Conducting a Virtual Flood for Devils Lake, North Dakota

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Abstract

This paper describes the process of planning and conducting a Virtual Flood of Devils Lake, North Dakota. A Virtual Flood is a workshop in which interested parties can use computer simulations to test flood fighting measures.

Devils Lake, a terminal lake located in North Dakota, has risen over 20 feet during the last four years. This increase in elevation has generated approximately $120 million in damages and mitigation efforts. In 1995, 1996 and 1997, the lake rose to levels hydrologists had said were possible, but improbable. Levees were built and then raised, and raised again. The St. Paul District of the US Army Corps of Engineers and the State of North Dakota are studying a plan to pump lake water into an adjacent river basin. The first analysis showed the costs for the pump were much greater than the benefits, but many distrusted the analysis because the economic benefits of the pumping plan were based on the estimate of probable future lake levels. The question in many peoples’ minds was, if we were forecasting lake levels better, would the benefits exceed the costs?

Late in 1997, the Corps, the state, and stakeholder groups agreed to participate in a Virtual Flood of Devils Lake. The goal of the Virtual Flood of Devils Lake, held on March 11, 1998 in Grand Forks, North Dakota, was to develop a common understanding among stakeholders and management agencies of the effectiveness of a proposed artificial outlet in reducing flood damages. The Virtual Flood demonstrated that the outlet would likely not reduce lake levels enough in the next several years to avoid other flood fighting costs, such as the construction of levees and road raises.

The Problem

Devils Lake is a closed basin lake, like the Great Salt Lake in Utah, meaning that water does not flow out of the lake except after periods of sustained high inputs, when the lake will spill into an adjacent lake (Stump Lake) or even into the next basin (Sheyenne River). This has not happened in recorded history (Figure 1). Water does leave the lake by evaporation, and in many years more water evaporates than enters the lake. For example, gage records show that Devils Lake dropped about forty feet
from the mid 1800's to 1940. But since 1940, the lake, with some temporary reversals, has risen to the highest levels recorded. Archeological evidence suggests that within the last 9000 years the lake level has fallen below its 1940 low and exceeded its current high.

In the last few years, the lake has engulfed some homes, while over one hundred homes have been relocated and several roads elevated to avoid flooding. The state has paid farmers in the basin millions of dollars to reduce flows into the lake by detaining it on their land. Levees have been built and then raised and raised again as the lake climbed to levels experts recently thought were improbable. In 1998, lake levels reached 1444.7 feet above mean sea level (msl), the highest level on record (1860 and beyond). Because the terrain is fairly flat, the area of the lake has increased as it has risen. Homes threatened by flooding in 1998 may have been miles from the lake shore in 1992. No one knows how much higher the lake will rise, but it could rise to as high as 1462 feet above mean sea level, approximately 18 feet above current levels. At that point, water would flow through Devils Lake and Stump Lake into the Sheyenne River. Those discharges could increase flooding and erosion in the Sheyenne and Red River of the North (to which the Sheyenne River is a tributary). The water quality of the discharge from East Stump Lake is expected to be much worse than the ambient quality of the Sheyenne River waters.

**Downstream Flooding and Water Quality.** The outlet would pump water from Devils Lake into the Sheyenne River, which flows into the Red River of the North. The Red River of the North flows between Minnesota and the Dakotas into Manitoba, Canada, where it empties into Lake Winnipeg. It experienced record flooding in 1997 when record snowfall and rapidly warming spring temperatures created record flood flows all along the Red River. When flood waters reached Manitoba, 28,000 people were evacuated. There was major damage outside Winnipeg, but the floodway and diking efforts saved the city from a catastrophe. Over 8,000 Canadian Armed Forces personnel participated in the flood-fighting effort and ring dikes built around eight "island communities" kept these communities dry through the flood. Discharges from the Devils Lake outlet would be limited so that farms along the Sheyenne River in North Dakota and the Red River of the North in Minnesota and Manitoba would not be inundated with more and saltier water.
The discharge from the outlet could also produce water quality problems along the Sheyenne River. Drinking water supplies of communities such as Valley City, ND could be contaminated enough by the discharge from the outlet to require additional treatment. If a natural spill from Devils Lake occurs, Red River flooding is likely and more intense but shorter term water quality degradation in the Red River would almost certainly occur. The discharge from a man made outlet could be controlled based on whether the discharge would create Red River flood damages. Flooding would increase erosion and the salty water could destroy the arability of the inundated land.

**Stakeholders.** Flooding threatens portions of Benson and Ramsey counties, including the Spirit Lake nation. In addition, the economy of the region has been hurt because the high lake levels have made it more difficult to use Devils Lake for fishing and boating. Should Devils Lake discharge into West and East Stump Lakes, the resultant change in salinity and water levels in those lakes would exacerbate the impacts on tourism. Workshop participants included agency representatives responsible for managing these problems or stakeholders who would be affected by the flooding or the outlet.

**Levees, relocations and upland flow detention.** Levees and relocations have reduced flood damages, but these measures are costly and disruptive, do not reduce lake levels or eliminate all flooding. The levee raise at the City of Devils Lake is being conducted in several increments. The first raise cost $25 million. It lengthened and added 5 feet in elevation to the original levee. At that point, the top of levee elevation was 1450, providing protection to elevation 1445. (The five foot freeboard allowed for wave action). This increment is essentially complete except for two of the pumping stations. The second increment cost $11 million and will raise the entire levee to 1452 (protection to 1447). Construction on this increment started on 6 July 1998 and was 50% complete in January 1999. The third increment cost $5 million, and will raise the entire levee to a level of protection of elevation 1450 (top of levee at elevation 1457). Construction on this last increment was started in September 1998. Total cost for the levee raise and extension is $41 million. These levees may be overtopped if the lake continues to rise. The state of North Dakota has also paid farmers in the upper basin (see Figure 2) to detain water on their land to reduce inflows to the lake, but, at least at the current investment level, that has not solved the flooding problem.

Consequently, the Corps and North Dakota began developing plans to build an artificial outlet from Devils Lake into the Sheyenne River. Under current plans, pumps situated at the west end of the lake would push water through a pipeline running southwest to the Sheyenne, with the insertion point upstream of Lake
Figure 2. Devils Lake Basin

Ashtabula, a Corps reservoir on the Sheyenne. The Sheyenne flows east and then north into the Red River of the North, which forms the boundary between North Dakota and Minnesota until it flows into the Canadian province of Manitoba. Thus, water pumped from Devils Lake, in diluted form, would find its way into Canada.

Uncertainty demands better decision tools. The outlet plan is itself controversial. There are several concerns regarding the cost-effectiveness of the outlet, the impact on water quality and flooding on the Sheyenne and Red River of the North, and the potential for introducing foreign species into the Sheyenne. There are also technical difficulties in estimating the outlet’s value as a flood damage reduction measure. It is unusually difficult to estimate the chance that Devils Lake will overtop existing protection. That means that benefit-cost estimates - the principal basis for Corps of Engineers recommendations under Federal rules - are especially uncertain. Previous Corps analyses have shown that the costs of an outlet would exceed the benefits, but these estimates were based on earlier (lower) lake levels, and used a forecasting model that estimated a low probability that Devils Lake would be as high as it is today. The Corps is currently updating the entire benefit-cost analysis, including future lake level probabilities.
In light of these difficulties, Dr. John Zirschky, then Assistant Secretary of the Army for Civil Works, asked the Corps’ Institute for Water Resources (IWR) to develop analytic tools that would help the Corps make a sound recommendation on the construction of an emergency outlet despite the uncertainty about the extent of the flood threat. The Virtual Flood was one of those tools. It was designed to help stakeholders and agencies, whether opponents or proponents of the outlet, to develop a common understanding of how the outlet would work and how it would affect them.

**Shared Vision Planning.** Shared Vision Planning is a marriage of systems engineering, public policy and public involvement. This approach was developed during the Corps’ National Drought Study (1989-1993) to help reduce impacts and conflicts associated with water resources management issues. The Devils Lake Virtual Flood was characteristic of the first part of a shared vision planning process, but much greater stakeholder involvement would be required to develop enough trust in the planning approach and tools.

The innovation at the heart of shared vision planning is the shared vision model. This type of model was conceived at the University of Washington by Professor Richard N. Palmer. Shared vision models are built using new, user-friendly, graphical simulation software. They bridge the gap between specialized computer analysis tools and the way people conceptualize problems and make decisions. The name shared vision models captures their most important advantage. Because experts and stakeholders can build these models together, including elements that interest each group, they become a trusted, consensus view of how the system in question works as a whole, and how it affects stakeholders and the environment. Shared vision models visibly connect stakeholder concerns to water management decisions. Without adding new bureaucracies or reassigning decision making authority, the shared vision model and the act of developing it create a virtual team of problem solvers that facilitates the integrated evaluation of the conditions they study.

The “planning” in shared vision planning is based on well established, time tested principles embodied in the US Water Resources Council’s “Principles and Guidelines”. Shared vision planning focuses on objectives rather than means, as Gilbert White proposed in his groundbreaking work of the late 1930’s. It embodies the principles of multiobjective water management developed by the Harvard Water Program in the 1950s, and applied by the Corps’ Harry Schwarz in the North Atlantic Regional Study, completed in 1972. Shared vision planning estimates the performance of alternative plans in achieving environmental, social and political objectives. Like Principles and Guidelines, Shared Vision Planning requires iterative planning, but Shared Vision Planning can be applied to any public decision making process that centers on a system that changes over time, and that provides benefits and requires opportunity costs.

**History of Virtual Testing for Droughts and Floods.** The idea of using simulations to help plan for severe hydrologic events has been around since the late 1970’s, but it has become much more practical and effective because of advances in computers and software. Dr. Richard N. Palmer (University of Washington) used a similar approach
to help resolve long term water supply issues in the Potomac River basin around 1980. In 1993, Dr. Palmer and the Institute for Water Resources used object-oriented software and personal computers to conduct a virtual drought for the City of Tacoma, the Muckleshoot Indian tribe, Washington State Department of Ecology, and the Corps’ Seattle District. Similar ideas were used in other IWR drought studies. IWR again partnered with Dr. Palmer and the University of Washington to apply shared vision planning in multi-objective water management scenarios for the Apalachicola-Chattahoochee-Flint and Alabama-Coosa-Tallapoosa River basin conflict in the southeastern United States, but no virtual events were used in that study. The authors of this paper developed and conducted this Virtual Flood. Dr. Palmer and Mr. Werick designed this Virtual Flood. Andrew Wood developed the simulation model. The Virtual Flood was held in March 11, 1998 at the Energy and Environmental Research Center, in Grand Forks, North Dakota. Thirty-nine representatives of federal, state, tribal and Canadian stakeholders.

**Objective of the Virtual Flood**

The objective of the Virtual Flood was to develop a common understanding of the effectiveness of the proposed outlet in reducing lake levels. Funding had already been appropriated by the U.S. Congress to begin construction of the outlet, but only if the Corps recommendation met very tough requirements. Information on the economic value of damages, costs of other flood damage reduction measures and environmental impacts were not available at the time the Virtual Flood was conducted, so the scope of the Virtual Flood was limited to the effect the proposed outlet would have on future lake levels.

**Hydrologic data for the Virtual Flood.** In the face of the uncertainty regarding future Devils Lake levels, the Corps asked the USGS to develop an autoregressive model that would generate 10,000 possible future traces to provide a probabilistic basis for what elevations were “expected”. The traces were generated using inflow to Devils Lake, precipitation on Devils Lake, and evaporation from Devils Lake, all by quarter year from 1950 to 1996. The model calculated 10,000 future inflow, precipitation and evaporation data sets, then used those synthetic data to calculate 10,000 sets of future lake levels, by quarter year, for the next 50 years. Inputs for successive quarters are drawn at random from the population suggested by the historic data, except that there is bias towards inflows similar to recently generated inflows. This characteristic means that the inflows generated in successive time periods are unlikely to switch from very wet to very dry, a condition unlikely to occur in reality because inflows are partly dependent on basin soil moisture which is slower to change than precipitation. The average of the 10,000 traces each quarter rises initially (biased because recent historic inflows have been high) and then heads towards about 1430.5, the elevation at which the average lake surface evaporation equals the average inflow. Individual traces, however, may peak at any time, may exceed 1462 or fall almost immediately and never return to today’s levels. (see Box ?) that can generate thousands of 50 year long time series of future lake levels. Each time series is called a trace. Taken collectively, these traces can be used to estimate the likelihood and
timing of future lake levels. For example, if only 12 of 10,000 traces exceed elevation 1462 feet msl, then the probability of Devils Lake exceeding 1462 in the next 50 years is estimated at 12/10,000 or 0.0012.

**Future Lake Level Trace Categories.** Most of the Virtual Flood workshop was based on the examination of individual traces. There were two reasons for not focusing on a statistical analysis of 10,000 traces. First, it is much easier to envision and discuss one possible future than 10,000 possible futures. Second, no one is sure that the 10,000 traces fairly represent the odds of future lake levels. For these reasons, most of the workshop was based on individual futures. Six traces were selected from the 10,000, representing four distinct management challenges. Each trace lasted 50 years (1998-2047). The categories were:

A. Devils Lake rising above elevation 1459 feet msl and thus spilling naturally into the Sheyenne River (two traces);
B. Devils Lake rising to between 1446.6 and 1459 feet msl, high enough to spill into Stump Lake, but not the Sheyenne (two traces);
C. Devils Lake stays between 1430 and 1446.6 feet msl; the lower bound of 1430 is still high enough to maintain a healthy fishery in the lake (one trace);
D. Devils Lake drops below 1430 feet msl, and undesirable outcome in terms of the fishery and lake recreation (one trace).

The analysis using individual traces was supplemented with statistical results from the 10,000 traces. These results were presented in the late afternoon.

**How Simulations Were Run.** IWR developed a simulation model expressly for the Virtual Flood, using STELLA® II software. The model replicates the mass balance portion of the USGS FORTRAN model, but has an easy to understand user interface that makes it easier for people to interact with the model. Each "flood" was based on one of the 10,000 USGS traces. The model was typically run twice, first without the outlet, and then with it. In some cases, other parameters were varied to determine the effect on results.

Because key variables could make a difference in the performance of the outlet, the simulation model used in the Virtual Flood was designed so that the effects of changes in these variables could be demonstrated easily. **Figure 3** shows the control panel of the model. The buttons on the far left (with labels such as “Elevations”) quickly display different outputs of the model. The exception is the “Clear Runs” button, which resets graphs and tables in the model. The three rotary style switches along the top allow the user to specify when the outlet pump would be operational (default value 2001), the maximum capacity of the pumps (default value 300 cubic feet per second - cfs), and the Devils Lake elevation at which the pumps would no longer be operated (default 1430 feet msl). The toggle switch on top allows the model to simulate lake levels with or without the outlet pumping. The lower row of rotary style switches
allow the user to vary the bankfull capacity of the Sheyenne River (default 600 cfs); the sulfate concentration limit on the Sheyenne where the outlet would discharge (default 450 mg/l), the lake elevation below which Upper Basin Storage would no longer be used (default elevation 1440) and the amount that inflows would be decreased annually by upper basin storage (default 20,000 acre-feet per year). Simulations were made during the Virtual Flood with reductions greater than 20,000 acre-feet, but participants were warned that no one knows if reductions of this magnitude would be possible or how much expense would be required to realize them. The upper basin rotary switches affect the model only if the lower toggle switch is flipped “ON”. The default settings for all these switches were used in all exercises except where otherwise noted.

**Example Trace.** Three of the six representative traces were run. A discussion of just one is included here for brevity’s sake. The second trace was the first of two taken from the Category A trace set, in which Devils Lake rises so high it spills naturally into the Sheyenne River. As Figure 4 shows, the outlet reduces lake levels slightly after the pumps start in 2001, but then Devils Lake reaches its peak despite the outlet. This is possible because the peak occurs just five years after the outlet starts pumping and because at elevations above 1461 feet msl a very large volume reduction is needed to effect even a small reduction in lake levels. In this extreme condition, the outlet would not preclude any flood fighting costs and would not prevent the uncontrolled release of water from the east end of Devils Lake. However, after the peak passes, the outlet would bring Devils Lake down considerably over time, so that fifty years from now, Devils Lake would be twelve feet lower than it would be with no outlet. In fact, in this
particular trace, the outlet would have reduced lake levels to 1423 feet msl, an elevation at which fish kills become a concern. For this trace, pumping is never limited by sulfate concentrations; in fact the maximum sulfate concentration increases only moderately because of pumping, from 204 to 282 (mg/l). Inflows this high would almost certainly be accompanied by high flows on the Sheyenne River, increasing the dilution effect, but reducing the quantity of water that could be added. The average sulfate concentrations at the insertion point increased from 98 mg/l to 133 mg/l because of the discharge from the outlet. The minimum concentration remained the same, occurring in a quarter where there was no pumping. In 2005, though, the outlet would not have measurably reduced lake levels because the extraordinarily high flows would have overwhelmed the pump and forced Devils Lake to an elevation where it would take very large volume reductions to produce even a small elevation reduction.

Figure 4. Devils Lake Elevations, Trace 2: Early Spill into the Sheyenne River
Conclusions

At the close of the Virtual Flood, these were the most important and widespread responses from participants:

- Most participants - including many outlet proponents - said that the outlet cannot be expected to reduce Devils Lake levels enough, or soon enough to significantly reduce additional flooding damages or to avoid the construction of more levees, relocations or road raises.

- Outlet proponents interpreted the results differently, saying that the long term reduction in lake levels and flooded area that the outlet can produce are worth its costs. They believe that the outlet must be used with relocations and land management changes to be more fully effective.

- There is still distrust of “models” and “forecasts” because for the last three years Devils Lake has risen to higher levels than the USGS had said were probable, and this made a few participants wary of the entire exercise;

- Some thought that the outlet would have appeared more effective had different traces been used in the simulation model. These kind of concerns are serious, but solvable. The model can be run with other traces. The software (STELLA II®) used for the Virtual Flood was selected because it is easy for non-modelers to use. The “Virtual Flood” and “Virtual Drought” concepts are part of shared vision planning, which is based on the premise that trust in analytic models can be built by developing and using models with stakeholders.

- Some outlet proponents and opponents hold positions not addressed in the Virtual Flood. Opponents continue to believe that upland land management could effectively reduce lake levels without the environmental consequences of an outlet, but there are no studies that establish the benefits or costs of such changes. The Virtual Flood also did not simulate lowering the divide between Devils and Stump Lake to spill water into Stump earlier. This alternative has not been studied in detail. Supporters argued that the damages caused by the next two feet of flooding would pay for the outlet, but the Virtual Flood showed that the outlet would prevent those damages only if the lake rose much more slowly than it has in recent years.

The issues of trace selection, distrust of models and forecasts, and meaningful definition of “effectiveness” could be addressed in a second Virtual Flood; if the effectiveness of upland land management alternatives were quantified, the result could also be built into the next Virtual Flood. Shared Vision Planning can build trust if it a continuing process. In this case, the Virtual Flood was valuable, but as an intervention in a good traditional planning process.