Appendix 11. Model Archive Summary for Orthophosphate at U.S. Geological Survey Site 07144780, North Fork Ninnescah River above Cheney Reservoir, Kansas, during January 1, 1999, through December 31, 2019

This model archive summary summarizes the orthophosphate (OP) model developed to compute hourly or daily OP concentrations during January 1, 1999, through December 31, 2019. This model supersedes all prior models used during this period. The methods used follow U.S. Geological Survey (USGS) guidance as referenced in relevant Office of Surface Water/Office of Water Quality Technical Memoranda and USGS Techniques and Methods, book 3, chapter C4 (Rasmussen and others, 2009).

Site and Model Information

Site number: 07144780
Site name: North Fork Ninnescah River above Cheney Reservoir, Kansas
Location: Lat 37°51'45", long 98°00'49" referenced to North American Datum of 1927, in NE 1/4 SE 1/4 NE 1/4 sec.19, T.25 S., R.6 W., Reno County, Kans., Hydrologic Unit 11030014, on right bank at upstream side of county highway bridge, 10 miles south of Hutchinson, 18.1 miles upstream from Cheney Dam.

Equipment: A YSI 6600 Extended Deployment System water-quality monitor equipped with sensors for water temperature, specific conductance, pH, dissolved oxygen, and turbidity (a YSI Model 6026 turbidity sensor [November 9, 1998, to December 1, 2010] and a YSI Model 6136 turbidity sensor [October 17, 2009, to November 12, 2015; March 31, 2017, to June 7, 2017]) (YSI Incorporated, 2007, 2012a). The YSI 6600 water-quality monitor was in operation during November 9, 1998, through November 12, 2015.

A Xylem YSI EXO2 water-quality monitor equipped with sensors for water temperature, specific conductance, dissolved oxygen, pH, and turbidity (YSI Incorporated, 2012b). The YSI EXO2 water-quality monitor began operation on November 13, 2015. Monitors were housed in a 4-inch diameter polyvinyl chloride (PVC) pipe and placed in a location representative of the stream cross section. Monitor readings were recorded and satellite transmitted hourly.

Date model was developed: April 26, 2019

Model calibration data period: January 26, 1999, to September 28, 2017

Model Data

All data were collected using USGS protocols (U.S. Geological Survey, 2006; Wagner and others, 2006; Sauer and Turnipseed, 2010; Turnipseed and Sauer, 2010) and are stored in the National Water Information System (NWIS) database (https://doi.org/10.5066/F7P55KJN; U.S. Geological Survey, 2020). Explanatory variables were evaluated individually and in combination. Potential explanatory variables included streamflow, water temperature, specific conductance, pH, dissolved oxygen, and turbidity. Seasonal components (sine and cosine variables) were also evaluated as explanatory variables.

The regression model is based on 108 concomitant values of discretely collected OP samples and continuously-measured specific conductance during January 26, 1999, through September 28, 2017. Discrete samples were collected over a range of streamflows. A total of 35 samples were below the minimum reporting level (less than [<] 0.01 milligram per liter [mg/L], <0.02 mg/L, <0.04 mg/L); therefore, a Tobit regression model was developed to compute estimates of OP using the absolute maximum likelihood estimation approach (Hald, 1949; Cohen, 1950; Tobin, 1958; Helsel and others, 2020). Summary statistics and the complete model-calibration data are provided below. Potential outliers were identified using the methods described in Rasmussen and others (2009). Additionally, outlier test criteria, including leverage and Cook's distance (Cook's D), were used to estimate potential outlier influence on the final Tobit regression model (Cook, 1977). The sample collected on March 22, 2006, had a large specific conductance value likely from previous road salt applications and was removed from the model calibration dataset.

Orthophosphate

Discrete samples were collected from the downstream side of the bridge or instream within 50 feet of the bridge using equal-width-increment, multiple vertical, single vertical, or the grab methods following U.S. Geological Survey (2006) and Rasmussen and others (2014). Discrete samples were collected on a semifixed to event based schedule ranging from 2 to 17 samples per year with a Federal Interagency Sedimentation Project U.S. DH–95 or D–95 with a Teflon bottle, cap, and nozzle depth-integrating sampler; a DH–81 with a Teflon bottle, cap, and nozzle hand sampler; or a grab sample with a Teflon bottle depending on sampling location. Samples are analyzed for OP by the Wichita Municipal Water and Wastewater Laboratory in Wichita, Kans., according to standard methods (American Public Health Association and others, 1995).

Continuous Data

Specific conductance was measured with a YSI 6600 sensor during November 9, 1998, through November 12, 2015, and a YSI EXO2 sensor during November 13, 2015, through December 31, 2019. Concomitant specific conductance values were time interpolated. If continuous data were not available (2 or more hours of specific conductance values bracketing the sample collection time were missing) because of fouling, changes in equipment, or unsuitable site conditions, then the field monitor specific conductance value measured sampling was substituted. If no concomitant continuous data were available, the sample was not included in the dataset.

Model Development

Stepwise regression analysis was done using R programming language (R Core Team, 2019) to relate discretely collected OP to specific conductance and other continuously measured data. The distribution of residuals was examined for normality and plots of residuals (the difference between the measured and model calculated values) compared to model calculated OP were examined for homoscedasticity (departures from zero did not change substantially over the range of model calculated values). Previously published explanatory variables were also strongly considered for continuity; however, the best explanatory variable(s) was ultimately selected. Previously published models had nontransformed response (y) variables; however, after reviewing the computed values, some of the predictions were negative and OP values cannot be negative. The response variable was log-transformed and reexamined (Helsel and others, 2020). It was determined the log-transformed version was the best possible model.

A total of 32.4 percent of the model-calibration dataset consisted of censored results (less than minimum reporting level). Tobit regression models were developed using absolute maximum likelihood estimation methods using the *smwrQW* (v.0.7.9) package in R programming language (R Core Team, 2019).

Specific conductance was selected as the best predictor of OP based on residual plots, a higher pseudocoefficient of determination (pseudo-R^2), and relatively low estimated standard residual error (RSE).

Model Summary

Summary of final OP regression analysis at USGS site 07144780:

OP-based model:

$$\log_{10}(OP) = -0.00144 \times SPC - 0.196 ,$$

where,

OP = orthophosphate, in milligrams per liter as phosphorus, and
SPC = specific conductance, in microsiemens per centimeter at 25 degrees Celsius.

The log-transformed model may be retransformed to original units so that OP can be calculated directly. The retransformation introduces a bias in the calculated constituent. This bias may be corrected using Duan's bias correction factor (BCF; Duan, 1983). For this model, the calculated BCF is 1.327. The retransformed model, accounting for BCF, is as follows:

$$OP = (10^{-0.00144 \times SPC} \times 10^{-0.196}) \times 1.327$$

Previous Models

Version	Model Equation	Reference
1.0	$OP = -0.0002 \times SPC + 0.237$	Christensen and others (2006)
1.1	$OP = -0.0002 \times SPC + 0.224$	Stone and others (2013)

Model Statistics, Plots and Data

Definitions for terms used in this output can be found at the end of this document.

Model

$\log_{10}(OP) = -0.00144 \times SPC - 0.196$

Computation method: Absolute Maximum Likelihood Estimation (AMLE)

Explanatory Variables

```
Coefficients:
             Estimate Std. Error z-score p-value
(Intercept) -0.196357  0.0918905  -2.137   0.041
SPC         -0.001442  0.0001073 -13.436   0.000
```

Basic Model Statistics

For a detailed definition and explanation of the terms used below, refer to Helsel and others (2020).

```
Estimated residual standard error (Unbiased) = 0.3457
Number of observations = 108, number censored = 35 (32.4 percent)

Log-likelihood (model) = -48.76
Log-likelihood (intercept only) = -105.1
  Chi-square = 112.8
  degrees of freedom = 1
  p-value = <0.0001

Computation method: AMLE

Pseudo-R-squared: 0.68

  Akaike Information Criterion: 103.5
  Bayesian Information Criterion: 111.6
```

Outlier Test Criteria

```
leverage   cooksD
 0.02778  0.69766
```

Flagged Observations

```
    Observations exceeding at least one test criterion
    logOrthoP  ycen    yhat    resids leverage    cooksD
25    -0.7447 FALSE -0.6937 -0.051049  0.02863 3.309e-04
26    -0.7447 FALSE -0.6888 -0.055974  0.02890 4.017e-04
28    -1.3979 FALSE -0.6908 -0.707144  0.02879 6.385e-02
29    -0.7212 FALSE -0.4902 -0.231061  0.04108 9.980e-03
```

```
32    -0.8539 FALSE -0.7023 -0.151544  0.02817 2.866e-03
41    -0.7696 FALSE -0.5684 -0.201104  0.03593 6.542e-03
42    -0.7959 FALSE -0.6431 -0.152774  0.03144 3.273e-03
52    -2.0000  TRUE -2.2577 -0.135296  0.03554 2.927e-03
58    -0.6778 FALSE -0.6447 -0.033113  0.03135 1.533e-04
62    -0.7959 FALSE -0.7051 -0.090789  0.02803 1.023e-03
74    -0.6990 FALSE -0.6339 -0.065114  0.03197 6.053e-04
76    -0.7696 FALSE -0.4220 -0.347597  0.04595 2.552e-02
79    -1.6990  TRUE -2.1760 -0.058085  0.03069 4.611e-04
89    -0.7447 FALSE -0.6598 -0.084924  0.03049 9.789e-04
91    -1.3979  TRUE -2.1856 -0.010402  0.03123 1.507e-05
96    -1.3979  TRUE -2.1700 -0.011534  0.03035 1.797e-05
99    -1.3979  TRUE -2.2613 -0.006135  0.03577 6.059e-06
100   -0.6198 FALSE -0.5213 -0.098515  0.03898 1.714e-03
103   -0.6778 FALSE -0.6173 -0.060502  0.03295 5.396e-04
```

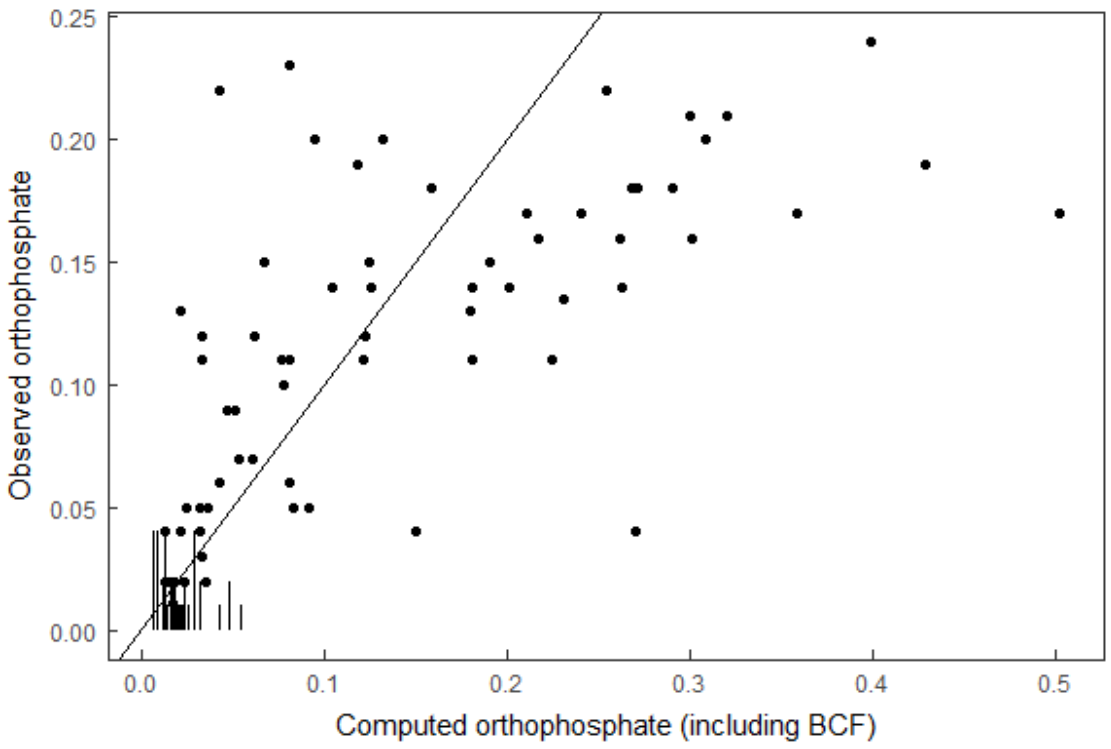
Bias correction factor

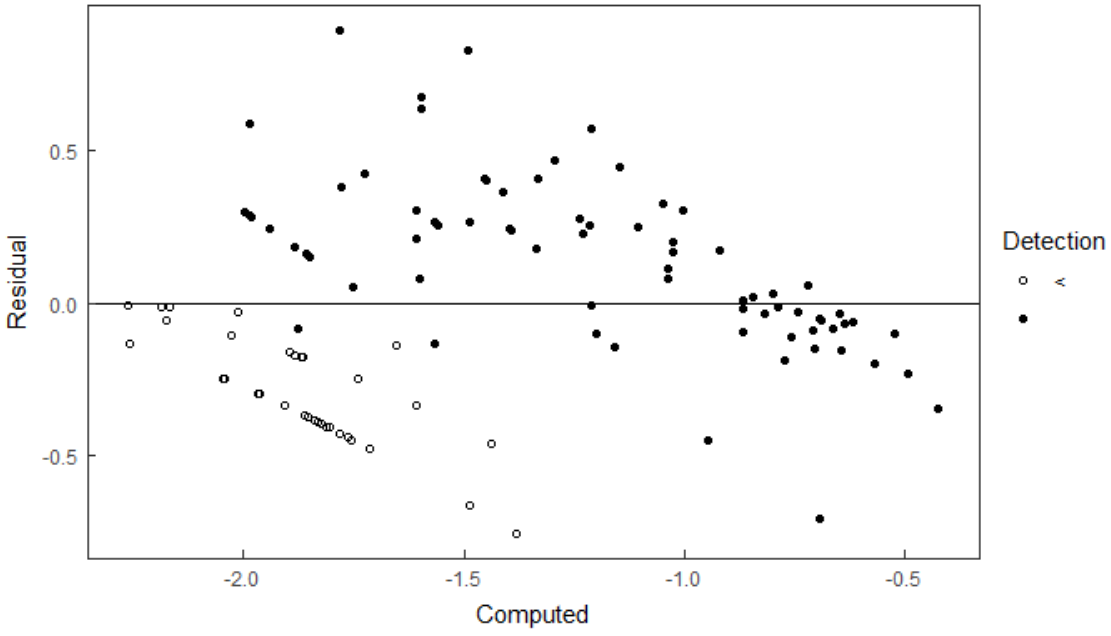
```
[1] 1.326756
```

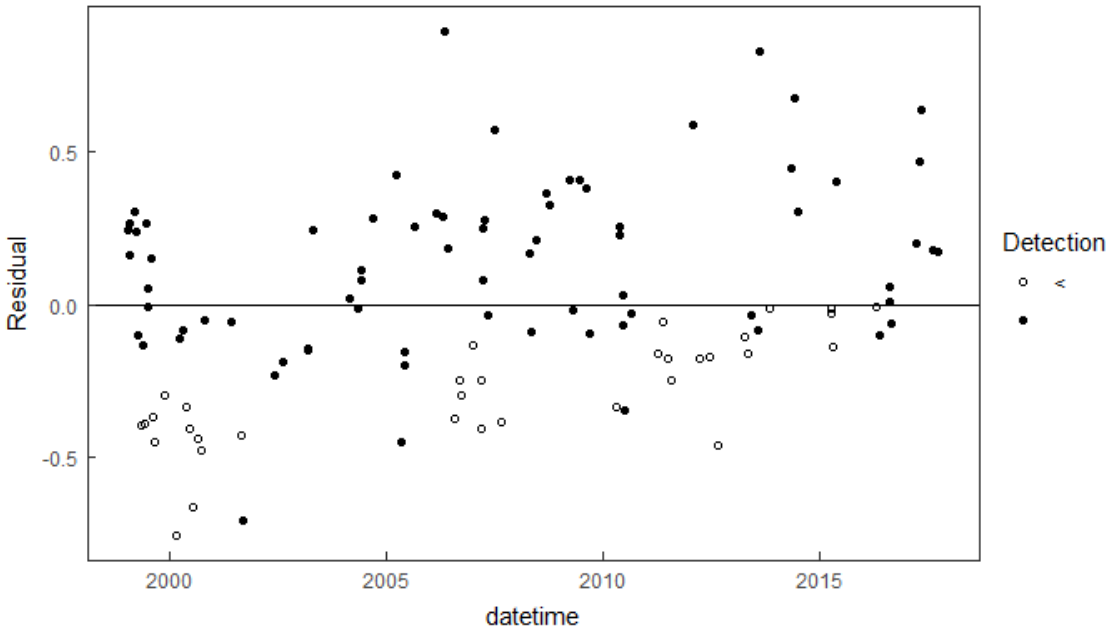
95% Confidence Intervals

```
                    2.5 %      97.5 %
(Intercept) -0.376459016 -0.01625475
SPC         -0.001651785 -0.00123124
```

Plots







Variable Summary Statistics

Independent Variable (xvar) - Specific Conductance

```
   Min. 1st Qu.  Median    Mean  3d Qu.    Max.
  156.5   549.3   896.6   846.2  1150.9  1432.5
```

Standard Deviation

```
[1] 348.1101
```

Dependent Variable (yvar) - Orthophosphate

```
    Min.  1st Qu.   Median     Mean     3d Qu.     Max.
   <0.01    <0.01     0.05    0.061       0.14     0.24
```

Standard Deviation

```
[1] 0.0956
```

Model-Calibration Data Set

	datetime	logOrthoP	logSPC	OrthoP	SPC	Computed_logOP	Computed_OP
1	1999-01-26 11:50:00	-1.7	3.08	0.02	1210	-1.941	0.01519
2	1999-01-31 14:25:00	-1.3	2.98	0.05	949	-1.565	0.03610
3	1999-02-03 10:45:00	-1.7	3.06	0.02	1154	-1.860	0.01833
4	1999-03-17 11:40:00	-1.3	2.99	0.05	979	-1.608	0.03271
5	1999-04-06 13:55:00	-1.15	2.92	0.07	829	-1.392	0.05386
6	1999-04-16 12:55:00	-1.3	2.84	0.05	697	-1.201	0.08348
7	1999-05-13 10:25:00	<-2	3.05	<0.01	1130	-1.825	0.01985
8	1999-05-24 10:45:00	-1.7	2.98	0.02	950	-1.566	0.03602
9	1999-06-10 12:00:00	<-2	3.05	<0.01	1133	-1.830	0.01962
10	1999-06-25 11:15:00	-1.22	2.95	0.06	896	-1.489	0.04306
11	1999-07-02 10:15:00	-1.22	2.85	0.06	705	-1.213	0.08132
12	1999-07-14 11:20:00	-1.7	3.03	0.02	1080	-1.754	0.02339
13	1999-07-29 09:55:00	-1.7	3.06	0.02	1147	-1.850	0.01875
14	1999-08-12 10:35:00	<-2	3.06	<0.01	1155	-1.862	0.01821
15	1999-08-26 10:50:00	<-2	3.03	<0.01	1081	-1.755	0.02331
16	1999-12-02 10:35:00	<-2	3.09	<0.01	1227	-1.965	0.01437
17	2000-02-25 10:40:00	<-2	2.92	<0.01	822	-1.382	0.05503
18	2000-03-24 13:50:00	-0.87	2.59	0.135	390	-0.758	0.23149
19	2000-04-27 10:45:00	-1.96	3.07	0.011	1165	-1.876	0.01764
20	2000-05-25 10:20:00	<-2	3.07	<0.01	1188	-1.909	0.01634
21	2000-06-21 12:00:00	<-2	3.05	<0.01	1117	-1.807	0.02069
22	2000-07-26 11:50:00	<-2	2.95	<0.01	896	-1.488	0.04312
23	2000-08-29 11:00:00	<-2	3.04	<0.01	1087	-1.764	0.02285
24	2000-09-28 10:30:00	<-2	3.02	<0.01	1054	-1.716	0.02550
25	2000-10-26 10:50:00	-0.745	2.54	0.18	345	-0.694	0.26850
26	2001-06-06 11:35:00	-0.745	2.53	0.18	342	-0.689	0.27156
27	2001-09-04 11:05:00	<-2	3.04	<0.01	1100	-1.783	0.02189
28	2001-09-19 10:25:00	-1.4	2.54	0.04	343	-0.691	0.27029
29	2002-06-12 11:10:00	-0.721	2.31	0.19	204	-0.490	0.42905
30	2002-08-14 11:35:00	-0.959	2.60	0.11	398	-0.770	0.22511
31	2003-03-18 12:00:00	-1.3	2.82	0.05	667	-1.158	0.09218
32	2003-03-19 12:20:00	-0.854	2.55	0.14	351	-0.702	0.26320
33	2003-04-21 11:30:00	-1.15	2.92	0.07	832	-1.397	0.05321
34	2004-03-05 12:10:00	-0.824	2.65	0.15	448	-0.842	0.19084
35	2004-05-14 10:35:00	-0.796	2.61	0.16	408	-0.785	0.21746
36	2004-06-14 09:45:00	-0.921	2.76	0.12	582	-1.036	0.12223
37	2004-06-14 09:50:00	-0.959	2.77	0.11	584	-1.038	0.12142
38	2004-09-08 10:25:00	-1.7	3.09	0.02	1240	-1.984	0.01375
39	2005-03-24 10:15:00	-1.3	3.03	0.05	1060	-1.725	0.02500
40	2005-05-16 11:40:00	-1.4	2.72	0.04	520	-0.947	0.15001
41	2005-06-10 10:55:00	-0.77	2.41	0.17	258	-0.569	0.35828
42	2005-06-13 09:25:00	-0.796	2.49	0.16	310	-0.643	0.30167
43	2005-08-29 09:35:00	-0.959	2.85	0.11	707	-1.216	0.08071
44	2006-03-02 09:50:00	-1.7	3.10	0.02	1250	-1.999	0.01330
45	2006-05-01 11:15:00	-1.7	3.09	0.02	1242	-1.988	0.01364
46	2006-05-12 10:30:00	-0.886	3.04	0.13	1100	-1.783	0.02189
47	2006-06-05 10:15:00	-1.7	3.07	0.02	1171	-1.885	0.01728
48	2006-07-31 10:30:00	<-2	3.06	<0.01	1150	-1.855	0.01854
49	2006-09-07 10:50:00	<-2	3.11	<0.01	1280	-2.042	0.01204
50	2006-09-21 10:00:00	<-2	3.09	<0.01	1230	-1.970	0.01422
51	2006-09-21 10:05:00	<-2	3.09	<0.01	1230	-1.970	0.01422
52	2007-01-09 10:30:00	<-2	3.16	<0.01	1430	-2.258	0.00732
53	2007-03-14 10:20:00	<-2	3.11	<0.01	1283	-2.047	0.01191
54	2007-03-22 10:00:00	<-2	3.05	<0.01	1120	-1.811	0.02048
55	2007-03-26 10:40:00	-1.52	2.99	0.03	974	-1.601	0.03322
56	2007-03-31 12:30:00	-0.854	2.80	0.14	629	-1.103	0.10457
57	2007-04-16 12:15:00	-0.959	2.86	0.11	722	-1.237	0.07692
58	2007-05-07 10:30:00	-0.678	2.49	0.21	311	-0.645	0.30059
59	2007-06-29 10:25:00	-0.638	2.85	0.23	704	-1.211	0.08166
60	2007-09-04 11:25:00	<-2	3.06	<0.01	1140	-1.840	0.01917
61	2008-04-24 11:40:00	-0.854	2.76	0.14	574	-1.024	0.12566
62	2008-05-09 11:35:00	-0.796	2.55	0.16	353	-0.705	0.26153
63	2008-06-19 09:45:00	-1.4	2.99	0.04	979	-1.608	0.03274
64	2008-09-15 10:55:00	-1.05	2.93	0.09	842	-1.411	0.05147
65	2008-10-16 10:10:00	-0.721	2.77	0.19	591	-1.048	0.11877

66	2009-03-31 11:20:00	-1.05	2.94	0.09	871	-1.452	0.04687	
67	2009-04-27 12:15:00	-0.886	2.67	0.13	466	-0.868	0.17981	
68	2009-06-17 10:40:00	-0.921	2.90	0.12	787	-1.331	0.06195	
69	2009-08-20 10:50:00	-1.4	3.04	0.04	1098	-1.780	0.02201	
70	2009-09-10 11:30:00	-0.959	2.67	0.11	464	-0.865	0.18086	
71	2010-04-23 10:00:00	<-1.7	2.99	<0.02	980	-1.610	0.03260	
72	2010-05-17 16:40:00	-1.3	2.98	0.05	945	-1.559	0.03666	
73	2010-05-27 10:00:00	-1	2.85	0.1	716	-1.229	0.07834	
74	2010-06-14 11:30:00	-0.699	2.48	0.2	304	-0.634	0.30817	
75	2010-06-16 10:15:00	-0.77	2.62	0.17	417	-0.798	0.21123	
76	2010-07-06 10:30:00	-0.77	2.19	0.17	156	-0.422	0.50207	
77	2010-08-25 11:00:00	-0.77	2.58	0.17	378	-0.741	0.24063	
78	2011-04-13 10:00:00	<-1.7	3.07	<0.02	1180	-1.898	0.01678	
79	2011-05-23 10:20:00	<-1.7	3.14	<0.02	1373	-2.177	0.00883	
80	2011-06-28 10:00:00	<-1.7	3.06	<0.02	1160	-1.869	0.01794	
81	2011-07-27 11:20:00	<-1.7	3.03	<0.02	1070	-1.739	0.02418	
82	2012-02-06 09:45:00	-1.4	3.09	0.04	1242	-1.988	0.01364	
83	2012-03-23 10:15:00	<-1.7	3.06	<0.02	1158	-1.865	0.01809	
84	2012-06-20 09:15:00	<-1.7	3.07	<0.02	1170	-1.883	0.01735	
85	2012-08-27 09:30:00	<-1.7	2.93	<0.02	860	-1.436	0.04856	
86	2013-04-11 10:10:00	<-1.7	3.10	<0.02	1270	-2.028	0.01245	
87	2013-05-10 10:00:00	<-1.7	3.07	<0.02	1180	-1.898	0.01678	
88	2013-05-31 10:00:00	-0.854	2.63	0.14	431	-0.818	0.20181	
89	2013-08-05 10:05:00	-0.745	2.51	0.18	322	-0.660	0.29029	
90	2013-08-16 08:30:00	-0.658	2.95	0.22	897	-1.490	0.04295	
91	2013-10-31 10:00:00	<-1.4	3.14	<0.04	1380	-2.186	0.00864	
92	2014-05-13 10:00:00	-0.699	2.82	0.2	659	-1.147	0.09466	
93	2014-06-10 10:30:00	-0.921	2.99	0.12	972	-1.597	0.03354	
94	2014-07-02 09:10:00	-0.699	2.75	0.2	559	-1.002	0.13193	
95	2015-04-08 09:45:00	<-1.4	3.10	<0.04	1260	-2.013	0.01287	
96	2015-04-14 09:55:00	<-1.4	3.14	<0.04	1369	-2.171	0.00896	
97	2015-04-21 10:15:00	<-1.4	3.00	<0.04	1010	-1.653	0.02951	
98	2015-05-26 10:45:00	-1.05	2.94	0.09	868	-1.448	0.04729	
99	2016-04-19 10:25:00	<-1.4	3.16	<0.04	1432	-2.262	0.00726	
100	2016-05-25 10:10:00	-0.62	2.35	0.24	225	-0.521	0.39940	
101	2016-08-07 12:30:00	-0.854	2.67	0.14	464	-0.865	0.18086	
102	2016-08-13 11:30:00	-0.658	2.56	0.22	361	-0.717	0.25461	
103	2016-08-27 09:20:00	-0.678	2.47	0.21	292	-0.617	0.32016	
104	2017-03-29 10:45:00	-0.824	2.76	0.15	576	-1.027	0.12469	
105	2017-04-20 12:00:00	-0.824	2.88	0.15	762	-1.295	0.06724	
106	2017-05-02 09:50:00	-0.959	2.99	0.11	972	-1.597	0.03354	
107	2017-08-11 11:00:00	-1.15	2.90	0.07	789	-1.334	0.06149	
108	2017-09-28 10:30:00	-0.745	2.70	0.18	502	-0.921	0.15924	

Definitions

OP: orthophosphate, in milligrams per liter as phosphorus (00671)
SPC: specific conductance, in microsiemens per centimeter at 25 degrees Celsius (00095)
Leverage: an outlier’s measure in the x-direction (Helsel and others, 2020).
p-value: the probability that the independent variable has no effect on the dependent variable (Helsel and others, 2020).
Pseudo-R-squared: pseudocoefficient of determination. An estimation of the proportion of variance in the response variable explained by the model (McKelvey and Zavoina, 1975).
z-score: the estimated coefficient divided by its associated standard error (Helsel and others, 2020).

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

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