Review of and Recommendations for Hydrologic-Monitoring Activities in Southern Plains Network, National Park Service

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Review of and Recommendations for Hydrologic-Monitoring Activities in Southern Plains Network, National Park Service

By

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ABSTRACT

This report provides water quality and water quantity monitoring guidelines (procedures and techniques) and associated protocols (rules and methods) developed by the Edwards Aquifer Research and Data Center (EARDC) of Texas State University for the Southern High Plains Network (SOPN) of the National Park Service (NPS). The development of guidelines and protocols with which SOPN might more efficiently and effectively conduct future water-monitoring activities (specific tasks) necessitated the evaluation of existing data from previous monitoring efforts and a review of current water quality and quantity monitoring activities. Consequently, project objectives were designed around first obtaining a thorough review of historic water quality trends reflected in the available databases for each park unit within the SOPN. This review covered primarily NPS's collection of STORET-based "Horizon" baseline data, which are viewable on the Internet at: http://www.nature.nps.gov/water/horizon.cfm.

During the latter part of 2006, SOPN provided selected "legacy" water quality data to EARDC. These data were reviewed, subjected to quality-control procedures, and compiled by EARDC into a Microsoft Access database containing a "dynamic graphing procedure" for displaying data for sites with a minimum of 10 years of record and 20 or more water quality records (Slone and others, 2007). Data from sites that did not meet these criteria also were evaluated by querying tables in the Access file that are organized by parks within the SOPN network. The primary data examined represent the priority NPS Vital-Sign constituents identified in the Statement of Work (project agreement between EARDC and SOPN), namely: water temperature, dissolved oxygen, pH, specific conductance, and fecal-indicator bacteria. However, other constituents such as concentrations of nutrients, major ions, heavy metals, and suspended sediment also were examined to provide a greater understanding of the relations among Vital-Sign constituents.

The legacy water quality data contained records through the early-to-mid 1990s; therefore, it was not possible to evaluate more recent water quality conditions for any SOPN park unit. Data more recent than that provided by the legacy database may be available in hard copy (log books, field-data sheets, and (or) spreadsheet) formats at individual park units; however, such data were not included in EARDC's evaluation of historic water quality data.

Visits to park study units during May 2007 revealed that relatively recent data exist for many sites in one hard-copy form or another. In addition to specific recommendations related to water quality monitoring for specific park units, it is recommended that NPS allocate resources to compile and maintain such data in Microsoft Excel or Access spreadsheets (or other electronically based information system) and that it be combined with the legacy data sets and re-analyzed for current status and updated trends in relevant water quality conditions.

Although the Statement of Work emphasizes a need for monitoring guidelines and protocols with respect to water quality, the need exists likewise for surface and groundwater quantity. Because water quantity data can help explain temporal and spatial variations in water quality and many site-specific water quality issues are linked to aspects of surface water and (or) groundwater quantity, numerous recommendations regarding water quantity monitoring are presented herein, as well. As with hard-copy versions of existing water quality data, it is likewise suggested that all non-electronic water quantity records be consolidated, to the extent practical, within an electronic (digital) database (such as Microsoft Xcel) and coordinated where possible with the operation of an appropriate NPS-wide or national- or state-related database system.

INTRODUCTION

Background

The National Park Service (NPS) has long recognized that both the protection and restoration of its water resources and associated aquatic life is critical for the continued appreciation by park visitors, as well as the support of Congress and the American taxpayer. In accordance with the public's desire for potable and recreational water supplies, fundamental components of the NPS's Inventory and Monitoring (I & M) Program are designed to "understand, maintain, restore, and protect the inherent integrity of the natural resources," as outlined by Perkins and others (2005; 2006). Not surprisingly, the protection and restoration of National Park resources are two of NPS's most important obligations (Sue Braumiller, NPS-SOPN Regional Hydrologist, written comm., 2007).

Specific objectives of NPS's I & M Program are to: (1) inventory existing water quality data, (2) establish water quality benchmarks, (3) identify potential water quality problems, and (4) establish a water quality database for each park. In 1993, NPS's Water Resource Division (WRD) initiated its Baseline Water Quality Data Inventory and Analysis Project to characterize baseline water quality information for every park containing appreciable natural resources. Equally important to NPS's overall mission are aspects of surface water and groundwater dynamics, namely the tracking and maintenance of surface-water discharge and groundwater (aquifer water) levels.

The Southern Plains Network (SOPN) is one of the 32 networks included in the Servicewide I & M Program and one of seven networks in the Intermountain Region of NPS. In 2005, SOPN began to develop its own plans for monitoring the water resources in each of its 11 park units, which included the documentation of background conditions and the tracking of progress toward NPS's long-term goal of improving overall water quality and the integrity of surface and groundwater quantity (Perkins and others, 2005). Accordingly, the SOPN selected 29 Vital Signs that appeared to best represent a comprehensive monitoring program for ecosystems within each of its network properties.

Because SOPN lacked internal resources to analyze historic water data and develop guidelines and protocols before initiating activities in support of NPS's I & M program, it sought assistance from qualified, outside entities. After consulting various public and private agencies in search of personnel experienced in the evaluation of water quality and quantity, SOPN accepted a proposal from the Edwards Aquifer Research and Data Center (EARDC) at Texas State University in San Marcos, Texas. The cooperative effort with EARDC began on August 20, 2006 with the purpose of developing guidelines and protocols for monitoring selected aspects of water quantity and quality at 10 of SOPN's 11 park units, with ALFL's situation to be included with the monitoring priorities of neighboring LAMR.

The purpose of this report, therefore, is to recommend water quality and water quantity monitoring guidelines (procedures and techniques) and associated protocols (rules and methods) with which SOPN might more efficiently and effectively conduct future water-monitoring activities (specific tasks). The development of guidelines and protocols for future monitoring activities necessitated the evaluation of existing data from previous monitoring efforts and a review of current water quality and quantity monitoring activities. Accordingly, project objectives were designed around first reviewing historic water quality trends reflected in the available databases for each park unit (Slone and others, 2007). This review covered primarily the "Horizon" baseline data (http://www.nature.nps.gov/water/horizon.cfm) for: (1) water temperature, (2) dissolved oxygen, (3) pH, (4) specific conductance, (5) turbidity, and other nutrient- and bacteria-related constituents.

In addition to EARDC's review of SOPN's historic water quality data, selected surface-water and groundwater quantity records were reviewed for inherent patterns and relevant trends, as were associated monitoring activities at most park units. During May 20-26 of 2007, EARDC's director (Dr. Glenn

Longley) plus staff biologist (Stephen Porter) and hydrogeologists (Raymond Slade and Rene Barker) toured SOPN study units to observe, first-hand, the prevailing hydrogeological conditions and administrative priorities, including onsite activities and the most-pressing water-resource concerns and monitoring needs, as perceived by SOPN personnel.

Study Area

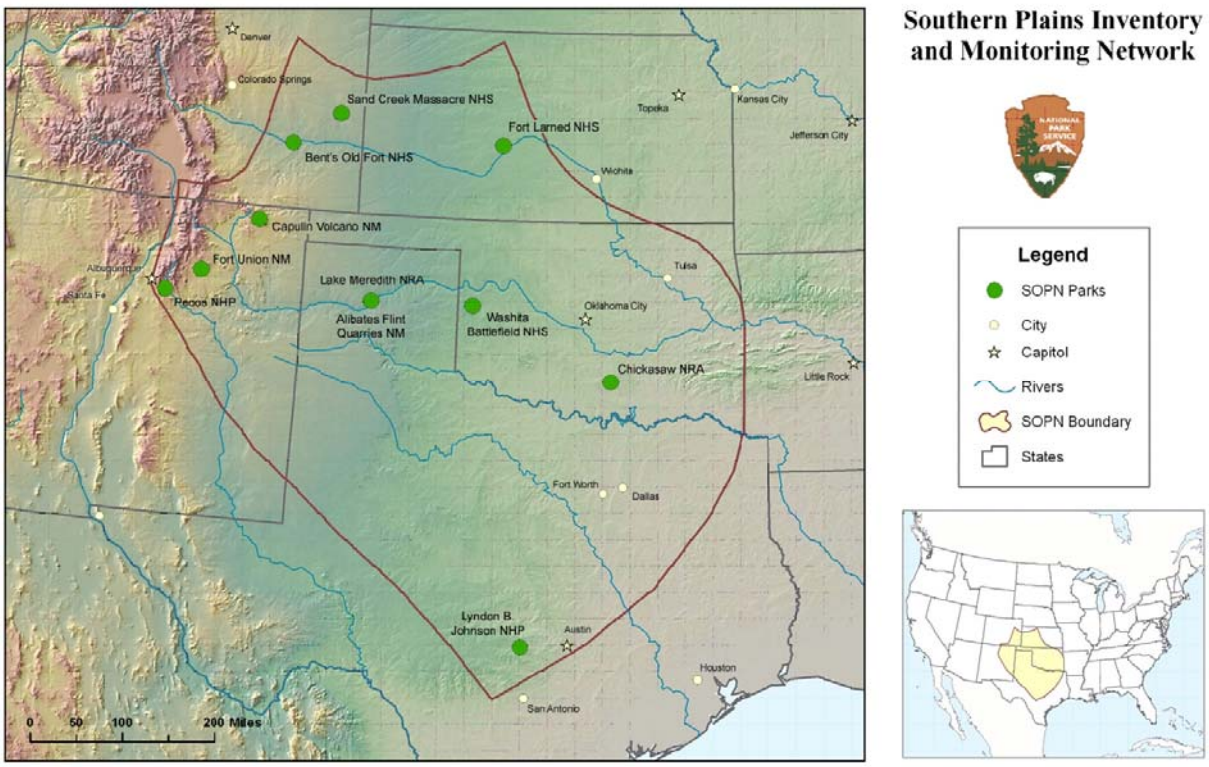


Figure 1. Location of study area, Southern Plains Inventory and Monitoring Network of the National Park Service.

The Southern Plains Network (SOPN) is composed of 11 National Park units in Colorado, Kansas, New Mexico, Oklahoma, and Texas (fig. 1), including four National Historic Sites, three National Monuments, two National Historical Parks, and two National Recreation Areas (Perkins and others, 2005, p. 10). SOPN's park units range in size from the 315 acres at Washita Battlefield National Historic Site to 46,349 acres at the Lake Meredith National Recreation Area. For simplicity, the names of the different park units were assigned acronyms (table 1); this abbreviated naming convention is used throughout the remainder of this report.

As true throughout most the Great Plains, SOPN's water resources are limited; only seven of the eleven network parks contain significant water bodies. As CAVO and FOUN have minimal water resources, their databases understandably offer little, if any, data with which to evaluate temporal trends. Although WABA and SAND have significant water resources, the extent of these resources are only minimally documented and, therefore, do not presently permit any sort of comprehensive water quality or water quantity evaluation.

Table 1. Key to Southern Plains Network park names and associated acronyms.

Alibates Flint Quarries National Monument	ALFL
Bent's Old Fort National Historic Site	BEOL
Capulin Volcano National Monument	CAVO
Chickasaw National Recreation Area	CHIC
Fort Larned National Historic Site	FOLS
Fort Union National Monument	FOUN
Lake Meredith National Recreation Area	LAMR
Lyndon B. Johnson National Historical Park	LYJO
Pecos National Historical Park	PECO
Sand Creek Massacre National Historic Site	SAND
Washita Battlefield National Historic Site	WABA

Bent's Old Fort National Historic Site (BEOL) covers 1.25 square miles (799 acres) of riparian floodplain along the Arkansas River in southeastern Colorado. The original adobe fort, which was constructed in 1833 to serve as a trade center on the Santa Fe Trail, was abandoned in 1849; the current National Historic Site was established in 1960.

BEOL falls within the Great Plains-Palouse Dry Steppe and the short-grass prairie ecoregion. Annual precipitation averages between 11 and 15 inches, of which roughly 70 percent falls during April through August and about 10 percent falls during November through February.

BEOL is underlain by the Arkansas River alluvial aquifer that is composed of up to 200 feet of unconsolidated clay, silt, sand, and gravel. Depths-to-groundwater, which range from less than a foot to 50 feet below land surface, generally lie within 5 - 10 feet of the surface (Weist and others, 1965). In addition to greater-than-normal precipitation during the 1990's [http://www.ocs.oregonstate.edu/index.html], waterlogging of onsite features during much of this decade has been attributed to increased stream stages in the Arkansas River and leakage from the upgradient Fort Lyons irrigation canal (Woods and others, 2002). Because precipitation since 1999 has been less than normal during all but two years (2001 and 2004), the threat to lower-lying parts of the renovated fort, including foundation and basement has subsided – at least for the time being (Sue Braumiller, NPS-SOPN Regional Hydrologist, written comm., 2007).

Capulin Volcano National Monument (CAVO), which covers nearly 1.25 square miles (793 acres) in northwestern New Mexico, was established to preserve a volcanic cinder cone that formed roughly 62,000 years ago.

Situated in the Great Plains-Palouse Dry Steppe Province, CAVO receives on average 16 – 20 inches of precipitation per year. The primary vegetation at CAVO include grasslands, which are growing upon the remnants of geologically recent lava flows, and piñon-juniper woodlands which appear to be encroaching into the grasslands on the flanks and on top of the cone.

Chickasaw National Recreation Area (CHIC) occupies 15.5 square miles (9,889 acres) of the Arbuckle Mountain geographic region and Red River drainage basin in south-central Oklahoma. CHIC was established in 1906 to protect unique recreational, cultural, and natural resources--including streams, lakes, and both freshwater and highly mineralized springs which are affected—if not controlled principally by—complex hydrogeological features.

Lying within the transition between Eastern deciduous forests and Western prairies, CHIC is located within the Subtropical Humid climatic zone, featuring a warm continental climate characterized by hot, humid summers with average maximum temperatures of 91° F. While upland areas are dominated by mixed, semi-arid native grasslands and oaks, riparian vegetation typifies the lowlands.

CHIC's two largest waterbodies are the Lake of the Arbuckles (surface area of 3,130 acres) and Veteran's Lake (64 acres), both of which support the park's drinking-water supply and water-based recreation, including fishing, boating, swimming, and water skiing (primary tourist attractions).

Fort Larned National Historic Site (FOLS) encompasses 1.1 square miles (718 acres) along the banks of the Pawnee River, most of which lies within the Pawnee River floodplain. FOLS is affected by a semi-arid continental climate characterized by highly variable and frequently changeable temperatures and precipitation. Low humidity and consistent breezes dominate the summertime, when maximum temperatures average about 89° F. Precipitation (including 20 inches of average-annual snowfall, averages about 23 inches per year, with most falling between August and October.

Prior to European settlement, the landscape at FOLS was covered with mixed-grass prairie and small wooded areas in the riparian areas of the Pawnee River. With agricultural development prairies were converted to croplands and woodlands were destroyed. The consequences of these changes are still a concern for Park managers today. Prairie restoration tops the list of management issues at this park.

The FOLS reach of the Pawnee River has been dry during most of the last 20 years due to groundwater declines in the adjacent aquifer as a result of its being pumped for water with which to irrigate nearby farmland. "It only flows now in response to large storms (significant runoff events)," according to Sue Braumiller (NPS-SOPN Regional Hydrologist, written comm., 2007).

Fort Union National Monument (FOUN) covers 1.1 square miles (721 acres) of high-desert terrain in northeastern New Mexico. FOUN was established in 1956 to preserve and protect a historically significant military fort situated on the Santa Fe Trail in north-central New Mexico.

Situated within the Arizona/New Mexico Plateau ecoregion (Omernik, 1987) at an elevation of 6,800 feet, FOUN's primary ecosystem is short-grass prairie. Annual precipitation averages between 16 – 20 inches/year, with the majority falling during May through September. Temperatures range between an average high of 80° F during June through August and an average low of 14° F during December through February.

Although there is no surface water within the park unit's boundary, Wolf Creek flows just outside FOUN's southern boundary, along the southwestern fringe of the Great Plains. Other than the possibility of very small—probably seasonal, intermittent, or infrequent—discharge into a west-draining arroyo immediately west of the Fort Union compound, there are no springs of significance at FOUN.

The two largest natural resource concerns for FOUN Park managers are invasive plant species and burrowing animals. Major landscape concern relates to erosion of old trails leading into and out from the fort. Because Wolf Creek flows near the monument's sewage lagoons, "meandering could affect the integrity of the lagoons over time," according to NPS personnel.

Lake Meredith National Recreation Area (LAMR) covers 72.4 square miles (46,349 acres) of the west Texas Panhandle. LAMR was established on November 28, 1990 to "provide for public outdoor recreation use and enjoyment of the lands and waters associated with Lake Meredith in the State of Texas, and to protect the scenic, scientific, cultural, and other values contributing to the public enjoyment of such lands and waters." Operated by the Canadian River Municipal Water Authority, Lake Meredith supplies water to 11 public water systems, including those serving Amarillo and Lubbock. Approximately 750,000 people are dependent upon these systems, through which water is delivered via 320 miles of pipeline.

LAMR is located in the Southwestern Tablelands ecoregion (Omernik, 1986), bounded by the Western High Plains ecoregion to the north and south of the Canadian River. The landscape, best characterized as rough and broken, can be divided into two distinct areas: the upland area including the mesa top with a steep, gravelly slope, and the bottomland area surrounding the reservoir. The semi-arid climate of the region is characterized by an average annual precipitation of 20 inches, 70 percent of which falls within the primary growing season of April through September. The summers are hot and dry and the winters are cold with almost continuous strong winds that cause evapotranspiration rates that are estimated to average 60 – 65 percent of precipitation.

Lyndon B. Johnson National Historical Park (LYJO) comprises one square mile (674 acres) in the Hill Country of south-central Texas. LYJO is composed of two districts: the LBJ Ranch and other properties in Johnson City, Texas. LYJO preserves the birthplace, boyhood home, ranch, and final resting place of the 36th president of the United States as well as several other structures associated with the president and his ancestors. The Pedernales River, a tributary to the Colorado River, flows through the Park, as well as smaller tributary streams. The park also contains several ponds.

LYJO is characterized by a landscape of gently rolling, forested hills and grasslands. LYJO's subtropical, subhumid nature of the region provides an annual-average precipitation of about 32 inches, with the majority falling during April through September. The climate is characterized by mostly sunny, mild climatic conditions with the exception of relatively high humidity and summertime temperatures that sometimes exceed 100º F. As winter temperatures typically hover about 50º F, snow and ice are rarities.

According to Sue Braumiller (NPS-SOPN Regional Hydrologist, written comm., 2007) park personnel are concerned about bank erosion as a "long-term issue." Unpublished documents (John Middleton, University of Texas-Austin Graduate Student, written comm., 2004; 2005) provide evidence of "significant" channel widening and areas of bank slumping near three onsite dams. To help stabilize the banks and minimize unwanted sedimentation behind the dams, efforts are underway or under consideration to restore riparian vegetation, introduce non-woody, relatively deep-rooted plants, implement bank-stabilizing structures, and limit cattle access to only the north side of the Pedernales River.

Pecos National Historical Park (PECO) has expanded to nearly 20 times its original size. From its original size of less than one-half square mile (340 acres) in 1965, the Pecos National Monument was expanded into the Pecos National Historical Park in 1990. With the addition of the Forked Lightning Ranch and additional smaller parcels, PECO now covers more than 10 square miles (6,670 acres). The park was established to preserve an exceptional cultural and natural area that has had a long human history.

Precipitation totals vary between 16 and 20 inches, with the majority falling during the summer. Temperatures range from an average high of 80º F during June through August to an average low of 15º F during December through February. Most of PECO lays in the upper Pecos River valley, bordered by the 13,000-foot Sangre de Cristo Mountains to the north, the rugged hills of the Tecolote Range to the east, and the steep Glorieta Mesa to the west.

PECO contains a 2.9 mile segment of the Pecos River, and the lower 3.2 miles of Glorieta Creek, a perennial tributary to the Pecos River. The Glorieta unit includes a mile-long reach of Glorieta Creek and a half-mile reach of Galisteo Creek.

Sand Creek Massacre National Historic Site (SAND) is a four-square mile (2,400 acre) site that lies along a 5.5 mile stretch of the Big Sandy Creek in southeastern Colorado. SAND's landscape is largely mixed-grass prairies and wooded riparian areas. Trees on the site are eastern cottonwood, found in evenaged groves close to current or historic seasonal stream traces of Big Sandy Creek. SAND is within the High Plains section of the Great Plains-Palouse Dry Steppe Province ecoregion.

Big Sandy Creek is an intermittent stream that, from the northwestern corner, meanders through central parts and across the southern boundary of SAND. Most of stream discharge through the site results in the form of short-term runoff (including limited base flow) from infrequent, but relatively intense spring and summer rainfall events. While severe flooding does not appear to occur as a frequent event, similar drainages in the area historically have experienced “nuisance” flooding as the result of highly localized summer thunderstorms (Noon and others, 2005, p, 5). Although the Big Sandy was observed in flood stage during latter parts of the wetter-than-normal 1990’s decade, during normal and dry years, the creek flows mostly locally or appears to exist only within streambed depressions. Historically the Big Sandy has not proven reliable as a source of potable or irrigation water.

SAND typically is subjected to predominantly clear, dry weather with moderate winds from the southeast. Precipitation, which averages about 13 – 14 inches per year, is somewhat evenly distributed among twelve months. Whereas summer thunderstorms typically bring torrential rains and sometimes hail, winter snowfall averages 27 inches annually. Temperatures range from an average 87°F during June through August to an average minimum of 14°F during December through February.

Washita Battlefield National Historic Site (WABA), which covers about one-half square mile (approximately 315 acres), was established in 1996 “to recognize the importance of the Battle of Washita as a nationally significant element of frontier military history and as a symbol of the struggles of the Southern Great Plains tribes to maintain control of their traditional use areas.” The most important water resource is the Washita River, along whose banks bands of Cheyenne Indians once camped under leadership of Chief Black Kettle.

WABA’s climate is subhumid, temperate, and continental. Characterized by hot summers, mild winters, and relatively high wind velocities, the weather produces wide fluctuations in precipitation. Maximum daily temperatures average 91° F during June through August; minimum temperatures average 23° F during December through February. Rainfall is poorly distributed throughout the typical year; most precipitation, which averages about 25 inches per year, falls April through August. The summer thunderstorms, which are frequently severe, can produce tornadoes.

Southern Plains Hydrologic-Monitoring Program

The Southern Plains Network currently is developing a long-term monitoring program for 11 national park units in Colorado, Kansas, New Mexico, Oklahoma, and Texas (http://www.nature.nps.gov/im/units/sopn/monitoring.cfm). This program uses ecological indicators, or Vital Signs, to track conditions and (or) identify changes in relevant onsite ecosystems. In order to identify and document changes in such ecosystems, certain elements must be monitored as a subset of the total park environment. These individual aspects include – among other environmental entities – water resources and various ecological, biological, and physical processes associated with water.

Vital Sign Indicators

Similar to how a person's vital signs (such as pulse count and breathing) are periodically checked, it is essential to monitor the vital signs of nature. NPS's Vital Signs are critical early-warning indicators of the overall health of the natural environment. As current funding precludes the SOPN from monitoring all 29 of its recognized Vital Signs, the network is devoting most of its effort toward monitoring 11 core Vital Signs deemed to best represent the health of SOPN's ecosystems (Perkins and others, 2006). Three of the most relevant signs are surface-water quality, surface-water quantity, and ground-water quantity.

The NPS (http://science.nature.nps.gov/im/monitor/ProgramGoals.cfm) defines Vital Signs as a "subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values." Vital Signs are key conditions or processes that most effectively indicate the health of an ecosystem. Vital Signs are considered any aspect of the environment that can be measured (or estimated) to provide useful perspectives into the state of the ecosystem.

Knowing the current status of its water resources is fundamental to NPS's ability to manage and maintain its park units for the enjoyment of future generations (Perkins and others, 2006, p. 1). NPS managers are confronted with increasingly complex and challenging issues that require a broad-based understanding of the status and trends of park resources as a basis for making decisions and working with other agencies and the public for the benefit of all. Despite being only a part of a larger environmental framework, each park unit must be managed in ways that address the constraints and limitations imposed by each unit's particular hydrologic and ecological setting.

Natural Resource Monitoring

A central component of NPS's stewardship (http://science.nature.nps.gov/im/monitor/ProgramGoals.cfm) involves natural resource monitoring, which is defined as the "systematic collection of data that produces new knowledge or relationships and usually involves an experimental approach, in which a hypothesis concerning the probable cause of an observation is tested in situations with and without the specified cause." In conjunction with natural resource inventories and research, natural resource monitoring provides information needed for effective, scientifically sound managerial decisions and resource protection (http://science.nature.nps.gov/im/monitor/ProgramGoals.cfm).

Natural resource inventories are comprehensive, point-in-time efforts to determine the location or condition of a resource, including the presence, distribution, and status of plants and animals, as well as physical resources such as the geology, air, and water. Monitoring differs from inventories through the added dimension of time; the overriding purpose of monitoring is to track a trend or detect change in a resource trend. Thus, natural-resource monitoring is defined (Elzinga and others, 1998) as, "the collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective."

Natural resource monitoring is important for two major reasons. First, site-specific information is needed to identify and better understand changes in complex, variable, and imperfectly understood natural systems. Second, monitoring helps determine whether observed changes are within the natural levels of variability or might be indicators of undesirable human influences.

Understanding the dynamic nature of park ecosystems and the superimposed effects of human activity is an essential management process required to "maintain, enhance, or restore the ecological integrity of park ecosystems and to avoid, minimize, or mitigate ecological threats" to such systems (Roman and Barrett, 1999). The information that results is analyzed and used as early detectors against potential resource problems, which enables park managers to take action on an as-needed basis to benefit the overall health of park resources.

Although detection of a change in a given water quality or quantity trend might necessitate managerial reaction, it might alternatively indicate a need for a different perspective and (or) approach to the monitoring process. A research design typically is required to determine the cause of changes detected through resource monitoring. Consequently, the development of monitoring protocols involves a research component to determine the appropriate spatial and temporal scale for such monitoring.

Objectives

The project's overall objective is to provide SOPN information it might use to more efficiently and effectively accomplish NPS's goal of maintaining or improving the quality and quantity of water resources within the National Park system. Accordingly, water-monitoring guidelines (procedures and techniques), protocols (rules and methods), and associated activities (specific tasks) are herein recommended toward:

(1) Providing a reasonable degree of uniformity among future SOPN efforts to monitor groundwater quantity and surface-water quantity and quality, while also addressing the particular needs of each SOPN park unit;

(2) Implementing a scientifically valid set of standard operating practices through which SOPN might:

- More effectively evaluate relevant groundwater and surface-water conditions and the ecological health of SOPN water bodies,
- Identify and quantify ─ through more intensive efforts ─ the importance of existing and (or) anticipated problems in selected parks,
- Identify and quantify sources or potential sources of pollution that cause or contribute to those problems, including point and nonpoint sources, and
- Evaluate the long-term effectiveness of ongoing efforts to minimize or eliminate pollution from those sources; and

(3) Providing for data compatibility in terms of how the resulting data are efficiently stored, maintained, and shared among various users both within and outside SOPN.

The water-monitoring guidelines, protocols, and associated activities recommended herein should enable the systematic collection of consistent information from a variety of monitoring sites, thus providing a scientific baseline of comparable data with which to more readily evaluate and better understand and respond to future water resource conditions.

Purpose and Scope

This report presents the results of the last two phases of a four-phased study undertaken cooperatively between SOPN and EARDC to develop long-term monitoring protocols for surface-water quantity and quality and groundwater quantity. This report results from work performed during August 2006 – August 2007 under the direct supervision of Dr. Glenn Longley, EARDC Director at Texas State University and Dr. Dustin (Dusty) Perkins and Dr. Robert Bennetts, (former and current SOPN Coordinators, respectively).

Phase 1 of the current study covered the retrieval and review of existing surface-water quality and quantity and groundwater quantity databases and associated monitoring activities and protocols. As part of **Phase 1**, SOPN provided EARDC with electronic water quality datasets for each park unit. **Phase 2** culminated with the development a statistical-based graphical program: the Dynamic Graphing Procedure (DGP), which computes and displays temporal trends in SOPN'S water quality data (Slone and others, 2007). During **Phase 3**, the DGP was used to analyze trends in the water quality data of individual park units and provide a basis for recommending activities and protocols herein. For the sake of efficiency and because the extent and depth of trend analysis could not be appreciated beforehand, the analyses focused on fewer sites with presumably the most meaningful data, rather than on more sites with seemingly little or ambiguous data.

SOPN's water-monitoring needs reflect NPS's larger I & M Program to develop a stronger scientific basis for the stewardship and management of our nation's natural resources. Accordingly, the purpose of this report is to recommend water quality and water quantity monitoring guidelines (procedures and techniques) and associated protocols (rules and methods) in regard to SOPN's continuing efforts to support NPS's I & M initiative. These recommendations are intended to satisfy the **Phase 4** objectives of EARDC's current project with SOPN.

Acknowledgements

EARDC is greatly indebted to SOPN park personnel for the time they took to introduce important aspects of their respective parks/sites during EARDC's one-week, June 2007 tour of SOPN's properties. Especially helpful was assistance from Dr. Robert Bennetts (NPS-SOPN acting director) and Heidi Sosinski (SOPN data manager) and the efforts and (or) staffs of: Ted Benson (PECO); Steve Burrough (CHIC); Paul Eubank (LAMR); Wendy Lauritzen (WABA); Chris Moos (CAVO); Fran Pannebaker; (BEOL and SAND); Felix Revello (FOLS); and Marie Frias Sauter (FOUN);

All park-unit maps and accompanying data tables (Appendices A and B) used herein to locate park features and sampling sites were compiled by Ms. Sosinski. Heidi's ability to create illustrations for the purposes of identifying water quality and water quantity features within a spatial context—a tedious task that is too-frequently overlooked—is sincerely appreciated.

Sue Braumiller (NPS-SOPN Regional Hydrologist) is thanked, likewise, for her time and effort to distribute and explain pertinent water-resource information for several park units.

Ms. Braumiller's and Tomye Folts-Zettner's (NPS-SOPN Ecologist) efforts to quickly review and provide relevant feedback on first-draft copies of this report are very much appreciated.

Glossaries of Water Science

To help with the interpretation of explanations and recommendations in this report, the use of a scientific glossary might prove helpful. For this purpose, an online aid is available at: http://capp.water.usgs.gov/GIP/h2o_gloss/.

Additionally, a hard-copy alternative is offered by the USGS (1974) and the following fundamental groundwater and surface-water terms are provided:

Aquifer: An underground layer or zone of porous rock that yields groundwater to wells and (or) springs.

Confined aquifer: An aquifer in which groundwater is contained under pressure that is significantly greater than atmospheric pressure.

Gage height (also **stream stage**): The vertical height of the stream surface above an arbitrary datum. The datum of the gage (zero gage height) usually is below the stream channel. The gage height is measured at a given position on the stream surface (in the specific pool at the streamgaging station) If the datum of the gage is mean sea level, the gage height value of the stream added to the gage datum also represents the elevation of the water surface at the gaging point.

Groundwater: The portion of the precipitation that has been absorbed by the ground and has become part of the groundwater

Hydraulic head: The level to which water rises in a confined aquifer.

Streamflow (also **discharge**): The volume of water flowing past a given point in the stream in a given period of time. Streamflow usually is reported as cubic feet per second (ft3/s).

Unconfined aquifer: An aquifer containing water that is not under pressure; the water level in such a well is the same as the water table outside the well.

Water level (also **water table**): The level below which an unconfined aquifer is saturated.

REVIEW OF EXISTING HYDROLOGIC-MONITORING ACTIVITIES

Monitoring Procedures

Surface-water quality has been monitored since the mid-1960s at many SOPN park sites, however, the constituents monitored and period of record varies considerably among sites and parks. Monitoring has been most consistent for the National Park Service (NPS) Southern Plains Inventory and Monitoring Network (SOPN) "core Vital-Sign constituents:" water temperature, dissolved oxygen, pH, specific conductance, and indicator bacteria (i.e. fecal coliform, total coliform, and fecal streptococcus bacteria). U.S. Environmental Protection Agency STORET "legacy" data were reviewed and provided by NPS personnel. The legacy data were reviewed, subjected to quality-control procedures, and compiled into an Microsoft Access database containing a dynamic graphing procedure for displaying data for sites with a minimum of 10 years of record and 20 or more water quality records (Sloan and others, 2007). Data from sites that did not meet those criteria also were evaluated by querying tables in the Access file that are organized by parks within the SOPN network. We primarily examined data representing the core Vital-Sign constituents identified in our Statement of Work; however, other constituents such as concentrations of nutrients, major ions, heavy metals, and suspended sediment also were examined to provide greater understanding of Vital-Sign constituent relations. Although relatively few trends or changes in water quality conditions were detected, this database can serve to document "baseline" conditions (mid-1960s through mid-1990s), and the variance associated with constituent data, with which more recent water quality data may be compared. These data will be valuable for evaluating water quality influences from future population growth and human activities occurring in stream and lake basins, as well as regional- and (or) global-scale environmental changes or trends that may occur in the future, particularly in remote park locations where local human influences are minimal.

Surface-Water Quality

Our analyses were restricted to the STORET legacy period of record that ended in 1999, thus our conclusions about water quality condition and trends are limited and may not be representative of current (2007) conditions. No water quality data were provided for four of the SOPN parks (CAVO, FOUN, SAND, and WABA). During our visits to the parks in May 2007, it became apparent that considerable data may exist in log books, field sheets, or paper copies of reports from water quality laboratories. There is a need for these data to be entered into a digital format, however, no standardized transactional database presently exists for park personnel to enter such data. Water quality and biological data from independent studies also exists for some parks (e.g. CHIC, LYJO, and PECO), however, no attempt has been made to compile and synthesize data from these studies into a report that could document "legacy" environmental conditions similar to what is being presented for water quality conditions in this report.

Analyses of data indicate that water quality conditions generally met aquatic-life criteria, with relatively few exceptions (e.g. low dissolved-oxygen concentrations or high pH values). Elevated indicator bacteria levels at some sites exceeded contact-recreational criteria, with levels at a few sites indicative of poorly-treated wastewater effluent and (or) influences from agricultural activities. Some sites appear to have been influenced by agricultural, urban, and (or) commercial (e.g. oil and gas production) activities, resulting in stream or lake eutrophication, sedimentation, or elevated concentrations of certain major irons (e.g. chloride and sulfate). Stream hydrology and (or) the quantity of lake storage influences water quality conditions at other sites. Because of the remote location of certain parks and sparse human development within the associated watersheds, water quality appears to be very good to excellent in a number of streams flowing through or near those parks.

Groundwater

Although groundwater is a major natural resource concern at several SOPN parks, groundwater quantity (aquifer water-level) conditions are monitored currently at only one of SOPN's 11 park units, CHIC. CHIC personnel are monitoring groundwater levels in four wells associated with this park unit (fig. CHICc). These observation wells are known as the East, West, South, and North Wells. All but the North Well are located inside park unit boundaries (Sue Braumiller, NPS-SOPN Regional Hydrologist, written comm., 2007).

The background and construction details for the East and West Wells are summarized by Hanson and Cates (1994, p.19-24). It appears that the USGS supervised the collection of water levels from the East and West wells during August 1972 through at least August 1995 – and perhaps through November 2002(?) – after which the NPS assumed monitoring duties.

According to Ms. Braumiller, he South and North Wells are relatively recent additions to CHIC's monitoring network, with data collection at the South Well beginning in June 1995. The North Well is a capped, "flowing artesian well at a retired power plant," with no other information available to reference herein. According to Ms. Braumiller, groundwater-level data are "downloaded monthly to bimonthly from In-Situ Mini-Trolls by park staff and archived at both the park and the NPS WRD Water Rights Branch."

Databases

Surface-Water Quality

As will be described in subsequent sections of this report, archival databases currently are maintained by the U.S. Environmental Protection Agency (e.g. STORET), the U.S. Geological Survey (e.g. NWIS), and most State agencies. There is an immediate need for a standardized transactional database that could be used by all NPS parks for the entry and management of water quality data. The need is particularly acute for entering and temporarily storing biological and stream-habitat data. Although there has been limited capability for entering biological data into STORET, it hasn't fully met the requirements of most environmental studies. Biological databases currently are under development by USEPA and USGS (NAWQA Program) and may be available for general use within the next several years. In the interim, biological data could be formatted and stored in a relational database such as Microsoft Access. The design of water quality and biological databases is beyond the scope of this report, however, the table structure given by Sloan and others (2007) could be used as an example of an appropriate data format that should be compatible with archival databases that will be available in the future.

Groundwater

A database of groundwater information can exist for water wells, test-observation holes, simple borings, or springs. As stated above, CHIC is the only SOPN park unit that currently supports any monitoring of groundwater quantity (Sue Braumiller, NPS-SOPN Regional Hydrologist, written comm., 2007). Accordingly, the status of groundwater databases associated with SOPN is known and reported herein only for CHIC. Likewise, groundwater hydrographs for three (East, West, and South) of CHIC's four monitoring wells were compiled and are shown in figures 2, 3, and 4.

In addition to Microsoft Excel spreadsheet files provided by Ms. Braumiller, the hydrographs for the East and West Wells are supported by data in the USGS's online (GWSI) database, accessible through the following URLs:

http://waterdata.usgs.gov/ok/nwis/inventory/?site_no=343017096561501&amp,
http://waterdata.usgs.gov/ok/nwis/inventory/?site_no=343022096565701&amp.

Although groundwater levels are not monitored currently (at least on a continuous basis) at BEOL, water levels were measured there during March – September, 2001 from 15 hand-augured and well-point driven piezometers. These sites were installed in association with a study conducted near that timeframe by Woods and others (2002). In addition to hydrographs for these observation wells, a table of associated water levels (relative to a local elevation datum) is provided therein (Woods and others, 2002, p. 20-22; p. 32). It is not known by EARDC whether these data are also maintained in NPS or GWSI-type (USGS) databases.

Although EARDC is not aware of additional groundwater-level monitoring at any of the remaining SOPN park units, we understand that any databases resulting from such activity in the past could contain relevant information with respect to historic groundwater quantity conditions at specific park units. For example, an internal NPS report for PECO (NPS, 1995), identifies some water-well and associated water-level information for individual wells on that property. However, other than understanding that some groundwater data for some PECO wells may be on file with the New Mexico State Engineers Office, EARDC is unable to judge whether any historic groundwater data exist within any active or abandoned database system for PECO.

GENERALIZED HYDROLOGIC-MONITORING RECOMMENDATIONS

Monitoring Methods

Monitoring methods represent the collection of data in order to document the quality and quantity of surface water and groundwater. The purpose of this section is to introduce the major types of monitoring methods and associated data collection that can be used to characterize water quality conditions and threats to the National Parks within the Southern Plains Inventory and Monitoring Network (SOPN). An explanation of the benefits of using such methods also is presented in this section. Gaging stations represent sites where hydrologic data are collected. The types of gaging stations and associated types of data collected for the stations are presented in table 2.

Surface Water quantity

Stream-flow methods provide data that can be used to complement quantitative, statistical analyses of water quality data values. Water-quality values can vary substantially with flow conditions, thus the variance and temporal trends in water quality values cannot be explained completely without accompanying stream-flow data.

Two types of streamflow data are available—stream stage and discharge (flow rates). Stage represents the vertical height of the stream surface above an arbitrary datum (see Glossary), and discharge represents the flow rate of the stream (i.e. cubic feet per second or gallons per minute).

Measuring stage and discharge includes the use of equipment to document real-time data for those constituents. Gaging a stream represents a systematic collection of discharge or stream stage data or both. Common methods for gaging streams are documented in a USGS report by Carter and Davidian (1968), available on the Internet at http://pubs.er.usgs.gov/usgspubs/twri/twri03A6.

Stage

Stage (gage height) data systematically collected with water quality data can be used to document approximate flow conditions for water quality data, thus could be useful in at least partly explaining the variance or temporal trends in water quality values. Although not as quantitative as discharge data, stage data are easier and less expensive than discharge data to measure or gage.

Stage can be measured in real time (instantaneously) by portable or installed equipment. The measurement of stage is presented in the section “Nonrecording gages”of a USGS report by Buchanan and Somers (1968) http://pubs.er.usgs.gov/usgspubs/twri/twri03A7. Stage measurements made by methods simpler and less expensive than those presented in this report can be found in table 3.

Stage also can be gaged with equipment that systematically senses and records such data on a continuous or periodic basis. Other sections in Buchanan and Somers (1968) present methods for gaging stage. Peak stages can be gaged by a simple method involving less than $100 of readily available equipment. These “crest-stage” gages are described on pages 27-28 of Buchanan and Somers (1968). Supplemental information regarding the installation and operation of crest-stage gages is presented in table 4 of this report.

Discharge

Discharge data are more meaningful than stage data for quantifying water quality data values. For example, the product of the water quality constituent concentration and the discharge value represents the instantaneous load (i.e., in pounds or kilograms) of a water quality constituent. Analyses of water quality data often can be interpreted and analyzed more meaningfully when their values can be expressed in units of load or "yield," the load divided by the basin area upstream from the point of measurement (i.e. pounds per square mile or kilograms per square kilometer).

Discharge can be directly or indirectly measured by many methods as described in a USGS report by Buchanan and Somers (1969) http://pubs.er.usgs.gov/usgspubs/twri/twri03A8 and by the U.S. Bureau of Reclamation report (2001) http://www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/. The most common method of measuring discharge involves the use of a meter that records velocity. The use of this and other equipment commonly used to measure discharge is presented by Buchanan and Somers (1969) http://pubs.er.usgs.gov/usgspubs/twri/twri03A8. Although acoustic velocity metering systems are expensive, they offer fast and reliable methods by which to measure discharge (refer to Laenen, 1985; http://pubs.er.usgs.gov/usgspubs/twri/twri03A17).

Other, less used, methods exist by which to measure discharge. A method to measure discharge using dye tracers is described by Kilpatrick (1985) http://pubs.er.usgs.gov/usgspubs/twri/twri03A16, and a method to measure discharge via boat is presented by Smoot and Novak (1969) http://pubs.er.usgs.gov/usgspubs/twri/twri03A11. Additionally, several methods exist by which to make indirect measurements of discharge. These methods include flow over a dam or weir (Hulsing, 1967) http://pubs.er.usgs.gov/usgspubs/twri/twri03A5, flow through a culvert (Bodhaine, 1968) http://pubs.er.usgs.gov/usgspubs/twri/twri03A3, and flow in natural channels (Dalrymple and Benson, 1968) http://pubs.er.usgs.gov/usgspubs/twri/twri03A2.

Gaging streamflow requires much time and expense but provides valuable data, especially when such data are used in conjunction with water quality data. Common methods for gaging streamflow are documented in a USGS report by Carter and Davidian (1968) http://pubs.er.usgs.gov/usgspubs/twri/twri03A6.

Other Streamflow Data

Other methods are available that can be used to characterize stream-flow and water quality conditions. Stream tracers can be used to interpret characteristics of streams; publications of USGS Standard Methods for Stream Tracer Injection Studies can be found at http://smig.usgs.gov/SMIG/tracer_methods.html.

One such method measures the time of travel and dispersion characteristics for streams. Such data are useful in determining the travel time and dilution characteristics for specific water quality contaminants in streams. Procedures for conducting such a study are presented by Hubbard and others (1982) http://pubs.er.usgs.gov/usgspubs/twri/twri03A9, and methods for sampling the dye used for such a study is presented by Wilson and others (1986) http://pubs.er.usgs.gov/usgspubs/twri/twri03A12.

Fluvial sediment can pose problems in streams, especially where construction or other land disturbance is occurring in the watershed. Collection and analyses of fluvial sediment data require specialized methods. Concepts for understanding and characterizing fluvial sediment are presented by Guy (1970) http://pubs.er.usgs.gov/usgspubs/twri/twri03C1. Field methods for measuring fluvial sediment are presented in a report by Edwards and Glysson (1999) http://pubs.er.usgs.gov/usgspubs/twri/twri03C2 and methods to compute fluvial-sediment discharge are given by Porterfield (1972) http://pubs.er.usgs.gov/usgspubs/twri/twri03C3.

Surface-Water Quality

Most of the water quality data collected by the SOPN parks represents manual sampling for physical properties (specific conductance, pH, and temperature) and dissolved-oxygen (DO) concentrations. A USGS report describing methods for such sampling is presented by Wilde and Radtke (1998) http://pubs.er.usgs.gov/usgspubs/twri/twri09A6. Field measurements for other water quality constituents also can be performed if appropriate sampling equipment is available. For example, turbidity, a measure of water clarity, represents one of the constituents that NPS may wish to consider for analyses.

Turbidity can represent an indirect measurement of suspended-sediment concentrations. Turbidity measurements are inexpensive and meaningful, especially for documenting increased suspended sediment in streams resulting from construction or other land-disturbance activities. Suspended sediment represents one of the more substantial threats to stream quality because land-disturbance activities affecting only a very small part of a watershed can cause orders-of-magnitude increases in suspended-sediment concentrations in receiving streams. Furthermore, substantial sediment loads can cause long-term damage to stream habitats and the aquatic organisms associated with those habitats. Additionally, other water quality constituents such as phosphorus, heavy metals, and certain pesticides can adsorb to suspended-sediment particles and be transported downstream with the sediment, potentially resulting in water quality problems considerably remote from their source.

Many other constituents can be analyzed in water samples, offering an insight or interpretation concerning the magnitude and source of contamination in streams, rivers, or lakes. However, the sources, identity, and extent of water quality contamination vary among parks as do the water quality constituents that would need to be monitored. Therefore, water quality sampling recommendations differ somewhat among parks and are presented in the Section V of this report. USGS guidelines for monitoring water quality may be found in U.S. Geological Survey (2007) (http://water.usgs.gov/owq/FieldManual/). A USGS report that discusses constituents important for documenting and interpreting water quality conditions (Hem, 1989) can be found on the Internet at http://pubs.usgs.gov/wsp/wsp2254/. This report also presents the meaning, significance, and potential sources of these constituents, and methods for analyzing and interpreting water quality data. Other manuals concerning water quality monitoring can be found on the U.S. Environmental Protection Agency (USEPA) www site: http://www.epa.gov/ebtpages/watewaterqualitymonitoring.html and subsequent URL links. A manual giving procedures and techniques for sampling streams also is presented by Wells and others (1990) http://pubs.er.usgs.gov/usgspubs/ofr/ofr90127.

Water-quality values can vary substantially with flow conditions (especially floods) and samples representing all such flow conditions often cannot be collected manually. Continuous water quality monitors can record values for water temperature, DO, pH, specific conductance, and several other constituents. An example of guidelines for operating such monitors is discussed by Wagner and others (2000) http://pubs.usgs.gov/tm/2006/tm1D3/. Continuous monitors also can be useful for recording constituent minima or maxima during a 24-hour period, for example, minimum DO concentrations and maximum temperature or pH. Continuous monitoring of DO and (or) pH at 15-minute intervals over a period of several days can be used to estimate rates of net primary productivity and respiration (Sorenson and others, 1999 (http://pubs.usgs.gov/of/1999/ofr99202/); Porter, 2000 (http://www.epa.gov/waterscience/criteria/nutrient/guidance/rivers/index.html; Appendix A25-A42); Peterson and others, 2001 (http://pubs.usgs.gov/wri/wri014238/); Peterson and Porter, 2002 (http://wy.water.usgs.gov/YELL/nwqmc/index.htm)), indicators of stream eutrophication and stress from microbial oxygen demand.

Automatic water quality sampling equipment often is used to collect water samples for laboratory analyses. Many options exist by which samplers can be programmed to collect water samples. Such options include discrete bottle sampling at specific time intervals, sampling at specific time intervals following a minimum streamflow threshold, or sampling at equal-flow volume intervals. Some samplers can be programmed to collect composite water samples in order to minimize laboratory analytical costs; such samplers can collect time- or volume-weighted composite samples. Suggestions for use of automatic samplers in streams are presented by Harmel and others (2003).

Groundwater

SOPN park managers are concerned about the current status as well as the future of groundwater in their respective park units. In the case of several parks (including BEOL, CHIC, FOLS, SAND, and WABA), groundwater historically has been a source of streamflow and (or) potential source of springflow and lake water (Sue Braumiller, NPS-SOPN Regional Hydrologist, written comm., 2007).

In addition to reflecting a park unit's aquatic well-being, groundwater is a vital aspect of the natural setting that can be used to help manage the interconnection among all park resources. Declines in groundwater levels typically indicate the impacts of nearby well withdrawals (pumping) on park-unit resources. Accordingly, the spatial and temporal distributions of groundwater should be monitored to: (1) better understand the local hydrologic system, (2) make advantageous regulatory decisions, and (3) predict the availability of water in anticipation of future demands.

Quantity

In accordance with present funding limitations, the SOPN is devoting most of its current monitoring resources to tracking the Vital Signs of resources deemed to most effectively represent the status of NPS's aquatic ecosystems (Perkins and others, 2006). In addition to surface-water quantity and quality, ground-water quantity (specifically, subsurface water-level information) is one of SOPN's three most important Vital Signs.

EARDC recommends that the fundamental objectives of SOPN's groundwater-monitoring program (http://www1.nature.nps.gov/im/units/sopn/monitor/vs/groundwater/groundwater.cfm) might be to:

- Determine the long-term trends in groundwater quantity (aquifer water levels); and
- Document changes in local environmental settings associated with hydrological changes resulting from, for example, groundwater pumping and changes in land use.

For details on how these objectives might be accomplished in the field, the reader is referred to Drost (2005), EPA (1986; 1987), and Wilde (2005). A summary of various techniques and use of associated equipment is provided below.

Groundwater levels are direct indicators of groundwater supply. Comparisons of groundwater elevations and groundwater flow directions on an annual, semi-annual, or more frequent basis can identify early indicators of changes in the groundwater resource and help understand how to protect against or correct unwanted impacts. Groundwater levels are measured from accessible wells during ground-water studies to help:

- Determine hydraulic gradients and the rates and directions of groundwater flow;
- Estimate aquifer hydraulic characteristics;
- Locate areas of groundwater recharge and discharge;
- Estimate the amount of groundwater in storage, or the change in aquifer storage over time; and
- Interpret the status of groundwater quality data.

Groundwater hydrographs are constructed from a series of water-level observations over time; thus, they provide a chronology of water-level fluctuations that can aid with the interpretation of temporal changes in water quality data. Hydrographs are typically used to establish management objectives and to understand changes in both groundwater quantity and quality resulting from changing water and land uses, hydrology, and climate.

Keeping track of groundwater levels involves obtaining the depths to water (below land surface) through the boreholes of accessible water wells. Whether used primarily for production (water-supply) or otherwise, wells used for the purpose of water-level monitoring are known as observation wells. An effective observation well, whether used also for domestic, irrigation, industrial, or public-supply purposes, must provide some means of accessing its water level at any time, during any condition.

In addition to Drost (2005), EPA (1986; 1987), and Wilde (2005), the U.S. Geological Survey – in association with its National Water Quality Assessment Program (NAWQA) – recommends specific procedures and protocols for the collection of various data from different kinds of wells under a variety of conditions (Lapham and others, 1995). This report (available online at http://water.usgs.gov/nawqa/OFR95-398.html) details the processes of monitoring well selection, installation and documentation of monitoring sites, and collection of hydrogeologic and geologic data.

Table 5 provides a comprehensive checklist of tools and equipment required for the effective periodic measurement of groundwater levels; the highlighted items are generally the most necessary or frequently used gear during routine visits to established observation sites. Quality assurance and quality control aspects of groundwater quantity monitoring – such as record keeping and recommended forms and formats for efficient database storage, maintenance, and retrieval – are summarized within the General Quality and Control section, below.

Equipment

Historically speaking, three most common means of measuring depths to water in groundwater wells (boreholes) have been the so-called (1) wetted (or graduated) steel-tape, (2) electric-tape, and (3) air-line methods (fig. 5). The associated equipment (fig. 6, A – C) is manually operated. In recent years, pressure transducers coupled to data loggers (fig. 6, D) have begun to replace the manually operated gear. For example, many consider pressure-sensitive transducers linked electronically to data loggers to be the most efficient way of tracking water levels continuously over time (Freeman and others, 2002), although this instrumentation is currently more expensive than the older counterparts when used for only periodic (noncontinuous) observation. For wells in which a direct measurement of water level is not possible, as in the case of a flowing well (when the hydraulic head exceeds the elevation of land surface), a pressure or head-gauge arrangement such as that depicted in figure 7 can be used (Heath, 1987, p. 73).

Graduated steel tapes are considered the most accurate for measuring the water level in nonflowing wells. Steel tape readings under the best of conditions are generally accurate to within 0.01 feet. The most popular steel (surveying or engineer's) tapes are commonly available in lengths of 100, 200, 300, and 500 feet. The lower few feet of the tape is coated with blue carpenter's chalk. The obvious difference between dry (unsubmerged) and wet (submerged) portions of the chalked section of steel tape denotes the length of tape immersed in water.

Electric tapes are relatively simple continuity detectors designed for lowering into a borehole. The most common e-lines are 500-foot versions comprised of two-conductor 16 – 22 gauge electrical cable wound inside a hand-cranked reel. E-lines operate on the principle that a circuit is completed when electrodes at the end of each cable are immersed in water. The reel contains space for a DC battery and an ammeter and (or) buzzer for signaling when the circuit closes. Electrodes are generally contained in a weighted probe that keeps the tape taut while providing some shielding of the electrodes against short circuiting as the probe is lowered into the borehole. The electric tapes generally are marked at 5-foot intervals with clamped-on metal bands.

Although electric tapes are typically bulkier, more cumbersome to use, and typically provide less accurate results than a steel tape, e-lines are the preferable alternative in some situations. In the event of water cascading down or dripping into the borehole from higher aquifers, it may be impossible to get a good water "cut" on a chalked steel tape. When a series of measurements are needed in quick succession, such as during an aquifer test, electric tapes offer the advantage of not having to be removed from the well between successive readings. It is generally impossible to obtain accurate steel-tape measurements from a pumping well, particularly from a well whose pumping water level is near the pump bowls. Electric tapes are also safer to use in pumping wells because the water is sensed as soon as the probe reaches the water surface and there is less danger of lowering the tape into the pump impellers.

Air lines are small diameter pipes (tubes) that drop from the tops of wells, through their casings, down several feet below the lowest anticipated water level. The air line works on the principle that the air pressure required to expunge all water from the submerged portion of the tube equals the water pressure of a column of water of that height (assuming one pound per square foot of air pressure equals 2.31 feet of water). An air-gauge reading is converted to the height of water column equaling the distance between the water level in the well and the bottom of the air line (fig. 5).

The air line method is especially useful in pumped wells or in wells where water turbulence precludes using one of the generally more accurate steel or e-line methods. Besides requiring an air-tight installation and knowing the exact length of air line, the accuracy of this method depends on the precision to which air pressure can be measured. Air line readings of groundwater levels are generally considered accurate to within plus or minus one foot.

Pressure transducers are water-level monitoring devices that are lowered into accessible wells on the end of a cable attached to a *data logger* at the surface (fig. 8). Water-level loggers typically incorporate micro-processing pressure sensors and battery power in a rugged enclosure designed for long-term underwater deployment. The pressure transducer measures the pressure due to the overlying column of water and transmits this information to the data logger via the attached cable. In recent years, as the need to monitor baseline and (or) document changing groundwater levels over time has increased, so has the use of pressure transducers and water-level data loggers.

The transducer-logger combination can be deployed and left to operate continuously in the field without attention for months, collecting water-level data at user-defined intervals and storing it digitally into logger memory. By operating in a continuous 24/7 monitoring mode, water-level loggers minimize the need for manual data-collection approaches and facilitate the simultaneous monitoring of multiple data-collection sites.

Water level loggers also automate the process of archiving and reporting data. Hydrologists can simply offload the logger data to a PDA or laptop PC and create detailed graphs or tables with the click of a mouse button. Charts created by Excel or vendor-provide software can be easily printed for documentation purposes while the electronic data are automatically achieved within any database of choice.

Water Pressure Gauges or *Transparent Tubes* can be used to measure hydraulic head in flowing wells. In topographically low areas underlain by confined aquifers, groundwater levels may stand in wells at some height above land surface. Referred to as areas of artesian head, these areas are characterized by sealed well installations and (or) flowing wells or springs. The measurement of groundwater heads in such areas (where the casings of wells do not extended above the static level) requires specialized equipment.

For wells equipped with a shut-off valve and fittings to which a pressure gauge or transparent (typically plastic) tube can be connected, the effective hydraulic head can be determined by connecting the gauge or tube to the appropriate fitting. In this case, the hydraulic head is measured directly (Heath, 1987, p.73).

Procedure and Protocol

Only a summary of possible procedures and protocols (rules and methods) for obtaining groundwater level are presented below. Detailed procedure and protocol guidelines relevant to various real-world conditions and circumstances are provided by Heath (1987), Freeman and others (2002), Drost (2005), and Lapham and others (1995).

An established *measuring point* must exist at each groundwater observation well to ensure comparability of water-level measurements taken on different dates or at different times from the same well and among all wells in a study area. Therefore, the first step in establishing an observation well is identifying and describing a measuring point (MP) to which all groundwater measurements will be referred (Drost, 2005, p.19). The MP typically is selected as the most convenient place from which to measure the depth to groundwater, and it must be clearly and permanently marked. This point is usually the top of the casing, well cap, or access port, whose position is referenced in terms of its distance above or below land surface datum (LSD).

Wetted- (Steel) Tape Method:

The wetted-tape method (Drost, 2005, p. 9) employs a graduated steel tape that is typically used with a narrow weight or probe attached to its end. The weight section – which is typically composed of stainless steel, copper, or lead (as dictated by water quality concerns) – is used to provide maximum plumbness and, hopefully, permit some feel for negotiating past down-hole obstructions. The graduations on the lower five or six feet of tape are coated with blue carpenter's chalk, which improves the visibility of the water line (CUT) and helps verify that it has contacted the groundwater surface.

The tape is lowered into the well until the lower part of the tape is submerged while an exact foot marker is held directly opposite or against the measuring point. The tape is then quickly withdrawn; the value held at the measuring point (HOLD) and the amount of tape that was submerged (CUT) are recorded appropriately. The amount of tape that was submerged is obvious from the change in color of the chalk coating. The depth to groundwater below the measuring point is determined by subtracting the length of wetted (submerged) tape from the total length of tape lowered (below the MP) into the well.

Electric-Tape Method:

The major difference between the wetted- (steel) tape method and the electric-tape (e-line) method is: when using a steel tape, the observed length of submerged tape (CUT) is subtracted from the HOLD mark, whereas when using an electric-tape, the subtracted amount is the distance (CUT) between the measuring point and the next higher marker on the e-line (HOLD). Before lowering the probe into the well, the electric circuitry should be checked by dipping the probe in water and observing the indicator.

The probe should be lowered slowly into the well until contact with the water surface is indicated by a deflected ammeter needle and (or) audio signal. The electric tape is pinched opposite the measuring point (HOLD) and partly withdrawn; the distance (CUT) between that pinched (HOLD) mark and the next higher tape marker is measured and subtracted (from the value that next higher marker) to obtain the depth to water below the MP. It is good practice to take a second or third check reading before withdrawing the electric tape from the well.

A pocket tape or carpenter's rule (graduated in tenths and hundredths) is used to measure the distance between the MP and the next higher marker. This distance is subtracted from the value of the next higher marker to determine the depth to water.

Air-Line Method:

To determine the depth to water with an air line, an air pump (or air compressor or tank) and a pressure gauge are attached to the top of the air line. Next, air is pumped into the air line until the pressure on the gauge increases to a maximum and stops. This means that all water has been forced out of the bottom of the air line and the air pressure in the line just balances the water pressure. Any additional air is released as bubbles from the base of the air line. As long as there are no leaks in the system, the pressure will hold at the maximum gauge reading, at least temporarily. The gauge reading is the pressure required to force water out of the air line which is also the pressure of the water column in the well above the bottom of the air line.

The air line method relies on the relationship between pressure and depth of the water. A pressure head of one pound per square inch (psi) is exerted by a column of fresh water 2.31 feet in height. Therefore (assuming the gauge reads in pounds per square inch), multiply the pressure reading by 2.31 to convert to feet of water. The depth to water in the well below the center of the gauge is calculated as the difference between the *exact* length of air line and the pressure required to purge all water from the bottom of the air line. For example, assume a pressure gauge hooked to a 95-foot air line reads 10 psi. This means the water level is 23.1 ft above the bottom of the air line; so the depth to water below the gauge is 71.9 feet [95ft – (10 psi X 2.31 ft/psi) = 71.9 ft].

The air line method is most commonly used in pumping wells. Accuracy can be assured by calibrating the pressure gauge against a dead-weight tester and the length of air line with an electric or steel tape.

Pressure Transducer and Data Logger Combination:

Each data logger and pressure transducer manufacturer will have different software and operating instructions. Therefore, the appropriate operation manual must be consulted regarding the operation of the specific data logger and pressure transducer that will be used. Pressure transducers are constructed to operate in various pressure ranges. It is extremely important that the pressure transducer be used in a manner consistent within the designed operating range of the instrument, or damage may occur. To insure against damaged instrumentation, it is important not to lower the transducer below the designed water depth and associated pressure range. A piezometer is strongly recommended to provide a protective housing around the transducer and to aid in its placement.

The pressure transducer is lowered into a well on a cable that attaches to the data logger at the surface. The pressure transducer measures the hydraulic pressure exerted by the overlying column of water and transmits this information to the data logger via the attached cable. The data logger can be programmed with a laptop computer and associated software to record the measurements on any schedule, ranging from seconds through several weeks.

The information collected includes pressure measurements and a time/date stamp that can be stored for periods of days to months depending on the frequency of sampling. Using a laptop computer and software, the pressure measurements can be converted to water levels and viewed directly on the computer or downloaded from the data logger into a number of different spreadsheet or text formats.

Data loggers/pressure transducers can be used to take frequent water level measurements to a precision of plus or minus 0.1 feet. Hand measurement of water levels, using a water level indicator, are needed to field check the data logger/pressure transducer readings. The typical setup for using a data logger and pressure transducer to measure water levels can be seen in figure 8.

Direct Reading of Hydraulic Head in Flowing (Artesian) Well:

The simplest method used to determine artesian head is to attach a pressure gauge near the top of a sealed observation well. With care, experience, and an appropriate gauge, pressure measurements can be obtained to within an accuracy of 0.1 foot. The gauge can often be secured to a pipe connected through the casing wall. Use a valve to first bleed all entrapped air from the closed system.

Ideally, the discharge from a flowing well should be shut off until the well equilibrates so that a static water level can be obtained. However, due to a variety of possible conditions, this may not always be possible. When the discharge from a flowing well is controlled with a valve or removable plug, it must be done gradually.

Depending on how the gauge is calibrated, the water level will be read directly or recorded as a pressure head and later converted to feet. If the pressure gauge used is calibrated in pounds per square inch, simply multiply the gauge reading by 2.31 to obtain the head of water above the gauge. Ideally, if conditions permit, a flow measurement should accompany a pressure reading.

Measuring the water level of a flowing well that is not equipped with a valve or threaded fitting requires a soil-test plug or similar device to control the flow and allow the temporary connection of a portable gauge (fig. 7). In such a case, the height of static water above a specified well-head datum might also be determined with a transparent plastic tube, assuming relatively low-pressure conditions prevail (Drost, 2005, p. 17).

Quality

Water-quality samples from wells can provide meaningful data regarding groundwater quality for many water quality constituents if appropriate methods are used to collect, preserve, transport, and analyze the samples. A thorough manual addressing field procedures for sampling wells is presented by the Texas Water Development Board (2003) http://www.twdb.state.tx.us/publications/manuals/UM-51/FieldManual.pdf. Additionally the USGS published a report that presents protocols and methods for collecting and documenting groundwater quality data (Koterba and others, 1995) http://water.usgs.gov/nawqa/OFR95-399.html. Additionally, a report recommending procedures for collection and analyses of groundwater samples for unstable water quality constituents is presented by Wood (1976) http://pubs.er.usgs.gov/usgspubs/twri/twri01D2.

Most of the same water quality procedures that apply to stream samples also apply to samples from springs. However, samples from wells and other bores often require special methods and techniques. Many details should be addressed prior to visiting wells for water quality sampling. The section “Initial trip planning and preparation” in the report by the Texas Water Development Board (2003, pg 5-10) http://www.twdb.state.tx.us/publications/manuals/UM-51/FieldManual.pdf presents many such considerations. Additionally, specific well purging procedures should be followed in order to take a water sample that would provide data values meaningful to the producing aquifer. Many such procedures are presented in pages 10-13 of the same report.

During purging, measurements of pH, temperature, and specific conductance typically are used to establish that the well has stabilized before sampling begins. Additionally, values for dissolved oxygen and other water quality constituents can change when samples are collected through a pump and thus typically are not measured from wells. Other parameters, such as oxidation reduction potential, alkalinity, and dissolved oxygen, are measured at the time of sampling because the dissolved gases may react during the holding time. These reactions change the chemical composition of the water, thus making any laboratory analysis at a later time inaccurate.

Biological

Monitoring the aquatic-life condition of streams, rivers, and lakes is an important consideration because aquatic biota integrate water quality conditions over time whereas water samples represent only the water-chemistry conditions present during the instant when samples were collected. Collection and analysis of macroinvertebrate (aquatic insects, snails, worms, and other invertebrate organisms) assemblages is the most common biological-monitoring protocol used by State and Federal agencies. Macroinvertebrates are excellent indicators of organic enrichment, low DO concentrations, and habitat conditions, and they integrate stream-quality conditions over the past several months to years. Benthic algae (periphyton) integrate water quality conditions over the past several weeks to months, and are excellent indicators of nutrient enrichment, major ions, pH, salinity, and water temperature. Monitoring fecal-indicator bacteria (e.g. *Escherichia coli*) and certain protozoans (i.e. *Cryptosporidium* and *Giardia*) is important for the protection of public water supplies (standards for total coliform bacteria) and park visitors engaging in contact-recreational activities (e.g. swimming, water skiing, and scuba diving). Habitat conditions are as important as water quality for evaluating stream condition and biological integrity.

Methods for collecting macroinvertebrates include rapid-bioassessment protocols (RBPs; Barbour and others, 1999; (http://www.epa.gov/OWOW/monitoring/rbp/) and semi-quantitative methods such as those employed by the USGS National Water Quality Assessment (NAWQA) Program (Moulton and others, 2002; (http://water.usgs.gov/nawqa/protocols/OFR02-150/index.html). Common to both protocols is the use of an aquatic "kick net," with 500 μm opening-mesh net, a sieve or sieve bucket with 500 μm opening mesh, sample containers and labels, and forceps for handling organisms (see Chapter 7 in Barbour and others, 1999 and figures 8 & 10 in Moulton and others, 2002). For the RBP method, the single habitat approach (method 7.1.1), riffles and runs within a 100 meter stream reach are sampled with 1 meter kick net as illustrated on p. 7-2 of the RBP protocol. Samples from riffles and runs are composited, resulting in a minimum of 2 square meters of stream-bottom area. For the RBP multi-habitat approach (method 7.2), a standard D-frame dip net (refer to p. 7-2 of the RBP protocol) is used to sample macroinvertebrates from multiple habitats. Samples are composited in relation to the relative abundance of habitats present in a 100 meter stream reach. For the NAWQA protocol, a rectangular kick net (Slack sampler) is used to collect macroinvertebrates from a designated "richest-targeted habitat," generally from a riffle or run with coarse-grained bottom material (gravel or cobble). Submerged woody debris (snags) often is the targeted habitat in streams without riffles or coarse-grained bottom material. Five discrete locations are sampled, resulting in a total area of 1.25 square meters sampled by this method (refer to p. 36-42 in the NAWQA protocol). Samples are preserved with either 95 percent ethanol (RBP) or 10 percent buffered formalin (NAWQA). Example field data forms are included with both protocols. If taxonomic expertise is not available from a local university, samples must be sent to a qualified laboratory for identification and enumeration. The estimated cost for processing macroinvertebrate samples ranges from about $150 to $350 per sample depending on how many organisms are counted and the level of taxonomic resolution (e.g. family or genus/species).

Methods for collecting benthic algae (periphyton) samples also include rapid-bioassessment and quantitative protocols (see references in previous paragraph). A rapid assessment of benthic-algal biomass and composition can be made using a viewing bucket and scoring system given by Stevenson and Bahls (1999). When present, large growths of filamentous algae or aquatic vascular plants can be collected (quantitatively), dried, and weighed on an analytical balance. The qualitative RBP periphyton-sampling approach involves sampling multiple stream microhabitats (e.g. submerged rocks, plants and sediments on the stream bottom) and compositing these subsamples into a single container for laboratory analysis of the relative abundance of algal species. This procedure is similar to the NAWQA qualitative multi-habitat (QMH) sample described by Porter and others (1993); (http://pubs.water.usgs.gov/ofr93-409) and Moulton and others (2002); (http://water.usgs.gov/nawqa/protocols/OFR02-150/index.html). Quantitative samples are collected from a single microhabitat (e.g. rocks or submerged woody debris) as described by the previous references, preserved with sufficient concentrated, buffered formalin to constitute a 5 percent solution in the final sample, and sent to a qualified laboratory. Laboratory results for qualitative samples include only the relative abundance of species whereas results from quantitative samples also provide determinations of abundance (i.e. cells/cm^2) and biovolume. The estimated cost for processing periphyton samples ranges from about \$150 to \$350 per sample depending on the number of organisms counted and the level of taxonomic resolution. Samples also can be collected for determinations of pigment content (i.e. chlorophyll *a*) and (or) biomass, indicators of the trophic condition of the stream or lake. The cost of laboratory analysis ranges from about \$50 to \$150 per sample. These analyses provide information about the abundance of algae but do not provide data about water quality conditions other than nutrient enrichment.

Methods for collecting samples for fecal-indicator bacteria are described by Myers and Sylvester (1997); (http://water.usgs.gov/owq/FieldManual/Chapter7/index.html) as well as by USEPA protocols (U.S. Environmental Protection Agency, 1978; 1982b; 1996; 2001, 2002a-c; refer to http://www.epa.gov/microbes/). Previously, fecal-indicator analyses focused on values for total coliform, fecal coliform, and fecal streptococcus bacteria, and a considerable amount of those data can be found in the NPS's STORET legacy database (the subject of this report). *Escherichia coli* (*E. coli*) and enterococci bacteria currently are the preferred indicators for recreational waters because both are superior to fecal coliform and fecal streptococci bacteria as predictors of swimming-associated gastroenteritis in streams, rivers, and lakes (Dufour and Cabelli, 1984). Samples are collected in pre-sterilized 125 mL bottles provided by the laboratory that will conduct the analysis. Samples generally need to be received by the analytical laboratory within 6 to 8 hours following collection or as indicated by the most recent U.S. EPA guidance. Laboratory costs generally range from \$15 to \$30 per sample, plus the cost of shipping or delivering the sample to the laboratory. Water-quality criteria for fecal-indicator bacteria are based on geometric means for 6 or more samples within a month; however, individual fecal coliform values exceeding 400 colonies per 100 mL or *E. coli* values exceeding 126 colonies per 100 mL generally indicate contamination by fecal material from wastewater discharges, septic tanks, and (or) agricultural influences (e.g. feedlots). Recent research has produced methods for determining sources of fecal-indicator bacteria in streams and rivers, however, many of the methods remain experimental. General information on microbial source-tracking and detection techniques, such as ribotyping (DNA fingerprinting), genetic enterovirus detection using PCR/rtPCR and IC/PCR, and pulse field gel electrophoreses (PFGE) can be found at http://water.usgs.gov/owq/microbial.html. Analyses for total coliform bacteria remain appropriate for public water supplies, in which no coliform bacteria should be present. Periodic analyses for certain protozoans (i.e. *Giardia* and *Cryptosporidium*) also should be considered for recreational waters where potential ingestion of water (e.g. from swimming or diving) may occur (http://www.epa.gov/safewater/lt2/training/module_crypto/images/pocketguide.pdf; http://www.epa.gov/safewater/disinfection/lt2/pdfs/guide_lt2_swmonitoringguidance.pdf).

Aquatic habitat assessments should be considered for stream and river sites where and when biological data are collected. As with macroinvertebrate and benthic algae methods, there are both rapid-bioassessment and quantitative protocols for evaluating the condition of in-stream and riparian habitats. A simple, low-cost assessment can be made with EPA's Visual-Based Habitat Assessment (Barbour and others, 1999, p. 5-6 through 5-31; (http://www.epa.gov/OWOW/monitoring/rbp/). Ten habitat parameters are evaluated and assigned scores ranging from 0 to 20. These scores can be summed and relativized to a scale of 0 to 100, or used as individual variables for multivariate analyses. This protocol is subject to among-investigator differences and probably has limited uses for measuring long-term trends in habitat condition. A more quantitative approach to habitat assessment, based on principles of fluvial geomorphology, (e.g. Fitzpatrick and others, 1998; (http://water.usgs.gov/nawqa/protocols/WRI98-

4052/index.html) requires measurement of a variety of physical features in the stream channel and riparian zone such as wetted-channel width and depth, bankfull width and depth, channel gradient, and major geomorphic channel features, in addition to measurements of velocity, depth, substrate size, riparian shading, and other features along 11 transects within a stream reach length defined as 20 times the average width of the channel. These measurements are surveyed to a permanent marker (e.g. a bridge marker or a lag bolt attached to a large tree) so that the same measurements can be repeated at the same stream locations indefinitely through time. Our recommendation is to conduct the visual-based assessment in combination with several (or more) quantitative measures dictated by specific park needs or issues that may be stream or park specific.

Databases

It is imperative that water-resource data are readily available and in digital format such that it can be retrieved easily and used for display, presentations, requests, or analyses. Additionally, it is important that the data-base format is consistent for all data and parks so that the data can be shared and (or) combined easily. Databases can be broadly categorized as "transactional," for initial entry of data, quality control, and temporary storage of data, and "archival," containing data that have passed quality-control and review (e.g. metadata) criteria. Archival data sets typically are "read-only" databases that are overseen by designated systems personnel. There is a current need for a uniform transactional data-base structure to allow park personnel (or a designated contractor) to enter data that presently exist only in paper form (i.e. laboratory reports, field log books, etc.). An initial work-around procedure could be to use Microsoft Excel spreadsheets to enter data in columns (variables or water quality constituents) by rows (site and (or) sample IDs) format. Considerable thought should be given to (1) data-format requirements of the archival database where the data ultimately will be stored, (2) user requirements, (3) how the data will be queried or summarized, and (4) how the database will record and process "censored" values (those less than laboratory-method detection or reporting limits). Individual Excel files can be imported as "tables" into a relational database such as Microsoft Access. Tables also can be created that provide landscape (e.g. GIS), stream-flow, and other ancillary environmental data with which water quality or ecological data may be compared. One or more variables (columns) in each table also need to be consistent among tables so that relational integrity may be established and queries can be written to produce output from a variety of individual tables. The structure of the DGP database prepared for this project (Sloan and others, 2007) can serve as an initial example of the proper format for entering data into Excel spreadsheets. Design of a uniform transactional database is well beyond the scope of this project; however, this task deserves the highest priority because of the need to update the legacy (STORET) database with data collected since the mid-to-late 1990s.

The EPA has two major databases for water quality, biological, and physical data. The Legacy Data Center (LDC) contains historical water quality data dating back to the early part of the 20th century and collected up to the end of 1998. STORET contains data collected beginning in 1999, along with older data that has been properly documented and migrated from the LDC. STORET (abbreviation for STOrage and RETrieval) is a data repository used by State environmental agencies, U.S. EPA and other Federal agencies, universities, and many volunteer monitoring groups. Information regarding the database is presented at http://www.epa.gov/storet/ and their data can be accessed at http://www.epa.gov/STORET/dbtop.html. The next generation of STORET, known as WQX (for Water Quality eXchange) will provide much more flexibility to users while retaining standard data elements that provide consistency and quality control (http://www.epa.gov/owow/monitoring/monintr.html). Monitoring organizations who wish to submit data to STORET must operate the STORET System locally. The local STORET System is a data-management system with data entry and reporting software modules that operate on personal computers. Information about accessing and using STORET as a data-storage repository is presented at http://www.epa.gov/STORET/about.html

The USGS investigates the occurrence, quantity, quality, distribution, and movement of surface and underground waters and disseminates the data to the public, State and local governments, public and private utilities, and other Federal agencies involved with managing water resources. The USGS maintains its National Water Information System (NWIS) at http://waterdata.usgs.gov/nwis. This system contains water resource data for surface and ground water. Information about this database is presented by US Geological Survey (2002); http://pubs.usgs.gov/fs/fs-128-02/. The USGS and EPA have agreed to use common definitions and formats to promote a common view of data between their two systems.

In order to evaluate and interpret water quality constituent values in park streams and lakes, such data initially should be compared with water quality criteria or standards. A list of EPA water quality criteria for various water uses is presented online at http://www.epa.gov/waterscience/criteria/. Within this www site is a list of drinking-water contaminants and their maximum contaminant levels (MCLs) that can be viewed at http://www.epa.gov/safewater/contaminants/index.html. Also presented is a list of contaminants and acute and chronic maximum levels for aquatic life http://www.epa.gov/waterscience/criteria/aqlife.html. Cultural eutrophication, a process of accelerated nutrient enrichment frequently resulting in excessive rates of primary productivity (nuisance algal blooms) and respiration (high oxygen demand), is a water quality concern in many streams and reservoirs. A list of nutrient criteria can be found at: http://www.epa.gov/waterscience/criteria/nutrient/. EPA nutrient criteria for streams and reservoirs lakes in (aggregations of Omernik Level 3) ecoregions of the U.S. is presented at http://www.epa.gov/waterscience/criteria/nutrient/ecoregions/sumtable.pdf, and a map showing "nutrient ecoregions" for those criteria is presented in figure 9.

Many methods exist by which water samples can be collected, transported, preserved, and analyzed in a laboratory. Any variance in these procedures can cause discrepancies in water quality values. Therefore, the EPA and USGS have developed standard methods for sampling and analyses and standard methods for identifying various water quality constituents. Parameter codes identifying water quality constituents are presented at http://64.233.169.104/search?q=cache:E-tfJ9hJMrkJ:nwis.waterdata.usgs.gov/usa/nwis/pmcodes+water+%22parameter+codes%22&hl=en&ct=clnk&cd=14&gl=us

Water-resource data collection programs typically are accompanied by methods and rules regarding quality control and quality assurance. Generalized quality assurance and control procedures for the NPS are discussed by Oakley and others (2003). The EPA and USGS have extensive documentation regarding the quality of their data; for example, the USGS quality control information may be found at http://water.usgs.gov/owq/quality.html.

Surface Water

A database for surface water quantity can represent data from many types of surface-water gaging stations (presented in table 2). The primary USGS surface-water database can be accessed online at http://waterdata.usgs.gov/nwis/sw, and information regarding the National Streamflow Information Program of the USGS can be found at http://water.usgs.gov/nsip/index.html.

As a minimum, the database for any NPS gaging station should include:

1. site location (latitude and longitude and verbal description relative to nearby physical features)
2. type of gaging station (as described in table 2)
3. date and time representing the data
4. data values
5. footnotes pertinent to data value or other related data or information (metadata).

A database of surface-water quality data can represent streams, reservoirs, lakes, springs, bays, and estuaries. USGS water quality data can be found at http://waterdata.usgs.gov/nwis/qw.
Ancillary data must accompany all water quality data values. Such metadata include information relevant to the following descriptors:

1. site location (latitude and longitude and verbal description relative to nearby physical features)
2. date and time of sample
3. sampling procedure (i.e., single position (e.g. center of stream channel), depth integrated, discharge integrated)
4. sampling method (i.e., manual sample, automatic sampler)
5. type of sample (i.e., discrete, volume or time weighted)
6. water quality constituent (standard parameter as listed above or other type)
7. water quality parameter number
8. water quality data value (along with unit for value)
9. streamflow discharge, gage height, or water surface elevation at time of sample
10. Footnotes pertinent to data value or any other sampling data or information (metadata)

Groundwater

Record Keeping

Record keeping and database management are two sometimes-overlooked aspects of groundwater monitoring. Without commitment to a logical record-keeping procedure with which to facilitate data analysis, the value gained from efforts to monitor groundwater may greatly diminish. Guideline and protocols relevant to the proper storage and management of groundwater data are provided by: U.S. Geological Survey (2005a; 2005b), Lapham and others (1995), Drost (2005), and Wilde (2005).

The most important, or minimal amount of data required for any site of periodic or continuous groundwater-monitoring are:

1. Name of well;
2. Location of well (latitude and longitude, plus state and (or) local numbering convention)
3. Land surface elevation (lsd);
4. Depth of well;
5. Cased and open intervals of well bore;
6. Date of initial water-level measurement;
7. Depth to initially measured static water level;
8. Elevation of initially measured static water level; and
9. Documentation of reference point (MP) from which the depth to groundwater should be consistently measured.

In the field, groundwater data can be recorded directly on simple notebook paper or a more sophisticated form, such as those shown in figure 10, and brought back to the office or compiled directly through a laptop into a commercially available spreadsheet format. However the data are recorded in the field, the data must be conditioned for safe-keeping within an appropriate groundwater database. Spreadsheet-based databases are generally linked to programs that provide (1) some means of electronically storing the information for ease of distribution and the creation of backup files, and (2) hydrographs that can be used to identify short-term (seasonal) fluctuations and (or) longer-term trends.

Database Management

State and federal water agencies agree that any water-level data shared outside their jurisdiction should be validated internally and deemed to adhere to a universally accepted set of guidelines such as those dictated for storage in the USGS's Water Information System (NWIS) database.

The USGS has established comprehensive sets of field-measurement protocols and parameter codes to aid the coding of water quantity data for storage in the NWIS (GWSI) system. The form on which the results of groundwater-level observations are recorded for subsequent entry into the NWIS system is shown in figure 10 (B). Table 6 summarizes the minimum information required for the electronic storage of groundwater (GWSI) and water quality (QWDATA) information in the USGS's NWIS database. Lapham and others (1995) and Wilde (2005) provide explanations of the most important GWSI and QWDATA protocols and associated coding parameters.

Biological

Although biological investigations of water quality have been conducted for many years, most of this data resides in databases or spreadsheets, in various formats, constructed by the investigators (e.g. academic institutions; State agencies, etc.) that are rarely comparable. Some biological data can be entered and managed in STORET, and this information is available online at http://www.epa.gov/storet/storet_bio_fact.pdf. Biological and water quality data generated by the USGS National Water Quality Assessment (NAWQA) Program can be found at URL http://water.usgs.gov/nawqa/ecology/data.html that provides links to the NAWQA Data Warehouse and other sources. Other, largely terrestrial, USGS biological databases are listed at URL http://search.usgs.gov/query.html?qt=Biological+databases&charset=iso-8859-1&col=faq&col=usgs including results from a number of National parks. Additional databases are listed by the U.S. EPA at URL http://nlquery.epa.gov/epasearch/epasearch?typeofsearch=epa&areaname=&areasidebar=epahome_sidebar&filter=&result_template=epafiles_default.xsl&querytext=biological+data+bases&image.x=12&image.y=10. The Integrated Taxonomic Information System (ITIS), an interagency database of plants and animals can be accessed at URL http://www.itis.gov. Links available from this site also lead to a list of taxonomic experts and species distributions, including regional or national maps of species occurrences and landscape features. Biological databases inherently are more complex than water quality databases because of multiple levels of taxonomic resolution (e.g. Division, Class, Order, Family, Genus, Species, etc.), multiple life stages (e.g. larvae, pupae, and adult insects), and considerable metadata that can be associated with the sample. Similarly, aquatic and terrestrial habitat data require storage of multiple variables, often along multiple transects. Work is in progress towards completion of transactional and archival biological databases for aquatic organisms by several Federal agencies (e.g. USGS and U.S. EPA).

General Quality Assurance and Control

Quality assurance generally consists of manuals, protocols, methods, and appropriate training required to perform a specific task (e.g. measuring dissolved oxygen or pH), whereas quality control represents a set of procedures designed to ensure the accuracy and precision of a measurement (e.g. water quality standards, repeated measures, matrix spikes, etc.). For measuring core Vital-Sign constituents, a prime concern is the calibration and maintenance of meters or data sondes used to measure water temperature, dissolved oxygen, pH, and specific conductance. This information typically is present in manuals provided by the manufacturer, however, additional information is provided by U.S. Environmental Protection Agency (1982b) and from a list of references found at http://search.usgs.gov/query.html?col=usgs&oq=url%3Awater.usgs.gov&rq=1&qt=quality+assurance, http://nlquery.epa.gov/epasearch/epasearch?typeofsearch=epa&areaname=&areasidebar=epahome_sideba

r&filter=&result_template=epafiles_default.xsl&querytext=quality+assurance&image.x=10&image.y=9, and http://nlquery.epa.gov/epasearch/epasearch?typeofsearch=epa&querytext=quality+control&submit=Go&originalquerytext=quality+assurance&areaname=&filterclause=&sessionid=A06DD5CA9A07FF891AC4159B961AE136&referer=http%3A%2F%2Fepa.gov%2F&prevtype=epa&result_template=epafiles_default.xsl&areasidebar=epahome_sidebar&areapagehead=epafiles_pagehead&areapagefoot=epafiles_pagefoot&stylesheet=http%3A%2F%2Fwww.epa.gov%2Fepafiles%2Fs%2Fepa.css. The use of a certified thermometer to compare with thermistor readings on a meter or data sonde, standards for pH (4, 7, and 10), standards for specific conductance (two or more certified standards that bracket the anticipated range of measurements), and proper calibration of dissolved-oxygen probes all are important QA/QC components for measuring these core Vital-Sign constituents. Certified standards for pH and specific conductance are available from instrument manufacturers and most scientific-supply companies (e.g. Fisher Scientific). Repeated measurements (and similar measurements by another technician) of these core variables should be recorded to evaluate precision. *E. coli* samples should be collected in sterile containers provided by the laboratory that will be performing the analysis and delivered or shipped to the laboratory within the required time limit. Duplicate samples should account for approximately 10 percent of the total number of samples collected. Quality assurance and control procedures for biological monitoring can be found in Moulton and others (2002); http://water.usgs.gov/nawqa/protocols/OFR02-150/index.html and Barbour and others (1999); http://www.epa.gov/OWOW/monitoring/rbp/.

Surface Water

Regarding the surface water data collection techniques recommended in this report, probably the best general method for quality assurance and quality control (QA-QC) is to measure the data, record the data, measure the data a second time, and then verify the recorded data. Lack of repetition or verification for data collection probably represents the largest single source for errors in such data.

A USGS plan for developing a quality assurance and quality control plan is presented at http://water.usgs.gov/osw/pubs/swqaplan.pdf. This plan is comprehensive regarding most activities involving surface water data collection.

USGS personnel within many states have prepared a QA-QC Plan for their State, each designed based on their particular program. Many of these plans are available online by searching the USGS Publication Warehouse online at http://pubs.er.usgs.gov/usgspubs/index.jsp?view=adv and typing the words “surface water quality assurance” into the “Search text in title” box and then clicking the “Search now” button at the page bottom.

The USGS Office of Surface Water presents and publishes many technical memorandums concerning surface-water data, analysis, publication policies and related topics. These memorandums are available online at http://water.usgs.gov/osw/pubs/oswtechmemosum.html. As indicated on this Web site, the memorandums are stored under many topics regarding surface water, not all of which relate to data collection.

Part of the USGS quality assurance program includes a Hydrologic Instrumentation Facility to facilitate hydrologic data-collection activities through the identification of needs, development of technical specifications, design or development of specialized interfaces, contracts and procurements, testing and evaluation, specialized field applications, repair and calibration, quality control and assurance, and storage and distribution of hydrologic instrumentation. That program is described on the Internet at http://wwwhif.er.usgs.gov/public/index.htm.

In regard to minimal or general quality assurance and control protocols associated with groundwater quantity monitoring, EPA (1986; 1987) recommends the following procedures:

1. All data must be documented on standard chain-of-custody forms, field-data sheets, groundwater level-data forms, or within personal/site logbooks;

2. All instrumentation must be operated in accordance with operating instructions as supplied by the manufacturer, unless otherwise specified in the work plan;

3. Equipment checkout and calibration activities must occur prior to sampling/operation, and they must be documented; and

4. Each water-level reading from any well should be measured at least twice in order to compare and verify results.

EPA additionally specifies that all persons involved with the collection of groundwater data must understand the functioning of the monitoring equipment and how to use that equipment to obtain reliable data. If bad readings or faulty equipment are not detected in the field, hours or days – if not months – of irretrievable data might be lost and (or) erroneous interpretations of ambiguous data might result. It is imperative, therefore, that the responsible personnel be adequately informed, trained, or otherwise capable of maintaining proper equipment operation.

Disinfecting Tape Weights, Probes, and Electrodes or Sensors

According to Drost (2005), the preferred method of equipment disinfection is to submerge the end of the tape and weights in a solution of household bleach. Generally only the first 5–10 ft of the tape can be disinfected through submergence. The remainder of the equipment can be disinfected by running the tape over a clean cloth soaked in the bleach solution as the tape is lowered into the well.

Latex gloves are recommended for the disinfecting procedure to increase the sanitary condition of the tape in addition to protecting the observer from bleach burns. When possible, the recommended procedure is to use the latex gloves for both the disinfecting procedure and the measurement itself. However, as this may be impractical when measuring deep water levels, leather gloves can be substituted.

Relation Between Groundwater Levels and Land Surface Datum

Knowing the depth to groundwater below land surface (land surface datum, or lsd) is more informative if the elevation of ground level is known. Such elevations can be either estimated from topographic maps or, preferably, surveyed from a benchmark of known elevation to a reference point on the well. Water-level altitudes (elevation of groundwater head) can then be determined by subtracting water-level measurements (depths to water, in feet below land surface) from an established land-surface reference, such as the North American Vertical Datum of 1988 (NAVD 88).

Accordingly, comparisons of groundwater altitudes can be made among other observation-well data for any given area of interest. Likewise, hydraulic gradients and directions of groundwater flow can be determined. All observation-well locations should be noted and compiled with universal GIS mapping standards in mind (http://www.fgdc.gov/).

Frequency and Timing of Groundwater-Level Measurements

The appropriate frequency for measuring water levels in wells depends most importantly on the nature of the aquifer under investigation and on the scope and stage of investigation (Thornhill, 1989); thus, the frequency of measurement should be adjusted to the circumstances and

For example, at the beginning of an investigation (when details of the groundwater system are yet unknown) water levels at key locations might be measured at regular intervals--for example, once a week for water-table conditions and once a month for confined conditions. Regardless of measurement frequency, water-level measurements at any given location should be made at approximately the same time of day whenever possible.

Hydrologically valid reasons support the measuring of groundwater levels during at least early-spring, mid-summer, and late-fall periods. In addition to maximizing the frequency of measurements in consideration of available personnel, equipment, and funding there are good reasons for measuring both static and pumping water-level conditions if and where possible (Taylor and Alley, 2001). Realistically, the inevitable limitations on human and financial resources available for the monitoring of groundwater levels will likely require that some choice be alternative water-level measuring scenarios.

Pitfalls of Groundwater-Level Monitoring and Possible Remedies

Most well installations of recent years offer some means of tape access, usually from near the top of casing. If such entry is not available, a suitable opening can, in most situations, be drilled through the casing and threaded for periodic use and resealing.

Drilled wells, especially those penetrating anything but unconsolidated alluvium, typically are not straight. They spiral downward and, as a result, the pump column rests in various places against the casing; this can block the path of a lowered tape, particularly the sounder (probe) or weight section. Careful jiggling of the probe or weight section can sometimes prompt the terminus of the tape or cable to snake around or slide past an obstruction.

Occasionally, the probe or weight section will become stuck in a well. When this happens, it is important not to pull so hard that large sections of the tape or cable break off without means of recover from the well. Any dislocated part of the tape should be tied off near the well head to insure that it doesn’t fall deeper into the well to perhaps get sucked into the pump impellers (bowls) or foul the operation of a submersible pump. The tied-off section can be checked periodically to see if vibrations over time have perhaps freed the tape from the well obstructions.

Deep-well turbine pumps with oil-lubricated shafts tend to exude excess oil, which typically drips down the well bore. Because oil is lighter than water, it collects on top of the water’s surface and typically obscures the water level. As oil is a poor conductor of electricity, it interferes with the electrical contact and can cause bogus tape readings. In the event of encountering an oil-coated water-level surface, cheesecloth can be wrapped around the probe, which can be dangled and jiggled until it becomes submerged by standing water. Coating the probe or electrical contacts with salt can increase its sensitivity so that a stronger, steadier reading might be obtained when it reaches the actual water level.

Traditionally, lead weights were used at the terminus of steel tapes and electric sounders to keep the tape taut and plumb. The weight was attached in such a way that, if it became lodged in a well, it could often be pulled free (Thornhill, 1989). In the event the weight separated from a tape in a well with a pump, the relative softness and malleability of the lead would presumably minimize any damage to the pump.

In consideration of the possibility of lead dissolution and associated water-quality contamination, the USGS has recently prohibited its employees from using lead weights for the measurement of groundwater levels (Lapham and others, 1995). Whether or not weights of alternative materials are sought, the possibility of breaching an effective health standard is still relevant. Currently the two most commonly recommended material for weights are copper and stainless steel.

Graduated steel tapes must be maintained in good working by periodically checking the tape for breaks or kinks. Assuming that the tape itself is in good working order, the following criterion related to tape accuracy is generally applicable.

According to the EPA (Thornhill, 1989; Lapham and others, 1995), the water-level observer should always make at least two measurements. Unless two measurements of a static-water level made within a few minutes agree within "about 0.01 or 0.02" foot in any observation well with a depth to water of less than two hundred feet, measurements should continue until the reason for the lack of agreement is determined or until the results are shown to be reliable. Standard USGS practice (U.S. Geological Survey, 1980, p. 2-8) for measuring static-water levels is to obtain two consecutive measurements that check within 0.01 foot.

If or when water is dripping into the borehole or down the wall of a casing, it may be impossible to get distinctive water "cut" on a chalked steel tape. In this case, an alternative method, such as an electric tape or air line should be used.

Unless the well is equipped with an access pipe that is placed to eliminate the possibility of lowering the tape into the pump impellers, the graduated-tape method should not be used to measure the pumping levels in the typical 6 – 14-inch diameter well. After each well measurement, the portion of the tape that was wetted should be disinfected (according to process summarized above) to avoid contamination of other wells.

Electric tapes (e-lines) should not be allowed to drag across the top of the casing or other sharp surfaces because the distance-marking bands can become displaced. Consequently, the placement and integrity of the bands should be checked frequently against a steel tape.

It is especially important to check the length of the electric line by measuring it against a steel tape after the line has been used for a long time or after it has been pulled hard in attempting to free the line. Some electric lines are subject to being permanently stretched.

Because the electric probe or weight section is larger in diameter than the cable, they can "hang" or otherwise become lodged in a well. Some tape users prefer to attach the probe or weight section in such a manner (for example, with light-duty fishing swivels) that the point of attachment between the probe or weight section is the weakest link in the entire line. Should the probe or weight section become "hung" in the well, the electric cable can be tugged free from the terminal section of the tape, thus allowing the cable itself to be withdrawn.

If an e-tape reading flickers or does not appear to reflect a steady reading, the water in the well may be turbulent. Depending on the extent of cascading water or the proximity of a pumping well's bowls, this situation can sometimes be remedied by turning down the e-tape's gain until a stable reading is achieved.

For water-level measurements of less than 250 feet, independent electric-tape readings of static water levels using the same tape should generally agree within +/- 0.05 feet. At greater depths, independent measurements may not agree this closely. However, at depths to water between 250 and 500 feet, the difference between independent measurements with the same tape should not exceed +/- 0.1 foot as a general rule – depending, of course, on variables such as well construction or whether or not the well is being pumped.

Air lines and all connections to the air line must be airtight throughout its entire length. If the line is broken or leaky, large errors may occur. A long-term increase in air-line pressure may indicate a gradual clogging of the air line. A relatively sudden decrease in air-line pressure may indicate a leak or break in the system. Air-line pressures that never go above a constant low value are generally an indication that the water level has dropped below the bottom of the air line. To minimize the effect of turbulence, the lower end of the air-line should be at least five feet above or below the pump intake.

If water-level readings ever become constant over time, regardless of the time of year or pumping status, the air line is functioning improperly and should not be used. This condition most likely results from a leak in the air-line system. The single most common cause is a hole that has corroded through the pipe or tubing due to age and the corrosive action of the associated groundwater. As a result, the effective length of the air line has changed so that the pressurized reading and apparent depth-to-water will always equate to the particular area of the leak. In this event, the air line must be replaced or abandoned as a possible means of monitoring water levels in that well.

Because *pressure transducers* are temperature sensitive and their attaching cables are subject to stretching with use over time, they must be both factory and field calibrated. Transducer reading should, therefore be checked periodically against steel or electric-tape measurements to monitor and correct for electronic drift and (or) cable slippage. Consequently, d*ata logger* reference depths must be reset occasionally to correct for detected disparities between tape and transducer reading.

As a general rule, pressure transducer- and data-logger failures or other operations problems with transducers and loggers are best remedied through inquiry or service contracts with the manufacturer, product vendor, or through some arrangement with a qualified maintenance alternative.

Training Plan for Hydrologic Data Collection

This section presents a preliminary plan for providing training to NPS personnel on methods to collect water resource data. The training would be conducted at the Edwards Aquifer Research and Data Center in San Marcos Texas by personnel from the Center and include 24 hours of training. Below is a summary of the suggested training subjects and total estimated cost for the training. Also included is a summary of the subject related experience for each of the major instructors.

Surface Water

The primary instructor would be Raymond Slade Jr., retired hydrologist with the USGS and a Registered and Certified Hydrologist. He was the surface water specialist for the USGS in Texas until he retired, is an Adjunct Professor who teaches a college course in water resource collection and analyses, and has many years of experience in data collection.

Methods to measure water surface stage (gage height) The benefits of such data are included in the section entitled "Stage". The training includes class room introduction, identification of equipment used to measure state, and a visit to the field to read stage in a nearby creek.

Methods to measure and estimate streamflow discharge The benefits of such data are included in section entitled "Discharge". The training includes class room introduction, identification of primary equipment, used to measure and estimate discharge and a visit to the field to demonstrate methods to measure and estimate stream discharge.

Inexpensive and simplified methods to establish a gaging station for gage height and discharge   The benefits of such data are included in sections entitled "Stage" and "Discharge". The training includes class room time to discuss procedures for establishing a gaging station and a visit to the field to demonstrate methods for doing such.

Basic data analyses to improve the data collection network   The training includes introduction and demonstration of selected basic data analyses tools, including graphical and statistical methods used to document bias and trends in databases.

Groundwater

The primary instructor would be Rene Barker, retired hydrologist with the USGS and a registered geologist. He has many years of experience in groundwater hydrology, hydraulics, and geology, including data collection and modeling of groundwater flow.

Methods to identify a network of wells for data collection   The training includes discussion and PowerPoint slide presentations regarding methods and practices used to identify a network of wells that would provide the data objectives for a designed groundwater monitoring program.

Methods for measuring water levels in wells The training includes classroom introduction to various methods and equipment used to measure water levels in wells and a visit to the field to demonstrate such methods.

Basic data analyses to improve the data collection network   The training includes introduction and demonstration of selected basic data analyses tools, including graphical and statistical methods used to document bias and trends in databases.

Biological

The primary instructor is Stephen Porter, retired USGS Regional Biologist and instructor for numerous water quality and ecology short courses at the USGS National Training Center in Denver, CO. Stephen has over 30 years of experience as a water quality biologist with State and Federal agencies and as an environmental consultant. The biological section of this training includes 2 hours of classroom instruction followed by 6 hours of hands-on training in a local stream.

Methods for collecting macroinvertebrates (aquatic insects, snails, worms, and other invertebrate organisms): Macroinvertebrates are excellent indicators of organic enrichment, dissolved-oxygen concentrations, and habitat conditions in streams, rivers, and lakes. These organisms integrate water quality and habitat conditions over the past couple months to years. Qualitative ("rapid bioassessment") and quantitative approaches to sample collection, analysis, and interpretation will be discussed.

Methods for collecting benthic algae (algae attached to submerged rocks, plants, and the stream bottom): Benthic algae (periphyton) are excellent indicators of nutrient enrichment, major ions and salinity, pH, dissolved oxygen, and certain metals. These organisms integrate water quality conditions over the past couple weeks to months. Qualitative ("rapid bioassessment") and quantitative approaches to sample collection, analysis, and interpretation will be discussed.

Methods for collecting samples of bacteria and other microorganisms Certain bacteria, protozoans, and algae suspended in the water column are pathogenic or otherwise toxic to humans. This section provides an introduction to collecting water samples for laboratory analyses of *Escherichia coli* and other fecal-indicator bacteria, *Cryptosporidium*, *Giardia*, and cyanobacterial ("blue-green algae") toxins. An introduction to study design and data interpretation will be provided. Inexpensive and simplified methods for estimating rates of stream productivity and microbial respiration will be demonstrated.

Methods for evaluating the quality of in-stream and riparian habitat: Habitat conditions are as important as water quality for evaluating stream condition and biological integrity. Qualitative ("rapid bioassessment") and quantitative approaches to habitat assessment will be discussed and demonstrated in the field.

Introduction to study design, preparing cost estimates, and analysis/interpretation of results**:** Important considerations for study design and implementation will be discussed. Calculation of biological metrics and other (quantitative) assessment approaches will be introduced. Estimates and ranges of biological-laboratory sample costs will be provided.

Training Costs

The training would be conduced at the Edwards aquifer Research and Data Center in San Marcos Texas and cost $4,500.

Equipment Needs and Estimated Costs

Surface-Water Monitoring

The USGS operates a Hydrologic Instrumentation Facility to facilitate hydrologic data-collection activities through the identification of needs, development of technical specifications, design or development of specialized interfaces, contracts and procurements, testing and evaluation, specialized field applications, repair and calibration, quality control and assurance, and storage and distribution of hydrologic instrumentation. They have an outreach program for assisting others with questions or problems—the link to that program is http://wwwhif.er.usgs.gov/public/outreach/index.htm.

Although the USGS does not sell gaging equipment, many commercial vendors offer hydrologic equipment used by the USGS and others. The authors of this report do not endorse any vendors or manufacturers of gaging equipment but one company having an extensive inventory of such equipment is Advanced Measurements and Controls Inc.—their gaging equipment, along with cost is presented online at http://www.h2oresources.net/. Another such company, Gurley Precision Instruments, presents their equipment online at http://www.gpi-hydro.com/.

A partial list of companies that sell specific hydrologic equipment is listed below.

Propeller velocity meters
- Rickly Hydrological Company- carries complete line of USGS standard equipment.
- Global Water- carries low cost probe.
- Swoffer Instruments, Inc.
- Gurley precision Instruments
- Great Atlantic trading Company

Electromagnetic velocity meters
- Marsh-McBirney, Inc.

Ultrasonic velocity meters
- Unidata, Inc

Acoustic doppler velocity profilers

[SonTek](#)
[Sunwest Technologies, Inc.](#)

Stage Measuring

Staff gages commonly are mounted in stream beds and on banks and used to measure stage. An example of such as gage is presented below.

USGS Staff Gage

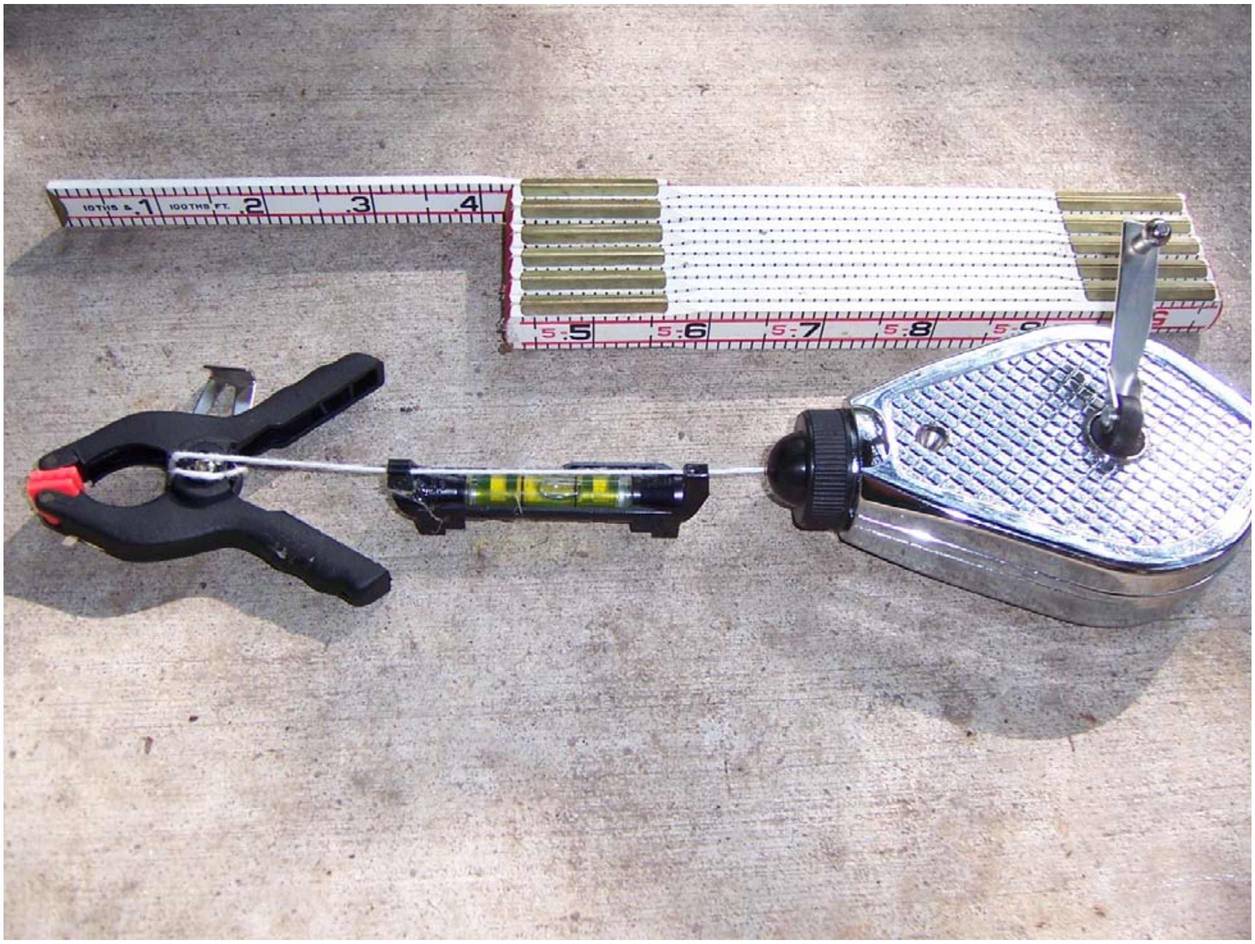
The staff gage is used for a quick visual indication of the surface level in reservoirs, rivers, streams, irrigation channels, weirs and flumes, and wherever accuracy and readability are important. These environmentally rugged iron gauges are finished with a special porcelain enamel to insure easy reading and resist rust or discoloration. They virtually never need replacement under normal conditions. Each gauge is accurately graduated and has grommeted holes for easy fastening to walls, piers and other structures.

Style A is the standard USGS gage and is 4 inches wide, marked at every foot, tenth, and 0.02 foot with total elevation, and is available in 3 1/3-foot sections for numbering 0 to 99-92 feet

Price:

Length (ft)	QTY	Price
3 1/3	0-5	$32.00
3 1/3	≥ 6	$28.00

However, as mentioned in the "Stage" section of this report, common equipment such as a string line, string level, a clamp, and an engineering folding rule (calibrated in feet, tenths, and hundredths of a foot) can be use to measure stage. That equipment is shown below.



The above equipment can be used to measure stage by attaching a clamp to the end of the string line and to the top of a stake or object with a known or established gage height—this could be a staff gage, top of a stake, nail in a tree or any fixed object. The string line then is drawn out over the water surface and the string level used to align the string on a horizontal plane. The vertical distance from the water surface to the string line then is measured and this distance subtracted from the gage height of the staff gage or other object, in order to obtain the gage height of the water surface. An example of this type of measurement is shown below.

Discharge Measuring

Discharge commonly is measured with a velocity meter attached to a wading rod. An example of a velocity meter is shown below. Smaller meters called "pygmy" meters commonly are used to measure velocity for very shallow water.

USGS Type AA - Model 6200......$745.00

The USGS Type AA current meter is commonly known as the Price- type current meter. This current meter is suspended in the water using a cable with sounding weight or wading rod (taking the tail section off) and will accurately measure streamflow velocities from 0.1 to 25 feet per second (0.03 to 7.6 meters per second).

The main features of this meter are the uniquely designed bucket wheel shaft bearings and the two post contact chamber. The bucket wheel has six conical shaped cups, is five inches (12.7 cm) in diameter and rotates on a vertical axis inside the yoke. The tungsten carbide bearings for the bucket wheel shaft are located in deeply recessed inverted cups. When the meter is in use, these cups become air chambers and the entrapped air effectively excludes water and silt from the bearing surfaces giving extremely low starting velocities and minimal friction in the bearings.

The contact chamber houses a penta gear and two binding posts, each having a fine platinum alloy contact wire. One wire makes contact with the bucket wheel shaft once during every revolution; the other is used when fast velocities are encountered, and makes contact with the penta gear once during every five revolutions of the bucket wheel.

Each current meter is provided with a U.S. Geological Survey approved standard rating table to convert bucket revolutions to stream velocity in either English units (feet per second) or metric units (meters per second), and spare parts, instrument oil, cleaning cloth, screwdriver and an instrument case with a water tight o-ring seal that floats if dropped in the water and provides proper protection of the meter during transportation and storage.

The meter is made from brass and stainless steel and all exposed surfaces are chrome plated for corrosion-free service.

An example of a wading rod to which the meter is attached is shown below.

USGS Top Setting Wading Rod

The standard USGS Top Setting Wading Rod is intended for use with the Type AA and pygmy current meters. It is designed for measuring shallow streams, with the standard English rod marked in feet and tenths and comes in 4, 6 and 8-foot long models. The standard metric rod marked in centimeter increments with a length of 1.2 meters. These wading rods also are available in lengths (up to 10 feet or 3 meters long) as desired by the customer.

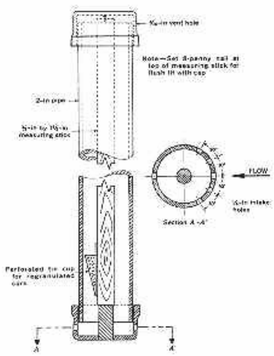
The anodized aluminum handle has an integral scale to indicate the correct setting of the current meter at the 0.2, 0.6 and 0.8- depth settings, which corresponds to the conventional two- position method. This unit permits convenient setting of the current meter at the proper depth. It allows the hydrologist to quickly set the meter at the correct depth without bringing the meter out of the water. The depth of the water is read on the graduated hex main rod. When the round setting rod is adjusted to the depth of the water, the current meter is automatically positioned for the 0.6-depth method (0.4-depth position up from the stream bed). Setting the unit to 1/2 the water depth will place the meter at the 0.2-depth up from the stream bed. Conversely, setting the unit to twice the water depth will place the meter at the 0.8-depth position up from the stream bed. The latter two positions correspond to the conventional two-position method. The electrical lead to the current meter is supplied, and a standard plug is fitted into the handle to accept the leads from a headphone, counter or AquaCalc 5000. The commonly used two prong connector can also be supplied as required. All parts are made of stainless steel, anodized aluminum and brass.

USGS Top Set Wading Rod (4 foot).....$355.00
USGS Top Set Wading Rod (6 foot).....$390.00
USGS Top Set Wading Rod (8 foot).....$445.00
USGS Top Set Wading Rod (10 foot)...$490.00

Stage Gaging

As mentioned in the "Stage" section of the report, a crest-stage gage represents a simple and inexpensive method to gage peak stage. An example of such a gage is presented below. Additional details for such a gage is presented on pages 27-28 in a report by Buchanan and Somers (1968) which is online at http://pubs.er.usgs.gov/usgspubs/twri/twri03A7. However, all such equipment represents standard hardware equipment which generally can be obtained from stores vending hardware and lumber.

USGS Crest-Stage Gage



The crest-stage gage is a device for obtaining the elevation of the flood crest of streams. The gage is widely used because it is simple, economical, reliable and easily installed.

Many different types of crest-stage gages have been tested by the Geological Survey. The one found most satisfactory is a vertical piece of 2-inch galvanized pipe with a wood staff held in a fixed position with relation to a datum reference. The bottom cap has six intake holes located so as to keep the non-hydrostatic drawdown or superelevation inside the pipe to a minimum. Tests have shown this arrangement of intake holes to be effective with velocities up to 10 feet per second, and at angles up to 30 degrees with the direction of flow. The top cap contains one small vent hole.

The bottom cap contains regranulated cork. As the water rises inside the pipe the cork floats on its surface. When the water reaches its peak and starts to recede, the cork adheres to the staff inside the pipe, thereby retaining the crest stage of the flood. The gage height of a peak is obtained by measuring the interval on the staff between the reference point and the floodmark.

Type C

While the standard gage is four feet in length, other lengths are also available. The type C gage is mounted on a steel pipe driven into the ground or attached to a fence post.

Model 9100 Type A: Galvanized steel 4' long (other lengths available) for mounting on a flat surface with brackets.
Model 9200 Type C: Galvanized steel 4' long for mounting on top of a steel pipe.
Model 9150 Type AP: Same as Type A in PVC material.
Model 9280 Granulated cork - 5# box

Call for pricing 1-800-897-6266

Groundwater quantity Monitoring

As the most common and generally effective groundwater quantity (water-level) monitoring equipment has been introduced and discussed above, under Groundwater Monitoring Methods, only estimated costs for that equipment and a list of vendors is provided below.

Table 7. Estimated costs, sources, and contacts for recommended groundwater-level monitoring devices

Device	Estimated Costs	Vendor Possibilities	Vendor Contact Information
Electric Tape	100-feet: $200 – 250 200-feet: $350 – 400 300-feet: $500 – 600	Solinest Fisher Global Water	http://www.solinst.com/ http://www.pollardwater.com/ http://www.envisupply.com
Steel Tape	100-feet: $250 – 400 200-feet: $400 – 500 300-feet: $500 – 750 500-feet: $750 – 1,000	Lufkin	http://www.forestry-suppliers.com http://www.technicaldevices.com/ http://www.engineersupply.com/ http://www.pemro.com/
Pressure Transducer and Data Logger Combination	$750 – 1,500 depending on application and accessories	Onset Computer Corporation; Campbell Scientific, Inc In-Situ, Inc;	http://www.onsetcomp.com/ http://www.campbellsci.com/ http://www.in-situ.com/
Soil-Test" Packer or Transparent Plastic Tube Assembly	$100 for materials, including pressure gage	Plumbing or hardware retailers	Local plumbing-supply warehouses

Water quality Monitoring

The principal equipment needed for measuring water temperature, dissolved oxygen, pH, and specific conductance is a multi-probe system such as the YSI 556 MPS (http://omnicontrols.com) or the Hydrolab Quanta system (http://hydrolab.com). Current (2007) price estimates for this type of instrument range from about $1,600 to $3,200, depending on which sensors are purchased for the unit. Consideration should be given to instruments that include a stirring device to enhance the accuracy of dissolved-oxygen measurements. These units typically do not include a data logger that would allow continuous measurements of core Vital-Sign constituents. Allowing for budgetary considerations, the recommended instrument would be a data sonde system (available from either Hydrolab or YSI) that includes a data logger to permit continuous (e.g. 15-minute intervals) recording of water quality conditions over a several day period. Cost estimates for this type of instrument range from about $5,000 to $6,500, including all necessary probes for monitoring designated Vital Signs. With cables of appropriate length, mini-sonde versions of this instrument (e.g. Hydrolab MS5), with a diameter of less than two inches, can be used to sample ground-water quality in wells in addition to surface water in streams or lakes. Although all parks should have a basic multi-probe instrument with which to monitor Vital Signs, the extra cost of the data sonde could be justified by the potential to measure Vital Signs in both surface and ground water and (or) fewer data sondes could be purchased and shared by parks within a region for periodic, extended (continuous) water quality monitoring.

Biological- and Stream-Habitat Monitoring

The principal equipment needed for collecting macroinvertebrate samples include a D-frame or rectangular kick net with 500 μm mesh opening (www.wildco.com), a large sieve (ASTM number 35 = 500 μm mesh size), a 5-gallon plastic bucket, forceps, sample containers, and preservative (ethanol or 10 percent buffered formalin). Current (2007) price estimates for kick nets range from less than $200 for a D-frame net to about $500 for the "Slack" sampler used by the USGS NAWQA Program (Moulton and others, 2002) http://water.usgs.gov/nawqa/protocols/OFR02-150/index.html. A large (12 inch diameter that will fit on a standard 5-gallon plastic bucket) sieve can be purchased from Fisher Scientific (http://www.fishersci.com) or other scientific-supply companies for about $100. The estimated cost for ancillary supplies for collecting macroinvertebrate and benthic algae samples (e.g. forceps, sample containers, sorting trays, etc.) is estimated to be less than $100. Equipment needed for habitat assessment varies in relation to whether rapid-bioassessment (Barbour and others, 1999) or quantitative (Fitzpatrick and others, 1998) approaches are employed. Minimally, a 100 m tape measure and water-velocity meter (see surface water section of this report) are required. Other equipment (e.g. a clinometer (about $200) and spherical densitometer (about $125)) are required for quantitative assessments (refer to Fitzpatrick and others, 1998; http://water.usgs.gov/nawqa/protocols/WRI98-4052/index.html).

RECOMMENDED HYDROLOGIC-MONITORING ACTIVITIES

Bent's Old Fort National Historic Site (BEOL)

Water Quality Issues and Problems

Agricultural runoff and urban discharges (marginal wastewater treatment in several upriver towns) were major influences on the water quality of the Arkansas River during the second half of the 20th century. Water quality data for Bent's Old Fort National Historic Site (NHS) were evaluated from the 1960s through the early 1990s for 3 monitoring sites on the Arkansas River (BEOL 19, 26, and 29), one site on Crooked Arroyo (BEOL 28), and one site on Horse Creek (BEOL 2) (fig. BEOL). Data from several other sites with shorter periods of record (BEOL 2, 3, 6, 7, and 9) also were examined. All of these sites are located outside the NHS boundary, and most of the Arkansas River sites are located over 5 miles upstream, near La Junta, CO. A USGS gaging station is located about 2 miles downstream from the NHS boundary (Arkansas River at Hadley, Co.; BEOL 7); however, water quality data provided for this site were limited to 3 samples.

Analysis of core Vital-Sign data (water temperature, dissolved oxygen (DO), pH, specific conductance, and indicator bacteria) generally indicate acceptable water quality conditions with the exception of fecal and total coliform bacteria at BEOL 29 (table 8). Median DO concentrations varied from 8.0 to 9.7 mg/L, with no values less than 4 mg/L, a generally recognized criterion for protection of aquatic life. Median pH values ranged from 7.5 to 8.2. Increases in pH values, from about 7.6 in 1961 to over 8.2 in 1993, were observed in the Arkansas River at La Junta, CO (fig. 11). Median values for specific conductance generally were less than 2,000 µS/cm in the Arkansas River and more than 2,000 µS/cm in tributary streams and irrigation canals.

Median coliform bacteria levels in the Arkansas River near La Junta (BEOL 29) were elevated. Fecal coliform values exceeded 400 colonies per 100 mL (primary-contact recreational criteria) in 48% of samples, and maximum total and fecal coliform values were indicative of sewage contamination. Although it is unknown whether these data represent current conditions in the Arkansas River near the NHS, we recommend initiation of routine water quality monitoring of these core constituents at BEOL 7. Elevated concentrations of nitrate, chloride, sulfate, and total dissolved solids at this site indicate influences from agricultural and urban activities in the region.

NHS personnel indicated concerns about selenium and heavy metals from hard-rock mining activities in the Arkansas River headwater segments, and fish-consumption advisories have been issued by the State of Colorado. Fishing is the predominant recreational use in the river. Bank stabilization also is a concern. According to NPS (1975a), the Arkansas River was deemed to be polluted with particulate matter from agricultural runoff, grazing animals, solid waste, and sewage effluent from several upriver towns with marginal wastewater-treatment facilities. Characterization of current water-chemistry conditions would be beneficial for the protection of visitors interested in water activities within the NHS boundary.

Surface-Water Quality

We recommend that water quality data collected since the early 1990s be compiled, incorporated into the historical database, and analyzed for water quality condition and trends, particularly for the USGS gaging station at BEOL 7. Because of the proximity to the NHS and the availability of streamflow data at this site, we recommend that BEOL 7 should be considered for future water quality monitoring activities. Weekly monitoring of core Vital-Sign constituents (water temperature, DO, pH, specific conductance, and *E. coli*), supplemented by seasonal, continuous (diel) monitoring of DO and pH would provide additional understanding of the chemical condition of the Arkansas River. Consideration also should be given to monthly monitoring of nutrient concentrations (e.g. nitrate) and major ions (e.g. chloride, sulfate, total dissolved solids).

Annual or seasonal monitoring of the aquatic biological condition (macroinvertebrates, including freshwater mussels, and (or) benthic algae) also is recommended because aquatic biota integrate water quality conditions over time and have direct relevance to the productivity of fisheries in the river. Concerns about bank stabilization could be better understood and quantified by in-stream and riparian assessments of habitat condition (for example Barbour and others, 1999; Fitzpatrick and others, 1998). Although a recent survey of vertebrates, amphibians, fish, and vascular plants conducted by Gionfriddo and others (2002) provides a valuable benchmark for future assessment of terrestrial and semi-aquatic biota, this study was limited to riparian wetlands within the NHS boundary along the Arkansas River. Because of concerns about maintaining the quality of riparian wetlands within the NHS (Fran Pannebaker, BEOL Chief of Natural Resources, pers. comm., 2007), we also recommend periodic monitoring of aquatic plants and animals similar to the approach taken by Gionfriddo and others (2002).

Groundwater

Given the backlog of groundwater data that results from previous studies such as Woods and others (2002), EARDC recommends that – to the extent practical – the existing groundwater-level data be consolidated within an electronic database (such as Microsoft Excel) and coordinated with the operation of an appropriate NPS-wide or national- or state-related database system (such as the USGS's NWIS-GWSI network).

Problems associated with water tables that are periodically higher than normal in the Arkansas River Valley – particularly within areas 15-20 miles upstream and downstream of BEOL – are well documented (Woods and others, 2002; Watts and Lindner-Lunsford, 1992). Aside from a general (widespread) waterlogging of topographically low areas, the local endangerment to foundations and subterranean rooms at Bent's Old Fort has raised the concern of park staff (Fran Pannebaker, BEOL Chief of Natural Resources, pers. comm., 2007). EARDC, therefore, recommends the renovation of at least the most readily recoverable hand-augured and well-point driven piezometers installed originally by Woods and others (2002) – in addition to a renewal of efforts to monitor groundwater levels through those renovated sites. According to Ms. Pannebaker, 13 of these piezometers are lined with 1.5-inch PVC and two with 3-inch steel casing. In addition to these shallow-aquifer piezometers, Ms. Pannebaker is aware of four onsite staff gages – two of which are situated in the bed of the adjacent Arkansas River, plus another two that are installed within nearby wetland areas.

Accordingly, EARDC recommends a review of existing staff gages and – if necessary – the placement of additional staff gages and (or) corresponding benchmarks with which to compare upland water levels with those in the wetlands and adjacent Arkansas River. Such a network of new and (or) additional datums would entail a survey with appropriate leveling instruments to link the groundwater and surface water datums and allow subsequent comparisons of aquifer-head and stream-stage information appropriately across the park unit.

Capulin Volcano National Monument (CAVO)

Water Quality Issues and Problems

No surface water was observed within or near the National Monument boundary.

Surface-Water Quality

No recommendations are made.

Groundwater

A water-supply well (of unknown depth and construction) taps volcanic terrain north of park headquarters on southern flank of volcano. Although park spokespeople indicated no current effort to monitor groundwater levels, EARDC recommends that:

1. Available well and water-level records be consolidated and used to better understand supply well's construction and history of water-level trends;

2. Attempt measurement of groundwater levels through casing of water-supply well, from top of sanitary seal (accessible inside pump/well enclosure?); and

3. To the extent practical, any resulting groundwater-level data be consolidated within an appropriate electronic database (such as Microsoft Excel) and coordinated with the operation of an NPS-wide or national- or state-related database system (such as the USGS's NWIS-GWSI network).

Chickasaw National Recreation Area (CHIC)

Water Quality Issues and Problems

Chickasaw National Recreation Area (NRA) offers a unique environmental setting relatively close to several major urban areas; however, water quality, particularly fecal-indicator bacterial counts, during 1974-94 was impaired by wastewater effluent discharges, agricultural activities, and other (unknown) sources. Sufficient data to examine water quality trends were available for only one site (CHIC 2; Rock Creek at Dougherty, OK), and those data were limited to water temperature collected between 1951 and 1962 (table 9). No significant trend was indicated. Specific conductance ranged from 299 to 3,040 µS/cm, pH from 7.0 to 8.7, and chloride concentrations varied from 10 to 800 mg/L. An additional 30 sites in Rock Creek (Fig. CHIC, table 10), 22 sites in Travertine Creek (table 11), three sites in Guy Sandy Creek, and four springs within the National Recreation Area (NRA) boundary (table 12) are reported; however, site data generally include relatively few samples representing limited periods of time.

Through the early 1990s, the water quality of Rock Creek generally met criteria suitable to sustain aquatic life; however, DO concentrations less than 4 mg/L were recorded occasionally at several sites (table 10). Values for pH ranged between 6.8 and 10.1. Values exceeding 9.0 were observed as maxima at several sites. Values for specific conductance (299 to 3,100 µS/cm) and chloride concentrations (36 to 1,375 mg/L) were quite variable, although it is unclear whether these ranges represent differences among sites or increases through time. Nutrient concentrations (total nitrogen and phosphorus) generally were low to moderate. Values for fecal coliform bacteria exceeded a (maximum) primary-contact recreational criterion of 400 colonies per 100 mL at most Rock Creek sites. Total coliform and fecal-streptococcus bacterial counts were similarly elevated.

Despite the absence of wastewater effluent influences on Travertine Creek, water quality was similar to conditions observed in Rock Creek (table 11), although specific conductance and chloride concentrations generally were less than reported from Rock Creek (table 10). Fecal-indicator bacterial counts were larger than expected, a concern for primary contact recreation in the stream. Fecal coliform counts from the primary spring discharges to Travertine Creek (Buffalo and Antelope Springs) were consistently low and in accordance with primary-contact recreational criteria (table 12). Potential sources of fecal contamination in Travertine Creek are unknown but warrant further study.

Although water quality complaints have been registered for Guy Sandy Creek (fig. CHIC; CHIC 145-147), occasional data reports from 1974-94 do not reveal significant problems, apart from slightly elevated nutrient concentrations (e.g. range of total phosphorus concentrations: 0.02 – 0.66 mg/L). Fecal coliform counts generally were much lower than observed in either Rock or Travertine Creeks (<1 – 1,300 colonies per 100 mL). Possible increases in agricultural activity in the Guy Sandy basin since that time period may have changed water quality conditions.

Water quality conditions in Lake of the Arbuckles and Veterans Lake are summarized by Steebin and Harp (1977) and Hanson and Cates (1994) who indicate "significant eutrophication in both the lake and inflow tributaries," in part, attributable to wastewater discharges into Rock Creek from the town of Sulphur, OK. Lake of the Arbuckles, a recreational and flood control reservoir constructed by the U.S. Bureau of Reclamation during the mid-1960s, serves as a water supply for several small towns in the area (Hanson and Cates, 1994). Recreational uses of the lakes include fishing, swimming, and boating. Lake of the Arbuckles supports a productive largemouth bass fishery (Steve Burrough, CHIC Chief of Resource Management, pers. comm., 2007); however, gizzard shad with melanomas have been reported from the lake as well as "sand" bass kills.

Surface-Water Quantity

Two prominent springs, Antelope and Buffalo Springs, exist inside the Recreational Area and contribute to the value and beauty of CHIC. However, the hydrogeologic setting of these springs deem the quantity and water quality of their flow sensitive to land development in the area, particularly in upgradient parts of the groundwater-flow system. The NPS desires to monitor the flow from both these springs in order to document the effects of such development with the intent of maintaining continued discharge (Sue Braumiller, NPS-SOPN Regional Hydrologist, verbal comm., 2007).

The flow for Antelope Springs has been gaged on a daily basis by the USGS since 1985. Data for this spring are presented on the Internet at http://nwis.waterdata.usgs.gov/ok/nwis/inventory/?site_no=07329849&amp. As this Internet page shows, water quality data for the spring exist for about 29 different dates—ranging mostly from 1986-89. Discharge measurements of springflow were made at the time the samples were collected—those values are stored along with the water quality data and available at the hyperlink above.

Buffalo Springs has not been gaged continuously for flow; but water quality samples have been collected from these springs on about 24 dates, ranging mostly from 1986-89. The data for this spring is provided online at http://nwis.waterdata.usgs.gov/ok/nwis/inventory/?site_no=07329847&amp. Although springflow discharge has not been gaged on a continuous basis, measurements of springflow made on dates the water was sampled are also available at the hyperlink above.

A review of the springflow measurements for both Antelope and Buffalo Springs indicates that 21 of their measurements were made on the same dates. If the discharge values for these springs were found to be statistically correlated, the flow from Antelope Springs might be used to estimate the discharge from Buffalo Springs. However, a scatter plot of common-date discharge values (fig. 12) shows these values to be highly *un*correlated. Therefore, the gaged discharge values for Antelope Springs probably can *not* be used to accurately predict the outflow from Buffalo Springs.

However, long-term water levels exist for two wells in the area. For nearly 30 years since 1972, the USGS measured the water level in well number 01S-03E-01 ABA 1, which is referred to as the East Well by NPS. Data for this well is accessible on the Internet at http://nwis.waterdata.usgs.gov/nwis/gwlevels?search_station_nm=01S-13E-01. (Note that the USGS website provides an incorrect site label (**13**E) for the East Well; the correct site id is 01S-**03**E-01 ABA 1).

Water levels also have been measured by the USGS and are available for well 01S-03W-01 BBB1 (referred to as the West Well by the NPS). Data for this well are online at http://nwis.waterdata.usgs.gov/nwis/gwlevels?search_station_nm=01S-03W-01.

Many common-date water level measurements exist for each of the above wells, as well as springflow from Buffalo Springs. The range in water levels for the West Well is very limited but those for the East Well vary at least 60 feet. The relation between common-date water levels in the East Well and springflow from Buffalo Springs is presented in figure 13. These water level and springflow data appear to be highly correlated. Therefore, it is recommended that water levels measured from the East Well might be used, in conjunction with the apparent graphical relation between such levels and discharge from Buffalo Springs, to estimate discharge for Buffalo Springs. As the USGS is no longer collecting data from the East Well, EARDC endorses SOPN's continued efforts to monitor conditions in this well.

Since 1906, several agencies (including the USGS and NPS) and other investigators have devised procedures for, and attempted to periodically estimate or measure the head and (or) outflow from, both Antelope and Buffalo Springs (Hanson and Cates, 1994, p. 10 – 13). Since the late 1960's, CHIC personnel have collected stage measurements from the main pools sustained by Antelope and Buffalo Springs. According to Ms. Braumiller, park personnel have collected periodic discharge measurements (with pygmy meter) on a quarterly basis in the stream "issuing from Vendome Well, along with sites on Travertine Creek, Rock Creek, and Antelope and Buffalo Springs." Although we wholeheartedly endorse a continuation of at least these efforts, EARDC recommends a further effort to automate the monitoring process at these CHIC sites with appropriately updated instrumentation where and when practical, assuming availability of funding and personnel.

Surface-Water Quality

Discussions with the NRA Chief during a site visit in May 2007 revealed considerable water quality data entered only on field forms or log books. We recommend that data collected since the early 1990s are compiled, incorporated with the historical database, and analyzed for condition and trends. Because there are presently no sites with sufficient period of record to serve as "trend sites," we suggest that core water quality monitoring is considered for sites with active stream gages. Periodic monitoring of core Vital-Sign constituents (water temperature, DO, pH, specific conductance, and *E. coli*) should be supplemented by seasonal monitoring of *E. coli* at beaches and other stream locations likely to attract human uses (e.g. swimming). Consideration also should be given to monitoring nutrient concentrations and major ions (e.g. chloride, sulfate, total dissolved solids). A synoptic study of selected historical sites focused on previous water quality problems should be considered to determine whether conditions have improved, degraded, or remained the same during the past decade. Limnological investigations of the Lake of the Arbuckles and Veterans Lake should be considered to evaluate current trophic condition, suitability for contact recreation (e.g. monitoring of *E. coli* levels, particularly at public beaches), and causes of fish tumors and periodic fish kills.

Annual or seasonal monitoring of the aquatic-biological condition (macroinvertebrates and (or) benthic algae) also is recommended because aquatic biota integrate water quality conditions over time. A number of terrestrial and aquatic ecological studies have been conducted in the past within the NRA boundary; we suggest that results are synthesized into a report describing historical ecological conditions, and a plan for ecological monitoring is established at sites at or near those selected for water-chemistry and indicator-bacteria monitoring. Chickasaw National Recreation Area offers a unique environmental setting within a half-day drive of several major urban centers. High priority should be given to documenting and preserving the quality of aquatic resources.

Groundwater

In addition to strongly endorsing SOPN's continued monitoring of water levels in the West (USGS Site Id 343022096565701), East (Id 343017096561501), South, and North Wells, EARDC suggests that existing water-level data be consolidated and coordinated within a master database (such as perhaps a NPS-wide or USGS NWIS/GWSI-type system). We recommend also that methods be considered for possibly monitoring the shut-in pressure from Vendome Well (USGS Station No. 07329851) and (or) from other free-flowing artesian wells in the vicinity.

The pattern of water-level fluctuation and similarity of bottom-hole elevations suggest there might be a relation between the source of Vendome Well discharge (which historically has averaged about 1.5 ft^3/s) and the pressure head in the West Well (Hanson and Cates, 1994; figs. 4, 5, and 13). While pointing out that dissimilar aspects of water chemistry and perhaps age probably make such a connection "remote," Sue Braumiller (NPS-SOPN Regional Hydrologist, written comm., 2007) suggests a potential correlation between water levels in West Well, discharge from Antelope Springs, and groundwater withdrawals from the city of Sulphur (Oklahoma) public-supply wells.

As noted above, under Surface-Water Quantity, a significant relation (fig. 13) does appear to exist between discharge from Buffalo Springs and contemporaneous water levels in East Well. As also noted above, the discharge from Buffalo Springs does *not* appear to correlate statistically with that from Antelope Springs (fig. 12), although other aspects of these two freshwater springs appear to suggest the effects of similar hydrogeologic controls (Hanson and Cates, 1994, p.10 - 19). In consideration of the complex, structurally altered hydrogeologic framework at CHIC and the obviously complicated, uncertain affects on the occurrence and availability of groundwater, prudence dictates an expansion of groundwater-data collection beyond the four currently monitored observation wells.

Accordingly, Ms. Braumiller indicates that CHIC has purchased an In-Situ miniTROLL pressure transducer, (with operational range of 0 – 30 psi) "for installation in the piping between the Vendome Well head and the fountain orifice, along with a timer-actuated butterfly valve for nightly shut-down of the well." Installation is pending upon a vault being constructed for the value and timer.

The amount of groundwater discharging from the area's Arbuckle and Simpson aquifers is a function of the prevailing hydraulic heads, which in turn reflect the viability of these aquifers as a natural resource and (or) potential water supply. Past investigations have attributed the area's highly mineralized water and flowing artesian wells to the deeper Simpson aquifer. The Arbuckle aquifer is generally considered the source of most fresh groundwater and springflow, particularly that discharging near CHIC's eastern boundary from Antelope and Buffalo Springs (Hanson and Cates, 1994).

Although artesian flow from the Arbuckle-Simpson aquifer system "has declined substantially" below that reported in 1939 (Hanson and Cates, 1994), many artesian wells remain. Conceivably, some might be available as observation wells. The more pressure heads and discharge rates monitored from the area's artesian system, the better the chances of understanding the dynamics of the entire groundwater-flow system and predicting the effects of future development on park resources.

The practicality and effectiveness of attempting to monitor the area's artesian conditions on a continuous and (or) widespread basis might be better appreciated if test readings could be first obtained from different wells under a variety of conditions. Obviously, the orifice on any available, free-flowing artesian well would have to be re-plumbed with a shut-off value (and timer?) and some manner of connecting a pressure gauge. For example, a "soil-test plug" or similar expandable packer (fig. 7) with associated clamps to contain the discharge (or perhaps an inline butterfly-type valve to control the outflow) is typically used for such temporary installations. An alternative opportunity might be to measure the head directly with a standpipe or transparent tube, as suggested by Drost (2005, p.17) for low-pressure configurations.

If outflow from representative flowing wells can be contained temporarily – but long enough for the effective hydraulic pressures to equilibrate – the pressure head could be measured and subsequently compared directly, not only to other hydraulic heads from other onsite observation wells, but also to contemporaneous discharges from Antelope and Buffalo Springs. As inferred by Hanson and Cates (1994), additional hydraulic head or discharge data from any of the available flowing wells would conceivably improve the current "understanding of how the geologic structure influences the ground-water system." These authors suggest additionally that geophysical surveys, test-hole drilling, and water quality sampling of wells and springs in the area might also help to better understand the prevailing flow system and hydrogeologic resources at CHIC.

A potential caveat that must be considered, however, before attempting to contain outflow from any of the flowing wells at CHIC – especially for any prolonged length of time – is the possibility of damage to a possibly already compromised casing due to the corrosional effects of highly mineralized water over time. According to Hanson and Cates (1994, p. 24), effort to monitor the shut-in pressure of Vendome or any similarly flowing well in the area "may be difficult to conduct without damaging the well because a pressure build-up in the wells may damage the casings, causing a permanent reduction or complete loss of flow from the wells." As Ms. Braumiller points out, however, the "slow closure of [a] butterfly valve (on a timer) will reduce the chances of damaging the well casing during closures to conserve water and get a good artesian pressure reading."

Fort Larned National Historic Site (FOLS)

Water Quality Issues and Problems

Water quality issues in the Pawnee River near the Fort Larned National Historical Site (NHS) are influenced by agricultural activities occurring in the basin; however, the modification of natural stream-flow conditions through the NHS is primarily responsible for degraded ecological and water quality conditions. Sufficient data to examine water quality trends were available for only one site (FOLS 4), located at the USGS gaging station about 15 miles upstream from the NHS (fig. FOLS). At this site, sufficient data were available for water temperature, pH, and specific conductance. A possible upward trend for water temperature from 1959 to 1995 was noted (fig. 14), however, regression results were not significant statistically. Additional water quality data are available for two historical sites near the NHS (FOLS 1: 1972 and 1975, and FOLS 2: 1975-81), and another site, about 5 miles upstream from the NHS (FOLS 3: 1990-97) (refer to fig. FOLS). Those sites may have been abandoned because of reduced flow in the Pawnee River, attributed to irrigation practices and sediment aggradation behind an irrigation dam upstream from the NHS. According to the Supervisory Park Ranger, Felix Revello (pers. comm., 2007), the Pawnee River was a perennial, sandy, clear water course, even during the dust-bowl era of the 1930s, and supported a productive fishery as late as the 1970s. The primary aquatic resource issue, presently, is a lack of flow in the old river channel on the NHS boundary.

Among the 4 monitoring sites, water quality generally was sufficient to meet aquatic life criteria; however, DO concentrations less than 4 mg/L occasionally were reported for FOLS 2 and FOLS 3. Specific conductance ranged from 110 to 1,220 μS/cm and pH varied from 6.8 to 8.6. No significant trends were noted for DO, pH, or specific conductance. Nutrient concentrations indicated influences from irrigated agricultural practices; for example, ammonia-nitrogen concentration maxima varied from 0.45 to 0.8 mg/L, nitrate maxima from 1.01 to 5.8 mg/L, and total phosphorus maxima ranged from 1.6 to 2.6 mg/L. Pesticide concentrations were detectable at all sites, however, values were less than those of concern to the health of aquatic organisms. Fecal-indicator bacteria counts occasionally exceeded contact-recreational criteria: fecal coliform bacteria values varied from 3 to 4,500 colonies per 100 mL; total coliform varied from 10 to 180,000 colonies per 100 mL; and fecal streptococcus bacteria ranged from less than 10 to 21,000 colonies per 100 mL. These values do not represent gross contamination from point sources (e.g. wastewater effluents) but may be reflective of livestock or other animals in the basin. Water turbidity in the Pawnee River frequently was high, with maxima ranging from 65 to 945 FTUs.

Delisle and Busby (2004) reported only six fish species (35% of those predicted to occur) from two locations in the Pawnee River within the NHS boundary during 2001. These two sites were the only sections of the river containing water at the time of the survey. The fish species collected were tolerant of poor water quality, including high turbidity and low oxygen availability, and reflected the pond-like condition of the river at Fort Larned. Somewhat similar (16 of 35 species predicted to occur) results were reported from surveys of amphibians and reptiles. The primary issue appeared to be lack of flow (isolated stagnant pools) in the river rather than a specific water chemistry problem.

Surface-Water Quality

The availability of water resources must have been an important consideration in the original selection of the site for Fort Larned. Agricultural and other land-use activities during the past several decades appear to have preempted the NHS from receiving its natural sources of surface water. The present condition of the Pawnee River, normally dry but receiving large pulses of water following major rain events, is not favorable for sustaining productive aquatic-life communities and good water quality. The National Park Service should consider attempting to work with local and State authorities to restore natural stream-flow conditions to the Pawnee River. The present low-flow, ponded condition of the river could be regarded as a nuisance during summer, a breeding ground for mosquitoes and other insects that could possibly be vectors of human pathogens. The primary goal should be to restore flow to the river.

Given the present condition of the Pawnee River, we recommend that the core Vital-Sign constituents (water temperature, DO, pH, specific conductance, and *E. coli*) are monitored following rain events that temporarily restore water to the river channel, supplemented by periodic monitoring of the water quality condition of the stagnant pools in the river. Monitoring of aquatic insects such as mosquitoes and other nuisance taxa is recommended to reduce the probability of infection to NHS visitors. When natural flow is restored to the river, we recommend seasonal monitoring of nutrient concentrations, agricultural pesticides, and biological indicators of stream condition (e.g. fish, macroinvertebrates, and benthic algae).

Groundwater

EARDC recommends that – to the extent practical – any existing groundwater-level data be consolidated within an appropriate NPS-wide or national- or state-related database system (such as the USGS's NWIS-GWSI network).

Based on the data available to EARDC, no additional groundwater-monitoring activities – or changes to the current activities – are recommended at this time.

Fort Union National Monument (FOUN)

Water Quality Issues and Problems

The only surface-water body near the Fort Union National Monument (NM) boundary is Wolf Creek, an intermittent stream tributary to the Mora River, located at the southwestern edge of the NM boundary. Four sites (FOUN 2-5) were sampled once in July 1956. Water temperature ranged from 11.9 to 14.5 ^{o}C, pH varied from 7.4 to 7.8, and specific conductance varied from 436 to 566 µS/cm.

Surface-Water Quality

EARDC recommends that limited water quality monitoring for core Vital-Sign constituents (water temperature, pH, DO, specific conductance, and *E. coli*) are initiated during periods of streamflow at or near the present location of FOUN 2 (refer to fig. FOUN). Because of the relatively remote location of the NM, a survey of terrestrial and aquatic organisms should be considered to serve as a baseline reference condition with which future environmental changes (if they occur) may be compared. We also recommend that FOUN review Jacobi's (1995) descriptions of biological assessments performed at the nearby Pecos National Historical Park (PECO) and consider conducting similar inventories of fish and aquatic macroinvertebrate resources at FOUN.

Groundwater

The water supply for FOUN is currently sustained by one groundwater production well, reported to be about 360 feet deep. Given the ease with which EARDC measured the water level in this water-supply well, EARDC recommends that the depth of the water table in the local alluvial aquifer be measured periodically (on quarterly basis?) from this onsite, NPS-owned and maintained water-supply well.

EARDC further recommends that – to the extent practical – the resulting groundwater-level data be consolidated within an electronic database (such as Microsoft Excel) and coordinated with the operation of an appropriate NPS-wide or national- or state-related database system (such as the USGS's NWIS-GWSI network).

Lake Meredith National Recreation Area (LAMR)

Water Quality Issues and Problems

Water-quality conditions in Lake Meredith appear to have been adversely affected through byproducts of hydrocarbon production – likely resulting from inadequate disposal of oil- and gas-field brines (Texas Groundwater Protection Committee, 1994) – and water withdrawal issues in the basin (Paul Eubank, former LAMR Chief of Resource Management, verbal comm., 2007). Significant upward trends in specific conductance values and concentrations of major ions (e.g. sodium, chloride, and sulfate) have occurred since the mid-1960s (figs. 15, 16 and 18 – 20). Variability in concentrations of major ions such as chloride is somewhat associated with year-to-year variability of the amount of water stored in the lake, with relatively higher concentrations observed during periods of lower storage (fig. 17); however, an overall upward trend in major-ion concentrations appears to be commensurate with increases in oil and gas production. Fish kills have been reported near the Meredith Lake dam, associated with blooms of toxic algae (*Prymnesium parvum*). Lake operations are managed by the Canadian River Municipal Water Authority, primarily as a water supply for the cities of Amarillo and Lubbock, TX and surrounding communities, and secondarily to provide recreational opportunities in a region where no comparable body of water exists (Kaiser and others, 1994). Primary recreational uses of the lake include swimming, water-skiing, diving, boating, and fishing. In addition to recreational uses, water quality needs exist for protection of aquatic life and riparian vegetation.

Lake Meredith contains a large number of legacy water quality sites (fig. LAMR; tables 13 - 19); data for dissolved oxygen (DO) concentrations and specific conductance are available for 16 sites, generally from the mid-1960s through the late 1990s. Median DO concentrations at those sites ranged from 8.0 to 9.0 mg/L with relatively few values less than 4.0 mg/L (table 14). Median specific conductance varied from 1,680 to 2,000 μS/cm (table 16), partially reflecting natural salinity in the Canadian River (Kaiser and others, 1994); however, values have nearly tripled near the Lake Meredith dam and other locations since the mid-1960s. Median values for pH ranged from 7.9 to 8.5 (table 15), and increased significantly between the mid-1960s and mid-1970s at the USGS gaging station (07227900) near the dam (fig. 20).

Indicator bacteria levels generally were low. Median total coliform bacteria levels (table 17) ranged from 2 to 12 colonies per 100 mL. Median fecal coliform levels were 3 colonies per 100 mL or less (table 18), with relatively few values (0 to 0.4% of samples) exceeding contact-recreational criteria of 400 colonies per 100 mL. Similarly, median fecal streptococcus bacteria values were less than 1 colony per 100 mL at 10 sites and 3 or less colonies per 100 mL at other sites (table 19). Maximum values for indicator bacteria generally were less than 1,000 colonies per 100 mL.

Surface-Water Quality

We recommend that water quality data collected since the late 1990s are consolidated with the legacy water quality data into a digital database and evaluated for current conditions and trends. We recommend weekly monitoring of core Vital-Sign constituents (water temperature, DO, pH, specific conductance, and *E. coli* bacteria), supplemented by one or more measurements of water clarity (e.g. Secchi depth, light-extinction, or total suspended sediment). Because of decadal-scale relations of major ions and specific conductance with lake levels (stage) and discharge, and the long period of monitoring record near the USGS gaging station near the dam, we recommend that this location (LAMR 6, 8-9) serve as a primary trend site for Lake Meredith. Because of low historical coliform and fecal streptococcus levels at most lake sites, we recommend that bacteria (*E. coli*) should be monitored only during the recreational season, at or near public swimming areas in the lake and below the dam.

A limnological survey of Lake Meredith should be considered to document the current trophic condition and to better understand water quality relations with toxic algal blooms occurring near the dam. The survey should include analyses of nutrient concentrations, phytoplankton composition and abundance, chlorophyll a, depth profiles of core Vital-Sign constituents, and measurements of light extinction. Because of the past occurrence of algae toxic to fish, assays of microcystin (a blue-green algal toxin that can affect humans) also should be considered for the survey, particularly in areas of public recreation. The survey could begin at the USGS gaging station near Amarillo, TX (07227500), and proceed downstream, from the lake headwater area near LAMR 69, through the middle segments (e.g. LAMR 49 or LAMR 50, to an area near the dam (LAMR 6, 8-9, 16-17). Water quality and algal variables also should be characterized near the swimming area below the dam.

Groundwater

All groundwater-supply and groundwater-testing issues at LAMR are being handled by the Canadian River Municipal Water Authority (CRMWA), whose Deputy General Manager is Chad Pernell (806-865-3325).

As LAMR's current dependency on groundwater apparently is being handled appropriately by CRMWA – and is, therefore, outside the scope of EARDC's objective to review and recommend groundwater quantity protocols for SOPN-dependant services – EARDC has no changes to recommend beyond a continuation of SOPN's current arrangement with CRMWA.

Lyndon B. Johnson National Historical Park (LYJO)

Water Quality Issues and Problems

Primary surface-water resources associated with the Lyndon B. Johnson National Historical Park (NHP) include the Pedernales River, that flows through the LBJ Ranch, and Town Creek (LYJO 4, 8, and 10), flowing within the park headquarters boundaries in Johnson City, TX. The quality of the Pedernales River, historically, has been excellent; however, increased population growth in the Texas Hill Country, in addition to agricultural activities in the basin, are beginning to exert an influence on water quality. Sufficient data to examine water quality condition and trends were available for seven sites on the Pedernales River. A number of these sites appear to be coincident (fig. LYJO), resulting in essentially 3 trend-site locations, one downstream from US 281 at Johnson City (LYJO 2, 3, 5, and 7), another at road FM 1320, about 6 miles downstream from the LBJ Ranch (LYJO 15-16) and 18 miles upstream from Johnson City, and a third site at Goehman Lane, about 12 miles upstream from LBJ Ranch and the town of Stonewall, TX (LYJO 39). A USGS gaging station (08153500) is located on the Pedernales River at the Johnson City site, and a discontinued USGS gage (08153000) is located near Stonewall, immediately upstream from the LBJ ranch. Designated uses of the Pedernales River include contact recreation, high-quality aquatic habitat, and public water supply (Kaiser and others, 1994)

Water quality data were evaluated from the mid-1960s through the early 1980s at two sites (LYJO 5 and 7), and from the mid-1980s through the late 1990s at five other sites (LYJO 2, 3, 15, 16, and 39) on the Pedernales River. Analyses of core Vital-Sign data (water temperature, dissolved oxygen (DO), pH, specific conductance, and indicator bacteria) generally indicate good water quality. Median DO concentrations ranged from 8.5 to 9.7 mg/L, pH values from 8.0 to 8.6, and specific conductance varied from 620 to 723 μS/cm (tables 20 and 21). By contrast, DO concentrations in Town Creek (LYJO 4, 8, and 10) generally were low (< 4.0 mg/L) and not sufficient for sustaining diverse aquatic communities. Water-quality exceedances for pH (> 9.0) were observed on about 2 percent of sampling dates for the Pedernales River at Johnson City (table 20; LYJO 2 and 3). Median fecal coliform values in the Pedernales River ranged from 36 colonies per 100 mL at the FM 1320 location (LYJO 15) to 61 colonies per 100 mL at Johnson City. Exceedances of primary-contact recreational criteria (> 400 colonies per 100 mL) occurred in about 10 percent of samples from LYJO 15 and over 14 percent of samples from

LYJO 2 (table 21). Relative increases in concentrations of nutrients and decreases of DO concentrations and water transparency (figs. 21- 24) in the Pedernales River since the mid-1980s probably reflect population increases in the scenic Hill Country that are likely to continue.

Surface-Water Quality

We recommend that water quality data collected since the late 1990s are consolidated with the legacy water quality data into a digital database and evaluated for current conditions and trends. We recommend weekly monitoring of core Vital-Sign constituents (water temperature, DO, pH, specific conductance and *E. coli* bacteria), supplemented by one or more measurements of water clarity (e.g. Secchi depth, light extinction, or total suspended sediment). To better understand potential eutrophication issues in the river, concentrations of nutrients and phytoplankton chlorophyll *a* should be considered at a frequency of monthly (legacy data are available from 1984 through 1999 at LYJO 2 and 16). Although the Johnson City site on the Pedernales River (e.g. LYJO 2) lies outside the park boundaries, we recommend continuance of water quality monitoring here because of the presence of the USGS gage and the long period of water quality record (since the mid-1960s). Similarly, the FM 1320 site on the Pedernales (e.g. LYJO 16) should be considered for retention although provision should be made for measuring or estimating stream flow at this location. A new monitoring station could be considered in the Pedernales River adjacent to the LBJ ranch. The discontinued USGS gaging station at Stonewall, TX could be re-established, with sampling conducted upstream and (or) downstream from the Lyndon B. Johnson State Park dam (TX 02544). Understanding of water quality conditions at this location would benefit visitors to the National Historical Park as well as the State Park facility. Consider exploring a resource-sharing arrangement with the Texas Parks and Wildlife Department.

Annual or seasonal monitoring of the aquatic-biological condition (fish, macroinvertebrates and (or) benthic algae) of the river also is recommended because aquatic biota integrate water quality conditions over time. Although review of existing Texas Council on Environmental Quality (TCEQ) and other State-agency biological data was beyond the scope of this report, those data should be compiled and analyzed for status and trends (if such data are available).

Groundwater

EARDC recommends that – to the extent practical – any existing groundwater-level data be consolidated within an electronic database (such as Microsoft Excel) and coordinated with the operation of an appropriate NPS-wide or national- or state-related database system (such as the USGS's NWIS-GWSI network).

Based on the data available to EARDC, no additional groundwater-monitoring activities – or changes to the current activities – are recommended at this time.

Pecos National Historical Park (PECO)

Water Quality Issues and Problems

The Pecos National Historical Park (NHP) lies within a scenic area that is easily accessible from major urban centers (e.g. Albuquerque and Santa Fe, NM); however, there are water quality concerns from historical hard-rock mining activities, particularly in the Terrero, NM area, population growth in and near the village of Pecos, NM, and potential nutrient enrichment from a fish hatchery located upstream from the village of Pecos. Although there is no public access to the Pecos River in the NHP at the present time, park personnel indicate that river access for fishing and related recreation is planned for the future. Fish surveys have been conducted in the Pecos River in the past, and a State advisory has been issued for excessive levels of mercury in fish tissue. Within the NHP boundary, there are three historical monitoring sites in the Pecos River and one in Glorieta Creek (fig. PECO). Data at these sites were limited to temperature, dissolved oxygen (DO), pH, and specific conductance values collected during 1994-95. Sufficient data were available to evaluate water quality conditions and trends at five Pecos River sites and one site each on Willow Creek (PECO 45), Holy Ghost Creek (PECO 39), and Rio Mora (PECO 50), all of which lie upstream from the village of Pecos and the NHP (fig. PECO). Data generally were available from the early 1980s through early 1990s at all sites; data records began during the early 1970s for 3 of those sites: PECO 8, 29, and 40 (fig. PECO). Two USGS gaging stations (08378000 and 08378500) are located on the Pecos River 10-15 miles upstream from the NHP, and another USGS gaging station (08377900) is located on the Rio Mora near Terrero, NM.

Analyses of data revealed good water quality conditions suitable to meet requirements of aquatic-life criteria (tables 22 and 23). Contact-recreational criteria for fecal coliform bacteria were exceeded in about 4 percent of samples collected from the Pecos River upstream from the village of Pecos (PECO 8), and about 1.5 percent of samples collected from the Rio Mora at the USGS gage (PECO 50)(table 22). Median values for specific conductance varied from 102 µS/cm in the Rio Mora to 289 µS/cm in Willow Creek, with maxima ranging from 207 to 350 µS/cm (table 23). All values are smaller than might be expected from streams influenced by mine drainage. Median pH values ranged from 7.6 to 8.3, with largest values observed in Willow Creek. Median total coliform, fecal coliform, and fecal streptococcus bacteria values were low, generally less than 26 colonies per 100 mL. Dissolved-oxygen concentrations in the Mora River varied from 4.3 to 13.4 mg/L (table 22). Specific conductance, pH, DO, and bacteria levels at other sites with fewer samples and less period of record were similar to those reported in tables 22 and 23.

Relatively few effects from hard-rock mining activities were noted in the legacy water quality database. Concentrations of most heavy metals were at or near laboratory reporting limits with the exception of zinc (50 to 970 µg/L) and aluminum (100 to 1,000 µg/L) concentrations, possibly exceeding aquatic-life criteria on occasion. Multiple reporting limits in the database for certain metals (e.g. silver, copper, and lead) may confound the interpretation of water quality “trends” at several sites. Concentrations of mercury, where reported, consistently were at the laboratory reporting level of 0.5 µg/L. Heavy-metal concentrations in streambed sediments (not reported) or in biological tissues may provide a better understanding of potential adverse effects from mining than concentrations in water samples.

Concentrations of nutrients generally were low. Total nitrogen concentrations ranged from 0.02 – 1.09 mg/L at sites upstream from the village of Pecos, 0.04 – 1.26 mg/L near the fish hatchery, and 0.21 – 0.78 downstream from the village of Pecos. Values for ammonia nitrogen varied from 0.004 - 0.75 mg/L at sites upstream from the village of Pecos, 0.013 – 0.44 mg/L near the fish hatchery, and 0.024 – 0.051 mg/L downstream from the village of Pecos. Similarly, total phosphorus concentrations varied from 0.005 – 0.29 mg/L at sites upstream from the village of Pecos, 0.01 – 0.23 mg/L near the fish hatchery, and 0.004 - 0.25 mg/L downstream from the village of Pecos. Although these values are not necessarily representative of current water quality conditions in the Pecos River and tributary streams, the legacy database does not contain information that would indicate significant nutrient influences from the fish hatchery or the village of Pecos on water quality conditions in the NHP. If there have been substantial increases in the population of Pecos and (or) changes in operations or management practices at the fish hatchery since the early 1990s, additional study of nutrient and potential eutrophication issues in the Pecos River may be warranted.

Surface-Water Quality

We recommend that water quality data collected since the early 1990s are consolidated with the legacy water quality data into a digital database and evaluated for current conditions and trends. We recommend weekly monitoring of core Vital-Sign constituents (water temperature, DO, pH, specific conductance, and *E. coli* bacteria) at three locations in or near the NHP, an upstream location in the Pecos River near the present location of PECO 5 and 6, a location on Glorieta Creek upstream from its confluence with the Pecos River, and a downstream location in the Pecos River near the present location of PECO 1 and 2. We also recommend collection of water samples from the upstream Pecos River location for monthly analyses of nutrient and suspended-sediment concentrations. Annual biological surveys at the three sites, consisting of sampling for macroinvertebrates and benthic algae, habitat assessment, and streamflow measurements, also should be considered at the three monitoring locations. Consideration should be given to repeating the water quality and macroinvertebrate studies reported by Jacobi (1995) and Jacobi and others (1998) at the same or similar site locations to determine whether water quality and biological conditions have improved during the past decade.

Because of the State advisory for mercury, we recommend that fishing at the proposed NHP access point should be restricted to a catch-and-release policy. Other potentially-adverse effects from historical mining activities were not revealed by the legacy water-chemistry database. If improved understanding of these potential effects is desirable, we suggest that a study design is developed for measuring heavy metals in streambed sediments and (or) aquatic biota (e.g. Carter and Porter, 1997) at selected locations in the basin upstream and within the NHP.

Groundwater

EARDC recommends that – to the extent practical – any existing or future groundwater-level data be consolidated within an electronic database (such as Microsoft Excel) and coordinated with the operation of an NPS-wide or national- or state-related database system (such as the USGS's NWIS-GWSI network).

Given the never-ending potential for drought and its associated water-shortage possibilities, EARDC further recommends that:

1. Water from "Trading Post" well by re-tested for previously reported excessive levels of VOC;

2. The "Trading Post" well be sounded for depth and considered as a long-term observation well from which its water level would be measured with an electric tape on quarterly basis—or, preferably, monitored continuously with pressure transducer and data logger; and

3. PECO consider measuring static water levels in "Visitor's Center" and "Forked Lightning Ranch" wells, both of which appear to offer tape access, on quarterly or more frequent basis.

Given the proximity of upgradient mining operations and the potential for associated acid-mine drainage (for example: prior reports of lead, zinc, and copper in trout tissue), EARDC additionally recommends that all drinking-water supply wells be tested at least annually for heavy metal concentrations outside EPA's recommended MCL criteria for such constituents.

Sand Creek Massacre National Historic Site (SAND)

Water Quality Issues and Problems

Surface water at Sand Creek Massacre National Historical Site (NHS) is limited to several perennial pools (wetlands) located in the dry channel of Sand Creek and a spring that provides flow to an intermittent stream tributary to the Sand Creek channel. NHS personnel indicated that flow rarely occurs in the Sand Creek channel, and the last time flow was observed was during 1999. A large grove of cottonwood trees is present in and along the old stream channel, possibly indicating a shallow source of ground water below the channel bottom. No legacy water quality data are available for the NHS.

Surface-Water Quality

We recommend that monthly monitoring of Vital-Sign constituents (exclusive of *E. coli*) is instituted in the wetland pools in the Sand Creek channel, supplemented by weekly monitoring of water quality conditions in Sand Creek during periods of stream flow. We also recommend that baseline ecological conditions are established for the wetland pools, including sampling for macroinvertebrates and benthic algae and a quantitative assessment of habitat features. Historical water quality conditions possibly could be inferred by obtaining sediment cores from the wetland pools, obtaining approximate dates of deposition from strata from the cores, and analyzing the strata for diatoms, pollen, and certain macroinvertebrate remnants (e.g. midge head capsules). Following establishment of a visitor's center at the NHS, routine monitoring for *E. coli* should be conducted in the wetland pools.

Groundwater

In consideration of plans for future development and facilities, accessible sources of groundwater and surface water should be periodically sampled and tested (before outset of public use) for both water quantity and quality to gather baseline groundwater-level and -quality data against which future data can be compared.

Accordingly, EARDC recommends that – to the extent practical – all existing and future groundwater-level data be consolidated within an electronic database (such as Microsoft Excel) and coordinated with the operation of an appropriate NPS-wide or national- or state-related database system (such as the USGS's NWIS-GWSI network).

Given that data from nearby shallow wells (Martin, 2006) indicate that groundwater constituents may exceed the recommended MCL criteria for public-supply drinking water, EARDC recommends that groundwater from recently drilled water-supply well near future site of visitors' center be periodically sampled and analyzed against effective drinking-water standards.

Recognizing that planned future facilities (parking lots and wastewater and sewage systems) pose potential threats to area's vulnerable, shallow alluvial aquifer, EARDC recommends that the locations of such facilities be thoroughly researched and thoughtfully placed to minimize risks.

To aid with intelligent placement of future facilities and track subsequent effect on local water-table, EARDC recommends that an array of PVC- or steel-lined, possibly sand-point driven observation wells be installed at hydrologically meaningful sites within areas of planned future construction. Despite numbering perhaps a dozen or more, such observation wells could be installed and monitored at reasonable and justifiable costs, considering–not only the short-term (pre-construction) benefits–but *especially* the longer-term benefits over future decades.

Given apparent extent and influence of Kern Spring's watershed, EARDC recommends that the water chemistry of Kern Spring discharge be periodically monitored to help ensure its viability as a potential source of potable freshwater for park visitors, site attractions, and future facilities near eastern perimeter of park property.

Washita Battlefield National Historic Site (WABA)

Water Quality Issues and Problems

Primary surface-water resources located in or near the Washita Battlefield National Historic Site (NHS) include the Washita River and Sergeant Major Creek. No legacy water quality data were provided by the National Park Service for this NHS, and no water quality monitoring is being done by NHS personnel. NHS personnel indicated concern about water quality effects from oil and gas production in the Washita basin. Other water quality influences from small towns and agricultural practices in the basin also are possible.

Surface-Water Quality

We recommend that weekly monitoring for core Vital-Sign constituents (water temperature, dissolved oxygen, pH, specific conductance, and *E. coli* bacteria) is initiated in the Washita River proximate to the location of the visitor's center presently under construction as well as in a selected location in Sergeant Major Creek. Baseline water chemistry conditions should be documented monthly for a minimum of one year. Water-chemistry constituents could include one or more of the following variables: nutrients, total suspended sediment, hardness, alkalinity, major ions, trace elements, and agricultural pesticides. We also recommend establishing baseline ecological conditions (fish, macroinvertebrates, benthic algae, and habitat conditions) for the Washita River site, followed by annual monitoring of those variables.

Groundwater

EARDC recommends that – to the extent practical – any existing groundwater-level data be consolidated within an electronic database (such as Microsoft Excel) and coordinated with the operation of an appropriate NPS-wide or national- or state-related database system (such as the USGS's NWIS-GWSI network).

Based on the data available to EARDC, no additional groundwater-monitoring activities – or changes to the current activities – are recommended at this time.

SUMMARY

This final section is devoted to a listing of activities by which EARDC believes SOPN might most efficiently and effectively employ the water quality and quantity monitoring guidelines and protocols recommended in previous sections of this report.

General Surface Water-Related Recommendations

- SOPN should be consider collecting water-stage data, if not stream-discharge data, for all sites of water quality sampling;

- Because stream-stage data are relatively simple and inexpensive to collect, consideration should be given to collecting such data when and where relevant to existing or perceived areas of environmental concern;

- All hydrologic data collected by SOPN should be stored in electronic files;

- The storage of water quality data should be accompanied by associated metadata;

- SOPN personnel might consider training for methods with which to collect stage- and stream-discharge data; and

- Considerations should be given to collecting turbidity data when and where water quality data are collected.

Water Quality-Related Recommendations

Bent's Old Fort National Historic Site (BEOL)

- Issues: agricultural runoff and urban discharges; high fecal-coliform levels; nutrient enrichment; selenium; heavy-metals from upstream mining activities
- Recommendations: Consolidate legacy water-quality data with data collected since the early 1990s into a digital database; evaluate current conditions and trends.
- Initiate weekly monitoring for priority Vital-Sign constituents in the Arkansas River downstream from the NHS (USGS gaging station at BEOL0007). Monitor *E. coli* rather than fecal-coliform bacteria.
- Consider continuous (diel) monitoring for DO and pH during low-flow conditions.
- Consider monthly monitoring for nutrients, major ions, metals, and agricultural pesticides.
- Consider seasonal monitoring for macroinvertebrates, benthic algae, and habitat conditions.

Capulin Volcano National Monument (CAVO)

- Issues: No surface water within boundary of National Monument
- Recommendations: None

Chickasaw National Recreation Area (CHIC)

- Issues: agricultural runoff and wastewater discharges; lake eutrophication (fish melanomas; fish kills); high fecal-coliform levels in tributary streams and beach areas; nutrient enrichment; considerable amount of data not in digital form.

- Recommendations: Consolidate legacy water-quality data with data collected since the early 1990s into a digital database; evaluate current conditions and trends.
- Initiate weekly monitoring for priority Vital-Sign constituents at selected sites in Rock Creek, Travertine Creek, Guy Sandy Creek, and swimming areas. Prioritize tributary sites with gaging stations. Monitor *E. coli* rather than fecal-coliform bacteria.
- Synoptic investigation of historical monitoring sites: Have conditions improved, degraded, or remained the same?
- Monthly monitoring of nutrient and major ion concentrations.
- Synthesize results of previous biological and water-quality studies conducted in the NRA into a summary report. Initiate biological monitoring (fish, macroinvertebrates, benthic algae, and habitat) at or near sites selected for water-chemistry monitoring.

Fort Larned National Historic Site (FOLS)

- Issues: altered streamflow conditions; agricultural runoff; nutrient enrichment; elevated fecal-coliform levels; impaired aquatic vertebrate communities.
- Recommendations: work with local and State agencies to help restore natural flow conditions in the Pawnee River near the NHS.
- Consolidate legacy water-quality data with data collected since the early 1990s into a digital database; evaluate current conditions and trends.
- Monitor priority Vital-Sign constituents following rain events and weekly in isolated pools near existing sites FOLS0001 and FOLS0002. Monitor *E. coli* rather than fecal-coliform bacteria. Survey pools for the presence of mosquito larvae or other aquatic insects associated with the transmission of human pathogens.
- Collaborate with the USGS to monitor nutrient, major ion, and agricultural-pesticide concentrations at the gaging station upstream from the NHS (FOLS0004). Consider monitoring fish, macroinvertebrates, benthic algae, and habitat at this site and at sites proximate to the NHS boundary.

Fort Union National Historic Site (FOUN)

- Issues: limited surface-water resources—Wolf Creek, an intermittent stream tributary to the Mora River that was monitored once in July 1956.
- Recommendations: Initiate weekly monitoring of Vital-Sign constituents in Wolf Creek during periods of stream flow.
- Consider establishing baseline ecological conditions (macroinvertebrates, benthic algae, and habitat conditions) for Wolf Creek near the NHS boundary (e.g. near FOUN0002 or FOUN0003) following an extended period of continuous stream flow,

Lake Meredith National Recreation Area / Alibates Flint Quarries National Monument (LAMR)

- Issues: oil and gas production in the basin is associated with significant upward trends in concentrations of major ions (e.g. chloride, sulfate) in Lake Meredith; fish kills from toxic algae blooms (*Prymnesium parvum*); concerns about declining lake levels, eutrophication, and fecal-indicator bacteria in recreational areas.
- Recommendations: Consolidate legacy water-quality data with data collected since the early 1990s into a digital database; evaluate current conditions and trends.
- Monitor Vital-Sign constituents at selected locations representative of lake water-quality and recreational areas such as beaches. Monitor *E. coli* rather than fecal-coliform bacteria.
- Consider limnological characterization of Lake Meredith along a longitudinal gradient from headwater segments (e.g. LAMR0069), through the middle segments (e.g. LAMR0049 or

LAMR0050), to near the dam (e.g. LAMR0016 or LAMR0017). Include phytoplankton investigation focused on occurrence and distribution of predominant taxa and (or) algal taxa associated with the production of toxins. Monitor microcystin (a blue-green algal toxin; a relatively inexpensive ELISA method is available) and *E. coli* levels in swimming areas.

Lyndon B. Johnson National Historical Park (LYJO)

- Issues: agricultural and urban runoff to the Pedernales River in a rapidly developing area (Texas Hill Country); nutrient enrichment and decreases in water clarity; fecal-coliform levels exceed contact-recreational criteria in over 10% of samples.
- Recommendations: Consolidate legacy water-quality data with data collected since the early 1990s into a digital database; evaluate current conditions and trends.
- Monitor Vital-Sign constituents weekly and following high-flow events at selected sites in the Pedernales River (e.g. near Johnson City, downstream from the LBJ Ranch (e.g. LYJO0015 or LYJO0016), and upstream from the LBJ Ranch (e.g. LYJO0039 or near the discontinued USGS gage in Stonewall, TX). Consider augmenting the priority Vital-Sign constituents with measurements of water clarity (e.g. Secchi depth, light-extinction measurements, total suspended-sediment concentrations, etc.)
- Initiate (or continue) monitoring of priority Vital-Sign constituents in Town Creek adjacent to NHP headquarters in Johnson City, TX.
- Consider seasonal assessments of biological condition (e.g. macroinvertebrates, benthic algae, and habitat assessments)

Pecos National Historical Park (PECO)

- Issues: urban wastewater discharges, septic tanks, and runoff from the village of Pecos, NM; heavy metals from historical mining activities; fish-consumption advisory for mercury.

- Recommendations: Consolidate legacy water-quality data with data collected since the early 1990s into a digital database; evaluate current conditions and trends.

- Initiate weekly monitoring of priority Vital-Sign constituents at selected Pecos River sites within or near the NHP boundary (e.g. PECO0001-0011); legacy water-quality sites are considerably upstream from the NHP and do not accurately represent possible influences from the village of Pecos. Establish one or more monitoring locations in Glorieta Creek.

- Consider seasonal assessments of biological condition (e.g. macroinvertebrates, benthic algae, and habitat assessments) at or near sites selected for water-quality monitoring

- If river access for fishing and related recreational uses is established, consider a catch-and-release policy for fishing and monitor *E. coli* levels at the access locations.

Sand Creek Massacre National Historic Site (SAND)

- Issues: surface water is limited to several shallow pools and Big Sandy Creek, an intermittent stream. No legacy water-quality data are available for the site.

- Recommendations: initiate periodic monitoring of priority Vital-Sign constituents in the pools and a selected location in Big Sandy Creek. Document the water quality transported through the old Sand Creek channel during any high-flow events.

- Consider establishing baseline ecological conditions (macroinvertebrates, benthic algae, and habitat conditions) in the pools and the selected location in Big Sandy Creek.

Washita Battlefield National Historic Site (WABA)

- Issues: NHS personnel indicated concern about oil and gas extraction activities upstream in the Washita River basin and stream-bank erosion; no legacy water-quality data are available for the site; probable agricultural and urban (small towns) runoff into the Washita River and Sergeant Major Creek.
- Recommendations: initiate weekly monitoring of priority Vital-Sign constituents in the Washita River near the new visitor's center and a location in Sergeant Major Creek.
- Consider establishing baseline ecological conditions (fish, macroinvertebrates, benthic algae, and habitat conditions) for the Washita River site.

Groundwater Quantity-Related Recommendations

Bent's Old Fort National Historic Site (BEOL)

- Consolidate and coordinate existing groundwater-level data with (NPS-wide / state / federal) electronic databases (such as USGS's NWIS-GWSI) and;

Selectively renovate and renew monitoring of groundwater levels in the local Arkansas River alluvium through piezometers installed originally by Woods and others (2002); and

- Install array of benchmarks and staff gages with which to compare upland groundwater levels with those in Casebolt wetland and adjacent stages in Arkansas River; and

- Install and "survey-in" the above-described network of groundwater and surface-water datum to link the resulting hydraulic head and stream stage data.

Capulin Volcano National Monument (CAVO)

Water-supply well (of unknown depth and construction) taps volcanic terrain north of park headquarters on southern flank of volcano.

Although park spokespeople indicated no current effort to monitor groundwater levels, it is recommended that:

- Available well and water-level records be consolidated and used to better understand supply well's construction and history of water-level trends;

- Attempt measurement of groundwater levels in local volcanic aquifer through casing of water-supply well, from top of sanitary seal (accessible inside pump/well enclosure?); and

- Coordinate resulting groundwater-level data with (NPS-wide / state / federal) electronic databases (such as USGS's NWIS-GWSI).

Chickasaw National Recreation Area (CHIC)

- Consolidate and coordinate all existing groundwater-level data with (NPS-wide / state / federal) electronic databases (such as USGS's NWIS-GWSI);

- Continue current monitoring of water levels in East, West, South, and North Wells;

- Because of apparent relation between discharge from Buffalo Springs and water levels in East Well, these water-level data might be used to better understand the distribution of current and future discharge from Buffalo Springs; and

- An attempt might be made to monitor the shut-in pressure in Vendome Well contemporaneously with periodic or continuous measurements of discharge from Buffalo and Antelope Springs and water levels in selected other wells of various depths and construction.

Fort Larned National Historic Site (FOLS)

- No change in groundwater-monitoring activities recommended at this time.

Fort Union National Monument (FOUN)

Current water needs sustained by onsite groundwater production well, reportedly about 300 feet deep. EARDC, therefore, recommends:

- Depth to underlying water table in local alluvial aquifer be measured periodically (on quarterly basis?) through this NPS-owned and maintained water-supply well; and

- Consolidate and coordinate resulting groundwater-level data with (NPS-wide / state / federal) electronic databases (such as USGS's NWIS-GWSI).

Lake Meredith National Recreation Area / Alibates Flint Quarries National Monument (LAMR-ALFL)

- No change in SOPN's current arrangement with Canadian River Municipal Water Authority (CRMWA) recommended at this time.

Lyndon B. Johnson National Historical Park (LYJO)

- No change in groundwater-monitoring activities recommended at this time.

Pecos National Historical Park (PECO)

- Consolidate and coordinate existing groundwater-level data with (NPS-wide / state / federal) electronic databases (such as USGS's NWIS-GWSI);

- Follow up testing water from "Trading Post" well for reported excessive levels of VOC;

- Sound "Trading Post" well for depth and consider measuring water level with electric tape on quarterly basis—or, preferably, monitor continuously with pressure transducer and data logger;

- Consider measuring static water levels in "Visitor's Center" and "Forked Lightning Ranch" wells, both of which appear to offer tape access, on quarterly or more frequent basis; and

- Given proximity of upgradient mine drainage and prior reports of lead, zinc, and copper, it is further recommended that all drinking-water supply wells be tested at least annually for heavy metal content.

Sand Creek Massacre National Historic Site (SAND)

- In consideration of plans for future development and facilities, accessible sources of groundwater and surface water should be periodically sampled and testing (before outset of public use) for both water quantity and quality to gather baseline groundwater-level and -quality data against which future data can be compared. Accordingly, EARDC recommends that all resulting data:

- Be coordinated with (local, state or federal) electronic databases (such as USGS's NWIS-GWSI).

- Given that data from nearby shallow wells indicate groundwater constituents may exceed recommended levels for public-supply drinking water, EARDC recommends that:

- Groundwater from recently drilled water-supply well near future site of visitors' center be periodically sampled and analyzed against effective drinking-water standards.

- Recognizing that planned future facilities (parking lots and wastewater and sewage systems) pose potential threats to area's vulnerable, shallow alluvial aquifer, EARDC recommends that the locations of such facilities be thoroughly researched and thoughtfully placed to minimize risk

- To aid with intelligent placement of future facilities and track subsequent effect on local water-table, EARDC recommends that an array of PVC-lined, sand-point driven observation wells be installed at hydrologically relevant sites within areas of planned future construction.

Given apparent extent and influence of Kern Spring's watershed, EARDC recommends that:

- Water chemistry of Kern Spring discharge be periodically monitored to help ensure its viability as a potential source of potable freshwater for park visitors, site attractions, and future facilities near eastern perimeter of park property.

Washita Battlefield National Historic Site (WABA)

- No change in groundwater-monitoring activities recommended at this time

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- USGS Water Data for Texas U.S. Geological Survey Texas Water Data
- Texas Water Development Board
- Texas Commission on Environmental Quality (formerly TNRCC)
- Texas Natural Resources Information System - Texas Data Online
- Texas Water Resources Institute at Texas A&M - Texas Waternet
- High Plains Underground Water Conservation District (Lubbock, Texas)
- North Plains Groundwater District (Dumas, Texas)
- Panhandle Groundwater Conservation District (White Deer, Texas)
- WaterShare - The Bureau of Reclamation's Virtual Water Conservation Center
- National Park Service - PARKNET
- National Weather Service - NOAA (Select zone 8 and "get data")
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APPENDICES A, B, C, & D follow...

APPENDIX A

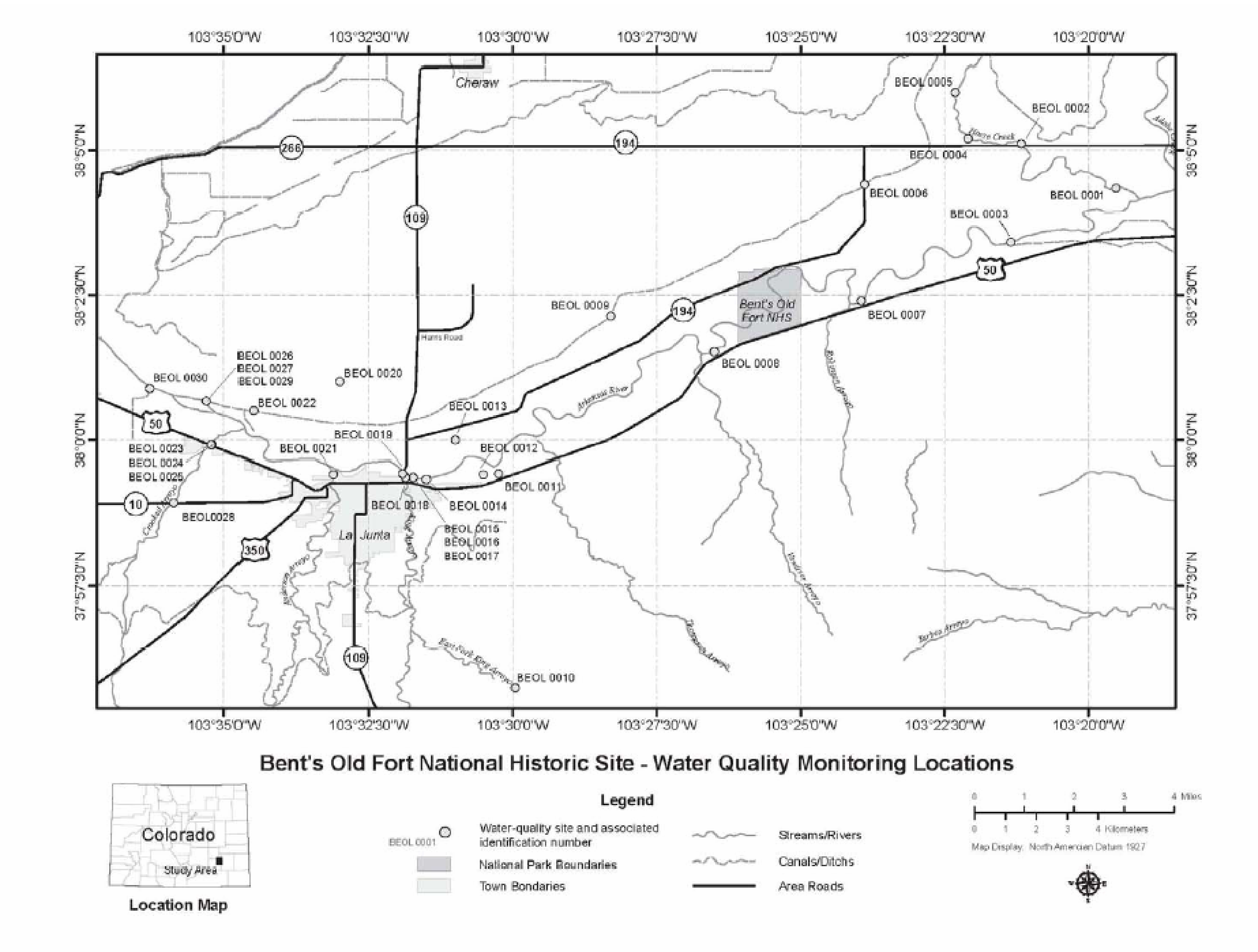


Figure BEOL. Map of water-quality monitoring locations near Bent's Old Fort National Historic Site.

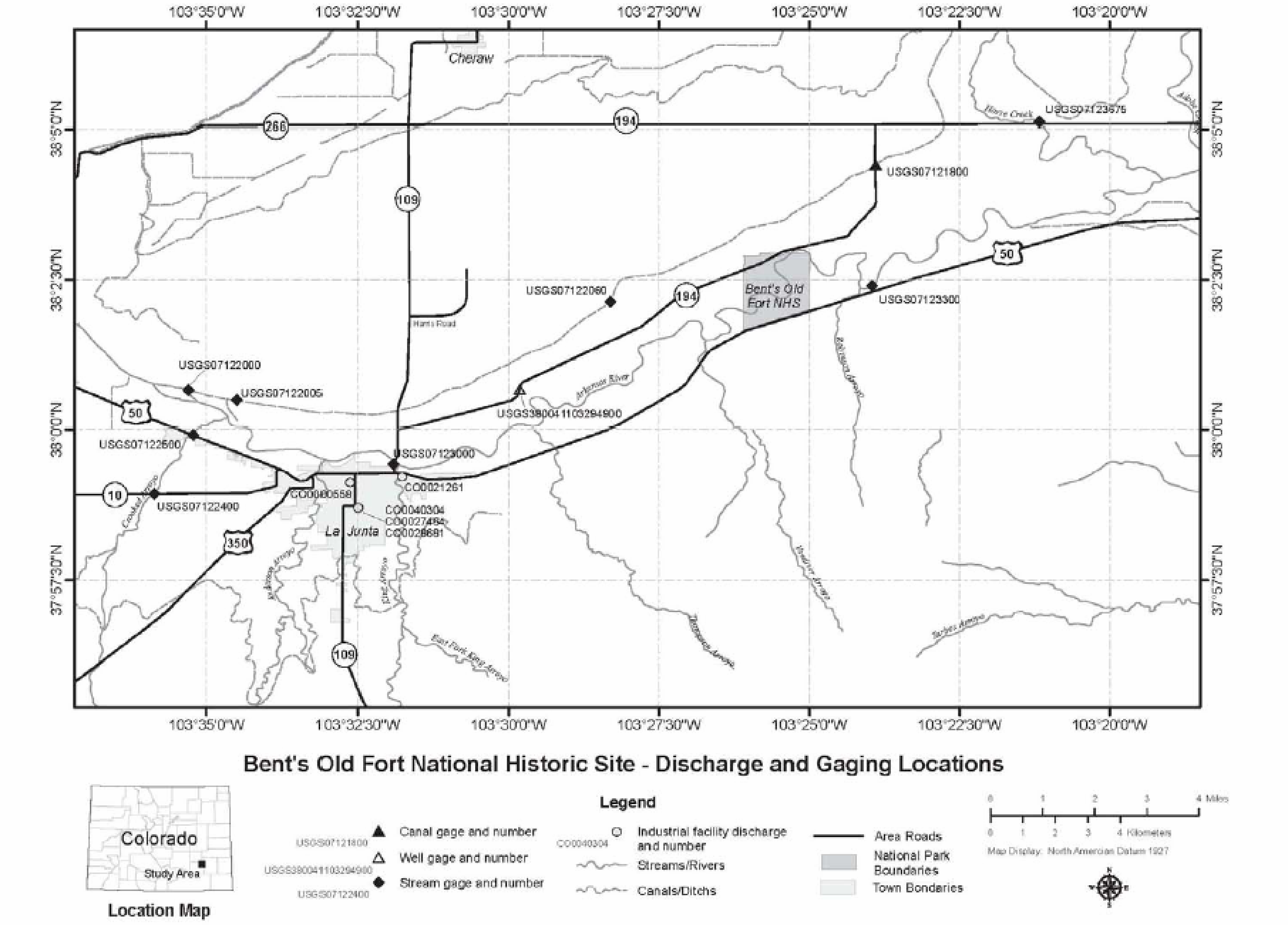


Figure BEOLa. Map of discharge and gaging locations near Bent's Old Fort National Historic Site.

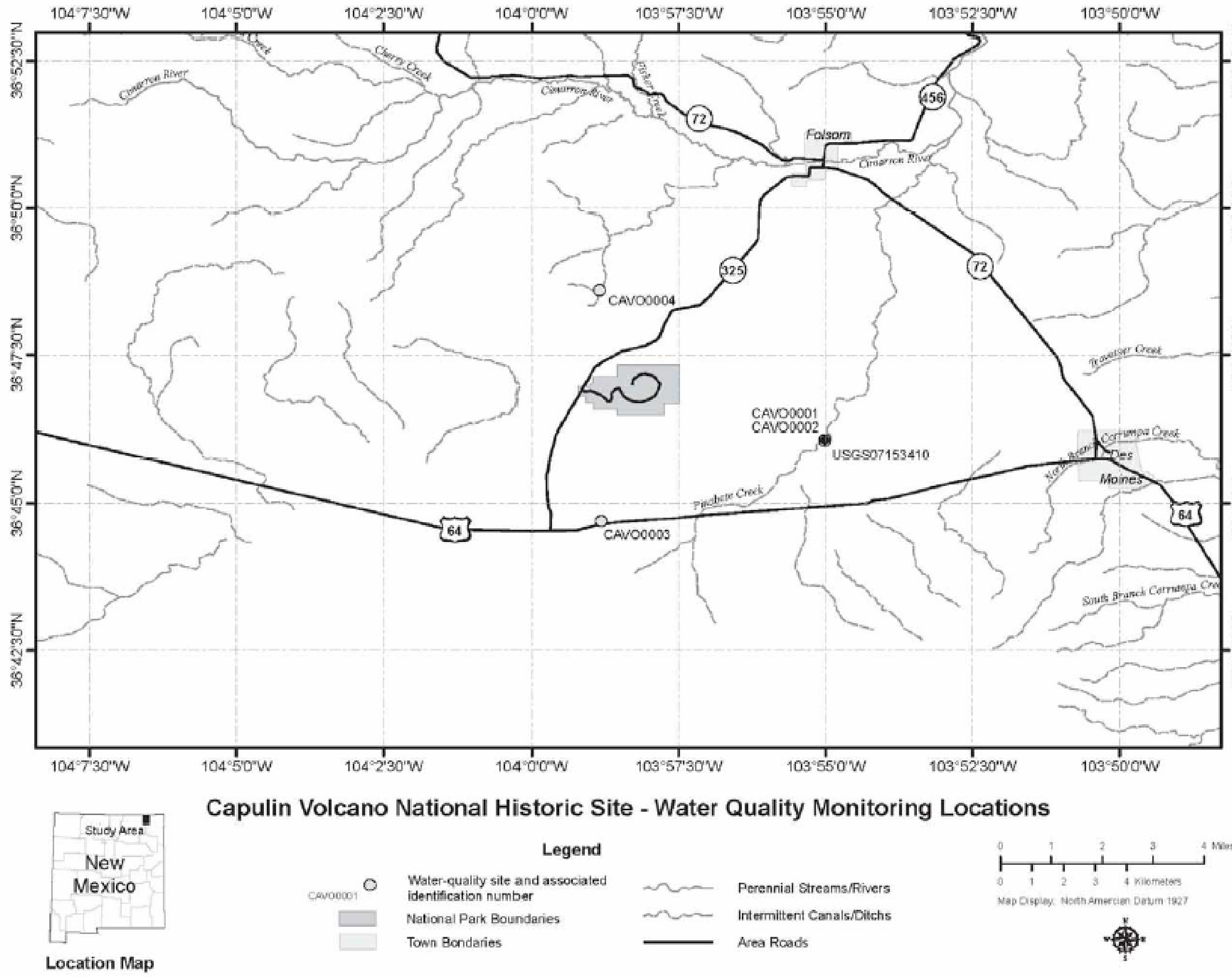


Figure CAVO. Map of water-quality monitoring locations near Capulin Volcano National Historic Site.

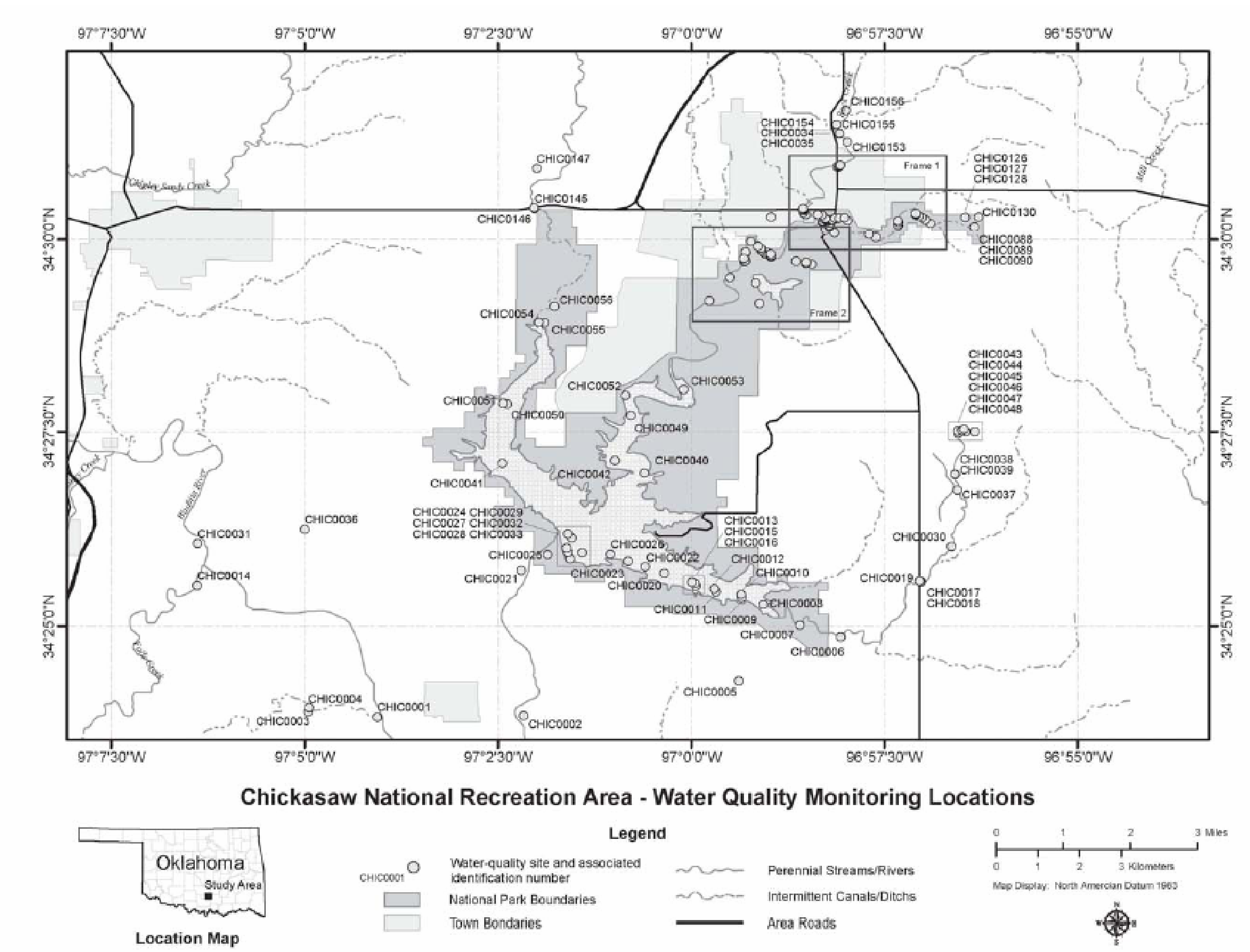


Figure CHIC. Map of water-quality monitoring locations in or near Chickasaw National Recreation Area.

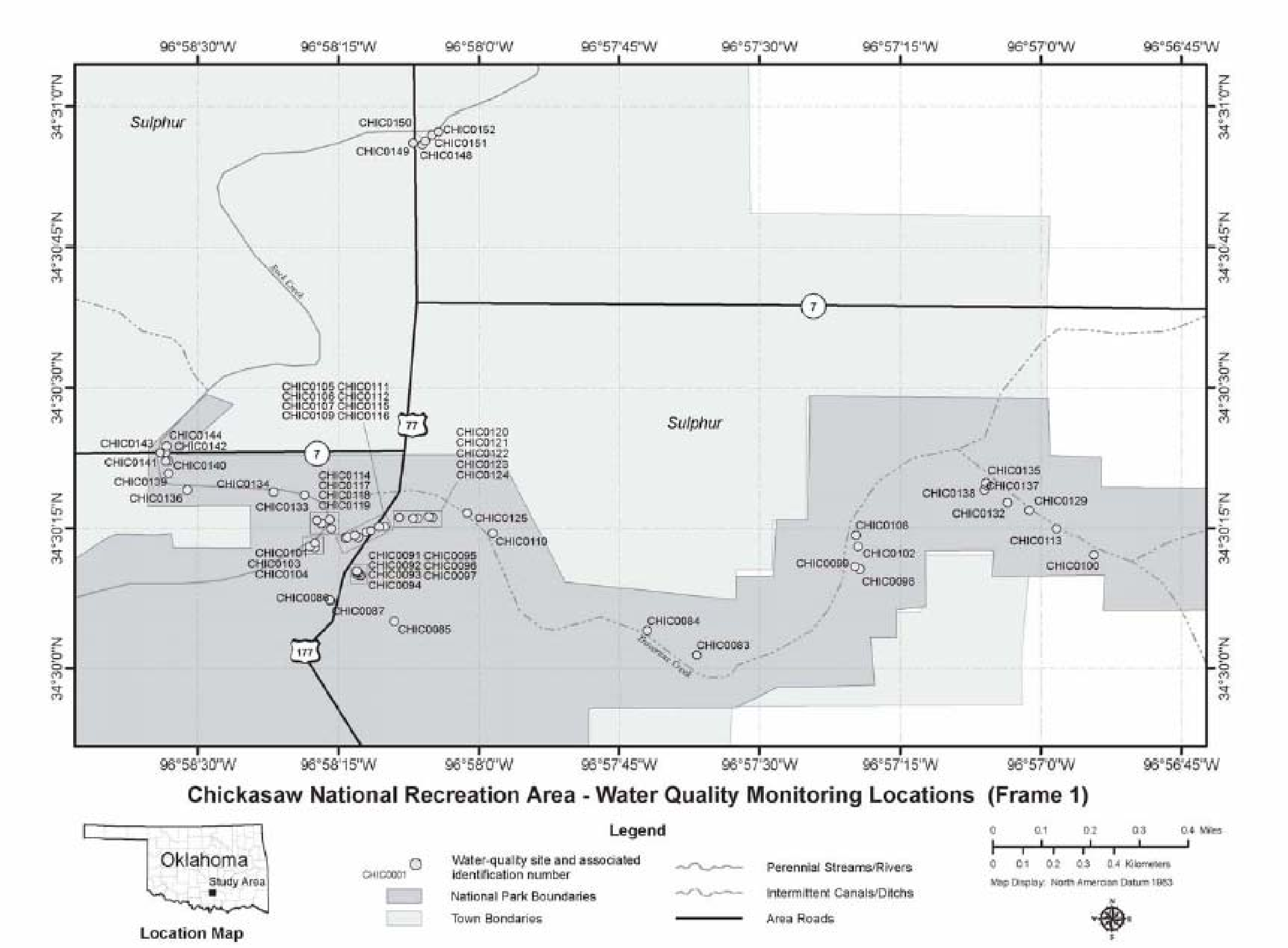


Figure CHICa. Map of water-quality monitoring locations (Frame 1) in or near Chickasaw National Recreation Area.

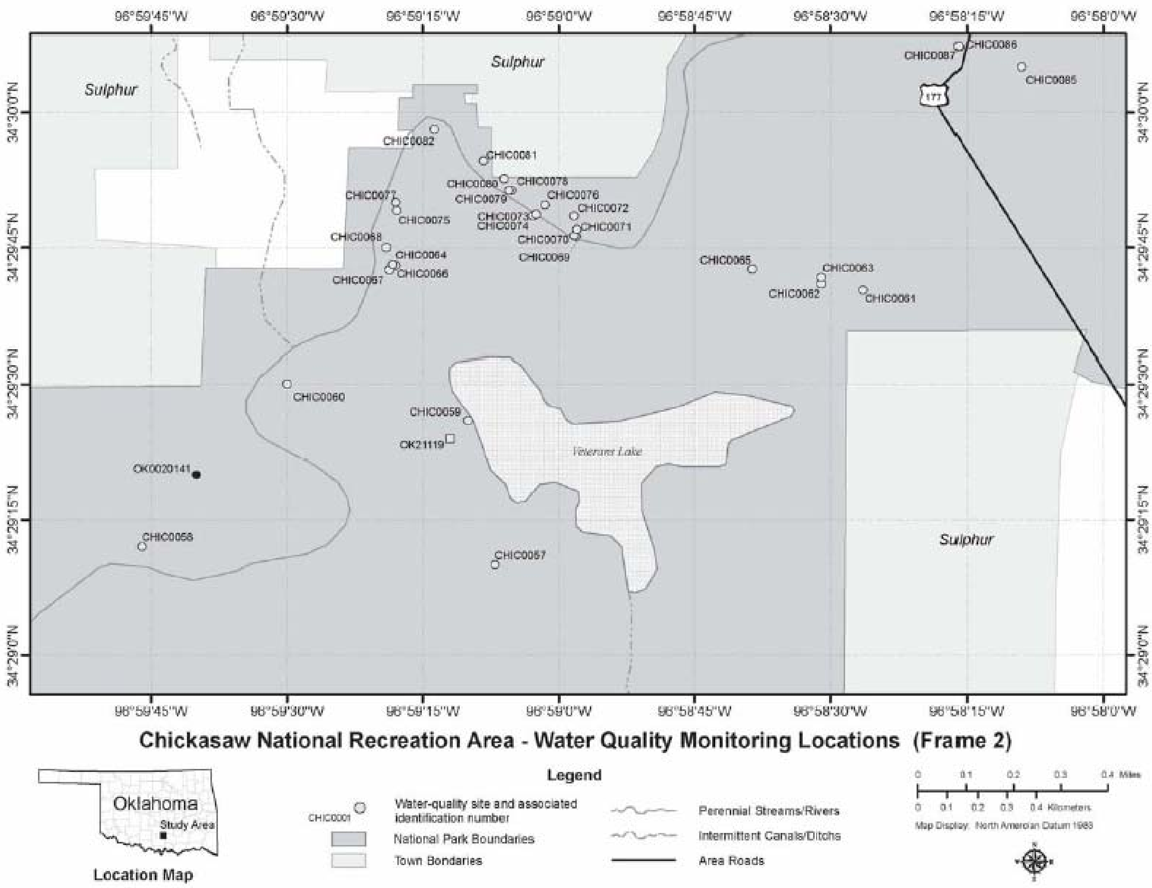


Figure CHICb. Map of water-quality monitoring locations (Frame 2) in or near Chickasaw National Recreation Area.

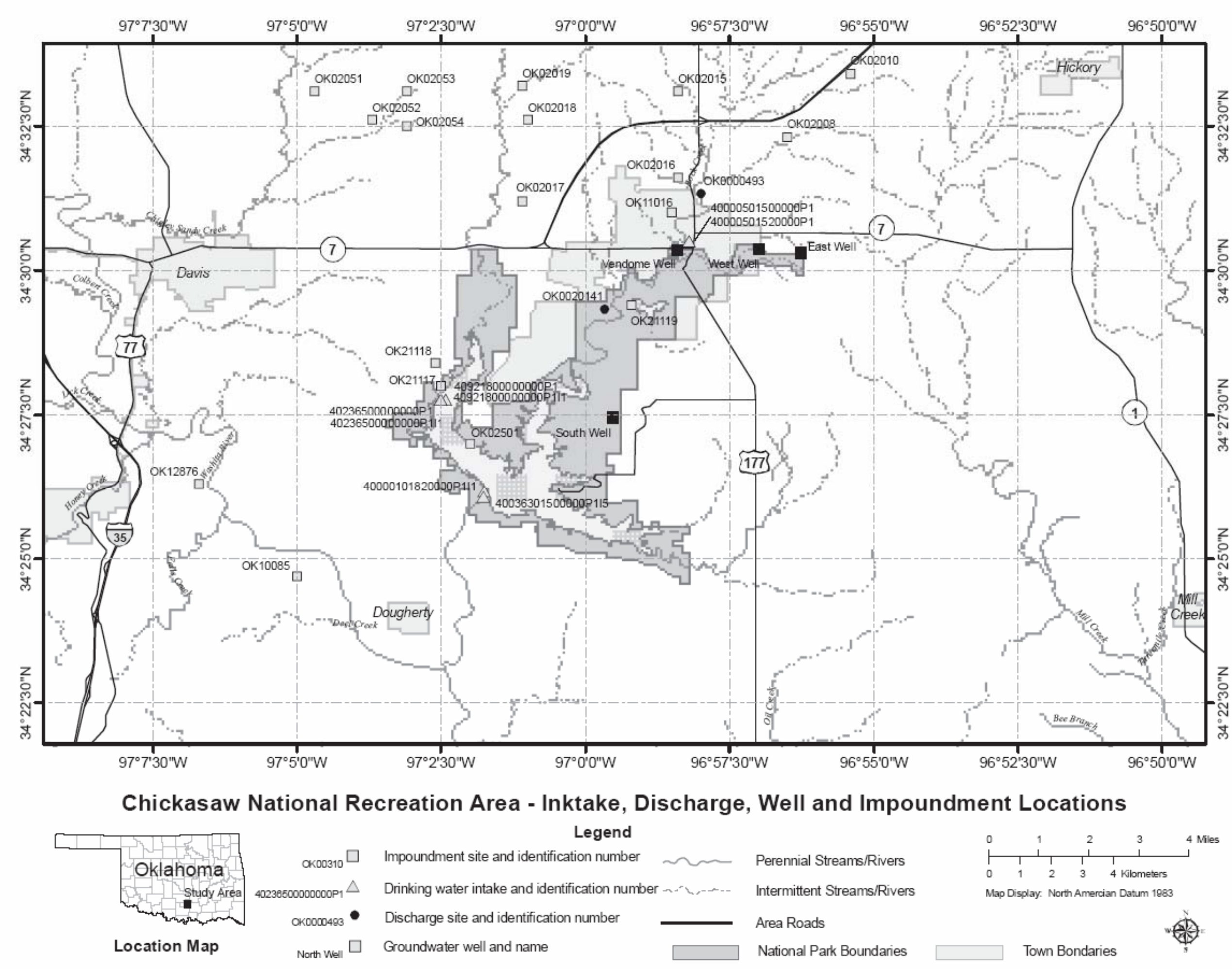


Figure CHICc. Map of intake, discharge, impoundment, and groundwater-observation well locations in or near Chickasaw National Recreational Area.

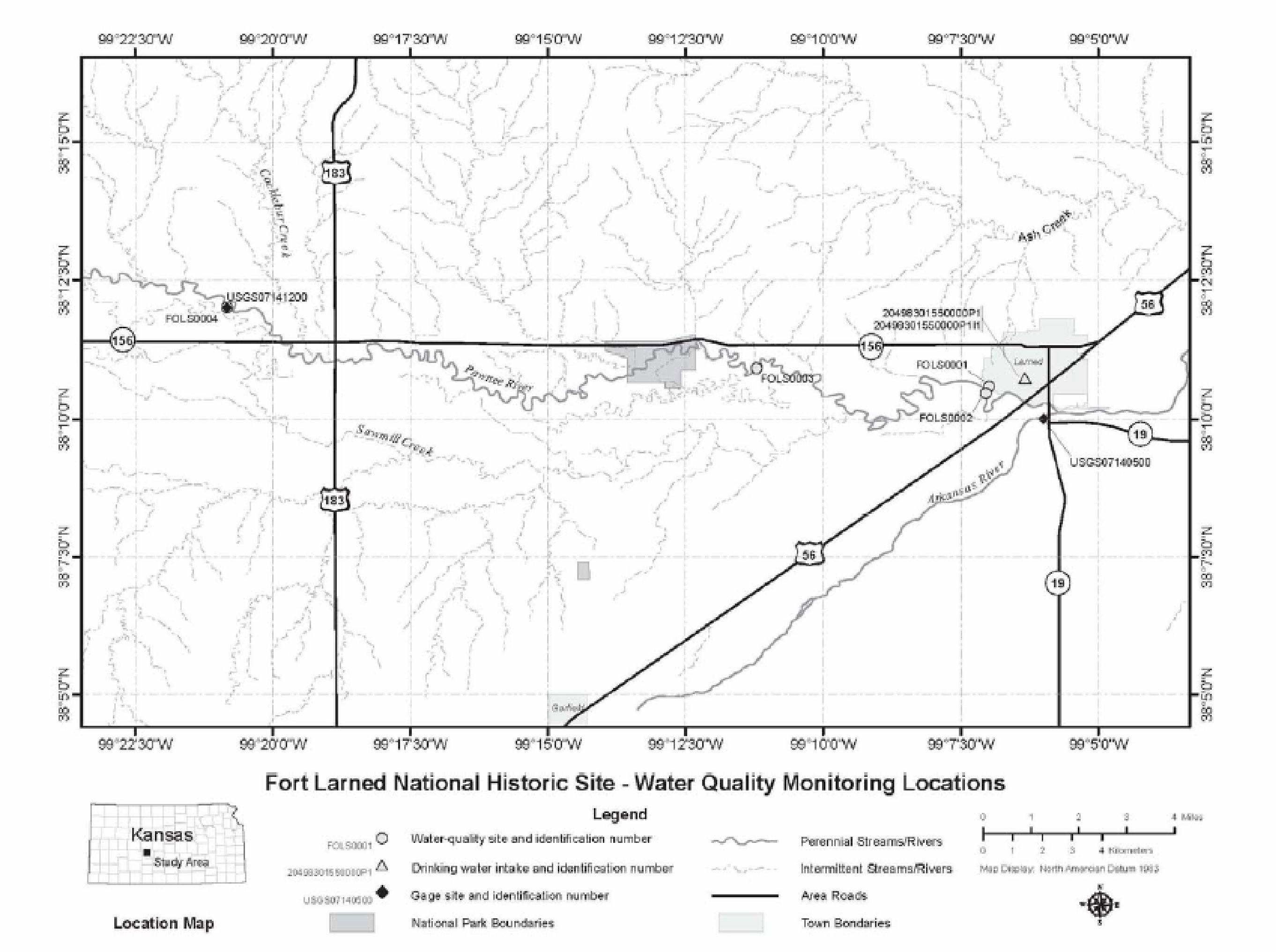


Figure FOLS. Map of water-quality monitoring locations in or near Fort Larned National Historic Site.

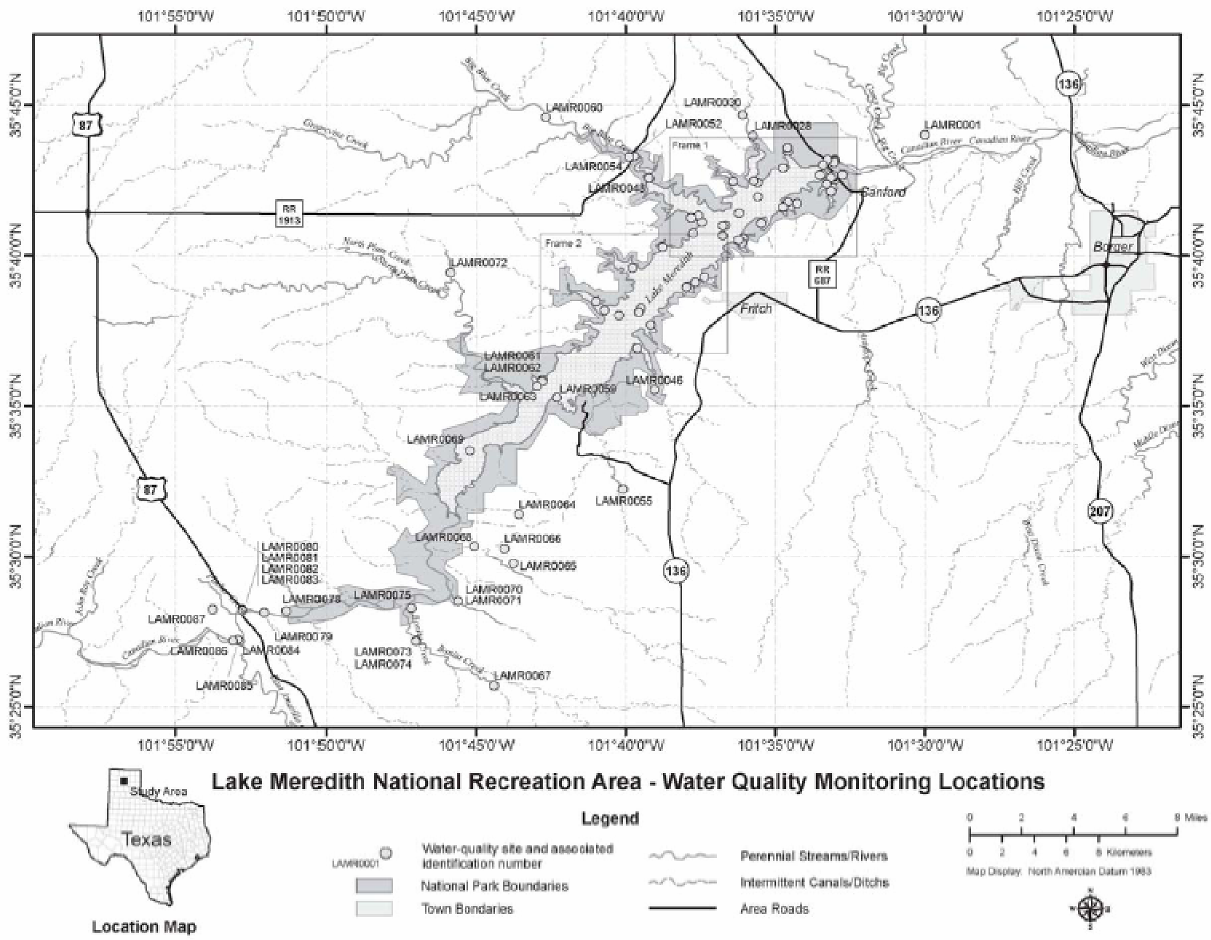


Figure LAMR. Map of water-quality monitoring locations in or near Lake Meredith National Recreation Area.

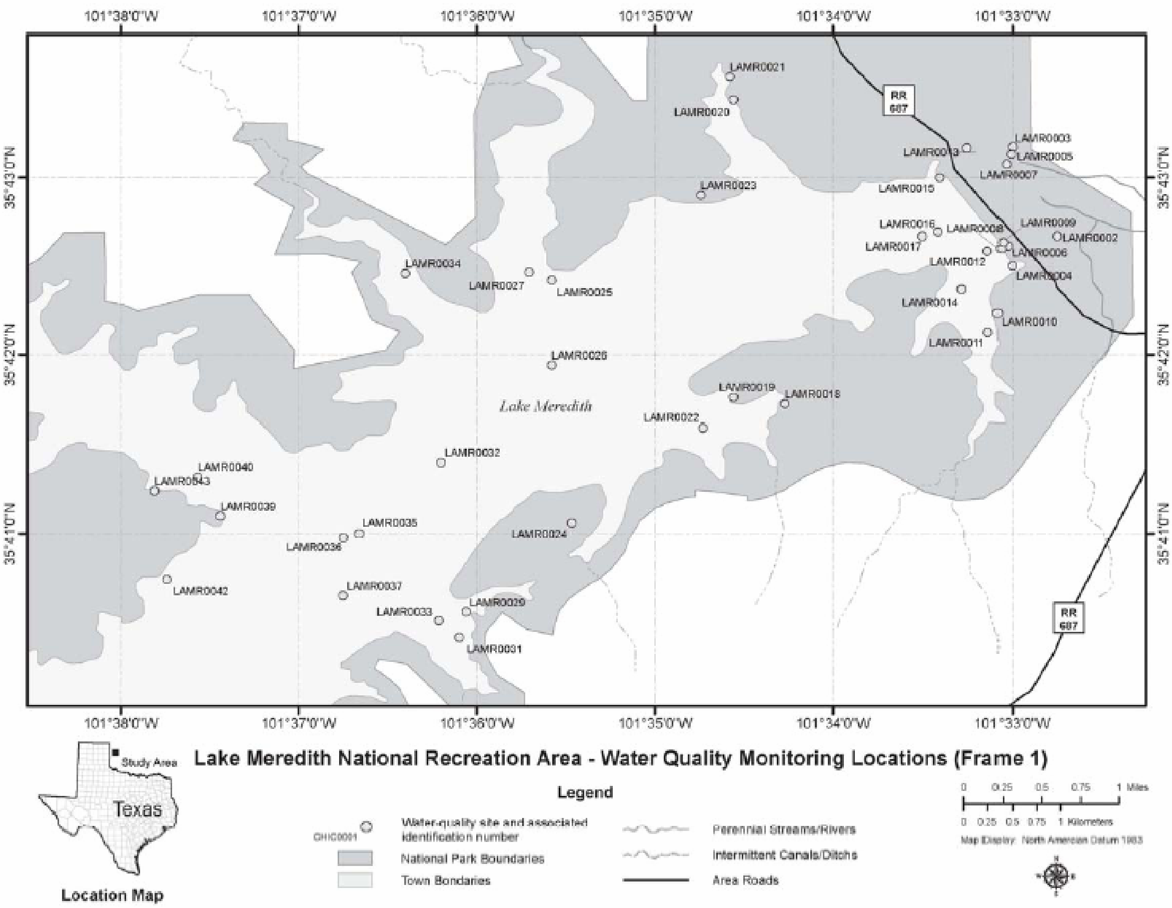


Figure LAMRa. Map of water-quality monitoring locations (Frame 1) in Lake Meredith National Recreation Area.

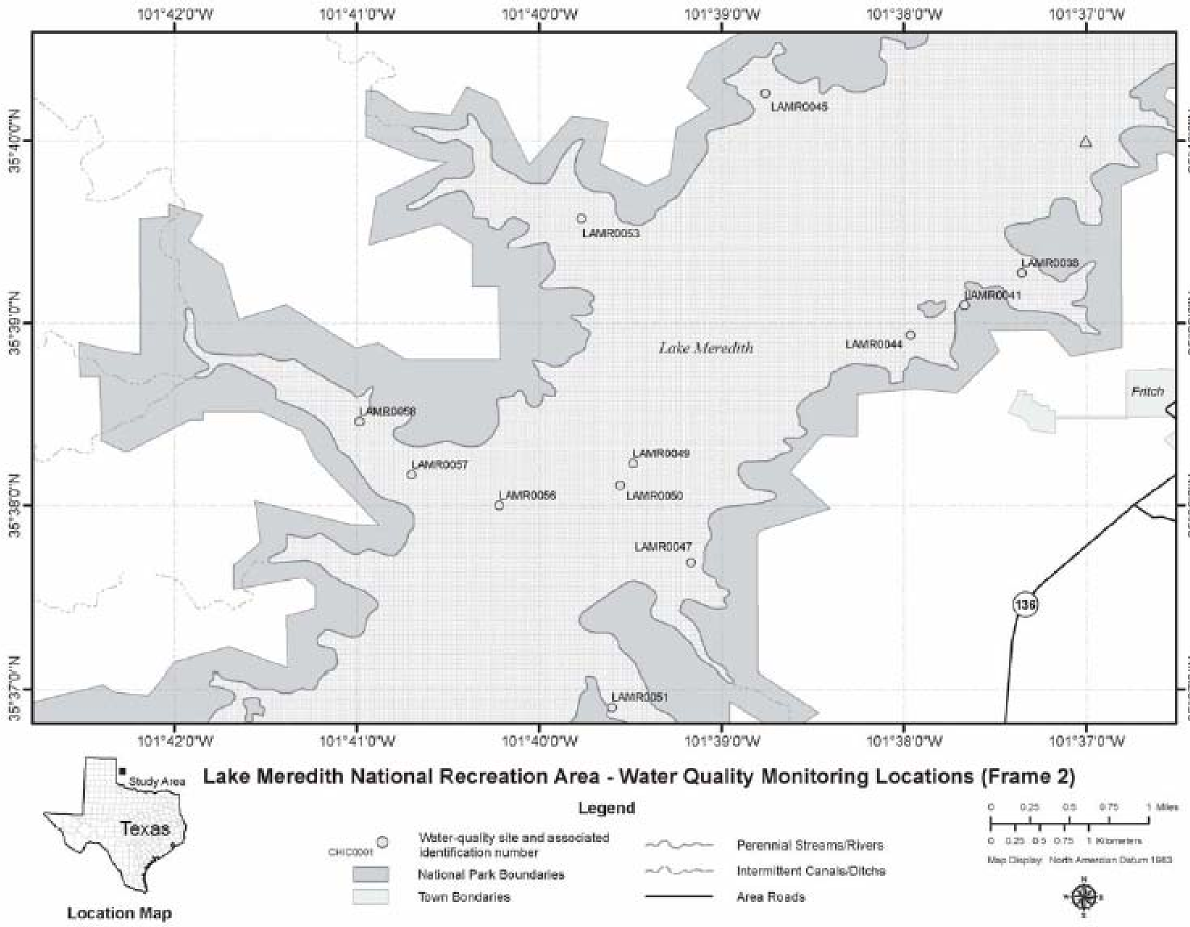


Figure LAMRb. Map of water-quality monitoring locations (Frame 2) in Lake Meredith National Recreation Area.

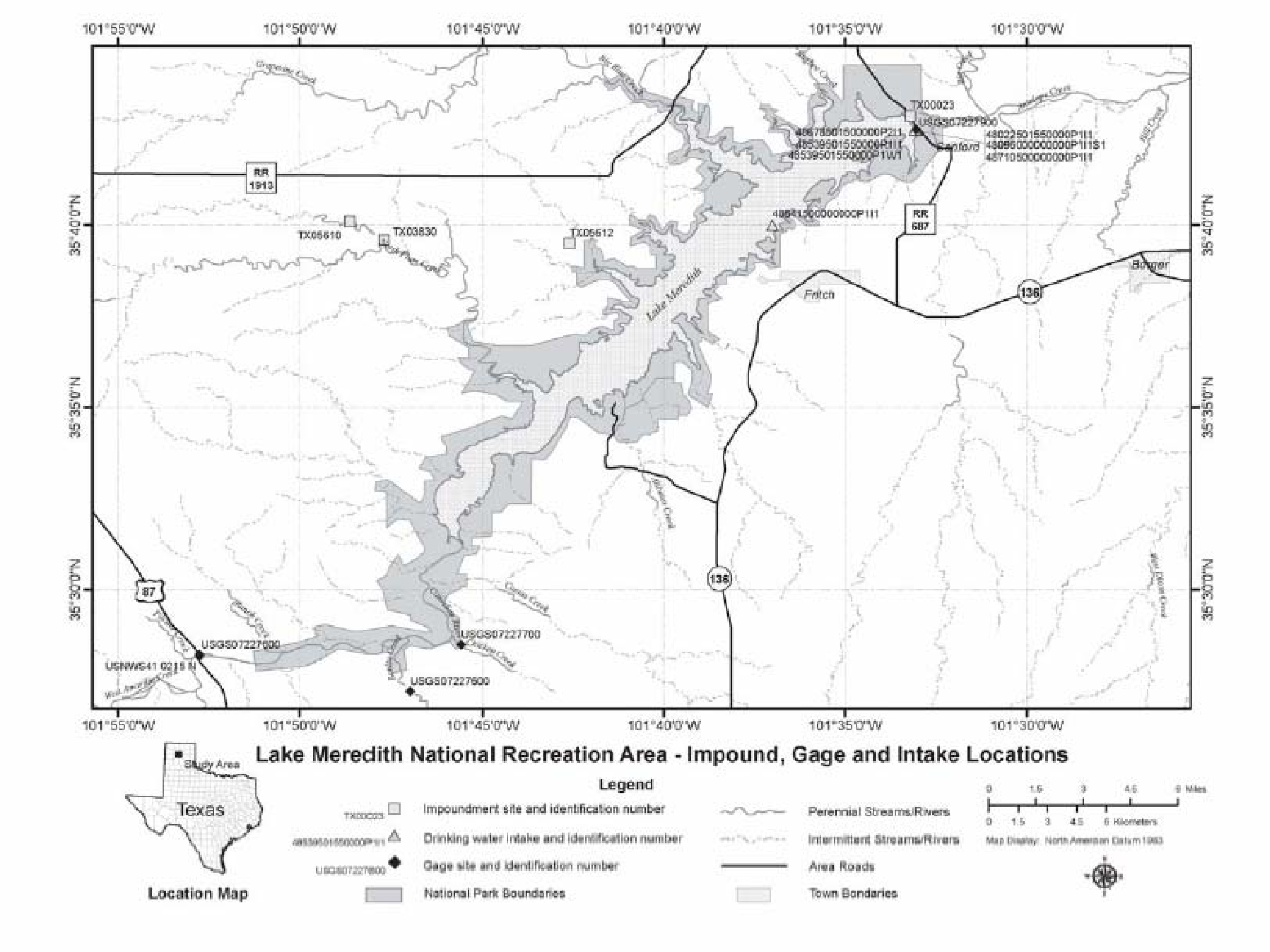


Figure LAMRc. Map of impoundment, gage, and intake locations in or near Lake Meredith National Recreation Area.

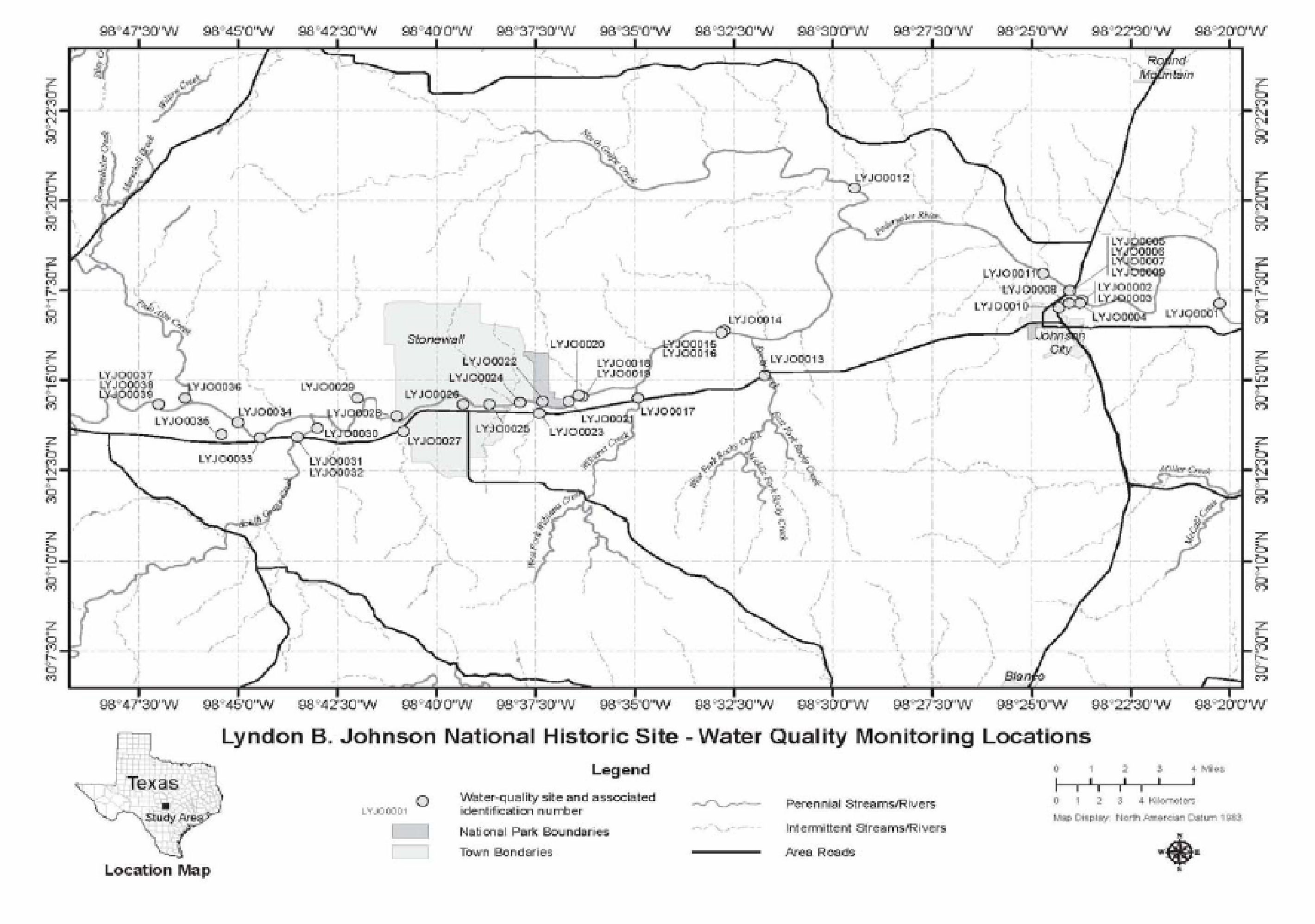


Figure LYJO. Map of water-quality monitoring locations near Lyndon B. Johnson National Historical Site.

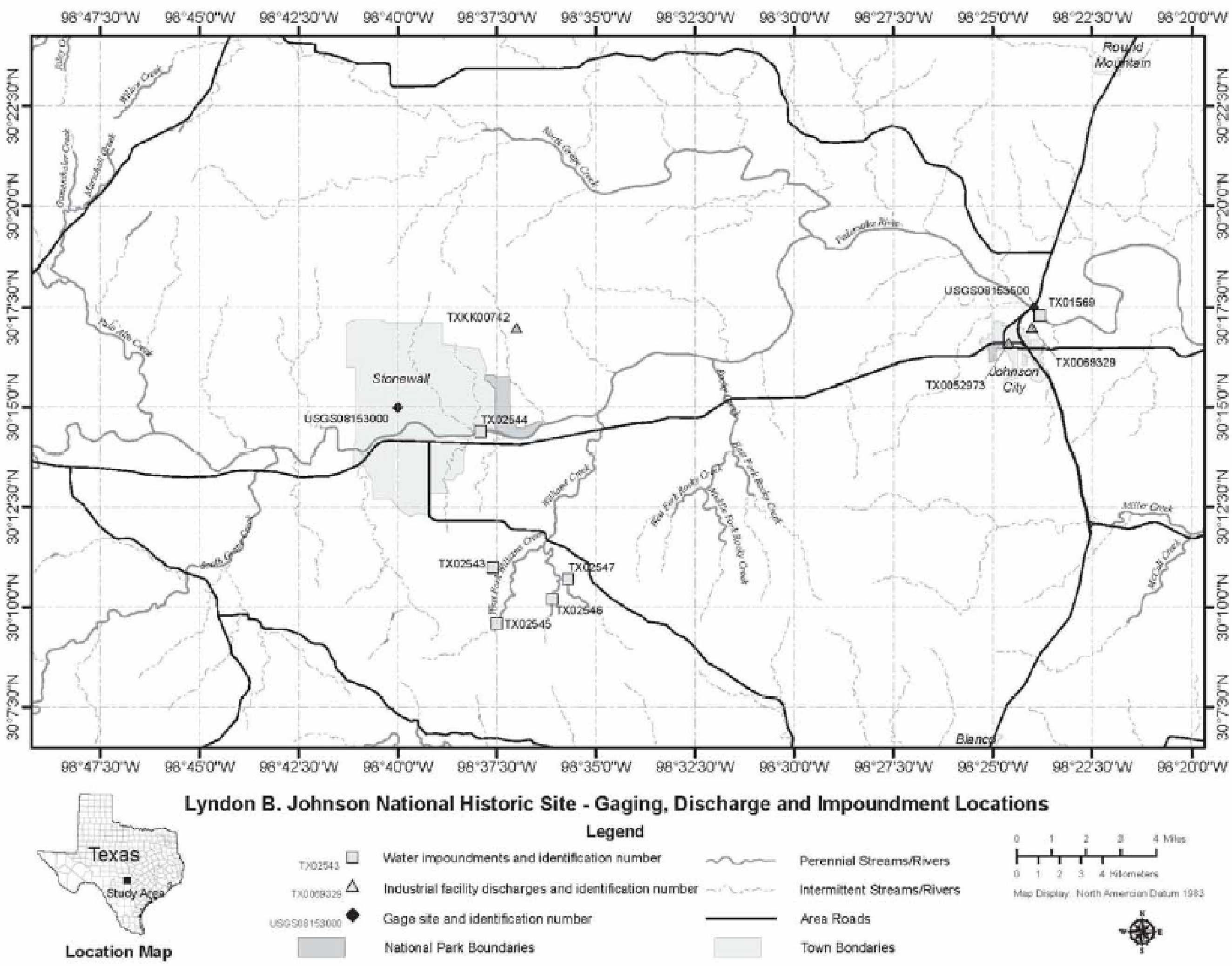


Figure LYJOa. Map of gaging, discharge, and impoundment locations near Lyndon B. Johnson National Historical Site.

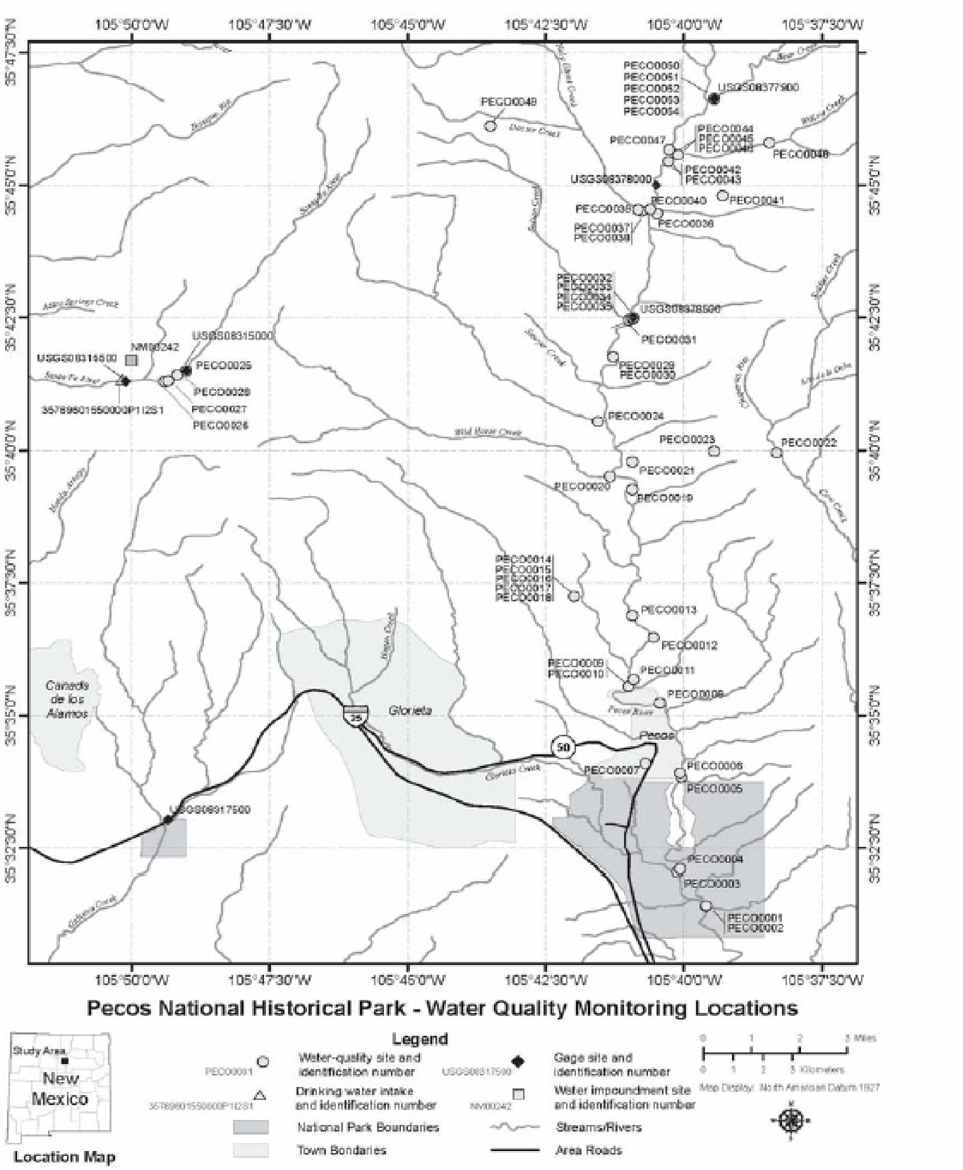


Figure PECO. Map of water-quality monitoring locations near Pecos National Historical Park.

APPENDIX B

Table BEOL. List of water-quality and gage locations near Bent's Old Fort National Historic Site.

Water Quality Sites

NPS Station ID	Latitude	Longitude	Station Location
BEOL 0001	38.072503	-103.325282	Horse Creek At Mouth Near Las Animas, Colo.
BEOL 0002	38.085281	-103.352782	Horse Creek Near Las Animas, Co.
BEOL 0003	38.056948	-103.355837	M-18 Ark At Consolid Can
BEOL 0004	38.086698	-103.36831	C22445
BEOL 0005	38.100003	-103.371892	C22444
BEOL 0006	38.073616	-103.39806	Fort Lyon Canal At Bent-otero County Line, Co.
BEOL 0007	38.040004	-103.39917	Arkansas River At Hadley, Co.
BEOL 0008	38.025281	-103.44167	M-20 Ark Riv Nr Bents Ft
BEOL 0009	38.035559	-103.471671	Fort Lyon Canal Near Casa, Co
BEOL 0010	37.928892	-103.499393	C30058
BEOL 0011	37.990559	-103.50417	Arkansas River Tributary Near La Junta, Co.
BEOL 0012	37.990281	-103.508615	Arkansas River Tributary No.2 Near La Junta, Co.
BEOL 0013	38.000005	-103.51667	Thompson Arroyo
BEOL 0014	37.988892	-103.525005	AT & SF RR La Junta
BEOL 0015	37.989448	-103.528892	La Junta Stp La Junta Colo
BEOL 0016	37.989448	-103.528892	La Junta Stp La Junta Colo
BEOL 0017	37.989448	-103.528892	La Junta Sewage Effluent At La Junta, Co.
BEOL 0018	37.989448	-103.531116	King Arroyo At La Junta, Co.
BEOL 0019	37.990559	-103.531949	Arkansas River At La Junta, Co.
BEOL 0020	38.016670	-103.550004	Vandiver Arroyo
BEOL 0021	37.990281	-103.551949	Anderson Arroyo At La Junta, Co.
BEOL 0022	38.008337	-103.575005	Fort Lyon Canal Near La Junta, Co.
BEOL 0023	37.998615	-103.58667	Crooked Arroyo At Highway 50 Near La Junta, Colo
BEOL 0025	37.998615	-103.586949	Crooked Arroyo Near La Junta, Co.
BEOL 0026	38.011116	-103.588338	Arkansas River Near La Junta, Co.
BEOL 0027	38.011116	-103.588338	M-22 Ark At Ft Lyon Can
BEOL 0028	37.982226	-103.597781	Crooked Arroyo Near Swink, Co.
BEOL 0029	38.011116	-103.588338	Arkansas River Near La Junta
BEOL 0030	38.014726	-103.604727	Ir-27 East Swink Drain

Gage Sites

Site ID	Latitude	Longitude	Station Name
USGS07121800	38.073612	-103.398056	Fort Lyon Canal At Ben
USGS07122000	38.011111	-103.588333	Arkansas River Near La Junta, Co.
USGS07122005	38.008333	-103.575	Fort Lyon Canal Near La Junta, Co.
USGS07122060	38.035556	-103.471667	Fort Lyon Canal Near Casa, Co.
USGS07122400	37.982222	-103.597778	Crooked Arroyo Near Swink, Co.
USGS07122500	37.998611	-103.586944	Crooked Arroyo Near La Junta, Co.
USGS07123000	37.990556	-103.531944	Arkansas River At La Junta, Co.
USGS07123300	38.040001	-103.39917	Arkansas River At Ha
USGS07123675	38.085278	-103.352778	Horse Creek Near Las Animas, Co.
USGS380041103294900	38.011389	-103.496944	Sc02305431abb1

Table CHIC. List of monitoring locations in or near Chickasaw National Recreation Area.

Water Impoundment Sites

Siteid	Latitude	Longitude	Station Name
OK00310	34.625000	-96.975000	ROCK CREEK SITE 4A
OK02006	34.598333	-97.021667	SCS ROCK CREEK SITE 2
OK02007	34.626667	-96.991667	SCS ROCK CREEK SITE 3
OK02008	34.538333	-96.941667	SCS ROCK CREEK SITE 17
OK02010	34.556667	-96.923333	SCS ROCK CREEK SITE 15
OK02013	34.573333	-96.945000	SCS ROCK CREEK SITE 12
OK02014	34.568333	-96.950000	SCS ROCK CREEK SITE 11
OK02015	34.551667	-96.973333	SCS ROCK CREEK SITE 10
OK02016	34.526667	-96.973333	SCS ROCK CREEK SITE 9
OK02017	34.520000	-97.018333	SCS ROCK CREEK SITE 8
OK02018	34.543333	-97.016667	SCS ROCK CREEK SITE 7
OK02019	34.553333	-97.018333	SCS ROCK CREEK SITE 6
OK02034	34.580000	-97.003333	SCS ROCK CREEK SITE 5
OK02048	34.606667	-97.051667	SCS CHIGLEY SANDY CREEK SITE 7
OK02051	34.551667	-97.078333	SCS CHIGLEY SANDY CREEK SITE 1
OK02052	34.543333	-97.061667	SCS CHIGLEY SANDY CREEK SITE 1
OK02053	34.551667	-97.051667	SCS CHIGLEY SANDY CREEK SITE 1
OK02054	34.541667	-97.051667	SCS CHIGLEY SANDY CREEK SITE 1
OK02501	34.450000	-97.033333	ARBUCKLE LAKE
OK10085	34.411667	-97.083333	AMOS CONST. CO.
OK11016	34.516667	-96.975000	LACY
OK12876	34.438333	-97.111667	HAGEE GSS NO.1
OK21117	34.466667	-97.041667	OKNONAME 09903
OK21118	34.473333	-97.043333	OKNONAME 09902
OK21119	34.490000	-96.986667	VETERANS LAKE

Drinking Water Intakes

Site ID	Latitude	Longitude	Station Name
40000101820000p1I1	34.436110	-97.029170	Arbuckle Lk
40000501500000p1	34.508340	-96.970000	Sulphur Wd
40000501520000p1	34.508340	-96.970000	Sulphur Wd
40036301500000p1I5	34.434440	-97.029440	Lake Of The Arbuckle
40236500000000p1	34.462500	-97.040280	Treatment Plant
40236500000000p1I1	34.462500	-97.040280	Arbuckle Lk
40921800000000p1	34.462500	-97.041660	Treatment Plant
40921800000000p1I1	34.462500	-97.041660	Arbuckle Lk

Industrial Facility Discharges

Site ID	Latitude	Longitude	Station Name
OK0000493	34.522222	-96.966666	OK GAS & ELEC ARBUCKLE
OK0020141	34.488888	-96.994444	SULPHUR, CITY OF

Water Quality Sites

NPS Station ID	Latitude	Longitude	Station Location
CHIC0001	34.396920	-97.067671	Deel Ck.200 Ft Upstream Of Washita R. Confluence
CHIC0002	34.397226	-97.036115	Rock Creek At Dougherty, Ok
CHIC0003	34.398059	-97.082588	Unnamed Spring 1.5 Miles West Of Dougherty
CHIC0004	34.399004	-97.082392	Unnamed Spring 1.5 Miles West Of Dougherty
CHIC0005	34.404727	-96.989726	02s-03e-09 Aab 1
CHIC0006	34.414226	-96.967809	Buckhorn Creek 3.3m Below Catfish Farm
CHIC0007	34.416837	-96.976587	Buckhorn Creek Branch Of Arbuckle Reservoir
CHIC0008	34.421282	-96.984504	Arbuckle Reservoir Buckhorn Ck. Branch 1m Depth
CHIC0009	34.422726	-96.989170	Arbuckle Reservoir Buckhorn Ck. Branch 2m Depth
CHIC0010	34.423449	-96.989253	Buckhorn Creek Arm Of Arbuckle Reservoir
CHIC0011	34.423976	-96.994671	Buckhorn Creek Branch Of Arbuckle Reservoir
CHIC0012	34.424670	-96.995059	Arbuckle Reservoir Buckhorn Ck. Branch 4m Depth
CHIC0013	34.425309	-96.999003	Buckhorn Creek Branch Of Arbuckle Reservoir
CHIC0014	34.425365	-97.106476	Falls Creek Above Price Falls
CHIC0015	34.425837	-96.999171	Arbuckle Lake
CHIC0016	34.426142	-96.999892	Arbuckle Reservoir Buckhorn Ck. Branch 7m Depth

Table CHIC. List of monitoring locations in or near Chickasaw National Recreation Area (cont.).

CHIC0017	34.426170	-96.950503	Buckhorn Creek 0.9m Below Catfish Farm
CHIC0018	34.426170	-96.950531	Buckhorn Creek At Highway 177
CHIC0019	34.426392	-96.950838	Buckhorne Creek
CHIC0020	34.428059	-97.005838	Arbuckle Reservoir Buckhorn Ck. Branch 11m Depth
CHIC0021	34.428615	-97.036670	Rock Creek
CHIC0022	34.429421	-97.009892	Arbuckle Reservoir Buckhorn Ck. Branch 15m Depth
CHIC0023	34.430670	-97.013642	Arbuckle Reservoir Buckhorn Ck. Branch 19m Depth
CHIC0024	34.431115	-97.026115	Arbuckle Lake
CHIC0025	34.432087	-97.030920	Arbuckle Dam Spillway
CHIC0026	34.432170	-97.017448	Arbuckle Reservoir Buckhorn Ck. Branch 24m Depth
CHIC0027	34.432476	-97.023531	Arbuckle Reservoir In Central Pool
CHIC0028	34.432587	-97.026588	Central Pool Near Dam On Arbuckle Reservoir
CHIC0029	34.433503	-97.026865	Arbuckle Reservoir Next To Arbuckle Dam
CHIC0030	34.433838	-96.943892	Buckhorn Creek Just Below Catfish Farm
CHIC0031	34.434448	-97.106393	02s-02e-33 Cbb 1
CHIC0032	34.435670	-97.025726	Central Pool Of Arbuckle Reservoir
CHIC0033	34.436615	-97.026616	Arbuckle Reservoir Near Central Pool
CHIC0034	34.522837	-96.968032	
CHIC0035	34.522837	-96.968032	
CHIC0036	34.437505	-97.083338	
CHIC0037	34.445699	-96.942671	Buckhorn Creek 1 Mile South Of Lowrance Springs
CHIC0038	34.449142	-96.943115	Buckhorn Creek 3/4 Mi. South Of Lowrance Springs
CHIC0039	34.449170	-96.943142	Buckhorn Creek 0.9m Below Lowrance Springs
CHIC0040	34.449366	-97.010087	Rock Creek Branch Of Arbuckle Reservoir
CHIC0041	34.451531	-97.040781	Guy Sandy Creek Branch Of Arbuckle Reservoir
CHIC0042	34.452059	-97.016476	Rock Creek Arm Of Arbuckle Reservoir
CHIC0043	34.458059	-96.942505	01s-03e-24 Bda 2 Lowrance Springs 1
CHIC0044	34.458338	-96.938893	Lowrance Springs Nr Drake, Ok
CHIC0045	34.458338	-96.940837	01s-03e-24 Acb 1 Lowrance Spring 2
CHIC0046	34.458531	-96.942588	Unnamed Spring Next To Lowrance Springs
CHIC0047	34.458615	-96.941670	01s-03e-24 Bda 1
CHIC0048	34.458837	-96.941254	Buckhorn Creek At Lowrance Springs
CHIC0049	34.461781	-97.013003	Rock Creek Branch Of Arbuckle Reservoir
CHIC0050	34.464338	-97.039781	Guy Sandy Creek Branch Of Arbuckle Reservoir
CHIC0051	34.464448	-97.040559	Arbuckle Lake
CHIC0052	34.466115	-97.014171	Arbuckle Lake
CHIC0053	34.467448	-97.001643	Rock Creek Branch Of Arbuckle Reservoir
CHIC0054	34.481892	-97.031615	Guy Sandy Creek Arm Of Arbuckle Reservoir
CHIC0055	34.481976	-97.032893	Guy Sandy Creek Branch Of Arbuckle Reservoir
CHIC0056	34.485448	-97.029531	Guy Sandy Creek Near Lake Of The Arbuckles
CHIC0057	34.486115	-96.985282	Rock Creek
CHIC0058	34.486671	-96.996116	01s-03e-09 Bdac 1 Sulphur Treatment Plant
CHIC0059	34.490559	-96.986115	Veterans Lake At Dam
CHIC0060	34.491670	-96.991671	Rock Creek S Of Platt Natl Pk Nr Sulphur, Ok
CHIC0061	34.494531	-96.974004	Sulphur Bromide Spring
CHIC0062	34.494726	-96.975281	01s-03e-03 Dcb 1 Ravine Spring
CHIC0063	34.494921	-96.975281	Taff's Spring
CHIC0064	34.495142	-96.988531	Rock Creek 200 Yd South Of Siphon At Campground
CHIC0065	34.495170	-96.977392	Red Flag Spring
CHIC0066	34.495281	-96.988337	Rock Creek At Sulphur, Ok
CHIC0067	34.495309	-96.988420	Rock Creek Below Inverted Siphon At Campgrounds
CHIC0068	34.495837	-96.988616	01s-03e-04 Dacd 1 Below Siphons Campground
CHIC0069	34.496170	-96.982810	Rock Creek At The Bromide Foot Bridge
CHIC0070	34.496198	-96.982866	Rock Creek Above Bromide Foot Bridge
CHIC0071	34.496393	-96.982782	01s-03e-03 Cbdb 1 Above Bromide Foot Bridg
CHIC0072	34.496809	-96.982866	Bromide Spring
CHIC0073	34.496809	-96.984116	Rock Creek North Of Veterans Lake
CHIC0074	34.496865	-96.984031	Unnamed Spring In Bed Of Rock Cr
CHIC0075	34.496977	-96.988309	Rock Creek At Sulphur Campgrounds
CHIC0076	34.497143	-96.983754	Medicine Spring
CHIC0077	34.497226	-96.988337	01s-03e-04 Dabd 1 Campground
CHIC0078	34.497587	-96.984781	Rock Creek South Of Campground Entrance Bridge
CHIC0079	34.497587	-96.984866	Rock Creek At Bromide Foot Bridge
CHIC0080	34.497948	-96.985005	Rock Creek At Bridge Near Campground
CHIC0081	34.498503	-96.985642	Rock Creek Campground Swim Area
CHIC0082	34.499476	-96.987142	Rock Creek Between 2 Siphons Near Campground
CHIC0083	34.500392	-96.960198	Travertine Creek Below The Swimming Area
CHIC0084	34.501115	-96.961670	01s-03e-02 Bdbd 1 Below Swimming Area

Table CHIC. List of monitoring locations in or near Chickasaw National Recreation Area (cont.).

CHIC0085	34.501392	-96.969170	01s-03e-03 Aaca 1 Travertine At Hwy 177
CHIC0086	34.502003	-96.971060	Hillside Spring Just West Of Highway 177
CHIC0087	34.502031	-96.971087	Hillside Spring
CHIC0088	34.502587	-96.939004	Buffalo Spring - The Source Of Travertine Creek
CHIC0089	34.502615	-96.938977	Buffalo Spring Near Travertine Creek
CHIC0090	34.502615	-96.938977	Buffalo Spring Near Travertine Creek
CHIC0091	34.502753	-96.970143	Pavilion Spring - Outlet A
CHIC0092	34.502753	-96.970199	Pavilion Spring Just East Of Highway 177
CHIC0093	34.502781	-96.970282	01s-03e-03 Aacd 1 Pavilion Spring
CHIC0094	34.502837	-96.970254	Pavilion Spring - Outlet B
CHIC0095	34.502837	-96.970254	Pavilion Spring - Outlet C
CHIC0096	34.502865	-96.970282	Pavilion Spring - Outlet D
CHIC0097	34.502892	-96.970282	Pavilion Spring - Outlet E
CHIC0098	34.502948	-96.955366	Travertine Creek At Bear Falls
CHIC0099	34.503031	-96.955504	Travertine Ck 250 Feet Ne Of Cold Spring Camp
CHIC0100	34.503365	-96.948420	Travertine Creek South Side Of The Nature Center
CHIC0101	34.503587	-96.971531	Rock Creek 50 Ft South Of Low Water Bridge
CHIC0102	34.503615	-96.955421	Travertine Ck .25 Miles Ne Of Cold Spring Camp
CHIC0103	34.503615	-96.971671	Rock Creek Near Lincoln Bridge
CHIC0104	34.503727	-96.971531	Rock Creek At Sandy Beach
CHIC0105	34.503865	-96.970615	Travertine Creek 100 Ft West Of Lincoln Bridge
CHIC0106	34.503893	-96.970254	Travertine Creek Upstream Of Inverted Siphon
CHIC0107	34.503893	-96.970559	01s-03e-03 Aaca 1 Inv. Siphon Lincoln Brid
CHIC0108	34.503948	-96.955476	Travertine Creek At Sycamore Crossing
CHIC0109	34.503948	-96.970337	Travertine Creek At Lincoln Bridge
CHIC0110	34.504003	-96.966255	Travertine Creek 1/2 Mile Nw Of Cold Spring Camp
CHIC0111	34.504059	-96.970005	Travertine Ck At Inverted Siphon Below Bridge
CHIC0112	34.504087	-96.969865	Travertine Creek 200 Ft East Of Lincoln Bridge
CHIC0113	34.504142	-96.949532	Travertine Creek Below The Nature Center
CHIC0114	34.504142	-96.971032	Rock Creek Near Black Sulphur Spring Pump House
CHIC0115	34.504198	-96.969449	Travertine Ck Between Lincoln & Hwy 177 Bridges
CHIC0116	34.504198	-96.969615	Travertine Creek At Lincoln Bridge
CHIC0117	34.504309	-96.971337	Black Sulphur Spring
CHIC0118	34.504392	-96.971476	Black Sulphur Spring
CHIC0119	34.504420	-96.971087	Rock Ck At Sandy Beach Upstream Of Travertine Ck
CHIC0120	34.504448	-96.968476	Discharge From Culvert 50 Ft East Of Bridge
CHIC0121	34.504448	-96.968616	01s-03e-03 Aaad 1 Culvert E. Of Hwy 177
CHIC0122	34.504477	-96.968032	Travertine Creek East Of CHIC_sch_t4_2
CHIC0123	34.504477	-96.969031	Travertine Creek At Hwy 177
CHIC0124	34.504503	-96.968143	Travertine Creek Near Culvert East Of Hwy 177
CHIC0125	34.504615	-96.967003	Travertine Creek At Central Campground Swim Area
CHIC0126	34.504643	-96.940948	Antelope Springs Near Travertine Creek
CHIC0127	34.504643	-96.940948	Antelope Springs Near Travertine Creek
CHIC0128	34.504670	-96.941031	Antelope Spring
CHIC0129	34.504698	-96.950337	Travertine Creek Below The Nature Center
CHIC0130	34.504726	-96.938059	01s-03e-01 Aba 1
CHIC0131	34.504726	-96.982782	01s-03e-03 Aabc 1 Sandy Beach
CHIC0132	34.504920	-96.950976	Travertine Creek At Little Niagara Waterfall
CHIC0133	34.505142	-96.971837	Rock Creek At Sandy Beach
CHIC0134	34.505227	-96.972754	Rock Creek At Black Sulphur Beach
CHIC0135	34.505282	-96.951671	01s-03e-02 Aaab 1 Little Niagra
CHIC0136	34.505282	-96.975310	Rock Creek Near Culvert At Hwy 7
CHIC0137	34.505420	-96.951616	Travertine Creek At Little Niagara Foot Bridge
CHIC0138	34.505503	-96.951616	Travertine Creek At Little Niagara
CHIC0139	34.505781	-96.975865	Storm Culvert 20 Ft South Of Broadway Bridge
CHIC0140	34.506143	-96.975865	Rock Creek South Of Broadway Bridge
CHIC0141	34.506143	-96.975948	Rock Creek At Hwy 7 Downstream From Bridge
CHIC0142	34.506392	-96.975948	Rock Creek At Hwy 7 Under Bridge
CHIC0143	34.506392	-96.976116	01s-03e-03 Abbb 1 Under Hwy 7 Bridge
CHIC0144	34.506587	-96.975920	Rock Creek Above Highway 7 Bridge
CHIC0145	34.506615	-97.033809	Guy Sandy Creek At Highway 7
CHIC0146	34.506753	-97.033892	Guy Sandy Creek At Highway 7 Bridge
CHIC0147	34.515281	-97.033338	Guy Sandy Creek
CHIC0148	34.515559	-96.968337	01n-03e-34 Adac 1 Below Hwy 177 Bridge
CHIC0149	34.515616	-96.968616	Rock Creek At Hwy 177 Downstream Of Bridge
CHIC0150	34.515671	-96.968253	Rock Creek Below Bridge 1/2 Mi East Of Lacy Lake
CHIC0151	34.515837	-96.968060	01n-03e-34 Adad 1 Above Hwy 177 Bridge
CHIC0152	34.515948	-96.967866	Rock Creek At Hwy 177 Upstream Of Bridge

Table CHIC. List of monitoring locations in or near Chickasaw National Recreation Area (cont.).

CHIC0153	34.520976	-96.966366	Rock Creek Below Og&e Cooling Water Discharge
CHIC0154	34.522837	-96.968032	Rock Creek At Og&e Cooling Water Discharge
CHIC0155	34.524754	-96.968755	Rock Creek Above Og&e Cooling Water Discharge
CHIC0156	34.527781	-96.966670	Rock Creek N Of Sulphur, Ok

Table FOLS. List of monitoring locations in or near Fort Larned National Historic Site.

Gage Sites

Site ID	Latitude	Longitude	Station Name
USGS07140500	38.166667	-99.100000	Arkansas River at Larned, KS
USGS07141200	38.200000	-99.347222	Pawnee River near Larned, KS

Drinking Water Sites

Site ID	Latitude	Longitude	Station Name
20498301550000P1	38.179160	-99.105550	Treatment Plant
20498301550000P1I1	38.179160	-99.105550	Deep Well

Water Quality Sites

NPS Station ID	Latitude	Longitude	Station Location
FOLS0001	38.176670	-99.116392	Pawnee River at Larned
FOLS0002	38.174448	-99.117421	Pawnee River at Larned
FOLS0003	38.182087	-99.186920	Pawnee River near Larned
FOLS0004	38.200004	-99.347227	Pawnee River at Rozel, KS

Water Quality Sites

NPS Station ID	Latitude	Longitude	Station Location
FOUN0001	35.861892	-105.001115	N12147
FOUN0002	35.898615	-105.016116	N12590
FOUN0003	35.899448	-105.018892	Mora County
FOUN0004	35.918615	-105.036115	Mora County Y
FOUN0005	35.92667	-105.049727	Mora County

Table LAMR. List of monitoring locations in or near Lake Meredith National Recreation Area.

Water Impoundment Sites

Site ID	Latitude	Longitude	Station Name
TX00023	35.716667	-101.553333	SANFORD DAM
TX03830	35.660000	-101.795000	WEYMOUTH MIDDLE LAKE DAM
TX05610	35.668333	-101.810000	THOMPSON ESTATE LAKE DAM
TX05612	35.658333	-101.710000	WEYMOUTH RANCH LOWER LAKE DAM

Drinking Water Intakes

Site ID	Latitude	Longitude	Station Name	Agency
48022501550000P1I1	35.710000	-101.550300	LAKE MEREDITH	AMARILLO PUBLIC WKS
48096000000000P1I1S1	35.710280	-101.551400	LAKE MEREDITH	BORGER MWS
48539501550000P1I1	35.710000	-101.550300	LAKE MEREDITH	LUBBOCK WATER DEPT
48539501550000P1W1	35.710000	-101.550300	SAND HILLS FIELD	LUBBOCK WATER DEPT
48678501500000P2I1	35.710280	-101.551400	LAKE MEREDITH	PAMPA MWS
48710500000000P1I1	35.710280	-101.551400	LAKE MEREDITH	PLAINVIEW PUBLIC WS
48841500000000P1I1	35.666670	-101.616700	LAKE MEREDITH	SLATON, CITY OF

Gage Sites

Site ID	Latitude	Longitude	Station Name
USGS07227500	35.470278	-101.879167	CANADIAN RIVER NR AMARILLO, TX
USGS07227600	35.453335	-101.783058	BONITA C NR AMARILLO
USGS07227700	35.474724	-101.759720	CHICKEN CR NR AMARIL
USGS07227900	35.710556	-101.550833	LAKE MEREDITH NR SANFORD, TX
USNWS41 0215 N	35.469444	-101.879166	AMARILLO 19N TEX ON

Water Quality Sites

NPS Site ID	Latitude	Longitude	Station Name
LAMR0001	35.733337	-101.500005	CAMEX INCORPORATED
LAMR0002	35.711115	-101.545837	AQUEDUCT
LAMR0003	35.719560	-101.549976	STILLING BASIN-NORTH
LAMR0004	35.708338	-101.550004	Lake Meredith Near the Dam
LAMR0005	35.718865	-101.550115	STILLING BASIN-CENTER
LAMR0006	35.710198	-101.550420	LAKE MEREDITH-INTAKE STRUCTURE
LAMR0007	35.717920	-101.550560	STILLING BASIN-SOUTH
LAMR0008	35.710004	-101.551003	LAKE MEREDITH-SOUTH CANYON
LAMR0009	35.710559	-101.550837	LAKE MEREDITH NR SANFORD, TX
LAMR0010	35.703892	-101.551366	HEADQUARTERS
LAMR0011	35.702087	-101.552198	LAKE MEREDITH-SOUTH CANYON
LAMR0012	35.709726	-101.552226	LAKE MEREDITH
LAMR0013	35.719448	-101.554171	CANADIAN RIVER
LAMR0014	35.706142	-101.554642	LAKE MEREDITH-SANFORD YAKE MARINA
LAMR0015	35.716670	-101.556671	LAKE MEREDITH AT DAM
LAMR0016	35.711559	-101.556865	SANFORD-YAKE AREA
LAMR0017	35.711115	-101.558337	Lake Meredith Reservoir Near Dam
LAMR0065	35.496003	-101.729003	018955
LAMR0066	35.504003	-101.734003	COETAS CREEK ON ALIBATES RANCH
LAMR0067	35.428004	-101.740004	018957
LAMR0018	35.695365	-101.571170	LAKE MEREDITH-CEDAR CANYON
LAMR0019	35.696003	-101.576004	LAKE MEREDITH-CEDAR CANYON
LAMR0020	35.724004	-101.576004	LAKE MEREDITH-NORTH CANYON
LAMR0021	35.726170	-101.576309	LAKE MEREDITH-NORTH CANYON
LAMR0022	35.693198	-101.578838	Lake Meredith Reservoir Near Cedar Canyon
LAMR0023	35.715005	-101.579004	LAKE MEREDITH-SW OF SOUTH CANYON
LAMR0024	35.684337	-101.591115	FRITCH FORTRESS WATER TOWER
LAMR0025	35.707004	-101.593004	LAKE MEREDITH-BUGBEE CANYON
LAMR0026	35.699003	-101.593004	LAKE MEREDITH-CENTER NEAR N.TURKEY CR.
LAMR0027	35.707754	-101.595088	Lake Meredith Reservoir Near Bugbee Canyon
LAMR0028	35.732866	-101.595531	BUGBEE CANYON
LAMR0029	35.676003	-101.601003	LAKE MEREDITH-MEREDITH CANYON
LAMR0030	35.744448	-101.601392	BUGBEE CREEK

Table LAMR. List of monitoring locations in or near Lake Meredith National Recreation Area (cont.).

LAMR0031	35.673559	-101.601615	LAKE MEREDITH-MEREDITH HARBOR
LAMR0032	35.690003	-101.603338	LAKE MEREDITH MID-LAKE BETWEEN BLUE EAST AND FRI
LAMR0033	35.675170	-101.603559	Lake Meredith Reservoir at Fritch Fortress
LAMR0034	35.707642	-101.606670	LAKE MEREDITH-NORTH TURKEY CREEK
LAMR0035	35.683309	-101.611004	CENTER OF LAKE MEREDITH
LAMR0036	35.682948	-101.612476	FRITCH FORTRESS-BLUE CREEK AREA
LAMR0037	35.677504	-101.612504	LAKE MEREDITH
LAMR0038	35.654559	-101.622559	LAKE MEREDITH-FRITCH CANYON
LAMR0039	35.685004	-101.624003	LAKE MEREDITH-BLUE WEST
LAMR0040	35.688698	-101.626087	Lake Meredith Reservoir Near Blue West Rec Area
LAMR0041	35.651615	-101.627810	LAKE MEREDITH-HARBOR BAY
LAMR0042	35.679004	-101.629003	LAKE MEREDITH-SW OF BLUE WEST
LAMR0043	35.687365	-101.630143	LAKE MEREDITH-BLUE WEST
LAMR0044	35.648892	-101.632726	Lake Meredith Reservoir Near Harbor Bay
LAMR0045	35.671003	-101.646004	LAKE MEREDITH-BASS BOAT
LAMR0046	35.592059	-101.650476	LAKE MEREDITH-SOUTH TURKEY CREEK
LAMR0047	35.628060	-101.652809	LAKE MEREDITH-SHORT CREEK
LAMR0048	35.709531	-101.653559	Lake Meredith in Blue (Creek) West Area
LAMR0049	35.637142	-101.658087	MARTINS CANYON-TURKEY CREEK AREA
LAMR0050	35.635142	-101.659254	LAKE MEREDITH-SANDY POINT
LAMR0051	35.615004	-101.660004	LAKE MEREDITH-SOUTH TURKEY CREEK
LAMR0052	35.721531	-101.661809	LAKE MEREDITH-BIG BLUE CANYON
LAMR0053	35.659559	-101.662810	LAKE MEREDITH-MARTINS CANYON
LAMR0054	35.721003	-101.664615	BIG BLUE CREEK 21 MILES SE OF DUMAS
LAMR0055	35.537003	-101.668003	018240
LAMR0056	35.633309	-101.670338	Lake Meredith Reservoir Near Evans Canyon
LAMR0057	35.636116	-101.678338	LAKE MEREDITH
LAMR0058	35.640976	-101.683088	LAKE MEREDITH-EVANS CANYON
LAMR0059	35.587698	-101.704837	LAKE MEREDITH-ALIBATES
LAMR0060	35.743059	-101.711116	BIG BLUE CREEK
LAMR0061	35.597587	-101.713115	LAKE MEREDITH-PLUM CREEK
LAMR0062	35.596670	-101.713338	LAKE MEREDITH MID-LAKE BETWEEN PLUM CREEK BOAT R
LAMR0063	35.594031	-101.716170	ALIBATES AREA
LAMR0064	35.523003	-101.726003	018328
LAMR0068	35.505227	-101.750699	COETAS CREEK
LAMR0069	35.558337	-101.753337	LAKE MEREDITH
LAMR0070	35.474865	-101.759837	CHICKEN CREEK
LAMR0071	35.475003	-101.760004	CHICKEN CREEK ON LX RANCH
LAMR0072	35.657003	-101.764003	018960
LAMR0073	35.453282	-101.783170	BONITA CREEK
LAMR0074	35.452781	-101.783338	BONITA CREEK
LAMR0075	35.471003	-101.786004	BONITA CREEK ON LX RANCH
LAMR0076	35.395559	-101.834171	EAST AMARILLO CREEK AT US 287
LAMR0077	35.395865	-101.834226	EAST AMARILLO CREEK AT 287
LAMR0078	35.469448	-101.854727	CANADIAN RIVER 2400 METERS DOWNSTREAM OF HWY 287
LAMR0079	35.468670	-101.867170	Fulton Ranch on Canadian River
LAMR0080	35.469948	-101.879227	CANADIAN RIVER AT 287
LAMR0081	35.470281	-101.879170	CANADIAN RIVER AT US 87-287
LAMR0082	35.470281	-101.879170	CANADIAN RIVER NR AMARILLO, TX
LAMR0083	35.470003	-101.879170	CANADIAN RIVER
LAMR0084	35.452781	-101.880282	EAST AMARILLO CREEK 10 METERS UPSTREAM OF CANADI
LAMR0085	35.453615	-101.881671	CANADIAN RIVER 10 METERS UPSTREAM OF EAST AMARIL
LAMR0086	35.453087	-101.884392	Canadian River 100 Yds Downstr. From AT&SF Brdge
LAMR0087	35.470281	-101.895838	Canadian River at US Hwy 87-287 Br N of Amarillo

Table LYJO. List of monitoring locations near Lyndon B. Johnson National Historic Site.

Gage Sites

Site ID	Latitude	Longitude	Station Name
USGS08153000	30.250000	-98.666667	Pedernales R At Stonewall, Tex.(Disc)
USGS08153500	30.291667	-98.399167	Pedernales River Nr Johnson City, Tx

Water Impoundment Sites

Site ID	Latitude	Longitude	Station Name
TX01569	30.288333	-98.396667	Lake Johnson City Dam
TX02543	30.183333	-98.626667	Williams Creek Ws Scs Site 4 D
TX02544	30.240000	-98.631667	Lyndon B Johnson State Park Da
TX02545	30.160000	-98.625000	Williams Creek Ws Scs Site 3 D
TX02546	30.170000	-98.601667	Williams Creek Ws Scs Site 2 D
TX02547	30.178333	-98.595000	Williams Creek Ws Scs Site 1 D

Industrial Facility Discharges

Site ID	Latitude	Longitude	Station Name
TX0052973	30.276666	-98.410000	Johnson City, City Of
TX0069329	30.283333	-98.400000	Johnson City City Of Wtp Blanc
TXKK00742	30.283055	-98.616666	Stonewall

Water Quality Sites

NPS Station ID	Latitude	Longitude	Station Location
LYJO0001	30.285559	-98.337782	Pedernales River At Pedernales Bend East Of John
LYJO0002	30.287200	-98.395600	Pedernales River 1/2 Mi Downstream Of Us 281
LYJO0003	30.287200	-98.395600	Pedernales River 1/2 Mi Downstream Of Sh 281 Nea
LYJO0004	30.285837	-98.396392	Town Creek 50 M Upstream Of Pedernales River Con
LYJO0005	30.291670	-98.398616	Pedernales River At Us 281 In Johnson City
LYJO0006	30.291670	-98.398616	Pedernales R. At Us Hwy 281
LYJO0007	30.291670	-98.399170	Pedernales River Nr Johnson City, TX
LYJO0008	30.285837	-98.400838	Town Creek 50 M Downstream Of Johnson City Wwtp
LYJO0009	30.291666	-98.400777	Pedernales R. Upstream Of Us 281 In Johnson City
LYJO0010	30.283615	-98.405281	Town Creek 20 M Downstream Of Us 281 In Johnson
LYJO0011	30.299726	-98.411948	Pedernales River At Pedernales River Estates
LYJO0012	30.339170	-98.491115	North Grape Creek At FM 1320
LYJO0013	30.252227	-98.528892	Rocky Creek At Us 290
LYJO0014	30.273059	-98.545837	Pedernales R. At RR 1320
LYJO0015	30.272003	-98.547004	Pedernales River At FM 1320
LYJO0016	30.272003	-98.547000	Pedernales River At FM 1320
LYJO0017	30.241670	-98.581948	Williams Creek At RR 1
LYJO0018	30.242503	-98.605281	Pedernales River At Park Road 49
LYJO0019	30.242476	-98.605420	Pedernales River At Park Road 49 Bridge
LYJO0020	30.243059	-98.606949	Pedernales R. At Whittington Cr.
LYJO0021	30.240281	-98.611115	Pedernales R. .5 Mi. Blow.arnelg
LYJO0022	30.240281	-98.622226	Pedernales R. 100 Yds. Abv. Arne
LYJO0023	30.234726	-98.623615	Arnelger Cr. Abve. Conf. Of Pede
LYJO0024	30.239781	-98.631643	Pedernales River At Hodges Dam
LYJO0025	30.238892	-98.644448	Pedernales R. .5 Mi. Below RR 16
LYJO0026	30.238892	-98.655560	Simon Burg Cattle Op. Stormwater
LYJO0027	30.226392	-98.680559	Threemile Cr. At Us Hwy 290
LYJO0028	30.233337	-98.683337	Pedernales R. 1.0 Mi. Bel. Cave
LYJO0029	30.241670	-98.700005	Cave Creek Abve. Conf. Of Pedern
LYJO0030	30.227782	-98.716670	Grape Cr. Abve. Conf. Of Pederna
LYJO0031	30.223059	-98.725004	South Grape Creek At Us 290
LYJO0032	30.223615	-98.725004	Grape Cr. At Us Hwy 290
LYJO0033	30.223337	-98.740837	Pedernales River At Blumenthal Road
LYJO0034	30.230559	-98.750005	Pedernales R. 0.5 Mi. Below Palo
LYJO0035	30.225003	-98.756948	Pedernales R. At Blumenthal

Table LYJO. List of monitoring locations near Lyndon B. Johnson National Historic Site (cont.).

LYJO0036	30.241670	-98.772227	Palo Alto Cr. Above Conf. Of Ped
LYJO0037	30.238892	-98.783338	Pedernales R. 3.0 Mi Below Us Hw
LYJO0038	30.238059	-98.783615	Pedernales River At Goehmann Lane East Of Freder
LYJO0039	30.238059	-98.783892	Pedernales River Goehman Lane

Table PECO. List of monitoring locations near Pecos National History Park.

Gage Sites

Site ID	Latitude	Longitude	Station Name
USGS08315000	35.691670	-105.816700	Santa Fe R at Monument
USGS08315500	35.688333	-105.835000	Mc Clure Reservoir Near Santa Fe
USGS08317500	35.550560	-105.822200	Galisteo Creek
USGS08377900	35.777222	-105.657500	Rio Mora near Terrero, NM
USGS08378000	35.750000	-105.675000	Pecos River near Cowles, NM
USGS08378500	35.708333	-105.681944	Pecos River near Pecos, NM

Drinking Water Sites

Site ID	Latitude	Longitude	Station Name
35789601550000P1I2S1	35.688890	-105.836100	Mc Clure Reservoir

Water Impoundment Sites

Site ID	Latitude	Longitude	Station Name
NM00242	35.695000	-105.833333	Mc Clure Reservoir

Water Quality Sites

NPS Station ID	Latitude	Longitude	Station Location
PECO0001	35.523892	-105.660004	Pecos River Nr Rowe At Old Colonias Road
PECO0002	35.524087	-105.659893	Pecos River At Colonias Bridge
PECO0003	35.534337	-105.668616	Glorieta Creek
PECO0004	35.535309	-105.667809	Pecos River At The Forked Lightning Ranch House
PECO0005	35.563892	-105.667504	Pecos R 3/4 Mile Blw Pecos, Nm
PECO0006	35.565281	-105.667781	Pecos River Blw Village Of Pecos Wwtf
PECO0007	35.568337	-105.678338	Pecos River Below Pecos Nm
PECO0008	35.587226	-105.673892	Pecos R At Bridge Ab Pecos, Nm
PECO0009	35.592504	-105.683337	Pecos River At Forest Boundary
PECO0010	35.592504	-105.683337	Pecos River At Monastary Lake
PECO0011	35.594698	-105.681865	Pecos River Due West Of Monastery Lake
PECO0012	35.607781	-105.675837	Pecos R Blw Lisboa Springs Hatch
PECO0013	35.614726	-105.682227	Pecos At Hatchery Diversion
PECO0014	35.620837	-105.699726	Hatchery Raceway B6
PECO0015	35.620837	-105.699726	Hatchery Raceway C6
PECO0016	35.620837	-105.699726	Hatchery Raceway C7
PECO0017	35.620837	-105.699726	Hatchery Raceway D1
PECO0018	35.621393	-105.700559	Hatchery Raceway A-8
PECO0019	35.654448	-105.682227	Pecos At Dalton Fishing Site
PECO0020	35.658503	-105.688893	Dalton Canyon Creek 20 M West Of Hwy 63 Brdg
PECO0021	35.663060	-105.682227	Pecos R At Dalton Fishing Site
PECO0022	35.665976	-105.638615	Upper Cow Creek At 1st Bridge On Fr92 On Sfnf
PECO0023	35.666392	-105.657503	Pecos R. Immed Abv. Mouth Of Rio Mora
PECO0024	35.675754	-105.692531	Macho Canyon Creek 10m West Of Hwy 63 Brdg
PECO0025	35.691670	-105.816700	Santa Fe R At Usgs Gaging Sta
PECO0026	35.688337	-105.823337	Santa Fe R Ab Mcclure Reservoir,nm
PECO0027	35.688615	-105.822226	Santa Fe River Above Mcclure Res
PECO0028	35.690368	-105.819497	Santa Fe River Above Mcclure Res
PECO0029	35.696115	-105.688060	Pecos River Above Windy Bridge
PECO0030	35.696115	-105.688060	Pecos River 50 Meters Below Windy Bridge
PECO0031	35.707671	-105.683254	Indian Creek 3m West Of Hwy 63 Brdg
PECO0032	35.708142	-105.682031	Pecos River At Usgs Gage 90m Upstream Indian Crk
PECO0033	35.708338	-105.681948	Pecos R Nr Pecos, Nm
PECO0034	35.708338	-105.681948	Pecos River At Usgs Gage
PECO0035	35.708338	-105.681948	Pecos River At Usgs Gage#8378500
PECO0036	35.741115	-105.674727	Pecos R. 50ft Abv Holyghost Cr
PECO0037	35.741948	-105.679448	Holy Ghost Creek Below Homes
PECO0038	35.741948	-105.679448	Holy Ghost Creek Below Homes
PECO0039	35.742309	-105.680476	Holy Ghost Cr 300m Upstrm Hwy63 Br Over Pecos R
PECO0040	35.742505	-105.676670	Pecos R At Terrero, Nm

Table PECO. List of monitoring locations near Pecos National History Park (cont.).

PECO0041	35.746670	-105.655004	Willow Creek Abv Spoils
PECO0042	35.757504	-105.671392	Low Cr Blw White Drain
PECO0043	35.758059	-105.670837	Low Cr Blw Beaver Ponds
PECO0044	35.759170	-105.669726	White Flow From Mine Spoils
PECO0045	35.759616	-105.668392	Willow Crk 70m Upstrm Hwy 63 Brdg
PECO0046	35.759726	-105.668893	Willow Cr Just Abv Sr 63 At Mine
PECO0047	35.761199	-105.671143	Pecos River 400m Above Confluence W Willow Ck
PECO0048	35.763337	-105.640837	Willow Cr .75 Mi Abv Forest Service Gate
PECO0049	35.768616	-105.725004	North Fork Of Tesuque Cr Blw Hyde Park (475) Rd
PECO0050	35.777226	-105.657503	Rio Mora Near Terrero, Nm
PECO0051	35.777226	-105.657503	Rio Mora At Usgs Gaging Station
PECO0052	35.777226	-105.657503	Rio Mora Nr Terrero
PECO0053	35.777226	-105.657503	Rio Mora At Usgs Gage 08377900
PECO0054	35.777226	-105.657503	Rio Mora At Terrero

APPENDIX C

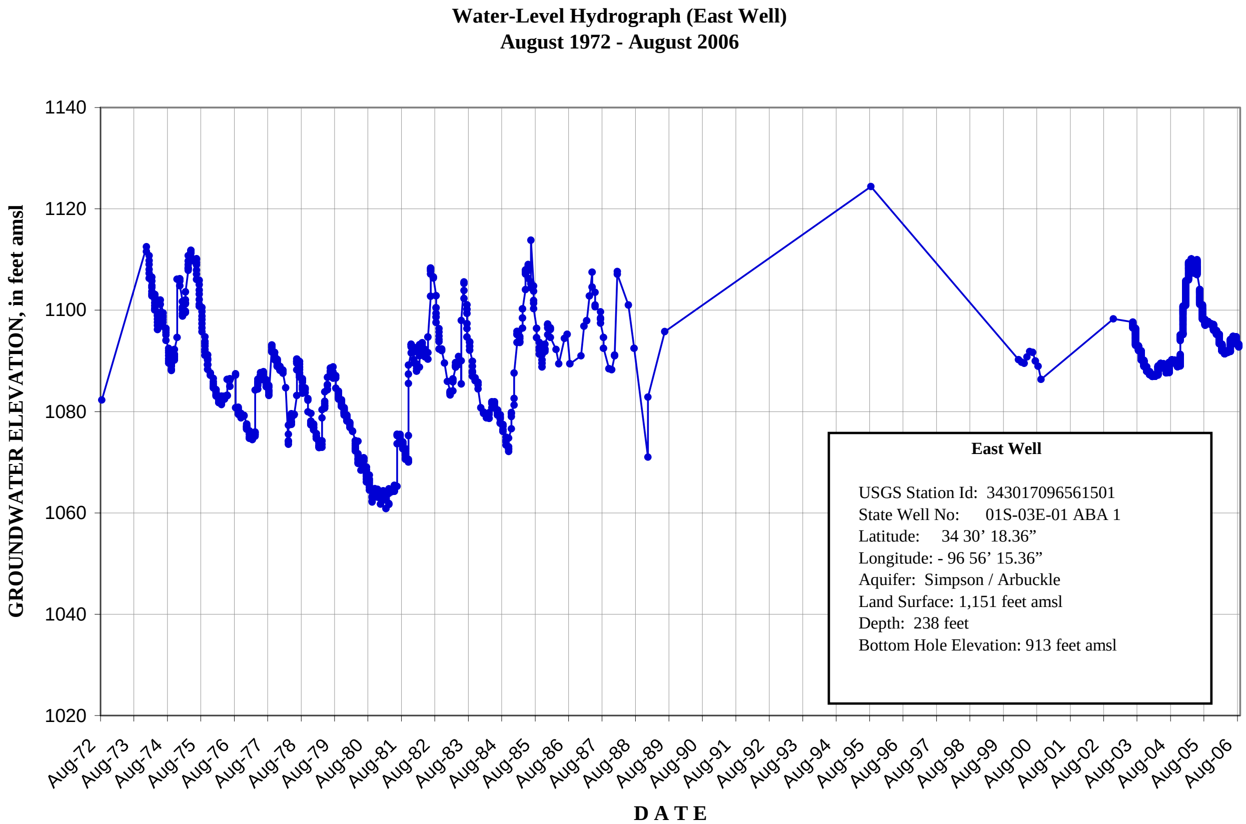


Figure 2. Water-level hydrograph, showing elevation of groundwater surface below East observation Well at Chickasaw National Recreational Area, August 1972 – August 2006.

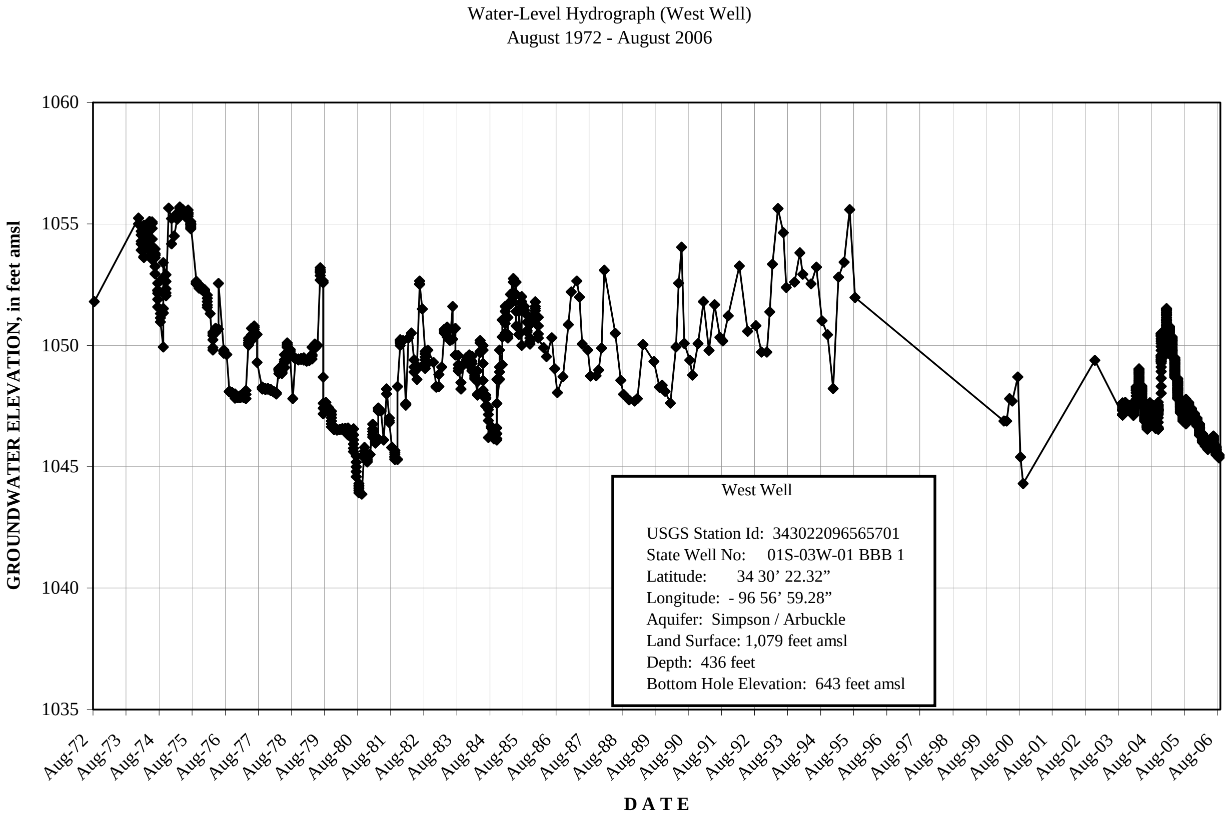


Figure 3. Water-level hydrograph, showing elevation of groundwater level below West observation Well at Chickasaw National Recreational Area, August 1972 – August 2006.

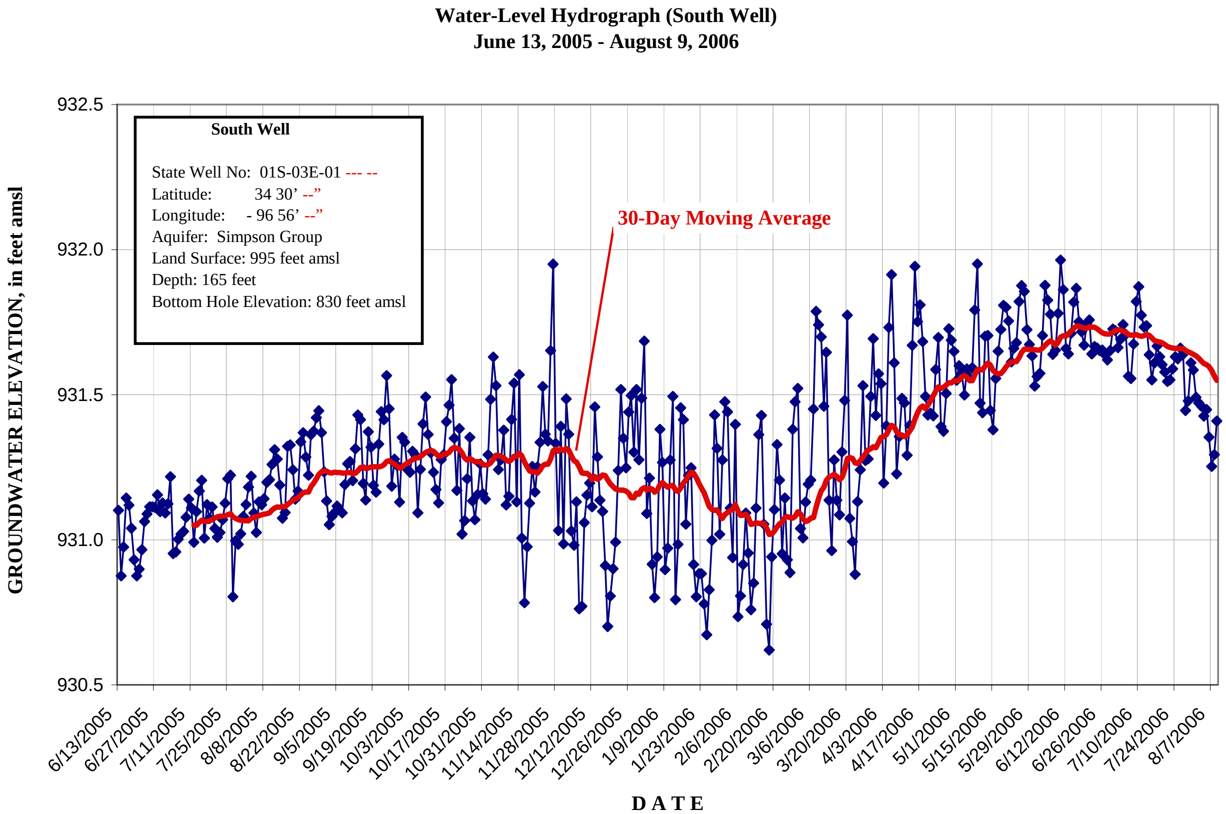
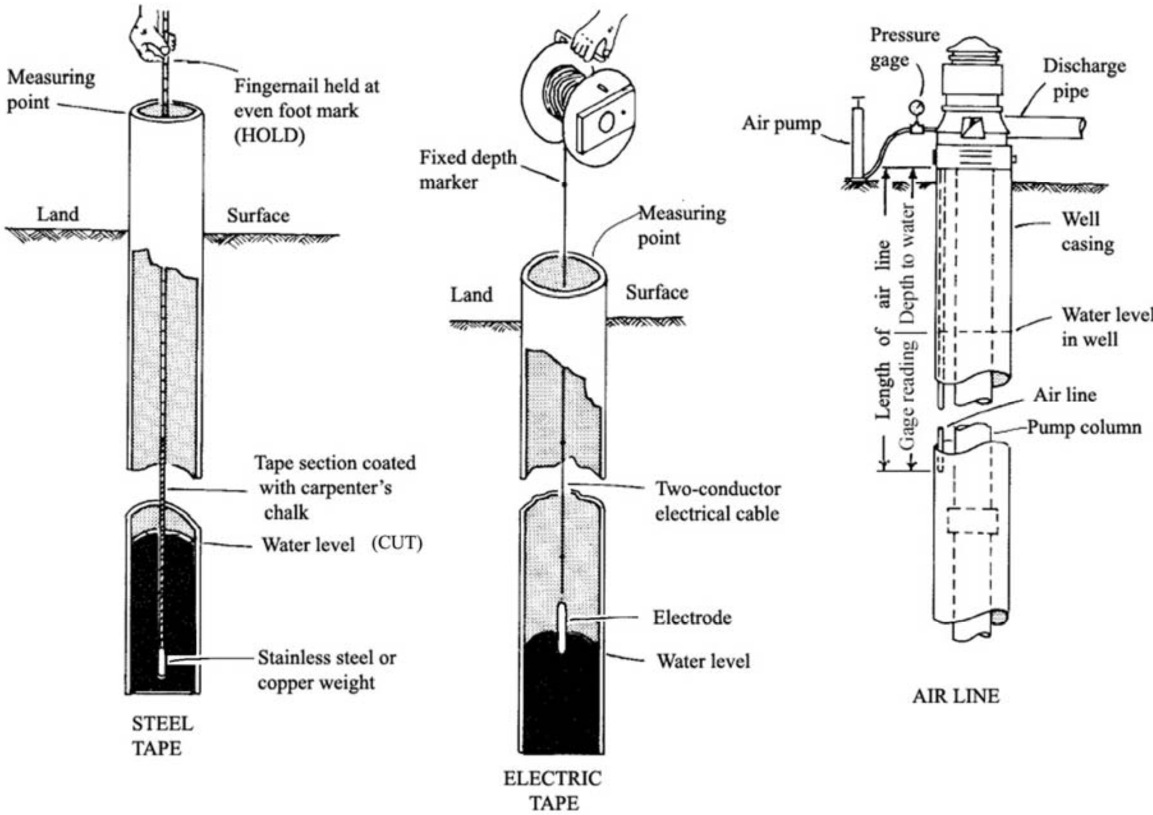


Figure 4. Water-level hydrograph, showing elevation of groundwater level below South observation Well at Chickasaw National Recreational Area, June 13, 2005 – August 9, 2006.

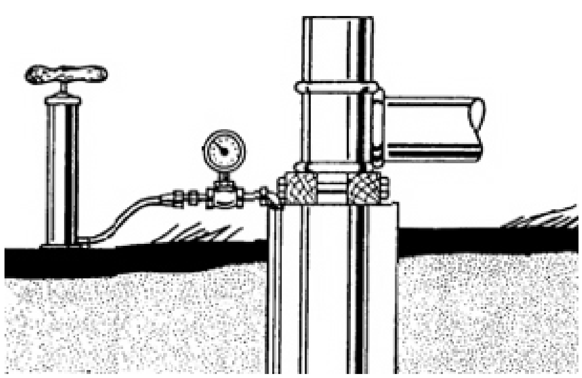


(A) (B) (C)

Figure 5. Most popular methods of obtaining depth to groundwater below land surface (Modified from Heath, 1983).

(A) Steel Tapes, Regular and Pocket-Sized

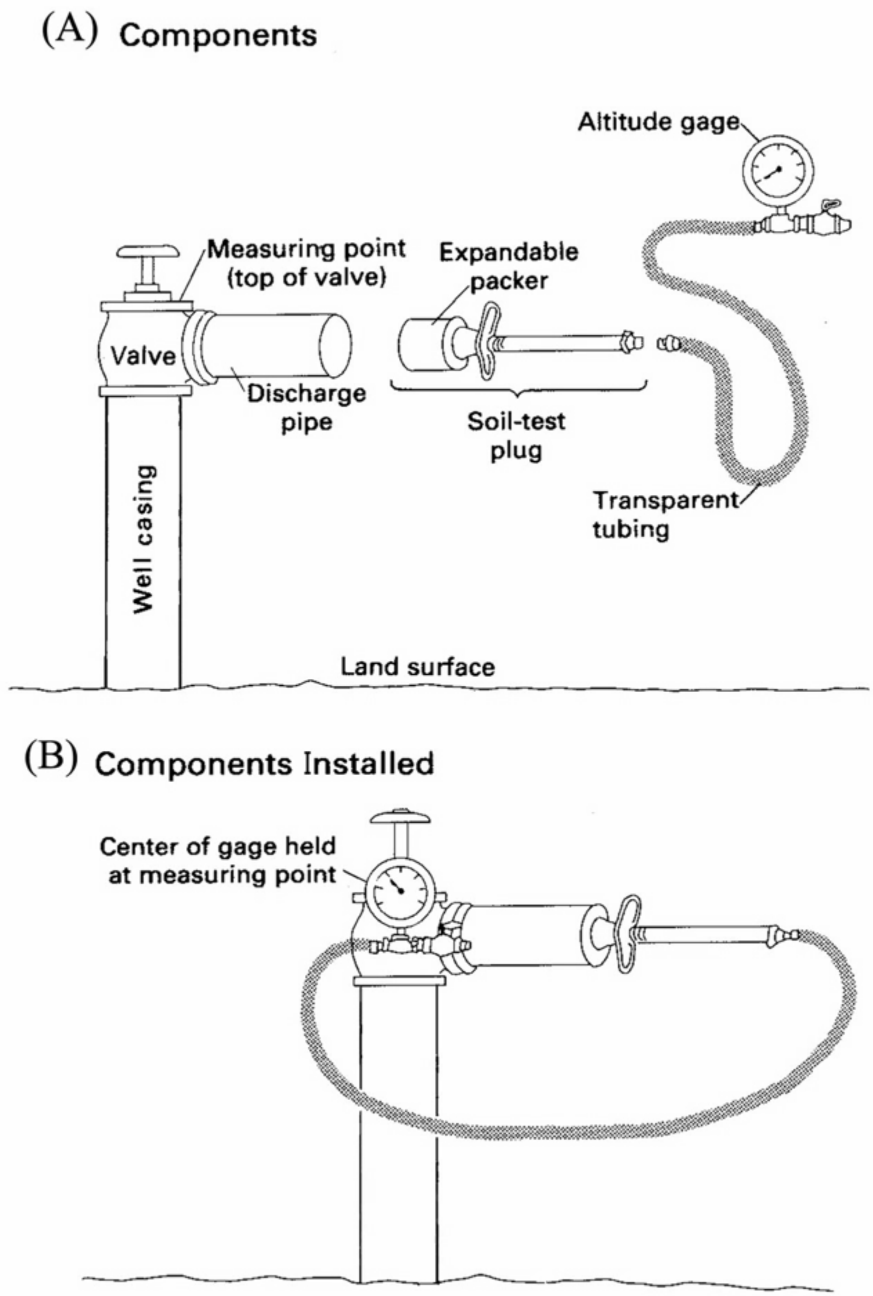
(B) Electric (E-Line) Tape



(C) Airline Water-Level Measuring System

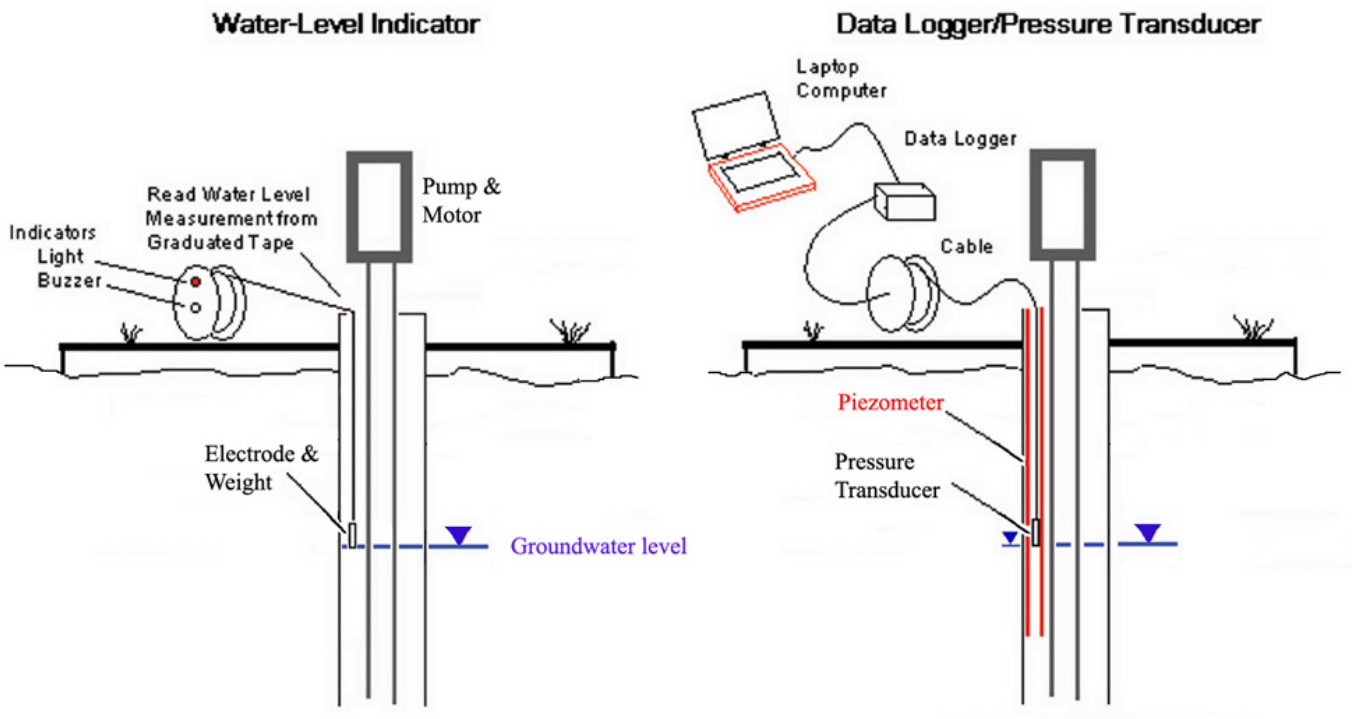
(D) Pressure Transducer / Data Logger

Figure 6. Classic, manually operated water-level measuring devices (A – C) and combination data logger and submersible pressure transducer (D) designed for remote monitoring and recording of groundwater levels.



(modified from Heath, 1987)

Figure 7. Components (A) of recommended assembly (B) for possibly measuring hydraulic head of groundwater in flowing wells (for example, at the Vendome Well in the Chickasaw National Recreational Area.



(A) (B)

Figure 8. Manually operated water-level indicator (electric tape) and digital-based data logger and pressure transducer of past (A) and present (B) technologies, respectively (Modified from Idaho Water Resources Institute).

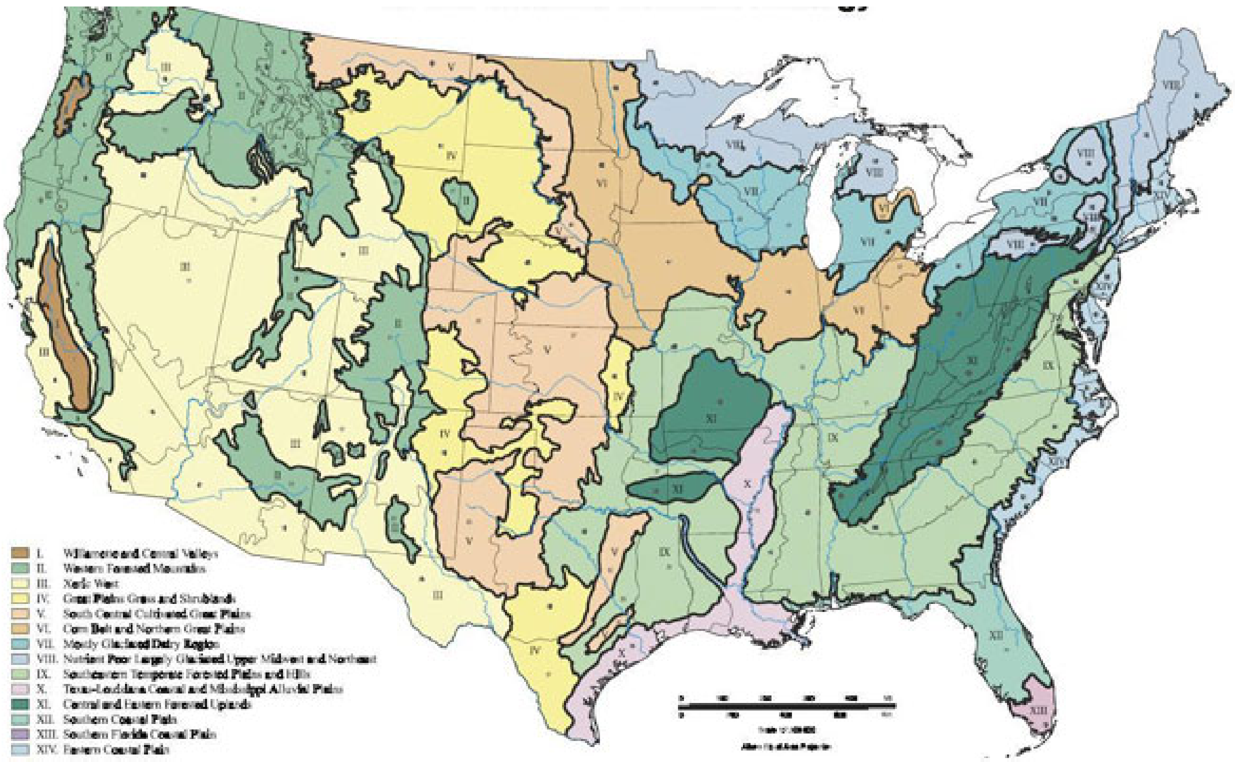


Figure 9. Draft aggregations of level III ecoregions for the National Nutrient Strategy

(A) Simple (Generic) Format

Groundwater-Level Data Form

PAGE __ OF __

SITE NAME:______________________ LOGGER NAME: ________________

LOG DATE: ______________________ MP to LSD adjustment + / - ________________

WELL NUMBER OR ID	TIME	HOLD	CUT	WATER LEVEL ABOVE / BELOW MP	MP to LSD ADJUST	WATER LEVEL ABOVE / BELOW LAND SURFACE

COMMENTS (pH, Temperature, Specific Conductance): ______________________________

Weather Conditions: ____

Other Significant Observations: ______________________________________

(B) Comprehensive (GWSI) Format

U.S. DEPT. OF INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

WELL NO. ______________
MP HEIGHT ______________

WATER-LEVEL DATA

Site Ident. No. | | | | | | | | | | | | | | | (5 – 19) R = 234 | * T = | A | *

DATE			WATER LEVEL (BELOW LSD)			STATUS			METHOD			HOLD	CUT	DEPTH BELOW MP	REMARKS	DATES PUNCHED/ ENTERED
235 #		*	237=		*	238=		*	239=		*					
235 #		*	237=		*	238=		*	239=		*					
235 #		*	237=		*	238=		*	239=		*					
235 #		*	237=		*	238=		*	239=		*					
235 #		*	237=		*	238=		*	239=		*					
235 #		*	237=		*	238=		*	239=		*					
235 #		*	237=		*	238=		*	239=		*					
235 #		*	237=		*	238=		*	239=		*					
235 #		*	237=		*	238=		*	239=		*					
235 #		*	237=		*	238=		*	239=		*					
235 #		*	237=		*	238=		*	239=		*					
235 #		*	237=		*	238=		*	239=		*					
235 #		*	237=		*	238=		*	239=		*					
235 #		*	237=		*	238=		*	239=		*					
235 #		*	237=		*	238=		*	239=		*					

Method of Measurement: 239 = A airline, C calibrated, airline, E estimated, G pressure, gage, H calibrated, pressure gage, L geophysical, logs, M manometer, R reported, S steel, tape, T electric, tape, Z other

Site Status: 238 = D dry, F flowing, G nearby, flowing, H nearby, recently flowing, Ø obstruction, P pumping, R recently, pumped, S nearby, pumping, T nearby, recently, Z other

MEASURING POINT

R = 320 | * T = | A D M | * (add, delete, modify)

M.P. Begin Date 321 # | *
M.P. End Date 322 = | *
M.P. Height 323 = | *
M.P. Remark 324 = | *

Figure 10. Simplified (A) and GWSI-compatible (B) forms on which to record observations of groundwater levels for storage, maintenance, and retrieval within USGS's National Water Information System (NWIS).

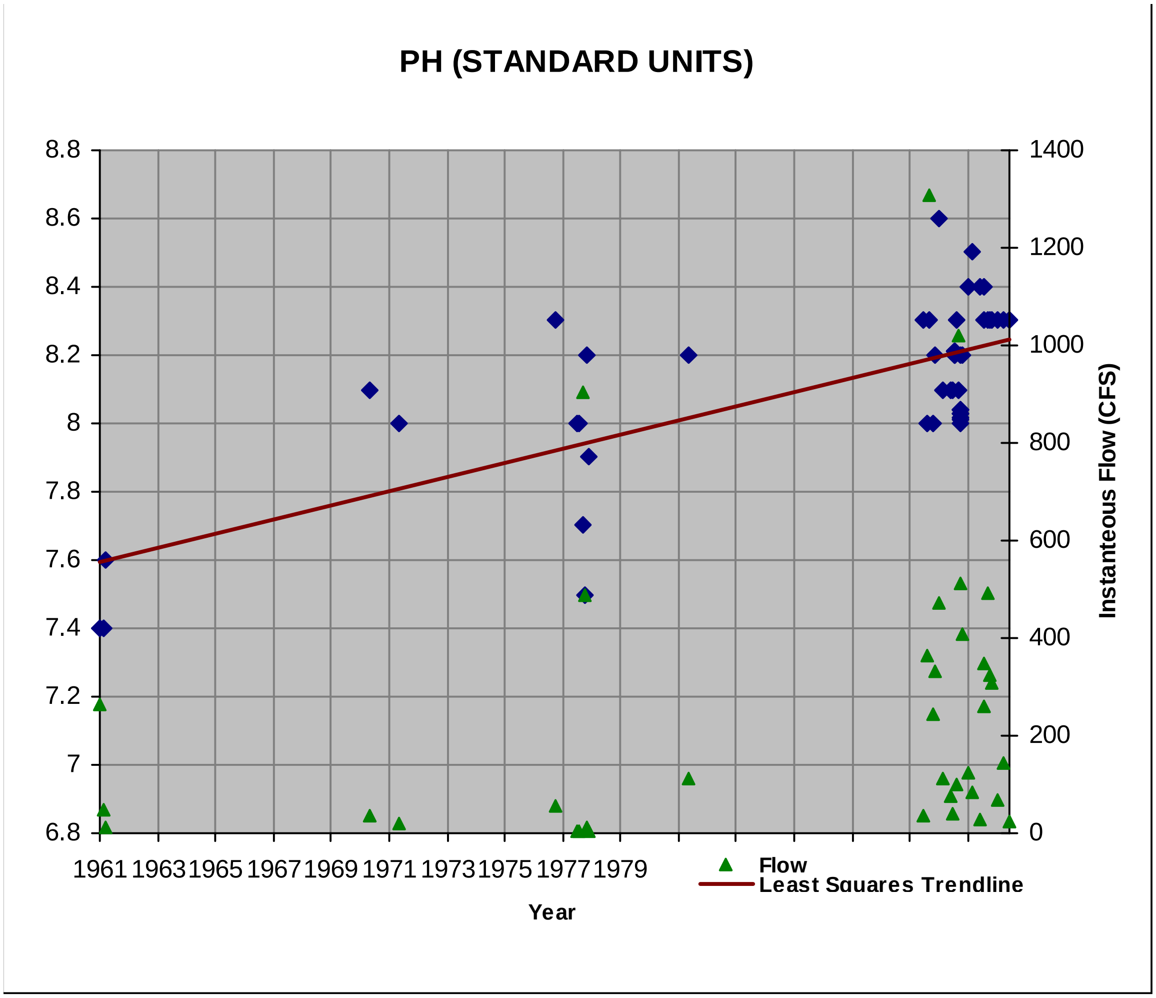


Figure 11. Increases of pH values in the Arkansas River at La Junta, Colorado between 1961 and 1995.

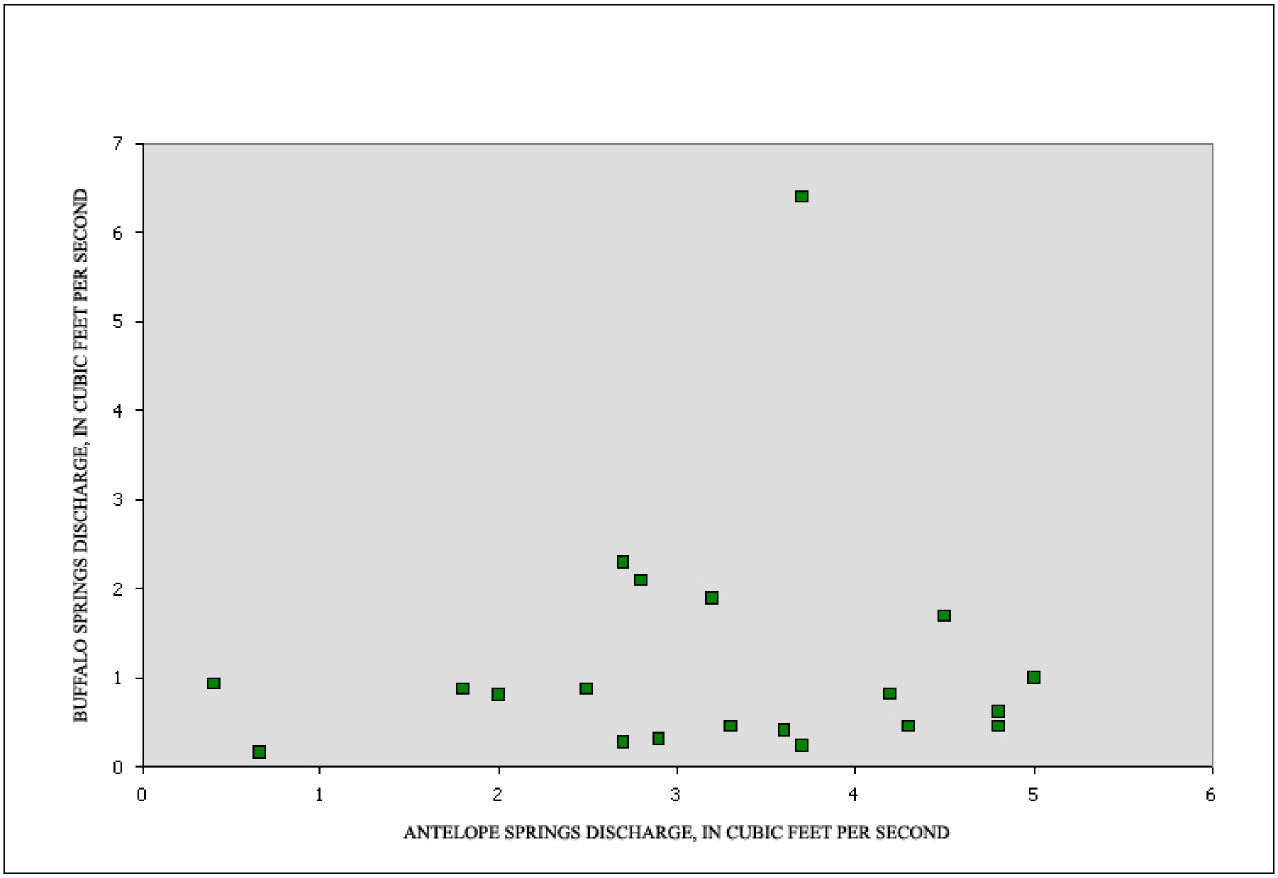


Figure 12. Scatterplot, showing lack of relation between common-date discharges from Antelope and Buffalo Springs in Chickasaw National Recreational Area during 1986 - 2002.

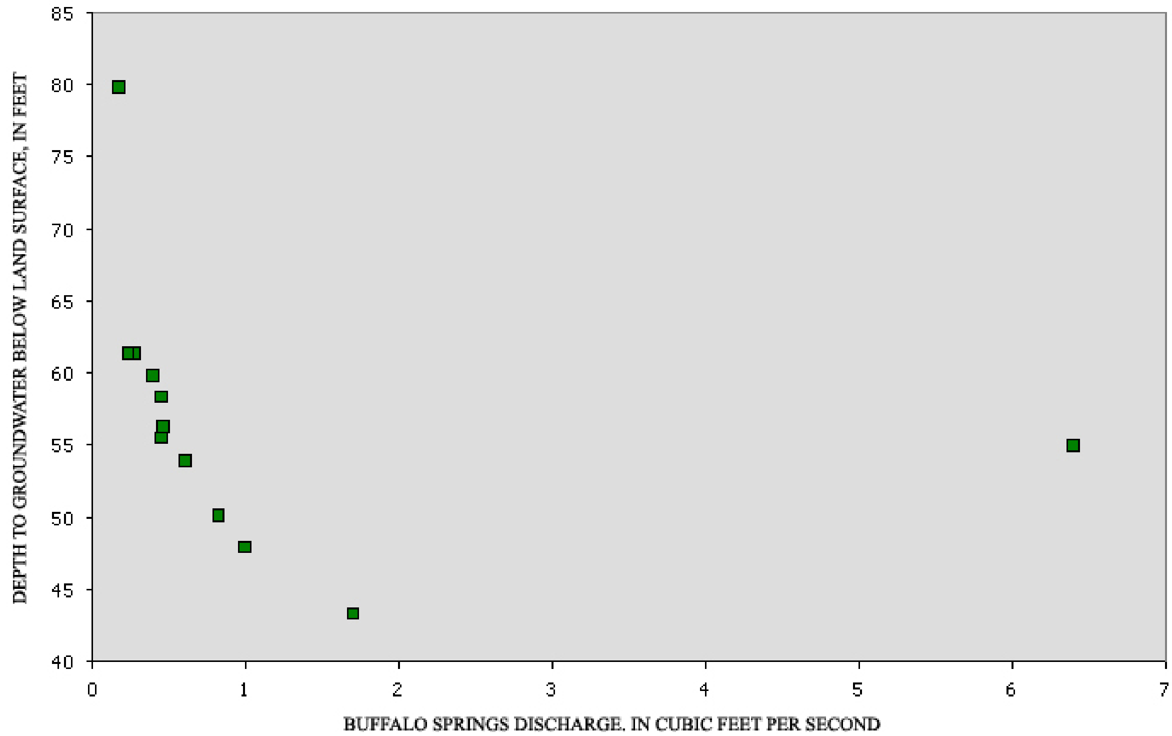


Figure 13. Scatterplot, showing relation between common-date discharge from Buffalo Springs and water level in East observation Well (01S-03E-01 ABA 1) at Chickasaw National Recreational Area during 1986-90.

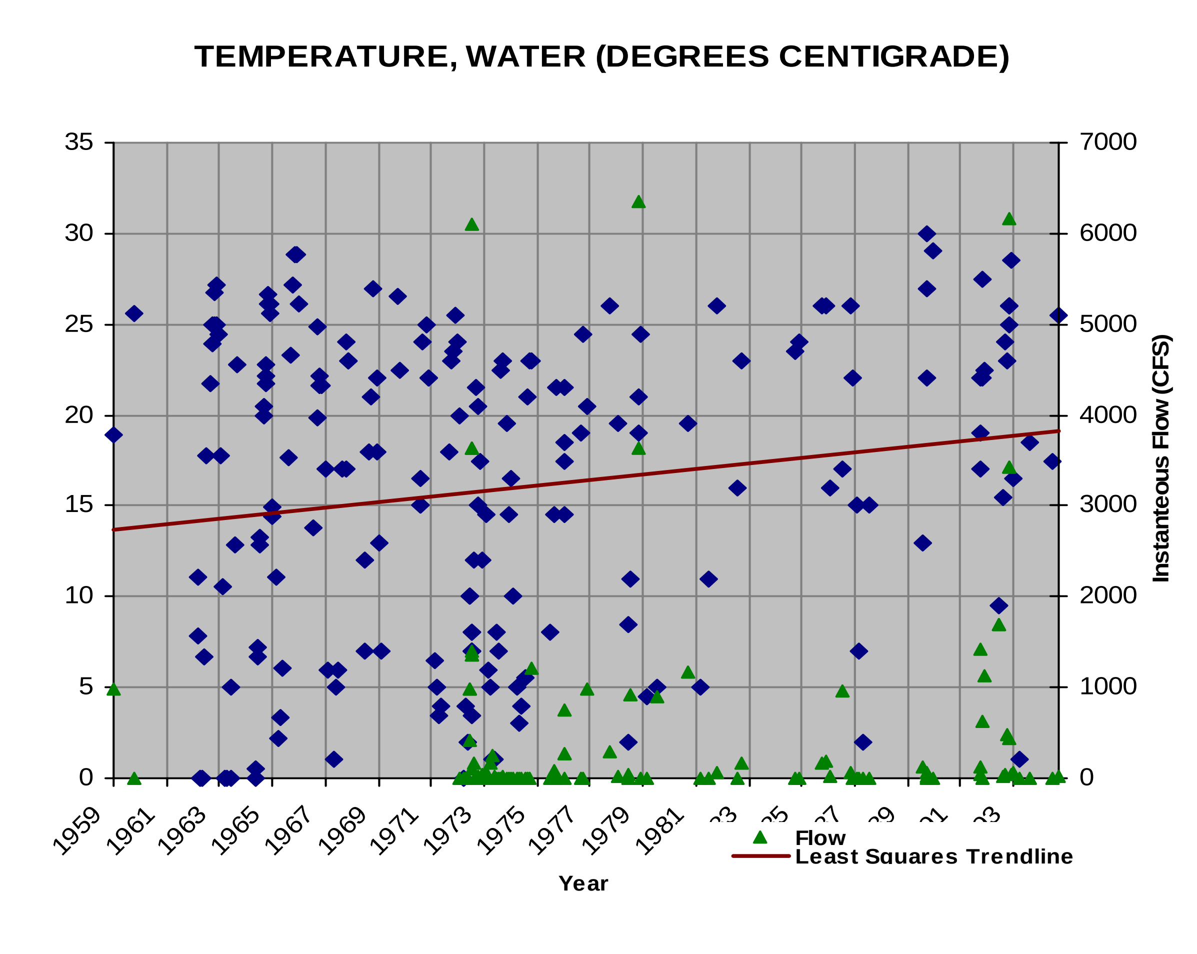


Figure 14. Increases of water temperature in the Pawnee River at Rozel, Kansas between 1959 and 1995.

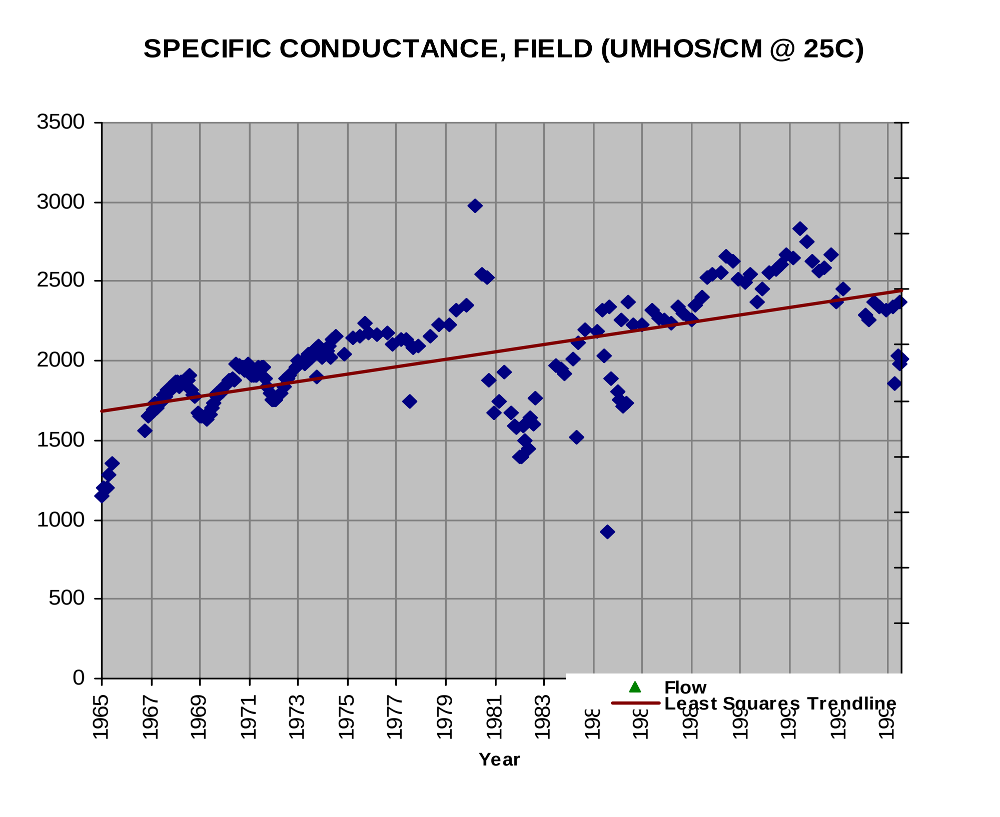


Figure 15. Increases of specific conductance in Lake Meredith near the intake structure from 1965 to 1997.

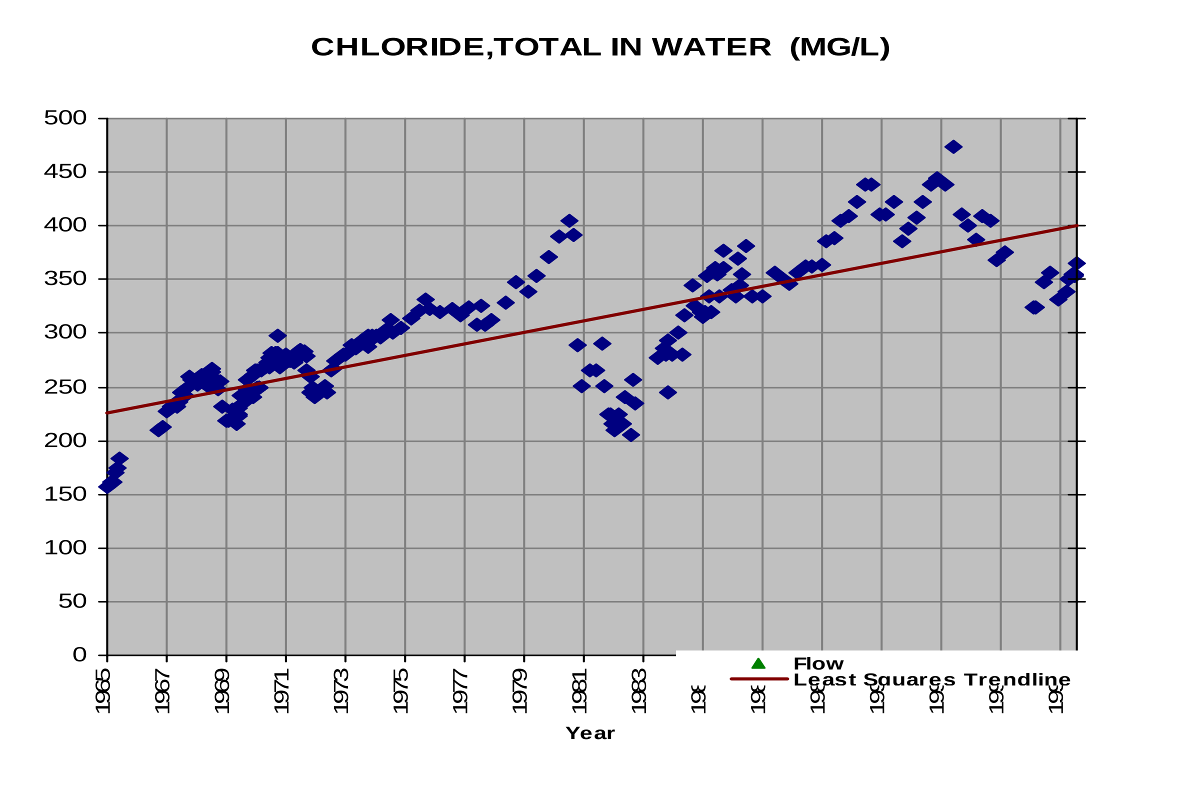


Figure 16. Increases of choride concentrations in Lake Meredith near the intake structure from 1965 to 1997.

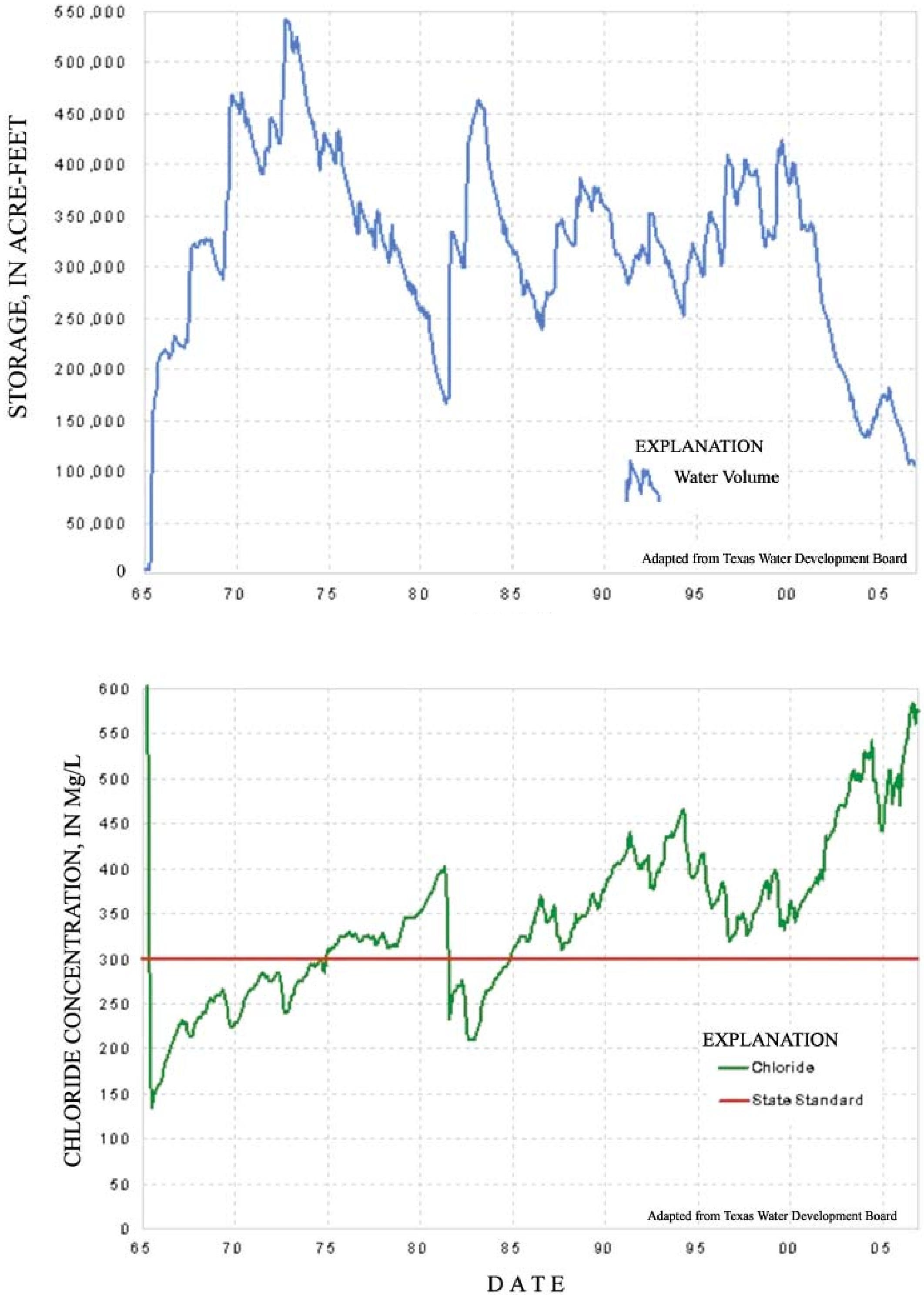


Figure 17. Comparison of total lake volume (storage) with chloride concentrations in Lake Meredith during 1965 – 2006.

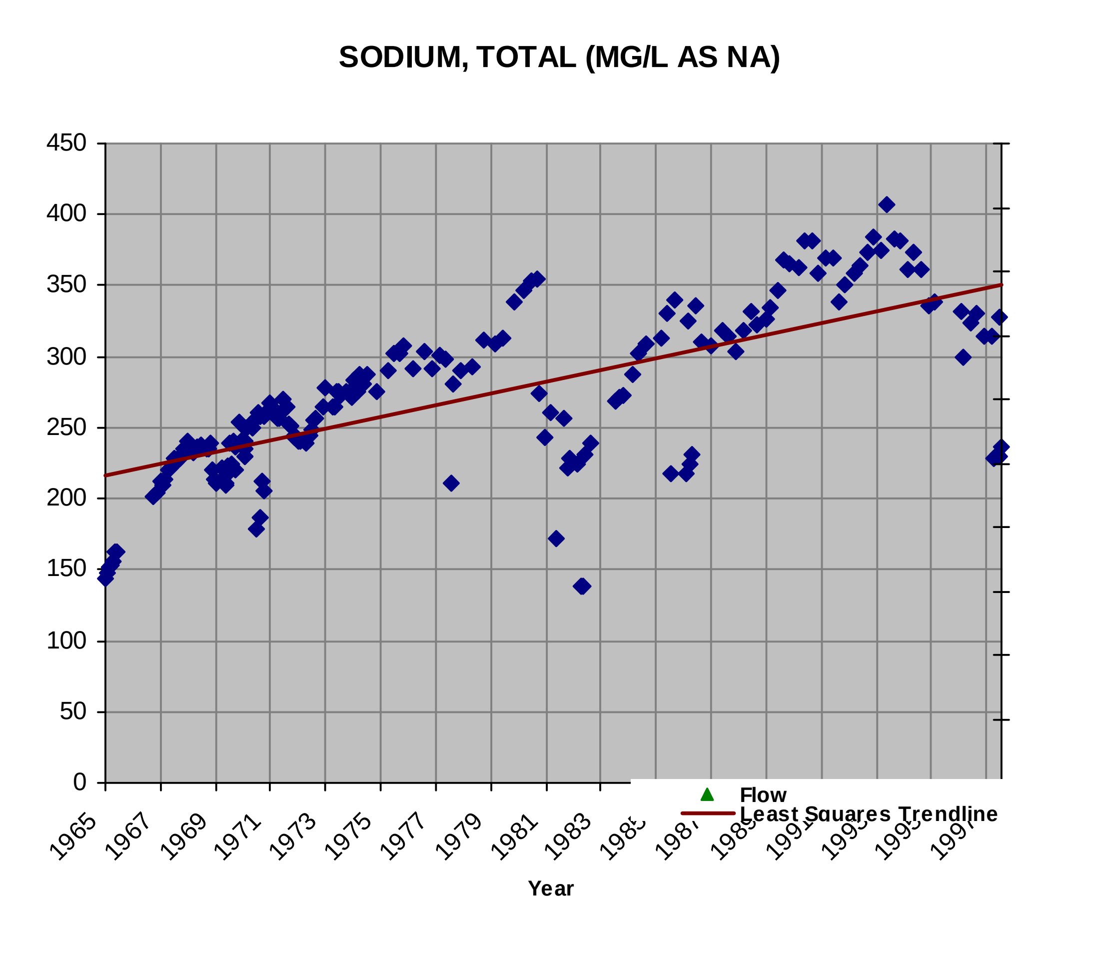


Figure 18. Increases of sodium concentrations in Lake Meredith near the intake structure from 1965 to 1997.

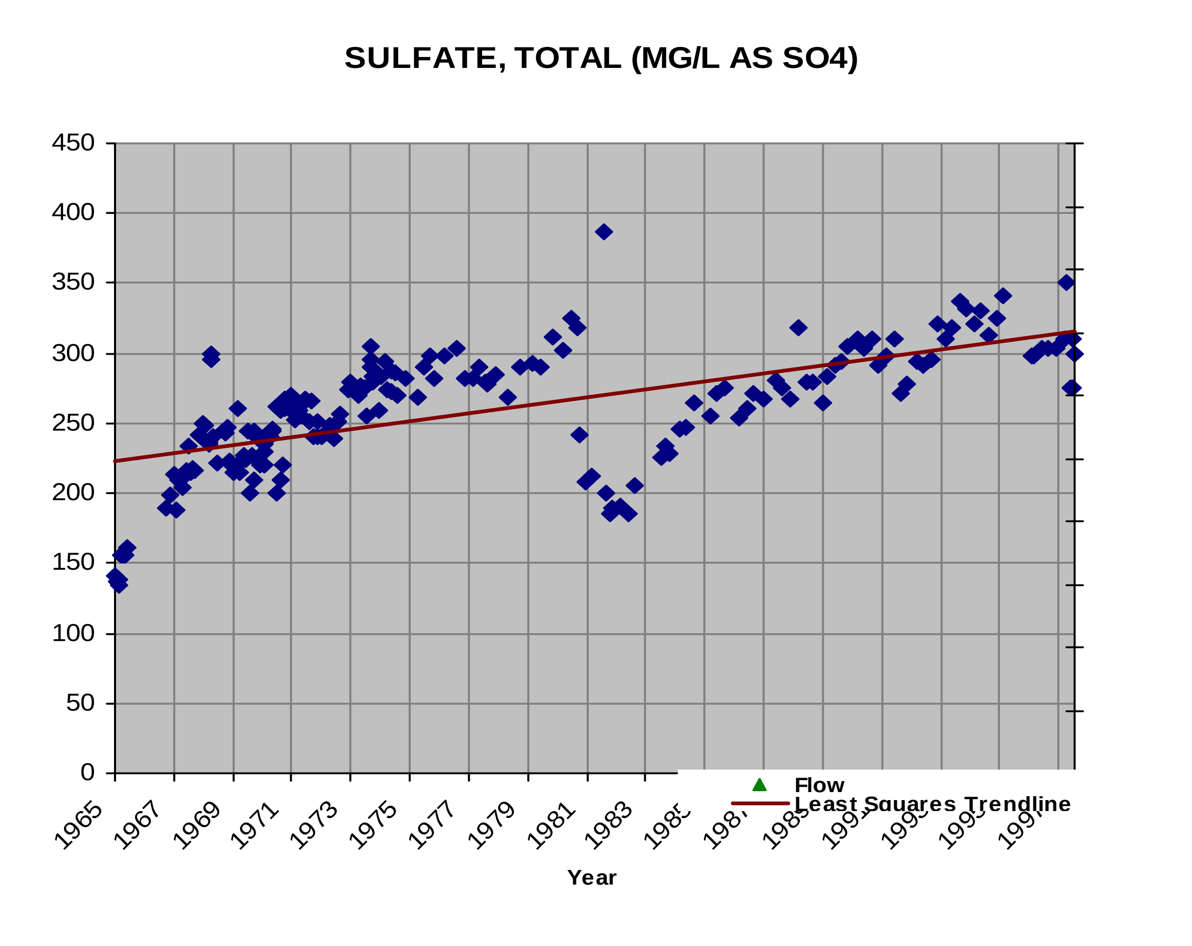


Figure 19. Increases of sulfate concentrations in Lake Meredith near the intake structure from 1965 to 1997.

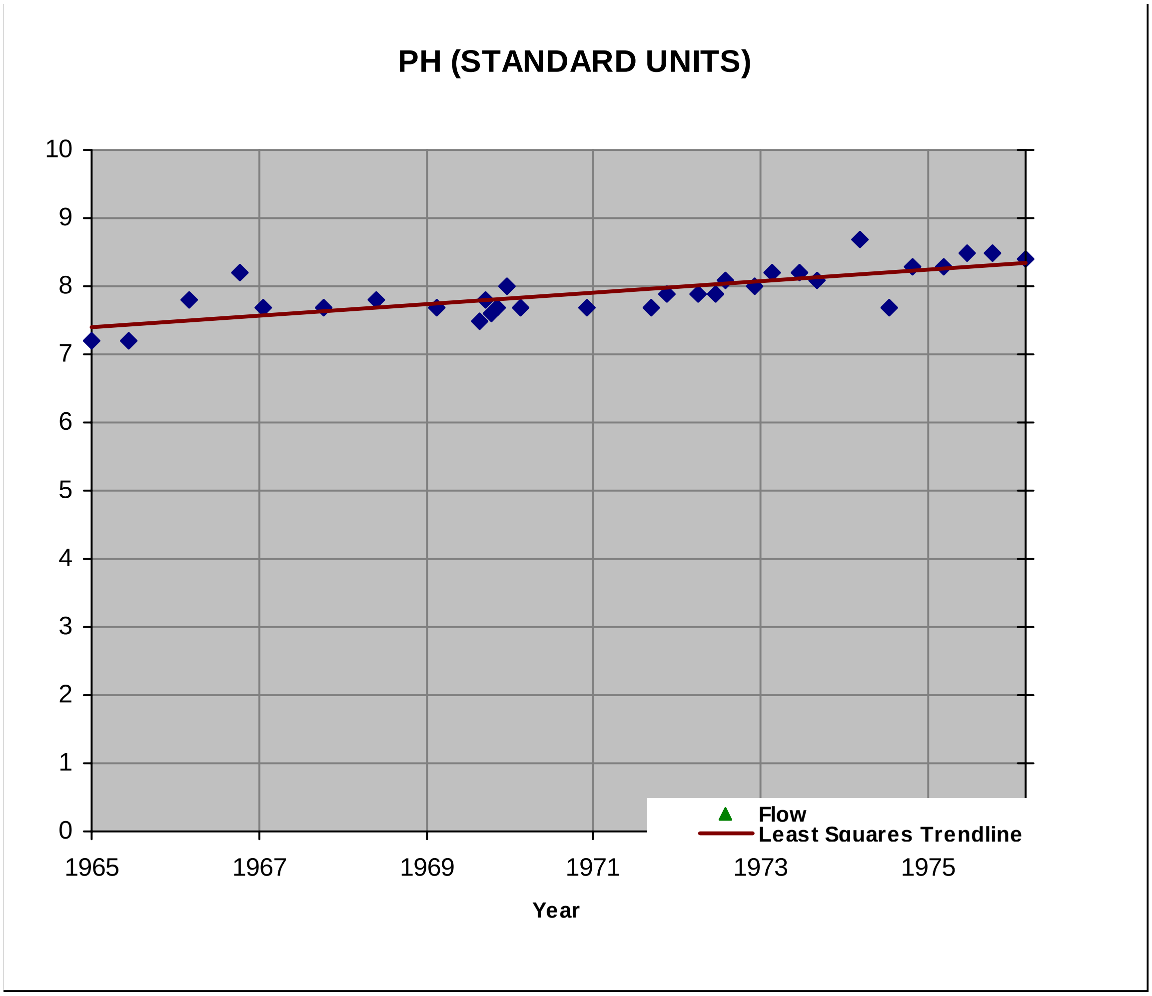


Figure 20. Increases of pH values in Lake Meredith near Sanford, Texas from 1965 to 1976.

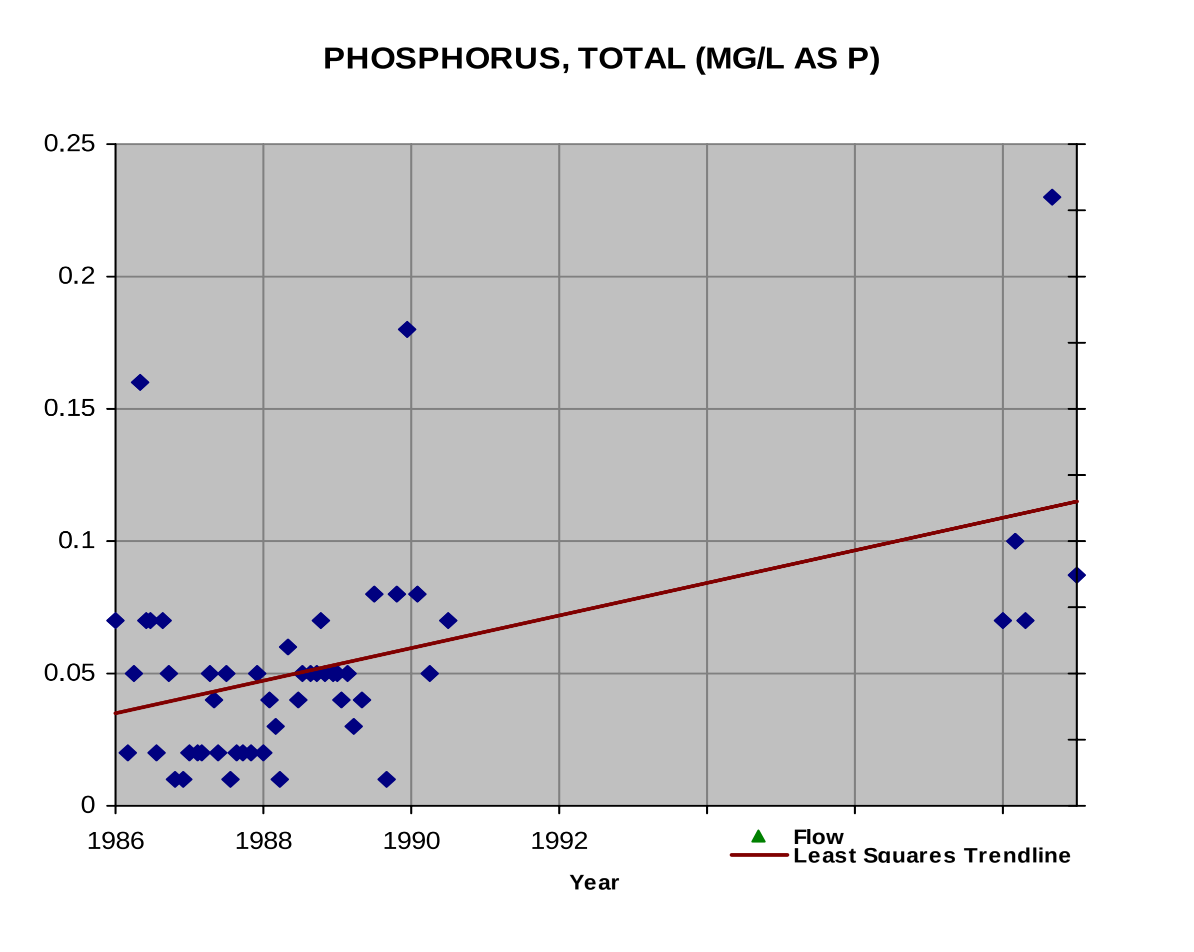


Figure 21. Increases of total phosphorus concentrations in the Pedernales River between 1986 and 1999.

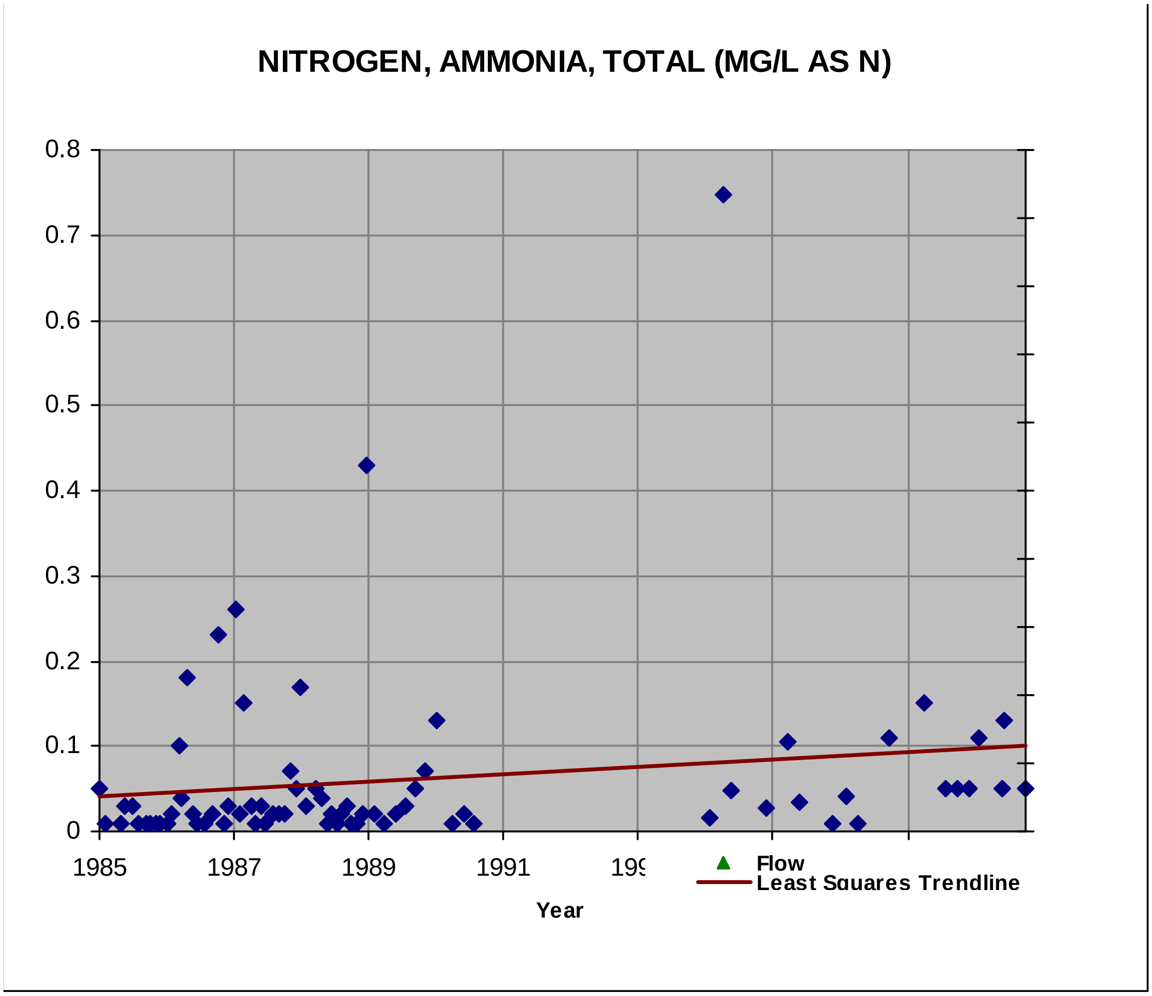


Figure 22. Increases of ammonia-nitrogen concentrations in the Pedernales River between 1985 and 1999.

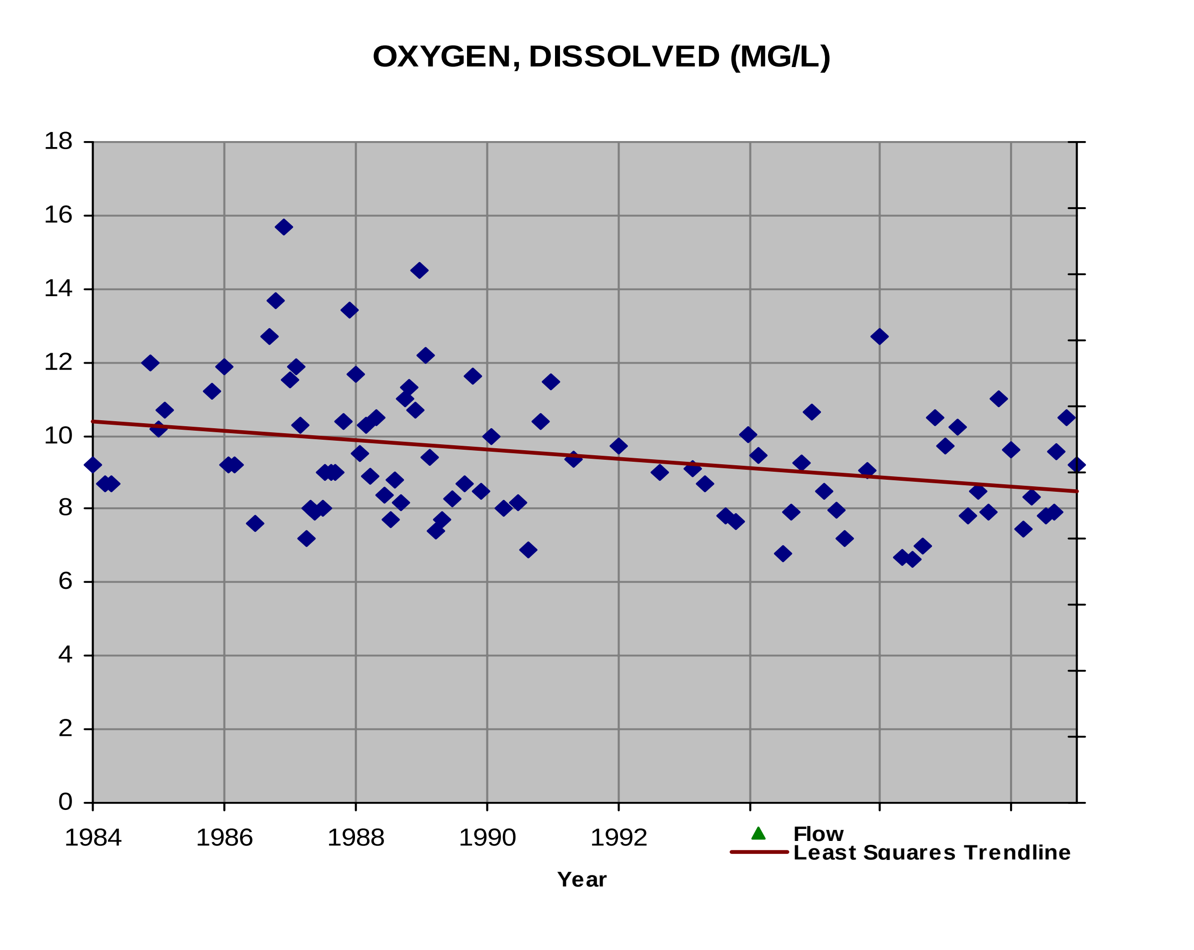


Figure 23. Decreases of dissolved-oxygen concentrations in the Pedernales River between 1984 and 1999.

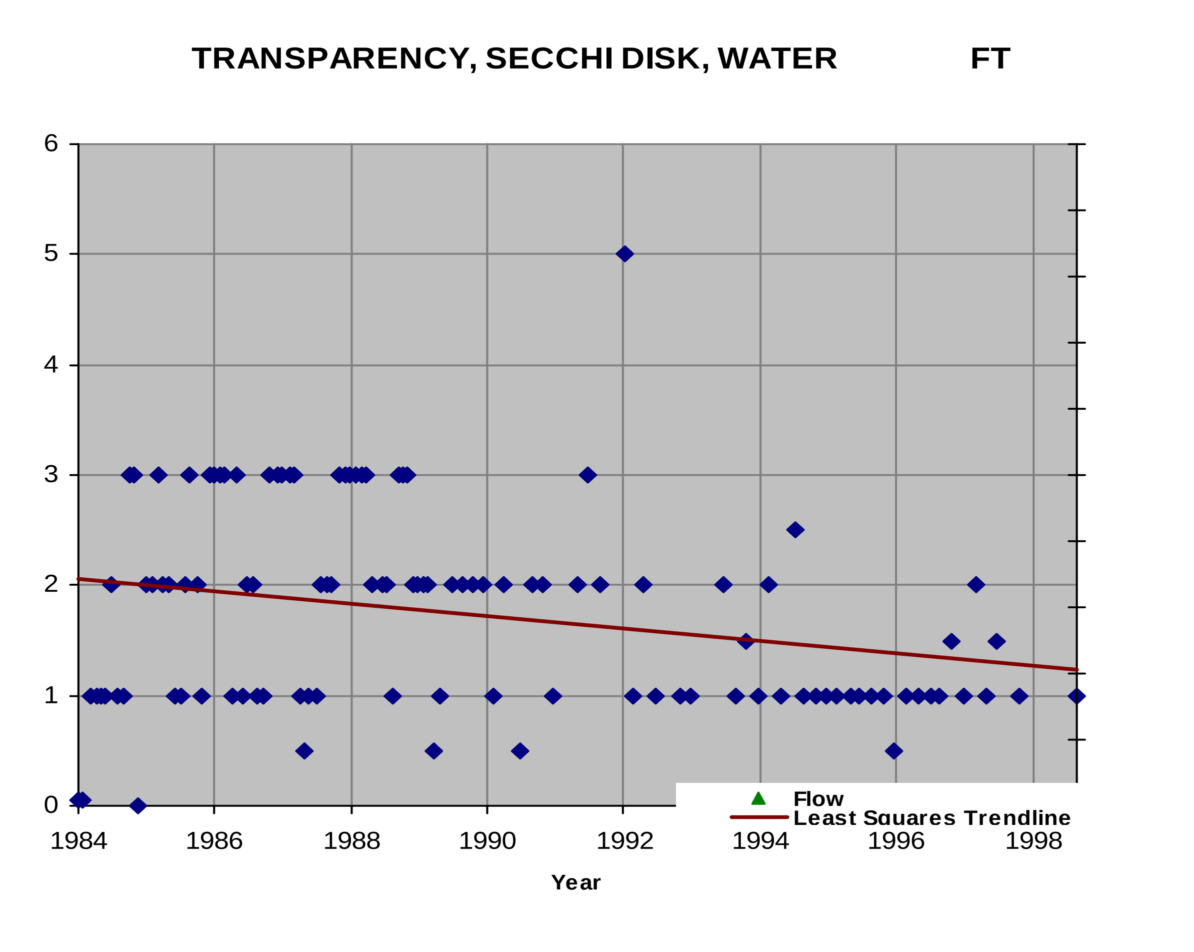


Figure 24. Decreases of water transparancy (Secchi depth) in the Pedernales River between 1984 and 1999.

APPENDIX D

Table 2. Types of surface-water gaging stations.

Streamflow gaging station types	**Type of data produced for station**
<u>Gage height stations</u>	
Periodic stage	Periodic manually measured gage heights
Crest-stage	Peak gage heights indicated on stick and manually read later
Low flow stage	Recorded gage heights below a designed threshold gage height [1]
Flood hydrograph stage	Recorded gage heights exceeding a designed threshold gage height [1]
Continuous-record stage	Recorded gage heights on a continuous basis [1]
<u>Discharge stations</u> [2]	
Periodic discharge	Periodic manually measured streamflow discharge
Crest-stage discharge	Peak gage heights and discharges indicated on stick and manually read later
Low flow discharge	Recorded gage heights and discharges below a designed threshold gage height or discharge [1]
Flood hydrograph discharge	Recorded gage heights and discharges exceeding a designed threshold gage height or discharge [1]
Continuous record discharge	Recorded gage-heights and discharges on a continuous basis [1]

Reservoir gaging station types	**Type of data produced for station**
<u>Gage height stations</u>	
Periodic stage	Periodic manually measured gage heights
Crest-stage	Peak gage heights indicated on stick and manually read later
Flood hydrograph stage	Recorded gage heights exceeding a designed threshold gage height [3]
Continuous record stage	Recorded gage heights on a continuous basis [3]
<u>Storage content stations</u> [4]	
Periodic contents	Periodic manually measured gage heights and contents
Crest-stage contents	Peak gage heights and contents indicated on stick and manually read later
Flood hydrograph contents	Recorded gage heights and contents exceeding a designed threshold gage height [3]
Continuous record contents	Recorded gage heights and contents on a continuous basis [3]

Footnotes:

[1] *Recorders can represent an analog or digital system*
Analog recorders usually record data on a graphic chart
Digital recorders record data at designed time intervals (i.e., 5, 15, 30 or 60 minutes)
For streamflow stations with recorders, the recorded data can be used to calculate mean and median values for gage height and/or discharge for daily, weekly, monthly, annual, and other durations.

[2] *A rating table relating gage heights to discharges must be developed for these stations and used to convert values of gage height to discharge.*

Table 3. Alternative methods by which to measure stream stage.

The major methods to measure and gage stream stage (gage height) are presented on the Internet at http://pubs.er.usgs.gov/usgspubs/twri/twri03A6. Methods to measure stage are presented in the section "Nonrecording gages" while methods to gage streams are presented in the other sections of the report. However, each of the methods described in the report require specialized and expensive equipment and specific technical knowledge regarding the installation and maintenance of the equipment. However, at least one other less intrusive and less expensive method can be used to measure stage. The method presented below requires only minimal equipment, all of which is readily available. The method is described below:
1. Locate a naturally occurring object or install an object to represent a gage height datum point on the stream bank located in the cross section where stream stages are needed. The object should be able to maintain an unchanged elevation throughout the period when gaging will occur. It should not be subject to being destroyed or moved by flooding or other methods. Examples of appropriate datum points represent an identifiable point on a large rock outcrop, a spike in a tree, or steel stake driven in the ground so that it would not be destroyed or moved by flooding. 2. Assign an arbitrary gage height to the datum point. The gage height should represent a value greater than the vertical distance from the datum point to the bottom of the stream channel at the gaging cross section so that negative gage heights would not be encountered. 3. Install a string level on a chalk line so that it can slide along the line, and attach a clamp to the end of a chalk line. Also, obtain a folding rule or retractable measuring tape that is graduated in hundredths and tenths of a foot rather than feet and inches. Such equipment is readily available at businesses that sell surveying equipment. 4. In order to measure the stream stage at a given time, attach the chalk line clamp to the datum point and unroll the string from the supply roll as you approach the edge of the stream—slide the string level on the line so that it is located adjacent to the string supply roll. 5. Stand over the edge of the water, pull the string until it is tight, and lower or raise the string until the string level indicates the string line to be exactly horizontal. 6. Use the folding rule or measuring tape to measure the vertical distance from the horizontal string line to the water surface. 7. Subtract that distance from the arbitrary gage height of the datum point in order to obtain the gage height for the stream surface at the time of measurement. 8. The location of the datum point should be accessible to the observer during all flow conditions. Typically the datum point is located on the bank that is easiest to access during flooding conditions.

Table 3. Alternative methods by which to measure stream stage, cont.

Many variations and improvements exist for this procedure. A few such methods are listed below:

1. Install multiple datum points on the same cross section so that the datum of the gage would not be lost if one of the datum points is moved or destroyed. However, the gage height for each datum point must be consistent within the same datum. For example, if datum point number 1 is exactly 1.00 feet lower in elevation than datum point number2, the gage height of datum point 1 must be exactly 1.00 feet lower than the gage height of datum point 2. The first established datum point can be assigned an arbitrary gage height, but subsequent datum points on the same cross section must be coordinated with the gage height of the first datum point. The use of a field survey instrument such as an engineering level provide a reliable and fast method to determine and document gage heights for datum points established after the first datum point.

2. Some datum points, especially in rock channels, can be located on the streambed by use of chisel or other marking device.

3. If the water surface is above a datum point and the datum point is visible beneath the water, the folding rule can be used to measure the vertical depth from the water surface to the submerged datum point. This depth is added to the gage height of this datum point in order to obtain the water surface gage height.

4. Datum points should be strategically located along the same cross section so that none of the datum points are too remote from the edge of the water surface during various flow conditions. For example, increased chalk line string lengths from the datum point to the edge of the water cause increased errors in establishing a true horizontal sting line, which caused increased errors in measuring the water surface gage height.

5. If multiple datum points are accessible for stage measurements, the stream gage height should be determined from each datum point as verification.

6. Levels should periodically be run to each of the datum points in order to assure their elevation has not changed. It is advisable to maintain at least 3 independent datum points in order to document which datum point has moved vertically. If one has moved or been destroyed, it should be immediately replaced by another datum point. Also, each of the datum points should be located in independent locations (i.e., not on the same tree or bridge) in order to minimize the chance of loosing more than one datum point if a structure is compromised.

7. In order to simplify the gaging process and minimize changes for erroneous stage measurements, a station description should be prepared for each gaging site. The station description should contain at least the following information:

   - Name of the stream and description of exact location of gaging station.
   - Name (i.e., DP1, DP2), exact location, and gage height for each datum point

8. An official field data sheet should be prepared and completed during each visit to a gage. Data entered on the sheet should include the datum point number used for the measurement, the vertical distance from the string to the water surface, and the calculated gage height of the water surface, based on the gage height of the datum and the measured vertical distance.

Table 4. Supplemental information regarding installation and operation of crest-stage gages.

Crest-stage gages record peak stages only but these data also can be used along with discharge data to record peak discharges. Information about crest-stage gages is presented on pages 27-28 of A USGS report on stage measurement in streams. The report is available as an Adobe PDF file online at http://pubs.er.usgs.gov/usgspubs/twri/twri03A7. Supplemental information about the installation and operation of crest-stage gages is presented below.

1. A nail can be put in the top of the stick so that the nail contacts the top cap when it is attached. The nail will keep the stick from floating.

2. A wire-mesh (i.e., screen door mesh) formed into a basket can be nailed or stapled to the bottom of the stick. This basket will retain the powdered cork.

3. Granulated cork is put in the basket to provide material to attach to the stick during the peak.

4. Redwood, cedar, or some type of wood resistant to wet rot is recommended.

5. The crest-stage gage (csg) does not have to be vertical. Sometimes csg's are installed at non-vertical angles along a stream bank in order to minimize the chance of it being destroyed by floods--if it is not vertical, the angle to vertical must be known and used to correct the gage height of the peak stage.

6. The pipe can be attached to trees, boulders, wingwalls, piles, etc. It should be remote from any channel constriction and located in a place protected from high velocity, which can cause drawdown or stack up of the water level in the pipe. High velocity also can damage the pipe. On a protected bank in a wide cross section downstream many feet downstream from a grove of trees is a good location.

7. PVC pipe can be used instead of metal.

8. The top cap must be vented to allow air to escape.

9. Holes for the bottom cap should be drilled as shown in the report above in order to minimize drawdown or stack up due to high velocity.

10. Crest-stage gages can be serviced from the top of bottom cap. The stick can be hinged to allow for bending during removal.

11. After the stick is removed and a folding rule or tape measure used to measure the distance to the attached cork, a line can be drawn on the stick and dated. The stick then should be cleaned, and the cork basket recharged.

Table 5. Check list of groundwater-level monitoring equipment (modified from Drost (2005).

[Imperative items highlighted]

Measuring Equipment:

- Steel measuring tapes; 100, 300, and (or) 500 ft
- Electric (E-line) tape; 300 ft and (or) 500 ft
- Pocket measuring tape (engineering scale)
- Tank of compressed air (with tie-downs)
- Pressure gage and regulator
- Bicycle pump
- Carpenter's blue chalk
- Measuring tape weights and spares (sausage-style; brass, copper, or stainless steel)
- Well-depth sounding weights and attaching swivels, wire, etc.
- Field instruction manual

Disinfecting and Cleaning Equipment:

- Bleach container, 5 gal
- Household bleach
- Alcohol wipes
- Latex gloves
- Tech and Chem-Wipes
- Paper towels

Safety Equipment:

- Floatation Vest, orange (appropriately sized)
- Safety glasses
- Hantavirus kit
- Half-mask respirators (small and large) and replacement filters
- Latex gloves
- Protective goggles
- Spray bottle for bleach solution
- Mosquito (insect) repellent

Office Supplies:

- Calculator
- Clipboard
- Pencils, pens, etc.
- Well-location map and scaling accessories

Tools:

- Shovel
- Pry bar, tapered end
- Crow bar
- Hack saw
- Wire brush
- Hammer
- Water-pump pliers
- Vice-grip pliers
- Diagonal wire cutters
- Screwdriver set
- File
- Chisel
- Set of Allen wrenches (standard)
- Set of Allen wrenches (metric)
- Socket wrenches (standard)
- Socket wrenches (metric)
- Pipe wrenches (8-, 10-, 14-, 18-, and 24-in.)
- Crescent wrenches (6-, 8-, 10-, and 12-in.)
- Machete

Miscellaneous:

- GPS unit
- Rags
- Raincoat (appropriately sized)
- Bucket, 5-gal, plastic
- Hand cleaner
- Whiskbroom
- Duct tape
- Electricians tape
- Flashlight
- WD-40 lubricant
- Gloves, leather or canvas
- Plastic garbage bags
- Paint stick (for marking measuring point)
- Well-casing sealing plugs (assorted sizes, threads, etc.)
- Nuts and bolts (various sizes)
- Batteries; spares for GPS [AA], flashlight [C], and e-line [9V])

Table 6. Minimum information required for electronic storage of site and groundwater-quality data in the U.S. Geological Survey's National Water Information System (NWIS).

[Modified from Ground-Water Site Inventory Schedule Form 9-1904-A, Revised June 2004, NWIS 4.4.]

Minimum required information for establishing a groundwater site in NWIS (GWSI)

Data description:

- Agency code
- Station Identification Number (latitude/longitude/sequence No.)
- Station Name
- Latitude
- Longitude
- Country
- Lat/Long Accuracy
- Lat/Long Method
- Lat/Long Datum
- Time Zone
- Daylight Savings Time Flag
- District/User
- State
- County
- Station Type
- Data Reliability
- Site Type
- Use of site

Minimum required information for storage of water-sample analyses in the water-quality subsystem of NWIS (QWDATA)

Data description:

- Agency code
- Station Identification Number
- Sample Medium
- Sample Type
- Hydrologic ("Hydro") Event
- Hydrologic ("Hydro") Condition
- Date (year month/day)
- Time (standard 24-hour clock time)
- Analysis Status
- Analysis Source

Table 8. Distribution of water temperature, dissolved oxygen, pH, specific conductance, and indicator bacteria near Bent's Old Fort NHS.

Station ID	BEOL 2	BEOL 19	BEOL 26	BEOL 28	BEOL 29	BEOL 19	BEOL 29	BEOL 19	BEOL 26	BEOL 29
Constituent	Water Temperature (°C)					Dissolved Oxygen (mg/L)		pH		
Minimum	1.0	0.0	0.0	0.0	-1.1	4.0	5.2	7.4	7.0	6.7
5%	3.0	4.0	0.6	4.0	0.0	6.5	7.0	7.5	7.3	7.2
25%	8.0	12.1	5.0	8.5	6.1	7.0	8.0	8.0	7.4	7.7
50%	15.0	19.5	10.9	14.0	13.3	8.0	9.7	8.2	7.5	8.0
75%	20.6	24.4	20.3	19.5	20.0	10.2	11.2	8.3	7.7	8.2
95%	26.9	29.0	25.9	23.7	23.9	11.7	12.9	8.4	8.1	8.6
Maximum	35.0	35.0	30.5	28.0	28.3	11.9	13.6	8.6	8.1	9.3
Mean	14.6	18.1	12.3	13.8	13.0	8.5	9.6	8.1	7.6	7.9
S.Dev.	7.9	8.2	8.6	6.5	3.4	2.0	1.9	0.2	0.2	0.4
C.V.	53.8%	45.1%	70.4%	47.2%	26.0%	23.0%	20.3%	3.0%	3.1%	5.2%
n	85	251	52	303	248	33	198	52	67	222

Station ID	BEOL 29	BEOL 29	BEOL 2	BEOL 19	BEOL 25	BEOL 26	BEOL 28	BEOL 29
Constituent	Fecal Coliform (colonies/100 mL)	Total Coliform (colonies/100 mL)	Specific Conductance (μS/cm)					
Minimum	2	40	1,200	530	1,500	536	125	493
5%	22	220	1,740	854	1,526	738	1,186	660
25%	150	953	3,600	1,071	1,803	1,293	1,530	1,208
50%	380	2,400	4,365	1,530	1,930	1,530	2,035	1,540
75%	2,300	11,425	5,000	2,338	2,208	1,720	3,000	1,821
95%	23,000	737,900	8,000	2,670	3,055	2,250	3,500	2,239
Maximum	4,900,000	13,000,000	8,160	2,860	3,080	2,440	4,500	2,560
Mean	39,518	214,705	4,486	1,709	2,038	1,489	2,248	1,504
S.Dev.	337,223	1,179,498	1,627	666	414	418	811	463
C.V.	853%	549%	36.3%	39.0%	20.3%	28.1%	36.1%	30.8%
n	239	161	90	71	27	67	296	231
% >400 colonies/100 mL	48.1%	N/A						

Table 9. Distribution of water temperature, pH, and specific conductance near Chickasaw NRA and Ft. Larned NHS.

Station ID	CHIC 2	FOLS 4	FOLS 4	FOLS 4
Constituent	Water Temperature (^oC)	Water Temperature (^oC)	pH	Specific Conductance (µS/cm)
Minimum	6.1	0.0	6.8	110
5%	7.8	1.0	7.2	200
25%	15.6	8.0	7.4	265
50%	20.0	17.6	7.6	380
75%	26.9	23.0	7.9	720
95%	29.0	26.9	8.3	990
Maximum	30.6	30.0	8.6	1860
Mean	20.1	16.0	7.7	488
S.Dev.	7.4	8.5	0.3	287
C.V.	36.7%	53.0%	4.5%	58.8%
n	51	198	158	180

Table 10. List of water quality sites in Rock Creek with ranges of constituent values. WT, water temperature; DO, dissolved oxygen; Cond, specific conductance; Fec Colif, fecal-coliform bacteria; Tot Colif, total-coliform bacteria; Fec Strep, fecal-streptococcus bacteria; TKN, total Kjeldahl nitrogen; TP, total phosphorus; K, * 1,000.

Station ID	Years	WT °C	DO mg/L	pH S.U.	Cond µS/cm	Fec Colif col/100 mL	Tot Colif col/100 mL	Fec Strep col/100 mL	Chloride mg/L	Sulfate mg/L	TKN mg/L	TP mg/L
CHIC 2	1951-62	6.1 - 30.6		7.0 - 8.7	299 - 3,040							
CHIC 57	1974-75										0.2 - 1.8	
CHIC 60	1959-60			8.2 - 8.5	423 - 2,040				48 - 500	28 - 38		
CHIC 64	1975-76						400 - 600					
CHIC 66	1991-95	7.6 - 27.2	7.6 - 13.9	7.8 - 9.1				100			< 0.2 - 0.7	<0.01-0.12
CHIC 67	1976	24 - 26	9.2 - 10.4	8.2 - 9.0		720	120,000		81 - 175			
CHIC 69	1975						8,000	100				
CHIC 70	1976			9.0					110			
CHIC 75	1976-77	5 - 27	7.1 - 14.6	7.7 - 10.1		<1 - 29.6K	6K - 830K	<1 - 39.5K	93 - 475		0.11 - 1.64	
CHIC 78	1975-76						<1 - 300	<1				
CHIC 79	1975					3,500						
CHIC 80	1987-94	2.5 - 24.1	3.1 - 12.7	7.0 - 8.6	332 - 1,150							0.03-0.52
CHIC 81	1975						200 - 1,600					
CHIC 82	1975-76						<1 - 200	<1				
CHIC 103	1987-93	3.7 - 24.6	3.3 - 12.4	6.9 - 8.6	339 - 1,180		200 - 1,600			11 - 42		0.02-0.82
CHIC 114	1987-93	1.5 - 26.7	1.9 - 13.3	7.0 - 8.7	357 - 2,790					12 - 56	0.04-0.88	0.04-0.46
CHIC 119	1975-76						1K - 340K	100 - 39K				
CHIC 133	1976-77	5.0 - 29.0	5.1 - 15.5	7.6 - 9.8		200 - 126K	10K - 1930K	100 - 44K	36 - 485		0.06-1.12	0.04-0.80
CHIC 134	1975					3,100						
CHIC 136	1976					204K	1320K					
CHIC 140	1976-76						200 - 2,400	100 - 500				
CHIC 141	1976	31	6	8.3					83			
CHIC 142	1976-77	4.0 - 28.0	5.7 - 14.3	6.8 - 8.9		100 - 32.1K	6.9K - 350K	660 - 37.5K	55 - 567		0.12-1.64	0.03-0.165
CHIC 144	1988-94	2.0 - 27.3	2.7 - 19.6	7.0 - 8.6	345 - 3,100					12 - 55		0.05-1.40
CHIC 149	1976-77	7.0 - 27.0	5.8 - 14.4	6.9 - 9.0		40 - 18.5K	20K - 260K	3.6K - 65K	59 - 580			
CHIC 150	1975-76						1,600-2,100	200 - 300				
CHIC 153	1976	10.0-17.0	7.5 - 13.4	7.1 - 8.5		<1 - 1,500	9K - 56K	600 - 240	193 - 730			
CHIC 154	1976	19.5-25.0	7.9 - 9.8	6.9 - 7.8					1280-1375			
CHIC 155	1976-77	8.0-14.0	8.5 - 11.2	6.9 - 9.1		<1 - 720	10K - 27K	10 - 1,900	43 - 110			
CHIC 156	1958-60	17.2-27.8		8.2 - 8.3	1100-2100				235 - 480			

Table 11. List of water quality sites in Travertine Creek with ranges of constituent values. WT, water temperature; DO, dissolved oxygen; Cond, specific conductance; Fec Colif, fecal-coliform bacteria; Tot Colif, total-coliform bacteria; Fec Strep, fecal-streptococcus bacteria; TKN, total Kjeldahl nitrogen; TP, total phosphorus; K, * 1,000.

Station ID	Years	WT °C	DO mg/L	pH S.U.	Cond µS/cm	Fec Colif col/100 mL	Tot Colif col/100 mL	Fec Strep col/100 mL	Chloride mg/L	Sulfate mg/L	TKN mg/L	TP mg/L
CHIC 83	1976-77	6.0 - 23.5	7.2 - 13.6	7.6 - 9.8		0 - 500K	400 - 78.8K	0 - 30K	3 - 8		0 - 0.23	0
CHIC 98	1975					2,500	<200 - 8K					
CHIC 99	1975					0	100					
CHIC 100	1975					0	600					
CHIC 102	1975					0	200					
CHIC 105	1975-76					0 - 1,500	1200 - 3200					
CHIC 106	1975					2,600	380K					
CHIC 108	1988-94	9.0 - 25.2	3.4 - 10.7	7.0 - 8.8	295 - 652					9 - 22		<0.01-0.34
CHIC 109	1987-94	5.9 - 25.2	3.0 - 12.2	6.9 - 8.7	311 - 1200					11 - 24		0.01-0.4
CHIC 110	1975-76					<1	<1					
CHIC 111	1976	22.0-26.0	9.3 - 9.6	8.0 - 9.0					61 - 70			
CHIC 112	1975					<1	3400					
CHIC 113	1976-77	17.0-22.0	7.1 - 10.0	8.0 - 9.0		<1 - 70K	2K - 38.5K	<1 - 20K	1 - 4			
CHIC 115	1975-76					300 - 1,500	900 - 2300					
CHIC 122	1975-76						<1	<1				
CHIC 123	1976	22.5-24.5	7.1 - 7.8	7.9		3,000	10K					
CHIC 124	1976-77	11.0-24.5	6.8 - 10.4	7.4 - 9.0		46K - 329K	1460K	25K - 37K	4 - 78			
CHIC 125	1975						<200					
CHIC 129	1975					400	2100-2700					
CHIC 132	1975						200-1150					
CHIC 137	1975-76						<1 - 1000	<1				
CHIC 138	1976					270	36K					

Table 12. List of water quality sites in CHIC spring discharges with ranges of constituent values. WT, water temperature; DO, dissolved oxygen; Cond, specific conductance; Fec Colif, fecal-coliform bacteria; Tot Colif, total-coliform bacteria; Fec Strep, fecal-streptococcus bacteria; TKN, total Kjeldahl nitrogen; TP, total phosphorus; K, * 1,000.

Station ID	Years	WT °C	DO mg/L	pH S.U.	Cond µS/cm	Fec Colif col/100 mL	Tot Colif col/100 mL	Fec Strep col/100 mL	Chloride mg/L	Sulfate mg/L
Buffalo Spring										
CHIC 88	1987-94	15.7-18.7	1.0 - 2.9	6.9 - 8.2	368 - 622					10 - 45
CHIC 89	1976		3.3 - 7.2			<1 - 130	800-7200	120 - 320		
CHIC 90	1975						2 - 200			
Pavilion Spring										
CHIC 91	1989-92	19.1-22.3		7.1 - 8.0	622 - 855					12 - 31
CHIC 92	1967					<1	<1	<1		
CHIC 94	1989-92	18.4-21.1		7.1 - 8.0	659 - 875					12 - 28
CHIC 95	1989-92	18.4-20.8		7.3 - 8.1	520 - 879					12 - 28
CHIC 96	1989-92	18.9-21.9		7.2 - 7.9	595 - 1,410					12 - 26
CHIC 97	1989-92	19.1-29.9		7.2 - 8.2	595 - 1,390					12 - 23
Black Sulfur Spring										
CHIC 117	1989-90	19.5-25.8		7.2 - 7.7	818 - 1,086					17 - 38
CHIC 118	1967					<1 - 7	<1 - 54			
Antelope Spring										
CHIC 126	1976	10	3.1 - 7.5	7.6 - 9.1		<1 - 50	2200-7100	10 - 220	4	
CHIC 127	1975						<1	<1		
CHIC 128	1987-94	12.3-20.1	0.1 - 9.8	6.9 - 8.4					3	12 - 24

Table 13. Distribution of water temperature (^{o}C) at Lake Meredith National Recreation Area

Station ID	LAMR 6	LAMR 8	LAMR 9	LAMR 15	LAMR 18	LAMR 19	LAMR 20	LAMR 23	LAMR 25
Minimum	1.9	4.4	3.0	0.6	3.5	4.4	4.4	4.4	4.4
5%	3.5	10.0	5.0	3.0	3.5	8.8	8.1	8.6	8.5
25%	13.0	14.3	6.0	8.2	9.4	14.5	13.8	15.0	14.4
50%	19.0	17.0	15.0	15.4	20.0	16.1	17.0	17.6	17.1
75%	23.0	21.0	21.4	22.5	23.6	21.0	21.0	21.0	21.0
95%	25.4	24.0	27.1	26.0	25.8	24.0	23.9	25.1	24.0
Maximum	27.8	24.4	28.0	28.3	26.7	24.4	24.0	27.0	24.0
Mean	17.1	17.2	14.6	15.2	16.9	17.0	16.9	17.6	17.1
S.Dev.	3.4	4.7	8.0	7.8	2.4	4.7	4.6	5.0	4.7
C.V.	20.2%	27.3%	54.9%	51.4%	22.7%	27.5%	27.2%	28.5%	27.7%
n	1644	51	35	668	41	52	49	46	50

Station ID	LAMR 26	LAMR 29	LAMR 34	LAMR 39	LAMR 42	LAMR 45	LAMR 51	LAMR 52
Minimum	4.4	4.4	2.3	4.4	4.4	4.4	4.4	2.2
5%	8.1	10.8	3.0	10.3	6.5	5.9	6.6	2.9
25%	14.6	13.4	5.9	14.6	12.9	12.9	12.8	5.7
50%	17.0	17.2	16.6	17.2	16.0	16.0	16.0	17.0
75%	21.0	21.0	24.1	21.0	20.3	20.4	19.6	23.9
95%	23.9	24.0	25.7	24.0	26.0	24.0	23.7	26.3
Maximum	24.0	24.0	30.0	24.4	27.0	24.0	24.8	28.0
Mean	16.9	17.1	15.6	17.3	16.7	16.1	15.8	15.8
S.Dev.	4.6	4.7	8.7	4.7	5.7	5.2	5.0	8.7
C.V.	27.4%	27.2%	55.8%	27.1%	34.4%	32.3%	31.7%	55.0%
n	49	51	101	47	33	29	27	87

Table 14. Distribution of dissolved oxygen (mg/L) at Lake Meredith National Recreation Area

Station ID	LAMR 6	LAMR 8	LAMR 15	LAMR 18	LAMR 19	LAMR 20	LAMR 23	LAMR 25
Minimum	0.0	6.4	0.0	7.0	5.3	4.4	4.8	4.8
5%	0.6	6.9	3.5	7.0	6.3	6.4	6.5	6.0
25%	6.6	7.9	7.4	7.7	8.0	7.9	8.0	8.0
50%	8.0	8.2	8.6	8.4	8.3	8.1	8.2	8.4
75%	9.7	9.0	10.2	10.1	9.0	9.0	9.2	9.0
95%	12.1	10.5	12.4	12.4	10.6	10.9	10.7	10.6
Maximum	23.0	11.0	18.2	12.6	11.0	11.0	11.3	11.0
Mean	7.9	8.5	8.6	9.0	8.4	8.4	8.5	8.5
S.Dev.	3.3	1.1	2.7	1.7	1.2	1.3	1.3	1.2
C.V.	42.2%	12.5%	31.2%	18.8%	14.1%	15.1%	15.0%	14.4%
n	1646	47	680	50	48	46	42	46
% < 4 mg/L	0.1	0	< 0.1	0	0	0	0	0

Station ID	LAMR 26	LAMR 29	LAMR 34	LAMR 39	LAMR 42	LAMR 45	LAMR 51	LAMR 52
Minimum	4.4	5.0	4.2	5.5	5.0	6.7	5.0	2.7
5%	6.4	6.4	6.5	6.3	5.6	6.8	6.0	6.3
25%	8.0	8.0	7.4	7.9	7.9	8.0	8.0	7.6
50%	8.2	8.4	9.0	8.2	8.1	8.1	8.1	8.8
75%	9.0	9.0	11.2	9.1	9.2	9.3	9.0	10.9
95%	10.6	10.6	12.8	10.5	10.5	10.5	10.1	12.4
Maximum	11.0	11.0	13.6	11.0	11.0	10.5	10.5	13.3
Mean	8.4	8.5	9.2	8.4	8.2	8.5	8.2	9.1
S.Dev.	1.2	1.2	2.2	1.2	1.5	1.0	1.2	2.0
C.V.	14.5%	14.0%	23.6%	14.5%	17.7%	11.6%	14.4%	22.4%
n	45	47	127	43	32	28	26	125
% < 4 mg/L	0	0	0	0	0	0	0	< 0.1

Table 15. Distribution of pH at Lake Meredith National Recreation Area

Station ID	LAMR 5	LAMR 6	LAMR 9	LAMR 15	LAMR 18	LAMR 28	LAMR 34	LAMR 38	LAMR 41	LAMR 52
Minimum	7.8	6.9	7.2	6.8	7.2	7.4	5.8	7.3	7.1	6.9
5%	8.0	7.9	7.2	7.5	7.4	7.6	7.0	8.0	7.9	7.4
25%	8.2	8.1	7.7	8.2	8.3	8.1	8.2	8.4	8.4	8.2
50%	8.3	8.2	7.9	8.4	8.4	8.4	8.4	8.5	8.5	8.4
75%	8.4	8.4	8.2	8.6	8.7	8.6	8.6	8.6	8.9	8.6
95%	8.5	8.5	8.5	9.0	8.9	8.9	9.0	9.0	8.9	8.9
Maximum	8.6	8.6	8.7	10.4	8.9	8.9	9.5	9.0	8.9	9.2
Mean	8.3	8.2	7.9	8.4	8.4	8.3	8.3	8.5	8.5	8.3
S.Dev.	0.2	0.2	0.4	0.4	0.4	0.4	0.6	0.3	0.4	0.4
C.V.	2.2%	2.6%	4.5%	4.9%	4.9%	5.2%	7.4%	3.7%	4.4%	5.2%
n	41	223	31	504	37	42	104	33	26	112
% > 9.0	0	0	0	2.2	0	0	2.9	0	0	2.7

Table 16. Distribution of specific conductance (μS/cm) at Lake Meredith National Recreation Area

Station ID	LAMR 5	LAMR 6	LAMR 8	LAMR 9	LAMR 15	LAMR 18	LAMR 19	LAMR 20	LAMR 25
Minimum	1,404	926	1,500	1,090	135	1,550	1,500	1,350	1,400
5%	1,598	1,450	1,565	1,304	872	1,550	1,533	1,378	1,490
25%	1,689	1,771	1,725	1,568	1,600	1,617	1,725	1,775	1,800
50%	1,793	1,958	1,850	1,680	1,861	1,744	1,850	1,900	1,950
75%	1,867	2,240	2,038	1,870	2,000	1,850	2,038	2,013	2,050
95%	1,979	2,608	2,370	2,509	2,390	1,900	2,370	2,281	2,272
Maximum	3,496	2,980	2,500	3,010	8,950	1,900	2,500	2,380	2,380
Mean	1,815	2,003	1,901	1,739	1,833	1,738	1,903	1,876	1,905
S.Dev.	301	348	235	346	657	129	234	253	220
C.V.	16.6%	17.4%	12.4%	19.9%	35.9%	7.4%	12.3%	13.5%	11.6%
n	39	190	23	39	543	34	23	21	22

Station ID	LAMR 26	LAMR 28	LAMR 29	LAMR 34	LAMR 38	LAMR 39	LAMR 41	LAMR 52
Minimum	1,550	600	1,350	145	1,194	1,350	1,575	140
5%	1,619	900	1,448	1,108	1,334	1,375	1,575	1,127
25%	1,800	1,600	1,725	1,738	1,600	1,800	1,600	1,710
50%	1,900	1,800	2,000	1,900	1,694	2,000	1,700	1,832
75%	2,013	1,850	2,050	2,140	1,788	2,075	1,900	1,924
95%	2,281	1,900	2,370	2,287	1,900	2,440	2,140	2,233
Maximum	2,380	1,900	2,500	2,380	1,900	2,500	2,499	2,640
Mean	1,922	1,663	1,901	1,852	1,683	1,918	1,764	1,772
S.Dev.	192	294	261	397	169	278	207	406
C.V.	10.0%	17.7%	13.7%	21.4%	10.0%	14.5%	11.8%	22.9%
n	21	30	23	113	25	20	22	104

Table 17. Distribution of total coliform bacteria (colonies per 100 mL) at Lake Meredith National Recreation Area

Station ID	LAMR 6	LAMR 11	LAMR 14	LAMR 15	LAMR 18	LAMR 21	LAMR 28
Minimum	0	0	0	0	0	0	0
5%	0	0	0	0	0	0	0
25%	0	3	3	1	0	0	0
50%	3	9	12	3	2	3	2
75%	9	24	36	12	6	6	6
95%	39	113	109	46	32	21	56
Maximum	336	342	9,600	480	140	174	540
Mean	9	25	52	14	7	5	12
S.Dev.	24	46	476	48	18	13	49
C.V.	271%	184%	920%	334%	245%	255%	398%
n	309	253	408	157	296	297	345

Station ID	LAMR 31	LAMR 34	LAMR 38	LAMR 41	LAMR 46	LAMR 47	LAMR 52
Minimum	0	0	0	0	0	0	0
5%	0	0	0	0	0	0	0
25%	0	0	0	0	0	0	0
50%	3	3	3	3	3	2	0
75%	6	6	6	6	9	6	3
95%	24	36	45	36	72	28	36
Maximum	720	414	780	660	480	570	540
Mean	8	8	11	9	15	8	9
S.Dev.	46	27	52	40	46	35	40
C.V.	566%	319%	471%	445%	304%	452%	460%
n	266	375	293	316	309	283	210

Table 18. Distribution of fecal coliform bacteria (colonies per 100 mL) at Lake Meredith National Recreation Area

Station ID		LAMR 3	LAMR 6	LAMR 7	LAMR 11	LAMR 14	LAMR 15	LAMR 18	LAMR 21
Minimum		0	0	0	0	0	1	0	0
	5%	0	0	0	0	0	1	0	0
	25%	0	0	0	0	0	1	0	0
	50%	1	0	2	3	3	3	0	0
	75%	10	3	12	9	12	10	0	0
	95%	182	9	140	48	49	10	10	6
Maximum		290	141	200	210	210	980	183	78
Mean		19	2	17	9	11	10	3	1
S.Dev.		61	10	46	20	24	65	14	6
C.V.		322%	412%	264%	225%	226%	657%	483%	425%
n		32	281	22	243	405	229	287	279
% > 400		0	0	0	0	0	0.4	0	0

Station ID		LAMR 28	LAMR 31	LAMR 34	LAMR 38	LAMR 41	LAMR 46	LAMR 47	LAMR 52
Minimum		0	0	0	0	0	0	0	0
	5%	0	0	0	0	0	0	0	0
	25%	0	0	0	0	0	0	0	0
	50%	0	0	0	0	0	0	0	0
	75%	0	0	3	0	1	3	3	2
	95%	10	10	15	12	10	23	12	23
Maximum		348	54	424	208	198	424	234	220
Mean		3	2	6	4	3	7	4	6
S.Dev.		21	6	34	18	16	30	21	22
C.V.		697%	321%	529%	469%	504%	450%	513%	385%
n		323	271	370	297	298	298	277	237
% > 400		0	0	0.3	0	0	0.3	0	0

Table 19. Distribution of fecal streptococcus bacteria (colonies per 100 mL) at Lake Meredith National Recreation Area

Station ID	LAMR 6	LAMR 11	LAMR 14	LAMR 15	LAMR 18	LAMR 21	LAMR 28
Minimum	0	0	0	0	0	0	0
5%	0	0	0	0	0	0	0
25%	0	0	0	0	0	0	0
50%	0	3	3	1	0	0	0
75%	3	6	9	3	3	3	3
95%	12	36	39	12	15	9	12
Maximum	69	105	108	57	159	60	58
Mean	3	8	9	3	3	2	3
S.Dev.	8	16	17	7	13	6	7
C.V.	271%	203%	193%	218%	395%	287%	268%
n	240	232	351	149	242	239	255

Station ID	LAMR 31	LAMR 34	LAMR 38	LAMR 41	LAMR 46	LAMR 47	LAMR 52
Minimum	0	0	0	0	0	0	0
5%	0	0	0	0	0	0	0
25%	0	0	0	0	0	0	0
50%	0	0	0	0	3	0	0
75%	3	6	4	3	9	3	3
95%	21	42	36	21	52	21	28
Maximum	180	861	159	75	861	75	290
Mean	5	11	8	4	15	4	8
S.Dev.	19	56	20	9	62	9	33
C.V.	358%	502%	271%	224%	402%	213%	426%
n	248	310	249	251	258	237	177

Table 20. Distribution of water temperature and pH near Lyndon B. Johnson NHS

Station ID	LYJO 2	LYJO 3	LYJO 5	LYJO 7	LYJO 15	LYJO 16	LYJO 39
Constituent			Water Temperature (^oC)				
Minimum	4.5	3.7	1.1	1.5	4.0	5.7	8.4
5%	6.6	11.8	7.8	8.2	9.7	6.9	11.3
25%	13.6	20.3	13.9	15.0	16.5	14.3	20.1
50%	21.4	25.9	21.1	21.5	23.1	19.0	27.1
75%	26.4	28.1	26.1	26.5	27.3	24.6	29.5
95%	29.2	32.2	30.0	30.0	30.8	29.0	32.8
Maximum	30.3	32.4	34.0	34.0	34.0	29.5	33.4
Mean	19.8	23.6	19.8	20.5	21.8	18.8	24.4
S.Dev.	7.5	6.6	7.5	7.5	7.0	7.0	7.1
C.V.	38.1%	27.8%	37.7%	36.4%	32.0%	36.9%	29.3%
n	49	41	89	116	74	68	28

Station ID	LYJO2	LYJO3	LYJO5	LYJO7	LYJO15	LYJO16	LYJO39
Constituent				pH			
Minimum	7.5	8.2	7.8	6.9	6.7	7.5	7.8
5%	8.0	8.3	8.0	7.3	8.1	7.9	7.8
25%	8.2	8.4	8.2	7.7	8.3	8.2	8.0
50%	8.4	8.6	8.3	8.0	8.4	8.3	8.2
75%	8.5	8.7	8.4	8.2	8.5	8.4	8.4
95%	8.8	9.0	8.6	8.4	8.6	8.7	8.5
Maximum	9.2	9.2	8.8	8.5	8.8	9.0	8.5
Mean	8.4	8.6	8.3	7.9	8.3	8.3	8.2
S.Dev.	0.3	0.2	0.2	0.4	0.3	0.3	0.2
C.V.	3.2%	2.5%	2.2%	4.7%	3.3%	3.1%	2.8%
n	49	40	64	72	74	64	27
% > 9.0	2.0	2.5	0	0	0	0	0

Table 21. Distribution of dissolved oxygen (mg/L), fecal coliform bacteria (colonies per 100 mL), and specific conductance (μS/cm) near Lyndon B. Johnson NHS.

Station ID	LYJO 2	LYJO 3	LYJO 5	LYJO 15	LYJO 16	LYJO 39		LYJO 2	LYJO 15	LYJO 16
Constituent	Dissolved Oxygen (mg/L)							Fecal Coliform (colonies/100 mL)		
Minimum	7.3	3.7	4.0	5.4	6.6	5.2		3	1	0
5%	7.6	4.6	6.5	6.6	7.0	6.4		4	1	7
25%	8.3	7.8	7.8	7.7	8.0	7.1		22	13	17
50%	9.7	8.5	8.6	8.7	9.2	8.5		61	36	43
75%	11.3	9.6	10.0	9.4	10.5	10.3		210	100	164
95%	12.6	12.3	12.3	11.4	12.7	12.2		1,105	2,975	1,080
Maximum	13.0	13.5	15.0	12.7	15.7	13.4		1,620	3,000	3,000
Mean	9.8	8.7	8.9	8.7	9.5	8.8		221	304	228
S.Dev.	1.7	2.1	1.9	1.5	1.8	2.0		366	802	537
C.V.	17.5%	23.7%	21.0%	16.7%	19.3%	22.6%		165.5%	263.6%	235.2%
n	49	40	88	75	89	28		56	39	74
% < 4.0	0	2.5	0	0	0	0	% > 400	14.3	10.3	12.2

Station ID	LYJO 2	LYJO 3	LYJO 5	LYJO 7	LYJO 15	LYJO 16	LYJO 39
Constituent	Specific Conductance (μS/cm)						
Minimum	324	411	380	205	62	371	473
5%	428	475	456	337	455	460	518
25%	561	598	598	557	617	630	643
50%	623	620	690	629	685	688	723
75%	722	653	758	717	739	768	764
95%	776	1,118	855	792	846	844	786
Maximum	821	1,319	860	830	996	869	787
Mean	630	661	676	615	670	684	690
S.Dev.	108	175	120	133	131	110	90
C.V.	17.1%	26.5%	17.8%	21.6%	19.6%	16.0%	13.1%
n	47	40	64	130	74	59	28

Table 22. Distribution of water temperature, pH, dissolved oxygen, and indicator bacteria near Pecos National History Park (NHP)

Station ID	PECO 8	PECO 29	PECO 39	PECO 40	PECO 45	PECO 50	PECO 50	PECO 50
Constituent	Water Temperature (^oC)						Total Coliform (colonies per 100 mL)	Fecal Streptococcus (colonies per 100 mL)
Minimum	7.0	5.6	1.0	0.5	0.5	0.0	0	0
5%	8.9	6.5	1.0	0.7	0.5	0.0	0	0
25%	12.5	10.7	2.0	7.4	2.1	0.5	0	3
50%	14.0	12.0	5.5	10.9	5.0	5.0	5	13
75%	15.4	13.7	11.0	12.6	10.0	10.0	28	27
95%	19.5	15.8	14.8	15.1	12.9	15.0	85	178
Maximum	22.0	19.5	15.0	18.0	14.8	19.5	172	500
Mean	14.0	11.9	6.5	9.8	5.9	5.7	20	39
S.Dev.	3.1	2.8	4.6	4.2	4.2	5.2	31	79
C.V.	21.9%	23.7%	70.0%	42.6%	70.5%	91.7%	155.4%	203.4%
n	36	37	26	56	31	316	62	64

Station ID	PECO 39	PECO 40	PECO 45	PECO 47	PECO 50	PECO 50		PECO 8	PECO 50
Constituent	pH					Dissolved Oxygen (mg/L)		Fecal Coliform (colonies per 100 mL)	
Minimum	7.3	7.7	7.8	7.6	6.5	4.3		1	0
5%	7.4	7.8	7.9	7.6	6.9	6.8		6	0
25%	7.6	8.0	8.1	7.8	7.4	8.6		16	0
50%	7.8	8.2	8.3	8.0	7.6	10.0		26	1
75%	8.1	8.3	8.4	8.2	8.0	10.9		52	4
95%	8.3	8.4	8.6	8.4	8.4	12.3		408	48
Maximum	8.4	8.4	8.7	8.5	9.0	13.4		1080	600
Mean	7.9	8.1	8.3	8.0	7.7	9.8		88	16
S.Dev.	0.3	0.2	0.2	0.2	0.5	1.7		208	77
C.V.	3.9%	2.3%	2.5%	3.0%	6.1%	17.7%		236.3%	474.1%
n	26	39	32	27	189	120		47	67
							% > 400	4.2	1.5

Table 23. Distribution of specific conductance (μS/cm) near Pecos National History Park (NHP)

Station ID	PECO 8	PECO 29	PECO 33	PECO 39	PECO 40	PECO 45	PECO 47	PECO 50
Minimum	124	99	118	82	94	5	105	34
5%	128	111	123	101	110	203	109	65
25%	149	128	151	134	127	263	119	84
50%	166	142	176	145	138	289	149	102
75%	180	161	193	188	182	311	186	117
95%	211	201	251	245	227	332	211	130
Maximum	240	207	350	272	243	334	246	223
Mean	166	146	178	159	154	277	156	102
S.Dev.	24	25	43	44	36	56	36	26
C.V.	14.6%	17.2%	24.4%	27.7%	23.6%	20.3%	23.1%	25.6%
n	38	39	49	30	66	38	33	190