IN-STREAM WATER-QUALITY ESTIMATION: CASE STUDIES IN REAL-TIME STREAM AND LAKE MONITORING IN THE CENTRAL USA

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International Symposium for 19th Anniversary of World Water Day
Seoul, Korea
21 March 2011

Abstract. Five U.S. Geological Survey case studies in real-time stream and lake monitoring are presented. The emphases of the case studies are in-stream biological characteristics, fecal coliform bacteria, atrazine, phosphorus, and taste-and-odor compounds.

INTRODUCTION

The U.S. Geological Survey (USGS) maintains a system of in-stream, continuous water-quality monitoring stations that can be used to provide the information necessary to ensure safe streams and lakes. Continuous, real-time data collected at those stations may include streamflow, specific conductance, pH, water temperature, turbidity, dissolved oxygen, nitrate, and fluorescence. In addition, regression equations may be developed to relate chemical concentrations in laboratory-analyzed discrete samples to surrogates in the continuous, real-time data obtained from in-stream sensor measurements. These regression equations can provide continuous records for chemicals of interest in real-time. The chemical concentrations estimated depend on the needs of the customer and can include sediment, major ions, nutrients, selected metals, atrazine, indicator bacteria, and taste-and-odor compounds. The uncertainty and probability of exceeding water-quality criteria also can be provided, which improves the characterization of water-quality conditions. This paper presents five case studies that demonstrate the ways in which the USGS provides continuous and real-time water-quality information to a variety of customers to achieve different objectives. The case studies are from Minnesota, Kansas, and Oklahoma in the central USA (fig. 1) and highlight different aspects of this method and the variety of surrogates used for estimation of stream and lake water quality.

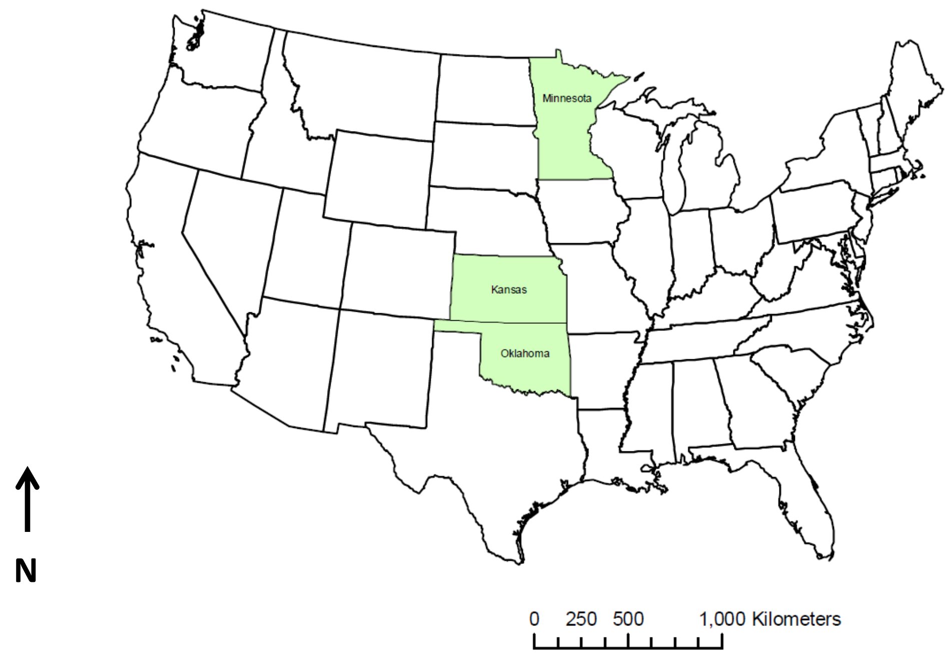

Figure 1. Map of the conterminous USA, showing location of Minnesota, Kansas, and Oklahoma.

STUDY METHODS

For these case studies, discrete water-quality samples were collected for chemicals of interest, such as sediment, chloride, nutrients, indicator bacteria, selected pesticides, and taste-and-odor compounds. Discrete samples were either collected manually or with an automated sampler. Discrete samples collected manually were collected either as a grab or a composite sample using depth- and width-integration techniques (Wilde and Radke, 1998). Depth- and width-integrated samples are representative of the average chemical composition of the stream cross-sectional area. Grab and automatic samples were collected from a single point in the stream. Lake samples were collected manually, just below the water surface and were not depth- and width-integrated. Discrete water samples were sent to a laboratory for chemical analyses.

Continuous data collected included stream stage (water-surface elevation). Streamflow was calculated by relating stream stage to streamflow using methods presented in Turnipseed and Sauer (2010) and Mueller and Wagner (2009). A water-quality monitor was installed in the stream and periodically checked and calibrated according to methods described in Wagner and others (2006) and the manufacturer’s instructions. Water-quality monitors were equipped with sensors that measure physical properties of water, which may include specific conductance, pH, water temperature, turbidity, dissolved oxygen, nitrate, and fluorescence.

The continuous data were recorded at 15- to 60-minute intervals and transmitted approximately every 1 to 4 hours via satellite to the USGS offices and distributed via the Internet. Regression models were developed between the easily monitored properties (streamflow, specific conductance, pH, water temperature, turbidity, dissolved oxygen, nitrate, fluorescence, and day of year) and physical, chemical, and biological characteristics of streams and lakes measured in discrete samples. Three of the five case studies provided these estimates of physical, chemical, or biological characteristics directly to the Internet in real time (Christensen and others, 2000; Christensen, 2001; and Christensen and others, 2006). Details on the development of the regression models are explained in USGS reports that describe the case studies and in Helsel and Hirsch (1992).

AGRICULTURAL LAND RETIREMENT AND BIOLOGICAL CHARACTERISTICS IN THE MINNESOTA RIVER BASIN, MINNESOTA, USA

The purpose of this study in the Minnesota River Basin, Minnesota, USA, was to determine the effects of agricultural land retirement on stream quality (Christensen and Lee, 2008; Christensen and others, 2009). This case study focuses on the benefits of having a continuous dataset, specifically dissolved-oxygen concentrations, for characterizing in-stream water quality and biology. Agricultural land is retired (taken out of crop production) through Federal and State programs in the USA designed to decrease erosion and improve water quality. The objectives of this study were to document the effects of agricultural land retirement programs, such as the Conservation Reserve Enhancement Program (CREP), Conservation Reserve Program (CRP), and the Re-invest In Minnesota (RIM) Program (these programs are described in Christensen and others, 2009). Water-quality and biological characteristics in three streams in the Minnesota River Basin were assessed using data collected during water years 2006–08 (a water year is from October 1st through September 30th, and is designated by the calendar year in which it ends). The responses of nutrient concentrations, suspended-sediment concentrations, and biological characteristics to agricultural land retirement were assessed (Christensen and others, 2009).

Chetomba Creek, West Fork Beaver Creek, and South Branch Rush River drainage subbasins (fig. 2), which range in size from about 200 to 400 square kilometers, have similar geologic and hydrologic settings but differ with respect to the amount, type, and location of retired agricultural land. Water quality was described by using multi-parameter monitors that measured specific conductance, pH, water temperature, dissolved oxygen, and turbidity. The continuous data were used to monitor the effects of agricultural land-retirement programs and large-scale best management practices on streams.

Temporal variation in water quality was characterized using data from in-stream water-quality monitors and storm-sediment data.

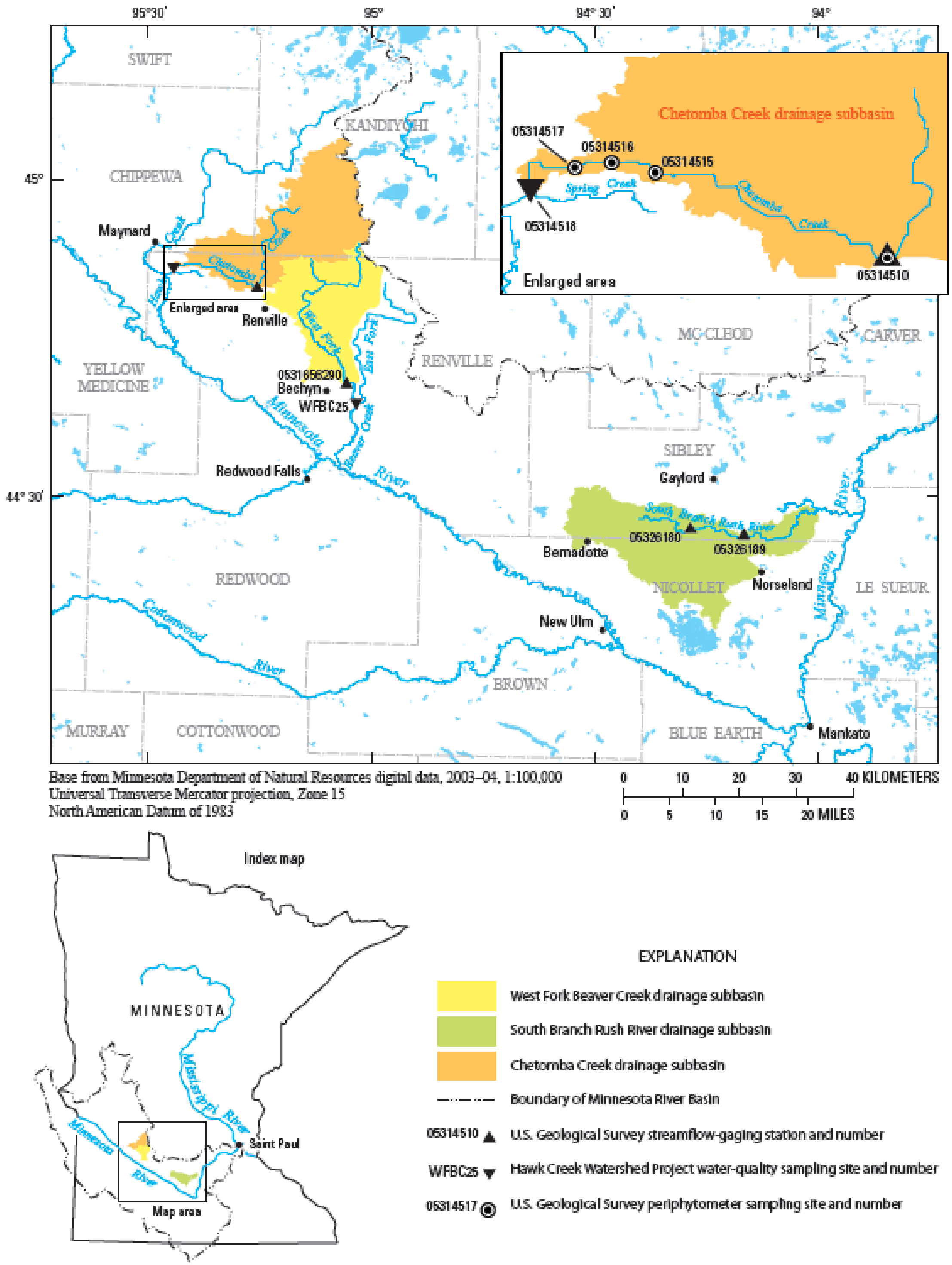

Figure 2. Location of the Minnesota River, location of sampling sites, and West Fork Beaver Creek, and South Branch Rush River, and Chetomba Creek drainage subbasins, Minnesota, USA (source: Christensen and others, 2009).

The water-quality monitors recorded and transmitted physical properties of water during the 2006–08 growing seasons (generally from April through August) at five sites (fig. 2). Generally, the same types of monitors and probes were used throughout the network to minimize measurement differences. The exception was the dissolved-oxygen probes. Newer optical dissolved-oxygen probes were used to replace older cell probes during 2008. The monitors and probes were connected to data-collection platforms at each streamflow-gaging station. Data collected during this study also included discrete water-quality samples, physical habitat characteristics, benthic algae, invertebrate identification, fish identification, algal biomass accumulation (periphytometer sampling), and land use. The real-time data were evaluated as they were transmitted, and sampling trips were scheduled on the basis of monitoring data.

The seasonal variability in stream water quality was evident in the continuous data (see for example fig. 3). The physical property data, performance of the water-quality monitors, and the quality of the data are presented and described in the Annual Data Reports of the USGS found on the Internet at *http://mn.water.usgs.gov/publications/pubswdr.html*. Specific conductance at the five sampling sites tended to vary with streamflow, usually decreasing during high streamflow and increasing during low streamflow. Diurnal variation in pH (and other water-quality properties) is captured using this method of data collection. These variations commonly are missed when only discrete water samples are collected. The diurnal variability of pH can be attributed to several factors, including photosynthesis, reaeration, respiration (Guasch and others, 1998), and plant uptake (Hessen and others, 1997). Predictably, temperature increased during the summer months with occasional decreases during storms. Temperature also varied diurnally. Continuous and real-time temperature measurements were important for these streams because of the focus on biological characteristics. Aquatic organisms are adapted to certain temperature ranges (Allan, 1995). Turbidity is an event-driven property of water that typically increases with increases in streamflow caused by erosion of soils and streambank sediments, but also increases with other stream disturbances such as animal activity. Seasonal variability in turbidity was not evident at the Minnesota River Basin sites. West Fork Beaver Creek had larger ambient turbidity but fewer event-driven increases in turbidity than the other streams.

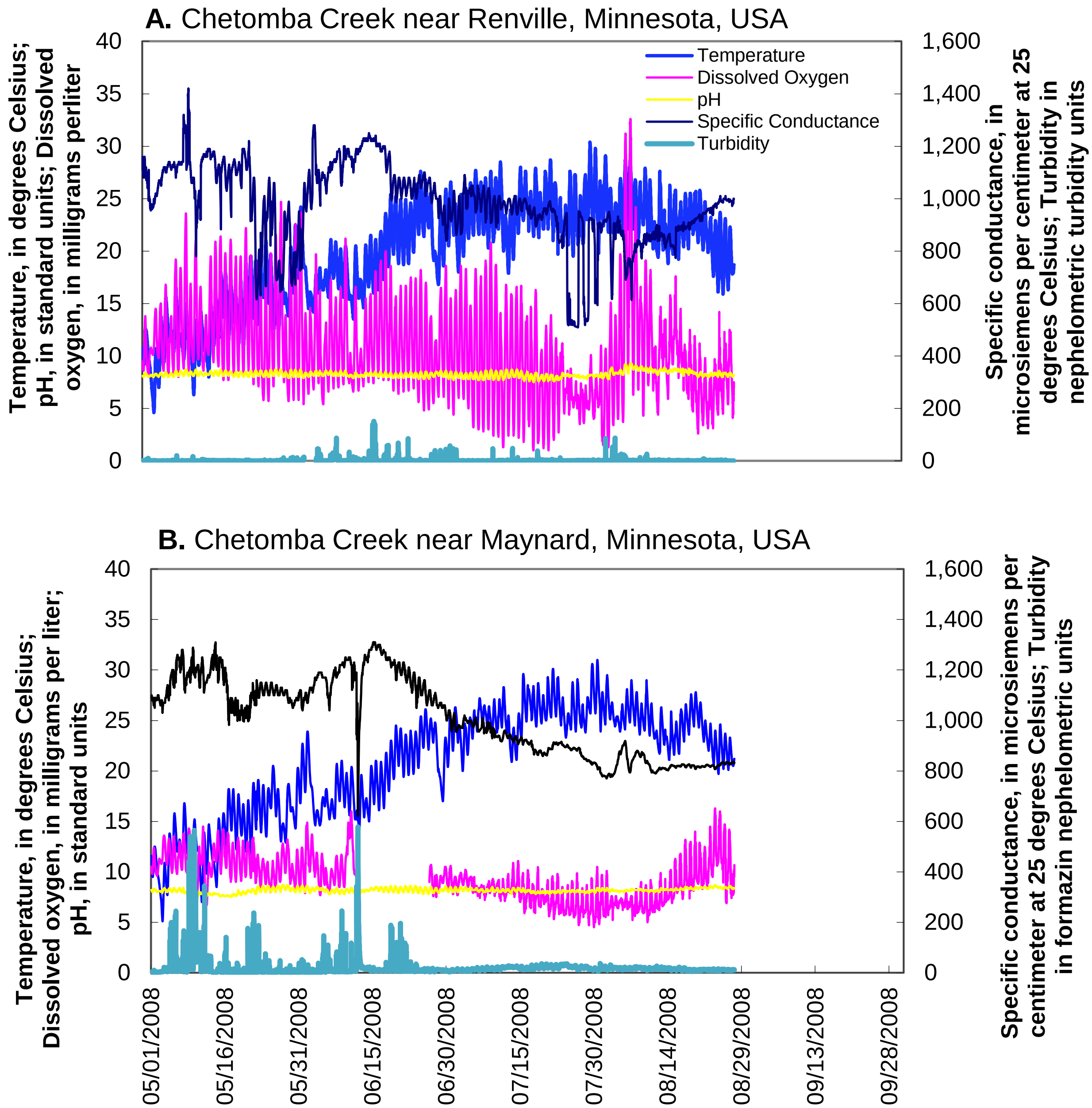

Figure 3. Continuous water-quality measurements of physical properties during the growing season for Chetomba Creek near Renville (station 05314518) and Chetomba Creek near Maynard (station 05314510), Minnesota, USA for 2008 (source: Christensen and others, 2009).

Dissolved oxygen was a primary focus of this study, due to the importance to fish. Dissolved oxygen had substantial diurnal variability (fig. 3). Dissolved-oxygen daily minima commonly are missed by manual sampling because of the time of the day the sample is collected. Logistically, the variability in dissolved-oxygen concentrations cannot be described without continuous data. Decreases in dissolved-oxygen concentrations tend to occur late in the summer when temperatures are higher and water levels and streamflow are lower. Chetomba Creek near Maynard (fig. 3B) stood out among the five sites for its small diurnal fluctuation in dissolved-oxygen concentrations. Chetomba Creek near Maynard had a drop structure where water is dropped to a lower level, dissipating energy and preventing the erosive effect of the water, before it reaches the water-quality monitoring site. This physical structure aerates the water, which leads to more stable dissolved-oxygen concentrations. In addition, there is a difference in land use between the upstream Chetomba Creek near Renville site and the downstream Chetomba Creek near Maynard site—with a substantial amount of riparian land retirement occurring between the two sites (fig. 2).

Fish and biological data were collected at three of the five sites (called primary data-collection sites). The Chetomba Creek site with the drop structure was not chosen for biological data collection because the researchers wanted to compare one site in each basin with similar hydrologic characteristics. The three sites compared were ranked from highest amount of land retirement (West Fork Beaver Creek, station 0531656290), moderate land retirement (Chetomba Creek, station 05314510), and lowest land retirement (South Branch Rush River, station 05326189) in the basin. Although South Branch Rush River had the lowest amount of land retirement in its basin as a whole, it had slightly more land retirement than Chetomba Creek within 50 meters of the stream.

In general, total nitrogen, suspended-sediment, and chlorophyll-*a* concentrations decreased, and fish resource quality improved with increasing land retirement. Total nitrogen concentrations were largest, with a mean of 15.0 milligrams per liter (mg/L), in water samples from the South Branch Rush River, a subbasin with little to no agricultural land retirement; total nitrogen concentrations were smaller in samples from Chetomba Creek (mean of 10.6 mg/L) and West Fork Beaver Creek (mean of 7.9 mg/L), which are subbasins with more riparian or upland land retirement at the basin scale. Total phosphorus concentrations were not related directly to differing land-retirement percentages with mean concentrations at primary data-collection sites of 0.259 mg/L in the West Fork Beaver Creek subbasin, 0.164 mg/L in the Chetomba Creek subbasin, and 0.180 mg/L in the South Branch Rush River subbasin. Fish data indicated better resource quality for the West Fork Beaver Creek subbasin than for other subbasins likely due to a combination of factors, including habitat quality, food resources, and dissolved-oxygen characteristics. Index of biotic integrity (IBI) scores increased as local land-retirement percentages (within 50 and 100 meters of the streams) increased.

Continuous data and analyses from this study were used to evaluate the success of agricultural management practices and land-retirement programs for improving stream quality. Surrogate relations can be developed from these records (Christensen, 2008), and the data can be used to guide decisions on which subbasins to concentrate efforts for improving stream quality.

FECAL COLIFORM BACTERIA IN THE QUIVIRA NATIONAL WILDLIFE REFUGE, KANSAS, USA

The purpose of this study was to characterize the surface-water quality of Rattlesnake Creek immediately upstream from the Quivira National Wildlife Refuge (fig. 4). This case study focuses on the estimation of fecal coliform bacteria, which is important to the health and safety of people who visit the refuge.

The Quivira National Wildlife Refuge is a wetland area located in the Rattlesnake Creek Basin in Kansas, USA (fig. 4). The refuge was established in 1953 to provide food, water, habitat, and protection for many species of birds, fish, and wildlife (Jian, 1998). Several species of waterfowl use the refuge in their annual migration, including the endangered Whooping Crane. The refuge is managed through the regulation of water levels in more than 30 marshes and ponds covering about 89 square kilometers.

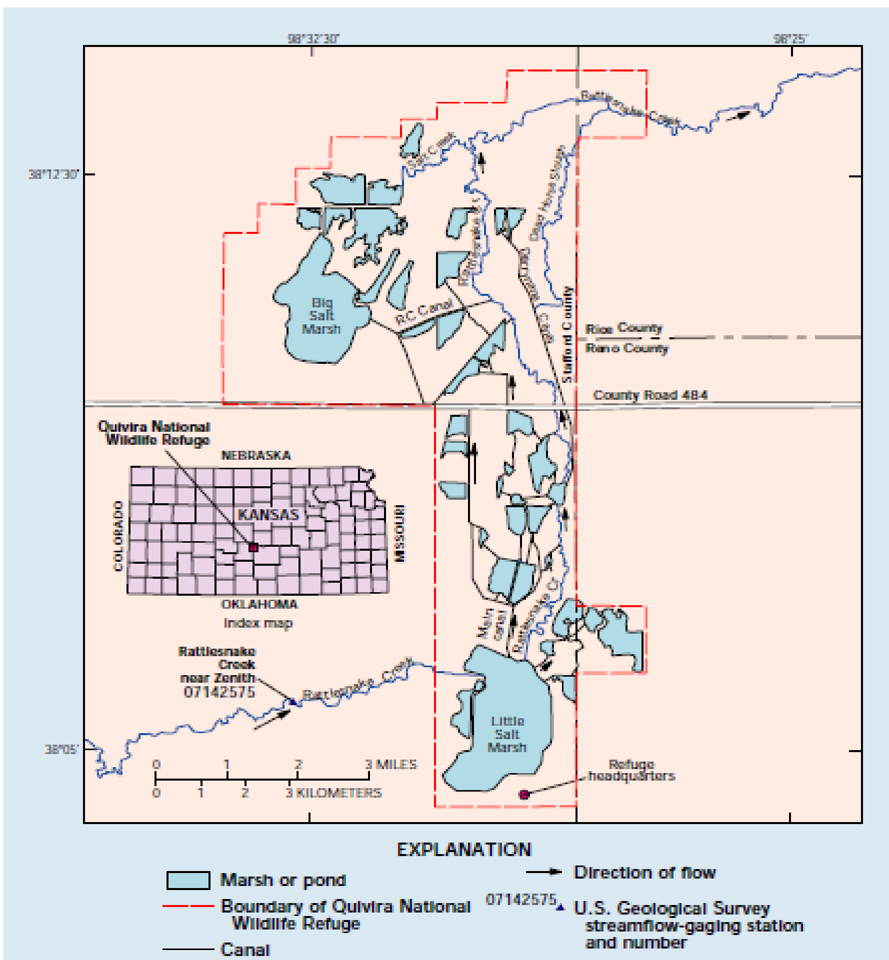

Figure 4. Location of Quivira National Refuge and Rattlesnake Creek, Kansas, USA (source: Christensen, 2001).

In the late summer during dry years, an adequate water supply is a problem as upstream water demands reduce the inflow from Rattlesnake Creek to the refuge. To sustain wildlife in the refuge, a dependable water supply of good quality is needed throughout the year.

Stream stage, streamflow, and the quality of water flowing from Rattlesnake Creek into the Quivira National Wildlife Refuge, were monitored by the USGS in cooperation with the U.S. Fish and Wildlife Service using in-stream real-time monitoring (Christensen, 1999). In addition, discrete water samples were collected periodically from December 1998 through June 2001. Those samples were analyzed for physical properties, dissolved solids, total suspended solids, suspended sediment, major ions, nutrients, metals, pesticides, and indicator bacteria (Christensen, 2001).

Because dissolved solids, sodium, chloride, fecal coliform bacteria, and other chemicals that may impair the health and habitat of fish and wildlife at the refuge cannot be measured continuously, regression equations were developed from a comparison of the analytical results of discrete samples and in-stream monitoring measurements of specific conductance, pH, water temperature, turbidity, and dissolved oxygen. A continuous record of estimated chemical concentrations was developed from continuously recorded in-stream measurements.

Through the least-squares regression process, certain explanatory variables were selected that had a significant relation (p-value less than 0.05) to the response variable. However, an explanatory variable was included in the regression equation only if there was a physical basis or explanation for its inclusion. Regression equations were developed between selected continuous water-quality variables and alkalinity, dissolved solids, total suspended-solids, suspended-sediment, sodium, chloride, fluoride, sulfate, nitrate, total organic nitrogen, and total phosphorus concentrations, and fecal coliform bacteria densities.

Measurement and real-time estimation of fecal coliform bacteria were of particular interest and the focus of this case study. The presence of fecal coliform bacteria in surface water indicates fecal contamination and possibly the presence of other microorganisms that could cause disease. Fecal coliform bacteria analyses also were chosen to highlight in this case study because the water-quality criteria for the State of Kansas specified limits of 200 colonies per 100 milliliters for primary contact recreation (such as swimming) and 2,000 colonies per 100 milliliters for secondary contact recreation (such as boating) (Kansas Department of Health and Environment, 2000). The Quivira National Wildlife Refuge is a destination for hunters, bird watchers, and other recreationalists, who may come into secondary contact with the water.

The regression equation developed to estimate continuous densities of fecal coliform bacteria was:

$\log_{10}FCB = -3.40\log_{10}WT + 0.432\log_{10}NTU + 6.53$ $R^2 = 0.661$

where *FCB* is fecal coliform bacteria in number of colonies per 100 milliliters, *WT* is water temperature in degrees Celsius, *NTU* is turbidity in nephelometric turbidity units, and R^2 is the coefficient of determination. A comparison of the measured and regression-estimated fecal coliform bacteria is shown in figure 5. The equations developed with this method are good only for the range in concentrations for the data used in their development. For this equation the range in fecal coliform bacteria was 90-20,000 colonies per 100 milliliters, the range in water temperature was 9.3-32.2 degrees Celsius, and the range for turbidity was 5-480 nephelometric turbidity units.

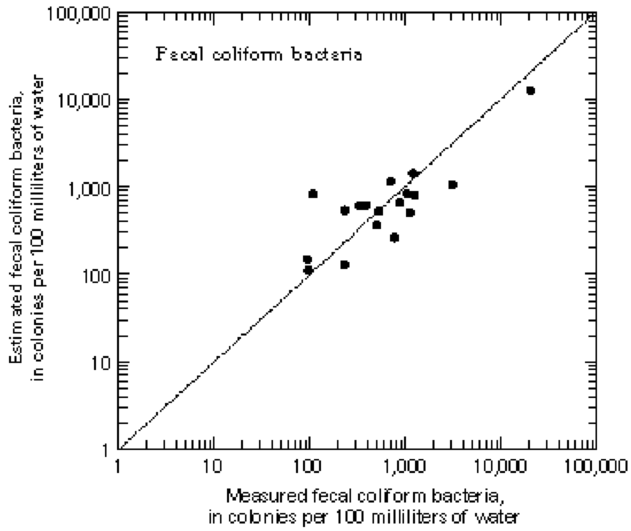

Figure 5. Comparison of measured and regression-estimated fecal coliform bacteria densities from December 1998 through June 2001 at Rattlesnake Creek near Zenith, Kansas, USA (source: Christensen, 2001).

Because runoff from a basin may transport fecal coliform bacteria to streams, bacteria densities generally vary with streamflow and time of year. Regression equations for fecal coliform bacteria in other studies have used time (either day of year or month of year) as the explanatory variable (Christensen and others, 2000, 2001). For the case study, however, no acceptable equation was found for the 23 samples collected between December 1998 and June 2001.

Bacteria densities are greatest during the summer months when recreational users may be exposed to the bacteria in surface water, therefore, the regression equation for fecal coliform was developed using data from only 18 samples collected during April 1 through October 31 (1998 through 2001). The regression equation is not valid for estimating fecal coliform bacteria densities for November through March. The relatively low R^2 for the fecal coliform bacteria equation (0.661) indicated that the equation has a higher degree of uncertainty compared with the R^2 for equations of other chemicals (0.710 to 0.960) in this study (Christensen, 2001). However, a large part of the uncertainty may be due to lack of precision in the analytical method rather than to lack of fit of the regression. Analytical error for the determination of fecal coliform bacteria can be as high as 50 percent (American Public Health Association and others, 1992); in addition, 3 of 18 water samples from the April 1 to October 31 dataset were not in the ideal colony count range (Myers and Wilde, 1999) for fecal coliform bacteria. Bacteria plate counts were outside the ideal range primarily for those samples with either very low or very high reported densities. Despite the uncertainty, the usefulness of regression-estimated concentrations to recreationalists and resource managers is evident (fig. 6).

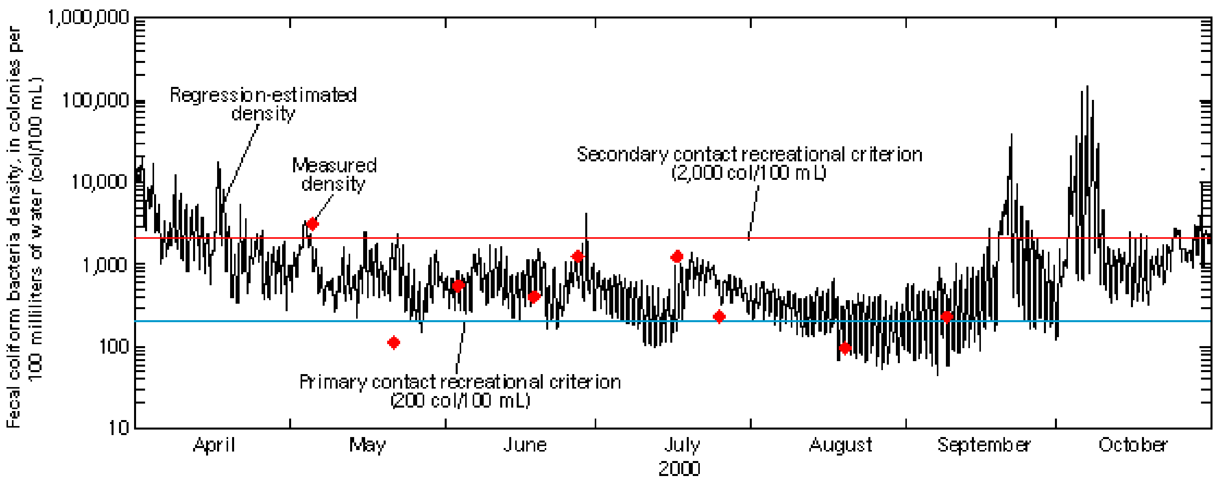

Figure 6. Comparison of measured and regression-estimated fecal coliform bacteria densities in water from April 1 through October 31, 2000, at Rattlesnake Creek near Zenith, Kansas, USA (source: Christensen, 2001).

The continuous and real-time nature of fecal coliform bacteria densities produced during this study (Christensen, 2001) may be important for resource managers, recreationalists, or others for evaluating water-diversion strategies, making water-use decisions, or assessing environmental effects in time to prevent adverse effects to visitors, fish, or aquatic life at the refuge.

ATRAZINE AND *EQUUS* BEDS GROUNDWATER RECHARGE DEMONSTRATION PROJECT, KANSAS, USA

The *Equus* Beds Groundwater Recharge Demonstration Project was designed to investigate the feasibility of using surface water from the Little Arkansas River to artificially recharge the *Equus* Beds aquifer (Ziegler and others, 1999; fig.7). The focus of this case study is the estimation of atrazine concentrations. Atrazine is a pesticide widely used in the Little Arkansas River Basin on corn crops and was identified by Ziegler and others (1999) as one of the primary constituents of concern for the recharge project.

The *Equus* Beds aquifer, which supplies some of the drinking water to the city of Wichita, is susceptible to chloride contamination (fig. 7). The source of the chloride is brine from oil and gas operations to the west. The recharge project may help improve water supply and reduce contamination of the aquifer by increasing its water level. An in-stream real-time monitoring system was developed by the USGS in Kansas in cooperation with the city of Wichita, to monitor the quality of the surface water used for artificial recharge (Christensen and others, 2000). Using real-time estimates of water quality for two USGS streamflow-gaging stations (stations 07143672 and 07144100) on the Little Arkansas River (fig. 7), the city of Wichita was able to determine when recharge was appropriate or when to treat the recharge water, thus preventing degradation of the *Equus* Beds aquifer by artificial recharge. The continuous real-time estimates of chemical concentrations provided by the monitoring system eliminated the waiting time for laboratory chemical analysis. Information from this monitoring system approach also may be used by downstream water suppliers to modify treatment of public water supplies.

Regression equations based on physical properties and analyses of water samples collected from 1995 to 1998 throughout 95 percent of the flow duration (fig. 8) were developed to estimate concentrations of seven chemicals including atrazine, the chemical highlighted in this case study, at two Little Arkansas River sites. Error was evaluated for the first year of data collection and each subsequent year, and a decrease in error was observed as the number of samples increased. Generally, 2 years of data (35 to 55 samples) collected throughout 90 to 95 percent of the flow duration for the period of record were sufficient to define the relation between a chemical and its surrogate(s). Relations and resulting equations were site specific.

Atrazine is of particular concern because of the potential effect of this pesticide on the water supply. During the growing season, March through September, automated samplers collected two or more samples per day at the two sampling sites (Christensen and Ziegler, 1998). During periods of low flow, October through February, fewer samples were collected, usually one per month. About 1,800 samples were analyzed for triazine herbicides by enzyme-linked immunosorbent assay (ELISA) (Thurman and others, 1990). The ELISA procedure is a cost-efficient and reliable indicator of atrazine. To confirm this, 191 samples also were analyzed by gas chromatography/mass spectrometry (GC/MS) to determine specific atrazine concentrations, which indicated that at least 90 percent of the triazine herbicide concentration determined by ELISA was atrazine (Christensen and Ziegler, 1998). Later analyses indicated 80 percent of the triazine herbicide concentration was atrazine (Christensen and Ziegler, 1998; Ziegler and others, 1999). During the growing season, linear interpolation was used to estimate concentrations between days with samples collected.

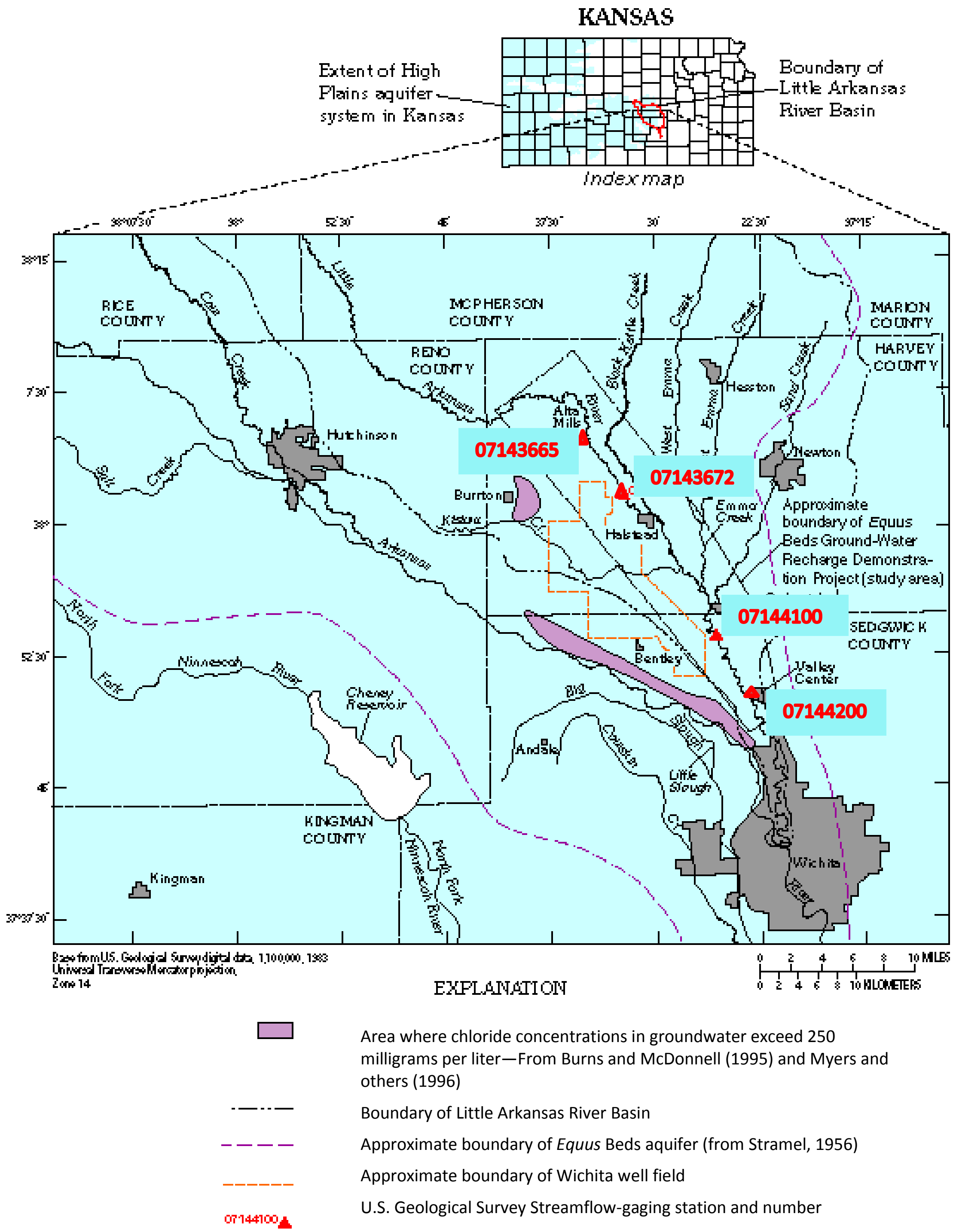

Figure 7. Location of Wichita well field, *Equus* Beds Groundwater Recharge Demonstration Project, Little Arkansas River, and areas where chloride concentrations in groundwater exceed 250 milligrams per liter in south-central Kansas, USA (source: Christensen and others, 2000).

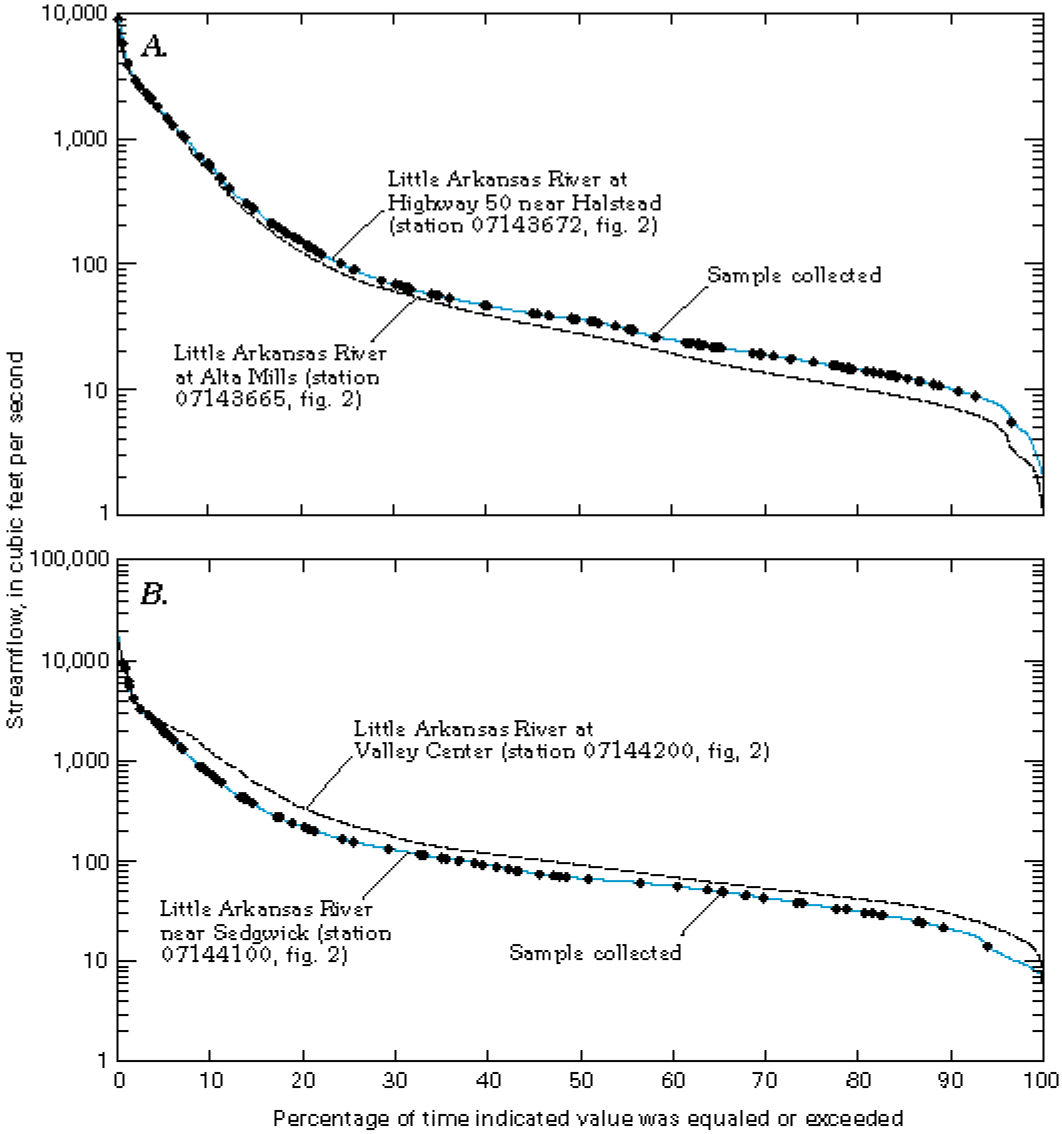

Figure 8. Flow-duration curves and samples collected from Little Arkansas River (A) at Alta Mills (1973–99), at Highway 50 near Halstead (1995–99), (B) near Sedgwick (1995–99), and at Valley Center (1922–99), Kansas, USA. Samples collected represent instantaneous streamflow during which each sample was collected (source: Christensen and others, 1999).

Although the ELISA results were available with a turnaround time of about 2 days, regression models were used to provide even more rapid dissemination of probable in-stream triazine concentrations. A regression model was developed at each site for triazine as follows:

Little Arkansas River at Highway 50 near Halstead (station 07143672)—

$$\log_{10}(triazine) = (1.42)e^{\frac{-(month-6.24)^2}{3.75}} - 0.0000288Q - 0.000581SC - 0.104\ ,\ R^2=0.777$$

Little Arkansas River near Sedgwick (station 07144100)—

$$\log_{10}(triazine) = (1.38)e^{\frac{-(month-5.94)^2}{3.92}} - 0.0000652Q - 0.000820SC - 0.0681, R^2=0.736$$

where *triazine* is the triazine concentration in micrograms per liter, *Q* is streamflow in cubic feet per second, and *SC* is specific conductance in microsiemens per centimeter at 25 degrees Celsius. The inverse relation with specific conductance is in agreement with the study by Ziegler and others (1999), which reported atrazine had an inverse relation with chloride and, therefore, with specific conductance. This inverse relation may be caused by chloride concentrations in the Little Arkansas River, which are associated with groundwater in the area. Chloride concentrations were large during the winter months when the percentage of streamflow coming from groundwater was high. During the winter months, atrazine concentrations were small in the Little Arkansas River, and atrazine concentrations in groundwater were very small or non-detectable in this area (Ziegler and others, 1999). The largest concentrations of atrazine in the Little Arkansas River occurred during the spring and summer when atrazine was applied to crops and when rainfall is most abundant (Christensen and Ziegler, 1998). Daily atrazine concentrations were largest in May through July (see for example fig. 9). Atrazine concentrations, therefore, are highly seasonal, which may account for the relation between time, streamflow, and triazine in the regression equation.

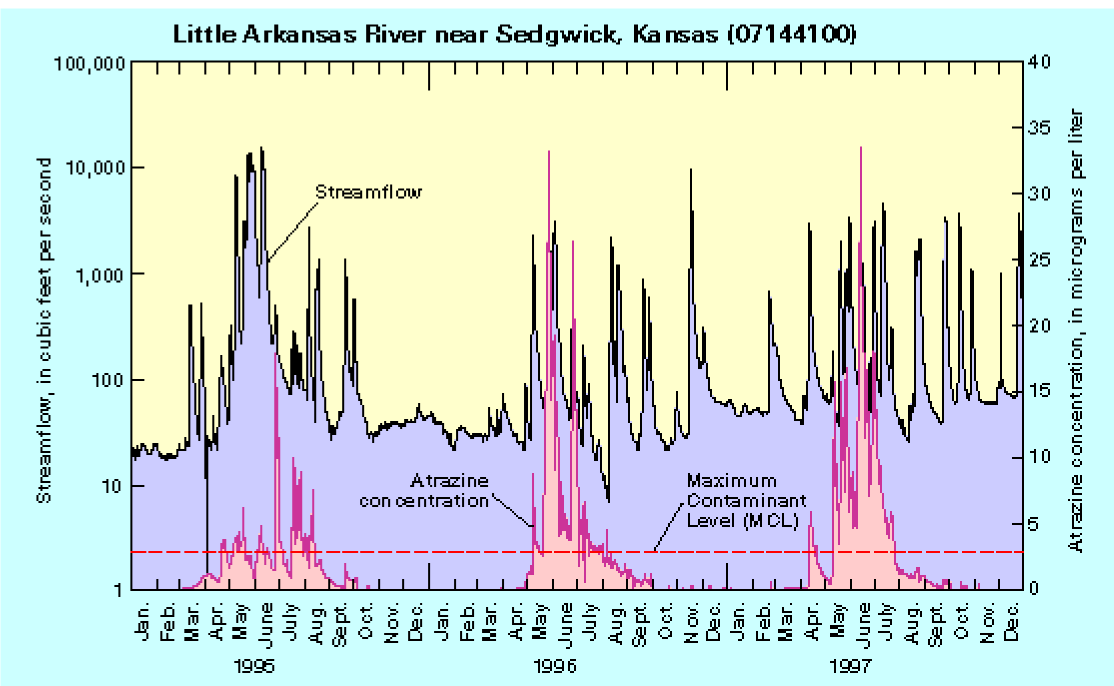

Figure 9. Daily mean streamflow and atrazine concentrations, 1995–97, for Little Arkansas River near Sedgwick, Kansas, USA (Source: Christensen and Ziegler, 1998).

Data from this study defined the seasonal distribution of atrazine in the Little Arkansas River and provided information related to timing and requirements for treatment of water withdrawn from the river for artificial recharge. During the growing season when streamflow generally is large and water is available for artificial recharge, atrazine concentrations also are high. Therefore, water treatment prior to recharge may be important to prevent degradation of the *Equus* Bed aquifer by atrazine.

ESTIMATION OF PHOSPHORUS IN THE EUCHA-SPAVINAW BASIN, OKLAHOMA, USA

The purpose of this study was to summarize nutrient concentrations estimated from continuous water-quality monitors in the Eucha-Spavinaw Basin in Arkansas and Oklahoma, USA (fig. 10). The focus of this case study is the estimation of phosphorus concentrations in order to better understand the causes of water-quality issues in Lake Eucha and Spavinaw Lake (Christensen and others, 2008).

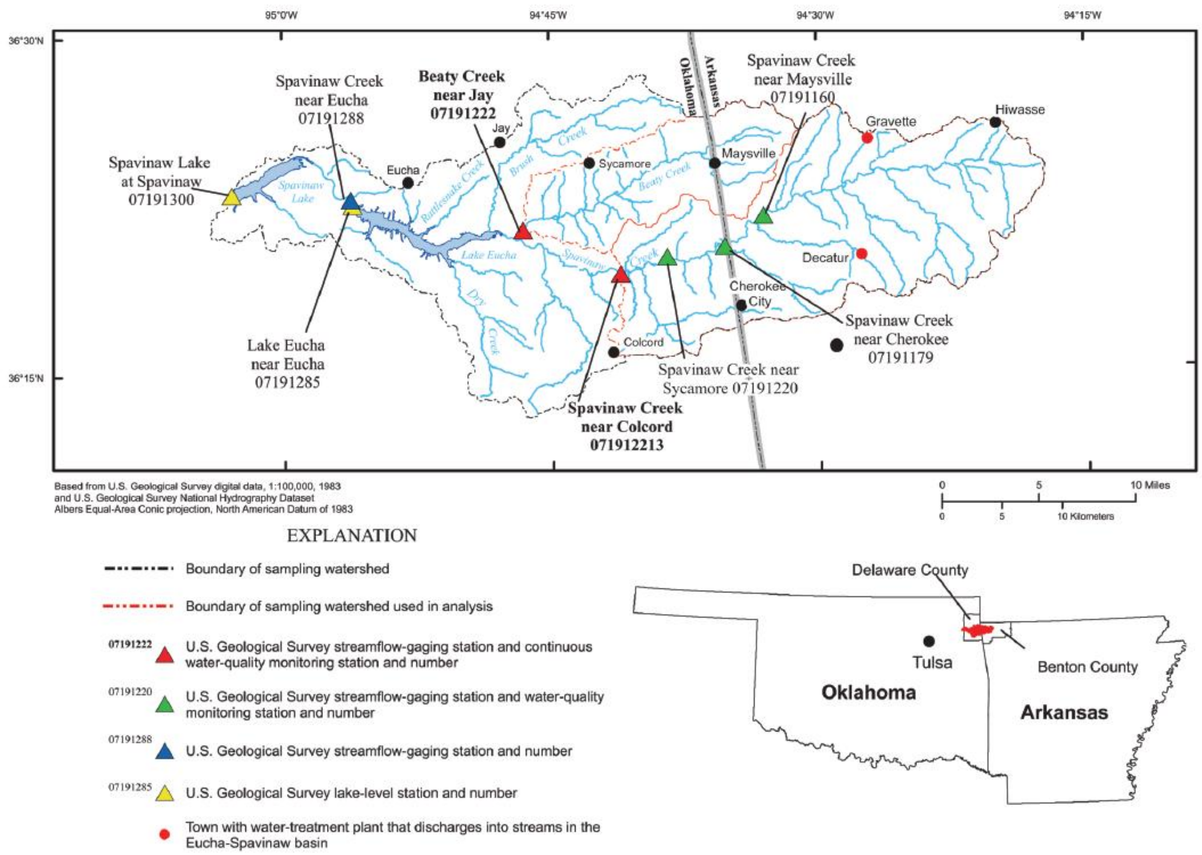

Figure 10. The Eucha-Spavinaw Basin, Arkansas and Oklahoma, USA, with locations of selected streamflow and water-quality stations (source: Christensen and others, 2008).

The Eucha-Spavinaw Basin (fig. 10) is the source of water for Lake Eucha and Spavinaw Lake, which are part of the water supply for the city of Tulsa, Oklahoma, USA. The city of Tulsa has received complaints of taste and odor in the finished drinking water because of deteriorating water quality. The deterioration is largely caused by algal growth from the input of nutrients from the Eucha-Spavinaw Basin. The USGS, in cooperation with the city of Tulsa, implemented a continuous, real-time water-quality monitoring program in the Eucha-Spavinaw Basin to better understand the sources of the nutrient loading.

The Eucha-Spavinaw Basin supports agriculture, forest, and small urban areas (Storm and others, 2002; DeLaune and others, 2006). The importance of agriculture in the basin is evident from the estimates of commercial fertilizer and manure applications for counties in the Eucha-Spavinaw Basin (Christensen and others, 2008). A possible major source of nutrients in the Eucha-Spavinaw Basin is the phosphorus-rich waste of commercial poultry growing operations (DeLaune and others, 2006). Poultry litter is used as a fertilizer for pastures in the basin.

Continuous water-quality monitors were installed at two existing continuous, real-time streamflow-gaging stations—Spavinaw Creek near Colcord, Oklahoma and Beaty Creek near Jay, Oklahoma, and data were collected from October 2004 through September 2007. Total phosphorus concentrations ranged from 0.04 to 1.5 mg/L for the water samples collected from Spavinaw Creek near Colcord and from 0.028 to 1.0 mg/L for the water samples collected from Beaty Creek near Jay. Data from water samples and in-stream monitors at Spavinaw and Beaty Creeks (specific conductance and turbidity) were used to develop regression equations relating in-stream water properties to total phosphorus concentrations. These equations were:

Spavinaw Creek near Colcord (071912213)—

$TP = 0.0009FNU + 0.001Q + 0.0806$, R^2=0.708

and

Beaty Creek near Jay (07191222)—

$TP = 0.0013FNU + 0.0003Q + 0.0425$, R^2=0.978

where *TP* is total phosphorus concentration in milligrams per liter, *FNU* is turbidity in formazin nephelometric units, and *Q* is streamflow in cubic feet per second.

The explanatory variables used for estimated total phosphorus concentrations at the Spavinaw and Beaty Creek sites were streamflow and turbidity. Total phosphorus and turbidity are related because turbidity is a measure of the amount of opaqueness caused by particulate matter in water and because phosphorus in water is mostly in the particulate form. The positive relation between total phosphorus and streamflow may indicate mostly nonpoint sources. When streamflow is high, runoff from the soils in the watershed is high and carries fertilizer, manure, and other chemicals to the stream. This phosphorus, in turn, flows to Lake Eucha providing nutrients for algae growth. Accelerated growth of algae can lead to eutrophication, which is undesirable for many reasons including taste and odor, fish health, aesthetics, and infilling of reservoirs.

The total phosphorus regression equation for Beaty Creek was similar to the equation for Spavinaw Creek. The equations developed for the Spavinaw and Beaty sites are site-specific and only valid for the concentration ranges of the explanatory variables used in the analysis. The range in estimated and measured total phosphorus concentrations was not well distributed for Spavinaw Creek or Beaty Creek (fig. 11). The Beaty equation is strongly influenced by one measurement at the high end. Although the equation coefficients did not change substantially when the high sample was omitted (Christensen and others, 2008), the range in estimated and measured phosphorus is not representative for the range of historical streamflow at the Beaty site. Visual evaluation of measured versus estimated plots for both regression equations (fig. 11) indicates that these sites would benefit from more high-flow and high-turbidity samples. In addition, all three study years had below-average annual precipitation for the area, and streamflow was especially low in water year 2006. Average nutrient concentrations from October 2004 through September 2007, which were drier than others, may not be good indicators of conditions in wetter years.

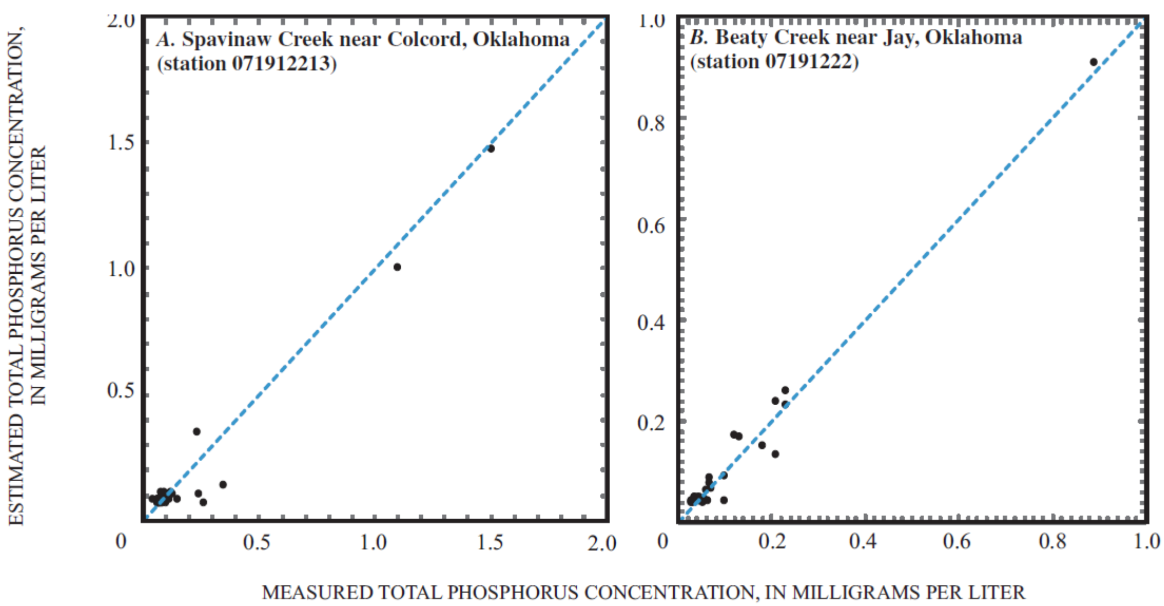

Figure 11. Comparison of measured and regression-estimated total phosphorus concentrations in water from (A) Spavinaw Creek and (B) Beaty Creek, Oklahoma, USA (source: Christensen and others, 2008).

The equations for the Spavinaw and Beaty sites were used to estimate instantaneous phosphorus concentrations, which can be used to compute loads and yields in real time in order to better characterize the effect of land-management practices in these watersheds on the transport of phosphorus to Lake Eucha and Spavinaw Lake. The methods used in this study show promise for monitoring future effectiveness of implemented best-management practices, early detection of taste-and-odor occurrences, and anticipating treatment needs for water suppliers.

TASTE-AND-ODOR COMPOUNDS IN CHENEY RESERVOIR, KANSAS, USA

The purpose of this study was to describe the water quality in the North Fork Ninnescah River and Cheney Reservoir in south-central Kansas, USA (fig. 12) and to investigate relations to taste-and-odor compounds. This case study focuses on the compound that was thought to cause the taste-and-odor issues in Cheney Reservoir, geosmin.

Cheney Reservoir, the primary water supply for the city of Wichita in south-central Kansas, and its main source of inflow, the North Fork Ninnescah River, were sampled between 1997 and 2003 for sediment, nutrients, and the taste-and-odor-causing compounds geosmin and 2-methylisoborneol (MIB) (Christensen and others, 2006). It is believed that objectionable tastes and odors in Cheney Reservoir result from cyanobacteria, also called blue-green algae (Smith and others, 2002), and there is concern about proliferation of algal growth in the reservoir. Both nutrients and suspended solids affect algal growth and may be a concern for taste-and-odor issues. The transport of nutrients and suspended solids from the North Fork Ninnescah River to Cheney Reservoir was monitored as part of an effort to understand and thereby mitigate algal proliferation.

Water samples from Cheney Reservoir were analyzed for geosmin and MIB, the two most common taste-and-odor causing compounds produced by cyanobacteria. MIB, with a reporting level of 0.005 micrograms per liter, was rarely detected in samples, indicating that geosmin is likely the primary source of objectionable tastes and odors.

A regression equation was developed between geosmin and the physical property measurements continuously recorded by water-quality monitor. The regression equation for geosmin was:

$\log Geo = -1.07 \log FNU - 0.0097 SC + 7.23$, R^2=0.709

where *Geo* is geosmin concentration in micrograms per liter, *FNU* is turbidity in formazin nephelometric units, and *SC*, is specific conductance in microsiemens per centimeter at 25 degrees Celsius. The geosmin regression equation was applied to water-quality monitor measurements, providing a continuous estimate of geosmin for 2003 (fig. 13). Relations between geosmin and turbidity and specific conductance may reflect the influence of light and nutrients on geosmin concentrations. The relation between geosmin and turbidity was negative, indicating geosmin concentrations decreased under low-light conditions. The negative association between geosmin concentrations and specific conductance may reflect the effect of nitrate on both cyanobacterial growth and geosmin production by cyanobacteria.

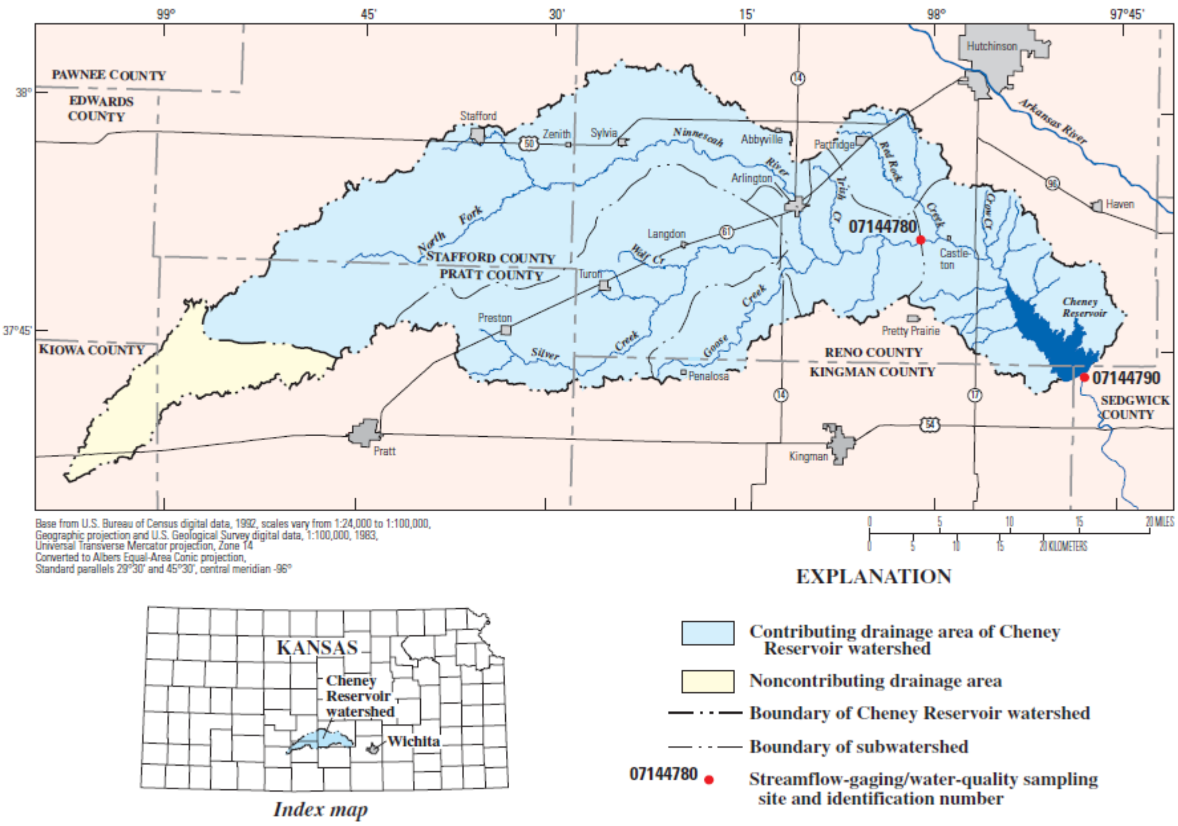

Figure 12. Location of Cheney Reservoir watershed and streamflow-gaging/water-quality sampling sites, south-central Kansas, USA (source: Christensen and others, 2006).

Evaluation of the current (2011) real-time geosmin regression equation for Cheney Reservoir indicates that, within existing limits of the calibration dataset (turbidity less than 36 formazin nephelometric units and specific conductance between 790-915 microsiemens per centimeter), geosmin estimates are conservative (the regression equation is more likely to overestimate concentrations than underestimate concentrations). The city of Wichita will be able to use this type of analysis to determine the probability of when concentrations of geosmin are likely to be at or greater than the human detection level of 0.01 microgram per liter. Knowledge gained from the continuous water-quality studies in Cheney Reservoir and its main source of inflow has assisted in the development, implementation, maintenance, and assessment of watershed-management goals and plans to maintain Cheney Reservoir as a public-water supply and recreational resource.

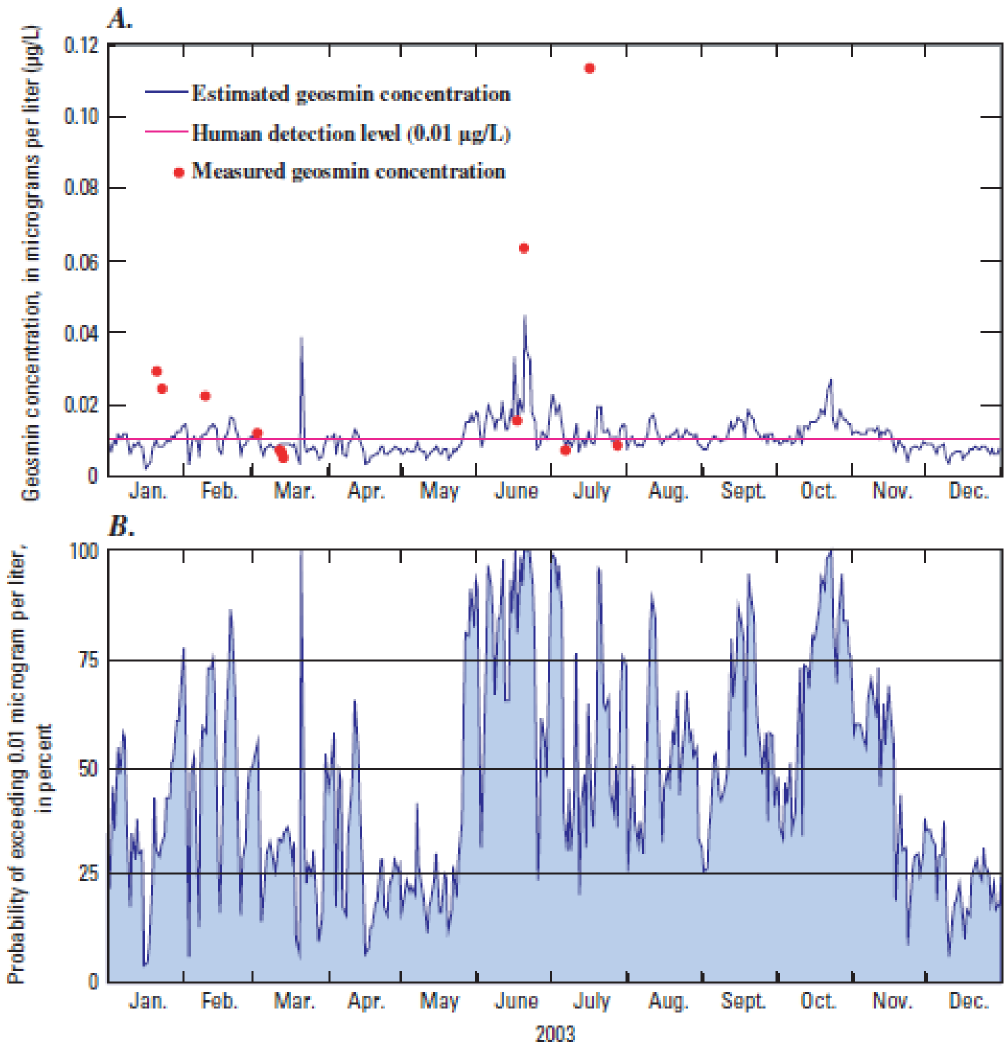

Figure 13. Comparison of (A) measured and regression-estimated geosmin concentrations in water samples from Cheney Reservoir, Kansas, USA, 2003, and (B) probability of exceeding the human detection level of 0.01 microgram per liter (source: Christensen and others, 2006).

CONCLUSIONS

The case studies presented herein cover a diverse range of chemical and biological characteristics using continuous, real-time, in-stream water-quality monitoring and surrogate relations. Additional research is available describing other surrogates and other constituents, such as sediment concentration (Rasmussen and others, 2009), bacteria concentrations (Rasmussen and Ziegler, 2003), major ions (Ryberg, 2006, 2007), and ecosystem processes such as stream metabolism (Graham and others, 2010). The network of real-time water-quality stations and data can be viewed at *http://waterwatch.usgs.gov/wqwatch/* or at *http://nrtwq.usgs.gov*, where several different chemicals are estimated for various sites, and shows the broad application and utility of this approach. Continuous in-stream water-quality and streamflow monitoring has the following uses:

- Enables identification of seasonal trends in physical properties and chemical constituents.
- May provide more accurate estimates for chemical loads transported in streams with estimates of the error.
- May decrease the need for some sampling or optimize timing of sample collection.
- Provides real-time information on the daily exposure of biota in the streams—in contrast to manual samples that were collected during daylight hours.
- Provides water-resource managers with the necessary information to make immediate decisions regarding their water supply.
- May help indicate which subbasin to concentrate efforts with regard to land-resource best-management practices.
- Allows recreationalists to make water-use decisions.

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