# Climate change impacts on North Dakota: agriculture and hydrology


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## Abstract

North Dakota is one of the principal producers of agricultural commodities in the USA, including over half of the total spring wheat production. While the region includes some of the best agricultural lands in the world, the steep temperature and precipitation gradients also make it one of the most sensitive to climate change. Over the 20th century, both the temperature and the pattern of precipitation in the state have changed; one of the most dramatic examples of the consequences of this change is the Devils Lake flooding. In two studies, we estimated the climate change impacts on crop yields and on the hydrology of the Devils Lake basin. The projections of six GCMs, driven by three SRES scenarios were statistically downscaled for multiple locations throughout the state, for the 2020s, 2050s, and 2080s climate. Averaged over all GCMs, there is a small increase in precipitation, by 0.6 – 1.1% in 2020s, 3.1 – 3.5% in 2050s, and 3.0 – 7.6% in 2080s. This change in precipitation varies with the seasons, with cold seasons becoming wetter and warm seasons not changing.


## Introduction

North Dakota is one of the principal producers of agricultural commodities in the nation, being the top producer of 12 commodities (North Dakota Agriculture 2010). One of the most important crops is spring wheat, of which North Dakota grows over half of the national production (290 out of 584 million bushels in 2009 - NASS, 2010). While the region has some of the best agricultural lands in the world in terms of their suitability for cultivation, the steep north-south temperature gradient and east-west precipitation gradient (Figure 1) also makes the region one of the most sensitive to climate change (Ramankutty et al. 2002). Multiple GCM projections demonstrate that in the future the temperatures in the region will increase, following the already established trend.

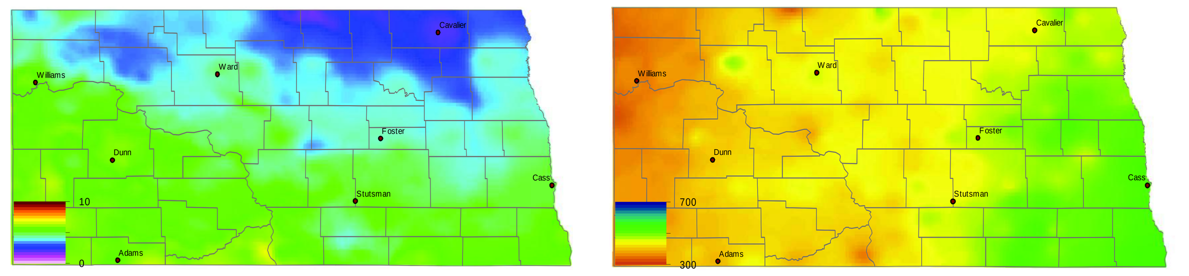

Figure 1. North Dakota climate (PRISM). Mean 1971-2000 annual temperature (C) and precipitation (mm). Locations of the test sites are marked on the map.

Devils Lake is a terminal lake with a surface area of about 500 km² in a 9,867 km² closed watershed, located in the northeastern part of North Dakota (Figure 2). The recent changes in climate interrupted the 5-7 year long wet/dry cycle, resulting in a persistently wet state. The change in the water balance has led to a substantial increase in the lake level from 427.0 m in 1940 to 434.6 m in 1993 to 443.2 m in 2011 (Figure 2). The resulting flooding has threatened the local communities, costing $1.6 billion in estimated losses thus far. If the elevation reaches 444.4 m, the saline, eutrophic lake will naturally spill into the Sheyenne River, eventually flowing into Lake Winnipeg.

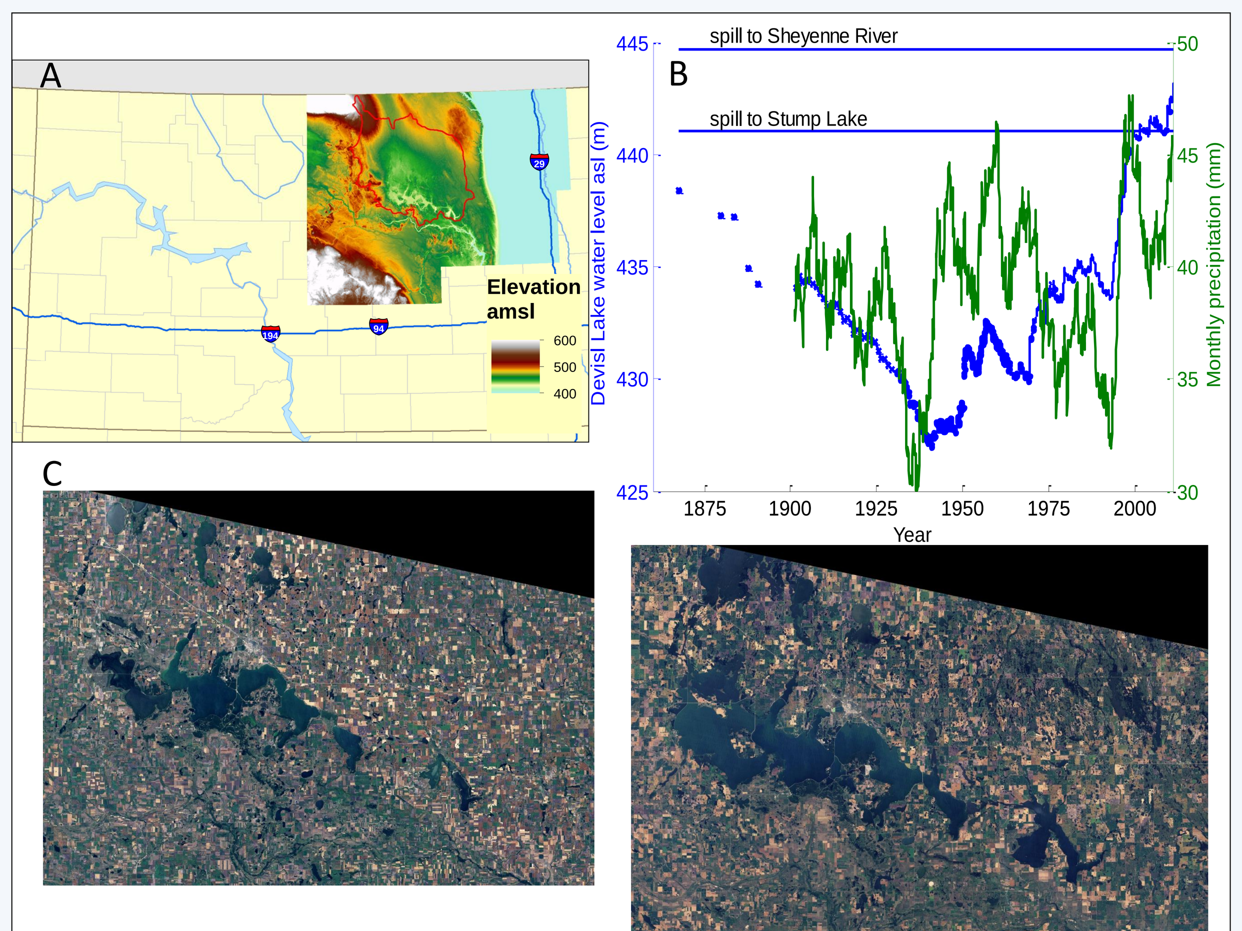


Figure 2. A: Devils Lake watershed location and DEM: B:: Variations in the Devils Lake amsl and monthly precipitations; C: Landsat 08.11.1984 and 09.01.2009 images.

## Climate change scenarios

The main objective of the study was to develop a set of relevant climate change scenarios for the Northern Great Plains, and to apply these scenarios in a study of climate change impacts on agriculture of the region and on hydrology of Devils Lake. For the agriculture model, we used the integrations of six different GCMs (CSMK3, GFCM21, GIAOM, HADCM3, MPEH5, and NCCCSM) running under three SRES scenarios (A1B, A2 and B1), statistically downscaled using LARS-WG weather generator for eight locations throughout the state.

Overall, all six GCMs project a substantial increase in the annual mean temperature in the region. Averaged across all six GCMs, the 2020s annual temperature increases by 0.6 °C for three scenarios under consideration, in 2050s annual temperature increases by 1.6-2.2 °C, and in 2080s annual temperature increases by 2.5-4.2 °C. For precipitation, in 2020s, the majority of GCMs project small increase in annual precipitation by up to 3.7%, while others project a small decrease of up to -1.2%. This change in precipitation varies across the seasons, with cold season becoming wetter, while the warm season precipitation does not change. The same trend exists in 2050s and 2080s: while the annual amount of precipitation increases (by 3.1 – 3.5% in 2050s and by 3.0 – 7.6% in 2080s, when averaged across all six GCMs), the entire precipitation change happens during the cold season with very small changes during the warm season. The increase in the temperature is being followed with an increase in PET – by 1.6% by 2020s, 5.1% by 2050s, and 8.0% by 2050s.

For the Devils Lake watershed, fine resolution daily synthetic climate was required to run the hydrological models. The remotely sensed NASA data products (Level 3 AIRS v. 5 temperature and TRMM TMPA 3B42 v. 6 precipitation) were converted to monthly and mixed with LARS-WG generated current and historical temperature and precipitation (Figure 3). To ensure the quality of the downscaled product, we evaluated both NASA products used in the study against the US HCN daily data and found a significant bias within the temperature product and no bias but an insufficient rain event detection skill in the precipitation product (POD ~ 0.3 – figure 4). The algorithm was corrected to reduce the effect of this bias. The final product contained 30 samples for each combination of six GCMs, three SRES scenarios, for 2020s, 2050s, and 2080s climate projections (Figure 5).

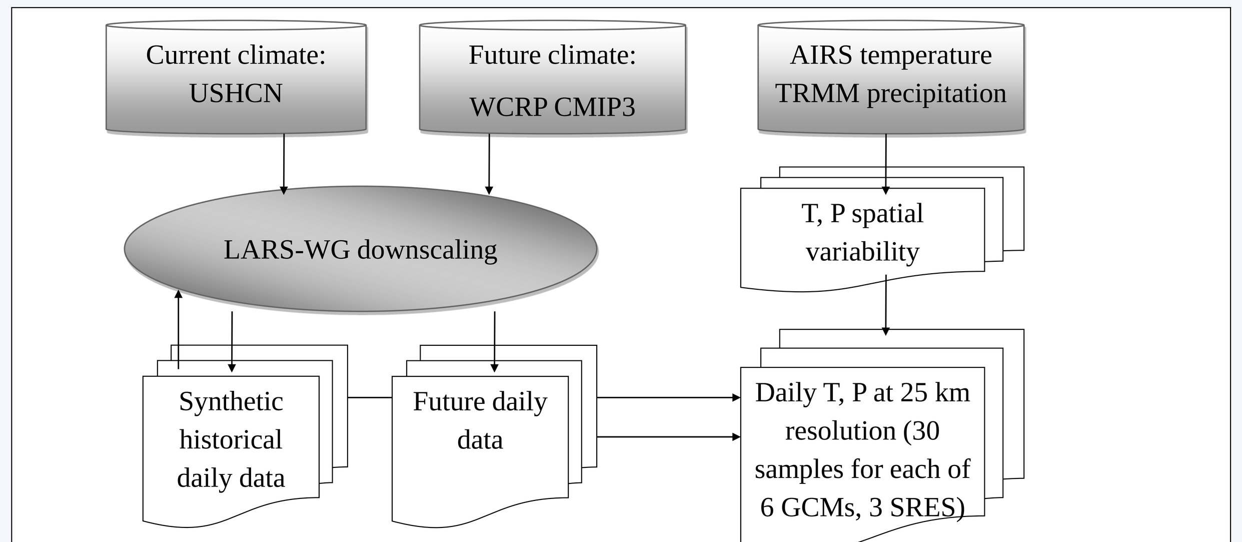


Figure 3. Downscaling of the climate change scenarios for the Devils Lake watershed.

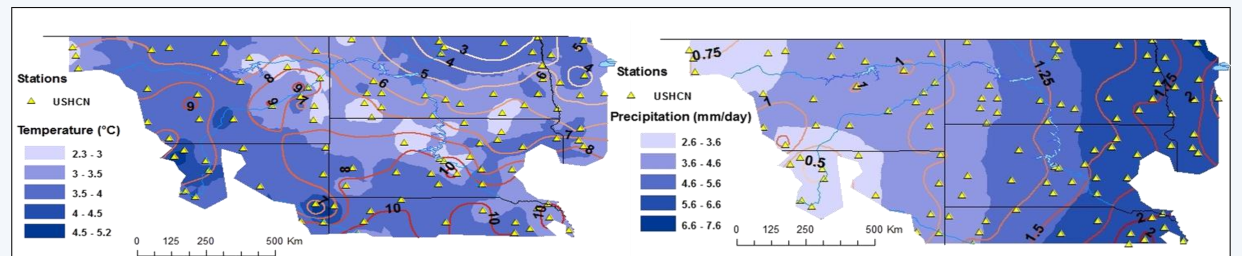

Figure 4. Comparison between the satellite and ground measurements: spatial variability of RMSD for corrected AIRS temperature (left) and precipitation (right). Isotherms and isohyets are based on the US HCN data.

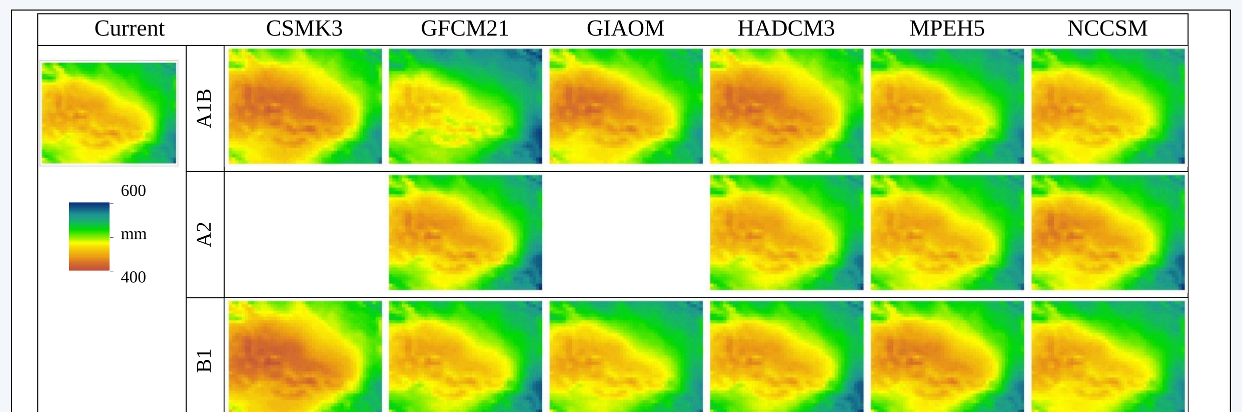


Figure 5. Example of the downscaled scenario: annual precipitation across the watershed for 2020s climate, compared to current.

## Results: Agriculture

Combined, modelled climate changes result in slight increase in the aridity of the climate (measured as a decrease in the UNEP drought index), with dryer summers and wetter winters. The resulting warmer, yet dryer conditions should make an inconsistent impact on agriculture: increasing yields in regions where the thermal regime is the principal limiting factor, decreasing yields in regions with limiting precipitation.

The daily climate projections were used as the input data CERES-wheat crop simulation model of the Decision Support System for Agrotechnology Transfer (DSSAT) to simulate the change in spring wheat production in eight locations selected in North Dakota. We calibrated the model using two sources of data. The NDSU Glenn hard red wheat variety trials (NDSU, 2010) represented the yields at the test locations under the optimal conditions and only for three years of the trial. The National Agricultural Statistics Service data (NASS, 2010) represented the mean county yields for multiple years, and were much lower than the yields at the NDSU experimental stations. Due to these large discrepancies between two sources of the data, during model calibration, rather than matching the yield data from NDSU or NASS statistics, we targeted representation of the spatial variability of the yield.

We used the CERES model from the DSSAT software product to simulate the impact of climate change to wheat yield in eight locations in North Dakota using the output of six GCMs run under three distinct SRES scenarios (for some GCMs, there was no data available for A2 scenario simulation), for three time periods: 2020s, 2050s, and 2080s. For each time period, we run DSSAT ten times under different synthetic weather conditions to adequately take into account climate variability. In general, averaged across the simulations and across all locations, the simulations demonstrated decline in yields: smaller (-3.6% ~ -4.0%) in 2020s and further decreasing to -8.8% ~ -19.8% in 2050s and to -13.0% ~ -20.4% in 2050s. However, the projection of this decrease differs dramatically between the outputs from different GCMs, with GFDL CM2.1 projections typically resulting in very large yield reductions and NASA GISS demonstrating relatively small reductions in the yield (Table 1, Figure 6).

| | | Foster | Dunn | Cass | Adams | Cavalier | Ward | Stutsman | Williams |
|---|---|---|---|---|---|---|---|---|---|
| 2020s | A1B | -6.0 | -10.7 | -3.6 | -0.6 | -6.1 | -7.3 | 2.7 | 1.9 |
| | A2 | -6.9 | -12.6 | -2.5 | -2.0 | -6.0 | -7.8 | 6.1 | -0.4 |
| | B1 | -5.3 | -10.8 | -2.3 | -0.3 | -4.6 | -10.0 | 3.3 | 0.9 |
| 2050s | A1B | -9.4 | -16.8 | -4.1 | -7.0 | -14.6 | -9.2 | -1.4 | -2.8 |
| | A2 | -11.0 | -22.7 | -3.7 | -6.6 | -20.3 | -13.3 | -2.9 | -5.8 |
| | B1 | -13.3 | -15.3 | -3.9 | -2.1 | -13.6 | -8.3 | 2.6 | -1.5 |
| 2080s | A1B | -15.2 | -28.6 | -9.3 | -7.2 | -21.9 | -12.3 | -0.2 | -7.9 |
| | A2 | -22.8 | -31.0 | -13.4 | -14.1 | -26.2 | -21.5 | -11.9 | -17.5 |
| | B1 | -11.8 | -21.4 | -5.1 | -4.5 | -14.4 | -11.3 | 1.4 | -3.4 |

Table 1. Mean yield change (percentage to the current climate simulated yield) for three time periods and three scenarios, averaged across six GCMs, percentage to current.

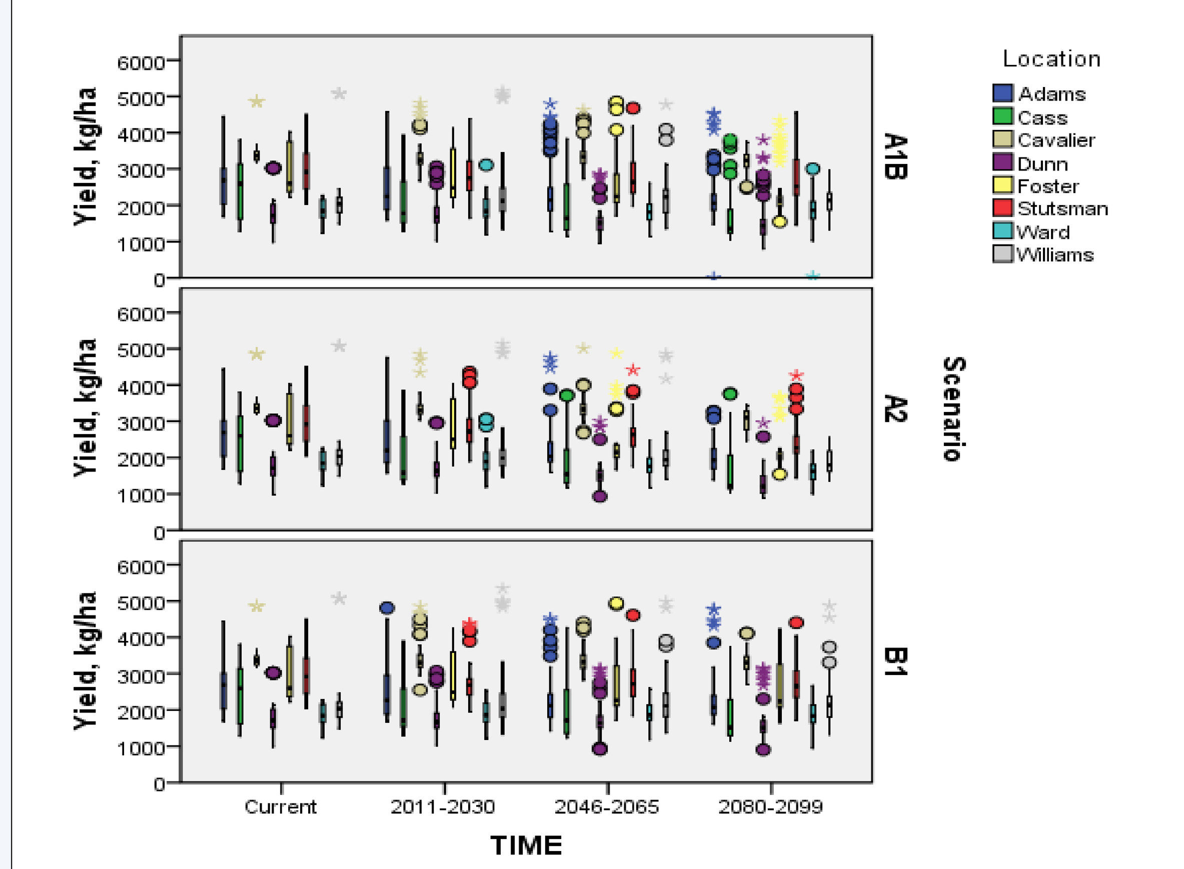


Figure 6. Change in simulated yield in 2020s, 2050s, and 2080s, for eight locations in North Dakota.

## Results: Devils Lake

We utilized three hydrological models to simulate the change in the Devils Lake area in response to the changes in climate: SWAT (Soil and Water Assessment Tool, supported by USDA) to model the effects of land use change on hydrology and water quality and the combination of HEC-HMS for modeling the watershed and HEC-ResSim for modeling the lake, both developed by Hydrologic Engineering Center (HEC) of U.S. Army Corps of Engineers. SWAT simulations of land use (figure 7) and climate change impacts are not completed and not presented in the poster, except in the validation part. For HEC-HMS, the Devils lake basin was delineated into eight subbasins, and further delineated into 97 interconnected sub-areas. For SWAT model, the watershed was divided into seven sub-watersheds.

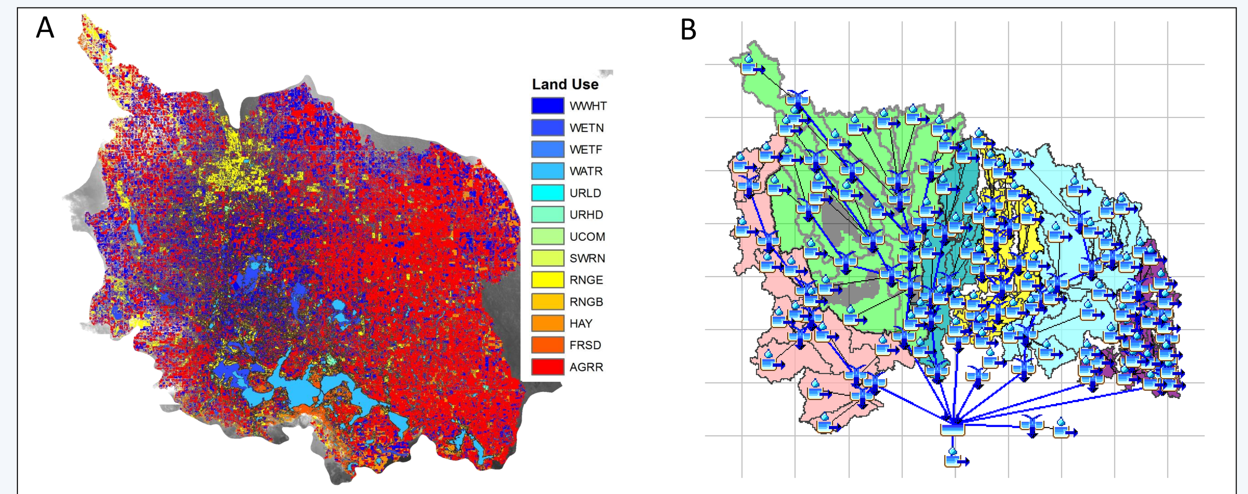


Figure 7. Land use (A) and HEC-HMS watershed delineation (B).
Abbreviations: WWHT: Winter Wheat; WETN: Wetlands-Non-Forested; WETF: Wetlands-Forested; WATR: Water; URLD: Residential-Low Density; URHD: Residential-High Density; UCOM: Commercial; SWRN: Southwestern US (Arid) Range; RNGE: Range-Grasses; RNGB: Range-Brush; HAY: Hay; FRSD: Forest-Deciduous; AGRR: Agricultural Land-Row Crops.

For model calibration, the 1991 – 2011 meteorological station data (SWAT) and 2001 – 2010 NASA data on temperature and precipitation (HEC-HMS) were used; simulated lake water level was compared to the USGS monitoring station data (Figure 8).

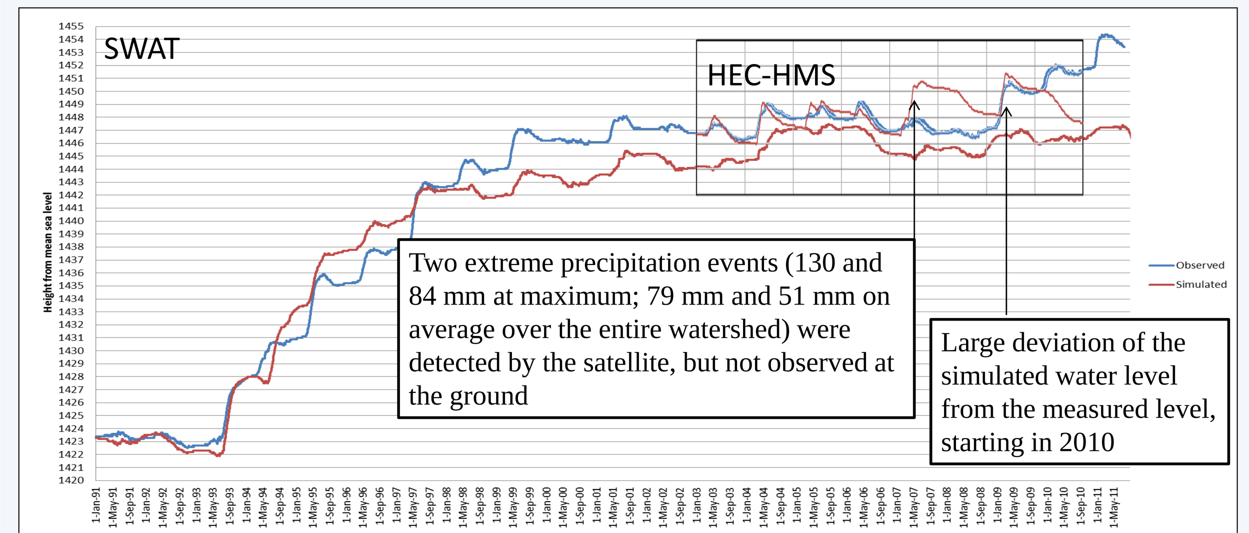


Figure 8. SWAT and HEC-HMS simulations of the Devils Lake water level (ft. amsl). Starting in 2010, both models heavily underestimate the lake water level.

The majority of HEC-HMS future climate simulations show decreasing water level (e.g., figure 9). However, prior to explanation of the deviation of simulated results from the measured lake water level, starting in 2010 (figure 8) and considering the effect of land use change, the uncertainty of these results will remain high.

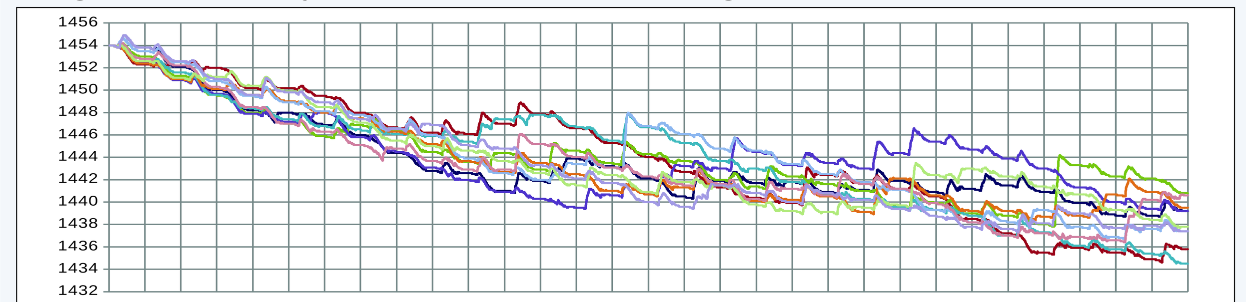

Figure 9. An example of HEC-HMS simulation of the Devils Lake water level (ft. amsl) under the 2020s CSMK3 A1B climate.


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