

Relations of Water-Quality Constituent Concentrations to Surrogate Measurements in the Lower Platte River Corridor, Nebraska, 2007 through 2011



Open-File Report 2014–1149

Cover photograph, looking northwest, upstream on the Platte River from bridge on Nebraska State Hwy 50, Nebraska, October 28, 2013. Photograph by Matt Moser, Nebraska Water Science Center.

Relations of Water-Quality Constituent Concentrations to Surrogate Measurements in the Lower Platte River Corridor, Nebraska, 2007 through 2011

By Nathaniel J. Schaepe, Philip J. Soenksen, and David L. Rus

Prepared in cooperation with the Lower Platte River Corridor Alliance and the Nebraska Environmental Trust

Open-File Report 2014–1149

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior

SALLY JEWELL, Secretary

U.S. Geological Survey

Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2014

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment, visit <http://www.usgs.gov> or call 1–888–ASK–USGS.

For an overview of USGS information products, including maps, imagery, and publications, visit <http://www.usgs.gov/pubprod>.

To order this and other USGS information products, visit <http://store.usgs.gov>.

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Although this information product, for the most part, is in the public domain, it also may contain copyrighted materials as noted in the text. Permission to reproduce copyrighted items must be secured from the copyright owner.

Suggested citation:

Schaepe, N.J., Soenksen, P.J., and Rus, D.L., 2014, Relations of water-quality constituent concentrations to surrogate measurements in the lower Platte River corridor, Nebraska, 2007 through 2011: U.S. Geological Survey Open-File Report 2014–1149, 16 p., <http://dx.doi.org/10.3133/ofr20141149>.

ISSN 2327–638X (online)

Contents

Abstract	1
Introduction	1
Purpose and Scope	2
Study Area	2
Approach and Methods	4
Collection and Analysis of Water Samples	4
U.S. Geological Survey Sampling Criteria and Methods.....	4
Nebraska Department of Environmental Quality Sampling Criteria and Methods	6
Surrogate Measurements—Water-Quality Physical Properties and Streamflow	6
Continuous Water-Quality Measurements	6
Streamflow Data	7
Periods of Missing Data	7
Quality Assurance and Quality Control	8
Development of Statistical Models.....	8
Relations of Sampled Constituents to Surrogate Measurements: Statistical Models	9
Nutrients.....	9
Major Ions.....	10
Pesticides.....	10
Suspended Sediment.....	10
<i>Escherichia coli</i> (<i>E. coli</i>) Bacteria	11
Summary	13
References Cited	13
Appendix: Sample Data Comparability	15

Figures

1. Map showing location of study area and water-quality monitoring sites on the main stem and tributaries of the lower Platte River in eastern Nebraska

Tables

1.	Water-quality constituent data from discrete samples collected by the U.S. Geological Survey (USGS) and the Nebraska Department of Environmental Quality (NDEQ) at four sites in the lower Platte River corridor, Nebraska during 2007 through 2011	5
2.	Range of values by monitoring site in continuous water-quality datasets for the lower Platte River corridor, Nebraska, collected during 2007 through 2011	7
3.	Regression models for selected water-quality constituents at four monitoring sites in the lower Platte River corridor, Nebraska, 2007 through 2011	11
1-1.	Summary of U.S. Geological Survey (USGS) and Nebraska Department of Environmental Quality (NDEQ) left-censored sample data excluded from sample method comparison analysis, lower Platte River corridor, Nebraska, during 2007 through 2011 ..	15
1-2.	Summary of statistical comparison of datasets collected using depth- and flow-integrated methods with those collected using single point (grab) sampling methods, lower Platte River corridor, Nebraska, during 2007 through 2011	16

Conversion Factors, Datums, and Water-Quality Units

Multiply	By	To obtain
Length		
inch (in.)	2.5400	centimeter (cm)
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.6092	kilometer (km)
Area		
square mile (mi ²)	2.5900	square kilometer (km ²)
Volume		
liter (L)	33.82	ounce, fluid (fl. oz)
liter (L)	0.2642	gallon (gal)
cubic feet (ft ³)	0.0283	cubic meter (m ³)
Flow rate		
cubic foot per second (ft ³ /s)	0.0283	cubic meter per second (m ³ /s)
Mass		
gram	0.03527	ounce, avoirdupois (oz)
Concentration		
microgram per liter (µg/L)	1	part per billion
milligram per liter (mg/L)	1	part per million
milligram per liter (mg/L)	0.058	grain per gallon (gr/gal)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$^{\circ}\text{F}=(1.8\times^{\circ}\text{C})+32$$

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Turbidity units are given in Formazin Nephelometric Units (FNU).

Relations of Water-Quality Constituent Concentrations to Surrogate Measurements in the Lower Platte River Corridor, Nebraska, 2007 through 2011

By Nathaniel J. Schaepe, Philip J. Soenksen, and David L. Rus

Abstract

The lower Platte River, Nebraska, provides drinking water, irrigation water, and in-stream flows for recreation, wildlife habitat, and vital habitats for several threatened and endangered species. The U.S. Geological Survey (USGS), in cooperation with the Lower Platte River Corridor Alliance (LPRCA) developed site-specific regression models for water-quality constituents at four sites (Shell Creek near Columbus, Nebraska [USGS site 06795500]; Elkhorn River at Waterloo, Nebr. [USGS site 06800500]; Salt Creek near Ashland, Nebr. [USGS site 06805000]; and Platte River at Louisville, Nebr. [USGS site 06805500]) in the lower Platte River corridor. The models were developed by relating continuously monitored water-quality properties (surrogate measurements) to discrete water-quality samples. These models enable existing web-based software to provide near-real-time estimates of stream-specific constituent concentrations to support natural resources management decisions.

Since 2007, USGS, in cooperation with the LPRCA, has continuously monitored four water-quality properties seasonally within the lower Platte River corridor: specific conductance, water temperature, dissolved oxygen, and turbidity. During 2007 through 2011, the USGS and the Nebraska Department of Environmental Quality collected and analyzed discrete water-quality samples for nutrients, major ions, pesticides, suspended sediment, and bacteria. These datasets were used to develop the regression models. This report documents the collection of these various water-quality datasets and the development of the site-specific regression models.

Regression models were developed for all four monitored sites. Constituent models for Shell Creek included nitrate plus nitrite, total phosphorus, orthophosphate, atrazine, acetochlor, suspended sediment, and *Escherichia coli* (*E. coli*) bacteria. Regression models that were developed for the Elkhorn River included nitrate plus nitrite, total Kjeldahl nitrogen, total phosphorus, orthophosphate, chloride, atrazine, acetochlor, suspended sediment, and *E. coli*. Models developed for Salt Creek included nitrate plus nitrite, total Kjeldahl nitrogen, suspended sediment, and *E. coli*. Lastly, models developed for the Platte River site included total Kjeldahl nitrogen, total phosphorus, sodium, metolachlor, atrazine, acetochlor, suspended sediment, and *E. coli*.

Introduction

The lower Platte River is an important resource for Nebraskans that serves a variety of uses including drinking-water supply, recreation, irrigation, and habitat for threatened and endangered species and other fish and wildlife. Resource managers of the lower Platte River rely on results of water-quality monitoring to make a range of decisions, such as whether management practices are effective or warranted, whether the source water supplying nearby drinking-water wells is safe, or whether swimming and boating in the river may expose recreationists to unsafe contaminant levels.

Since 2007, the U.S. Geological Survey (USGS), in cooperation with the Lower Platte River Corridor Alliance (members include three Nebraska Natural Resources Districts, [Lower Platte South, Lower Platte North, and Papio-Missouri River] and six state agencies [Nebraska Department of Environmental Quality, Nebraska Department of Natural Resources, Nebraska Department of Health and Human Services, Nebraska Game and Parks Commission, University of Nebraska-Lincoln School of Natural Resources Conservation and Survey Division and Nebraska Water Center, and the Nebraska Military Department]) has operated water-quality monitors at several sites within the lower Platte River corridor (fig. 1). Continuously monitored properties include water temperature, specific conductance, dissolved oxygen, and turbidity; and monitoring seasons included most of each year (typically March through October). In addition, discrete water-quality samples were collected periodically from several of the continuously monitored sites by multiple agencies. The data resulting from these efforts were reported by agency publications and Web sites, such as the biennial Water-Quality Integrated Report (Nebraska Department of Environmental Quality, 2010, 2012) or the USGS National Water Information System (<http://nwis.waterdata.usgs.gov/nwis>). This report documents statistical relations between continuous water-quality-property data and discrete water-quality samples, which were developed to estimate concentrations or densities of water-quality constituents of interest on a continuous basis. High temporal resolution can be particularly important following rainstorm events when runoff-laden streamflow might contain high levels of contaminants such as suspended

sediment, pesticides, and *Escherichia coli* (*E. coli*) bacteria. During these events water-quality conditions can change quickly and events may only last for a short time during which manual sampling crews may not have opportunity to travel between and sample at more than a small number of sites. Real-time constituent data have been made publicly available by the USGS through the National Real-Time Water Quality (NRTWQ) web site (<http://nrtwq.usgs.gov>).

Purpose and Scope

The purpose of this report is to document statistical relations of concentrations of selected water-quality constituents to concomitant sensor measurements of physical properties (surrogates) at several representative monitoring sites in the lower Platte River corridor. These relations will support the implementation of an internet-based system for presenting continuous estimates of constituent concentrations and loads to the public in near-real time through the NRTWQ webpage (<http://nrtwq.usgs.gov>). Providing real-time estimates of constituent-concentration data can enable resource managers to make well informed water-quality management decisions.

Four USGS monitoring sites were included in this study. In an upstream to downstream direction these were Shell Creek near Columbus, Nebraska (USGS site 06795500); Elkhorn River at Waterloo, Nebr. (USGS site 06800500); Salt Creek near Ashland, Nebr. (USGS site 06805000); and Platte River at Louisville, Nebr. (USGS site 06805500)(fig. 1). These sites will hereinafter be called Shell Creek, Elkhorn River, Salt Creek, and Platte River, respectively. These sites were selected to represent the lower Platte River and its major subbasins in the study area.

Constituent models developed for Shell Creek included nitrate plus nitrite, total phosphorus, orthophosphate, atrazine, acetochlor, suspended sediment, and *E. coli* bacteria. Models that were developed for the Elkhorn River included nitrate plus nitrite, total Kjeldahl nitrogen, total phosphorus, orthophosphate, chloride, atrazine, acetochlor, suspended sediment, and *E. coli*. Models developed for Salt Creek included nitrate plus nitrite, total Kjeldahl nitrogen, suspended sediment, and

E. coli. Lastly, models developed for the Platte River site included total Kjeldahl nitrogen, total phosphorus, sodium, metolachlor, atrazine, acetochlor, suspended sediment, and *E. coli*. Data used for the analyses described in this report were collected during 2007 through 2011.

Study Area

The area for this study includes the Platte River corridor, downstream from the confluence with the Loup River near Columbus, Nebr., and extending 103 miles to its mouth at the Missouri River, hereinafter referred to as the lower Platte River corridor (LPRC) (fig. 1). Though most of the Platte River Basin is situated upstream from the Loup River confluence, streamflow in the LPRC originates primarily from the tributaries within the LPRC, especially from the Loup River, the corresponding Loup River Canal, and the Elkhorn River. Mean annual streamflow increases by about 450 percent between the confluence with the Loup River and the Platte River mouth (Dietsch and others, 2009). The Loup River drains approximately 15,100 square miles (mi²) and the flow is delivered to the Platte River at its mouth and at the spillway of the Loup River Power Canal. Hydropower return outflows from the Loup River Power Canal introduce an oscillatory streamflow pattern to the lower Platte River (Elliott and others, 2009). Shell Creek is another tributary to the Platte River that drains a highly agricultural watershed of about 500 mi². It has been reported that animal waste from lagoons or tank trucks is the suspected source of organic pollution released into Shell Creek on various occasions, usually during higher streamflows (Hammel, 2008). The Elkhorn River drains approximately 7,000 mi² and enters the Platte River from the north just upstream from the mouth of Salt Creek. Salt Creek flows south to north to the Platte River and drains approximately 1,600 mi², including the city of Lincoln. Although the focus of this study was on the lower Platte River main stem, tributary sites were included as part of a regional approach to help identify the relative contributions of water-quality constituents from larger subbasins.

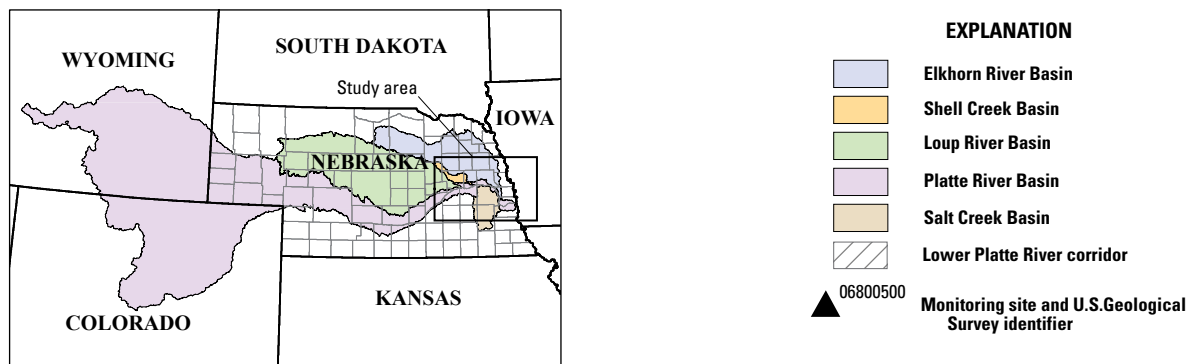
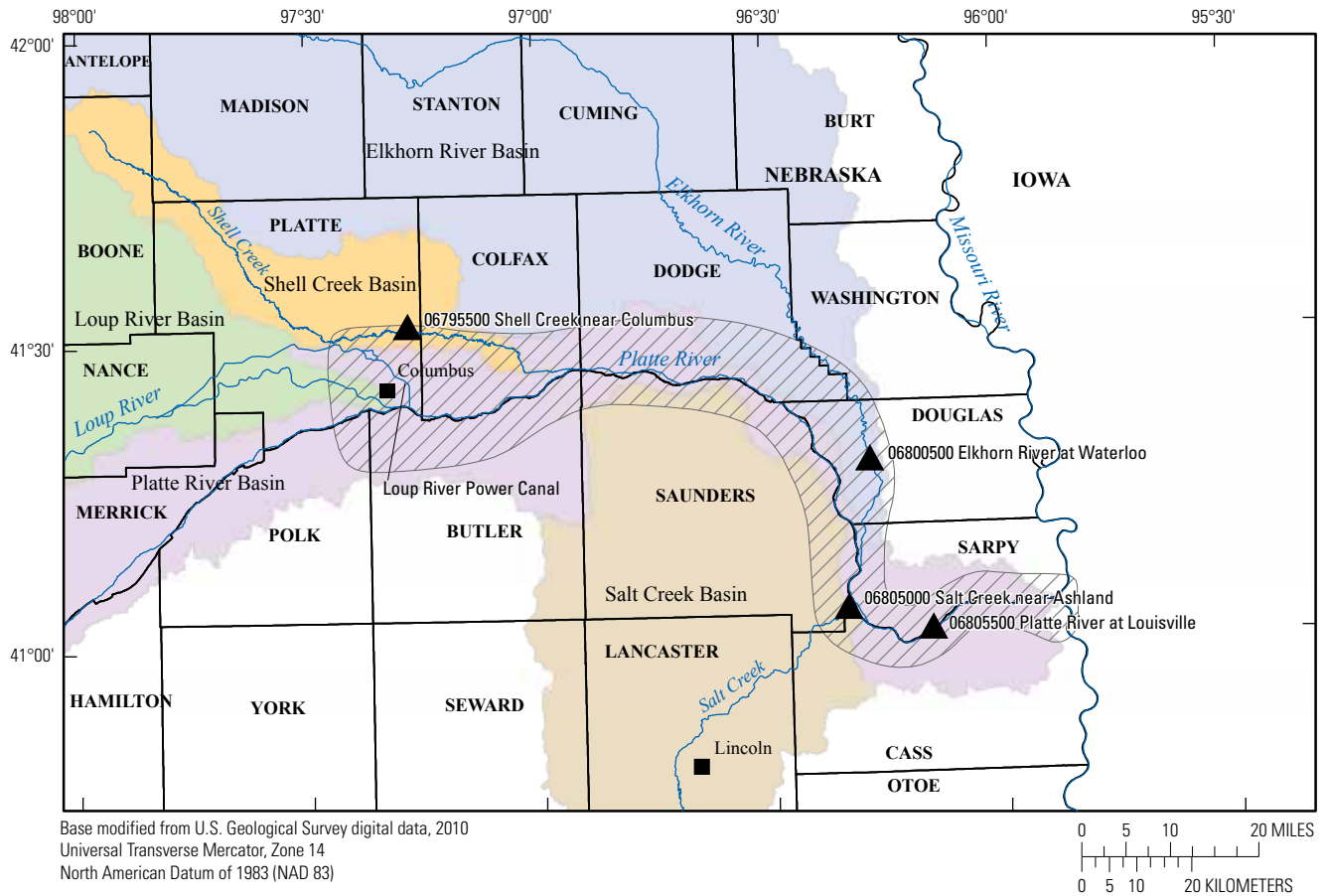


Figure 1. Location of study area and water-quality monitoring sites on the main stem and tributaries of the lower Platte River in eastern Nebraska.

Approach and Methods

The general approach used to develop statistical models was to compile laboratory-analyzed constituent concentrations and concurrent measurements of surrogate water properties, and then to develop statistical models to relate the constituent concentrations to the surrogate water properties. All of the sites, with the exception of Salt Creek, had water-quality concentration data for bacteria, nutrients, major ions, pesticides, and sediment, as well as concomitant continuous surrogate property data (streamflow, water temperature, specific conductance, dissolved oxygen, and turbidity). Salt Creek did not have major ions or pesticide water-quality constituent data, or real-time streamflow data available. Analytical laboratory determinations from periodic water samples provided water-quality constituent concentrations. Surrogate data were collected either from continuous in-place sensor measurements or determinations made using discrete samples collected during periodic sampling. Linear-regression techniques were used to develop statistical models that were statistically valid and physically meaningful for each monitoring site.

Collection and Analysis of Water Samples

Discrete water-quality samples were collected separately by USGS and Nebraska Department of Environmental Quality (NDEQ) personnel. Except for the *E. coli* bacteria sampling by the USGS, each agency collected samples on regular time schedules and did not target specific ranges of streamflows. In addition to the scheduled sampling, efforts were made by the USGS to collect samples for determining *E. coli* bacteria density over a wide range of flows at each site; thus, some higher flows were specifically targeted and a larger proportion of higher flows likely were represented in those data.

U.S. Geological Survey Sampling Criteria and Methods

The USGS collected discrete water-quality samples during 2007 through 2011. Except for *E. coli* bacteria sampling at all sites, and nutrient sampling at Salt Creek, all USGS samples were collected at a fixed-time interval as part of the National Water-Quality Assessment (NAWQA) Program (<http://water.usgs.gov/nawqa/>). Sampled constituents included nutrients (nitrogen and phosphorus species), pesticides (atrazine, metolachlor, and acetochlor), major ions (sodium and chloride), suspended sediment, and bacteria (*E. coli*).

Whereas NAWQA samples were collected at the Platte River every year during this study, NAWQA samples at Shell Creek were collected exclusively in 2009 and at Elkhorn River in 2007 and 2011. Nutrient, pesticide, and suspended-sediment concentration samples were collected following

protocols documented in the USGS *National Field Manual* (U.S. Geological Survey, variously dated). Sample collection was done at all streamflow rates either by wading or suspending equipment from a bridge. Samples from each vertically sampled interval were composited and mixed in a churn splitter before representative subsamples for each type of analyses were drawn off. All nutrient, major-ion and pesticide samples were analyzed at the USGS National Water Quality Laboratory (NWQL) at Denver, Colorado, and analyzed according to methods described in Fishman and Friedman (1989), and Sandstrom and others (2001). Suspended-sediment samples were analyzed at the USGS sediment laboratory at Iowa City, Iowa, according to methods presented in Guy (1969).

Samples were collected at Salt Creek during 2009 through 2011. Only *E. coli* samples were collected in 2009, and sampling for nutrients and suspended sediment was added in 2010. Depth- and width-integrating techniques (Wilde, 2008; U.S. Geological Survey, 2006) were used for sampling at all sites, but Salt Creek samples were collected by a single hydrologic technician; thus, it was not possible to maintain the standard practice whereby separate technicians are designated “clean hands” and “dirty hands,” respectively (U.S. Geological Survey, variously dated).

A series of point samples and single-vertical depth-integrated samples for bacteria and suspended sediment also were collected at the water-quality sensor location at each site for this study. These samples tended to correspond to field visits for the maintenance of monitoring equipment or with periodic or event-oriented sampling. For this type of sampling, higher flows were opportunistically sampled to cover as wide a range in streamflows as possible. Bacteria samples were collected in a sterilized bottle dipped into the water adjacent to the monitor, if the stream was wadeable; otherwise, it was lowered from the bridge into the upper part of the water profile near the location of the water quality monitor in a weighted-bottle sampler. The water samples collected for bacterial determinations were analyzed within 24 hours at the Nebraska Public Health Environmental Laboratory (NPHEL), Lincoln, Nebr., operated by the Nebraska Department of Health and Human Services (NDHHS) using the Quantitray 2000 method (IDEXX, 2006). For suspended-sediment sampling, the preferred method was to collect a depth-integrating sample, as done for the flow-weighted samples, but for sensor-collocated samples the entire water column was collected at a single vertical at the water-quality monitor (WQM) location. During high flows, the weighted-bottle method was used because the turbulent flows around the piers where the WQMs were located made it difficult to use the depth-integrating sampler without damaging it. The single-vertical suspended-sediment samples near the monitors allowed for concentrations to be compared to the flow-weighted concentrations collected for the NAWQA program to evaluate representativeness.

Table 1. Water-quality constituent data from discrete samples collected by the U.S. Geological Survey (USGS) and the Nebraska Department of Environmental Quality (NDEQ) at four sites in the lower Platte River corridor, Nebraska during 2007 through 2011.[*n*, sample size; St. dev., standard deviation; —, no data available; <, less than]

Water-quality constituent	NDEQ				USGS			
	<i>n</i>	Range	Median	St. dev.	<i>n</i>	Range	Median	St. dev.
Shell Creek near Columbus (06795500)								
Nitrogen as nitrate and nitrite, water, filtered, milligrams per liter	59	1.83–14.0	3.70	2.01	27	1.28–6.00	3.42	1.26
Phosphorus, water, unfiltered, total as phosphorus, milligrams per liter	59	0.29–8.21	0.49	1.66	27	0.22–3.25	0.39	0.64
Orthophosphate, water, filtered, milligrams per liter as phosphorus	—	—	—	—	27	0.10–0.47	0.25	0.11
Atrazine, water, filtered, recoverable, micrograms per liter	44	0.01–36.3	0.47	5.84	24	0.02–15.5	0.45	3.75
Acetochlor, water, filtered, recoverable, micrograms per liter	44	0.07–29.3	0.98	4.98	24	<0.01–4.56	0.09	1.18
Suspended sediment concentration, milligrams per liter	—	—	—	—	36	10.0–5,370	161	882
<i>Escherichia coli</i> , defined substrate technology, water, most probable number per 100 milliliters	—	—	—	—	13	100–170,000	900	53,418
Elkhorn River at Waterloo (06800500)								
Nitrogen as nitrate and nitrite, water, filtered, milligrams per liter	60	0.50–5.75	3.32	1.17	36	0.53–5.97	3.69	1.32
Total Kjeldahl nitrogen, water unfiltered, milligrams per liter	60	0.67–5.23	2.04	1.13	—	—	—	—
Phosphorus, water, unfiltered, total as phosphorus, milligrams per liter	60	0.34–2.18	0.56	0.45	36	0.27–1.96	0.65	0.39
Orthophosphate, water, filtered, milligrams per liter as phosphorus	—	—	—	—	36	0.01–0.48	0.26	0.41
Chloride, water, filtered, milligrams per liter	60	3.58–15.6	11.9	2.44	35	6.49–17.4	11.2	2.42
Atrazine, water, filtered, recoverable, micrograms per liter	45	<0.05–4.12	0.17	1.00	32	0.02–7.54	0.22	1.43
Acetochlor, water, filtered, recoverable, micrograms per liter	45	<0.07–4.73	0.20	0.92	32	<0.01–4.01	0.05	0.71
Suspended sediment concentration, milligrams per liter	—	—	—	—	49	16–9,820	644	1,568
<i>Escherichia coli</i> , defined substrate technology, water, most probable number per 100 milliliters	20	55.5–19,863	220	4,463	22	0–200,000	890	42,785
Salt Creek near Ashland (06805000)								
Nitrogen as nitrate and nitrite, water, filtered, milligrams per liter	—	—	—	—	15	0.66–3.44	2.52	0.79
Total Kjeldahl nitrogen, water unfiltered, milligrams per liter	—	—	—	—	15	0.68–4.30	1.00	1.34
Suspended sediment concentration, milligrams per liter	—	—	—	—	16	31–2,080	104	776
<i>Escherichia coli</i> , defined substrate technology, water, most probable number per 100 milliliters	—	—	—	—	23	80–120,000	700	25,215
Platte River at Louisville (06805500)								
Total Kjeldahl nitrogen, water unfiltered, milligrams per liter	60	0.58–8.40	2.13	1.36	50	0.39–8.00	1.74	1.49
Phosphorus, water, unfiltered, total as phosphorus, milligrams per liter	60	0.25–2.87	0.53	0.53	82	0.24–2.54	0.51	0.45
Sodium, water, filtered, milligrams per liter	12	20.8–52.0	28.9	9.10	50	15.2–111	52.7	19.8
Metolachlor, water, filtered, recoverable, micrograms per liter	45	<0.07–2.93	0.18	0.67	63	0.01–3.91	0.09	0.85
Atrazine, water, filtered, recoverable, micrograms per liter	45	<0.05–8.03	0.27	1.87	63	0.03–6.38	0.20	1.48
Acetochlor, water, filtered, recoverable, micrograms per liter	45	<0.07–10.1	0.28	1.84	63	0.00–2.93	0.02	0.59
Suspended sediment concentration, milligrams per liter	—	—	—	—	74	23.0–5,170	660	999
<i>Escherichia coli</i> , defined substrate technology, water, most probable number per 100 milliliters	—	—	—	—	46	2.50–20,000	610	4,592

Nebraska Department of Environmental Quality Sampling Criteria and Methods

NDEQ samples were collected at all four sites as part of the statewide Ambient Stream Monitoring Program and the Basin Rotation Program. Although the programs have different objectives, some stations are included in both programs. Except for Salt Creek, all of the sites used for this study are included in both programs, and samples collected for each program are included in the analyzed dataset. Sampled constituents include nutrients (nitrogen and phosphorus species), pesticides (atrazine, metolachlor, and acetochlor), major ions (sodium and chloride), and bacteria (*E. coli*). However, available data did not include data for all constituents at all three sites.

The Ambient Stream Monitoring Program is designed to determine long-term status and trends in water quality of the State's streams (John Lund, written and oral commun., 2012). As part of the program's monitoring design, monthly samples are collected at about the same time of each month. Pesticide samples are collected during April through September. The Basin Rotation Program is designed to provide data for beneficial use assessments, trend analysis, identification of impaired waters, and determination of total maximum daily loads for impaired waters (John Lund, written and oral commun., 2012). In a given year, sites are sampled more frequently than for the Ambient Stream Monitoring Program, but only at sites in selected basins that are sampled on a 6-year rotation. The 2009 sampling rotation included Shell Creek and Platte River and the 2010 rotation included Elkhorn River. In the selected basins, samples were collected weekly during May through September, and included the same constituents of interest as for the Ambient Stream Monitoring Program.

Grab samples were collected in the thalweg of the stream. Efforts were made to avoid sampling from the water surface by inserting the sample bottle, top down, to the desired depth (usually about 8–10 inches) before filling. Bottles are triple-rinsed with native water before the final fill. For most samples, some air-filled head space is allowed to facilitate mixing in the laboratory. For large streams or when the thalweg is too deep or swift to wade, samples are collected as close to the ideal location as possible. During floods, it is assumed by NDEQ that even a sample near the edge should be representative because of turbulent mixing (John Lund, written and oral commun., 2012). Nutrients and major ions were analyzed according to standard methods (American Public Health Association and others, 2005) at NPHEL. Bacterial samples were analyzed at the NDEQ laboratory, Lincoln, Nebr., using the Quantitray method (IDEXX, 2006). Pesticide samples were screened at the NPHEL for acetochlor, atrazine, and metolachlor using immunoassay methods (Abraxis Corporation, 2010a, 2010b, and 2010c).

Surrogate Measurements—Water-Quality Physical Properties and Streamflow

Continuous measurements of several water-quality physical properties and streamflow (surrogates) were collected by USGS at each site. Continuous water-quality physical-property measurements were made using YSI 6600 Extended Deployment System (EDS) multiparameter WQMs that typically were deployed from March through October from 2007 through 2011. The WQMs measured water temperature, specific conductance, dissolved oxygen, and turbidity in real-time and are the source of the near-real-time data for continued monitoring, which will allow for implementation of the USGS NRTWQ (<http://nrtwq.usgs.gov>), an internet-based system for presenting continuous estimates of constituent concentrations and loads to the public. Streamflow values associated with USGS and NDEQ water samples were determined from water-level records of stage sensors and stage-streamflow ratings as part of the ongoing USGS stream-gaging program.

Continuous Water-Quality Measurements

Except for the 2007 measurements at Shell Creek and Elkhorn River, continuous records of water temperature, specific conductance (SC), dissolved oxygen (DO), and turbidity were measured by USGS at all of the study sites during the 2007 through 2011 monitoring periods. A YSI 6600 EDS WQM was deployed at each site and was typically equipped with a YSI 6560 temperature and conductivity probe, a YSI 6150 luminescent dissolved-oxygen probe, and a YSI model 6136 turbidity probe. During 2007, there was no WQM deployed at Shell Creek and only water temperature and SC were measured at Elkhorn River. Data were collected at a 15-minute time interval and transmitted by satellite telemetry every 1–4 hours to the USGS data servers that processed incoming transmissions and incorporated them into publicly available NWIS time-series records (<http://nwis.waterdata.usgs.gov/nwis>).

The operation of each WQM and the subsequent processing of the measured data followed the guidelines and standard operating procedures of Wagner and others (2006). Corrections to the data were applied based on the results of field maintenance visits. Occasionally, the upper limit of the turbidity probe was exceeded by the in-stream conditions, in which case the corresponding data were censored. This typically took place during runoff events, and was more frequently observed at the two smaller streams—Shell Creek and Salt Creek. On at least an annual basis, the data were assessed a rating of excellent, good, fair, or poor based on the overall quality of the daily data collected throughout the year. Data not meeting the minimum thresholds of at least poor quality (as outlined by Wagner and others, 2006) were subsequently deleted.

WQM placement was based primarily on maximizing the probability to remain in direct contact with flowing water over the entire range of streamflow conditions yet simultaneously minimizing vulnerability to floating debris. At each of the four

Table 2. Range of values by monitoring site in continuous water-quality datasets for the lower Platte River corridor, Nebraska, collected during 2007 through 2011.

[>, greater than; —, no data available]

Period	Water temperature (degrees Celsius)	Streamflow (cubic feet per second)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Turbidity (formazin nephelometric units)	Dissolved oxygen (milligrams per liter)
Shell Creek near Columbus (06795500)					
April 2008–October 2011	1.4–31.3	11–11,200	120–996	3.7–>1,000	0.1–26.1
Elkhorn River at Waterloo (06800500)					
June 2007–October 2011	2.6–13.5	562–23,800	161–738	21–>1,000	3.0–21.1
Salt Creek near Ashland (06805000)					
April 2009–October 2011	3.5–32.8	—	180–4,150	2.3–>1,000	0.9–22.1
Platte River at Louisville (06805500)					
May 2007–October 2011	2.1–33.4	2,740–136,000	257–2,000	24–>1,000	3.2–17.5

sites, the WQM was suspended directly within the current by a tether from the bridge. For protection from debris and vandalism, the WQMs were encased in PVC cylinders with 4-inch-diameter side holes to allow movement of water past the probes. This deployment configuration provided the greatest adaptability to changing channel conditions. Though the location of the WQMs remained unchanged during the study period at Salt and Shell Creek, the WQMs were periodically moved at the Elkhorn and Platte River to remain submerged in currents as the river channels shifted laterally. Mixing characteristics of the streams also were considered for WQM placement.

As streams get wider they require longer distances to become fully mixed downstream from tributary confluences (Yotsukura and Sayre, 1976). A retrieval of recent (since 2003) streamflow measurements at each of the sites indicates median widths of 20.5, 117, 246, and 1,039 feet at Shell Creek, Salt Creek, Elkhorn River, and Platte River, respectively. As a result, it was anticipated that Shell Creek would be the most fully mixed and the Platte River would be the least mixed of the four sites. Therefore, cross-sectional water-quality surveys were periodically made to evaluate the ongoing representativeness of the monitored flow (Wagner and others, 2006, p. 10). These surveys suggested well-mixed conditions at Salt Creek, Shell Creek, and Elkhorn River. Therefore, the WQM data at these three sites were considered representative of the entire channel and the effect on the data from periodically moving the WQM at Elkhorn River was probably negligible.

As expected, cross-sectional water-quality surveys collected between 2008 and 2010 indicated poorly-mixed streamflow at Platte River with specific conductance values varying between 26 and 87 percent from right bank (higher values) to left bank (lower values). Though the deployment of multiple WQMs along the Platte River cross-section was explored in 2007, ultimately it was determined a single WQM location was the more feasible option rather than attempting to characterize mixing effects on a continuous basis. Consequently, any choice of a monitoring location was a compromise at the

Platte River site. The WQM was moved as needed during the study to reposition to a flowing channel. Despite the poorly mixed conditions, the cross-sectional surveys suggested that the selected monitoring locations were fairly representative of the average water-quality conditions in the stream, if not the extremes in water quality associated with runoff. Nonetheless, any statistical relations of the WQM data to laboratory measurements of water-quality constituents for the Platte River site were expected to have more uncertainty than those for other sites.

Streamflow Data

For this study, streamflow values were taken directly from the NWIS time-series record (<http://nwis.waterdata.usgs.gov/nwis>) of USGS-approved instantaneous values or by interpolation between those values, to identify the streamflow rate synchronous with discrete water-quality sample times. Streamflow data were not available at Salt Creek.

Periods of Missing Data

Excessive fouling, equipment malfunctions, and equipment limitations introduced periods of missing or censored data into the WQM record. These data were not interpolated for this report because of the potential inconsistencies this would introduce between datasets used in this report and those stored in the NWIS database, for which water-quality estimates are not allowed (Wagner and others, 2006).

This decision had the greatest effect on constituents that were related to turbidity. In addition to the presence of gaps, turbidity data were often right-censored, that is, the actual turbidity was greater than the operating limit (approximately 1,000 Formazin Nephelometric Units) of the YSI 6136 turbidimeter, leading to time-series turbidity data that have periods dominated by censored values (interval estimates with an unbounded upper limit). These periods often were associated

with runoff conditions that may correspond to a large portion of the mass transport of a given constituent. Because of this, the authors attempted to develop point estimates of the actual turbidity during these periods of right-censored values. After investigating several estimation methods it was determined that none were reliable and as a result, no point estimates were substituted for right-censored turbidity data for this report.

Quality Assurance and Quality Control

Blank, replicate, and pesticide standard-reference samples were collected for quality assurance and quality control (QA/QC) purposes.

NAWQA blank water samples were analyzed for nitrate plus nitrate (13 samples), orthophosphate (13 samples), total phosphorus (9 samples), suspended sediment (5 samples), sodium (3 samples), and pesticides (8 samples); these blank samples were field blanks collected on-site at all sites except for Salt Creek. All analytical results from these blank samples were below the minimum reporting limit except for one nitrate plus nitrite determination (0.02 milligrams per liter [mg/L]).

NAWQA field replicate-pair samples were collected for nitrate plus nitrate (9 sample pairs), orthophosphate (9 sample pairs), total phosphorus (9 sample pairs), suspended sediment (9 sample pairs), sodium (1 sample pair), chloride (6 sample pairs), *E. coli* (4 sample pairs), and pesticides (9 sample pairs each for atrazine, metolachlor, and acetochlor). Replicability can be measured as a relative percentage difference (RPD) using the following equation:

$$RPD = \left[|A - B| / \left(\frac{A+B}{2} \right) \right] \times 100 \quad (1)$$

where *A* and *B* are the replicate-pair concentrations. The median RPDs of nitrate plus nitrate, orthophosphate, total phosphorus, suspended sediment, sodium, chloride, *E. coli*, atrazine, metolachlor, and acetochlor were 2 percent, 2 percent, 9 percent, 12 percent, 1 percent, 1 percent, 19 percent, 5 percent, 6 percent, and 3 percent, respectively.

The USGS collected seven pesticide reference samples during 2007 through 2011 to verify that laboratory analysis was yielding satisfactory results. Pesticide reference samples were collected once a year at Platte River from 2008 through 2011; once during 2007 and once during 2011 for Elkhorn River; and once during 2009 for Shell Creek. All results were satisfactory.

NDEQ QA/QC samples were collected concurrently with 10 percent of the discrete water-quality samples. Field blanks and field replicates were collected simultaneously during a water-quality sampling trip and the QA/QC samples were analyzed to determine the validity of results from the sampling trip. If it was determined from the QA/QC samples that constituent results were suspect then that constituent data from that field trip were not released.

Development of Statistical Models

Water-quality constituents were related to continuously available surrogate measurements using ordinary least-squares (OLS)-estimated regression models. Because parsimonious models were preferred, simple linear-regression models with single explanatory variables initially were developed. However, additional variables were added as needed and appropriate, but models were limited to no more than three explanatory variables. Data for the response variable—discretely sampled water-quality constituents—and one or more explanatory variables—WQM data, streamflow, and seasonality—were analyzed using the TIBCO Spotfire S+® software package (S+, TIBCO Software Inc., 2008).

WQM and streamflow data associated with each sample were compiled and added to the constituent-concentration dataset. Based on the data comparability analyses, the USGS and NDEQ datasets, except for acetochlor, were combined for Shell Creek and Elkhorn River, but not for the Platte River (appendix). Only USGS data were available for Salt Creek. Hydrologic data often are positively skewed (Helsel and Hirsch, 2002). After reviewing normal-quantiles plots, base-10 logarithmic transformations were applied to analytical-laboratory concentrations, WQM data, and streamflow rates when deemed applicable. A seasonality variable was added to the datasets using a periodic function that included the sine and cosine of the elapsed fraction of the year associated with the date when sampled (Helsel and Hirsch, 2002). For regression analyses, left-censored values (below the reporting or detection limit) in the discrete-samples dataset were replaced by simple substitution with a value one-fourth of the censoring limit. Simple substitution was selected because the amount of data with left-censored values in each dataset comprised less than 15 percent (U.S. Environmental Protection Agency, 2009). Only the pesticide dataset had left-censored values. The model datasets with left-censored data were 14 percent of atrazine data and 4 percent of acetochlor data for Shell Creek; 15 percent of atrazine data and 7 percent of acetochlor data for Elkhorn River; 12 percent of metolachlor data, 5 percent of atrazine data, and 4 percent of acetochlor data for Platte River. Because the models did not use interpolated values below the minimum reporting limits any estimates of concentrations below the minimum reporting limit provided by the models should not be considered reliable. Any sample with right-censored data (typically associated with turbidity values or bacteriological data above operating limits of the equipment) for the variables in a given model were excluded from the regression analyses.

Discrete-sample result and WQM-data outliers were identified by residuals plots (standard and studentized) and outlier statistics (leverage, studentized residuals). Studentized residuals were used because they are independent of scale (Cook and Weisberg, 1982) and most of the models were log-transformed models. Outliers were removed if justifiable reasons were determined; reasons included unstable WQM values (measurement values fluctuating more than 20 percent

within an hour of discrete-sample collection), grab samples collected at high flows, which are presumed to poorly represent the stream, and results outside the measuring range of the instrumentation such as was discussed above in the “Periods of Missing Data” section. Before model development some discrete water-quality data outliers were deleted as a result of previous quality-assurance checks associated with other ongoing projects. The number of outliers that were removed before statistical analysis related to this report is unknown. Of the remaining discrete water-quality data, less than 1 percent were determined to be outliers for model development. These outliers were not included in any statistical analysis that led to model development.

Regression models were developed following guidelines from Helsel and Hirsch (2002) and Rasmussen and others (2009) using the programs in TIBCO Spotfire S+® software (TIBCO Software, Inc., 2008). Initially, scatterplot matrices of the response and explanatory variables for each site were visually examined to identify any obvious patterns or the form of possible bivariate relations between the response and explanatory variables. Simple linear regression analysis was then used to explore all possible relations. If the bivariate models were not adequate (adjusted coefficient of determination [R^2] < 0.5, or evident patterns in residual plots) then the stepwise regression tool was used to identify other potential models. In cases where no visual determination was possible, the stepwise tool was used solely to provide an evaluation starting point.

Each model was evaluated using diagnostic plots (residuals compared to predicted, measured compared to predicted, residual quantiles compared to normal quantiles) to ensure that there were no gross violations of the assumptions underlying OLS regression. In addition, the explanatory variables in each model were evaluated for their conceptual plausibility as predictors of the constituent they were being related to. The sign of a coefficient indicated whether there was a direct or inverse relation between the response and explanatory variable. If relation type was determined to be contrary to past empirical data (for example, suspended sediment concentration decreasing with increasing streamflow), other surrogate models were considered. Models that included variables contributing insignificant (p -value > 0.05) explanatory power were discarded, with the exception of the seasonality variables. Because seasonality was represented by two variables (the sine and cosine of the fraction of the year), only one of the two variables needed to have significant explanatory power for both to be retained. For those models considered valid and significant for a given constituent, diagnostic statistics (root-mean-square-error; adjusted R^2) were compared to determine the optimal model. Models with a single explanatory variable were preferred and additional variables were only added in cases where significant improvement was seen due to addition of the variable. The authors defined significant improvement as an increase of the adjusted R^2 by at least 0.1, or a removal of evident patterns in the residual plots. Models were limited to no more than three explanatory variables.

Since many of the models use log-transformed data, a bias correction factor (Duan, 1983) was calculated and reported for all models. This corrects for the low bias estimate (Helsel and Hirsch, 2002) that is introduced from transforming the data from log-units back into its original units. In addition, a multiplier (RMSE multiplied by the two-tailed Student's t value at the 95-percent confidence level) was calculated, which can be used to calculate either the 95-percent confidence interval or the 95-percent prediction interval.

It is important to note that although a regression model's explanatory power was evaluated and acceptable, future predictive performance may be poor during periods where concomitant surrogate data are outside the range of values (table 2, at the end of this report) used for development of the models. Specifically, during periods of high turbidities, which are beyond the turbidimeter measurement range as discussed in the “Periods of Missing Data” section of the report, these models should not be used. Any predicted values reported on the NRTWQ Web site during periods where concomitant surrogate data stray outside the range of values used for development of the models should be used only with the knowledge that there is large uncertainty associated with them.

Relations of Sampled Constituents to Surrogate Measurements—Statistical Models

Regression models were developed for all four monitored sites to relate several of the discretely sampled constituents to continuously monitored surrogates. Model performance varied but, in general, the Shell Creek, Elkhorn River, and Salt Creek models performed better than the Platte River models. Nutrients, pesticides, suspended sediment, and *E. coli* generally were positively correlated with turbidity, whereas major ions were correlated to specific conductance.

Nutrients

The best and most useful regression models for nutrient concentrations at most sampling sites were those using turbidity as an explanatory variable. In some cases, the amount of variance explained in total nitrogen and nitrate plus nitrite (NO_x) models increased by adding SC, whereas DO was a better second predictor of orthophosphate. Some of the nutrient models were improved through inclusion of some measure of seasonality; in some cases the added seasonal component was water temperature and in others the date-derived variables improved model diagnostics.

Models for nitrate and nitrite (NO_x) were developed for Shell Creek, Elkhorn River, and Salt Creek. Turbidity and SC helped explain the variance in concentration of NO_x for Shell Creek and Elkhorn River, where positive model coefficients were determined for turbidity and SC. However, for the Salt Creek model SC alone was a better indicator of NO_x concentrations (table 3, at end of this report).

Models for total Kjeldahl nitrogen (TKN) were developed for all sites except Shell Creek where no samples were analyzed for total Kjeldahl nitrogen. SC best explained the variance of TKN in the Elkhorn River model. The best indicator of TKN concentrations in the Salt Creek and Platte River models was turbidity. In both of these models TKN was positively correlated with turbidity (table 3).

As with nitrogen, total phosphorus was most frequently explained by turbidity. An adequate model was not able to be developed for Salt Creek, but models were developed for all three of the remaining streams. In each case, turbidity best explained the variance of total phosphorus concentrations in a bivariate model, with values for both variables first transformed to logarithms (table 3, at the end of this report).

Models for orthophosphate (PO_4) were developed for Shell Creek and Elkhorn River. Orthophosphate data were not available for Salt Creek and relations between orthophosphate concentrations and measured properties in the Platte River were not adequate for the estimation of a reliable model. DO was the primary explanatory variable for both models of PO_4 reported in table 3. In the Shell Creek model, DO was combined with the seasonal variables and temperature to explain the variance of PO_4 in the model. DO was combined with streamflow and temperature to explain the variance of PO_4 in the Elkhorn River model (table 3). In both cases DO was negatively correlated to orthophosphate. This decrease in dissolved oxygen levels during periods of elevated orthophosphate concentrations is most likely related to increases in bacterial consumption of oxygen caused by increases in aquatic plant life (mostly periphyton at the Elkhorn River site) that thrive on orthophosphates (Welch and Jacoby, 2004).

Major Ions

Although chloride and sodium concentrations were measured at Shell Creek, Elkhorn River, and Platte River, only the Elkhorn River chloride and Platte River sodium models were deemed adequate. Specific conductance is a measure of the ionized substances in the water, which means it is usually the best surrogate for ion concentrations (Rasmussen and others, 2005). However, the sodium model for the Platte River was better related to turbidity and temperature. The poor relation between specific conductance and sodium at the Platte River is most likely related to mixing issues. Changes in the overall specific conductance at Platte River may not be identified if localized conditions in the vicinity of the WQM are not substantially altered. Specific conductance was used to develop a model for chloride at Elkhorn River. The model that was selected was positively correlated with specific conductance and negatively correlated with streamflow (table 3).

Pesticides

All sites were sampled for pesticides except Salt Creek. Three of the most commonly detected pesticide compounds in the study area were targeted for model development—metolachlor, atrazine, and acetochlor. Pesticide models generally had larger residuals than models developed for other constituents, so bounds on confidence and prediction intervals are greater. Models for metolachlor were only developed for the Platte River. Metolachlor data were available for Shell Creek and Elkhorn River as well, but they did not correlate well with the available explanatory variables. Models for atrazine and acetochlor were developed for the three sites where data were available (Shell Creek, Elkhorn River, and Platte River). As mentioned in the “Development of Statistical Models” section, only USGS data were used to develop the acetochlor models. All models used turbidity and seasonality as explanatory variables (table 3). The Elkhorn River acetochlor model required an additional explanatory term, streamflow. The positive correlation between pesticide concentrations and turbidity, combined with the seasonal interaction, indicates that pesticide concentrations are related to runoff events as well as seasonal dependencies in agricultural practices and the fate (assimilation, degradation, or decreasing availability as sources are transported by runoff) of applied compounds.

Suspended Sediment

Turbidity is usually a suitable surrogate for suspended-sediment concentrations because turbidity increases with an increase in the volumetric density of particles in water (Gippel, 1995; Pfannkuche and Schmidt, 2003; Stubblefield and others, 2007). This was true for all of the sampled streams except for the Platte River. The Platte River is poorly mixed, which may be responsible for the poor relation between suspended sediment and turbidity at that site. Another possibility is that there are fine sand particles and silt or clay particles in suspension in the Platte River. Gippel (1995) stated that the relation between turbidity and suspended sediment will remain linear as long as the physical properties of the particles in suspension remain constant. In the Platte River the properties of the suspended mixture of particle sizes can vary. These two issues are most likely responsible for the poorer relation at Platte River. Adding water temperature to the model slightly improved its performance. Lower water temperatures increase the viscosity of the water, which leads to less sediment transport (Julien, 1994). By using water temperature and turbidity the model accounted for 58 percent of the variance in suspended-sediment concentrations.

All three of the models for suspended sediment at Shell Creek, Elkhorn River, and Salt Creek used turbidity as the lone explanatory variable. The Elkhorn River, like the Platte River, has varying particle sizes in suspension, which could explain why the model is not as robust as the Shell Creek and Salt Creek models (table 3).

Escherichia coli (E. coli) Bacteria

E. coli data varied greatly among similar streamflows, which led to poor model performance compared to models of other constituents. This could be related to laboratory analysis issues or other variables such as mixing. Even though model performance was generally poor compared to other constituent models, reportable *E. coli* models were developed for all study sites. In all four models *E. coli* density was positively

correlated with turbidity (table 3). *E. coli* are transported on suspended material, so turbidity is generally a good indicator of *E. coli* densities (Stone and others, 2013). Turbidity was the primary explanatory variable in all models for *E. coli*. For the Shell Creek model, inclusion of SC as a second negatively-correlated variable improved model performance.

Table 3. Regression models for selected water-quality constituents at four monitoring sites in the lower Platte River corridor, Nebraska, 2007 through 2011.

[*n*, sample size; RMSE, root mean square error; *R*², coefficient of determination; *t*(*SE*), two-tailed Student's *t* multiplied by the root mean square error, which can be used to calculate either 95-percent prediction or 95-percent confidence intervals; *DO*, dissolved oxygen in milligrams per liter; *SC*, specific conductance in microsiemens per centimeter at 25 degrees Celsius; *Q*, streamflow in cubic feet per second; *Temp*, water temperature in degrees Celsius; *Turb*, turbidity in formazin nephelometric units; sin, sine; cos, cosine; *D*, day of year in numeric format; <, less than]

Constituent	Equation	Range of variable values used in model	<i>n</i>	RMSE, in constituent units	Adjusted <i>R</i> ² (dimensionless)	Bias correction factor (Duan, 1983)	<i>t</i> (<i>SE</i>)
Shell Creek near Columbus (06795500)							
Nitrogen as nitrate and nitrite (<i>NO_x</i>), water, filtered, milligrams per liter	$NO_x = 0.0102Turb + 0.0168SC - 8.8188$	<i>Turb</i> : 15–960 <i>SC</i> : 223–796 <i>NO_x</i> : 1.28–6.65	52	0.94	0.70	1.00	1.5768
Phosphorus (<i>P</i>), water, unfiltered, total as phosphorus milligrams per liter	$\log_{10}(P) = 0.4504\log_{10}(Turb) - 1.1116$	<i>Turb</i> : 15–960 <i>P</i> : 0.24–5.44	53	0.08	0.86	1.02	0.1292
Orthophosphate (<i>PO₄</i>), water, filtered, milligrams per liter as phosphorus	$\log_{10}(PO_4) = -1.4401\log_{10}(DO) - 0.8261\log_{10}(Temp) - 0.1463\sin\left(\frac{2\pi D}{365}\right) - 0.2640\cos\left(\frac{2\pi D}{365}\right) + 1.6142$	<i>DO</i> : 4.5–13.8 <i>Temp</i> : 3.7–25.8 <i>PO₄</i> : 0.10–0.47	22	0.11	0.67	1.02	0.6560
Atrazine (<i>Atr</i>), water, filtered, recoverable, micrograms per liter	$\log_{10}(Atr) = 0.6975\log_{10}(Turb) + 0.4713\sin\left(\frac{2\pi D}{365}\right) - 0.9344\cos\left(\frac{2\pi D}{365}\right) - 2.1940$	<i>Turb</i> : 15–960 <i>Atr</i> : <0.05–15.50	42	0.40	0.64	1.49	0.6735
Acetochlor (<i>Acet</i>), water, filtered, recoverable, micrograms per liter	$\log_{10}(Acet) = 1.0763\log_{10}(Turb) + 0.6499\sin\left(\frac{2\pi D}{365}\right) - 0.5458\cos\left(\frac{2\pi D}{365}\right) - 3.3421$	<i>Turb</i> : 15–960 <i>Acet</i> : <0.01–11.00	20	0.51	0.62	1.73	0.8879
Suspended sediment concentration (<i>SSC</i>), milligrams per liter	$\log_{10}(SSC) = 0.9887\log_{10}(Turb) + 0.3461$	<i>Turb</i> : 8.1–840 <i>SSC</i> : 10–2,670	40	0.14	0.93	1.06	0.2426
<i>Escherichia coli</i> (<i>E. coli</i>), defined substrate technology, water, most probable number per 100 milliliters	$\log_{10}(E. coli) = 0.9637\log_{10}(Turb) - 3.8001\log_{10}(SC) + 12.0344$	<i>Turb</i> : 8.1–810 <i>E. coli</i> : 100–170,000	20	0.38	0.83	1.33	0.6595
Elkhorn River at Waterloo (06800500)							
Nitrogen as nitrate and nitrite (<i>NO_x</i>), water, filtered, milligrams per liter	$NO_x = 0.0119SC + 0.0018Turb - 4.2960$	<i>SC</i> : 367–718 <i>Turb</i> : 40–790 <i>NO_x</i> : 0.90–5.12	44	0.63	0.68	1.00	1.0575
Total Kjeldahl nitrogen (<i>TKN</i>), water unfiltered, milligrams per liter	$\log_{10}(TKN) = -2.4932\log_{10}(SC) + 7.2147$	<i>SC</i> : 384–718 <i>TKN</i> : 0.91–5.23	39	0.10	0.72	1.01	0.1697
Phosphorus (<i>P</i>), water, unfiltered, total as phosphorus milligrams per liter	$\log_{10}(P) = 0.5158\log_{10}(Turb) - 1.2672$	<i>Turb</i> : 15–960 <i>P</i> : 0.24–5.44	46	0.06	0.91	1.01	0.1047
Orthophosphate (<i>PO₄</i>), water, filtered, milligrams per liter as phosphorus	$PO_4 = \left(\frac{-0.0096Q}{1000}\right) - 0.0596DO - 0.0064Temp + 0.9086$	<i>DO</i> : 5.0–12.1 <i>Temp</i> : 8.2–30.2 <i>PO₄</i> : 0.01–0.30	15	0.03	0.91	1.00	0.0474
Chloride (<i>Cl</i>), water, filtered, milligrams per liter	$\log_{10}(Cl) = -0.2573\log_{10}(Q) + 0.3549\log_{10}(SC) + 0.9343$	<i>SC</i> : 277–719 <i>Q</i> : 728–53,500 <i>Cl</i> : 3.58–15.58	62	0.06	0.78	1.01	0.0932

Table 3. Regression models for selected water-quality constituents at four monitoring sites in the lower Platte River corridor, Nebraska, 2007 through 2011.—Continued

[*n*, sample size; RMSE, root mean square error; R^2 , coefficient of determination; $t(SE)$, two-tailed Student's *t* multiplied by the root mean square error, which can be used to calculate either 95-percent prediction or 95-percent confidence intervals; *DO*, dissolved oxygen in milligrams per liter; *SC*, specific conductance in microsiemens per centimeter at 25 degrees Celsius; *Q*, streamflow in cubic feet per second; *Temp*, water temperature in degrees Celsius; *Turb*, turbidity in formazin nephelometric units; sin, sine; cos, cosine; *D*, day of year in numeric format; <, less than]

Constituent	Equation	Range of variable values used in model	<i>n</i>	RMSE, in constituent units	Adjusted R^2 (dimensionless)	Bias correction factor (Duan, 1983)	$t(SE)$
Elkhorn River at Waterloo (06800500)—Continued							
Atrazine (<i>Atr</i>), water, filtered, recoverable, micrograms per liter	$\log_{10}(Atr) = 0.5358 \log_{10}(Turb) + 0.3597 \sin\left(\frac{2\pi D}{365}\right) - 1.2798 \cos\left(\frac{2\pi D}{365}\right) - 2.7532$	<i>Turb</i> : 40–810 <i>Atr</i> : <0.05–7.54	46	0.49	0.52	1.89	0.8216
Acetochlor (<i>Acet</i>), water, filtered, recoverable, micrograms per liter	$\log_{10}(Acet) = -3.0048 \log_{10}(Q) + 1.3320 \log_{10}(Turb) + 1.5751 \sin\left(\frac{2\pi D}{365}\right) - 1.5277 \cos\left(\frac{2\pi D}{365}\right) + 5.0847$	<i>Q</i> : 943–53,500 <i>Turb</i> : 40–810 <i>Acet</i> : <0.01–4.01	13	0.36	0.82	1.23	0.8576
Suspended sediment concentration (<i>SSC</i>), milligrams per liter	$\log_{10}(SSC) = 0.7992 \log_{10}(Turb) + 1.0471$	<i>Turb</i> : 47–790 <i>SSC</i> : 170–2,560	26	0.16	0.78	1.06	0.2772
<i>Escherichia coli</i> (<i>E. coli</i>), defined substrate technology, water, most probable number per 100 milliliters	$\log_{10}(E. coli) = 1.7193 \log_{10}(Turb) - 0.8799$	<i>Turb</i> : 44–810 <i>E. coli</i> : 10–21,000	37	0.48	0.65	2.03	0.8110
Salt Creek near Ashland (06805000)							
Nitrogen as nitrate and nitrite (NO_x), water, filtered, milligrams per liter	$\log_{10}(NO_x) = 0.4320 \log_{10}(SC) - 1.0301$	<i>SC</i> : 226–3,180 NO_x : 0.83–3.44	14	0.08	0.76	1.01	0.1384
Total Kjeldahl nitrogen (<i>TKN</i>), water unfiltered, milligrams per liter	$\log_{10}(TKN) = 0.4797 \log_{10}(Turb) - 0.8086$	<i>Turb</i> : 16–755 <i>TKN</i> : 0.68–4.3	13	0.06	0.96	1.01	0.1126
Suspended sediment concentration (<i>SSC</i>), milligrams per liter	$\log_{10}(SSC) = 1.0892 \log_{10}(Turb) + 0.1446$	<i>Turb</i> : 16–755 <i>SSC</i> : 31–2,080	12	0.08	0.99	1.01	0.1414
<i>Escherichia coli</i> (<i>E. coli</i>), defined substrate technology, water, most probable number per 100 milliliters	$\log_{10}(E. coli) = 1.2885 \log_{10}(Turb) + 0.5918$	<i>Turb</i> : 16–755 <i>E. coli</i> : 80–120,000	20	0.40	0.77	1.54	0.6858
Platte River at Louisville (06805500)							
Total Kjeldahl nitrogen (<i>TKN</i>), water unfiltered, milligrams per liter	$\log_{10}(TKN) = 0.4369 \log_{10}(Turb) - 0.5855$	<i>Turb</i> : 41–920 <i>TKN</i> : 1.1–8.0	26	0.11	0.70	1.03	0.1841
Phosphorus (<i>P</i>), water, unfiltered, total as phosphorus milligrams per liter	$\log_{10}(P) = 0.5375 \log_{10}(Turb) - 1.3277$	<i>Turb</i> : 38–920 <i>P</i> : 0.25–3.39	46	0.08	0.86	1.01	0.1273
Sodium (<i>Na</i>), water, filtered, milligrams per liter	$\log_{10}(Na) = -0.4310 \log_{10}(Turb) + 0.2628 \log_{10}(Temp) + 2.2679$	<i>Turb</i> : 41–900 <i>Temp</i> : 8.3–30.0 <i>Na</i> : 16.9–89.3	26	0.08	0.78	1.02	0.1416
Metolachlor (<i>Meto</i>) water, filtered, recoverable, micrograms per liter	$\log_{10}(Meto) = 0.8568 \log_{10}(Turb) + 0.3730 \sin\left(\frac{2\pi D}{365}\right) - 1.1903 \cos\left(\frac{2\pi D}{365}\right) - 3.4660$	<i>Turb</i> : 38–920 <i>Meto</i> : 0.02–3.91	45	0.28	0.79	1.22	0.4796
Atrazine (<i>Atr</i>), water, filtered, recoverable, micrograms per liter	$\log_{10}(Atr) = 0.5236 \log_{10}(Turb) + 0.3869 \sin\left(\frac{2\pi D}{365}\right) - 1.2295 \cos\left(\frac{2\pi D}{365}\right) - 2.3704$	<i>Turb</i> : 38–920 <i>Atr</i> : <0.05–8.3	45	0.33	0.68	1.29	0.5505
Acetochlor (<i>Acet</i>), water, filtered, recoverable, micrograms per liter	$\log_{10}(Acet) = 0.9762 \log_{10}(Turb) + 0.7211 \sin\left(\frac{2\pi D}{365}\right) - 0.6695 \cos\left(\frac{2\pi D}{365}\right) - 3.8261$	<i>Turb</i> : 38–920 <i>Acet</i> : <0.01–10.12	45	0.40	0.70	1.42	0.6779
Suspended sediment concentration (<i>SSC</i>), milligrams per liter	$\log_{10}(SSC) = 0.7783 \log_{10}(Turb) - 1.0080 \log_{10}(Temp) + 2.6016$	<i>Turb</i> : 38–900 <i>Temp</i> : 8.3–30.0 <i>SSC</i> : 124–5,170	45	0.24	0.58	1.18	0.4054
<i>Escherichia coli</i> (<i>E. coli</i>), defined substrate technology, water, most probable number per 100 milliliters	$\log_{10}(E. coli) = 2.1737 \log_{10}(Turb) - 2.1339$	<i>Turb</i> : 38–810 <i>E. coli</i> : 65–20,000	40	0.75	0.55	3.43	1.2584

Summary

The lower Platte River is an important resource for Nebraskans that serves a variety of uses including drinking-water supply, recreation, irrigation, and habitat for threatened and endangered species and other fish and wildlife. Resource managers of the lower Platte River rely on water-quality monitoring to make a range of decisions, such as whether management practices are effective or warranted, whether the source water supplying nearby drinking-water wells is safe, or whether swimming and boating in the river may expose recreationists to unsafe contaminant levels. The USGS, in cooperation with the Lower Platte River Corridor Alliance, continuously monitored water-quality measures (specific conductance, dissolved oxygen, water temperature, and turbidity) at four sites (Shell Creek near Columbus, Elkhorn River at Waterloo, Salt Creek near Ashland, and Platte River near Louisville) in the lower Platte River corridor during 2007 through 2011. During the same time period, discrete water quality samples were collected at each of these sites and analyzed for nutrients, major ions, suspended sediment, and bacteria. Discrete pesticide samples also were collected, except at Salt Creek. Continuous water-quality data were used to develop statistical relations with discretely collected constituent concentrations using regression models. These regression models are used to estimate water-quality constituent concentrations in near-real time using surrogate measures. The estimated concentrations will be served to the public through an online portal (<http://nrtwq.usgs.gov>).

Regression models were developed for all four monitored sites to relate several of the discretely sampled constituents to continuously monitored surrogates. Constituent models for Shell Creek included nitrate plus nitrite, total phosphorus, orthophosphate, atrazine, acetochlor, suspended sediment, and *Escherichia coli* (*E. coli*) bacteria. Regression models that were developed for the Elkhorn River included nitrate plus nitrite, total Kjeldahl nitrogen, total phosphorus, orthophosphate, chloride, atrazine, acetochlor, suspended sediment, and *E. coli*. Models developed for Salt Creek included nitrate plus nitrite, total Kjeldahl nitrogen, suspended sediment, and *E. coli*. Lastly, models developed for the Platte River site included total Kjeldahl nitrogen, total phosphorus, sodium, metolachlor, atrazine, acetochlor, suspended sediment, and *E. coli*.

Model performance varied, but in general, the Shell Creek, Elkhorn River, and Salt Creek models performed better than the Platte River models. Nutrients, pesticides, suspended sediment, and *E. coli* were generally positively correlated with turbidity, whereas major ions were correlated to specific conductance.

References Cited

- Abraxis Corporation, 2010a, Acetochlor ELISA user guide: Warminster, Pa., Abraxis Corporation, accessed May 2013 at <http://www.abraxiskits.com/moreinfo/PN500021USER.pdf>.
- Abraxis Corporation, 2010b, Atrazine ELISA user guide: Warminster, Pa., Abraxis Corporation, accessed May 2013 at <http://www.abraxiskits.com/moreinfo/PN500001USER.pdf>.
- Abraxis Corporation, 2010c, Metolachlor ELISA user guide: Warminster, Pa., Abraxis Corporation, accessed May 2013 at <http://www.abraxiskits.com/moreinfo/PN500061USER.pdf>.
- American Public Health Association, American Water Works Association, and Water Environment Federation, 2005, Standard methods for the examination of water and wastewater (19th ed.): Washington D.C., American Public Health Association, 905 p.
- Cook, D. R., and Weisberg, S., 1982, Residuals and influence in regression: New York, Chapman and Hall, 225 p.
- Dietsch, B.J., Godberson, J.A., and Steele, G.V., 2009, Trends in streamflow characteristics of selected sites in the Elkhorn River, Salt Creek, and lower Platte River basins, eastern Nebraska, 1928–2004, and evaluation of streamflows in relation to instream-flow criteria, 1953–2004: U.S. Geological Survey Scientific Investigations Report 2009–5011, 93 p. with appendixes.
- Duan, N., 1983, Smearing estimate: A nonparametric retransformation method: Journal of the American Statistical Association, v. 78, no. 383, p. 605–610.
- Elliott, C.M., Huhmann, B.L., and Jacobson, R.B., 2009, Geomorphic classification of the lower Platte River, Nebraska: U.S. Geological Survey Scientific Investigations Report 2009–5198, 29 p.
- Fishman, M.J., and Friedman, L.C., 1989, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 545 p.
- Gippel, C., 1995, Potential of turbidity monitoring for measuring the transport of suspended solids in streams: Hydrological Processes 9, p. 83–97.
- Guy, H.P., 1969, Laboratory theory and methods for sediment analysis: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. C1, 58 p.
- Hammel, P., 2008, Who's polluting Shell Creek?: Omaha World Herald, March 13, 2008, p. A1–A2.

- Helsel, D.R., and Hirsch, R.M., 2002, Statistical methods in water resources—Hydrologic analysis and interpretation: U.S. Geological Survey Techniques of Water-Resources Investigations, book 4, chap. A3, 510 p. (Also available at <http://pubs.usgs.gov/twri/twri4a3/>.)
- IDEXX, 2006, IDEXX Quanti-Tray/2000 insert and most probable number (MPN) table: Westbrook, Maine, IDEXX, accessed July 2008 at http://www.idexx.com/pdf/en_us/water/qt97mpntable.pdf.
- Julien, P.Y., 1994, Erosion and sedimentation: Cambridge, United Kingdom, Cambridge University Press, 277 p.
- Nebraska Department of Environmental Quality, 2010, 2010 Water quality integrated report: Nebraska Department of Water Quality, Water Quality Division Report, 293 p.
- Nebraska Department of Environmental Quality, 2012, 2012 Water quality integrated report: Nebraska Department of Water Quality, Water Quality Division Report, 321 p.
- Pfannkuche, J., and Schmidt, A., 2003, Determination of suspended particulate matter concentration from turbidity measurements: Particle size effects and calibration procedures: Hydrological Processes, v. 17, p. 1,951–1,963.
- Rasmussen, P.P., Gray, J.R., Glysson, G.D., and Ziegler, A.C., 2009, Guidelines and procedures for computing time-series suspended-sediment concentrations and loads from in-stream turbidity-sensor and streamflow data: U.S. Geological Survey Techniques and Methods, book 3, chap. C4, 52 p.
- Rasmussen, T.J., Ziegler, A.C., and Rasmussen, P.P., 2005, Estimation of constituent concentrations, densities, loads, and yields in lower Kansas River, northeast Kansas, using regression models and continuous water-quality monitoring, January 2000 through December 2003: U.S. Geological Survey Scientific Investigations Report 2005–5165, 117 p.
- Sandstrom, M.W., Stoppel, M.E., Foreman, W.T., and Schroeder, M.P., 2001, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of moderate-use pesticides and selected degradates in water by C-18 solid-phase extraction and gas chromatography/mass spectrometry: U.S. Geological Survey Water-Resources Investigations Report 01–4098, 70 p.
- Stone, M.L., Graham, J.L., and Gatotho, J.W., 2013, Continuous real-time water-quality monitoring and regression analysis to compute constituent concentrations and loads in the North Fork Ninnescah River upstream from Cheney Reservoir, south-central Kansas, 1999–2012: U.S. Geological Survey Scientific Investigations Report 2013–5071, 44 p.
- Stubblefield, A.P., Reuter, J.E., Dahlgren, R.A., Goldman, C.R., 2007, Use of turbidometry to characterize suspended sediment and phosphorus fluxes in the Lake Tahoe basin, California, USA: Hydrological Processes, v. 21, p. 281–291.
- TIBCO Software, Inc., 2008, TIBCO Spotfire S+® 8.1 for Windows® user's guide: TIBCO Software Inc., variously paged.
- U.S. Environmental Protection Agency, 2009, Statistical analysis of groundwater monitoring data at RCRA facilities—Unified guidance: U.S. Environmental Protection Agency, EPA 530/R-09-007, 888 p. (Also available at <http://www.itrcweb.org/gsmc-1/Content/Resources/Unified%20Guidance%202009.pdf>.)
- U.S. Geological Survey, 2006, Collection of water samples (ver. 2.0): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A4, 166 p.
- U.S. Geological Survey, variously dated, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chaps. A1–A9. (Also available at <http://pubs.water.usgs.gov/twri9A>.)
- Wagner, R.J., Boulger, R.W., Jr., Oblinger, C.J., and Smith, B.A., 2006, Guidelines and standard procedures for continuous water-quality monitors—Station operation, record computation, and data reporting: U.S. Geological Survey Techniques and Methods 1–D3, 51 p. plus attachments. (Also available at <http://pubs.usgs.gov/tm/2006/tm1D3/>.)
- Welch, E.B., and Jacoby, J.M., 2004, Pollutant effects in freshwater: applied limnology (3rd ed.): New York, Spon Press, 504 p.
- Wilde, F.D., ed., 2008, Field measurements, in National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A6, p. 3–20.
- Yotsukura, N., and Sayre, W.W., 1976, Transverse mixing in natural channels: Water Resources Research, v. 12, p. 695–704.

Appendix—Sample Data Comparability

Water-quality data from U.S. Geological Survey (USGS) equal-width increment (EWI) samples and Nebraska Department of Environmental Quality (NDEQ) grab samples were compared to determine whether data from the two independent data sources were significantly different, thus precluding their combined use in the development of regression models. Since NDEQ and USGS samples were not collected concurrently, it was not possible to directly compare discrete-sample data. Instead a two-tailed Wilcoxon rank-sum test was used to identify whether datasets were significantly different (p -value < 0.2). This nonparametric test was selected to avoid making assumptions about the distribution of the two datasets (Helsel and Hirsch, 2002). Only water-quality data collected by one

agency within a 1-month time span from similar data collected by the other agency were included in the analysis to ensure that only data collected during similar time periods were compared. In addition, streamflow magnitudes associated with the discrete water-quality samples (used in comparison analysis) were compared to ensure that streamflow during USGS sample collection did not significantly differ (p -value < 0.2 significance level) from streamflow during NDEQ sample collection.

Left-censored water-quality data (values below the method detection limit) were not included in the analysis. Left-censored data were confined to the pesticide datasets for all sites (table 1–1).

Table 1-1. Summary of U.S. Geological Survey (USGS) and Nebraska Department of Environmental Quality (NDEQ) left-censored sample data excluded from sample method comparison analysis, lower Platte River corridor, Nebraska, during 2007 through 2011.

[All constituents were determined from either unfiltered or filtered using up to 0.45-micron pore size; NO₃, concentration of nitrate plus nitrite, as nitrogen; minimum reporting levels are reported in micrograms per liter for atrazine, metolachlor, and acetochlor, and milligrams per liter for NO₃; UKN, unknown]

Constituent	USGS samples			NDEQ samples		
	Number of equal-width increment samples	Minimum reporting level	Number of samples with concentrations below minimum reporting level	Number of single-point samples	Minimum reporting level	Number of samples with concentrations below minimum reporting level
Shell Creek near Columbus (06795500)						
Atrazine	20	0.01	0	24	0.05	4
Metolachlor	21	0.01	0	24	0.07	1
Acetochlor	22	0.01	2	23	0.07	0
Elkhorn River at Waterloo (06800500)						
Atrazine	15	0.01	0	10	0.05	1
Metolachlor	13	0.01	0	9	0.07	3
Acetochlor	15	0.01	0	10	0.07	0
Platte River at Louisville (06805500)						
Nitrogen (NO ₃)	51	0.06 (2007), 0.04 (2008–11)	4	51	UKN	0
Metolachlor	38	0.01	0	44	0.07	11
Atrazine	43	0.01	0	45	0.05	5
Acetochlor	44	0.01	0	45	0.07	1

Differences between the datasets representing comparisons of EWI and single-point sample methods correspond to the mixing characteristics of the three sites—at Shell Creek, with well-mixed flow, there was one significant difference out of six comparisons; whereas, for the Platte River, with poorly-mixed flow, there were five significant differences out of eight comparisons. For the Elkhorn River, with fairly well-mixed flow, there was 1 significant difference out of 6 comparisons (table 1-2).

For Shell Creek and Elkhorn River, the results support combining the USGS (EWI) and NDEQ (single-point) datasets for the various constituents, with the exception of acetochlor. The acetochlor data for Shell Creek and Elkhorn River resulted in *p*-values of less than 0.01 for the intermethod comparisons (table 1-2) indicating that data from samples collected by the different agencies is not comparable. Since the differences determined using acetochlor concentrations were independent of the sites, this could indicate that they were

related to something other than non-uniform mixing, such as differences in analytical laboratory methods, or possible sample contamination.

Elkhorn River was the only site where *Escherichia coli* samples were collected by NDEQ. USGS and NDEQ collected single-point samples. Since the sampling method and analysis method were the same the results were combined.

Many of the Platte River water-quality constituent datasets varied between agencies, presumably because of the different sampling methods (table 1-2). The significant differences in concentrations likely were the result of the methods different capabilities in relation to poorly mixed streamflow, as discussed in the “Continuous Water-Quality Measurements” section above. Under such conditions, the single-point sampling method was not expected to achieve similar results as the EWI sampling method. As a result, constituent data sources were not combined for the Platte River.

Table 1–2. Summary of statistical comparison of datasets collected using depth- and flow-integrated methods with those collected using single point (grab) sampling methods, lower Platte River corridor, Nebraska, during 2007 through 2011.

[Except as otherwise indicated, all constituents were determined from either unfiltered or filtered using up to 0.45-micron pore size; *p*-value is probability of falsely declaring a significant difference in concentrations between the two compared sample groups; NO_x, concentration of nitrate plus nitrite, as nitrogen; *p*-value is level of significance as a decimal fraction; datasets with *p*-values greater than 0.2 were combined; >, greater than; <, less than]

Period	Constituent	Number of equal-width increment samples	Number of single-point samples	<i>p</i> -value from streamflow comparison during collection period	<i>p</i> -value from constituent comparison
Shell Creek near Columbus (06795500)					
May 2008–Oct. 2009	Nitrogen (NO _x)	24	29	>0.5	>0.5
	Total phosphorus	24	29	>0.5	0.27
	Atrazine	20	20	>0.5	>0.5
	Metolachlor	21	23	>0.5	>0.5
	Acetochlor	20	23	>0.5	0.0003
Elkhorn River at Waterloo (06800500)					
Mar.–Sept. 2007, Oct. 2010–Apr. 2011	Nitrogen (NO _x)	19	17	>0.5	0.40
	Total phosphorus	19	17	>0.5	>0.5
	Chloride	19	17	>0.5	0.28
	Atrazine	15	9	>0.5	>0.5
	Metolachlor	13	6	>0.5	>0.5
	Acetochlor	15	10	>0.5	0.0014
Platte River at Louisville (06805500)					
Mar. 2007–Apr. 2011	Nitrogen (total Kjeldahl)	29	44	0.16	0.30
	Nitrogen (NO _x)	47	51	0.36	0.03
	Total phosphorus	54	59	0.30	>0.5
	Sodium	30	9	0.39	0.0012
	Chloride	53	59	0.32	<0.0001
	Atrazine	43	40	0.32	>0.5
	Metolachlor	38	33	>0.5	0.13
	Acetochlor	44	44	0.22	<0.0001

Publishing support provided by:
Rolla Publishing Service Center

For more information concerning this publication, contact:
Director, USGS Nebraska Water Science Center
5231 South 19th Street
Lincoln, Nebraska 68512
(402) 328-4100

Or visit the Nebraska Water Science Center Web site at:
<http://ne.water.usgs.gov/>

