Combined Sewer Overflows in Seattle, Washington

Lisa Thompson
GIS in Water Resources
Fall 2017

Contents

Figures

Introduction

What are Combined Sewer Overflows?

Combined sewer systems were designed in the early 1900s to carry sewage from buildings as well as stormwater runoff from streets and rooftops in a single pipe. Under normal conditions, it transports the wastewater and stormwater it collects to a sewage treatment plant for treatment, then discharges the treated effluent to a water body. When it rains, the pipes can become overloaded. Combined sewer overflows (CSOs) are relief points in older sewer systems that carry sewage and stormwater in the same pipe. When heavy rains fill the pipes, CSOs release sewage and stormwater into water bodies. While these relief points provide a "safety valve" that prevents back-ups of untreated wastewater into homes and businesses, flooding in city streets, or bursting underground pipes, the discharge of this untreated wastewater threatens both human and aquatic health.

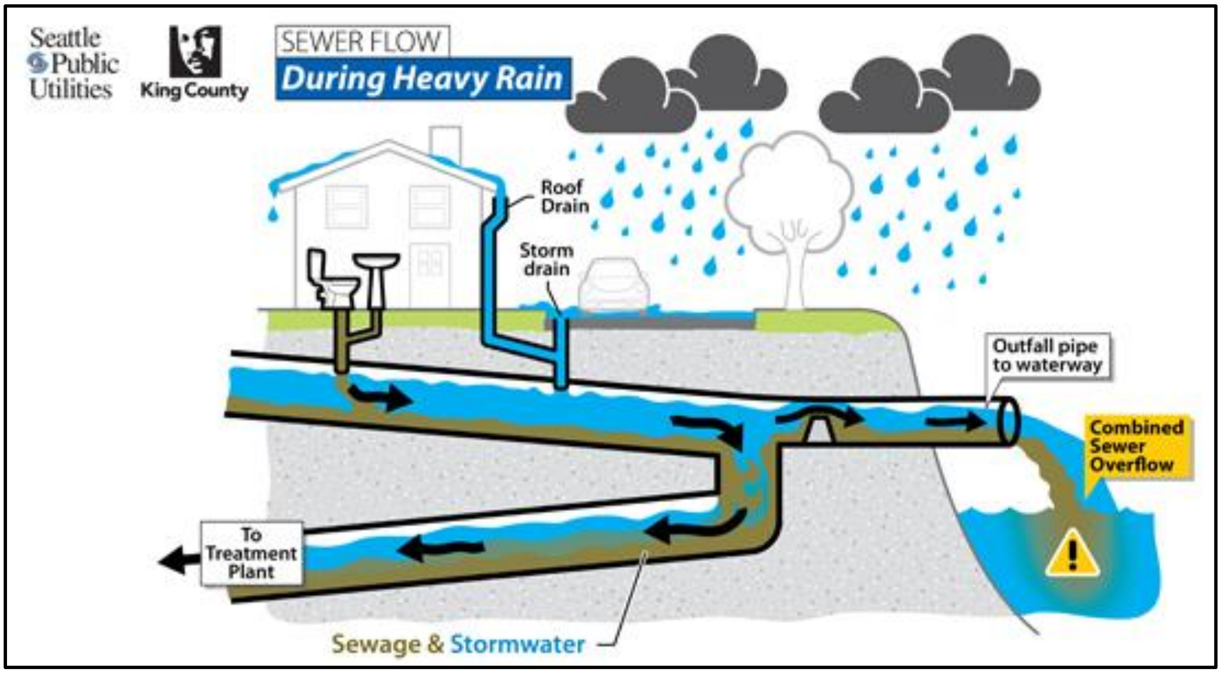

Figure 1. A combined sewer system

Regulatory Requirements

Almost 860 municipalities across the United States have combined sewer systems [4]. These systems are regulated through the Environmental Protection Agency (EPA) by the National Pollutant Discharge Elimination System (NPDES) permit program. The Clean Water Act requires that CSOs occur no more than once per outfall per year over a 20-year rolling average. In 2009, the EPA issued a compliance order to direct the City of Seattle and King County to step up efforts to reduce CSOs. Seattle is required to reduce overflows to an average of no more than one overflow per outfall per year by 2030.

Some actions Seattle is taking include: reducing CSOs through operation and maintenance, maximizing flow to treatment plants, notifying the public, monitoring CSO outfalls, and executing capital improvement projects [7]. The main method to reduce CSOs is to build infrastructure to store stormwater during heavy rain events and then slowly release it to the treatment plant.

Project Overview

Objective

This project used GIS to study combined sewer overflow systems in Seattle, WA. The objective of this project was to use GIS to determine a method of prioritizing CSO improvements. This was executed by (1) delineating catchment areas associated to specific CSO locations, (2) creating maps of overflow volumes at a subset of CSOs, and (3) relating precipitation in a catchment with the volume of the overflow.

Study Area

Seattle is in the Pacific Northwest in Washington State (Figure 2). It is surrounded by water: to the west is the Puget Sound, to the east is Lake Washington, and cutting through the middle is the Ship Canal and Lake Union (Figure 3).

Figure 2. Location of Seattle in Washington State

Figure 3. Water bodies in Seattle

The combined sewer system was built as Seattle grew during the early 1900s, as an economical way to handle wastewater and stormwater. One advantage of this system is that most of the time when rainfall is low to moderate, both the stormwater and wastewater go to the treatment plant before being discharged. Each year, on average, more than 300 sewage overflows send millions of gallons of raw sewage and stormwater into Seattle's creeks, lakes, the Ship Canal, the Duwamish River, and Elliott Bay. These CSOs create significant health and environmental risks. King County manages the 38 CSOs that serve areas that are greater than 1000 acres while the City of Seattle manages the CSOs that serve smaller areas.

Figure 4 is a map of Seattle with the CSOs managed by King County in red and the CSOs managed by the City of Seattle in orange. The outfall locations were extracted from NPDES permits for King County and the City of Seattle.

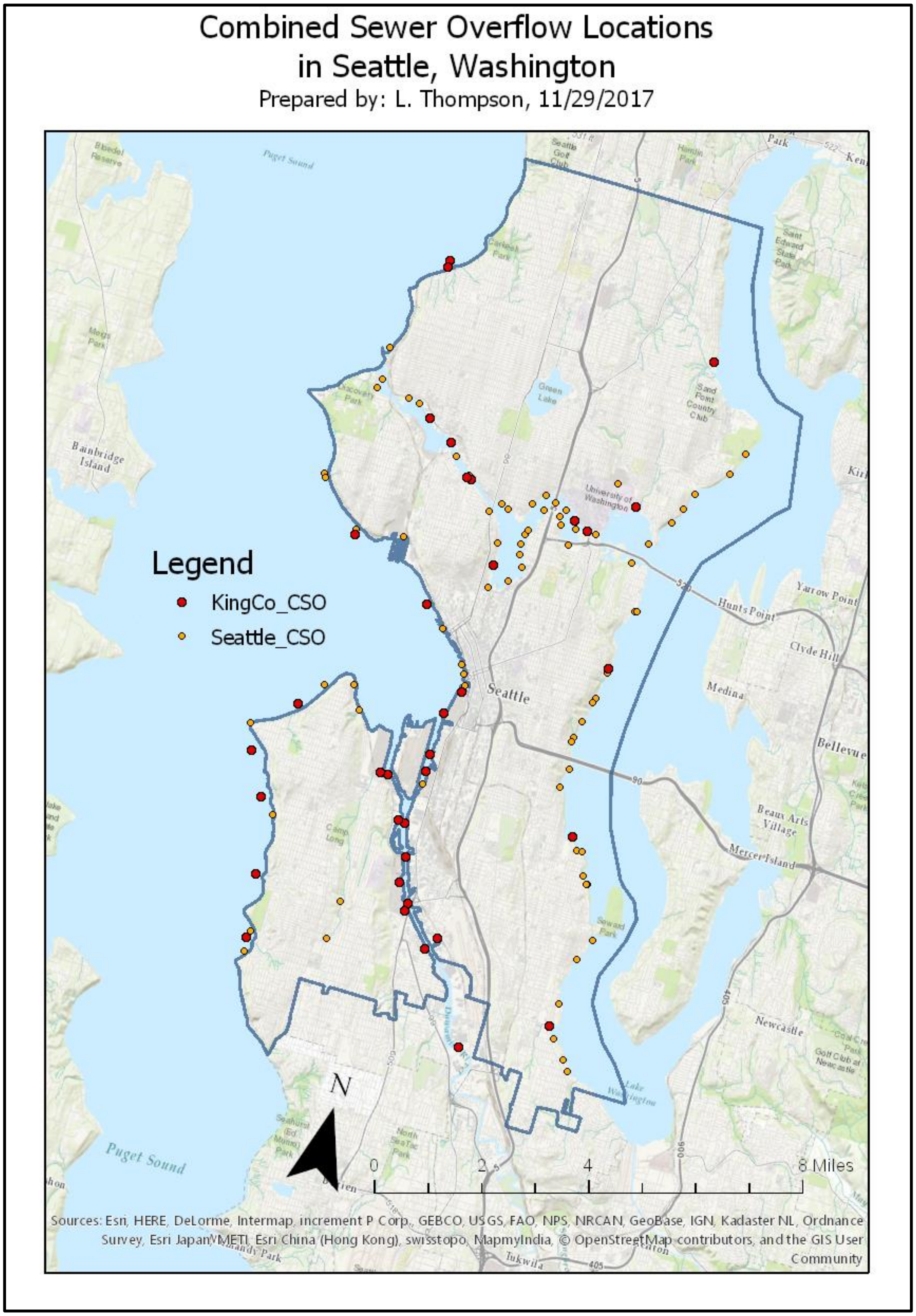

Figure 4. Map of the CSOs in Seattle

Methods

Data Acquisition

The following data was used to perform the analysis:

Data	Source
30-meter DEM, catchment boundaries	USGS NHDPlus [6]
Seattle shapefile	U.S. Census Bureau [1]
CSO locations, overflow volumes, precipitation	Washington Department of Ecology, Permit and Reporting Information System (PARIS) [8]
CSO basins	University of Washington [3]

Processing

The Washington Department of Ecology PARIS system was used to extract data for the CSOs. The latitude/longitude data was extracted into an Excel file and uploaded into GIS as X-Y data. This is where the CSO locations shown in Figure 4 came from.

To perform this analysis, the Seattle boundary was used to snip the 30-meter NHDPlus DEM raster. After the DEM was clipped, the GIS Aspect, Flow Accumulation, and Flow Direction tools were used (Figure 5).

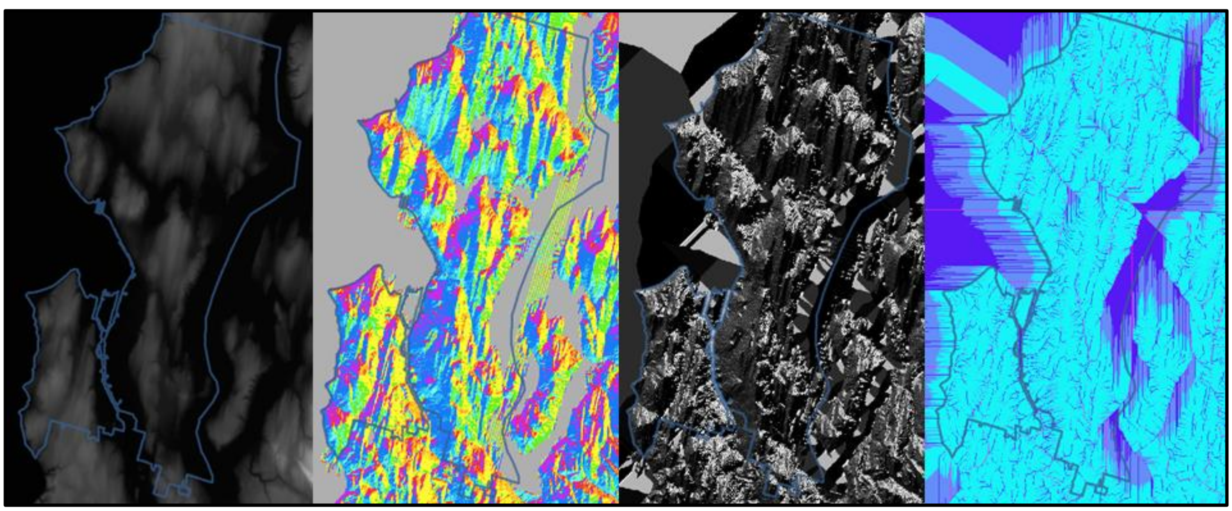

Figure 5. DEM, Aspect, Flow Direction, Flow Accumulation

Next, stream delineation threshold values were used to create catchments. This was somewhat of a trial and error process. The goal was to create catchments that aligned with the NHDPlus catchments as well as being small enough to divide areas that discharge into each CSO outfall. Figure 6 shows the catchments that were created from a 100-cell threshold (green) in relation to the NHDPlus catchments (purple). Most of the catchments line up with the NHDPlus catchments. However, using the 100-cell threshold created too many catchments to readily work with. Looking at the catchments in relation to the CSOs (Figure 7), it looks nearly impossible to determine the catchment area going to the CSO outfalls.

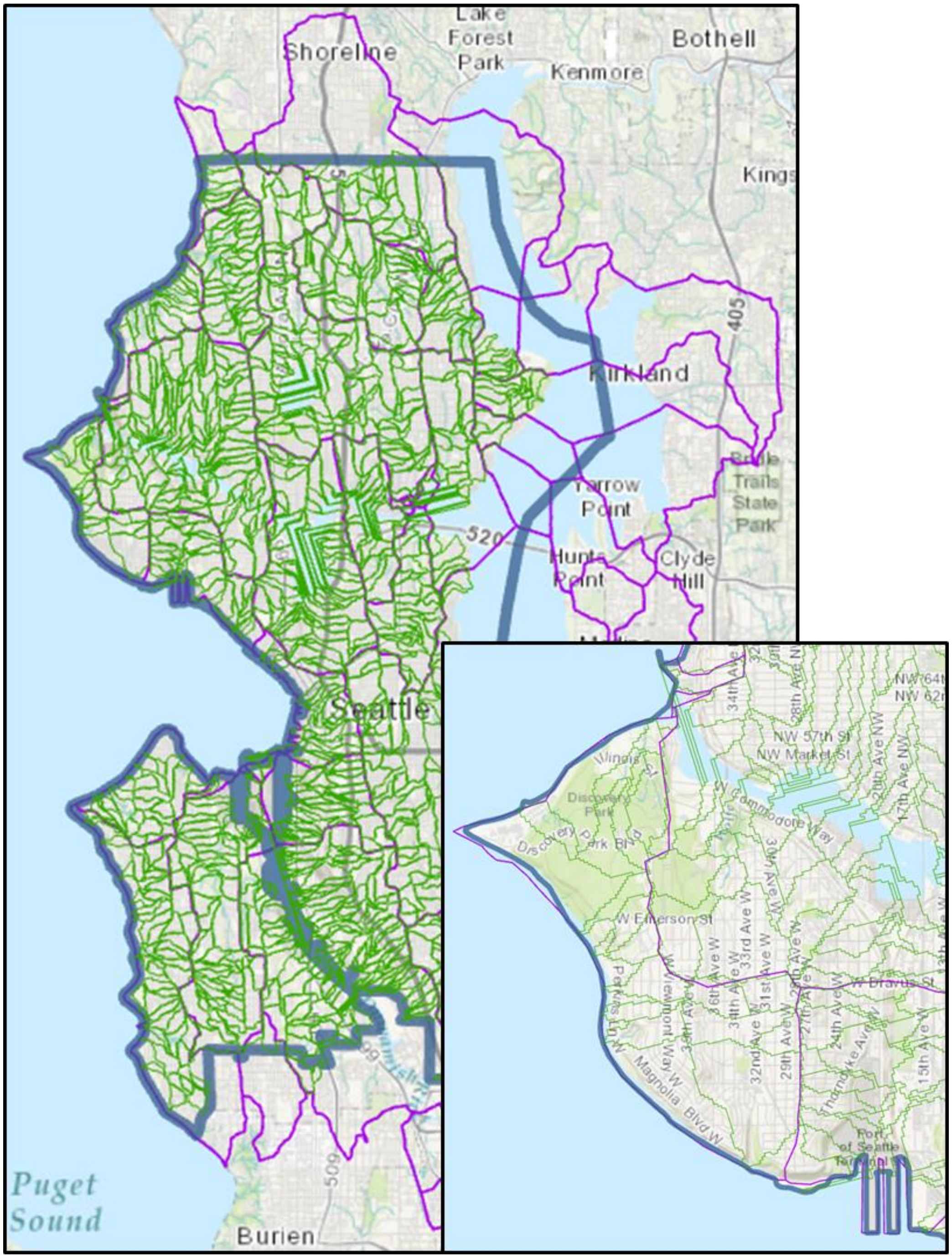

Figure 6. 100-cell threshold catchments vs. NHDPlus catchments

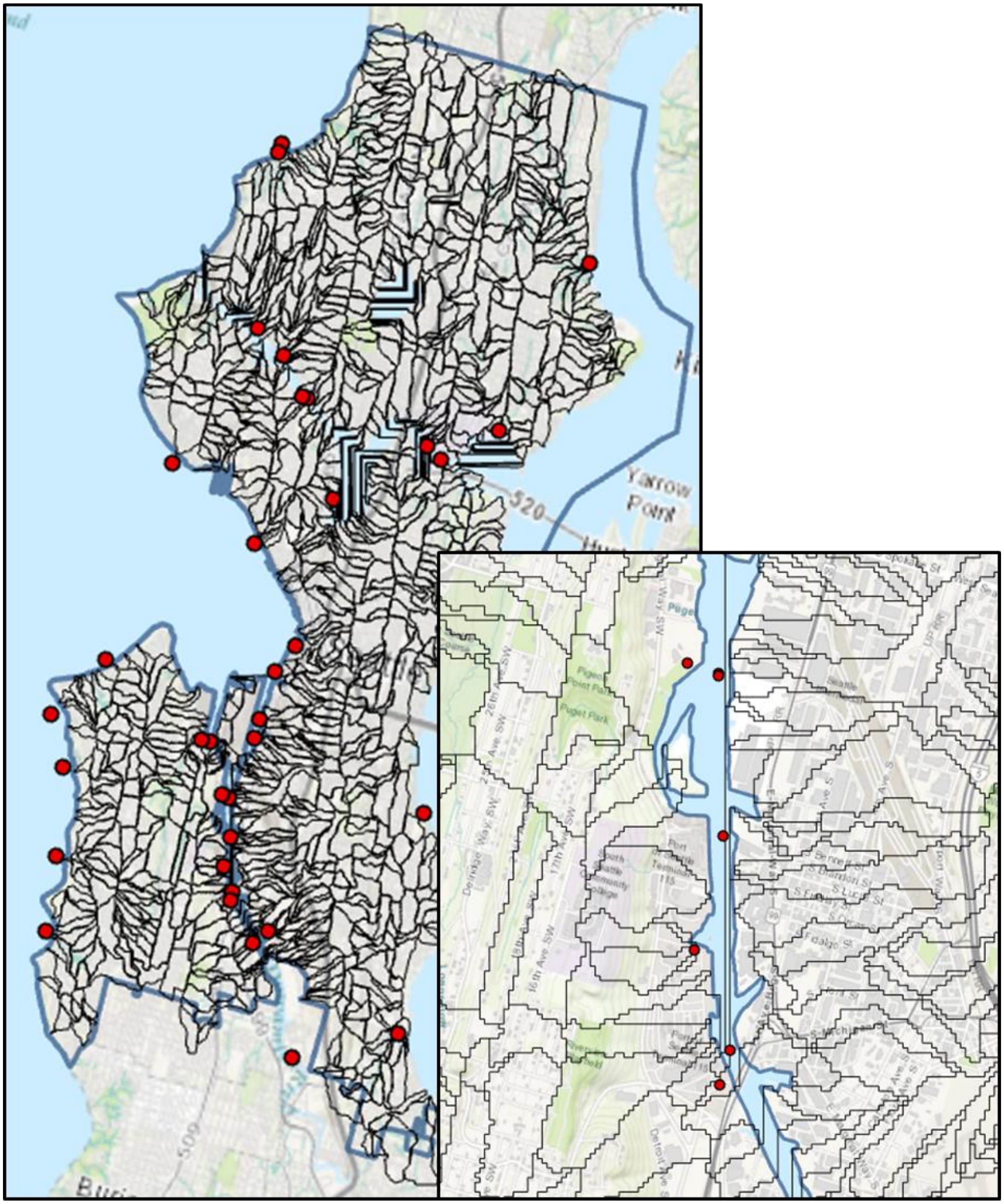

Figure 7. 100-cell threshold catchments and CSOs

Other stream delineation threshold values were used before settling on a 500-cell stream delineation threshold. The 500-cell threshold seemed like it created catchments of reasonable size to speculate where the catchment would discharge. As seen in Figures 8 and 9, the catchments generally seem to align well with the locations of CSOs.

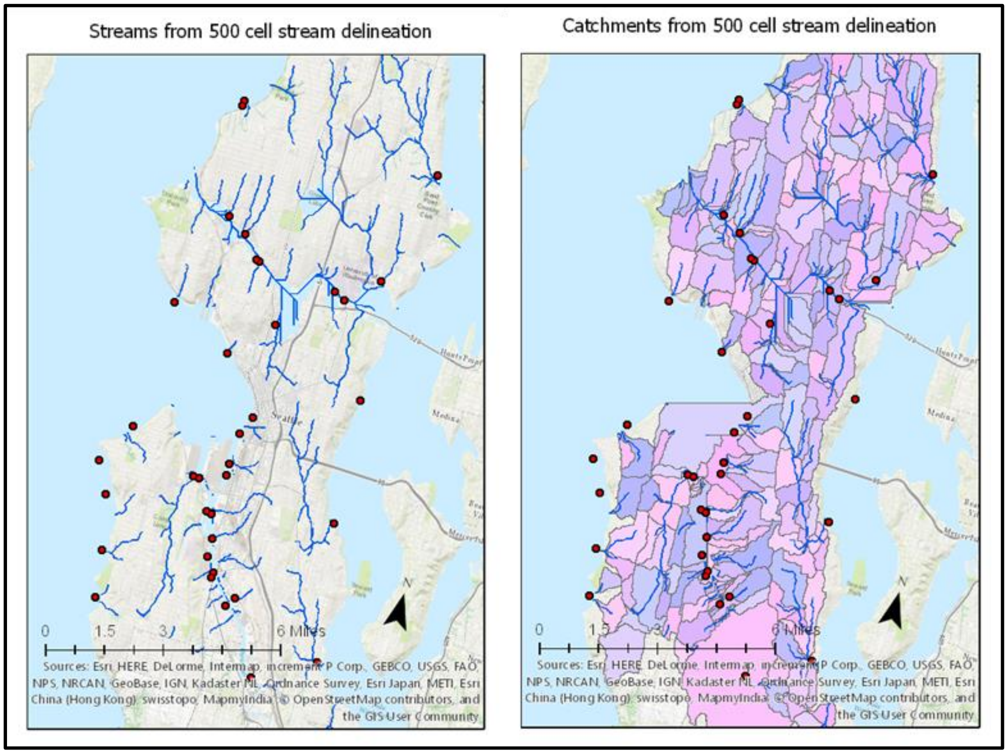

Figure 8. 500-cell threshold

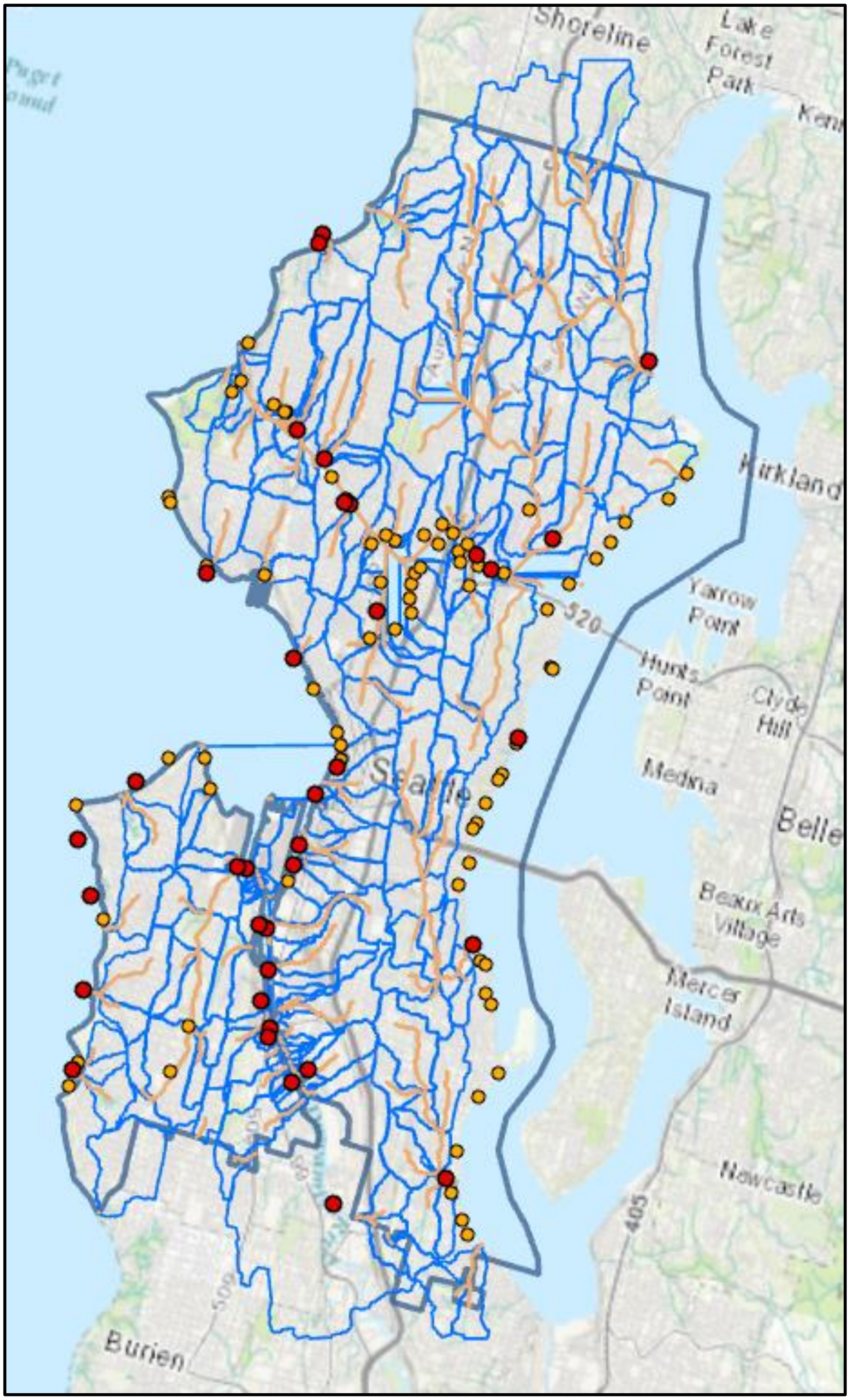

Figure 9. 500-cell stream delineation threshold

Results and Discussion

In addition to creating catchment areas and relating them to CSO outfalls, overflows as a result of the two largest rain events in 2016 were mapped. Per the *2016 Annual CSO and Consent Decree Report*, October was the month with the most rainfall at 10.1 inches. Over the month, Seattle experienced 56 untreated overflow events causing 321 million gallons of untreated discharge to enter water bodies. The largest rain event occurred on October 13, 2016. This 2.9-inch rain event caused 15 untreated overflow events and 157 million gallons of untreated discharge to enter water bodies. The relative discharge volumes of these 15 untreated events can be seen in Figure 10.

Table 1. October 13, 2016 overflows

Outfall Name	**Volume (gallons)**	**Precipitation (inches)**
11th Ave NW (AKA East Ballard)	914,147	2.47
Magnolia Overflow	179,913	2.71
3rd Ave W and Ewing St	752,349	2.48
Montlake Overflow	6,814,668	2.92
University Regulator	7,818,091	2.92
King Street Regulator	47,006	2.10
Kingdome	846,412	2.22
Lander St Regulator	41,338,754	3.82
Hanford No 1 Overflow	7,894,103	2.96
Hanford No 2 Regulator	63,450,560	3.82
Chelan Ave Regulator	3,503,359	2.97
Michigan S Regulator	6,504,633	3.18
Brandon Street Regulator	4,081,289	2.97
Michigan W Regulator	217,254	2.96
63rd Avenue SW Pump Station	12,521,126	2.96

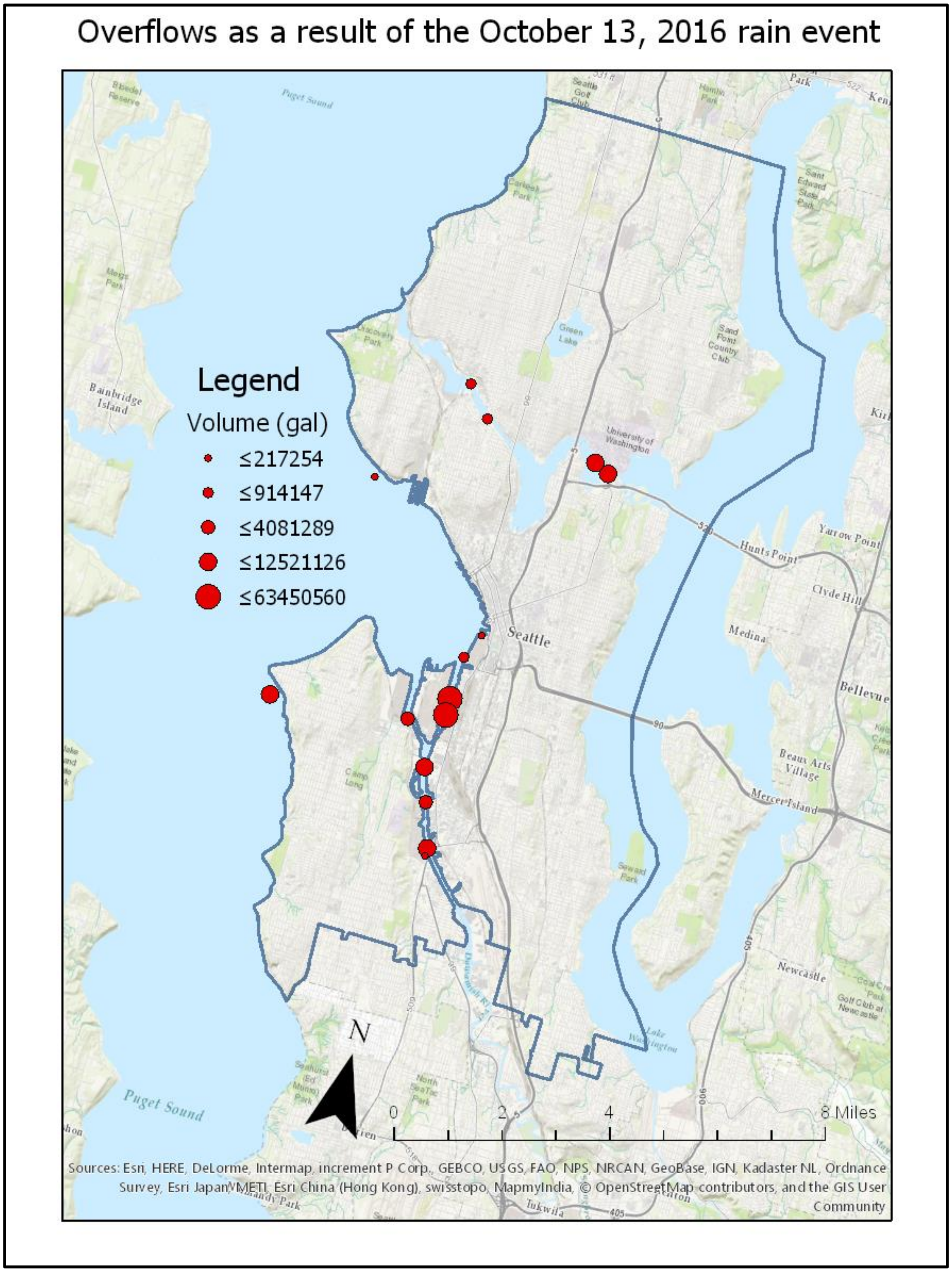

Figure 10. October 13, 2016 overflows

The month with the second highest precipitation was January (7.45 inches), resulting in 49 untreated events and a total overflow volume of 370 million gallons. The largest rain event in January began on January 21. The relative discharge volumes of the 17 overflows from January 21 can be seen in Figure 11.

Table 2. January 21, 2016 overflows

Outfall Name	**Volume (gallons)**	**Precipitation (inches)**
11th Ave NW (AKA East Ballard)	2,196,997	4.17
Belvoir Pump Station Emergency Overflow	32,105	3.15
Montlake Overflow	7,732,835	3.15
University Regulator	28,199,892	3.54
King Street Regulator	2,723,693	1.32
Kingdome	4,255,669	1.85
Lander St Regulator	57,539,128	3.42
Hanford No 1 Overflow	5,068,755	3.4
Hanford No 2 Regulator	62,085,671	3.42
Chelan Ave Regulator	1,258,382	2.87
Terminal 115 Overflow	257,576	1.63
Michigan S Regulator	2,018,222	1.62
Brandon Street Regulator	3,962,505	2.84
Michigan W Regulator	342,685	1.62
North Beach Pump Station (wet well)	2,222,495	4.21
63rd Avenue SW Pump Station	16,752,831	2.89
Murray Street Pump Station	89,866	2.7

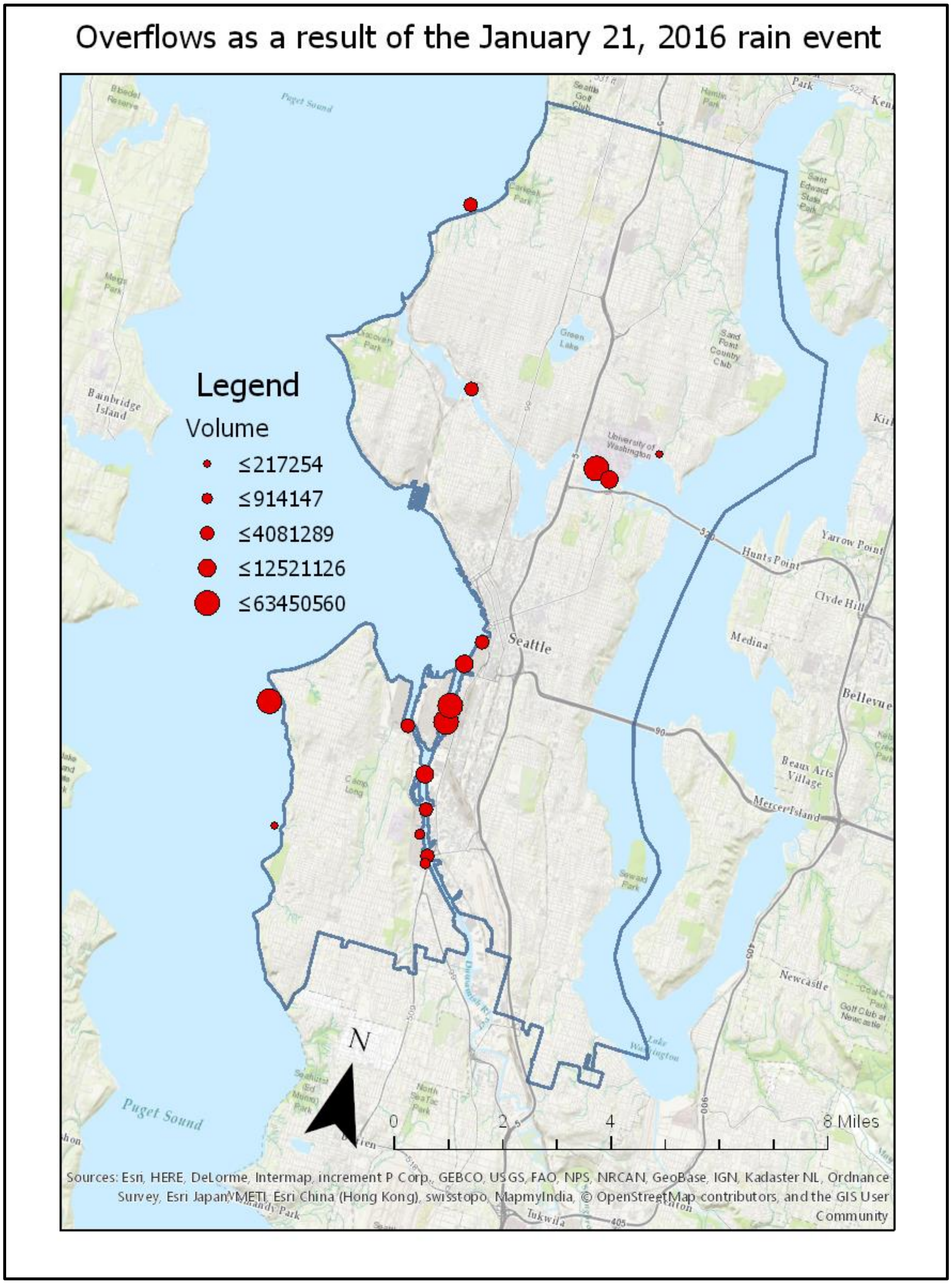

Figure 11. January 21, 2016 overflows

As can be seen from comparing the overflows from October 13 and January 21, the outfalls with larger overflows in October are the same outfalls with larger overflows in January. High overflow volumes would be one indicator to determine which CSOs should be improved first.

Next, three of the eight CSO outfalls that had more than ten overflows in 2016 were chosen for additional analysis. For these three CSOs, the relationship between precipitation and overflow volume were compared. These are both values that were reported in the *2016 Annual CSO and Consent Decree Report* [9]. The three CSOs that were studied were 11th Ave NW, Montlake Overflow, and Hanford #2, shown in Figure 12.

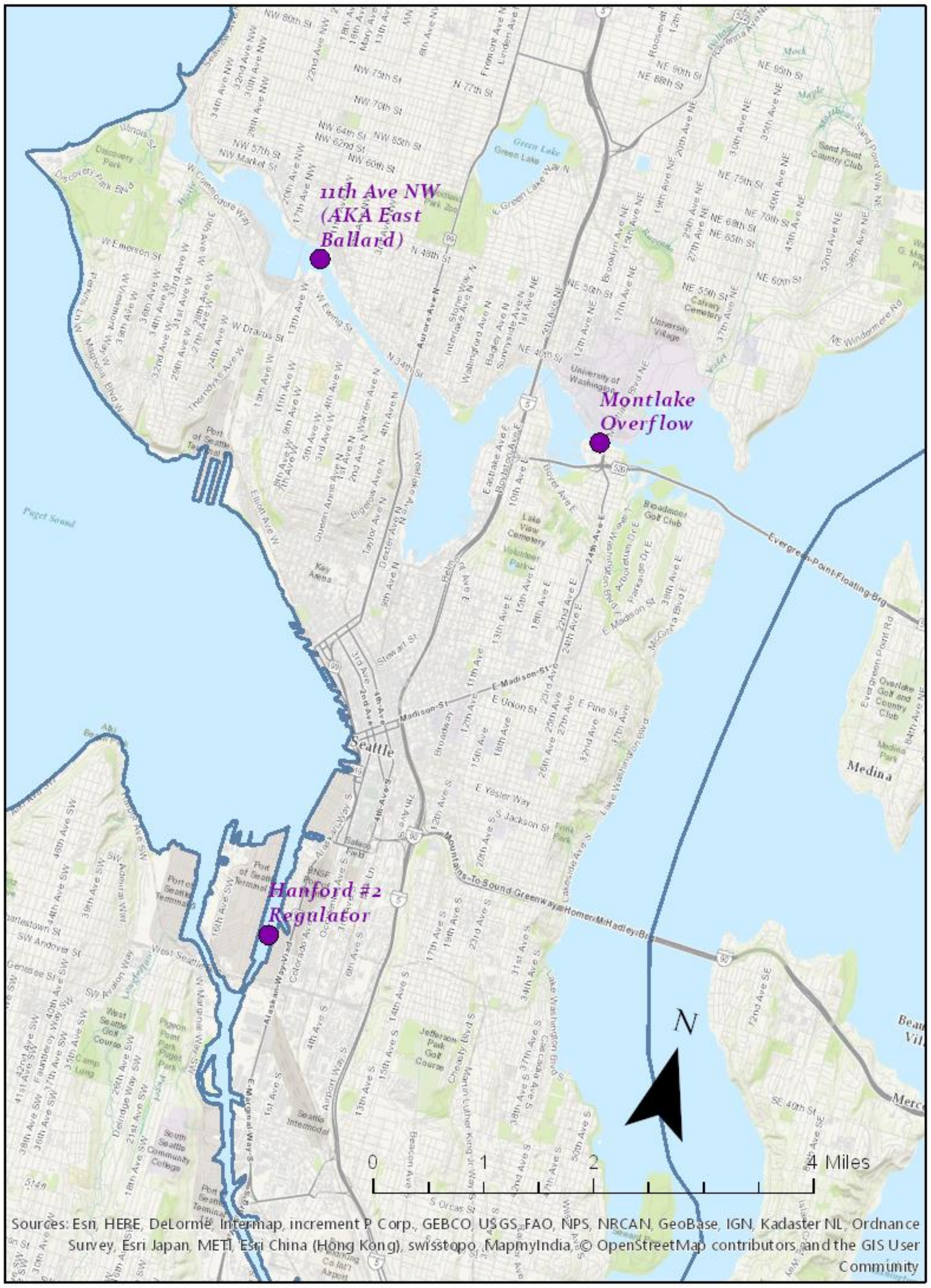

Figure 12. Subset outfall locations

The graphs of the overflow volume and precipitation for the three outfalls mapped in Figure 12 are seen in Figures 13, 14, and 15.

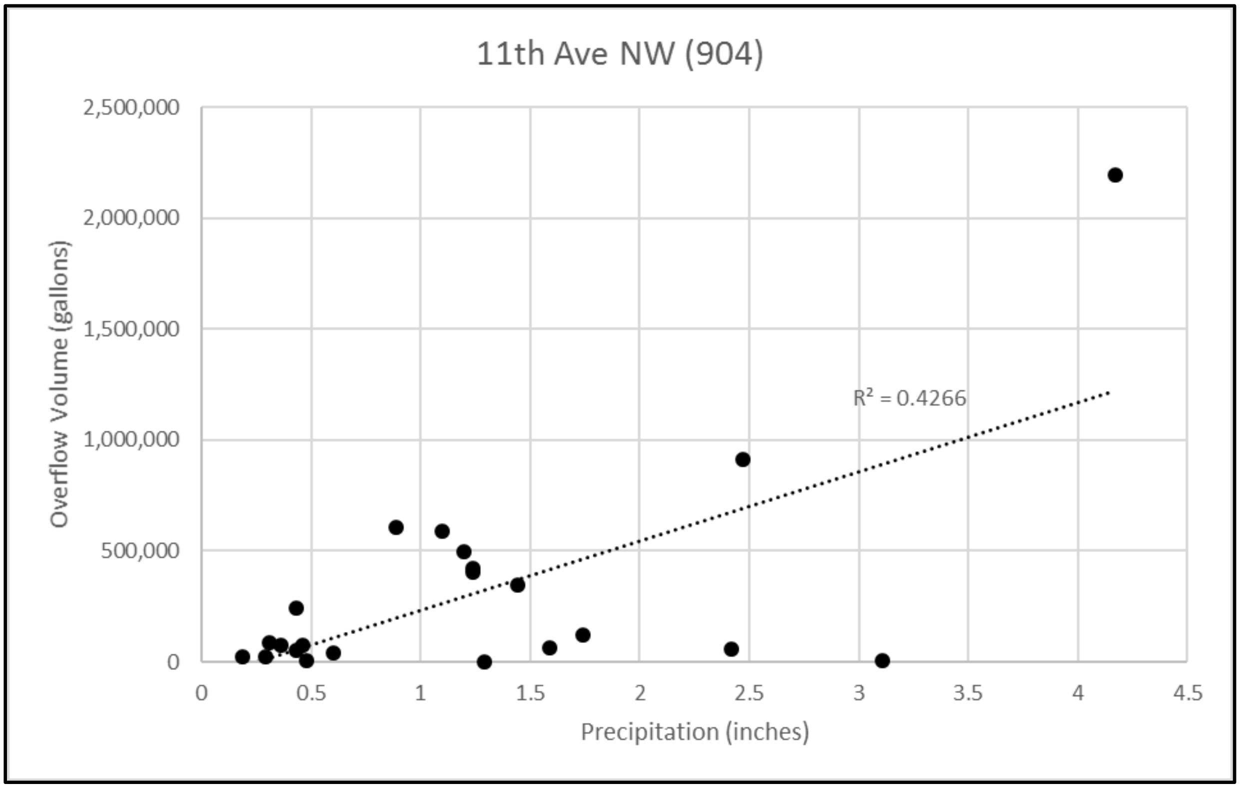

Figure 13. 11th Ave NW Overflow

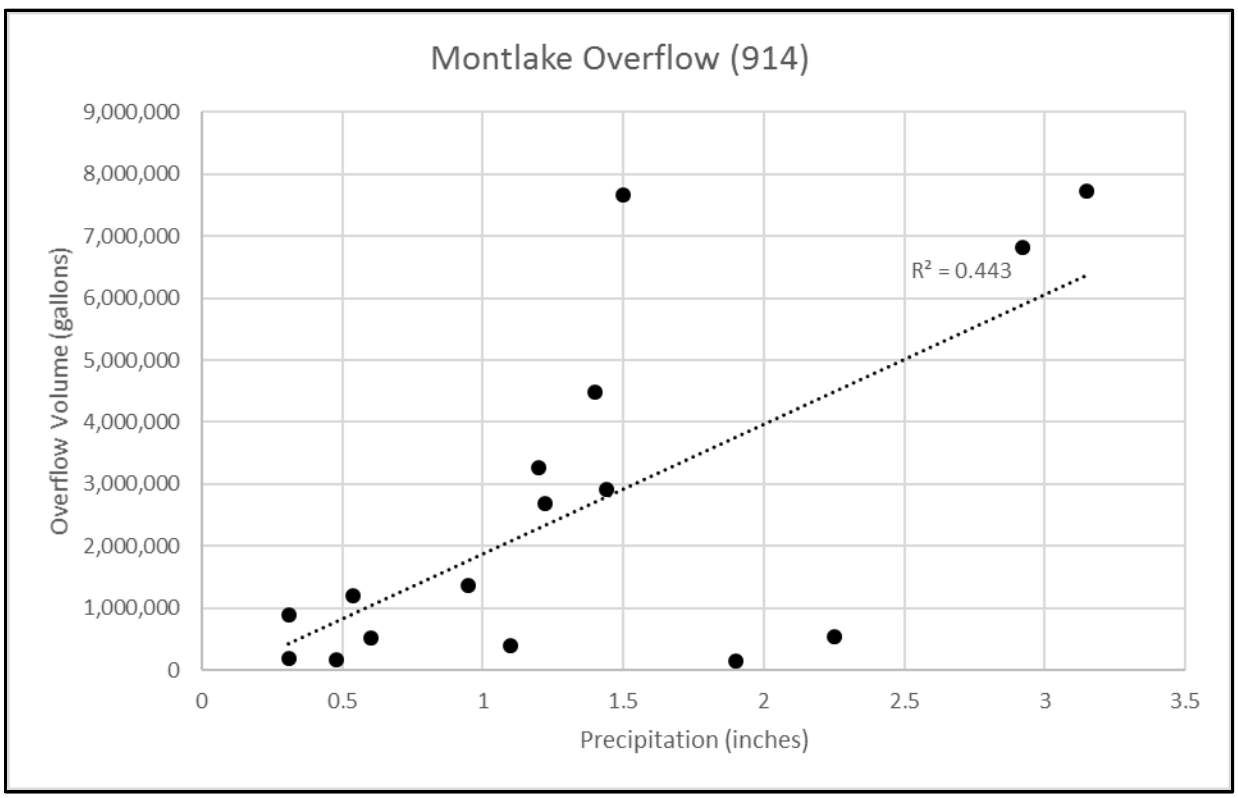

Figure 14. Montlake Overflow

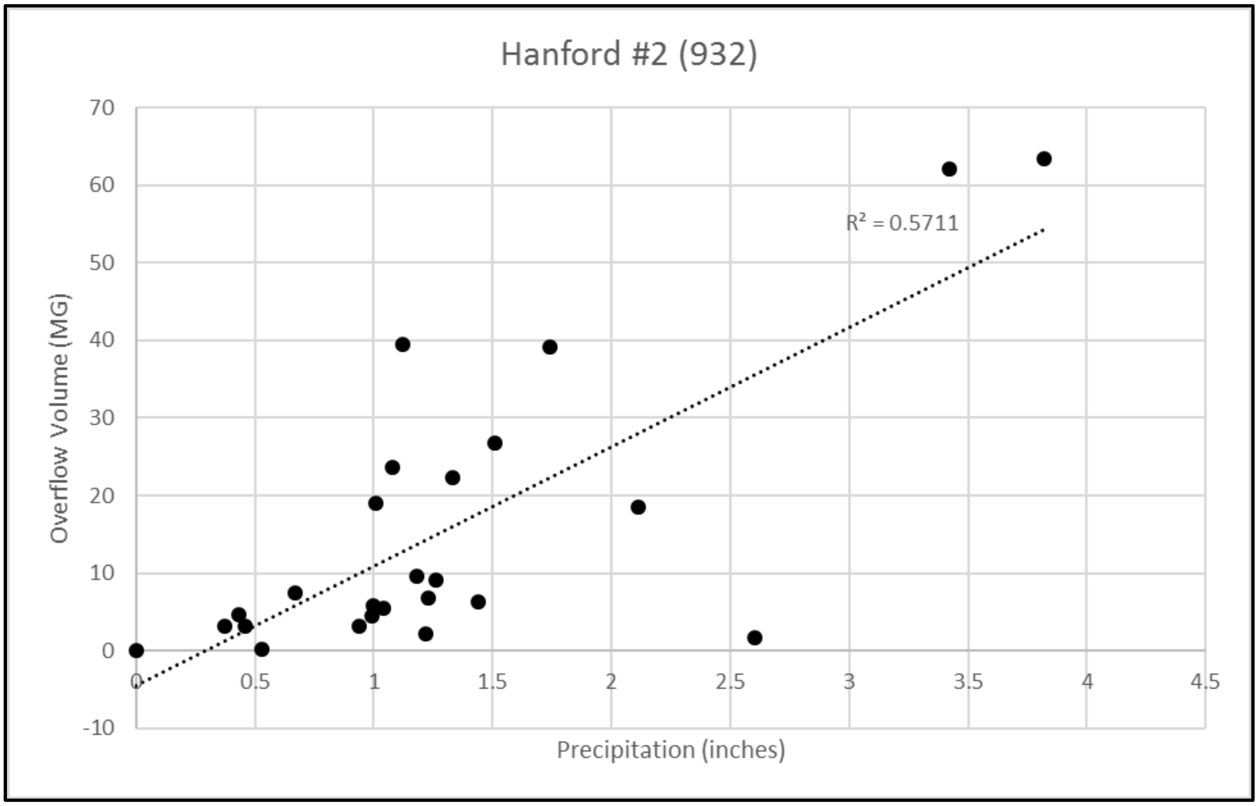

Figure 15. Hanford #2 Overflow

Are seen from the graphs above, there is a positive correlation between precipitation and overflow volume. However, the R^2 values indicate that this correlation is not strong. Some possible reasons for this poor correlation could be the fact that additional conditions such as previous rainfall or stormwater storage capacities could be different for each rain event. Even without the strong fit, these graphs could still be useful to predict overflow volumes given forecasted rain events.

Next, the catchments created from the 500-cell stream delineation at each of the three overflows were mapped. In some cases, multiple catchments were included because they appeared to have the same outlet. This process was quite speculative. The delineated catchments for each of the three overflows can be seen in Figures 16, 17, and 18.

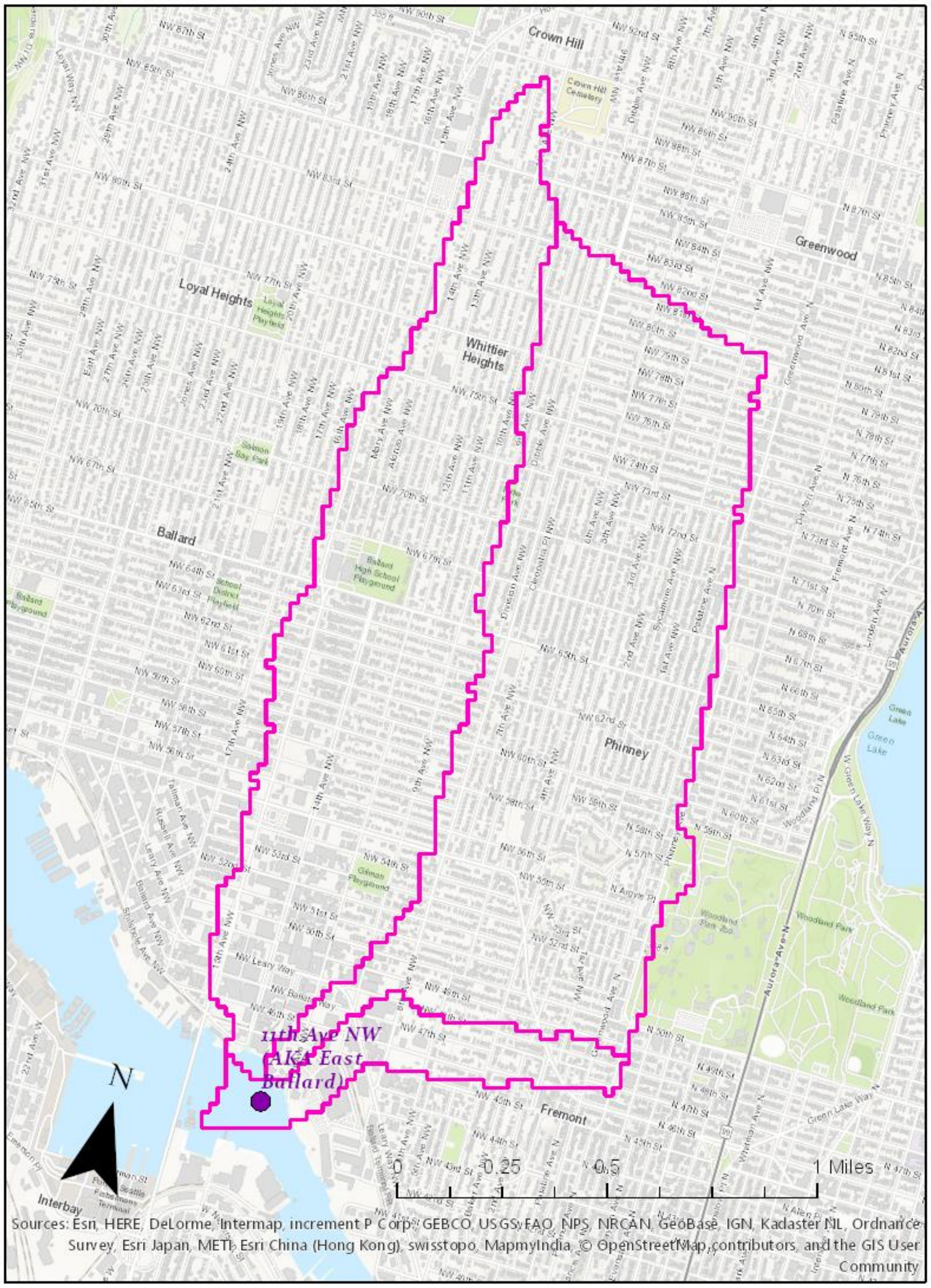

Figure 16. 11th Ave NW catchments

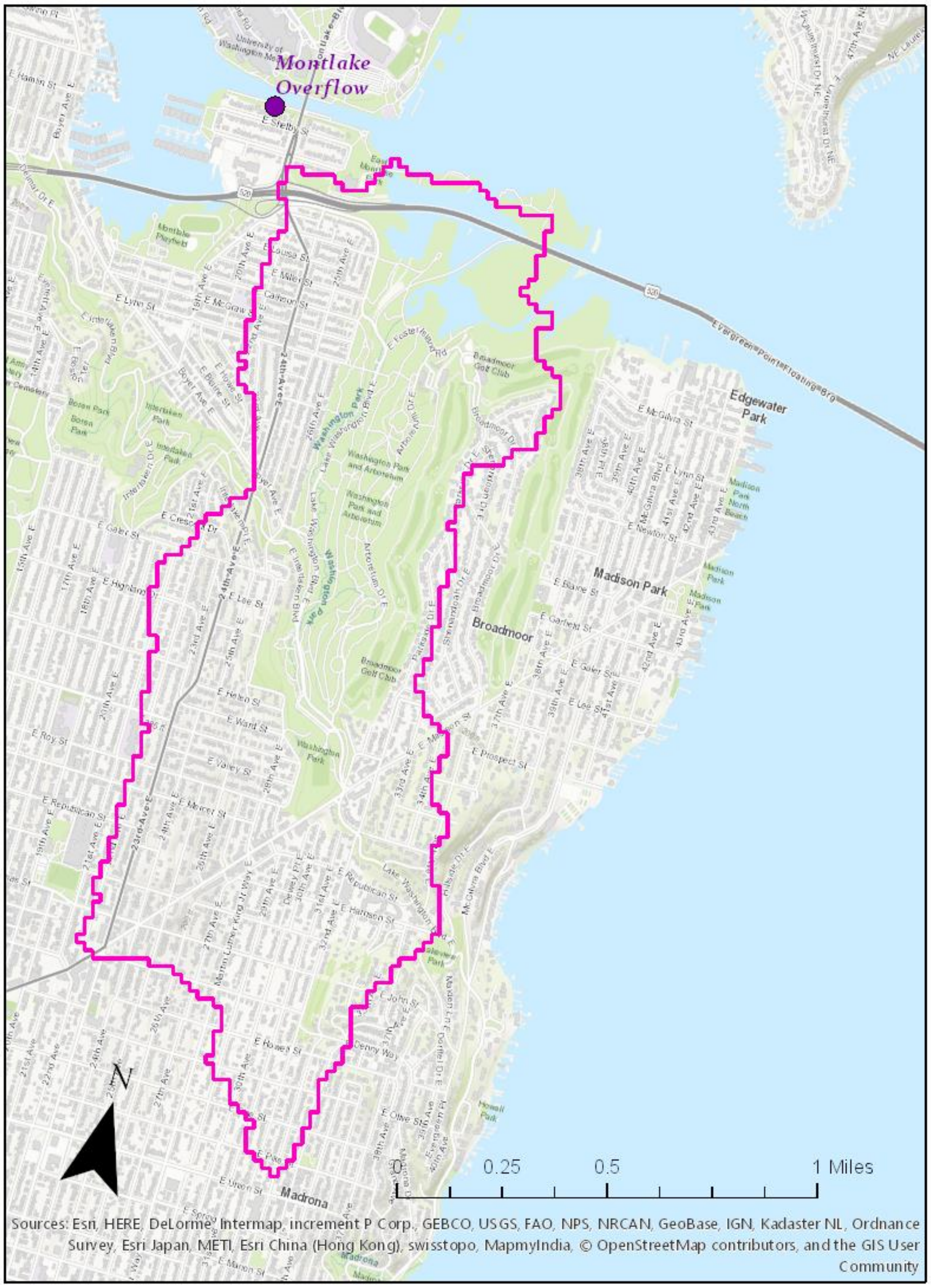

Figure 17. Montlake Overflow catchment

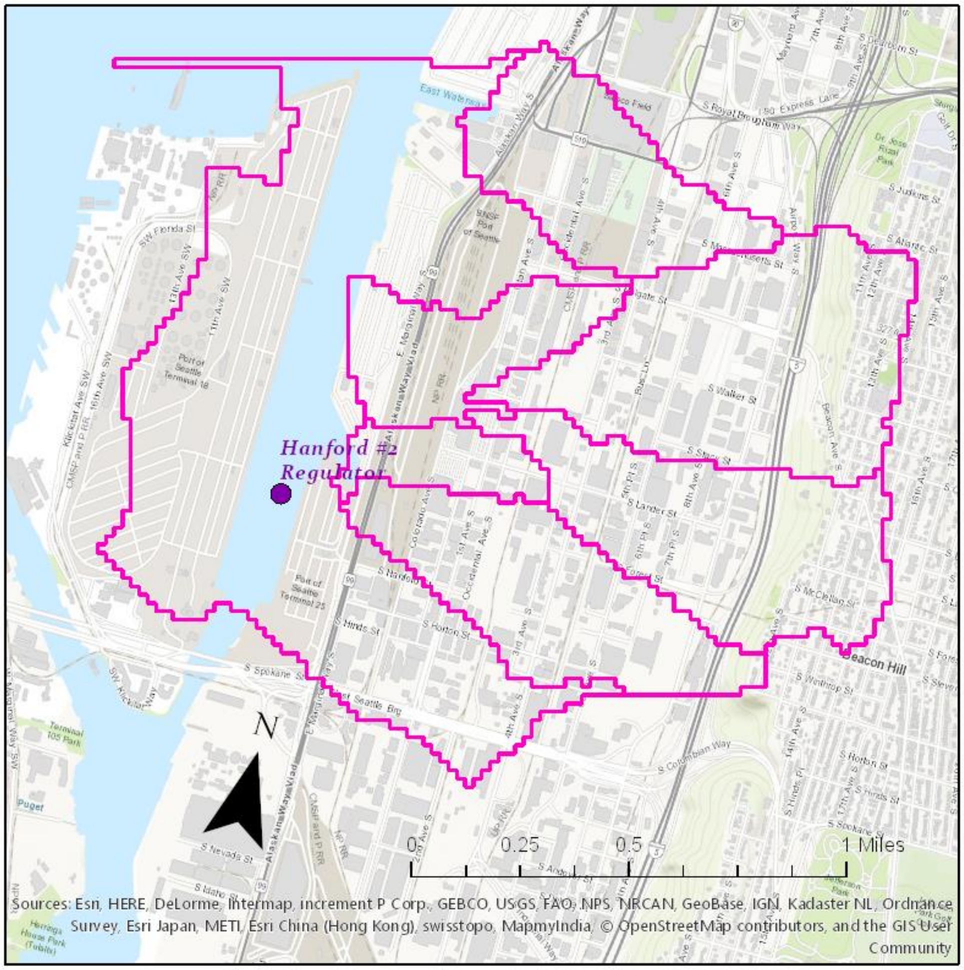

Figure 18. Hanford #2 catchments

After creating the above catchment areas, the 'runoff volumes' were calculated using catchment areas and precipitation data. This volume was then compared to the overflow volume. It was expected that there would be a correlation between total catchment runoff volume and outfall overflow volume.

The overflow volume is the volume reported by the City of Seattle for the overflows that occurred in 2016. The runoff volume uses the basin area that was determined using GIS (as seen in Figures 16, 17, and 18) multiplied by the precipitation data that the City of Seattle reported along with the overflow volume for each overflow occurrence.

A runoff coefficient of 0.7 was assumed considering that these basins contain a combination of residential, commercial, and industrial land [2]. This was not an accurate assumption for all basins. For example, in Figure 17, the catchment area includes Washington Park and Arboretum which would have a runoff coefficient less than 0.7.

An example of the overflow volume / runoff volume calculation is as follows:

$$\frac{Overflow\ Volume}{Runoff\ Volume} = \frac{(overflow\ volume)}{(runoff\ coefficient)(catchment\ area)(precipitation)}$$

$$\frac{Overflow\ Volume}{Runoff\ Volume} = \frac{2196997\ gal}{(0.7)(5148047\ ft^2)(0.3475\ ft)\left(\frac{7.48\ gal}{1\ ft^3}\right)} = 0.23$$

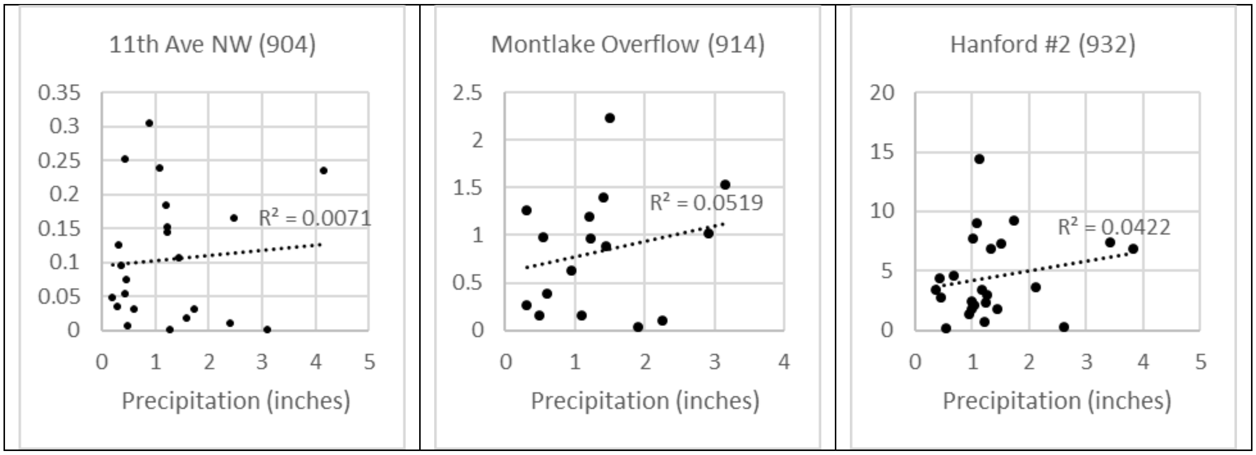

Figure 19. Relationship between precipitation and overflow volume/runoff volume

Figure 19 shows the relationships between precipitation and the ratio of overflow volume to runoff volume. As seen by the R^2 value, there is no correlation between the precipitation and the ratio of overflow volume to calculated runoff volume.

This suggests that there are other factors that need to be considered in addition to precipitation to estimate overflow volumes. For example, sewer locations were not considered. Depending on the location of sewers, water from outside the catchment could discharge at the outfall. Additionally, the catchment areas generated from the 500-cell threshold could not be representative of the actual basin. These could be two reasons for the poor correlation between catchment area and overflow volumes.

After performing this analysis, a shapefile with some CSO basins was found [3]. While this shapefile was not used in the analysis, it is interesting to visually compare the CSO basins to the catchments generated from the 500-cell stream delineation. Some catchment areas link up relatively well, while others seem quite different.

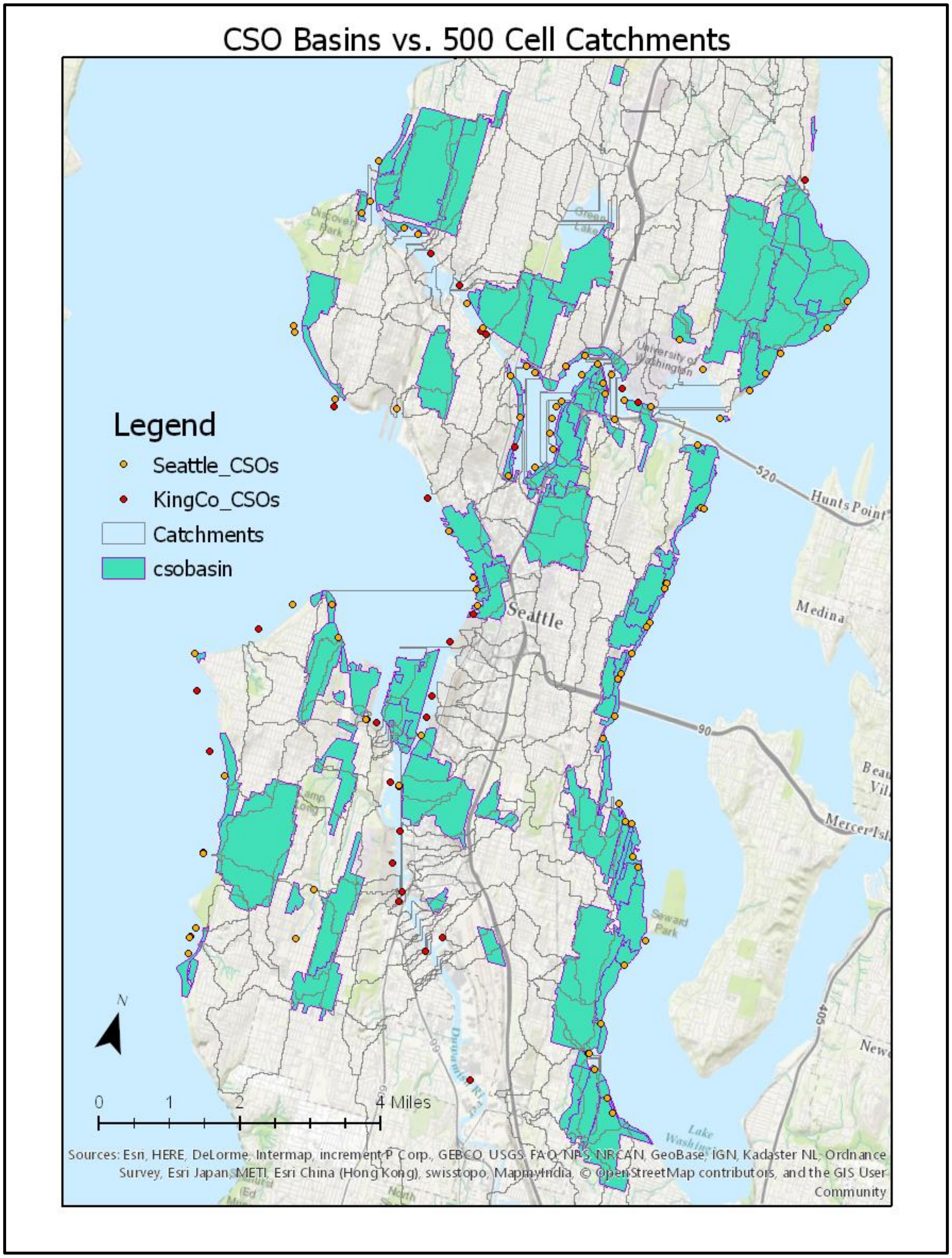

Figure 20. CSO basins vs. 500-cell threshold catchments

Conclusions

It has been useful to develop maps to visualize CSO locations and their relative overflow volumes. However, based on these analyses, it is difficult to develop any conclusive results regarding catchment area, precipitation, and overflow volume. It was somewhat difficult to create catchments from the DEM that closely matched the outfalls.

One of the main limitations to this GIS analysis is likely the fact that sewer lines were not included. Sewer lines may bring water from areas outside of the catchment into the catchment which would then discharged at the outfall. This water volume was not accounted for in the analysis. Another thing that was not accounted for was catchment-specific stormwater storage capacity. This storage would decrease the overall catchment runoff volume. Another potential issue is that there may be other stormwater discharge points in some areas besides the CSOs that were not considered.

Seattle and King County have already developed a plan and schedule for fixing CSOs. All the CSO projects were prioritized based on their protection of public health, the environment, and endangered species back in 1999 [5]. The CSOs were prioritized into 4 categorizes as broken down below:

Priority	Location
1	Near the Puget Sound Beaches
2	East end of the Ship Canal
3	Along the Duwamish River and in Elliott Bay
4	West End of the Ship Canal

The three main outfalls that were studied in this report were the 11th Ave NW, Montlake Overflow, and Hanford #2. There is a project currently underway to improve the 11th Ave NW overflow. A 2.7 mile, 14-18 foot diameter underground storage tunnel is being built to capture and temporarily store more than 15 million gallons of stormwater [5]. This project is estimated to be operational in 2026. To improve the Montlake Overflow, a storage tank is planned to be built with construction being complete in 2028. For the Hanford #2 overflow, the plan is to build a high rate clarification treatment facility and make modifications to the existing conveyance system. This project is estimated to be complete in 2030.

References

[1] Branch, Geographic Products. "TIGER Products." TIGER Products - Geography - U.S. Census Bureau, 1 Sept. 2012, www.census.gov/geo/maps-data/data/tiger.html.

[2] Bedient, Philip B., et al. *Hydrology and Floodplain Analysis*. Pearson, 2013 (pg. 361).

[3] City of Seattle GIS Data. University of Washington, wagda.lib.washington.edu/data/geography/wa_cities/seattle/index.html.

[4] "Combined Sewer Overflows (CSOs)." EPA, Environmental Protection Agency, 16 Dec. 2016, www.epa.gov/npdes/combined-sewer-overflows-csos.

[5] "King County Is Protecting Our Waters." King County Is Protecting Our Waters - King County, www.kingcounty.gov/services/environment/wastewater/cso.aspx.

[6] Murdock, Austin. "USGS - National Hydrography Dataset." U.S. Geological Survey - National Hydrography Dataset, nhd.usgs.gov/.

[7] "Sewage Overflow Prevention." Sewage Overflow Prevention--Seattle Public Utilities, www.seattle.gov/util/environmentconservation/projects/sewageoverflowprevention/.

[8] "Washington State Water Quality Permit Data." Washington State Water Quality Permit Data | Water Quality Program | Washington State Department of Ecology, 24 Feb. 2010, www.ecy.wa.gov/programs/wq/permits/paris/index.html.

[9] *2016 Annual CSO and Consent Decree Report*. King County, July 2017.