers say that this technology is important because it represents a fast and inexpensive tool to study possible groundwater flow paths in karst terrains and other fissurred aquifers. For details, call Kresic at (817) 921-7506, or Morgan at (817) 921-7273. Kresic's e-mail address is kresic@gamma.is.tcu.edu.

Rice University Scientists Look to History to Gather Clues on Mercury Pollution

A Rice University researcher believes that Texas history may hold a key to learning more about mercury pollution in coastal bays and estuaries. Kathy Balshaw-Biddle of the Rice U. Energy and Environmental Systems Institute conducted the study, along with Fred Earley of Law Engineering of Houston, and Janet Wagner of J.K. Wagner and Company in Houston.

The researchers first traced and examined human activities at specific places and times that may have led to mercury pollution. They found that tanneries at Port Lavaca and Indianola would have likely used mercury from the 1870s to 1900. Later, many mercury intensive industries including book-binders and printers, brick and tile plants and gunsmiths were being established at Houston and Galveston. Balshaw-Biddle and Earley then evaluated levels of mercury-contaminated sediments along the Texas coast, using information from the Texas Natural Resource Commission STORET database and samples collected in 1991 as part of the Galveston Bay National Estuary Program.

The results show that mercury concentrations are highest in sediments near the outfall of ship channels in Houston, Texas City, Matagorda, Port Lavaca and Anahuac, where industrial activities were concentrated. The researchers also evaluated new technologies

to treat mercury-contaminated wastes including the use of a polymer sponge, pore filtration, and air sparging. For details, call Balshaw-Biddle at (713) 527-4700.