2019

Characterization of the Lower Willamette Basin, OR using ArcGIS

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Table of Contents

Introduction

Understanding flow distribution, elevation and available water storage within a watershed is important for water resource management. Geographic information systems are one way to effectively display this data both visually and through data tables. This report focuses on the Lower Willamette Basin, a central watershed in the Portland metropolitan area.

The objective of this project is two-fold: to build a base dataset in ArcGIS for the Lower Willamette Basin and to identify areas at risk for high runoff rates. The base dataset is designed to characterize the watershed in terms of HUC divisions, flow distribution, elevation, precipitation and hydrologic soil type. The feature classes and rasters created can be used to calculate useful parameters in water resource engineering such as mean annual flow, drainage density, and average precipitation. In addition, comparing data on precipitation and available water storage in soil can help identify areas at risk for drainage and/or flooding issues. This can be further investigated to determine improvements in stormwater infrastructure (i.e. bioswales) and to prioritize drainage infrastructure projects which prevent these areas from becoming problematic.

Site Description

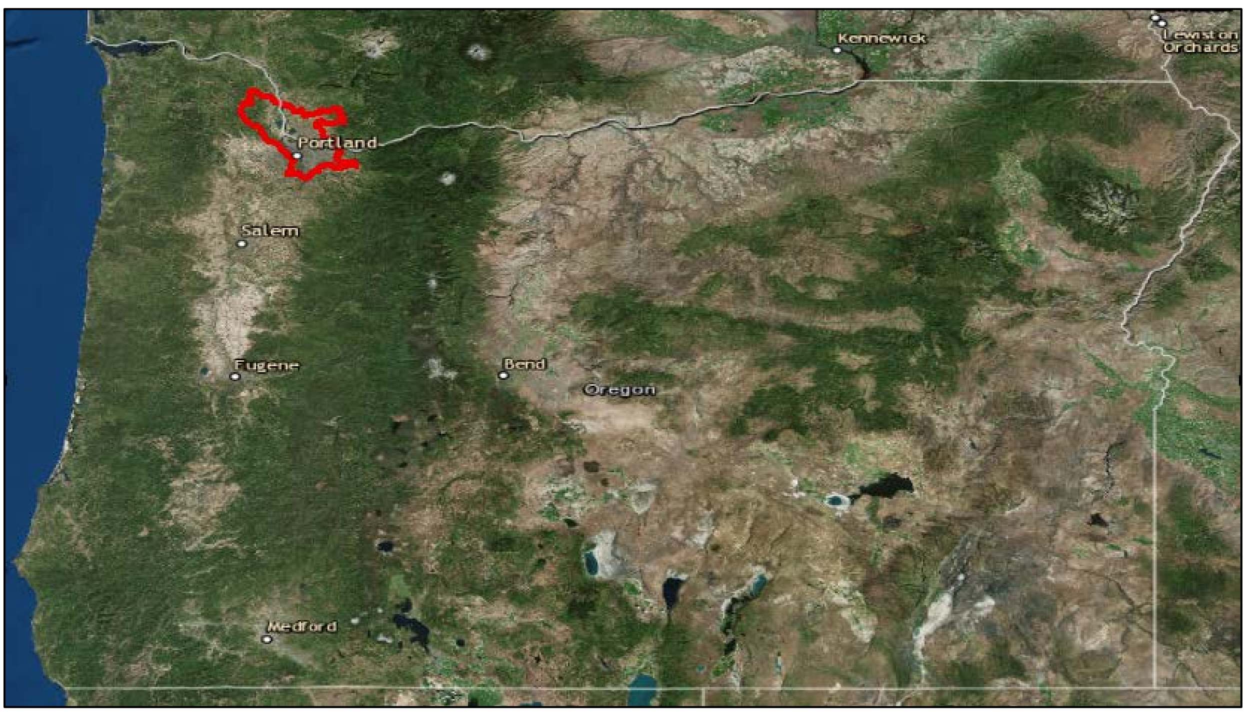

Figure 1. *Location of Lower Willamette Basin in Oregon and Washington, U.S (with ESRI imagery basemap).*

The Lower Willamette Basin (HUC-8 17090012), located near Portland, OR (see Figures 1 and 2). This watershed is approximately 644 square miles and collects water from four local counties: Columbia, Multnomah, Clark and Clackamas. Main bodies of water in this watershed include the Willamette River, Columbia River, Scappoose Creek and Johnson Creek. 90% of the watershed is privately owned and mostly comprised of forests (40%), water/wetlands (37%) and grain crops/pastures (10%) (USDA NRCS, 2005). Local agricultural practices strongly influences water quality in this watershed. The Lower Willamette Watershed has diverse topography, with the coastal cascades on its western border (approx. 1,500-2,000 ft in elevation), the western cascades in the southeast of the basin (approx. 5,000-6,000 ft in elevation) and a combination of Willamette Valley plains (100-300 ft in elevation) and Willamette Valley foothills (1,000-2,000 ft in elevation) between the two cascades. The majority of the watershed receives an average of 39-51" of precipitation per year (Uhrich, M., and Wentz, D., 1999)

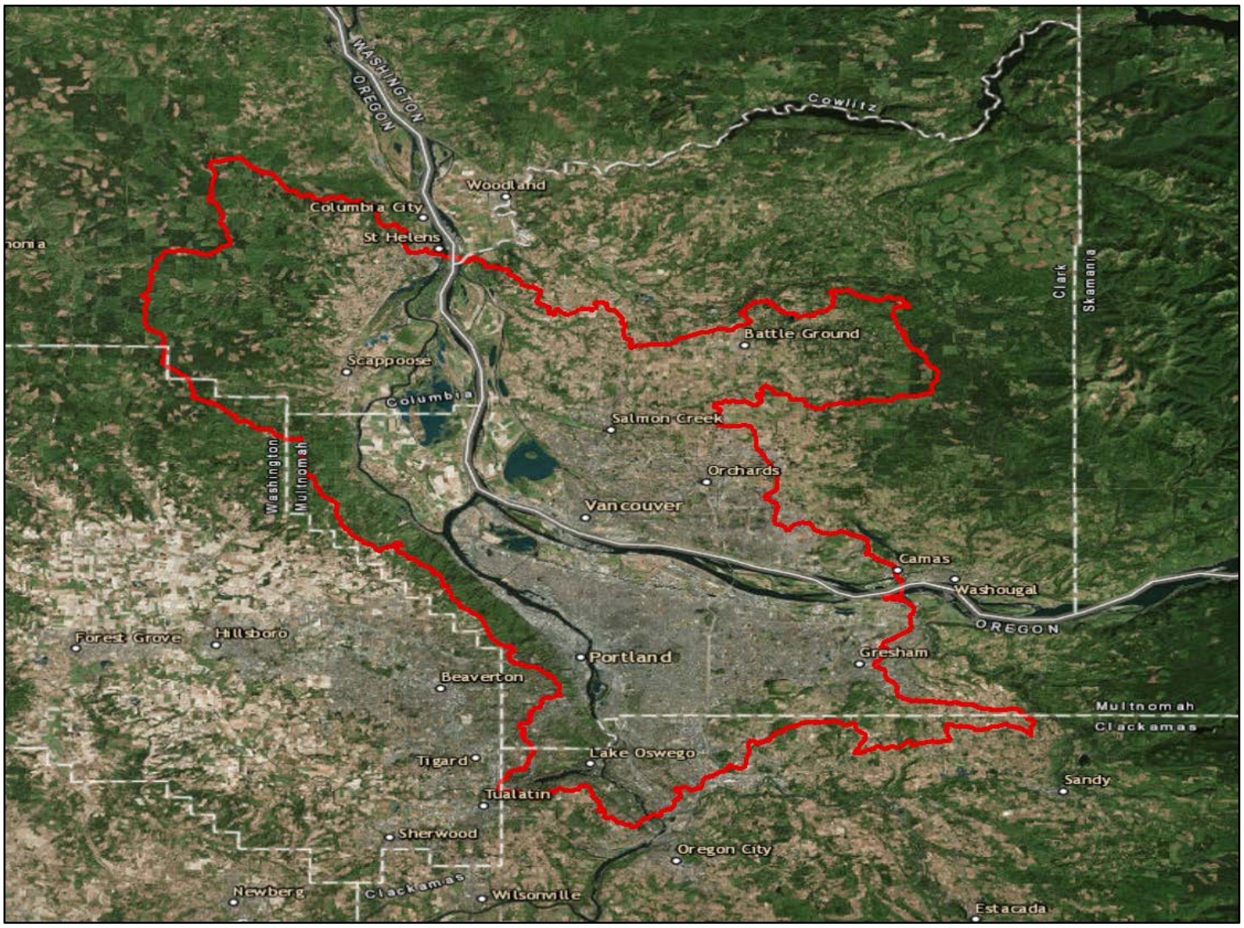

Figure 2. *Map of the Lower Willamette Basin, which includes the major cities of Portland, OR and Vancouver, WA (with ESRI imagery basemap).*

Data

All data was projected to NAD 1983 State Plane Oregon North FIPS 3601, which is a Lambert Conic projection in units of U.S. feet.

WBD Snapshot (NHD subwatershed data)
- Source: NHDPlus (http://horizon-systems.com/NHDPlus/NHDPlusV2_17.php)
- Coordinates: Geographic Coordinates, NAD 1983
- This vector dataset provides the HUC-8, HUC-10 and HUC-12 subwatersheds in the Pacific Northwest. The data was projected in

NHD Snapshot (NHD flowline data)
- Source: NHDPlus (http://horizon-systems.com/NHDPlus/NHDPlusV2_17.php)
- Coordinates: Geographic Coordinates, NAD 1983
- This vector dataset provides flowlines throughout the Pacific Northwest.

EROM Extension (NHD Extended Runoff Method data)
- Source: NHDPlus (http://horizon-systems.com/NHDPlus/NHDPlusV2_17.php)
- This data table includes flowline identification (COMID, ReachCodes) for the Pacific Northwest region. It also includes calculated mean annual flow per flowline segment, denoted by COMID.

Oregon Digital Elevation Model
- Source: Oregon Geospatial Data Gateway
- Coordinates: Geographic Coordinates, NAD 1983
- This 10-m raster contains elevation data across Oregon. The raster was masked to the Oregon-portion of the Lower Willamette Basin, projected in North Oregon State Plane coordinates and was used for slope and terrain analysis.

Precipitation data
- Source: PRISM Climate Group (http://www.prism.oregonstate.edu/normals/)
- Coordinates: Geographic Coordinates, NAD 1983
- This 800-m raster contains annual precipitation data across the United States, as averaged over the period of 1981-2010. The raster was masked to the Lower Willamette Basin, projected in North Oregon State Plane coordinates and was used for precipitation analysis.

Soil data
- Source: SSURGO (https://esri.maps.arcgis.com/apps/View/index.html?appid=cdc49bd63ea54dd2977f3f2853e07fff)
- Coordinates: Geographic Coordinates, NAD 1983
- This shapefile describes the type of soil located within the Lower Willamette Basin. It also includes water storage data (0-150 cm), meaning the amount of water that can be stored in the top 1.5 m of soil.

GIS Methods

HUC-10 and 12 Subwatersheds

The very first step was to create a geodatabase in the Catalog. Within the geodatabase, a base dataset was created, where all shapefiles will be saved.

After adding the WBD shapefile in ArcMaps, the 'Select by Attributes' tool was used to isolate the Lower Willamette Basin (HUC-8 17090012), as Figure 3 illustrates below.

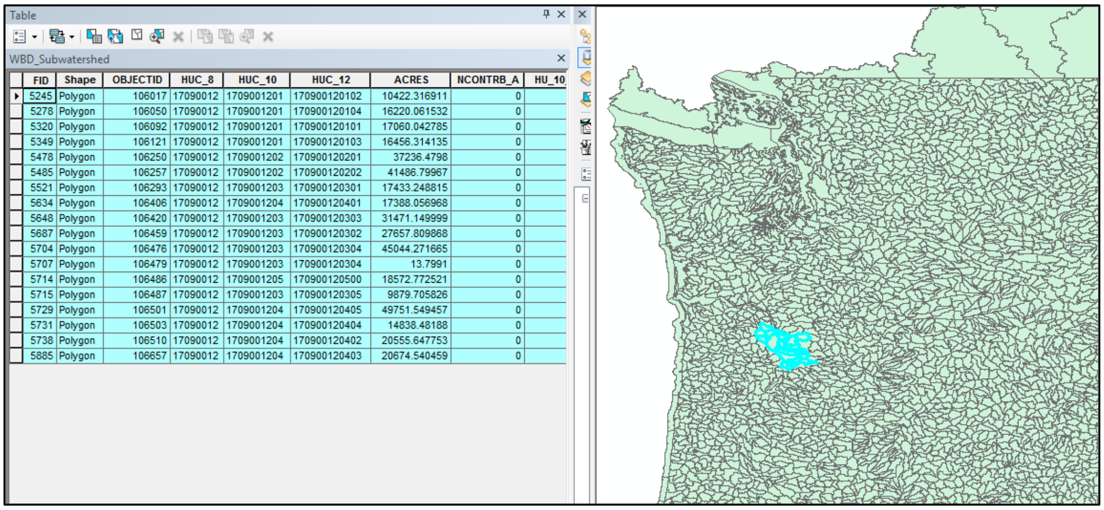

Table
WBD_Subwatershed

FID	Shape	OBJECTID	HUC_8	HUC_10	HUC_12	ACRES	NCONTRB_A	HU_10
5245	Polygon	106017	17090012	1709001201	170900120102	10422.316911	0	
5278	Polygon	106050	17090012	1709001201	170900120104	16220.061532	0	
5320	Polygon	106092	17090012	1709001201	170900120101	17060.042785	0	
5349	Polygon	106121	17090012	1709001201	170900120103	16456.314135	0	
5478	Polygon	106250	17090012	1709001202	170900120201	37236.4798	0	
5485	Polygon	106257	17090012	1709001202	170900120202	41486.79967	0	
5521	Polygon	106293	17090012	1709001203	170900120301	17433.248815	0	
5634	Polygon	106406	17090012	1709001204	170900120401	17388.056968	0	
5648	Polygon	106420	17090012	1709001203	170900120303	31471.149999	0	
5687	Polygon	106459	17090012	1709001203	170900120302	27657.809868	0	
5704	Polygon	106476	17090012	1709001203	170900120304	45044.271665	0	
5707	Polygon	106479	17090012	1709001203	170900120304	13.7991	0	
5714	Polygon	106486	17090012	1709001205	170900120500	18572.772521	0	
5715	Polygon	106487	17090012	1709001203	170900120305	9879.705826	0	
5729	Polygon	106501	17090012	1709001204	170900120405	49751.549457	0	
5731	Polygon	106503	17090012	1709001204	170900120404	14838.48188	0	
5738	Polygon	106510	17090012	1709001204	170900120402	20555.647753	0	
5885	Polygon	106657	17090012	1709001204	170900120403	20674.540459	0	

Figure 3. *Using the 'Select by Attributes' tool to isolate a HUC-8 watershed from the WBD shapefile from NHDPlus.*

The isolated layer displayed the HUC-10 and HUC-12 subwatersheds only within the Lower Willamette Basin. A basin boundary was then created using the 'dissolve' tool based on the HUC-8 field in the Watershed layer, creating a new feature class. Both layers were projected into NAD 1983 State Plane Oregon North FIPS 3601 coordinates using the 'Project' tool. The resulting map is shown below in Figure 4.

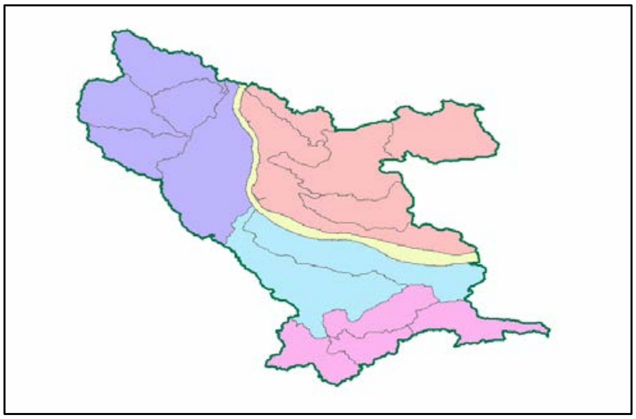

Figure 4. *Map of the Lower Willamette Basin showing the five HUC-10 subwatersheds and 17 HUC-12 subwatersheds.*

The acreage for each HUC-12 subwatershed was then extracted from the attribute table of the Watershed layer. Additionally, the 'Symbology' tab under Properties was used to display the watershed according to HUC-10 and HUC-12 subwatershed boundaries. The ESRI topography basemap was added for context.

Flowlines

NHD Snapshot shapefile was uploaded on top of the Watershed layer. 'Select by Location' was then used with the NHD shapefile as the target layer and the basin boundary feature class as the source layer to select only the streams within the Lower Willamette Basin. By exporting the selected data, I was able to create a new feature class of flowlines and add the layer to the map. This shapefile was then projected into NAD 1983 State Plane Oregon North FIPS 3601 coordinates using the 'Project' tool.

Drainage density was calculated by dividing the statistical sum of the 'LengthKM' column in the Flowlines attribute table by the statistical sum of the 'Acreage' column in the Watershed attribute table. Next, the EROM_Extension file was joined with the NHD flowline attribute table by linking COMIDs. The COMID is an NHD naming system that uniquely identifies each flowline. This process allowed the mean annual flow to be copied from the EROM_Extension file and pasted in the flowlines attribute table by use of 'Field Calculator'. The symbology was changed to graduated symbols, setting the value field to mean annual flow. The resulting map displays the distribution and degree of flow denoted by line weight. Major waterbodies were then labeled using the 'Callout' feature of the Drawing toolbox.

To analyze the mean annual flow while excluding the major flows, the 'Select by Attributes' tool was used to select all flowlines other than the Columbia River, Willamette River and Columbia Slough (see Figure 5).

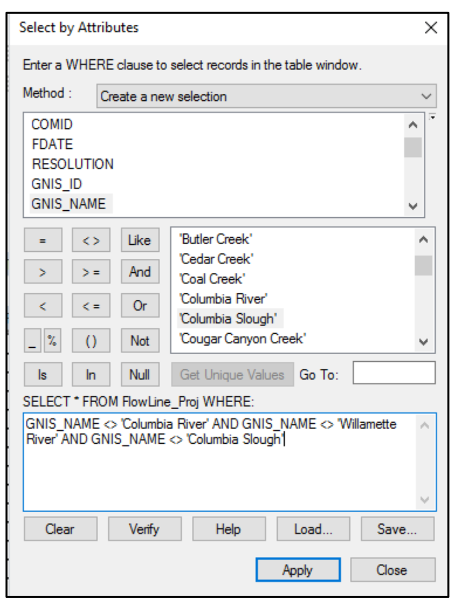

Figure 5. *Using the 'Select by Attributes' tool to select all flowlines other than the Columbia River, Willamette River and Columbia Slough.*

Elevation

The Oregon DEM was masked to the Lower Willamette Basin by using the 'Extract by Mask' tool with the projected Watershed layer as an input. The masked DEM was then projected into NAD 1983 State Plane Oregon North FIPS 3601 coordinates using the 'Project Raster' tool.

The Spatial Analyst tool, 'Slope' was used to calculate the percent rise across the watershed and the 'Hillshade' tool was used to illustrate the variance in elevation utilizing a shading technique (Z factor of 10). In order to analyze elevation within each HUC-12 subwatershed, 'Zonal Statistics as Table' was used with the Watershed layer and project DEM as inputs. The table was saved as a dBase file and imported in Microsoft Excel, which allowed me to further analyze the trends and create graphs to depict relationships. To find the point of highest elevation, the 'Raster Calculator' was used to produce a binary raster based on a specified constraint. The constraint was determined in a trial-and-error approach, as it can be difficult to find the individual cell of highest elevation if the constraint is too tight. The highest point of elevation was denoted using the Drawing toolbox.

Precipitation

An 800-m raster containing precipitation data across the United States was uploaded in ArcMaps and masked to the Watershed (HUC-8) boundary layer using the 'Extract by Mask' tool. The DEM was then projected into NAD 1983 State Plane Oregon North FIPS 3601 coordinates using the 'Project Raster' tool. The projected raster was then classified into five groups, by altering the Symbology properties, in order to show a more defined distinction between each elevation subrange of values.

'Zonal Statistics as Table' was used to calculate statistics on annual precipitation per HUC-12 subwatershed. The table was exported as a dBase file and opened in Microsoft Excel for further analysis. 'Raster Calculator' was used to create a binary raster that displayed cells with precipitation values greater than 1600 mm (see Figure 6).

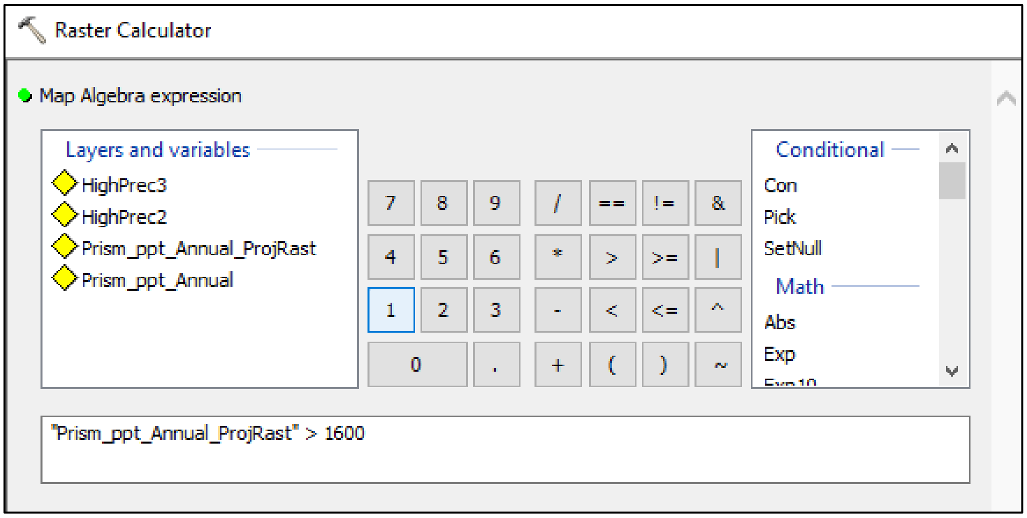

Figure 6. *Using the 'Raster Calculator' tool to create a binary raster that characterizes the data as "true" or "false" based on a specified constraint. In this case, the output raster displays cells with precipitation values greater than 1600 mm/yr.*

Soil Analysis

Vector data describing the soil distribution of the Lower Willamette Basin was downloaded from SSURGO Downloader and uploaded in ArcGIS. The layer was projected to coordinates consistent with the other layers and the symbology was changed to illustrate available water storage (0-100 cm), broken into five ranges.

The 'Select by Attributes' tool was used to select each hydrologic soil group and sum the area that group occupies in the basin. This technique was repeated to determine the sum and mean available water storage (0-150 cm) per hydrologic soil group. The collected data was copied into an Excel table to determine major characteristics and relationships.

Flow Charts of Major Processing Steps:

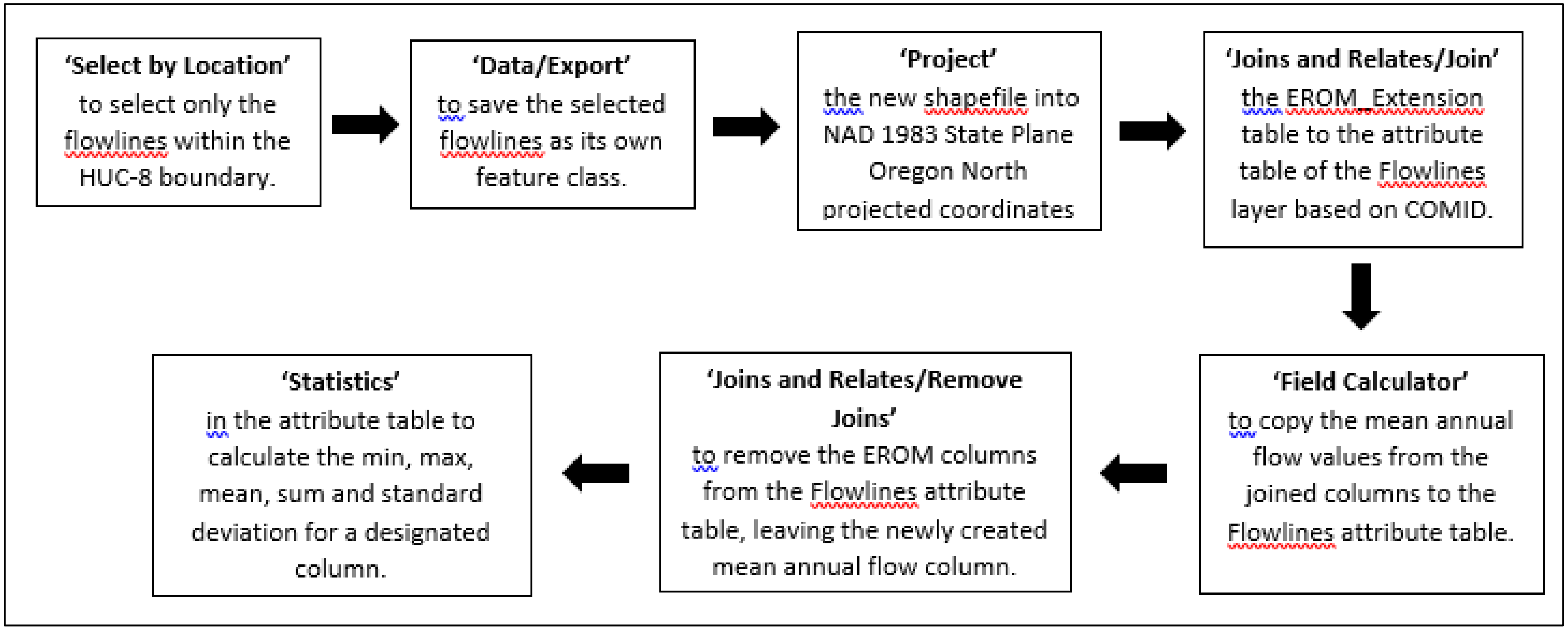

Figure 7. *Flow chart of the major processing steps for the analysis of flowline data.*

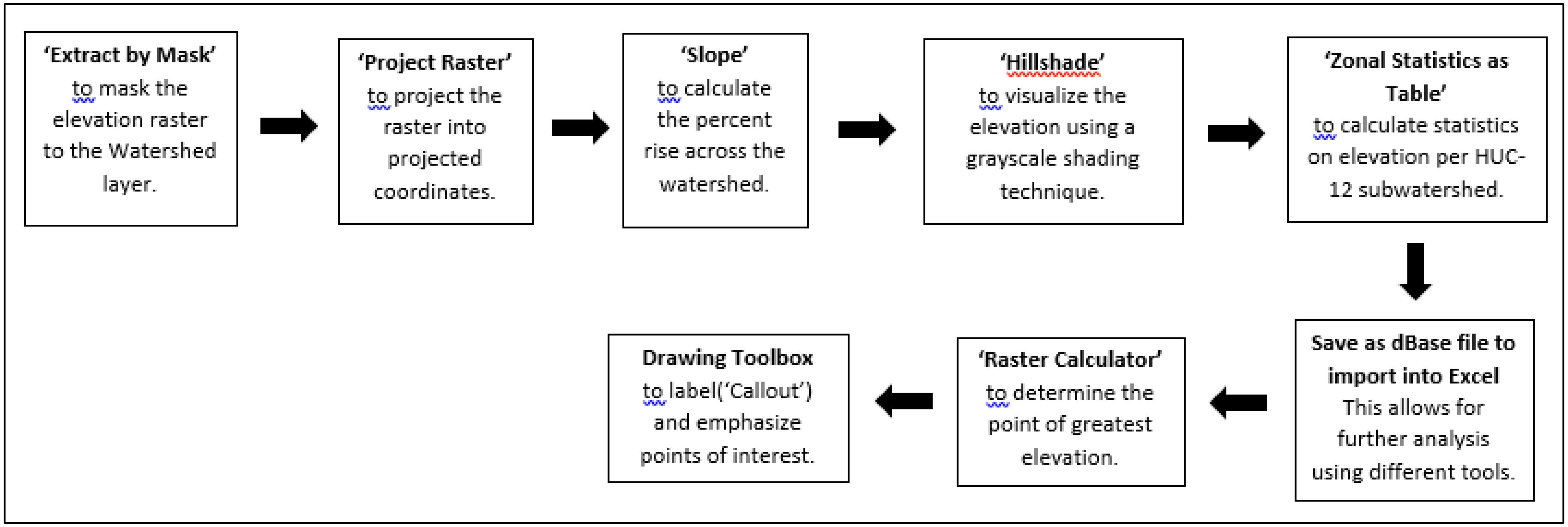

Figure 8. *Flow chart of the major processing steps for the analysis of elevation data.*

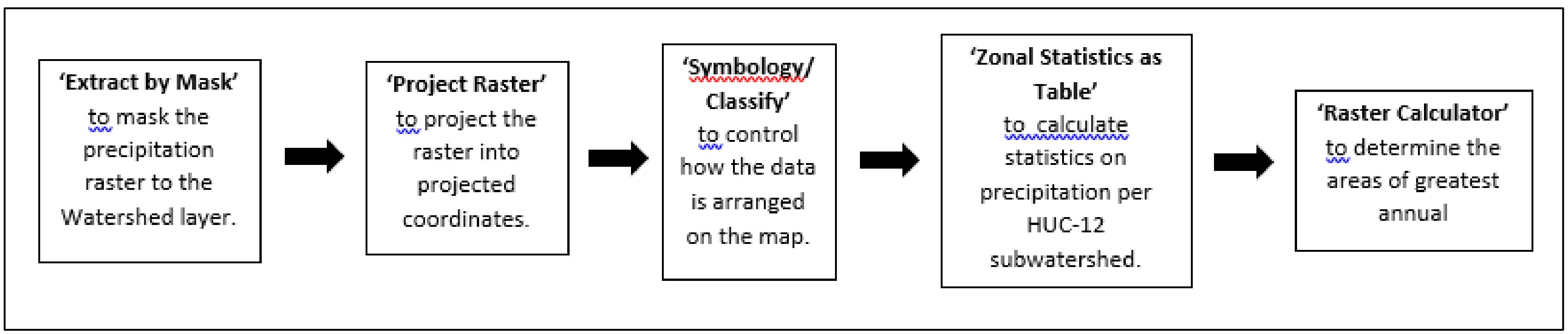

Figure 9. *Flow chart of the major processing steps for the analysis of precipitation data.*

Results & Discussion

HUC-10 and 12 Subwatersheds

The Lower Willamette Basin has an eight-digit HUC of 17090012. The basin is comprised of five HUC-10 subwatersheds (displayed in Figure 10) and 17 HUC-12 subwatersheds (illustrated in Figure 11). NHD watershed boundary data was used to depict these and calculate the area of each HUC-12 subwatershed.

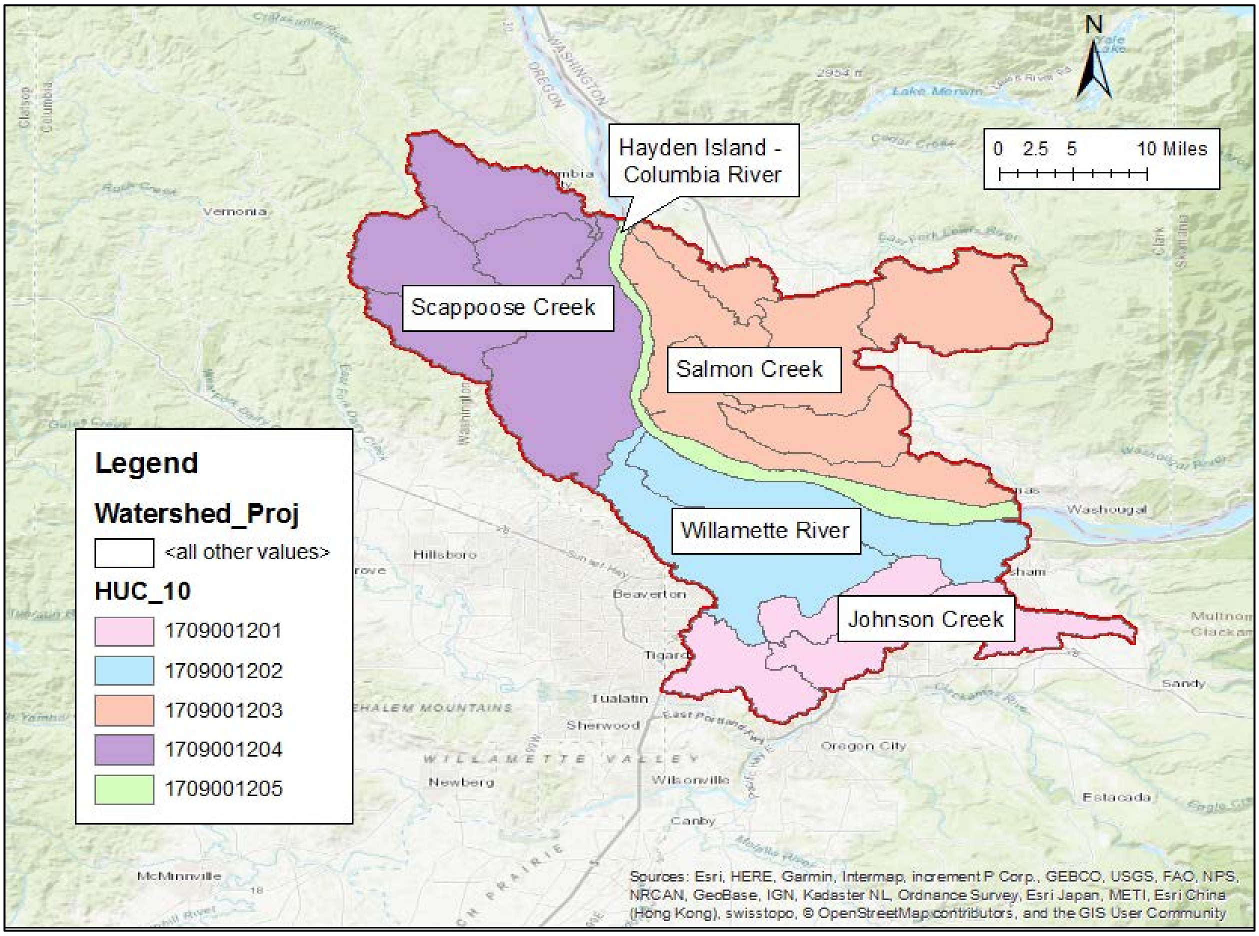

Figure 10. *Map of the five HUC-10 subwatersheds within the Lower Willamette Basin. The legend denotes each by their HUC-10 digits, the first eight of which area all the same because they are all in the HUC-8 17090012.*

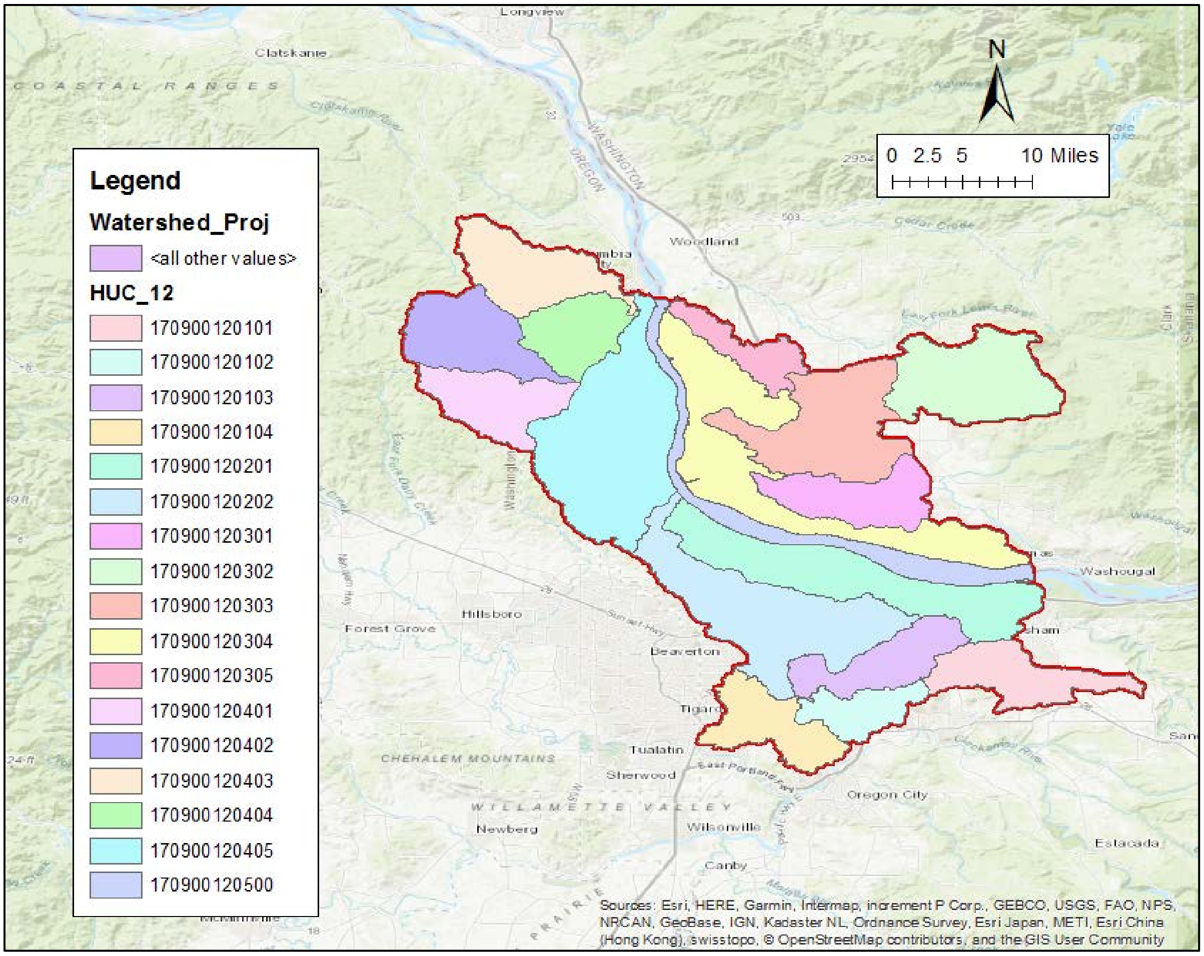

Figure 11. *Map of the 17 HUC-12 subwatersheds within the Lower Willamette Basin. The legend denotes each according to their HUC-12 digits and the basin boundary is in red.*

The largest HUC-12 is the Gilbert River – Frontal Columbia River subwatershed (17090012405), at nearly 78 square miles. The smallest HUC-12, at approximately 25 square miles, is Oswego Creek (170900120104). This subwatershed is located in the southwest portion of the basin. A summary of the HUC-12 areas is provided in Table 1 below.

HUC 10 Name	HUC 12 Name	Area (acres)	Area (sq mi)
Johnson Creek	Kellogg Creek	10,422	16.3
	Oswego Creek – Willamette River	16,220	25.3
	Upper Johnson Creek	17,060	26.7
	Lower Johnson Creek	16,456	25.7
Willamette River – Frontal Columbia River	Columbia Slough – Frontal Columbia River	37,236	58.2
	Willamette River	41,486	64.8
Salmon Creek – Frontal Columbia River	Burnt Bridge Creek	17,433	27.2
	Lower Salmon River	31,471	49.2
	Upper Salmon River	27,658	43.2
	Lake River – Frontal Columbia River	45,044	70.4
	Gee Creek	9,880	15.4
Hayden Island - Columbia River	Hayden Island – Columbia River	18,572	29.0
Scappoose Creek-Frontal Columbia River	South Scappoose Creek	17,388	27.2
	Gilbert River – Frontal Columbia River	49,752	77.7
	Scappoose Creek	14,838	23.2
	North Scappoose Creek	20,556	32.1
	Milton Creek	20,675	32.3
	Total	**412,150**	**644.0**

Table 1. *Summary of areas for each HUC-12 subwatershed in the Lower Willamette Basin.*

Flowlines

Once the NHD flowlines data and WBD data were projected in North Oregon State Plane Lambert Conical coordinates, the EROM_Extension file was joined with the NHD flowline attribute table by linking COMIDs. This process allowed the mean annual flow to be copied from the EROM_Extension file and pasted in the flowlines attribute table. The mean annual flows are summarized in Table 2. A map was also created to illustrate streams based on their mean annual flow (see **Appendix B**). This map illustrates the distribution of flows and can be used to approximate the relative flow accumulation at the end of various streams. Although it is outside the scope of this study, flow accumulation can be calculated and analyzed using a DEM of the basin in ArcMaps. Unsurprisingly, the greatest mean annual flow is found in the Columbia river, a water body that dominates this watershed. Excluding major water bodies such as the Columbia River, Willamette River and Columbia Slough, the average mean annual flow throughout the basin is approximately 40 cfs (compared to 5,817 cfs when all streams are taken into account) and the maximum annual flow is 6,500 cfs (compared to 237,000 cfs). The sharp difference in mean and maximum flows when the major rivers are excluded demonstrates the high degree to which those water bodies drive the hydrologic characteristics of the watershed. This also shows how statistical analysis of watersheds can vary based on the details of how they calculate their parameters.

Using the sum of flow lengths from the attribute table of NHD flowlines layer and the total acreage of the WBD dataset, the drainage density of the entire watershed was estimated to be 0.701 km/km^2 (see **Appendix F**). The drainage density being less than 1 km/km^2 indicates that this watershed has permeable terrain and thus fairly low runoff potential (Farooq, S., 2018).

Elevation

A digital elevation model (DEM) of the Oregon portion of the Lower Willamette watershed was obtained from Geospatial Data Gateway and projected into the North Oregon State Plane Lambert Conic coordinates (see Figure 12). The point of highest elevation was determined using the Raster Calculator, which produces a binary raster with areas that either meet the parameter specified (true) or do not meet the parameter (false). The northwest border of the basin had the highest elevation, of approximately 2,131 ft. This conclusion makes sense because the point corresponds to a densely forested, mountainous area where hiking is common.

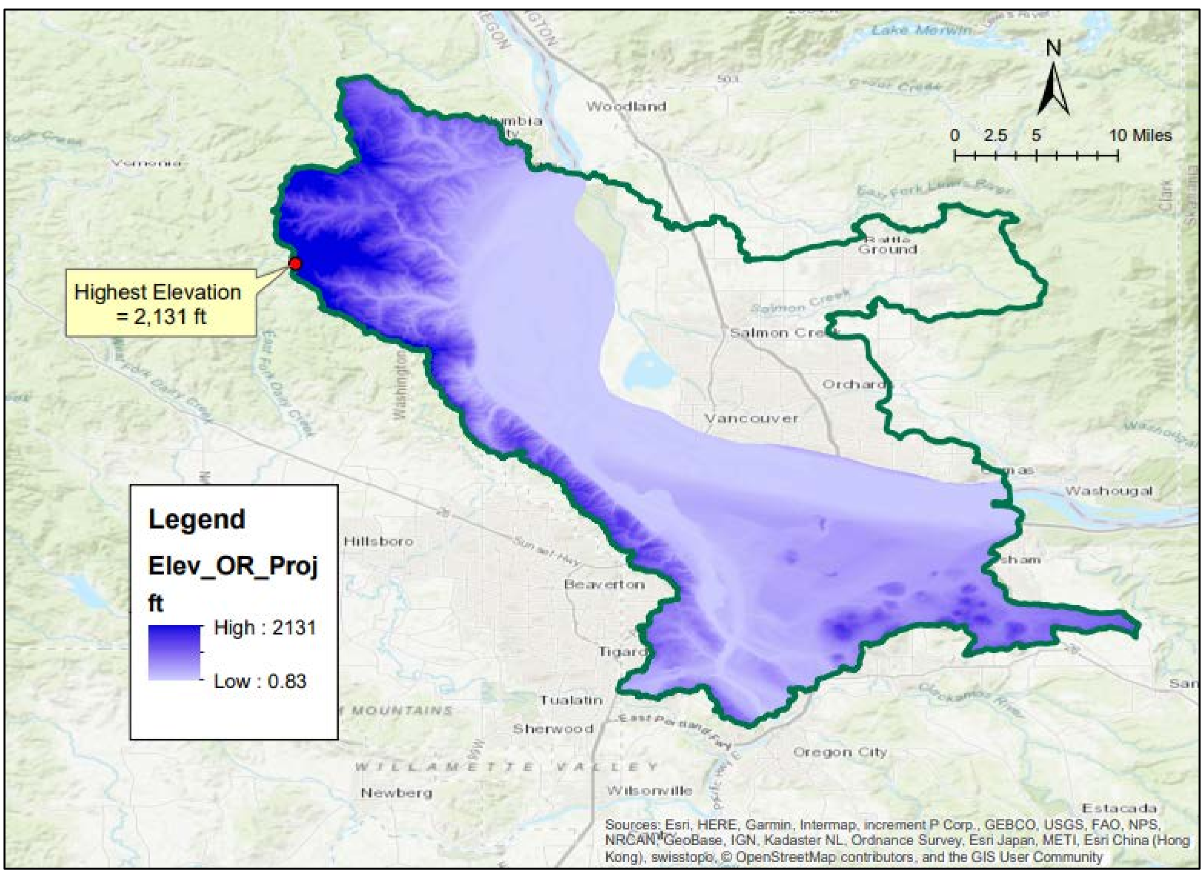

Figure 12. *Projected DEM of the Oregon portion of the Lower Willamette Basin showing elevation. The red circle indicates the point of highest elevation in the DEM, determined using Raster Calculator.*

Elevation across the Oregon portion of the Lower Willamette watershed was then analyzed using the slope and aspect functions in ArcGIS. Figure 13 illustrates the variance in slope across the DEM. There are essentially two major portions of the area shown below; one is where the Columbia River, Columbia Slough and Sauvie's Island are located. The remainder of the DEM has much greater variety in slope, particularly on the western border as this area contains more mountainous terrain.

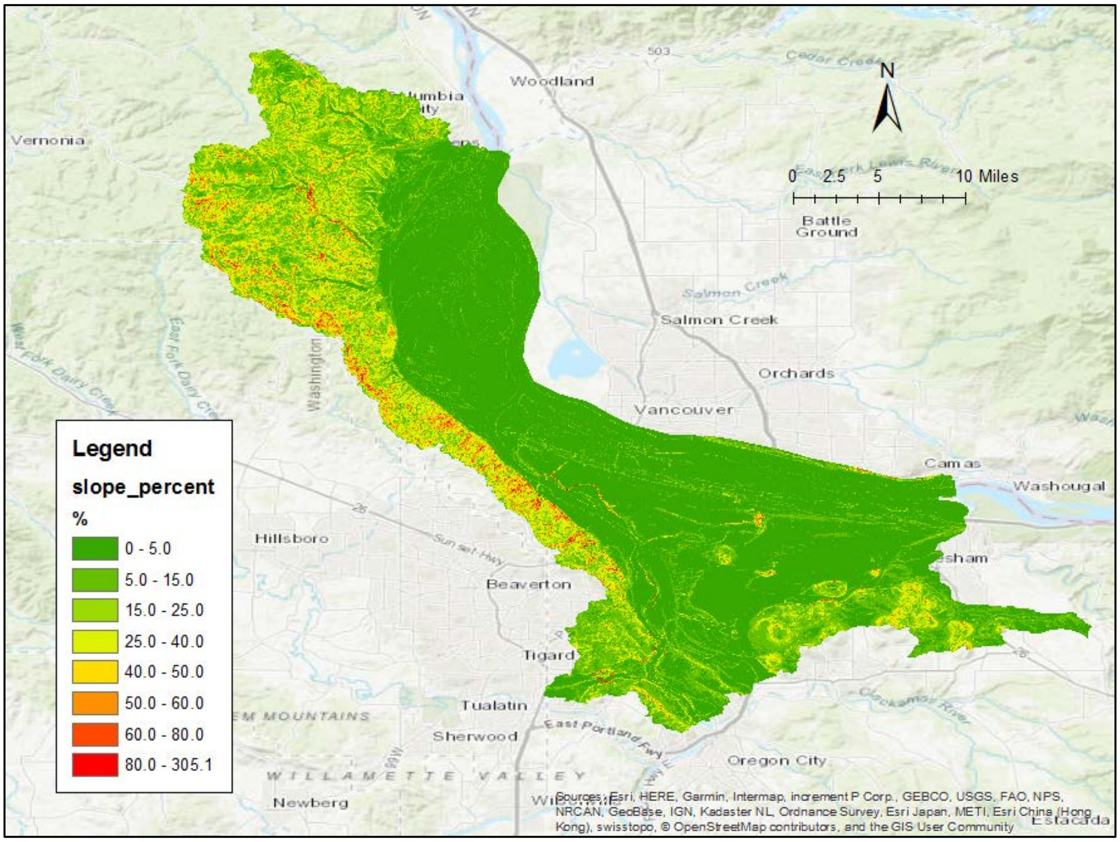

Figure 13. *Slope (%) analysis across the Oregon portion of the Lower Willamette Basin using ArcGIS.*

Figure 14 below illustrates this contrast more clearly. Position 1 labeled on the map is an example of high variance in slope (15-65%), and corresponds to the Tualatin Mountains. Position 2 denotes a relatively flat area and is where Sauvie's Island is located.

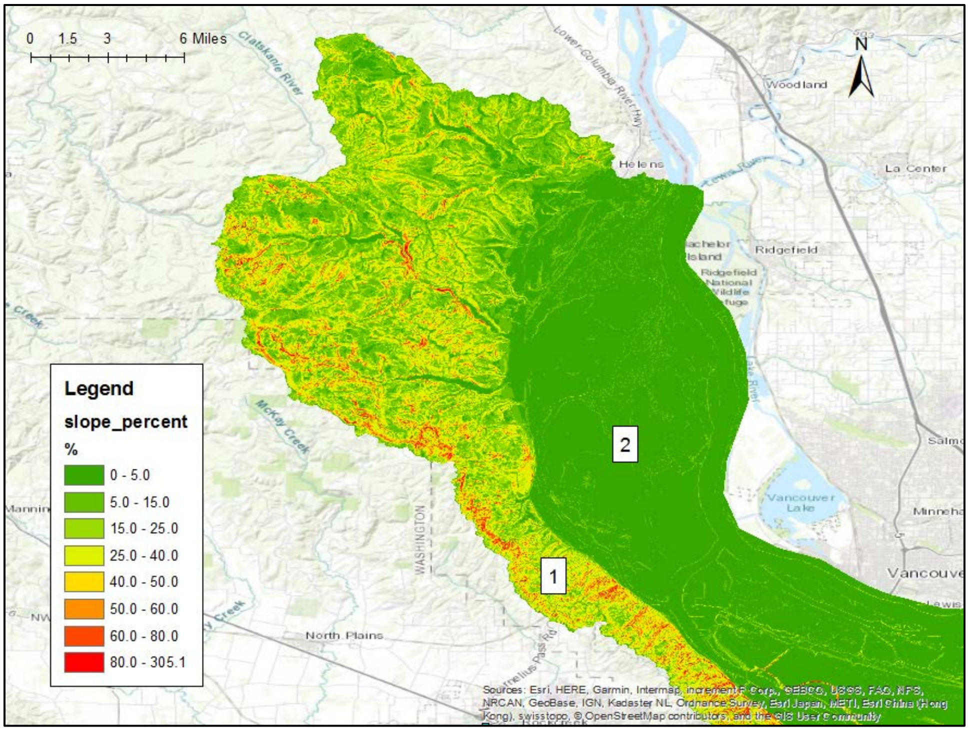

Figure 14. *Comparison of slope variance with topographical features in the Lower Willamette Basin. Position 1 indicates an area of great variance in slope and corresponds to the Tualatin Mountain range, where Forest Park is located. Position 2 represents an area of relatively uniform, low slope. This is an area where the Columbia River passes through and where Sauvie's Island is located.*

The 'Zonal Statistics as Table' tool in ArcGIS was used to analyze elevation data per HUC-12 subwatershed (see **Appendix D**). This analysis was limited because the DEM only contained elevation data for the Oregon portion of the Lower Willamette Basin. However, the elevation statistics are still relevant and can convey a great deal of information. The greatest range of elevation was found in the South Scappoose Creek subwatershed, where the highest elevation of 2,131 ft is located. The greatest mean elevation across subwatershed was found in North Scappoose Creek. As expected, the lowest elevation was found in the Willamette River and the lowest mean elevation was found in the Hayden Island – Columbia River subwatershed.

Another visualization of the terrain was created using the Hillshade feature in ArcGIS (see Figure 15). Hillshade is a 3-D imaging technique that uses a fixed sun position to shade the terrain surface to emphasize variance in elevation. This map further illustrates the distinct difference in terrain on the east and west of the Willamette River.

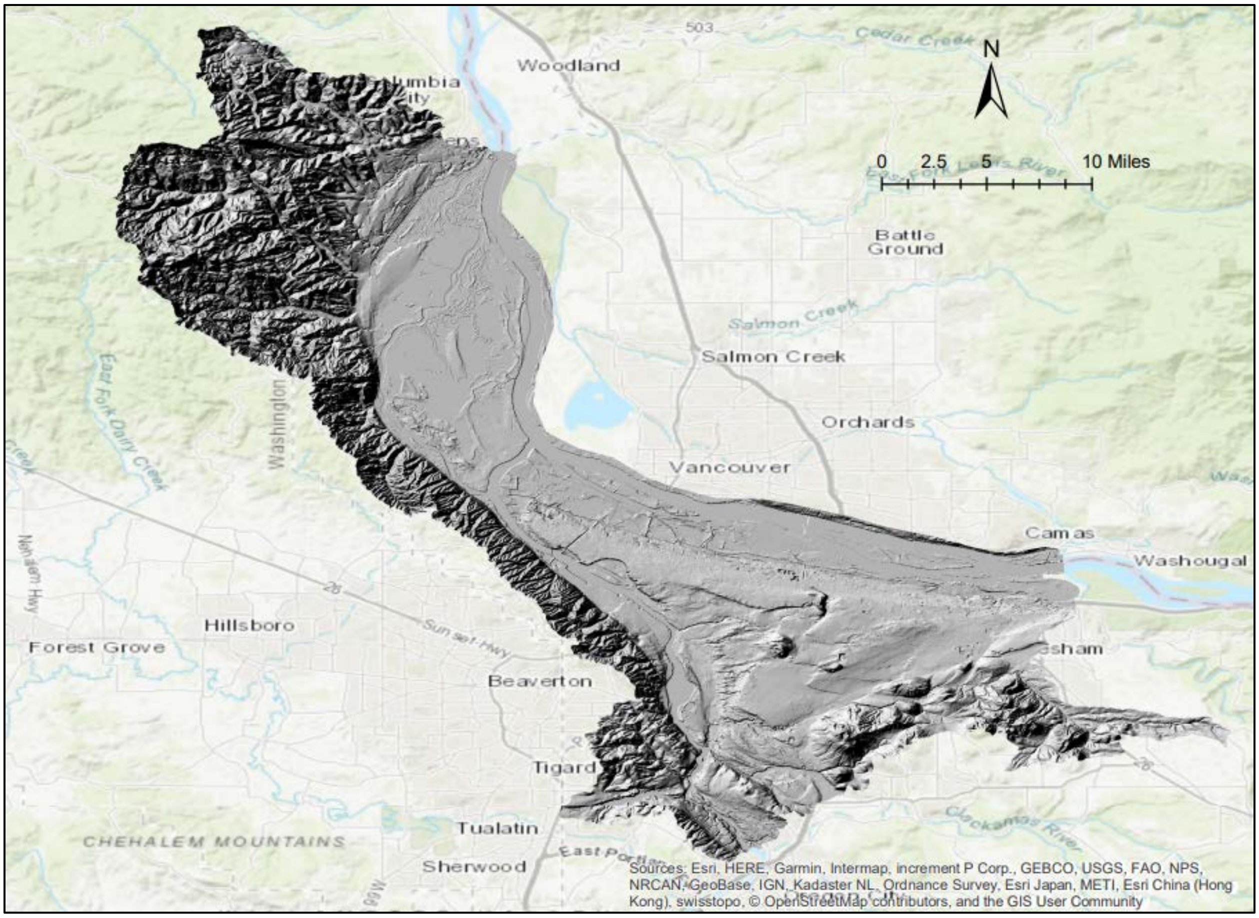

Figure 15. *Map of the Oregon portion of the Lower Willamette Basin using the Hillshade feature in ArcGIS with Z factor of 10.*

This analysis demonstrates the wide variety of topography in the Lower Willamette Basin and can be used to predict the flow of precipitation and streams. However, it is not a complete analysis without a DEM of the Washington portion of the watershed.

Precipitation

Annual precipitation data was obtained as an 800-m raster of the United States. This data was masked to the Lower Willamette Basin and projected into North Oregon State Plane Lambert Conic coordinates. The projected raster was then classified into five groups to illustrate the distribution of precipitation across the basin. As Figure 16 illustrates, the center of the watershed has the lowest precipitation while the northern and eastern edges have the greatest. The outer edges are the more mountainous regions while the center contains the slough and major rivers. This data supports the trend that average precipitation is directly proportional to elevation.

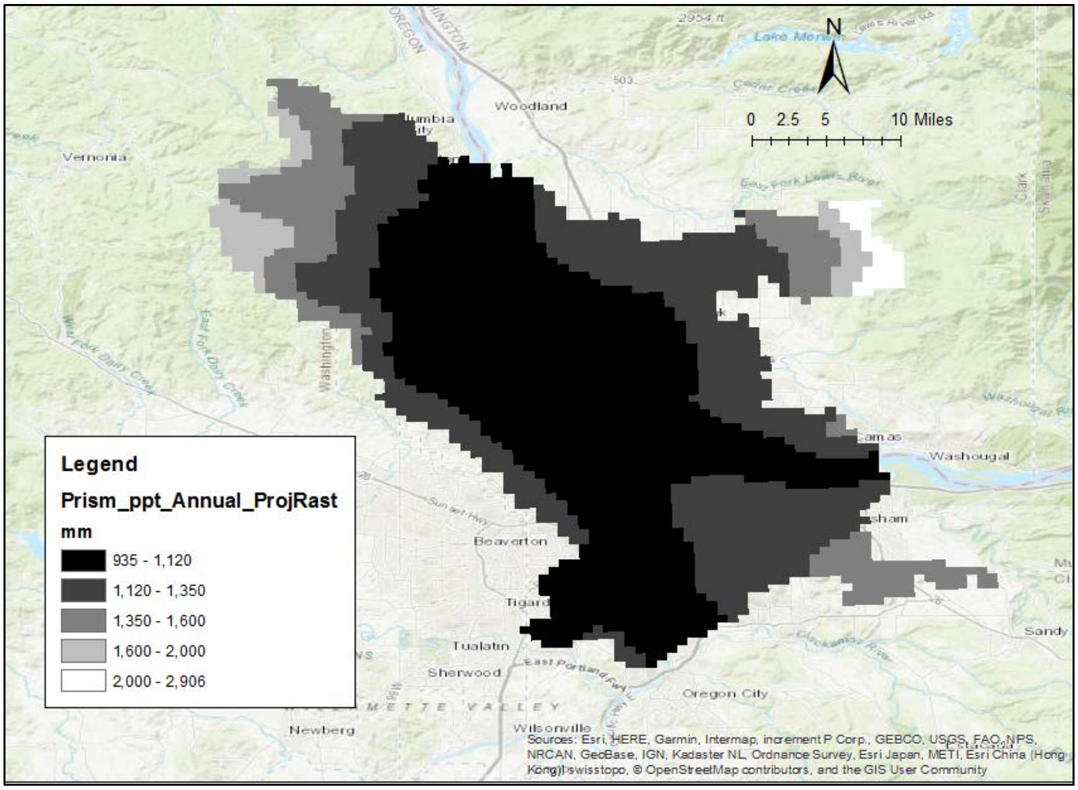

Figure 16. *Map of annual precipitation across the Lower Willamette Basin averaged from 1981-2010.*

The 'Zonal Statistics as Table' tool was used to analyze annual precipitation across each HUC-12 subwatershed using the OBJECTID field. A summary of these results can be found in **Appendix E**. The Upper Salmon River subwatershed had the largest range in annual precipitation and had the greatest mean precipitation value. Contrastly, the lowest mean precipitation was found in the Hayden Island – Columbia River subwatershed. These findings can be used to calculate runoff ratios for each subwatershed, which is important for local geotechnical and stormwater engineering.

Soil Type Distribution

Soil data was obtained from SSURGO, clipped to the Lower Willamette Basin and projected in North Oregon State Plane Lambert Conic coordinates. The information of focus in this dataset was the hydrologic soil group and available water storage (0-150 cm and 0-100 cm). Available water storage is an important characteristic of watersheds because it is used to predict runoff rates, drought and to design and operate drainage systems.

A map was created to display available water storage in the top 1m of soil across the basin (see Figure 17). There is a relatively wide range of available water storage, with the greatest amount in the northern region of the watershed. Near the Columbia and Willamette rivers, there is considerably less water storage, which aids in moving runoff to those major water bodies.

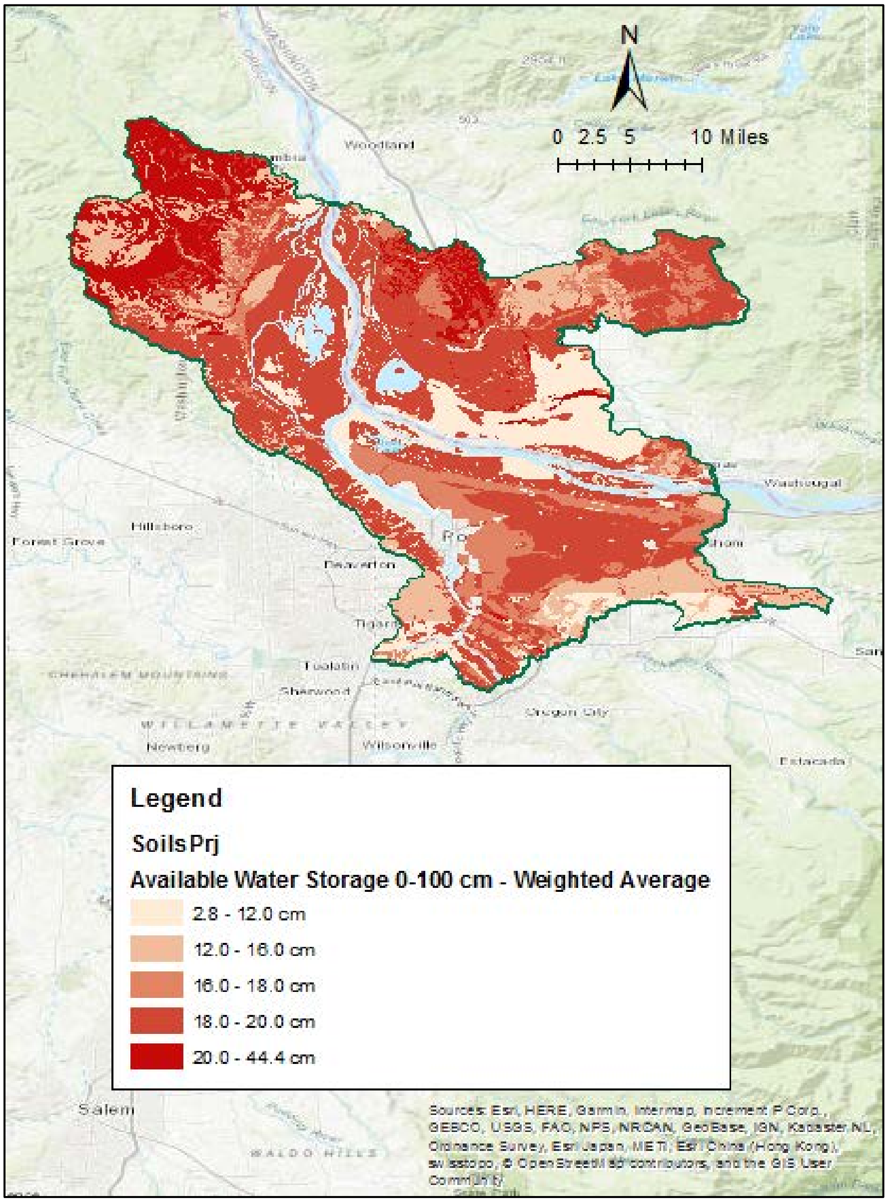

Figure 17. *Map of the available water storage in the top 1m of soil across the Lower Willamette Basin.*

There are six hydrologic soil groups in this watershed, including A, B, C, D, B/D and C/D. The 'Select by Attributes' feature was used to calculate the total area that each soil group occupies in the Lower Willamette Basin. These results are summarized in Table 2 below.

Hydrologic Soil Group	Total Area (sq mile)
A	25.79
B	157.89
C	255.87
D	25.50
B/D	18.29
C/D	42.03

Table 2. *Total area each hydrologic soil group occupies in the Lower Willamette Basin.*

From this information, it can be deduced that the majority of soil in the basin is type B and C. To understand the significance of these results, one must first understand the difference between each hydrologic soil group. Table 3 compares the composition and relative runoff potential of each soil group. Type B has less clay and more sand compared to Type C, which yields greater water infiltration potential. It would be reasonable to assume Type B has greater available water storage, as it has greater porosity. If runoff rates become an issue, perhaps adding Type B soil could help mitigate this and provide more water to local vegetation.

Hydrologic Soil Group	Composition	Relative Runoff Potential when Wet	Relative Water Infiltration Potential
A	Mostly sand and gravel	Low	High (well-drained)
B	10-20% clay, 50-90% sand	Moderately Low	Moderately High
C	20-40% clay, <50% sand, rest loam and silt	Moderately High	Moderately Low
D	>40% clay, <50% sand	High	Low

Table 3. *Comparison of the composition and properties of hydrologic soil groups (USDA NRCS, 2007)*

To verify this assumption, a graph was created to determine a relationship between hydrologic soil group and average available water storage (see Figure 18). Based on this analysis, it was verified that soil group B has a greater amount of available water storage. Hydrologic soil group A had the lowest amount of water storage, even though its properties yield low runoff rates. This must mean that this group can drain so effectively that not much water is retained in the top 1.5 m of soil. Overall, B/D showed the greatest amount of water storage. This dual group means that the soil is characterized as group B when drained and group D when undrained.

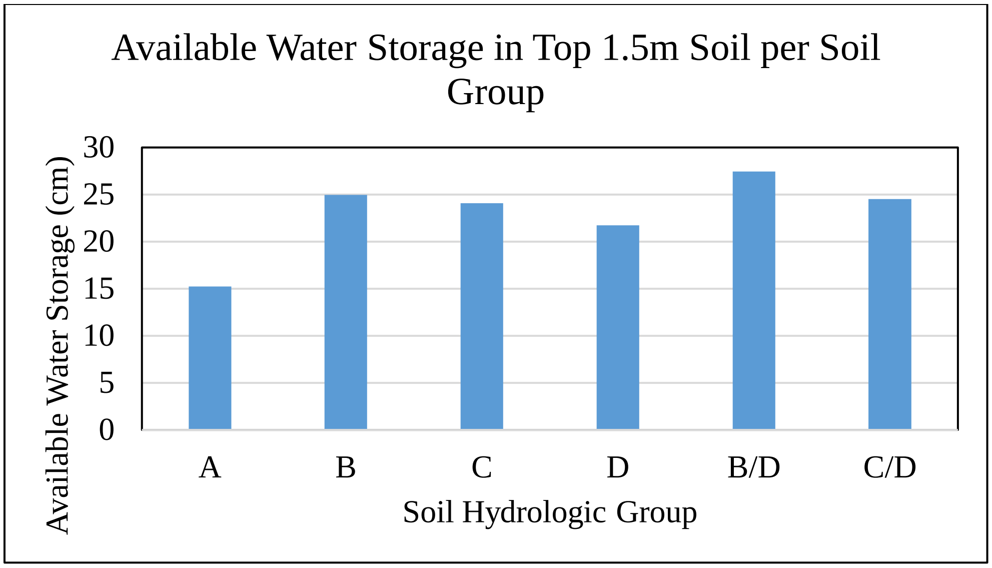

Figure 18. *Average available water storage (0-150 cm) per hydrologic soil group in the Lower Willamette Basin.*

Using the available water storage (0-150 cm) and the area that each soil group occupies, an average volume of water storage was determined for each soil group in the Lower Willamette Basin. These values were graphed and compared (see Figure 19). Although soil group C offered a relatively moderate amount of water storage, it provided the greatest amount of water volume overall because of its abundance in the watershed. An interesting observation is that although the B/D soil group provided the greatest amount of water storage (cm) in the top 1.5 m of soil, its existence is limited in the basin.

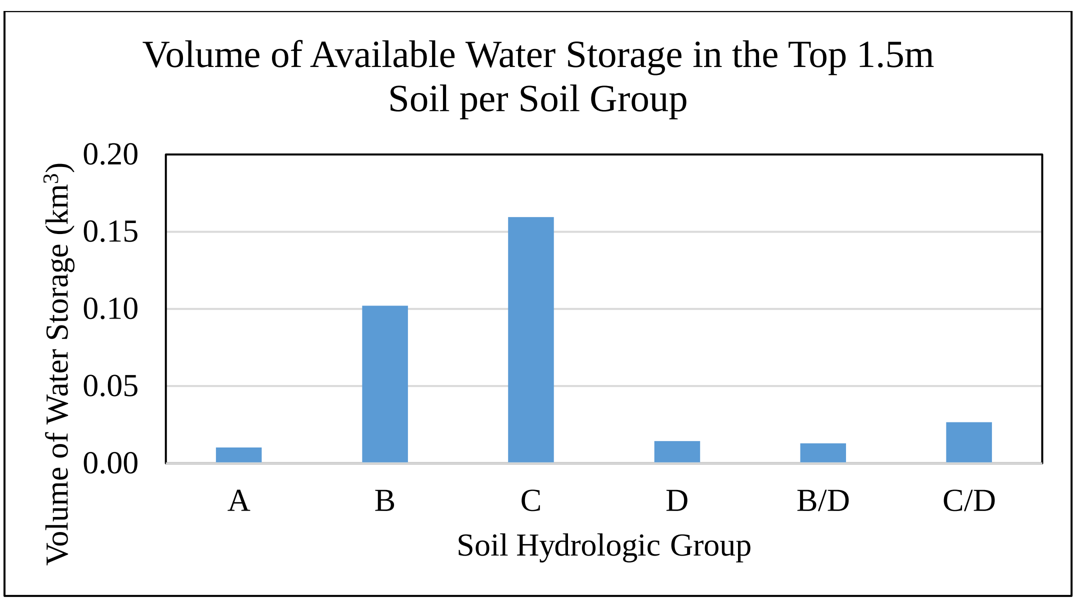

Figure 19. *Average volume of available water storage in the top 1.5 m of soil per hydrologic soil group in the Lower Willamette Basin.*

Identifying Areas of High Runoff Potential

Using the ‘Raster Calculator’ tool and the precipitation raster, areas of greatest precipitation were identified within the Lower Willamette Basin. The selected constraint was areas with precipitation greater than 1,600 mm per year. This constraint was chosen because it includes precipitation values in the upper quartile of the range. The resulting binary raster was layered on top of the map of available water storage (0-100 cm) to determine if there were areas of particularly high runoff potential, indicated by high precipitation and low available water storage. A professional map illustrating these results can be found in **Appendix C**.

Based on this analysis, two of the three areas of greatest precipitation were identified as having potentially high runoff rates. A zoomed map of these areas can be found in Figure 20 below. Relating Figure 20 to Figures 12-15 illustrating elevation show that these outlined areas have the greatest elevations in the watershed, which increases rate of runoff. Although this analysis alone does not demonstrate a definite problem with runoff and/or flooding, it does highlight potential high-risk areas. These areas should be monitored closely, as this may aid in predicting hydrological behavior. It is also important that these areas have updated drainage infrastructure. Thus, identifying these potential high-risk areas allows for prioritization of public projects.

Further research should be conducted to compare these areas of potential high runoff rates to retention areas and utility networks throughout the watershed in order to determine areas of most hydraulic concern. Stream gage data in these areas could also be used to investigate the degree of monitoring and determine its sufficiency. In addition, optimization of monitoring methods and predictive models could be considered to improve the accuracy of precipitation data, as the data seemed to vary based on the source. A major limitation in my analysis was the low resolution of my precipitation data. A lower resolution is beneficial for ease of analysis, as it does not take as long for ArcGIS to process, but that convenience is offered with the cost of precision. Using a raster with a smaller grid cell size would produce more accurate results and should be used in further analysis.

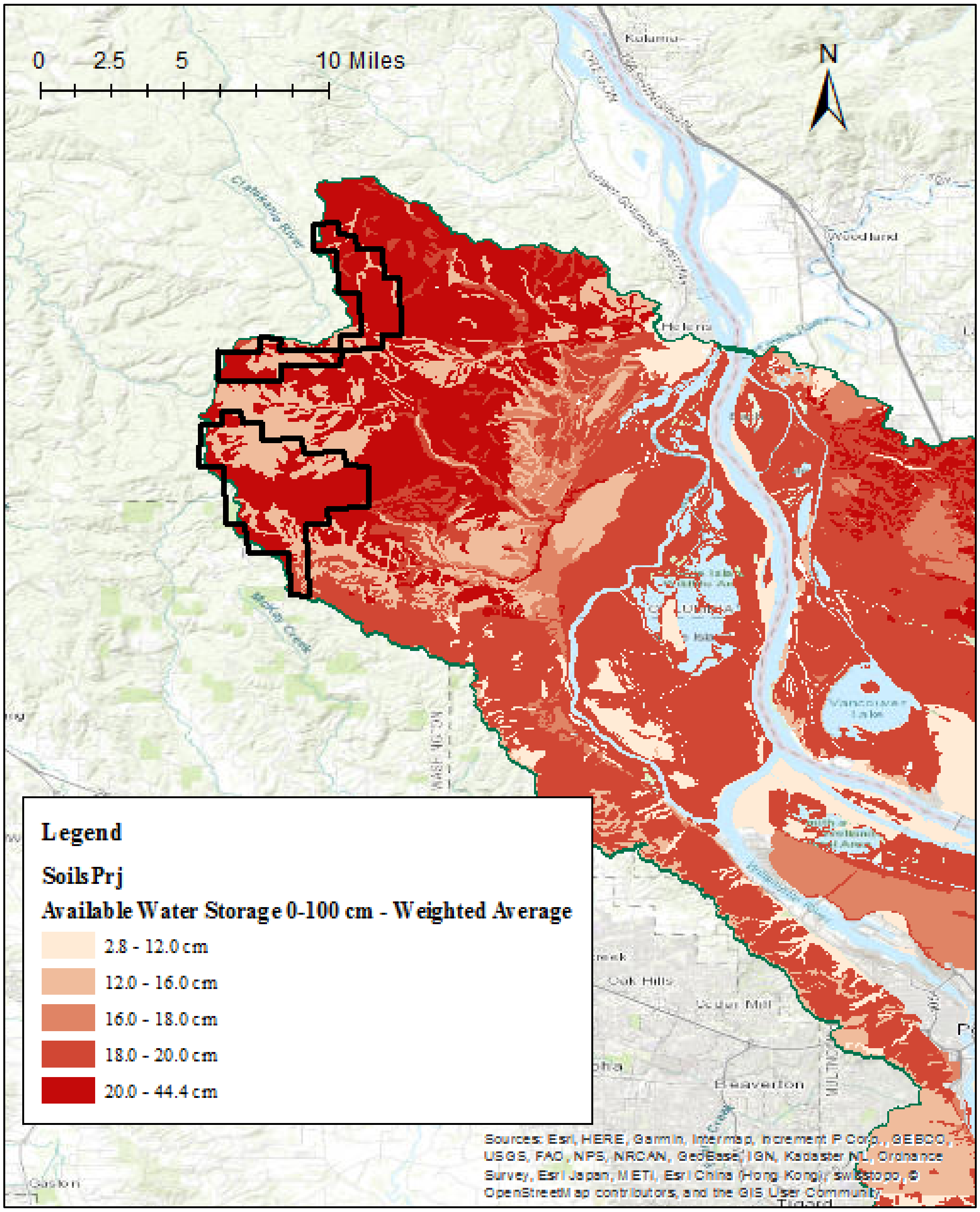

Figure 20. *Map showing the available water storage in the top 1m of soil within areas of greatest precipitation, designated by black outlines.*

Appendices

Appendix A: Bibliography

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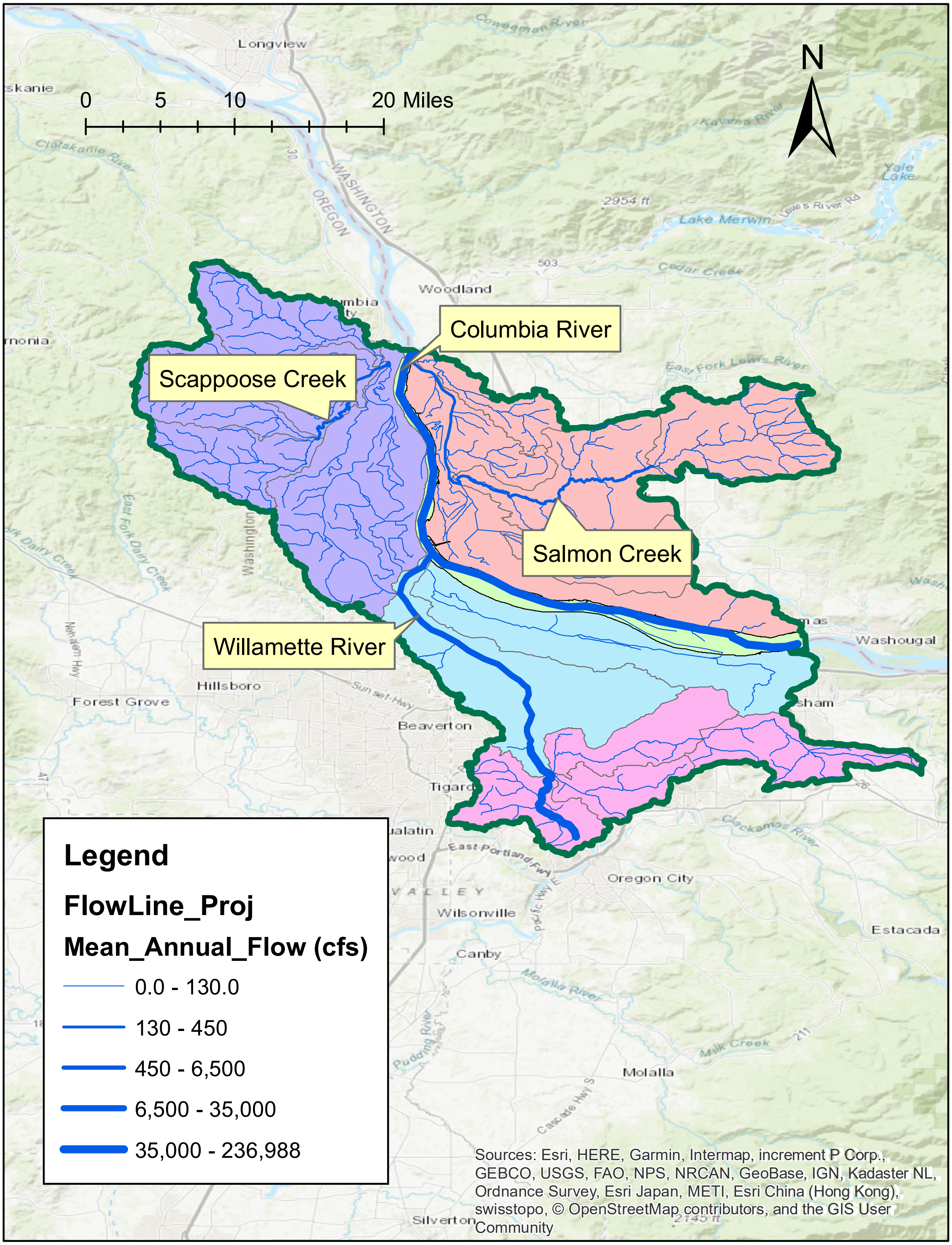
USDA National Resource Conservation Service (2007). "Hydrologic Soil Groups." Part 630 Hydrology National Engineering Handbook, https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17757.wba (accessed March 16, 2019).

Appendix B: Map of Mean Annual Flow across the Lower Willamette Basin

See map attached.

Mean Annual Flow in the Lower Willamette Basin

Created by: Lauren Tetzloff

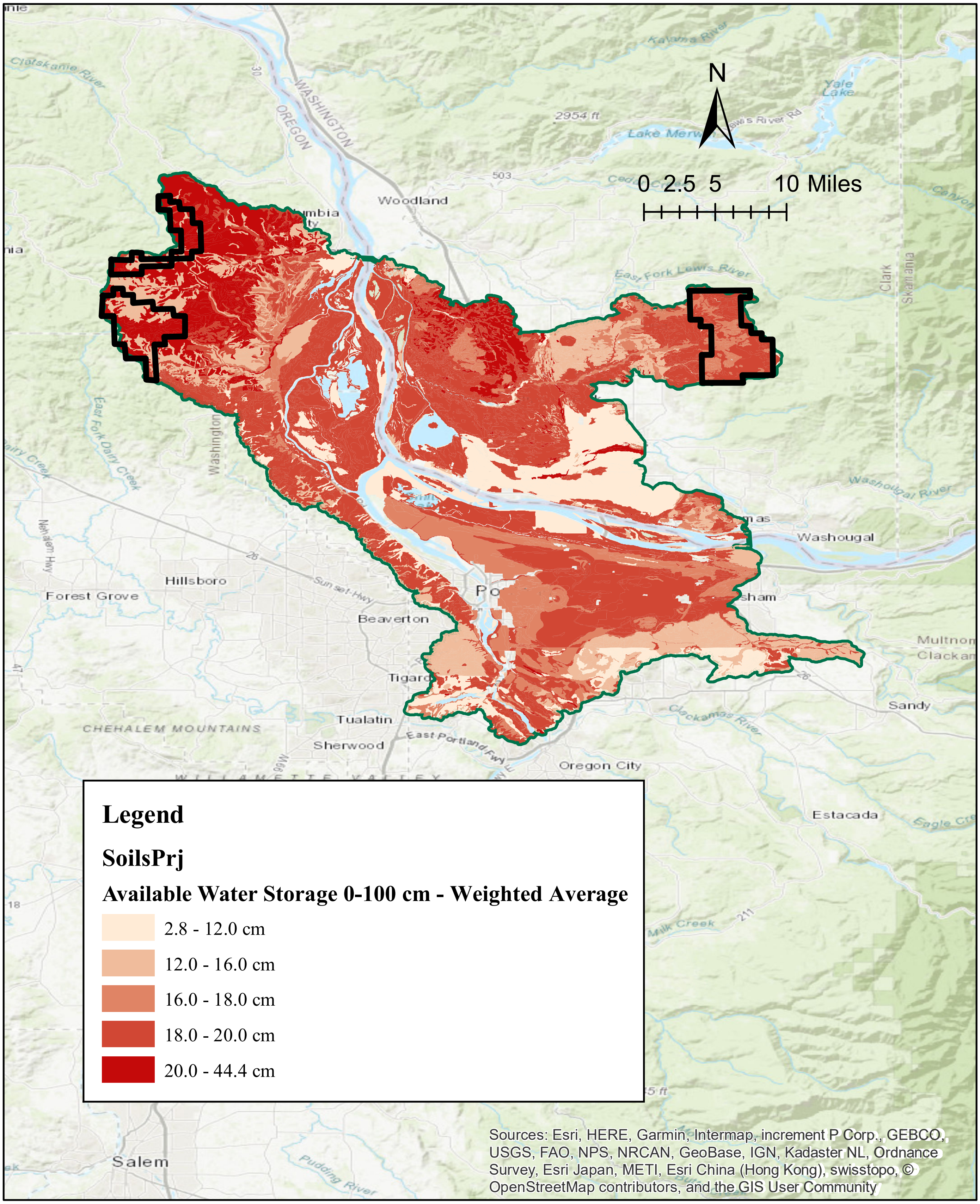


Appendix C: Map of Available Water Storage in Areas of High Precipitation

See map attached.

Available Water Storage (0-100 cm) in Areas of High Precipitation

Created by: Lauren Tetzloff



Appendix D: Zonal Statistics as Table for Elevation Data

The Zonal Statistics as Table tool in ArcMaps was used to obtain statistics on elevation per HUC-12 subwatershed in the Lower Willamette Basin. Inputs included the projected WBD data and the Oregon DEM. Note that because the DEM only included the Oregon portion of the Lower Willamette Basin, not all subwatersheds are included in the table below. ObjectID was the reference column in the watershed attribute table. Note that all values are in units of ft (except for area which is in units of ft^2)

OBJECTID	HUC-12	HUC-12 Name	AREA	MIN	MAX	RANGE	MEAN	STD
106017	170900120102	Kellogg Creek	453679300	3.7	1093	1089	273	203
106050	170900120104	Oswego Creek-Willamette River	705948700	2.3	970	968	275	186
106092	170900120101	Upper Johnson Creek	742339500	235.2	1125	890	527	157
106121	170900120103	Lower Johnson Creek	716704400	4.9	1088	1083	263	148
106250	170900120201	Columbia Slough-Frontal Columbia River	1621520800	0.8	642	642	103	101
106257	170900120202	Willamette River	1806609800	1.1	1253	1252	270	268
106406	170900120401	South Scappoose Creek	757107100	23.1	2131	2108	863	518
106476	170900120304	Lake River-Frontal Columbia River	243455200	1.8	311	309	46	53
106486	170900120500	Hayden Island-Columbia River	807287300	1.7	51	49	11	7
106487	170900120305	Gee Creek	1043300	6.0	21	15	12	3
106501	170900120405	Gilbert River-Frontal Columbia River	2166649800	1.9	1522	1520	161	292
106503	170900120404	Scappoose Creek	646308100	1.9	1034	1032	216	208
106510	170900120402	North Scappoose Creek	895205500	24.2	2099	2075	1029	391
106657	170900120403	Milton Creek	900174200	5.0	1562	1557	627	298

Appendix E: Zonal Statistics as Table for Precipitation Data

The ‘Zonal Statistics as Table’ tool was used to analyze annual precipitation data according to each subwatershed in the Lower Willamette Basin. All data is in units of mm.

OBJECTID	HUC-12	HUC-12 Name	MIN	MAX	RANGE	MEAN	STD	SUM
106017	170900120102	Kellogg Creek	1059	1310	250	1131	86	78027
106050	170900120104	Oswego Creek-Willamette River	1036	1222	186	1097	29	115190
106092	170900120101	Upper Johnson Creek	1240	1531	291	1387	72	142830
106121	170900120103	Lower Johnson Creek	1073	1300	227	1155	59	118936
106250	170900120201	Columbia Slough-Frontal Columbia River	935	1301	367	1065	82	248196
106257	170900120202	Willamette River	988	1276	288	1114	50	294174
106293	170900120301	Burnt Bridge Creek	997	1214	216	1117	62	126188
106406	170900120401	South Scappoose Creek	1075	1831	756	1409	215	159164
106420	170900120303	Lower Salmon River	1016	1285	269	1139	75	222088
106459	170900120302	Upper Salmon River	1254	2906	1652	1710	467	280499
106476	170900120304	Lake River-Frontal Columbia River	971	1397	427	1084	96	303469
106486	170900120500	Hayden Island-Columbia River	964	1219	255	1037	58	123395
106487	170900120305	Gee Creek	1059	1211	152	1163	41	60492
106501	170900120405	Gilbert River-Frontal Columbia River	997	1446	450	1090	85	345673
106503	170900120404	Scappoose Creek	1079	1440	361	1172	90	110166
106510	170900120402	North Scappoose Creek	1093	1835	742	1529	146	186502
106657	170900120403	Milton Creek	1086	1691	605	1401	152	173714

Appendix F: Calculation of Drainage density

Sum of LengthKM column in Flowlines layer = 1,169.396 km

Sum of Acres column in Watershed layer = 412,163.049 acres

$$Drainage\ Density = \frac{1{,}169.396\ km}{(412{,}163.049\ acres)\left(\frac{km^2}{247.105\ acres}\right)}$$

$$Drainage\ Density = 0.701\ km^{-1}$$