

The Fate of Devils Lake: An Interwoven Aftermath of Agriculture and Climate Change

Xiaodong Zhang

Department of Earth System Science and Policy, University of North Dakota
zhang@aero.und.edu

Abstract: A dry period in the mid-20th century caused the lake area to become greatly reduced, allowing people to build and begin farming on the floodplain. Since 1993, Devils Lake has risen a dramatic 8.5 m in elevation to 442 m, flooding both residential and agricultural zones in the surrounding area. Rising another 3 feet to an elevation of 445 m, the lake would overflow. To date, \$1 billion in federal, state and local funds have been spent to help mitigate flooding in the Devils Lake basin. It will cost several hundreds of millions if protection of overflow is needed. Some communities, displaced families and businesses have lost everything, and the future of those who remain is clouded by the very real possibility of continued disaster. A model is currently under development that will incorporate satellite observation to investigate the effect on the lake level of agriculture expansion and future climate change. The results will be of great value in helping local community to solve a real problem and make a wise (and educated) decision..

Keywords: Devils Lake; flooding; remote sensing; land use change; climate change.

1. Introduction

The Devils Lake basin is a 9,868 km² closed basin in the Red River of the North Basin (Fig. 1). At current water levels, the lake itself has no natural outlet and is deemed as an endorheic (terminal) lake with evaporation serving as the only mechanism of water loss.

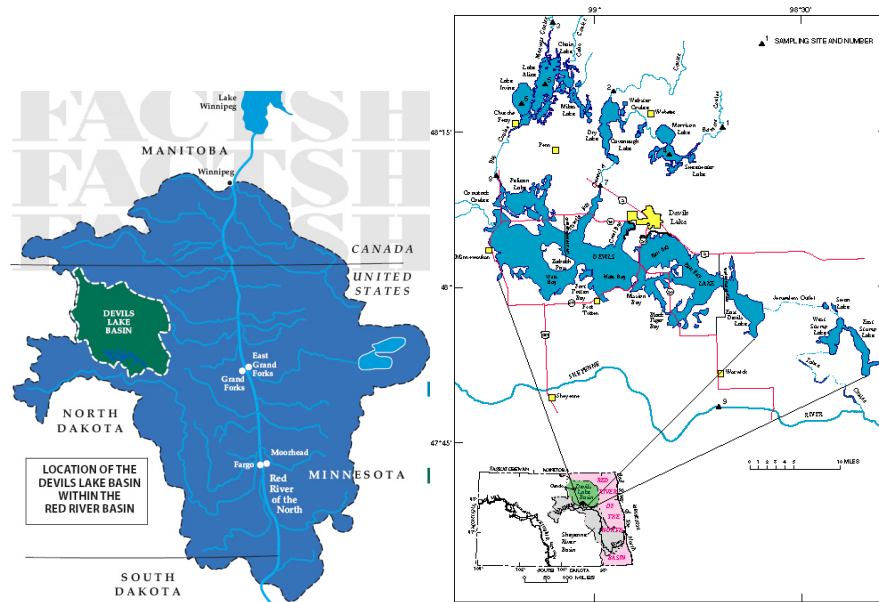


Fig. 1 The Devils Lake basin and the Devils Lake.

At the elevation of 441 m above sea level (asl), Devils Lake starts to spill into Stump Lake to the east. And at an elevation of about 444.7 m asl, the combined lakes begin to spill through Tolna Coulee into the Sheyenne River, a tributary of the Red River, which flows into Canada. Since the end of glaciations about 10,000 years ago, Devils Lake has been fluctuating from overflowing to dry [Bluemle, 1991]. Research by the North Dakota Geological Survey indicates Devils Lake has overflowed into the Sheyenne River at least twice during the past 4,000 years and has spilled into the Stump Lakes several times [Bluemle, 1991; Murphy et al., 1997].

In 1867, when lake surface elevation was first measured, the lake stood at elevation 438 m asl, covered about 337 km², and contained about 1.85 km³ water. By 1940, after several years of extreme drought, the lake had diminished even further, dropping to a record-low elevation of 427 m asl and covering only 26 km² [Wiche and Pusc, 1994]. Since 1940, the lake has exhibited a dramatic resurgence – particularly over the past 16 years – largely in response to a substantially wetter climate (Fig. 2). On April 2, 2010, Devils Lake crept to a new record level, surpassing the previous record of 442.18 m asl, set on June 27, 2009. Today, the lake covered about 622 km² and contained about 4.07 km³ of water.

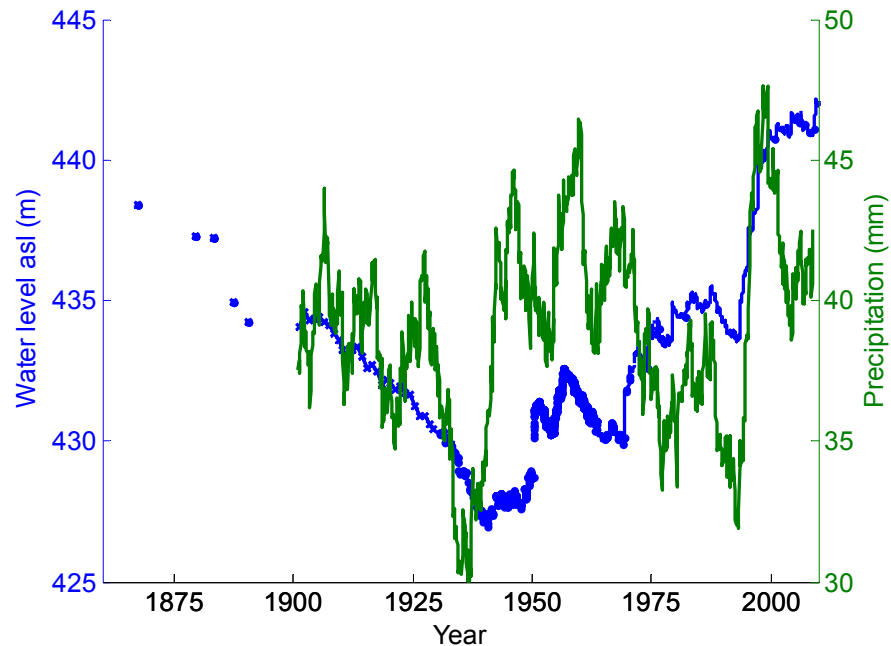


Fig. 2. Water level of Devils Lake and monthly precipitation recorded at the U.S. Historical Climatology Network station Langdon, ND (48.7622 N, 98.3447 W). The precipitation data was smoothed by a 6-year running window.

Unlike riverine floods, which are primarily triggered by short-term precipitation or snowmelt events, Devils Lake flooding primarily depends on long-term climatic conditions in the basin. Water rises slowly, but the higher water levels persist. Therefore, understanding future regional climate under all possible scenarios is critical for understanding the hydrology of the lake.

Retreat of glacier about 10,000 years ago not only left Devils Lake but also created numerous potholes, which had given the North Dakota's prairies the title "America's Duck Factory". Rapid agricultural expansion had drained nearly all of the prairie wetlands in North Dakota by 1930's. The research conducted by West Consultant Group in 2001 showed that 374 km² of wetland in the Devils Lake basin had been drained [West Consultants, 2001]. United States Fish and Wildlife Service estimated that 769 km² of wetland have been drained, as compared to the estimate of 607 km² given by North Dakota State Water Commission [Noone, 2003]. Some of the conservation groups claim that 1416

km² of wetland have been drained. Drainage of wetlands in the glaciated prairie region can greatly increase discharges [Moore and Larson, 2980]. At present, 70% of land in the Devils Lake basin is used for crop production and 21% is used for ranching or participates in Conservation Resource Program (Fig. 3).

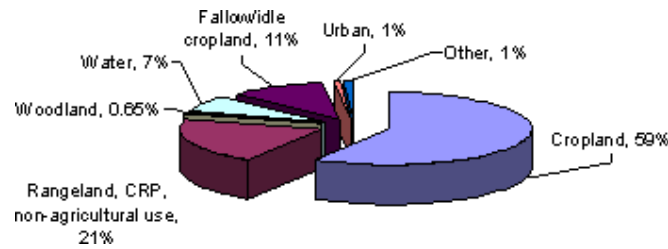


Fig. 3 Land use in Devils Lake basin for 2000

Modern records show that water levels in Devils Lake have increased dramatically three times (Fig. 2), during the years 1940 – 1956, 1983 – 1987 and recently since 1993. However, the recent rise inflicted the most significant damage because much of the area's development occurred during the previous period of low lake levels. So far, an estimated \$1 billion has been spent on flood mitigation. However, because of the nature of encroachment of lake rising, many of the flood mitigation projects were planned for short term benefit. Had it be known that the wet cycle would last up to now, many decision would have been made differently, probably saving a significant amount of money (Belford, personal communication).

If the current wet cycle continues, an improved knowledge of how the lake levels will respond to the future climate is critical for making decisions with long term applicability. Currently, a Devils Lake stochastic simulation model developed by the U.S. Geological Survey (USGS) [Vecchia, 2002; 2008] is being used to predict the potential water level. The analyses, in terms of exceedance probability, however, are all based on ground observations (e.g., lake or rain gauges) and on the assumption that the climate is stationary - regional climate do not change with time. Thus, the impacts of future climate change and climate policy on regional hydrology are not incorporated into the decision-making process.

In this study, the hydrological state of Devils Lake in the future was evaluated by driving a distributed hydrological model with different climate change scenarios using multiple General Circulation Models (GCM) projections. A salient feature of our approach is that NASA's satellite observations data were used, both providing a more uniform and denser distribution of input parameters required for the hydrologic modelling than ground-based observations and serving as a basis for generation of future climate scenarios.

2. Method and Data

Because the Devils Lake Basin is much larger than the lake area itself, a hydrologic model is essential to characterize the precipitation–runoff process. The lakes and channels are frozen for the majority of the winter months, while snow covers the overland basin areas. Thus, the capability to model water movement within the basin is even more critical. For engineering design purposes, the hydrologic and hydraulic models must be able to provide lake levels at sub-feet accuracy. Notably, an inch in lake level can imply a 10,000-acre-foot difference in the calculated water balance [Vecchia, 2008]. A combination of a distributed hydrologic model and a detailed lake/reservoir hydraulic model is, thus, needed to provide lake level information at sub-feet accuracy. The U.S. Army Corps of Engineers' Hydrologic Modeling System (HEC-HMS) for the rainfall-runoff model and the Reservoir System Simulation model (HEC-ResSim) for reservoir modeling and flow routing were used for hydrological modelling. For detailed description of the models and the associated results, refer to a companion paper by Lim et al. [2010].

Comprehensive analysis of possible impacts of climate change requires a set of simulations combining a variety of GCM runs under a variety of scenarios because 1) different paths of

economic and societal development will have different radiative forcing; 2) the results of different GCMs diverge from each other; and 3) even a single GCM running under the same scenario will return different results due to stochastic nature of weather generation. We will estimate future climate conditions in the Devils Lake region by combining the historical data on temperature, precipitation, air humidity, and wind speed with an ensemble of GCM projections. For base climate, we will use the 1971-2000 monthly values for temperature and precipitation. For future climate, we extract monthly projections of seven different GCMs: CCMA_T63, CSIRO, GFDL_CM2, GISS_E-R, MPI, NCAR_PCM, and UKMO, for three pre-set time periods, 2020s, 2050s, and 2080s. Additionally, for each of the GCMs we employ three SRES scenarios, A1B, A2, and B1, [IPCC, 2000]. For detailed description on climate modelling, refer to a companion paper by Kirilenko [2010].

A variety of NASA data products and model outputs, including precipitation, temperature, soil moisture, and other parameters, were used as inputs to the project’s hydrological and climate models. Table 1 summarizes the prospective data.

Table 1. Prospective NASA data products and parameters to be used.

Instrument/Model/Parameter	Spatial Resolution	Spatial Coverage	Temporal Resolution	Temporal Coverage
LPRM ^a Soil Moisture (AMSR-E, TMI, SSM/I, SMMR)	¼ deg	Global	Daily	2002-Present
TMPA ^b Precipitation (TMI, SSM/I, AMSR-E, AMSU-B)	¼ deg	Global 50N-50S	3-hourly, Daily	1998-Present
Aqua AIRS Surface Air Temperature	1.0 deg	Global	Gridded	2002-Present
GLDAS ^c Surface Radiation, Snow Water Equivalent, etc.	¼ deg	Global	3-hourly	2000-Present

^aLand Parameter Retrieval Model; ^bTRMM Multi-satellite Precipitation Analysis; ^dGlobal Land Data Assimilation System.

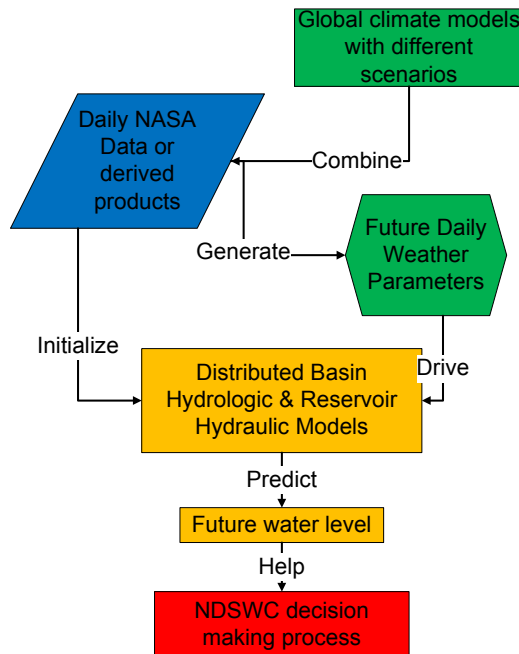


Fig. 4. Flowchart of predicting future water level.

Fig. 4 summarizes the process of combining climate model, hydrological model and NASA data in predicting future water level. In addition climate scenarios, the models developed

can also be used to investigate the impact of different land use/land change on the lake hydrology.

3. Results

The extent of expansion of Devils Lake can be clearly seen from a time series of satellite imagery (Fig. 5). From 1991 (Fig. 5-a) to 2009 (Fig. 5-c), the main water body of Devils Lake had expanded 453 km² (Fig. 5-d), with immediate loss of fertile land and commodity valued between \$60 - \$100 million. In Fig. 5, only the main water body of Devils Lake was shown. Including the smaller lakes in the upper drainage basin (Fig. 1), the rising water has inundated 598 km² of land, with a loss of \$130 million in land and commodity.

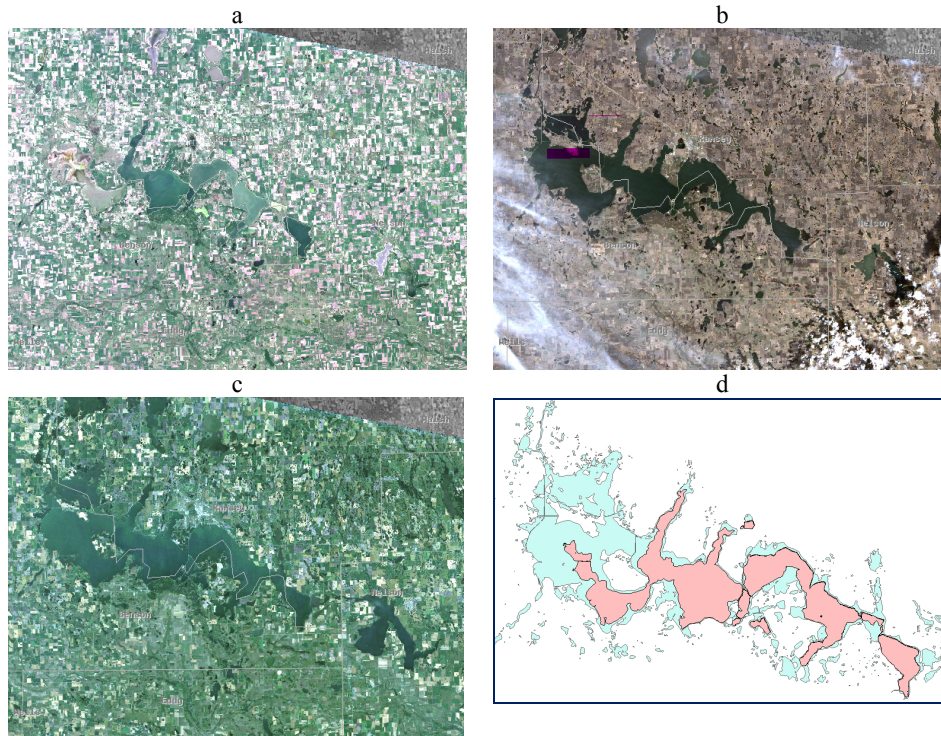


Fig. 5. Landsat images (true color composite with bands 4, 3 and 2) over Devils Lake on June 12, 1991 (a); May 3, 2000 (b); September 1, 2009 (c); and the delineations of the lake area in 1991 and 2009 (d).

Satellite data from NASA's Tropical Rainfall Measuring Mission (TRMM) for precipitation, from Advanced Microwave Scanning Radiometer – Earth Observing System (AMSR-E) on soil moisture, and from Atmospheric Infrared Sounder (AIRS) for air temperature were used to provide input parameters for the hydrologic models (Fig. 6). As shown in Fig. 2, the increase in precipitation during the past 17 years is the major reason for the lake rise and expansion. However, the soil moisture concentration, which currently is not measured regularly on the ground, is also important in regulating the discharge of water into the streams. The measurements from AMSR-E, even though only valid for the top few centimetres of soil, can provide at least an approximate estimate of saturation state of the soil. The air temperature near surface is an important parameter for estimating potential evapotranspiration and snow melting. The latter is of particular importance because spring melting of snow leads to rapid rises in water level.

Preliminary comparison showed that the satellite-derived precipitation measurement agree well with the rain-gauge measured values on the ground (Fig. 7), with a correlation

coefficient of 0.97. Currently, the satellite data on the other parameters of air temperature and soil moisture is being evaluated against the ground measurements.

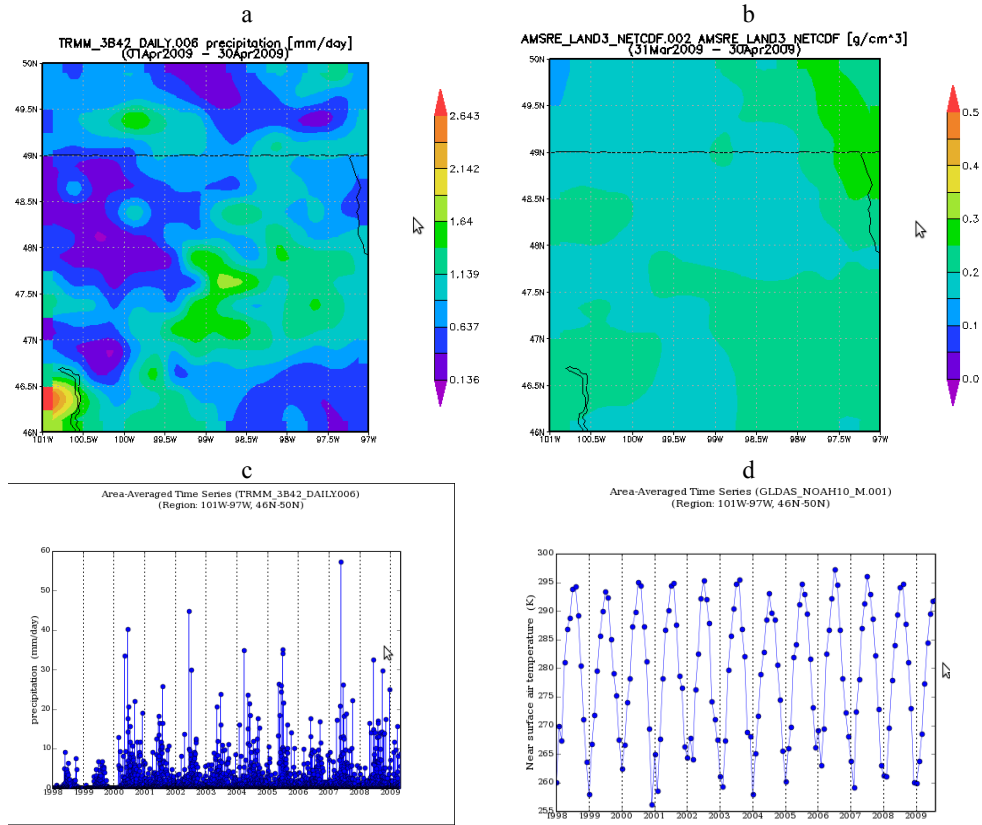


Fig. 6. Examples of satellite derived parameters used as inputs to the hydrologic and hydraulic models as well as to the weather generator. (a) TRMM precipitation, (b) AMSR-E soil moisture, (c) and (d) time-series of TRMM precipitation and AIRS air temperature near the surface over the entire basin from 1998 to 2009.

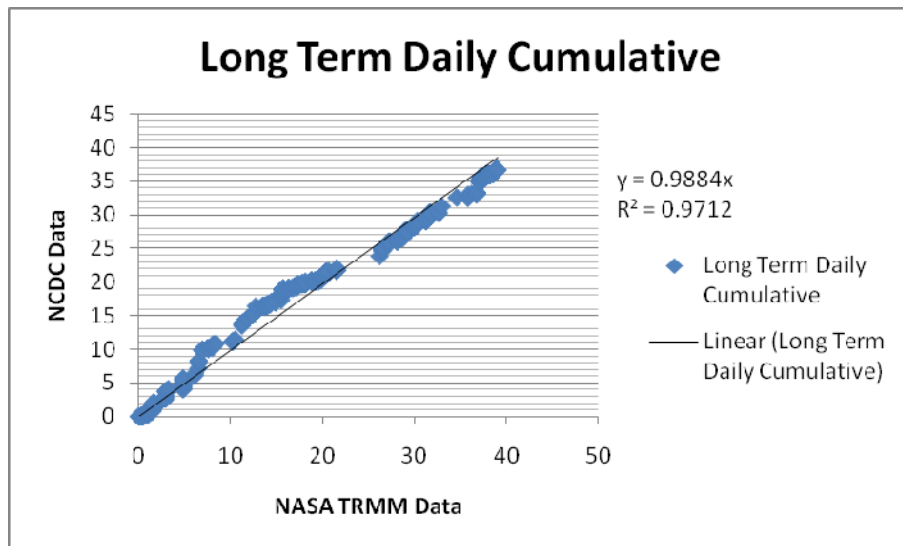


Fig. 7. Daily-cumulative precipitations measured by the rain gauge (maintained by National Climate Data Center) and TRMM in the years of 2001 and 2002.

4. Conclusions

With nearly \$1 billion has been spent on mitigating flood impacts caused by rising water of Devils Lake, the future variation of the lake is of great concern to people, the government agencies and all parties involved. Because of non-stationary nature of climate, especially under the anthropogenic influence due to continuously increased release of green house gases, future climate projections need to be investigated for a variety of possible scenarios. A physical hydrologic model combining watershed and reservoir is under development and will be used to evaluate how the changing climate in the future will affect the water level. Satellite observations, continuous and well distributed spatially, will improve the accuracy of the model. A combination of climate model, hydrologic model and remote sensing offers great potentials in helping decision making of real world problems related to water.

ACKNOWLEDGMENTS

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