# Appendix A

# Data Acquisition and Assessment

# Draft

# Lake Oologah TMDL Report

**Prepared for:**

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# 1. INTRODUCTION AND BACKGROUND

## 1.1 Purpose

This report describes the data acquisition and assessment activities conducted in support of a modeling framework including a watershed hydrology and water quality model of the Verdigris Basin and a 3-Dimensional hydrodynamic and water quality model of Lake Oologah for the Oklahoma Department of Environmental Quality.

The HSPF watershed model will be set up to account for the processes of rain-induced watershed surface runoff, infiltration, overland sediment and nutrient buildup and washoff, in-stream sediment transport and nutrient biochemical kinetics, and algae and dissolved oxygen (DO) dynamics. The EFDC lake model will be set up to simulate the stage, water temperature, sediment transport, nutrient cycle, dissolved oxygen depletion, algae growth, and sediment diagenesis in Lake Oologah. Tributary inflows and pollutant loads to the lake from the upstream and surrounding watersheds are obtained from the HSPF watershed model.

Finally, the developed, calibrated, and validated watershed and lake models will be used for the calculation of Total Maximum Daily Loads (TMDL).

## 1.2 Background

Lake Oologah is a reservoir located in northeastern Oklahoma in Rogers County near the towns of Oologah, Nowata, and Claremore. The reservoir is at the downstream end of the Middle Verdigris River Basin (HUC8: 11070103) with a contributing drainage area of 4,339 square miles that includes both Kansas and Oklahoma (USACE, Tulsa District) (Figure 1). The Lake Oologah dam (-95.679 Longitude, 36.4225 Latitude) is located on the Middle Verdigris River at river mile 90.2, about 2 miles southeast of Oologah in Rogers County, Oklahoma, and about 27 miles northeast of Tulsa in Tulsa County, Oklahoma.

Under authorization of the Flood Control Act of 1938, the reservoir was constructed by the US Army Corps of Engineers, Tulsa District. Construction began in 1950 and, after some project delays, the project was completed in 1974 and the USACE continues to manage the lake. The purpose of the reservoir is flood control, water supply, navigation, recreation, and propagation of fish and wildlife. Normal pool surface area of the lake is 31,040 acres, the mean depth is 18.7 feet, and the storage volume is 553,400 acre-ft.

The City of Tulsa obtains approximately 40-50% of its water supply needs from Lake Oologah. The reservoir also serves as a raw water source for Public Service of Oklahoma, the City of Collinsville, Rural Water Districts of Rogers, Nowata, and Washington County, the City of Chelsea, and the City of Claremore (Oklahoma Department of Wildlife Conservation, Oologah Lake Management Plan, 2008). Raw water resource issues include taste and odor complaints and, beginning in 2003, the presence of zebra mussels throughout the lake and a dense accumulation of mussels in the water intake (City of Tulsa, Tulsa Comprehensive Water System Study, 2006).

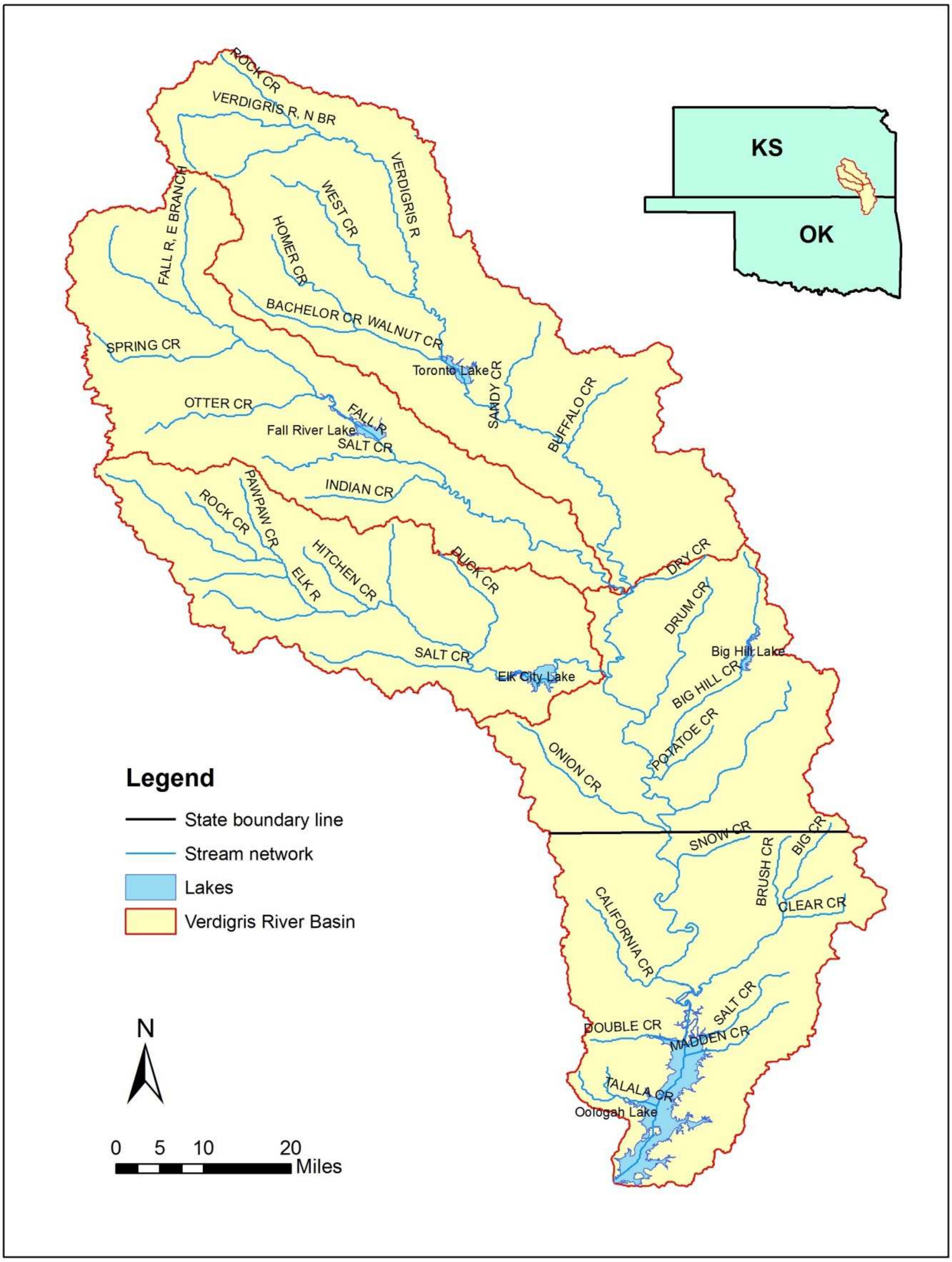


Figure 1 Location of Verdigris River Basin and Lake Oologah

The Water Body ID (WBID) for the lake is OK121510010020-00 and water quality conditions in the lake are monitored by the Oklahoma Water Resources Board (OWRB) at 7 station locations as part of the Beneficial Use Monitoring Program (BUMP). Based on data collected in 2012 and the Trophic State Index, OWRB has classified the lake as eutrophic. The Oklahoma 303(d) List of Impaired Waters for 2012 identifies impairments of Lake Oologah because of dissolved oxygen and turbidity. Within the Middle Verdigris River Basin, Big Creek and California Creek in Oklahoma are also identified as impaired for dissolved oxygen, as shown in Figure 2.

TMDL evaluations are needed for Lake Oologah to address dissolved oxygen and turbidity impairments. TMDL evaluations are also needed for Big Creek and California Creek to address dissolved oxygen impairments from organic enrichment. The TMDL evaluation requires the development of a linked watershed and lake model framework for the entire Verdigris River Basin to quantify the cause-effect relationships between external flows and pollutant loads from the watershed and in-lake water quality conditions.

Through review of existing watershed and lake models developed for the Verdigris River Basin and Lake Oologah, Hydrological Simulation Program–FORTRAN (HSPF) (Bicknell et al, 2001) has been identified and selected as the most appropriate modeling tool for development of a watershed model of the Verdigris River Basin and Environmental Fluid Dynamics Code (EFDC) (USEPA, 2013) has been identified and selected as the most appropriate modeling tool for development of a hydrodynamic, sediment transport, water quality and sediment diagenesis model of Lake Oologah.

The data sources and data availability for the development of the watershed model using HSPF and a lake model using EFDC are documented in this report. Based on our evaluation of availability of data required for the development of watershed and lake models, the most appropriate years for model calibration and validation will be proposed.

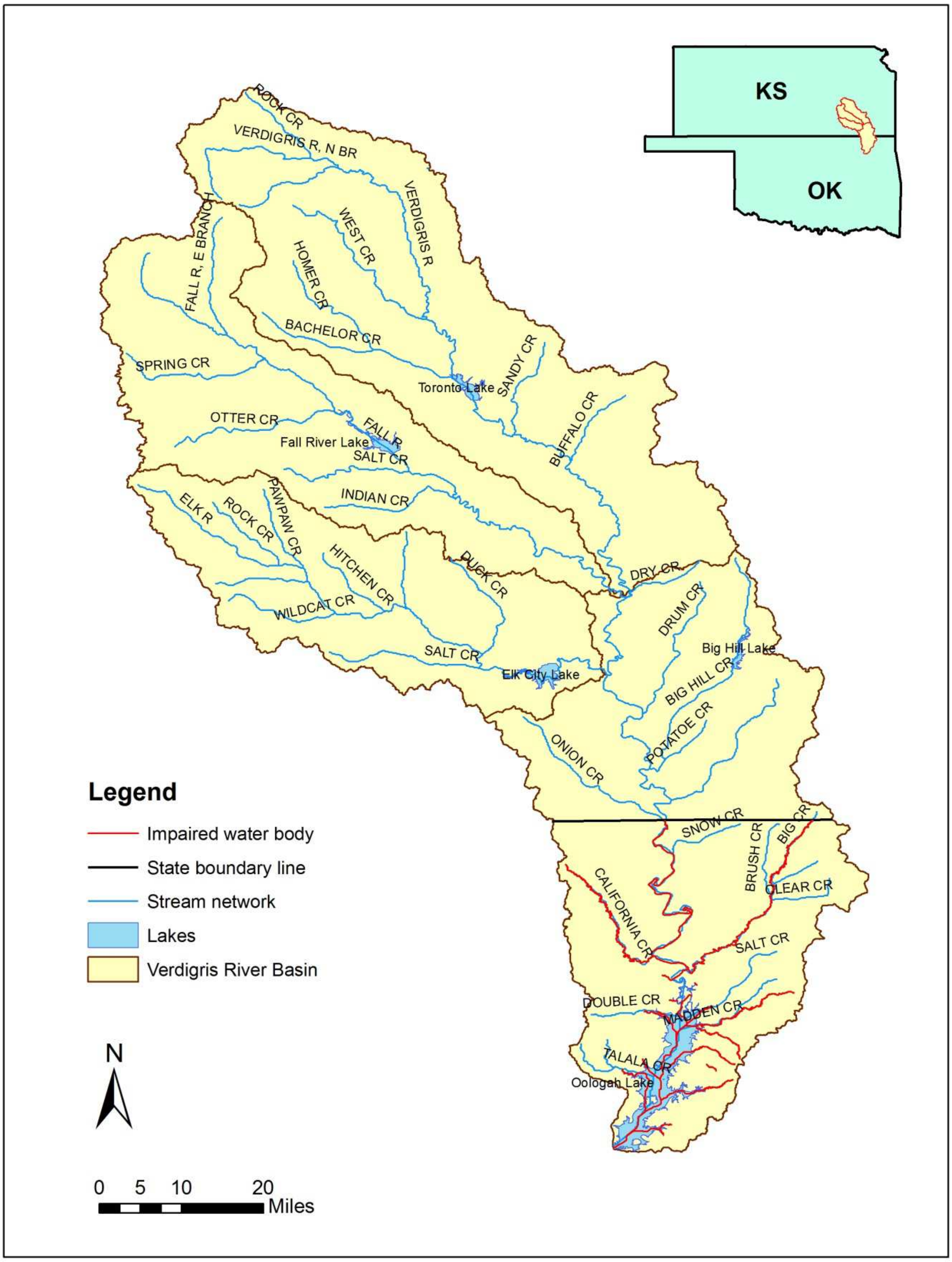


Figure 2 Impaired Water Bodies in 303(d) List in the State of Oklahoma

# 2. Data Collection and Evaluation For HSPF Watershed Model

The setup, calibration, and validation of a watershed HSPF hydrological and water quality model for Verdigris River Basin include the following procedure.

- Delineate the Verdigris River Basin into sub-basins to properly represent spatial variations of rainfall, land use, soil type, and topography of the watershed based on the digital elevation model (DEM) data and stream network;
- Calculate the area of each land use category for each sub-basin;
- Calculate the area of each hydrologic soil group for each sub-sub-basin;
- Collect and process atmospheric data and assign the data from meteorological stations to sub-basins to represent the spatial variations of rainfall;
- Collect and process the NPDES facilities and develop the time series data of flow and water quality constituents as the boundary conditions;
- Collect and process the observed flow and water quality data in the Verdigris River Basin for model-data comparison;
- Evaluate the collected data and determine the calibration and validation periods;
- Calibrate the watershed model in the sequence of flow, water temperature, sediment, nutrient, chlorophyll a, and dissolved oxygen; and
- Validate the watershed model.

Besides Lake Oologah, there are additional four federal lakes located in the Verdigris River Basin: Fall River Lake, Elk City Lake, Toronto Lake, and Big Hill Lake, as shown in Figure 1. For the development of watershed model for the Verdigris River Basin, these four lakes can be excluded from the watershed modeling domain. Instead, time series data of flow and water quality constituents discharging from the dams of these four lakes can be compiled as the upstream boundary conditions of the watershed model.

The collected water quality data for the Verdigris River Basin include water temperature, total suspended solids, dissolved oxygen, chlorophyll a, nitrogen species (nitrate, nitrite, ammonium, and organic nitrogen), and phosphorus species (ortho-phosphate and organic phosphorus).

## 2.1 Digital Elevation Model (DEM)

The USGS 1/3-Arc Second National Elevation Dataset (10 m x 10 m) will be used to delineate the entire Verdigris River Basin (HUC8: 11070101, 11070102, 11070103, and 11070104). The USGS NED data were downloaded for the entire Verdigris River Basin. These data were merged and then clipped based on the Verdigris River Basin boundary, as shown in Figure 3.

The USGS DEM data are used to calculate the length, slope, and FTABLE of the river channel for each sub-basin. The FTABLE describes the hydrology of a river reach or reservoir (RCHRES) segment by defining the functional relationship between water depth, surface area, water volume, and outflow in the segment (Bicknell et al., 2001).

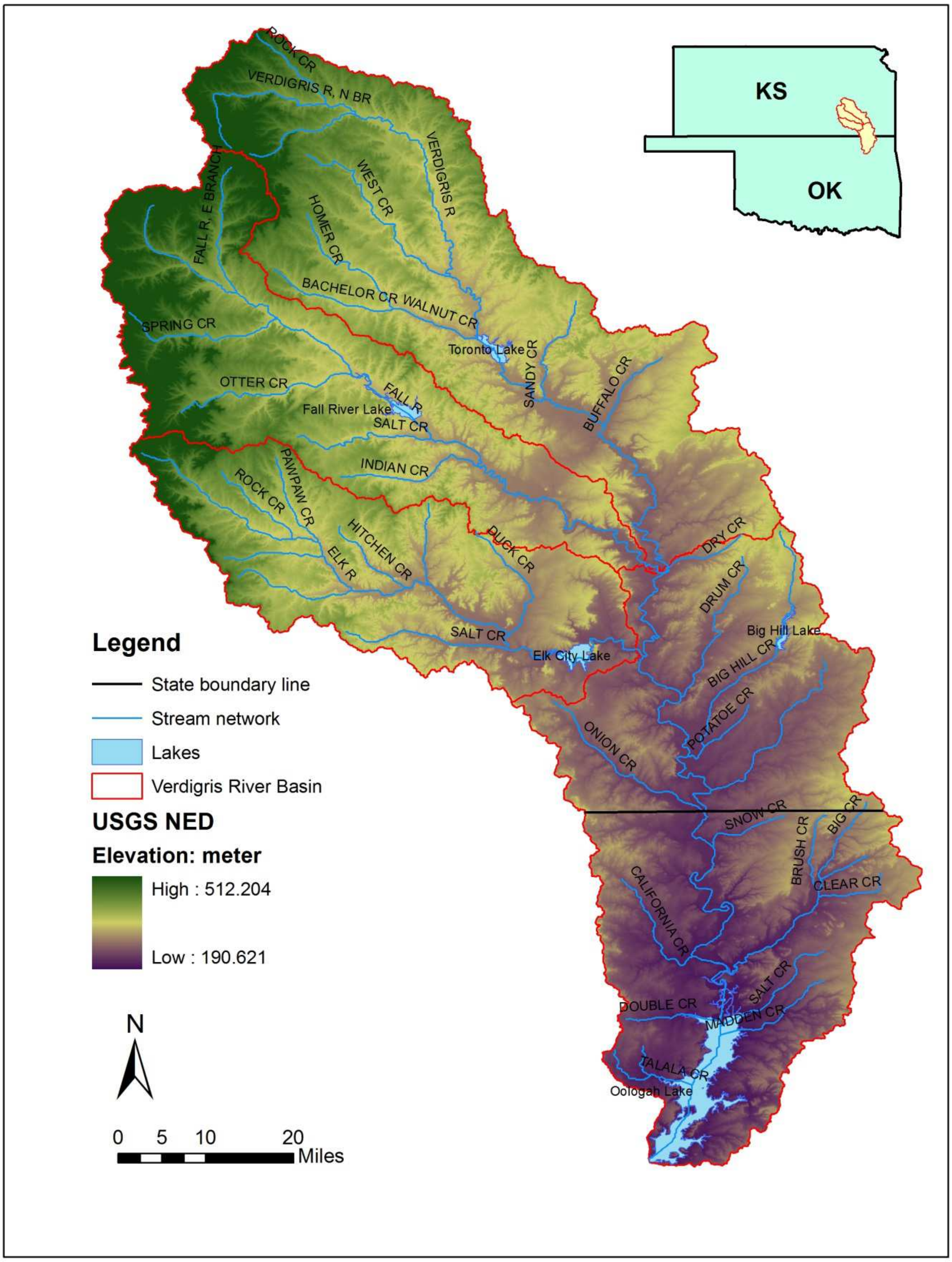


Figure 3 USGS NED DEM Data in the Verdigris River Basin

## 2.2 Landuse Data

The USGS NLCD data are available for both 2006 and 2011. After the calibration and validation periods are determined, the appropriate NLCD data can be used in the watershed HSPF model. The landuse data of the NLCD 2011 are given in Figure 4 and Table 1. As shown in Figure 4 and Table 1, the grassland and pasture are the major landuse categories, covering over 70% of the total study area.

The landuse data are used to calculate the area of each landuse category for each sub-basin. Many hydrological and water quality parameters of HSPF model, such as nutrient accumulation rate, are landuse-specific. During the model calibration process, different values can be applied to simulate the hydrological and water quality processes for different landuses. For example, cropland has higher value of inorganic nutrient accumulation rate due to fertilization than other landuses.

Table 1 2011 NLCD Landuse Data of the Verdigris River Basin

| Landuse Category | NLCD Code | Area (acres) | Percentage |
|---|---|---|---|
| Open Water | 11 | 58,820 | 2.15% |
| Developed, Open Space | 21 | 100,509 | 3.67% |
| Developed, Low Intensity | 22 | 21,481 | 0.79% |
| Developed, Medium Intensity | 23 | 4,085 | 0.15% |
| Developed, High Intensity | 24 | 1,129 | 0.04% |
| Barren Land | 31 | 2,430 | 0.09% |
| Deciduous Forest | 41 | 265,542 | 9.71% |
| Evergreen Forest | 42 | 1,058 | 0.04% |
| Mixed Forest | 43 | 7,254 | 0.27% |
| Shrub/Scrub | 52 | 951 | 0.03% |
| Grassland/Herbaceous | 71 | 1,122,991 | 41.05% |
| Pasture/Hay | 81 | 896,350 | 32.77% |
| Cultivated Crops | 82 | 236,248 | 8.64% |
| Woody Wetlands | 90 | 15,308 | 0.56% |
| Emergent Herbaceous Wetlands | 95 | 1,378 | 0.05% |
| Total | | 2,735,536 | 100.00% |

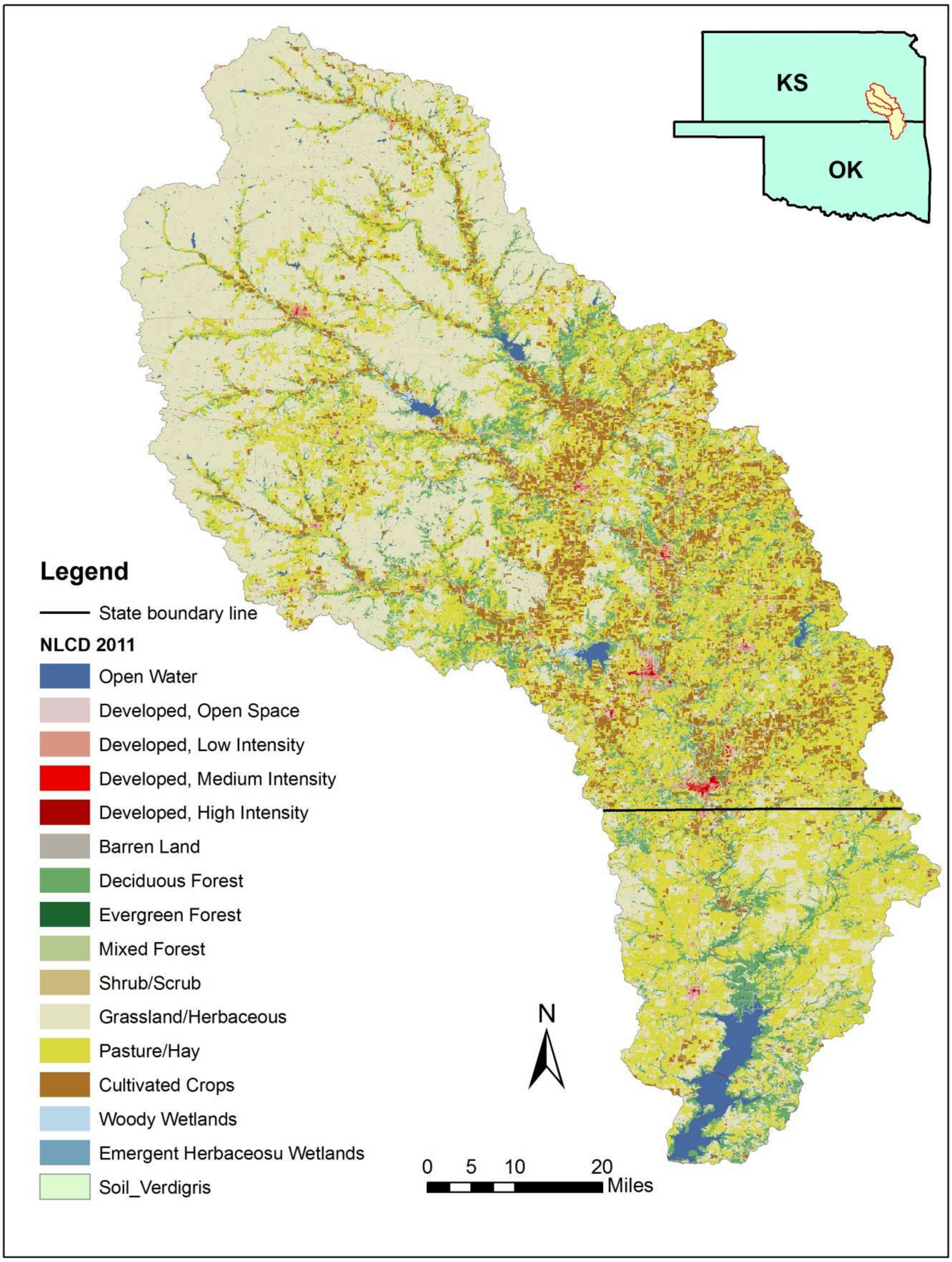


Figure 4 NLCD 2011 Data of the Verdigris River Basin

## 2.3 Soil Data

The STATESGO data of USDA are downloaded for states of Kansas and Oklahoma and then adjusted based on the boundary of the Verdigris River Basin, as shown in Figure 5 and Table 2.

As shown in Table 2, the majority of the soils in the Verdigris River Basin can be classified into the category of hydrological soil group C and D, which have lower rates of infiltration. Soil data can provide useful information for determining infiltration capacity during the HSPF watershed model calibration process.

Table 2 USDA STATESGO Data of the Verdigris River Basin

| Hydrologic Soil Group | Area (acre) | Percentage |
|---|---|---|
| B | 565,800 | 20.67% |
| C | 1,145,738 | 41.85% |
| D | 989,800 | 36.15% |
| Water | 36,482 | 1.33% |
| Total | 2,737,821 | 100.00% |

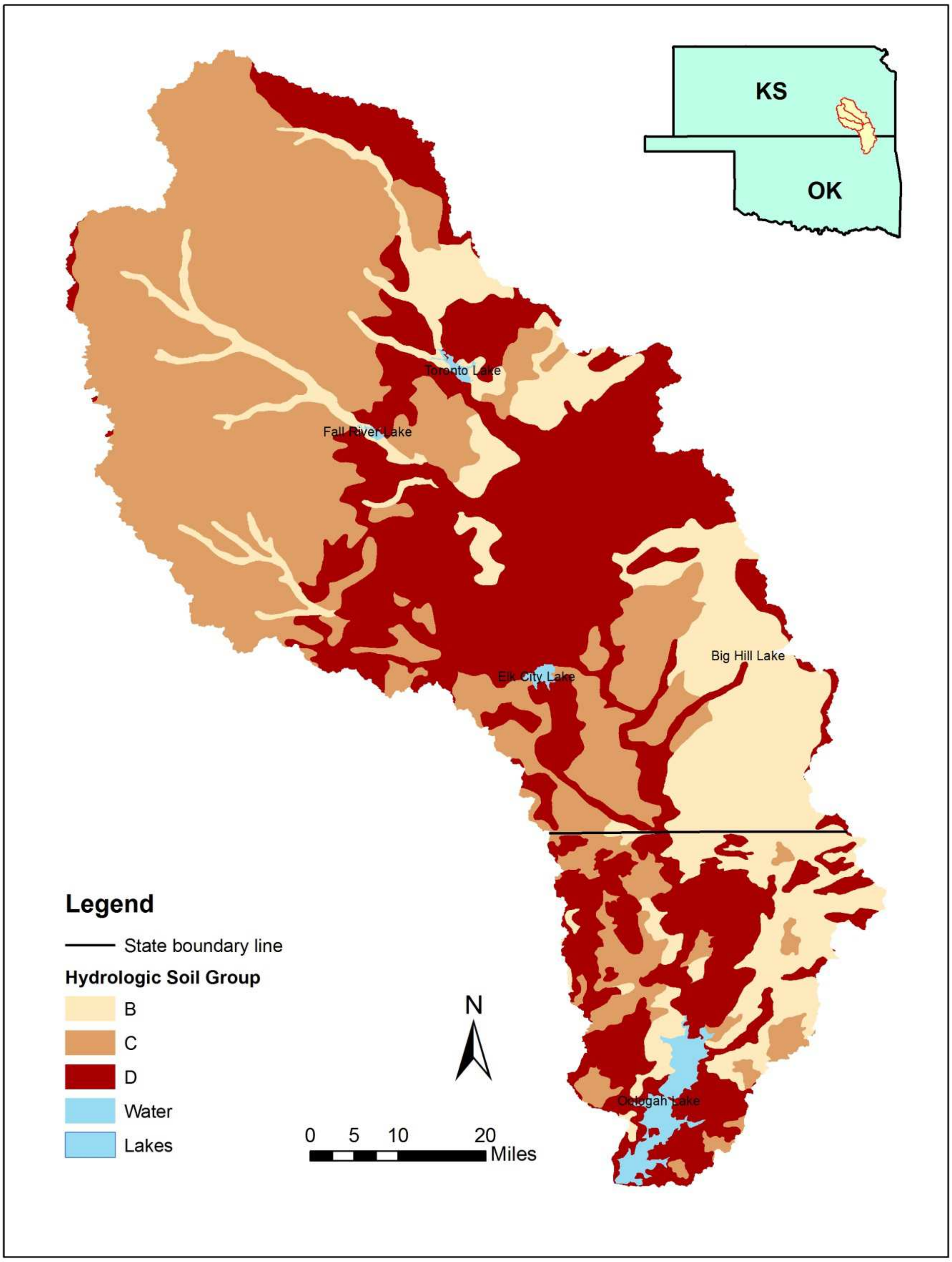


Figure 5 USDA STATESGO Data of the Verdigris River Basin

## 2.4 Meteorological Data

HSPF uses meteorological data to generate runoff and pollutant loads. Seven meteorological variables are required for hydrologic and water quality simulation using HSPF. These variables are precipitation, evapotranspiration, air temperature, dew point temperature, wind speed, solar radiation, and cloud cover. Meteorological data are available from National Climatic Data Center (NCDC) and Oklahoma MESONET.

### *2.4.1 Oklahoma MESONET*

The Oklahoma MESONET consists of 120 automated stations covering Oklahoma (https://www.mesonet.org/index.php/site/about). The network was designed and implemented by scientists at the University of Oklahoma (OU) and at Oklahoma State University (OSU).

The monitored variables include air temperature, dew point temperature, relative humidity, rainfall, wind speed, wind direction, air pressure, and solar radiation. The meteorological data are monitored at 5-minute intervals. Evapotranspiration and cloud cover data are not available.

There are seven MESONET stations close to the Verdigris River Basin, as shown in Figure 6 and Table 3. The Oklahoma MESONET data cannot be downloaded freely but can be obtained through ODEQ.

Table 3 Summary of Oklahoma MESONET Meteorological Data Station Information

| Station ID | Station Name | County | Latitude | Longitude | Start | End | Data Interval |
|---|---|---|---|---|---|---|---|
| COPA | Copan | Washington | 36.90987 | -95.88553 | 2003 | Present | 5-miute |
| INOL | Inola | Rogers | 36.14246 | -95.45067 | 2003 | Present | 5-miute |
| PRYO | Pryor | Mayes | 36.36914 | -95.27138 | 2003 | Present | 5-miute |
| SKIA | Skiatook | Osage | 36.41530 | -96.03706 | 2003 | Present | 5-miute |
| TULN | Tulsa | Tulsa | 36.19666 | -95.93883 | 2003 | Present | 5-miute |
| VINI | Vinita | Craig | 36.77536 | -95.22094 | 2003 | Present | 5-miute |
| WYNO | Wynona | Osage | 36.51806 | -96.34222 | 2003 | Present | 5-miute |

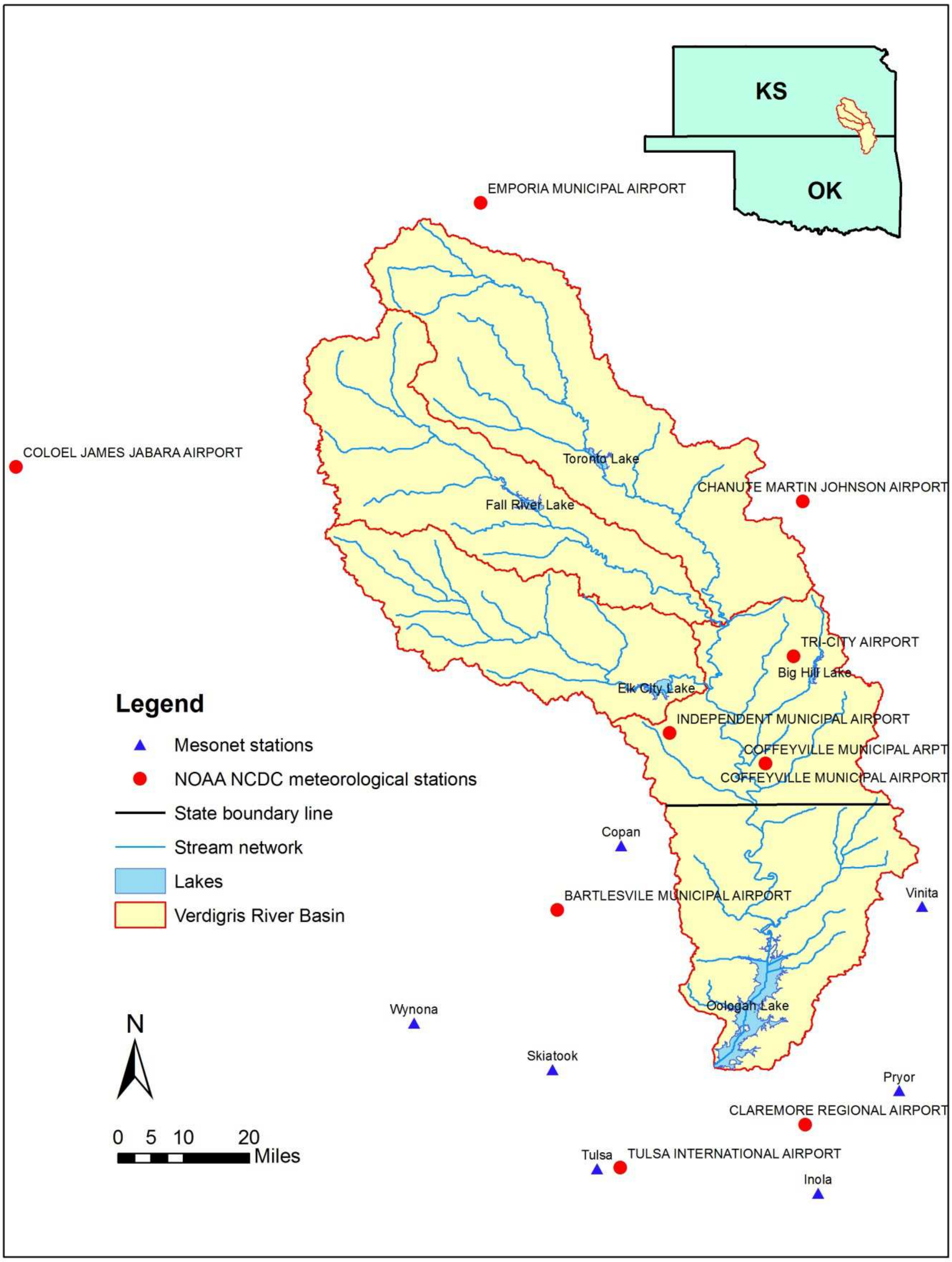


Figure 6 Locations of NOAA NCDC and Oklahoma MESONET Stations

### 2.4.2 National Climatic Data Center (NCDC)

Meteorological data was collected from the National Oceanic & Atmospheric Administration's (NOAA) NCDC website (http://www.ncdc.noaa.gov/oa/ncdc.html). Ten meteorological data stations were found to be potentially useful as input data for the watershed HSPF model, as shown in Figure 6 and Table 4.

The monitored variables include air temperature, dew point temperature, relative humidity, rainfall, wind speed, wind direction, air pressure, and sky condition. The meteorological data are monitored at 1-hour intervals.

Table 4 Summary of NOAA NCDC Meteorological Data Station Information

| Station Name | WBAN ID | Latitude | Longitude | Start | End | Data Interval |
|---|---|---|---|---|---|---|
| COFFEYVILLE MUNICIPAL ARPT | 93967 | 37.091 | -95.566 | 2003 | Present | Hourly |
| CLAREMORE REGIONAL AIRPORT | 53940 | 36.294 | -95.479 | 2003 | Present | Hourly |
| BARTLESVILE MUNICIPAL AIRPORT | 03959 | 36.768 | -96.026 | 2003 | Present | Hourly |
| INDEPENDENT MUNICIPAL AIRPORT | 00141 | 37.158 | -95.778 | 2003 | Present | Hourly |
| COFFEYVILLE MUNICIPAL AIRPORT | 93967 | 37.091 | -95.566 | 2003 | Present | Hourly |
| TRI-CITY AIRPORT | 3998 | 37.328 | -95.504 | 2003 | Present | Hourly |
| CHANUTE MARTIN JOHNSON AIRPORT | 13981 | 37.67 | -95.484 | 2003 | Present | Hourly |
| EMPORIA MUNICIPAL AIRPORT | 13989 | 38.329 | -96.195 | 2003 | Present | Hourly |
| COLOEL JAMES JABARA AIRPORT | 03974 | 37.746 | -97.221 | 2003 | Present | Hourly |
| TULSA INTERNATIONAL AIRPORT | 13968 | 36.199 | -95.887 | 2003 | Present | Hourly |

The meteorological data from these NOAA NCDC and Oklahoma MESONET stations are likely to be adequate to capture the spatial variations in the meteorological factors for hydrologic modeling.

## 2.5 Discharge Data

### *2.5.1 USGS Flow Data*

Long-term observed discharge data in the model domain are available from USGS. There are a total of seven USGS stations located in the Verdigris River Basin, where discharge data are available at six USGS stations for the period during 2003 to 2014 (Figure 7 and Table 5). Discharge data from these six USGS stations can be used for model-data comparison to evaluate the performance of the developed hydrologic model.

Table 5 Summary of USGS Discharge Data Station Information

| Station ID | Latitude | Longitude | Station Name | Start | End | Data Interval |
|---|---|---|---|---|---|---|
| 07171000 | 36.851111 | -95.585833 | Verdigris River near Lenapah, OK | 2003 | Present | Daily |
| 07170990 | 37.005278 | -95.592500 | Verdigris River at Coffeyville, KS | 2003 | Present | Daily |
| 07170500 | 37.223611 | -95.677500 | Verdigris River at Independence, KS | 2003 | Present | Daily |
| 07166500 | 37.529722 | -95.674444 | Verdigris River near Altoona, KS | 2003 | Present | Daily |
| 07169500 | 37.508333 | -95.833333 | Fall River at Fredonia, KS | 2003 | Present | Daily |
| 07170700 | 37.266667 | -95.468889 | Big Hill Creek near Cherryvale, KS | 2003 | Present | Daily |

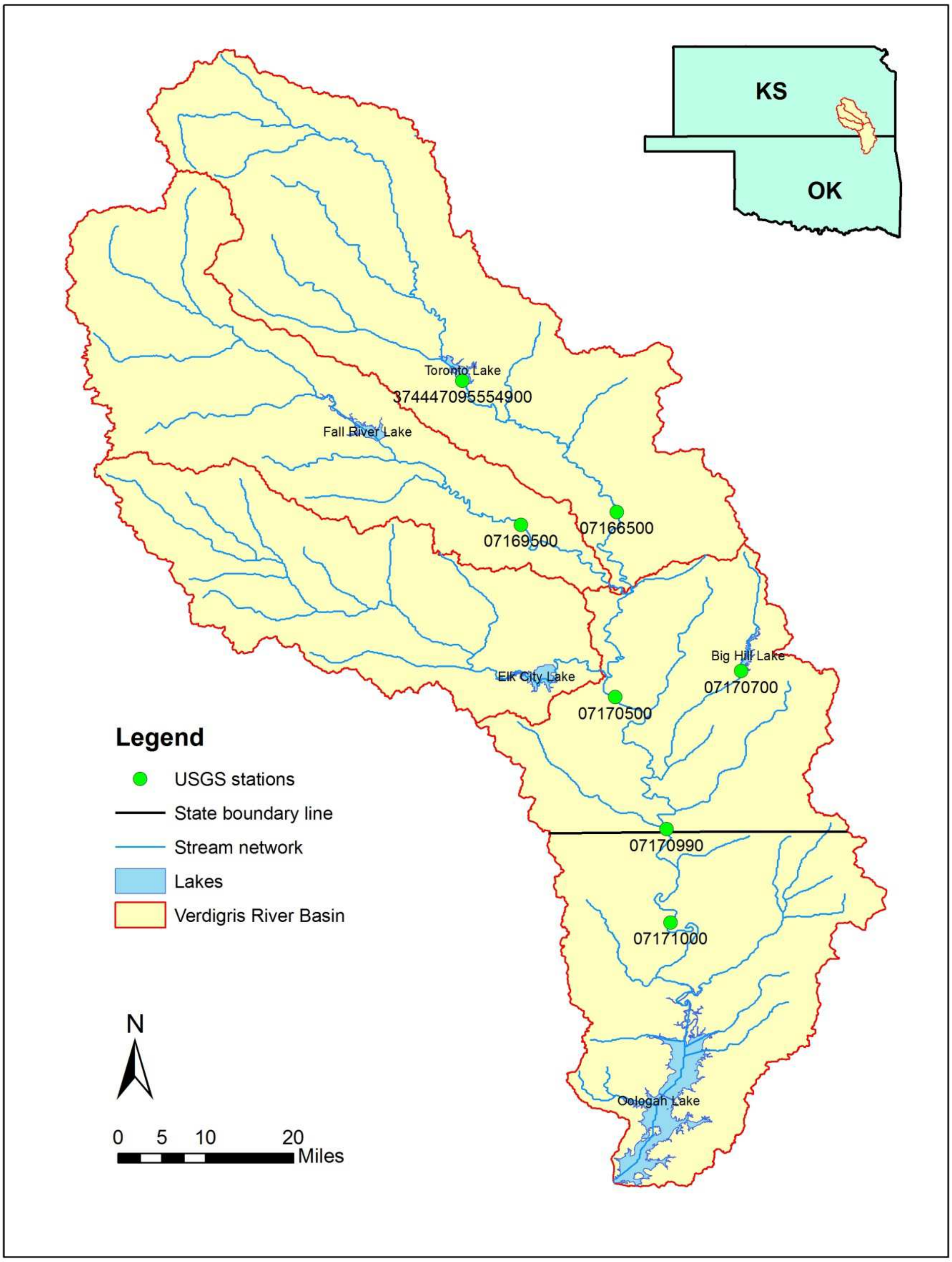


Figure 7 Locations of USGS Stations in the Verdigris River Basin

### 2.5.2 USACE Flow Data

With funding provided by the Tulsa Metropolitan Utilities Authority for a multi-year assessment study (USACE and City of Tulsa, 2012), the USACE Tulsa District and City of Tulsa prepared the "Oologah Lake Watershed Assessment Study". The flow data in the Verdigris River Basin monitored by USACE are available at five stations (Figure 8 and Table 6). Flow data were observed hourly during 2003 to 2009.

Station ER-1 is located in the controlled portion of the Verdigris River Basin, the upstream of Elk City Lake, which is the outside of the watershed model domain. Flow data from the remaining four stations can be used for model calibration and validation.

Table 6 Summary of USACE Discharge Data Station Information

| Station Code | State | County | Stream | Description | Latitude | Longitude |
|---|---|---|---|---|---|---|
| FR-1 | KS | Wilson | Fall River | Fall River at Fredonia, KS | 37.508333 | -95.833333 |
| ER-1 | KS | Elk | Elk River | Elk River at Elk Falls, KS | 37.375556 | -96.185278 |
| BC-1 | OK | Nowata | Big Creek | Big Creek near Childers, OK | 36.785556 | -95.470000 |
| VR-2 | OK | Nowata | Verdigris River | Verdigris River near Lenapah, OK | 36.851111 | -95.585833 |
| VR-3 | KS | Wilson | Verdigris River | Verdigris River near Neodesha, KS | 37.418333 | -95.671389 |

Within the Verdigris River Basin, besides Oologah Lake, there are additional four federal reservoirs: Fall River Lake, Toronto Lake, Elk City Lake, Big Hill Lake, which are all located in the state of Kansas. The hourly dam release data from these federal reservoirs were recorded during 2003 to 2009 by USACE. The count of flow data available for these stations is given in Table 7.

Table 7 Summary of Flow Data Available at the Upstream Federal Reservoirs

| Year | Big Hill Lake | Elk City Lake | Fall River Lake | Toronto Lake |
|---|---|---|---|---|
| 2003 | 8693 | 8754 | 8760 | 8760 |
| 2004 | 8690 | 8784 | 8784 | 8784 |
| 2005 | 8728 | 8760 | 8760 | 8760 |
| 2006 | 8665 | 8760 | 8758 | 8757 |
| 2007 | 8734 | 8760 | 8760 | 8760 |
| 2008 | 8784 | 8784 | 8784 | 8784 |
| 2009 | 8648 | 8755 | 8755 | 8755 |

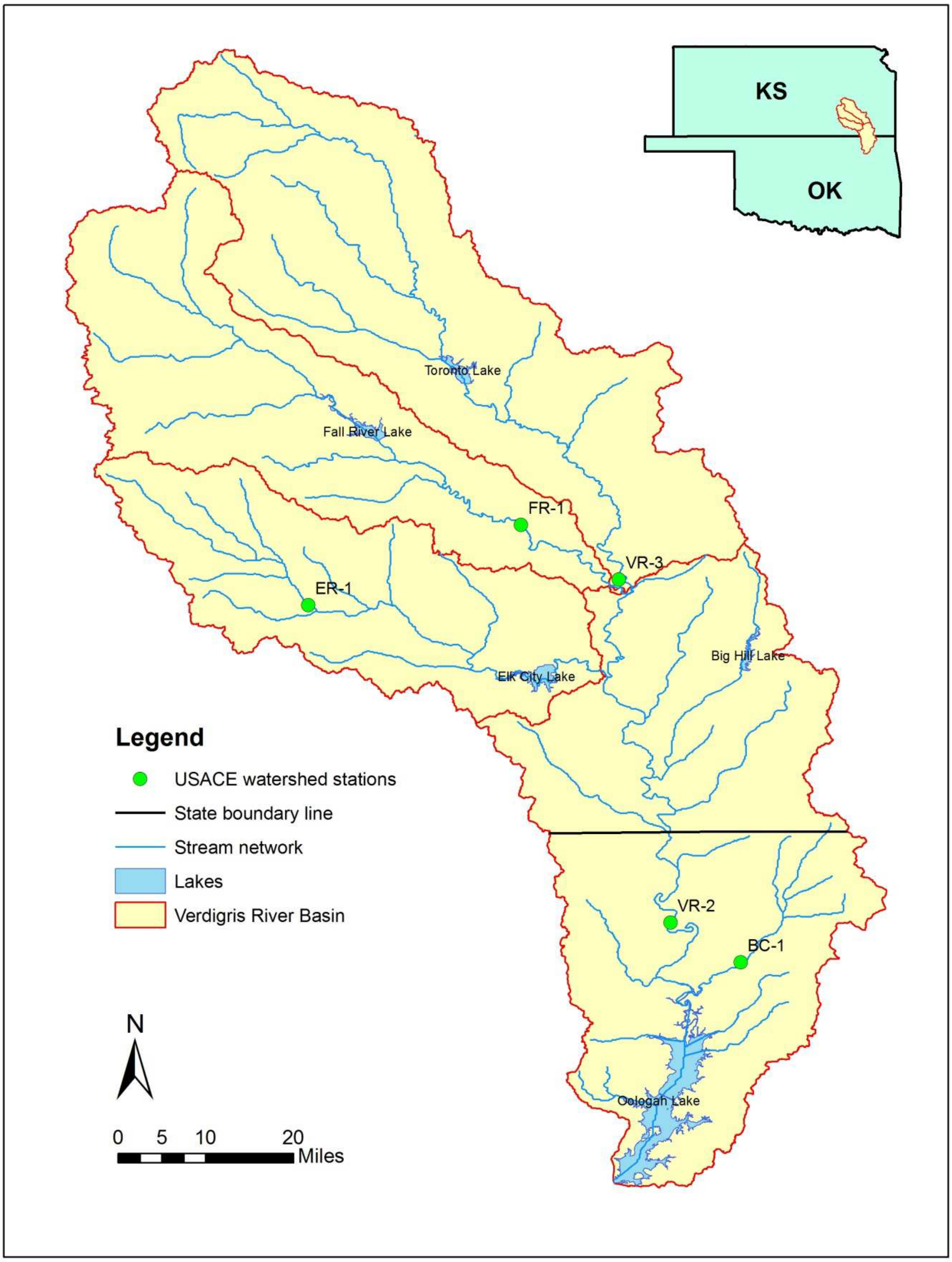


Figure 8 Locations of USACE Flow Stations in the Verdigris River Basin

## 2.6 Water Quality Data

### 2.6.1 USGS Monitoring Program

Grab samples are collected by the USGS monitoring program. There are a total of six USGS stations, where water quality data are available during the period of 2003 to 2014 (Figure 7). The summary of the water quality data in these six stations is given in Table 8. The observed water quality data in water column are available at all stations except station 374447095554900, where only sediment chemistry data are available.

In most of cases, the water quality parameters are monitored twice a year and the majority of the data were collected in 2009 and 2010, as seen in Table 8. Hence, the data from USGS monitoring program can be used for visual comparison to evaluate model performance.

Table 8 Summary of USGS Water Quality Data Stations

| USGS Stations | 2003 | 2008 | 2009 | 2010 |
|---|---|---|---|---|
| **07170500** | | | | |
| Water temperature | 2 | | | |
| **07170700** | | | | |
| Water temperature | 5 | | | |
| **07166500** | | | | |
| Water temperature | 2 | | 2 | 2 |
| DO | | | 2 | 2 |
| DO saturation | | | 2 | 2 |
| TSS | | | 2 | 2 |
| Turbidity | | | 2 | 2 |
| **07169500** | | | | |
| Water temperature | 5 | | 2 | |
| DO | | | 2 | |
| DO saturation | | | 2 | |
| TSS | | | 2 | |
| Turbidity | | | 2 | |
| **07170990** | | | | |
| Water temperature | 2 | | 4 | 4 |
| DO | | | 4 | 4 |
| DO saturation | | | 4 | 4 |
| TSS | | | 4 | 4 |
| Turbidity | | | 4 | 4 |
| **374447095554900** | | | | |
| TP in sediment DW (mg/kg) | | 14 | | |
| TOC in sediment DW (mg/kg) | | 14 | | |
| Total carbon in sediment DW (mg/kg) | | 14 | | |
| TN in sediment DW (mg/kg) | | 14 | | |

### 2.6.2 US EPA STOrage and RETrieval Data Warehouse (STORET)

Water quality data was downloaded from the US EPA STORET online data base for stations located in the Verdigris River Basin for the time period of 2003 to 2014 (http://www.epa.gov/storet/dbtop.html).

Figure 9 depicts the locations of the EPA STORET data stations within the model domain. Detailed information of latitude and longitude is given in Table 9. The summary of water quality constituent data is given in Table 10.

Generally, water quality data are collected bi-monthly. As shown in Figure 9, both red circles and green triangles represent the EPA STORET stations. The stations shown by green triangles have at least one year of complete bi-monthly observed data, which can be used for calculation of statistics for model-data comparison. Stations shown by red circles only have sparsely collected water quality data, and only can be used for visual comparison.

At all four lakes, the water quality data are collected sparsely, and not useful for the development of the upstream boundary for the watershed model.

Table 9 USEPA STORET Water Quality Data Stations

| Agency | Station ID | Latitude | Longitude |
|---|---|---|---|
| EPA | FW08KS015 | 37.39741 | -95.679909 |
| EPA | LM010701 | 37.15984 | -95.68298 |
| EPA | LM011801 | 37.78518 | -95.84277 |
| EPA | LM015101 | 37.697 | -95.67885 |
| EPA | LM022501 | 37.70917 | -95.7225 |
| EPA | LM023001 | 37.65549 | -96.06029 |
| EPA | LM024001 | 37.7416 | -95.91536 |
| EPA | LM025001 | 37.27654 | -95.7923 |
| EPA | LM031001 | 37.27355 | -95.47285 |
| EPA | LM049601 | 37.47828 | -95.49786 |
| EPA | LM053801 | 37.82873 | -95.80244 |
| EPA | LM071601 | 37.25976 | -95.54602 |
| EPA | LM071701 | 37.03583 | -95.39361 |
| EPA | LM072101 | 37.62774 | -96.16992 |
| EPA | LM072201 | 37.47834 | -95.47951 |
| EPA | LM072901 | 37.04353 | -95.64715 |
| EPA | OK121510-02-0050C | 36.7802 | -95.6657 |
| EPA | OK121510-03-0010D | 36.7853 | -95.4634 |
| EPA | SC105 | 37.32676 | -95.68463 |
| EPA | SC215 | 37.00553 | -95.59228 |
| EPA | SC561 | 37.52999 | -95.67501 |
| EPA | SC562 | 37.43219 | -95.72315 |
| EPA | SC563 | 37.17256 | -95.65707 |
| EPA | SC606 | 37.04245 | -95.54884 |
| EPA | SC607 | 37.08761 | -95.60184 |
| EPA | SC608 | 37.00654 | -95.61635 |
| EPA | SC696 | 37.45522 | -95.65151 |
| EPA | SC699 | 37.22479 | -95.60877 |
| EPA | SP813 | 37.73411 | -95.85457 |
| EPA | SPA159 | 37.39724 | -95.67912 |
| EPA | SPA180 | 37.07818 | -95.56766 |
| EPA | SPA196 | 37.66891 | -95.83277 |
| EPA | SPA200 | 37.22364 | -95.67804 |
| EPA | SPA383 | 37.60241 | -95.5642 |
| EPA | SPB004 | 37.0731 | -95.46758 |

Table 10 Summary of USEPA STORET Water Quality Data Stations

| Water Quality Constituents | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ammonia | 51 | 52 | 38 | 41 | 72 | 40 | 57 | 37 | 21 | 25 | 39 |
| Ammonia as N | | | | 10 | 22 | 8 | | | 10 | 6 | |
| Chlorophyll a, corrected for pheophytin | 6 | 13 | 4 | 6 | 16 | 6 | | 14 | 2 | 6 | 4 |
| Depth, Secchi disk depth | | 5 | 2 | 3 | 9 | 3 | | 7 | | 2 | |
| Kjeldahl nitrogen | 51 | 51 | 38 | 41 | 72 | 40 | 57 | 37 | 21 | 25 | 39 |
| Kjeldahl nitrogen as N | | | | 10 | 22 | 8 | | | 8 | 18 | |
| Nitrate | 51 | 52 | 38 | 41 | 72 | 40 | 58 | 37 | 21 | 25 | 39 |
| Nitrate as N | | | | 10 | 22 | 8 | | | 9 | 18 | |
| Nitrite | 51 | 52 | 38 | 41 | 72 | 40 | 58 | 37 | 21 | 25 | 39 |
| Nitrite as N | | | | | | | | | 12 | 18 | |
| Organic carbon | 51 | 52 | 38 | 41 | 72 | 40 | 58 | 37 | 21 | 25 | 39 |
| Orthophosphate | 51 | 52 | 38 | 41 | 72 | 40 | 57 | 37 | 21 | 25 | 39 |
| Orthophosphate as P | | | | 10 | 22 | 8 | | | 11 | 18 | |
| Phosphorus | 51 | 49 | 38 | 41 | 71 | 40 | 58 | 37 | 21 | 25 | 39 |
| Phosphorus as P | | | | 10 | 22 | 8 | | | 8 | 18 | |
| Temperature, water | 61 | 87 | 50 | 59 | 112 | 48 | 57 | 43 | 35 | 41 | 39 |
| Total suspended solids | 51 | 52 | 38 | 51 | 94 | 48 | 58 | 37 | 32 | 43 | 39 |
| Turbidity | 61 | 52 | 38 | 51 | 94 | 48 | 58 | 37 | 37 | 41 | 39 |
| DO | 61 | 49 | 38 | 53 | 93 | 48 | 58 | 37 | 35 | 39 | 39 |

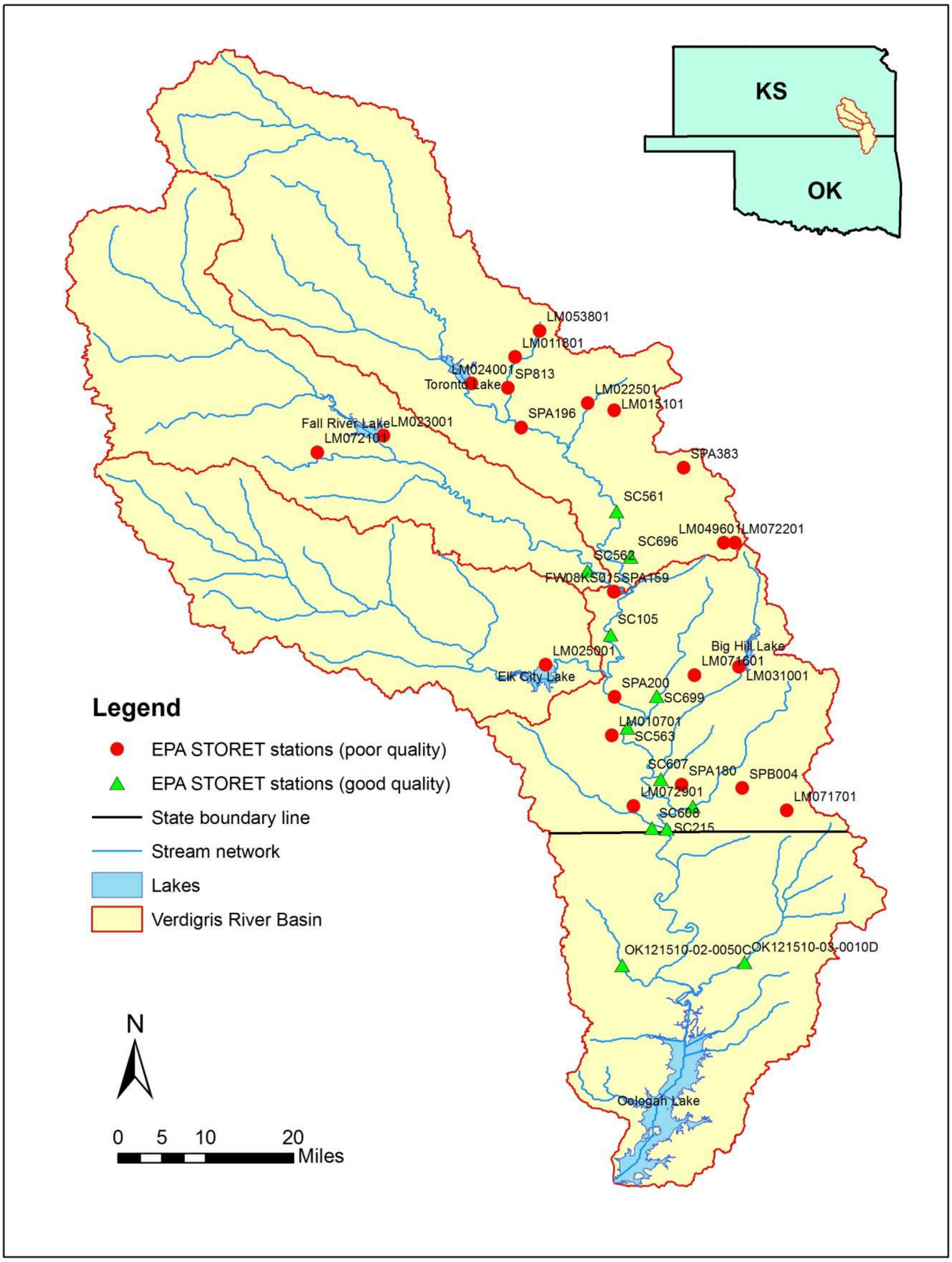


Figure 9 Locations of EPA STORET Water Quality Data Stations

### 2.6.3 Oklahoma Water Resources Board (OWRB)

There is one OWRB water quality station (121510020010-001AT) in the Verdigris River Basin, as shown in Figure 10. The summary of availability of water quality data during 2003 to 2014 is given in Table 11. Water quality data from this station can be used for calculating statistics of model-data comparison.

Table 11 Summary of the Collected Water Quality Data at OWRB Station 121510020010-001AT

| Water Quality Constituents | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chlorophyll a | 4 | 7 | 7 | 6 | 20 | 14 | 5 | 7 | 3 | 6 | 8 | 5 |
| DISS OXY SATURATION | 8 | 10 | 9 | 9 | 9 | 6 | 7 | 7 | 4 | 6 | 8 | 4 |
| DISSOLVED OXYGEN | 8 | 10 | 9 | 9 | 9 | 6 | 7 | 7 | 4 | 6 | 8 | 4 |
| Nitrogen, Ammonia | 12 | 17 | 13 | 10 | 10 | | 8 | 6 | 2 | 4 | 3 | |
| Nitrogen, Ammonia Total (mg/L as N ) | | | | | 9 | 13 | 4 | 3 | 2 | 2 | 6 | 4 |
| Nitrogen, Kjeldahl | 12 | 17 | 18 | 15 | 21 | 13 | 12 | 8 | 4 | 6 | 8 | 5 |
| Nitrogen, Nitrate as N | 12 | 10 | 1 | | | | | | | | | |
| Nitrogen, Nitrate/Nitrite as N | | | 9 | 10 | 21 | 13 | 12 | 8 | 4 | 6 | 8 | 5 |
| Nitrogen, Nitrite as N | 12 | 10 | 1 | | | | | | | | | |
| Nitrogen, Total | | | | | | | | | | | 8 | 5 |
| Ortho Phosphate | | | | | 8 | 12 | 4 | | 1 | | 6 | 1 |
| Phosphorous, Ortho | 12 | 10 | 10 | 10 | 10 | | 8 | 9 | 3 | 6 | 2 | |
| Phosphorous, Total | 12 | 17 | 18 | 15 | 21 | 13 | 12 | 8 | 4 | 6 | 8 | 5 |
| Turbidity | 8 | 10 | 9 | 9 | 21 | 11 | 13 | 9 | 5 | 9 | 8 | 4 |
| Water Temperature | 8 | 10 | 9 | 9 | 9 | 6 | 7 | 7 | 4 | 6 | 8 | 4 |

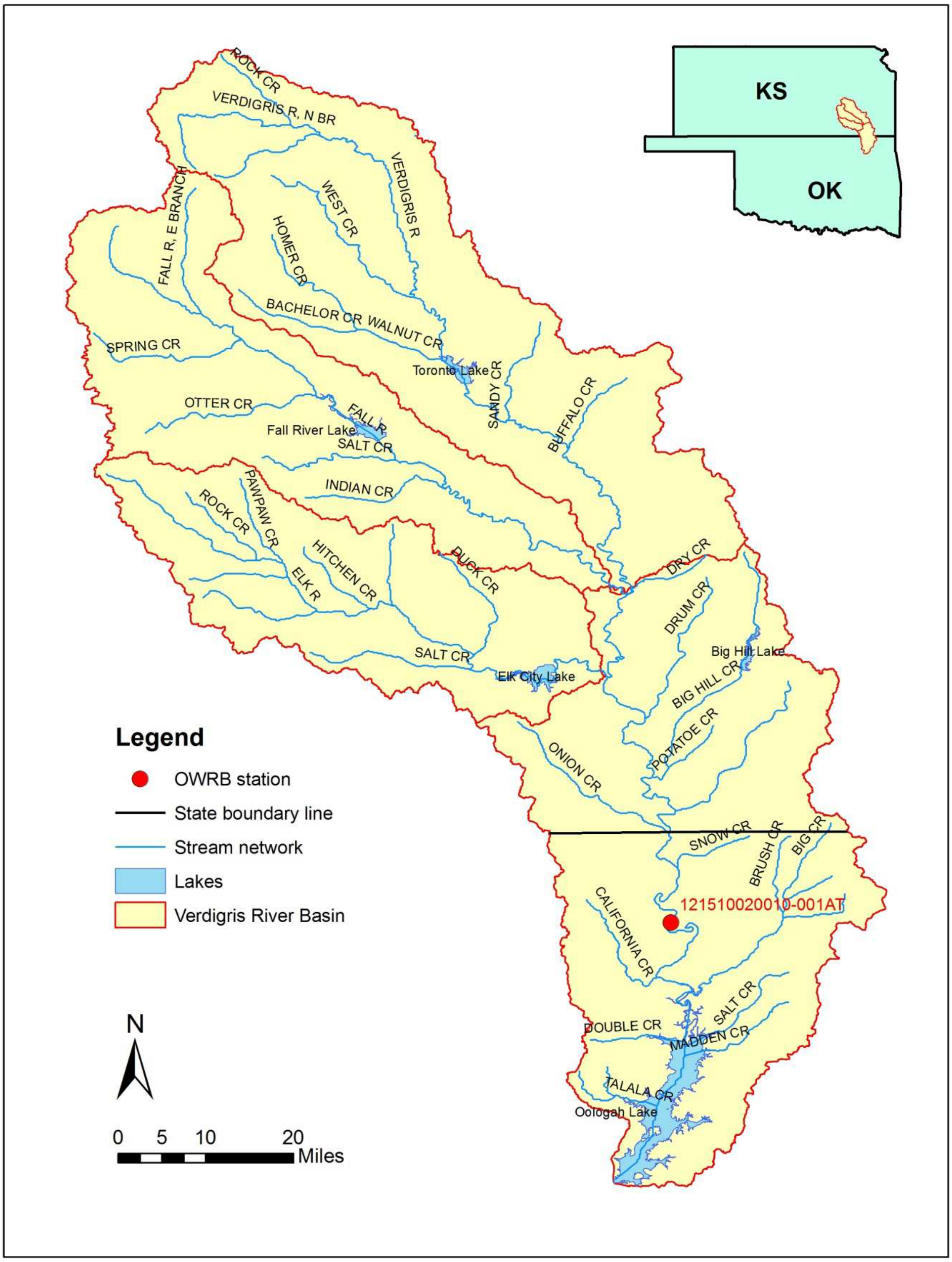


Figure 10 Location of the OWRB Station in Verdigris River Basin

### 2.6.4 United States Army Corps of Engineers (USACE)

For the four upstream federal reservoirs, the monthly water quality data are available by the Watershed Assessment Study conducted by USACE and City of Tulsa. The monthly observed water quality data are available during February of 2003 to April of 2009 at multiple depths. The monitored water quality constituents include water temperature, total suspended solids, dissolved oxygen, ammonium, nitrate, total Kjeldahl nitrogen, total phosphorus, dissolved phosphate, total organic carbon, and chlorophyll a. The summary of data availability for all water quality constituents are shown in Table 12.

Table 12 Summary of Water Quality Data Available at the Upstream Federal Reservoirs

| Year | Big Hill Lake | Elk City Lake | Fall River Lake | Toronto Lake |
|---|---|---|---|---|
| 2003 | 67 | 28 | 82 | 74 |
| 2004 | 84 | 12 | 84 | 109 |
| 2005 | 146 | 10 | 86 | 84 |
| 2006 | 239 | 12 | 123 | 114 |
| 2007 | 128 | 11 | 116 | 105 |
| 2008 | 159 | 82 | 139 | 129 |
| 2009 | 42 | 3 | 21 | 23 |

For the Watershed Assessment Study, probes were used to automatically collect the hourly flow water temperature, dissolved oxygen and turbidity during 2003 to 2009 at five stream sites in the Verdigris River Basin (Figure 8 and Table 10). Monthly grab samples were also collected for analysis of water temperature, total suspended solids, dissolved oxygen, ammonium, nitrate, total Kjeldahl nitrogen, total phosphorus, dissolved phosphate, total organic carbon, and chlorophyll a.

## 2.7 NPDES Data

The information of EPA NPDES facilities in the Verdigris River Basin is downloaded from the EPA website (http://www.epa.gov/enviro/facts/pcs-icis/search.html), as shown in Figure 11 and Table 13. The time series data of flow and water quality constituents are needed to set up as the boundary conditions of the watershed model. There are a total of 81 permits are issued to discharge flow into the Verdigris River Basin. The majority of the NPDES facilities (74) are located in the State of Kansas.

However, very few discharge data are available from the EPA warehouse. Personal requests were made to the Kansas Department of Health and Environment for DMR data of these facilities located in Kansas. Many NPDES facilities are industrial stormwater general permits and construction stormwater general permits, and there are no monitoring data for these facilities. Some NPDES permits are typically ready mix plants and quarries or extraction/processing facilities that typically do not discharge. Some NPDES facilities are lagoon systems, which typically are not sampled for nutrients.

Eventually, the long list of NPDES facilities in Kansas was narrowed down to a short list of 10 facilities, as shown in Table 14.

Table 13 Information of EPA NPDES Facilities in the Verdigris River Basin

| NPDES ID | FACILITY NAME | COUNTY NAME | PERMIT ISS | PERMIT EXP | Latitude | Longitude |
|---|---|---|---|---|---|---|
| OKG040022 | PHOENIX COAL CO.-ALLUWE NO. 2 | ROGERS | 11/12/2013 | 10/31/2018 | 36.591111 | -95.494722 |
| OKG040028 | PHOENIX COAL CO., INC.-KELLY RANCH MINE | CRAIG | 11/15/2013 | 10/31/2018 | 36.645250 | -95.394500 |
| OK0045829 | APAC-CENTRAL-NOWATA QUARRY | NOWATA | 6/7/2011 | 6/30/2016 | 36.704556 | -95.577833 |
| OK0025470 | NOWATA | NOWATA | 6/26/2012 | 6/30/2017 | 36.709556 | -95.625861 |
| OKP003004 | BRENNTAG SOUTHWEST INC NOWA TA | NOWATA | 3/16/2010 | 3/31/2015 | 36.721667 | -95.630556 |
| OK0020796 | DELAWARE | NOWATA | 8/10/2012 | 8/31/2017 | 36.775167 | -95.630083 |
| OK0020117 | SOUTH COFFEYVILLE WWT | NOWATA | 12/7/2011 | 12/31/2016 | 36.998639 | -95.612361 |
| KS0050733 | COFFEYVILLE, CITY OF | MONTGOMERY | 10/1/2012 | 9/30/2016 | 37.006469 | -95.609672 |
| KSR000038 | ACME FOUNDRY INC | MONTGOMERY | 11/1/2011 | 10/31/2016 | 37.027313 | -95.622187 |
| KSR000274 | UNION PACIFIC RR-COFFEYVILLE | MONTGOMERY | 11/1/2011 | 10/31/2016 | 37.028897 | -95.622814 |
| KSR000758 | MAGIC CIRCLE MANUFACTURING | MONTGOMERY | 4/20/2012 | 10/31/2016 | 37.032131 | -95.638318 |
| KSR110193 | MORROW FOUNDRY INC | MONTGOMERY | 6/10/2014 | 3/1/2017 | 37.032170 | -95.632250 |
| KSR109019 | SCOTT MASSMAN | MONTGOMERY | 2/28/2013 | 3/1/2017 | 37.037140 | -95.616330 |
| KS0080039 | COFFEYVILLE, CITY OF | MONTGOMERY | 3/1/2012 | 2/28/2017 | 37.037628 | -95.612893 |
| KS0081264 | TYRO, CITY OF TYRO WASTEWATER PLANT | MONTGOMERY | 10/1/2011 | 9/30/2016 | 37.037861 | -95.810917 |
| KS0082074 | COFFEYVILLE CONCRETE | MONTGOMERY | 1/1/2012 | 12/31/2016 | 37.043167 | -95.530583 |
| KS0082171 | COFFEYVILLE CONCRETE | MONTGOMERY | 12/1/2011 | 11/30/2016 | 37.043167 | -95.530583 |
| KS0115461 | COFFEYVILLE CONCRETE | MONTGOMERY | 8/1/2011 | 7/31/2016 | 37.043167 | -95.530583 |
| KS0000248 | COFFEYVILLE RESOURCES REFINING & MARKETING | MONTGOMERY | 12/1/2012 | 11/30/2017 | 37.043300 | -95.610800 |
| KSR000241 | RANDY POST | MONTGOMERY | 11/1/2011 | 10/31/2016 | 37.044494 | -95.609119 |
| KSR000238 | COFFEYVILLE RESOURCES NITROGEN FERTILIZERS LLC | MONTGOMERY | 11/1/2011 | 10/31/2016 | 37.045360 | -95.605170 |
| KSR105184 | COFFEYVILLE RESOURCES NITROGEN FERTILIZERS LLC | MONTGOMERY | 3/2/2012 | 3/1/2017 | 37.045360 | -95.605170 |
| KSR000317 | MISTIE BINTLIFF | MONTGOMERY | 11/1/2011 | 10/31/2016 | 37.045524 | -95.629261 |
| KSR000347 | TESSENDERLO KERLEY INC. | MONTGOMERY | 11/1/2011 | 10/31/2016 | 37.048587 | -95.611253 |
| KS0024759 | EDNA WASTEWATER PLANT | LABETTE | 4/1/2011 | 3/31/2016 | 37.055800 | -95.365700 |

| NPDES ID | FACILITY NAME | COUNTY NAME | PERMIT ISS | PERMIT EXP | Latitude | Longitude |
|---|---|---|---|---|---|---|
| KS0048062 | DEARING SEWER TREATMENT PLANT C/O CITY HALL | MONTGOMERY | 10/1/2011 | 9/30/2016 | 37.056158 | -95.710549 |
| KSR105901 | WADE A. WARNER | MONTGOMERY | 3/2/2012 | 3/1/2017 | 37.103606 | -95.568524 |
| KSR108401 | WADE A. WARNER | MONTGOMERY | 6/1/2012 | 3/1/2017 | 37.103606 | -95.568524 |
| KS0119300 | PATTERSON FARMS/ FIDELITY ENERGY/JOHN N. DENMAN | MONTGOMERY | 10/13/2004 | 10/12/2009 | 37.190550 | -95.892210 |
| KS0116980 | MOUND VALLEY WASTEWATER PLANT | LABETTE | 4/1/2011 | 3/31/2016 | 37.204495 | -95.410928 |
| KS0001210 | HEARTLAND CEMENT CO DBA BUZZI UNICEM USA | MONTGOMERY | 2/1/2006 | 1/31/2011 | 37.210000 | -95.676400 |
| KSR000671 | HEARTLAND CEMENT CO DBA BUZZI UNICEM USA | MONTGOMERY | 11/1/2011 | 10/31/2016 | 37.210000 | -95.676400 |
| KSR000365 | COMMERCIAL METALS COMPANY | MONTGOMERY | 11/1/2011 | 10/31/2016 | 37.219738 | -95.723889 |
| KSR110058 | DOUG BOWER | MONTGOMERY | 5/5/2014 | 3/1/2017 | 37.221870 | -95.724930 |
| KSR110052 | MICKY WEBB | MONTGOMERY | 5/8/2014 | 3/1/2017 | 37.223487 | -95.705308 |
| KSR109676 | TONY ROYSE | MONTGOMERY | 10/25/2013 | 3/1/2017 | 37.223487 | -95.705308 |
| KSR110248 | ROBERT BEVER | MONTGOMERY | 6/25/2014 | 3/1/2017 | 37.224360 | -95.703940 |
| KSR106770 | INDEPENDENCE USD 446 | MONTGOMERY | 3/2/2012 | 3/1/2017 | 37.228250 | -95.710760 |
| KS0095486 | INDEPENDENCE WASTEWATER PLANT | MONTGOMERY | 12/1/2012 | 12/31/2016 | 37.228841 | -95.692941 |
| KSG110008 | INDEPENDENCE READY MIX | MONTGOMERY | 10/1/2012 | 9/30/2017 | 37.232960 | -95.710720 |
| KSR000138 | STANDARD MOTOR PRODUCTS | MONTGOMERY | 11/1/2011 | 10/31/2016 | 37.236390 | -95.722630 |
| KSR107906 | MARTIN ESTATES | MONTGOMERY | 3/2/2012 | 3/1/2017 | 37.241590 | -95.715220 |
| KS0099333 | MAGELLAN PIPELINE CO. -INDEPENDENCE | MONTGOMERY | 9/1/2013 | 12/31/2017 | 37.255890 | -95.716000 |
| KS0096938 | PUBLIC WHOLESALE WATER DIST #4 | MONTGOMERY | 1/1/2012 | 12/31/2016 | 37.262361 | -95.461306 |
| KS0094803 | CHERRYVALE WASTEWATER PLANT WADE WEBBER, PUBLIC WORKS DIR. | MONTGOMERY | 7/1/2011 | 6/30/2016 | 37.276028 | -95.582556 |
| KS0087114 | SPRINGER, LEE (ELEVATOR FACILITY | MONTGOMERY | 11/10/2008 | 11/9/2013 | 37.327290 | -95.750220 |
| KS0086193 | MONTGOMERY CO SD #5 SYCAMORE DONNIE PLISEK | MONTGOMERY | 10/1/2012 | 12/31/2016 | 37.327611 | -95.705750 |
| KS0085448 | SPRINGER, DALE - MAIN FARM | MONTGOMERY | 6/30/2014 | 6/29/2019 | 37.329400 | -95.765410 |
| KS0095249 | KDOT - MONTGOMERY CO. | MONTGOMERY | 10/1/2011 | 9/30/2016 | 37.351240 | -95.525310 |
| KS0093238 | NELSON QUARRIES, INC. | MONTGOMERY | 1/1/2012 | 12/31/2016 | 37.352889 | -95.529056 |
| KS0088871 | MIDWEST MINERALS, INC. #27 NEODESHA QUARRY | WILSON | 1/1/2012 | 12/31/2016 | 37.411889 | -95.753333 |
| KSR106834 | CASEY'S GENERAL STORE - #1396 | WILSON | 3/2/2012 | 3/1/2017 | 37.417492 | -95.675213 |
| KSR108921 | M E C COMPANY | WILSON | 1/17/2013 | 3/1/2017 | 37.417520 | -95.690318 |
| KSR000046 | HOWARD ENTERPRISES | WILSON | 11/1/2011 | 10/31/2016 | 37.421660 | -95.687610 |

| NPDES ID | FACILITY NAME | COUNTY NAME | PERMIT ISS | PERMIT EXP | Latitude | Longitude |
|---|---|---|---|---|---|---|
| KSR000319 | HOWARD ENTERPRISES | WILSON | 11/1/2011 | 10/31/2016 | 37.421660 | -95.687610 |
| KSR000511 | HOWARD ENTERPRISES | WILSON | 11/1/2011 | 10/31/2016 | 37.421660 | -95.687610 |
| KS0096385 | BP PRODUCTS N. AMERICA, INC. | WILSON | 3/1/2012 | 2/28/2017 | 37.428420 | -95.688230 |
| KS0025658 | NEODESHA, CITY OF | WILSON | 7/1/2011 | 6/30/2016 | 37.432093 | -95.683690 |
| KSR000047 | GREG TERNES, ENV. MGR. | WILSON | 11/1/2011 | 10/31/2016 | 37.433289 | -95.697362 |
| KSR000048 | MILLER TRANSP INC | WILSON | 11/1/2011 | 10/31/2016 | 37.435696 | -95.683692 |
| KS0026450 | THAYER SEWER TREATMENT PLANT C/O CITY HALL | NEOSHO | 10/1/2012 | 12/31/2016 | 37.487880 | -95.470880 |
| KSR000519 | CONSOLIDATED OIL WELL SERVICE, | NEOSHO | 11/1/2011 | 10/31/2016 | 37.494710 | -95.479750 |
| KS0099678 | STARBUCK ROCK -FREDONIA QUARRY | WILSON | 5/1/2013 | 12/31/2017 | 37.501010 | -95.839300 |
| KSR000113 | SYSTECH ENVIRONMENTAL CORP. | WILSON | 11/1/2011 | 10/31/2016 | 37.507728 | -95.824133 |
| KS0000884 | LAFARGE MIDWEST, INC. | WILSON | 1/1/2009 | 10/31/2013 | 37.508942 | -95.822476 |
| KS0088242 | LAFARGE MIDWEST, INC. | WILSON | 9/1/2012 | 12/31/2016 | 37.508942 | -95.822476 |
| KS0027511 | ALTOONA SEWER TREATMENT PLANT C/O CITY HALL | WILSON | 8/1/2011 | 6/30/2016 | 37.522893 | -95.662331 |
| KS0099261 | MIDWEST MINERAL - ALTOONA QUARRY | WILSON | 1/1/2012 | 12/31/2016 | 37.528250 | -95.699417 |
| KS0099520 | R. PUCKETT FARMS-WHITESANDSTONE QUARRY | WILSON | 1/1/2013 | 12/31/2017 | 37.532611 | -95.816437 |
| KS0045985 | FREDONIA WASTE WATER TREATMENT PLANT C/O CITY HALL | WILSON | 10/1/2012 | 12/31/2016 | 37.532704 | -95.826473 |
| KSR000045 | FARWELL INC | WILSON | 11/1/2011 | 10/31/2016 | 37.545573 | -95.829447 |
| KS0116963 | FALL RIVER MUNICIPAL WASTE WATER TREATMENT FACILITY C/O CITY HALL | GREENWOOD | 10/1/2011 | 9/30/2016 | 37.609899 | -96.028059 |
| KS0029076 | SEVERY WASTE WATER TREATMENT FACILITY C/O CITY HALL | GREENWOOD | 4/1/2011 | 3/31/2016 | 37.621030 | -96.226810 |
| KS0089583 | APAC-KANSAS, INC SHEARS DIV | GREENWOOD | 1/1/2012 | 12/31/2016 | 37.628694 | -96.059389 |
| KS0090263 | MARTIN MARIETTA (SEVERY/BLAKE) | GREENWOOD | 1/1/2012 | 12/31/2016 | 37.634194 | -96.179556 |
| KSR106882 | COYVILLE QUARRY | WOODSON | 3/2/2012 | 3/1/2017 | 37.657331 | -95.905727 |
| KSR108137 | COYVILLE QUARRY | WOODSON | 3/2/2012 | 3/1/2017 | 37.657331 | -95.905727 |
| KS0099848 | BHR SHALE QUARRY | WILSON | 11/1/2013 | 10/31/2018 | 37.668553 | -95.791107 |
| KS0088374 | MICRO-LITE, L.L.C. | WILSON | 5/1/2006 | 4/30/2011 | 37.708596 | -95.704740 |
| KS0094722 | BUFFALO WASTE WATER TREATMENT PLANT C/O CITY HALL | WILSON | 7/1/2011 | 6/30/2016 | 37.710931 | -95.698692 |
| KS0089788 | KDWP - CROSS TIMBERS - HONOR CAMP | WOODSON | 10/1/2011 | 9/30/2016 | 37.744690 | -95.906740 |

Table 14 EPA NPDES Facilities Having DMR Data

| NPDES ID | FACILITY NAME | COUNTY NAME | PERMIT_ISS | PERMIT_EXP | Latitude | Longitude |
|---|---|---|---|---|---|---|
| **Kansas** | | | | | | |
| KS0000248 | COFFEYVILLE RESOURCES REFINING & MARKETING | MONTGOMERY | 12/1/2012 | 11/30/2017 | 37.04 | -95.61 |
| KS0001210 | HEARTLAND CEMENT CO DBA BUZZI UNICEM USA | MONTGOMERY | 2/1/2006 | 1/31/2011 | 37.21 | -95.68 |
| KS0095486 | INDEPENDENCE WASTEWATER PLANT PLANT MANAGER | MONTGOMERY | 12/1/2012 | 12/31/2016 | 37.23 | -95.69 |
| KS0099333 | MAGELLAN PIPELINE CO. -INDEPENDENCE | MONTGOMERY | 9/1/2013 | 12/31/2017 | 37.26 | -95.72 |
| KS0094803 | CHERRYVALE WASTEWATER PLANT WADE WEBBER, PUBLIC WORKS DIR. | MONTGOMERY | 7/1/2011 | 6/30/2016 | 37.28 | -95.58 |
| KS0096385 | BP PRODUCTS N. AMERICA, INC. | WILSON | 3/1/2012 | 2/28/2017 | 37.43 | -95.69 |
| KS0025658 | NEODESHA, CITY OF | WILSON | 7/1/2011 | 6/30/2016 | 37.43 | -95.68 |
| KS0027511 | ALTOONA SEWER TREATMENT PLANT C/O CITY HALL | WILSON | 8/1/2011 | 6/30/2016 | 37.52 | -95.66 |
| KS0045985 | FREDONIA WASTE WATER TREATMENT PLANT C/O CITY HALL | WILSON | 10/1/2012 | 12/31/2016 | 37.53 | -95.83 |
| KS0050733 | COFFEYVILLE, CITY OF | MONTGOMERY | 10/1/2012 | 9/30/2016 | 37.01 | -95.61 |
| **Oklahoma** | | | | | | |
| OK0045349 | ROGERS CO RWD # 3 | ROGERS | 7/14/2011 | 7/31/2016 | 36.42 | -95.66 |
| OK0045357 | RWD #4 ROGERS CO. WTP | ROGERS | 7/14/2011 | 7/31/2016 | 36.44 | -95.67 |
| OKG040022 | PHOENIX COAL CO.-ALLUWE NO. 2 | ROGERS | 11/12/2013 | 10/31/2018 | 36.59 | -95.49 |
| OKG040028 | PHOENIX COAL CO., INC.-KELLY RANCH MINE | CRAIG | 11/15/2013 | 10/31/2018 | 36.65 | -95.39 |
| OK0045829 | APAC-CENTRAL-NOWATA QUARRY | NOWATA | 6/7/2011 | 6/30/2016 | 36.70 | -95.58 |
| OK0025470 | NOWATA | NOWATA | 6/26/2012 | 6/30/2017 | 36.71 | -95.63 |
| OKP003004 | BRENNTAG SOUTHWEST INC NOWA TA | NOWATA | 3/16/2010 | 3/31/2015 | 36.72 | -95.63 |
| OK0020796 | DELAWARE | NOWATA | 8/10/2012 | 8/31/2017 | 36.78 | -95.63 |
| OK0020117 | SOUTH COFFEYVILLE WWT | NOWATA | 12/7/2011 | 12/31/2016 | 37.00 | -95.61 |

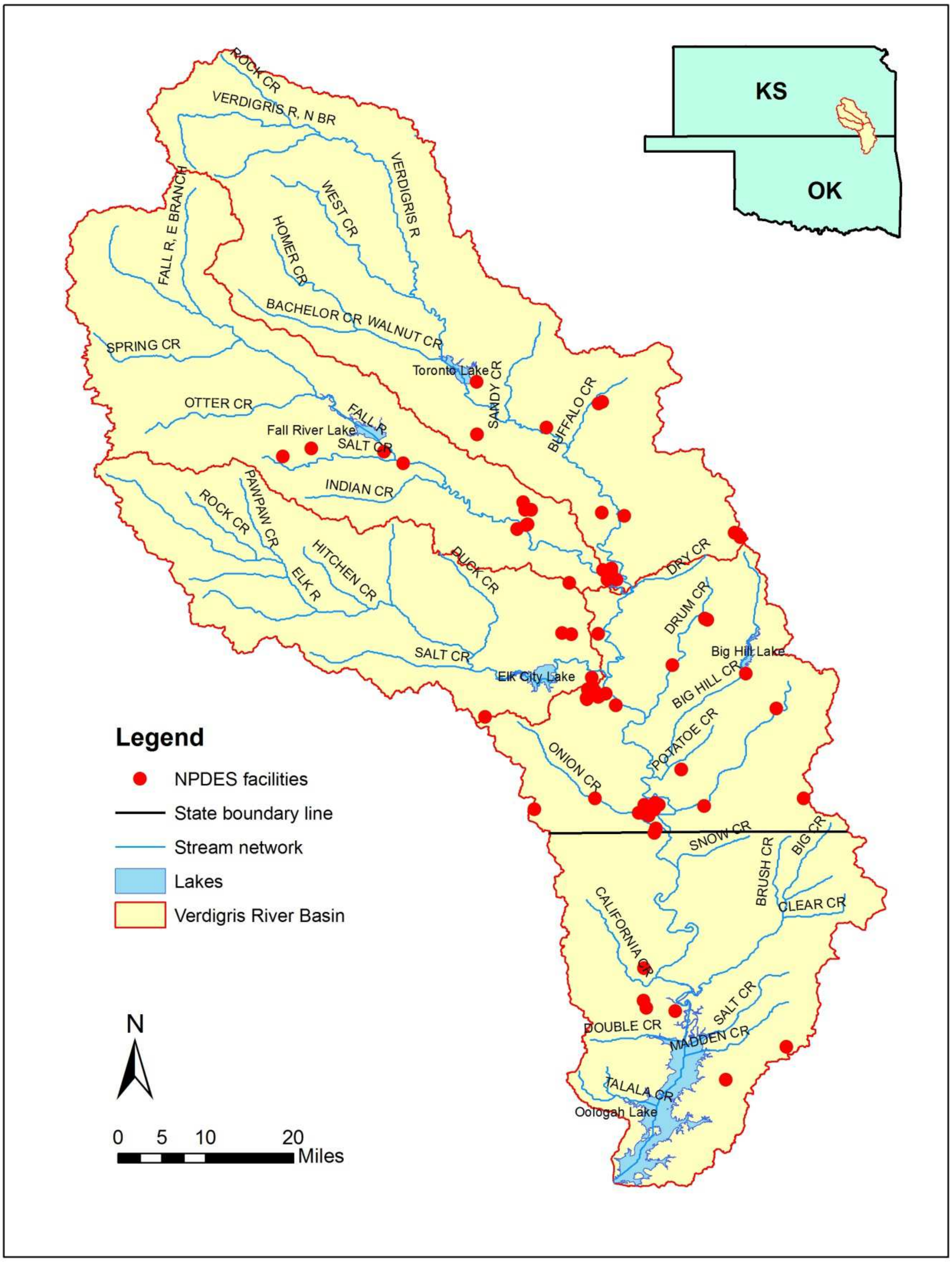


Figure 11 Locations of EPA NPDES Facilities

# 3. Data Collection and Evaluation for EFDC Lake Model

The setup of a hydrodynamic and water quality model for Lake Oologah using EFDC includes the following procedure.

- Develop the model grids to capture the lateral and longitudinal variations in water quality constituents based on the shoreline boundary;
- Interpolate the bathymetry data to the entire modeling domain;
- Check the depth-storage relationship with the observed data;
- Determine the number of vertical layers to capture the vertical variations in water quality constituents;
- Collect and process the meteorological data;
- Create the flow boundaries from the dam, major tributaries, and overland runoff and develop the time series data of flow and water quality constituents as the boundary conditions;
- Create the flow boundaries from the NPDES facilities and develop the time series data of flow and water quality constituents as the boundary conditions;
- Create the flow boundaries from the water withdrawal structures and develop the time series data of flow as the boundary condition;
- Check the flow balance and create another flow boundary for balanced flow;
- Calibrate the lake model in the sequence of stage, water temperature, total suspended sediment, nutrient, chlorophyll a, and dissolved oxygen; and
- Validate the model.

## 3.1 Shoreline and Bathymetry Data

The shore data of Lake Oologah can be downloaded from the USGS website. Although OWRB has systematically collected bathymetric data for many lakes in Oklahoma, a bathymetric survey for Lake Oologah is not listed on the OWRB website. The bathymetry data of Lake Oologah can be obtained from the Lake Oologah Watershed Assessment Study (USACE and City of Tulsa, 2012).

## 3.2 Meteorological Data

There are four NOAA NCDC stations and six Oklahoma MESONET stations around the Lake Oologah, as shown in Figure 6. Data from these stations will be adequate to capture the spatial variations in the meteorological factors for hydrodynamic modeling.

## 3.3 Stage and Dam Release Data

The stage data and discharge release from Lake Oologah is downloaded from the Tulsa District of USACE (http://www.swt-wc.usace.army.mil/OOLO.lakepage.html) (Figure 12). The daily stage and discharge data are available beginning January of 1994. The stage data is used to calibrate and validate the EFDC model. Discharge data can be used to develop the flow boundary condition for the lake EFDC model. The stage-volume data are also available to compare with the EFDC model.

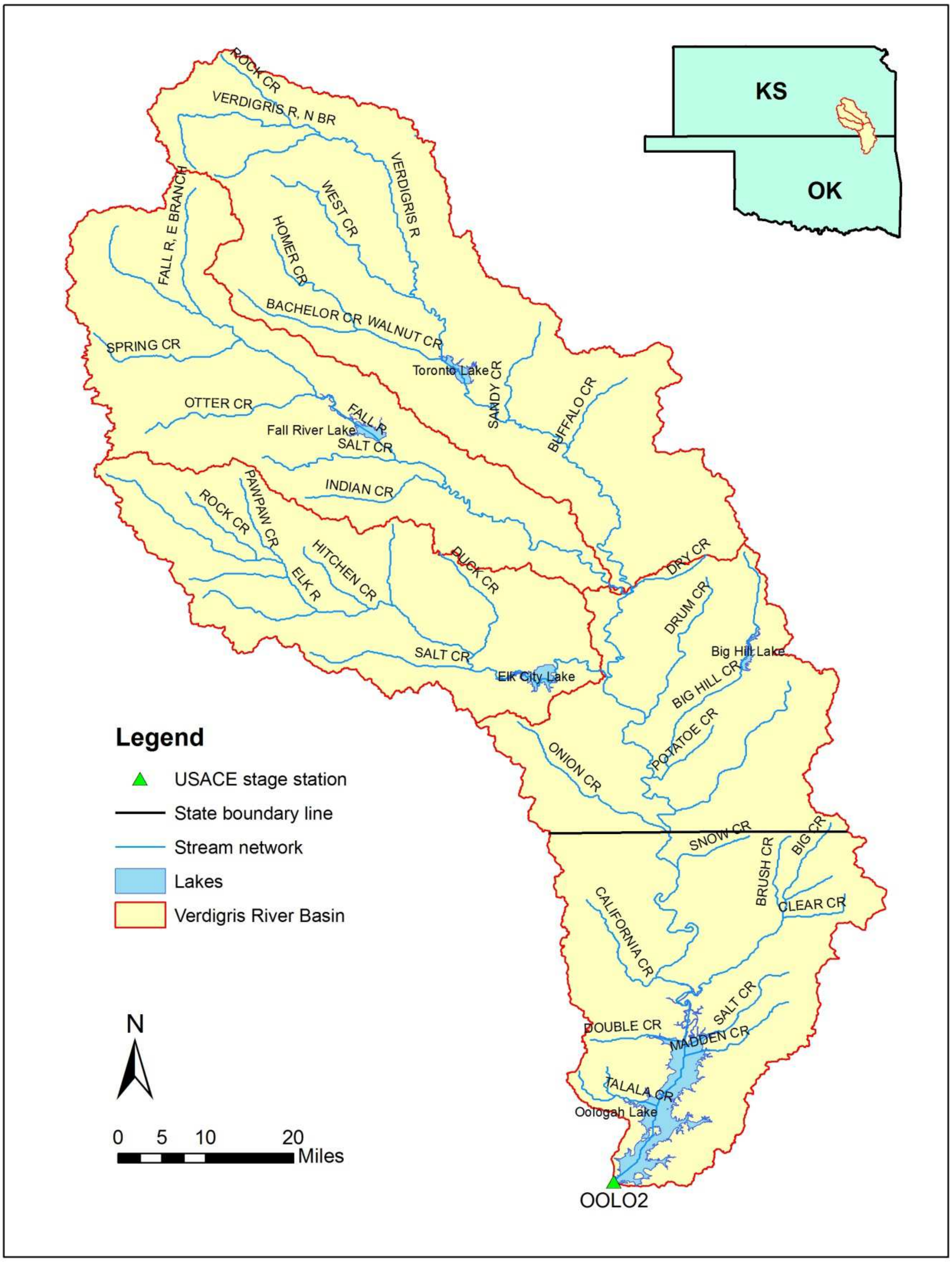


Figure 12 Location of UASCE Stage Station

## 3.4 NPDES Data

There are no industrial or domestic wastewater discharging into the Lake Oologah. Two water supply permits from Lake Oologah are issued. These two permits are from NPDES facilities of OK0045349 and OK0045357, as shown in Figure 13.

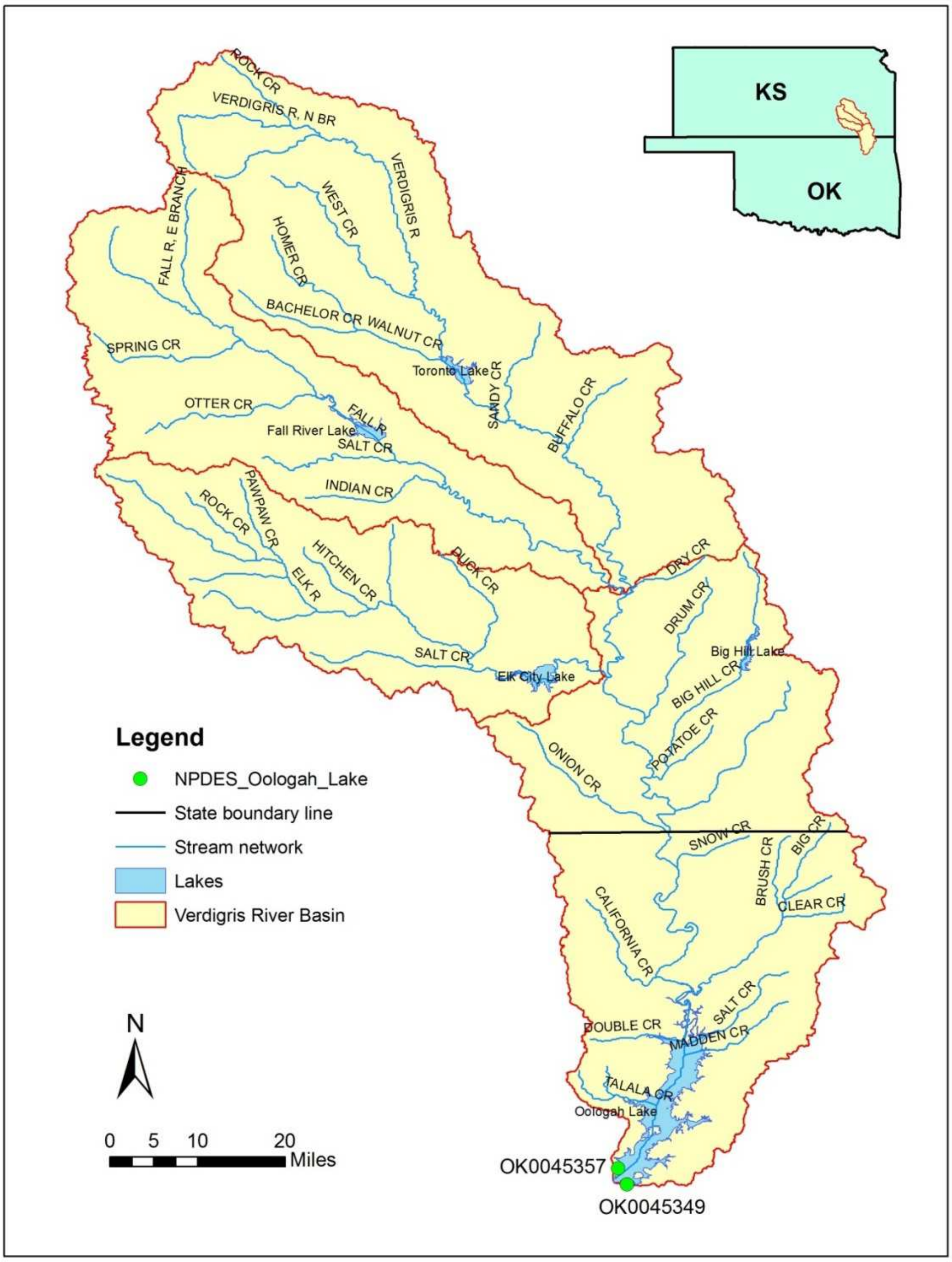


Figure 13 Locations of EPA NPDES Facilities in Lake Oologah

## 3.5 Water Quality Data

### *3.5.1 Oklahoma Water Resources Board (OWRB)*

The water quality data are available at seven OWRB stations, as shown in Figure 14. For the station located in the forebay area (121510010020-01), the data are observed at both surface and bottom layers. For the other six stations, water quality data are only available at the surface layer.

Detailed summary of the OWRB data during 2003 to 2014 is given in Table 15. In most cases, the number of observed data for one particular water quality constituent is less than 5. Hence, the OWRB data can be used for the visual comparison between EFDC model and observed data.

Table 15 Summary of OWRB Water Quality Data in Lake Oologah

| OWRB Stations | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **121510010020-01B** | | | | | | | | | | | | |
| Chlorophyll a | 1 | 1 | 1 | | 1 | 3 | | | | | | |
| Nitrogen, Ammonia | 3 | 2 | 1 | | | | | | | | | |
| Nitrogen, Kjeldahl | 3 | 2 | 1 | | | | | | | | | |
| Nitrogen, Nitrate as N | 3 | 2 | 1 | | | | | | | | | |
| Nitrogen, Nitrite as N | 3 | 2 | 1 | | | | | | | | | |
| Phosphorous, Ortho | 3 | 2 | 1 | | | | | | | | | |
| Phosphorous, Total | 3 | 2 | 1 | | | | | | | | | |
| Secchi Depth | | 2 | 1 | | | | | | | | | |
| Turbidity, Field | | 2 | 1 | | | | | | | | | |
| **121510010020-01S** | | | | | | | | | | | | |
| Chlorophyll a | 6 | 2 | 3 | | 2 | 6 | | | 2 | 6 | 2 | 4 |
| Nitrogen, Ammonia | 8 | 2 | 9 | | | | | | | | | |
| Nitrogen, Kjeldahl | 8 | 2 | 9 | | 1 | 8 | | | 2 | 6 | 2 | 4 |
| Nitrogen, Nitrate as N | 8 | 2 | 3 | | | | | | | | | |
| Nitrogen, Nitrate/Nitrite as N | | | 6 | | 1 | 8 | | | 2 | 6 | 2 | 4 |
| Nitrogen, Nitrite as N | 8 | 2 | 3 | | | | | | | | | |
| Nitrogen, Total | | | | | | | | | | | 2 | 4 |
| Phosphorous, Ortho | 8 | 2 | 9 | | 1 | 8 | | | | | | |
| Phosphorous, Total | 8 | 2 | 9 | | 1 | 8 | | | 2 | 6 | 2 | 4 |
| Secchi Depth | | 1 | 6 | | | | | | 1 | 3 | 1 | 2 |
| Turbidity, Field | | 1 | 6 | | | | | | | 6 | 2 | 4 |
| **121510010020-02** | | | | | | | | | | | | |
| Chlorophyll a | 3 | 1 | 2 | | 1 | 3 | | | 1 | 3 | 1 | 2 |
| Nitrogen, Ammonia | 3 | 1 | 3 | | | | | | | | | |
| Nitrogen, Kjeldahl | 3 | 1 | 3 | | 1 | 3 | | | 1 | 3 | 1 | 2 |
| Nitrogen, Nitrate as N | 3 | 1 | 1 | | | | | | | | | |
| Nitrogen, Nitrate/Nitrite as N | | | 2 | | 1 | 3 | | | 1 | 3 | 1 | 2 |
| Nitrogen, Nitrite as N | 3 | 1 | 1 | | | | | | | | | |
| Nitrogen, Total | | | | | | | | | | | 1 | 2 |
| Phosphorous, Ortho | 3 | 1 | 3 | | 1 | 3 | | | | | | |
| Phosphorous, Total | 3 | 1 | 3 | | 1 | 3 | | | 1 | 3 | 1 | 2 |

| OWRB Stations | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Secchi Depth | | 1 | 3 | | | | | | 1 | 3 | 1 | 1 |
| Turbidity, Field | | 1 | 3 | | | | | | | 3 | 1 | 2 |
| **121510010020-03** | | | | | | | | | | | | |
| Chlorophyll a | 3 | 1 | 2 | | 1 | 3 | | | 1 | 2 | 1 | 2 |
| Nitrogen, Ammonia | 3 | 1 | 3 | | | | | | | | | |
| Nitrogen, Kjeldahl | 3 | 1 | 3 | | 1 | 3 | | | 1 | 3 | 1 | 2 |
| Nitrogen, Nitrate as N | 3 | 1 | 1 | | | | | | | | | |
| Nitrogen, Nitrate/Nitrite as N | | | 2 | | 1 | 3 | | | 1 | 3 | 1 | 2 |
| Nitrogen, Nitrite as N | 3 | 1 | 1 | | | | | | | | | |
| Nitrogen, Total | | | | | | | | | | | 1 | 2 |
| Phosphorous, Ortho | 3 | 1 | 3 | | 1 | 3 | | | | | | |
| Phosphorous, Total | 3 | 1 | 3 | | 1 | 3 | | | 1 | 3 | 1 | 2 |
| Secchi Depth | | 1 | 3 | | | | | | 1 | 3 | 1 | 2 |
| Turbidity, Field | | 1 | 3 | | | | | | | 3 | 1 | 2 |
| **121510010020-04** | | | | | | | | | | | | |
| Chlorophyll a | 3 | 1 | 2 | | 1 | 3 | | | 1 | 3 | 1 | 2 |
| Nitrogen, Ammonia | 3 | 1 | 3 | | | | | | | | | |
| Nitrogen, Kjeldahl | 3 | 1 | 3 | | 1 | 3 | | | 1 | 3 | 1 | 2 |
| Nitrogen, Nitrate as N | 3 | 1 | 1 | | | | | | | | | |
| Nitrogen, Nitrate/Nitrite as N | | | 2 | | 1 | 3 | | | 1 | 3 | 1 | 2 |
| Nitrogen, Nitrite as N | 3 | 1 | 1 | | | | | | | | | |
| Nitrogen, Total | | | | | | | | | | | 1 | 2 |
| Phosphorous, Ortho | 3 | 1 | 3 | | 1 | 3 | | | | | | |
| Phosphorous, Total | 3 | 1 | 3 | | 1 | 3 | | | 1 | 3 | 1 | 2 |
| Secchi Depth | | 1 | 3 | | | | | | 1 | 3 | 1 | 2 |
| Turbidity, Field | | 1 | 3 | | | | | | | 3 | 1 | 2 |
| **121510010020-05** | | | | | | | | | | | | |
| Chlorophyll a | 3 | 1 | 2 | | 1 | 3 | | | 1 | 3 | 1 | 2 |
| Nitrogen, Ammonia | 3 | 1 | 3 | | | | | | | | | |
| Nitrogen, Kjeldahl | 3 | 1 | 3 | | 1 | 3 | | | 1 | 3 | 1 | 2 |
| Nitrogen, Nitrate as N | 3 | 1 | 1 | | | | | | | | | |
| Nitrogen, Nitrate/Nitrite as N | | | 2 | | 1 | 3 | | | 1 | 3 | 1 | 2 |
| Nitrogen, Nitrite as N | 3 | 1 | 1 | | | | | | | | | |
| Nitrogen, Total | | | | | | | | | | | 1 | 2 |
| Phosphorous, Ortho | 3 | 1 | 3 | | 1 | 3 | | | | | | |
| Phosphorous, Total | 3 | 1 | 3 | | 1 | 3 | | | 1 | 3 | 1 | 2 |
| Secchi Depth | | 1 | 3 | | | | | | 1 | 3 | 1 | 2 |
| Turbidity, Field | | 1 | 3 | | | | | | | 3 | 1 | 2 |
| **121510010020-06** | | | | | | | | | | | | |
| Chlorophyll a | 2 | 1 | 2 | | 1 | 3 | | | 1 | 3 | 1 | 2 |
| Nitrogen, Ammonia | 2 | 1 | 3 | | | | | | | | | |
| Nitrogen, Kjeldahl | 2 | 1 | 3 | | 1 | 3 | | | 1 | 3 | 1 | 2 |
| Nitrogen, Nitrate as N | 2 | 1 | 1 | | | | | | | | | |
| Nitrogen, Nitrate/Nitrite as N | | | 2 | | 1 | 3 | | | 1 | 3 | 1 | 2 |
| Nitrogen, Nitrite as N | 2 | 1 | 1 | | | | | | | | | |
| Nitrogen, Total | | | | | | | | | | | 1 | 2 |

| OWRB Stations | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Phosphorous, Ortho | 2 | 1 | 3 | | 1 | 3 | | | | | | |
| Phosphorous, Total | 2 | 1 | 3 | | 1 | 3 | | | 1 | 3 | 1 | 2 |
| Secchi Depth | | 1 | 3 | | | | | | 1 | 3 | 1 | 2 |
| Turbidity, Field | | 1 | 3 | | | | | | | 3 | 1 | 2 |
| **121510010020-07** | | | | | | | | | | | | |
| Chlorophyll a | 2 | 1 | 2 | | 1 | 3 | | | 1 | 3 | 1 | 2 |
| Nitrogen, Ammonia | 2 | 1 | 3 | | | | | | | | | |
| Nitrogen, Kjeldahl | 2 | 1 | 3 | | 1 | 3 | | | 1 | 3 | 1 | 2 |
| Nitrogen, Nitrate as N | 2 | 1 | 1 | | | | | | | | | |
| Nitrogen, Nitrate/Nitrite as N | | | 2 | | 1 | 3 | | | 1 | 3 | 1 | 2 |
| Nitrogen, Nitrite as N | 2 | 1 | 1 | | | | | | | | | |
| Nitrogen, Total | | | | | | | | | | | 1 | 2 |
| Phosphorous, Ortho | 2 | 1 | 3 | | 1 | 3 | | | | | | |
| Phosphorous, Total | 2 | 1 | 3 | | 1 | 3 | | | 1 | 3 | 1 | 2 |
| Secchi Depth | | 1 | 3 | | | | | | 1 | 3 | | 2 |
| Turbidity, Field | | 1 | 3 | | | | | | | 3 | | 2 |

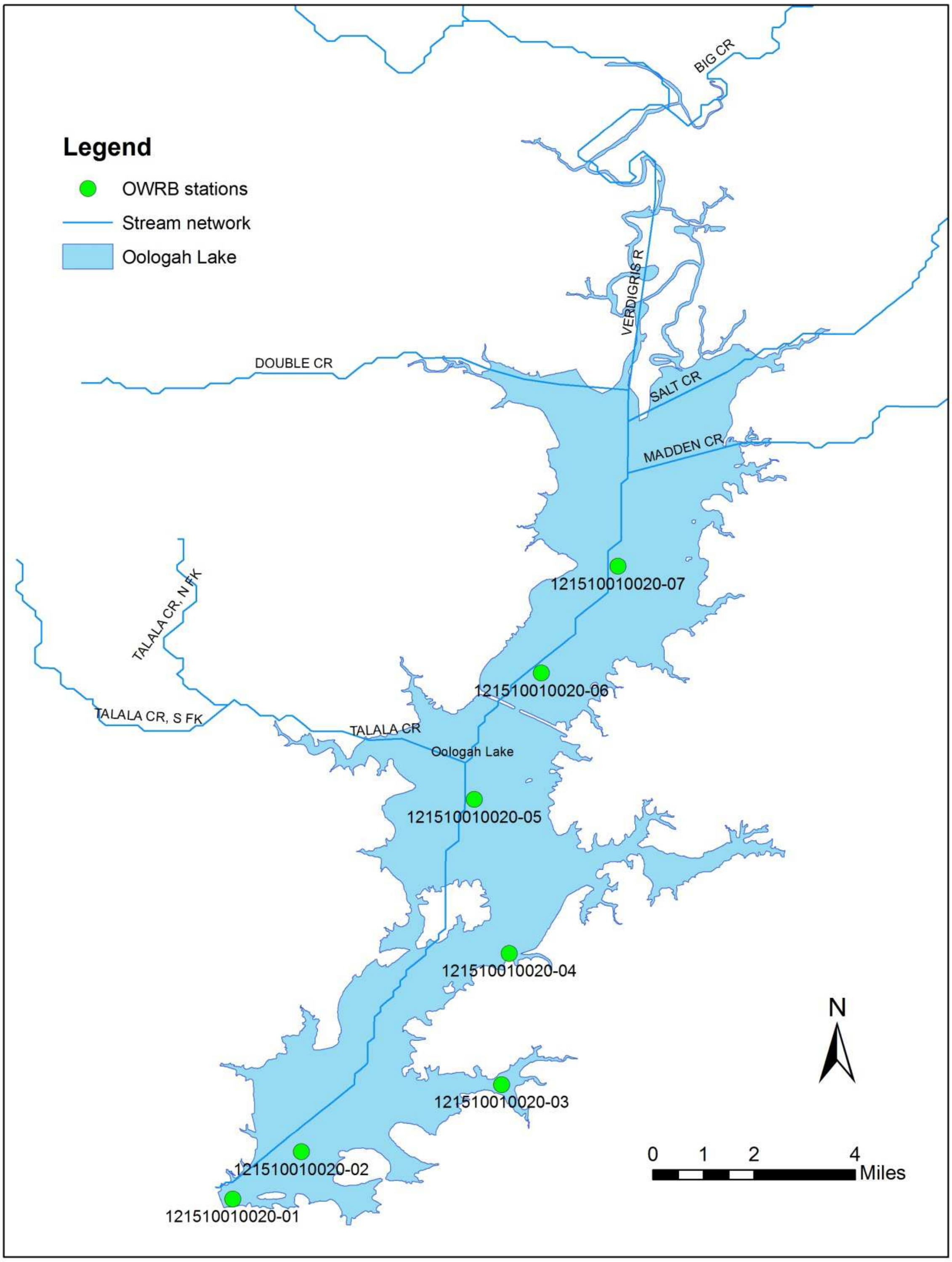


Figure 14 Locations of the OWRB Stations in Lake Oologah

### *3.5.2 United States Army Corps of Engineers (USACE)*

In Lake Oologah, the monthly water quality data are available during February of 2003 to April of 2009 at five stations by Lake Oologah Watershed Assessment Study (USACE and City of Tulsa, 2012). Locations of these five stations are given in Figure 15 and Table 16. Monitored water quality constituents are water temperature, total suspended solids, dissolved oxygen, ammonium, nitrate, total Kjeldahl nitrogen, total phosphorus, dissolved phosphate, total organic carbon, and chlorophyll a. At station OOL_1, there are observed water quality data at both surface and bottom layers.

Table 16 Information of the Observed Stations at Lake Oologah

| Station Code | Location Description | Latitude | Longitude |
|---|---|---|---|
| OOL_1 | Damsite at buoy line over river channel; most downstream site of the lake | 36.422333 | -95.677917 |
| OOL_2 | Upstream of OOL_1; by Goose Island | 36.493650 | -95.610233 |
| OOL_3 | Upstream of OOL_2; approximately 1 km downstream of Wigdon Bridge | 36.554933 | -95.599417 |
| OOL_4 | Upstream of OOL_3; west of Highway 28 Bridge | 36.599883 | -95.575833 |
| OOL_5 | Mouth of Double Creek Cove; most upstream site of the lake | 36.649633 | -95.579333 |

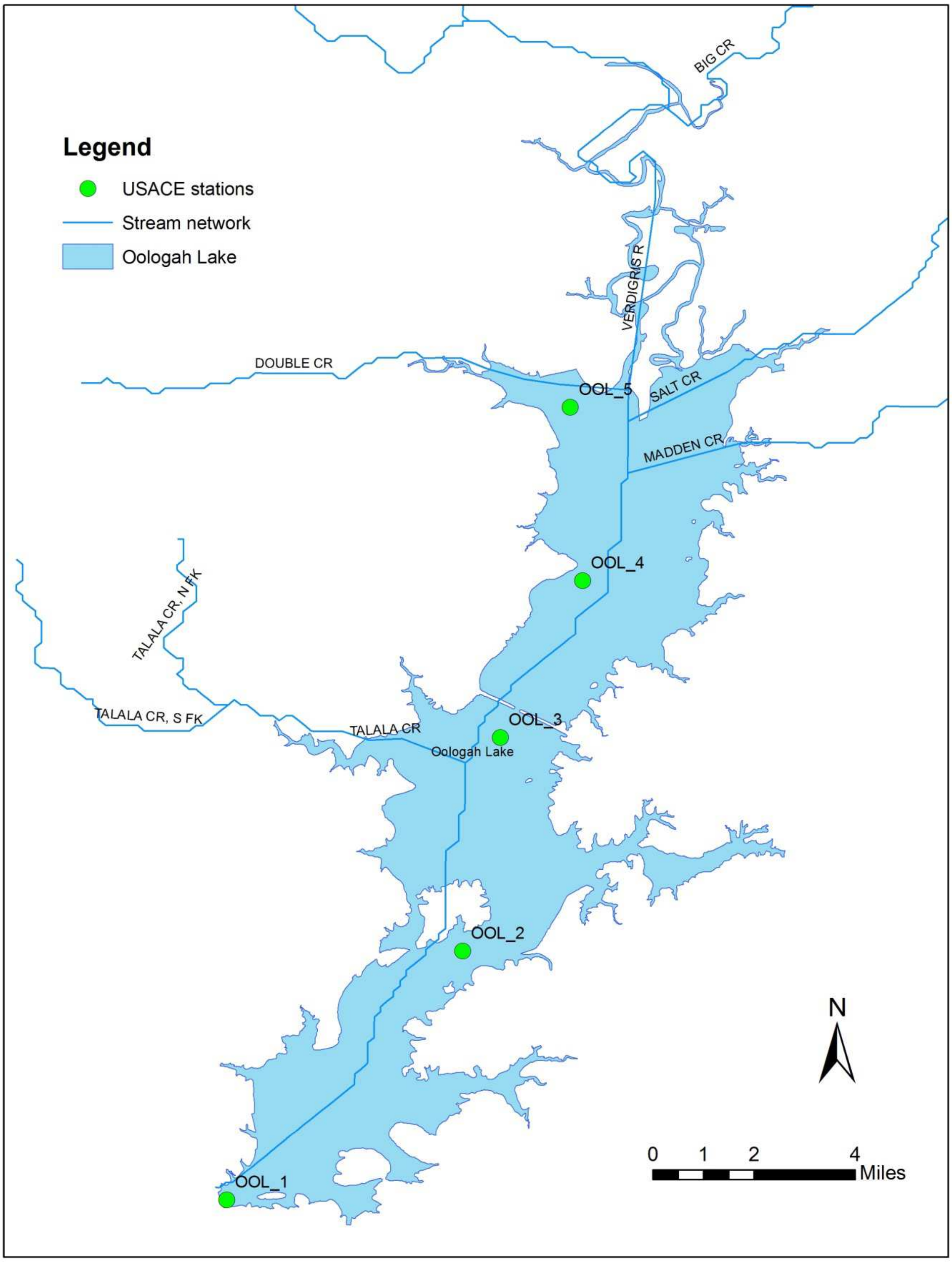


Figure 15 Locations of the USACE Stations in Lake Oologah

## 3.6 Sediment Bed Chemistry Data

For the Lake Oologah Watershed Assessment Study (USACE and City of Tulsa, 2012), the sediment chemistry data were collected in 2000 and 2001 at the routine Lake Oologah water quality sampling sites, as shown in Figure 16. The collected parameters useful for the lake sediment diagenesis modeling are total phosphorus, total nitrogen, and total organic carbon contents in sediment. These sediment chemistry data can be used to set up the initial conditions for sediment diagenesis simulation.

## 3.7 Nutrient Atmospheric Deposition Data

Since lakes have large surface area, the nutrient from atmospheric deposition might be an important contributor. The nutrient data from dry atmospheric deposition are available at Clean Air Status and Trends Network (CASTNET) Station CHE185 (Figure 16). Nutrient data from wet atmospheric deposition are available at station AR27 by National Atmospheric Deposition Program (NADP) (Figure 16), which is the closest NADP station having complete data. Detailed information of these two stations is given in Table 17.

Table 17 Information of the Observed Stations for Atmospheric Deposition

| Site Name | Program | Site ID | Latitude | Longitude | County | State |
|---|---|---|---|---|---|---|
| Cherokee Nation | CASTNET | CHE185 | 35.751 | -94.670 | Adair | OK |
| Fayetteville | NADP/NTN | AR27 | 36.101 | -94.174 | Washington | AR |

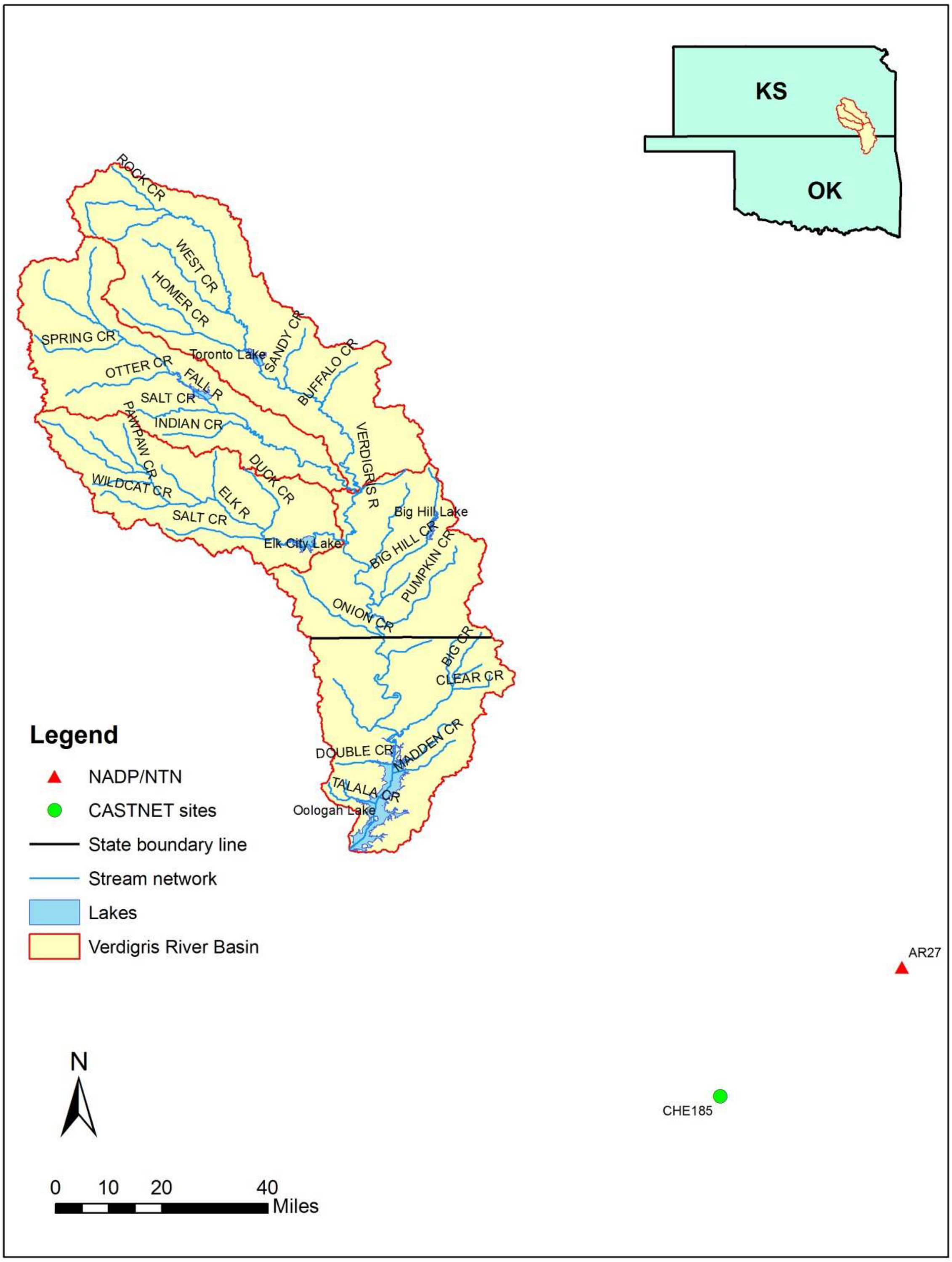


Figure 16 Locations of the EPA CASTNET Station and NADP/NTP Station

# 4. Proposed Periods For Lake and Watershed Models

## 4.1 Proposed Periods for Watershed Mode

One unique characteristic of the Verdigris River Basin is that there are four federal reservoirs in the upstream of Verdigris River: Toronto Lake, Fall River Lake, Elk City Lake, and Big Hill Lake. These reservoirs receive the nutrients from the upstream Verdigris River Basin and then discharge into the downstream river by regulated dam release.

Watershed model HSPF is not the suitable tool to simulate the nutrient cycle in these lakes and the export of nutrients from these lakes to the Verdigris River. Watershed model HSPF will be used to simulate the uncontrolled sections of the Verdigris River Basin, downstream areas of these four federal reservoirs.

Instead of explicitly modeling the nutrient export from these lakes to the downstream Verdigris River, observed dam discharge and water quality data can be used to develop the upstream boundary condition for the watershed model of HSPF.

The hourly dam release and monthly water quality data are available during February of 2003 to April of 2009 by Lake Oologah Watershed Assessment Study (USACE and City of Tulsa, 2012). Any consecutive three years during 2003 to 2008 can be the modeling period of watershed model.

An important factor of choosing the watershed modeling period is the hydrologic conditions. It is the best that the modeling period covers the dry, normal, and wet conditions. Annual rainfall data during 1999 to 2014 at Coffeyville Municipal Airport are given in Table 18 and Figure 18. The location of Coffeyville Municipal Airport is shown in Figure 6.

Period of 2005 to 2007 was selected as the modeling period of watershed model HSPF because this period covers dry, wet, and close to normal hydrological conditions (Figure 18). Year 2006 is a dry year, with annual rainfall of 30.06 inches, corresponding to 10$^{th}$ percentile of annual rainfall during 1999 to 2014. Year 2007 is a wet year, with annual rainfall of 53.18 inches, corresponding to over 90$^{th}$ percentile value. Year 2005 is close to normal year, with annual rainfall of 35.26 inches, close to the median annual rainfall of 36.5 inches.

## 4.2 Proposed Periods for Lake Model

For Lake Oologah, important nutrient contributors are atmospheric deposition, internal sediment diagenesis, and the Verdigris River and surrounding watersheds. There are only two water supply NPDES facilities in Lake Oologah, and there are no municipal and industrial NPDES permits to discharge nutrients into Lake Oologah.

For the lake modeling of nutrient cycle using EFDC, the atmospheric deposition data are available at EPA CASTNET and NADP/NTP stations. The sediment chemistry data from Lake Oologah Watershed Assessment Study (USACE and City of Tulsa, 2012) are available to define the initial conditions for modeling the sediment diagenesis.

The nutrient contributions from the Verdigris River and surrounding watersheds is determined by watershed modeling of nutrient cycle in the Verdigris River Basin using HSPF. Hence, the calibration and validation periods of the Oologah Lake EFDC model is determined by the watershed modeling periods.

As stated in Section 4.1, watershed modeling period is narrowed down to 2005 to 2007. Since year 2006 is a dry year and year 2007 is a wet year, these two years are selected as the lake EFDC model calibration and validation periods.

Table 18 Annual Rainfall During 2003 to 2014 at Coffeyville Municipal Airport

| Year | Rainfall |
|---|---|
| 1999 | 40.14 |
| 2000 | 37.01 |
| 2001 | 29.25 |
| 2002 | 35.60 |
| 2003 | 49.35 |
| 2004 | 42.37 |
| 2005 | 35.26 |
| 2006 | 30.06 |
| 2007 | 53.18 |
| 2008 | 54.46 |
| 2009 | 49.09 |
| 2010 | 36.01 |
| 2011 | 40.17 |
| 2012 | 32.17 |
| 2013 | 35.84 |
| 2014 | 26.64 |

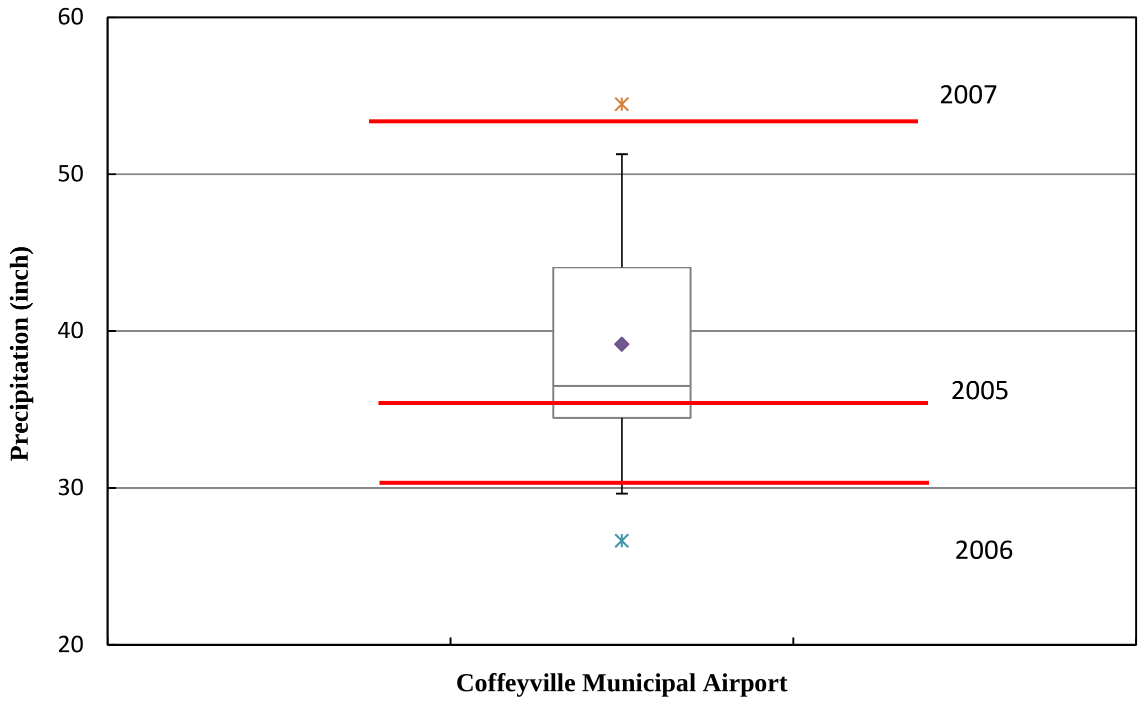


Figure 17 Box-whisker Plot of Precipitation During 2003 to 2014 at Coffeyville Municipal Airport

# 5. SUMMARY

The objective of this data acquisition project is to assess the data availability for the development of watershed HSPF model of the Verdigris River Basin and EFDC model of Lake Oologah and propose the best modeling periods having enough data to define the boundary conditions.

Watershed modeling domain will be limited to the uncontrolled section of the Verdigris River Basin. Dam discharge and monthly water quality data during February of 2003 to April of 2009 from the four federal reservoirs are available by Lake Oologah Watershed Assessment Study (USACE and City of Tulsa, 2012). The modeling period for the watershed model HSPF was chosen from 2005 to 2007, which covers the dry, wet, and close to normal hydrologic conditions. The modeling calibration and validation period for the EFDC model was determined to be 2006 and 2007.

# 6. References

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