1. Abstract

Estimation of precipitation extremes is critical to the design of stormwater infrastructure. The standard approach is to estimate frequency distributions of precipitation extremes for given accumulation intervals, and to design stormwater structures to withstand these storms. We examine, whether there is evidence of changes in the frequency distributions of precipitation extremes for three major metropolitan areas of Washington State: Seattle, Vancouver, and Spokane. The historical record is based on hourly precipitation records for gauges surrounding the metropolitan areas for the time period 1970–2010. We analyze changes over this period through comparison of estimated frequency distributions fitted to annual maximum precipitation. Possible changes in future precipitation are assessed using two runs of the Weather Research and Forecast (WRF) regional climate model, using CCAM and CSYM to general boundary conditions, for the time periods 1970–2000 and 2020–2050. Annual maximum precipitation from the model output was analyzed for a 10 day to 30 day durations in stations in the SeaTac area, which were downscaled and bias corrected in order to point estimates at SeaTac International Airport. The downscaled and bias corrected hourly precipitation sequence was used as input to the HSPF hydrologic model, from which simulated annual maximum discharge for several urban watersheds was analyzed using the model framework.

3. Historical Analysis – Methods

The Regional Frequency Analysis, a technique adapted from the regional L-moments method of Hosking and Wallis (1997) was used to evaluate changes in rainfall extremes over the period 1956–2000 for a wide range of frequencies and durations. The precipitation frequency analysis was performed for aggregates of hourly precipitation ranging from one hour to ten days for the three metropolitan areas: Seattle, the Puget Sound, Vancouver, and Spokane. Regions. A frequency distribution is fitted to a set of stations within each region having similar climatic conditions. The National Climatic Data Center (NCDC) hourly precipitation archives. Station selection criteria for inclusion is shown in Figure A and listed in Table A. The minimum requirement for inclusion was a reported period of record of 40 years, with minimal missing data. Annual maximum precipitation depths for multiple durations were identified for each station, and combined into pools in order to calculate regional L-moments, L-moments (Hosking and Wallis, 1987; Frei and Kääb 1996). These parameters were then used to fit data to Generalized Extreme Value (GEV) distributions and to generate regional growth curves. Uncertainty bounds about the GEV distributions were provided. Statistical significance for differences in the entire distribution was found by using the Wilcoxon rank-sum test with p-values, as well as a significance level of 0.05.

2. Introduction and Background

Typically, urban stormwater infrastructure is designed to manage the runoff from “design” rainfall events of specified duration (e.g., 24 hours) and return periods (e.g., 100 years). The projected change of extreme precipitation is a particular concern (e.g., the 24-hour, 100-year flood) without reference to the precipitation that produced it. Historical management goals for urban stormwater have emphasized safe conveyance, with more recent attention also given to the consequences of non-exceeding streamflow events on the physical and biological integrity of downstream channels. Future storms that may alter precipitation intensity or duration would likely have severe consequences for urban stormwater facilities, particularly where stormwater detention and conveyance facilities were designed under assumptions that no longer apply. The complexities of uncertainty and the economic impact of increasing the capacity of stormwater facilities, or the reliability of key elements of stormwater conveyance, could be substantial.

This study addresses the following questions:

What are the historic trends in precipitation extremes across Washington State?
What are the projected trends in precipitation extremes over the next 50 years in the state’s urban areas?
What are the likely consequences of future changes in precipitation extremes on urban stormwater infrastructure?

Prior studies provide a good methodological starting point for identifying the most likely consequences of climate change on stormwater infrastructure, along with an initial list of potentially useful adaptation measures. Their greatest shortcoming, however, lies uniformly in their presumptive, but poorly documented, and bias corrected data for 1970–2005 (“52-year” record) and 2010–2015 (“10-year” record). Simulations for both periods were bias-corrected and standardization of precipitation extremes have been performed using the Regional Frequency Analysis (RFA). A further step in this analysis focused on the precipitation series of the Seattle, Washington region. The precipitation analysis has been performed for all urban storms, and the bias-corrected data simulated at the monthly level. The bias correction procedure followed the methods of Hosking and Wallis (2006). The monthly data for grid boxes were bias corrected so that they had the same probability distributions as the observed data from SeaTac airport, which was the same data used in the historical analysis described above. (See reference for detailed explanation).

Hydrologic simulation: We analyzed two Seattle-area watershed, the lower Carnation and the upper Carnation Creek, because they encompass physical and land-use characteristics typical of the central Puget Lowland (Figure B). The lower Carnation watershed is Seattle’s largest creek basin, with approximately 28.5 km² (11 sq mi) of mixed commercial and residential land use. Upper Carnation is a mixed-land-use 1.4 km² (0.56 sq mi) watershed that drains into the coastal waters of Lake Washington. Hydrologic simulations of streamflow in these two watersheds were generated by the Hydrologic Simulation Program–Fortran (HSPF; Bikerman et al., 1996) . HSPF is a lumped-parameter model that simulates streamflow at multiple points along a selected channel network from a time series of meteorological variables. The basin precipitation data from the HSPF model were used as input to MAR01 and HSPF01 streamflow in both the lower Carnation and the upper Carnation Creek watersheds.

4. Bias Correction & Projected Stream flow – Methods

Two global climate models (Table B) simulated precipitation extremes for the period 1970–2000 and 2020–2050. Simulations for both periods were bias-corrected and standardization of precipitation extremes have been performed using the Regional Frequency Analysis (RFA). A further step in this analysis focused on the precipitation series of the Seattle, Washington region. The precipitation analysis has been performed for all urban storms, and the bias-corrected data simulated at the monthly level. The bias correction procedure followed the methods of Hosking and Wallis (2006). The monthly data for grid boxes were bias corrected so that they had the same probability distributions as the observed data from SeaTac airport, which was the same data used in the historical analysis described above. (See reference for detailed explanation).

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5. Results and Conclusions

Results are summarized as three key conclusions:

1. Historical precipitation extremes have generally increased over the last 50 years, particularly in the Puget Sound region and to a lesser extent in the Spokane region. Existing drainage infrastructure designed using mid-20th century rainfall records may already be subject to severe overdesign due to storm intensities exceeding those observed over the last 50 years. For all but the shortest durations, however, precipitation extremes have declined in the Vancouver region, and likely will continue to decline in the future.

The summarized results in Table C present the average of changes in design precipitation across all recurrence intervals, which is a realization of the same magnitude of change observed in the 5-year events. Sample GEV distributions (Figure C) show annual maxima indicate the likelihood of data within a single storm duration. Based on these spatially variable results, it is not possible to discern the patterns of future change in Washington State, and adaptations will need to be region-specific.

2. Regional climate models project increases in precipitation extremes in the Puget Sound region but their predictions vary substantially. Differences between the underlying global climate models, and uncertainties in the downscaled model results, suggest that precipitation changes through 2050 may be difficult to distinguish from natural variability for the period of analysis. Figure G, at right, indicates that despite both models projecting increases in 2020–2050 relative to their 1970–2000 results and relative to the observed 1970–2000 record, the observed record for 1981 to 2005 is nearly as high as the largest projection in 2020–2050.

Although the historical analyses suggest that the magnitude of future increases is plausible (and, in fact, consistent with past trends), the differences between model predictions are sufficiently large to carry potentially significant consequences for their influence on urban stormwater structures.

3. Hydrologic modeling of two urban creeks in central Puget Sound, driven by rainfall simulations, from a regional climate model, suggest overall increases in peak annual discharge over the next 50 years. Magnitudes of projected changes vary widely, however, ranging from declines of 25% to increases of more than 50%, depending on the rainfall intensity and duration of the underlying global climate model. Results of the hydrologic modeling (Table D and Figure E) on two urban watersheds in the central Puget Sound region affirm and extend both the broad trends and the substantial uncertainty evident in the downscaled analysis. For the largest modeled watersheds, simulations predict general agreement that precipitation increases will result in increases in streamflow, although the range of increases is highly variable depending on the selected return period, study duration, and the underlying (GCM) scenario. The results are too large in which to predict engineering designs. The comprehensive, systematic, and transparent approach to hydrologic simulation provides more confidence in the hydrometeorological model simulations on the net direction of change (i.e., a future increase or a future decrease) and the choice of GCM scenario.

6. Acknowledgements
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