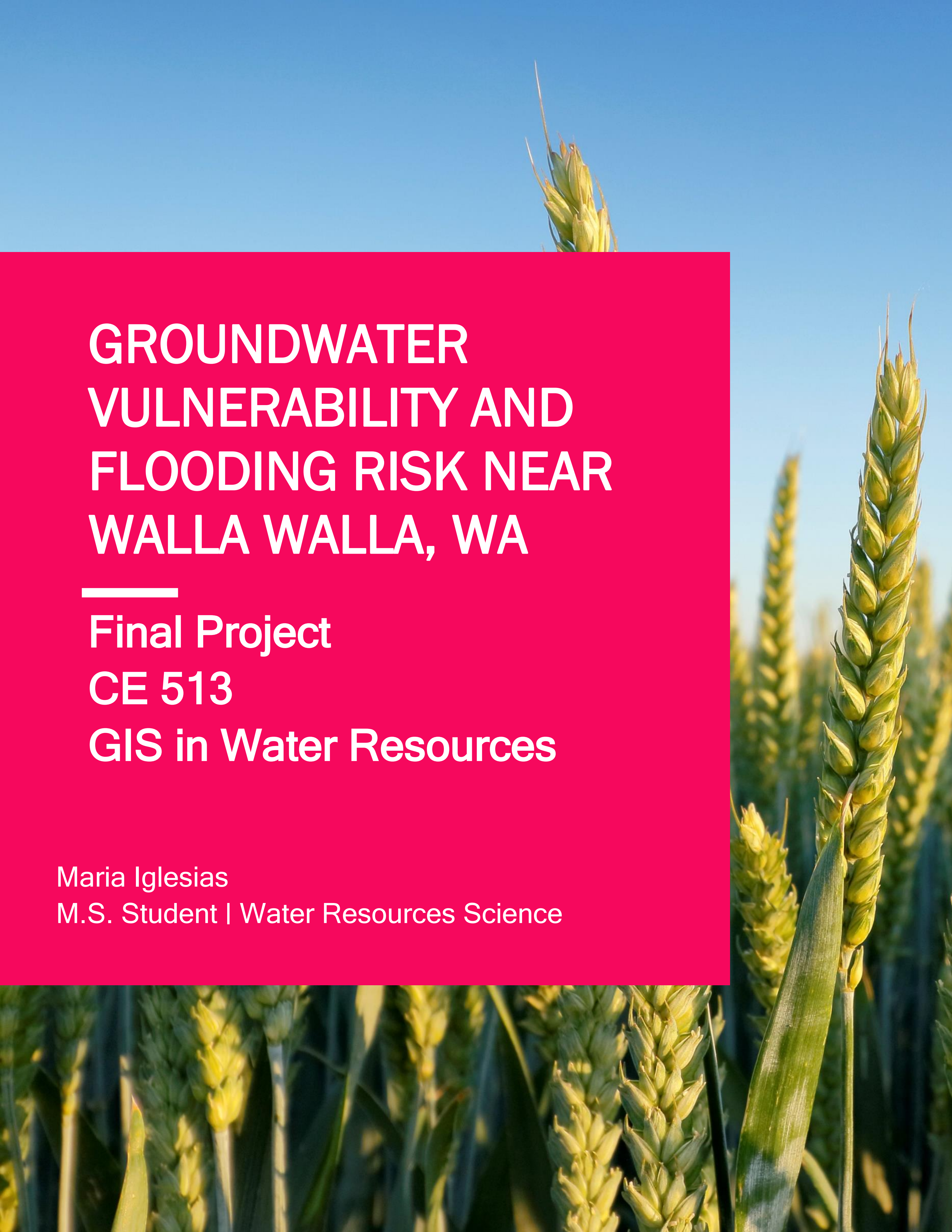

GROUNDWATER VULNERABILITY AND FLOODING RISK NEAR WALLA WALLA, WA

Final Project
CE 513
GIS in Water Resources

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M.S. Student | Water Resources Science

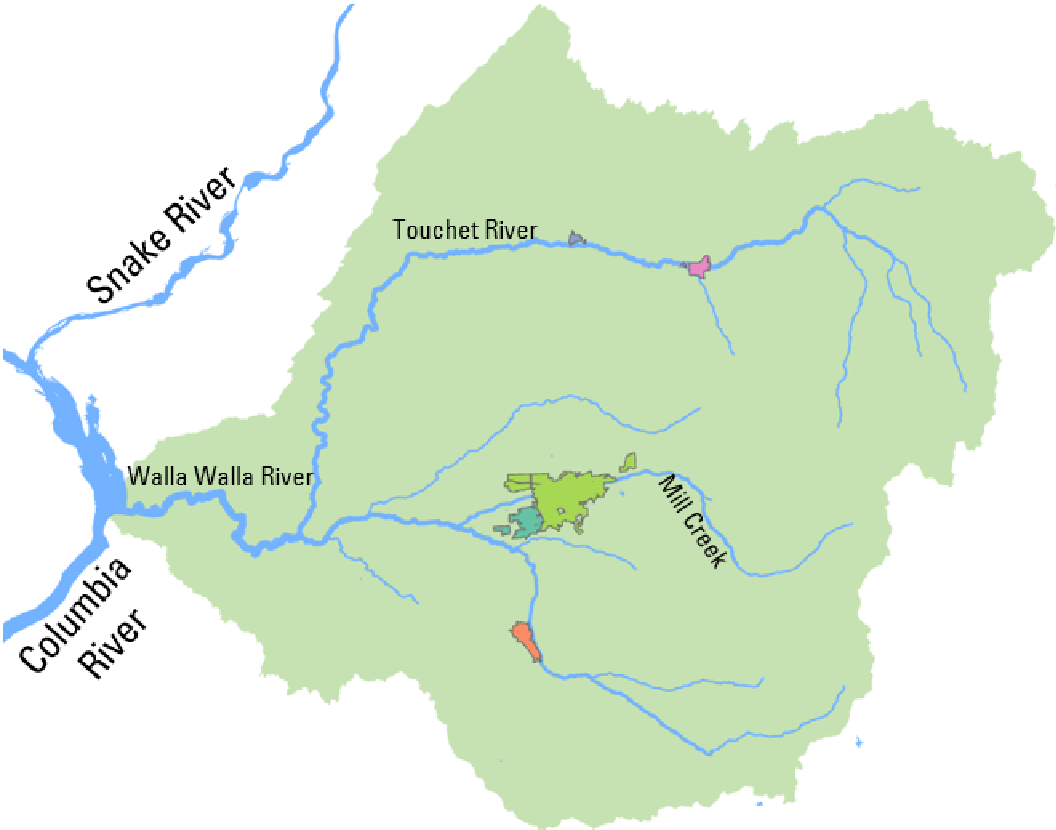
Introduction

Groundwater is a vital resource for communities across the Western United States. Like many others, the city of Walla Walla, relies on mostly groundwater for their drinking water, as well as for agricultural processes. Due to the underlying geological setting that the city sits atop, groundwater is vast, often occurring at many different depths. However, inherent weather patterns, climate change, as well as consumption patterns have made groundwater a resource that is quickly being depleted. Conversations around water stress and lowered groundwater levels, often go hand in hand with contamination. After all, the solution to pollution is dilution. Polluted groundwater can be intensified when an aquifer is being depleted, especially at a rate higher than it is being recharged. This is of great concern for sole source aquifers, where a community relies, at least 50% on groundwater, for its drinking water needs (EPA, 2022). This is the case with Walla Walla. Understanding how water moves along the landscape, how it enters the aquifer and what contaminants it carries, is important in starting to solve pollution issues. This project presents a tool that can help identify areas where groundwater resources may be vulnerable and sensitive to contamination, using biophysical geographical data and a simple model. This groundwater contamination sensitivity model (GCSM) uses soil data, land cover data and a flooding model, to predict where contaminants might enter the aquifer at a higher rate or in greater amount. This is especially important, for communities like Walla Walla, which like most of western WA and OR, has intensive agricultural operations, that stretch along its border.

Study Area

The city of Walla Walla, WA, is located within Walla Walla county and the Walla Walla basin. The Walla Walla basin is a transboundary basin, that covers parts of both Oregon and Washington.

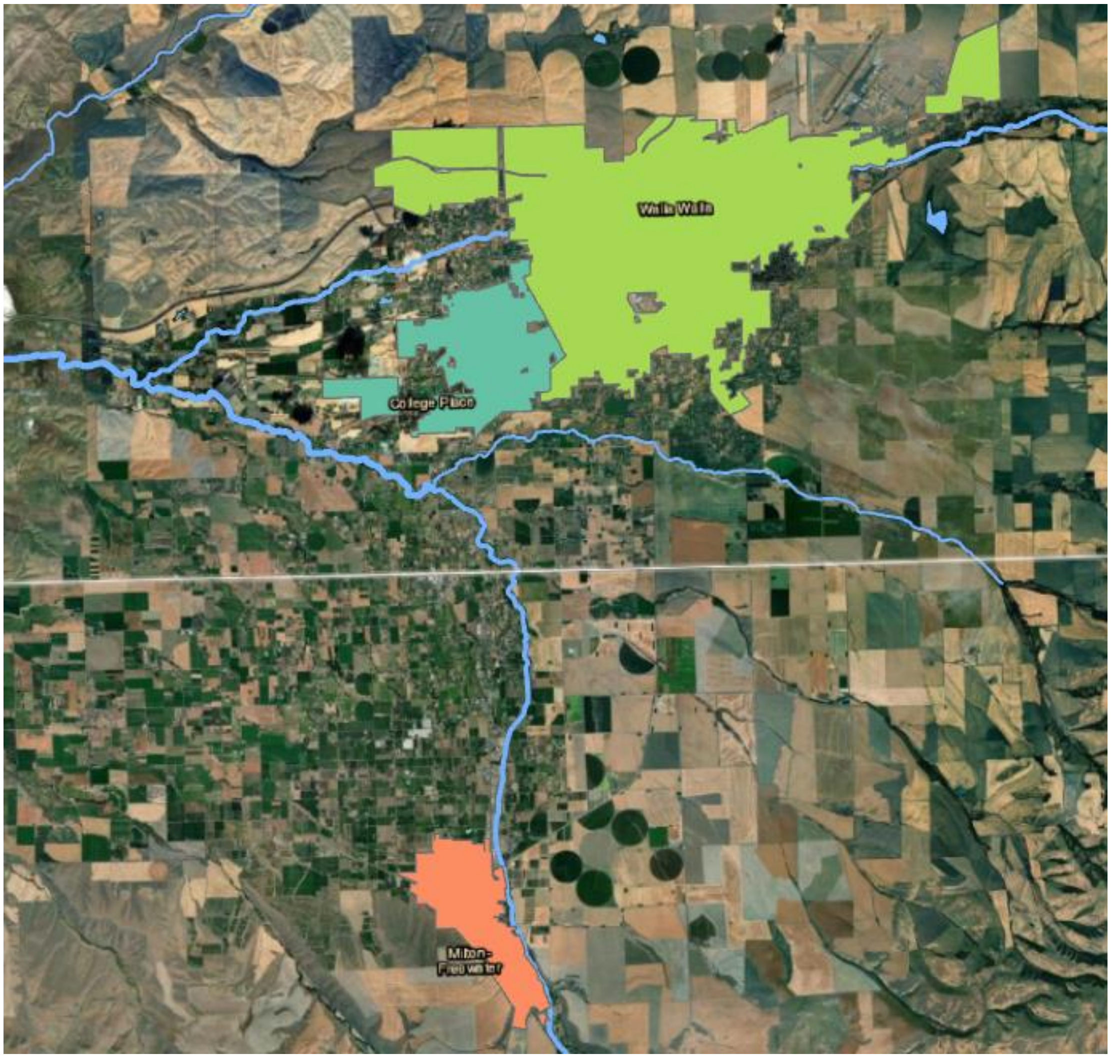
Figure 1. Walla Walla River Basin



<u>Walla Walla and College Place</u>

Walla Walla is the largest city in the county and in the basin, with a population of 33,927 in 2021. Attached to Walla Walla is a suburb, called College Place. Between these two communities, there is about 45,000 people living in this area. The city was first founded in the mid-1800s as settlers started to occupy the Western US (Paulus, 2008). As the gold rush settled in, the city grew substantially in size.

Figure 2. Walla Walla, College Place and Milton-Freewater near the Oregon-Washington border

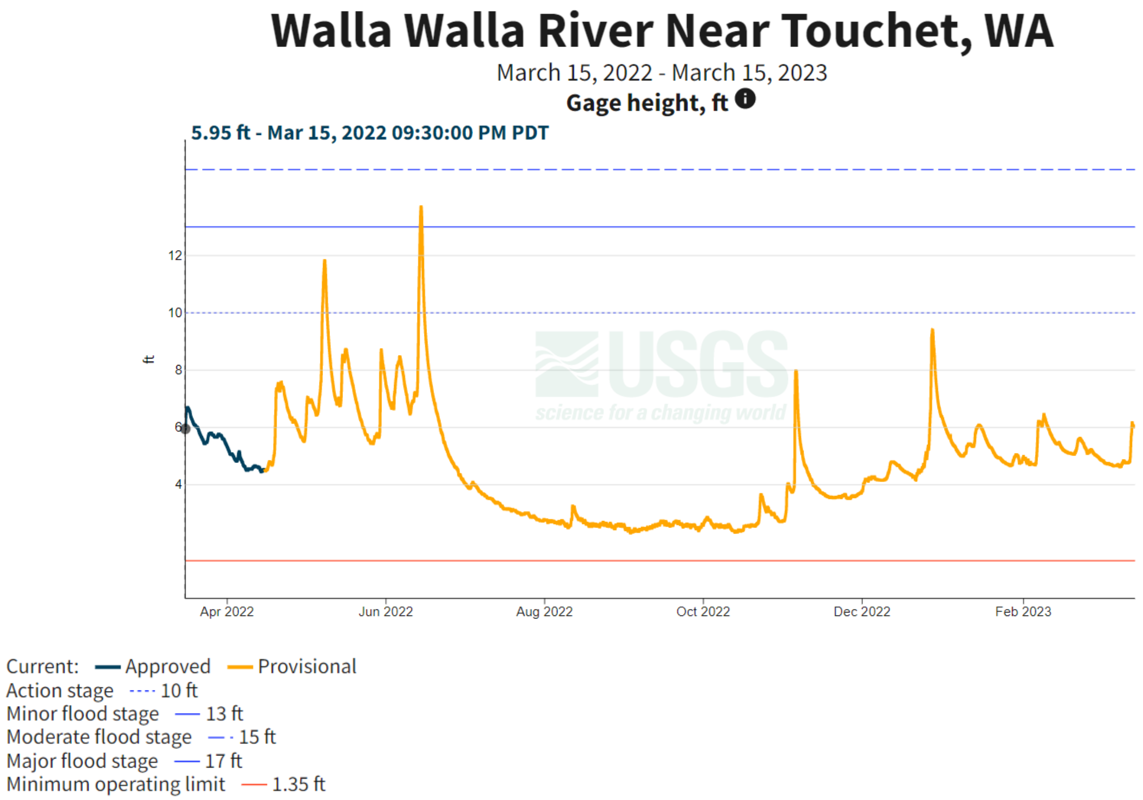


After the gold rush, Walla Walla became an agricultural center, often referred to as the “cradle of Pacific Northwest history” and a “garden city”. Some of the crops that were common during this period are still being harvested today. Onions, wine, apples and peas were all grown during this time. Today, agriculture is still a large part of Walla Walla’s economy and culture. The most common crops grown here are onions, wine grapes, potatoes and wheat. Most of these crops require a lot of water to grow. Domestic and commercial wells are common, especially since a lot of farmers have high water rights. Municipal water supplies, rely on water from Mill Creek Watershed and Dry Creek Watershed during the winter and spring months, and from groundwater during the summer and fall months, which they abstract from 7 deep basalt wells (City of Walla Walla, 2022).

The Walla Walla Basin and CRBG

The Walla Walla River is a tributary of the Columbia River. As many surface water systems in this region, the Walla Walla River, interacts a lot with groundwater. It has a low flow during the late summer months and a high flow during the late spring months. Summer flow is considered mostly baseflow, meaning all the flow comes from a groundwater source. Spring flows, mostly come from snow melt and precipitation in the Blue Mountains and provide most of the water that the river will receive. Flooding, although not extremely common, does occur, as showcased in the figure below.

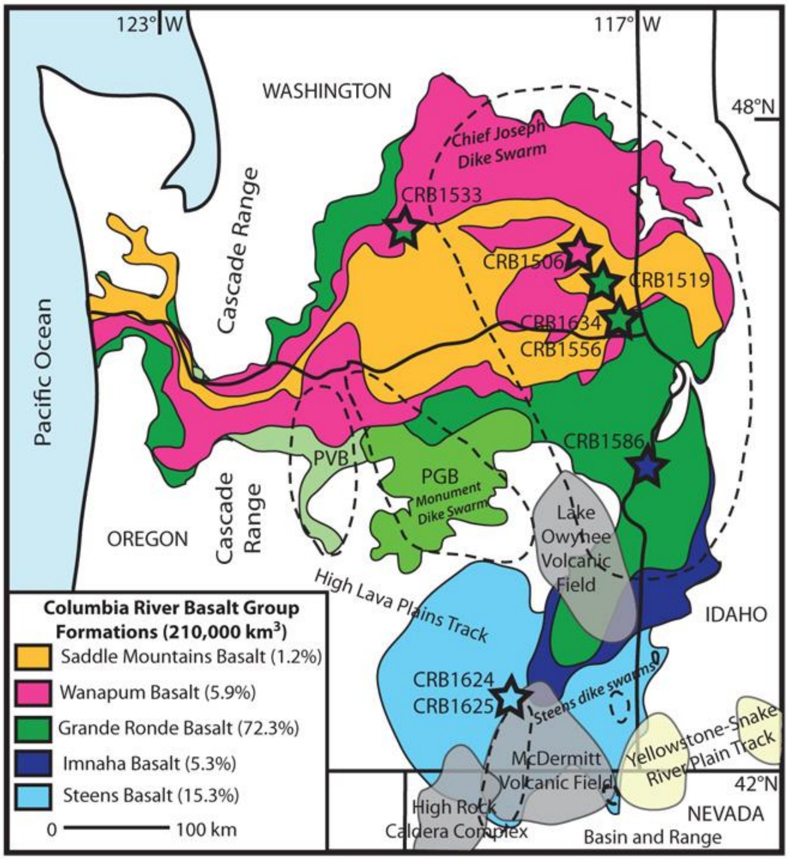
Figure 3. Walla Walla River annual hydrograph (USGS, March 2022-March 2023)



Spikes indicate peak flow, where flooding is at a higher risk. The solid blue line indicates a minor flood stage height. Last year, this threshold was passed on June 14th, 2022.

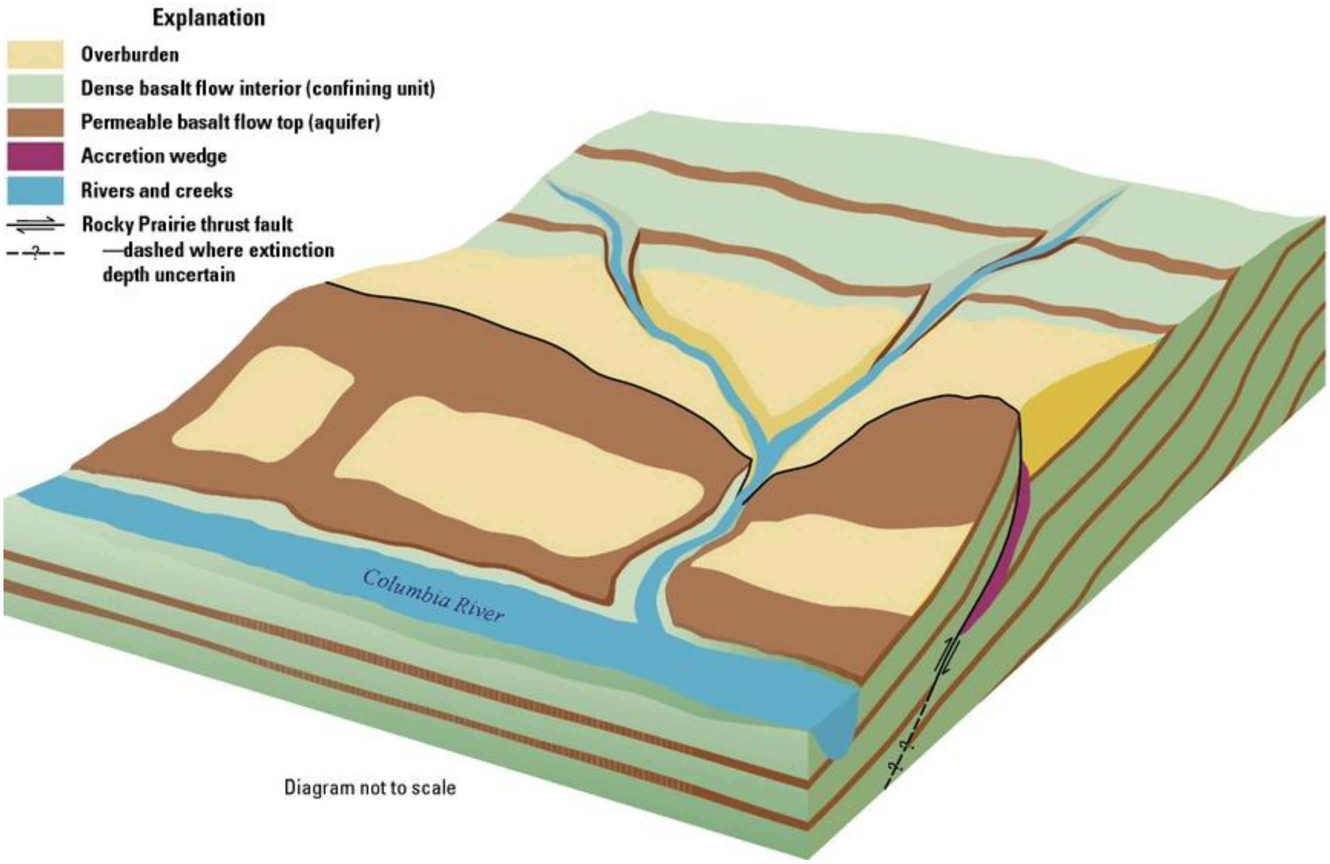
Similarly, the basin, the county, and the city, all lie above a basalt formation, commonly referred to as the Columbia River Basalt Group or CRBG.

Figure 4. Columbia River Basalt Group geographic location (Kasbohm and Schoene, 2018)



The CRBG, was formed from a series of continental lava flows and subsequent floods that resulted in thick basalt layers. The eruptions that caused these lava flows, occurred 350 times, over 11.2 million years (Camp et al., 2017). The youngest of these lava flows is 5.5 million years, however, 97% of these lava flows, occurred over the span of 1.1 million years, about 16.7 million years ago. This has resulted in very marked layers of permeable basalt, overlaid by impermeable, more dense basalt. Essentially, layers and layers of confined aquifers, some with water that is millions of years old and will most likely not be recharged anytime soon.

Figure 5. CRBG and layered basalt aquifers and aquitards (Burns, 2014)

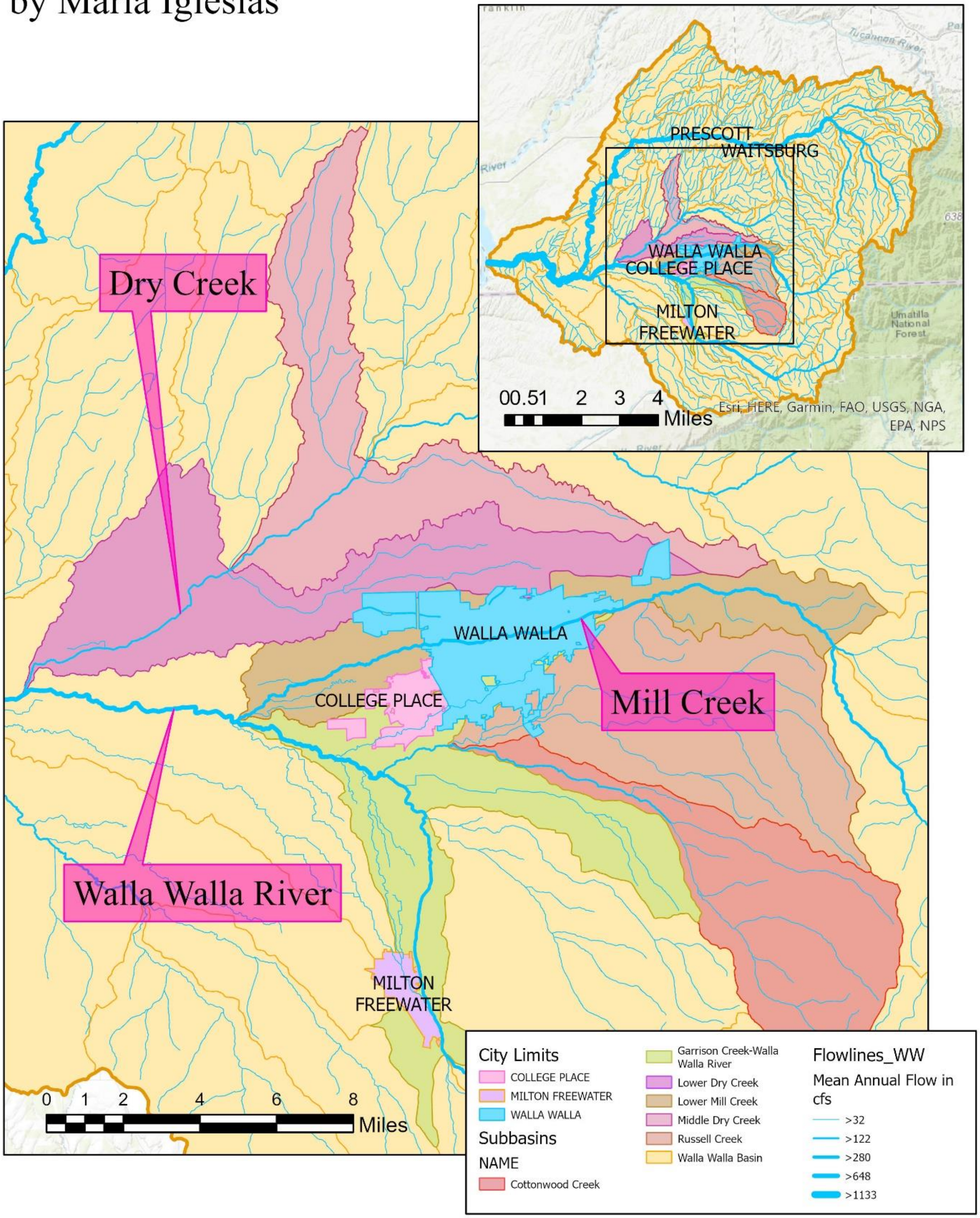


HUC12 Study Area

The study area was then chosen to include the city of Walla Walla and the city of College Place, as well as include the HUC12 subbasins of the reaches of the Dry Creek and Mill Creek that pass by the city. Since the aquifers are not delineated in this area, given they are really spread out and most likely a system of aquifers, as described above, choosing the area this way made more sense. It included the drinking and agricultural sources of water for the city and the surrounding areas. 6 different HUC12 subbasins were selected to form the study area. This area included also parts of the Walla Walla River and the city of Milton-Freewater, OR. Below is a professional layout of the study area, showing the extent it covers of the greater Walla Walla basin, as well as the three main flowlines that flow through it.

Map of Subbasins near Walla Walla, WA and Milton-Freewater, OR

by Maria Iglesias



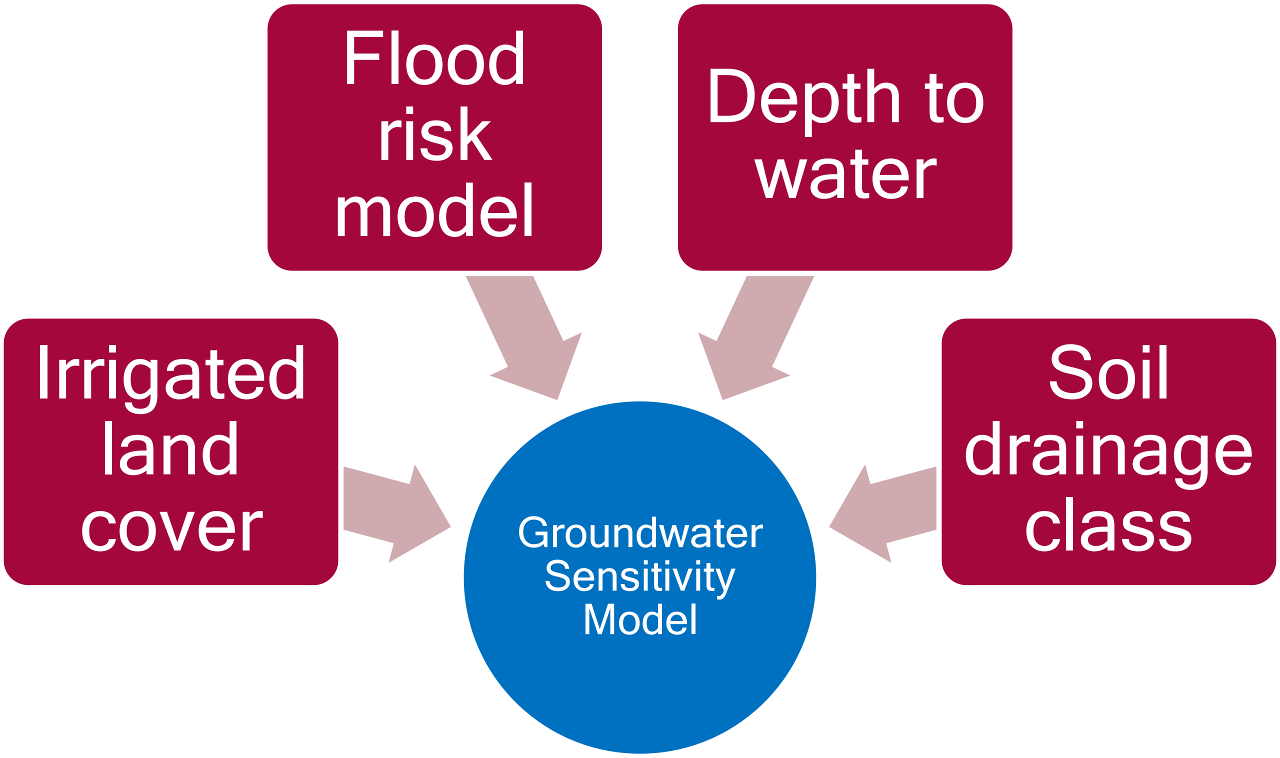
Methodology

After delineating a relevant study area, that captured the interaction between groundwater and surface water, as well as varying water uses and contamination sources, a conceptual model was developed, from which a geospatial model would be created from.

The Groundwater Sensitivity Model (GWSM)

The Groundwater Sensitivity Model, took into account two main things: the likelihood of a contaminant existing across the landscape and the likelihood of that contaminant entering the aquifer. In other words, it identifies areas that are more likely to receive surface runoff (transport vehicle). This includes areas that flood and areas that are irrigated. It also identifies areas that are more likely to transport contaminants into the aquifer system (transport route). This includes areas with a shallow water table and areas with high drainage class soils. Below is a conceptual model, showcasing the parameters that went into the GWSM.

Figure 6. Conceptual model of the GWSM



This model also relies on another model that was constructed, the Flood Risk Model. Later, the methodology behind this model is discussed.

The GWSM required data from different sources on soils, land use and the constructed FRM. The model was completed using raster calculator, after all data was collected, projected, rasterized and classified. Each parameter occupied the same weight, given that there are two classes of parameters and each have two parameters (contaminant vehicles and contaminant transport route). Below is a table including all the data used for this model (FRM is simplified)

Table 1. GWSM data details

Data	Source	Resolution	Projection
Land cover	NLCD	30m x 30m	Universal Transverse Mercator, North American Datum 1983
Soil drainage class	SSURGO	1:12,000 to 1:63,360	Decimal Degrees, World Geodetic System 1984
Water depth	Walla Walla Watershed Council	Point source data	NAD 1983 UTM Zone 11N
Flood Risk Model	Created	30m x 30m	NAD 1983 UTM Zone 11N

Data Management

Data used for this model was easy to access, however, two particular datasets had to be constructed: the depth to water table data and the flood risk model data. Below is a detail description of how they were constructed.

Depth to water table

Although SSURGO provides extremely useful soils data, and proved to be a valuable resource for both the soils drainage class and hydrologic group, some of the data included is not spatially complete. This was the case with the depth to water table data. Below is a map of just how incomplete this information was, for the whole study site.

Figure 7. Depth to water table SSURGO data

This dataset was unusable for the model and would've thrown the results off by a lot. Instead, using geospatial statistics tools and point data from the Walla Walla Watershed Council, a dataset with a higher coverage was constructed. There were a total of 21 monitoring wells that had been recorded by the WWWC, within this site, that were made publicly available for download. They included data on water table elevation. Using a DEM and this water table elevation, the depth to water table was calculated. This is a better measurement, since it is relative to the elevation across the landscape and standardized each measurement to fit out "shallow-deep" criteria. Although not a lot of points, this was the best alternative for the situation at hand. The points were used to run the IDW (inverse distance weighted) tool, which is an interpolation tool that uses a linearly weighted combination of a set of sample points where the weight assigned is a function of inverse distance. This gives you a raster in which the cell value was determined using this technique.

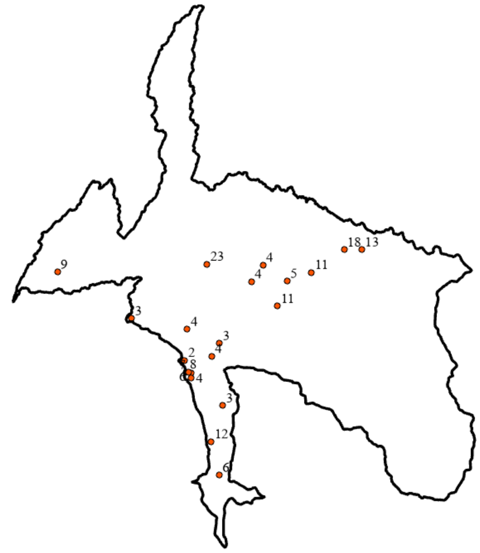
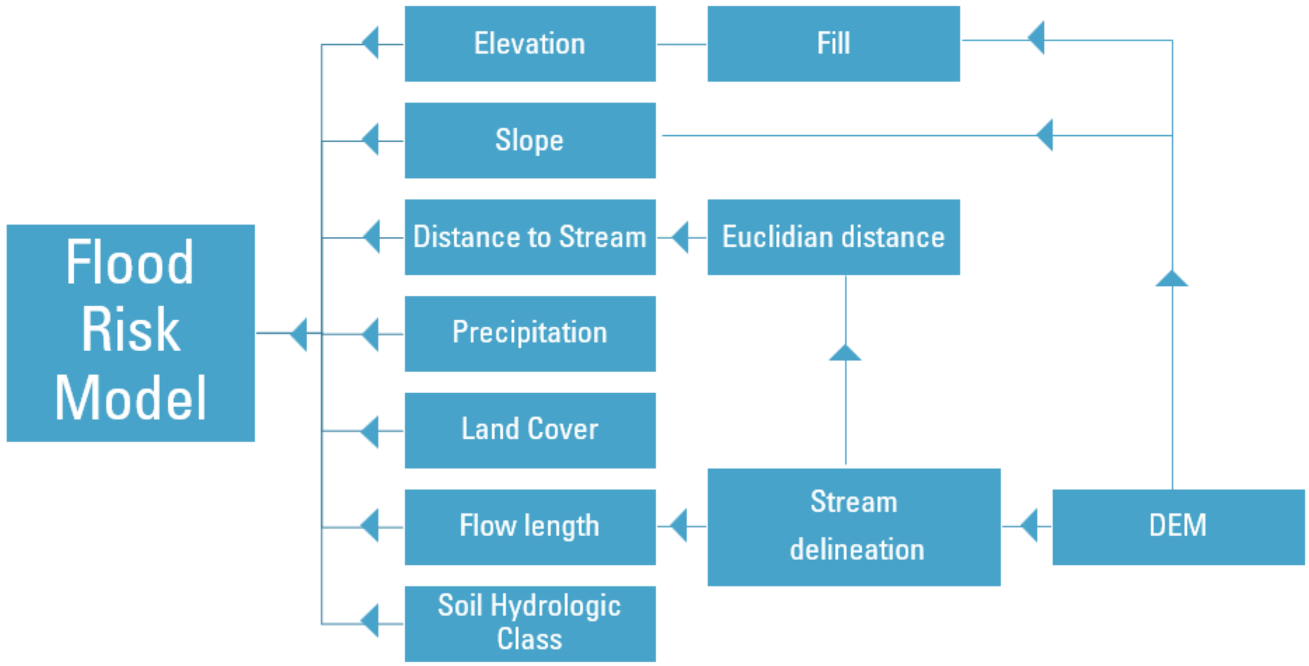


Figure 8. Monitoring points and associated depth to water table values

Flood Risk Model

Constructing a flood model was necessary for this site, since I wanted to include flooding parameters outside of riverine flooding scenarios. I constructed a bathtub model, where the model reviewed 7 different criteria and weighed them accordingly. The following flow chart shows the conceptual model behind the FRM.

Figure 9. FRD conceptual model



This model takes into account water entering the "bathtub" or the surface of the study area, and the ability of the "bathtub" to get rid of water. Anything that overflows the bathtub, is considered flooding. Unfortunately, due to the resolution of some of the data, this is not the most accurate model, however it can helps us find general areas where flood is of concern. Below is a description of the raw data used in this model.

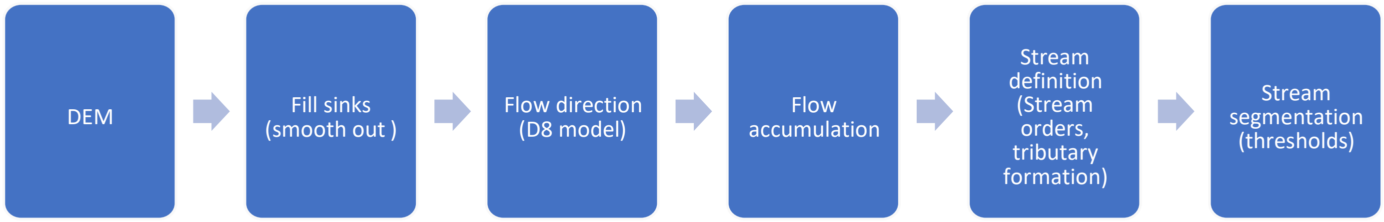
Table 2. FRM data details

Data	Source	Resolution	Projection
Land Cover	NLCD	30m x 30m	Universal Transverse Mercator, North American Datum 1983
Soil hydrologic group	SSURGO	1:12,000 to 1:63,360	Decimal Degrees, World Geodetic System 1984
DEM	NED	10m x 10m	The North American Datum of 1983 (NAD83)
Average Annual Precipitation	PRISM	800m x 800m	NAD 1983 UTM Zone 11N

Once the data was collected, vector data was converted into raster data, following the lowest resolution data in the dataset: land cover. All vectors were converted into 30m resolution rasters and all data was projected onto NAD 1983 UTM 11N, to reduce distortion.

Using the DEM available, streams were delineated using spatial analyst tools as described below.

Figure 10. Stream delineation flowchart



Once streams were delineated, flow length was calculated as well as the distance to the stream, using the Euclidian distance tool and the flow length tool. Flow length is an important measurement, because it tells us about how long a particular segment of stream is, and therefore, how much water it most likely holds. This is a similar type of calculation to defining a stream order. The Euclidian distance tool, allows us to know how close we are to a stream, or the nearest drainage point. As water moves across the landscape, this is important. Once all data was constructed, they were all reclassified into 5 classes, using natural breaks (jenks) to break each class up. The higher the class, the higher the risk of flooding. Data layers like precipitation, had a higher number class associated with a higher value. However, data layers like elevation, had a higher number class associated with a lower value. Qualitative data, like land cover, was classified using the following conversion, where infiltration/runoff likelihood was used to determine the classification for each land cover type.

Table 3. Land cover reclassification key

Class	Land Cover	Land Cover ID
1	Deciduous forest, evergreen forest, mixed forest	41, 42, 43
2	Shrub/scrub, grasslands/herbaceous	71, 52
3	Developed open space, barren land, pasture/hay, cultivated crops	21, 31, 81, 82
4	Developed low intensity, developed medium intensity	22, 23
5	Water, developed high intensity, woody wetlands, emergent herbaceous wetlands	11, 24, 90, 95

Once reclassified, all the parameters were modeled using the weighted sum tool, which allows you to add raster values together, with weights attached to each parameter. Below is a breakdown of the parameter weights used in the model. The most heavy parameters were elevation and slope and the lightest parameters were distance to stream and flow length.

Table 4. Flood Risk Model parameter weights

Criteria	Weight
Elevation	25
Land cover	10
Soil hydrologic class	10
Distance to stream	7
Precipitation	18
Slope	25
Flow length	5
Total	100

Finalizing GWSM

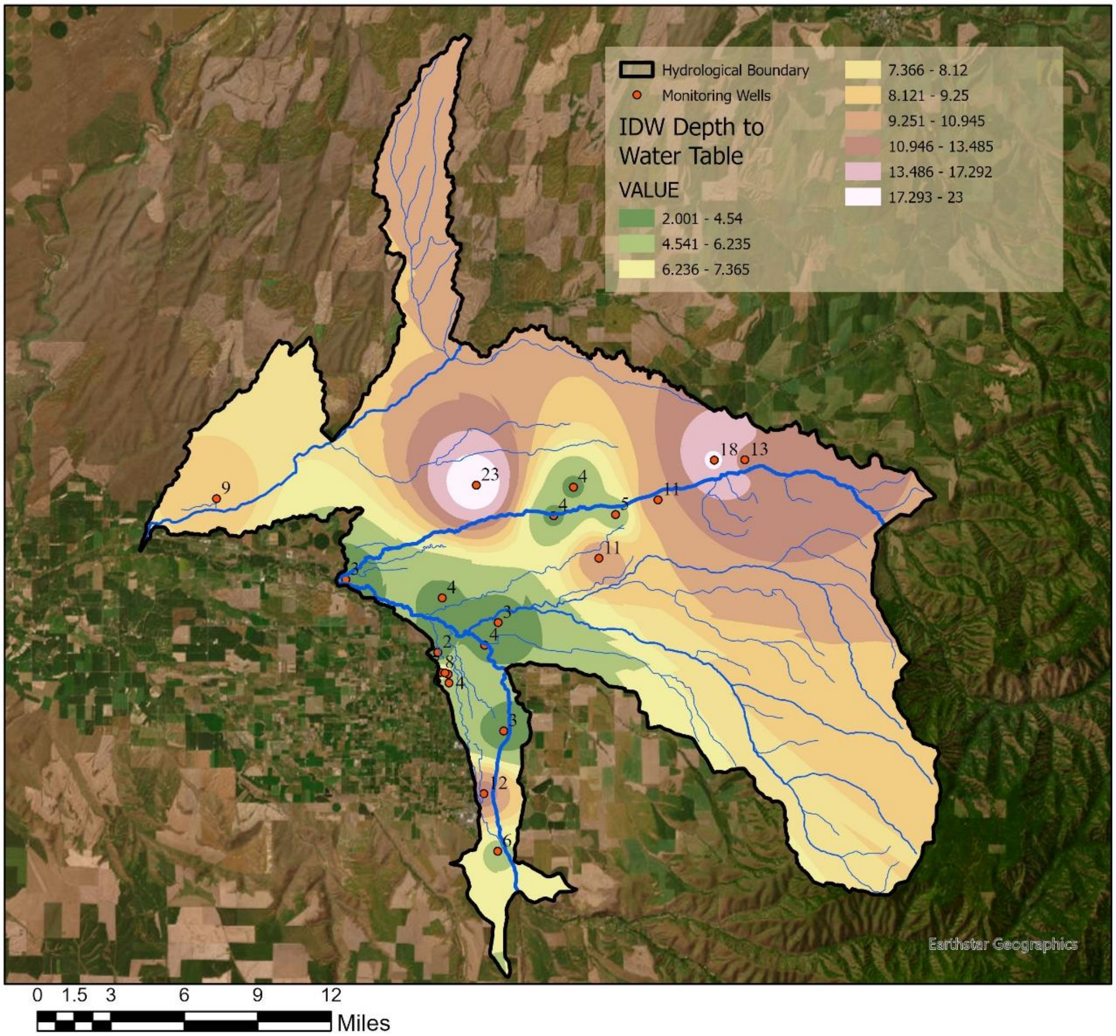
Once all the data for the Groundwater Sensitivity Model was collected, similarly to the FRM, all parameters were reclassified into 5 classes, using natural breaks (jenks). The model was completed using raster calculator, since all 4 parameters occupied the same weight.

Results + Discussion

Depth to water table

After using the IDW tool to interpolate depth to water across the study area, the results were the following.

Figure 11. IDW tool results

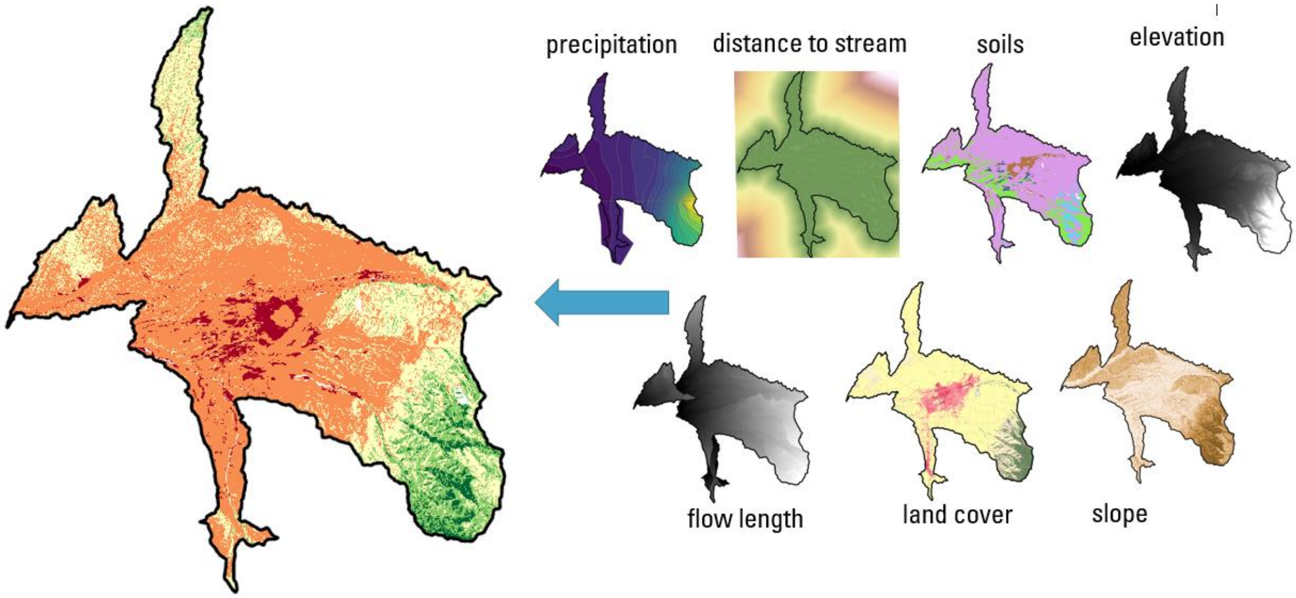


Depending on how close the data points were to each other, the result was of higher or lesser quality. Unfortunately, a lot of jagged edges seem to appear throughout, especially in areas with little to no data points. However, a lot of the data points coincide with areas where agriculture and development are mostly occurring, and where contaminants would most likely be, so this is not of huge concern.

Flood Risk Model

The flood risk model was constructed using the data that was previously discussed. Below is a schematic of the data that went in, after collection and creation (in the case of slope, filled DEM, stream length and stream distance). All these layers were reclassified, and the result is shown on the left side and on the figure below it.

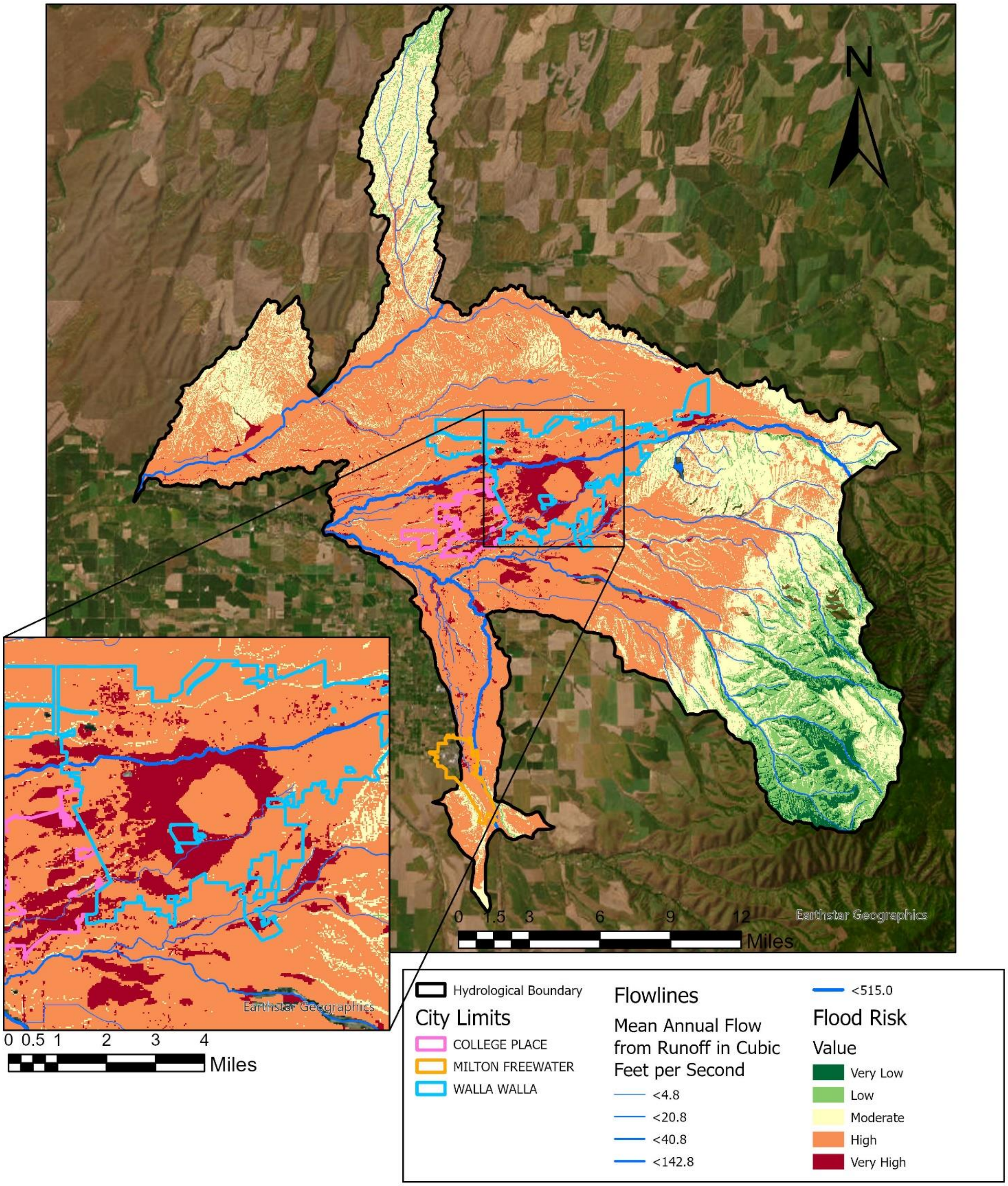
Figure 12. Flood Risk Model schematic



The results suggest that the center of the study area has the highest risk of flooding. While the SE portion of the study area has the lowest risk of flooding. This makes sense considering slope and elevation were the heaviest parameters in the model. It might me prudent to exclude high elevation areas from the model in the future since they may appear to be skewing the results. This is even more evident when we see that most of the valley has a high or very high risk of flooding.

Flood Risk Map near Walla Walla, WA

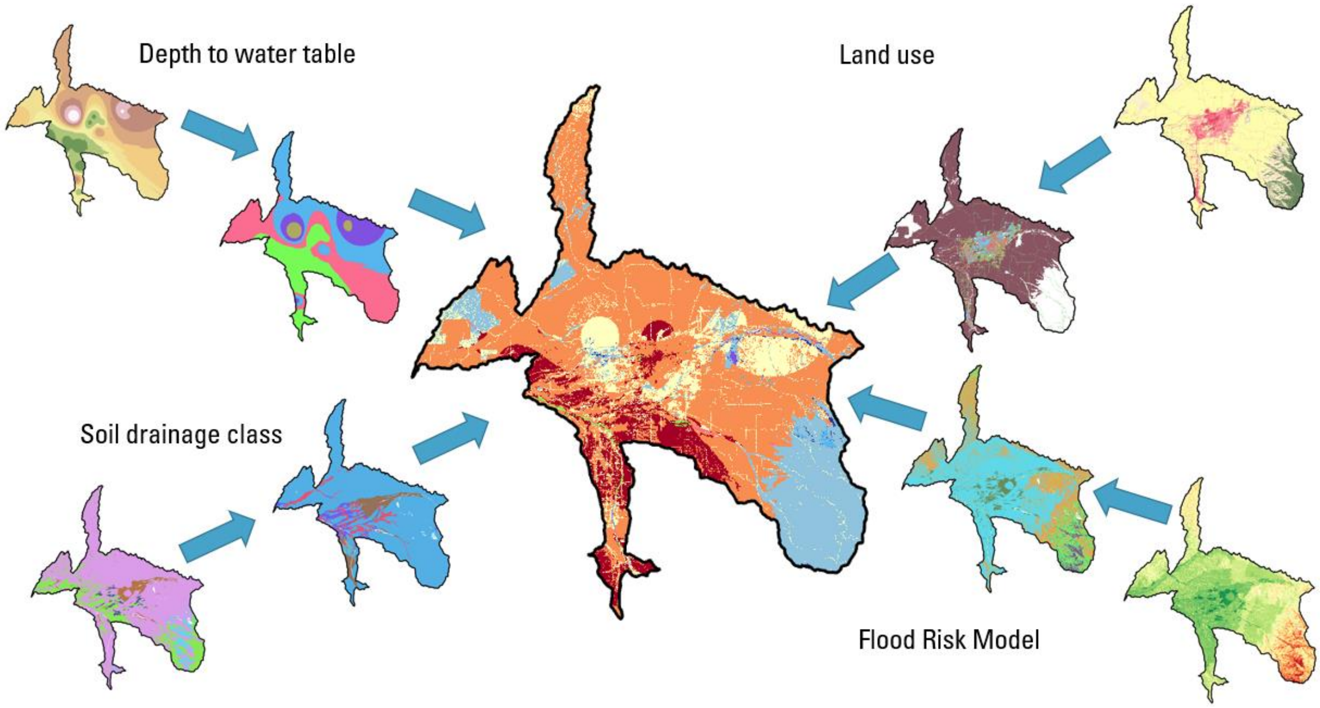
by Maria Iglesias



Groundwater Sensitivity Model

Finally, the GWSM was constructed with the four data that were previously discussed. As shown below, all data were reclassified into 5 classes and added together to form the Groundwater Sensitivity Model.

Figure 13. GWSM schematic



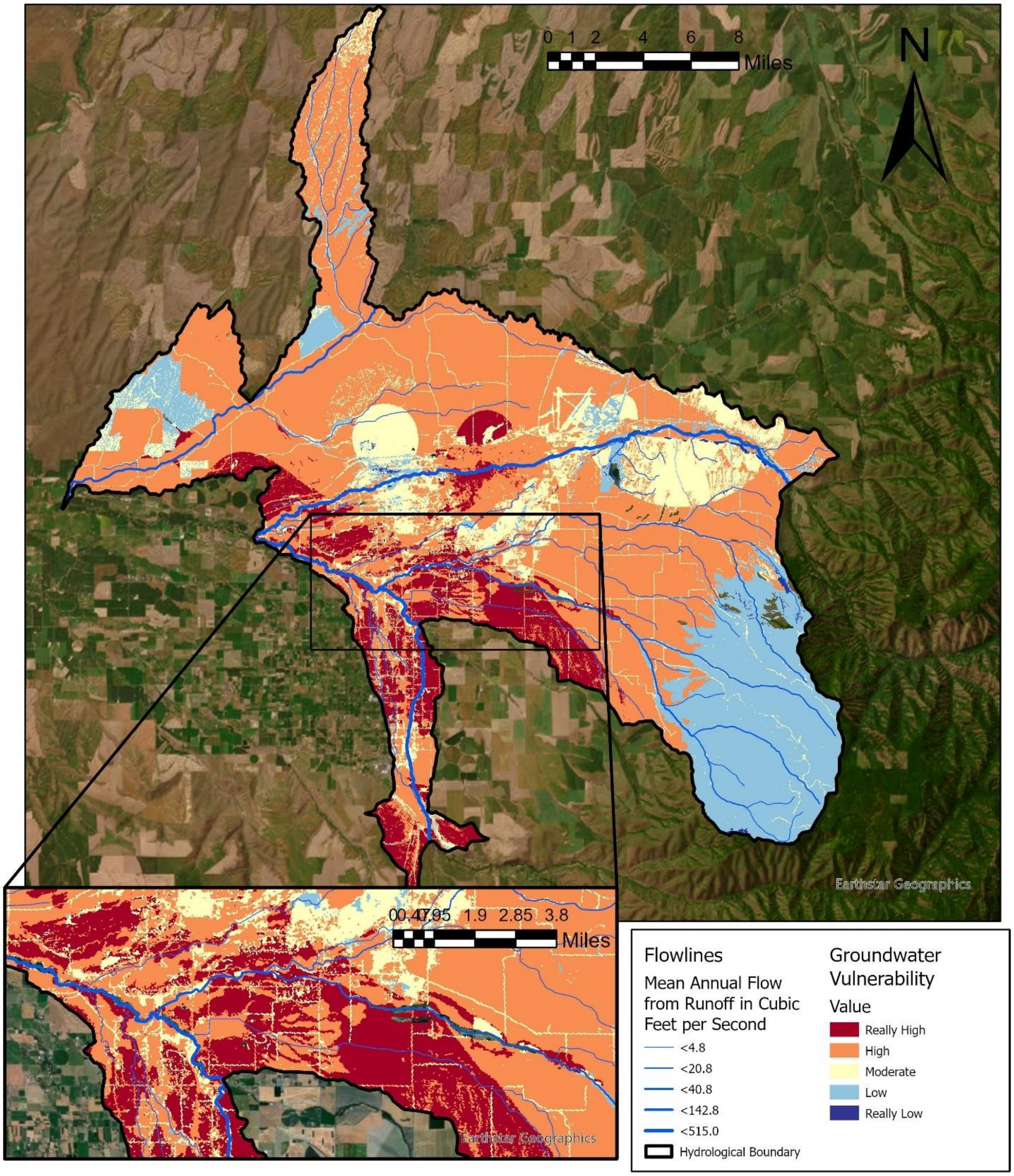
From the figure above and below, we can see that the results suggest areas that are the most sensitive to groundwater contamination, seem to be concentrated in the central and northern portions of the study area. This makes sense, since both the soil drainage class data and the depth to water data, have the highest richness here, and show that these areas have the shallowest water table. Again, the blue mountains, and other really high elevation areas showed vastly different results. It may be a good idea to change the size of the study area, to exclude these “extremes.”

Overall, this model’s results coincide with the hypothesis I had when I first started this project. I would love to have better depth to water table data in the future, and possibly tweak my models to better fit this particular landscape.

A scary conclusion from the results are that areas near urban centers seem to be the most at risk for contamination. This is especially worrisome, since the city of Walla Walla as well as College Place, rely heavily on groundwater during the summer months.

Groundwater Contamination Vulnerability near Walla Walla, WA

by Maria Iglesias



Course webpage

http://web.engr.oregonstate.edu/~iglesiam

Citations

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