Appendix B

Figures

Analysis of Toxic Pollutant Sources and Characteristics Contributing to Water Quality Impairments in the Willamette River Basin

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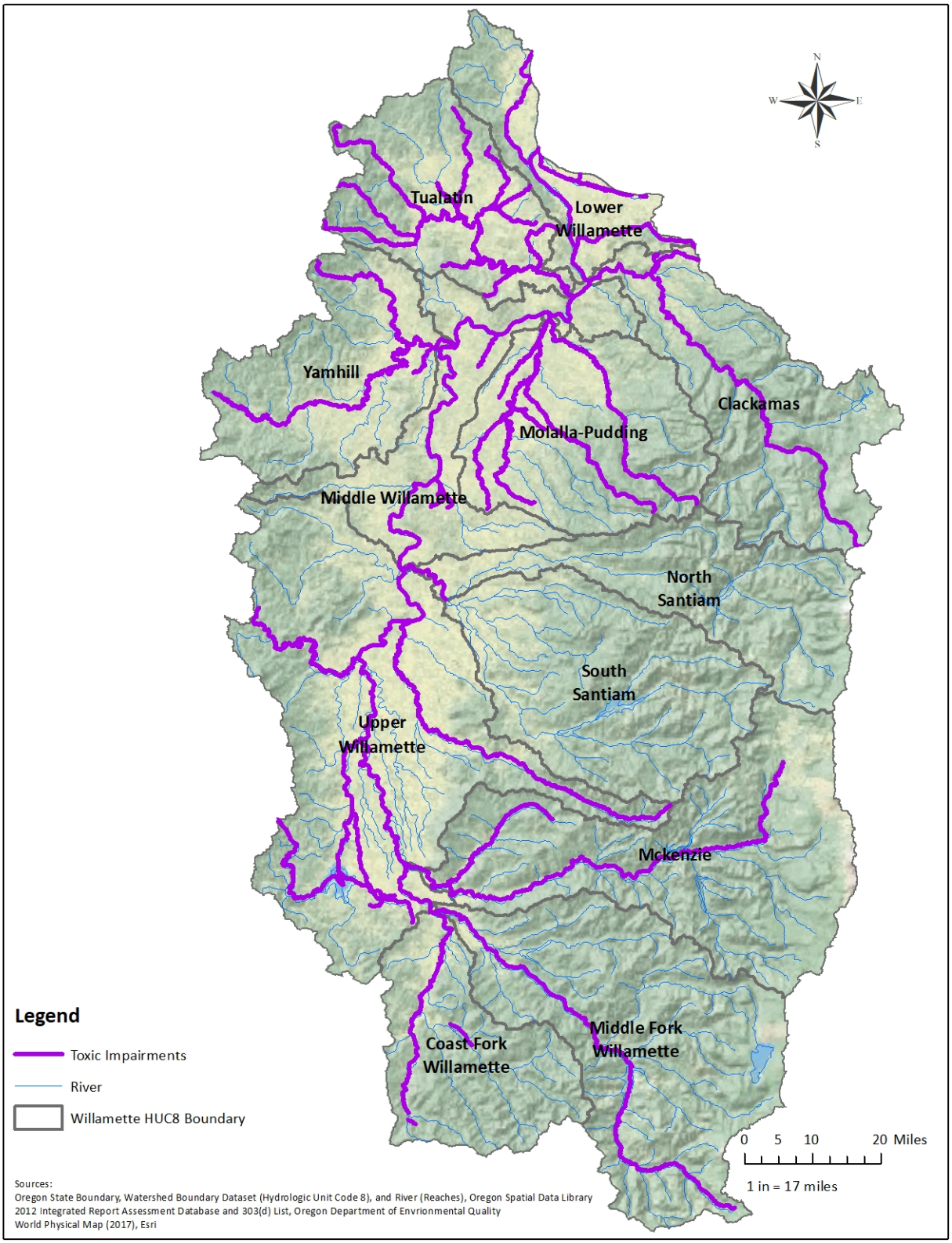

Figure 1. Topographic map and toxic pollutant impairments of the Willamette Basin. Map shows Oregon's 303(d) listed rivers and streams as Category 5 (Needing TMDLs) by subbasin (purple lines) evaluated at the 8-digit fourth-level USGS Hydrologic Unit Code (HUC) (DEQ, 2012; OSDL, 2017).

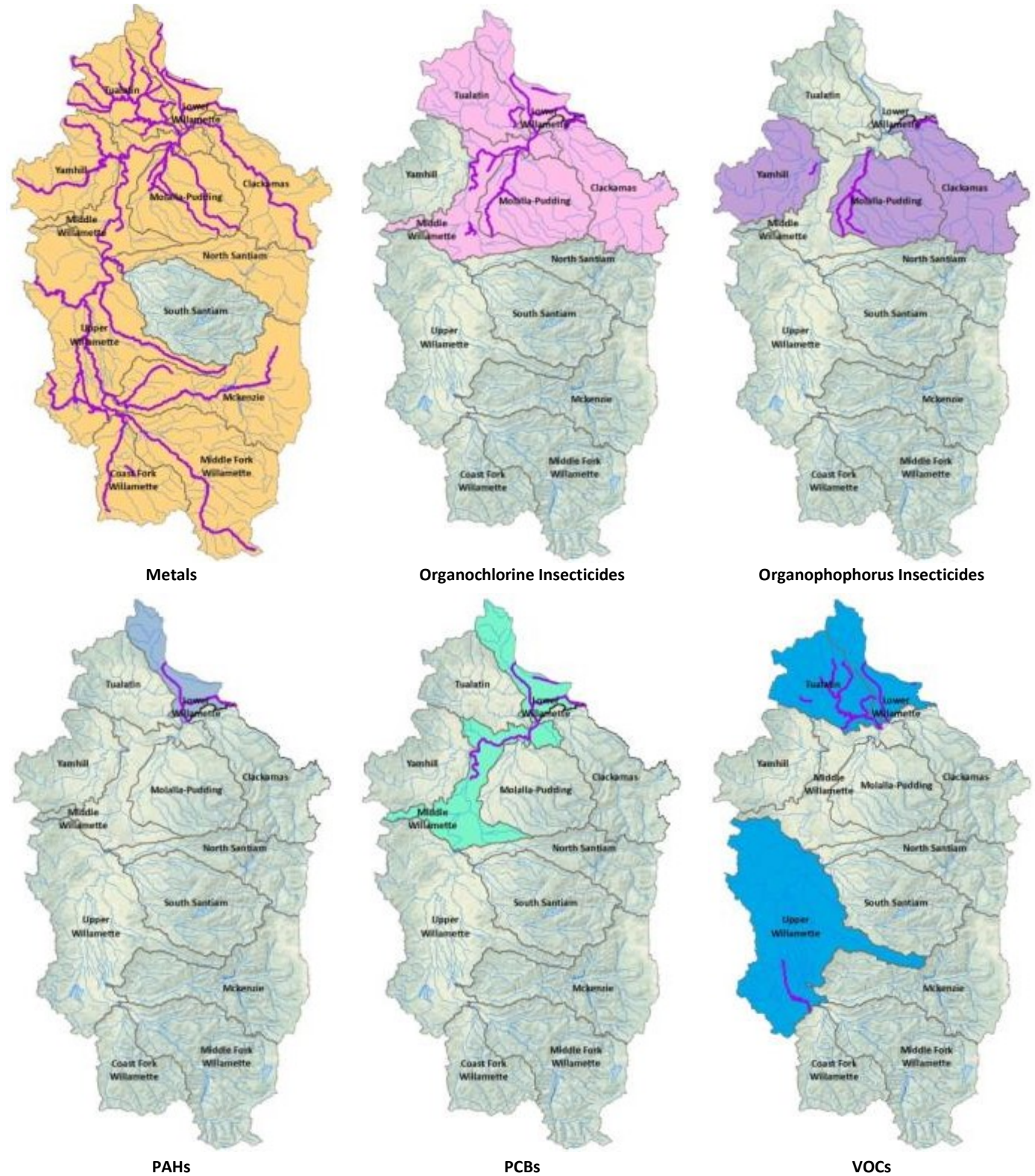

Figure 2. Toxic pollutant impairments in the Willamette Basin by toxic pollutant class. Individual Basin maps show toxic pollutant Impairments (purple lines) evaluated by subbasin (color associated with each toxic pollutant class) at the 8-digit fourth-level USGS Hydrologic Unit Code (HUC) (DEQ, 2012; OSDL, 2017).

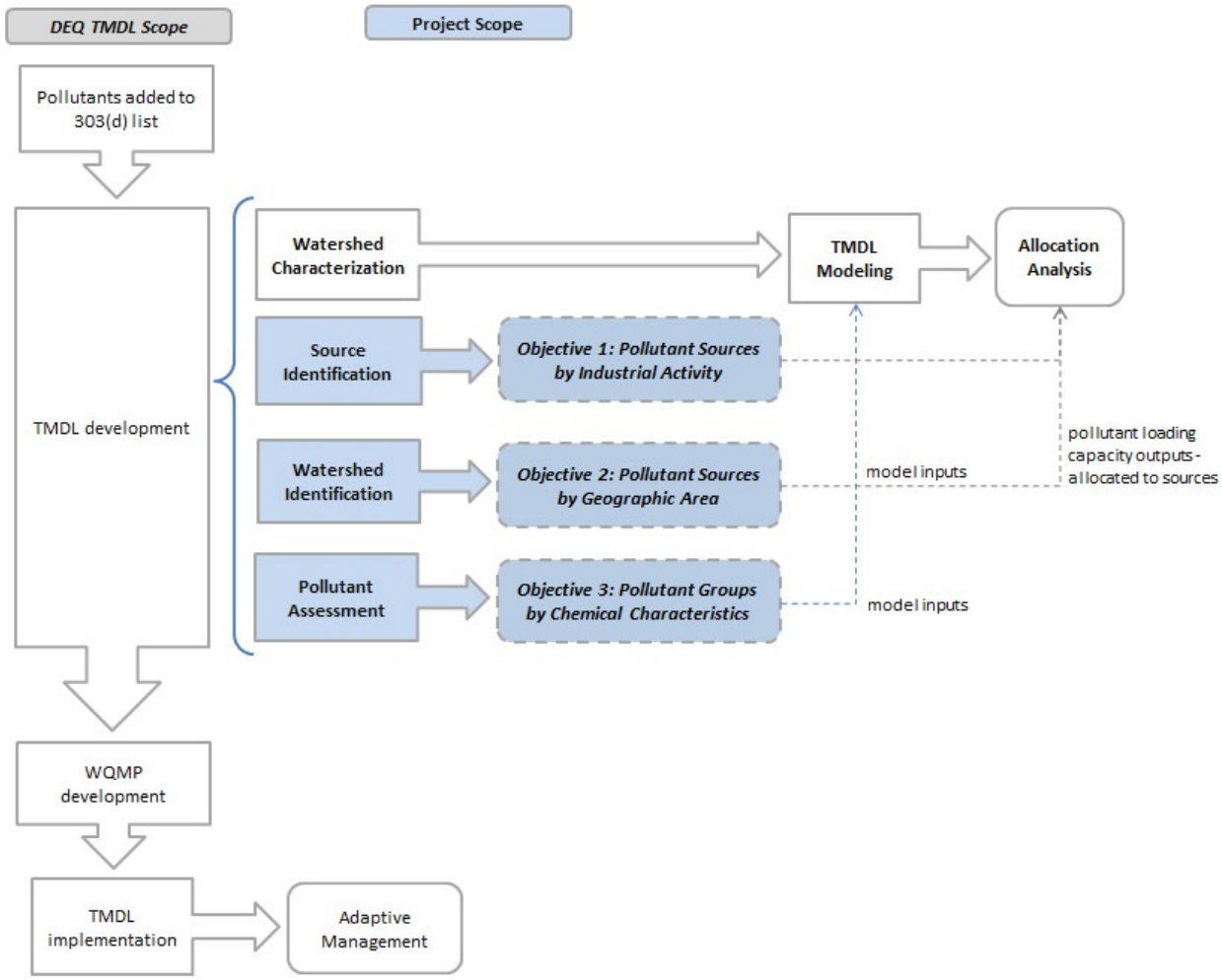

Figure 3. Flow chart of Oregon DEQ's TMDL development process and Project scope. Chart shows the general process of TMDL development at the DEQ and the tasks involved in each step. The tasks comprising the Project scope are shaded blue. DEQ = (Oregon) Department of Environmental Quality. TMDL = Total Maximum Daily Load. WQMP = Water Quality Management Plan.

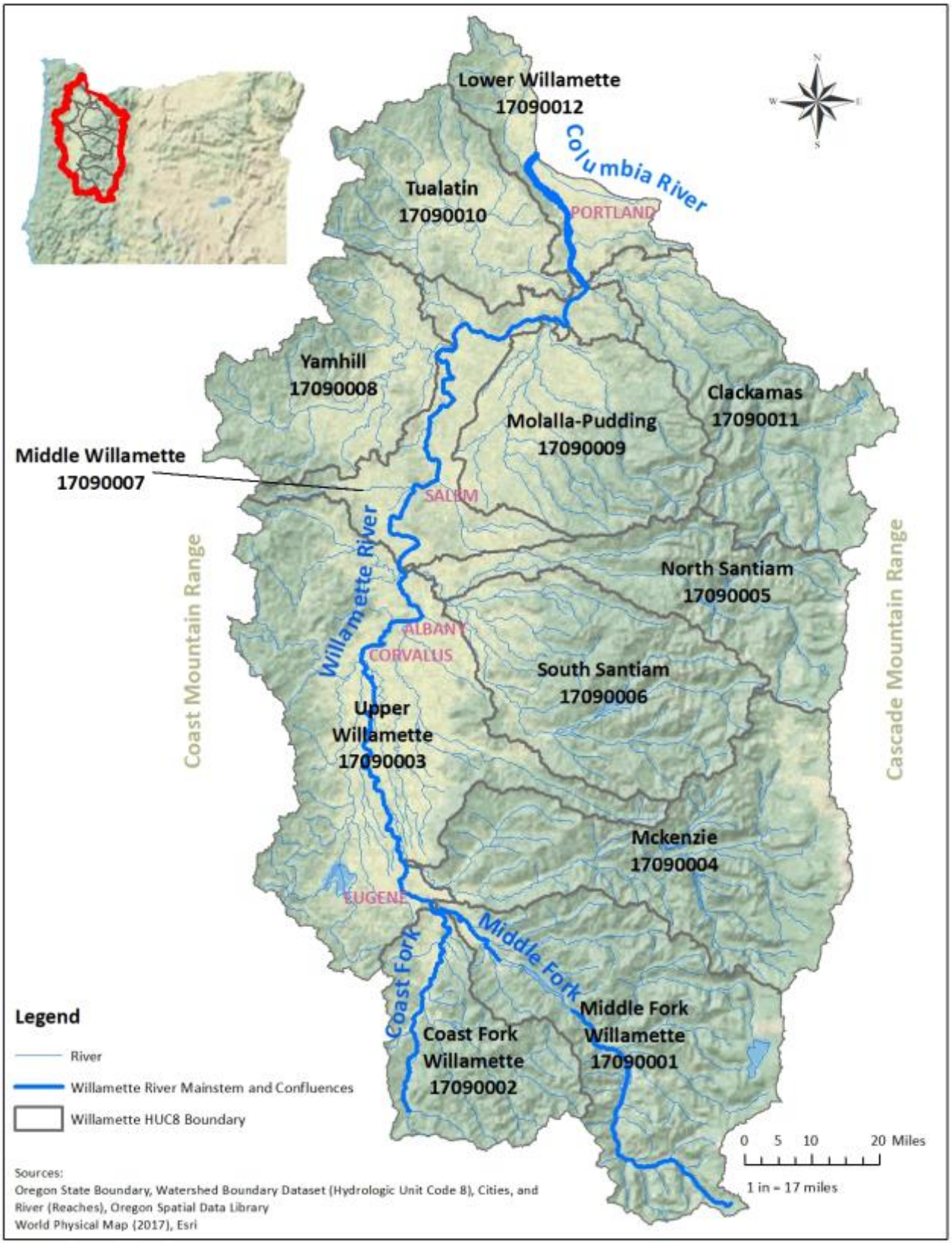

Figure 4. Topographic map of the Willamette Basin. Map shows tributaries of and confluences to the main stem Willamette River flowing through 12 subbasins identified at the 8-digit fourth-level USGS Hydrologic Unit Code (HUC). The Project study area includes only 11 of the subbasins: no toxic pollutant impairments were identified in the South Santiam.

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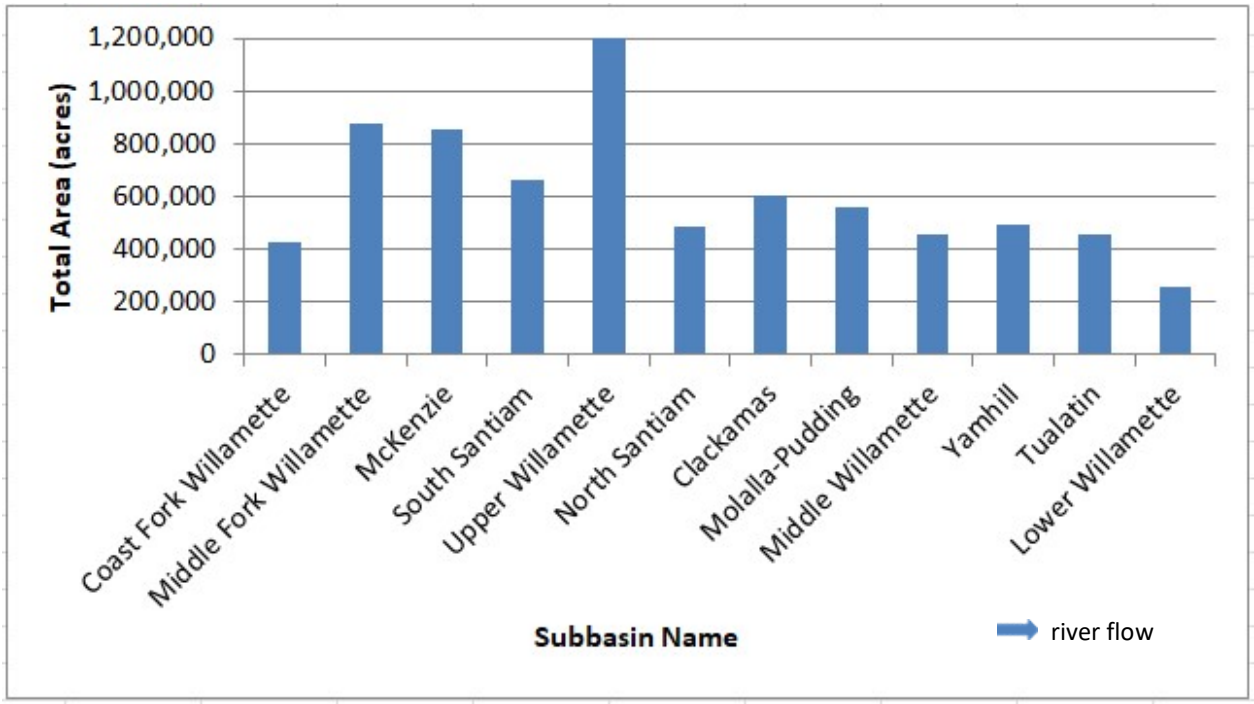


Figure 5. Land area of the Willamette Basin by subbasin. Land area evaluated at the 8-digit fourth-level USGS Hydrologic Unit Code (HUC) using the Oregon Watershed Boundary Dataset (OSDL, 2017). Land area presented in the chart by subbasin from upstream (left) to downstream (right) location in the Basin (i.e., south to north).

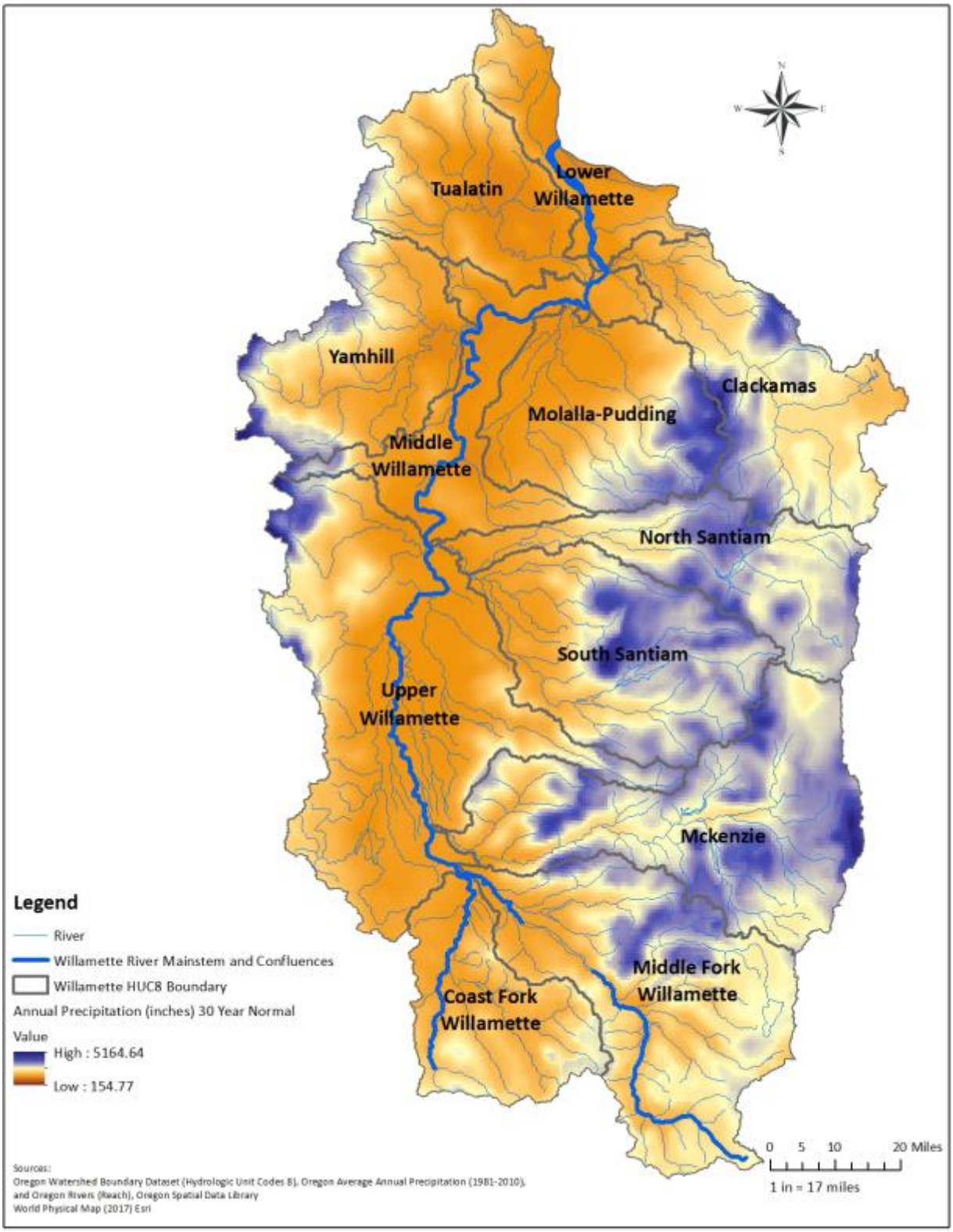


Figure 6. Map of annual precipitation (30-year normal) in the Willamette Basin. Map shows annual rainfall (in inches) for the period of 1981 to 2010 with tributaries of and confluences to the main stem Willamette River flowing through 12 subbasins identified at the 8-digit fourth-level USGS Hydrologic Unit Code (HUC) (OSDL, 2016, 2017). Amount of precpitation shown in descending color gradients: high to low from dark blue, to orange, to yellow.

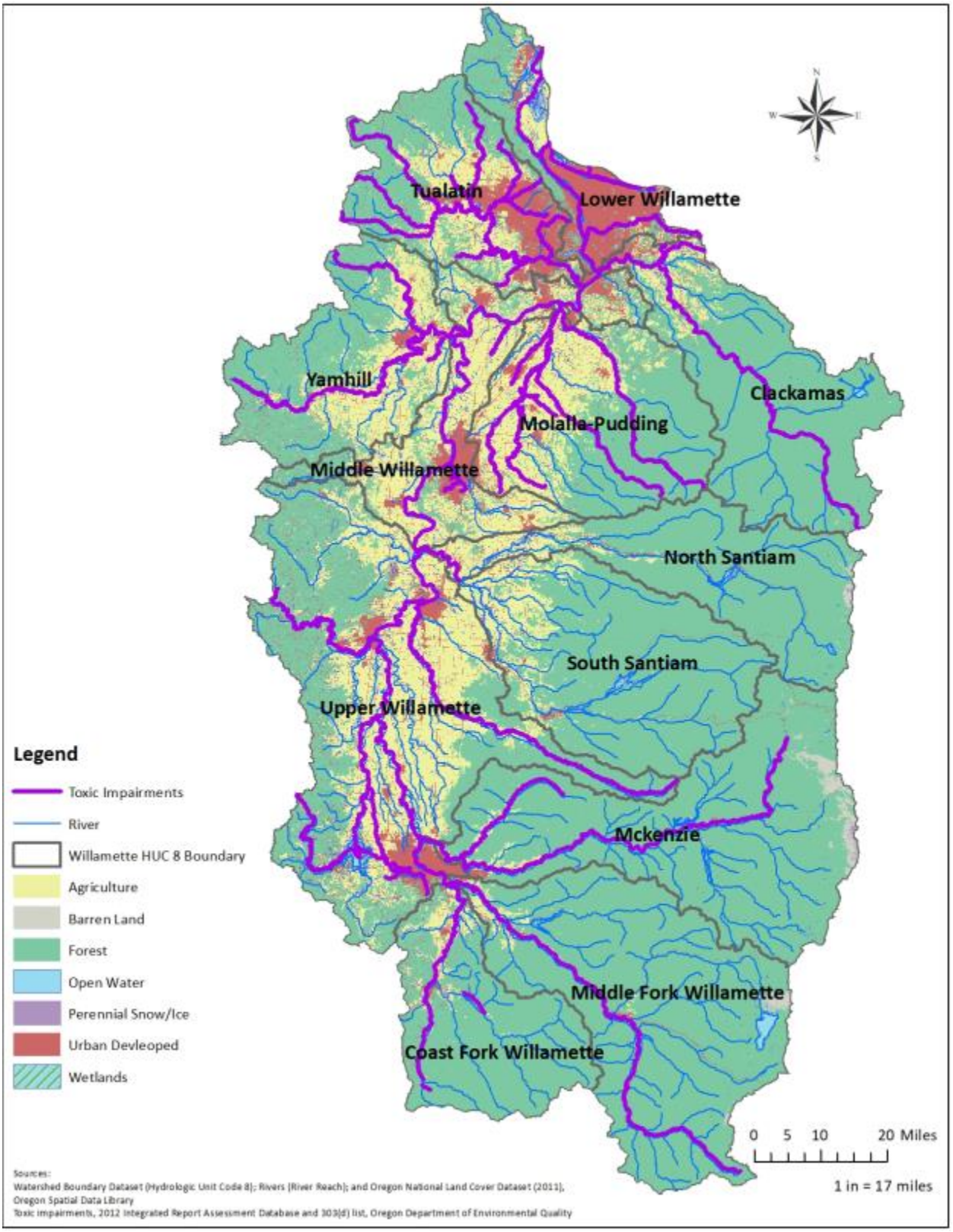


Figure 7. Map of land cover and use in the Willamette Basin. Map shows land cover and associated uses throughout the Basin based on the 2011 National Land Cover Dataset and tributaries of the Willamette River wtih toxic pollutant impairments flowing through 12 subbasins identified at the 8-digit fourth-level USGS Hydrologic Unit Code (HUC) (DEQ, 2012; OSDL, 2011, 2017).

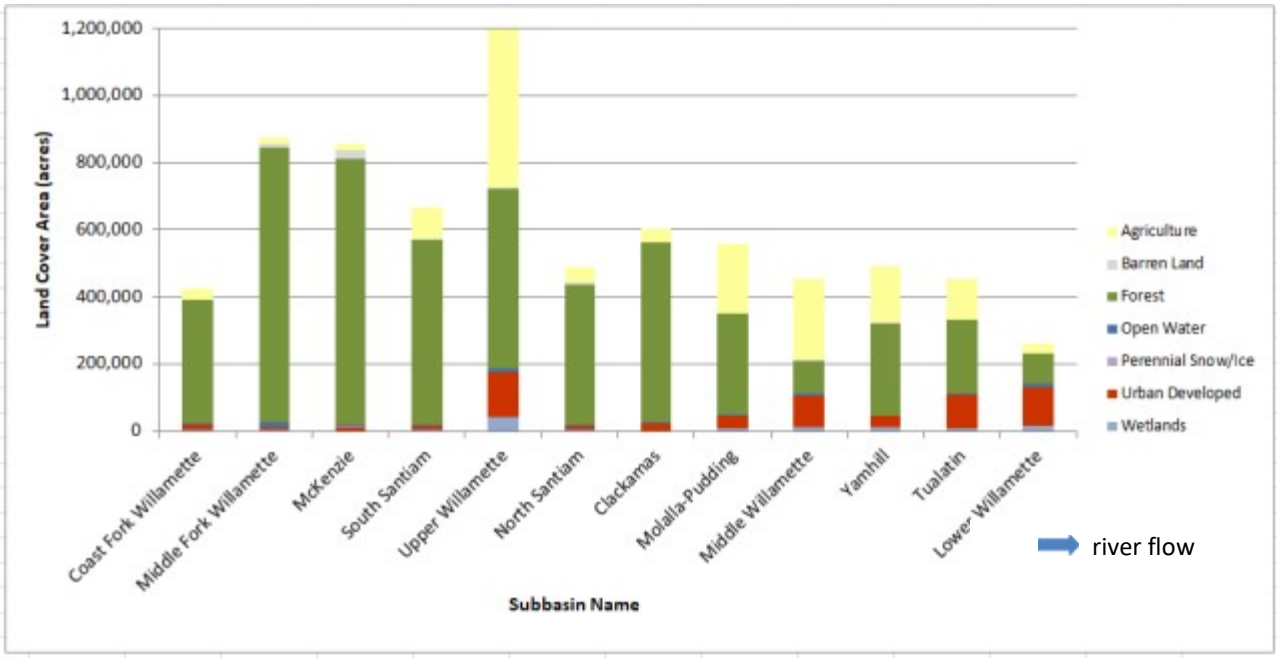


Figure 8. Land use of the Willamette Basin by subbasin. Land use evaluated at the 8-digit fourth-level USGS Hydrologic Unit Code intersected with the National Land Cover Data Set for Oregon using ArcGIS version 10.5.1 (OSDL, 2011, 2017). Land use presented in the chart by subbasin from upstream (left) to downstream (right) location in the Basin (i.e., south to north).

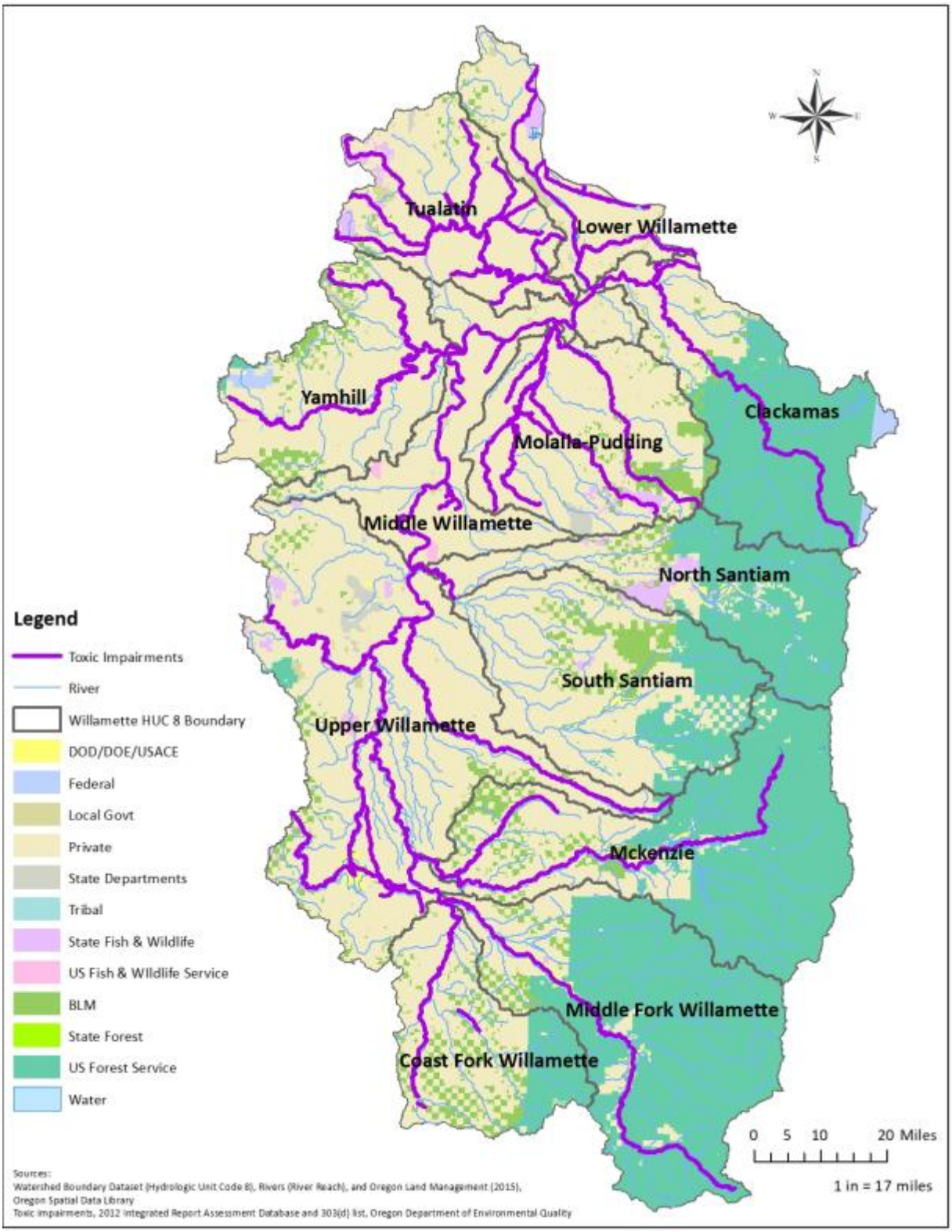


Figure 9. Map of land ownership and management in the Willamette Basin. Map shows land areas and the associated agency management based on the 2015 land management dataset and tributaries of the Willamette River and toxic pollutant impairments flowing through 12 subbasins identified at the 8-digit fourth-level USGS Hydrologic Unit Code (HUC) (DEQ, 2012; OSDL, 2015, 2017). BLM = Bureau of Land Management. DOD = Department of Defense. DOE = Department of Energy. USACE = U.S. Army Corps of Engineers.

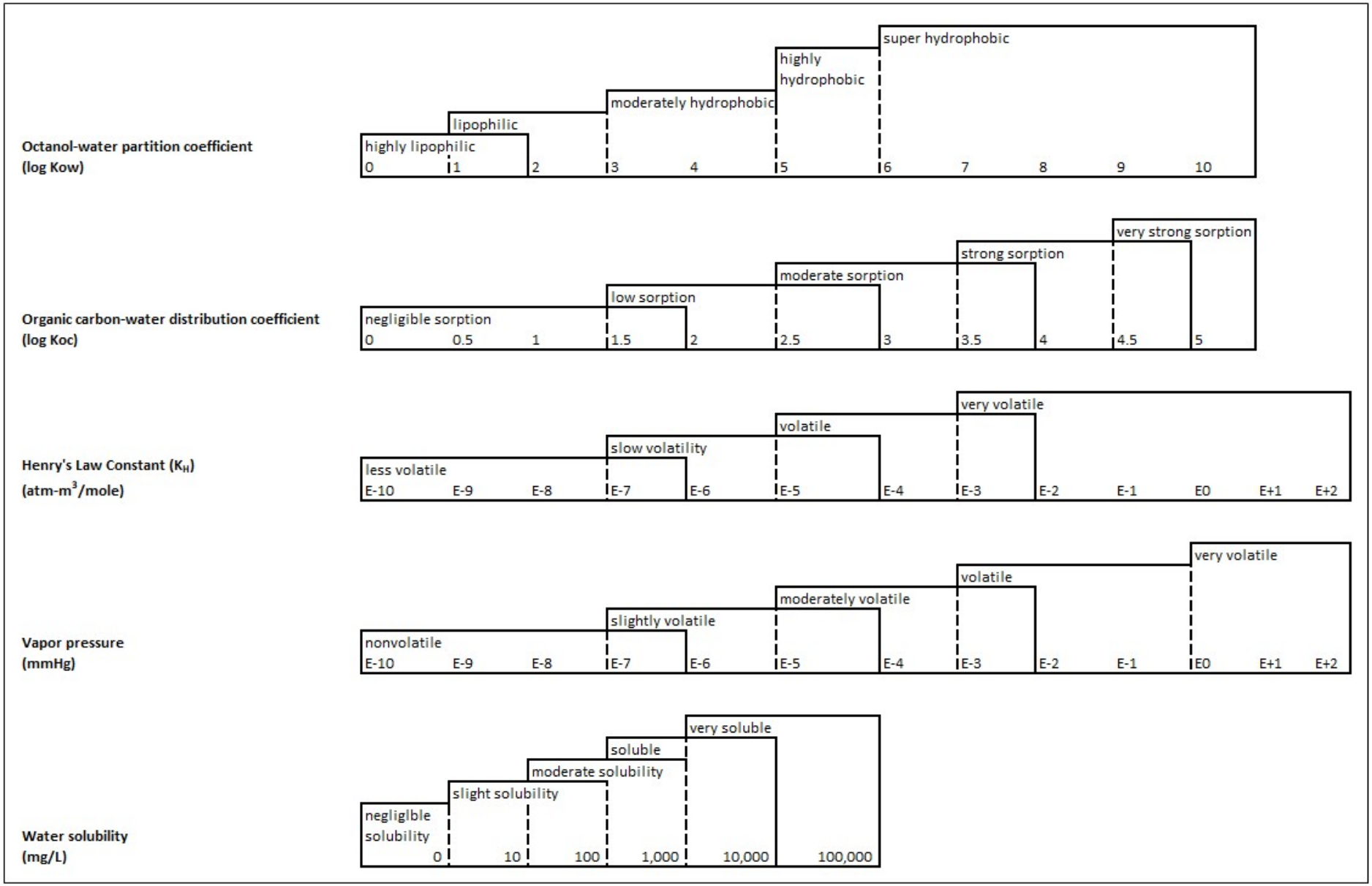
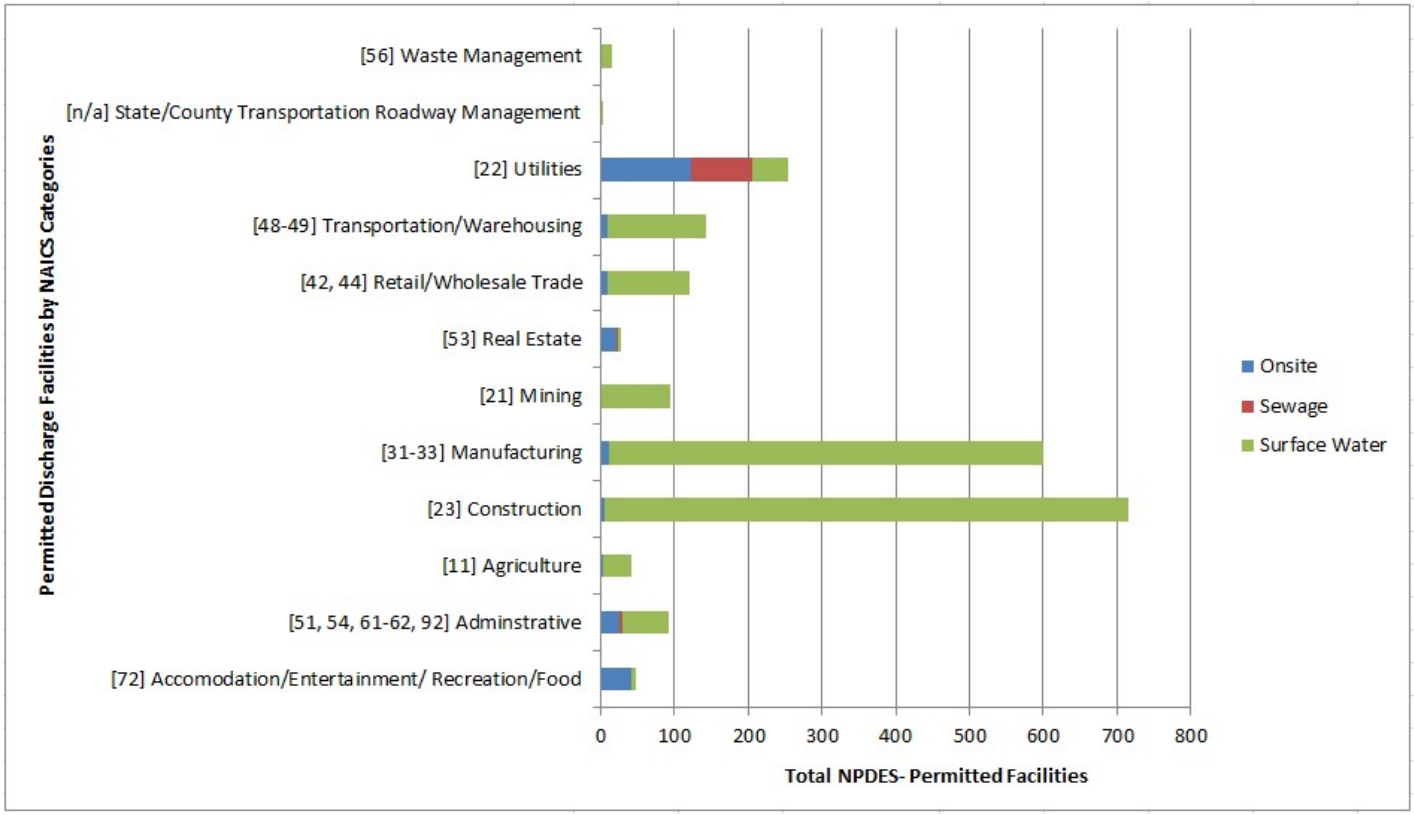


Figure 10. Chemical characteristic behaviors of toxic pollutants. Values associated with each of the five chemical characteristics evaluated for this Project, from top to bottom: octanol-water partition coefficient (log K_{OW}), organic carbon-water distribution coefficient (log K_{OC}), Henry's Law Constant (where E refers to scientific notation of 10 to the nth power), vapor pressure (where E refers to scientific notation of 10 to the nth power), and water solubility (where values are orders of magnitude) (EPA, 2012; Rand, 1995).



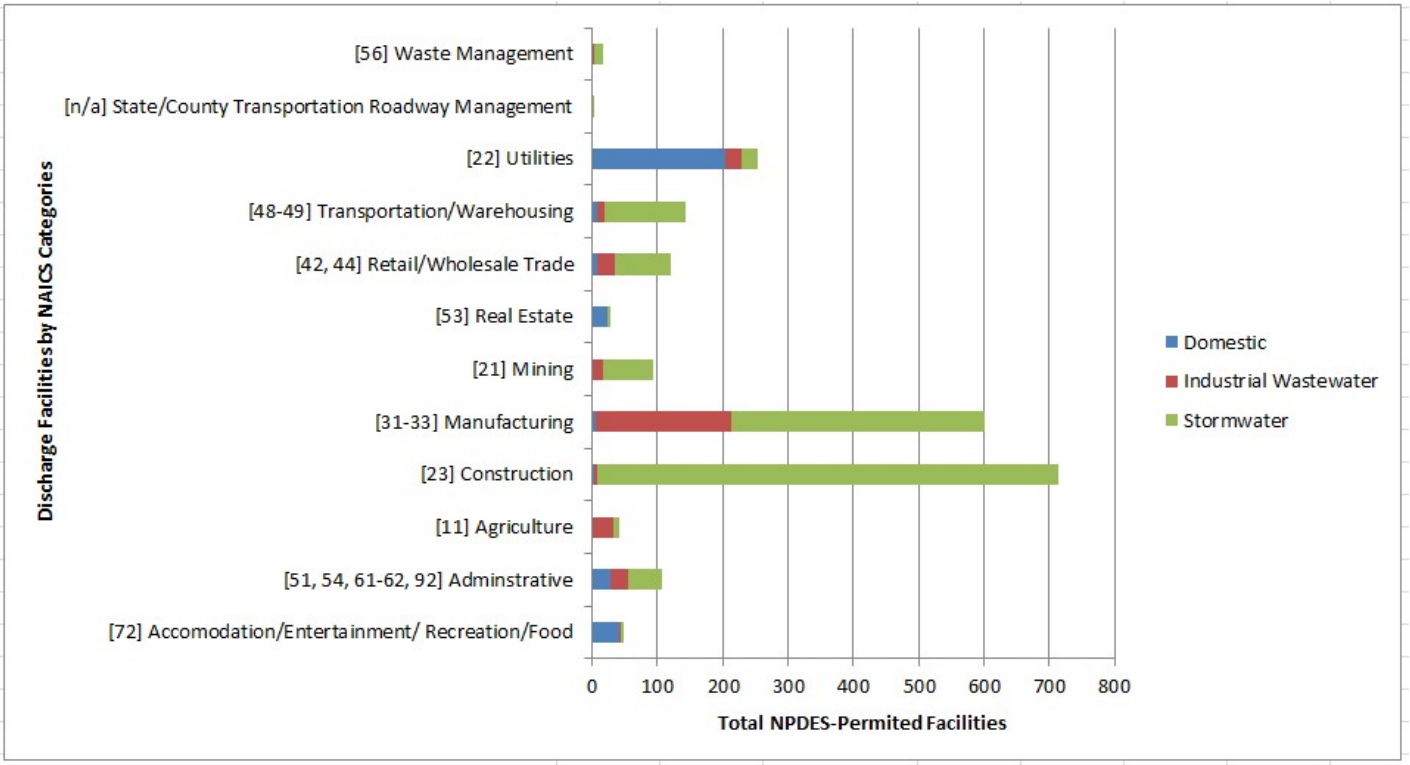


Figure 11. Point source discharge facilities in the Willamette Basin by industry category and discharge endpoint/waste stream. Facilities permitted to discharge stormwater/wastewater to surface waters of the Basin under NPDES permits evaluated according to their primary NAICS code and categorized by general industry activities (DEQ, 2017). Top: discharge endpoint of stormwater/wastewater discharges from permitted discharge facilities. Bottom: discharge waste streams from permitted discharge facilities.

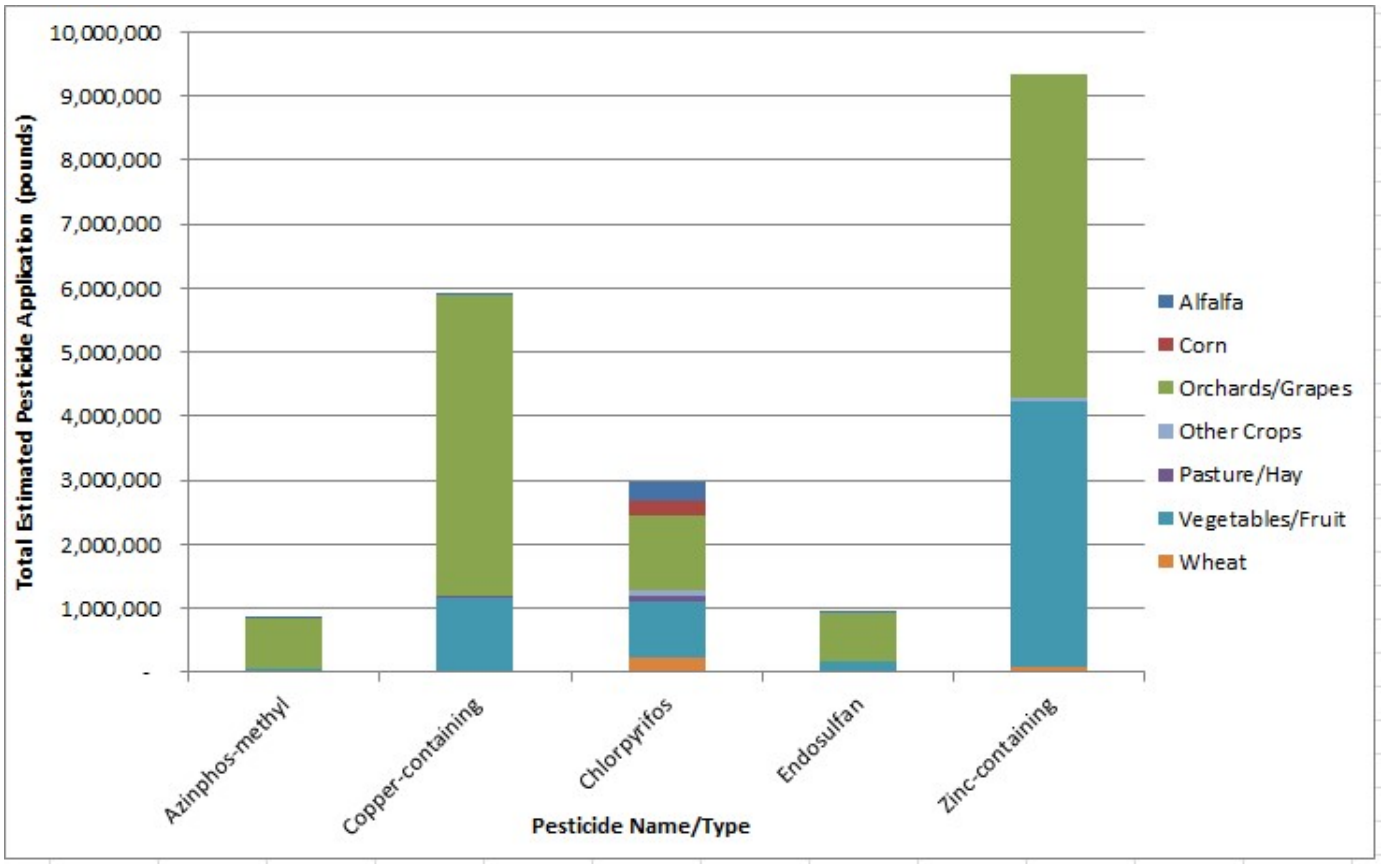


Figure 12. Pesticide applications in the Willamette Basin by crop and toxic pollutants. Pesticide applications at the county level (in kilograms and converted to pounds) reported by farms to the United States Department of Agriculture. Pesticide applications reported by the USGS' National Water Quality Assessment Pesticide National Synthesis Project and evaluated on agricultural land use only for the period of 2000 to 2016 (USGS, 2017). Pesticides evaluated as pesticides containing toxic pollutants: copper, zinc, azinphos-methyl, chlorpyrifos, and endosulfan.

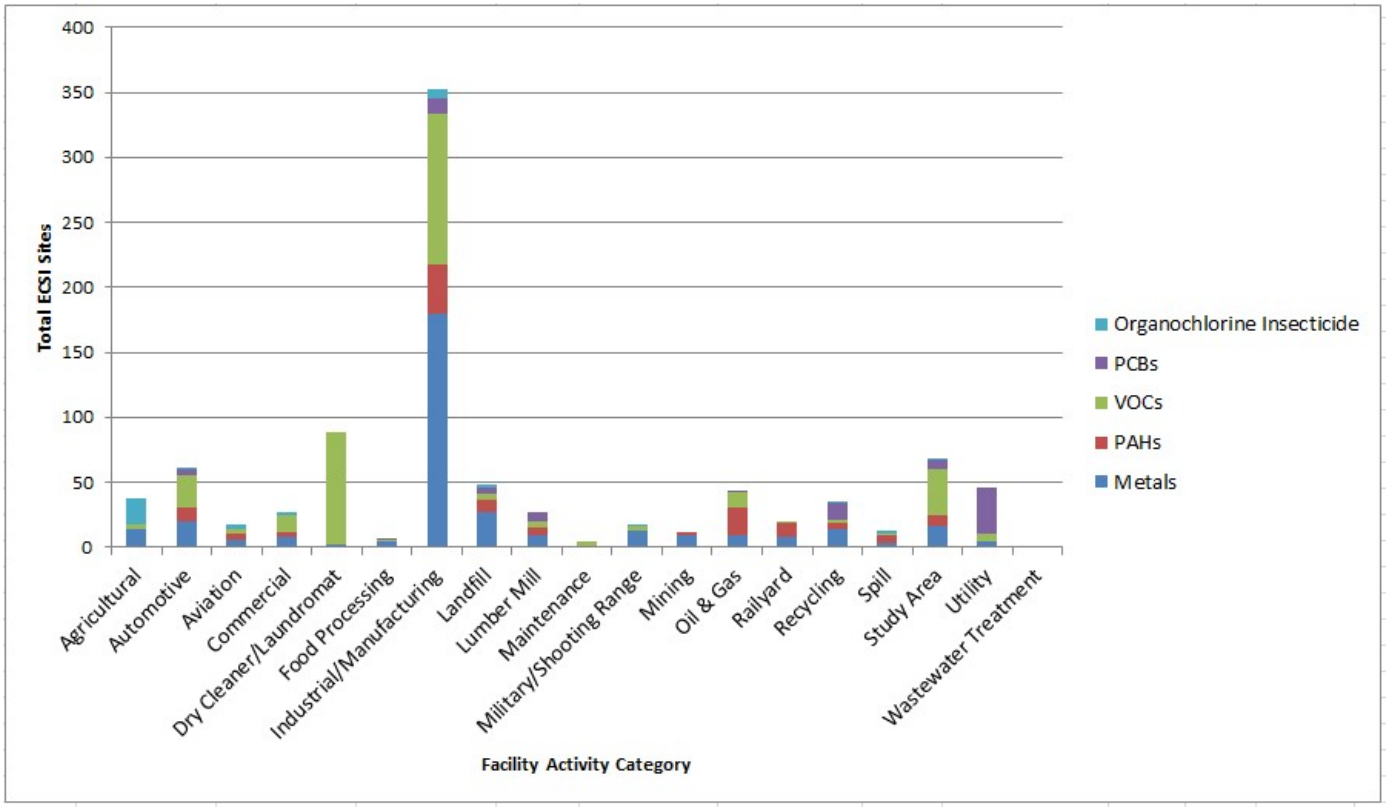


Figure 13. ECSI Site nonpoint sources in the Willamette Basin by industry activity and toxic pollutants. Environmental Cleanup Site Information (ECSI) sites in the Basin associated with toxic pollutant contamination impacting the sites. ECSI Sites evaluated in DEQ's ECSI database only impacted with the Basin's toxic pollutants. Industry activity categories (19 total) created based on review of the ECSI database reported facility information (DEQ, 2018c). PAHs = polycyclic aromatic hydrocarbons. PCBs = polychlorinated biphenyls. VOCs = volatile organic compounds.

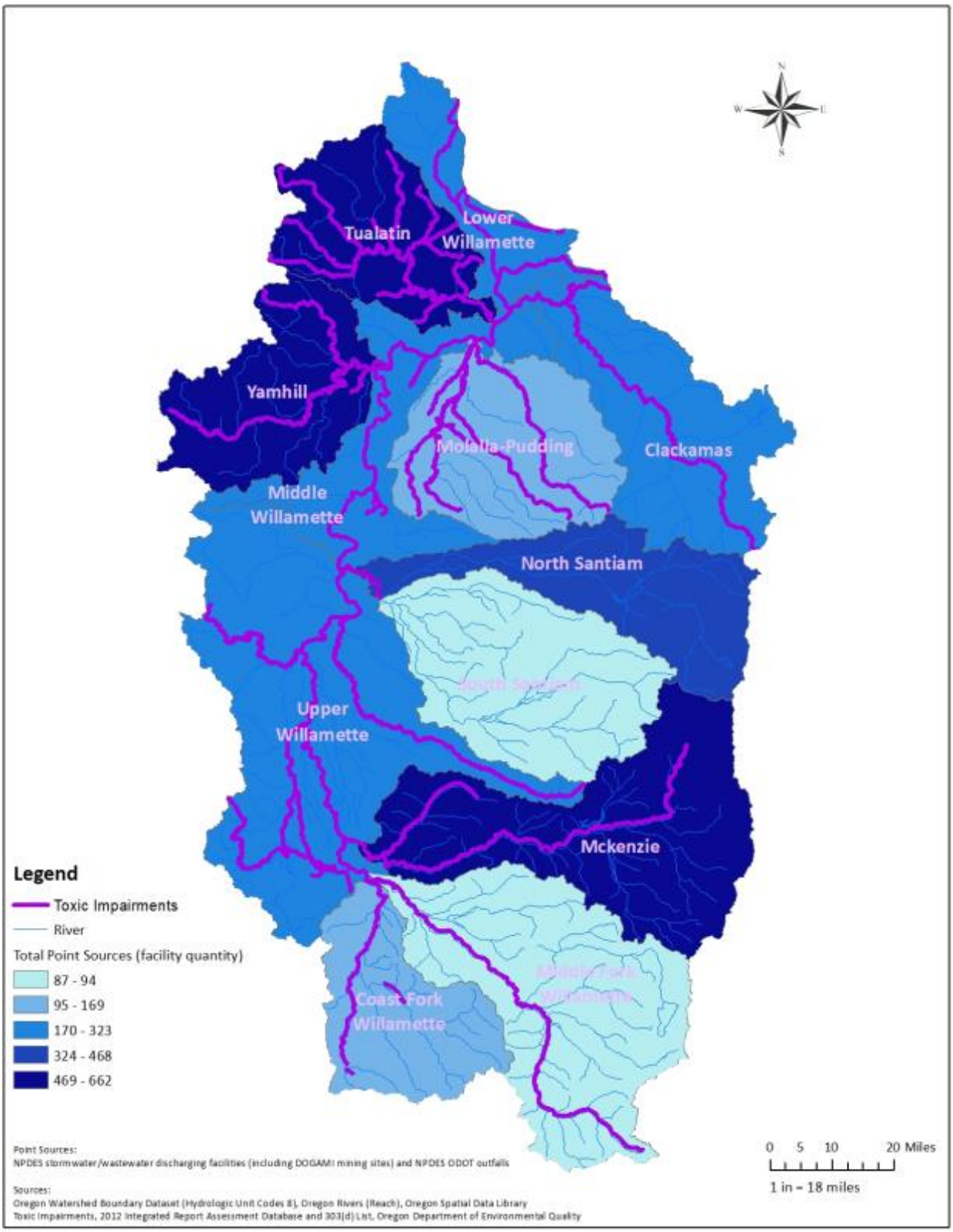


Figure 14. Total point sources of the Willamette Basin by subbasin. Chlorophleth map showing total quantity of point sources by subbasin and toxic pollutant impairments flowing through the subbasins identified at the 8-digit fourth-level USGS Hydrologic Unit Code (HUC) (DEQ, 2012; OSDL, 2017).

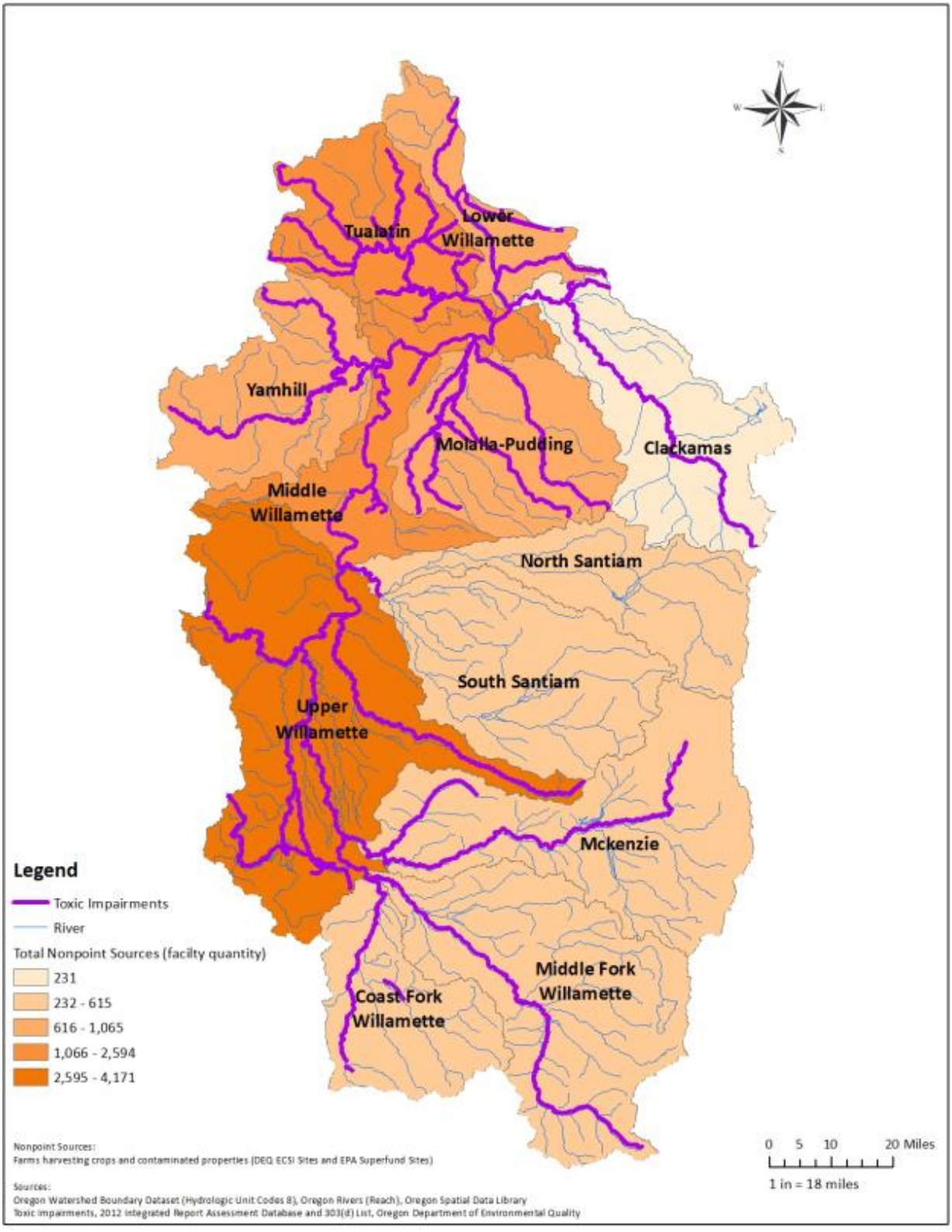


Figure 15. Total nonpoint sources of the Willamette Basin by subbasin. Chlorophleth map showing total nonpoint sources by subbasin and toxic pollutant impairments flowing through the subbasins identified at the 8-digit fourth-level USGS Hydrologic Unit Code (HUC) (DEQ, 2012; OSDL, 2017).

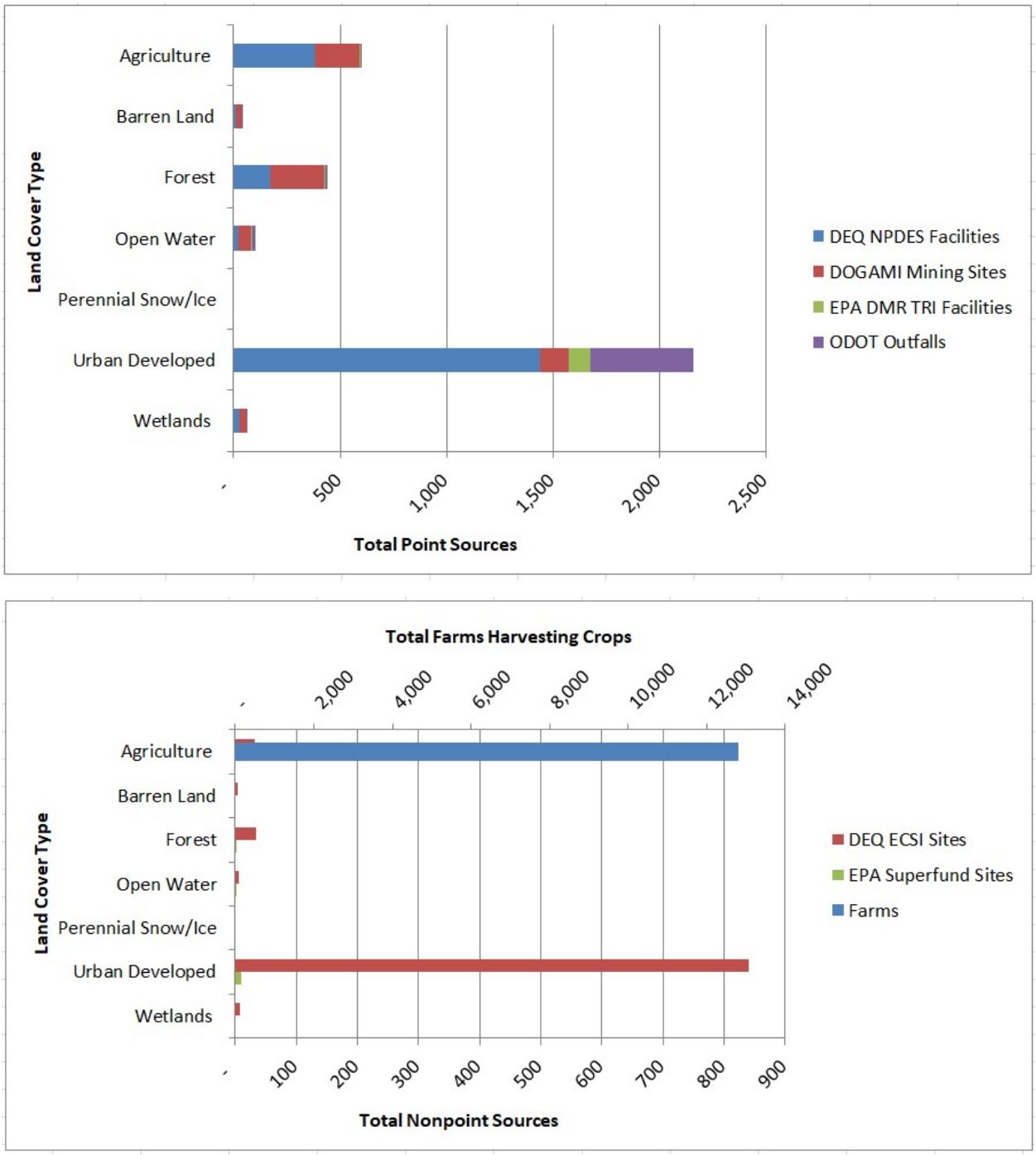


Figure 16. Total point and nonpoint sources of the Willamette Basin by land cover. Top: total quantity of point sources with permitted discharges of stormwater/wastewater to surface waters of the Basin associated with the land cover of the facility location. Bottom: total quantity of nonpoint sources with toxic pollutant contamination (ECSI and Superfund Sites) and pesticide applications (farms) associated with the land cover of the facility location. Pesticide applications evaluated only on agricultural land. DOGAMI = Department of Geology and Mineral Industries. DMR = Discharge Monitoring Report. TRI = Toxic Release Inventory. ODOT = Oregon Department of Transportation.

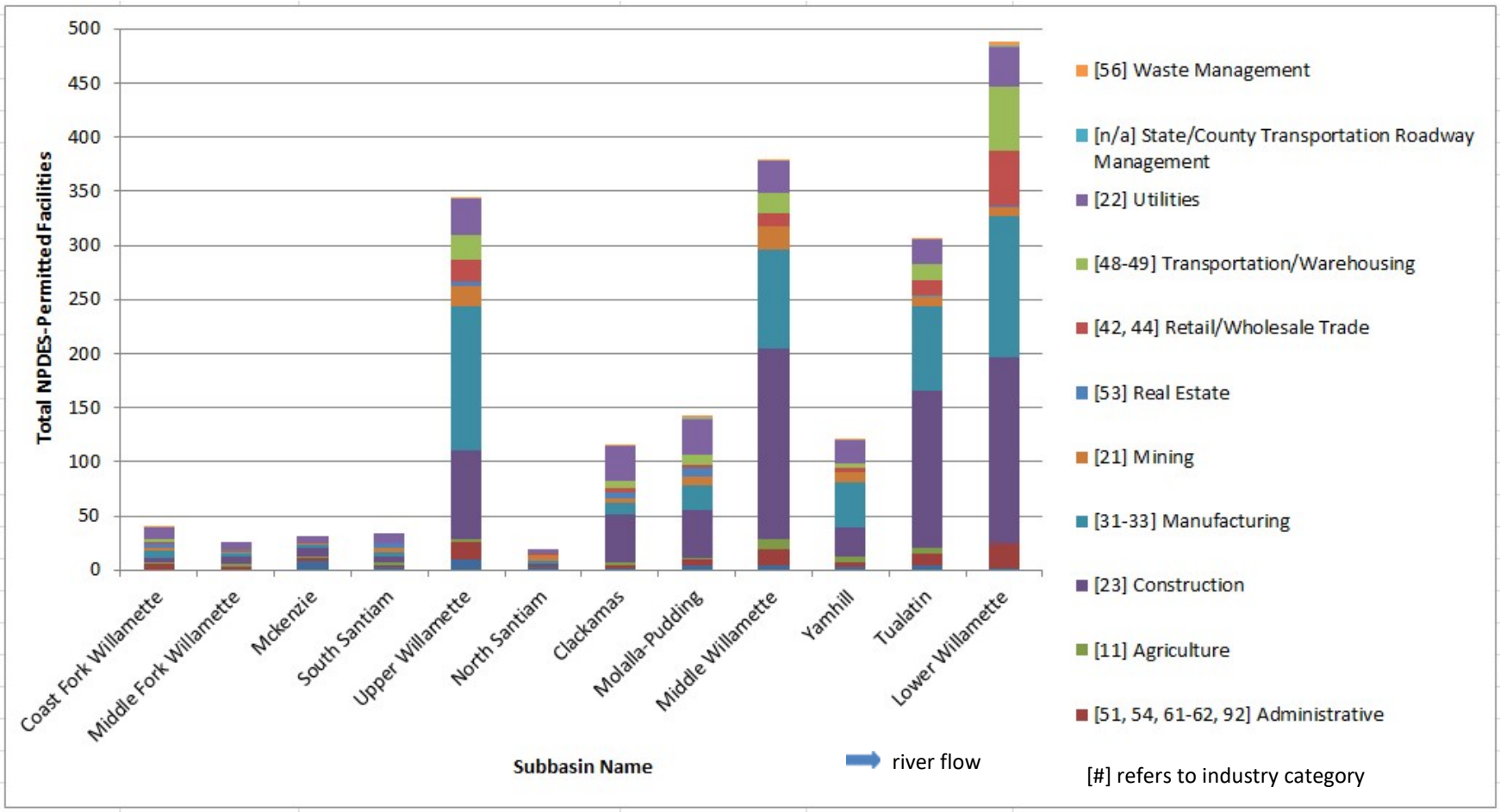


Figure 17. Point source discharge facilities in the Willamette Basin by industry and subbasin. Facilities discharge stormwater/wastewater to surface waters of the Basin under National Pollutant Discharge Elimination System (NPDES) permits, identified in DEQ's Wastewater permit database. Facilities evaluated by primary NAICS code and categorized by general industry activities (DEQ, 2017). Total point sources presented by subbasin from upstream (left) to downstream (right) location in the Basin (i.e., south to north).

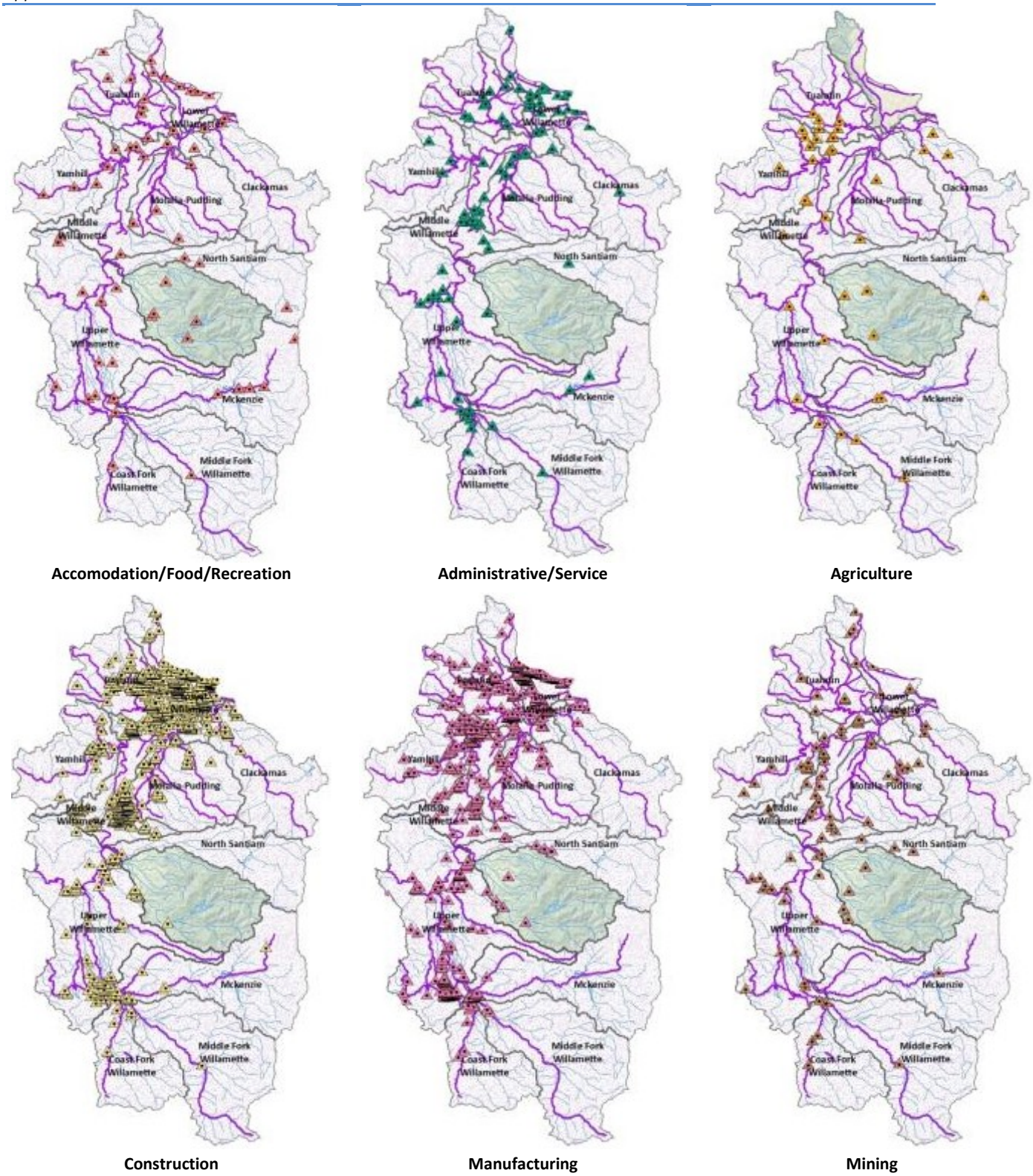


Figure 18. Point source discharge facilities in the Willamette Basin by industrial sector category (A-M). Facilities discharging stormwater/wastewater under National Pollutant Discharge Elimination System (NPDES) permits (triangles) evaluated by primary NAICS codes categorized by general industry activities and subbasin (shaded where sources present) at the 8-digit fourth-level USGS Hydrologic Unit Code (HUC) (DEQ, 2012, 2017). Toxic pollutant impairments (purple lines) shown flowing through the subbasins (DEQ, 2012).

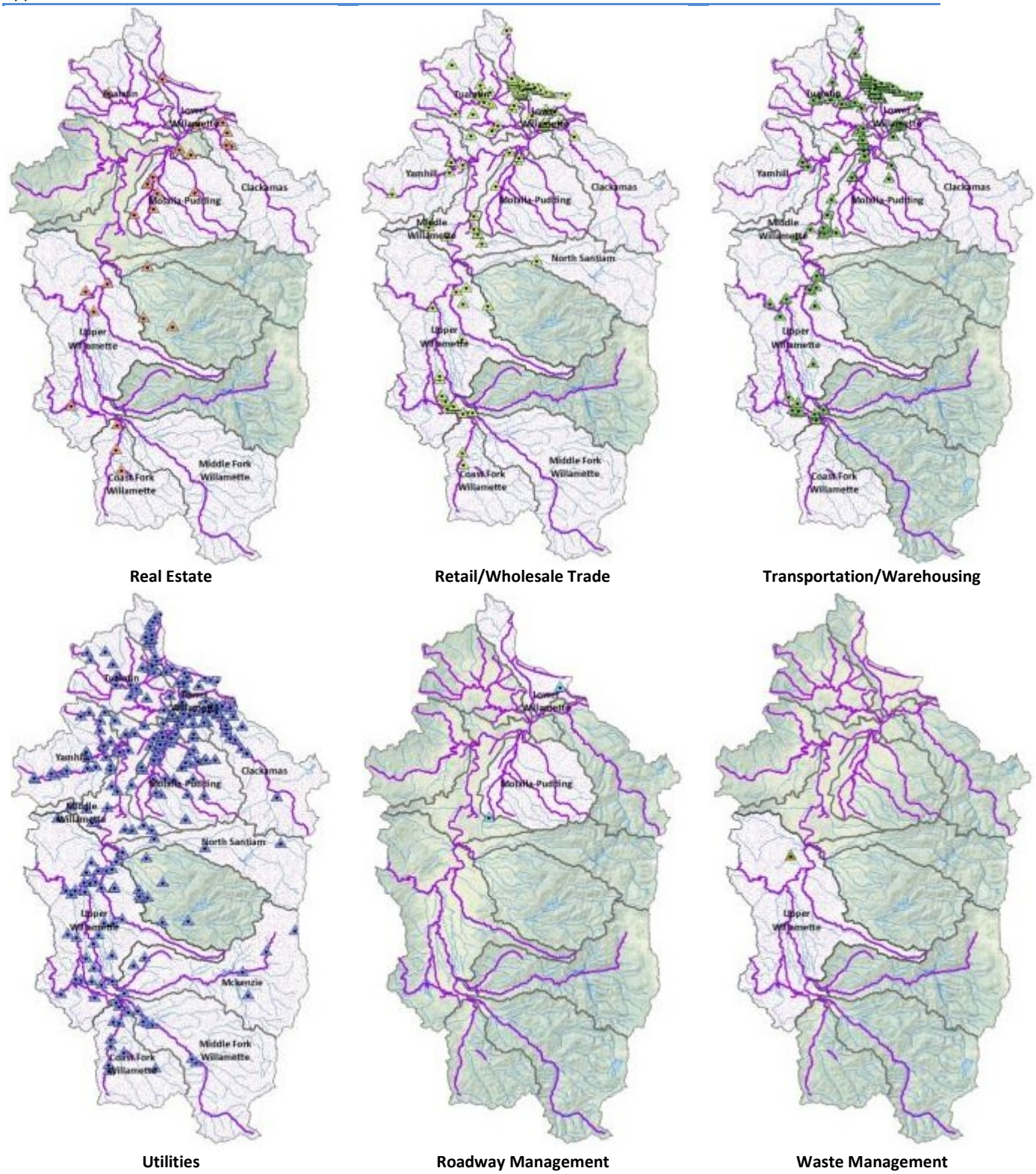


Figure 19. Point source discharge facilities in the Willamette Basin by industrial sector category (R-W). Facilities discharging stormwater/wastewater under National Pollutant Discharge Elimination System (NPDES) permits (triangles) evaluated by primary NAICS codes categorized by general industry activities and subbasin (shaded where sources present) at the 8-digit fourth-level USGS Hydrologic Unit Code (HUC) (DEQ, 2012, 2017). Toxic pollutant impairments (purple lines) shown flowing through the subbasins (DEQ, 2012).

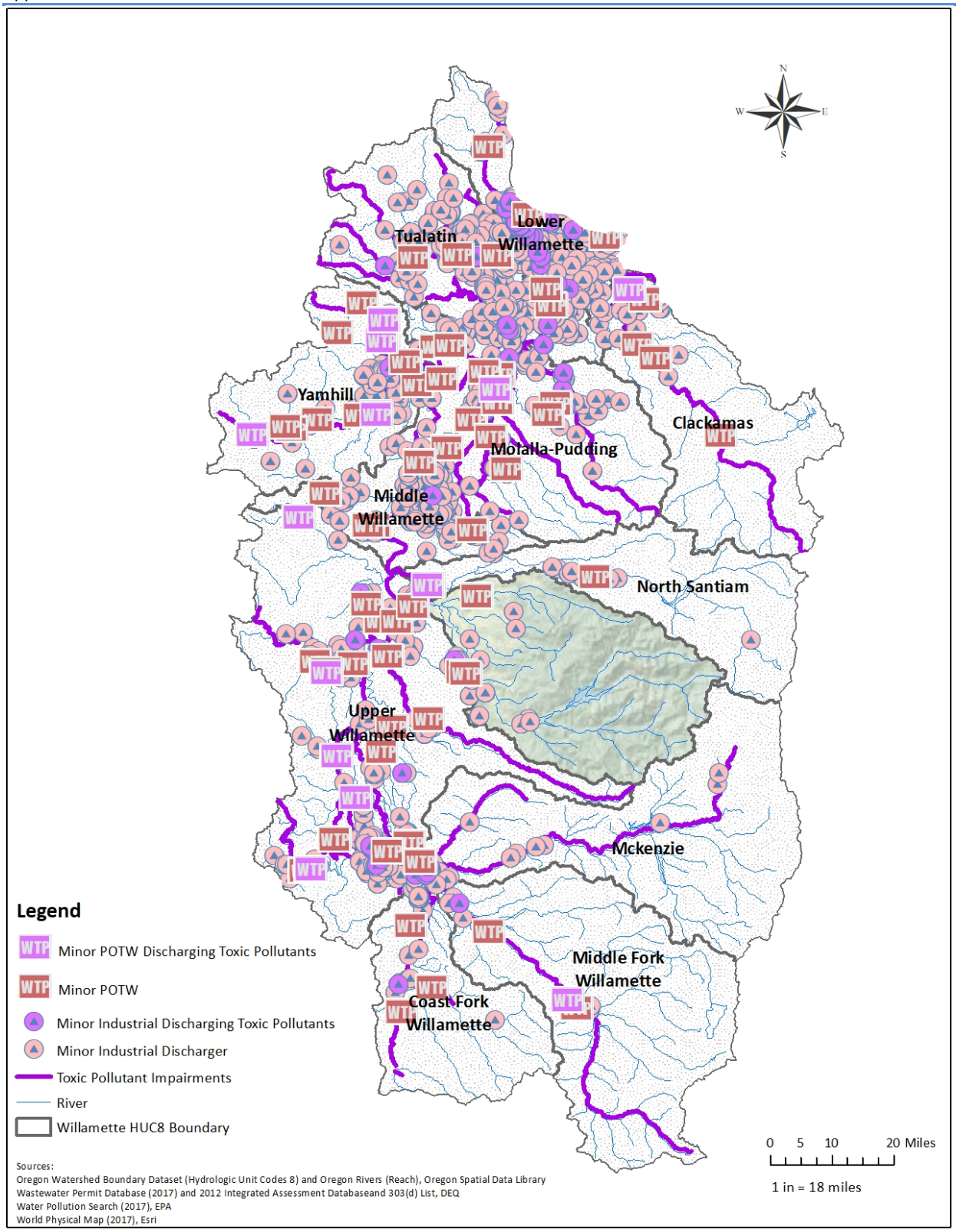


Figure 20. Minor POTW and industrial point source discharge facilities in the Willamette Basin. Topographic map shows NPDES-permitted stormwater/wastewater discharge facilities and toxic pollutant impairments flowing through the subbasins (shaded where sources present) identified at the 8-digit fourth-level USGS Hydrologic Unit Code (HUC) (DEQ, 2012, 2017; OSDL, 2017). Point sources include minor class dischargers: publicly owned treatment works (POTWs) and industrial facilities (i.e., non-POTWs). Point sources also include minor class dischargers with reported toxic pollutant loads (EPA, 2017b).

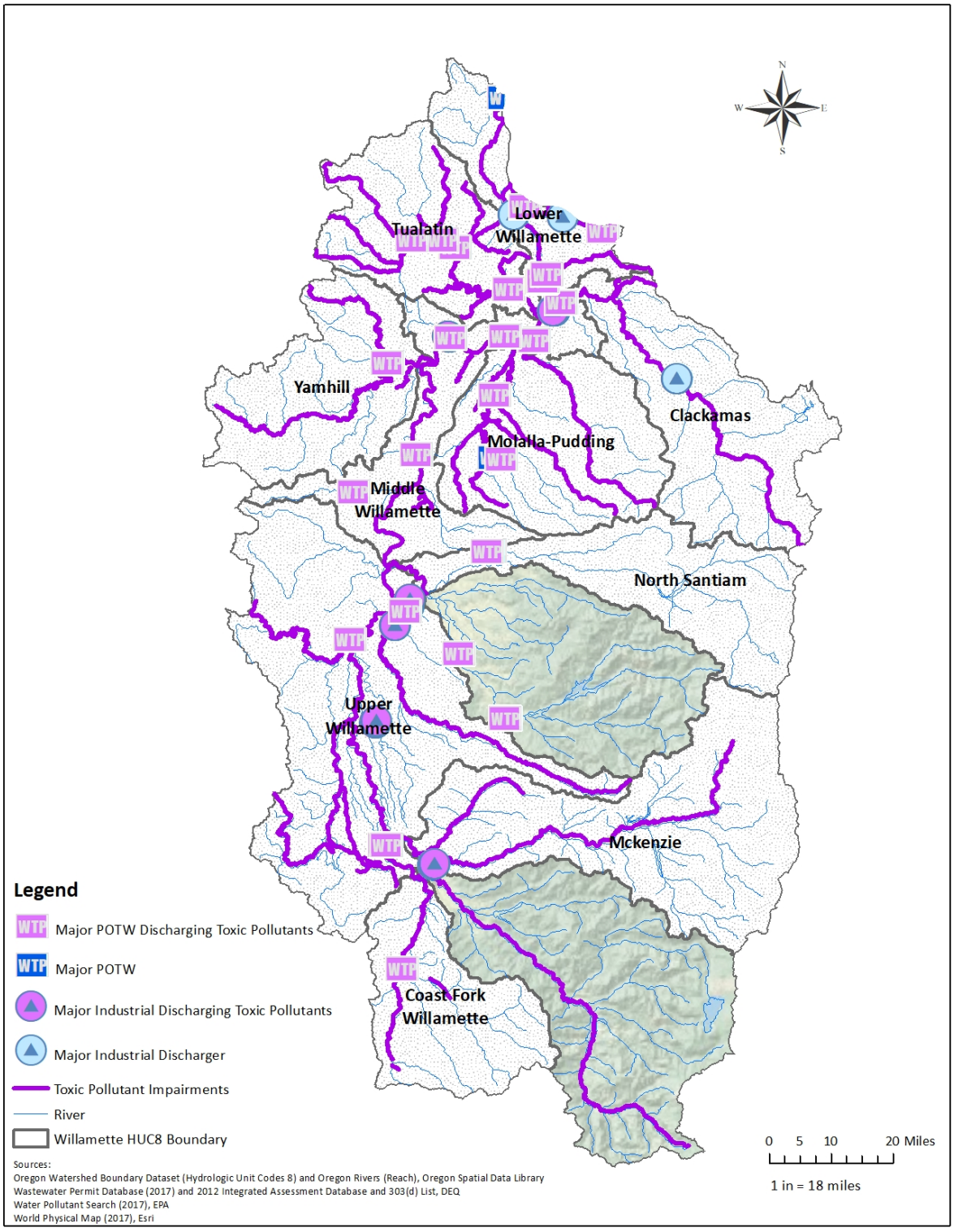


Figure 21. Major POTW and industrial point source discharge facilities in the Willamette Basin. Topographic map shows NPDES-permitted stormwater/wastewater discharge facilities and toxic pollutant impairments flowing through the subbasins (shaded where sources present) identified at the 8-digit fourth-level USGS Hydrologic Unit Code (HUC) (DEQ, 2012, 2017; OSDL, 2017). Point sources include major class dischargers: publicly owned treatment works (POTWs) and industrial facilities (i.e., non-POTWs).

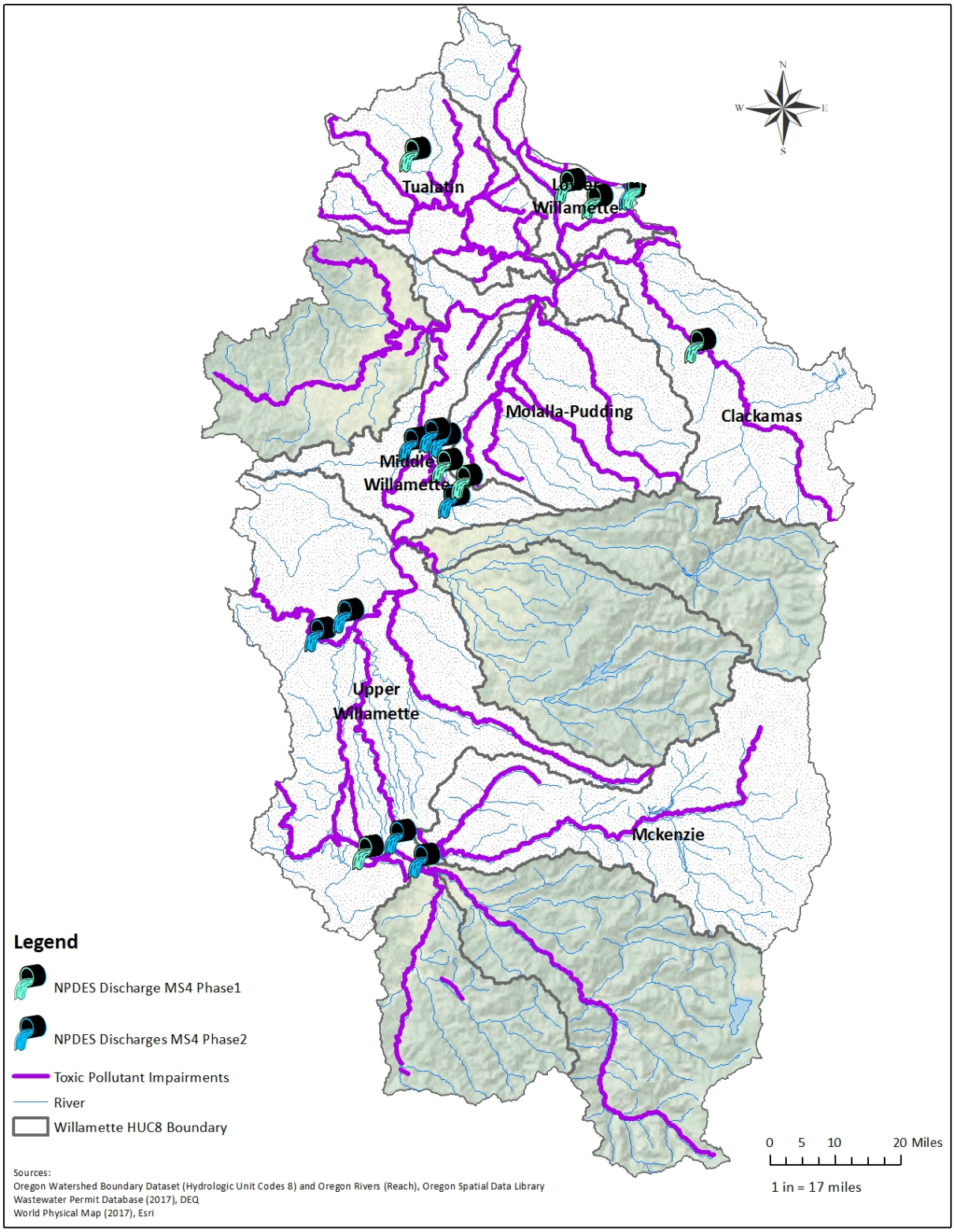


Figure 22. MS4-permitted point source discharge facilities in the Willamette Basin. Topographic map shows NPDES-permitted stormwater discharge facilities and toxic pollutant impairments flowing through the subbasins (shaded where sources present) identified at the 8-digit fourth-level USGS Hydrologic Unit Code (HUC) (DEQ, 2012, 2017; OSDL, 2017). Point sources include municipal storm sewer system (MS4) dischargers: Phase 1 and Phase 2.

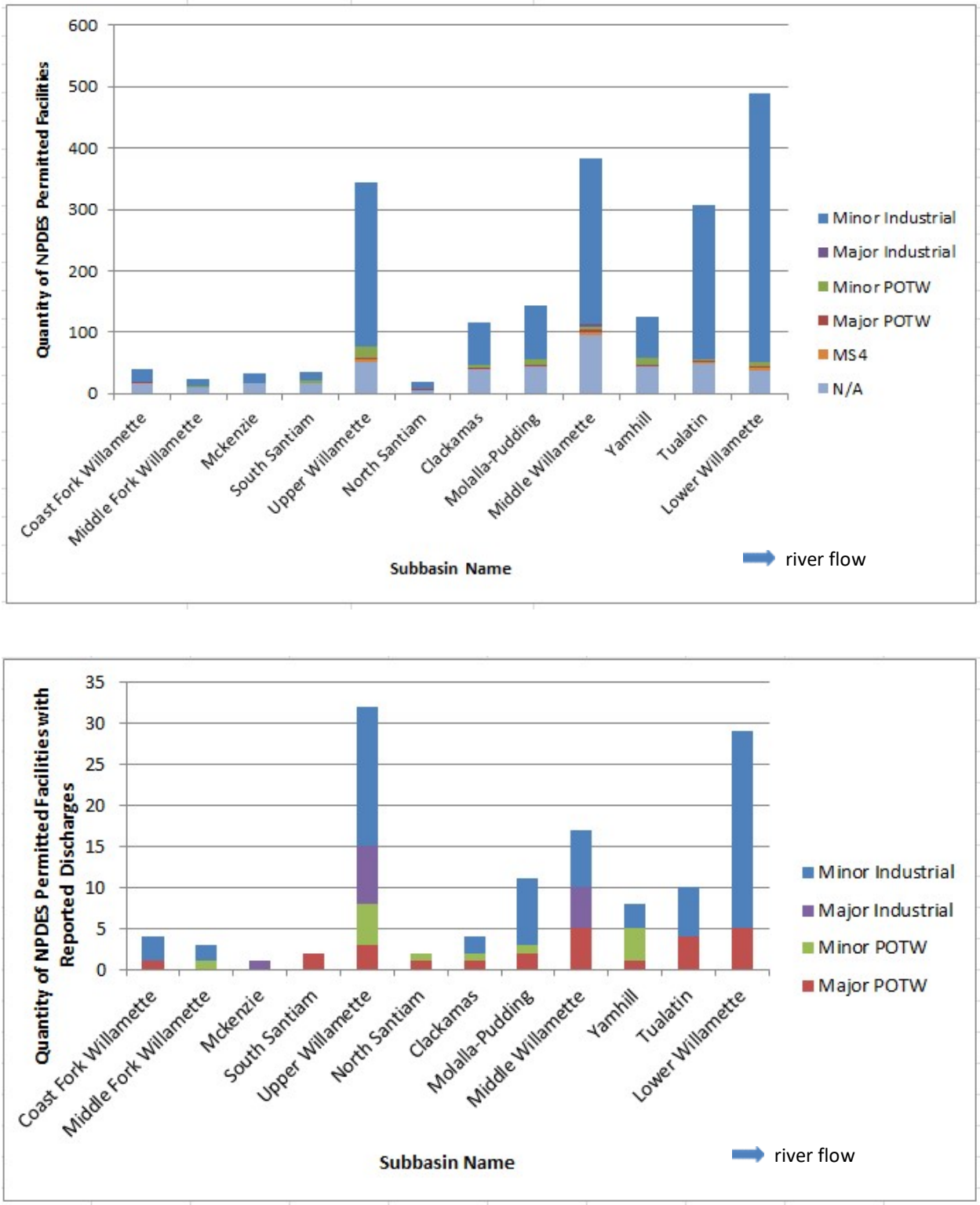


Figure 23. Comparison of POTW and industrial point source discharge facilities in the Willamette Basin by subbasin. Top: total quantity of NPDES-permitted stormwater/wastewater discharge facilities by subbasin identified in DEQ's wastewater permit database (DEQ, 2017). Bottom: total quantity of NPDES-permitted stormwater/wastewater discharge facilities by subbasin with reported toxic pollutant discharges identified in EPA's water pollutant search database (EPA, 2017b).

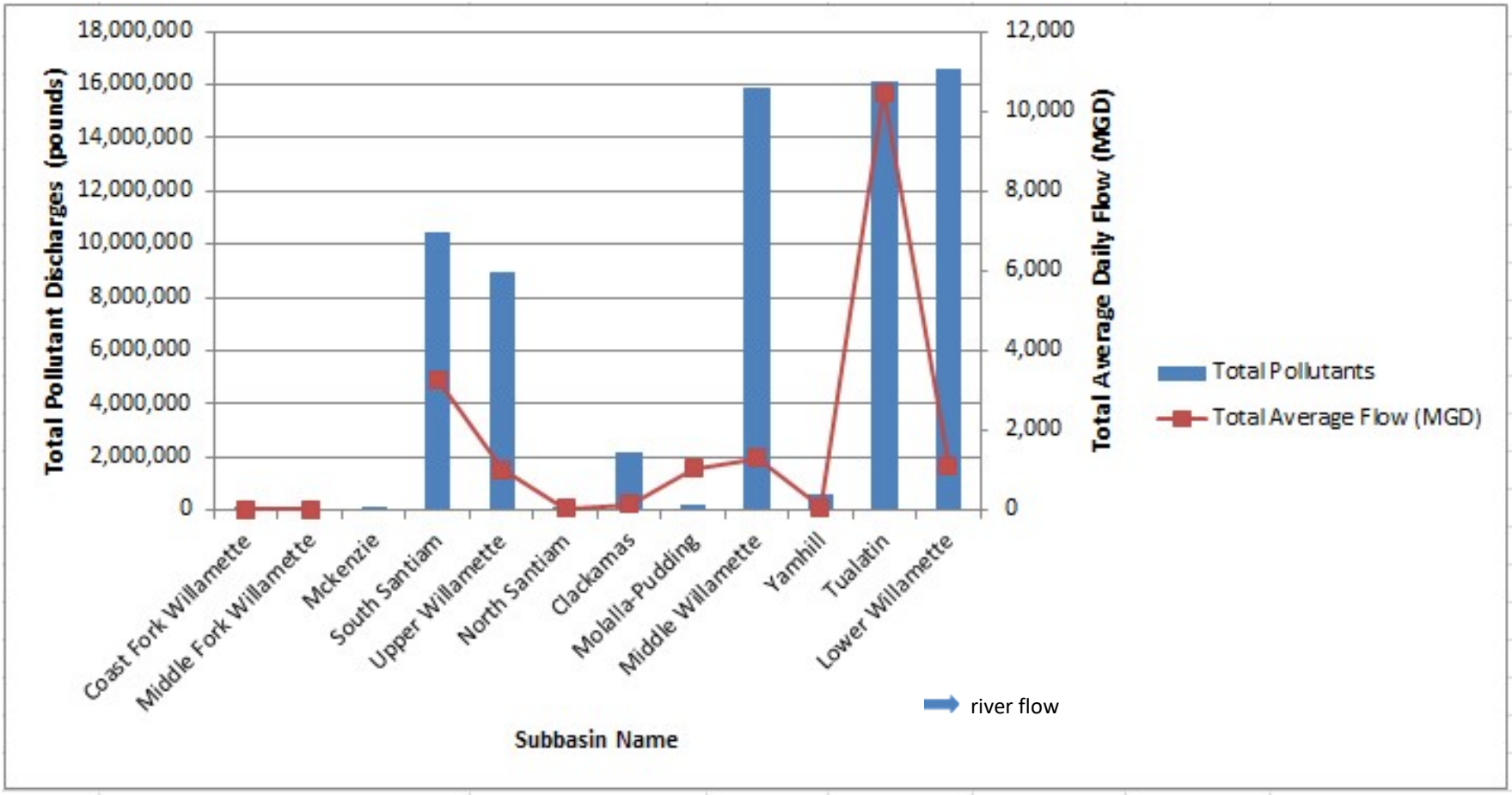


Figure 24. Point source discharge facilities reporting discharges and toxic pollutant loads in the Willamette Basin by subbasin. Total pollutant loads and total average daily flow discharged to surface waters of the Basin evaluated for the years 2007 to 2015. Facilities report stormwater/wastewater discharge volumes and toxic pollutant loads to EPA's Toxic Release Inventory (TRI). Average flow and total pollutants were not reported for facilities located in the McKenzie and Middle Fork Willamette subbasins (EPA, 2017a). Total pollutant discharges presented by subbasin from upstream (left) to downstream (right) location in the Basin (i.e., south to north).

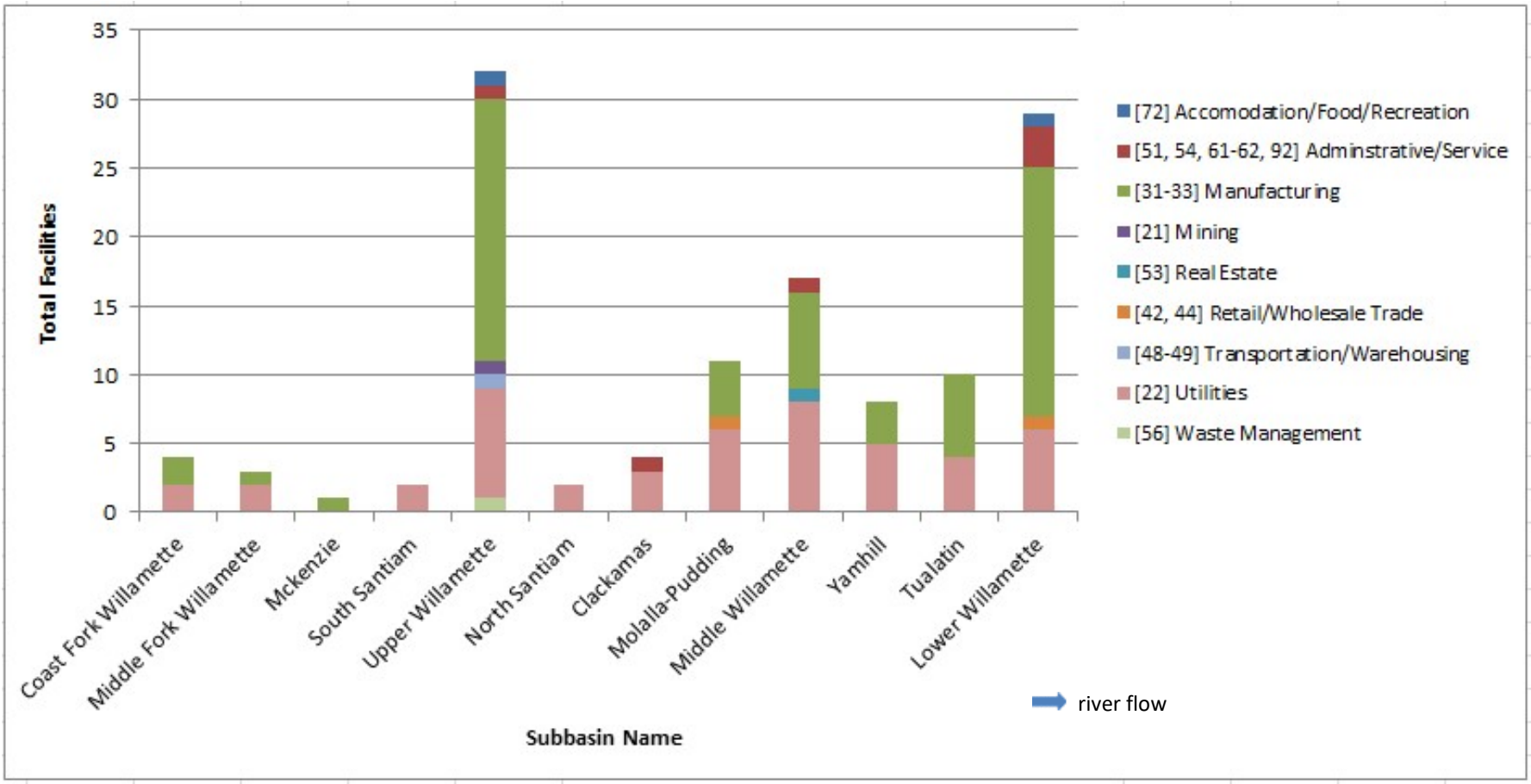


Figure 25. NPDES-permitted point source discharge facilities reporting discharges in the Willamette Basin by industry and subbasin. Facilities permitted to discharge stormwater/wastewater to surface waters of the Basin reporting discharge volumes and toxic pollutant loads annually to EPA's Toxic Release Inventory (TRI). Facilities evaluated by primary NAICS code and categorized by general industry activity for the period of 2007 to 2015 (EPA, 2017a). Total point sources presented by subbasin from upstream (left) to downstream (right) location in the Basin (i.e., south to north).

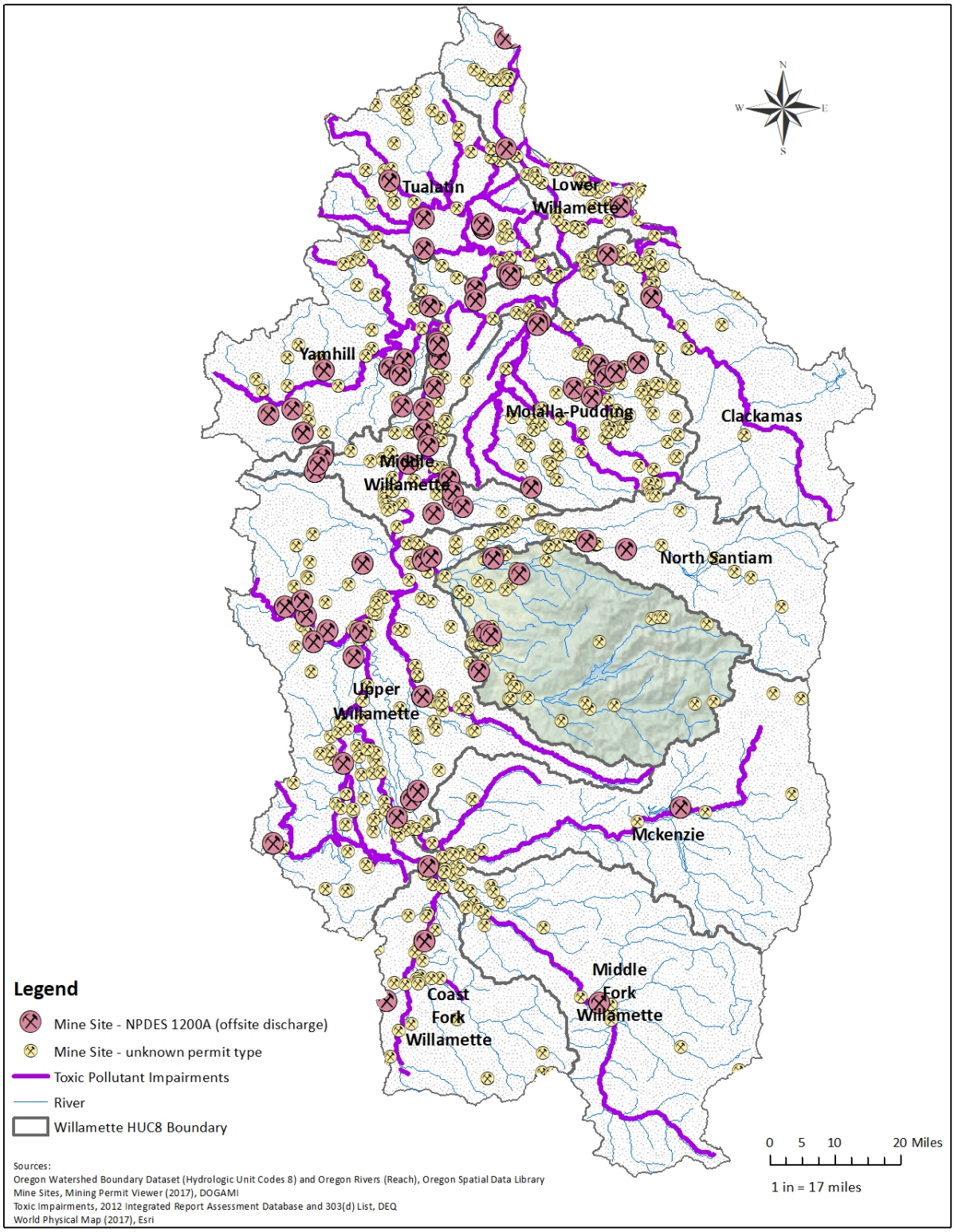


Figure 26. DOGAMI mining site point sources in the Willamette Basin. Topographic map shows NPDES-permitted mine sites with stormwater/wastewater discharges and toxic pollutant impairments flowing through the subbasins (shaded where sources present) identified at the 8-digit fourth-level USGS Hydrologic Unit Code (HUC) (DEQ, 2012; DOGAMI, 2017; OSDL, 2017). Point sources include 1200A permitted mine sites (offsite discharges) and mine sites with unknown permits by the Department of Geology and Mineral Industries (DOGAMI).

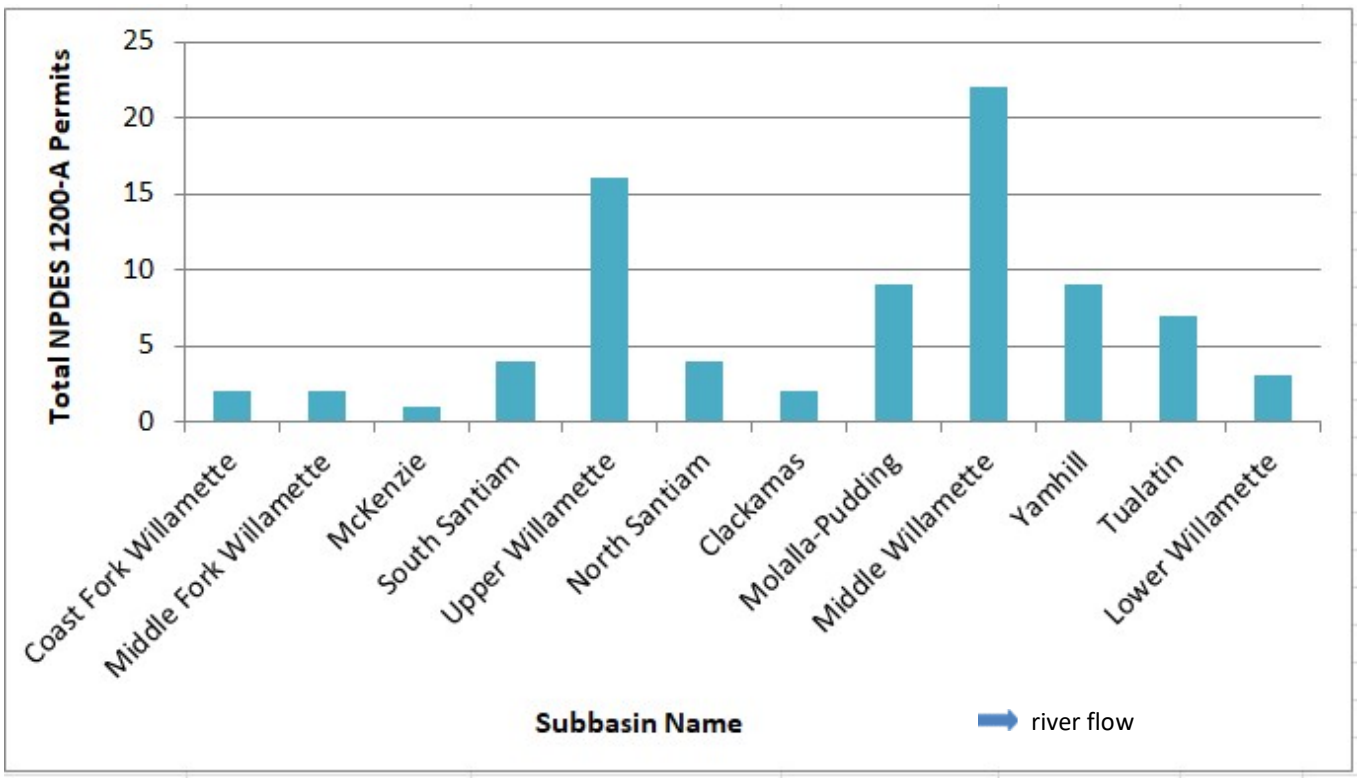


Figure 27. Mining site point sources with discharges in the Willamette Basin by subbasin. Mining sites permitted to discharge stormwater/wastewater offsite under a National Pollutant Discharge Elimination System (NPDES) 1200-A permit (DOGAMI, 2017). Total point sources presented by subbasin from upstream (left) to downstream (right) location in the Basin (i.e., south to north).

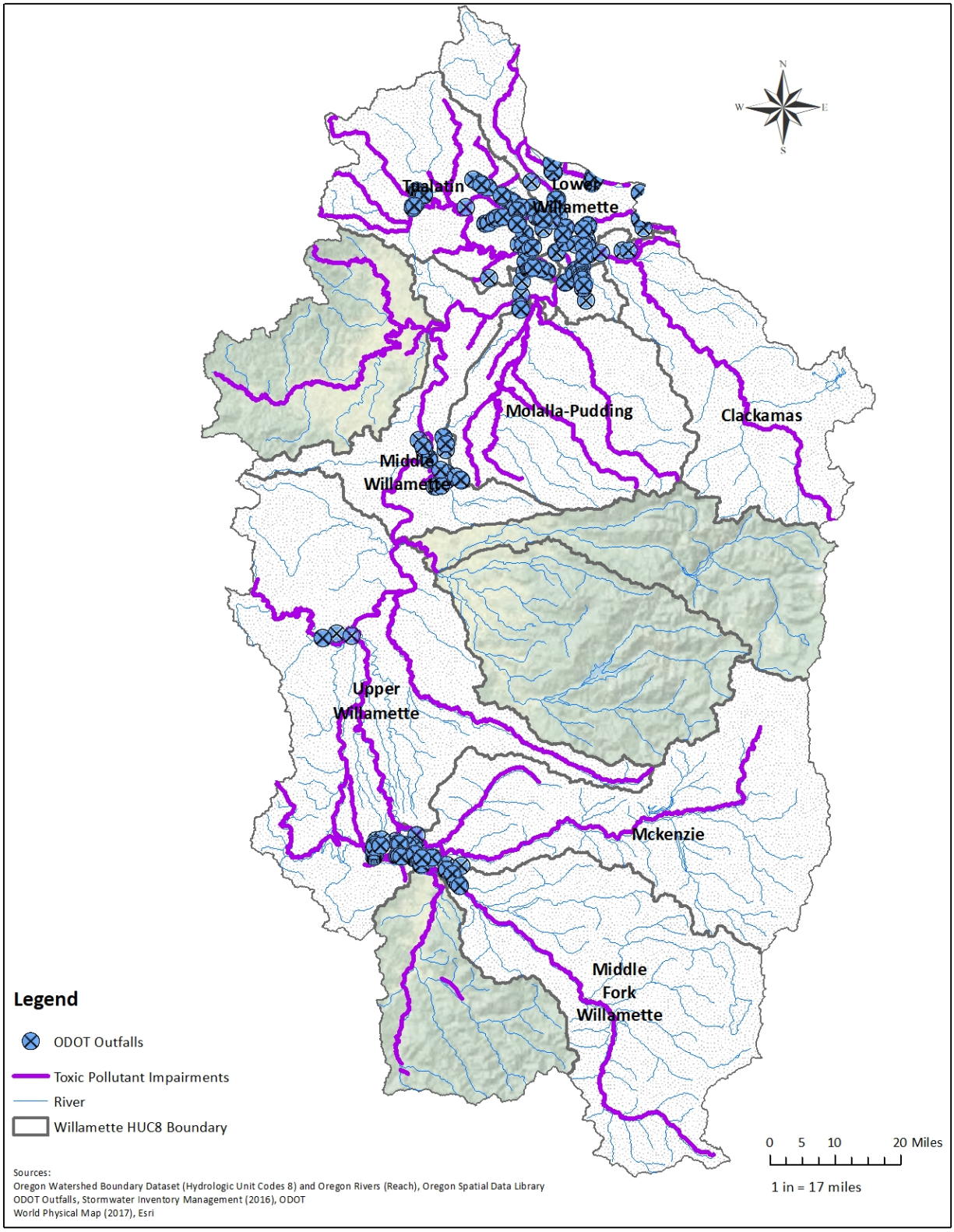


Figure 28. ODOT roadway outfall point sources in the Willamette Basin. Topographic map shows NPDES-permitted outfalls owned/operated by Oregon Department of Transporation (ODOT) and toxic pollutant impairments flowing through the subbasins (shaded where sources present) identified at the 8-digit fourth-level USGS Hydrologic Unit Code (HUC) (DEQ, 2012; ODOT, 2016; OSDL, 2017).

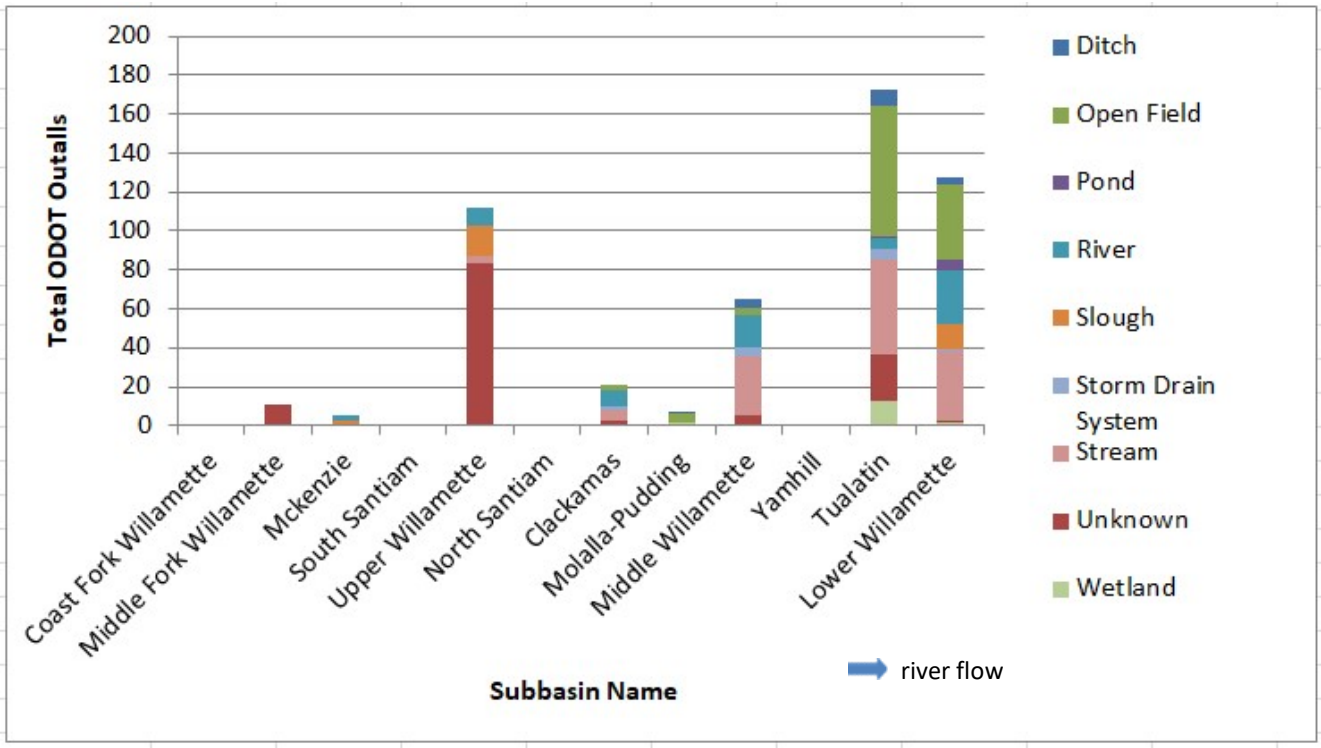


Figure 29. ODOT roadway outfall point sources of the Willamette Basin by subbasin and end discharge. Stormwater discharges from state roadways via Oregon Department of Transportation (ODOT)-managed outfalls under National Pollutant Discharge Elimination System (NPDES) permits (ODOT, 2016). Total point sources presented by subbasin from upstream (left) to downstream (right) location in the Basin (i.e., south to north).

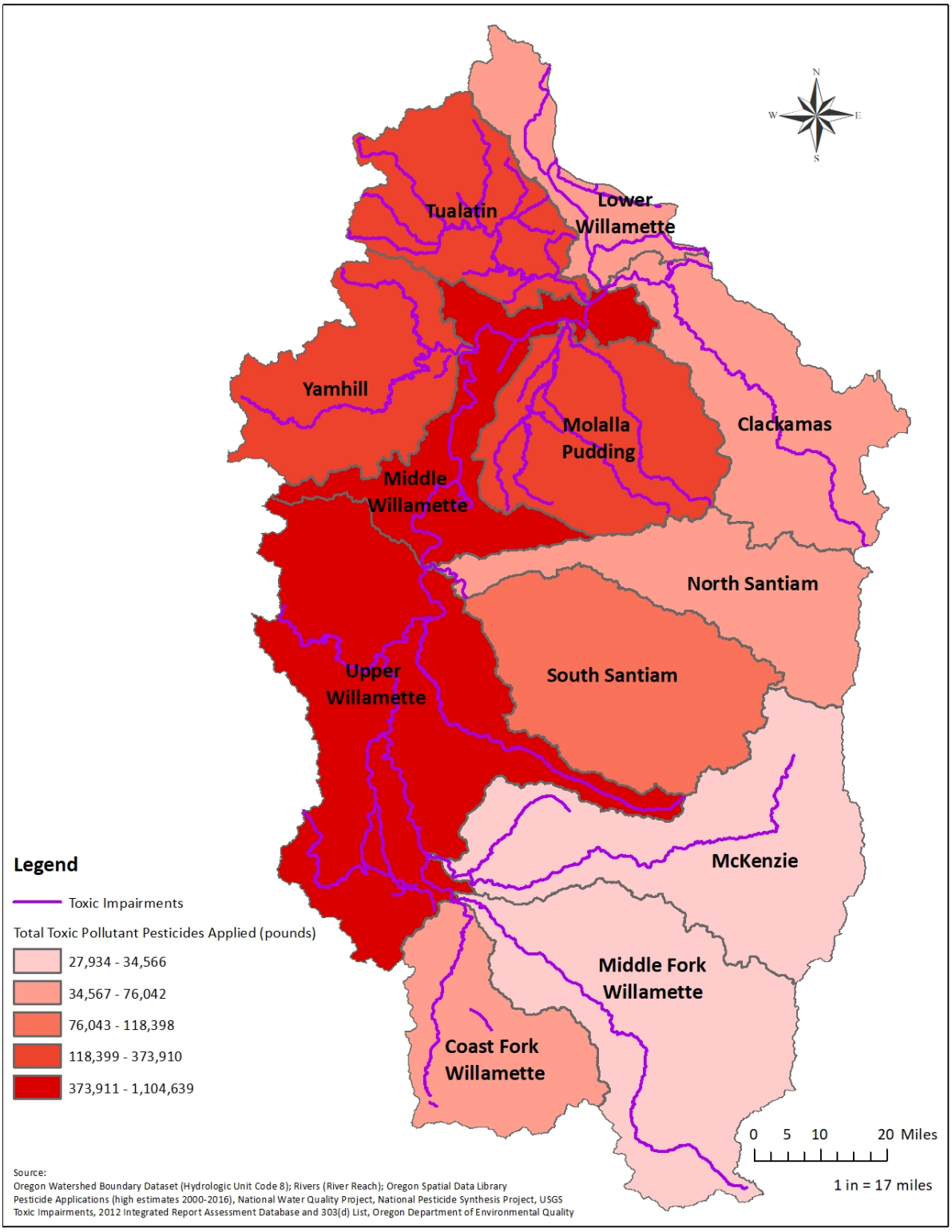


Figure 30. Total pesticide applications in the Willamette Basin. Chlorophleth map showing total pounds of toxic-pollutant pesticide applications (2000 to 2016) by subbasin and toxic pollutant impairments flowing through the subbasins identified at the 8-digit fourth-level USGS Hydrologic Unit Code (HUC) (DEQ, 2012; OSDL, 2017; USGS, 2017). Pesticide applications reported by the USGS' *National Water Quality Assessment Pesticide National Synthesis Project* and evaluated on agricultural land use only for the period of 2000 to 2016. Total pesticides applications for the Basin evaluated only for pesticides containing the Basin's toxic pollutants: copper, zinc, azinphos-methyl, chlorpyrifos, and endosulfan.

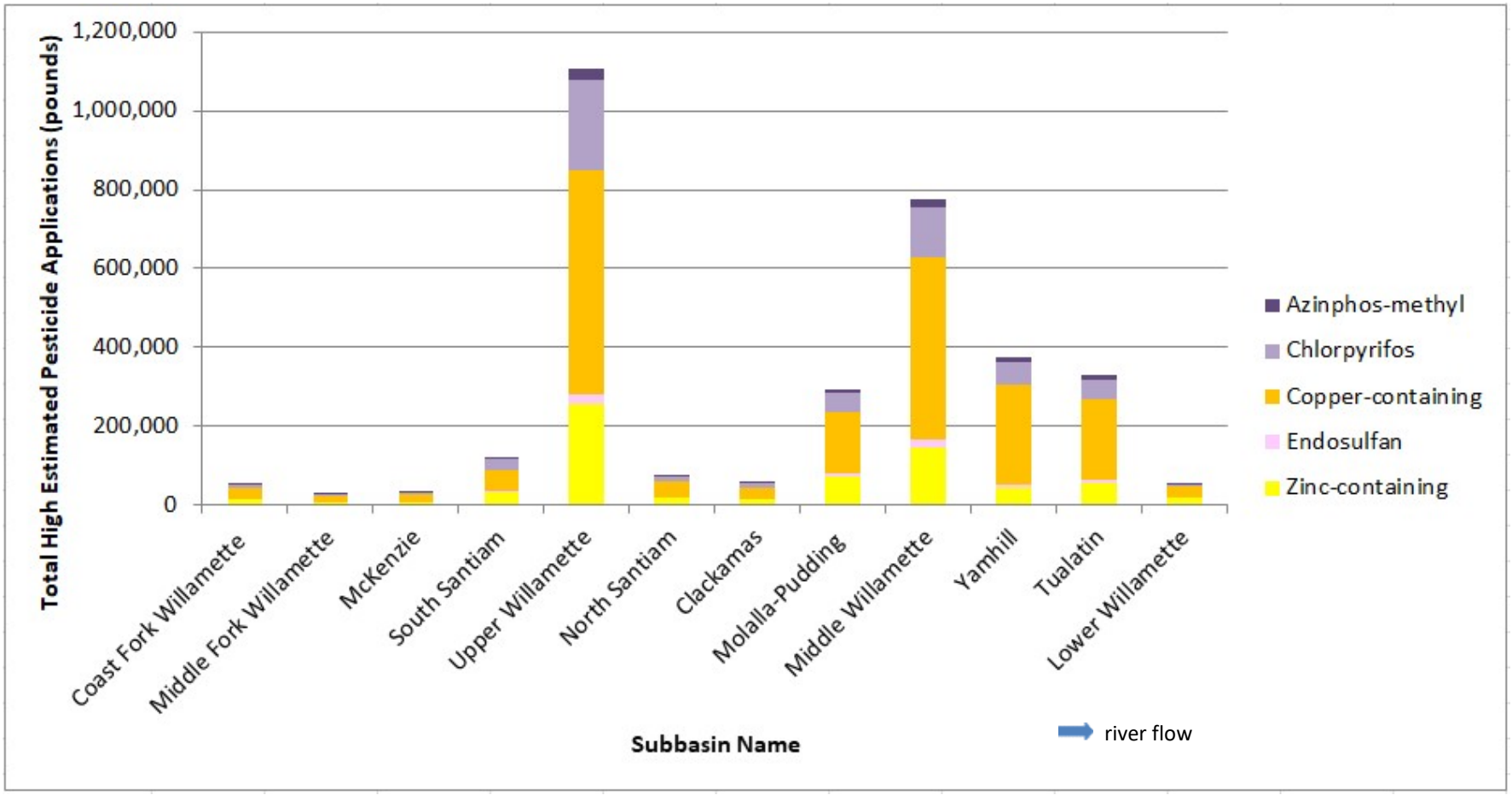


Figure 31. Pesticide applications in the Willamette Basin by subbasin and toxic pollutant. Pesticide applications (in pounds) for the period of 2000 to 2016. Pesticide applications are reported to the United States Department of Agriculture by farms at the county level. Geospatial processing techniques were applied to estimate subbasin applications (USGS, 2017). Total nonpoint sources presented by subbasin from upstream (left) to downstream (right) location in the Basin (i.e., south to north).

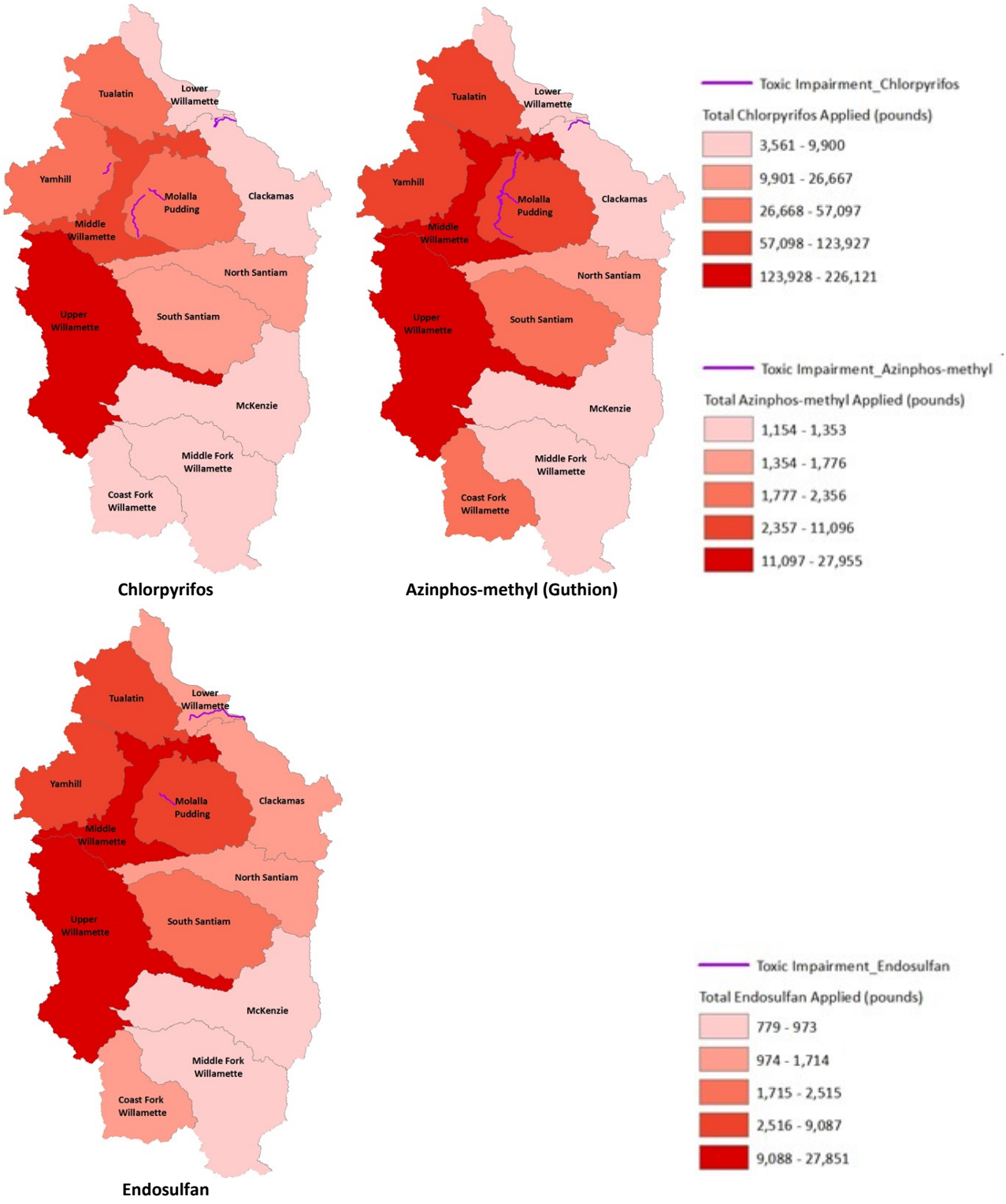
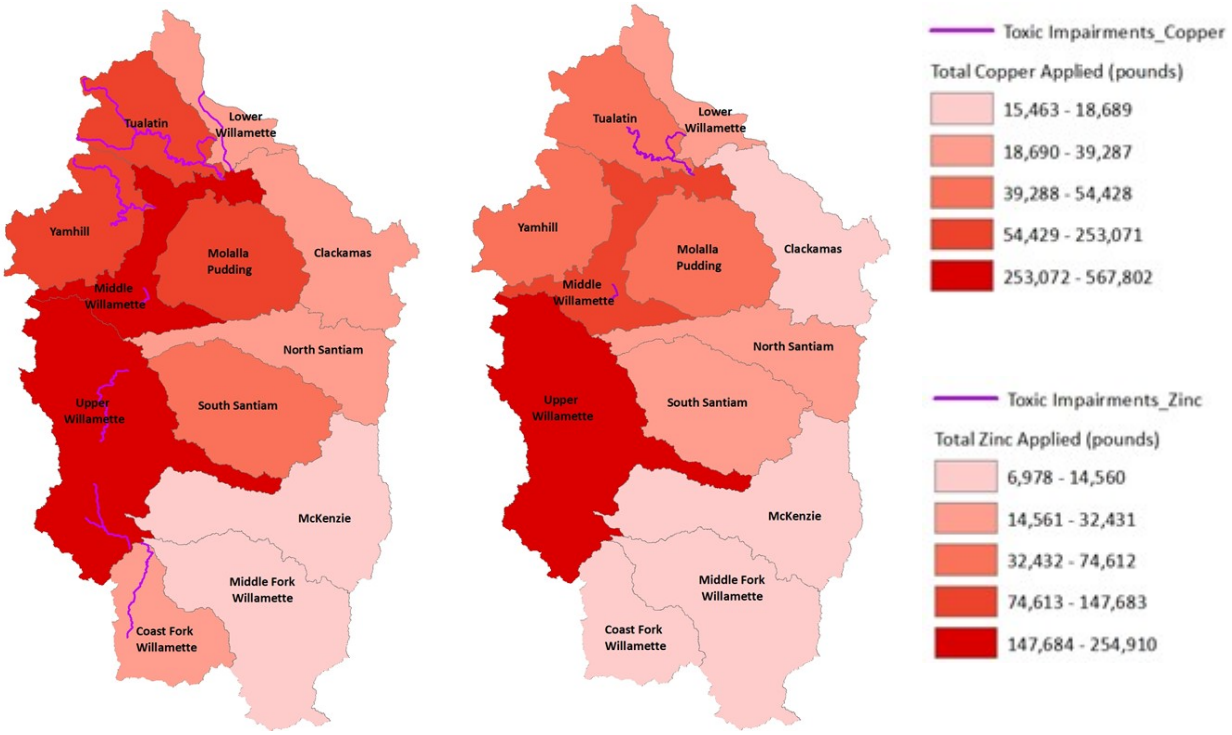


Figure 32. Insecticide-containing pesticide applications in the Willamette Basin. Chlorophleth map showing total pounds of organophosphorus insecticde- (top) and total organochlorine inseticide- (bottom) containing pesticide applications (2000 to 2016) by subbasin and toxic pollutant impairments (purple lines) of insecticides flowing through the subbasins identified at the 8-digit fourth-level USGS Hydrologic Unit Code (HUC) (DEQ, 2012; OSDL, 2017). Pesticide applications reported in the USGS' National Water Quality Assessment Pesticide National Synthesis Project database (2000 to 2016). Pesticide applications evaluated on agricultural land only for pesticides containing the Basin's toxic pollutants, following the USGS' methodology, using the National Land Cover Dataset (2011) (OSDL, 2011).



Copper **Zinc**

Figure 33. Metals-containing pesticide applications in the Willamette Basin. Chlorophleth map showing total pounds of copper- and zinc-containing pesticide applications (2000 to 2016) by subbasin and toxic pollutant impairments (purple lines) of copper and zinc flowing through the subbasins identified at the 8-digit fourth-level USGS Hydrologic Unit Code (HUC) (DEQ, 2012; OSDL, 2017). Pesticide applications reported in the USGS' National Water Quality Assessment Pesticide National Synthesis Project database (2000 to 2016). Pesticide applications evaluated on agricultural land only for pesticides containing the Basin's toxic pollutants, following the USGS' methodology, using the National Land Cover Dataset (2011) (OSDL, 2011).

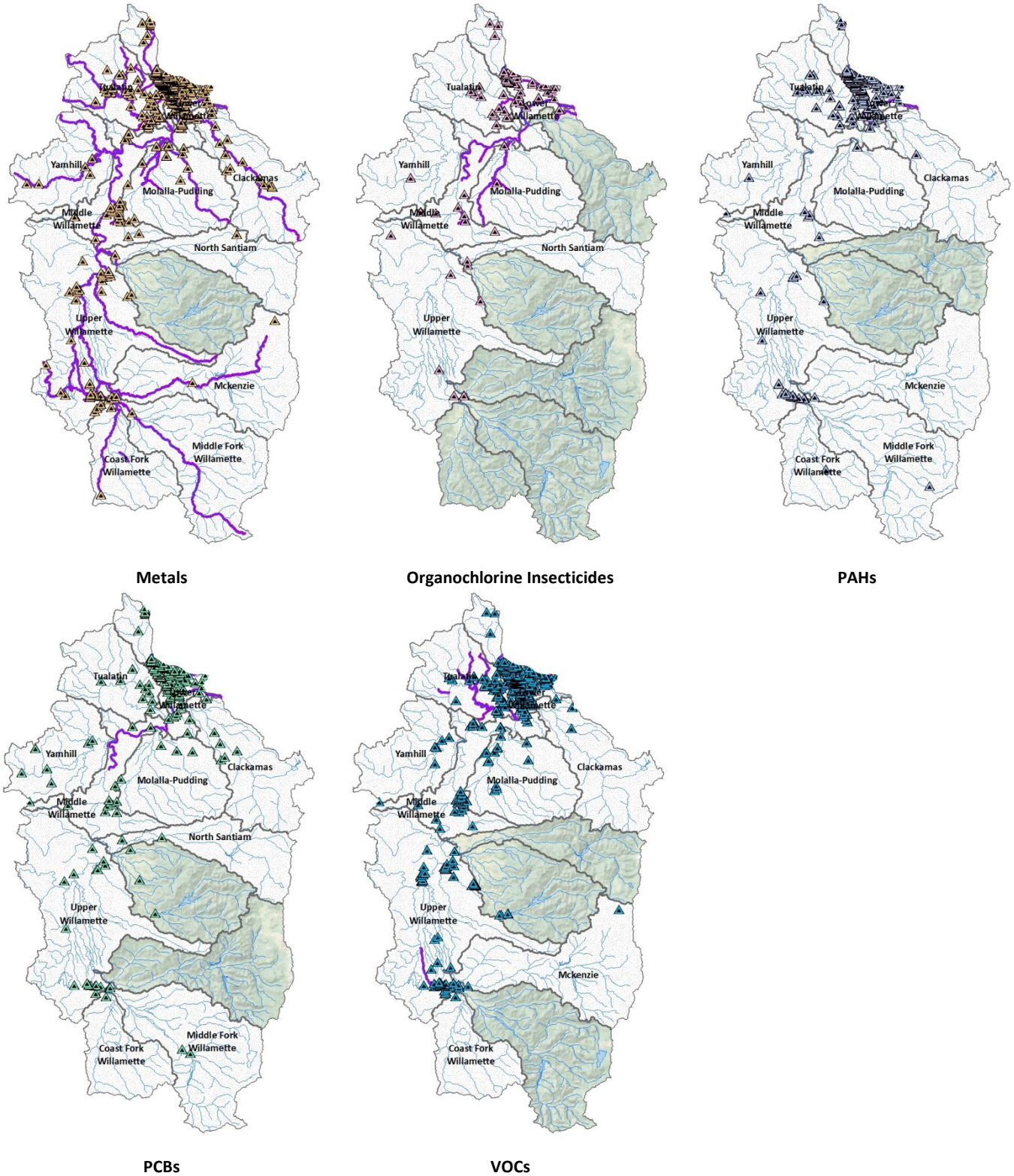


Figure 34. ECSI Site nonpoint sources of the Willamette Basin. DEQ Environmental Cleanup Information System (ECSI) sites (triangles) evaluated by toxic pollutant class and subbasin (shaded where sources present) at the 8-digit fourth-level USGS Hydrologic Unit Code (HUC) (DEQ, 2012, 2017; OSDL, 2017). PAHs = polycyclic aromatic hydrocarbons. PCBs = polychlorinated biphenyls. VOCs = volatile organic compounds.

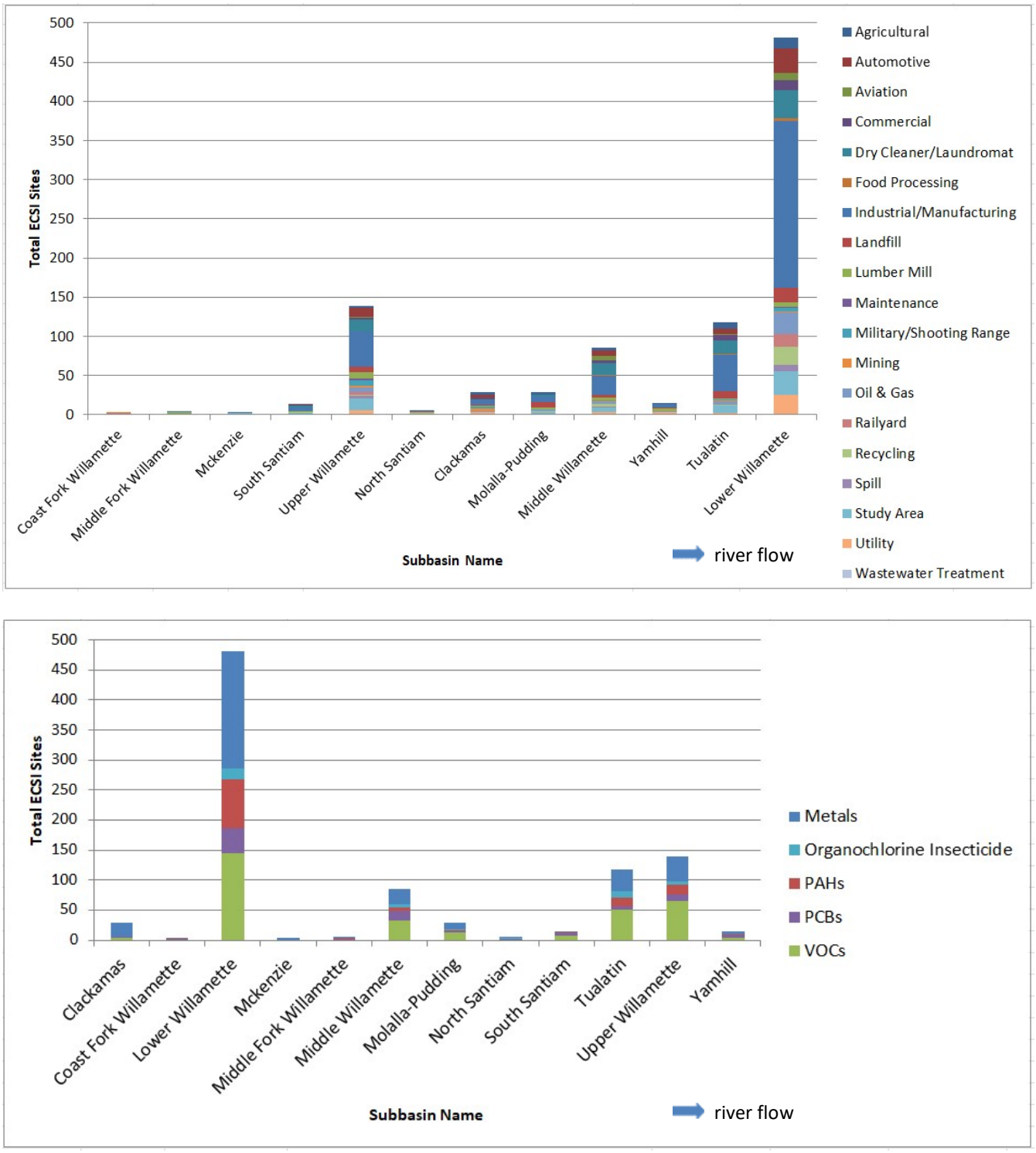


Figure 35. ECSI Site nonpoint sources in the Willamette Basin by subbasin, industry activity, and toxic pollutant. Environmental Cleanup Site Information (ECSI) sites in the Basin based on industry category (top) and toxic pollutant contamination impacting the sites (bottom). ECSI Sites evaluated in DEQ's ECSI database only impacted with the Basin's toxic pollutants. Industry activity categories (19 total) created based on review of the ECSI database reported facility information (DEQ, 2018c). Total nonpoint sources presented by subbasin from upstream (left) to downstream (right) location in the Basin (i.e., south to north). PAHs = polycyclic aromatic hydrocarbons. PCBs = polychlorinated biphenyls. VOCs = volatile organic compounds.

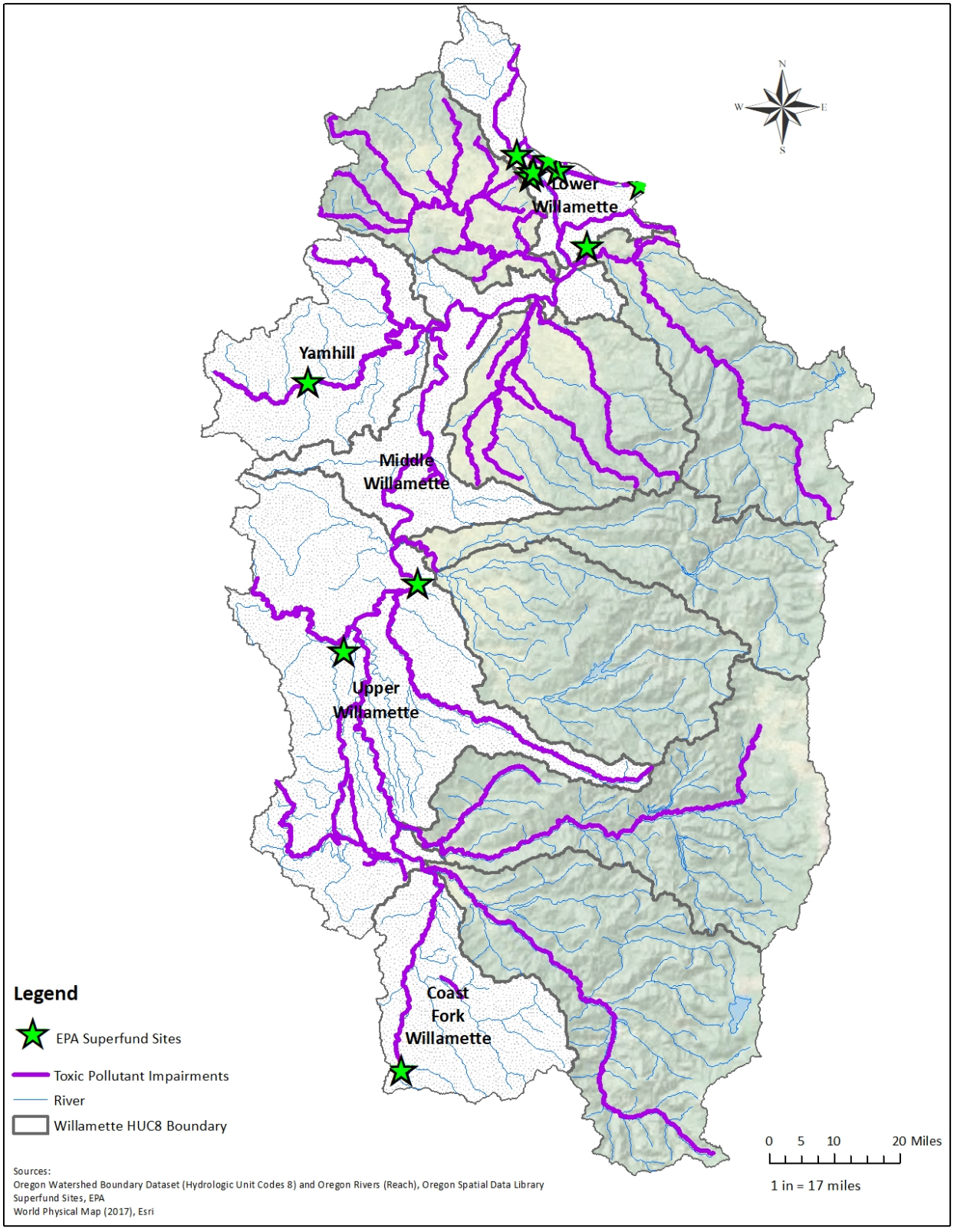


Figure 36. EPA Superfund Sites nonpoint sources of the Willamette Basin. EPA Superfund Sites (green stars) evaluated by subbasin (shaded where sources present) at the 8-digit fourth-level USGS Hydrologic Unit Code (HUC) (DEQ, 2012; EPA, 2018; OSDL, 2017). Superfund Sites contaminated in soil, surface water, or groundwater with toxic pollutants.

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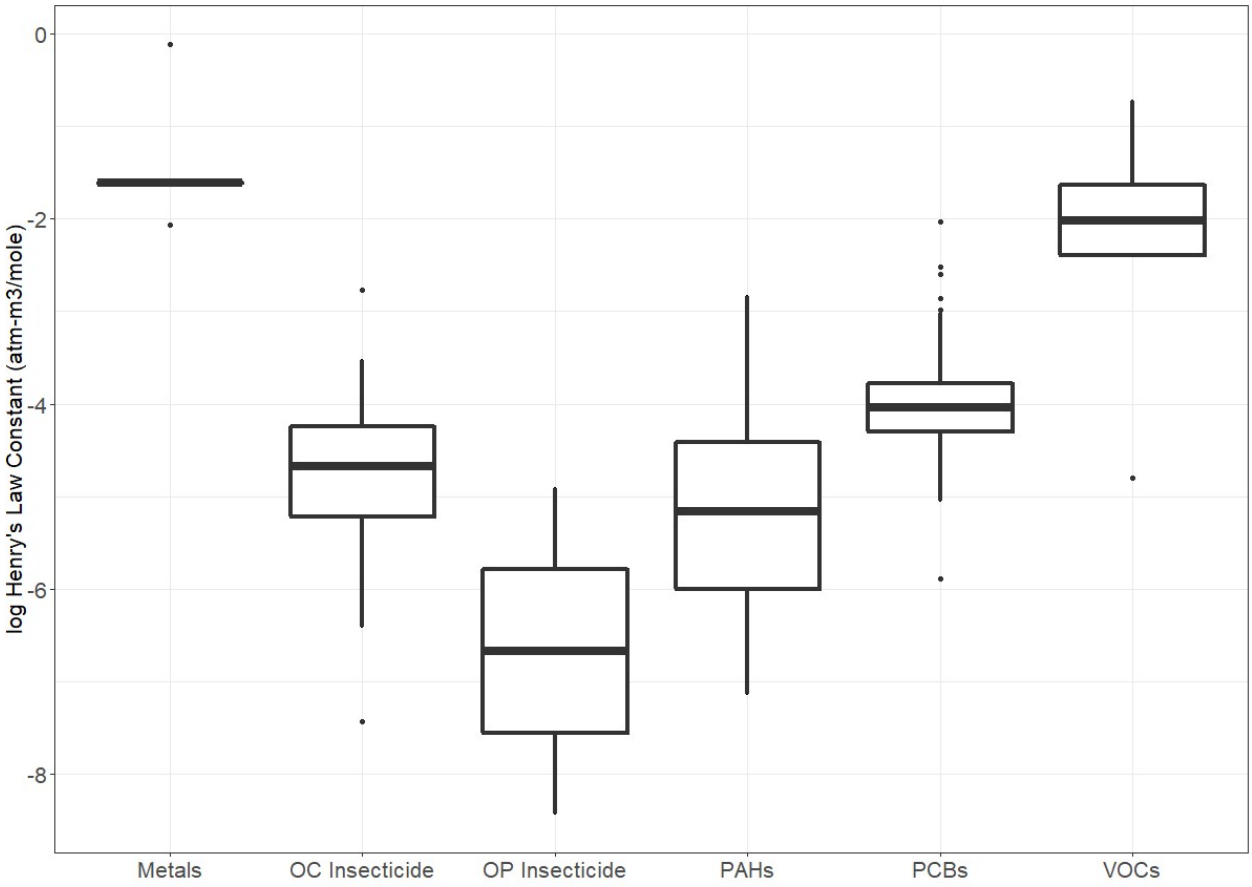


Figure 37. Summary statistics box plots by toxic pollutant class: Henry's Law Constant. Henry's Law Constant values in units of atmospheres-cubic meter per mole (atm-m^3/mole). Total toxic pollutants in each toxic pollutant class: metals (n = 9), OP = Organophosphorus (n = 2), OC = Organochlorine (n = 11), PAHs (n = 17), PCBs (n = 209), and VOCs (n = 8). Box plots generated in R (R Development Core Team, 2016).

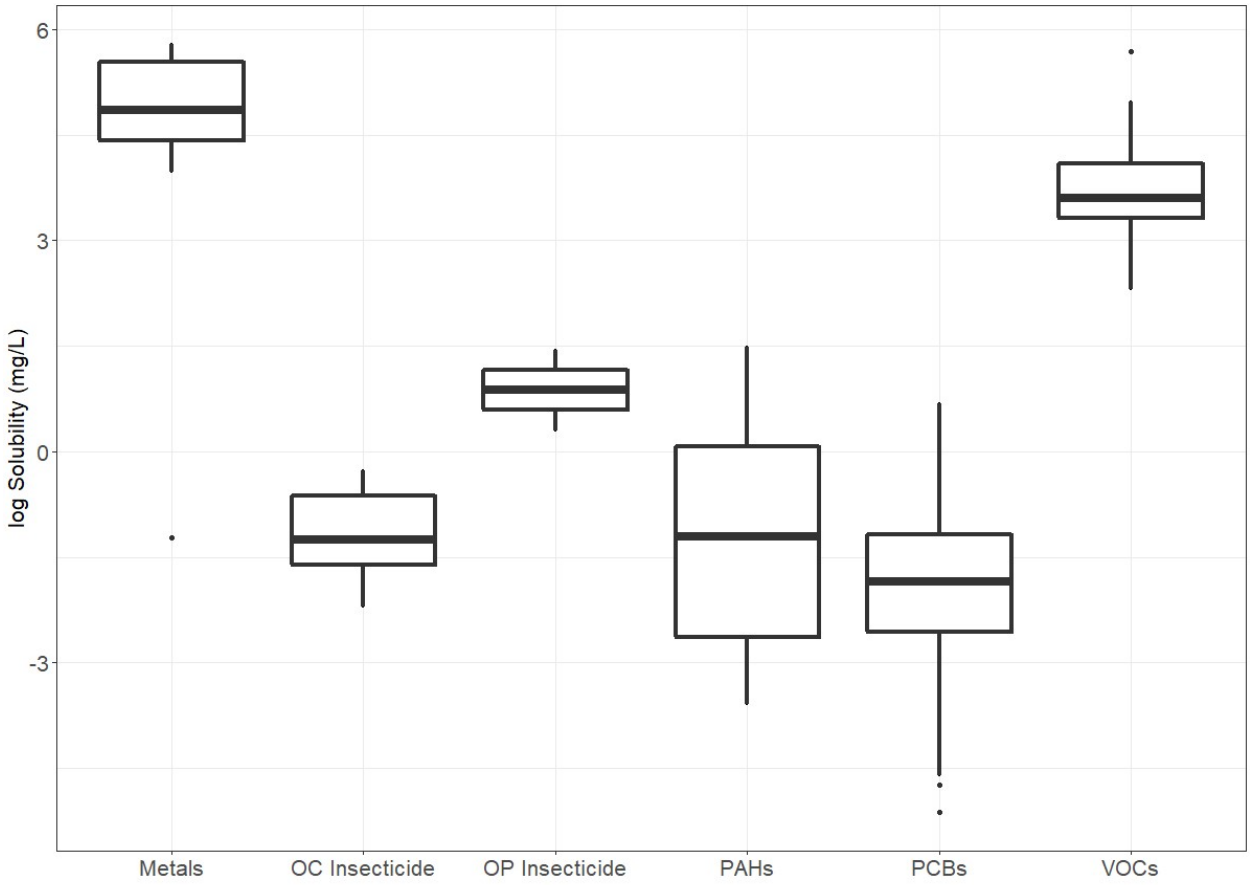


Figure 38. Summary statistics box plots by toxic pollutant class: solubility. Solubility values in units of milligrams per liter (mg/L). Total toxic pollutants in each toxic pollutant class: metals (n = 9), OP = Organophosphorus (n = 2), OC = Organochlorine (n = 11), PAHs (n = 17), PCBs (n = 209), and VOCs (n = 8). Box plots generated in R (R Development Core Team, 2016).

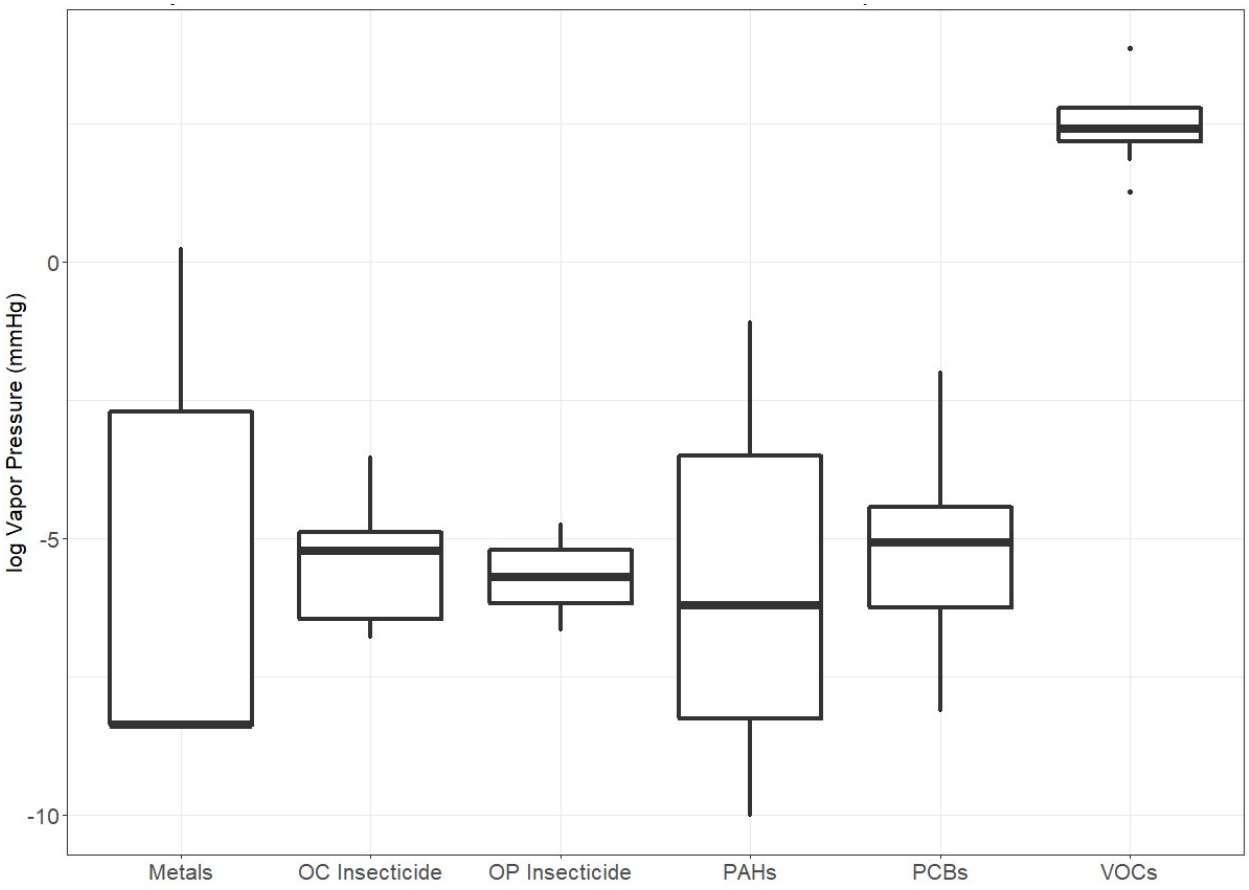


Figure 39. Summary statistics box plots by toxic pollutant class: vapor pressure. Vapor pressure values in units of millimeters of mercury (mmHg). Total toxic pollutants in each toxic pollutant class: metals (n = 9), OP = Organophosphorus (n = 2), OC = Organochlorine (n = 11), PAHs (n = 17), PCBs (n = 209), and VOCs (n = 8). Box plots generated in R (R Development Core Team, 2016).

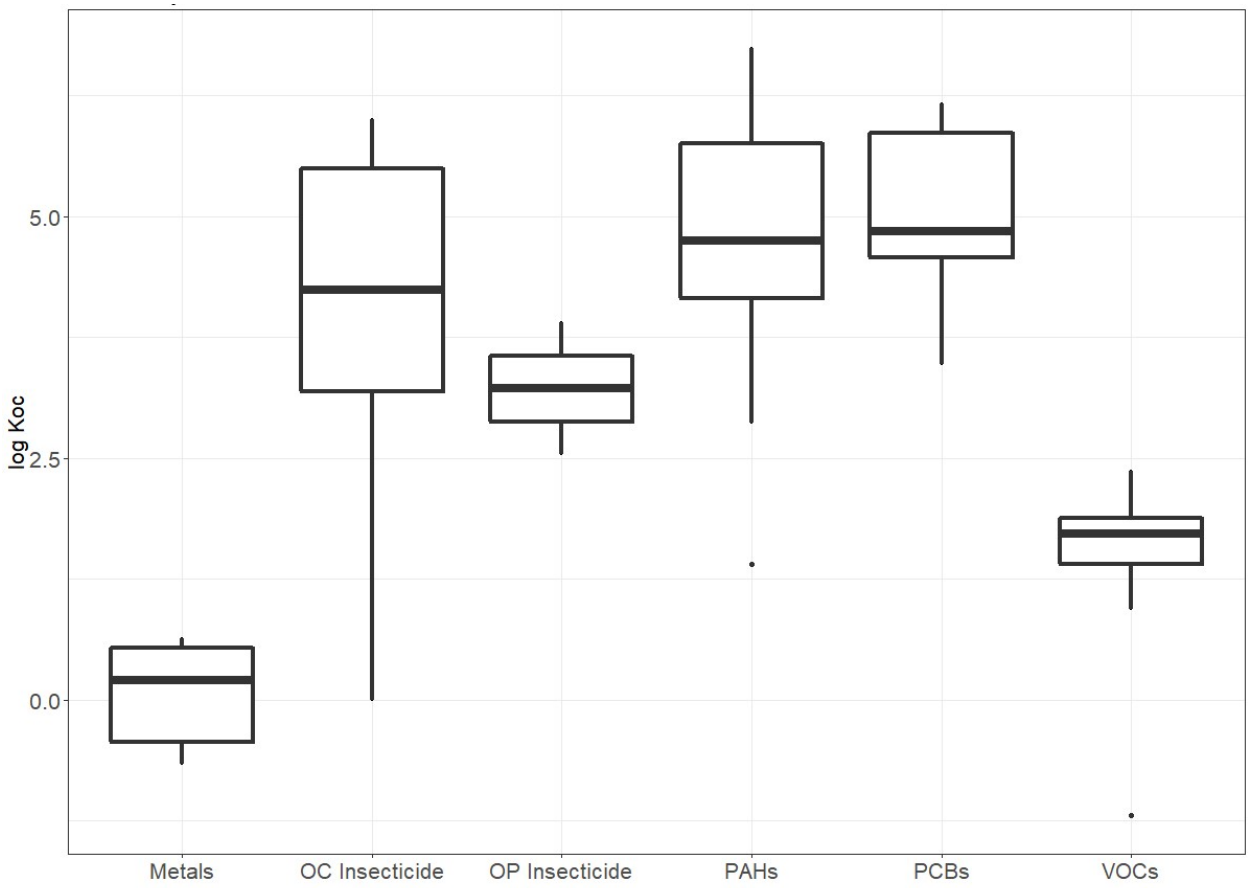


Figure 40. Summary statistics box plots by toxic pollutant class: K_{OC}. K_{OC} (organic carbon-water distribution coefficient) values are unit-less logarithmic values. Total toxic pollutants in each toxic pollutant class: metals (n = 9), OP = Organophosphorus (n = 2), OC = Organochlorine (n = 11), PAHs (n = 17), PCBs (n = 209), and VOCs (n = 8). Box plots generated in R (R Development Core Team, 2016).

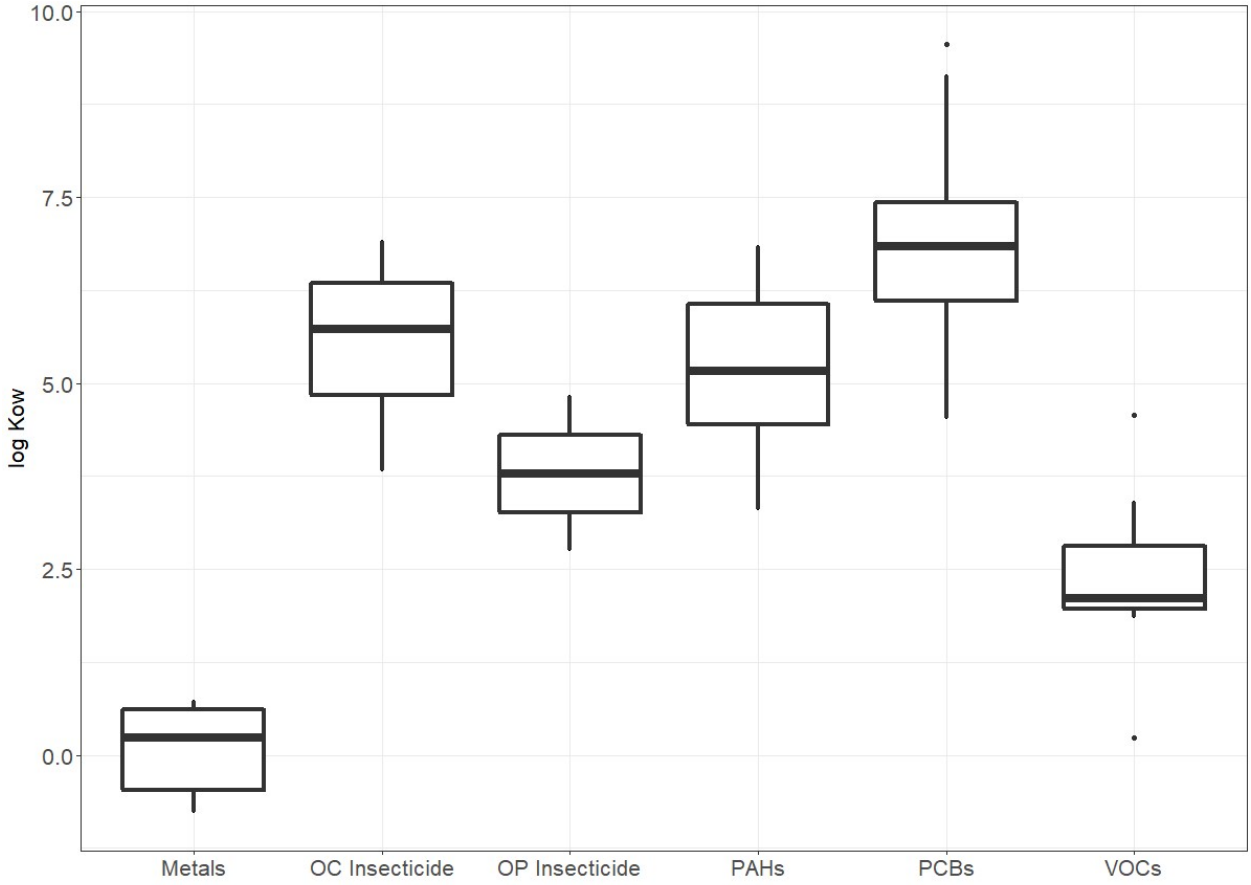


Figure 41. Summary statistics box plots by toxic pollutant class: K_{ow}. K_{OW} (octanol-water partition coefficient) values are unit-less logarithmic values. Total toxic pollutants in each toxic pollutant class: metals (n = 9), OP = Organophosphorus (n = 2), OC = Organochlorine (n = 11), PAHs (n = 17), PCBs (n = 209), and VOCs (n = 8). Box plots generated in R (R Development Core Team, 2016).

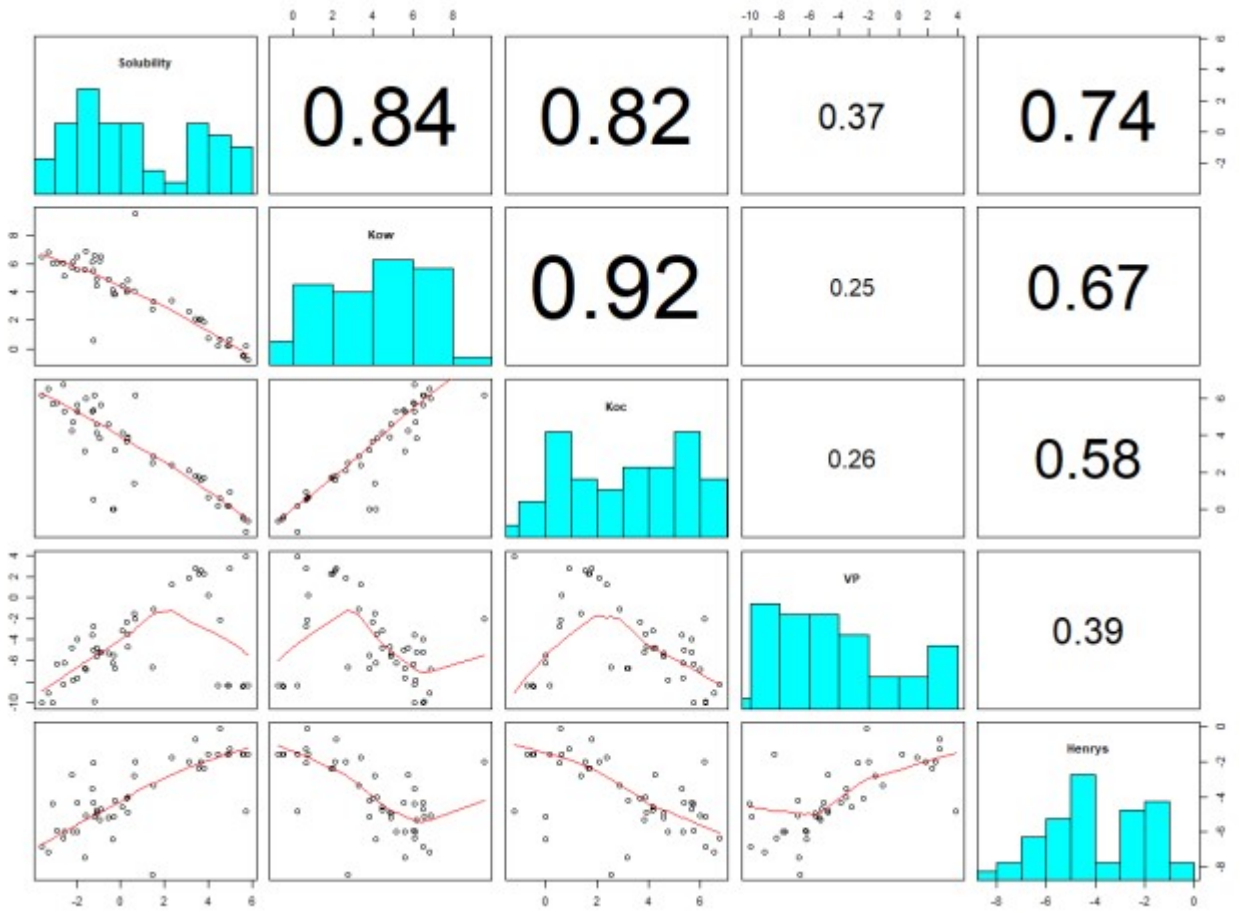


Figure 42. Correlation matrix of toxic pollutant chemical characteristics. Data inputted as logarithmic values and evaluated in R (R Development Core Team, 2016). From top left to bottom right: solubility, octanol-water partition coefficient (K_{OW}), organic carbon-water distribution coefficient (K_{OC}), vapor pressure (VP), and Henry's Law Constant (Henrys) The turquoise bar charts along the diagonal are histograms illustrating the distribution of the characteristic values. The points with red lines are pair-wise scatter plots with fitted lines showing relationships amongst the characteristic values. The bolded numerical values in the upper triangle portion are the Spearman's rank correlation coefficients for each pair of characteristics (0.84, solubility versus K_{OW}; 0.38, solubility versus vapor pressure; 0.75, solubility versus Henrys, etc.). Graph generated in R (R Development Core Team, 2016).

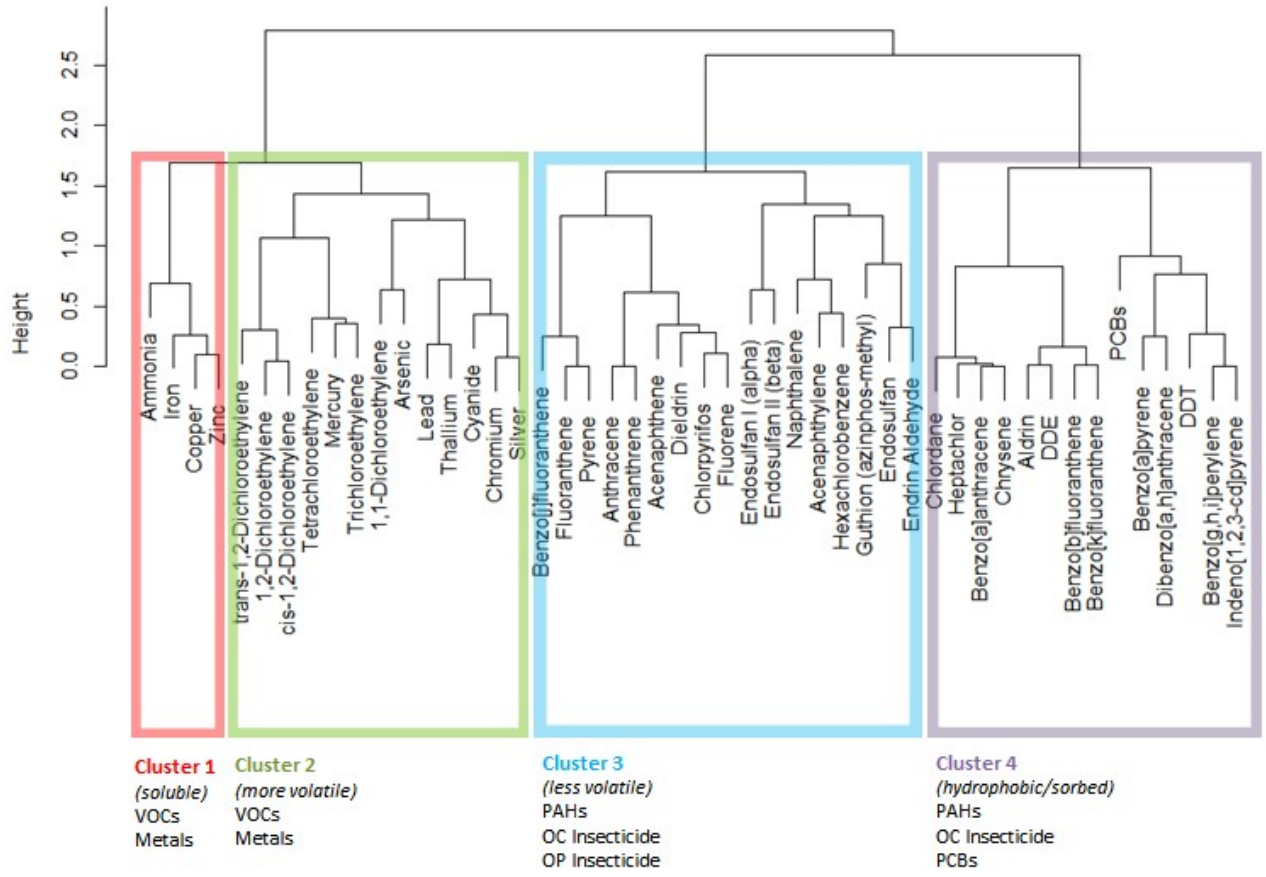


Figure 43. Dendrogram of toxic pollutant clusters. Toxic pollutants grouped into four clusters based on inputs of five chemical characteristics: solubility, vapor pressure, Henry's Law Constant, octanol-water partition coefficient (K_{OW}), and organic carbon-water distribution coefficient (log K_{OC}). OC = organochlorine insecticides; OP = organophosphorus insecticides; VOCs = volatile organic compounds; PAHs = polycyclic aromatic hydrocarbons; PCBS = polychlorinated biphenyls. The cluster analysis was predetermined with a cluster of four, where: Cluster 1 (n = 4), Cluster 2 (n = 13), Cluster 3 (n = 17), and Cluster 4 (n = 14). Cluster analysis evaluated in R (R Development Core Team, 2016). Toxic pollutants sharing similarities in chemical characteristics are in similar clusters and toxic pollutants sharing fewer similarities are in different clusters.

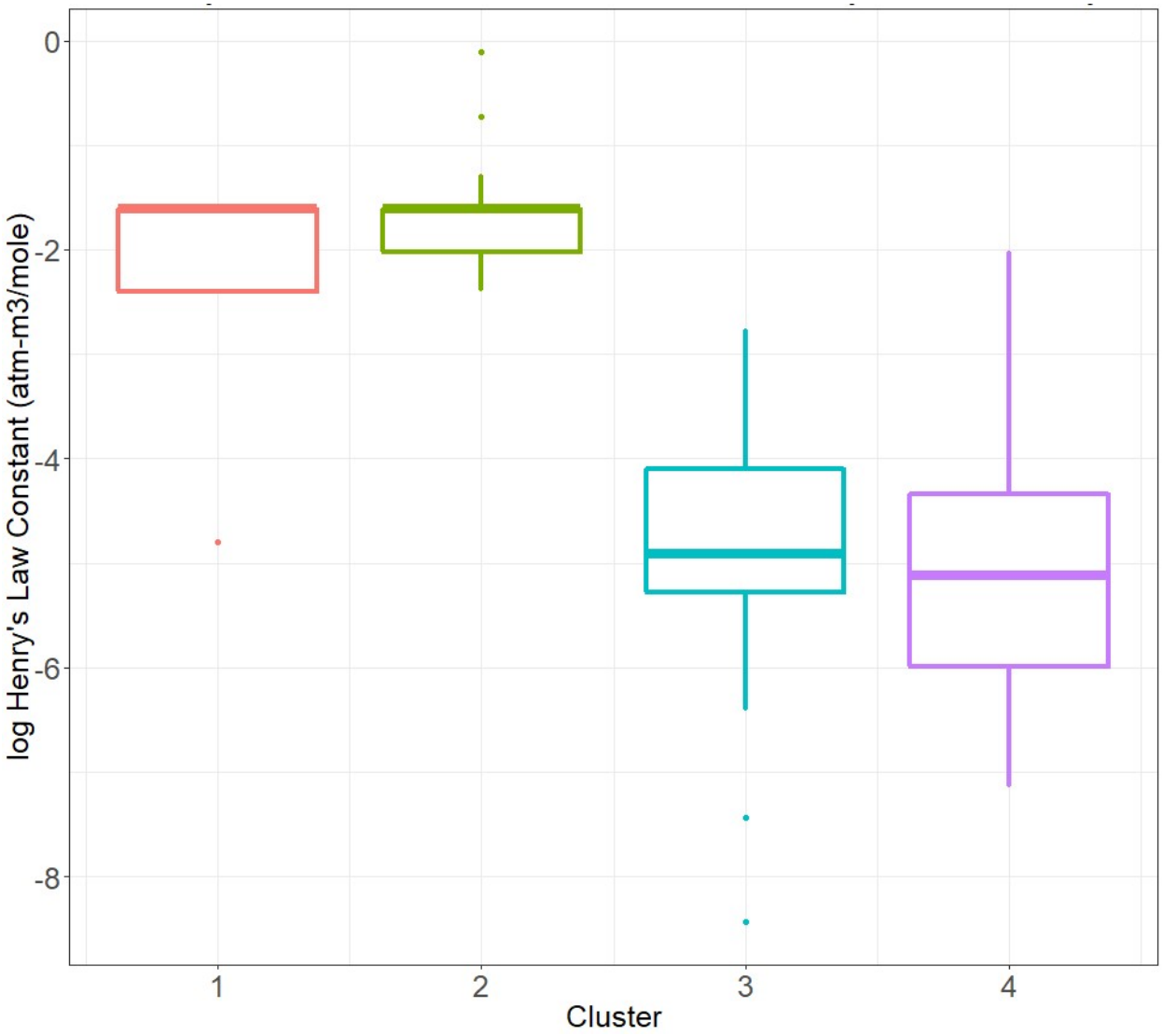


Figure 44. Summary statistics box plots of toxic pollutant clusters: Henry's Law Constant. Henry's Law Constant values are in units of atmospheres-cubic meters per mole (atm-m^3/mole). Total toxic pollutants in each cluster based on similarities in Henry's Law Constant values: Cluster 1 (n = 4), Cluster 2 (n = 13), Cluster 3 (n = 17), and Cluster 4 (n = 14). Cluster analysis evaluated and box plots generated in R (R Development Core Team, 2016).

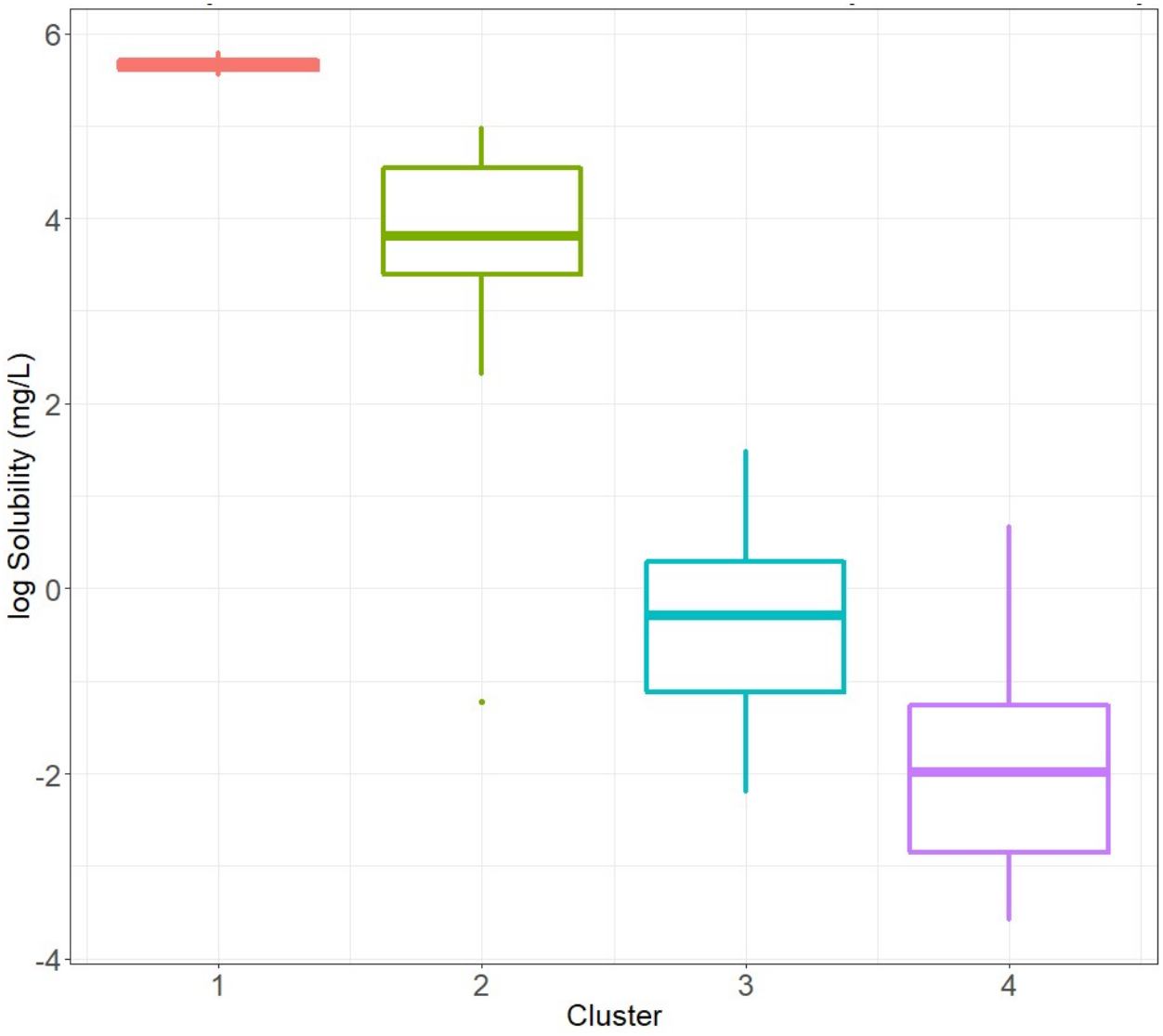


Figure 45. Summary statistics box plots of toxic pollutant clusters: solubility. Solubility values in units of milligrams per liter (mg/L). Total toxic pollutants in each cluster based on similarities in solubility values: Cluster 1 (n = 4), Cluster 2 (n = 13), Cluster 3 (n = 17), and Cluster 4 (n = 14). Cluster analysis evaluated and box plots generated in R (R Development Core Team, 2016).

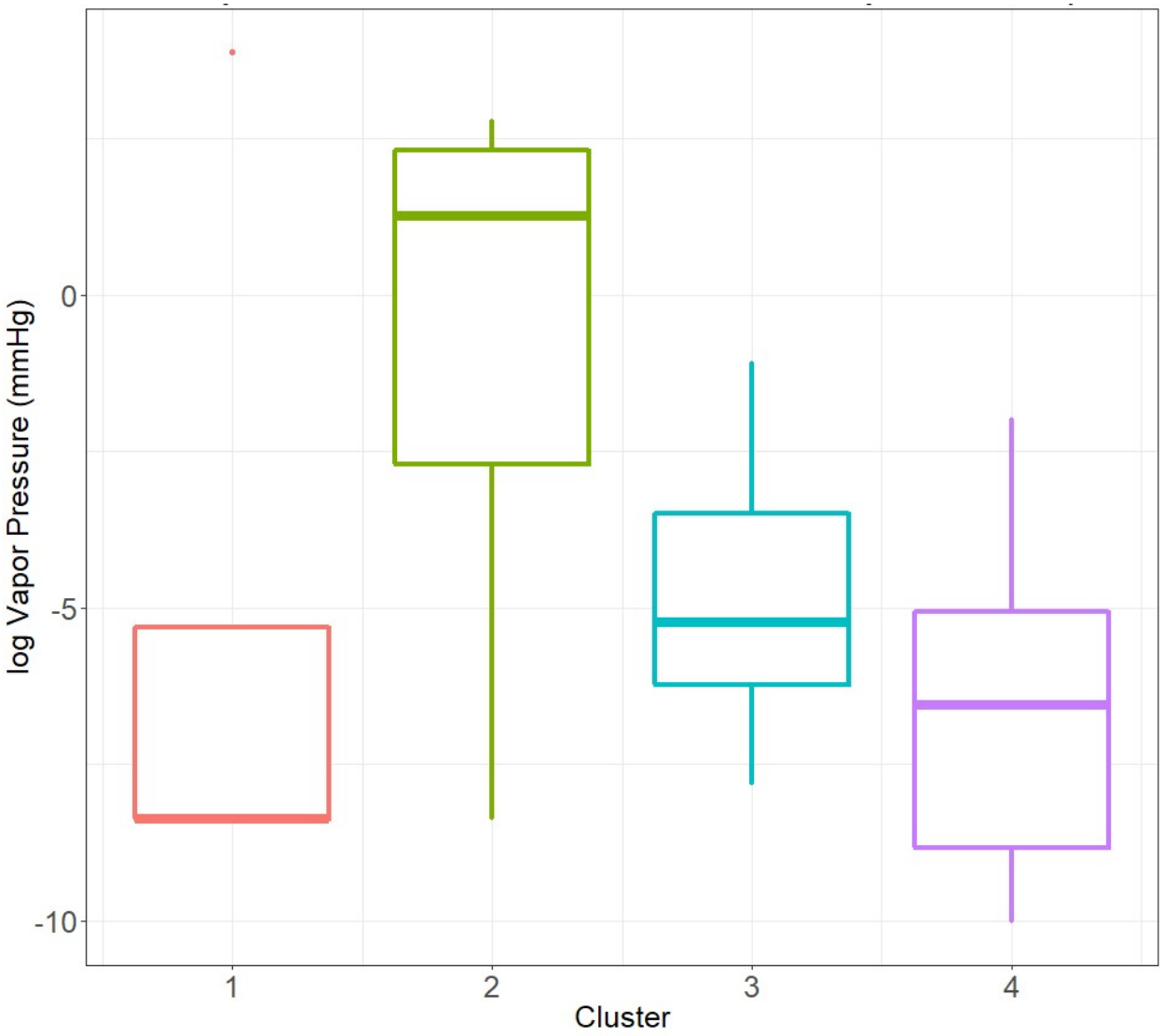


Figure 46. Summary statistics box plots of toxic pollutant clusters: vapor pressure. Vapor pressure values in units of millimeters of mercury (mmHg). Total toxic pollutants in each cluster based on similarities in vapor pressure values: Cluster 1 (n = 4), Cluster 2 (n = 13), Cluster 3 (n = 17), and Cluster 4 (n = 14). Cluster analysis evaluated and box plots generated in R (R Development Core Team, 2016).

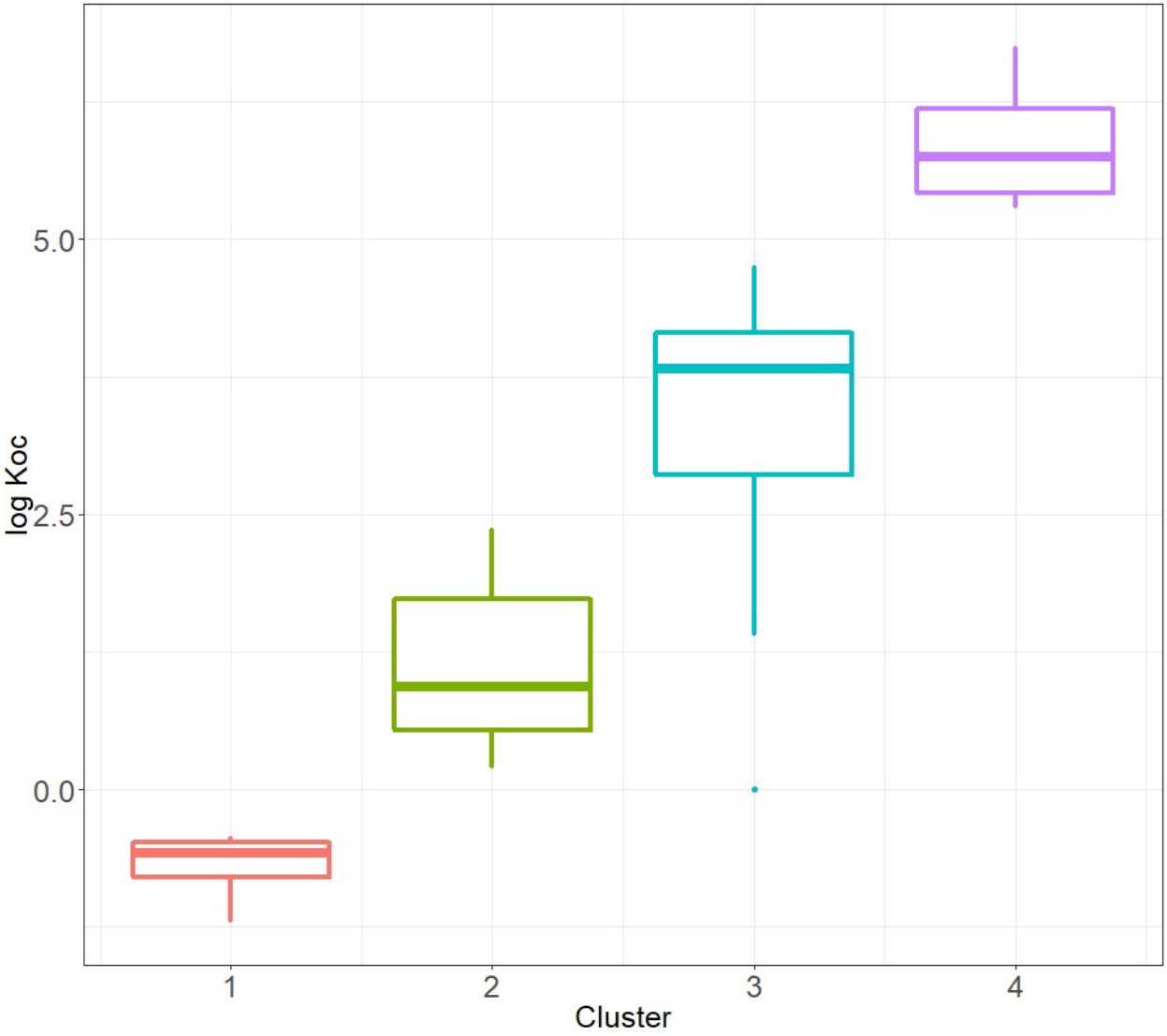


Figure 47. Summary statistics box plots of toxic pollutant clusters: K_{OC}. K_{OC} (organic carbon-water distribution coefficient) values are unit-less logarithmic values. Total toxic pollutants in each cluster based on similarities in K_{OC} values: Cluster 1 (n = 4), Cluster 2 (n = 13), Cluster 3 (n = 17), and Cluster 4 (n = 14). Cluster analysis evaluated and box plots generated in R (R Development Core Team, 2016).

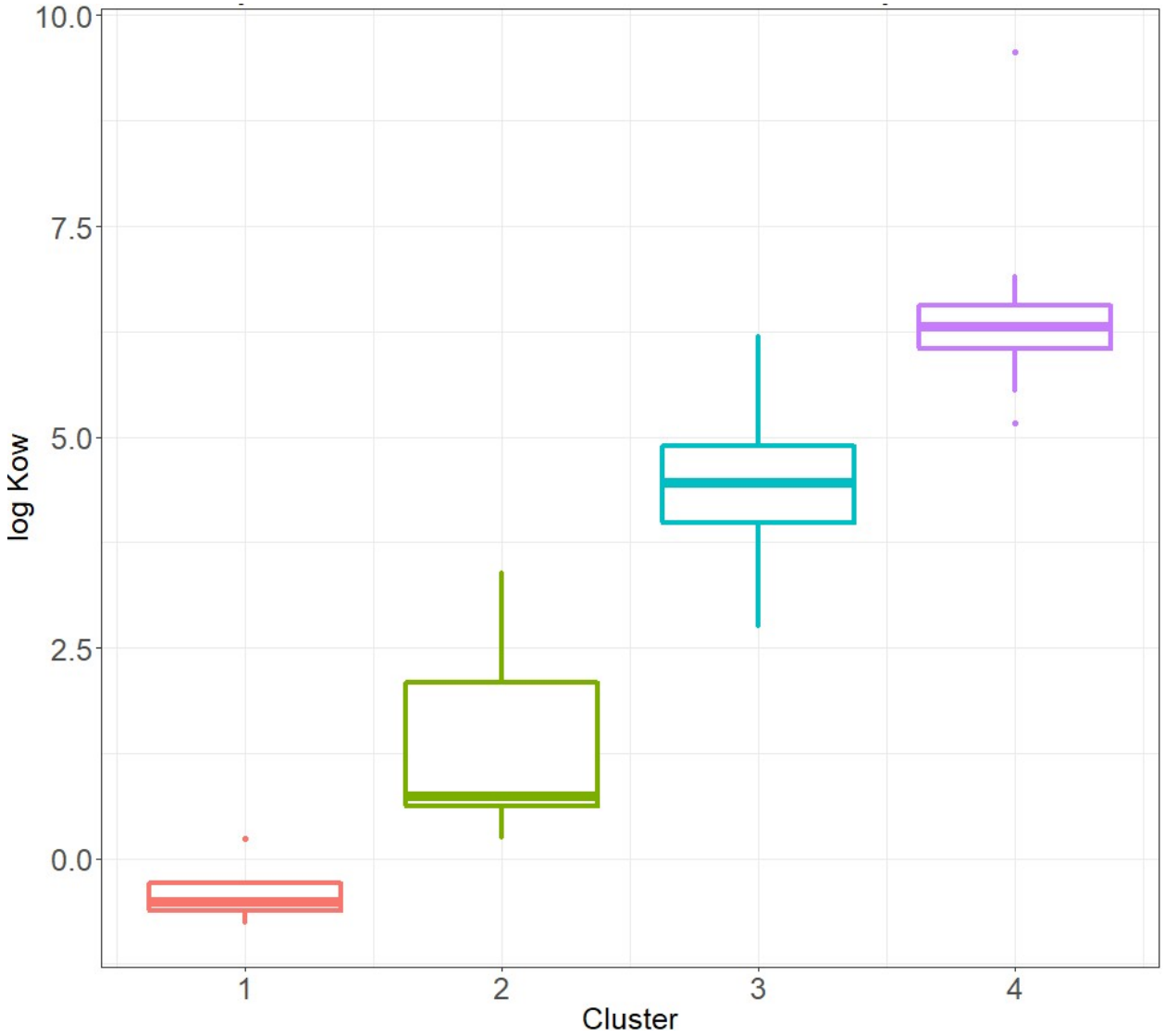


Figure 48. Summary statistics box plots of toxic pollutant clusters: K_{ow}. K_{OW} (octanol-water partition coefficient) values are unit-less logarithmic values. Total toxic pollutants in each cluster based on similarities in K_{OW} values: Cluster 1 (n = 4), Cluster 2 (n = 13), Cluster 3 (n = 17), and Cluster 4 (n = 14). Cluster analysis evaluated and box plots generated in R (R Development Core Team, 2016).

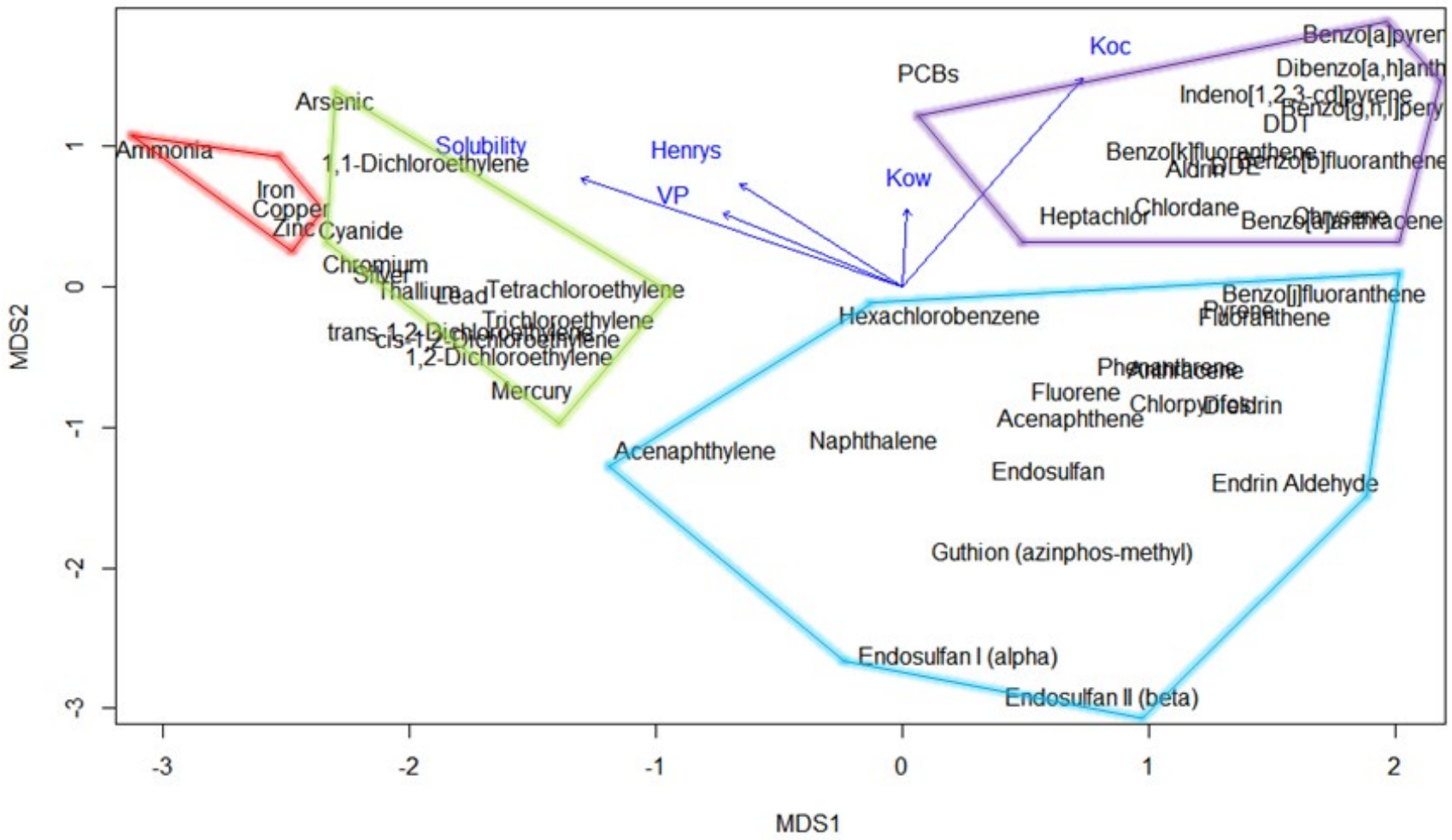


Figure 49. NMDS plot of toxic pollutants with relation to chemical characteristics. Toxic pollutants (n=48) superimposed with clusters from the hierarchical cluster analysis, plotted in the two-dimensional multivariate space according to similarities (and dissimilarities) of the Bray-Curtis distance matrix conducted in R (R Development Core Team, 2016). Cluster 1 = red; Cluster 2 = green; Cluster 3 = turquoise; and Cluster 4 = purple. Clusters associated with chemical characteristic data for each of the Basin's toxic pollutants: solubility, vapor pressure (VP), Henry's Law Constant (Henrys), octanol-water partition coefficient (K_{OW},), and organic carbon-water distribution coefficient (K_{OC}). Stress value = 0.08742.

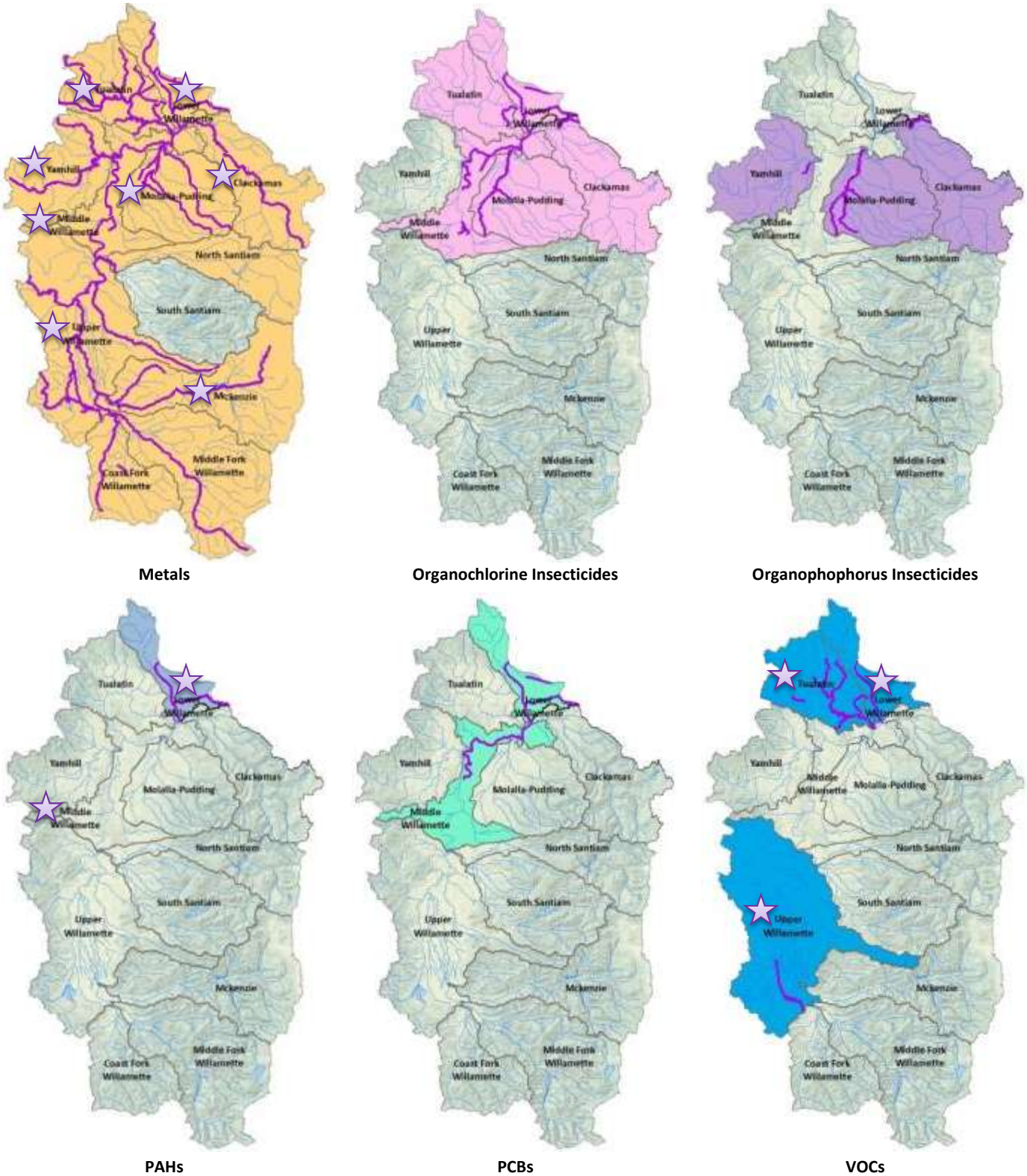


Figure 50. Comparison of toxic pollutant impairments in the Willamette Basin by toxic pollutant class and reported toxic pollutant discharge facilities by subbasin. Toxic pollutant Impairments (purple lines) evaluated by subbasin (color associated with toxic pollutant class) at the 8-digit fourth-level USGS Hydrologic Unit Code (HUC) (DEQ, 2012; OSDL, 2017). Purple stars in subbasins indicate that toxic pollutant class was reported in offsite discharges from NPDES-permitted facilities located in those subbasins (EPA, 2017b).

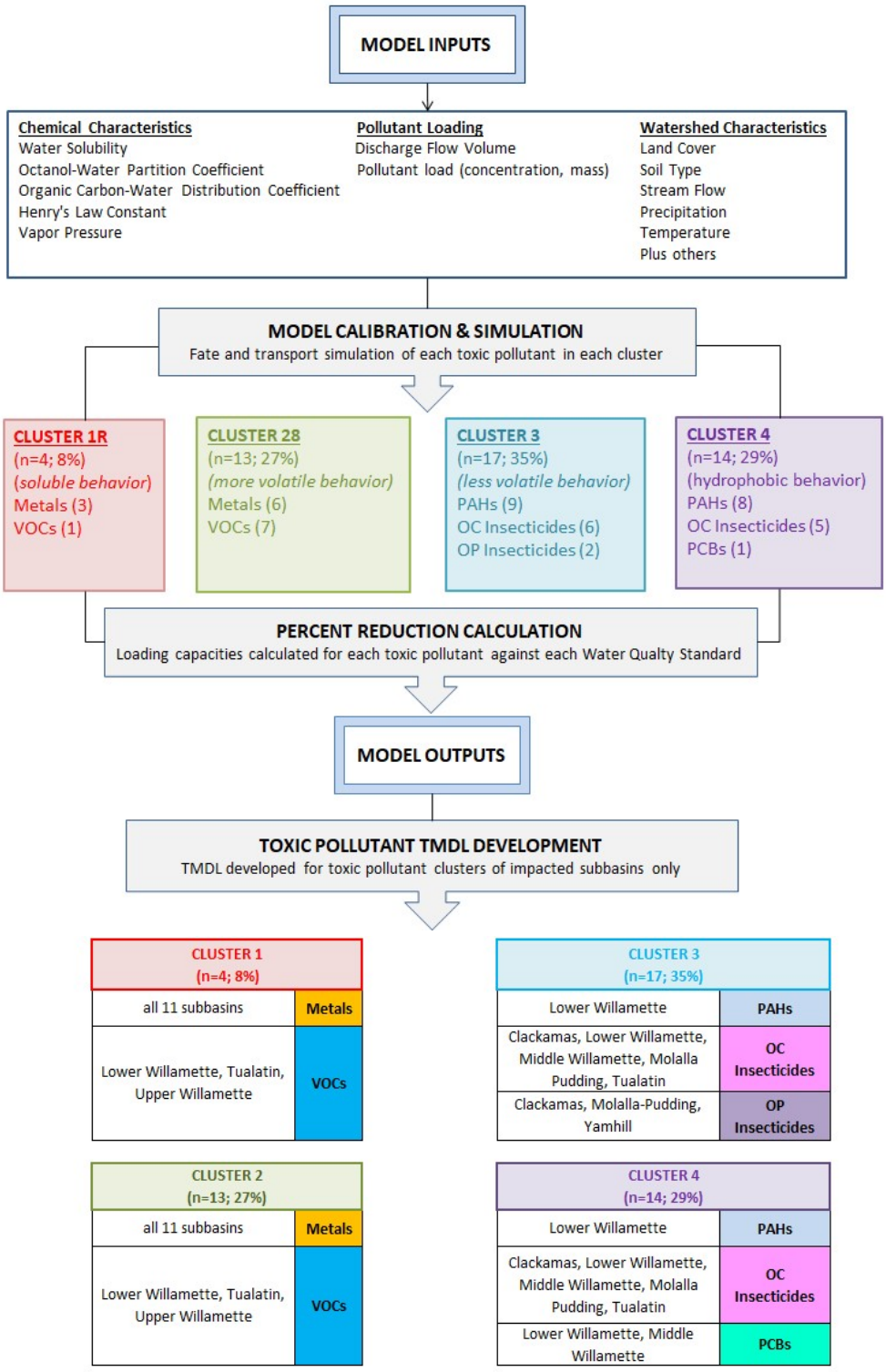
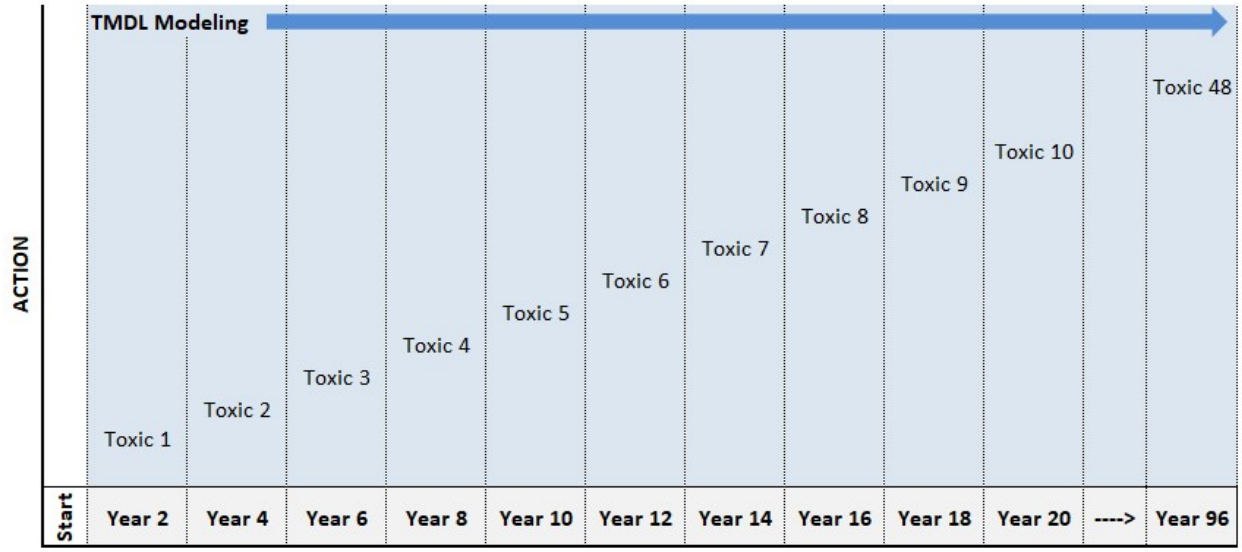


Figure 51. Framework for toxic pollutant TMDL development strategies in the Willamette Basin. Conceptual schematic illustrating the generalized process of toxic pollutant TMDL development in the Basin by applying the study results. Clustered toxic pollutants based on similar chemical characteristics can be simulated in water quality modeling to calculate toxic pollutant load reductions for each individual toxic pollutant. TMDLs can be developed for clustered toxic pollutants only for impacted subbasins. OC=organochlorine insecticide; OP = organophosphorus insecticide; VOC = volatile organic compound; PAHs = polycyclic aromatic hydrocarbons; PCBs = polychlorinated biphenyls; TMDLs = Total Maximum Daily Loads.

A)



B)

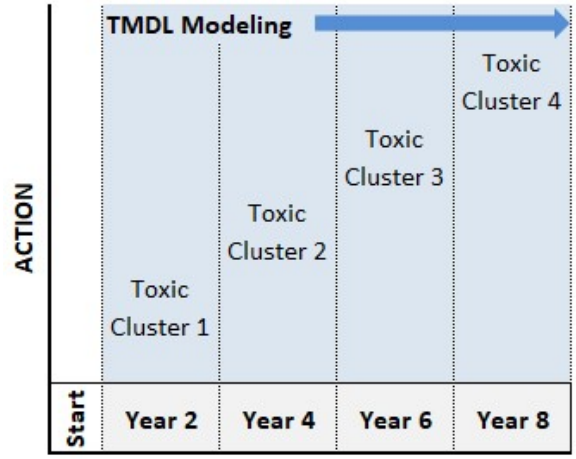


Figure 52. Timeline comparison of Willamette Basin toxic pollutant TMDL development efforts. **A)** Estimated timeline to develop 48 toxic pollutant TMDLS with current DEQ method. **B)** Estimated timeline to develop 48 toxic pollutant TMDLs with the proposed strategy of modeling toxic pollutant clusters. The two timelines assume one toxic pollutant is modeled (and the associated TMDL completed) at a time, at 24 months each. TMDL = Total Maximum Daily Load.

References

DEQ. (2012). Oregon's 2012 Integrated Report Assessment Database and 303(d) List. Retrieved February 24, 2017, from http://www.deq.state.or.us/wq/assessment/rpt2012/search.asp

DEQ. (2017). Wastewater Permits Database. Retrieved November 1, 2017, from https://www.deq.state.or.us/wq/sisdata/sisdata.asp

DEQ. (2018). Environmental Cleanup Site Information Database. Retrieved May 18, 2018, from https://www.oregon.gov/deq/Hazards-and-Cleanup/env-cleanup/Pages/ecsi.aspx

DOGAMI. (2017). Mining Permit Viewer. Retrieved October 13, 2017, from http://www.oregongeology.org/mlrr/permitviewer.htm

EPA. (2012). *Sustainable Futures / P2 Framework Manual 2012 EPA-748-B12-001 Chapter 5 Estimating Physical / Chemical and Environmental Fate Properties with EPI Suite™*. Retrieved from https://www.epa.gov/sites/production/files/2015-05/documents/05.pdf

EPA. (2017a). Enforcement and Compliance History Online, Water Pollutant Loading Tool, Water Pollution Search. Retrieved October 24, 2017, from https://echo.epa.gov/trends/loading-tool/water-pollution-search

EPA. (2017b). Water Pollution Search, Water Pollutant Loading Tool. Retrieved October 24, 2017, from https://echo.epa.gov/trends/loading-tool/water-pollution-search

EPA. (2018). National Priorities List and Superfund Alternative Approach Sites Search. Retrieved January 10, 2018, from https://www.epa.gov/superfund/search-superfund-sites-where-you-live

ESRI. (2017). ArcMap version 10.5.1. Retrieved from http://desktop.arcgis.com/en/arcmap/

ODOT. (2016). *Stormwater Outfall Inventory Management*. Retrieved from https://www.oregon.gov/ODOT/GeoEnvironmental/Pages/Stormwater.aspx

OSDL. (2011). Oregon NLCD Land Cover 2011. Retrieved April 15, 2018, from http://spatialdata.oregonexplorer.info/geoportal/details;id=81916ee1b2b741c0aacb814ee8e73af9

OSDL. (2015). Oregon Land Management 2015. Retrieved April 15, 2018, from http://spatialdata.oregonexplorer.info/geoportal/details;id=9b644e0f7a7d4124a50f6b35c05626ae

OSDL. (2016). Oregon Average Annual Precipitation 1981-2010 PRISM. Retrieved June 15, 2018, from http://spatialdata.oregonexplorer.info/geoportal/details;id=3697813012da4982b34f93077f83a7a1

OSDL. (2017). Oregon Watershed Boundary Dataset. Retrieved December 13, 2017, from http://spatialdata.oregonexplorer.info/geoportal/details;id=4b1b008d5a764a209b2df040689c0779

R Development Core Team. (2016). The R Project for Statistical Computing. Retrieved from http://www.rstudio.com/.

Rand, G. M. (1995). *Fundamentals of Aquatic Toxicology: Effects, Environmental Fate, and Risk Assessment* (2nd ed.).

USGS. (2017). National Water Quality Assessment Project, Pesticide National Synthesis Project. Retrieved July 8, 2018, from https://water.usgs.gov/nawqa/pnsp/usage/maps/county-level/