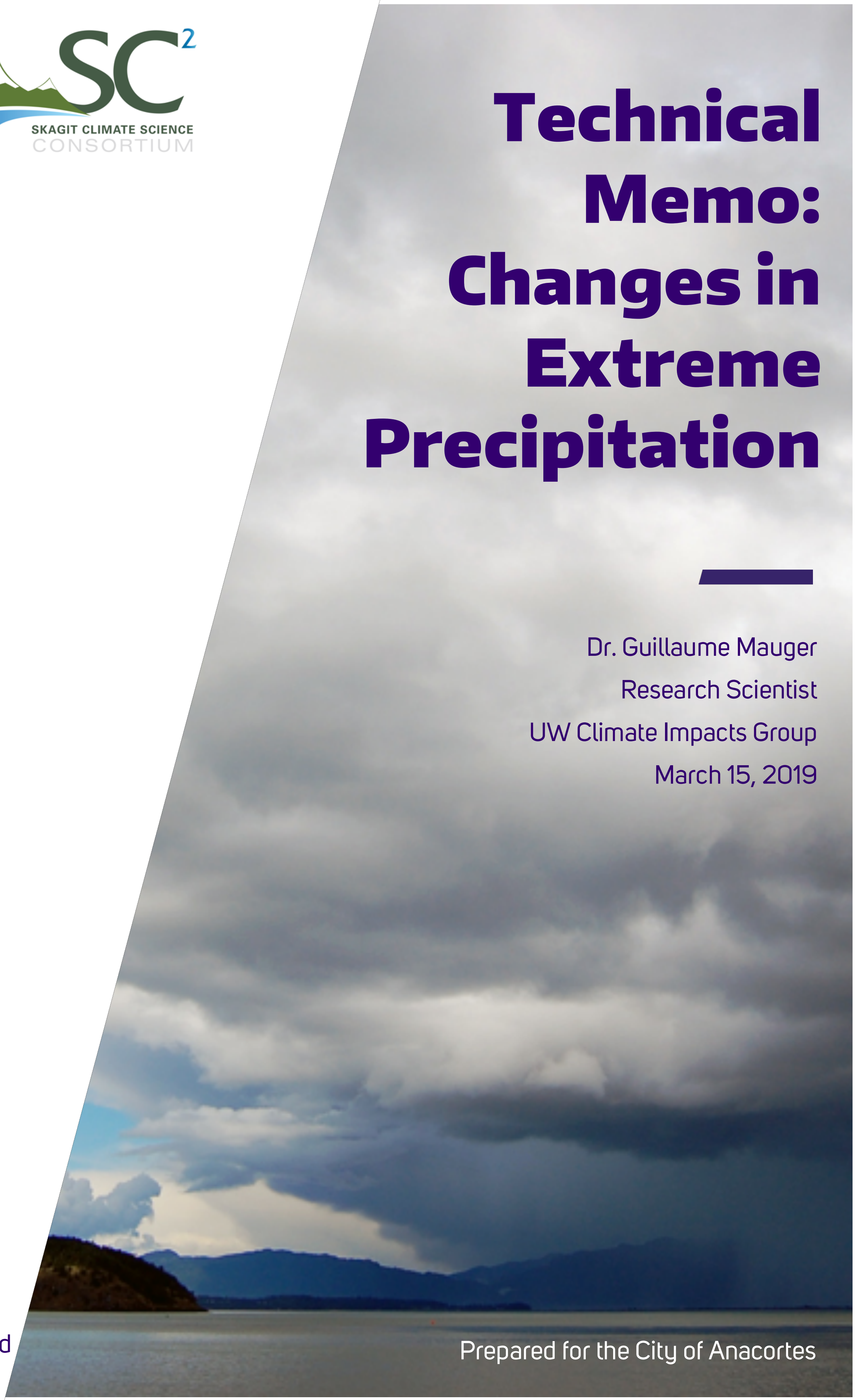

Technical Memo: Changes in Extreme Precipitation

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SUMMARY

Extreme precipitation events are a concern for stormwater management. Many jurisdictions in Puget Sound are experiencing more frequent stormwater challenges, and are exploring solutions to reduce stormwater risks and increase long-term resilience. In Anacortes, current stormwater issues are isolated to winter storm events – summer events, such as thunderstorms, have not been an issue. Staff at the City cited specific management issues associated with particular flow levels within the stormwater system. The amount of water entering the stormwater system is related to both instantaneous and antecedent precipitation totals, over durations ranging from 15 minutes to 5 days. In general, the city has only experienced Combined Sewer Overflow (CSO) events when daily total rainfall exceeds 0.5 in., and even for higher precipitation totals CSO events have only happened when the preceding days have also been wet. Because antecedent conditions are so important, it is difficult to identify a specific precipitation threshold related to flow exceedances in the stormwater system. Instead, the city has hired HDR Inc. to conduct continuous simulations of the system, which can account for the combined effects of antecedent and instantaneous precipitation.

Looking back at past trends in extreme precipitation, existing studies do not show a clear climate change influence on trends in western Washington. This means that any recent increases in stormwater challenges are most likely a result of either natural variations in extreme precipitation or some other factor, such as aging infrastructure, changes in land use, etc.

Looking forward, in contrast, there is clear evidence for an increase in the intensity of heavy rains in the future. Climate change is expected to lead to more intense heavy rain events in western Washington, primarily by increasing the amount of water supplied to winter storms. These changes could further stress Anacortes' stormwater system.

The primary study (Warner et al., 2015) evaluating future changes in extreme precipitation projects a +22% increase (range: +5 to +34%) in the heaviest rain events for each winter, by the end of the century, assuming greenhouse gas emissions continue to increase without any reductions in this century. Preliminary results from another study (Mauger et al., 2018) suggest that the increases in intensity of heavy rain events are modest for the first half of the 21st century, and do not emerge as a clear increasing trend until after 2050.

These projections are based on global model projections and therefore reflect an average for all of western Washington and Oregon; changes for any particular location, such as Anacortes, may be higher and lower than this regional average projection – and may not even be within the +5 to +34% range identified by Warner et al. (2015). In addition, the percentage increases in precipitation apply to the largest daily precipitation events in each winter and do not address

changes for other precipitation durations (e.g., hourly, 6-hourly) or for other extreme statistics (e.g., the 2-, 10- and 25-year events). This is an important distinction for stormwater managers, and for the City of Anacortes, since management is typically focused on a combination of both short (hourly or shorter) and long (2- to 5-day) precipitation durations, and infrastructure design is often focused on specific recurrence intervals, such as the 25-year event.

The UW Climate Impacts Group (UW CIG) is currently producing localized future projections of extreme precipitation using a new set of regional climate model simulations covering the Pacific Northwest. Local governments are seeking these new projections because they are more suitable for stormwater management planning at a city or county scale. King County, Everett, the Port Gamble S'Klallam Tribe, and Thurston County have all invested in this work because it provides more localized information and includes hourly precipitation, meaning that projections can be assessed for any precipitation duration from hourly to longer time scales. These projections can be used in traditional event-based stormwater design and management as well as with the continuous stormwater planning models currently under development by HDR. In both cases, the projections may provide useful information for evaluating the potential future performance of the City's stormwater system.

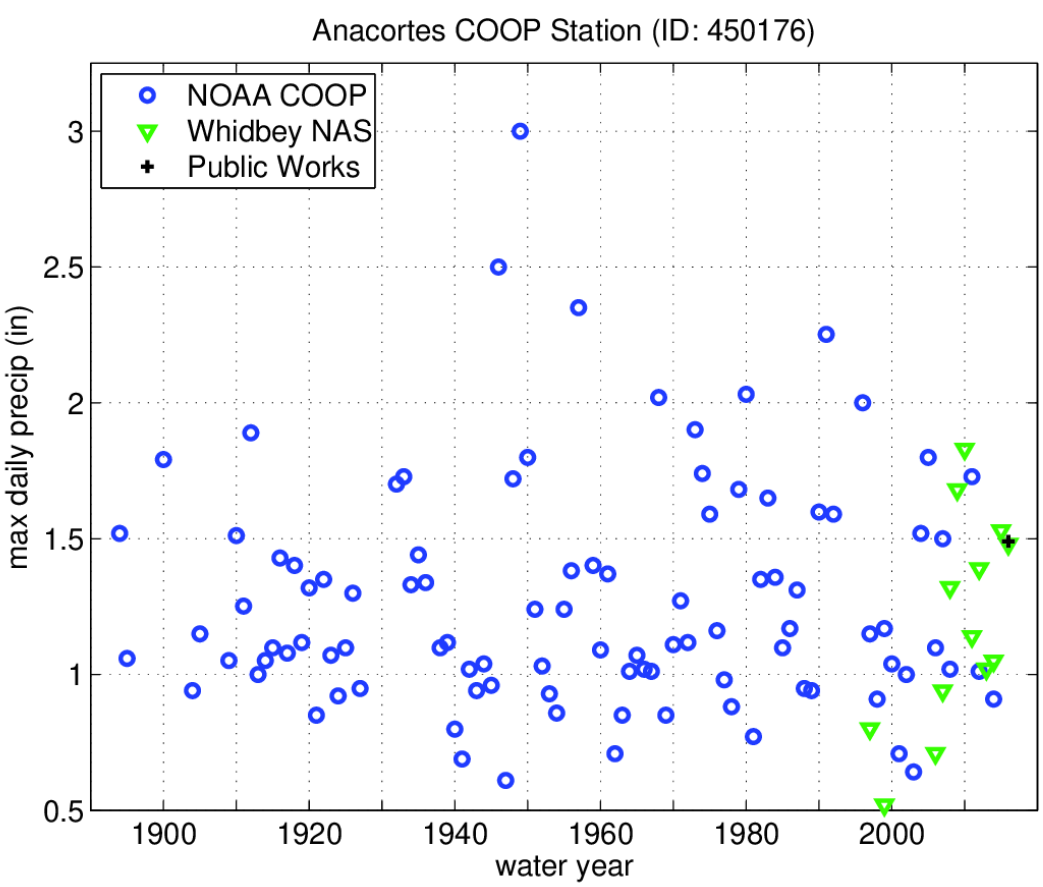


Figure 1. Historical observations of extreme precipitation near Anacortes for each water year. Results are shown for three rain gauges: (1) the NOAA COOP Anacortes gauge (ID: 450176), (2) the Whidbey Naval Air Station (NAS) gauge (ID: 24255), and (3) the gauge maintained by the Anacortes Public Works department. All show the same range of extreme precipitation values.

Additional detail on each of the above points is provided in the following sections.

Looking back: Extreme Precipitation Information and Historical Trends

> ***Nearly all extreme precipitation in western Washington occurs during Atmospheric River events.*** Sometimes colloquially referred to as “pineapple express” events, Atmospheric River events are characterized by the large “river” of moisture transporting water vapor from the tropics into the heart of low pressure systems reaching the Pacific Northwest. Warner et al. (2012) showed that extreme precipitation in the Pacific Northwest is almost always associated with storms of this kind.

> ***The amount of precipitation during the big events varies a lot from year-to-year.*** Precipitation is highly variable, especially extreme events which are by definition rare. This results in ongoing fluctuations between wet years and dry years and wet decades and dry decades, which make it difficult to distinguish long-term trends from random variability. For example, estimates from the Whidbey Island Naval Air Station rain gauge indicate an average of about 1” for the annual maximum of daily precipitation, but this can vary from 0.5” to over 3” in any given year (see Figure 1).

> ***Large-scale fluctuations in weather patterns have a minor effect on precipitation extremes.*** El Niño, the Pacific Decadal Oscillation (PDO), the North Atlantic Oscillation (NAO), and other patterns of climate variability can affect weather patterns in the Pacific Northwest. However, the link to extreme precipitation is minor, if present at all. Some studies find no link (e.g. Schubert et al., 2008), while others find a very weak relationship between these patterns and extreme precipitation (DeFlorio et al., 2013; Whan and Zwiers, 2017).

> ***Scientists generally assume that trends observed over time periods shorter than 30 years are unreliable,*** given the large fluctuations associated with natural variability. For extreme precipitation events, an even longer record may be required to distinguish a trend from the “noise” of natural variability.

> ***The presence of a trend in impacts, such as more frequent CSO events, does not necessarily imply that climate change is the cause.*** Many factors can alter the consequences of extreme precipitation events on stormwater infrastructure, including natural variability, aging infrastructure, or changes in land use.

> ***Historical trends in heavy rainfall are ambiguous for western Washington*** – results depend on the datasets and methods used in the analysis. Although most studies find

increases in both the frequency and intensity of heavy precipitation in Western Washington (Madsen et al., 2007; Mass et al., 2011; Rath et al., 2017; Rosenberg et al., 2010), not all trends are statistically significant. For example, one study examined trends for nine different durations ranging from 1-hour to 10-day precipitation extremes at SeaTac. Although results indicated positive trends for all durations, only one of the nine was statistically-significant at a 95% confidence level (Rosenberg et al., 2010). The lack of statistical significance means that we cannot yet rule out the possibility that the observed trends are simply due to random chance as opposed to a long-term trend.

Making Sense of Climate Change Projections

Globally, greenhouse gas concentrations have risen substantially as a result of human activities, and have been a primary driver of warming. To make projections of future climate, scientists use "what if" scenarios of plausible future greenhouse gas emissions to drive computer model simulations of the earth's climate. There are multiple greenhouse gas scenarios, numerous global climate models – each constructed slightly differently – and multiple techniques for "downscaling" coarse global model projections to local scales. The many possible combinations of scenarios, models, and downscaling techniques are used to estimate a range of possible future climates. The range reflects some of the important unknowns regarding future choices in energy and technology, and in our understanding of the climate system. As scientists develop new scenarios or improve models and downscaling procedures, projections are periodically updated.

Looking Forward: Projected Changes in Extreme Precipitation

> ***Winter precipitation extremes are projected to increase.*** Heavy rainfall events – so-called "Atmospheric River" events – are expected to become more severe. Global models project that the heaviest 24-hour rain events in western Oregon and Washington will intensify by +22%, on average, by the 2080s (2070-2099, relative to 1970-1999; Warner et al., 2015). These high intensity events are also projected to occur more frequently: occurring about seven days per year (range: four to nine days per year) by the 2080s in comparison to two days per year historically (Warner et al., 2015). Another study evaluating extreme rainfall projections for the Sea-Tac weather station reported similar results (Rosenberg et al., 2010). Preliminary results from Mauger et al. (2018) indicate

that changes are modest until mid-century, accelerating thereafter. Warner et al. (2015) do not address changes before the 2080s.

> ***The main driver of extreme precipitation changes is that warmer air holds more water.*** Warner et al. (2015) show that the projected increase in the intensity of heavy rain events is primarily driven by an increase in the supply of water vapor to Atmospheric River events in the Pacific Northwest.

> ***Projected shifts in the storm track are small.*** Possible increases in variability in the speed or position of the jet stream are speculative and may not significantly affect precipitation in the Puget Sound region. Warming is expected to cause the storm tracks to shift towards the poles, and possibly alter the frequency and magnitude of high and low pressure events. The climate model projections used in IPCC (2013) project a northward shift of about 1° latitude (or approximately 70 miles) in the average position of the North Pacific storm track. This is a small shift and would not substantially alter the precipitation reaching the Puget Sound region (Barnes et al., 2013). Similarly, climate models do not project a change in wind speed or the strength of low pressure systems. Although some studies suggest that warming will result in a "wavier" (i.e., more variable) storm track (Barnes et al., 2013; Liu et al., 2012; Petoukhov et al., 2013), this is considered highly speculative. The behavior of the jet stream is governed by many factors; understanding how these combine to drive changes in its behavior is still an active area of research (Barnes et al., 2015; Thomas, 2014). In addition, it is unclear how such changes might affect the Puget Sound region (Salathé et al. 2015).

> ***Research is lacking regarding the effect of climate change on thunderstorms and lightning in the Puget Sound region.*** Thunderstorms are rare in the Puget Sound region due to cold ocean temperatures and warm upper air, and do not appear to affect stormwater management in Anacortes. Nonetheless, it is worth noting that research is lacking on future changes in thunderstoms. Climate change results in competing effects: reductions in summer precipitation may cause thunderstorm activity to decrease, while increased land surface temperatures may trigger more thunderstorms. Changes in atmospheric circulation could also affect thunderstorm activity (Melillo et al., 2014; Kunkel et al., 2013). It is not known how these effects will combine to affect the frequency and intensity of thunderstorms in Anacortes or elsewhere in the Pacific Northwest.

Limitations to the existing projections

Existing projections of extreme precipitation, produced by Warner et al. (2015), are limited in four ways that are important to understand and consider:

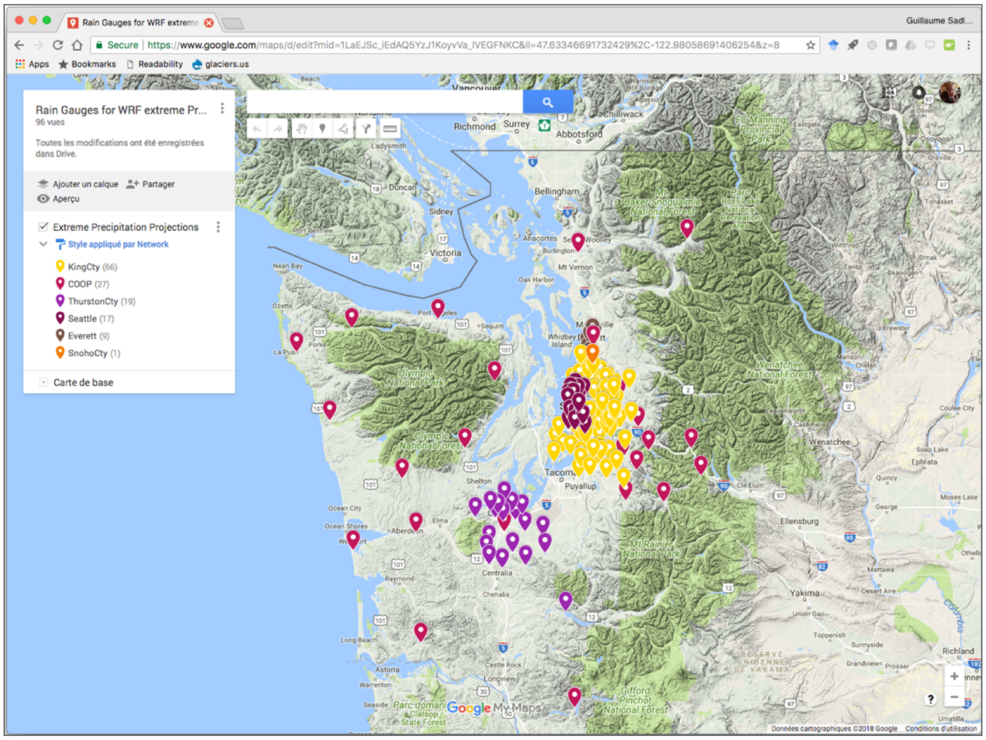
1. Global climate model projections give the regional-average change for all of western Washington and Oregon. The changes expected for Anacortes could be higher or lower than the regional average.
2. The analysis only considers daily precipitation. Both shorter (e.g., 1-hour) and longer (e.g., 3-day) durations are important for stormwater management in Anacortes, and these may not change by the same amount.
3. The projections only consider one measure of extreme precipitation: the top 1% of daily precipitation events. Stormwater planning is typically linked to a specific extreme statistic, such as the 25-year event.
4. Projections were developed solely for the end of the century and do not address nearer-term changes.

Local Projections of Changing Extreme Precipitation

Global climate model projections are too coarse to assess local-scale changes in extreme precipitation. Salathé et al. (2014) show that regional climate models are needed to accurately "downscale" global climate model projections of precipitation extremes to smaller scales such as cities and counties.

At the request of a number of local and tribal governments, UW CIG is currently producing localized projections of extreme precipitation using a new set of regional climate model projections covering the Pacific Northwest. The new projections provide future precipitation estimates at a spatial resolution of 12 km (~8 miles), at an hourly time step, for the years 1970 through 2099. This information could be used in the continuous simulations currently under development by HDR, or to develop future intensity-duration-frequency curves for use in stormwater management and design.

Preliminary results indicate that projected changes are different for different locations, precipitation durations, and extreme statistics. The primary disadvantages of these new projections are that the spatial resolution is still somewhat coarse, and, since the approach is relatively new, the methods used to run and analyze the regional climate model are continuing to evolve. King County, Everett, the Port Gamble S'Klallam Tribe, and Thurston County have all invested in obtaining localized projections for each of their jurisdictions (Figure 2). Since the jurisdiction-specific analyses are keyed to rain gauge data from each entity, results are currently only available for the stations identified in Figure 2. For Anacortes, the closest station is the NOAA



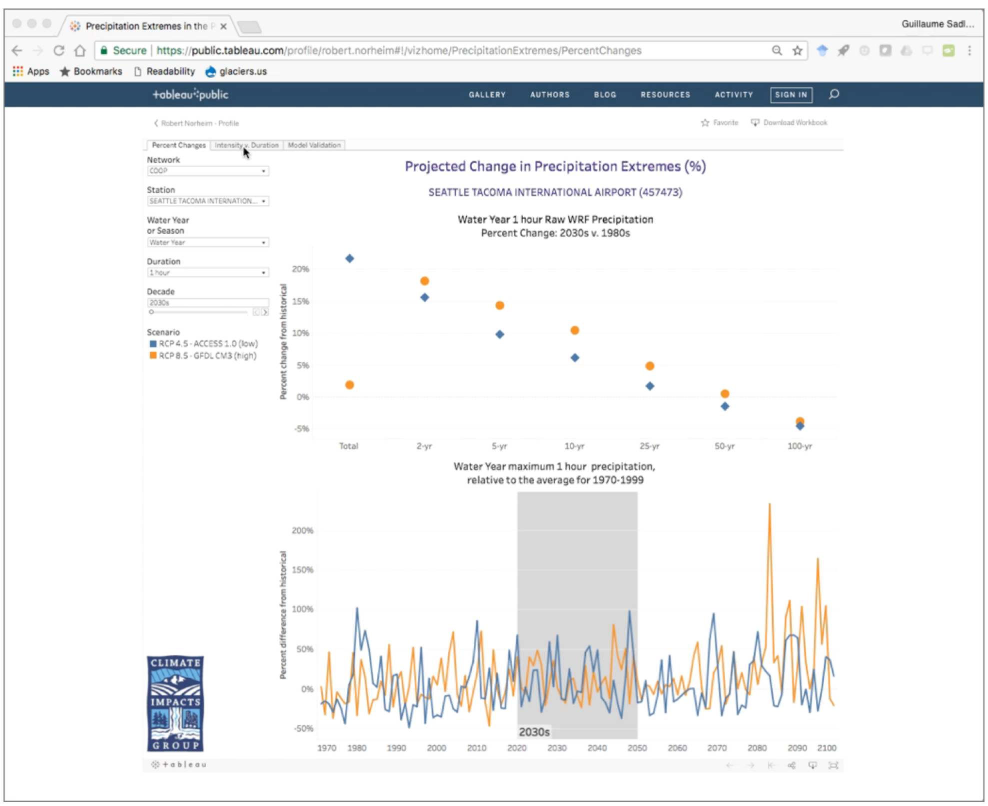


Figure 2. Screenshots of the stations used to analyze extreme precipitation changes for each jurisdiction (top) and the interactive tool designed to allow users to quickly survey the results (bottom). All products are still in development, scheduled for completion by June 30th, 2019.

COOP weather station in Burlington (ID: 450986). Although results for the NOAA gauges have not been analyzed in the same amount of detail as those gauge locations identified by the above jurisdictions, and the projections for Burlington could be different from those for Anacortes, the results for the Burlington site could nonetheless be used to provide a first look at the implications for stormwater management in Anacortes.

The primary reason to opt for these more detailed projections is if the additional information can be useful for planning and design. For example, if projections for a different time period would be helpful, or if more localized information, other precipitation durations, or a particular set of extreme statistics would be useful. Several jurisdictions are using the data in urban stormwater planning and design. King County's Wastewater Treatment Division, for example, has developed a scaling based on the projections, which they are using to evaluate design performance. Similarly, their Water and Land Resources Division is using the new projections to drive hydrologic models evaluating the performance of proposed capital projects in rural areas. Although the exact budget would depend on the scope of the work desired, the cost for other jurisdictions has ranged from $30,000-$60,000. This cost builds on, and leverages, significantly larger investments contributed by King County and others to develop the projections that make this finer level of analysis possible.

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