USGS
science for a changing world

Prepared in cooperation with the U.S. Environmental Protection Agency

Air- and Stream-Water-Temperature Trends in the Chesapeake Bay Region, 1960–2014

By John D. Jastram and Karen C. Rice

Open-File Report 2015–1207

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: 2015

Suggested citation:
Jastram, J.D., and Rice, K.C., 2015, Air- and stream-water-temperature trends in the Chesapeake Bay region, 1960–2014: U.S. Geological Survey Open-File Report 2015–1207, 28 p., http://dx.doi.org/10.3133/ofr20151207.

ISSN 2331-1258 (online)

Preface

This report documents an update to the air-temperature and stream-water-temperature trend analyses presented in Rice and Jastram (2015). This update extends the analysis period (1960–2010) to include data collected through the end of the 2014 water year (September 30, 2014). Methods of analysis are presented in Rice and Jastram (2015). This updated analysis was performed for inclusion of air-temperature and stream-water-temperature trends as indicators of climate change in the U.S. Environmental Protection Agency's "Climate Change Indicators in the United States, 2016" report.

Acknowledgments

The authors thank the cooperator, the U.S. Environmental Protection Agency, for support of this scientific work. In particular, we thank Michael Kolian for initiating this effort and for his contributions to the report.
Thorough reviews were provided by James Webber and John Clune, U.S. Geological Survey, whose comments improved the clarity of the report.

Contents

Figures

Table

Conversion Factors

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as °F = (1.8 × °C) + 32.

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as °C = (°F – 32) / 1.8.

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Abbreviations

AT	Air temperature
EPA	U.S. Environmental Protection Agency
NOAA	National Atmospheric and Oceanic Administration
USGS	U.S. Geological Survey
WT	Water temperature

Air- and Stream-Water-Temperature Trends in the Chesapeake Bay Region, 1960–2014

By John D. Jastram and Karen C. Rice

Introduction

Water temperature is a basic, but important, measure of the condition of all aquatic environments, including the flowing waters in the streams that drain our landscape and the receiving waters of those streams. Climatic conditions have a strong influence on water temperature, which is therefore naturally variable both in time and across the landscape. Changes to natural water-temperature regimes, however, can result in a myriad of effects on aquatic organisms, water quality, circulation patterns, recreation, industry, and utility operations. For example, most species of fish, insects, and other organisms, as well as aquatic vegetation, are highly dependent on water temperature. Warming waters can result in shifts in floral and faunal species distributions (Short and Neckles, 1999; Beitinger and others 2000; Coles and Jones, 2000), including invasive species and pathogens previously unable to inhabit the once cooler streams. Many chemical processes are temperature dependent, with reactions occurring faster in warmer conditions, leading to degraded water quality as contaminants are released into waterways at greater rates (Duan and Kaushal, 2013). Circulation patterns in receiving waters, such as bays and estuaries, can change as a result of warmer inflows from streams, thereby affecting organisms in those receiving waters. Changes in abundance of some aquatic species and (or) degradation of water quality can reduce the recreational value of water bodies as waters are perceived as less desirable for water-related activities or as sportfish become less available for anglers. Finally, increasing water temperatures can affect industry and utilities as the thermal capacity is reduced, making the water less effective for cooling purposes.

Chesapeake Bay is the largest estuary in the United States. Eutrophication, the enrichment of a water body with excess nutrients, has plagued the bay for decades and has led to extensive restoration efforts throughout the bay watershed. The warming of stream water can exacerbate eutrophication through increased release of nutrients from in-stream sediments (Duan and Kaushal, 2013), so understanding changes in stream-water temperature throughout the bay watershed is critical to resource managers seeking to restore the bay ecosystem.

The U.S. Environmental Protection Agency (EPA) uses indicators that "represent the state or trend of certain environmental or societal conditions … to track and better understand the effects of changes in the Earth's climate" (U.S. Environmental Protection Agency, 2014). Updates to these indicators are published biennially by the EPA. The U.S. Geological Survey (USGS), in cooperation with the EPA, has completed analyses of air- and stream-water-temperature trends in the Chesapeake Bay region to be included as an indicator in a future release of the EPA report.

About the Indicator

The National Oceanic and Atmospheric Administration (NOAA) operates meteorological monitoring stations, which routinely measure air temperature (AT) and other meteorological variables, throughout the United States. The AT trends for this indicator are determined from monthly mean AT data for the period January 1, 1960, through September 30, 2014, from 79 NOAA meteorological monitoring stations located within or near the Chesapeake Bay watershed. The U.S. Geological Survey (USGS) measures streamflow in rivers and streams across the United States at monitoring stations called streamgages, and stream-water temperature (WT) is measured periodically at these stations. The WT trends for this indicator are determined from instantaneous WT data collected from January 1, 1960, through September 30, 2014, at 129 streamgages within or near the Chesapeake Bay watershed. Methods of data acquisition, processing, and analysis are described in Rice and Jastram (2015).

This indicator includes evaluations of AT and WT trends within or near the Chesapeake Bay watershed for the nearly 55-year period of 1960–2014. The direction, magnitude, and statistical significance of AT (fig. 1) and WT (fig. 2) trends are shown on maps. Station location and trend-analysis details for individual AT and WT stations are provided in appendixes 1 and 2, respectively, and plotted in in appendixes 3 and 4, respectively.

Key Points

- From 1960 through 2014, AT increased significantly at 63 of 79 stations analyzed within and near the Chesapeake Bay watershed, and decreased significantly at 4 stations (table 1; fig. 3).
- Regionally, the median of significant AT trends was 0.020 degree Celsius (°C) per year with a range of −0.02 to 0.04 °C.
- Trends in AT were relatively consistent throughout the study area.
- From 1960 through 2014, WT increased significantly at 53 of 129 stations analyzed in the region. Stream-water temperature decreased significantly at 7 of those 129 stations over the same period.
- Regionally, the median of significant WT trends was 0.026 °C per year with a range of −0.08 to 0.08 °C per year.
- Increases in WT occurred at the greatest rates in the southern part of the study area.
- Compared to AT trend results for data spanning 1960–2010 (Rice and Jastram, 2015), two more stations had significantly increasing trends during the period 1960–2014, and one more station had a significantly decreasing trend during the period 1960–2014.
- Compared to WT trend results for data spanning 1960–2010 (Rice and Jastram, 2015), four more stations had significantly increasing trends during the period 1960–2014, and one less station had a significantly decreasing trend during the period 1960–2014.

Table 1. Summary of trend-analysis results for air and stream-water temperature, Chesapeake Bay region, 1960–2014.

Statistic	Air temperature		Water temperature	
	1960–2014	1960–2010[a]	1960–2014	1960–2010[a]
Number of stations	79[b]	85	129	129
Number of significant trends	67	64	60	57
Number of significant increasing trends	63	61	53	49
Number of significant decreasing trends	4	3	7	8
Range of trends, in degrees Celsius per year	−0.022–0.045	−0.018–0.057	−0.080–0.081	−0.095–0.095
Median of significant trends	0.020	0.023	0.026	0.028

[a] From Rice and Jastram, 2015.

[b] Six of the 85 stations were discontinued between 2010 and 2014.

Indicator Notes

Water temperature in streams can be affected by factors other than climate, including industrial discharges, hydrologic alteration (for example, channelization, piping, and impoundment), land cover, location, and topography. For this indicator, WT measurements from all available streamgages with appropriate records within the study area were used, as described in Rice and Jastram (2015), regardless of potential influences from anthropogenic disturbances. A comparison, using the Rank-Sum test (Helsel and Hirsch, 2002), of relatively undisturbed reference stations (n = 35), as determined by Falcone (2011), with all other stations (n = 94) in the dataset demonstrated no significant difference (alpha = 0.05) in trends between the two groups of stations.

Data Sources

AT data were collected by NOAA and were downloaded from the National Centers for Environmental Information Web site (http://www.ncdc.noaa.gov). WT data were collected by the USGS and were retrieved from the National Water Information System. These data are from stations selected according to the criteria described in Rice and Jastram (2015).

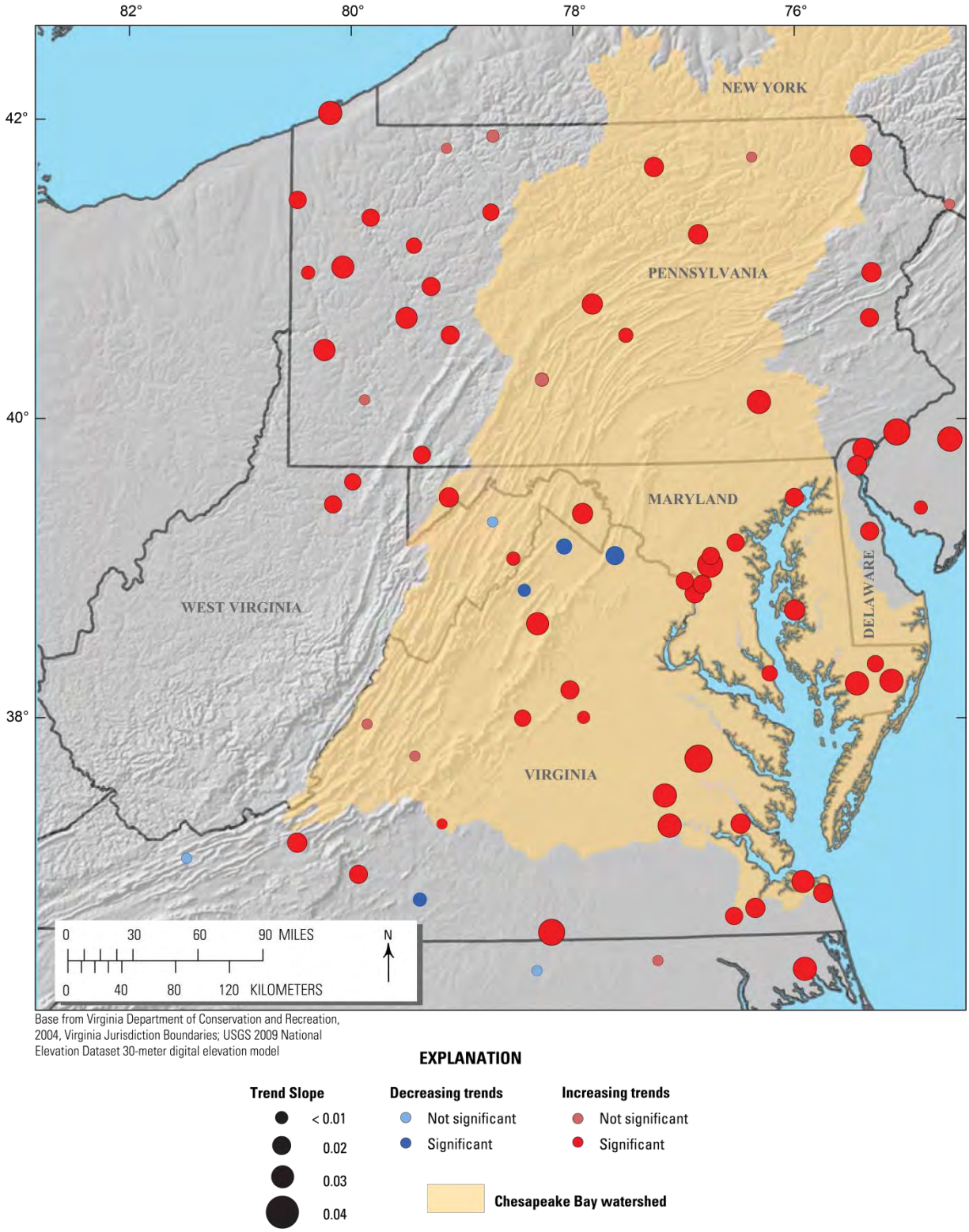


Figure 1. Locations of air-temperature measurement stations and results of trend analyses at those stations, Chesapeake Bay region, 1960–2014.

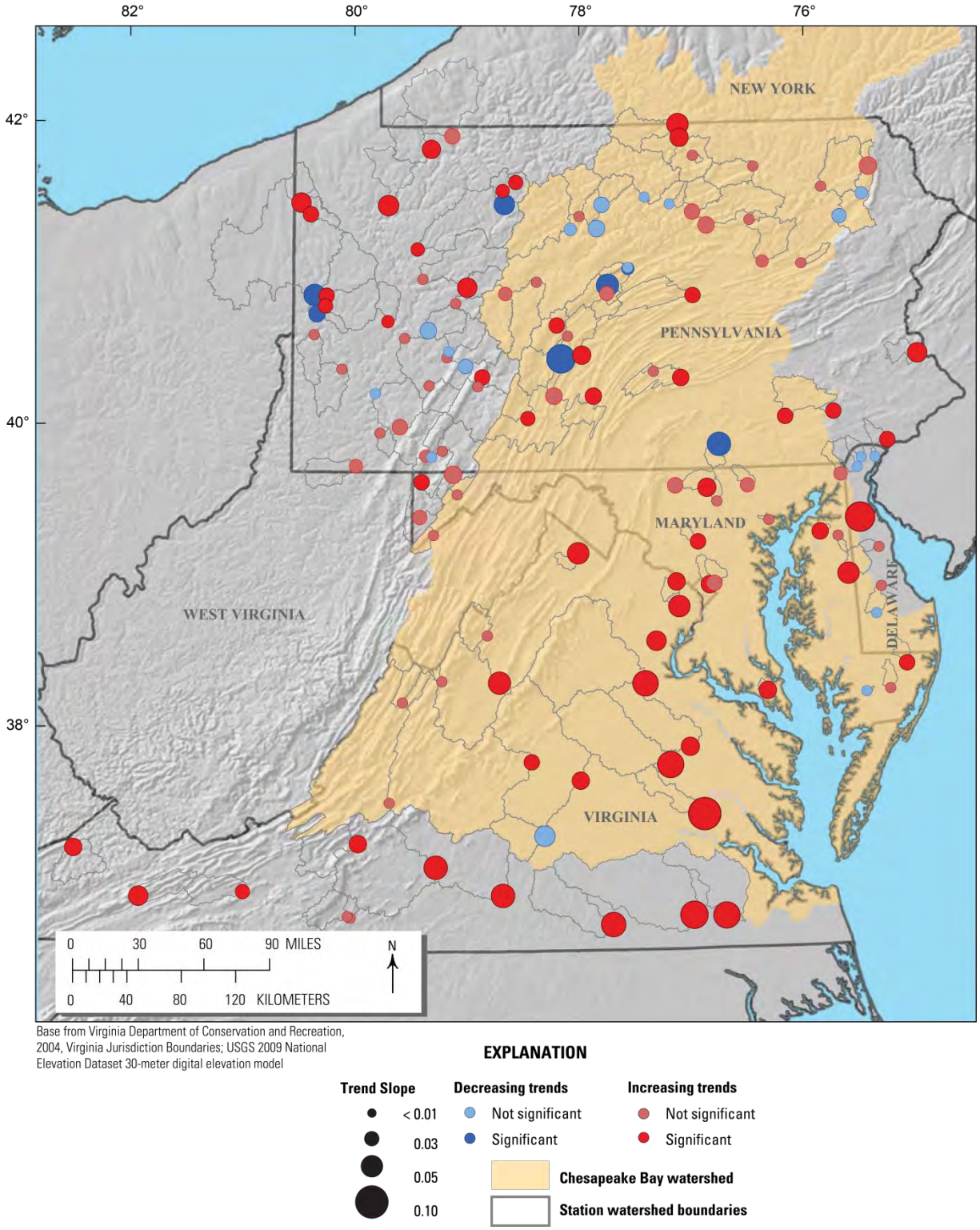


Figure 2. Locations of stream-water-temperature measurement stations and results of trend analyses at those stations, Chesapeake Bay region, 1960–2014.

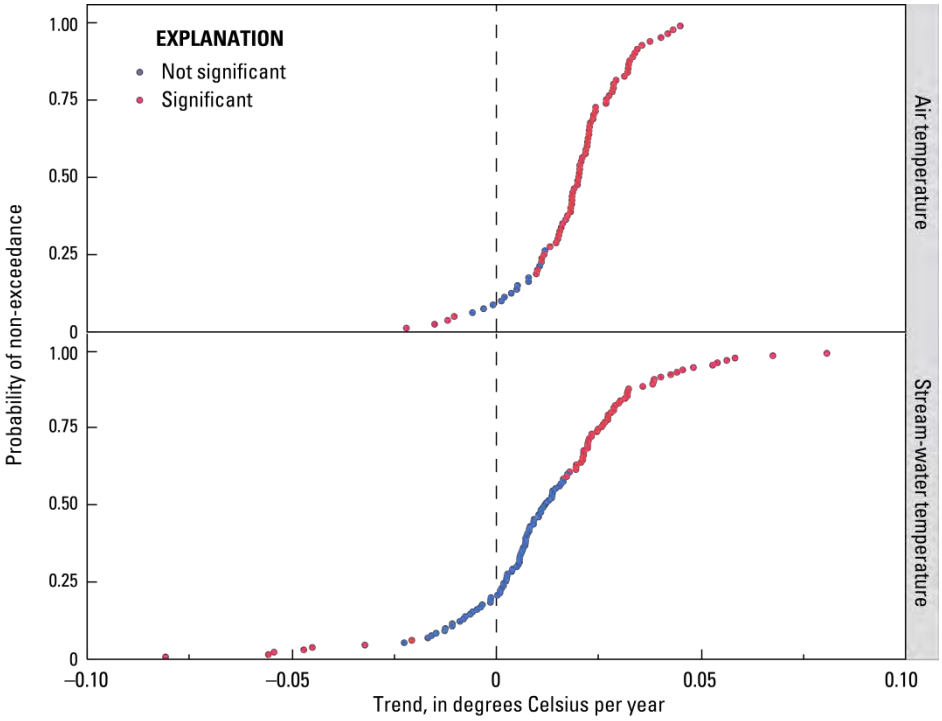


Figure 3. Non-exceedance probabilities and model significance for air- and stream-water-temperature trends, Chesapeake Bay region, 1960–2014.

References Cited

Beitinger, T.L., Bennett, W.A., and McCauley, R.W., 2000, Temperature tolerances of North American freshwater fishes exposed to dynamic changes in temperature: Environmental Biology of Fishes, v. 58, no. 3, p. 237–275.

Coles, J.F., and Jones, R.C., 2000, Effect of temperature on photosynthesis-light response and growth of four phytoplankton species isolated from a tidal freshwater river: Journal of Phycology, v. 36, no. 1, p. 7–16.

Duan, S.W., and Kaushal, S.S., 2013, Warming increases carbon and nutrient fluxes from sediments in streams across land use: Biogeosciences, v. 10, no. 2, p. 1193–1207.

Falcone, J.A., 2011, GAGES–II, Geospatial Attributes of Gages for Evaluating Streamflow [digital spatial dataset], accessed August 5, 2015, at http://water.usgs.gov/GIS/metadata/usgswrd/XML/gagesII_Sept2011.xml.

Helsel, D.R., and Hirsch, R.M., 2002, Statistical methods in water resources: U.S. Geological Survey Techniques of Water-Resources Investigations, book 4, chap. A3, 523 p.

Rice, K.C., and Jastram, J.D., 2015, Rising air and stream-water temperatures in Chesapeake Bay region, USA: Climatic Change, v. 128, no. 1, p. 127–138.

Short, F.T., and Neckles, H.A., 1999, The effects of global climate change on seagrasses: Aquatic Botany, v. 63, no. 3–4, p. 169–196.

U.S. Environmental Protection Agency, 2014, Climate change indicators in the United States, 2014 (3d ed.): EPA 430-R-14-004, accessed August 17, 2015, at http://www.epa.gov/climatechange/indicators.

Appendix 1. Air-temperature station information and results of trend analyses, Chesapeake Bay region, 1960–2014.

[north latitude and west longitude given in decimal degrees; m, meter; N, number; C, Celsius; <, less than]

Air-temperature station name	Short name	Latitude	Longitude	Elevation, m	Observations, N	Intercept	Trend, in degrees C per year	p-value of trend
ABERDEEN PHILLIPS FIELD MD US	ABERD, MD	39.467	-76.153	16	583	-34.029	0.021	0.0006
ALLENTOWN LEHIGH VALLEY INTERNATIONAL AIRPORT PA US	ALLEN, PA	40.650	-75.437	118	660	-32.517	0.020	<0.0001
ALTOONA BLAIR CO AIRPORT PA US	ALTOO, PA	40.300	-78.317	450	628	-19.212	0.012	0.05
BALTIMORE WASHINGTON INTERNATIONAL AIRPORT MD US	BALTI, MD	39.179	-76.671	46	660	-31.012	0.019	0.0001
BELTSVILLE MD US	BELTS, MD	39.038	-76.897	38	642	-63.672	0.038	<0.0001
BLACKSBURG NATIONAL WEATHER SERVICE OFFICE VA US	BLACK, VA	37.203	-80.415	621	647	-37.077	0.022	<0.0001
BRADFORD 4 SW RES 5 PA US	BRADF, PA	41.929	-78.728	512	655	-17.843	0.011	0.0552
BURKES GARDEN VA US	BURKE, VA	37.088	-81.334	1,000	659	10.584	-0.006	0.2208
CANOE BROOK NJ US	CANOE, NJ	40.749	-74.351	55	648	-72.122	0.045	<0.0001
CHARLOTTEBURG RESERVOIR NJ US	CHARL, NJ	41.041	-74.430	226	635	-57.442	0.036	<0.0001
CHARLOTTESVILLE 2 W VA US	CHARL, VA	38.033	-78.518	265	651	-27.064	0.016	0.0011
CHATHAM VA US	CHATH, VA	36.826	-79.387	204	641	19.272	-0.012	0.0152
CLARION 3 SW PA US	CLARI, PA	41.199	-79.434	333	643	-23.380	0.015	0.0107
CONFLUENCE 1 SW DAM PA US	CONFL, PA	39.800	-79.367	454	659	-30.276	0.018	0.0008
DALECARLIA RESERVOIR DC US	DALEC, DC	38.934	-77.116	46	648	-28.409	0.018	0.0008
DONORA 1 SW PA US	DONOR, PA	40.169	-79.865	243	654	-8.650	0.005	0.3457
DOVER DE US	DOVER, DE	39.222	-75.517	9	653	-32.682	0.020	<0.0001
ELIZABETH CITY NC US	ELIZA, NC	36.314	-76.207	3	636	-51.270	0.031	<0.0001
ERIE INTERNATIONAL AIRPORT PA US	ERIE, PA	42.083	-80.183	224	660	-53.332	0.034	<0.0001
FAIRMONT WV US	FAIRM, WV	39.467	-80.133	396	660	-29.645	0.017	0.0014
FORD CITY 4 S DAM PA US	FORD, PA	40.717	-79.500	287	648	-44.016	0.027	<0.0001
FRANKLIN PA US	FRANK, PA	41.385	-79.818	303	644	-31.555	0.019	0.0006

Appendix 1. Air-temperature station information and results of trend analyses, Chesapeake Bay region, 1960–2014.—Continued

[north latitude and west longitude given in decimal degrees; m, meter; N, number; C, Celsius; <, less than]

Air-temperature station name	Short name	Latitude	Longitude	Elevation, m	Observations, N	Intercept	Trend, in degrees C per year	p-value of trend
HENDERSON 2 NNW NC US	HENDE, NC	36.346	-78.422	150	628	5.330	-0.003	0.521
HIGHTSTOWN 2 W NJ US	HIGHT, NJ	40.278	-74.534	31	660	-25.989	0.015	0.0008
HOLLAND 1 E VA US	HOLLA, VA	36.683	-76.780	24	660	-30.543	0.018	<0.0001
HOPEWELL VA US	HOPEW, VA	37.300	-77.296	12	647	-53.096	0.032	<0.0001
HOT SPRINGS VA US	HOT S, VA	37.999	-79.833	678	620	-6.273	0.004	0.4669
INDIAN MILLS NJ US	INDIA, NJ	39.814	-74.788	30	654	-59.307	0.034	<0.0001
INDIANA 3 SE PA US	INDIA, PA	40.600	-79.117	336	657	-34.713	0.020	0.0002
JACKSON NC US	JACKS, NC	36.399	-77.418	40	650	-2.005	0.001	0.8025
JAMESTOWN 2 NW PA US	JAMES, PA	41.500	-80.467	318	658	-32.249	0.019	0.0005
JOHN H KERR DAM VA US	JOHN, VA	36.600	-78.294	86	652	-64.785	0.040	<0.0001
LANDISVILLE 2 NW PA US	LANDI, PA	40.116	-76.432	111	659	-50.891	0.032	<0.0001
LAUREL 3 W MD US	LAURE, MD	39.095	-76.888	97	610	-30.593	0.018	0.0005
LEWISTOWN PA US	LEWIS, PA	40.585	-77.576	143	649	-22.168	0.013	0.0072
LEXINGTON VA US	LEXIN, VA	37.786	-79.430	326	644	-3.222	0.002	0.6984
LINCOLN VA US	LINCO, VA	39.113	-77.711	153	649	36.427	-0.022	<0.0001
LOUISA VA US	LOUIS, VA	38.035	-78.001	130	659	-16.910	0.010	0.0356
LURAY 5 E VA US	LURAY, VA	38.667	-78.382	375	613	-46.166	0.029	<0.0001
LYNCHBURG REGIONAL AIRPORT VA US	LYNCH, VA	37.331	-79.201	285	660	-16.634	0.010	0.036
MARTINSBURG EASTERN WV REGIONAL AIRPORT WV US	MARTI, WV	39.400	-77.983	163	660	-36.060	0.024	<0.0001
MILLVILLE MUNICIPAL AIRPORT NJ US	MILLV, NJ	39.367	-75.067	22	654	-18.298	0.011	0.0206
MORGANTOWN LOCK AND DAM WV US	MORGA, WV	39.617	-79.967	252	643	-24.080	0.015	0.0101
NATIONAL ARBORETUM DC US	NATIO, DC	38.907	-76.968	17	641	-33.386	0.020	<0.0001
NEW CASTLE 1 N PA US	NEW C, PA	41.017	-80.366	252	645	-18.617	0.011	0.0479
NORFOLK INTERNATIONAL AIRPORT VA US	NORFO, VA	36.899	-76.198	8	660	-44.305	0.029	<0.0001

Appendix 1. Air-temperature station information and results of trend analyses, Chesapeake Bay region, 1960–2014.—Continued

[north latitude and west longitude given in decimal degrees; m, meter; N, number; C, Celsius; <, less than]

Air-temperature station name	Short name	Latitude	Longitude	Elevation, m	Observations, N	Intercept	Trend, in degrees C per year	p-value of trend
OCEANA NAS VA US	OCEAN, VA	36.818	-76.032	7	621	-36.331	0.023	<0.0001
PATUXENT RIVER NAS MD US	PATUX, MD	38.298	-76.417	12	631	-20.873	0.015	0.0099
PHILADELPHIA INTERNATIONAL AIRPORT PA US	PHILA, PA	39.879	-75.243	4	660	-67.707	0.042	<0.0001
PIEDMONT RESEARCH STATION VA US	PIEDM, VA	38.220	-78.114	157	659	-33.732	0.020	<0.0001
PITTSBURGH INTERNATIONAL AIRPORT PA US	PITTS, PA	40.500	-80.220	356	660	-47.416	0.028	<0.0001
PLEASANT MOUNT 1 W PA US	PLEAS, PA	41.734	-75.450	549	652	-48.178	0.027	<0.0001
PORT JERVIS NY US	PORT, NY	41.382	-74.683	143	653	-8.283	0.005	0.3038
PRINCESS ANNE MD US	PRINC, MD	38.211	-75.680	6	620	-53.907	0.033	<0.0001
PUTNEYVILLE 2 SE DAM PA US	PUTNE, PA	40.924	-79.283	389	656	-33.979	0.020	0.0003
RICHMOND INTERNATIONAL AIRPORT VA US	RICHM, VA	37.502	-77.330	52	660	-52.975	0.032	<0.0001
RIDGWAY PA US	RIDGW, PA	41.419	-78.752	417	660	-27.456	0.016	0.0028
ROCKY MOUNT VA US	ROCKY, VA	36.994	-79.899	377	651	-35.018	0.021	<0.0001
ROMNEY 1 SW WV US	ROMNE, WV	39.351	-78.757	206	652	1.397	-0.001	0.8679
ROYAL OAK 2 SSW MD US	ROYAL, MD	38.716	-76.185	3	657	-40.281	0.024	<0.0001
SALISBURY WICOMICO REGIONAL AIRPORT MD US	SALIS, MD	38.335	-75.516	18	660	-27.094	0.017	0.0008
SAVAGE RIVER DAM MD US	SAVAG, MD	39.515	-79.135	456	657	-39.523	0.022	<0.0001
SLIPPERY ROCK PA US	SLIPP, PA	41.055	-80.062	390	659	-42.688	0.029	<0.0001
SNOW HILL 4 N MD US	SNOW, MD	38.217	-75.387	8	651	-57.399	0.033	<0.0001
STATE COLLEGE PA US	STATE, PA	40.799	-77.867	358	646	-41.730	0.024	<0.0001
SUFFOLK LAKE KILBY VA US	SUFFO, VA	36.733	-76.600	6	659	-36.079	0.023	<0.0001
TOWANDA 1 S PA US	TOWAN, PA	41.754	-76.425	230	648	-13.937	0.008	0.1064
WALKERTON 2 NW VA US	WALKE, VA	37.744	-77.039	14	650	-70.361	0.043	<0.0001
WARDENSVILLE RM FARM WV US	WARDE, WV	39.103	-78.583	293	655	-20.003	0.012	0.0163
WARREN PA US	WARRE, PA	41.849	-79.143	378	658	-13.298	0.008	0.1402

Appendix 1. Air-temperature station information and results of trend analyses, Chesapeake Bay region, 1960–2014.—Continued

[north latitude and west longitude given in decimal degrees; m, meter; N, number; C, Celsius; <, less than]

Air-temperature station name	Short name	Latitude	Longitude	Elevation, m	Observations, N	Intercept	Trend, in degrees C per year	p-value of trend
WASHINGTON REAGAN NATIONAL AIRPORT VA US	WASHI, VA	38.850	-77.033	7	660	-35.897	0.022	<0.0001
WELLSBORO 4 SW PA US	WELLS, PA	41.705	-77.296	569	596	-40.615	0.023	<0.0001
WILKES BARRE SCRANTON INTERNATIONAL AIRPORT PA US	WILKE, PA	40.954	-75.401	188	660	-37.297	0.022	<0.0001
WILLIAMSPORT LYCOMING CO AIRPORT PA US	WILLI, PA	41.248	-76.918	159	660	-39.559	0.024	<0.0001
WILLIAMSBURG 2 N VA US	WILLI, VA	37.299	-76.701	21	660	-37.084	0.022	<0.0001
WILMINGTON NEW CASTLE CO AIRPORT DE US	WILMI, DE	39.668	-75.600	23	660	-37.582	0.023	<0.0001
WILMNGTON PORTER RSV DE US	WILMN, DE	39.774	-75.541	83	659	-47.381	0.028	<0.0001
WINCHESTER 7 SE VA US	WINCH, VA	39.181	-78.145	218	641	24.867	-0.015	0.0055
WOODSTOCK 2 NE VA US	WOODS, VA	38.891	-78.491	235	659	16.966	-0.010	0.042

Appendix 2. Water-temperature station information and results of trend analyses, Chesapeake Bay region, 1960–2014.

[USGS, U.S. Geological Survey; ID, identification number; north latitude and west longitude given in decimal degrees; m, meter; km^2, square kilometer; N, number; C, Celsius; SLR, simple linear regression on anomalies; C-O, Cochrane-Orcutt; nr, near; <, less than; latitude, longitude, elevation, and drainage area are from Falcone (2011)]

Water-temperature station name	USGS station ID	Latitude	Longitude	Elevation, m	Drainage area, km^2	Observations, N	Intercept	Trend, degrees C per year	p-value of trend	Method
Tohickon Creek nr Pipersville, PA	01459500	40.434	-75.117	82	254.2	319	-63.771	0.032	0.0013	SLR
Chester Creek nr Chester, PA	01477000	39.869	-75.408	14	157	302	-44.313	0.022	0.008	SLR
Shellpot Creek at Wilmington, DE	01477800	39.761	-75.519	8	18.9	502	15.038	-0.008	0.3645	SLR
White Clay Creek nr Newark, DE	01479000	39.699	-75.675	5	230.8	509	17.693	-0.009	0.2255	SLR
Red Clay Creek at Wooddale, DE	01480000	39.763	-75.637	30	122.6	427	2.763	-0.001	0.8718	SLR
West Branch Brandywine Creek nr Honey Brook, PA	01480300	40.073	-75.861	184	47.7	355	0.022	0.022	0.0191	C-O
Blackbird Creek at Blackbird, DE	01483200	39.366	-75.669	5	10.8	423	0.068	0.068	<0.0001	C-O
St Jones River at Dover, DE	01483700	39.164	-75.519	3	81	526	0.009	0.009	0.2955	C-O
Beaverdam Branch at Houston, DE	01484100	38.906	-75.513	11	9	455	-4.990	0.003	0.6862	SLR
Pocomoke River nr Willards, MD	01485000	38.389	-75.324	5	137.9	407	-42.379	0.021	0.0079	SLR
Nassawango Creek nr Snow Hill, MD	01485500	38.229	-75.471	4	141.5	460	-14.738	0.007	0.3375	SLR
Manokin Branch nr Princess Anne, MD	01486000	38.214	-75.671	3	11.2	406	-0.003	-0.003	0.7462	C-O
Nanticoke River nr Bridgeville, DE	01487000	38.728	-75.562	5	187.4	442	2.928	-0.001	0.8463	SLR
Choptank River nr Greensboro, MD	01491000	38.997	-75.786	4	292	598	0.040	0.040	<0.0001	C-O
Unicorn Branch nr Millington, MD	01493000	39.250	-75.861	4	50.9	428	0.006	0.006	0.5711	C-O

Appendix 2. Water-temperature station information and results of trend analyses, Chesapeake Bay region, 1960–2014.—Continued

[USGS, U.S. Geological Survey; ID, identification number; north latitude and west longitude given in decimal degrees; m, meter; km^2, square kilometer; N, number; C, Celsius; SLR, simple linear regression on anomalies; C-O, Cochrane-Orcutt; nr, near; <, less than; latitude, longitude, elevation, and drainage area are from Falcone (2011)]

Water-temperature station name	USGS station ID	Latitude	Longitude	Elevation, m	Drainage area, km^2	Observations, N	Intercept	Trend, degrees C per year	p-value of trend	Method
Morgan Creek nr Kennedyville, MD	01493500	39.280	-76.015	5	33	474	0.026	0.026	0.0086	C-O
Big Elk Creek at Elk Mills, MD	01495000	39.657	-75.822	27	138.2	428	-21.671	0.011	0.2087	SLR
Corey Creek nr Mainesburg, PA	01516500	41.791	-77.015	410	31.5	412	0.007	0.007	0.54	C-O
Tioga River at Tioga, PA	01518000	41.908	-77.129	314	724.5	339	-59.406	0.030	0.0013	SLR
Cowanesque River nr Lawrenceville, PA	01520000	41.997	-77.140	315	776.3	471	0.039	0.039	0.0003	C-O
Towanda Creek nr Monroeton, PA	01532000	41.707	-76.485	236	553.9	377	0.006	0.006	0.5732	C-O
Tunkhannock Creek nr Tunkhannock, PA	01534000	41.558	-75.895	189	1016.9	312	-14.192	0.007	0.4162	SLR
Lackawanna River nr Forest City, PA	01534300	41.680	-75.472	479	98.5	312	-34.417	0.017	0.0768	SLR
Lackawanna River at Archbald, PA	01534500	41.505	-75.542	275	281.8	318	21.390	-0.011	0.1935	SLR
Lackawanna River at Old Forge, PA	01536000	41.359	-75.744	184	863.1	281	24.681	-0.012	0.1807	SLR
Wapwallopen Creek nr Wapwallopen, PA	01538000	41.059	-76.094	235	103.1	343	-12.672	0.006	0.4125	SLR
Fishing Creek nr Bloomsburg, PA	01539000	41.078	-76.431	168	701.8	345	0.010	0.010	0.2543	C-O
West Branch Susquehanna River at Bower, PA	01541000	40.897	-78.677	366	817.7	304	0.011	0.011	0.3012	C-O
Clearfield Creek at Dimeling, PA	01541500	40.972	-78.406	355	960.2	315	-11.290	0.006	0.5713	SLR
Sinnemahoning Creek at Sinnemahoning, PA	01543500	41.317	-78.103	231	1778.3	334	-0.011	-0.011	0.3778	C-O
First Fork Sinnemahoning Cr nr Sinnemahoning, PA	01544000	41.402	-78.024	282	635	353	0.004	0.004	0.7176	C-O

Appendix 2. Water-temperature station information and results of trend analyses, Chesapeake Bay region, 1960–2014.—Continued

[USGS, U.S. Geological Survey; ID, identification number; north latitude and west longitude given in decimal degrees; m, meter; km^2, square kilometer; N, number; C, Celsius; SLR, simple linear regression on anomalies; C-O, Cochrane-Orcutt; nr, near; <, less than; latitude, longitude, elevation, and drainage area are from Falcone (2011)]

Water-temperature station name	USGS station ID	Latitude	Longitude	Elevation, m	Drainage area, km^2	Observations, N	Intercept	Trend, degrees C per year	p-value of trend	Method
Kettle Creek at Cross Fork, PA	01544500	41.476	-77.826	315	355.1	386	29.205	-0.015	0.1153	SLR
Kettle Creek nr Westport, PA	01545000	41.320	-77.874	238	604.3	364	-0.017	-0.017	0.0905	C-O
Spring Creek nr Axemann, PA	01546500	40.890	-77.794	251	223.7	377	-24.246	0.012	0.0899	SLR
Bald Eagle Creek Bl Spring Creek at Milesburg, PA	01547200	40.943	-77.786	209	694.3	321	-0.054	-0.054	<0.0001	C-O
Bald Eagle Creek at Blanchard, PA	01547500	41.052	-77.604	188	878.2	383	-0.021	-0.021	0.0038	C-O
Marsh Creek at Blanchard, PA	01547700	41.060	-77.606	186	113.5	401	-0.006	-0.006	0.4852	C-O
Pine Creek at Cedar Run, PA	01548500	41.522	-77.447	239	1557	343	11.560	-0.006	0.4689	SLR
Blockhouse Creek nr English Center, PA	01549500	41.474	-77.231	319	97.5	377	-0.005	-0.005	0.5946	C-O
Lycoming Creek nr Trout Run, PA	01550000	41.418	-77.033	212	452.7	412	-26.836	0.014	0.0628	SLR
Loyalsock Creek at Loyalsockville, PA	01552000	41.325	-76.912	180	1129.5	361	-30.662	0.015	0.0528	SLR
Muncy Creek nr Sonestown, PA	01552500	41.357	-76.535	335	60.6	379	-7.875	0.004	0.5924	SLR
Penns Creek at Penns Creek, PA	01555000	40.867	-77.048	158	792.6	321	-46.134	0.023	0.023	SLR
Frankstown Br Juniata River at Williamsburg, PA	01556000	40.463	-78.200	269	749.6	317	-0.081	-0.081	<0.0001	C-O
Bald Eagle Creek at Tyrone, PA	01557500	40.684	-78.234	290	115.3	363	0.022	0.022	0.0318	C-O
Little Juniata River at Spruce Creek, PA	01558000	40.613	-78.141	230	572.5	351	-9.900	0.005	0.4419	SLR
Juniata River at Huntingdon, PA	01559000	40.485	-78.019	176	2111.3	318	-60.172	0.030	0.0003	SLR

Appendix 2. Water-temperature station information and results of trend analyses, Chesapeake Bay region, 1960–2014.—Continued

[USGS, U.S. Geological Survey; ID, identification number; north latitude and west longitude given in decimal degrees; m, meter; km^2, square kilometer; N, number; C, Celsius; SLR, simple linear regression on anomalies; C-O, Cochrane-Orcutt; nr, near; <, less than; latitude, longitude, elevation, and drainage area are from Falcone (2011)]

Water-temperature station name	USGS station ID	Latitude	Longitude	Elevation, m	Drainage area, km^2	Observations, N	Intercept	Trend, degrees C per year	p-value of trend	Method
Dunning Creek at Belden, PA	01560000	40.072	-78.493	328	444.6	349	-38.628	0.019	0.0171	SLR
Raystown Branch Juniata River at Saxton, PA	01562000	40.216	-78.265	243	1944	311	0.016	0.016	0.158	C-O
Aughwick Creek nr Three Springs, PA	01564500	40.213	-77.925	189	445.6	347	0.025	0.025	0.0257	C-O
Bixler Run nr Loysville, PA	01567500	40.371	-77.402	184	38.8	355	0.003	0.003	0.807	C-O
Sherman Creek at Shermans Dale, PA	01568000	40.323	-77.169	131	534.4	319	-48.817	0.025	0.016	SLR
Codorus Creek at Spring Grove, PA	01574500	39.879	-76.853	132	195.8	319	-0.056	-0.056	<0.0001	C-O
Conestoga River at Lancaster, PA	01576500	40.050	-76.277	84	837.2	330	-42.448	0.021	0.0175	SLR
Little Falls at Blue Mount, MD	01582000	39.604	-76.620	137	139.2	303	-25.444	0.013	0.1594	SLR
Whitemarsh Run at White Marsh, MD	01585100	39.371	-76.446	15	19.7	262	-16.395	0.008	0.5118	SLR
Cranberry Branch nr Westminster, MD	01585500	39.593	-76.968	209	8.4	316	-57.700	0.029	0.0011	SLR
North Branch Patapsco River at Cedarhurst, MD	01586000	39.504	-76.885	134	144.5	292	0.005	0.005	0.6372	C-O
Patuxent River nr Unity, MD	01591000	39.238	-77.056	114	89	300	-42.385	0.021	0.0149	SLR
North Branch Potomac River at Steyer, MD	01595000	39.302	-79.307	699	190.1	351	-0.494	0.000	0.9803	SLR
Savage River nr Barton, MD	01596500	39.570	-79.102	490	124.7	408	-1.761	0.001	0.91	SLR
Opequon Creek nr Berryville, VA	01615000	39.175	-78.078	162	149.5	349	0.038	0.038	0.0001	C-O
North River nr Stokesville, VA	01620500	38.335	-79.239	665	44.7	391	-15.152	0.008	0.2783	SLR
S F Shenandoah River nr	01628500	38.323	-78.755	322	2792.9	334	0.043	0.043	<0.0001	C-O

Appendix 2. Water-temperature station information and results of trend analyses, Chesapeake Bay region, 1960–2014.—Continued

[USGS, U.S. Geological Survey; ID, identification number; north latitude and west longitude given in decimal degrees; m, meter; km^2, square kilometer; N, number; C, Celsius; SLR, simple linear regression on anomalies; C-O, Cochrane-Orcutt; nr, near; <, less than; latitude, longitude, elevation, and drainage area are from Falcone (2011)]

Water-temperature station name	USGS station ID	Latitude	Longitude	Elevation, m	Drainage area, km^2	Observations, N	Intercept	Trend, degrees C per year	p-value of trend	Method
Lynnwood, VA										
N F Shenandoah River at Cootes Store, VA	01632000	38.637	-78.853	322	543.4	340	-18.149	0.009	0.2576	SLR
Big Pipe Creek at Bruceville, MD	01639500	39.612	-77.237	108	267.2	298	-27.366	0.014	0.1607	SLR
Difficult Run nr Great Falls, VA	01646000	38.976	-77.246	54	149.9	407	-52.705	0.027	0.0011	SLR
Northeast Branch Anacostia River at Riverdale, MD	01649500	38.960	-76.926	7	188.1	316	0.014	0.014	0.3129	C-O
Northwest Br Anacostia River Nr Hyattsville, MD	01651000	38.952	-76.966	8	127.8	300	0.027	0.027	0.0428	C-O
Accotink Creek nr Annandale, VA	01654000	38.813	-77.228	61	60.7	446	-76.249	0.038	<0.0001	SLR
S F Quantico Creek nr Independent Hill, VA	01658500	38.587	-77.429	74	19.3	412	0.032	0.032	0.0041	C-O
St Marys River at Great Mills, MD	01661500	38.242	-76.504	3	65.4	263	-54.340	0.027	0.0083	SLR
Rappahannock River nr Fredericksburg, VA	01668000	38.308	-77.529	24	4135	348	0.053	0.053	<0.0001	C-O
Pamunkey River nr Hanover, VA	01673000	37.768	-77.332	15	2796.3	413	-111.885	0.056	<0.0001	SLR
Mattaponi River nr Beulahville, VA	01674500	37.884	-77.165	15	1554.8	391	-57.064	0.029	0.0001	SLR
Bullpasture River at Williamsville, VA	02015700	38.195	-79.570	515	285.4	400	0.008	0.008	0.3898	C-O
James River at Buchanan, VA	02019500	37.531	-79.679	248	5378.5	278	-11.738	0.006	0.5318	SLR
James River at Scottsville, VA	02029000	37.797	-78.491	75	11875.8	282	0.023	0.023	0.0242	C-O
James River at Cartersville, VA	02035000	37.671	-78.086	61	16207.1	460	0.027	0.027	0.007	C-O

Appendix 2. Water-temperature station information and results of trend analyses, Chesapeake Bay region, 1960–2014.—Continued

[USGS, U.S. Geological Survey; ID, identification number; north latitude and west longitude given in decimal degrees; m, meter; km^2, square kilometer; N, number; C, Celsius; SLR, simple linear regression on anomalies; C-O, Cochrane-Orcutt; nr, near; <, less than; latitude, longitude, elevation, and drainage area are from Falcone (2011)]

Water-temperature station name	USGS station ID	Latitude	Longitude	Elevation, m	Drainage area, km^2	Observations, N	Intercept	Trend, degrees C per year	p-value of trend	Method
Appomattox River at Farmville, VA	02039500	37.307	-78.389	92	784.8	334	-0.023	-0.023	0.1413	C-O
Chickahominy River nr Providence Forge, VA	02042500	37.436	-77.061	5	646.9	392	-160.408	0.081	<0.0001	SLR
Nottoway River nr Sebrell, VA	02047000	36.770	-77.166	4	3731.4	349	0.058	0.058	<0.0001	C-O
Blackwater River nr Franklin, VA	02049500	36.763	-76.898	2	1582.7	323	0.054	0.054	<0.0001	C-O
Meherrin River nr Lawrenceville, VA	02051500	36.717	-77.832	57	1428.7	328	0.048	0.048	<0.0001	C-O
Roanoke River at Roanoke, VA	02055000	37.258	-79.939	284	996.6	383	-55.719	0.028	0.0002	SLR
Roanoke River at Altavista, VA	02060500	37.105	-79.295	171	4617.8	283	0.044	0.044	<0.0001	C-O
Roanoke (Staunton) River at Randolph, VA	02066000	36.915	-78.741	109	7686.3	298	0.046	0.046	0.0002	C-O
Smith River nr Philpott, VA	02072000	36.781	-80.025	256	557.7	304	0.006	0.006	0.5976	C-O
Smith River at Bassett, VA	02072500	36.770	-80.001	241	670.1	359	0.002	0.002	0.8553	C-O
Conewango Creek at Russell, PA	03015000	41.938	-79.133	375	2083.3	399	-27.222	0.014	0.0737	SLR
Brokenstraw Creek at Youngsville, PA	03015500	41.853	-79.317	364	784.9	446	-56.888	0.029	0.0002	SLR
Oil Creek at Rouseville, PA	03020500	41.482	-79.695	318	730.6	424	-70.999	0.036	0.0003	SLR
Sevenmile Run nr Rasselas, PA	03026500	41.631	-78.577	516	20.3	422	-38.642	0.019	0.0071	SLR
West Branch Clarion River at Wilcox, PA	03028000	41.575	-78.692	459	161.1	425	-35.560	0.018	0.0183	SLR
Clarion River at Johnsonburg, PA	03028500	41.486	-78.678	435	527.4	383	89.154	-0.045	<0.0001	SLR
Clarion River nr Piney, PA	03030500	41.193	-79.440	314	2501.2	379	0.017	0.017	0.0391	C-O

Appendix 2. Water-temperature station information and results of trend analyses, Chesapeake Bay region, 1960–2014.—Continued

[USGS, U.S. Geological Survey; ID, identification number; north latitude and west longitude given in decimal degrees; m, meter; km^2, square kilometer; N, number; C, Celsius; SLR, simple linear regression on anomalies; C-O, Cochrane-Orcutt; nr, near; <, less than; latitude, longitude, elevation, and drainage area are from Falcone (2011)]

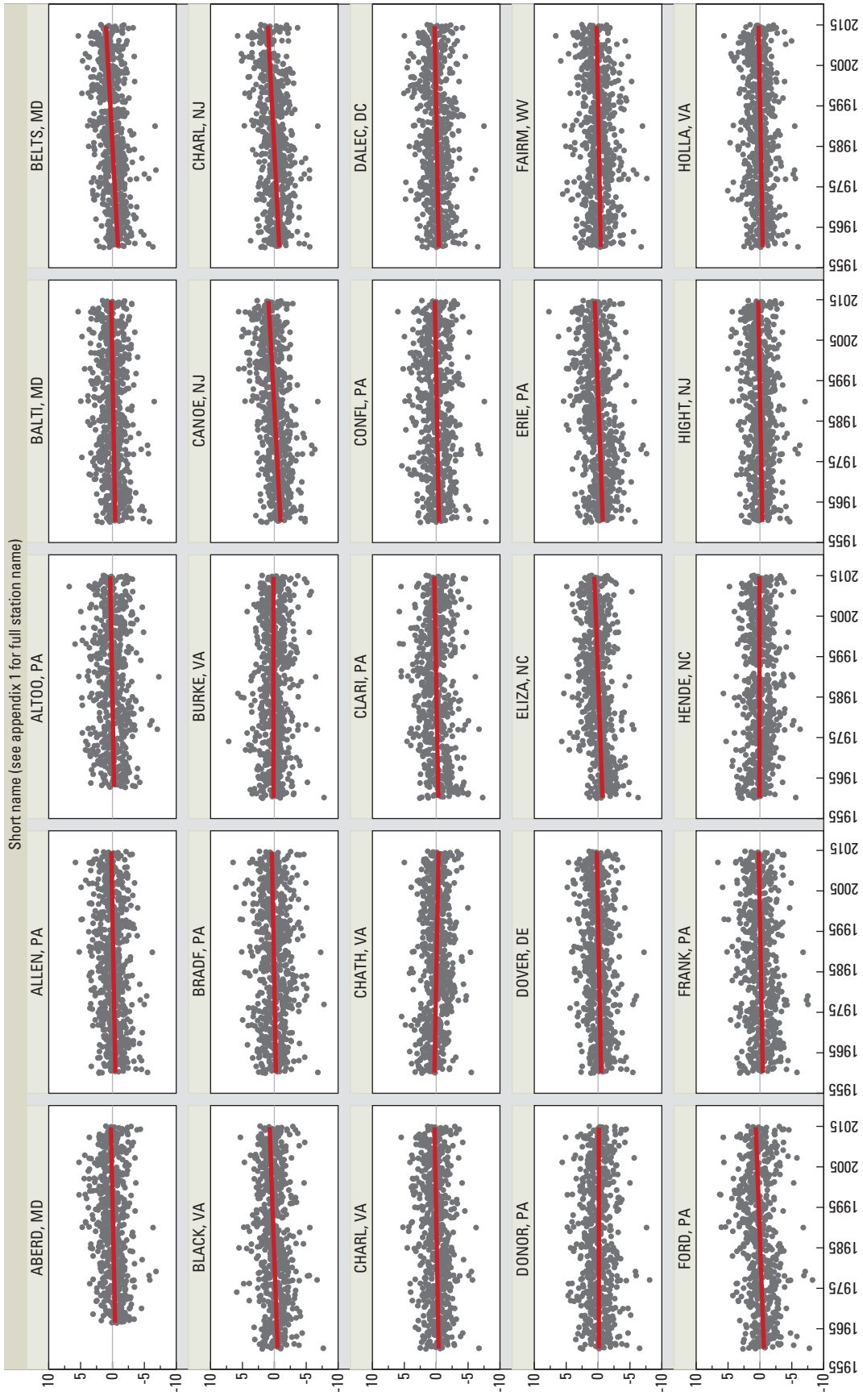
Water-temperature station name	USGS station ID	Latitude	Longitude	Elevation, m	Drainage area, km^2	Observations, N	Intercept	Trend, degrees C per year	p-value of trend	Method
Redbank Creek at St. Charles, PA	03032500	40.995	-79.394	302	1376.6	406	-2.631	0.001	0.8804	SLR
Mahoning Creek at Punxsutawney, PA	03034000	40.939	-79.008	365	407.6	424	-62.453	0.031	0.0004	SLR
Little Mahoning Creek at McCormick, PA	03034500	40.836	-79.110	362	226.1	447	0.009	0.009	0.329	C-O
Crooked Creek at Idaho, PA	03038000	40.655	-79.349	297	493.7	435	-0.016	-0.016	0.1134	C-O
Stonycreek River at Ferndale, PA	03040000	40.286	-78.921	363	1171.5	416	-14.214	0.007	0.392	SLR
Little Conemaugh River at East Conemaugh, PA	03041000	40.346	-78.883	376	480.7	413	0.022	0.022	0.0225	C-O
Conemaugh River at Seward, PA	03041500	40.419	-79.026	330	1863.6	376	-0.013	-0.013	0.2215	C-O
Blacklick Creek at Josephine, PA	03042000	40.477	-79.187	303	499.3	448	-3.424	0.002	0.8362	SLR
Two Lick Creek at Graceton, PA	03042500	40.517	-79.172	305	440.9	441	7.592	-0.004	0.6262	SLR
Loyalhanna Creek at Kingston, PA	03045000	40.293	-79.341	311	444	431	0.007	0.007	0.5099	C-O
Kiskiminetas River at Vandergrift, PA	03048500	40.605	-79.552	231	4729	341	-1.945	0.001	0.922	SLR
Buffalo Creek nr Freeport, PA	03049000	40.716	-79.699	243	357.2	462	-32.483	0.016	0.0474	SLR
Dunkard Creek at Shannopin, PA	03072000	39.759	-79.971	283	588.4	422	-21.603	0.011	0.2051	SLR
Redstone Creek at Waltersburg, PA	03074500	39.980	-79.764	273	191.1	437	0.008	0.008	0.4139	C-O
Youghiogheny River nr Oakland, MD	03075500	39.422	-79.424	719	347.6	358	-23.447	0.012	0.1964	SLR
Youghiogheny River at Friendsville, MD	03076500	39.654	-79.408	459	761.8	332	-42.004	0.021	0.0131	SLR
Casselman River at Grantsville, MD	03078000	39.702	-79.136	649	161.5	408	-32.517	0.016	0.0625	SLR

Appendix 2. Water-temperature station information and results of trend analyses, Chesapeake Bay region, 1960–2014.—Continued

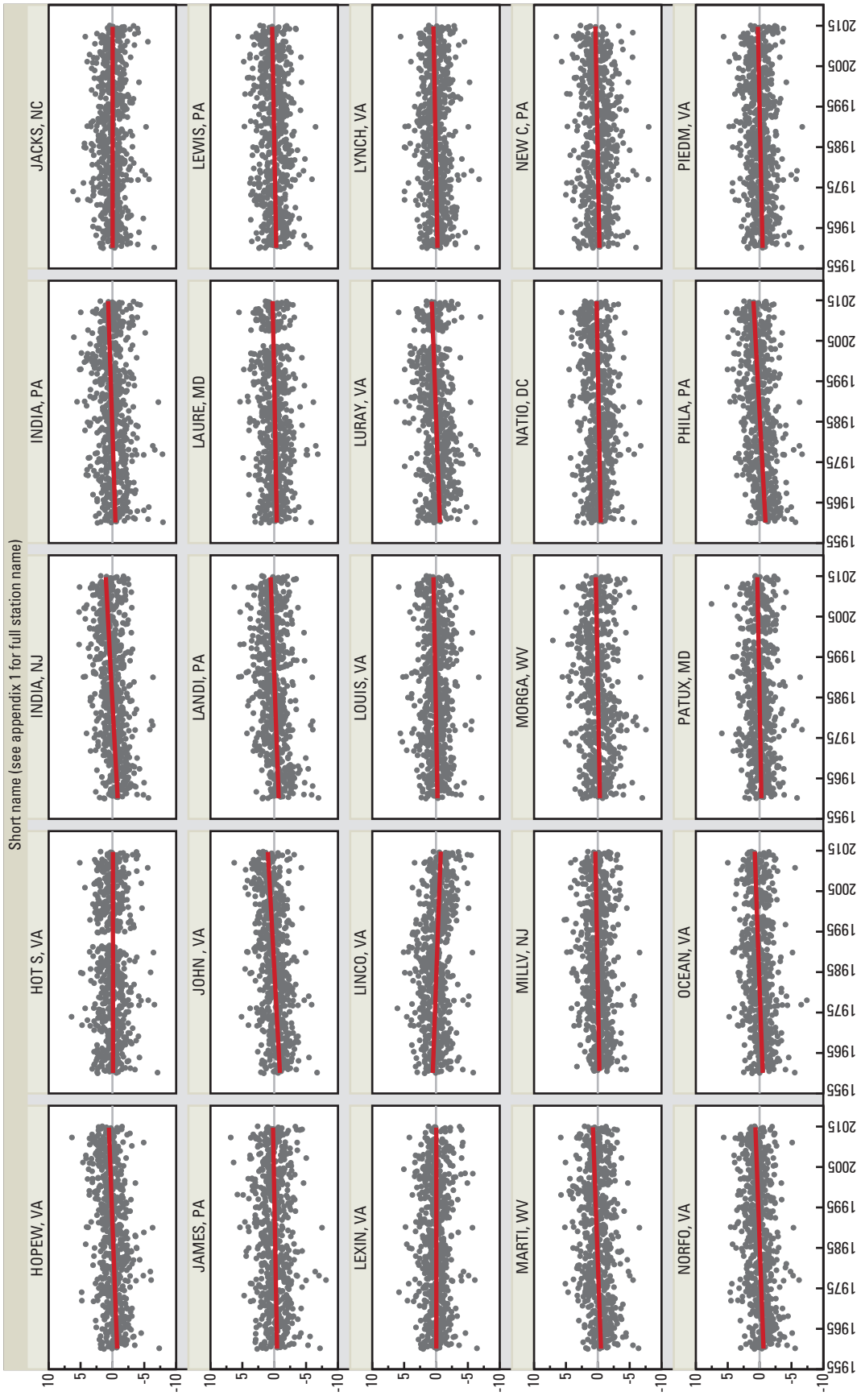
[USGS, U.S. Geological Survey; ID, identification number; north latitude and west longitude given in decimal degrees; m, meter; km^2, square kilometer; N, number; C, Celsius; SLR, simple linear regression on anomalies; C-O, Cochrane-Orcutt; nr, near; <, less than; latitude, longitude, elevation, and drainage area are from Falcone (2011)]

Water-temperature station name	USGS station ID	Latitude	Longitude	Elevation, m	Drainage area, km^2	Observations, N	Intercept	Trend, degrees C per year	p-value of trend	Method
Casselman River at Markleton, PA	03079000	39.860	-79.229	512	990.8	392	0.003	0.003	0.8059	C-O
Laurel Hill Creek at Ursina, PA	03080000	39.820	-79.321	418	313.3	431	-0.008	-0.008	0.4805	C-O
Youghiogheny River Below Confluence, PA	03081000	39.828	-79.373	401	2659.9	340	0.010	0.010	0.2891	C-O
Youghiogheny River at Connellsville, PA	03082500	40.018	-79.593	267	3426.3	389	0.014	0.014	0.1512	C-O
Youghiogheny River at Sutersville, PA	03083500	40.240	-79.807	224	4429.5	356	2.588	-0.001	0.884	SLR
Chartiers Creek at Carnegie, PA	03085500	40.401	-80.096	232	666.9	402	0.002	0.002	0.8332	C-O
Shenango River at Pymatuning Dam, PA	03101500	41.498	-80.460	299	420.2	392	-63.510	0.032	<0.0001	SLR
Little Shenango River at Greenville, PA	03102500	41.422	-80.376	302	241.7	456	0.023	0.023	0.0099	C-O
Beaver River at Wampum, PA	03105500	40.889	-80.337	234	5752.9	363	-0.047	-0.047	0.0005	C-O
Connoquenessing Creek nr Zelienople, PA	03106000	40.817	-80.242	267	921.4	436	-38.768	0.020	0.0256	SLR
Slippery Rock Creek at Wurtemburg, PA	03106500	40.884	-80.234	264	1043.4	429	0.021	0.021	0.0331	C-O
Beaver River at Beaver Falls, PA	03107500	40.763	-80.315	230	8034.3	308	-0.032	-0.032	0.0319	C-O
Raccoon Creek at Moffatts Mill, PA	03108000	40.628	-80.338	228	463.5	458	0.007	0.007	0.4546	C-O
Reed Creek at Grahams Forge, VA	03167000	36.939	-80.887	590	669	369	-41.126	0.021	0.0076	SLR
Russell Fork at Haysi, VA	03208500	37.207	-82.296	379	740.9	437	-51.839	0.026	0.0011	SLR
N F Holston River nr Saltville, VA	03488000	36.897	-81.746	533	578.2	539	0.032	0.032	0.0002	C-O

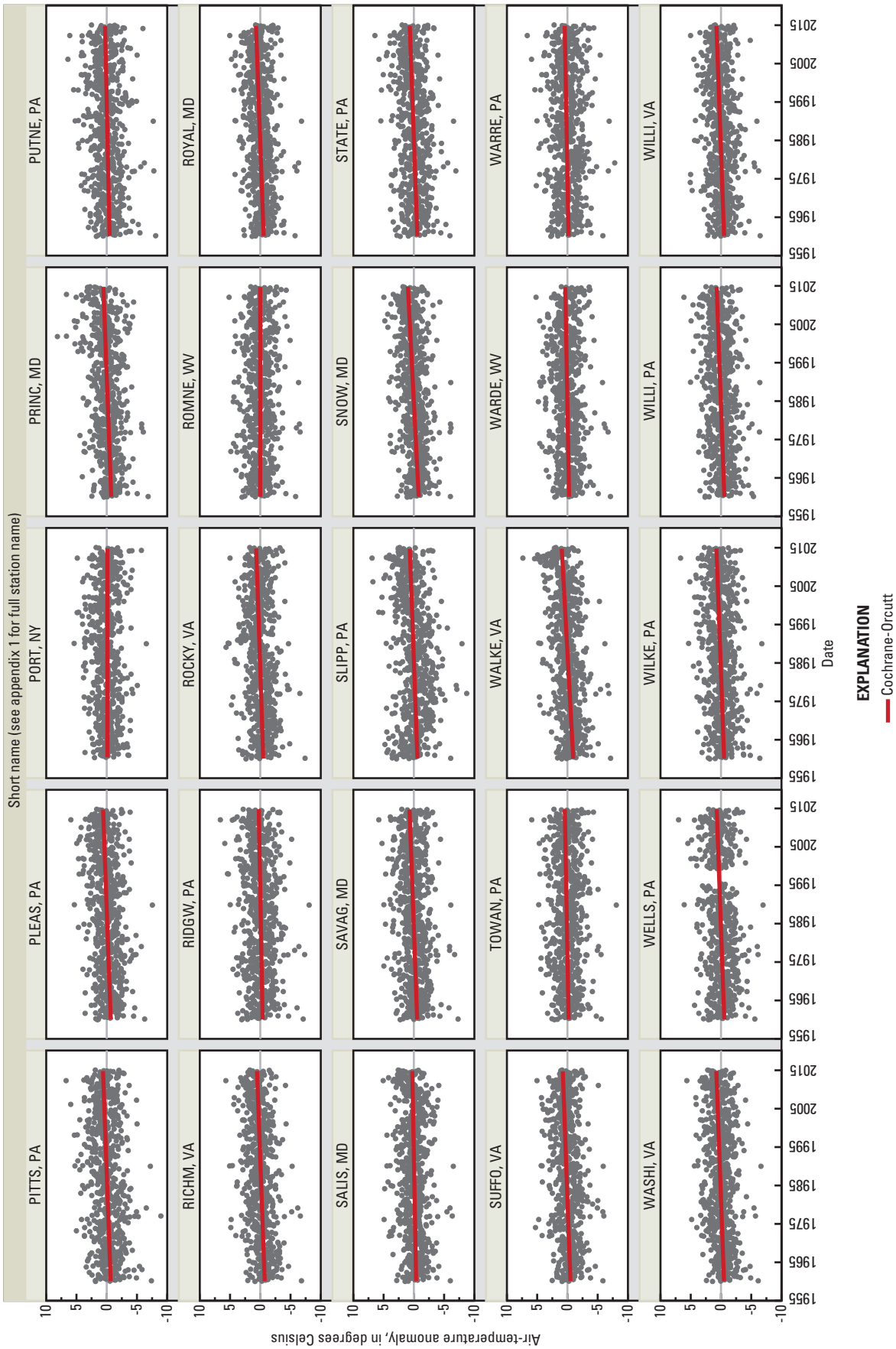
Appendix 3. Timeseries plots of air-temperature anomalies with trend lines, Chesapeake Bay region, 1960–2014.



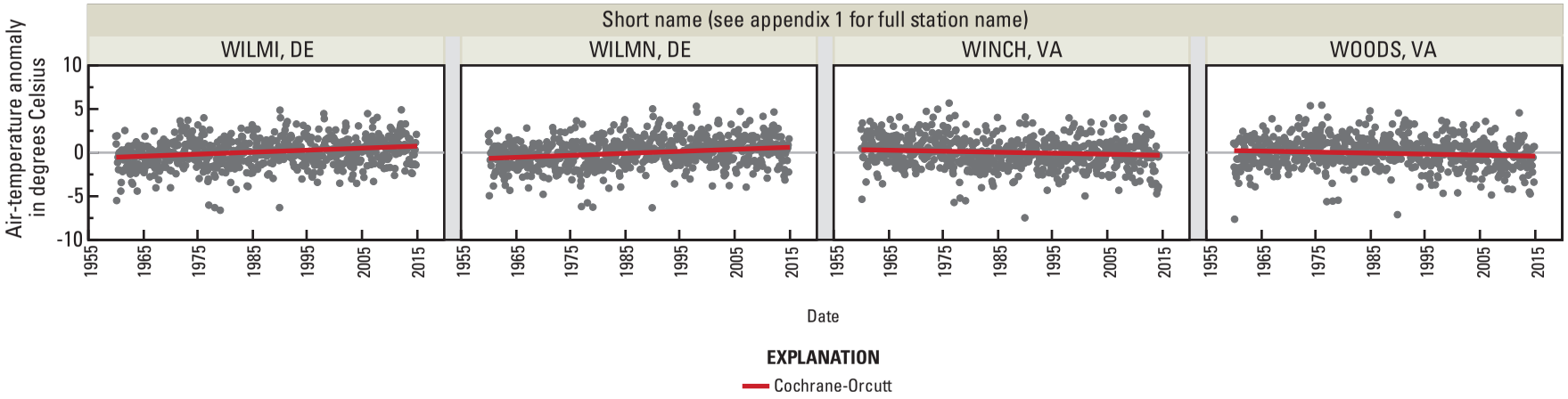
Appendix 3. Timeseries plots of air-temperature anomalies with trend lines, Chesapeake Bay region, 1960–2014.—Continued



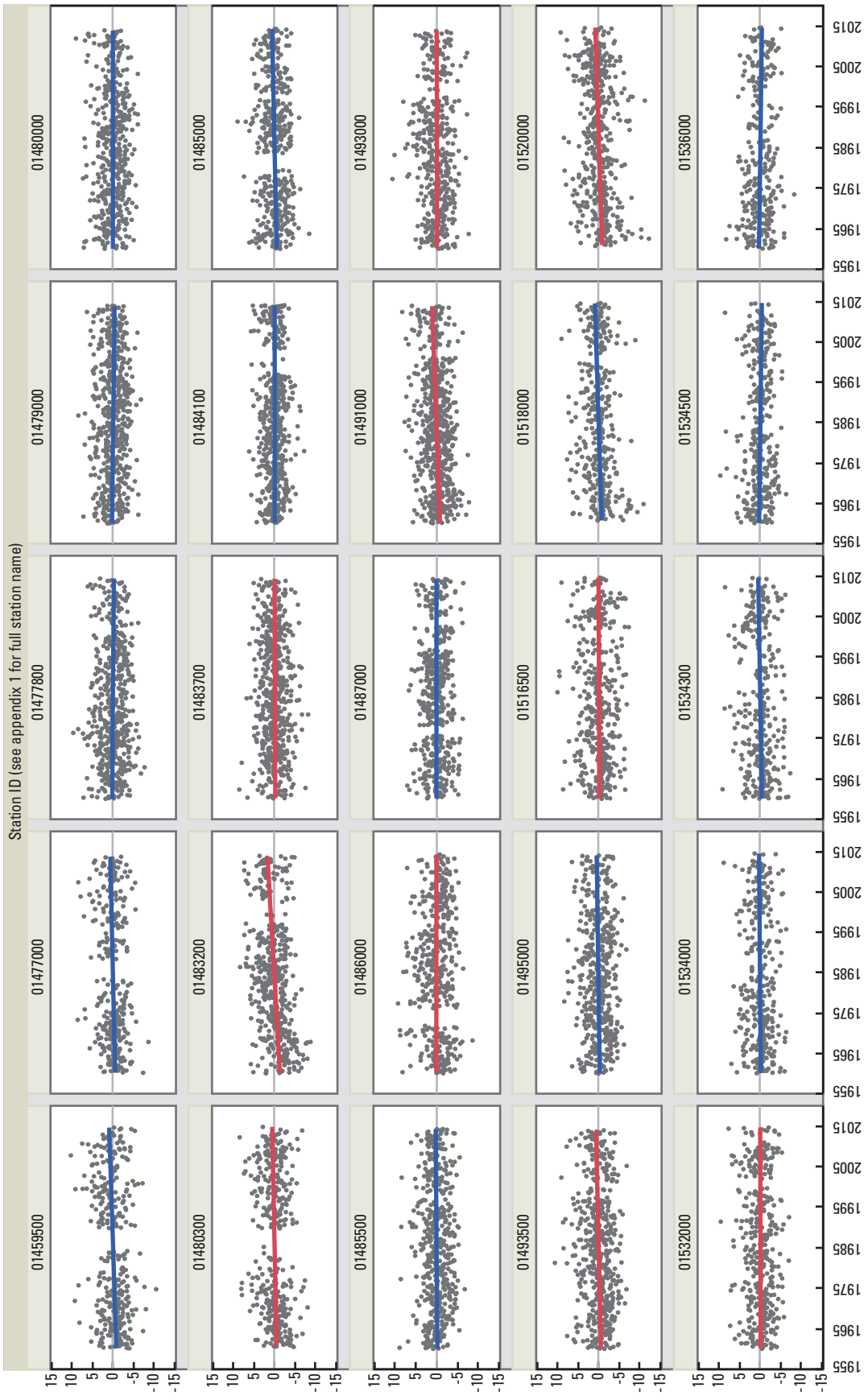
Appendix 3. Timeseries plots of air-temperature anomalies with trend lines, Chesapeake Bay region, 1960–2014.—Continued



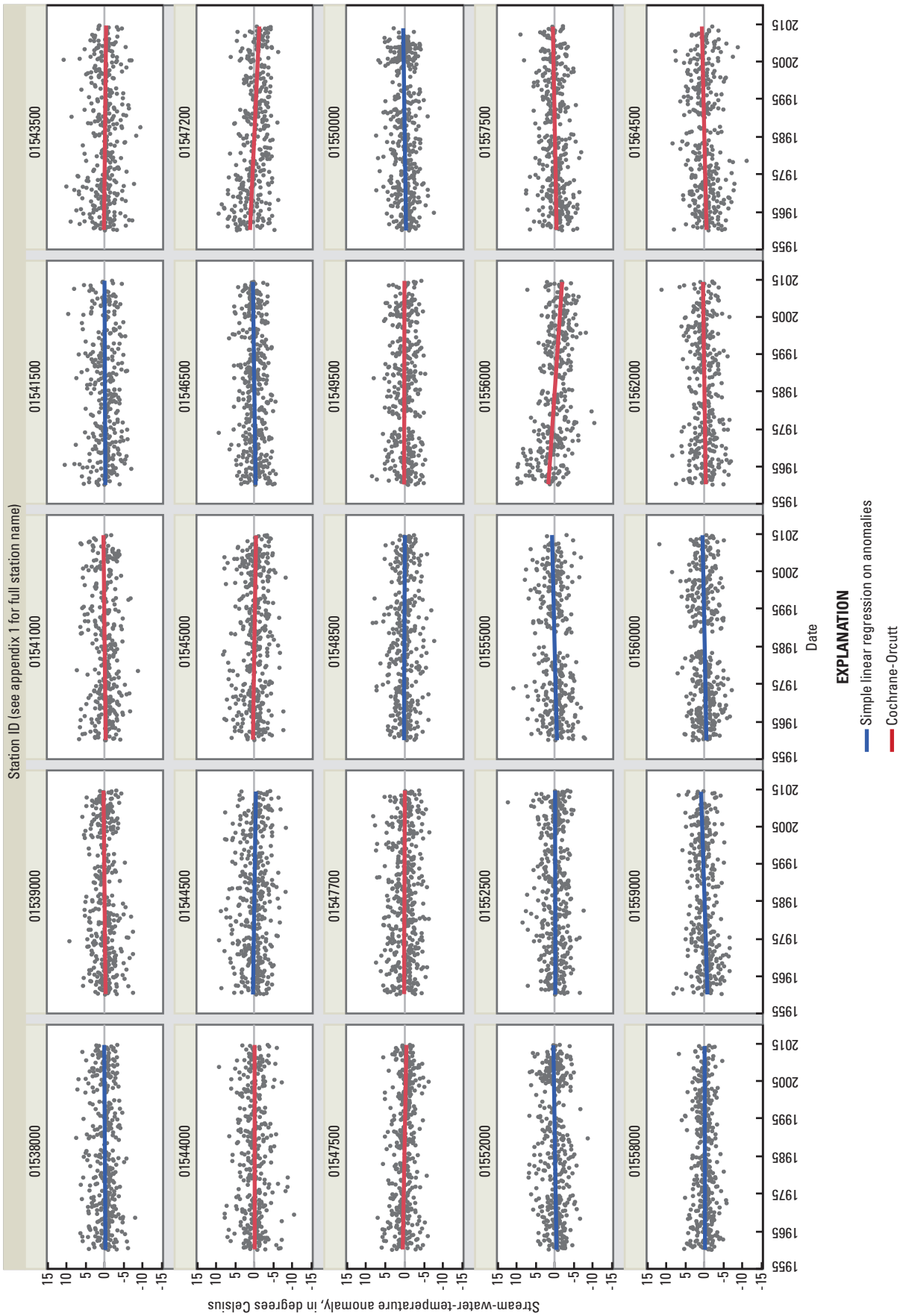
Appendix 3. Timeseries plots of air-temperature anomalies with trend lines, Chesapeake Bay region, 1960–2014.—Continued



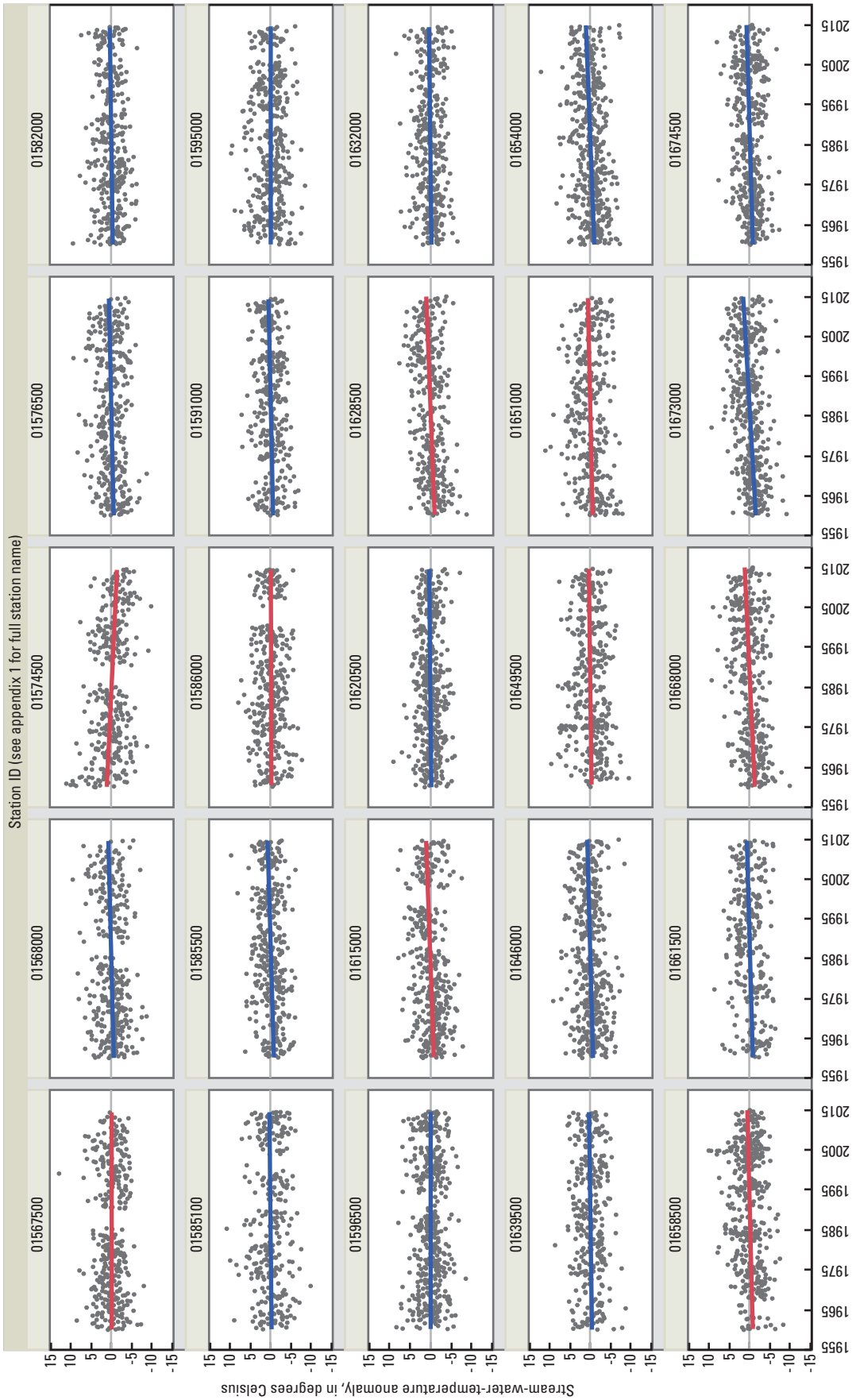
Appendix 4. Timeseries plots of stream-water-temperature anomalies with trend lines, Chesapeake Bay region, 1960–2014.



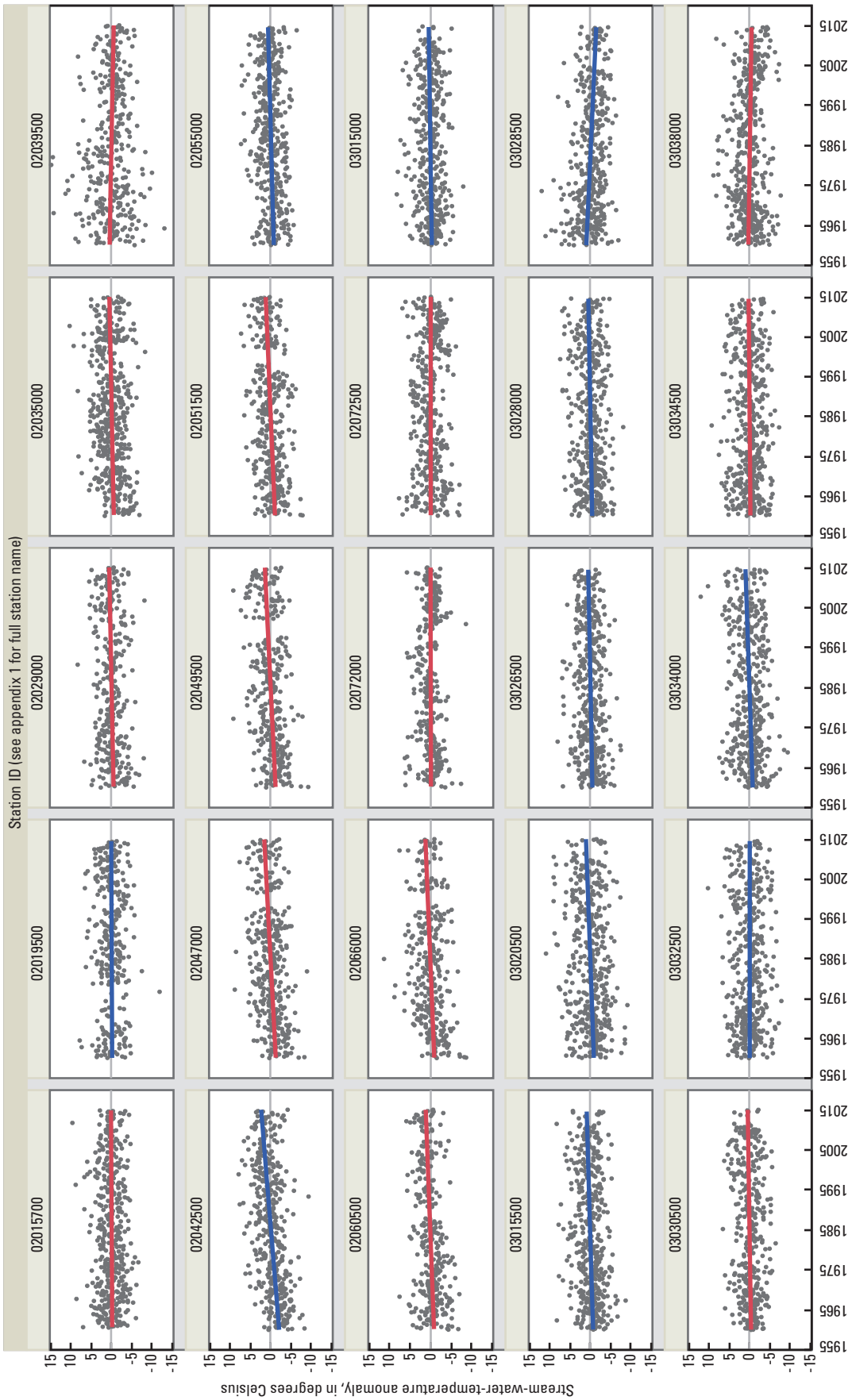
Appendix 4. Timeseries plots of stream-water-temperature anomalies with trend lines, Chesapeake Bay region, 1960–2014.—Continued



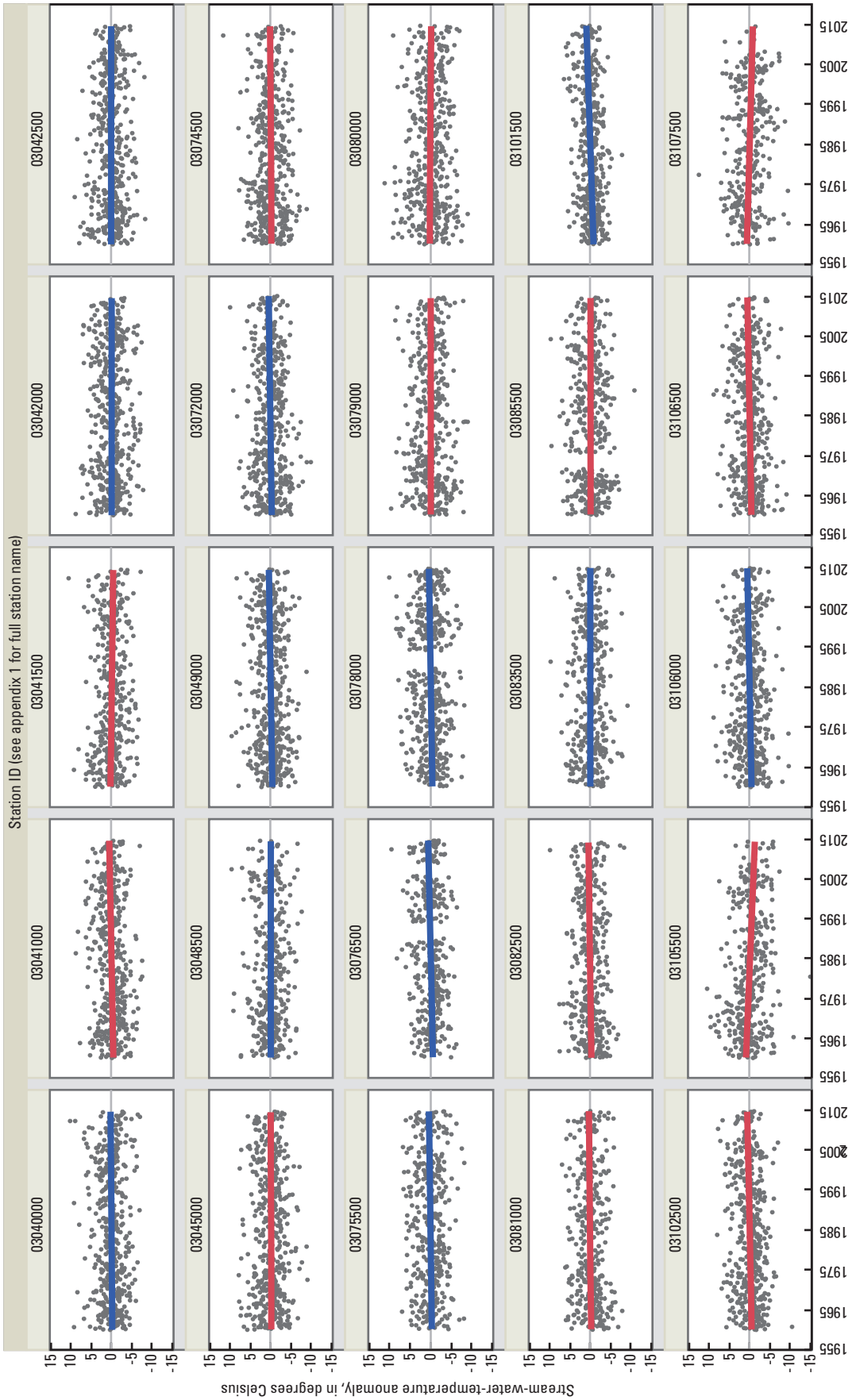
Appendix 4. Timeseries plots of stream-water-temperature anomalies with trend lines, Chesapeake Bay region, 1960–2014.—Continued



Appendix 4. Timeseries plots of stream-water-temperature anomalies with trend lines, Chesapeake Bay region, 1960–2014.—Continued



Appendix 4. Timeseries plots of stream-water-temperature anomalies with trend lines, Chesapeake Bay region, 1960–2014.—Continued



Appendix 4. Timeseries plots of stream-water-temperature anomalies with trend lines, Chesapeake Bay region, 1960–2014.—Continued