Watershed & Water Quality Modeling Framework for the Harpeth River Watershed

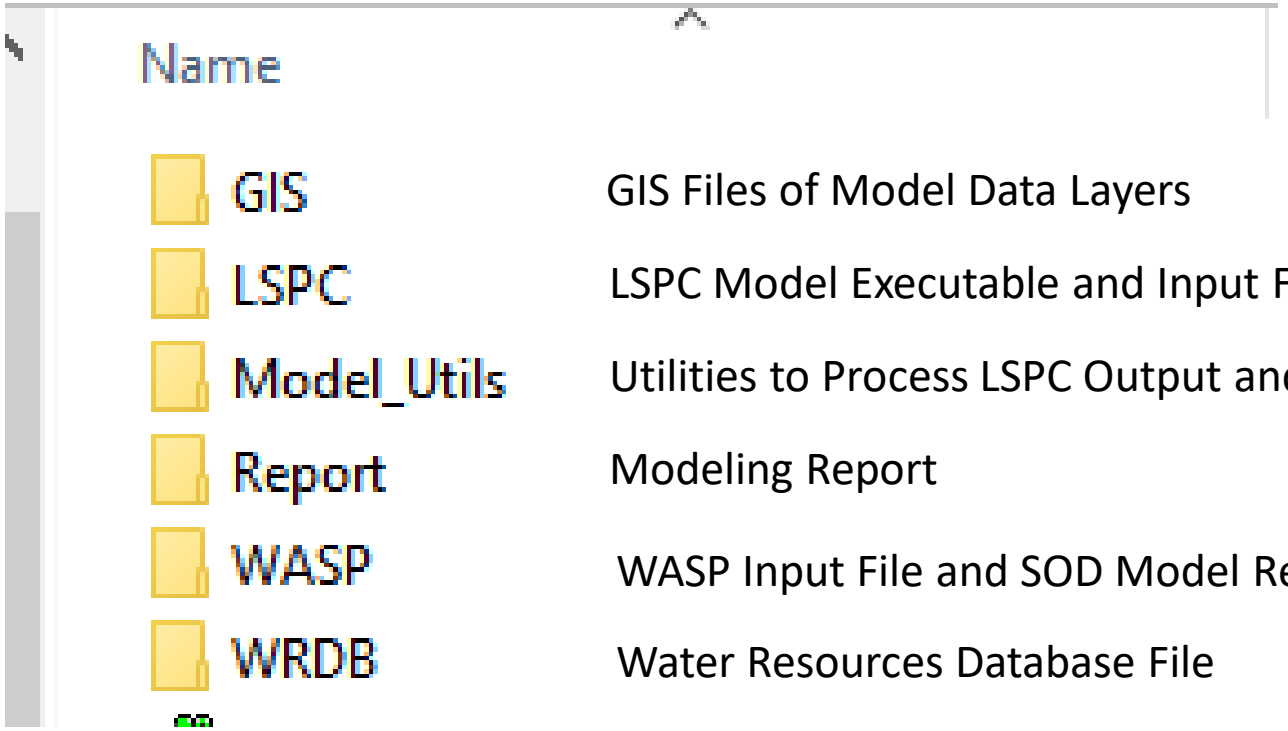
EPA Region 4 Modelers

- Project Lead – Tim Wool, wool.tim@epa.gov
- Watershed Model -- Glenn Fernandez
- Point Source & Ambient Monitoring – John Davis

Objectives

- Overview of Data Sources
- Overview of the Modeling Framework
- Description of the Modeling Package
  - Reports
  - Database Management
  - Watershed Model (LSPC)
  - Water Quality Model (WASP)
- Calibration Objectives/Results
- Next Steps

Content of Modeling Package



GIS Files of Model Data Layers

LSPC Model Executable and Input Files

Utilities to Process LSPC Output and WASP Tools

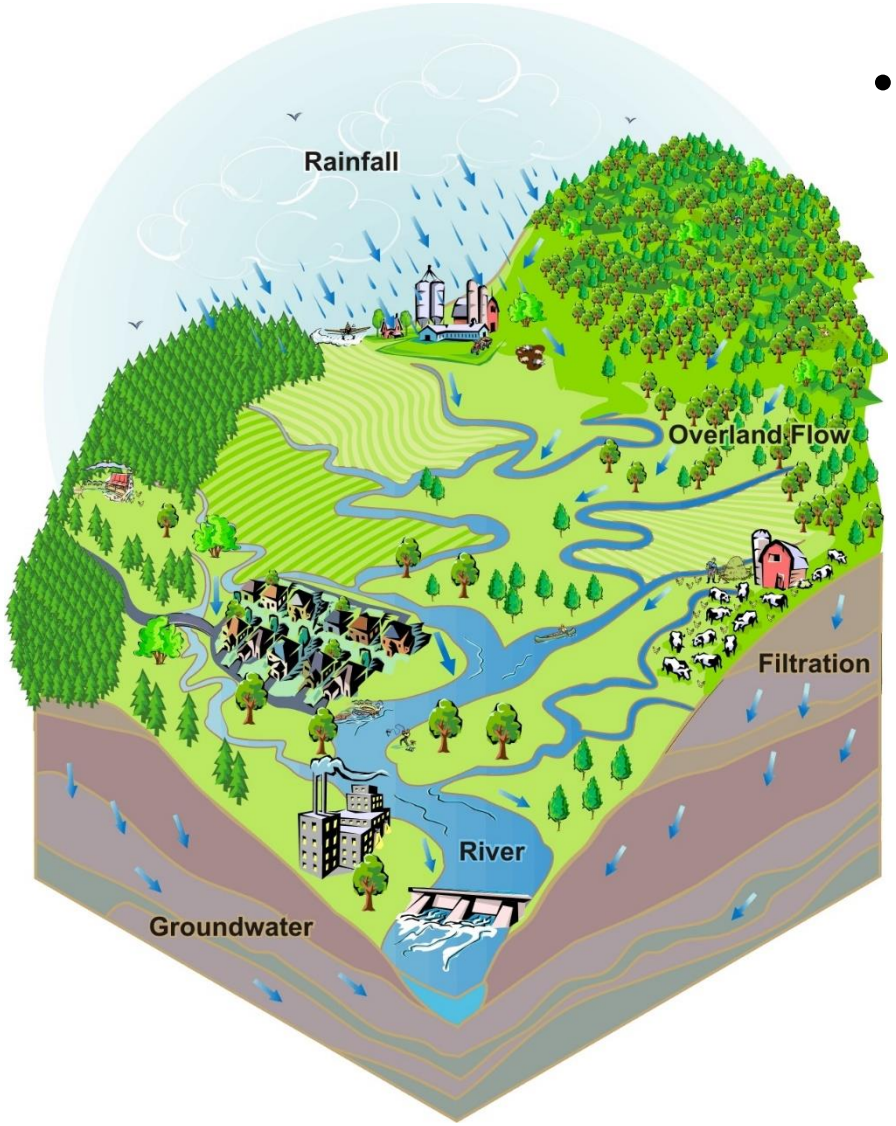
Modeling Report

WASP Input File and SOD Model Restart File

Water Resources Database File

WATERSHED MODEL

Why a Watershed Model

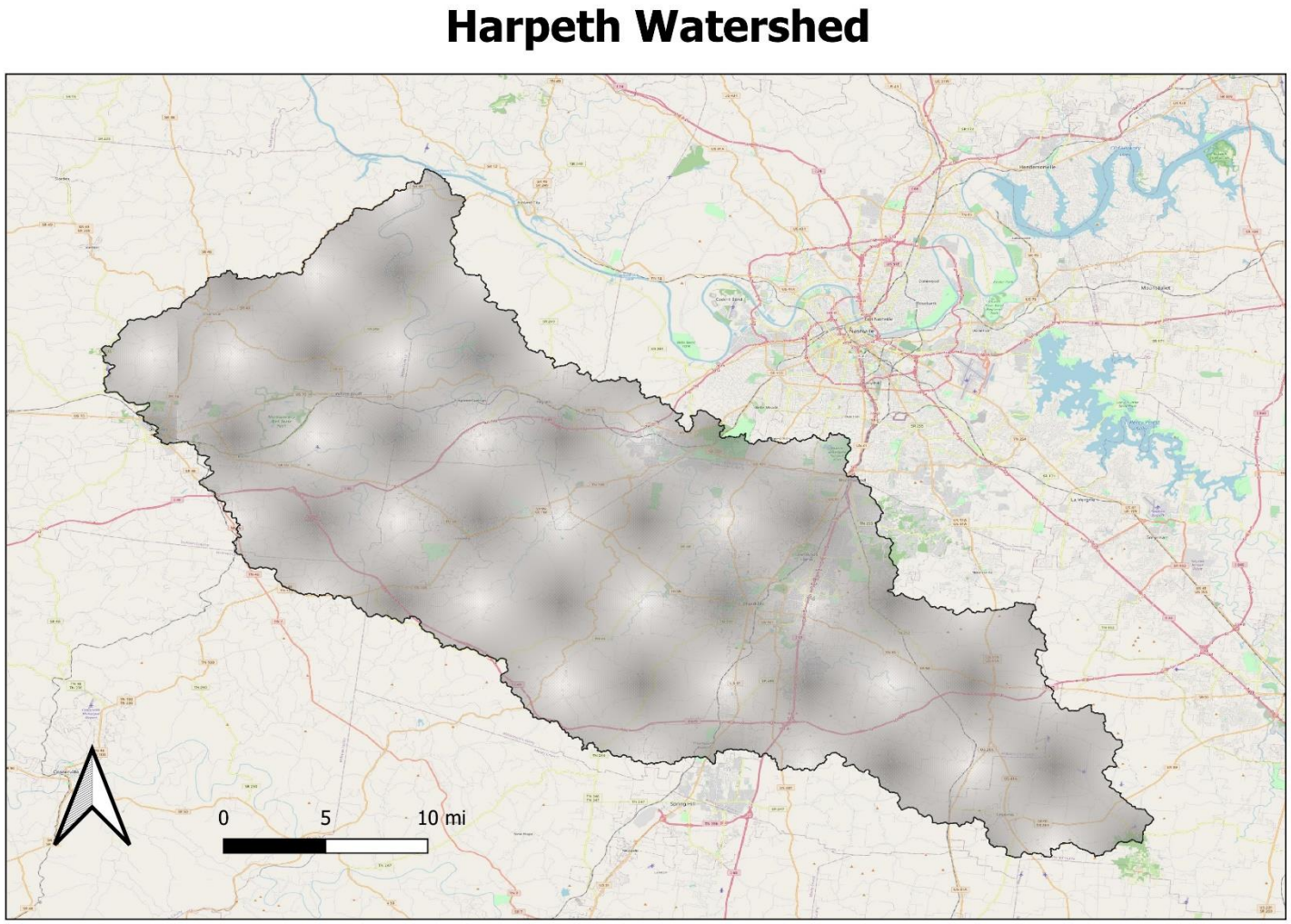


- Provides Linkage between meteorological Events
  - Non-Point Source Loading
    - Diffuse loadings from Landuse Practices
  - Flow contribution to Harpeth River
    - Land Surface Runoff
    - Interflow
    - Groundwater/Base Flow

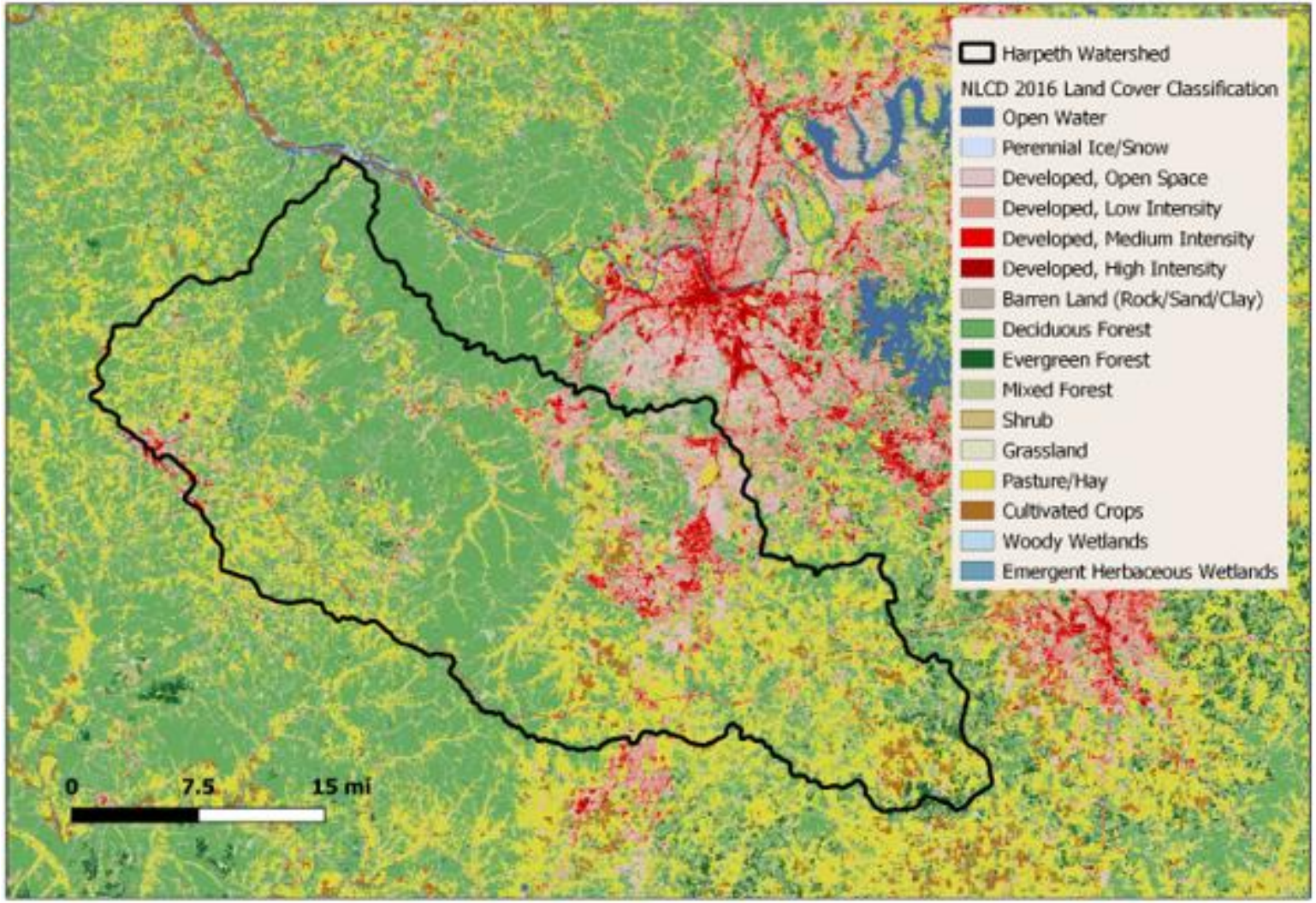
LSPC Watershed Model

- Simulates Daily Non-Point Source Loads
  - Flow
  - Total Nitrogen
  - Total Phosphorus
  - CBOD
  - Inorganic Solids
  - Dissolved Oxygen
  - Water Temperature

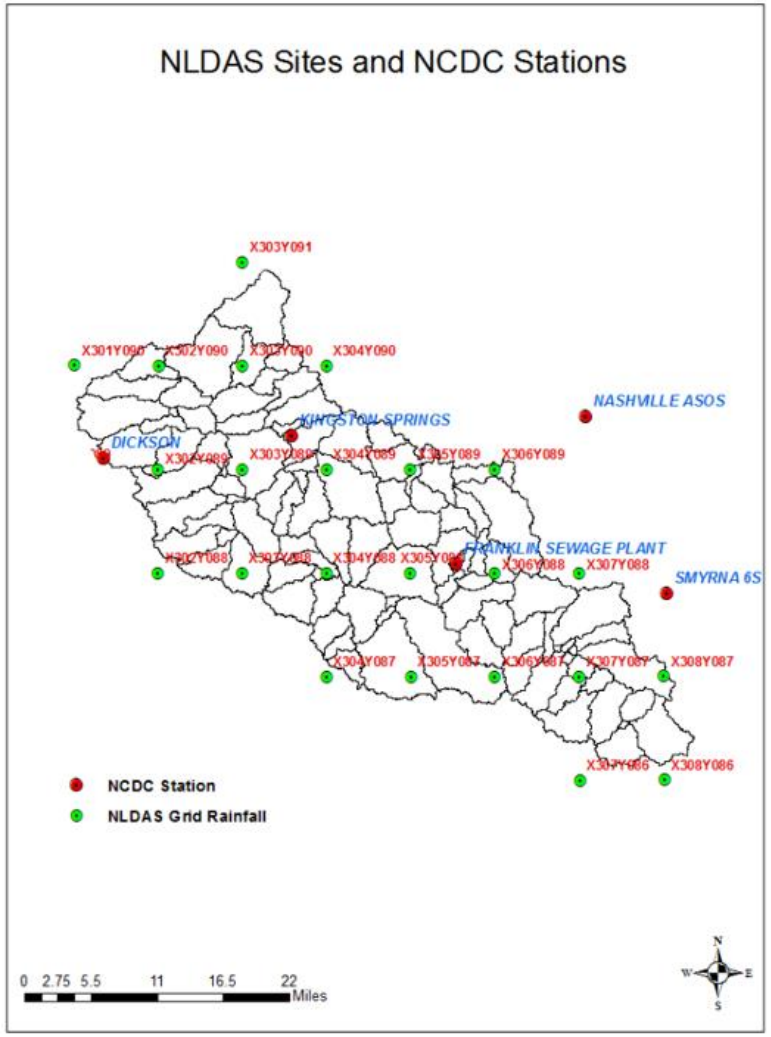
Area of the Harpeth River Models



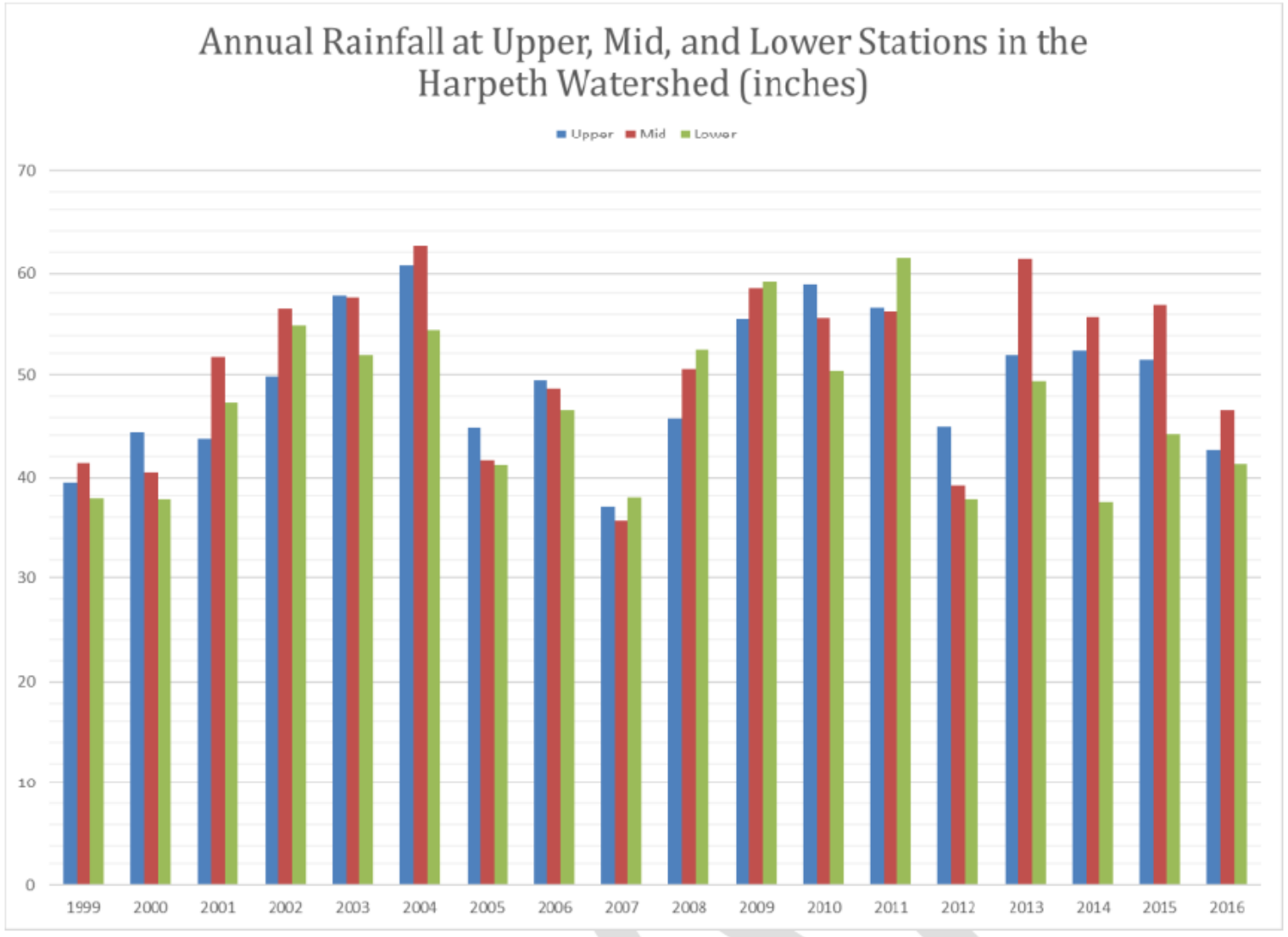
Landuse Classification



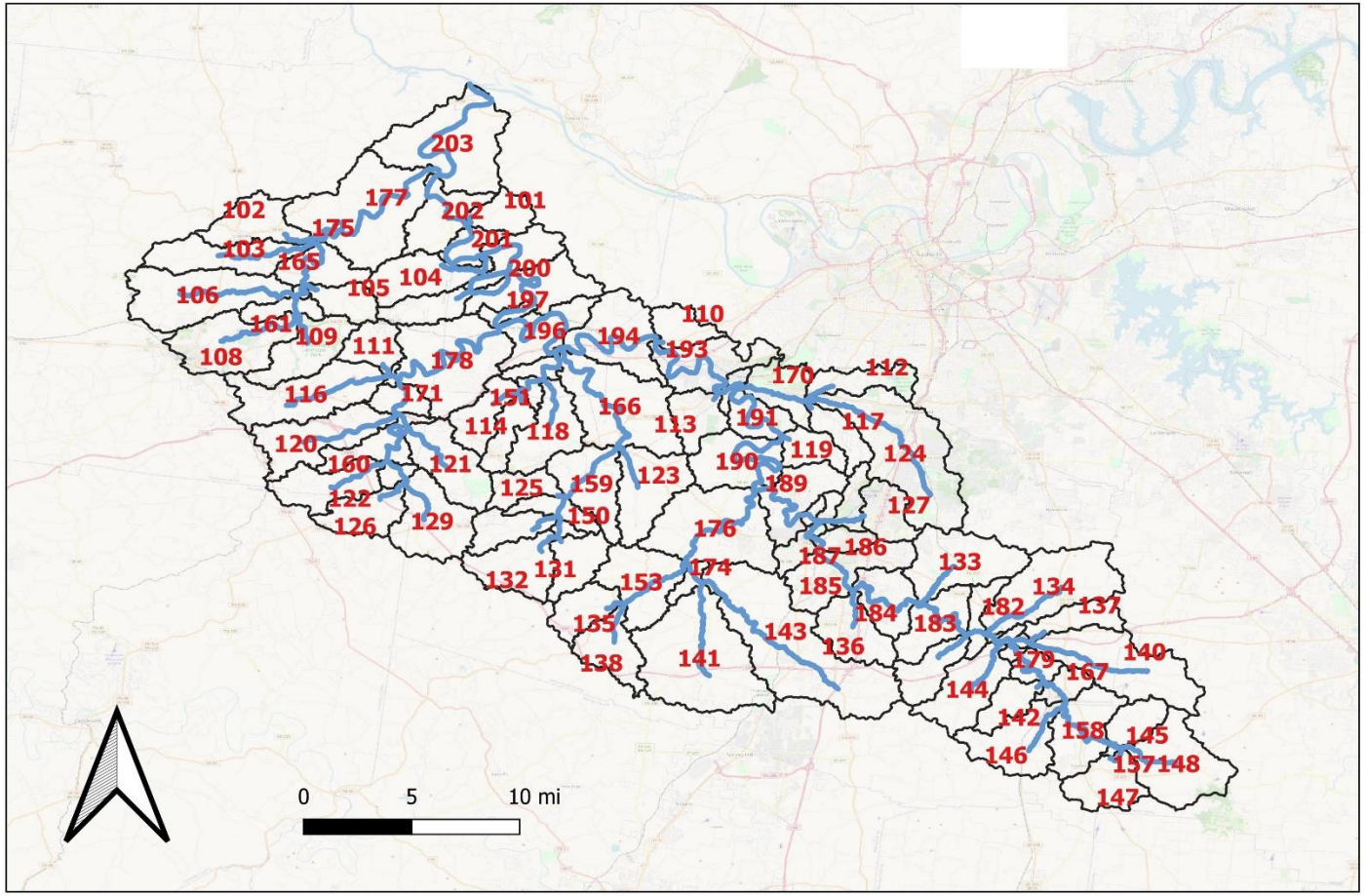
Weather Stations



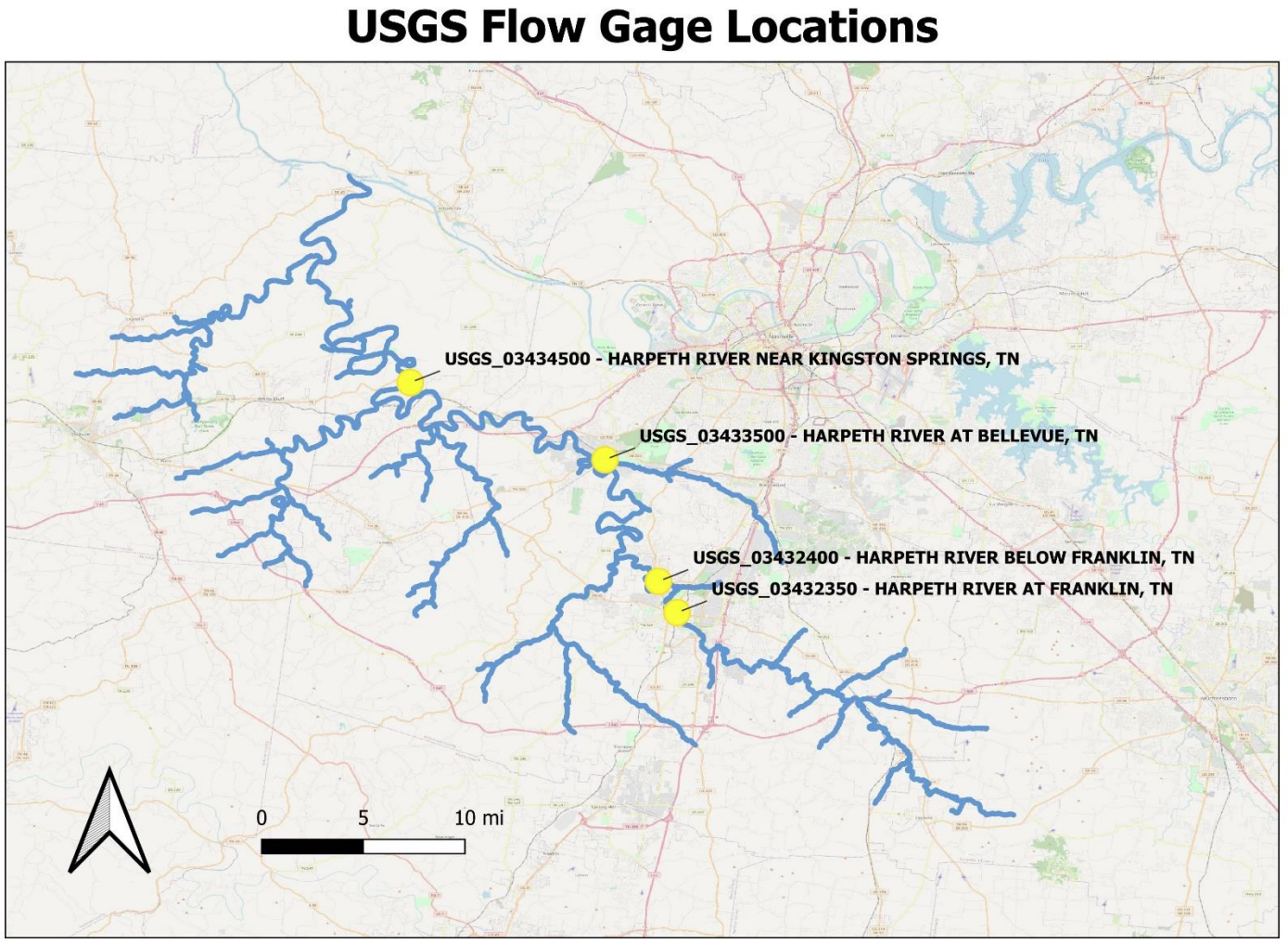

MyFreePPT


Annual Rainfall at Upper, Mid, and Lower Stations in the Harpeth Watershed (inches)
Upper
Mid
Lower
70
60
50
40
30
20
10
0
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016

Watershed Model Subbasin Delienation



Flow Calibration Stations



WATER QUALITY MODEL

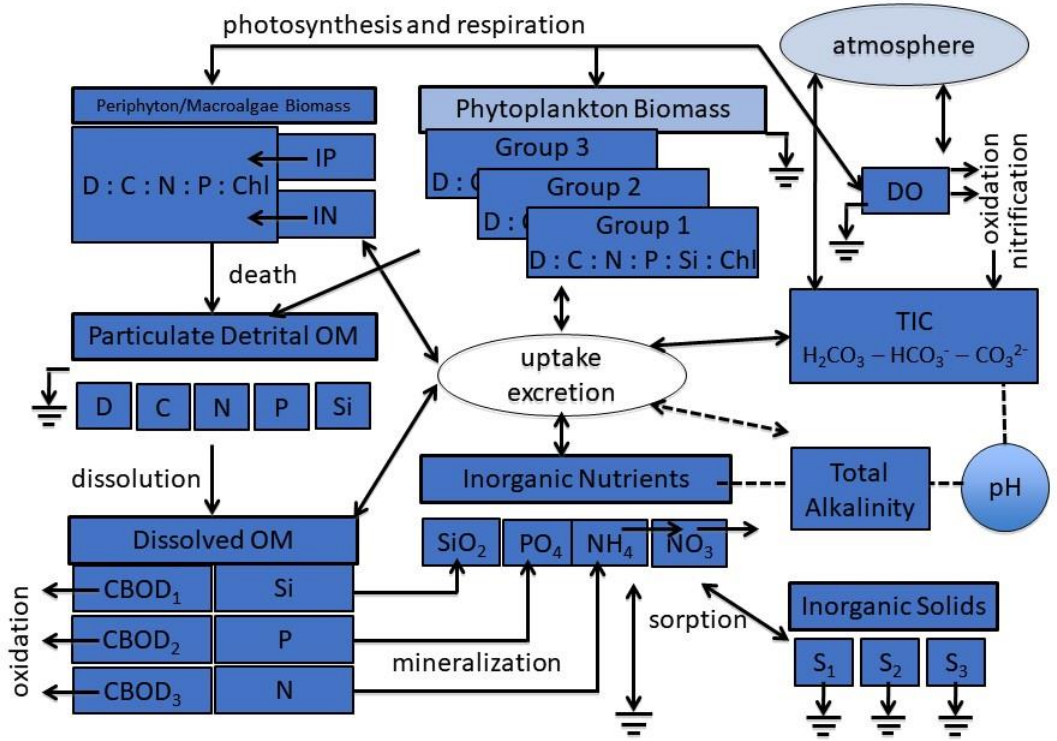
Water Quality Model

- Kinetics and Transport More Sophisticated
- Integrates the Flows and Loads from the watershed model with Flows and Loads from the Point Sources
- Scenario Investigation allows manipulation of modeling assumptions to determine potential water quality outcomes

Water Quality Model

- Response Variables
  - Dissolved Oxygen/Sediment Oxygen Demand
  - Algae/Chlorophyll a (biomass)
  - Flow
- Provide Detailed Loading Analysis
  - Point vs. Non-Point Sources
  - Estimate of Loading Sources

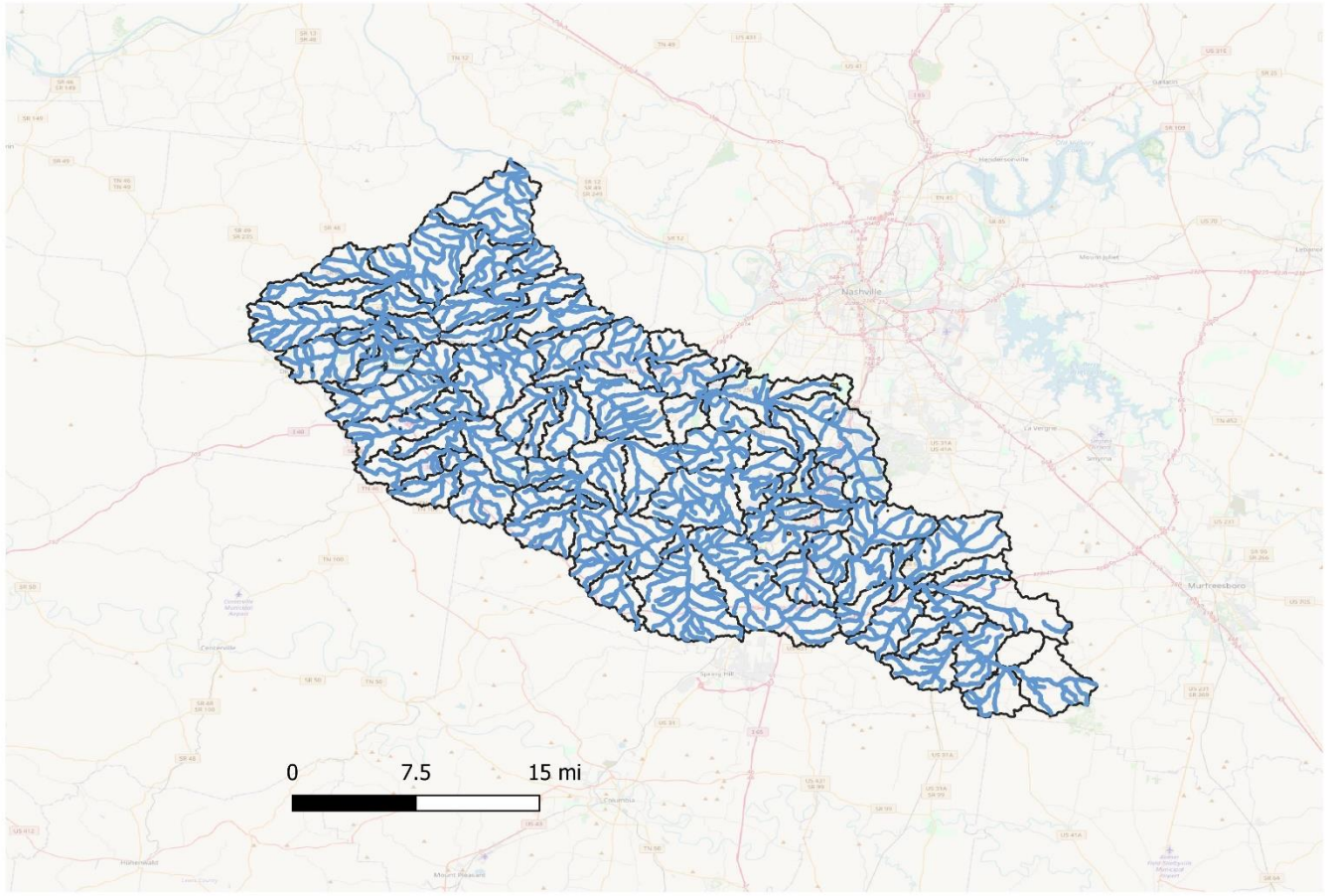
Water Quality Model (WASP)



Water Quality Model State Variables

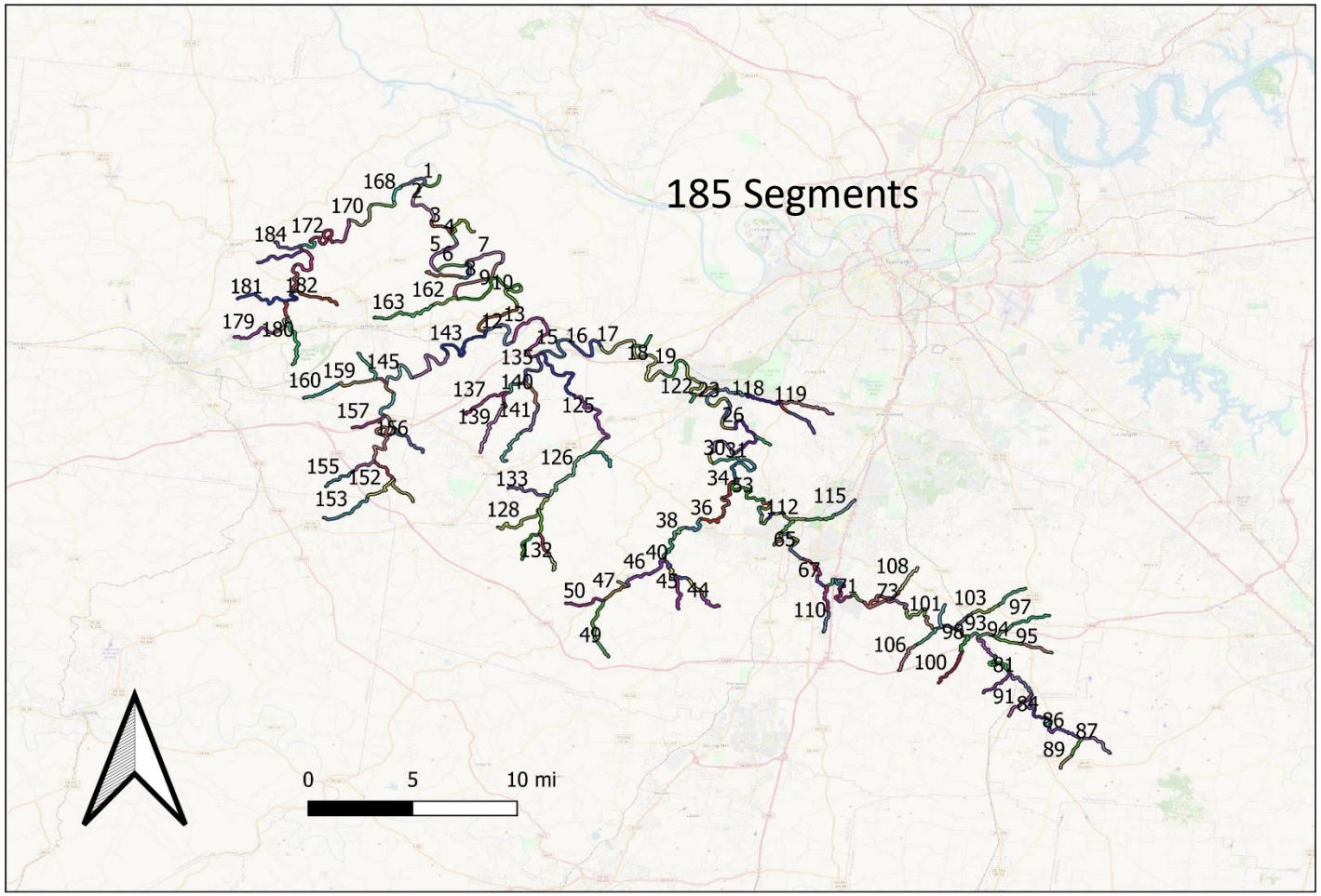
- Nitrogen – (Ammonia, Nitrate, DON, PON)
- Phosphorus – (Inorganic P, DOP, POP)
- CBOD/POC (Watershed, NPDES, Biotic)
- Algae (Single Homogeneous Group)
- Dissolved Oxygen
- Water Temperature
- Water Age

WASP Model Segmentation

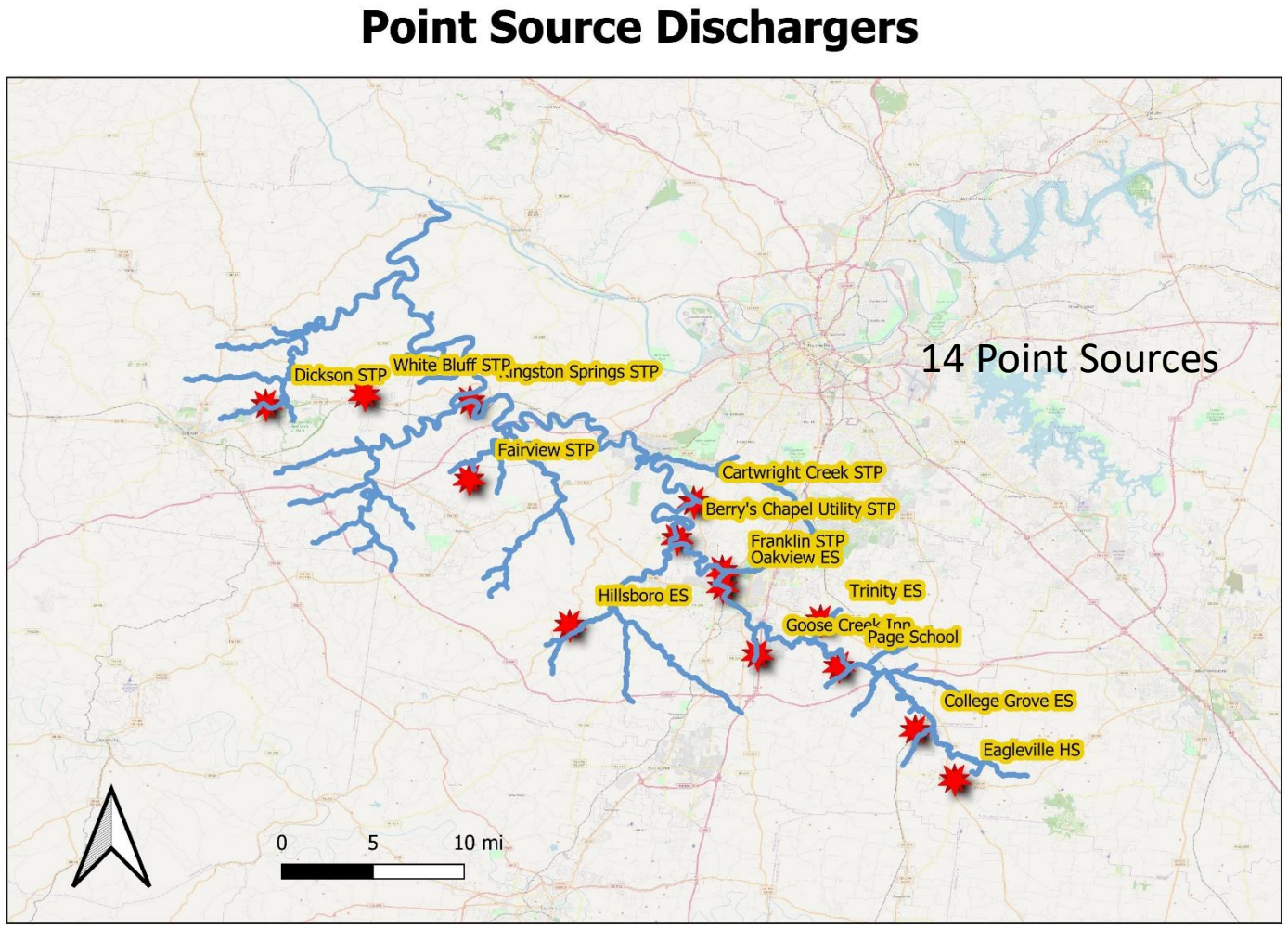


WASP Model Network

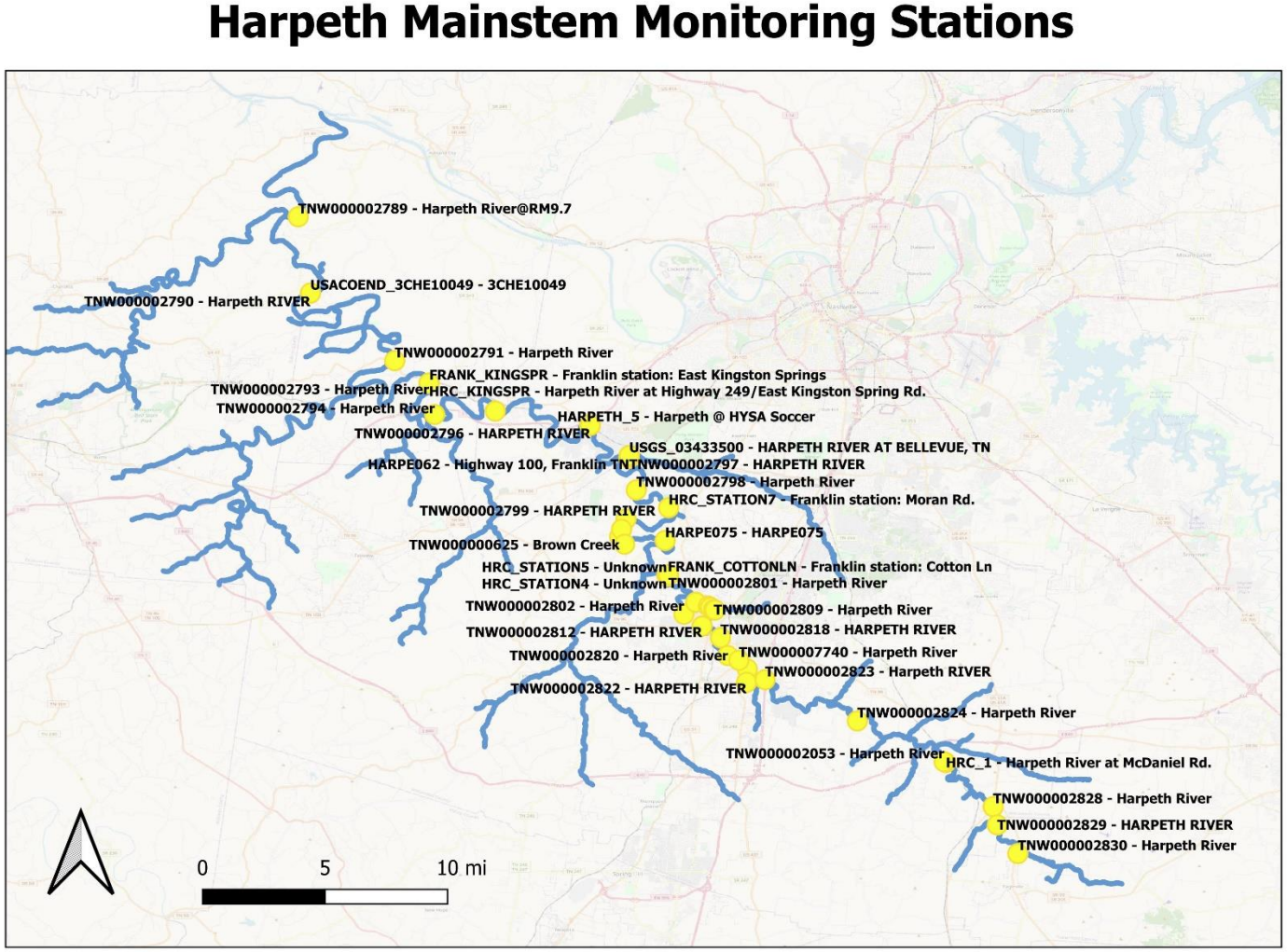
Harpeth River Water Quality Model Segmentation



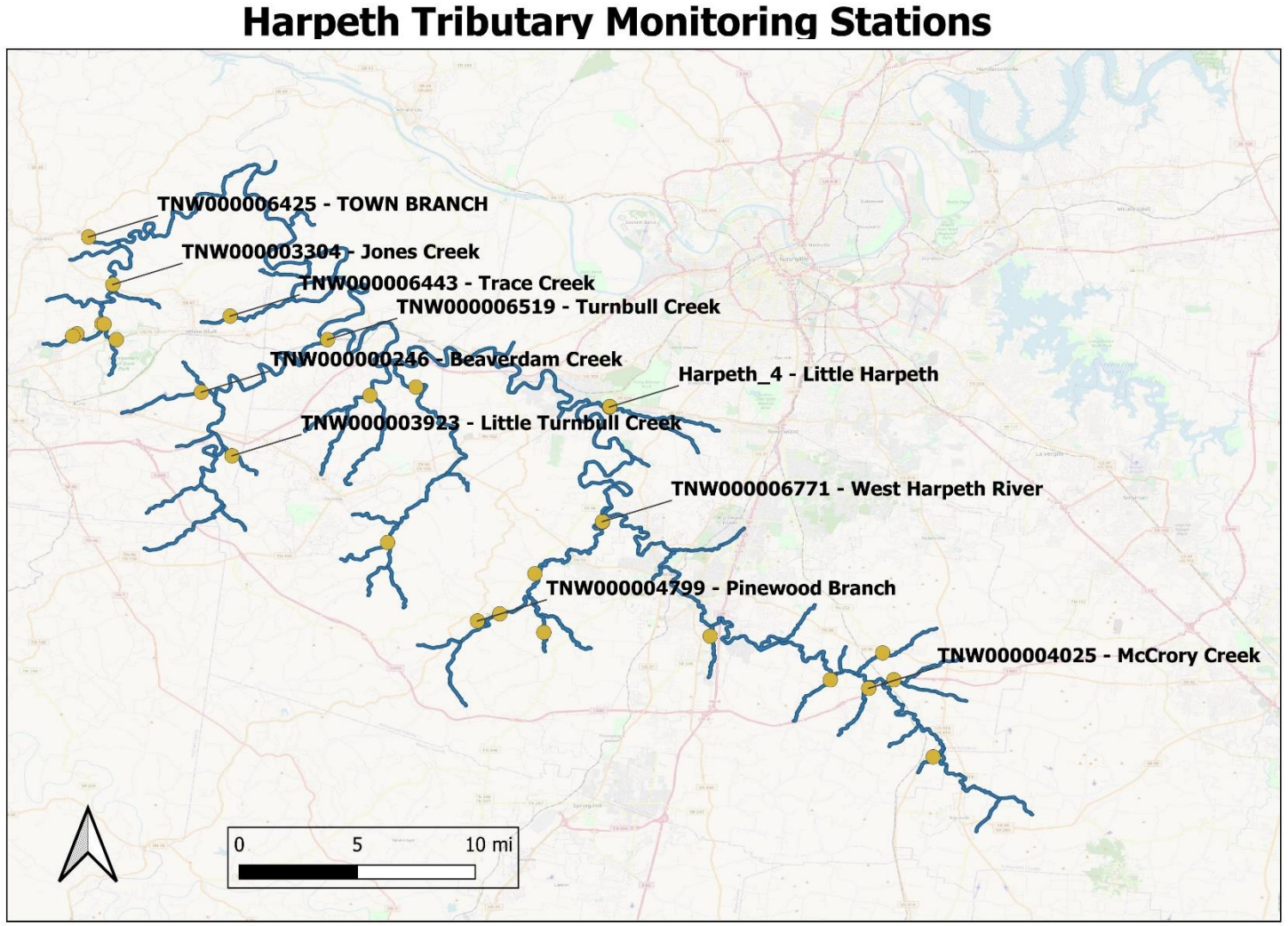
NPDES Dischargers in the Model



Mainstem Monitoring Stations



Tributary Monitoring Stations



MODELING REPORT

Modeling Report

Harpeth River, TN

November 20, 2020

Draft Revision 4

Appendix A: LSPC Harpeth Watershed Model Calibration

G. Fernandez, Ph.D. and A. Howell

Background on LSPC Watershed Model

The Loading Simulation Program C++ (LSPC version 4.1) model is a lumped parameter, semi-physical watershed hydrology and water quality model. Model parameterization is grouped by hydrologic response units (HRUs) within sub-basins, and the model domain is delineated based on soil type and land use, as opposed to a distributed and cell-based parameterization. It is a semi-physical model with the physical processes of the hydrologic cycle represented; however, the physics behind each of the processes are solved empirically and/or conceptually. For example, soil water flow is not modeled by solving the physical theory of unsaturated-saturated flow as represented by one dimensional (1-D) Richard's equation (Richard, 1931). Soil water flow in LSPC is 'bucket-hydrology' - a water balance approach where the soil column is divided into two zones and water flows from one zone to the other when the nominal storages are met. This method does not address upward flows in the soil column.

The LSPC streamflow hydraulics are simplified using a kinematic approximation to the 1-D Saint Venant dynamic equation (Cunge et al., 1980; Yeh et al., 1995). The kinematic wave approximation is a water balance-storage routing where the momentum equation is simplified with the Manning's equation (Manning, 1891). With the kinematic wave assumption, inertial forces are neglected, and hydraulics are dominated by gravity waves with one-directional downstream wave flow. LSPC cannot address backwater effects and attenuation of flow due to in-stream structures like culverts. The overland flow hydraulics also use the storage routing approach and do not solve the overland flow equation as represented by the equivalent 2-D Saint Venant dynamic equation (Cunge et al., 1980; Yeh et al., 1995). The LSPC surface runoff generation is predominantly Hortonian where water flows horizontally across land surfaces when rainfall has exceeded infiltration capacity and depression storage capacity (Horton, 1933). This is in contrast to saturation excess surface runoff models, where surface runoff is generated when the groundwater table rises to the surface, as in lowland areas. When evaluating the calibration results, one should take into consideration the above physical basis of the model and the intended purpose of the model.

Despite the simplified processes discussed above, the LSPC meets the requirements of this specific modeling project, and has also been successfully applied to a range of similar projects on a national basis. Although more detailed watershed models are available and may be applicable, it is a best management practice to choose the simplest model that meets the needs of a modeling project. The more comprehensive the model, the more model parameterization is required.

Harpeth Watershed Model

The Harpeth watershed model was setup with:

1. 100 sub-basins and corresponding reaches

Contents

SEDIMENT OXYGEN DEMAND ANALYSIS

HARPETH RIVER SYSTEM
CHEATHAM, DAVIDSON, AND WILLIAMSON COUNTIES, TENNESSEE

HARPETH CONSERVANCY
BRENTWOOD, TENNESSEE

Prepared by:

Nicholas Carmean
Richard W. Rogers

AquAeTer, Inc.
Brentwood, TN

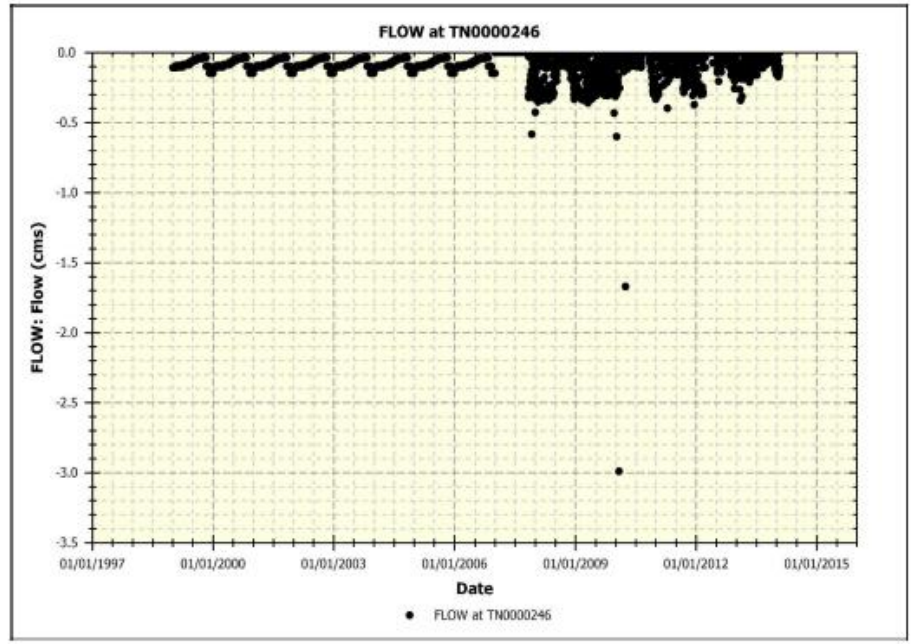
November 2017

AquAeTer

Appendix C: Permitted Facilities (Withdrawals and Discharges)

Graphical representations are provided of each parameter used to represent the waste-stream of each discharging facility represented in the Harpeth Model. Additionally, the negative flow (i.e., withdrawal) associated with the City of Franklin permitted water treatment plant is provided in this section. The purpose of these graphs are to provide TDEC with a visually method to QA/QC the characterization of point sources in the model. Please review these graphs to ensure all facilities are accurately represented. Also, these graphs represent the full datasets developed for each facility.

City of Franklin – Withdrawal TN000246

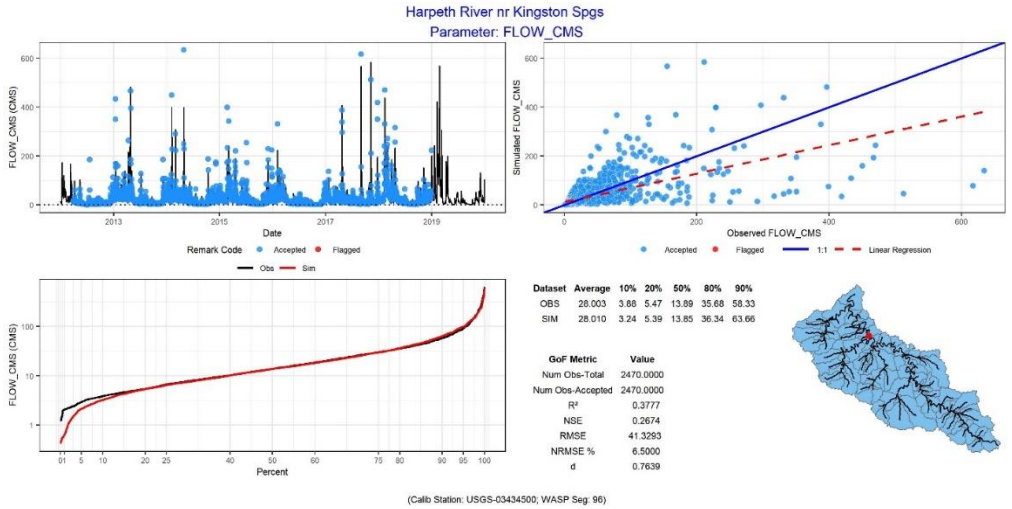


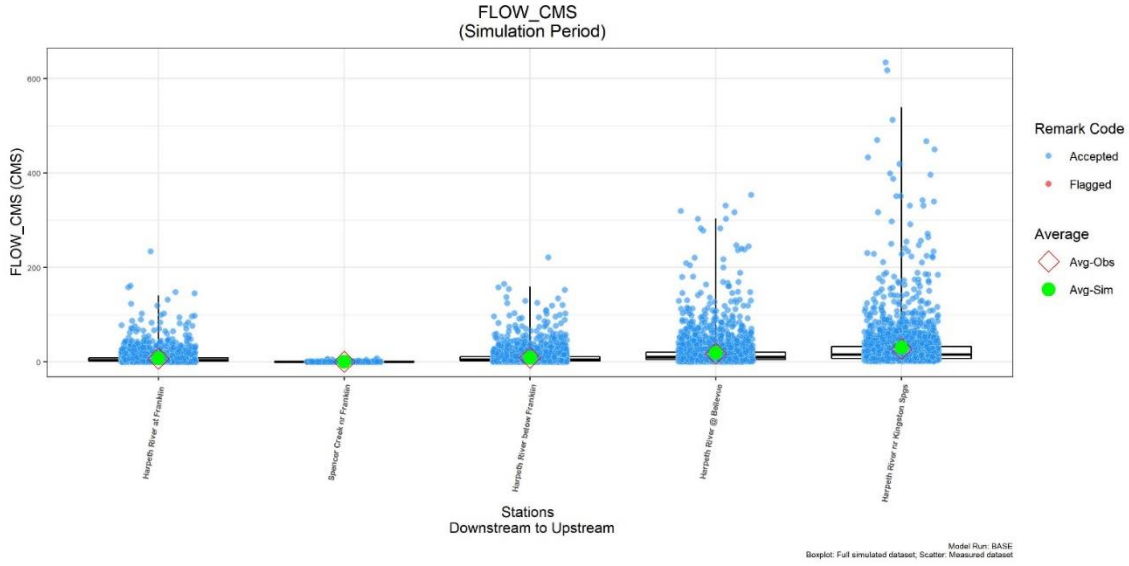
MODEL CALIBRATION OBJECTIVES

Model Calibration

- Watershed Model
  - Flow
  - Load/Concentration (TN, TP, CBOD, DO, TEMP)
- Water Quality Model
  - Flow Confirmation
  - Concentration (TN, NH3, NOX, TP, DIP, CBOD, DO, CHLA, TEMP)

Qualitative Comparison





Quantitative Comparison

Metric	Harpeth River at Kingston Spring	Harpeth River at Hwy 100	Harpeth River at Cotton Lane	Harpeth River Downstream of Franklin Outfall	Harpeth River at Trinity Rd.	Harpeth River at McDaniel Rd.	Harpeth River at College Grove/Rivers Edge	Average
Number Obs-Total	47	108	61	643	23	95	22	142.7143
Number Obs-Accepted	47	108	61	643	23	95	22	142.7143
Observed Mean	8.736	8.394	8.666	7.684	8.717	8.285	7.29	8.2531
Observed Variance	3.509	4.041	4.113	2.72	8.106	4.086	6.778	4.7647
Simulation Mean	8.777	8.404	8.592	7.871	8.789	8.126	7.856	8.345
Simulation Variance	1.642	1.735	1.987	1.139	1.567	0.989	0.869	1.4183
Mean Error	0.0419	0.0103	-0.0735	0.1872	0.073	-0.1595	0.5661	0.0922
Mean Absolute Error	0.981	0.8514	0.9737	0.9795	1.5914	1.2192	1.6867	1.1833
RMSE	1.2365	1.0685	1.2311	1.2337	2.0607	1.7075	2.3387	1.5538
NRMSE %	16.8	10.3	17.4	12.6	17.9	16.7	21.8	16.2143
R^2	0.5594	0.7624	0.6374	0.4532	0.5402	0.2871	0.2153	0.4936
Spearman Coeff.	0.7877	0.8038	0.7897	0.5919	0.8241	0.4604	0.432	0.6699
PBias	0.5	0.1	-0.8	2.4	0.8	-1.9	7.8	1.2714
Nash	0.5548	0.7148	0.6254	0.4396	0.4523	0.2788	0.1546	0.46
Index of Agreement	0.828	0.8905	0.8596	0.771	0.7067	0.6388	0.5007	0.7422
Kling-Gupta Effic. Modified	0.5932	0.6318	0.6392	0.507	0.3768	0.3186	0.1403	0.4581
Kling-Gupta Pear. Coeff.	0.7479	0.8732	0.7984	0.6732	0.735	0.5358	0.464	0.6896
Kling-Gupta Beta (Ratio Means)	1.0048	1.0012	0.9915	1.0244	1.0084	0.9807	1.0776	1.0127
Kling-Gupta Gamma (Ratio CV)	0.6808	0.6544	0.701	0.6317	0.436	0.5016	0.3324	0.5626

WATER RESOURCES DATABASE

Water Resources Database (WRDB)

- Public Open-Source Data Management System
- Designed Specifically to Support Water Quality Monitoring and Modeling Activities
- Download WRDB from

www.wrdb.com

WRDB

- Organization of both monitoring data and model simulation data
- Provide timeseries data to the water quality model
- Tabular and Graphical comparison of monitoring and simulation results

WRDB Overview

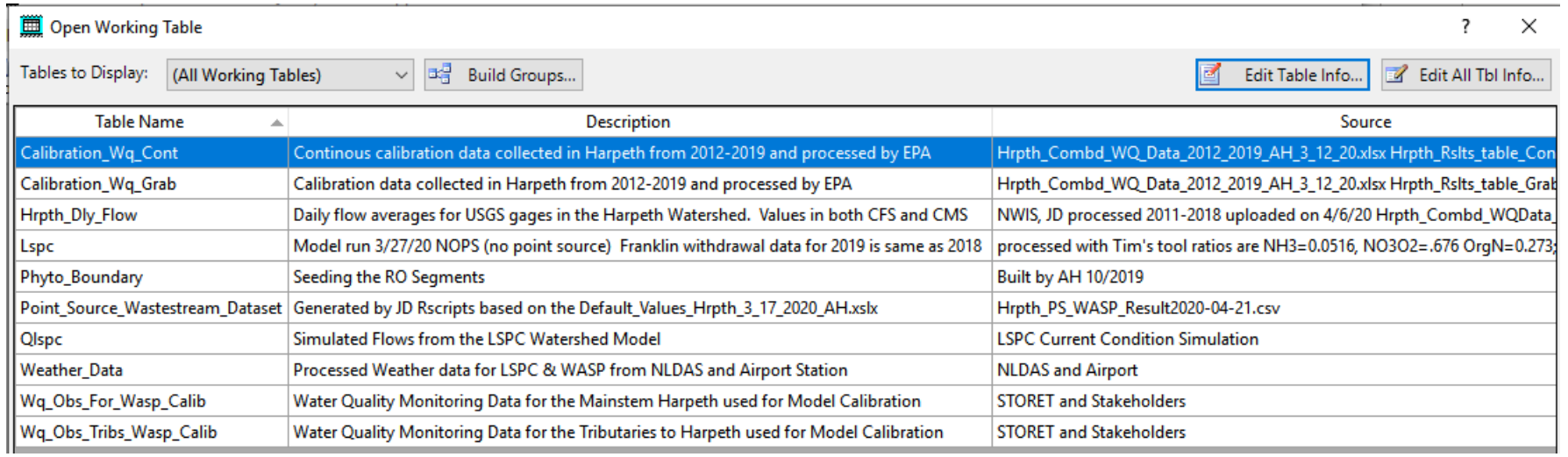
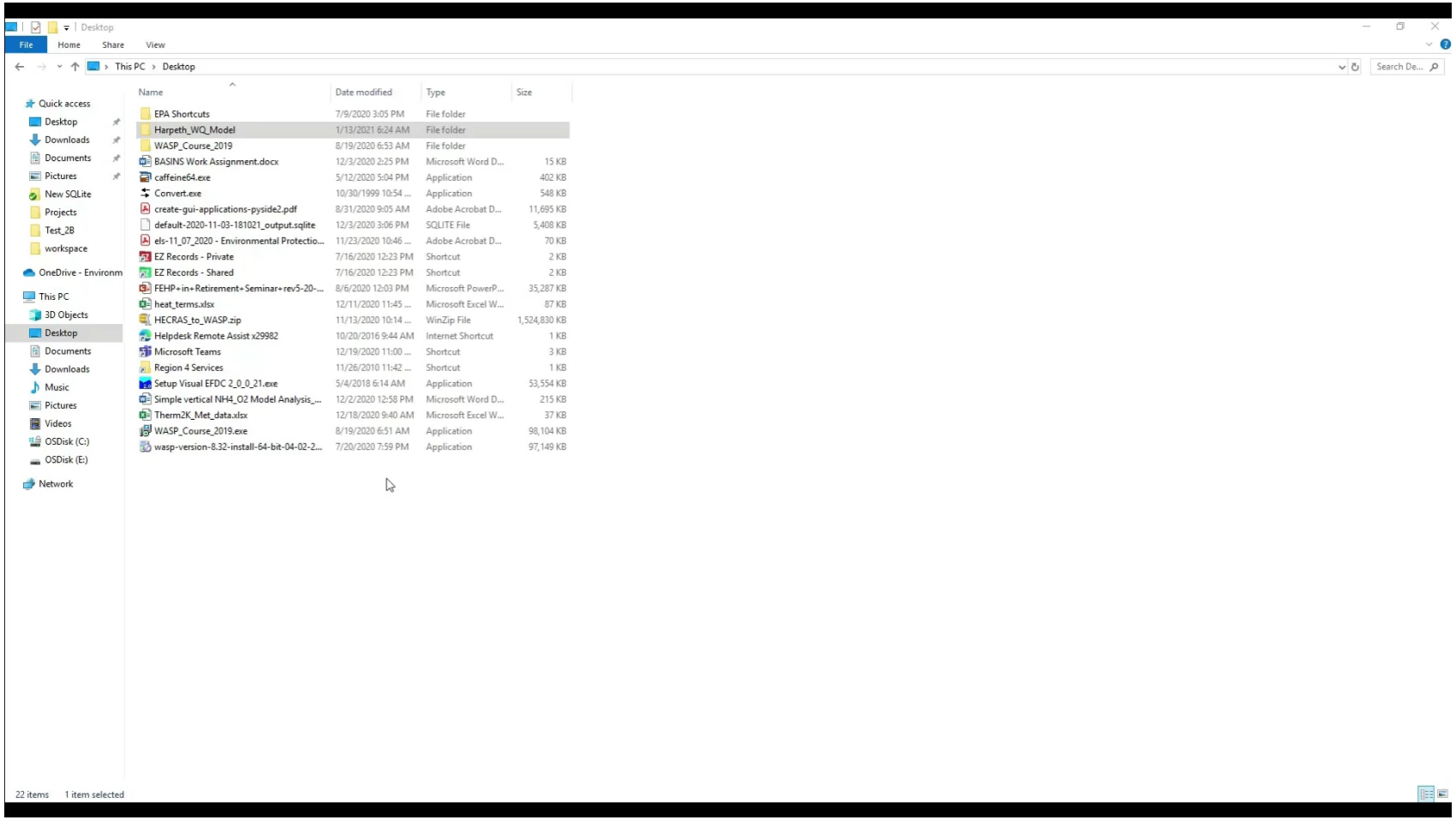
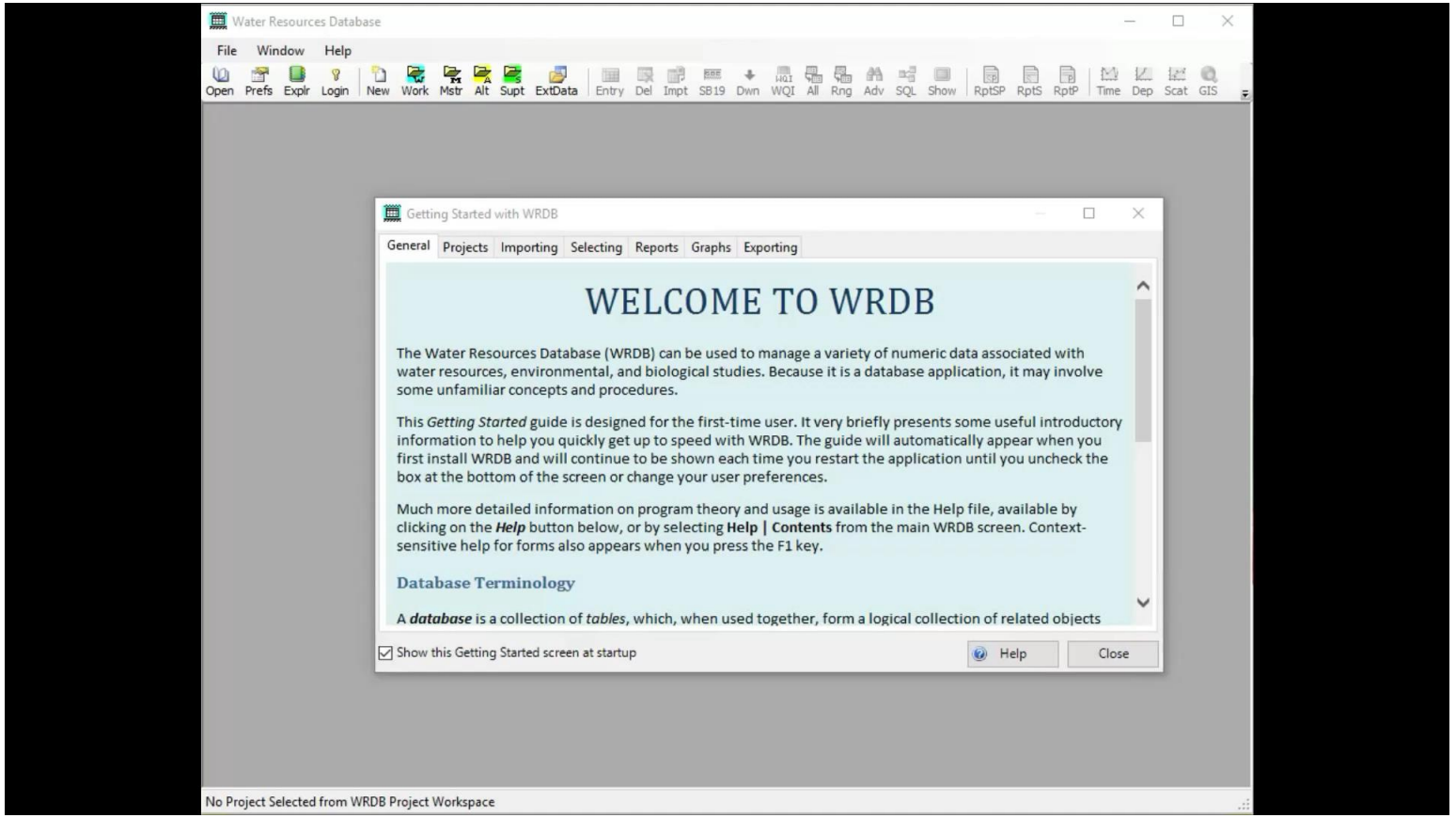


Table Name	Description	Source
Calibration_Wq_Cont	Continous calibration data collected in Harpeth from 2012-2019 and processed by EPA	Hrpth_Combd_WQ_Data_2012_2019_AH_3_12_20.xlsx Hrpth_Rslts_table_Con
Calibration_Wq_Grab	Calibration data collected in Harpeth from 2012-2019 and processed by EPA	Hrpth_Combd_WQ_Data_2012_2019_AH_3_12_20.xlsx Hrpth_Rslts_table_Grab
Hrpth_Dly_Flow	Daily flow averages for USGS gages in the Harpeth Watershed. Values in both CFS and CMS	NWIS, JD processed 2011-2018 uploaded on 4/6/20 Hrpth_Combd_WQData_
Lspc	Model run 3/27/20 NOPS (no point source) Franklin withdrawal data for 2019 is same as 2018	processed with Tim's tool ratios are NH3=0.0516, NO3O2=.676 OrgN=0.273;
Phyto_Boundary	Seeding the RO Segments	Built by AH 10/2019
Point_Source_Wastestream_Dataset	Generated by JD Rscripts based on the Default_Values_Hrpth_3_17_2020_AH.xslx	Hrpth_PS_WASP_Result2020-04-21.csv
Qlspc	Simulated Flows from the LSPC Watershed Model	LSPC Current Condition Simulation
Weather_Data	Processed Weather data for LSPC & WASP from NLDAS and Airport Station	NLDAS and Airport
Wq_Obs_For_Wasp_Calib	Water Quality Monitoring Data for the Mainstem Harpeth used for Model Calibration	STORET and Stakeholders
Wq_Obs_Tribs_Wasp_Calib	Water Quality Monitoring Data for the Tributaries to Harpeth used for Model Calibration	STORET and Stakeholders

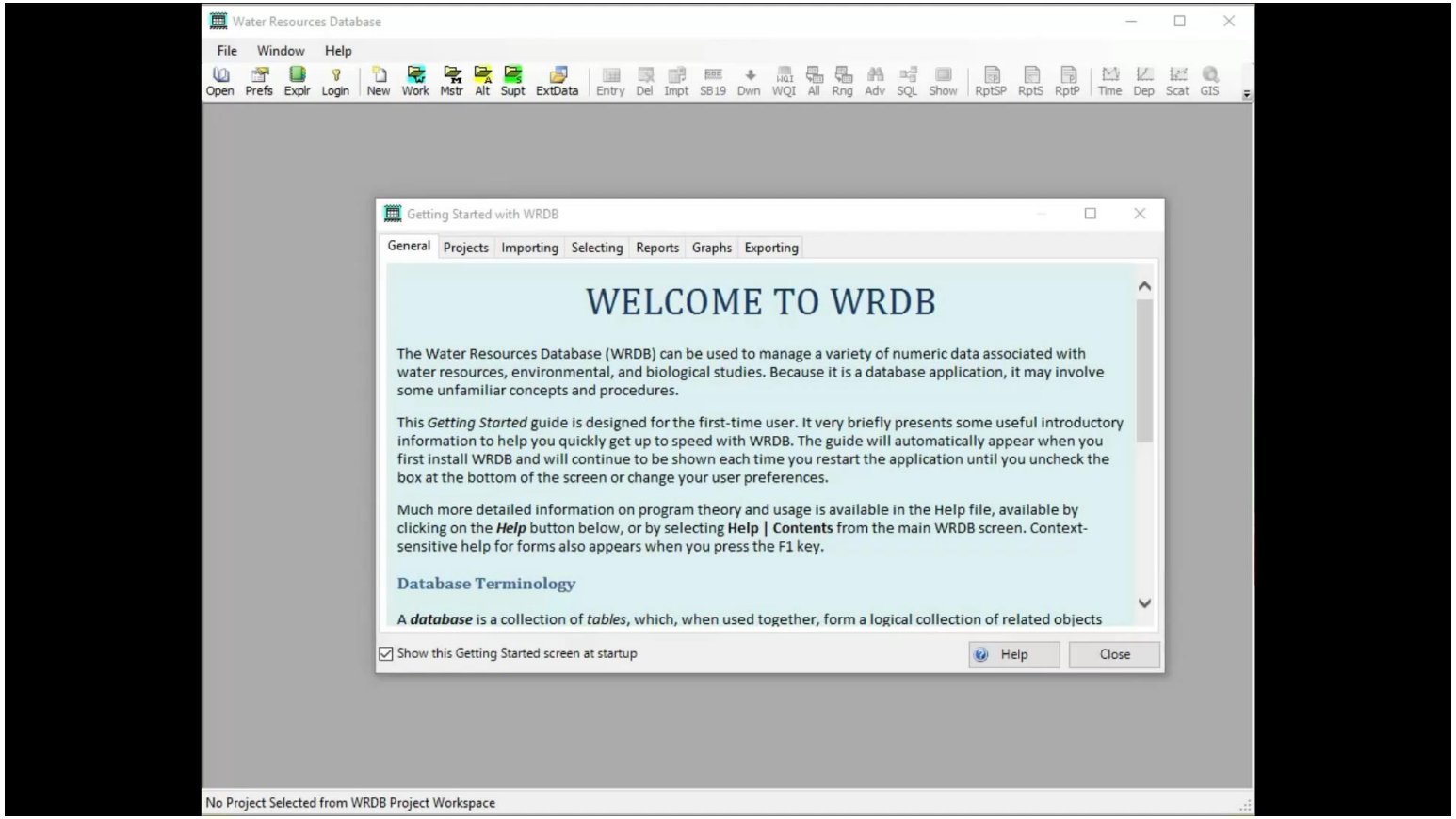
Unzipping Harpeth WRDB File



Restoring Harpeth WRDB Project

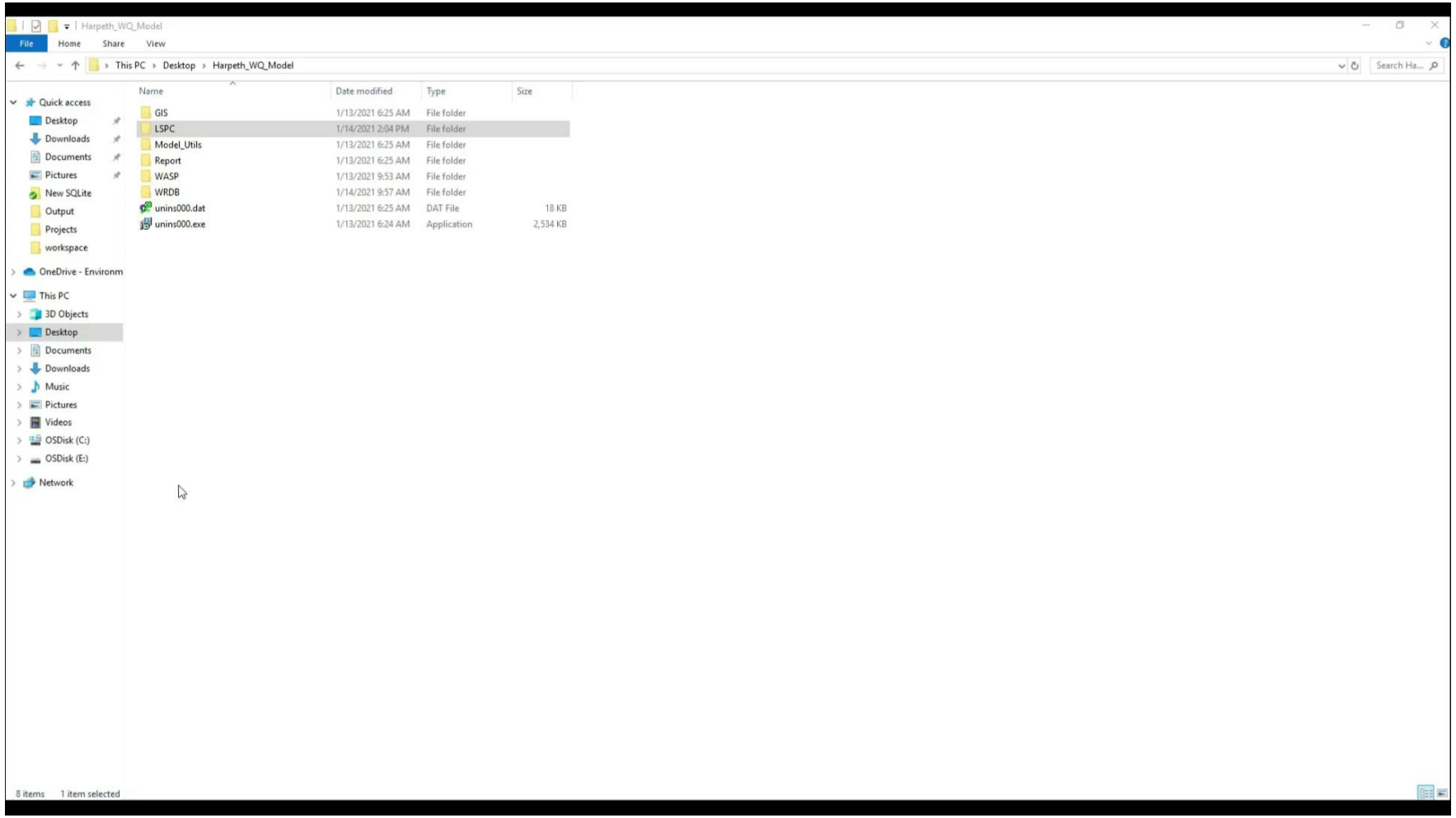


Adding File to WRDB



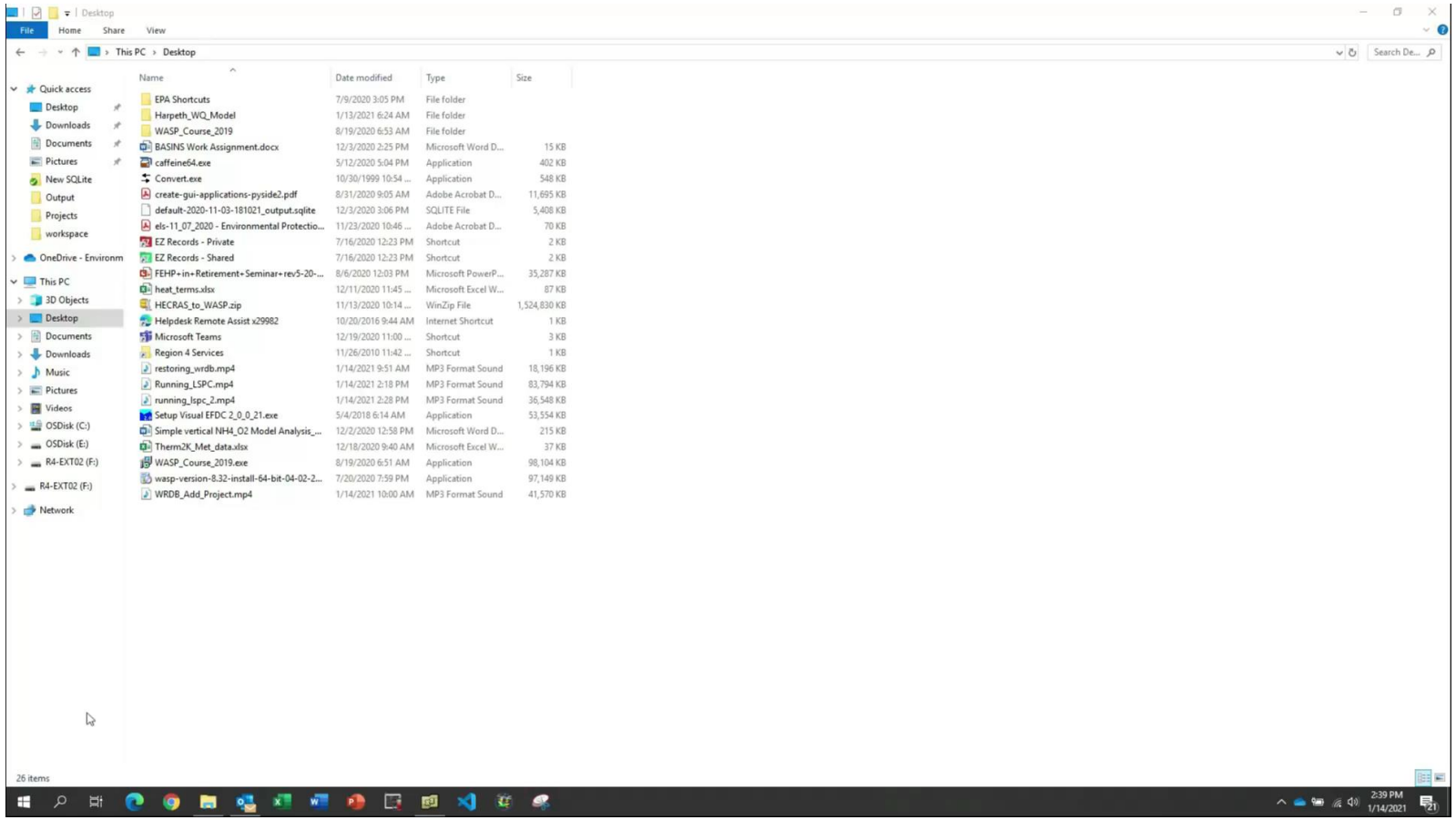
LSPC – WATERSHED MODEL

Running LSPC



WASP – WATER QUALITY MODEL

Running WASP



WASP Tutorials are available at: www.epawasp.com

NEXT STEPS/QUESTIONS