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List of Abbreviations

µg/L	microgram(s) per liter
AMI	automatic metering infrastructure
BAC	biologically active carbon
BC	Brown and Caldwell
BDL	below detection limits
DBP	disinfection by-product
DO	dissolved oxygen
DRWP	Dublin Road Water Plant
EPA	(Ohio) Environmental Protection Agency
EQIP	Environmental Quality Incentives Program
ft	foot/feet
GCM	global climate model
HAA	haloacetic acid
HCWP	Hap Cremean Water Plant
HPO_4	mono hydrogen phosphate
H_2PO_4	dihydrogen phosphate
MCL	maximum contaminant level
mgd	million gallon(s) per day
mg/L	milligram(s) per liter
MORPC	Mid-Ohio Regional Planning Commission
NH_3-N	ammonia nitrogen
NOAA	National Oceanic and Atmospheric Administration
NOM	natural organic matter
NO_x-N	nitrate-nitrite nitrogen
NO_2-N	nitrite nitrogen
NRCS	Natural Resources Conservation Service
NTU	nephelometric turbidity unit
O&M	operation and maintenance
OP	ortho-phosphate
OP-P	ortho-phosphate (as phosphorus)
org/L	organism(s) per liter
OWDA	Ohio Water Development Authority
PAC	powdered activated carbon
PAWP	Parsons Avenue Water Plant
PCU	platinum-cobalt unit
PO_4	phosphorous
SDT	Secchi-disk transparency
TIN	total inorganic nitrogen
TM	Technical Memorandum
TMDL	Total Maximum Daily Load
TN	total nitrogen
T&O	taste and odor
TOC	total organic carbon
TP	total phosphorus
TSI	Trophic State Index
TSS	total suspended solids
TTHM	total trihalomethane
USACE	US Army Corps of Engineers
USGS	U.S. Geological Survey
WHO	World Health Organization
WRF	Water Research Foundation

Acknowledgements

Brown and Caldwell acknowledges the valuable contributions made by the Mid-Ohio Regional Planning Commission (MORPC) in conducting the Sustaining Scioto Study. Specifically, the project team recognizes the following organizations for their efforts:

Project partners:

- City of Columbus Public Utilities
- Del-Co Water Company, Inc.
- Ohio Water Development Authority
- U.S. Geological Survey
- Water Research Foundation and Project Advisory Committee

The water quality data presented in this TM were collected and provided by the City of Columbus Public Utilities (Columbus). The data are based on a compilation of Columbus's annual report data. Columbus's data were used to reflect the overall water quality conditions throughout the Upper Scioto River Watershed. Columbus was able to provide a vast amount of water quality data for evaluating historic trends and predicting changes in water quality due to climate change.

Based on the water quality data reviewed for this TM, Columbus is in full compliance with state and national drinking water requirements and is proactively installing advanced treatment processes to address new regulations and potential changes in raw water quality. Furthermore, Columbus' water quality data collection efforts provide a good historical baseline for water quality in the region.

Executive Summary

The Mid-Ohio Regional Planning Commission (MORPC), in partnership with the City of Columbus, Ohio, Department of Public Utilities (Columbus); Del-Co Water Company (Del-Co), Inc.; U.S. Geological Survey (USGS); Water Research Foundation (WRF); and Ohio Water Development Authority (OWDA), has initiated a study of climate change effects on water supply and water quality in the Upper Scioto River study area. The primary objective of this project is to develop an Adaptive Management Plan for the region to guide actions to maintain a resilient water supply system.

The Upper Scioto River basin provides water to more than 2 million people and encompasses 17 counties. Nine water treatment facilities draw a total average surface flow of approximately 170 million gallons per day (mgd) from the watershed. Thirteen wastewater treatment facilities discharge a combined average daily flow of about 190 mgd. The watershed includes the Scioto River, Big Walnut Creek, Alum Creek, and Olentangy River, and Delaware Reservoir. There are four large reservoirs in the area: Alum Creek, Hoover, Griggs, and O'Shaughnessy.

Prior to developing the Adaptive Management Plan, Brown and Caldwell (BC) analyzed historic surface water quality data (1977 through 2013) collected and provided by Columbus to determine current conditions and trends in the study area. Historical precipitation data were reviewed to identify periods of drought and periods of heavy rainfall. The USGS watershed modeling, conducted as part of this project, predicts an increase in air temperature and more extreme and intense weather events. Trends in future water quality as a result of climate change were hypothesized based on the USGS modeling results.

<u>Herbicides and Pesticides</u>

The study area's predominate land use is agriculture with extensive row crop production (66 percent of the basin is agriculture and 12 percent is forested [U.S. Census Bureau, 2014]). Of the herbicides, sampling showed atrazine most frequently and at the highest concentrations in the reservoirs.

As temperatures increase in the future, the length of the growing season is expected to increase. Two growing seasons may even be possible for some crops. These factors could lead to additional future herbicide and pesticide application in the watershed.

In the future more intense storm events may also contribute to higher herbicide and pesticide concentrations in stormwater runoff. Higher herbicide and pesticide runoff concentrations would increase reservoir concentrations which may require additional treatment at drinking water plants, resulting in higher operation and maintenance costs. With the potential future increase in herbicide and pesticide use, watershed-based pollutant reduction programs should be considered where local governments collaborate with state or regional agricultural agencies to reduce pollutant concentrations and control drinking water treatment costs.

<u>Nutrients (Nitrogen and Phosphorus) and Algal Blooms</u>

For all of the measured nutrients, concentrations in Alum Creek below the Alum Creek Reservoir dam were typically the lowest, followed closely by the Hoover Reservoir. The measured nutrient concentrations in the O'Shaughnessy and Griggs reservoirs are comparable and generally substantially higher (up to an order of magnitude or more for peak values) than Alum Creek and Hoover Reservoir. This difference is primarily a function of the size, volume, and depth of the reservoirs. The O'Shaughnessy and Griggs reservoirs are much smaller and basically reflect the water quality in the Scioto River. The water quality in the O'Shaughnessy and Griggs reservoirs changes quickly in response to rain events. Columbus indicated the mean residence time in O'Shaughnessy and Griggs reservoirs is roughly 12 days each, but can be as short as 2 days under high flow conditions. In comparison, Columbus indicated the mean residence time in Hoover Reservoir is approximately 180 days and Alum Creek Reservoir is even longer.

Over the period from 1987 through 2013, several apparent nutrient trends were observed:

- Total phosphorous (TP) and ortho-phosphate (as phosphorus, OP-P) concentrations appear to be increasing in O'Shaughnessy and Griggs reservoirs and may be increasing in Hoover Reservoir and Alum Creek Reservoir.
- Total inorganic nitrogen (TIN) concentration appears to be decreasing in all four reservoirs.
- TP, OP-P, and TIN trends are expected to continue in the future because of development in the watershed combined with climate change.
- Balanced or nitrogen-limited conditions in the O'Shaughnessy and Griggs reservoirs are expected to continue in the future because of declining TIN concentrations and increasing TP concentrations.
- Hoover Reservoir and Alum Creek Reservoir are expected to continue their trend to balanced or phosphorus limitation. This situation is a concern because of increasing TP and decreasing TIN concentrations in the study area and the potential growth of cyanobacteria.

During wet periods, reservoir water quality will continue to be more sensitive to phosphorus inputs because of an excess of available nitrogen. During dryer periods, both phosphorus and nitrogen inputs will continue to have a strong influence on reservoir water quality.

Conclusions

Two primary factors will influence future surface water quality within the study area: changes in climate and watershed land use. The main climate change issues are increasing temperatures and more extreme and intense weather. Warmer air temperatures will produce warmer water temperatures. Algae and cyanobacteria thrive in warmer water with abundant nutrients. More extreme weather likely translates into longer periods of drought when vegetation will be diminished or lost. More intense storm events following drought will produce large turbidity, organic, and nutrient loads from watershed wash-off and in-stream erosion, which will be conveyed through area streams to reservoirs. These changes likely will increase organic and nutrient loads to area streams and reservoirs, decrease dissolved oxygen (DO) concentrations, increase algae and cyanobacteria blooms, and generally degrade surface water quality.

The study area is largely undeveloped or currently used for agriculture. Some land uses will change into residential, commercial, and industrial properties. Development is expected to increase phosphorus loads to area streams and reservoirs in the future because of increases in stormwater runoff volume, wastewater effluent discharges, and home sewage treatment system discharges.

Pathogens are another pollutant of concern in the study area. Although not a concern related to drinking water because of disinfection, elevated pathogen concentrations in reservoirs are a concern because of their potential impact on aquatic life and human health. Pathogens were not evaluated as part of this study, but they are included in the Big Walnut Creek TMDL. Ohio EPA discussed them in the Middle Scioto River basin study. If current practices continue, pathogen concentrations are expected to increase because of rising temperatures and additional stormwater runoff and home sewage treatment system discharges from development.

Based on the analysis of existing water quality data and the anticipated effects from climate change and development, the following long-term trends are probable in the study area:

- Increase in turbidity
- Elevated peak herbicide concentrations
- Increase in organics concentrations and disinfection by-product (DPB) formation potential
- Increase in TP concentrations
- Decrease in TIN concentrations
- Increase in pathogens
- Decrease in DO concentrations
- More frequent and intense algae and cyanobacteria blooms
- More taste and odor and toxin issues

Because of the documented existing water quality impairments and anticipated future trends, strategies should be implemented in the watershed in a collaborative manner between local governments and state/regional entities to reduce organic, nutrient, and pathogen loads to streams and reservoirs. The primary watershed pollutant sources include: stormwater runoff from urban and agricultural land; discharges from wastewater treatment facilities and home sewage treatment systems; groundwater; decomposition of organic matter; and soil erosion. Both structural and non-structural practices should be considered in the watershed to protect and improve water quality and maintain reservoir volume as discussed in the Adaptive Management Plan.

Further assessment of reservoir sediment accumulation and internal nutrient loads should be completed to understand fully changes in reservoir storage volume and importance of all nutrient sources. Internal nutrient sources include: seasonal turnover events; groundwater seepage into the reservoirs; and sediment nutrient flux. The significance of reservoir internal nutrient sources is unknown now. Once understood, strategies should be implemented to reduce internal nutrient sources and maintain reservoir storage volume.

Reservoir operational changes should be considered to help reduce reservoir pollutant, algae, and cyanobacteria concentrations. In recent years, the Hoover and Alum Creek reservoirs have experienced the highest cyanobacteria densities and are the immediate concern.

In recent years, the Hoover and Alum Creek reservoirs are experiencing the highest cyanobacteria densities and are the immediate concern.

Based solely on the current regional surface water quality conditions, watershed pollutant load reductions and revised reservoir operational strategies are warranted now.

It is important to reinforce that, based solely on the current regional surface water quality conditions summarized in this technical memorandum, watershed pollutant load reductions and revised reservoir operational strategies are warranted now. Adopting such changes is independent of the future water quality impacts as a result of climate change. The implementation of pollutant load reduction and operational strategies should reduce the potential for drinking water taste and odor issues and harmful algal blooms, and protect aquatic life and human health. The Adaptive Management Plan presents and discusses these strategies.

Section 1: Project Background

This Technical Memorandum (TM) No. 5 provides an overview of water quality in the Upper Scioto River basin. Section 1 includes a project overview, a summary of the monitoring locations and collected water quality data, and a description of outreach related to water quality management/water treatment.

1.1 Project Overview

The Mid-Ohio Regional Planning Commission (MORPC), in partnership with the City of Columbus, Ohio, Department of Public Utilities (Columbus); Del-Co Water Company, Inc. (Del-Co); U.S. Geological Survey (USGS); Water Research Foundation (WRF); and Ohio Water Development Authority (OWDA), has initiated a study of climate change effects on water supply and water quality in the Upper Scioto River basin. The primary objective of this project is to develop an adaptive management plan for the region to guide actions to maintain a resilient water supply system.

The concerns related to the potential impacts of climate change on water and wastewater utilities are exacerbated in central Ohio, where 85 percent of daily municipal water usage is supplied by surface water. With such a strong dependence on surface water, utilities have concerns related to the impact of oscillating weather patterns associated with climate change on the reliability and quality of supply sources. To maintain a resilient water supply system, utilities must develop a comprehensive understanding of the increased risks to their systems and craft new management strategies to address these risks.

1.2 Project Location

The Sustaining Scioto project area encompasses the Upper Scioto River basin from its headwaters in northern Ohio to just north of Circleville in the south. A map of the project area is shown on Figure 1-1.

This 3,200-square-mile watershed provides water to more than 2 million people; encompasses 17 counties; and includes the Scioto River, Big Walnut Creek, Alum Creek, and Olentangy River. The Upper Scioto River watershed also includes the O'Shaughnessy, Griggs, Hoover and Alum Creek reservoirs and Delaware Reservoir. The primary land cover in the basin is mostly agricultural (66 percent) with some forest (12 percent) and development (20 percent), and a small percentage (2 percent) of open water, grasslands, and wetlands (U.S. Census Bureau, 2014).

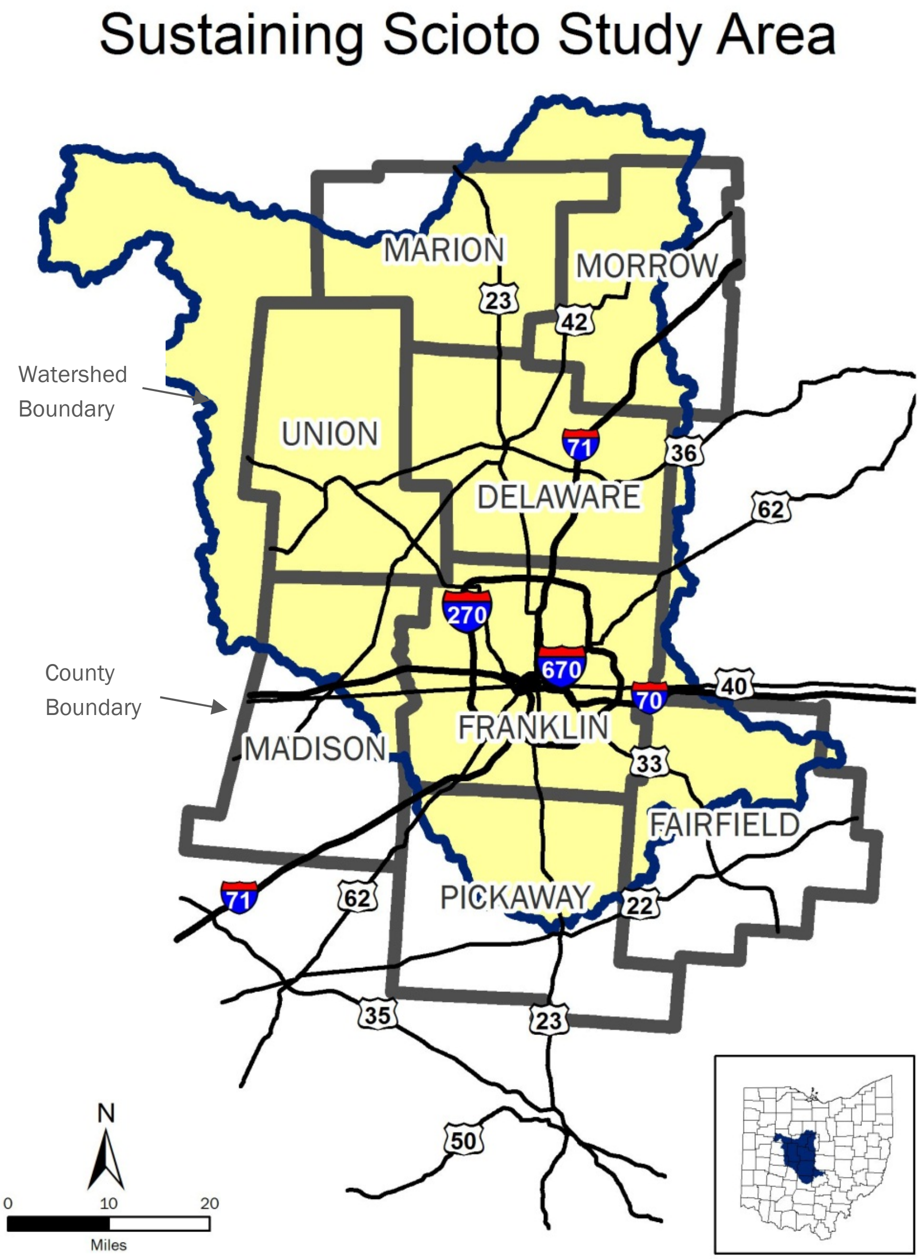

Figure 1-1. Map of the Sustaining Scioto project area

1.3 Monitoring Locations

To understand the water quality discussion, it is important to understand the monitoring locations and relationships between the various water supply components. The nine subwatersheds composing the Upper Scioto River study area are shown on Figure 1-2. These subwatersheds drain to the south and eventually join the Scioto River south of Columbus. The water treatment and wastewater treatment plants and the surface water monitoring locations in the study area are shown on Figure 1-3.

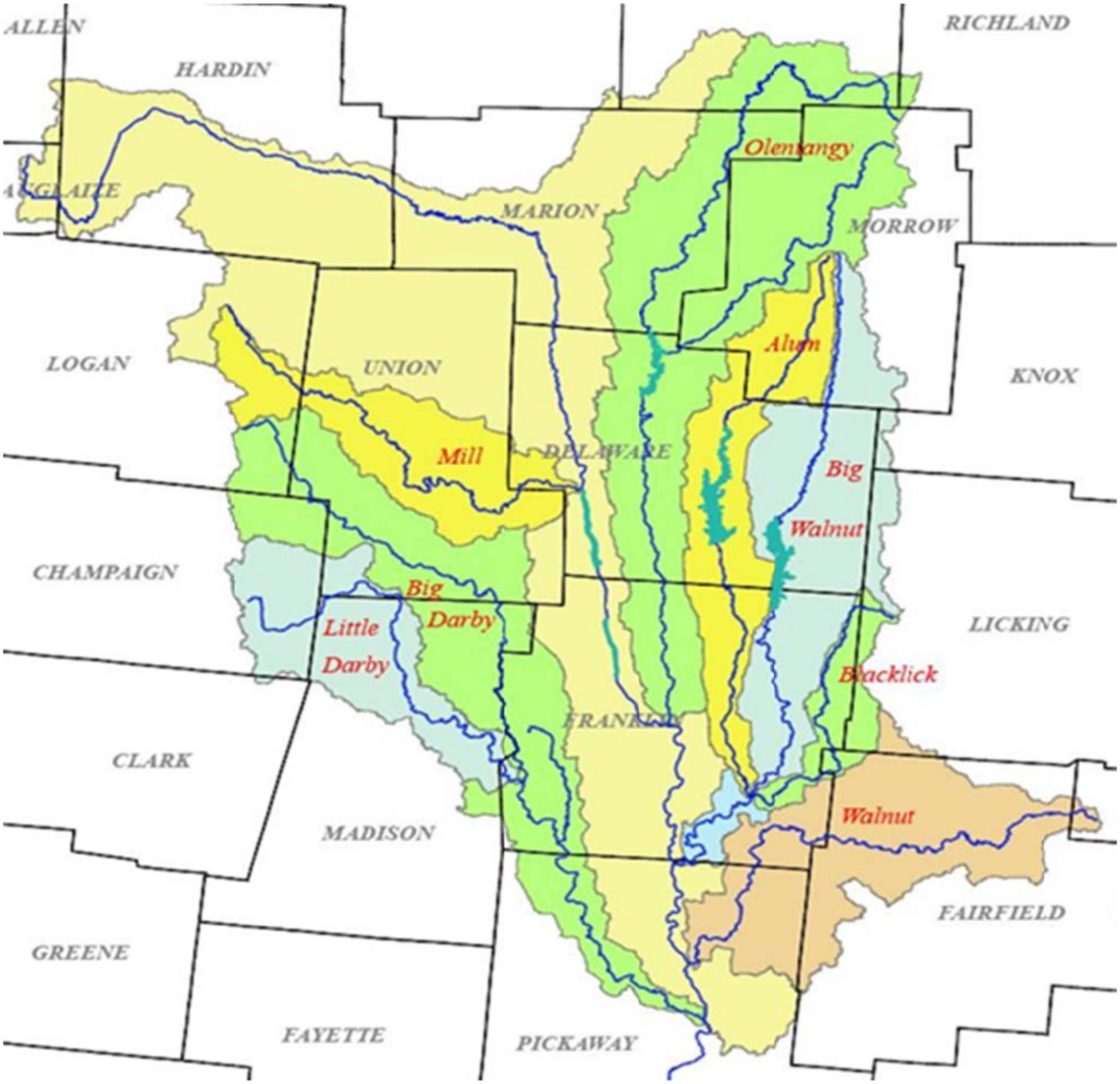

Figure 1-2. Sustaining Scioto study area subwatersheds

Nine water treatment facilities draw a total average surface flow of approximately 170 million gallons per day (mgd) from the watershed. Thirteen wastewater treatment facilities discharge a combined average daily flow of about 190 mgd. The average daily wastewater discharge exceeds the average daily surface water withdrawal due to the groundwater withdrawals for potable water supplies. The basin is primarily rural and agricultural with more development near the City of Delaware (Delaware); the greater Columbus metro area; and small pockets of urbanization in cities such as Galion, Kenton, Marion, and Marysville.

On the Scioto River, the most upstream reservoir is the O'Shaughnessy Reservoir. This reservoir is a widened section of the Scioto River. The Griggs Reservoir is also a widened section of the Scioto River located downstream of the O'Shaughnessy Reservoir. The Dublin Road Water Plant (DRWP) draws raw water from the Scioto River downstream of Griggs Reservoir and is therefore affected by the raw water quality in both the O'Shaughnessy and Griggs reservoirs. Because these two reservoirs are relatively small and in-line with the Scioto River, water quality is highly variable and can change rapidly during storm events. The water quality in these reservoirs and the DRWP intake is generally a reflection of the water quality in the Scioto River. Columbus indicated the mean residence time in O'Shaughnessy and Griggs reservoirs is approximately 12 days.

The water quality in O'Shaughnessy and Griggs reservoirs and the DRWP intake is generally a reflection of the water quality in the Scioto River and can change rapidly during storm events.

Columbus and Del-Co Water recently completed the construction of a new offline, upground reservoir, the John R. Doutt Upground Reservoir, with an intake on the Scioto River that is upstream of both O'Shaughnessy and Griggs reservoirs (near Hoskins Road). Columbus, which operates the reservoir, selectively pumps water from the Scioto River to this reservoir to augment available water storage from this supply source. Pumping of water from the river to the upground reservoir is planned during higher stream flow conditions. Pollutant concentrations typically increase with increasing flow during and after storm events. It will be important to monitor pollutant concentrations and pump water to the upground reservoir when concentrations are lower. It is anticipated that Columbus will selectively pump to the reservoir during periods of high water quality, thereby minimizing water quality issues within the upground storage reservoir.

The Hoover Reservoir is located east of the Scioto River in a separate subwatershed on Big Walnut Creek. The Alum Creek Reservoir is located on Alum Creek, a tributary to Big Walnut Creek. Alum Creek discharges into Big Walnut Creek well south of the Hoover Reservoir. Water is pumped from the Alum Creek Reservoir to the Hoover Reservoir to supplement Hoover Reservoir capacity. The Alum Creek and Hoover reservoirs are much larger than the O'Shaughnessy and Griggs reservoirs and are capable of diluting and assimilating watershed pollutant loads within the reservoirs. Water quality changes occur more slowly over time in the Alum Creek and Hoover reservoirs. Columbus indicated the mean residence time in Hoover Reservoir is approximately 180 days and in Alum Creek Reservoir is even longer. The Hoover Reservoir supplies raw water to the Hap Cremean Water Plant (HCWP).

Water quality changes occur more slowly in the Alum Creek and Hoover reservoirs over time.

The Parsons Avenue Water Plant (PAWP) is located south of Columbus currently drawing raw water from groundwater wells. The existing collector wells are located in an area adjacent to the Scioto River and Big Walnut Creek near sand and gravel mining operations.

The City of Westerville (Westerville) withdraws raw water for treatment from Alum Creek downstream of the Alum Creek Reservoir. Westerville also uses groundwater wells to supplement its surface water source.

The Del-Co Water Company's primary sources of water are the Olentangy River and the Alum Creek Reservoir. These surface water sources supply water to three of the system's four water treatment plants: the Olentangy Plant, the Ralph E. Scott (Alum Creek) Plant, and the Timothy F. McNamara (Old State). When stream flows are adequate, Del-Co pumps water from the Olentangy River below Delaware Reservoir and from Alum Creek below the Alum Creek Reservoir to offline upground reservoirs for storage prior to treatment. Del-Co's fourth water plant is a groundwater plant in Knox County, which is treated by the Thomas E. Steward Plant. The fourth plant is only used as a peaking plant and has not been used in a number of years.

Similar to Columbus, it will be important to monitor pollutant concentrations and pump water to the upground reservoirs when concentrations are lower. Del-Co also relies on groundwater for its raw water supply.

The City of Delaware also withdraws raw water from the Olentangy River below Delaware Reservoir and treats the water at the Delaware Water Treatment Facility. The City has the capability to blend this surface water with groundwater from several wells located at the treatment facility. The City of Marysville (Marysville) relies on surface water from Mill Creek, a tributary to the Scioto River, and groundwater wells for its water supply. Numerous other surface water monitoring sites are located within the study area, as shown on Figure 1-3. Data from these monitoring locations is collected and maintained by Columbus.

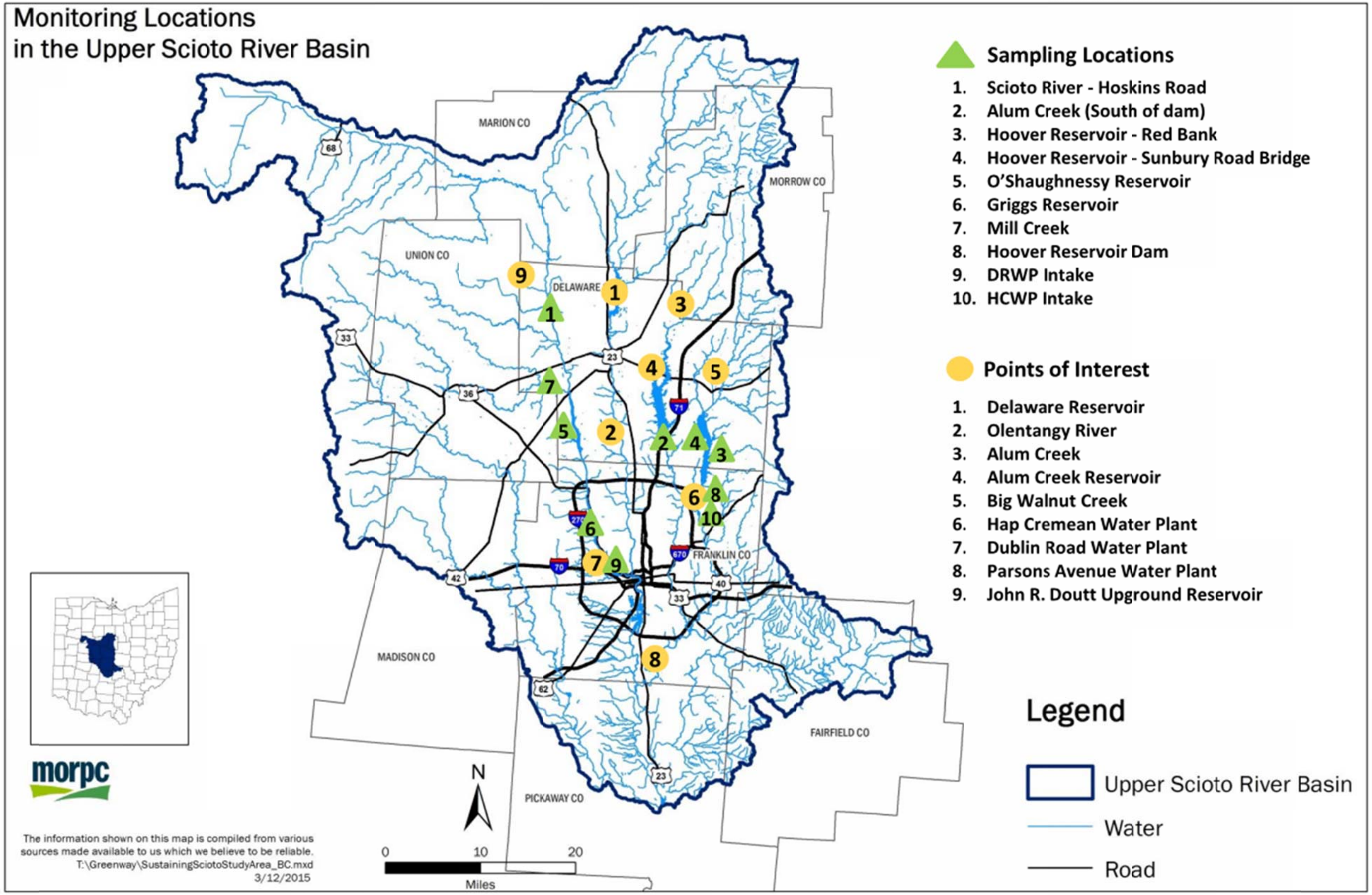

Figure 1-3. Points of interest and monitoring locations in the Upper Scioto River basin

1.4 Climate Change Adaptation Questionnaire

A climate change adaptation questionnaire was circulated by BC to water utility managers and plant managers within each municipality in the study area. The questionnaire was developed to help understand source water quality issues for each municipality and current practices to promote water supply resiliency and infrastructure reliability. A copy of the questionnaire is provided in Appendix A. All municipalities that responded had a high level of confidence that their community will be able to provide a high-quality water supply to meet water demands for the next 30 years. Based on responses to the questionnaire, Columbus, Del-Co, and Marysville currently monitor their surface water supply systems for drought conditions (i.e., precipitation, reservoir levels, and stream flows) taste and odors (T&O), algal blooms, and high-turbidity events. The Marysville monitors algal blooms by observation only at this time, but plans to obtain testing equipment in the future. Marysville and Columbus also monitor for high-organics events. Each municipality has an action plan in place to address source water quality issues. Depending on the water quality issue, the reactions varied between municipalities. Actions include using a different water supply source, adjusting chemical feed at the water treatment plant, and adjusting treatment at the source.

All municipalities that responded to the questionnaire had a high level of confidence that their community will be able to provide a high-quality water supply to meet water demands for the next 30 years.

The approach to water conservation practices differs among municipalities. Del-Co uses water restrictions while Marysville uses tiered rates, and Columbus practices a combination of watering restrictions, plumbing code requirements, and public education. Westerville and Columbus are experiencing declines in per capita water use. Westerville has implemented demand restrictions for lawn watering, and has reduced the need for capacity expansion. Westerville is also implementing an automatic metering infrastructure (AMI) program. Delaware has not needed to initiate any restriction before. If it became necessary, Delaware would use a watering restriction.

Under the water supply management category all municipalities responded that they have a long-range water supply plan and drought management plan in place. Currently Columbus is developing its watershed management plan. Marysville is developing an emergency supply source through coordination with Del-Co to establish a system interconnection. Delaware does not have an emergency supply source/agreement now. To meet future water needs, Del-Co and Columbus plan to use upground reservoirs. Westerville plans to expand supply using additional groundwater wells. Facility upgrades in the region have addressed water quality concerns and increased capacity.

In terms of infrastructure reliability, all municipalities stated that their critical water system infrastructure is outside the 100-year floodplain. However, the response was mixed on whether the facilities were flood-proof or had backup power.

Overall, the questionnaire helped the project team understand the key issues for each municipality, the extent of their water supply management planning, and regional coordination efforts.

Section 2: Historical Precipitation

A review of historical annual precipitation data was completed by BC to evaluate annual rainfall depths and identify periods of drought and heavier rainfall. Periods of drought and heavier rainfall can occur in years with annual precipitation above or below the long term average. Figure 2-1 includes historical annual precipitation data from the National Weather Service, Port Columbus Station. The average annual precipitation from 1981 through 2013 was 37.7 inches. The region received well above average amounts of precipitation during 1990 and 2011. The maximum annual precipitation during this period was 56.9 inches (51 percent above average), recorded in 2011. The region also experienced drought conditions (less than 30 inches of annual precipitation) in 1987, 1999, and 2010. The minimum annual precipitation during this period was 24.2 inches, in 1999 (36 percent below average).

The highest average monthly rainfall occurs in May through July, at more than 4 inches. The minimum average monthly precipitation occurs in February, at just over 2 inches. Average monthly precipitation is relatively consistent throughout the year, but actual precipitation rarely follows the average patterns.

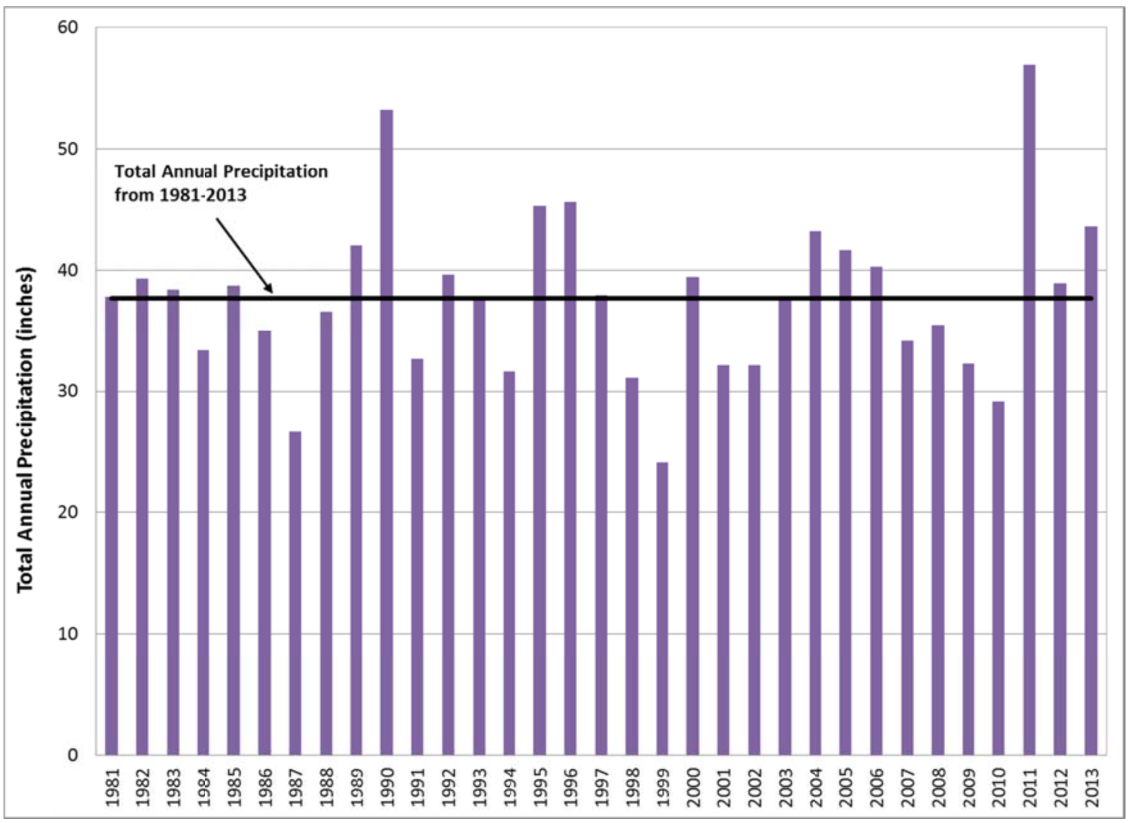

Figure 2-1. Historical precipitation data at the Port Columbus Station from 1981 to 2013

Source: National Weather Service

Daily precipitation collected by the National Oceanic and Atmospheric Administration (NOAA) at the Westerville, Ohio, weather station from January 2009 to December 2011 is shown on Figure 2-2. This station is located close to Hoover and Alum Creek reservoirs. In Section 3, comparisons of water quality data for wet and dry periods are discussed from January 2009 to December 2011. This time period included total annual precipitation substantially above and below the long-term, annual average of approximately 38 inches. Over 7 inches of rainfall occurred between May 11 and June 9, 2010, during the third driest year (between 1981 and 2013). From July 14 to September 22, 2010, only 2.8 inches of rain was measured. In 2011, over 5 inches of rain fell in two days, July 23 and 24, and almost 17 inches of rain was measured between June 10 and August 25.

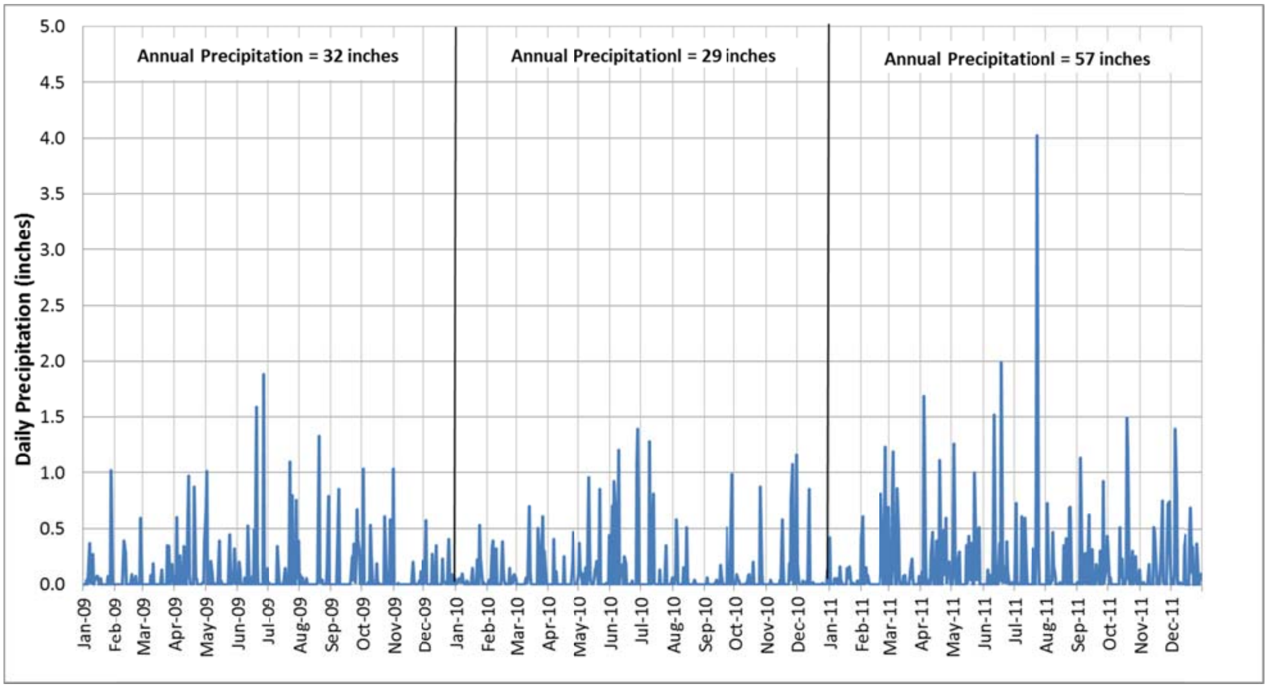

Figure 2-2. Daily precipitation from January 2009 through December 2011 at Westerville, Ohio Station

Source: National Oceanic and Atmospheric Administration, Westerville weather station

2.1 USGS Climatic Modeling

The USGS studied the potential effects of projected 21st-century climate changes on temperature, streamflow, and reservoir water-level characteristics in the Upper Scioto River basin. The USGS used four global climate models (GCMs) to understand the potential range of climatic conditions given different carbon emission scenarios.

The results from the USGS climate modeling are presented in a technical report on the modeling that was conducted as part of this project (Ebner et al., 2015). The modeling predicts an increase in air temperature by 1 to 12 degrees Fahrenheit in the year 2085 (Ebner et al., 2015). The analysis of monthly precipitation was not as conclusive. Depending on the modeling scenario, precipitation and streamflows may increase or decrease (Ebner et al., 2015). The modeling showed that there could be more extreme weather (more extended droughts and more extreme and intense rainfall events).

Section 3: Water Quality Data

The water quality data, collected and maintained by Columbus, were used to characterize the region's water quality. This data included stream, reservoir, drinking water intake, and customer complaints. Raw water quality parameters evaluated in this TM include: turbidity; organics; herbicides and pesticides; color; nutrients; algae; zooplankton; and cyanobacteria. Available Columbus data from 1977 through 2013 were collected and analyzed as summarized in the following sections. The assessment includes the identification of water quality trends over this 30 year period and predicted future water quality in the region based on observed trends and expected changes in climate conditions.

3.1 Turbidity

Turbidity is the cloudiness or haziness in water caused by small particles that are generally invisible to the naked eye. After rain events, an increase in water turbidity is common and results in decreased surface water clarity. Turbidity increase results from stream channel and watershed soil erosion and wash-off of pollutants from surfaces in the watershed. Light penetration is lower in turbid water, and therefore turbidity can reduce the growth of algae in lakes and reservoirs. Turbidity provides an indication of solids loading, which can fill area drainage systems and reservoirs causing flooding and reducing water storage and pollutant assimilative capacity.

Turbidity measurements at the DRWP intake and the HCWP intake between 1999 and 2013 were analyzed to identify apparent trends. Mean values were calculated for each month and the mean monthly turbidity data is provided in Figure 3-1.

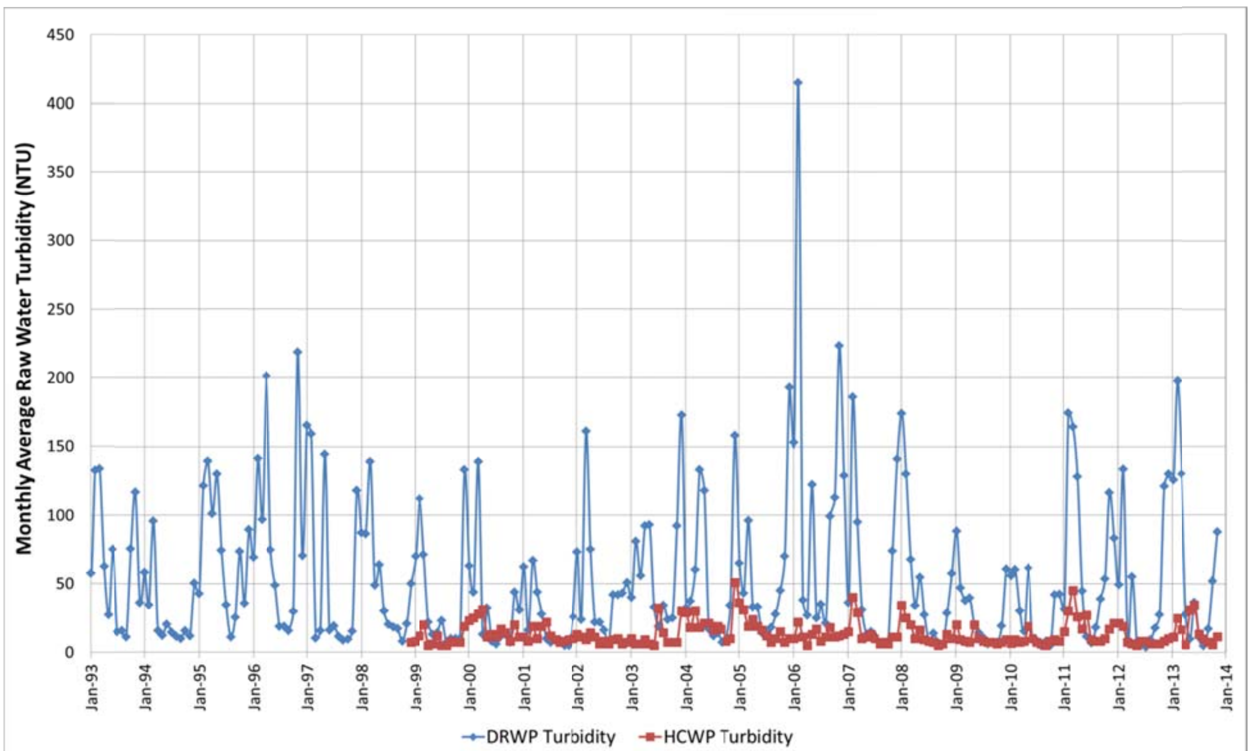

Figure 3-1. Historical raw water mean monthly turbidity values at the Dublin Road Water Plant and Hap Cremean Water Plant intakes

The mean monthly turbidity spikes seasonally, most typically between December and March. Monthly turbidity values were much higher at the DRWP intake when compared to the HCWP intake. Lower turbidity values at the HCWP are expected because the Hoover Reservoir has a long residence time, and turbidity has time to dissipate in the reservoir during runoff events.

From 2003 to 2013 (11 years), mean monthly turbidity at the DRWP intake ranged from near zero to over 400 nephelometric turbidity units (NTU); the highest value occurred during one month in early 2006. Mean monthly turbidity was highly variable during this 11-year period and was generally less than 200 NTU. Mean monthly turbidity exceeded 100 NTU during 25 months and exceeded 200 NTU during 2 months. The average annual precipitation during this period was approximately 39 inches.

From 1993 through 2002 (10 years), the mean monthly turbidity of water collected at the DRWP intake ranged from near zero to a value of 220 NTU in late 1996. Mean monthly turbidity was highly variable during this period and was generally less than 150 NTU. During 20 months mean turbidity exceeded 100 NTU and 200 NTU was exceeded during 2 months. The average annual precipitation during this period was approximately 36 inches, or slightly below average.

Raw water mean monthly turbidity values at the DRWP intake appear to be similar during these two time periods with no apparent increasing or declining trend. The extreme mean monthly turbidity value of over 400 NTU in March 2006 was almost double the highest value measured during the earlier time period. The measured rainfall during March 2006 was only 3.4 inches; however there was a 2.2 inch storm event on March 12 and 13.

Rainfall Influence on Turbidity

Water turbidity typically increases rapidly and substantially during and immediately after a storm event. For this reason it is difficult to relate mean monthly turbidity values based on periodic monitoring to individual rainfall events. A plot of mean monthly turbidities at the DRWP intake along with monthly average daily precipitation values is shown on Figure 3-2. The heavy rains in May and early June 2010 produced elevated turbidity. Turbidity values during the dryer periods in 2010 were much lower. During 2011 turbidity values increased substantially in February with heavy rainfall but then slowly declined during continued heavy rainfall until late November. Similar to TOC and other pollutants of interest, there are numerous other factors that affect turbidity values such as antecedent rainfall.

Construction activities that include land disturbance are one of the primary sources of turbidity in a community. Large areas of unvegetated soil can be exposed to rainfall producing substantial surface water turbidity. It is extremely important to require and enforce strict erosion and pollution control requirements on all land development projects in the watershed to reduce turbidity sources as much as possible.

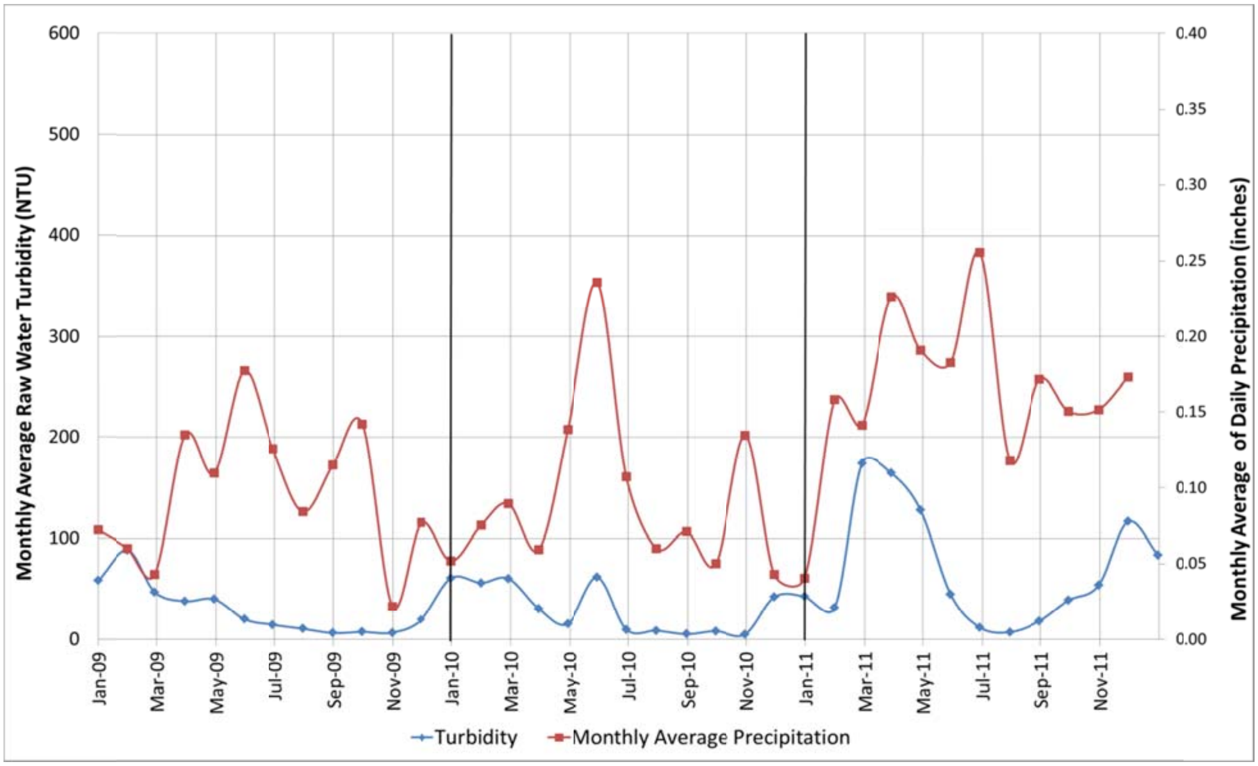

Figure 3-2. Monthly average turbidity and precipitation values for Dublin Road Water Plant from 2009 through 2011

Potential Changes Due to Climate Change

Elevated turbidity is normally associated with substantial rain events and is an indication of suspended solids loading (soil particles). More extreme and intense weather is expected in the future due to climate change. Drought followed by more intense storms will likely increase the concentration of turbidity in runoff, which will translate into higher turbidity concentrations in raw water supplies. Elevated turbidity values in the future would increase the solids loading to water supply reservoirs and reduce reservoir water storage in a shorter time period. Loss of storage would also reduce the reservoir residence time and assimilative capacity for pollutant attenuation. Reservoir solids accumulation should be monitored and at some point in the future, solids removal may be necessary to restore adequate water storage.

> Drought followed by more intense storms will likely increase the concentration of turbidity in runoff, which will translate into higher turbidity concentrations in the raw water supplies. Additional chemical would be needed at the surface water plants to remove the excess turbidity and additional solids would be produced, which may require additional solids handling and storage space.

Elevated turbidity at the water treatment plant intake can normally be removed using existing treatment processes with additional chemical use although there is a practical limit of approximately 800 NTU. As raw water turbidity increases, the volume of residual solids produced by the water plant also increases. This reduces the life of the solids storage area and additional solids handling equipment and space may be needed.

3.2 Total Organic Carbon (TOC)

Total organic carbon (TOC) in source waters comes from decaying natural organic matter (NOM) as well as synthetic sources. Humic acid and fulvic acid are examples of NOM. Some detergents, pesticides, fertilizers, herbicides, industrial chemicals, and chlorinated organics are examples of synthetic sources of TOC. A portion of the NOM reacts with chlorine to create disinfection by-products (DBPs), regulated drinking water contaminants.

Raw water TOC data for the two Columbus surface water treatment plants is shown in Figure 3-3. TOC values typically range from 3.5 to 13.5 mg/L in study area surface waters. Depending on weather, season, and operations, the raw water TOC concentration peaks at different times throughout the year. When comparing the three Columbus water plants, TOC concentrations were highest in the raw water at DRWP. From 1987 to 2013, influent raw water TOC concentrations typically ranged from 4.5 to 10 mg/L. At HCWP, raw water TOC normally ranged from 4.5 to 6.5 mg/L. Raw water TOC concentrations were relatively constant over the past 27 years with no apparent increasing or decreasing trend.

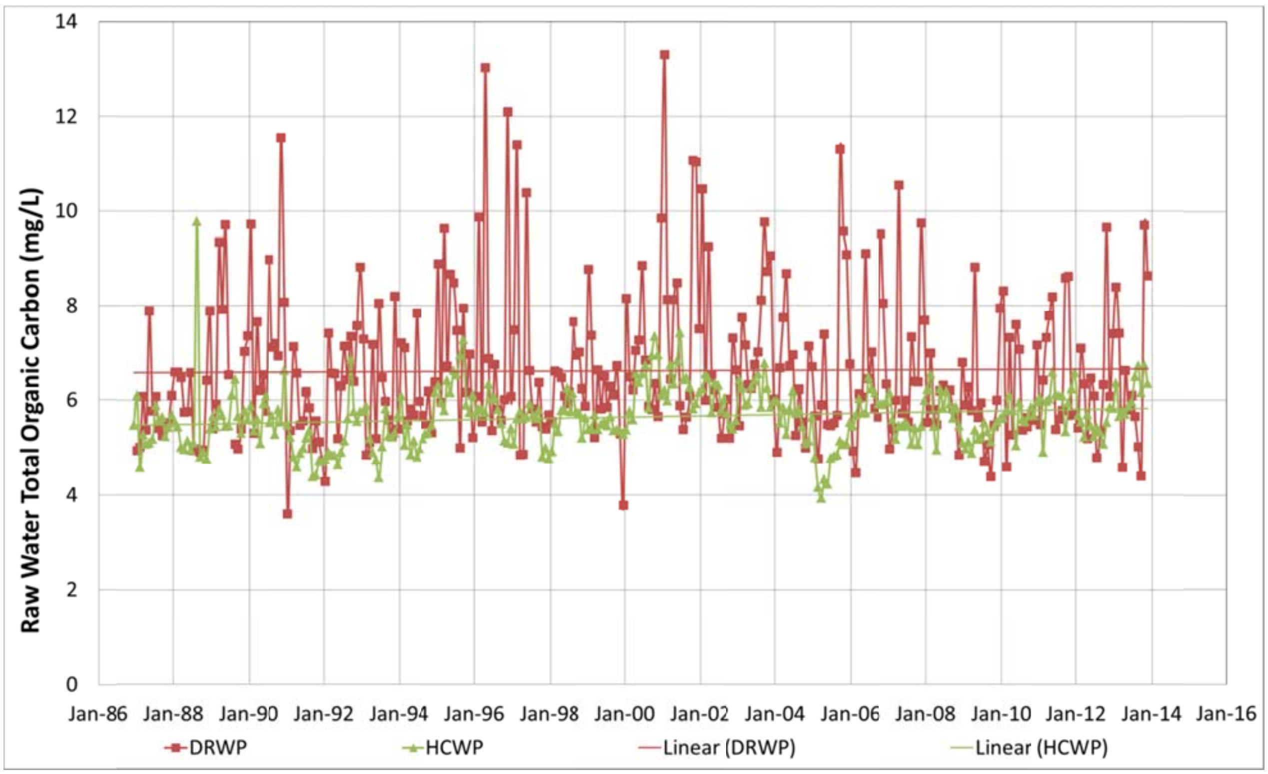

Figure 3-3. Raw water total organic carbon concentrations from 1987 to 2013

Linear trends lines are shown on the figure to capture the general trends in historical total organic carbon data.

Rainfall Influence on Total Organic Carbon (TOC) Concentration

TOC concentrations for 2010 and for the DRWP intake and the HCWP intake and daily precipitation are shown on Figure 3-4. The TOC concentrations at the HCWP intake were similar in 2010 and 2011 and only varied from 5.0 mg/L to 6.5 mg/L. Rainfall does not appear to have much effect on the TOC concentration at the HCWP intake. This is presumably due to the long residence time and assimilative capacity of the Hoover and Alum Creek reservoirs. The peak TOC concentration was slightly (0.5 mg/L) higher in 2011, a very wet year, than in 2010.

TOC values from the DRWP intake were more variable with higher peaks and concentrations ranging from 4.5 to 8.5 mg/L in 2010 and 2011. In 2010, higher concentrations were observed during the wetter spring and early summer. TOC values were consistently lower throughout the dryer fall and early winter.

During the very wet year of 2011, TOC concentrations at DRWP increased through the spring and early summer then dropped substantially during July and August before increasing again in October. The peak TOC values measured in October were slightly higher in 2011. In contrast the TOC concentrations during the dry fall and early winter of 2010 were substantially lower than TOC values during the same time in 2011. During the 5.23 inches of rainfall in late July 2011, the TOC concentrations were at their lowest level. This appears to be an example of cleaner water flushing through O’Shaughnessy and Griggs, the short detention time reservoirs.

Rainfall has some impact on TOC concentrations at the DRWP intake but there are many other factors at play including: time of year; status of vegetation in the watershed; reservoir biology; antecedent rainfall; and activities in the watershed such as chemical application. For example, more organic material would be present in the spring and fall that can be carried into area surface waters with stormwater runoff. Substantial rainfall following an extended dry period would convey more organic material to the reservoirs during these times. In comparison, rainfall during the summer months would not convey as much organic material. Substantial rainfall following a recent rain event would be expected to produce much lower TOC concentrations.

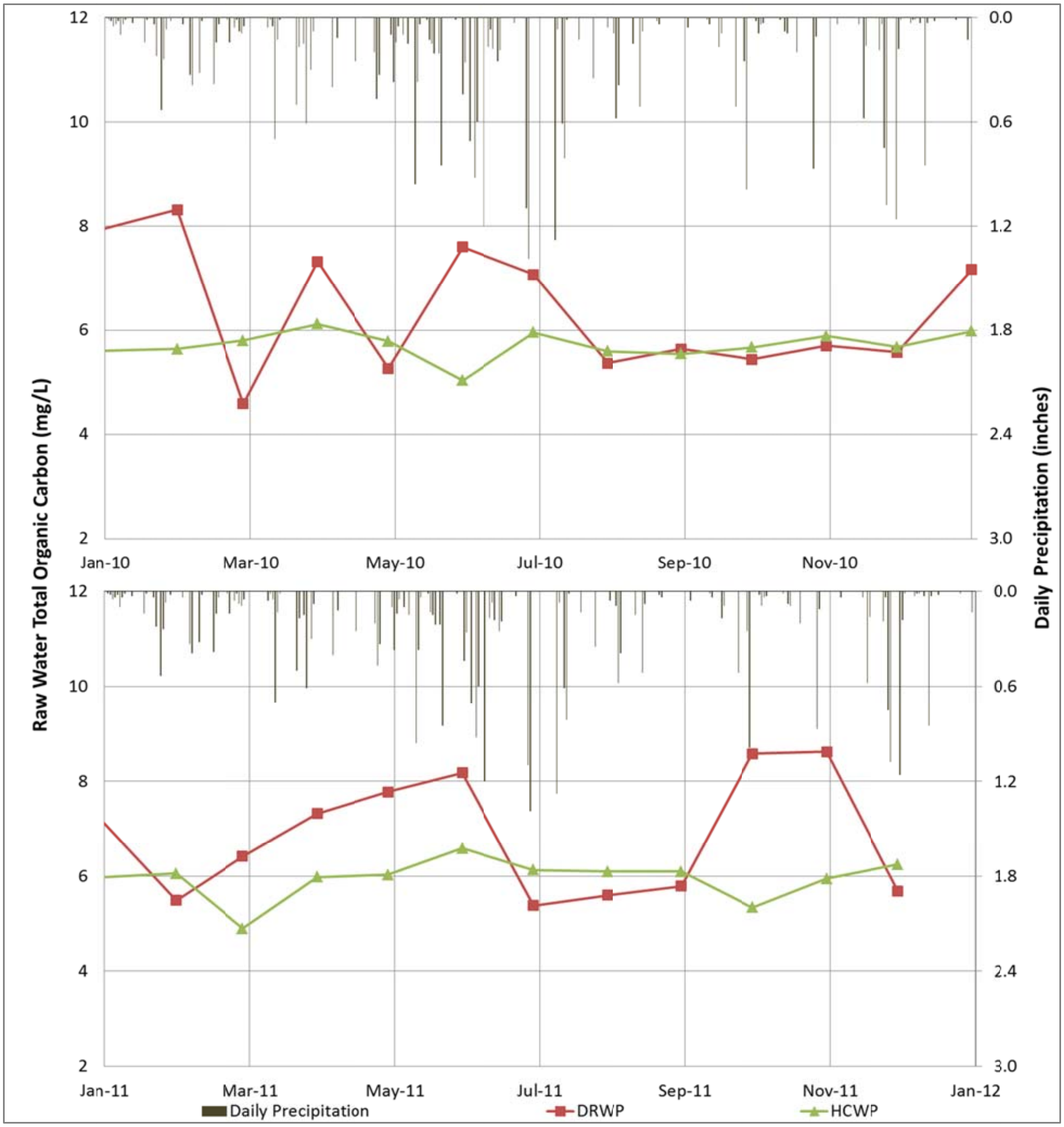

Figure 3-4. Raw water intake total organic carbon concentrations and daily rainfall in 2010 and 2011

Potential Changes Due to Climate Change

More extreme and intense weather is expected in the future as a result of climate change. Drought and more intense storms are likely to increase the concentration of NOM in runoff, which will translate into higher NOM concentrations in the reservoirs and raw water intakes. More extreme weather translates into longer periods of drought when vegetation will be diminished or lost. More intense storm events following drought will produce higher NOM concentrations from watershed wash-off and in-stream erosion, which will be conveyed through area streams to reservoirs.

Water temperatures also are expected to increase in the future because of climate change. DBP formation increases with increasing temperature (Singer et al., 1992). The speciation of TTHMs and haloacetic acids (HAAs) also can shift with increasing temperature. For instance, at 24 degrees Celsius, higher total trihalomethane (TTHM) concentrations are expected, while higher HAA values are expected at temperatures near 3 degrees Celsius (USEPA, 2003). Chlorine demand may be greater because of warmer temperatures; this change would require higher doses to maintain chlorine residual in the water distribution system. All of these factors could increase the formation of DBPs in the future, requiring additional organics removal prior to disinfection. Additional treatment would translate into higher O&M costs.

More extreme weather and higher temperatures could increase the formation of DBPs in the future, requiring additional organics removal prior to disinfection. Additional treatment would translate into higher O&M costs.

In addition to the traditional coagulation/settling/filtration processes used for the removal of NOM from surface drinking water sources, Columbus will provide enhanced treatment for the removal of DBP precursors (PAC, ozone, and biofiltration). Other utilities in the region have also made upgrades to their facilities for water quality instead of capacity reasons.

3.3 Herbicides and Pesticides

A majority of the study area is used for agriculture with extensive row crop production. Growers use herbicides and pesticides to control the growth of weeds and limit insect damage. Herbicide and pesticide water sampling data from 1987 through 2013 for three of the reservoirs that serve Columbus (O'Shaughnessy, Griggs, and Hoover) and downstream of Alum Creek Reservoir, which provides drinking water to Columbus, Del-Co, and Westerville. Reservoir herbicide and pesticide data (in micrograms per Liter [µg/L]) collected from 1987 through 2013 are summarized in Table 3-1.

Of the herbicides, atrazine was detected most frequently and at the highest concentrations in the reservoirs. Atrazine is normally applied as an herbicide in the spring. Of the four locations, the highest atrazine concentrations were measured in the O'Shaughnessy and Griggs reservoirs, which have very short residence times and receive discharges from a largely agricultural watershed. Measured atrazine values collected from 1987 through 2013 for three of the reservoirs that serve Columbus (O'Shaughnessy, Griggs, and Hoover) and downstream of the Alum Creek Reservoir are shown on Figure 3-5. Based on an analysis of the atrazine concentrations over time, there appears to be a slight decreasing trend. This trend is more pronounced in Hoover Reservoir and downstream of Alum Creek Reservoir than in O'Shaughnessy and Griggs reservoirs.

Table 3-1. Summary of Upper Scioto River Basin Reservoir Herbicide and Pesticide Concentrations from 1987 to 2013 (μg/L)

Parameter	Alum Creek[1]	Reservoir		
		Griggs	Hoover	O'Shaughnessy
Atrazine				
Average Concentration	0.98	1.79	1.49	1.94
Maximum Concentration	6.73	22.17	11.89	23.88
Alachlor				
Average Concentration	0.25	0.46	0.33	0.46
Maximum Concentration	0.98	4.36	1.85	6.75
Simazine				
Average Concentration	0.32	0.42	0.44	0.43
Maximum Concentration	4.94	3.92	1.72	4.38

[1]Water samples collected in Alum Creek downstream of the Alum Creek Reservoir Dam

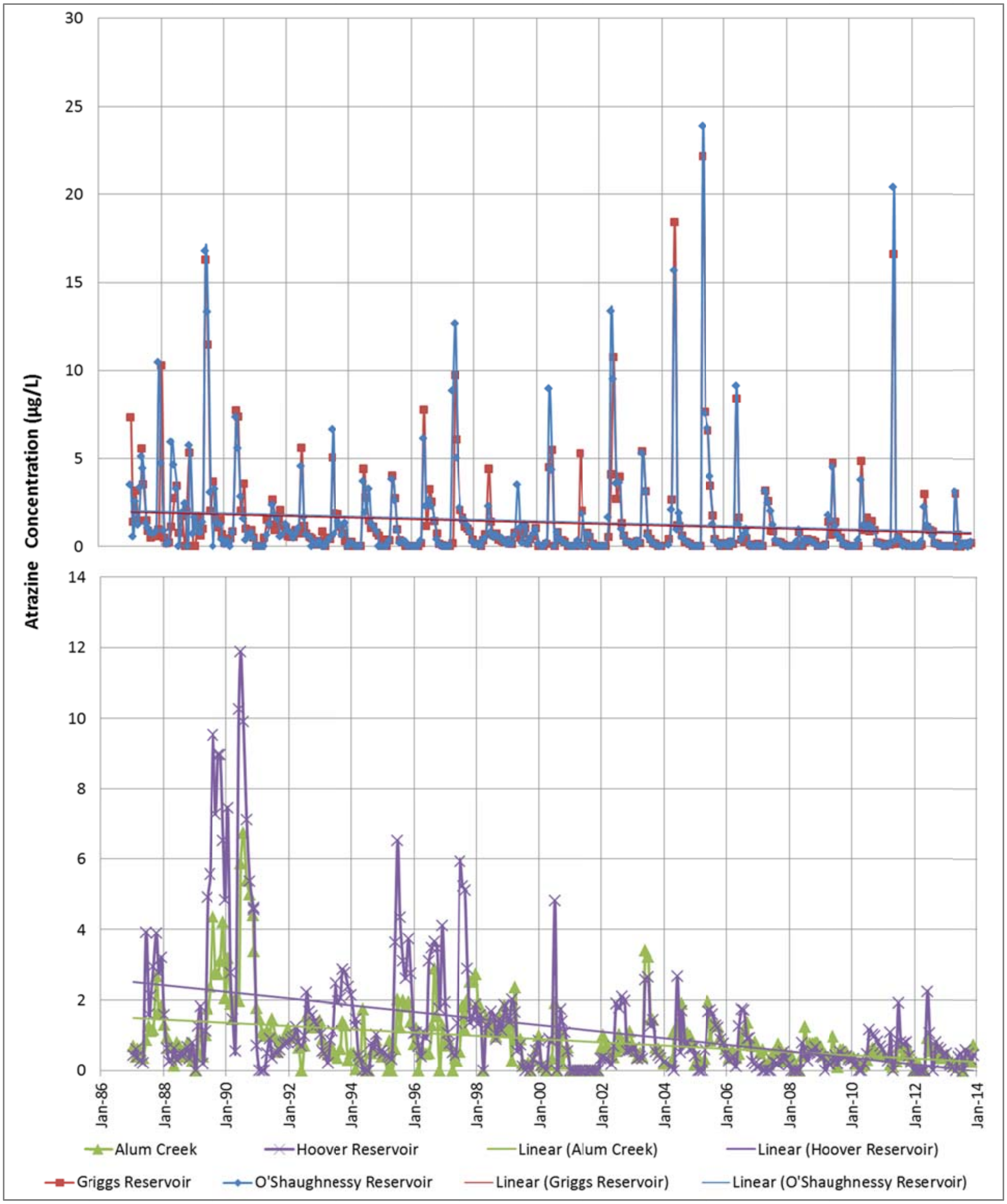

Figure 3-5. Upper Scioto River basin reservoir atrazine concentrations from 1987 to 2013

Water samples collected in Alum Creek, downstream of the Alum Creek Reservoir Dam.

Linear trends lines are shown on the figure to capture the general trends in historical atrazine data.

In 1990 atrazine concentrations exceeded 10 µg/L in Hoover Reservoir and from 1995 to 1998 atrazine concentrations commonly exceeded 3 µg/L. Due to concerns over increasing atrazine concentrations, a special Environmental Quality Incentives Program (EQIP) was implemented by the Natural Resources Conservation Service (NRCS) in 1999 in the Hoover Reservoir watershed (from passage of the 1996 Farm Bill). EQIP was a voluntary program that provides financial incentives and technical assistance to agricultural producers, through contracts up to a maximum of 10 years in duration, to reduce reservoir atrazine concentrations and maintain concentrations below the drinking water standard. The effect of EQIP in this region is summarized in King et al., 2012.

From 2001 through 2011, the atrazine concentration in the Hoover Reservoir remained below 3 µg/L. This was lower than the atrazine concentrations in the O'Shaughnessy and Griggs reservoirs, which were greater than 3 µg/L during the summer season. EQIP ended in 2009 although Hoover Reservoir atrazine values have remained below 3 µg/L through the end of 2013.

Rainfall Influence on Atrazine Concentrations

Atrazine values in 2009, 2010, and 2011 in O'Shaughnessy and Griggs reservoirs are plotted with daily precipitation in Figure 3-6. This time period was selected due to the below average annual precipitation in 2009 and 2010 followed by the near record setting annual precipitation in 2011. The maximum annual atrazine values were observed during a single monitoring event in the late spring or early summer each year following herbicide application and ample rainfall. This peak value is substantially larger than the background concentration during other times of the year. Once the excess atrazine has been flushed from the field and drainage system, no further atrazine spikes were observed even with excessive rainfall in July and August 2011.

The rapid concentration increase followed by an equally rapid decline is due to the characteristics of atrazine and the short residence time in these connected reservoirs on the Scioto River. The peak atrazine concentrations measured in 2011 were almost 4 times the concentrations measured in 2009 and 2010. This is apparently from the excessive rainfall in spring and early summer of 2011. Over 8 inches of rainfall was measured just for the one month period between April 4 and May 3, 2011. This indicates that rainfall intensity does appear to affect peak atrazine concentrations in the surface water system. If more intense storm events occur in the future due to climate change, higher herbicide concentrations may be observed in O'Shaughnessy and Griggs reservoirs.

A similar plot for atrazine concentrations in Hoover Reservoir during 2009, 2010, and 2011 is provided in Figure 3-7. Increases in reservoir atrazine concentrations in Hoover Reservoir are slower to respond and not as large. Once the peak value is reached over a several month period in mid to late summer the atrazine concentration slowly decreased until the next growing season. An exception to this was observed in 2011 with values dropping faster due to excessive rainfall in the summer and fall. The peak atrazine concentrations in Hoover Reservoir were substantially lower than the peak concentrations in O'Shaughnessy and Griggs reservoirs. The primary reason for the gradual increase and then decline in atrazine concentration is the much longer residence time in Hoover Reservoir.

The peak atrazine concentration in Hoover Reservoir in 2011 was about 4 times as large as the peak value in 2009 and twice as large as 2010. Although the annual precipitation in 2010 was well below average more than 7 inches of rain fell between May 11 and June 10. Similar to the observation for O'Shaughnessy and Griggs reservoirs rainfall intensity does appear to affect the peak concentration in Hoover Reservoir.

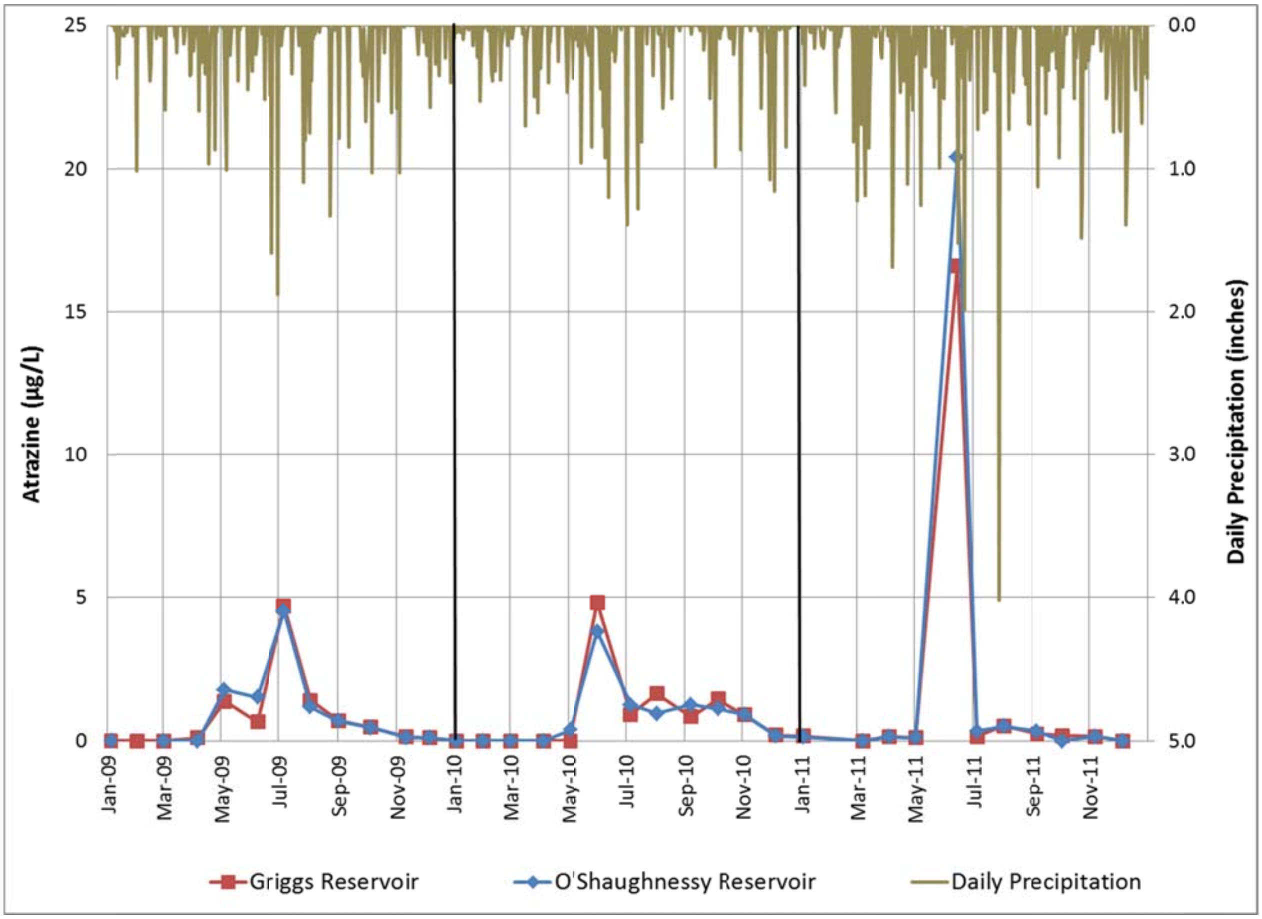

Figure 3-6. Atrazine concentrations and daily precipitation in O'Shaughnessy and Griggs reservoirs in 2009, 2010, and 2011

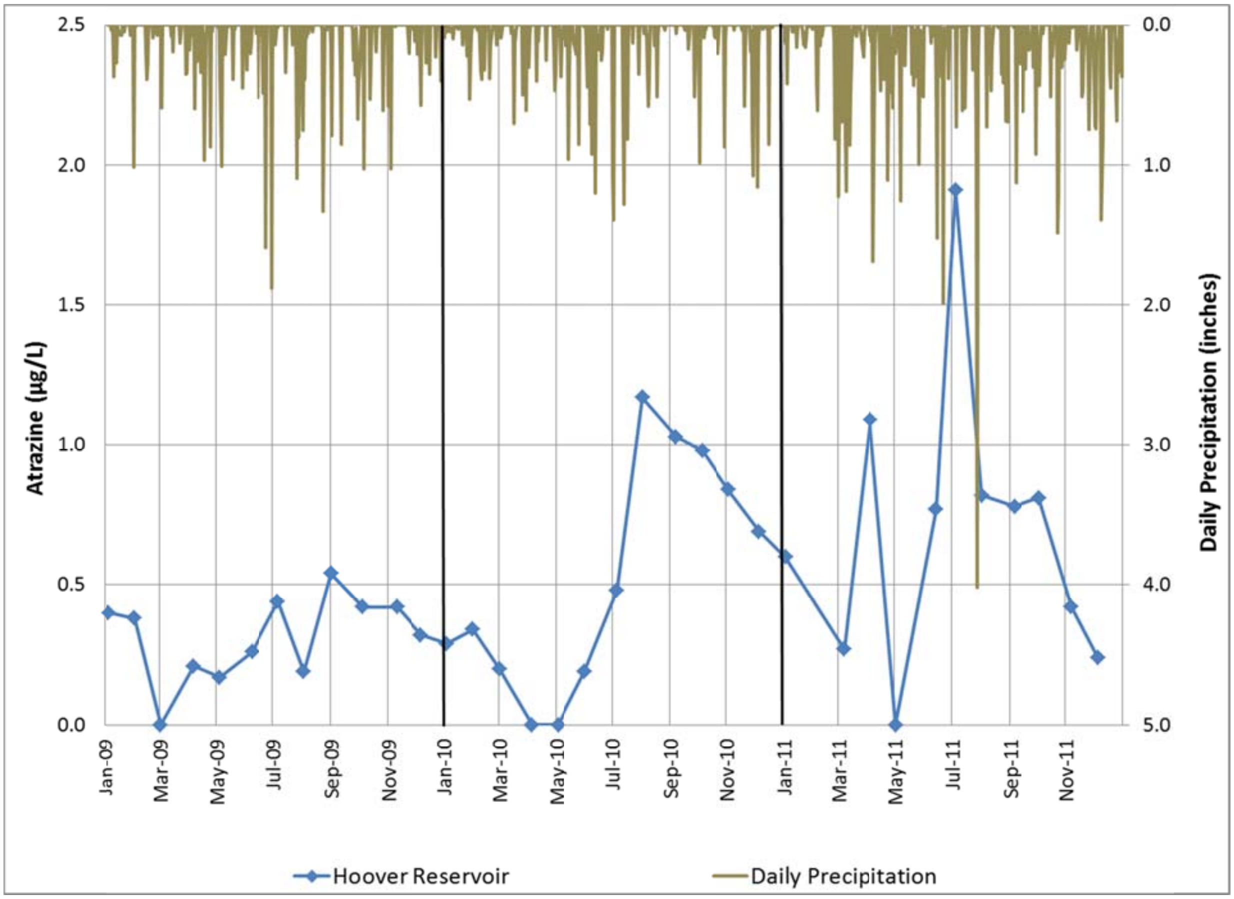

Figure 3-7. Atrazine concentrations and daily precipitation in Hoover Reservoir in 2009, 2010, and 2011

Potential Changes Due to Climate Change

Herbicide and pesticide concentrations in the study area surface water system are primarily a function of chemical selection, application process and timing, and weather. As temperatures increase in the future, the length of the growing season is expected to increase. Two growing seasons may even be possible for some crops. In addition, weeds and insects can become resistant to chemicals, requiring the use of more or different compounds. These factors could lead to additional future herbicide and pesticide application in the watershed.

Longer growing seasons, associated with climate change may lead to increased herbicide and pesticide application rates in the watershed.

Higher herbicide runoff concentrations would increase reservoir concentrations and require additional treatment at drinking water plants.

The highest atrazine concentrations are typically measured during or shortly after a major rain event following the growers' atrazine application. In the future, more intense storm events also may contribute to higher herbicide and pesticide concentrations in stormwater runoff. Higher runoff concentrations would increase reservoir concentrations and require additional treatment at drinking water plants, resulting in higher operation and maintenance (O&M) costs.

Water utilities in the region have been upgrading their facilities due to water quality concerns being the significant driver compared to facility expansion for capacity reasons. For example, Columbus has been very proactive and already completed the addition of advanced treatment processes (powdered activated carbon [PAC]) for the removal of herbicides and pesticides from their drinking water sources. Columbus continues to construct additional advanced treatment processes (ozone) at their surface water plants.

In addition to built infrastructure, watershed based programs, such as EQIP, can be an effective non-structural best management practice for the removal of herbicides, pesticides, and other non-point source pollutants. Implementation of non-structural practices can help to reduce water treatment costs by reducing surface water pollutant concentrations.

3.4 Nutrients (Nitrogen and Phosphorus)

Nutrients are almost always present in natural surface waters and are essential for life. Nutrient enriched surface waters can produce a wide variety of issues including: algae and cyanobacteria blooms; public health and safety concerns; taste and odor issues; and loss of aesthetic and economic value.

The primary sources of nutrients (nitrogen and phosphorus) in the watershed include: stormwater runoff from urban and agricultural land; groundwater; discharges from wastewater treatment facilities and home sewage treatment systems; decomposition of organic matter; soil erosion; and atmospheric deposition. The study area is primarily agricultural, which typically produces elevated total inorganic nitrogen (TIN) concentrations and loads. The higher cost and more careful application of fertilizer in recent years may have reduced nitrogen loads leaving agricultural lands.

It is important to recognize that surface water nutrient concentrations are a function of: watershed water volume inputs and nutrient loads (external); internal loads (seasonal turnover events, groundwater seepage, sediment nutrient flux); and the assimilative capacity of the surface water. The assimilative capacity is primarily a function of surface area, dimensions, depth, permanent pool volume, biology, and residence time.

Surface water samples were collected and analyzed by Columbus from each of the four reservoir monitoring locations in the study area from 1987 through 2013. Samples were collected from O'Shaughnessy, Griggs, and Hoover reservoirs. Alum Creek Reservoir samples were collected from Alum Creek downstream of the Alum Creek Reservoir dam. Discharges from the Alum Creek reservoir are controlled by the US Army Corps of Engineers (USACE). USACE has the ability to discharge water from different reservoir depths. The samples collected from Alum Creek may be a result of discharges at different depths and the discharge depth for each monitoring event is not known. This could affect the reported nutrient concentrations.

From 1987 to 2005 samples were collected once per month at the surface. Sample collection frequency increased to twice per month from 2006 to present. The increase in sample collection frequency in later years may affect the trend analysis results. With less frequent sample collection, peak values may have been missed producing the appearance of lower values in the earlier years.

Another major factor impacting the nutrient data assessment is the changes in laboratory method detection limits. Starting in 2002, the method detection limits for total phosphorus (TP) and ortho-phosphate (as phosphorus, OP-P) were changed from 0.02 to 0.05 mg/L. Starting in 2002, the method detection limits for nitrate-nitrite nitrogen (NO_x-N) was changed from 0.2 to 0.5 mg/L and ammonia nitrogen (NH_3-N) was changed from 0.02 to 0.05 mg/L. This mainly affects the lower nutrient concentrations in Hoover Reservoir and Alum Creek downstream of the dam at Alum Creek

Reservoir. Many of the TP and OP-P values from Hoover Reservoir and Alum Creek downstream of the dam at Alum Creek Reservoir are below the detection limit and therefore the actual phosphorus values are not known for these samples. One-half of the detection limit value was used for analysis but the actual values may be higher or lower than this value.

Reservoir water samples were collected and analyzed by the Columbus for TP, OP-P, nitrate-nitrite nitrogen (NOx-N), and NH3-N. Plots of the nutrient data from 1987 to 2013 were created and reviewed by BC to identify any apparent increasing or declining concentration trends during this 27-year period. Plots of TIN concentration were created by summing the concentration of NOx-N and NH3-N. Organic nitrogen concentrations were not reported in the data so total nitrogen (TN) could not be calculated.

For all of the measured nutrient species, concentrations in Alum Creek below the Alum Creek Reservoir dam were typically the lowest, followed closely by the concentrations in Hoover Reservoir. The measured nutrient concentrations in the O'Shaughnessy and Griggs reservoirs are comparable and generally substantially higher (up to an order of magnitude or more for peak values) than Alum Creek and Hoover Reservoir. This difference is primarily a function of the size, volume, and depth of the reservoirs. The O'Shaughnessy and Griggs reservoirs are much smaller and basically reflect the water quality in the Scioto River. The water quality in the O'Shaughnessy and Griggs reservoirs changes quickly in response to rain events. Columbus indicated the mean residence time in O'Shaughnessy and Griggs reservoirs is approximately 12 days but can be as short as 2 days under high flow conditions. In comparison, Columbus indicated the mean residence time in Hoover Reservoir is approximately 180 days and Alum Creek Reservoir is even longer.

The Alum Creek and Hoover reservoirs are much larger and capable of diluting and assimilating watershed nutrient loads within the reservoirs. Water quality changes occur more slowly over time in the Alum Creek and Hoover reservoirs. This was observed in the atrazine and TOC data presented earlier in this section. The water quality in these deeper, more stratified reservoirs can be more influenced by longer-term watershed nutrient loads (external loads) and internal nutrient loads including: seasonal turnover events; sediment flux; and groundwater seepage.

Water quality in the Alum Creek and Hoover reservoirs changes slowly over time; in these deeper, more stratified reservoirs water quality is more influenced by spring and fall turnover events and longer-term nutrient loadings.

Seasonal reservoir turnover events due to air and water temperature changes can produce algae and cyanobacteria blooms due to a potential rapid increase in water column nutrient concentrations. Larger and more stratified surface waters can also be more influenced by internal nutrient loadings including groundwater seepage and sediment nutrient flux. Under anoxic lake bottom conditions, loosely bound phosphorus in the sediments can be released into the water column increasing water column nutrient, algae, and cyanobacteria concentrations.

3.4.1 Total Phosphorus (TP) and Ortho-Phosphate Phosphorus (OP-P)

This section includes analyses of total phosphorus (TP) and ortho-phosphate phosphorus (OP-P) concentrations measured in the study area. Orthophosphates are the inorganic forms of phosphate; such as phosphorous (PO4), mono hydrogen phosphate (HPO4) and dihydrogen phosphate (H2PO4). These are the forms of phosphates used heavily in fertilizers and are often introduced to surface waters through stormwater runoff. A majority of measured orthophosphates are reactive meaning they are readily available food for algae growth. Total phosphorus includes all forms of phosphorus including dissolved and particulate forms, and organic and inorganic species.

3.4.1.1 Reservoir Trends from 1987 to 2013

> The concentration of TP and OP-P appear to be increasing in Griggs and O'Shaughnessy reservoirs. This trend is expected to continue in the future.

Historical TP and OP-P concentrations are plotted in Figures 3-8 and 3-9, respectively. Based on the measured values from 1987 to 2013, the concentrations of TP and OP-P appear to be increasing in the O'Shaughnessy and Griggs reservoirs. Based on analysis of TP trend over time, the trend line value increased from approximately 0.13 mg/L in 1987 to 0.21 mg/L in 2013. In the late 1980s and early 1990s, most TP concentrations were in the range of 0.05 mg/L to 0.20 mg/L, with only a small number of values above 0.3 mg/L. In the 2000s, many TP values were in the range of 0.3 mg/L to 0.5 mg/L.

OP-P concentrations in the O'Shaughnessy and Griggs reservoirs also appear to be increasing. Based on a similar analysis, the trend line OP-P concentration increased from approximately 0.09 mg/L in 1987 to 0.12 mg/L in 2013. In the late 1980s and early 1990s, most OP-P concentrations were in the range of 0.05 mg/L to 0.2 mg/L, with only a small number of values above 0.2 mg/L. In the 2000s, many OP-P values were in the range of 0.2 mg/L to 0.3 mg/L, and numerous values were above 0.3 mg/L.

TP and OP-P concentration trends in Alum Creek below the reservoir and Hoover Reservoir are more difficult to evaluate. This is primarily due to the change in laboratory method detection limits in 2002. It was not possible to complete a meaningful trend analysis using Alum Creek and Hoover reservoirs TP and OP-P data. Many TP and OP-P concentrations were below the method detection limit.

From 1987 to 1994 the peak TP value in the Alum Creek and Hoover reservoirs, approximately 0.15 mg/L, was similar to the peak value observed between 2004 and 2013. From 1995 to 2003, the peak TP concentration was lower, approximately 0.10 mg/L.

From 1987 to 2000, there were 12 TP measurements greater than or equal to 0.10 mg/L in Alum Creek and Hoover Reservoir. All but 2 of these were in Hoover Reservoir. From 2001 to 2013 there were 25 TP measurements greater than or equal to 0.10 mg/L. Only two of these were in Alum Creek. For OP-P there were 17 values greater than 0.05 mg/L from 1987 to 2000 and 21 values greater than 0.05 mg/L from 2001 to 2013. In the mid to late 2000s there were many more TP values exceeding 0.1 mg/L for the Hoover Reservoir and 0.05 mg/L for the Alum Creek Reservoir.

These results are inconclusive since additional samples were collected in later years and water may have been discharged from different depths in Alum Creek reservoir. It is possible that elevated TP and OP concentrations are present more frequently in the Alum Creek and Hoover Reservoir in more recent years. Reducing the TP and OP-P laboratory method detection limits is recommended to create a more complete and precise dataset and allow trend analysis in the future.

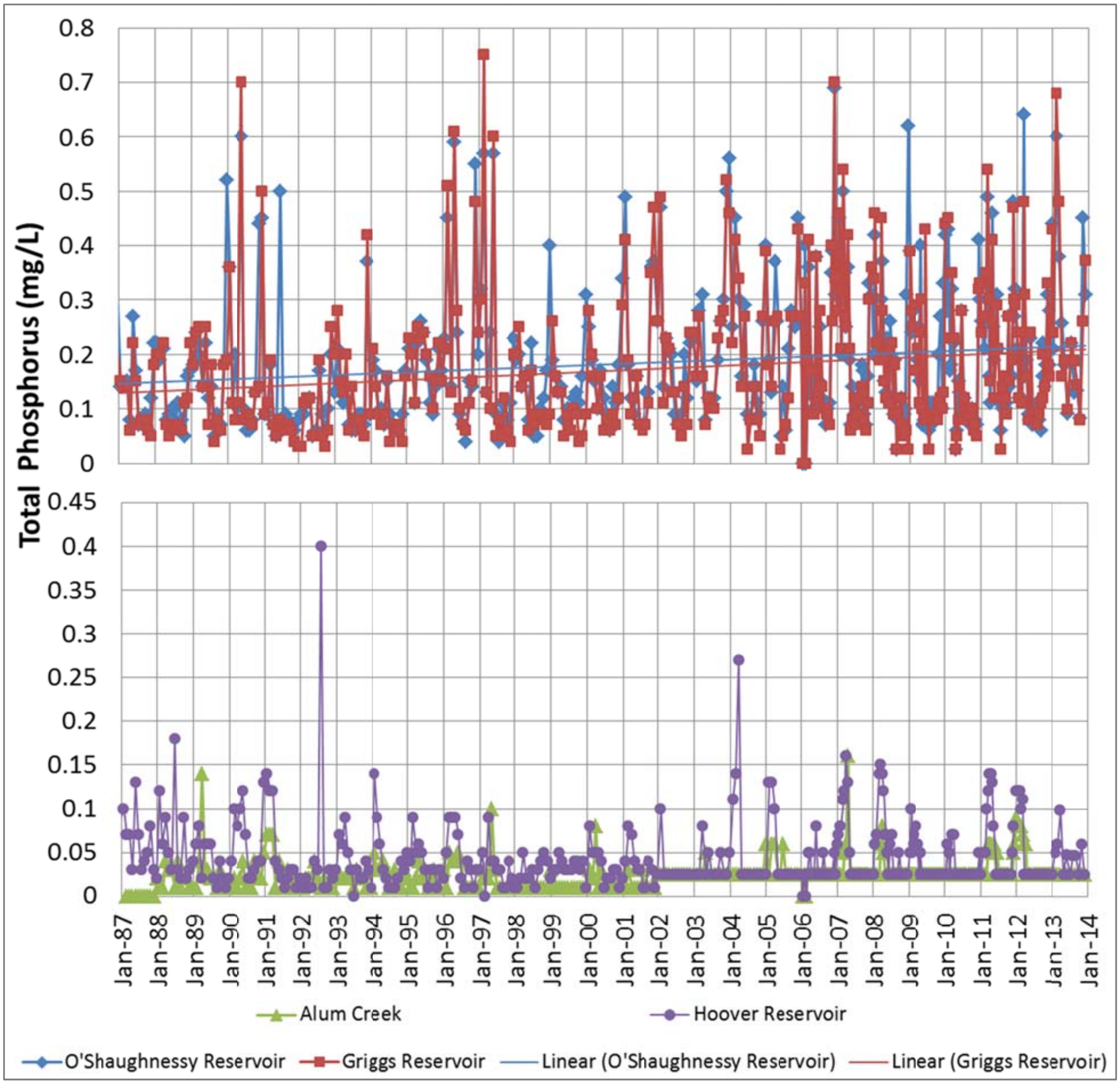

Figure 3-8. Upper Scioto River basin reservoir total phosphorus concentrations from 1987 to 2013

Water samples collected in Alum Creek downstream of the Alum Creek Reservoir Dam

In 2002, the detection limit for TP increased from 0.02 mg/L to 0.05 mg/L.

Linear trends lines are shown on the figure to capture the general trends in historical total phosphorus concentrations.

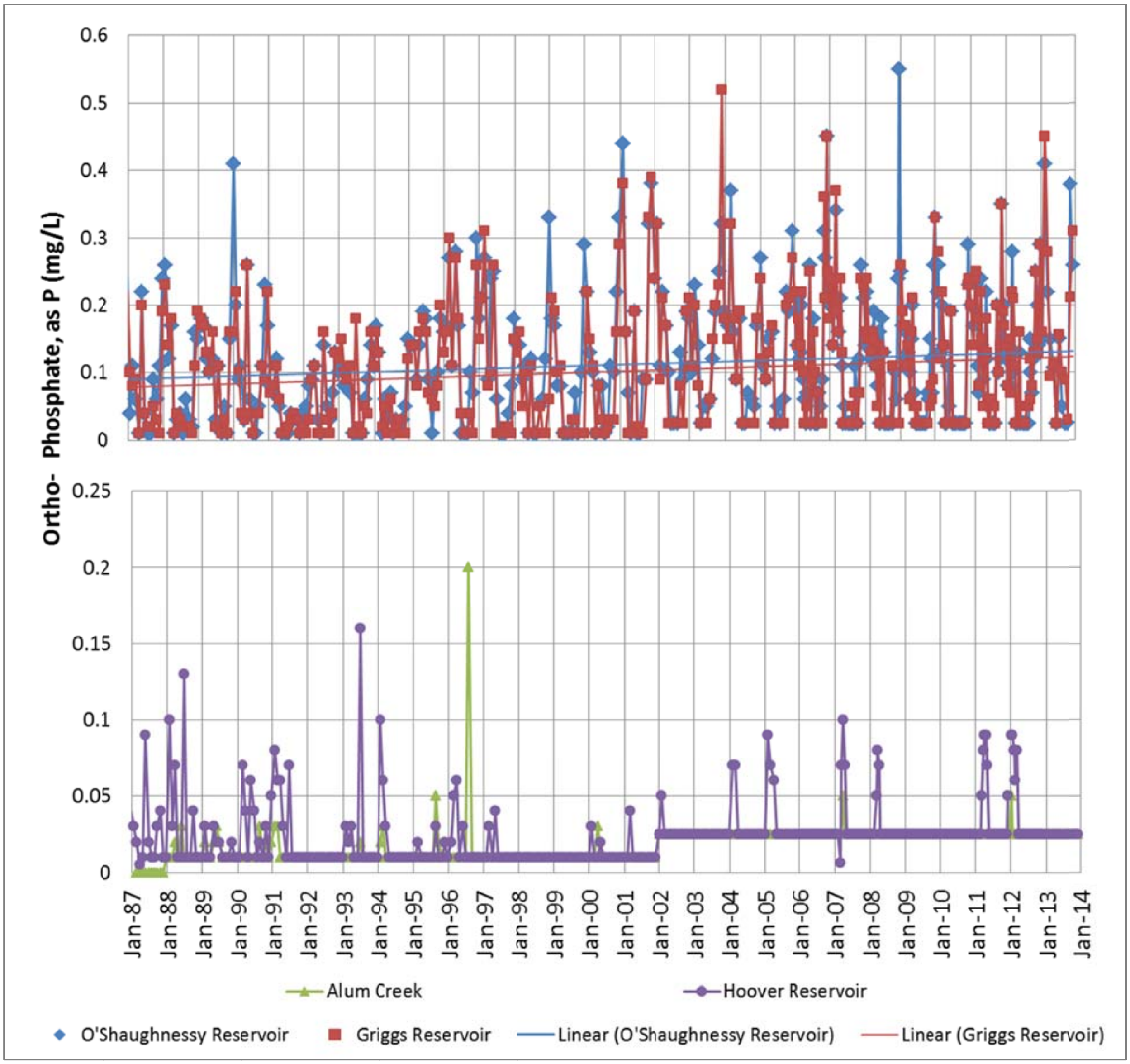

Figure 3-9. Upper Scioto River basin reservoir ortho-phosphate (as P) concentrations from 1987 through 2013

Water samples collected in Alum Creek downstream of the Alum Creek Reservoir Dam

In 2002, the detection limit for OP-P increased from 0.02 mg/L to 0.05 mg/L.

Linear trends lines are shown on the figure to capture the general trends in historical ortho-phosphate phosphorus concentrations.

3.4.1.2 Rainfall Influence on Phosphorus Concentrations

Further review of nutrient data for 2010 and 2011 was completed by BC to identify any apparent relationships between precipitation and nutrient concentrations, and assist in developing climate change mitigation strategies. 2011 was a very wet year, with 56.9 inches of precipitation; the 29.1 inches of precipitation in 2010 was well below the annual average.

Figure 3-10 includes measured O'Shaughnessy and Griggs reservoirs TP concentrations for 2010 and 2011 along with total weekly precipitation. Peak TP and OP-P concentrations were higher in 2011 compared to 2010. In 2011, there were 8 events with reservoir TP greater than or equal to 0.3 mg/L. In 2010, there were only 5 events with reservoir TP values greater than or equal to 0.3 mg/L. All of these TP peaks occurred fairly rapidly following rainfall. Although 2010 was a dry year overall, more than 7 inches of rain fell from May 11 to June 10. This produced a corresponding increase in TP concentration from 0.05 mg/L to approximately 0.3 mg/L. TP values returned to about 0.1 mg/L throughout an extended dry period from July through October.

In 2011, peak O'Shaughnessy and Griggs reservoir TP concentrations were observed after substantial rainfall in April, late March/early April, June, September, and November. The lowest TP values of the year were observed during relatively dry weather in May, July, August, and early September. TP concentrations also dropped during October following a very wet period. Rainfall following a very wet period may produce lower pollutant concentrations because the source has already been washed from the contributing watershed.

The measured TP concentrations for Hoover Reservoir and Alum Creek downstream of Alum Creek Reservoir dam in 2010 and 2011 are much different as plotted in Figure 3-11. In 2010, the only TP values above the laboratory method detection limit occurred in Hoover Reservoir in February, March, April and December. During these times the TP concentration increased from below detection limits (BDL = 0.05 mg/L) to between 0.05 and 0.07 mg/L. These TP increases occurred after some rainfall preceded by dry weather.

In 2011, the TP concentration in Hoover Reservoir increased from BDL in January to 0.05 mg/L in February. The TP value continued to increase slowly to a peak annual value of 0.14 mg/L in April. The TP concentration then started a gradual decline to BDL in June. The reduction occurred during relatively dry weather in May which continued in July, August, and early September. The TP concentration peaked once again to 0.08 mg/L in December following substantial precipitation. The rising concentration from January to April was likely due to a number of factors including substantial precipitation along with a preceding dry period and build-up of watershed pollutants. The TP increase in December was similar: affected by precipitation but also potentially internal sources. A similar peak occurred during a much drier 2010.

OP-P concentrations followed the same general annual patterns as TP as shown on Figure 3-12 and 3-13. In O'Shaughnessy and Griggs reservoirs, the peak value was approximately the same, 0.35 mg/L. In 2010 the OP-P concentration was BDL for half the year including most of the summer. OP-P values during 2011 were higher with concentrations BDL for only about 2 months (July and August).

In 2010, there were no Hoover Reservoir and Alum Creek OP-P values above the method detection limit. During 2011, the OP-P concentration in Hoover Reservoir increased slowly from February to April to a peak annual value of 0.09 mg/L. The value declined to BDL in May and remained there until a slight increase to 0.05 mg/L in December. The percentage of TP present as OP-P ranged from near zero to almost 100 percent.

The concentration of TP and OP-P in runoff and surface waters is influenced by rainfall and numerous other factors including the application of manure and chemical fertilizers and internal loadings. Nutrient concentrations commonly increase following a rain event which is preceded by dry weather. Elevated concentrations are expected following the application of fertilizers in the watershed and ample rain to produce substantial watershed runoff. Elevated nutrient concentrations can also be measured in the early winter following seasonal leaf fall/vegetation changes and sufficient rainfall.

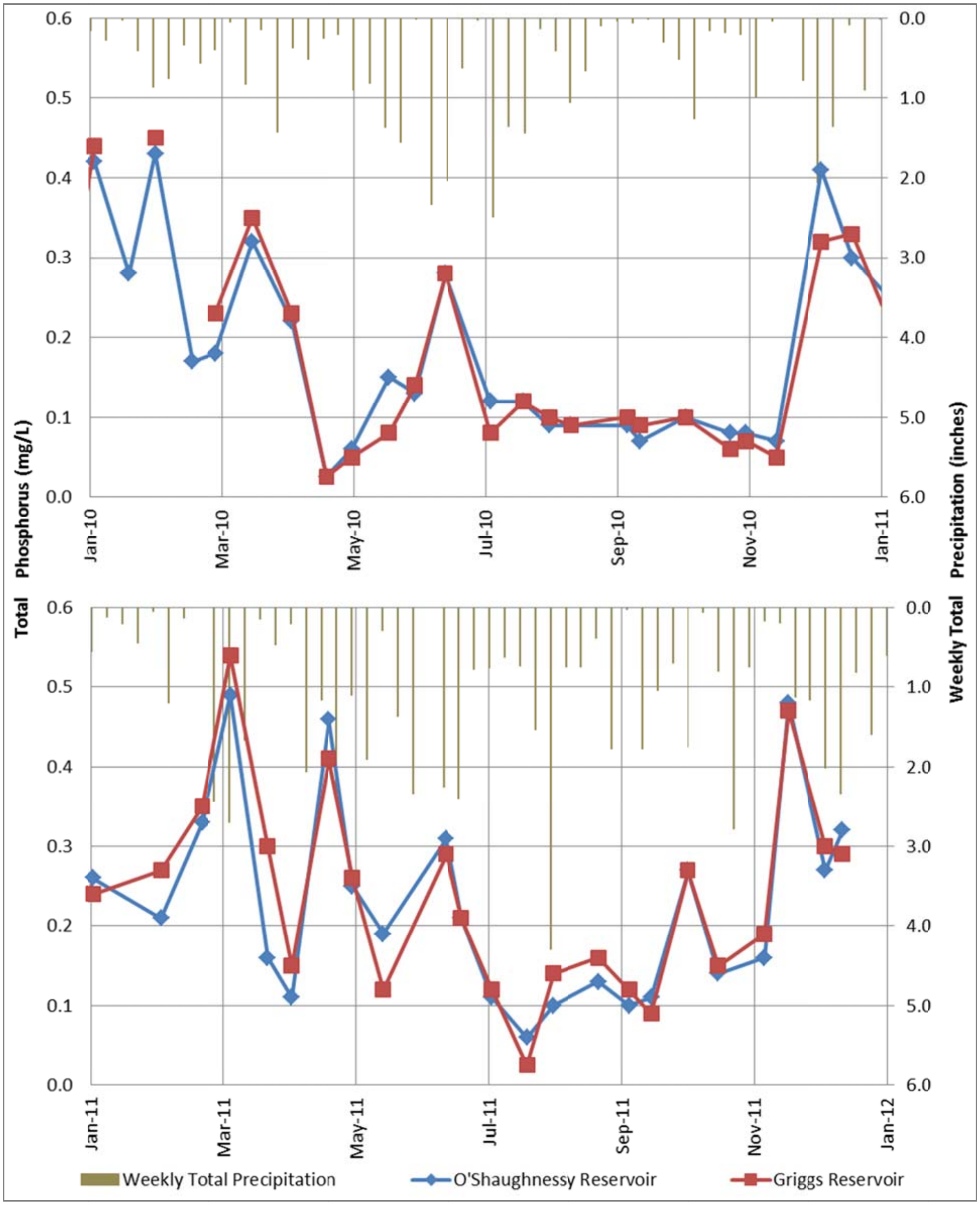

Figure 3-10. O'Shaughnessy and Griggs reservoirs total phosphorus concentrations and total weekly precipitation in 2010 and 2011

Note: 2010 Precipitation = 29.1 inches; 2011 precipitation = 56.9 inches.

In 2002, the detection limit for TP increased from 0.02 mg/L to 0.05 mg/L.

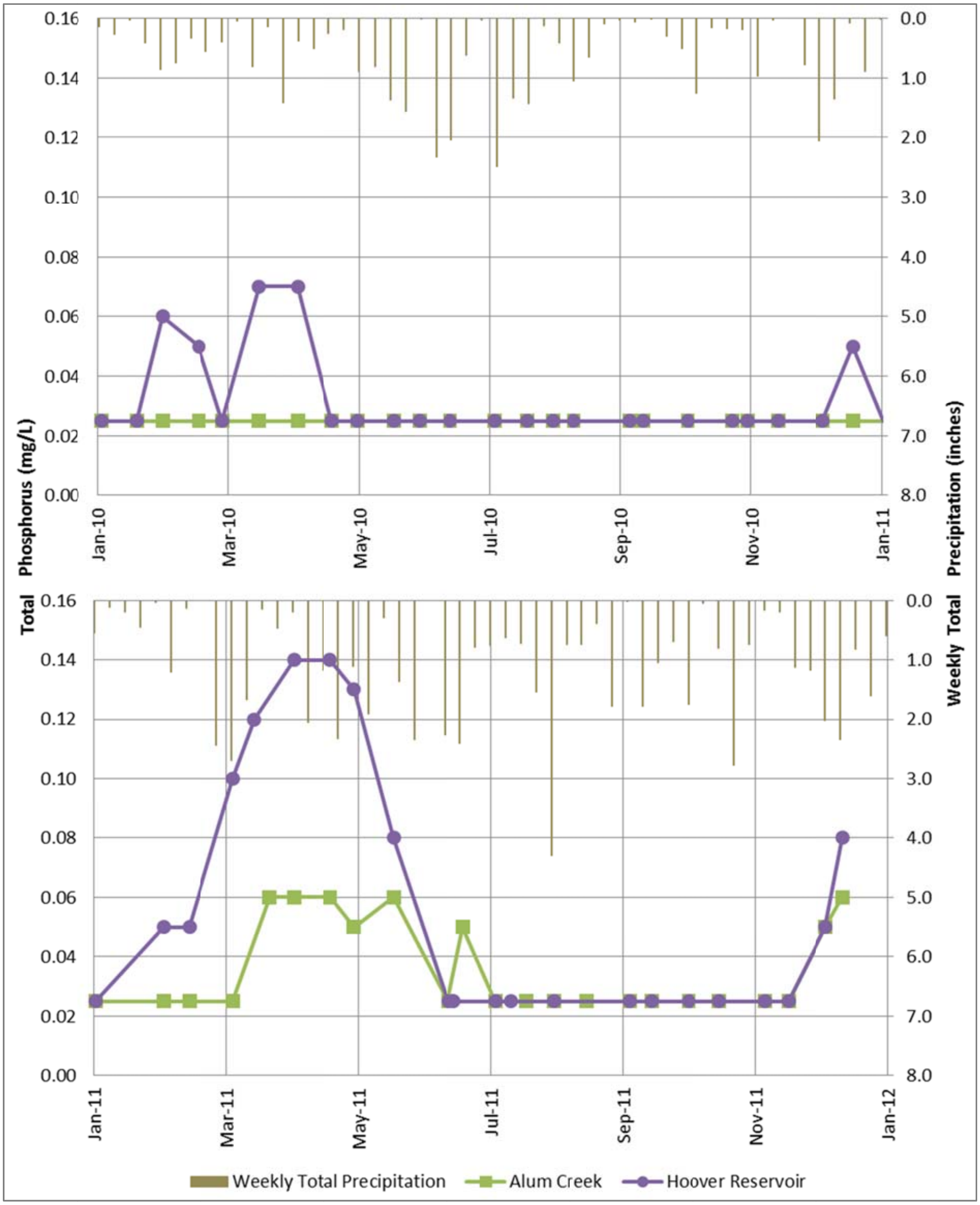

Figure 3-11. Alum Creek and Hoover reservoirs total phosphorus concentrations and total weekly precipitation in 2010 and 2011

Note: 2010 Precipitation = 29.1 inches; 2011 precipitation = 56.9 inches.

Water samples collected in Alum Creek downstream of the Alum Creek Reservoir Dam

In 2002, the detection limit for TP increased from 0.02 mg/L to 0.05 mg/L.

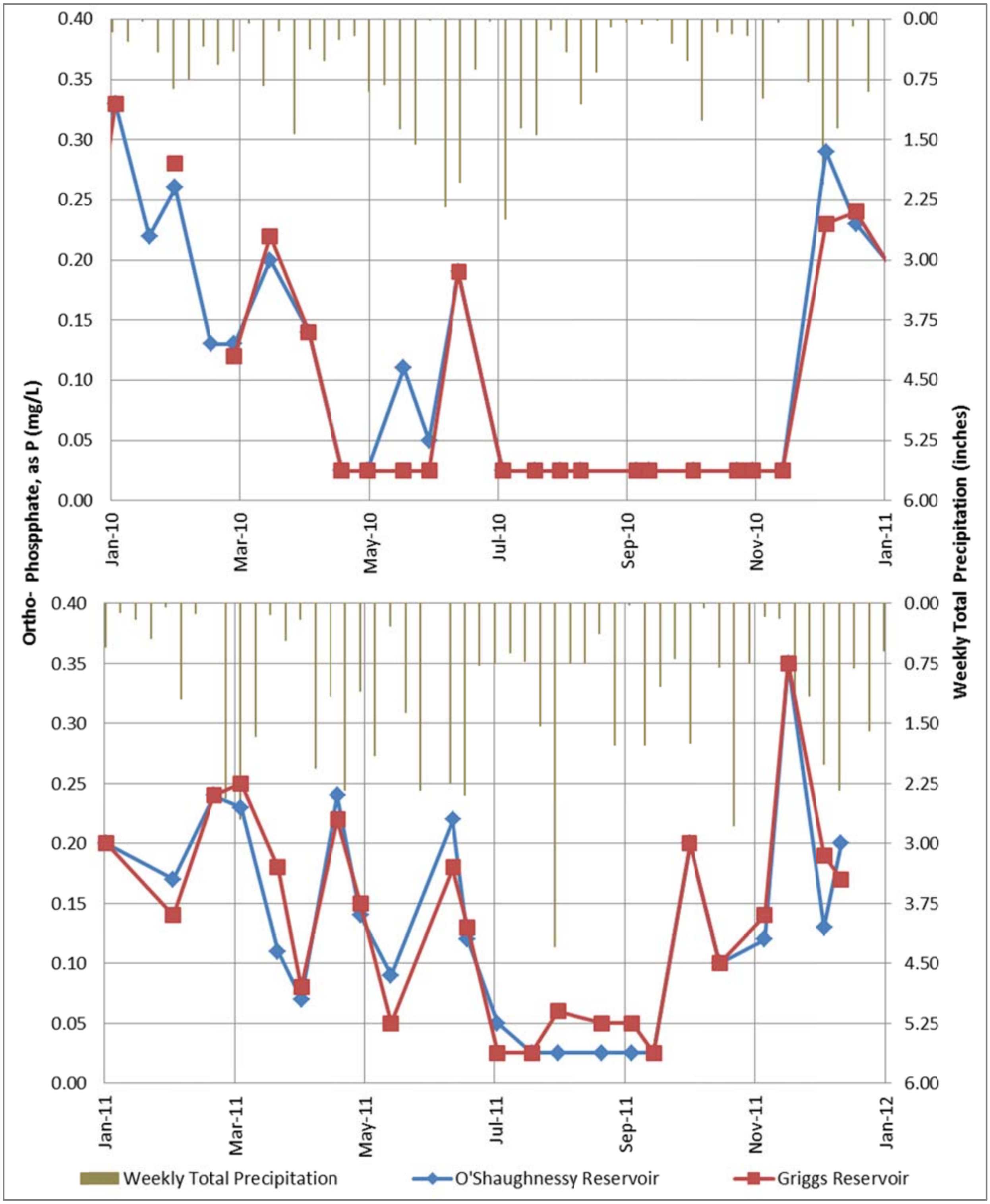

Figure 3-12. O'Shaughnessy and Griggs reservoirs ortho-phosphate (as P) concentrations and total weekly precipitation in 2010 and 2011

Note: 2010 Precipitation = 29.1 inches; 2011 precipitation = 56.9 inches.

In 2002, the detection limit for OP-P increased from 0.02 mg/L to 0.05 mg/L.

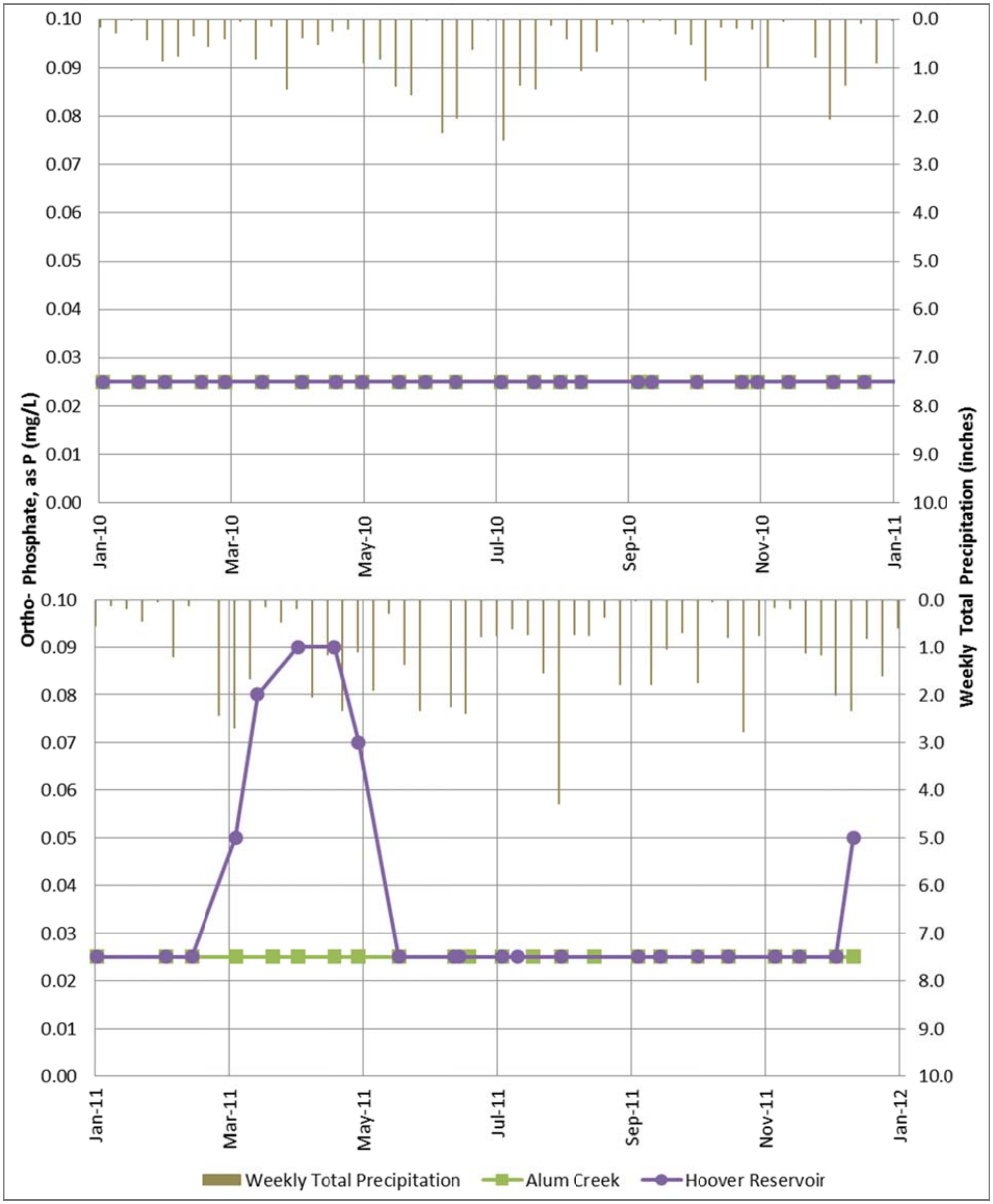

Figure 3-13. Alum Creek and Hoover reservoirs ortho-phosphate concentrations and total weekly precipitation in 2010 and 2011

Note: 2010 Precipitation = 29.1 inches; 2011 precipitation = 56.9 inches.

Water samples collected in Alum Creek downstream of the Alum Creek Reservoir Dam

In 2002, the detection limit for OP-P increased from 0.02 mg/L to 0.05 mg/L.

3.4.1.3 Mill Creek

Samples were collected by Columbus approximately monthly in 2006 through 2011 in Mill Creek (tributary to the Scioto River) and analyzed for TP and OP-P. TP and OP-P concentrations were highly variable from month to month, but the minimum and maximum measured values in the creek were comparable to values measured in the O'Shaughnessy and Griggs reservoirs. In 2011, TP concentration ranged from 0.07 mg/L in April to 0.48 mg/L in August.

Generally the range of TP values measured in the creek in earlier years was similar to the concentrations measured in 2011; however, the data show a few exceptions. In Mill Creek in 2008, TP values reached 4.8 mg/L in October and November, an order of magnitude higher than values measured in other years. The cause of the very elevated TP values in 2008 is thought to be a new wastewater treatment system discharge. The total annual precipitation in 2008 was about 36 inches, which is slightly below average. An interesting observation is that the minimum and maximum TP values were measured during different months each year.

3.4.1.4 Scioto River at Hoskins Road

This monitoring location is relatively close to the raw water intake for the upground reservoirs. Water samples were collected once or twice per month in the Scioto River at Hoskins Road and analyzed for TP and OP-P in 2011. TP and OP-P concentrations were similar to values measured in the O'Shaughnessy and Griggs reservoirs. The minimum OP-P concentration of 0.10 mg/L was measured in both April and November. The minimum TP concentration of 0.12 mg/L was measured in November. The maximum OP-P and TP concentrations measured in March 2011 were 0.41 mg/L and 0.97 mg/L, respectively.

Pumping of water from the river to the upground reservoirs is planned by Columbus during higher stream flow conditions. TP concentration typically increases with increasing flow during and after storm events and seasonally due to the application of fertilizer. It will be important to monitor TP and OP concentrations and pump water to the upground reservoirs when concentrations are lower. Additional management measures should be available to improve reservoir water quality if nutrient concentrations become elevated.

3.4.2 Total Inorganic Nitrogen (TIN, Nitrate-Nitrite Nitrogen + Ammonia Nitrogen)

The section includes an analysis of TIN (as N) concentrations in the study area.

3.4.2.1 Reservoir Trends from 1987 to 2013

Concentrations of TIN, the sum of nitrate-nitrite (NO_x-N), and ammonia (NH_3-N), from 1987 to 2013 are plotted in Figure 3-14. For most monitoring dates practically all of the TIN was in the form of nitrate. The finished drinking water standard for nitrate is 10 mg/L. In Alum Creek downstream of the Alum Creek Reservoir dam, TIN concentrations ranged from 0.13 mg/L to 3.40 mg/L. In the Hoover Reservoir, TIN concentrations ranged from 0.11 mg/L to 3.61 mg/L.

The TIN concentrations in the Griggs Reservoir were substantially higher, ranging from 0.11 mg/L to 12 mg/L. Most TIN values in the Griggs Reservoir were between 0.2 mg/L and 6 mg/L. In the O'Shaughnessy Reservoir, TIN concentrations were similar to those in the Griggs Reservoir and ranged from 0.11 mg/L to 13.5 mg/L. Most TIN values in the O'Shaughnessy Reservoir were also between 0.2 mg/L and 6 mg/L. Elevated TIN values are the direct result of stormwater runoff from agricultural lands. Corn production with tile drainage produces runoff with especially high nitrate concentrations. TIN concentrations are lower in Hoover Reservoir and Alum Creek partially due to the much larger reservoir size and ability to assimilate nutrients.

Based on the measured TIN values from 1987 to 2013, the concentration of TIN appears to be decreasing in all four reservoirs. Continued lower values are expected in the future as the watershed develops.

Based on a trend analysis of the measured TIN values from 1987 to 2013, the concentration of TIN appears to be decreasing in all four reservoirs. The TIN trend line for O'Shaughnessy and Griggs reservoirs decreases from approximately 4.2 mg/L in 1987 to 2.6 mg/L in 2013. In both the O'Shaughnessy and Griggs reservoirs in the late 1980s through the early 2000s, there are many more TIN measurements above 6 mg/L than in later years.

For Hoover Reservoir and Alum Creek the TIN trend line decreases from approximately 2.2 mg/L in 1987 to 1.4 mg/L in 2013. In the Hoover Reservoir in the late 1980s through the early 2000s, data provided by Columbus show numerous TIN concentrations between 2 mg/L and 4 mg/L. In later years only a few TIN measurements exceeded 2 mg/L. In earlier years, the TIN concentrations in Alum Creek were commonly above 2 mg/L. After 2002, there is only one value above 2 mg/L.

Almost all of the inorganic nitrogen in the four reservoirs is in the form of NOx-N for all sampling events and practically all of the NOx-N is nitrate-N. Some samples contain a small amount of nitrite nitrogen (NO2-N) and the NOx-N test measures both nitrite and nitrate. NH3-N concentrations are typically very low although a small number of samples contained elevated ammonia. NOx-N concentrations therefore produce the exact same annual pattern as TIN for all four reservoirs. The declining TIN concentrations are a direct result of declining NOx-N concentrations.

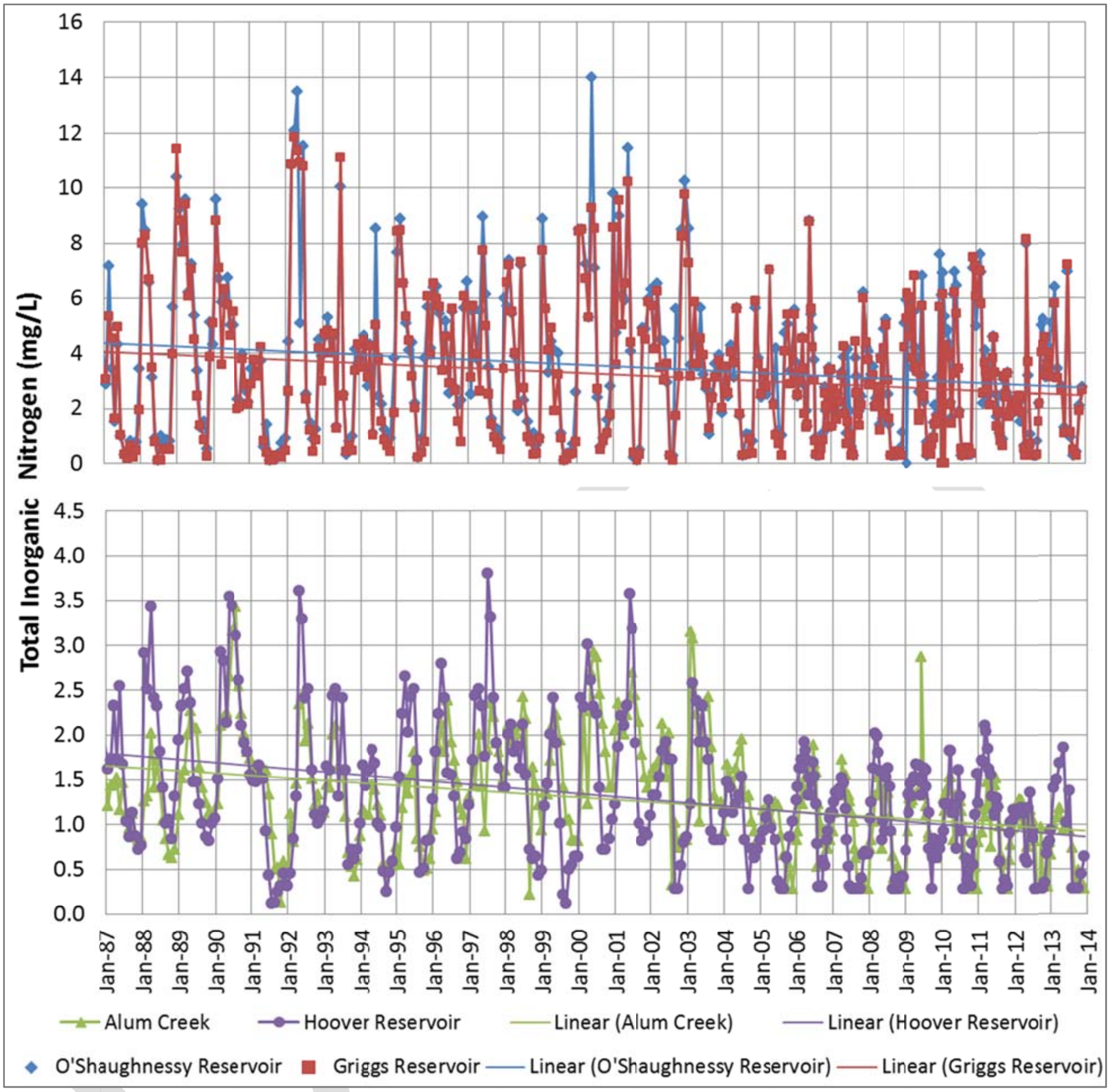

Figure 3-14. Upper Scioto River basin reservoir total inorganic nitrogen (as N) concentrations from 1987 to 2013

Water samples collected in Alum Creek downstream of the Alum Creek Reservoir Dam

In 2002, the detection limit for NO_x-N increased from 0.20 mg/L to 0.50 mg/L and NH_3-N increased from 0.02 mg/L to 0.05 mg/L.

Linear trends lines are shown on the figure to capture the general trends in historical total inorganic nitrogen concentrations.

3.4.2.2 Rainfall Influence on TIN Concentrations

O'Shaughnessy and Griggs reservoirs TIN concentration appear to closely correlate with precipitation and agricultural activities in the watershed as shown on Figure 3-15. In 2010, TIN concentrations are declining from January through April during a relatively dry period. With more than 7 inches of rainfall in May and early June TIN concentrations increase rapidly from approximately 1.5 mg/L to 6-7 mg/L. The TIN values then decline through July to below the laboratory method detection limit (0.50 mg/L). The TIN concentrations remain below detection limits through November then increases rapidly to about 7 mg/L in December following an extended dry period and then substantial precipitation. Lower TIN values are generally associated with lower precipitation during the growing season when inorganic nitrogen is consumed by vegetation.

In 2011, a very wet year, the O'Shaughnessy and Griggs reservoirs TIN concentration never dropped below the laboratory method detection limit. The lowest values were observed in mid-July through mid-September. This period is the only time during the year when TIN values dropped below 2 mg/L. The peak O'Shaughnessy and Griggs reservoirs TIN concentration occurred in February, with another lesser peak in June following two months of heavy rainfall. A third, lesser peak occurred in September and again in November after substantial rainfall. During an extended wet period such as 2011 it is possible to wash off TIN sources from the watershed followed by lower TIN concentrations with continuing rainfall. The status of agricultural activities, time of year, and internal reservoir processes also impacts the TIN concentration in runoff and surface waters.

TIN concentrations and total weekly precipitation for Hoover Reservoir and Alum Creek downstream of the Alum Creek Reservoir in 2010 and 2011 are shown on Figure 3-16. TIN concentrations in Hoover Reservoir and Alum Creek followed a similar pattern as O'Shaughnessy and Griggs reservoirs with less extreme variability and lower values. TIN concentrations had a similar response to rainfall in May 2010, and spring and fall 2011. TIN values were near or below the laboratory method detection limit for about 5 months in 2010 and only 3 months in 2011.

The lower TIN variability in Hoover Reservoir and Alum Creek downstream of Alum Creek Reservoir is due to the large permanent pool volume and long residence time in these reservoirs. The mean residence time in Hoover Reservoir is reported to be approximately 180 days and Alum Creek Reservoir is even longer. Nutrient concentrations at these locations are reduced by in-reservoir dilution and assimilation. In contrast, the indicated mean residence time in O'Shaughnessy and Griggs reservoirs is 12 days.

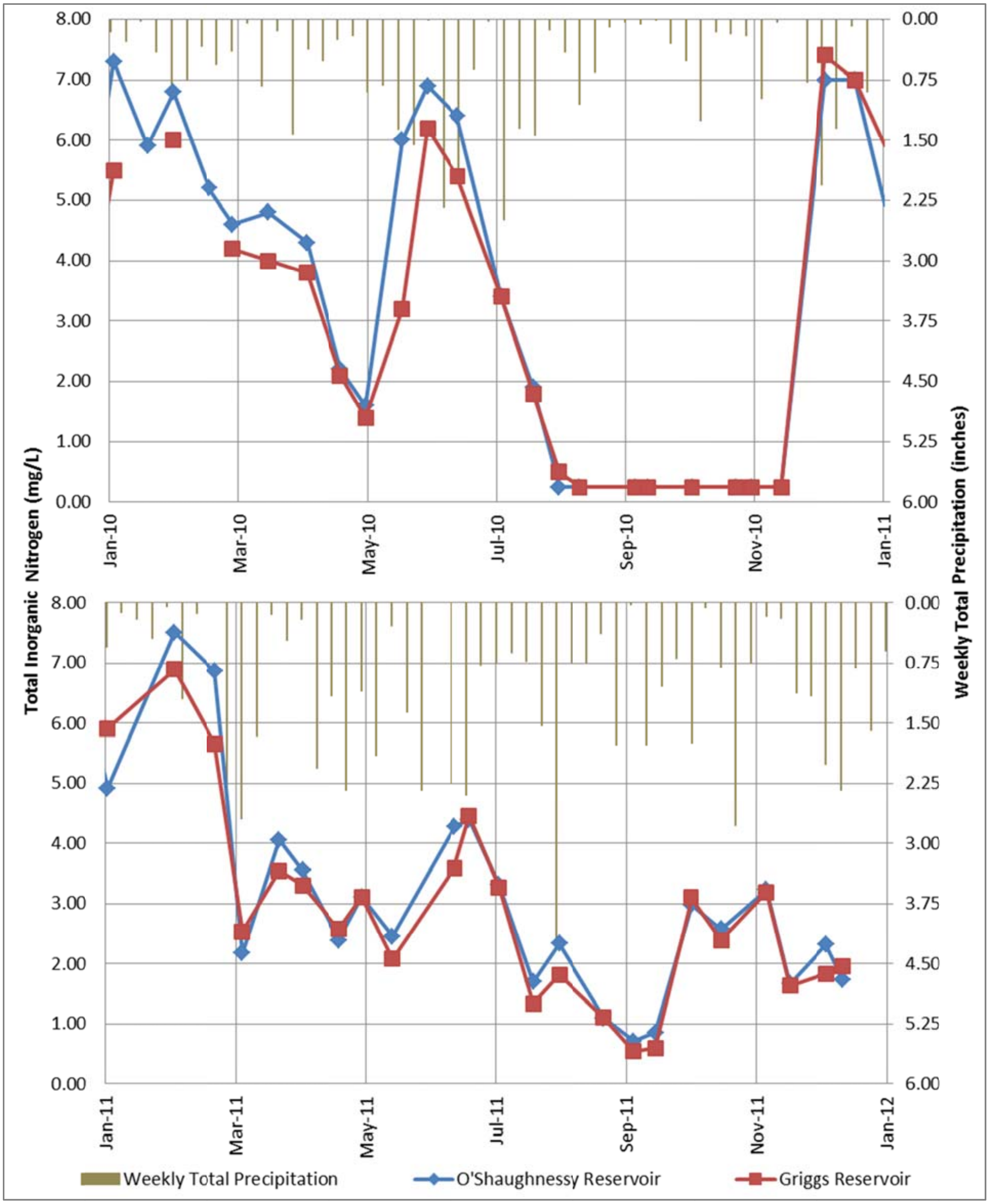

Figure 3-15. Upper Scioto River basin reservoir total inorganic nitrogen (as N) concentrations and total weekly precipitation in 2010 and 2011

In 2002, the detection limit for NO_x-N increased from 0.20 mg/L to 0.50 mg/L and NH_3-N increased from 0.02 mg/L to 0.05 mg/L.

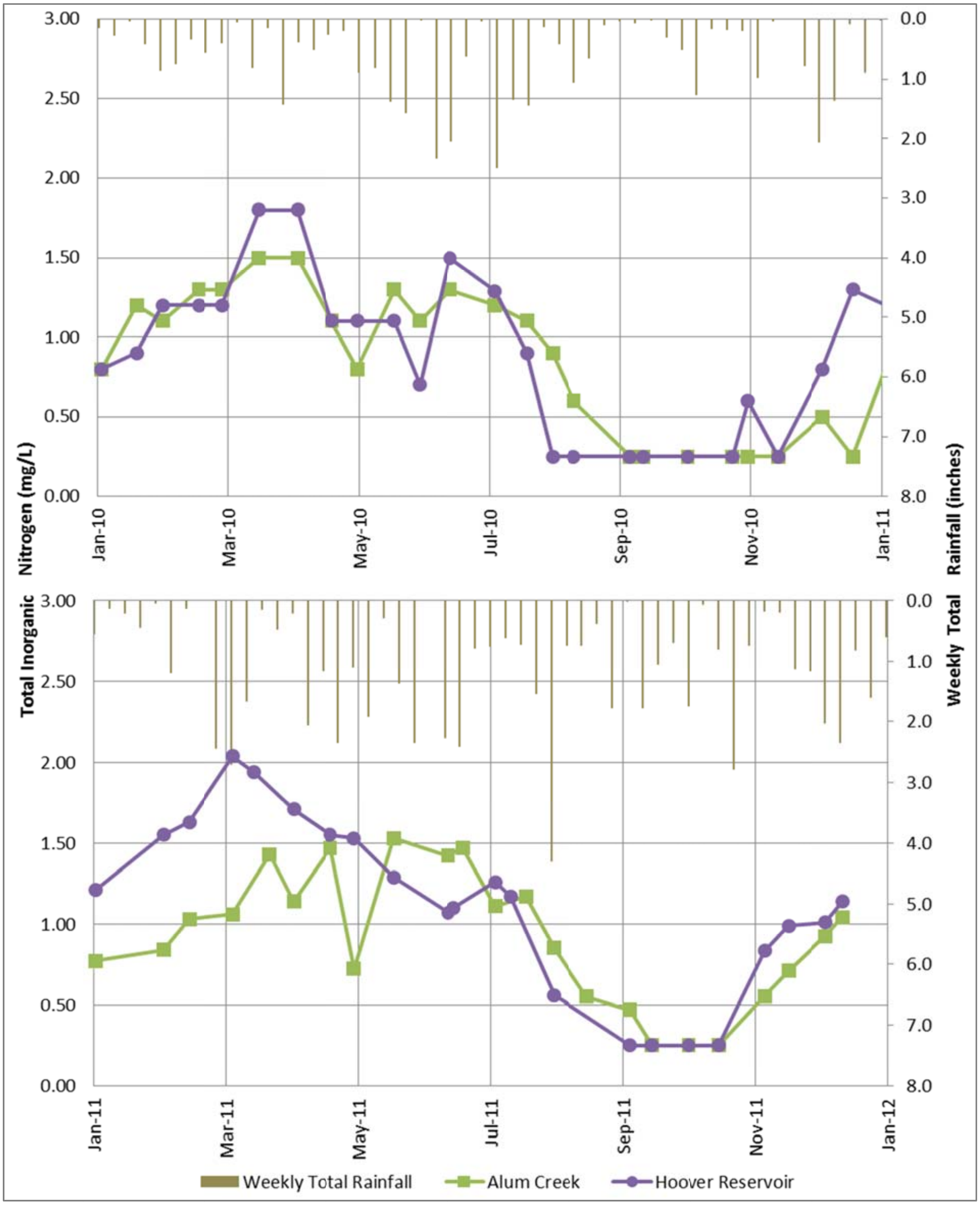

Figure 3-16. Upper Scioto River basin reservoir total inorganic nitrogen (as N) concentrations and total weekly precipitation

Water samples collected in Alum Creek downstream of the Alum Creek Reservoir Dam

In 2002, the detection limit for NO_x-N increased from 0.20 mg/L to 0.50 mg/L and NH_3-N increased from 0.02 mg/L to 0.05 mg/L.

3.4.2.3 Mill Creek

From 2006 through 2011, samples were collected by Columbus approximately monthly in Mill Creek (tributary to the Scioto River). These samples were analyzed for NOx-N and NH3-N. NOx-N and NH3-N concentrations and were highly variable from month to month, but the minimum and maximum measured values were comparable. In 2011, measured TIN concentrations ranged from 0.33 mg/L in April to 5.66 mg/L in January.

Generally the TIN range measured in earlier years was similar to the concentrations measured in 2011; however, there were a few exceptions. In Mill Creek in 1992, TIN values reached 28 mg/L in June. In 1994 and 1996, TIN values above 13 mg/L were measured. The cause of the very elevated TIN value in 1992 is unknown. This creek does receive treated wastewater effluent. The total annual precipitation in 1992 was about 40 inches, which is slightly above average. An interesting observation is that the minimum and maximum TIN values in each creek were measured during different months each year. TIN concentrations in this watershed are primarily influenced by wastewater discharges, farming practices, and the associated watershed runoff.

3.4.2.4 Scioto River at Hoskins Road

This monitoring location is relatively close to the raw water intake for the upground reservoirs. Columbus collected water samples once or twice per month in the Scioto River at Hoskins Road and analyzed for nitrate nitrogen in 2006 through 2011. In all years except 2011, nitrate nitrogen concentrations fell below the detection limit of 0.5 mg/L at least one month each year. Water sample nitrate nitrogen concentrations fell below the detection limit during July, August, or October each year. In 2011, a very wet year, the minimum nitrate nitrogen concentration was 1.0 mg/L in August.

Sampling each year showed peak nitrate nitrogen concentrations in April, May, July, or October. Over this 6-year period the maximum nitrate nitrogen value was 16.3 mg/L in May 2006. The maximum annual nitrate concentrations were as follows:

- 2006: 16.3 mg/L
- 2007: 4.1 mg/L
- 2008: 5.9 mg/L
- 2009: 6.9 mg/L
- 2010: 8.5 mg/L
- 2011: 5.1 mg/L

Pumping of water from the river to the upground reservoir is planned during higher stream flow conditions. TIN concentration typically increases with increasing flow during and after storm events. Similar to TP, it will be important to monitor TIN concentrations and pump water to the upground reservoir when concentrations are lower. Additional management measures should be available to improve reservoir water quality if nutrient concentrations become elevated.

3.4.3 Total Nitrogen to Total Phosphorus Ratio

Both nitrogen and phosphorus are necessary for algal growth. It is common to calculate the ratio of total nitrogen to total phosphorus (TN:TP) to determine if algal growth is limited by nitrogen, phosphorus, or both nutrients (balanced or co-limited). This is not true for cyanobacteria which are also called “blue green algae”. Cyanobacteria, as discussed in Section 3.5, can fix nitrogen from the atmosphere and therefore have a competitive advantage in lower nitrogen waters. Although algal productivity is normally limited by nitrogen and/or phosphorus, the quantity of algae present can still be substantial including algae and cyanobacteria blooms, and taste and odor issues. Columbus only measured the inorganic portion (TIN) of TN; therefore TIN was used to calculate the nutrient ratio.

Generally, if the TN:TP ratio is less than 10, the surface water is considered nitrogen-limited. A TN:TP ratio between 10 and 30 indicates balanced or co-limitation, and a ratio greater than 30 indicates phosphorus limitation. Other factors, such as color, turbidity, light penetration, and water movement, also affect algae and cyanobacteria growth. One approach to protect or improve surface water quality is to limit the concentration of one or both of the nutrients, thereby controlling algae growth.

> The limiting nutrient in all four reservoirs changes rapidly from month to month and varies widely from year to year. During wet years, reservoir water quality is more sensitive to phosphorus inputs because of an excess of available nitrogen. During dry years, nitrogen and phosphorus inputs have a strong influence on reservoir water quality.

For all four locations, but especially Hoover Reservoir and Alum Creek downstream of Alum Creek Reservoir dam, more recent TIN:TP values are generally lower and much less variable. This favors the growth of cyanobacteria. Based on the preceding description, the limiting nutrient in all four reservoirs changes rapidly from month to month and varies widely from year to year. During wet periods, reservoir water quality is more sensitive to phosphorus inputs because of an excess of available nitrogen. Both phosphorus and nitrogen inputs have a strong influence on reservoir water quality during dry periods. During wet periods with high flow and turbidity fewer algae are typically present in the reservoirs.

3.4.4 Nutrient Loading Summary

Over the period from 1987 through 2013, several apparent nutrient trends are:

- TP and OP-P concentrations appear to be increasing in O'Shaughnessy and Griggs reservoirs and may be increasing in Hoover Reservoir and Alum Creek Reservoir.
- TIN concentration appears to be decreasing in all four reservoirs.
- TP, OP-P, and TIN trends are expected to continue in the future because of development in the watershed combined with climate change.
- Balanced or nitrogen-limited conditions in the O'Shaughnessy and Griggs reservoirs are expected to continue in the future because of declining TIN concentrations and increasing TP concentrations.
- Hoover Reservoir and Alum Creek Reservoir are expected to continue their trend to balanced or phosphorus limitation. This is a concern because of increasing TP and decreasing TIN concentrations in the study area and the potential growth of cyanobacteria.
- During wet years, reservoir water quality will continue to be more sensitive to phosphorus inputs because of an excess of available nitrogen. During dry years, nitrogen inputs will continue to have a stronger influence on reservoir water quality.

3.4.5 Potential Nutrient Changes Due to Climate Change

Because the agricultural land in the study area is not irrigated, substantial water discharges occur only during storm events. If land is converted from agriculture to urban land use in the future, nitrogen concentrations and loads are expected to continue to decrease. This is partially a function of a reduction in groundwater infiltration and stormwater runoff nitrogen concentrations and is expected to occur slowly over many years. Although wastewater and septic system discharges will increase with development, the net nitrogen load is expected to decrease over time. The nitrogen load from wastewater and septic system discharges is small compared to the overall watershed nitrogen load from all sources.

Phosphorus concentrations and loads are expected to continue to increase in the future because of an increase in stormwater runoff volume from additional impervious areas.

Phosphorus concentrations and loads are expected to continue to increase because of an increase in stormwater runoff volume from additional impervious areas and additional wastewater and septic system discharges. Intense storm events can produce runoff with elevated nitrogen and phosphorus concentrations on a short-term basis. This effect is more evident in the O'Shaughnessy and Griggs reservoirs because of their small water volume compared to the Hoover Reservoir and Alum Creek Reservoir. The Alum Creek and Hoover reservoirs are much larger and are capable of diluting and assimilating watershed nutrient loads within the reservoirs. Water quality changes occur more slowly in the Alum Creek and Hoover reservoirs over time. The water quality in these deeper, more stratified reservoirs is more influenced by spring and fall turnover events and longer-term nutrient loadings. Lower TIN:TP ratios in the reservoirs in the future will favor the growth of cyanobacteria. This is a primary concern especially in Alum Creek and Hoover reservoirs.

3.5 Algae and Cyanobacteria

Algae are a very large and diverse group of simple organisms, ranging from single cells to large plants. They are present in almost all freshwater systems and consume available forms of nitrogen and phosphorus. Typically the quantity of algae increases with increasing nitrogen and phosphorus loads. Algae need more nitrogen than phosphorus (ratio of 10:1 to 30:1). Other factors play key roles in the production and quantity of algae present, including predators such as zooplankton, herbicides, water color and turbidity, water movement, and sunlight (energy).

Of primary concern in lakes and reservoirs is the presence of cyanobacteria, aka, "blue-green" algae. These bacteria (not a true alga) can out-compete algae because of their ability to move up in the water column to capture more sunlight. Cyanobacteria can also fix nitrogen from the atmosphere and therefore have a competitive advantage over algae in lower nitrogen waters. Cyanobacteria thrive in warm, slow-moving water with an abundance of nutrients and sunlight. Some species are common in colder surface waters. Blue-green algae are a concern because of their ability to release toxins, which are harmful to aquatic life and humans. Cyanobacteria produce neurotoxins and peptide hepatotoxins, such as microcystin and cyanopeptolin (Tooming-Klunderud, 2007). Currently the conditions and timing associated with toxin release is not fully understood. Cyanobacteria are commonly present in surface waters but not actively releasing toxins.

Water samples were collected and analyzed by Columbus from 2002 to 2006 and from 2008 to 2012 for different forms of algae, cyanobacteria, and dinoflagellates at up to seven study area locations. The seven locations include the HCWP intake, Hoover Reservoir Dam, Hoover Reservoir - Red Bank, Hoover Reservoir - Sunbury Road Bridge, DRWP intake, O'Shaughnessy Reservoir and Griggs Reservoir.

The reservoir and water intake monitoring results for green algae and cyanobacteria from 2002 to 2006 were compared to the results from 2008 to 2012 to identify apparent trends. Both 5-year periods had very similar precipitation. The total precipitation from 2002 to 2006 was 195 inches, or 39 inches per year. The total precipitation from 2008 to 2012 was 193 inches, or 38.6 inches per year. Both means are very close to the long-term average annual precipitation of approximately 38 inches. No comparison is provided for the Hoover Dam because data were available only from 2010 to 2012.

Figure 3-17 includes a summary of green algae data for the DRWP and HCWP intakes, Hoover Dam and Griggs Reservoir. Between 2008 and 2012, green algae counts at the various monitoring locations ranged from 100 to 10 million organisms per liter (org/L). Green algae counts appear to be increasing over time at all locations. This change is likely in response to the measured increase in TP concentrations (discussed in Section 3.4.1) and water temperature in all reservoirs. The largest increases are at the O'Shaughnessy and Griggs reservoirs. These reservoirs typically have the highest peak concentrations. Green algae counts in O'Shaughnessy Reservoir between 2002 and 2006 ranged from 300 to 150,000 organisms per liter (org/L). Most values were in the range of 700 to 30,000 org/L. Between 2008 and 2012 green algae counts ranged from 900 and 5,000,000 org/L. Most values were between 3,000 and 80,000 org/L. Green algae counts in Griggs Reservoir between 2002 and 2006 ranged from 700 to 900,000 org/L. Most values were in the range of 2,000 to 30,000 org/L. Between 2008 and 2012 green algae counts ranged from 800 and 10,000,000 org/L.

The peak green algae concentrations at the Hoover Dam and HCWP intake were generally higher during 2011, a very wet year, compared to 2010, a dry year. Conversely, the peak green algae counts in Griggs Reservoir were higher during 2010. This is likely a function of the size of the reservoir. The large flow of water is flushing Griggs Reservoir while simply adding additional load to Hoover Reservoir. The data generally showed the highest green algae counts in May and the lowest values in January.

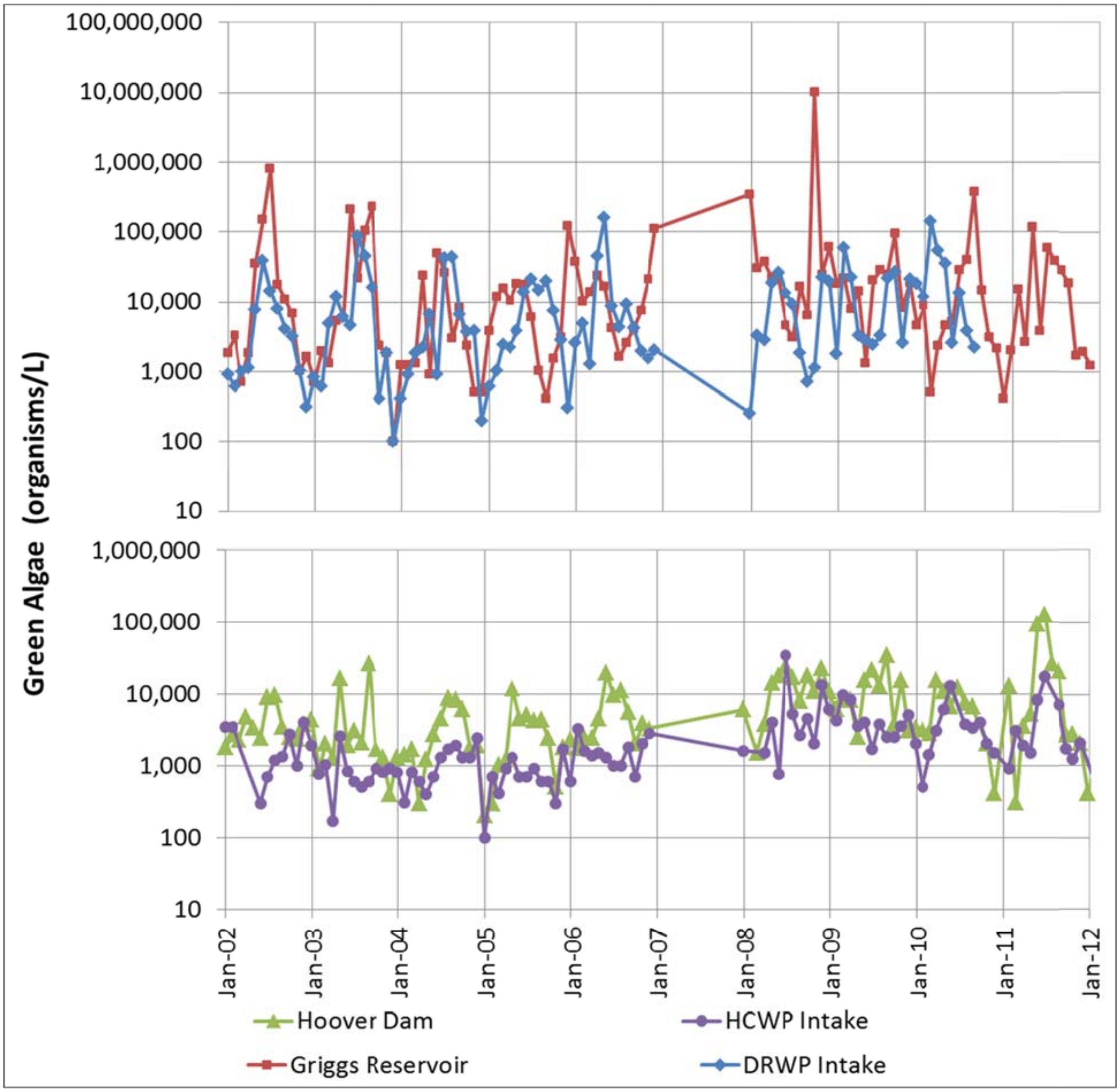

Figure 3-17. Reservoir and raw water intake green algae counts from 2002 to 2011

Values measured as zero are not shown on this logarithmic plot.

Figures 3-18 includes data for cyanobacteria for the water plant intakes, Hoover Dam, and Griggs Reservoir. Between 2008 and 2012 cyanobacteria counts (blue-green algae) ranged from 100 to 800,000 org/L at the two water plant intake monitoring locations. When comparing the HCWP and DRWP intakes, the cyanobacteria concentrations were higher at the DRWP intake from 2002 through 2007 while lower at the HCWP intake. From 2008 through 2012, cyanobacteria counts increased substantially at the HCWP intake on Big Walnut Creek while decreasing at the DRWP intake. In recent years, the highest peak concentrations

Cyanobacteria counts have been increasing at the HCWP Intake and decreasing at the DRWP intake.

are typically measured at the Hoover Dam and can be up to two orders of magnitude higher than values in Griggs Reservoir. One possible explanation is the phosphorus limitation in the Hoover and Alum Creek reservoirs and the possible increasing TP concentration in combination with the longer residence time in Hoover Reservoir.

Measured peak cyanobacteria concentrations were higher in Griggs Reservoir in 2011 than in 2010, while values at the DRWP intake were higher in 2010.

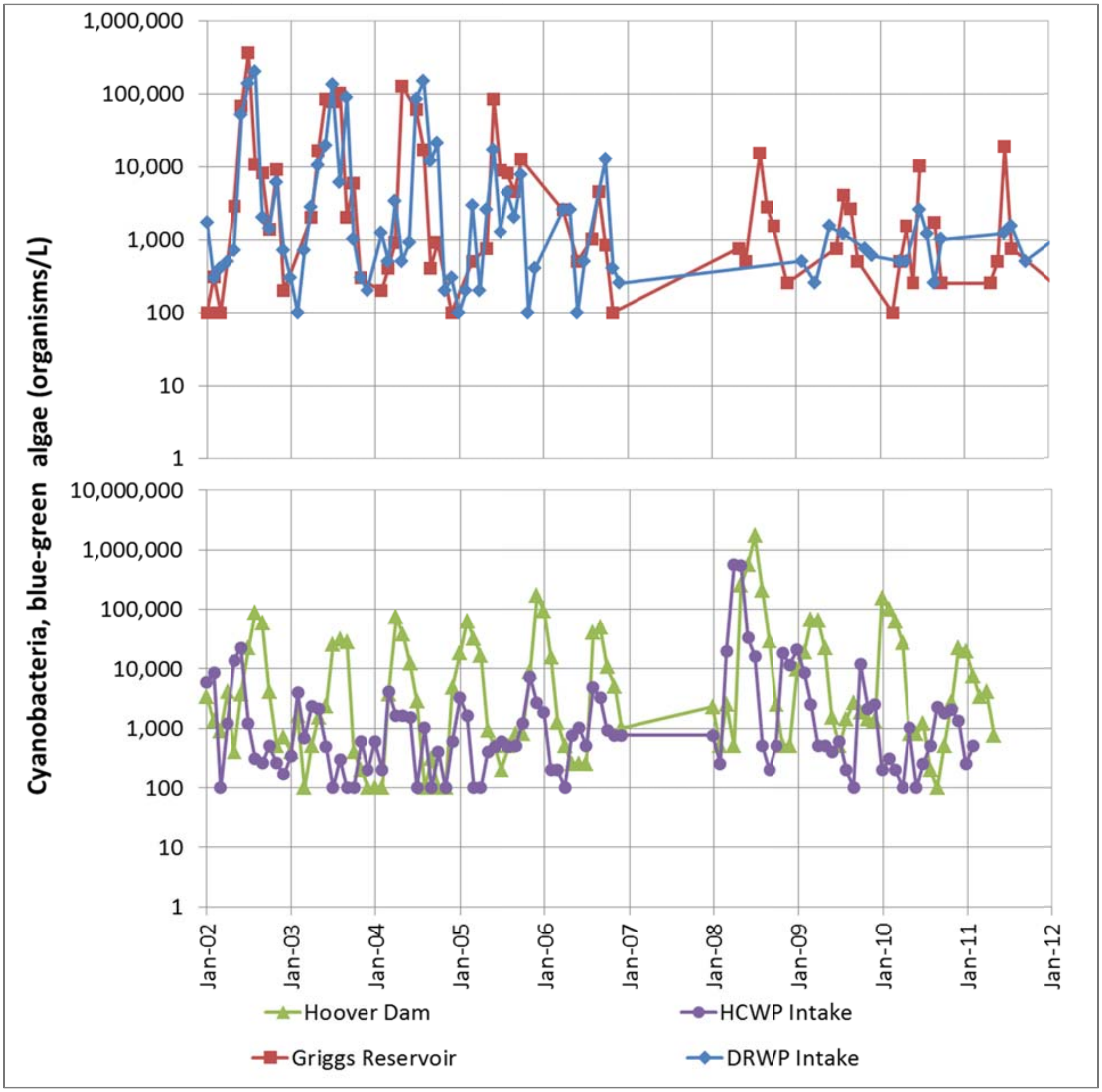

Figure 3-18. Reservoir and raw water intake cyanobacteria (blue-green algae) counts from 2002 to 2011

Values measured as zero are not shown on this logarithmic plot

3.6 Microcystin

Columbus sampled and analyzed several water samples in 2009, 2011, 2012, 2013, and 2014 for microcystin, a toxin released by cyanobacteria. Sampling locations included the HCWP intake, HCWP finished water, and the Hoover Reservoir. In 1998, the World Health Organization (WHO) released a provisional drinking water guideline of 1 µg/L for microcystin, but for no other toxins.

In June of 2014 Ohio Environmental Protection Agency (EPA) issued the draft Public Water System Harmful Algal Bloom Response Strategy to protect people from toxins produced by cyanobacteria that may be in drinking water sources at concentrations that can affect human health. The strategy identifies toxin levels of concern that will be used to make advisory decisions. Sampling targets four toxins that may be present at levels of concern and compare them to threshold criteria established by the State of Ohio.

In recent years Microcystin values have exceeded the state reporting limit of 0.3 µg/L. This trend is expected to continue in the future.

A summary of the microcystin monitoring results include:

- In 2009, all 12 water samples were below the Ohio EPA reporting limit of 0.3 µg/L with one exception.
- On August 14, 2009, the measured microcystin concentration was 4.38 µg/L. This was the highest value measured during the 5-year period. The sample was collected from foam on the surface of Hoover Reservoir at the dam. This appears to be a data anomaly since the sample was not collected from beneath the water surface.
- In 2011, one Hoover Reservoir value from July 13 was 0.37 µg/L. The other eight values in 2011 were below the reporting limit.
- All three values in 2012 were below the reporting limit.
- In 2013, 22 water samples were analyzed. Five Hoover Reservoir water samples collected in July and August, ranging from 0.35 µg/L to 0.96 µg/L, exceeded the reporting limit.
- In 2014, 13 water samples were collected from the Hoover Reservoir. Between July 28 and September 29, all nine samples exceeded the reporting limit with values from 0.34 µg/L to 1.97 µg/L. Two of the HCWP intake samples slightly exceeded the reporting limit, with values of 0.35 µg/L and 0.46 µg/L in September.

3.7 Taste and Odor Complaints

Taste and odor (T&O) complaints can stem from biological or chemical causes. Conditions in source water, during treatment, or in distribution systems can result in T&O complaints. The presence of salts and metals can produce undesirable flavors. Green algae can create a grassy or fishy odor. Blue-green algae in surface supplies produce compounds that cause earthy/musty odors. DBPs can cause off-flavors. Ammonia can produce a “chemical” taste. Some consumers are much more sensitive to T&O issues than others.

Historical customer T&O complaints from 1977 to 2013 are provided in Figure 3-19. T&O complaints at the two surface water plants (DRWP and HCWP) typically ranged from 50 to 150 per year. From reviewing the historical T&O complaint data, two noteworthy spikes were observed by Columbus staff. More than 1,100 customers complained about T&O in 1998 and 1,600 T&O complaints were recorded in 2013. The HCWP service area experienced the highest number of complaints. In 2013, the sampling showed elevated ammonia concentrations in the Hoover Reservoir. No other available water quality parameters were outside the range of typical values in the Hoover Reservoir in 1998 or 2013; however, algal concentrations are unavailable for either of these years. The T&O complaints may have been attributed to elevated blue-green algae during this time.

Potential Changes Due to Climate Change

A wide variety of potential T&O sources exist in drinking water. Based on historical complaint information and climate change scenarios, it is difficult to predict future changes in T&O issues. As discussed in Section 3.5, green and blue-green algae concentrations in the Hoover Reservoir are likely to increase in the future as a result of elevated temperatures and increased nutrient runoff. Turbidity, color, and TOC also may increase in the future. All of these parameters could create additional T&O complaints.

In the future, surface water plants in the region may need to utilize additional treatment processes at the water plants to reduce complaint numbers. The enhanced treatment processes (PAC and ozone) added by Columbus are effective for removing many of the taste and odor sources from drinking water surface sources. Operation and maintenance costs may increase in the future due to additional use of these enhanced processes.

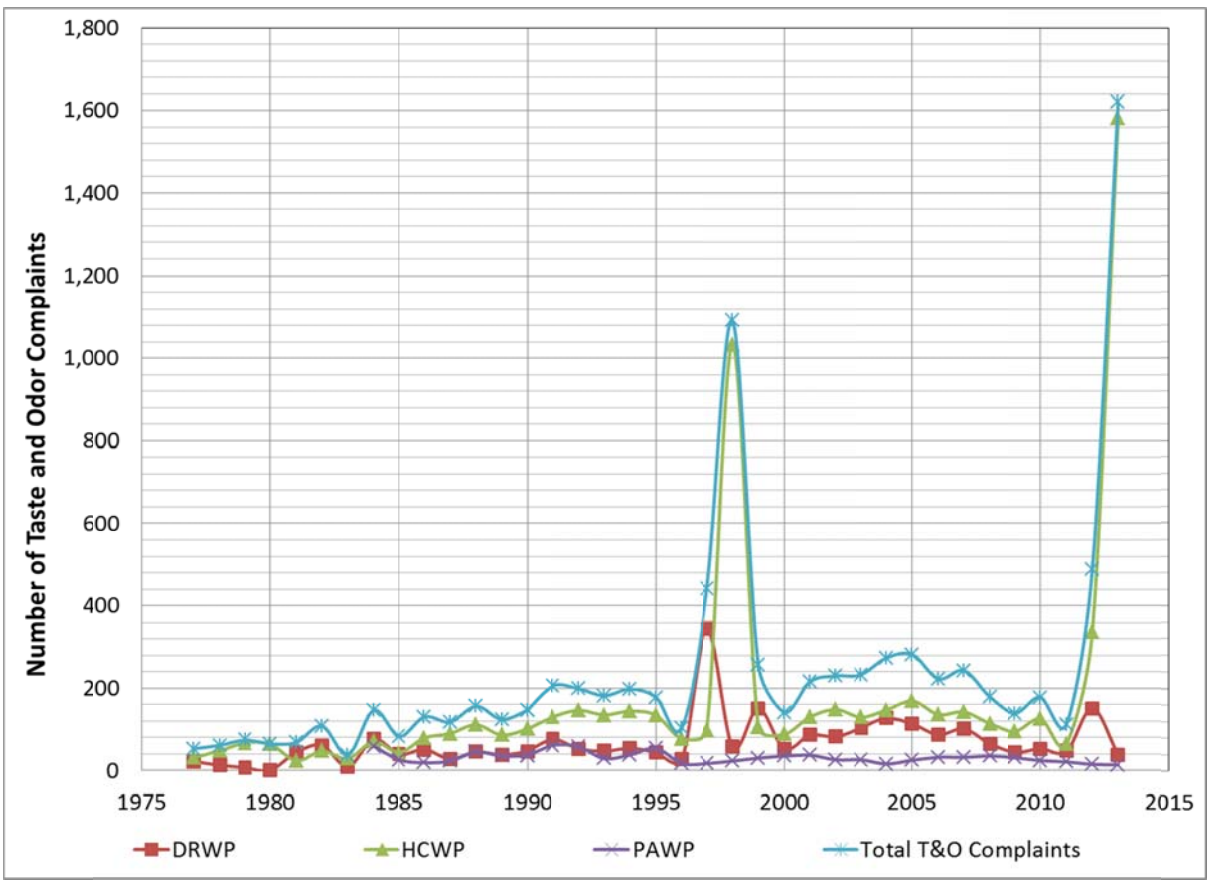

Figure 3-19. City of Columbus historical customer taste and odor complaints from 1977 to 2013

Section 4: Water Quality Impairments

This section summarizes the water quality impairments for the reservoirs in the study area.

4.1 O'Shaughnessy and Griggs Reservoirs

In 2012 Ohio EPA published Technical Report EAS/2012-12-12, *Biological and Water Quality Study of the Middle Scioto River and Select Tributaries, 2010.* This report describes water quality impairments in the middle Scioto River basin related to nutrients, organics, and bacteria. Enrichment sources include combined sewer overflows, home sewage treatment systems, yard maintenance, livestock, and agriculture. The report includes monitoring data and proposed Lake Habitat Aquatic Life Criteria for the O'Shaughnessy and Griggs reservoirs.

Table 4-1 summarizes the Lake Habitat Aquatic Life Criteria and the median values reported for O'Shaughnessy and Griggs Reservoirs from the Ohio EPA report (Ohio EPA, 2012). The median values from May through October in 2010 in the epilimnion of stratified lakes and throughout the water column in unstratified lakes, as measured by Ohio EPA, are provided in Table 4-1 (Ohio EPA, 2012).

Table 4-1. Evaluation of Lake Habitat Aquatic Life Criteria and O'Shaughnessy and Griggs Reservoir Median Levels

Parameter	Lake Aquatic Life Criteria	O'Shaughnessy Reservoir Median Values	Griggs Reservoir Median Values
Total nitrogen	930 µg/L	3,760 µg/L	3,052 µg/L
Total phosphorus	34 µg/L	57 µg/L	92 µg/L
Chlorophyll-a	14 µg/L	52 µg/L	50.6 µg/L
Dissolved oxygen	6.0 mg/L	< 6.0 mg/L for 2 of 11 events	< 6.0 mg/L for 4 of 11 events

Median values were measured from May through October in 2010 by Ohio EPA in the epilimnion of stratified lakes and throughout the water column of unstratified lakes.

For comparison to the Ohio EPA Lake Habitat criteria, the State of Wisconsin selected 30 to 40 µg/L as an acceptable reservoir TP concentration. Illinois recently developed a lake TP concentration target of 50 µg/L.

Water samples were collected from the O'Shaughnessy and Griggs reservoirs in 2011 and 2012 and analyzed for chlorophyll-a. Peak spring/summer values ranged from 45 to 54 µg/L in the O'Shaughnessy Reservoir and 45 to 67 µg/L in the Griggs Reservoir. Lower spring and fall values ranged from 5.5 to 21 µg/L in the O'Shaughnessy Reservoir and 2.4 to 28 µg/L in the Griggs Reservoir. These chlorophyll-a values are comparable to the concentrations measured by Ohio EPA in 2010.

The measured reservoir TN, TP, chlorophyll-a, and DO concentrations are in excess of Ohio EPA's Lake Habitat Aquatic Life Criteria. The nutrient monitoring results discussed in Section 3.4 included similar or even higher concentrations, also exceeding the reservoir criteria. Elevated water turbidity and color may have contributed to lower-than-expected algal growth. In fact, based on the measured nutrient concentrations, algae and chlorophyll-a concentrations are expected to be higher than reported. The water color and turbidity in surface waters throughout the region appear to be suppressing algal growth to some extent.

Measured O'Shaughnessy and Griggs reservoirs TN, TP, chlorophyll-a, and DO concentrations exceed Ohio EPA's Lake Habitat Aquatic Life Criteria.

4.2 Hoover Reservoir and Alum Creek Reservoir

In 2005, Ohio EPA published the Final Total Maximum Daily Load (TMDL) for Big Walnut Creek watershed. The Big Walnut Creek watershed includes the Alum Creek watershed and both the Hoover and Alum Creek reservoirs. The TMDL describes widespread impairments due to flow alteration, habitat alteration, siltation, nutrients, pathogens, and organic enrichment. The primary causes include crop production, channelization, range land, and home sewage treatment systems. More than half of the watershed land use is in agriculture, primarily row crop.

Although the TMDL includes no specific nutrient load reduction requirements for the Hoover and Alum Creek reservoirs, TP and fecal coliform load reductions are specified throughout the watershed. TP load reductions up to 65 percent are specified for the main stem of Big Walnut Creek. Fecal coliform load reductions of 91 percent are specified in the TMDL.

During 2011 and 2012, TP concentrations in the Hoover Reservoir varied from below detection limits (0.05 mg/L) to 0.14 mg/L. The Alum Creek Reservoir had the lowest TP concentrations of the four reservoirs, ranging from below detection limits (0.05 mg/L) to 0.09 mg/L. Many measured TP concentrations exceeded Ohio EPA's Lake Habitat Aquatic Life Criteria (34 µg/L). Because some of the values are below the TP detection limit, it is not possible to calculate an accurate median value.

Water samples were collected from the Hoover Reservoir in 2011, 2012, and early 2013 and analyzed for chlorophyll-a. Peak spring/summer values ranged from 17 to 18 µg/L. Lower spring and fall values ranged from 3.0 to 13 µg/L.

> The measured TP and chlorophyll-a concentrations for the Hoover and Alum Creek reservoirs are substantially less than those for the O'Shaughnessy and Griggs reservoirs, but are still indicative of very productive systems.

The recorded TP and chlorophyll-a concentrations for the Hoover and Alum Creek reservoirs are substantially less than those for the Griggs and O'Shaughnessy reservoirs, but are still indicative of very productive systems as described in the following section.

4.3 Olentangy River

The Olentangy River flows through the central portion of the study area and discharges into the Scioto River south of Columbus. Delaware Reservoir is located on the Olentangy River. Ohio EPA published a TMDL for the Olentangy River watershed in August 2007. The TMDL addresses widespread water quality and habitat impairments throughout the Upper, Middle, and Lower river segments and Whetstone Creek for total phosphorus, sediment, habitat, and pathogens. Impairment causes are very similar to the other watersheds in the study area including crop production, stream channelization, livestock production, home sewage treatment systems, and stormwater runoff in urban areas. A large percentage of the watershed is agricultural. Ohio EPA reported existing pollutant concentrations ranged from 0.07 mg/L to 0.40 mg/L for TP, 8 mg/L to 40 mg/L for total suspended solids (TSS), and 286 to 2,413 counts/100 mL for fecal coliform (MPN, geometric mean).

The target surface water quality concentrations range from 0.11 mg/L to 0.16 mg/L for TP, 26 mg/L to 44 mg/L for TSS, and 1000 counts/100 mL for fecal coliform. The TMDL specifies total load reductions by segment which range from 0 to 71 percent for TP, 65 to 90 percent for TSS, and 90 to 96 percent for fecal coliform. Pollutant load reductions from 0 to 100 percent are specified for each identified source.

4.4 Reservoir Trophic State

Lakes and reservoirs can be classified into one of the four following primary productivity categories: oligotrophic (very low algal concentrations, very clear water); mesotrophic (moderate algal concentrations, moderate water clarity); eutrophic (high algal concentrations, poor water clarity); and hypereutrophic (excess algal concentrations, very poor water clarity).

Lake trophic condition and Trophic State Index (TSI) refer to the relative primary productivity in a lake. Carlson (1977) developed empirical relationships between TSI and Secchi-disk transparency (SDT), in-lake chlorophyll-a concentration, and in-lake TP concentration according to the following equations:

(1) *TSI = 60 – 14.41 ln (SDT feet * 0.3048)*

(2) *TSI = 9.81 ln Chl-a (µg/L) + 30.6*

(3) *TSI = 14.41 ln TP (µg/L) + 4.15*

A summary of TSI categories and typical corresponding Secchi disk depths, and chlorophyll-a and TP concentrations, are provided in Table 4-2.

Table 4-2. Summary of Lake Trophic Conditions and Water Quality Characteristics

Lake trophic condition	Carlson TSI	Secchi disk depth (SDT, ft)	Chlorophyll–a (µg/L)	TP (µg/L)
Oligotrophic	< 38	> 15	< 2.2	< 10
Mesotrophic	38–48	7.5–15	2.2–6	10–20
Eutrophic	49–61	3–7.4	6.1–22	20.1–50
Hypereutrophic	> 61	< 3	> 22	> 50

From 2010 through 2012, TP concentrations in the O'Shaughnessy and Griggs reservoirs consistently exceeded 50 µg/L. A vast majority of the chlorophyll-a concentrations exceeded 22 µg/L. Based on the TP and chlorophyll-a values listed in Table 4-2, both reservoirs are presently hypereutrophic year-round. This finding indicates that the O'Shaughnessy and Griggs reservoirs are highly productive and susceptible to algae and cyanobacteria blooms and toxin release.

The TP concentrations in the Hoover and Alum Creek reservoirs throughout the year are not known because of the TP laboratory detection limit. Since 2002, the detection limit for TP has been 0.05 mg/L. The TP concentrations in both reservoirs were above 0.05 mg/L during at least several months in 2011 and 2012. The TP concentration for the other months is not known. In the Hoover Reservoir, chlorophyll-a concentrations are currently in the 6 to 22 µg/L range.

Based on the TP and chlorophyll-a values in Table 4-2, the Hoover Reservoir is eutrophic for at least half the year and likely mesotrophic during the remaining months. The Alum Creek Reservoir is likely mesotrophic for much of the year with periodic eutrophic conditions. It is advisable to reduce the TP laboratory method detection limit to 0.01 mg/L. This would allow for the proper tracking of TP concentrations in the Hoover and Alum Creek reservoirs.

All reservoirs are productive and susceptible to algae and cyanobacteria blooms and toxin release. Higher temperatures and more extreme weather will increase the potential for toxin release in the future.

There are documented nutrient-related water quality impairments below the Hoover Dam in Big Walnut Creek as summarized in the final TMDL for Big Walnut Creek as discussed in Section 4.2. In addition, the Columbus data shows elevated algae and cyanobacteria counts in the Hoover Reservoir, as summarized in Section 3.5.

With higher temperatures and more extreme weather likely in the future due to climate change in combination with additional development, TP and chlorophyll-a concentrations are expected to increase. Without improvements in current practices these changes will produce a corresponding increase in trophic state in area reservoirs and declining water quality. The reservoirs will be more prone to algae and cyanobacteria blooms and the release of toxins.

Section 5: Conclusions

Two primary factors will influence future surface water quality within the study area: changes in climate and watershed land use. The main climate change issues are increasing temperatures and more extreme and intense weather. Warmer air temperatures will produce warmer water temperatures. Algae and cyanobacteria thrive in warmer water with abundant nutrients. More extreme weather likely translates into longer periods of drought when vegetation will be diminished or lost. More intense storm events following drought will produce large turbidity, organic, and nutrient loads from watershed wash-off and in-stream erosion, which will be conveyed through area streams to reservoirs. These changes will likely increase organic and nutrient loads to area streams and reservoirs, decrease DO concentrations, increase algae and cyanobacteria blooms and generally degrade surface water quality.

The study area is largely undeveloped or currently used for agriculture. Some land uses will change into residential, commercial, and industrial properties. Development is expected to increase phosphorus loads to area streams and reservoirs in the future because of increases in stormwater runoff volume, wastewater effluent discharges, and home sewage treatment system discharges.

Pathogens are another pollutant of concern in the study area. Although not a concern related to drinking water because of disinfection, elevated pathogen concentrations in reservoirs are a concern because of their potential impact on aquatic life and human health. Pathogens were not evaluated as part of this study, but they are included in the Big Walnut Creek TMDL. Ohio EPA discussed them in the Middle Scioto River basin study. If current practices continue, pathogen concentrations are expected to increase because of rising temperatures and additional stormwater runoff and home sewage treatment system discharges from development.

Based on the analysis of existing water quality data and the anticipated effects from climate change and development, the following long-term trends are probable in the study area:

- Increase in turbidity
- Elevated peak herbicide concentrations
- Increase in organics concentrations and DPB formation potential
- Increase in TP concentrations
- Decrease in TIN concentrations
- Increase in pathogens
- Decrease in DO concentrations
- More frequent and intense algae and cyanobacteria blooms

- More taste and odor and toxin issues

As described in Section 3.5, data show an apparent trend with decreasing cyanobacteria densities in the O'Shaughnessy and Griggs reservoirs. Because of the uncertainties associated with both cyanobacteria growth and climate change, it is difficult to predict future trends. These reservoirs are considered hypereutrophic; highly productive surface waters are prone to cyanobacteria growth. Whether or not cyanobacteria densities increase in the future, it is likely that the O'Shaughnessy and Griggs reservoirs will experience periodic cyanobacteria blooms and toxin release. It is possible that such blooms will be more frequent and intense.

Because of the documented existing water quality impairments and anticipated future trends, strategies should be implemented in the watershed to reduce organic, nutrient, and pathogen loads to streams and reservoirs. The primary sources of pollutants in the watershed include: stormwater runoff from urban and agricultural land; discharges from wastewater treatment facilities and home sewage treatment systems; groundwater; decomposition of organic matter; and soil erosion. Both structural and non-structural practices should be included in the watershed to protect and improve water quality and maintain reservoir volume as discussed in the Adaptive Management Plan.

Further assessment of reservoir sediment accumulation and internal nutrient loads should be completed to fully understand changes in reservoir storage volume and magnitude of all nutrient sources. Internal sources include: seasonal turnover events; groundwater seepage; and sediment nutrient flux. The significance of reservoir internal nutrient sources is unknown at this time. Once understood, strategies should be implemented to reduce internal nutrient sources and maintain reservoir storage volume.

Reservoir operational changes should be considered to help reduce reservoir pollutant, algae, and cyanobacteria concentrations. In recent years, the Hoover and Alum Creek reservoirs have experienced the highest cyanobacteria densities and are the immediate concern.

In recent years, the Hoover and Alum Creek reservoirs are experiencing the highest cyanobacteria densities and are the immediate concern.

It is important to reinforce that, based solely on the current regional surface water quality conditions summarized in this section, watershed pollutant load reductions and reservoir operational strategies are warranted now. Adopting such changes is independent of the future water quality impacts as a result of climate change. The implementation of pollutant load reduction and operational strategies should reduce the potential for drinking water T&O issues and harmful algal blooms, and protect aquatic life and human health. The Adaptive Management Plan presents and discusses these strategies for the Upper Scioto River Watershed.

Based solely on the current regional surface water quality conditions, watershed pollutant load reductions and reservoir operational strategies are warranted now.

Section 6: References

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Attachment A: Color

Numerous potential sources of color are found in water, including suspended and dissolved particles, dissolved organic matter, natural dissolved organic acids, and algae. Water color values measured by the City of Columbus (Columbus) at the DRWP intake from 1993 through 2013 were collected, reviewed, and plotted by BC to identify apparent trends. A plot of the color data is provided in Figure A-1.

Between 1993 and 2002 water color ranged from 13 platinum-cobalt units (PCU) to a single measurement of 52 PCU in late 2001. Most values fell between 15 and 40 PCU.

From 2003 to 2013 water color ranged from 10 PCU to over 70 PCU. Sixteen values exceeded 50 PCU and 3 values, 70 PCU. Higher color values were typically measured early and late in the year. Lower values were observed during the middle portion of the year.

Data shows an apparent increasing trend in raw water color at the DRWP intake. As discussed in the previous section, the average annual precipitation during the two time periods was similar and close to average. Although not discussed in detail in this report, water conductivity and total dissolved solids at the DRWP intake did not increase during 2003 to 2013 as compared to 1993 through 2002. One explanation for the higher color values could be more intense rainfall, which is carrying more naturally occurring color compounds to the water supply system. Increasing color at the surface water plant intake may continue in the future because of drought followed by more intense storm events.

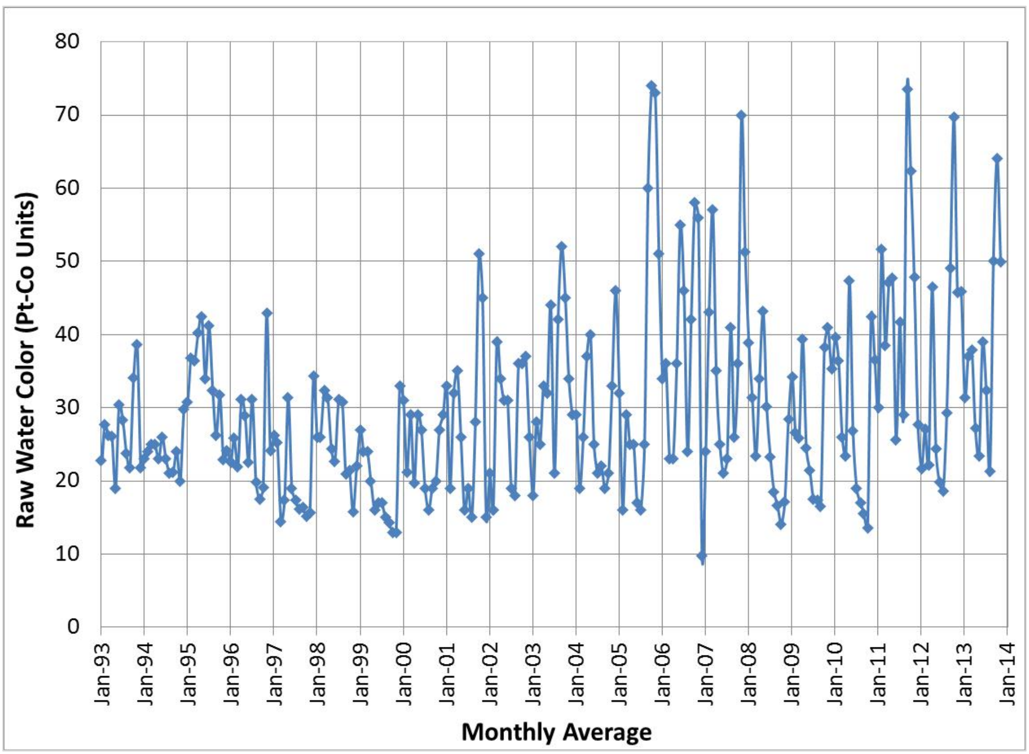

Figure A-1. Historical raw water color data for Dublin Road Water Plant

Attachment B: Zooplankton

Zooplankton play a vital role in a lake's or reservoir's ecosystem and food chain. Unlike algae, zooplankton are microscopic animals that do not produce their own food. They can consume large quantities of algae (green and others) that may otherwise grow uncontrolled. A community of zooplankton can filter through the volume of an entire lake in a matter of days, improving water quality and clarity. Unfortunately, zooplankton do not consume cyanobacteria. Lakes with healthy populations of zooplankton generally have lower algae concentrations and better water quality.

Water samples were collected and analyzed by Columbus from 2002 to 2006 and from 2008 to 2012 for at up to seven study area locations. The seven locations include the HCWP intake, Hoover Dam, Red Bank, Sunbury Road Bridge, DRWP intake, Griggs Reservoir, and O'Shaughnessy Reservoir.

Zooplankton counts for the DRWP and HCWP intakes are shown in Figure B-1. Figure B-2 includes a summary of the zooplankton counts for five monitoring locations upstream of the intake structures. Between 2008 and 2012, zooplankton counts ranged from 100 to 40,000 org/L at the various monitoring locations. Zooplankton concentrations are increasing at the HCWP intake and decreasing slightly at the DRWP intake. Zooplankton concentrations were generally higher in 2011, a very wet year, than in 2010, a dry year.

Zooplankton feed on green and other algae (not cyanobacteria) and generally peak at or near the same time. Although green algae counts are increasing throughout the study area, zooplankton trends were not apparent at the Griggs and O'Shaughnessy reservoirs. Additional factors including temperature, cyanobacteria counts, and predators impact the concentration of zooplankton.

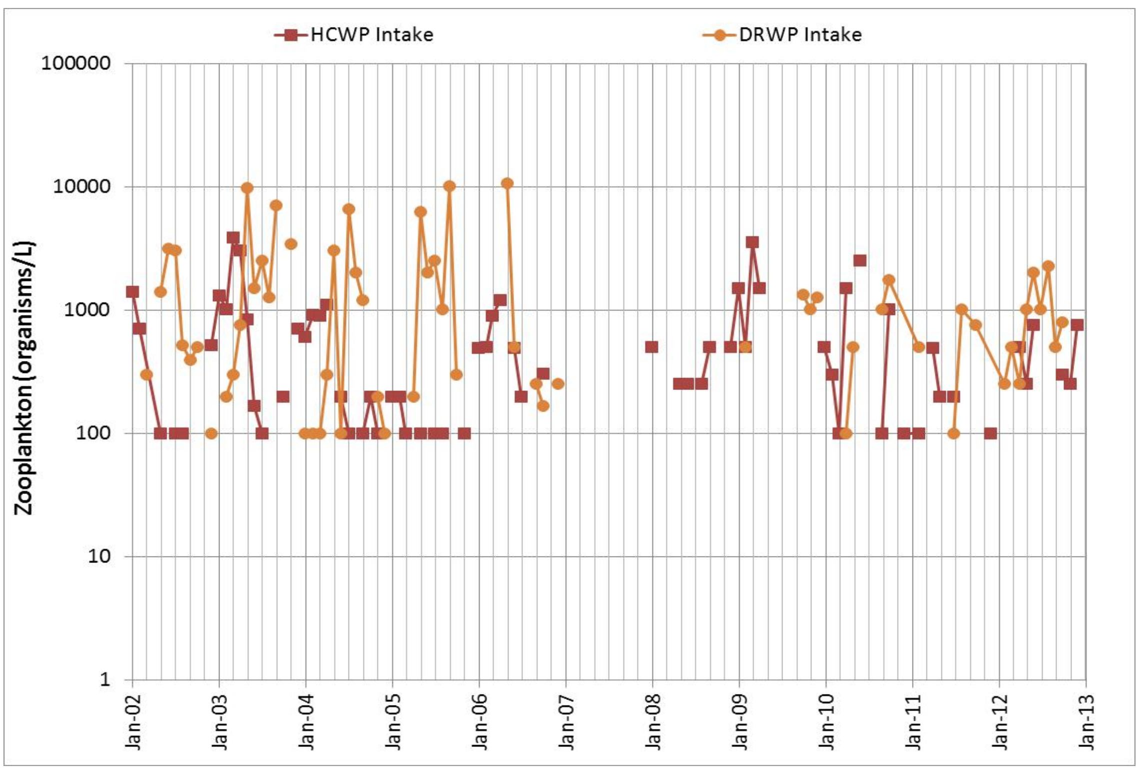

Figure B-1. Zooplankton counts: DRWP and HCWP intakes

Values measured as zero are not shown on this logarithmic plot.

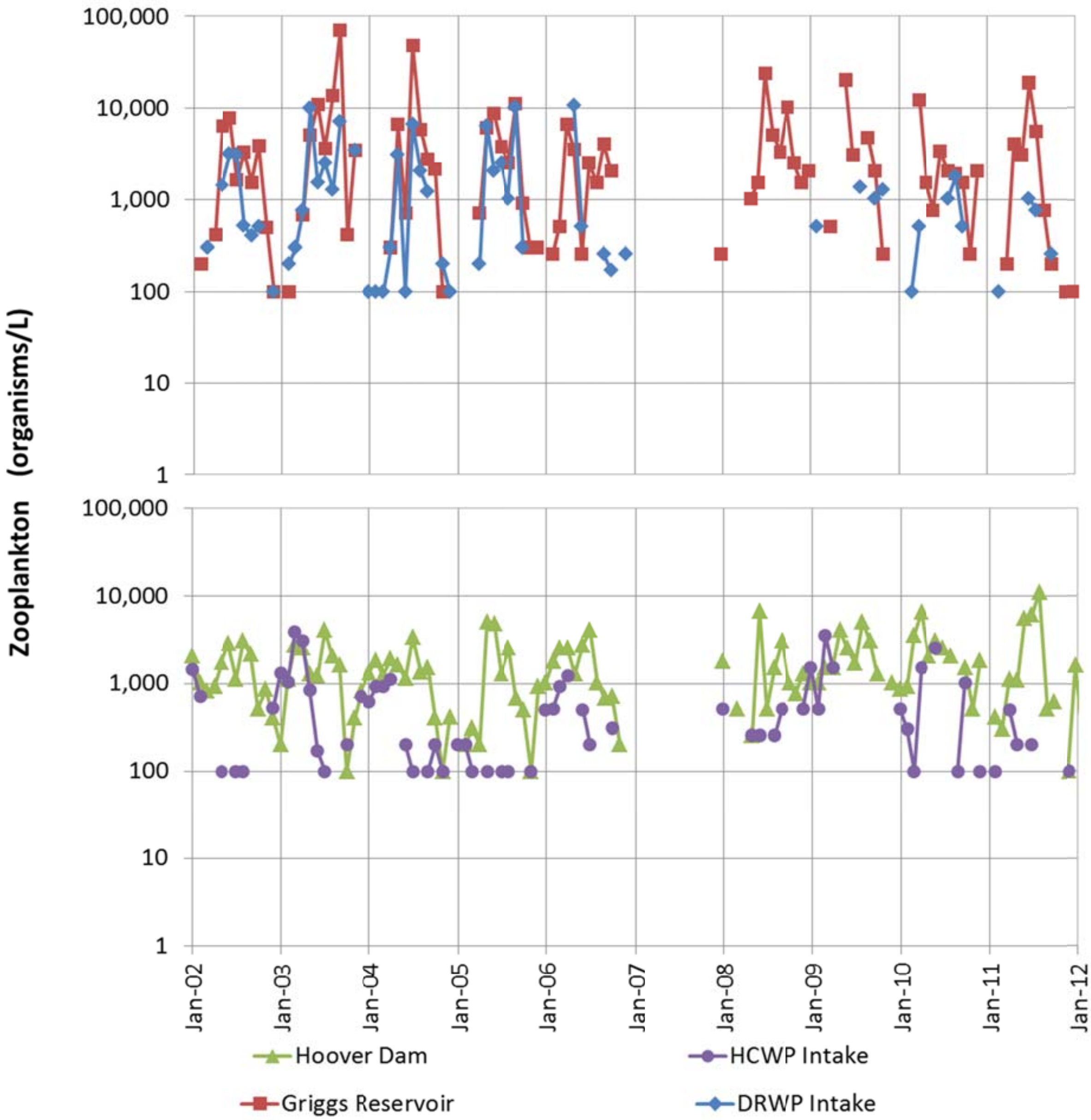

Figure B-2. Zooplankton counts: Upper Scioto River basin

Values measured as zero are not shown on this logarithmic plot.

Attachment C: Bokes Creek, Fulton Creek, and Ottawa Creek TP, OP-P, NO_x-N, and NH_3-N

Samples were collected by Columbus approximately monthly in 2006 through 2011 in Bokes, Fulton, and Ottawa creeks (tributaries to the Scioto River) and analyzed for TP, OP-P, NOx-N, and NH3-N. TP and OP-P concentrations were highly variable from month to month, but the minimum and maximum measured values in each creek were comparable to values measured in the O'Shaughnessy and Griggs reservoirs. In the most recent year, 2011, TP concentration ranges in these three creeks were measured as follows:

- Bokes Creek: 0.03 mg/L in February to 0.63 mg/L in March
- Fulton Creek: 0.03 mg/L in April to 0.62 mg/L in May
- Ottawa Creek: 0.03 mg/L in February and November to 0.54 mg/L in May

Generally the range of TP values measured in the three creeks in earlier years was similar to the concentrations measured in 2011; however, data show a few exceptions. An interesting observation is that the minimum and maximum TP values in each creek were measured during different months each year.

NOx-N and NH3-N concentrations were also highly variable from month to month, but the minimum and maximum measured values in each creek were comparable. In 2011, TIN concentrations were:

- Bokes Creek: 0.93 mg/L in April to 8.98 mg/L in January
- Fulton Creek: 0.85 mg/L in August to 9.16 mg/L in January
- Ottawa Creek: 0.33 mg/L in November to 5.53 mg/L in January

Generally the TIN range measured in the three creeks in earlier years was similar to the concentrations measured in 2011. The minimum and maximum TIN values in each creek were measured during different months each year. TIN values also fluctuated broadly from one month to the next. TIN concentrations in these tributaries are primarily influenced by weather, farming practices, rainfall, and the associated watershed runoff.

Attachment D: Total Nitrogen to Total Phosphorus Ratio (TN:TP Ratio)

Both nitrogen and phosphorus are necessary for algal growth. It is common to calculate the ratio of total nitrogen to total phosphorus (TN:TP) to determine if algal growth is limited by nitrogen, phosphorus, or both nutrients (balanced or co-limited). This is not true for cyanobacteria which are also called “blue green algae”. Cyanobacteria, as discussed in Section 3.5, can fix nitrogen from the atmosphere and therefore are not typically nitrogen limited. Cyanobacteria have a competitive advantage over algae in lower nitrogen waters. The TN:TP ratio is a primary factor in the type of algae present. Lower ratios tend to favor cyanobacteria growth because of their ability to obtain nitrogen from the atmosphere. Higher TN:TP ratios favor the growth of green algae and diatoms. For this reason in higher ratios are preferred.

Although algal productivity is normally limited by nitrogen and/or phosphorus, the quantity of algae and cyanobacteria present can still be substantial, producing algae and cyanobacteria blooms, and taste and odor issues. In this case, Columbus only measured the inorganic portion (TIN) of TN, therefore TIN was used to calculate the nutrient ratio.

Generally, if the TN:TP ratio is less than 10, the surface water is considered nitrogen-limited. A TN:TP ratio between 10 and 30 indicates balanced or co-limitation, and a ratio greater than 30 indicates phosphorus limitation. Other factors, such as color, turbidity, light penetration, and water movement, also affect algae and cyanobacteria growth. One approach to protect or improve surface water quality is to limit the concentration of one or both of the nutrients, thereby controlling algae growth.

Using the data from 1987 to 2013, the ratio of TIN to TP concentration (TIN:TP) was calculated for each reservoir. As a result of the highly variable TIN and TP concentrations in the four reservoirs, the corresponding TIN:TP values are highly variable from month to month throughout each year. From 1987 to 2013 the calculated TIN:TP ranged as follows:

- Alum Creek downstream of the Alum Creek Reservoir dam: 5 to 345
- Griggs Reservoir: 2 to 220
- Hoover Reservoir: 2 to 360
- O’Shaughnessy Reservoir: 2 to 190

A majority of the TN:TP values range between the following values:

- Alum Creek Reservoir: 10 to 200
- Griggs Reservoir: 5 to 40
- Hoover Reservoir: 10 to 100
- O’Shaughnessy Reservoir: 10 to 50

Data Trends

From 1987 to 2002, TIN:TP values collected by Columbus for the O’Shaughnessy Reservoir are split between balanced (10 to 30) and phosphorus-limited (>30). From 2003 forward, TIN:TP values for the O’Shaughnessy Reservoir are consistently between 10 and 30, indicating a balanced condition.

For the Griggs Reservoir from 1987 through 2002, a majority of TIN:TP values indicate a balanced condition with some values indicating phosphorus and nitrogen limitation on certain sampling dates. Later TIN:TP values for the Griggs Reservoir indicate that the reservoir is nitrogen-limited about half the time and balanced the other half.

From 1987 to 2002, a majority of TIN:TP values for the Hoover and Alum Creek reservoirs are above 30, indicating phosphorus limitation. After 2002, the reservoirs are balanced about half the time and phosphorus-limited the other half.

For all four reservoirs, but especially the Hoover and Alum Creek reservoirs, more recent TIN:TP values are generally lower and much less variable. This favors the growth of cyanobacteria. The lower TIN:TP values are likely due to the generally lower TIN and higher TP concentrations in later years. The Griggs Reservoir is nitrogen-limited about half the time. Phosphorus limitation is associated primarily with the Hoover and Alum Creek reservoirs during half of the year.

Based on the preceding description, the limiting nutrient in all four reservoirs changes rapidly from month to month and varies widely from year to year. The O'Shaughnessy and Griggs reservoirs did not experience phosphorus limitation at any time during 2011, 2012, or 2013. Nitrogen limitation was generally observed in the spring, late summer, fall, and early winter. The Alum Creek and Hoover reservoirs do not typically experience nitrogen limitation, but can be phosphorus-limited at almost any time of the year. This is primarily a result of the generally low TP concentrations in these reservoirs.

> The limiting nutrient in all four reservoirs changes rapidly from month to month and varies widely from year to year. During wet years, reservoir water quality is more sensitive to phosphorus inputs because of an excess of available nitrogen. During dry years, both phosphorus and nitrogen inputs have a strong influence on reservoir water quality.

In 2011, a very wet year, data shows less nitrogen limitation in the O'Shaughnessy and Griggs reservoirs than in 2012 and 2013. There was also more phosphorus limitation in the Hoover Reservoir in 2011. Both of these trends are most likely due to additional rainfall-driven nitrogen inputs. Based on these observations during wet years, reservoir water quality is more sensitive to phosphorus inputs because of an excess of available nitrogen. During dry periods, both phosphorus and nitrogen inputs have a strong influence on reservoir water quality. During wet periods with high flow and turbidity fewer algae are typically present in the reservoirs.