

The Development of Hydrologic Scenarios for the Detroit District COE Potential Damage Study

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Introduction

The U.S. Army Corps of Engineers (USACE), along with key cooperators, have initiated an extensive and long-term assessment of potential shoreline damages over the next 50 years due to fluctuating lake levels along the Lake Michigan shoreline. The study is expected to be conducted over a four-year period with completion by October 2000. It is dedicated to meeting several recommendations that came out of the 1986-93 International Joint Commission (IJC) Great Lakes Levels Reference Study. The Great Lakes Environment Laboratory (GLERL) of the U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA) was requested to hydrological scenarios in support of this study.

The GLERL was responsible for generating a series of alternate hydrologic scenarios based upon water supply sequences for each of the Great Lakes which would generally represent similar conditions as seen in the recent past and plausible extreme conditions over the 50-year planning horizon of the Lake Michigan Potential Damage Study. These scenarios are to include monthly mean water levels for each of the Great Lakes.

The number of alternate hydrologic scenarios generated will strongly influence the level of effort and resources required, in order to conduct economic impact analyses. A USACE study team identified five critical alternative scenarios to be generated:

1. Using existing recorded ranges on each lake, generate a scenario with similar frequencies of recorded extremes.
2. Using existing recorded ranges on each lake, generate a scenario with increased frequencies of extremes.
3. Generate a scenario with increased frequencies of low water levels on each of the lakes.
4. Generate a scenario with increased frequencies of high water levels on each of the lakes.
5. Generate a scenario with an increase in frequencies of extremes for both high and low water levels.

As a result of a May 1999 meeting between representatives of GLERL and USACE, two additional scenarios were added.

6. Generate a scenario that includes the highest monthly water level centered in a 50 year time series.
7. Generate a scenario that includes the lowest monthly water level centered in a 50

year time series.

Basic Data

The only available data set for developing the required scenarios is a time series of 49,950 years of simulated lake level data. This data was simulated by routing a time series of 49,950 years net basin supply data (Rassam et al. 1992) through a hydrologic response model of the Great Lakes system which includes the modified regulation plans for Lakes Superior and Ontario (Lee et al. 1994). The net basin water supplies were generated by using a shifting-level multivariate autoregressive (SL/AR(1)) model (Salas and Boes 1980) based upon historical water supplies to the individual Great Lakes for the time period 1900-1989. The model was designed to preserve on an annual basis, the spatial cross-correlation of order zero between lakes, the annual serial correlation, shifts in the historical supply series, and the means and standard deviations. In addition, it was designed to preserve the monthly means and standard deviations of the net basin supplies (Lee et al. 1994). The results of the simulations were judged relative to those of the 1900-1989 period using 16 evaluation statistics (Rassam et al. 1992). The model satisfactorily reproduced both annual and monthly net basin supply and water level statistics. These data are on a monthly basis for all the lakes with the exception of Lake Ontario, which are on a quarter monthly basis (Lee et al. 1994).

Approach

The various scenarios were selected using a sliding 50-year window passed through the entire data set. For each of the five scenarios, several 50-year blocks of data were identified which met the criteria. Percentiles were calculated from the lake levels for the years of record for a selected site and the selected 50-year blocks. The selected site for Lakes Michigan-Huron was Harbor Beach. The percentiles were developed by dividing the range of levels for each lake (minimum to maximum) into equal bins of 0.05 feet. The bins were filled based on how many values in a scenario fell between the minimum and maximum values for each bin. The percentiles for the selected 50-year blocks were then plotted versus the percentiles for the years of record. A representative 50-year block was chosen for each of the five scenarios, based on a visual assessment of the plots that met the various criteria.

For scenario 1, high and low water level values for the years of record were compared to the high and low values for each of the 50-year blocks in the simulated water level data. Matching blocks were chosen based on a maximum tolerance of 0.05 feet. Scenario 2 was selected much like the first. The only difference was in the maximum tolerance. It was increased to 0.07 feet.

For scenario 3, matches were chosen from blocks which had high water levels that exceeded the years of record maximum by at least 1.5 feet. Selection scenario 4 was much like the third except that low water levels were compared.

Matches were chosen for scenario 5 from those blocks which exceeded both the high and low water levels (of the years of record) by at least 0.07 feet.

A match was chosen for scenario 6 by finding the maximum lake level value in the 49,950 years of data. The scenario consisted of the levels from 25 years before the maximum through 25 years after the maximum. Scenario 7 was chosen in a similar manner with one exception: the minimum value was used not the maximum.

Results

Figures 1-7 show the scenarios chosen for Lake Michigan-Huron for the seven scenarios. The detailed water level data are given in Tables 1-7. The thicker line on all the figures represents the data for the years of record, 1900-1997. For scenarios 6 and 7 (figures 6 and 7), the lake levels were plotted, not the percentiles. This was done because scenarios 6 and 7 were formulated to show lake level trends before and after the extreme condition.

Discussion

The 50-year blocks representing the extremes for the non-regulated lakes, Lakes Michigan-Huron and Lake Erie, display a significant divergence from the data for the years of record. In addition, the 50-year blocks chosen as matching the years of record (figures 1and 2) did reasonably match the years of record.

However, the results for the regulated Lakes, Superior and Ontario, appear less reliable. In the case of the regulated lakes, there were few choices for plausible scenarios. For a few of the scenarios on the regulated lakes, there were no 50-year blocks which met the necessary criteria (0.05 and 0.07 tolerances for Lake Ontario). Regulation compresses the extreme ranges on Lakes Superior and Ontario (see figures 19-21). Due to this compression, there are many duplicate scenarios (scenarios with the same range). As a result, you might have five scenarios which fit the criteria but since their ranges are so close to one another, only one will be chosen.

The reflectivity of the scenarios to conditions outside the historical record can be assessed in a general sense through comparisons with paleo lake levels. A comparison of the scenarios with data presented at a recent workshop on paleo lake levels (Sellinger and Quinn, 1999) show general agreement of the 50 year scenarios for extreme conditions with derived paleo lake levels

over the past 3000 years

Conclusions

Based upon the results, the scenarios chosen for the non-regulated lakes represent plausible, future extreme conditions. However, care must be taken with regulated lakes, because lake level fluctuations are directly a function of the regulation plan in use at the time. The scenarios for Lake Ontario (see figures 19-21), for example, as one would expect exhibit smaller range of extremes than those for the non-regulated lakes, namely Lakes Michigan-Huron (see figures 3-5).

For Lake Superior, several 50-year blocks were identified for the third scenario. However, no 50-year blocks met the criteria for the first and second scenarios and only one met the criteria for the fifth scenario. In addition, the 50-year blocks identified for the fourth scenario only met the criteria up to the 5th-percentile (see figure 17) and violated the criteria everywhere else. These results show that identifying plausible scenarios for the regulated lakes using simulated lake levels based upon present regulation plans are difficult as future regulation may not be the same as used in the past.

References

- Lee, D. H., Quinn, F. H., Sparks, D., and Rassam, J. C. 1994, Modification of Great Lakes regulation plans for simulation of maximum Lake Ontario outflows. *Journal of Great Lakes Research* 20(3):569-582.
- Rassam, J.C., Fagherazzi, L. D., Bobee, B., Mathier, L., Roy, R., and Carballada, L. 1992, *Beauharnois-Les Cedres Spillway Design Flood Study with a Stochastic Approach*. Hydro-Quebec, Montreal, Quebec.
- Salas, J. D., and Boes, D. C. 1980. Shifting level modelling of hydrological series. *Advances in Water Resources* 3:59-63.
- Sellinger, C., and Quinn, F. H., Editors. Proceedings of the Great Lakes paleo-levels workshop: the last 4000 years. *NOAA Technical Memorandum ERL GLERL 113* pp. 43 1999.

Figure 1 - Scenario 1 for Lakes Michigan-Huron

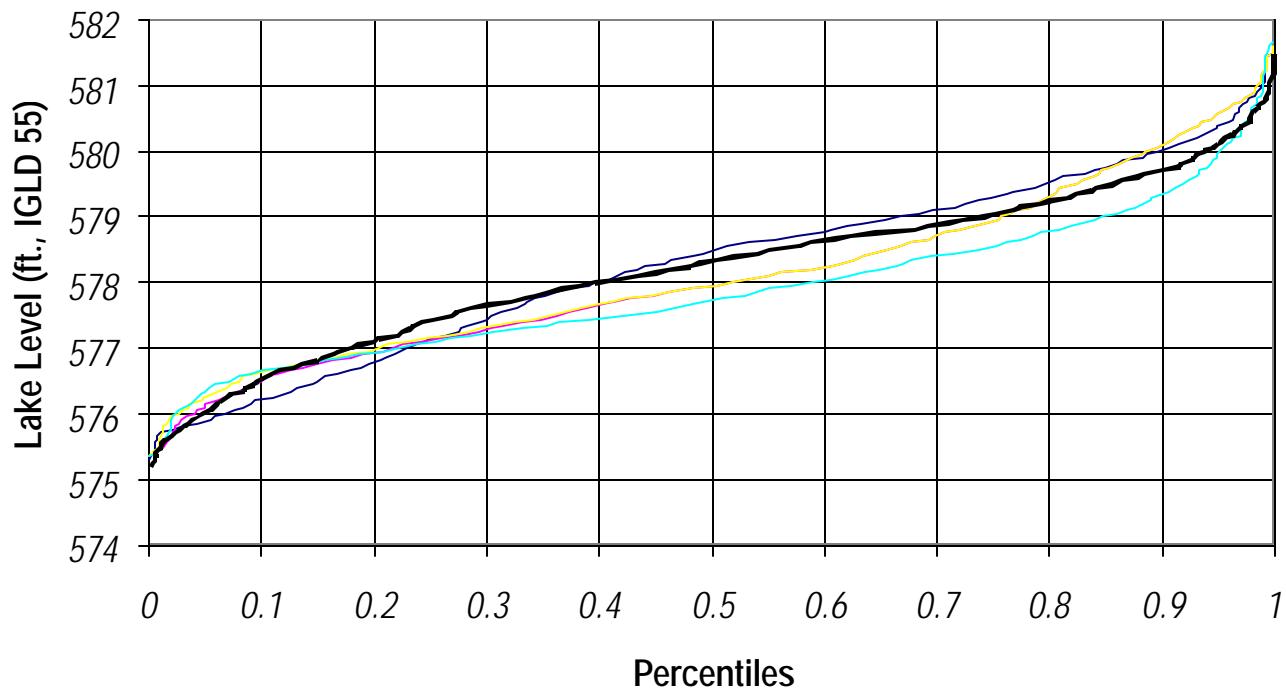


Figure 2 - Scenario 2 for Lakes Michigan-Huron

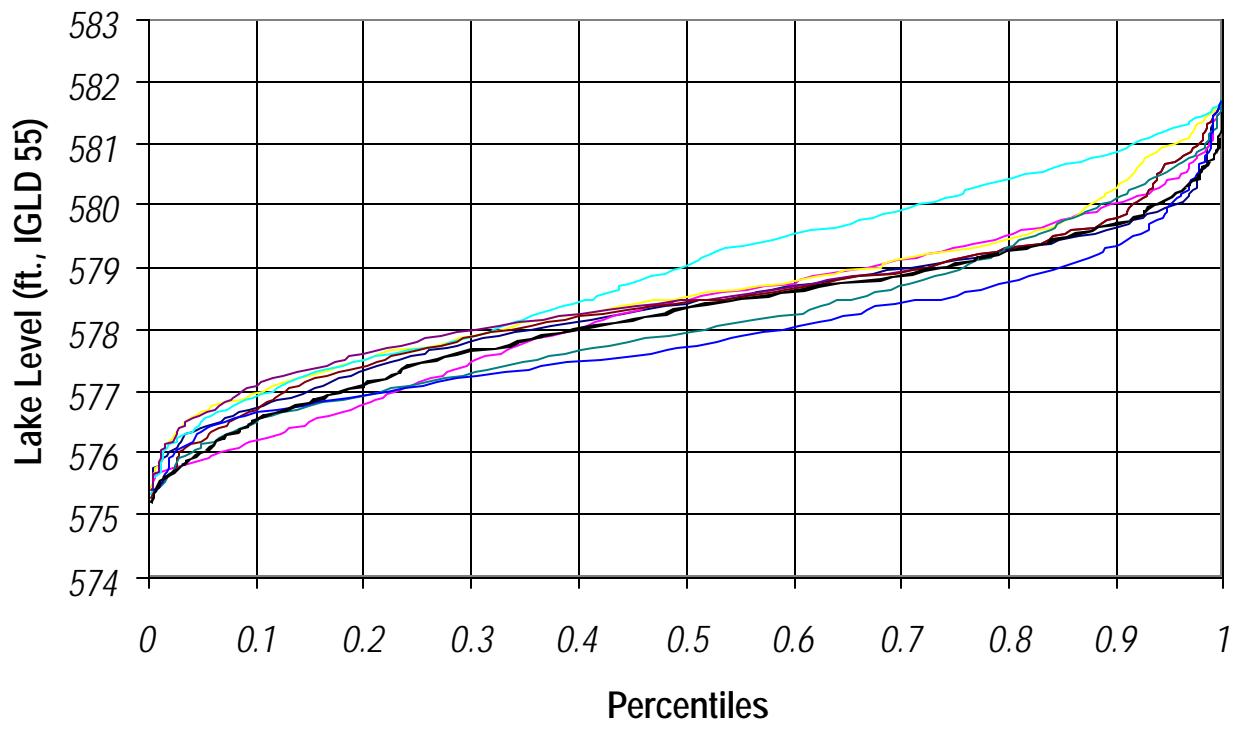


Figure 3 - Scenario 3 for Lakes Michigan-Huron

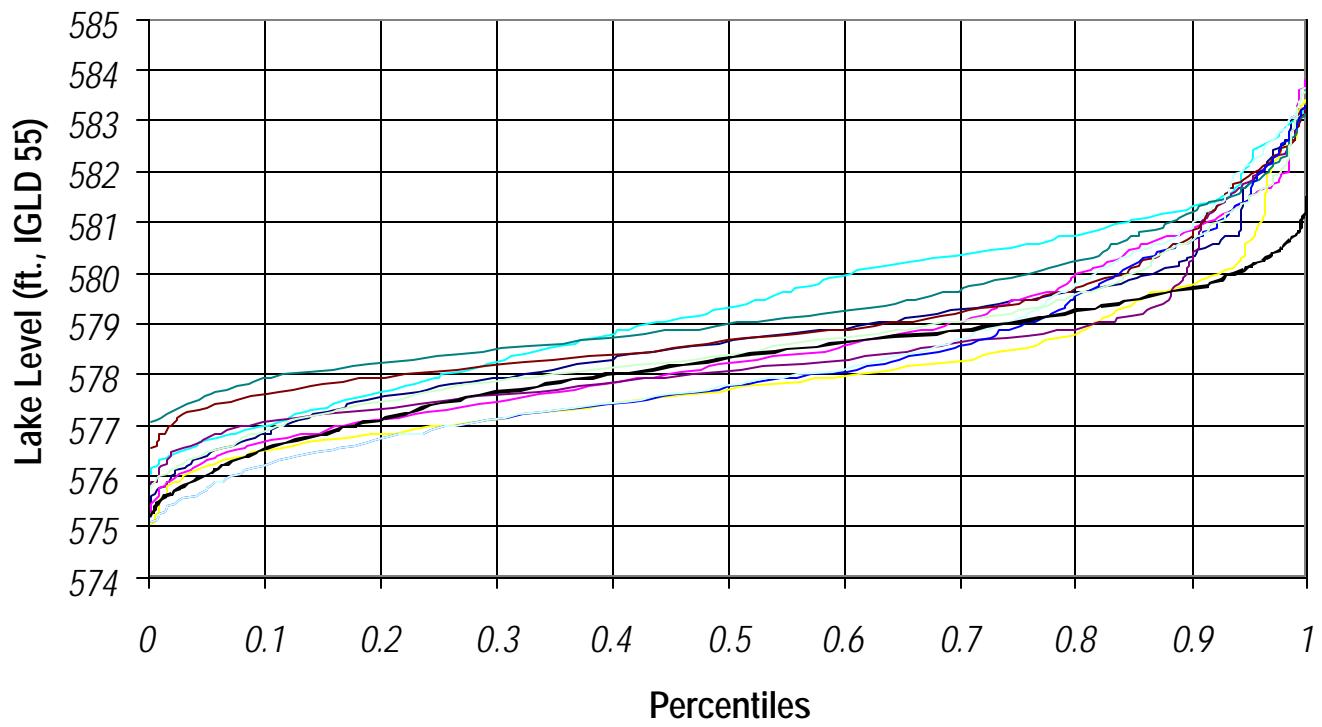


Figure 4 - Scenario 4 for Lakes Michigan-Huron

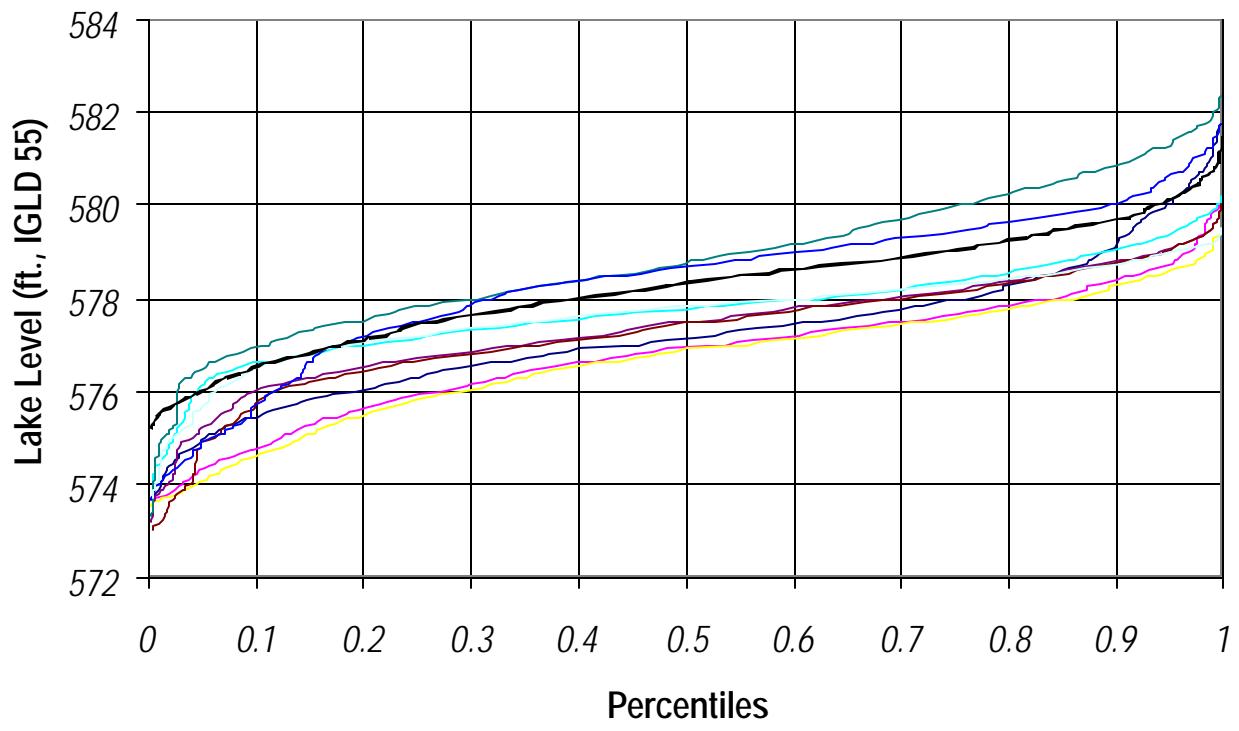


Figure 5 - Scenario 5 for Lakes Michigan-Huron

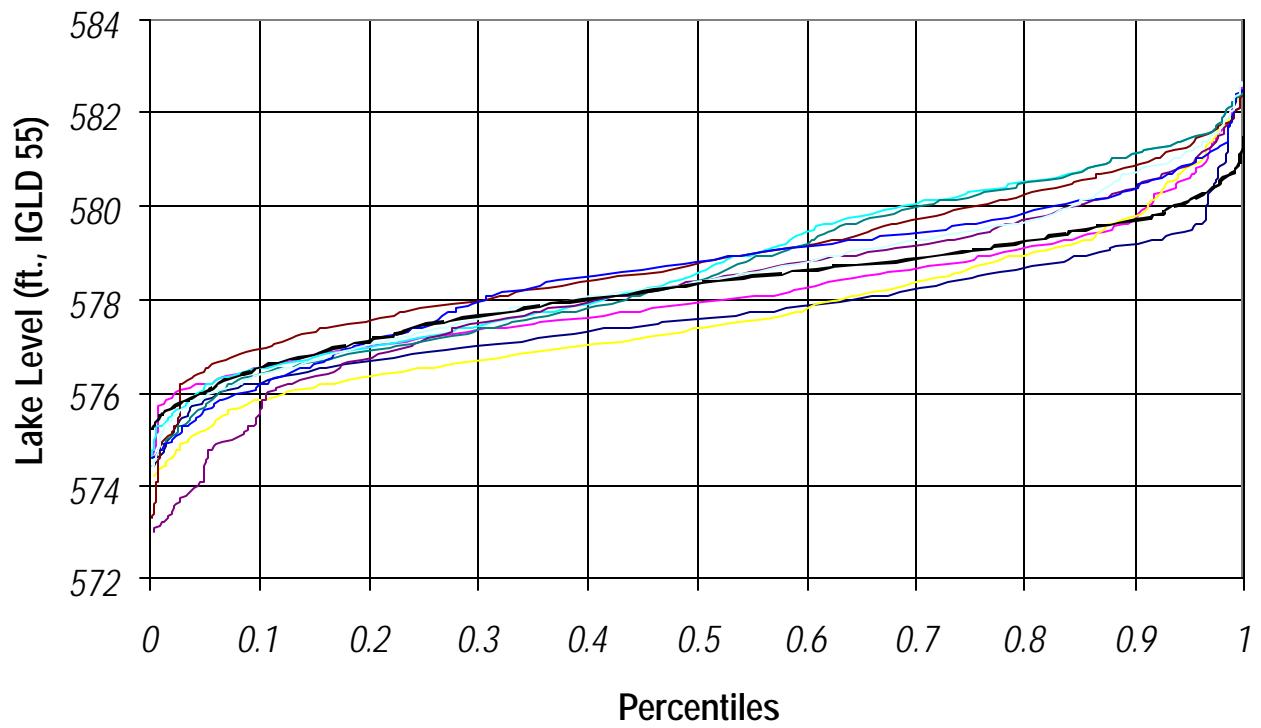


Figure 6 - Scenario 6 for Lakes Michigan-Huron

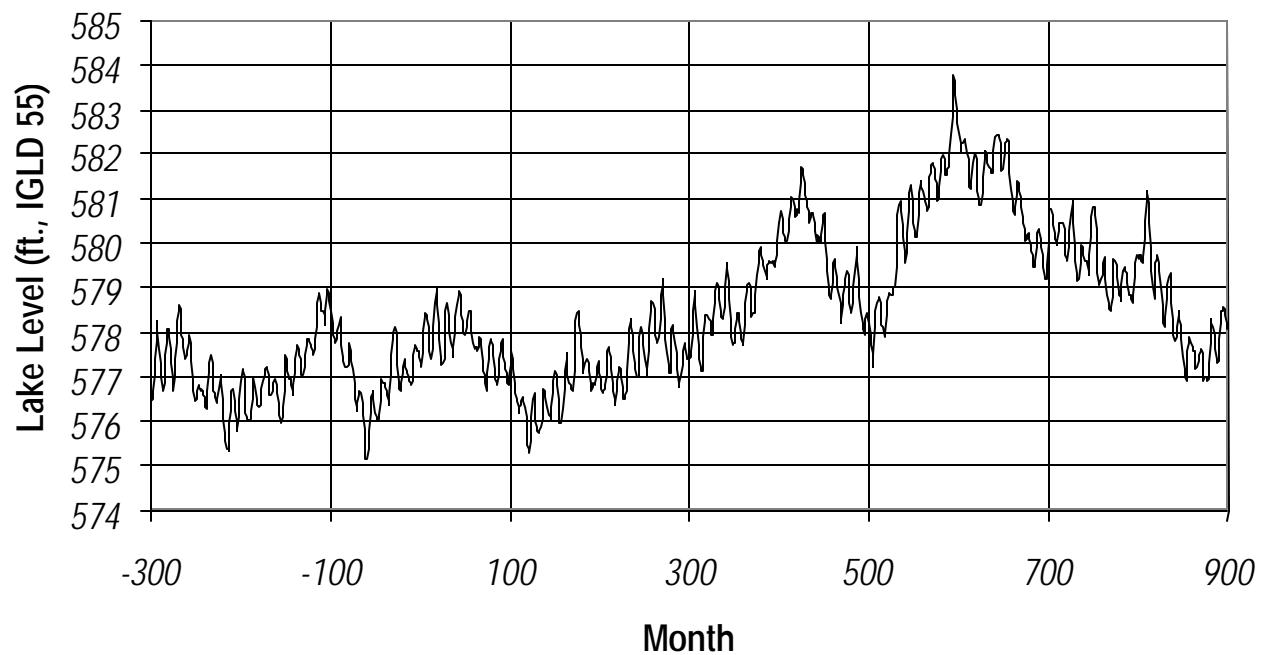


Figure 7 - Scenario 7 for Lakes Michigan-Huron

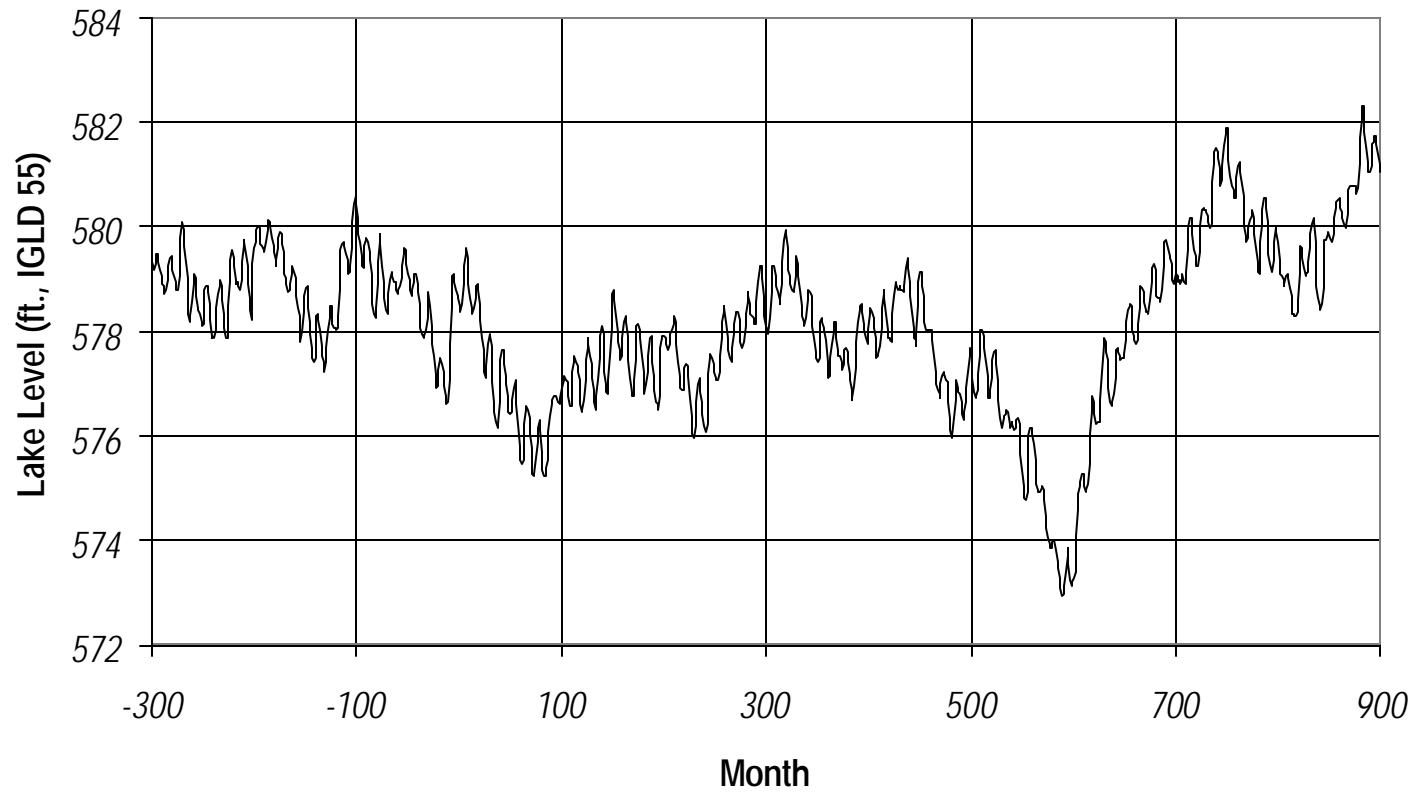


Figure 8 - Scenario 1 for Lake Erie

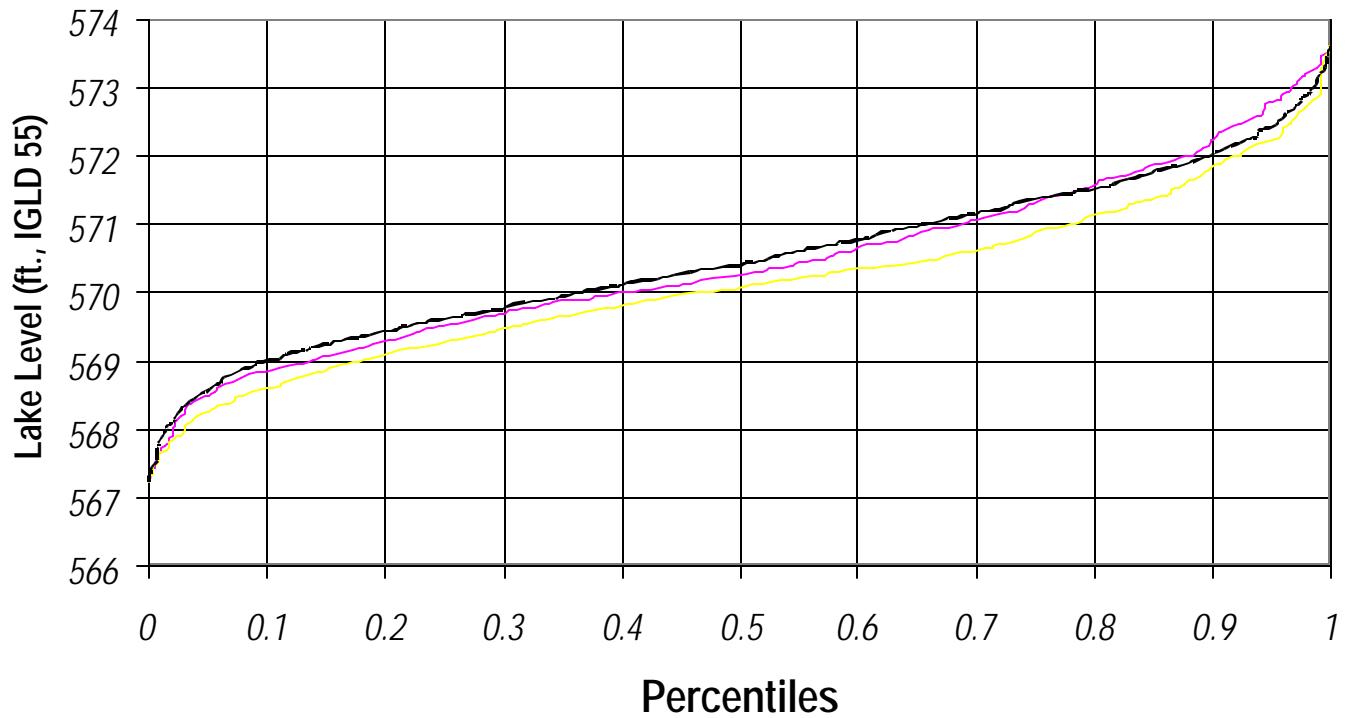


Figure 9 - Scenario 2 for Lake Erie

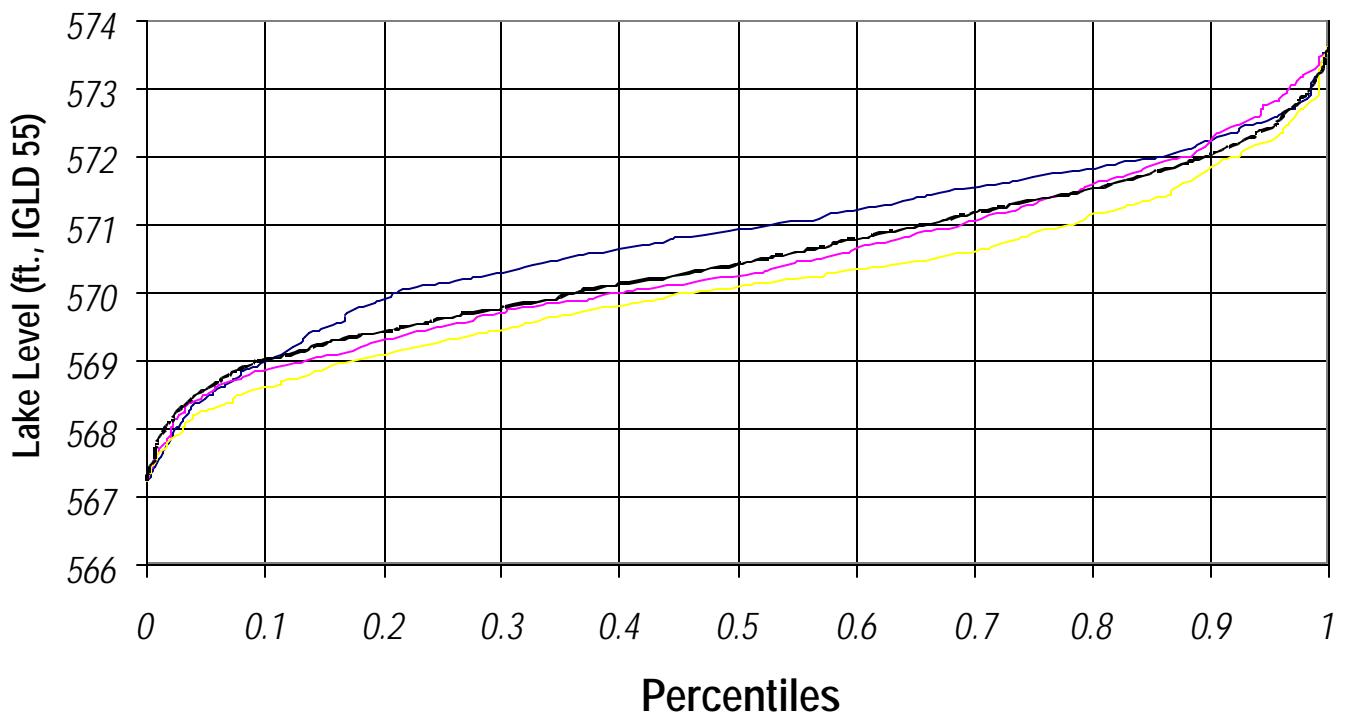


Figure 10 - Scenario 3 for Lake Erie

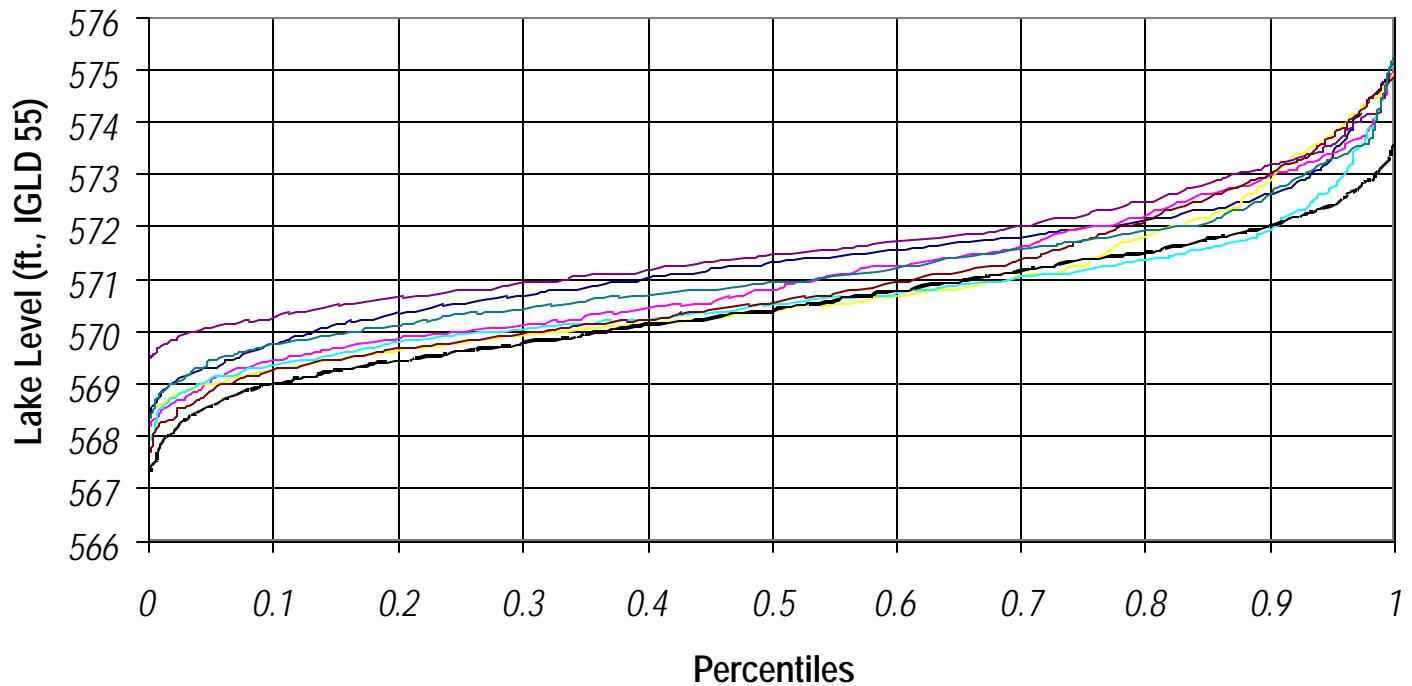


Figure 11 - Scenario 4 for Lake Erie

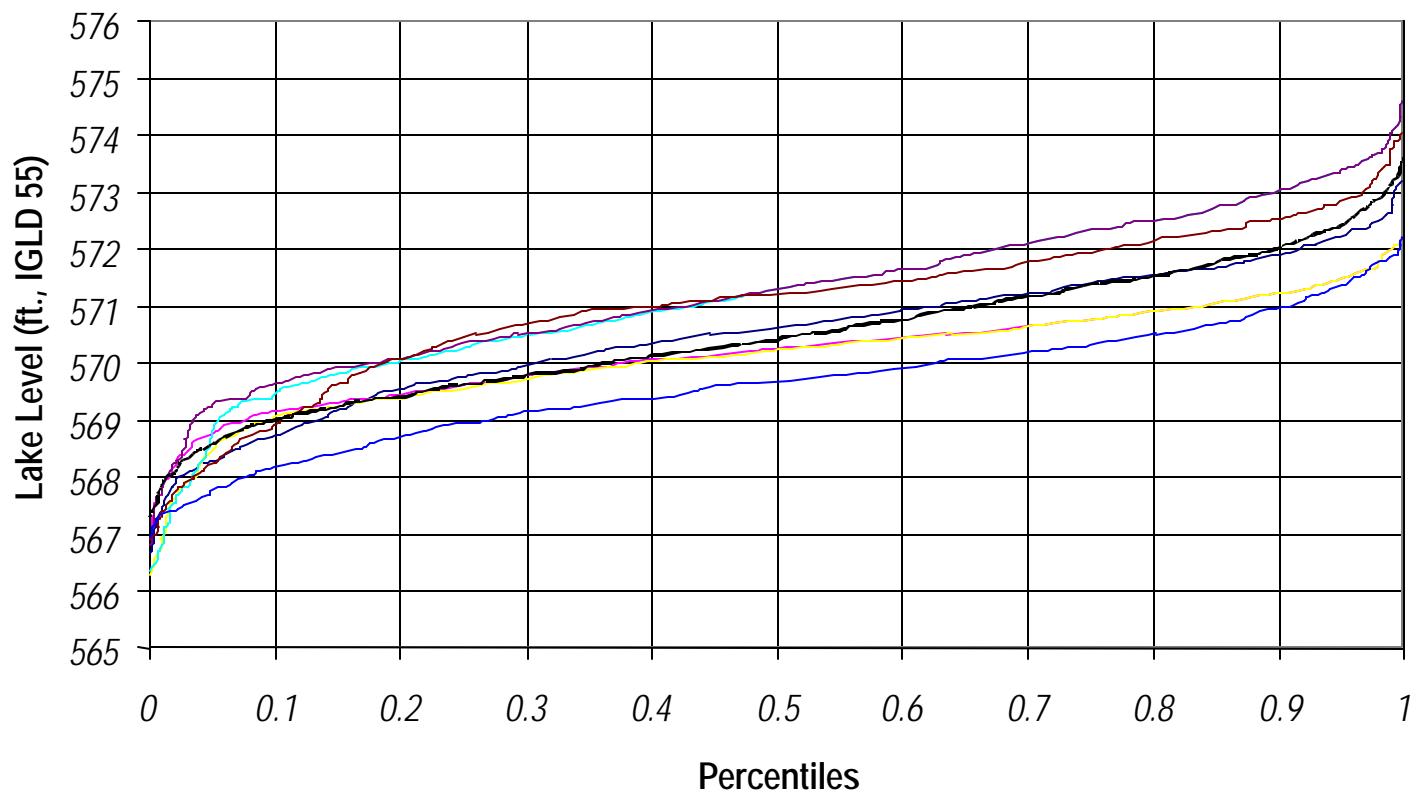


Figure 12 - Scenario 5 for Lake Erie

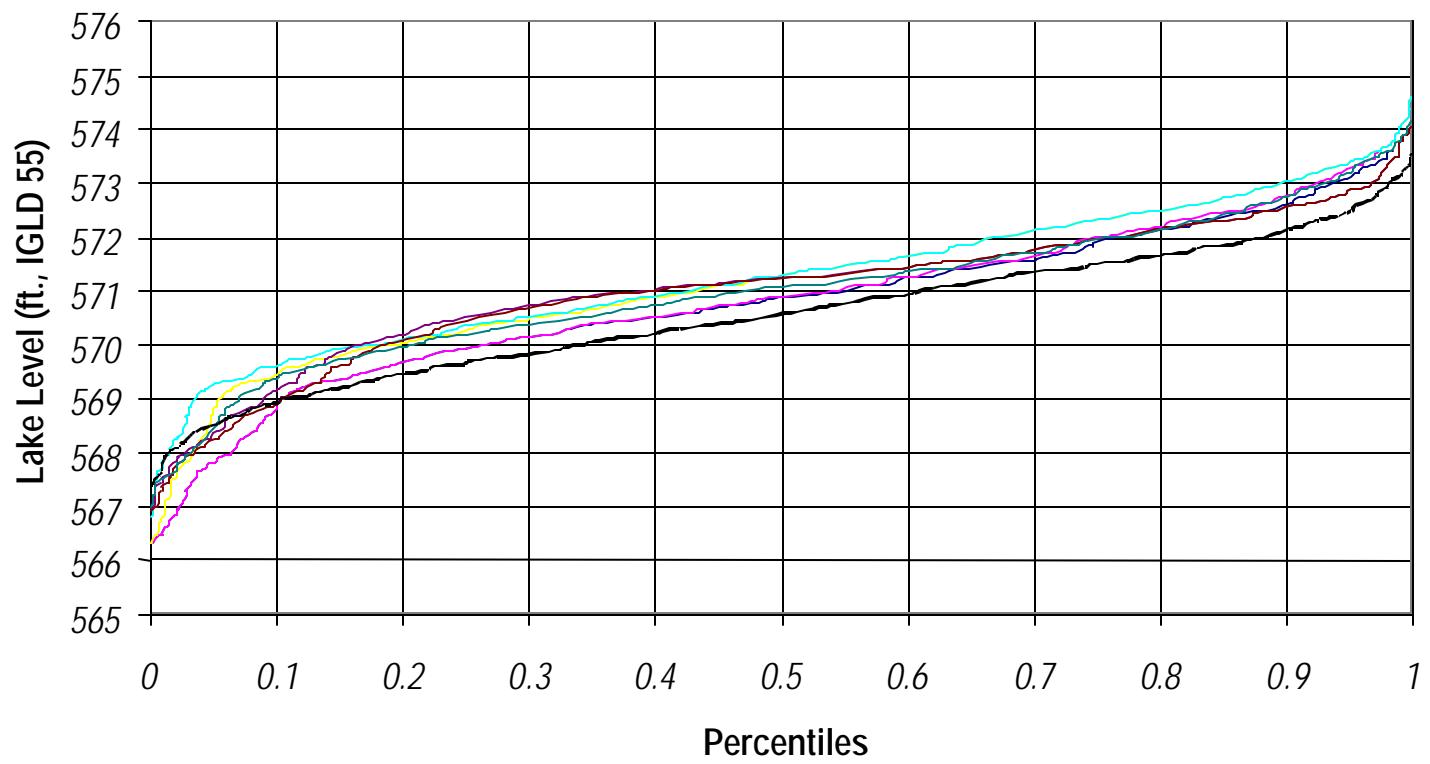


Figure 13 - Scenario 6 for Lake Erie

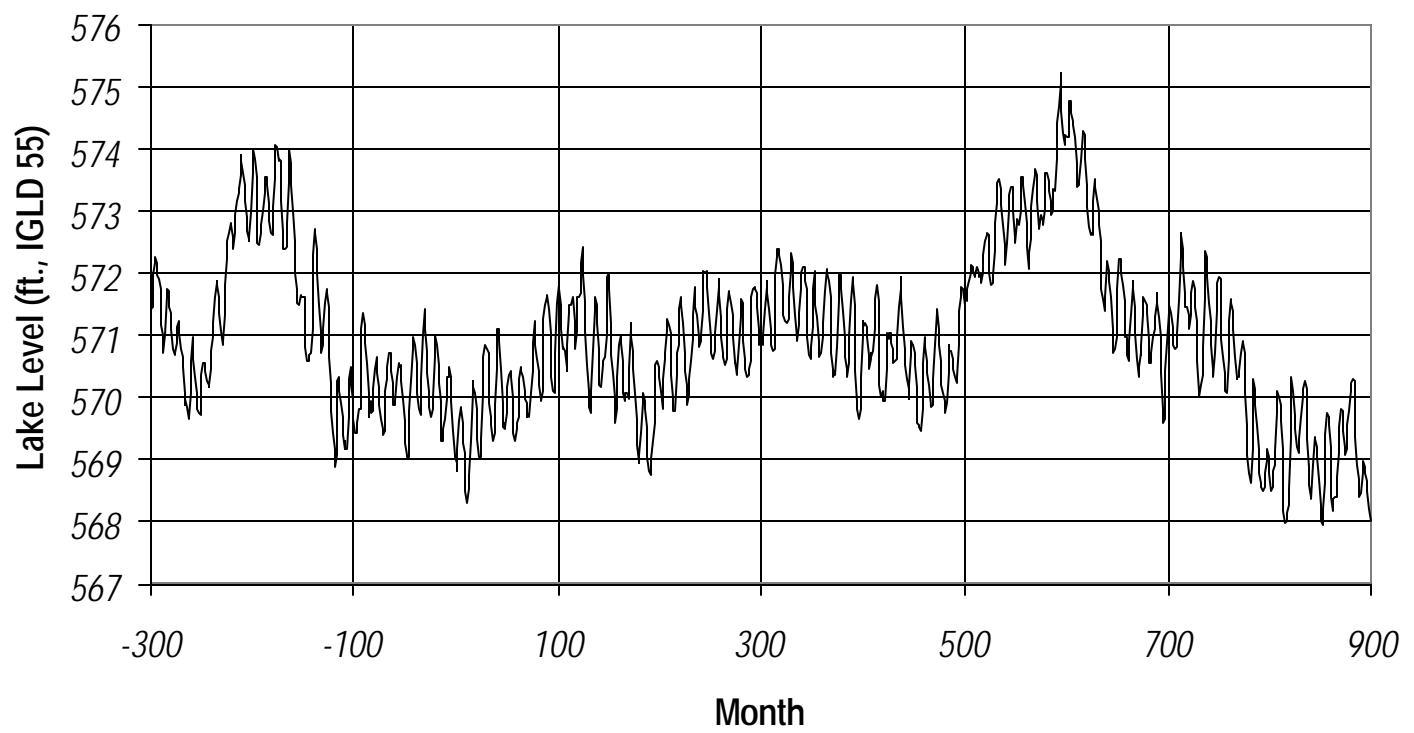


Figure 14 - Scenario 7 for Lake Erie

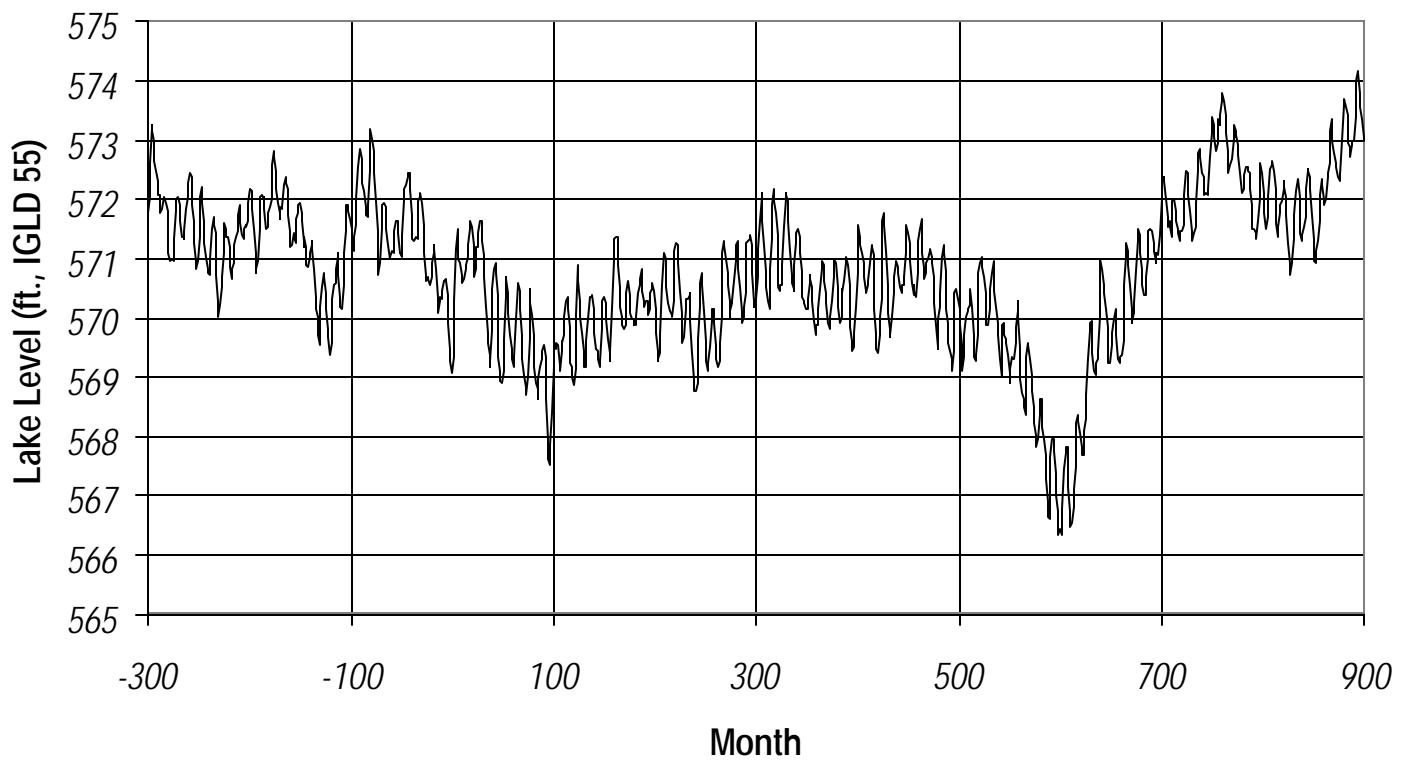


Figure 15 - Scenarios 1 and 2 for Lake Superior

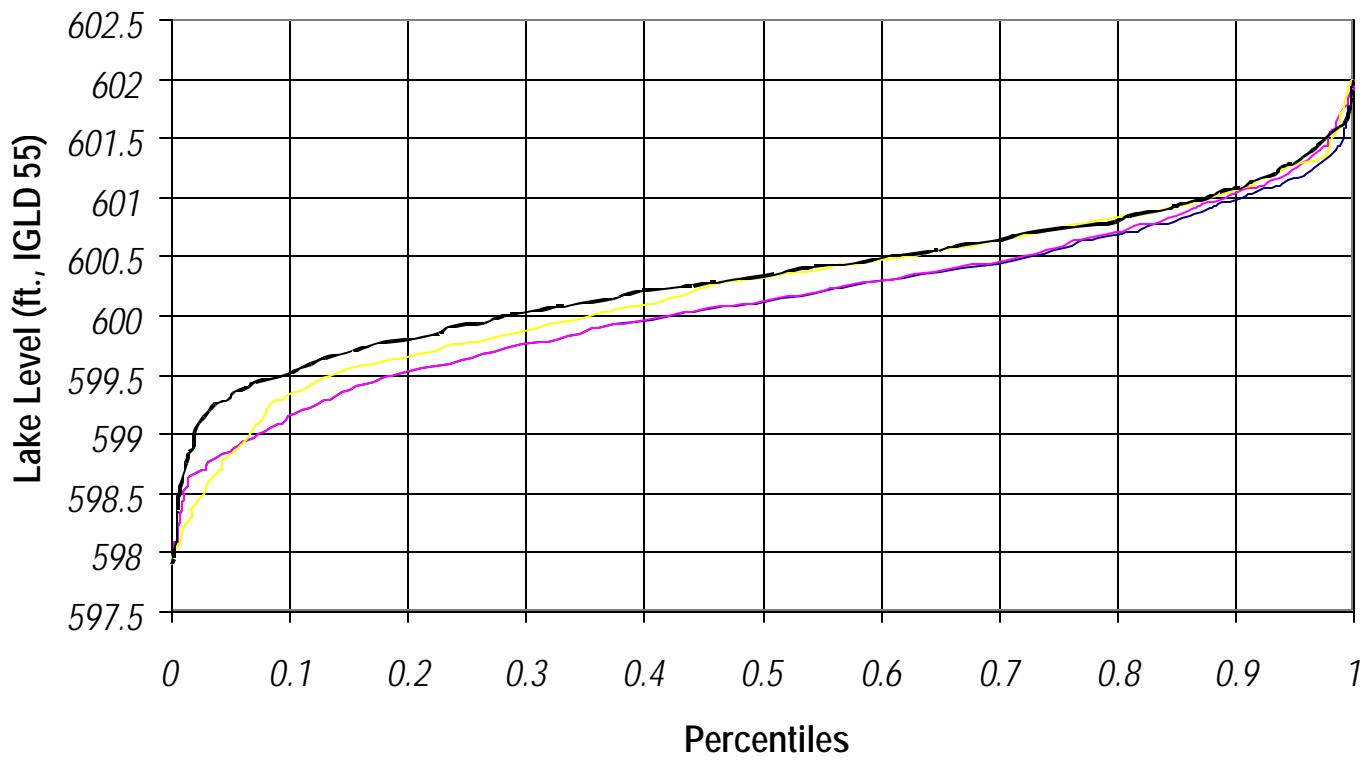


Figure 16 - Scenario 3 for Lake Superior

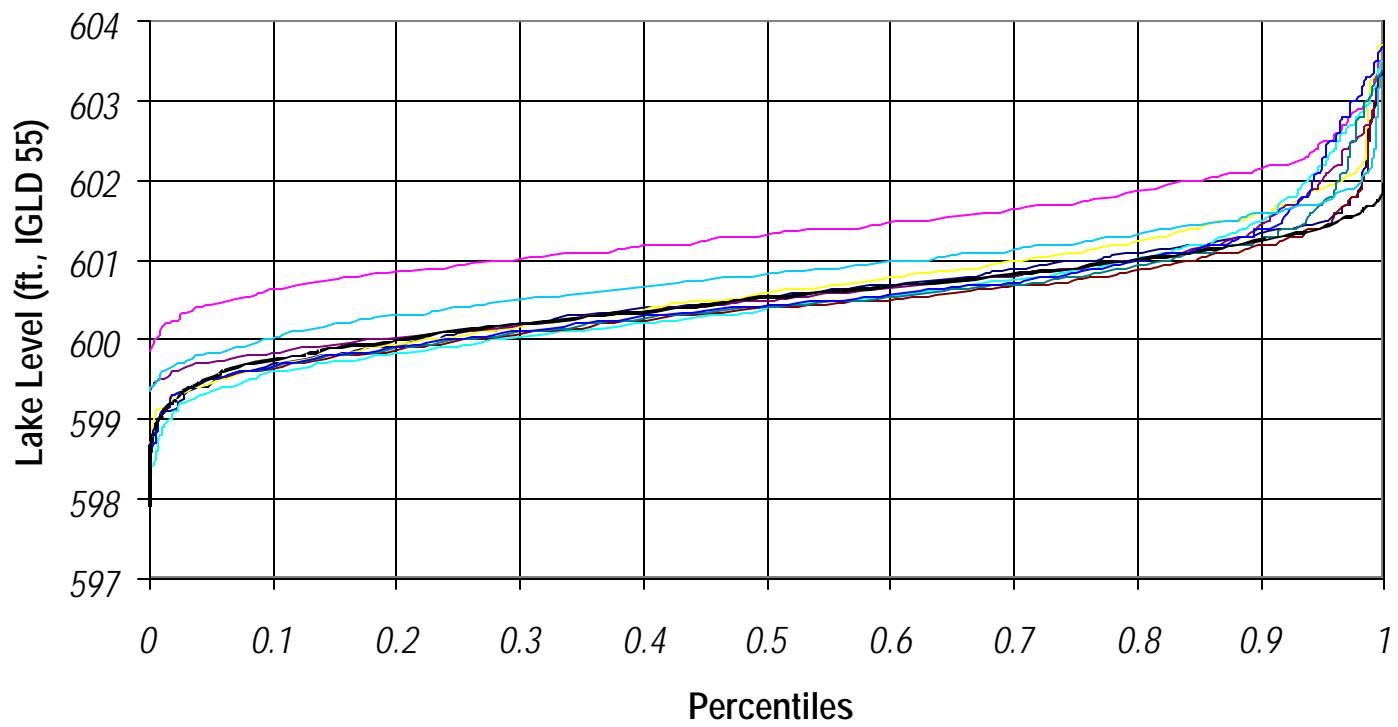


Figure 17 - Scenario 4 for Lake Superior

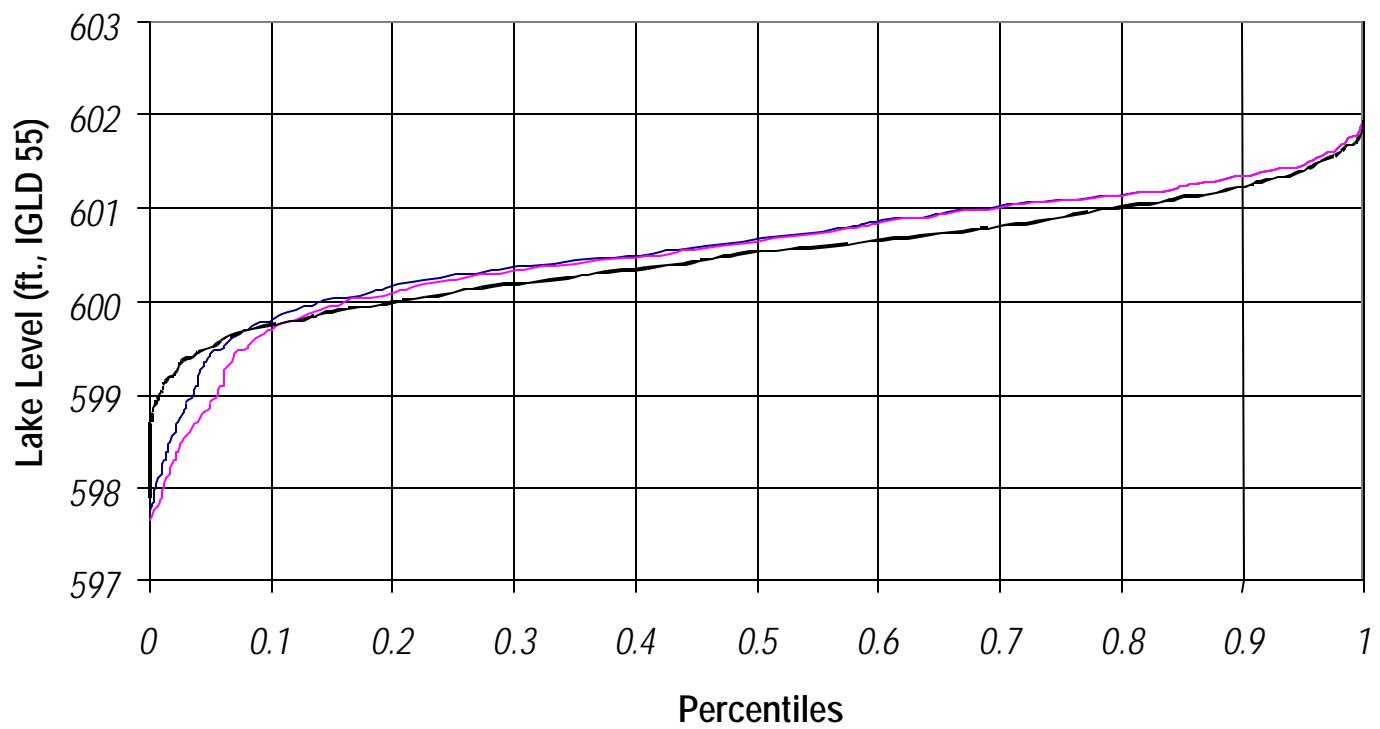


Figure 18 - Scenario 5 for Lake Superior

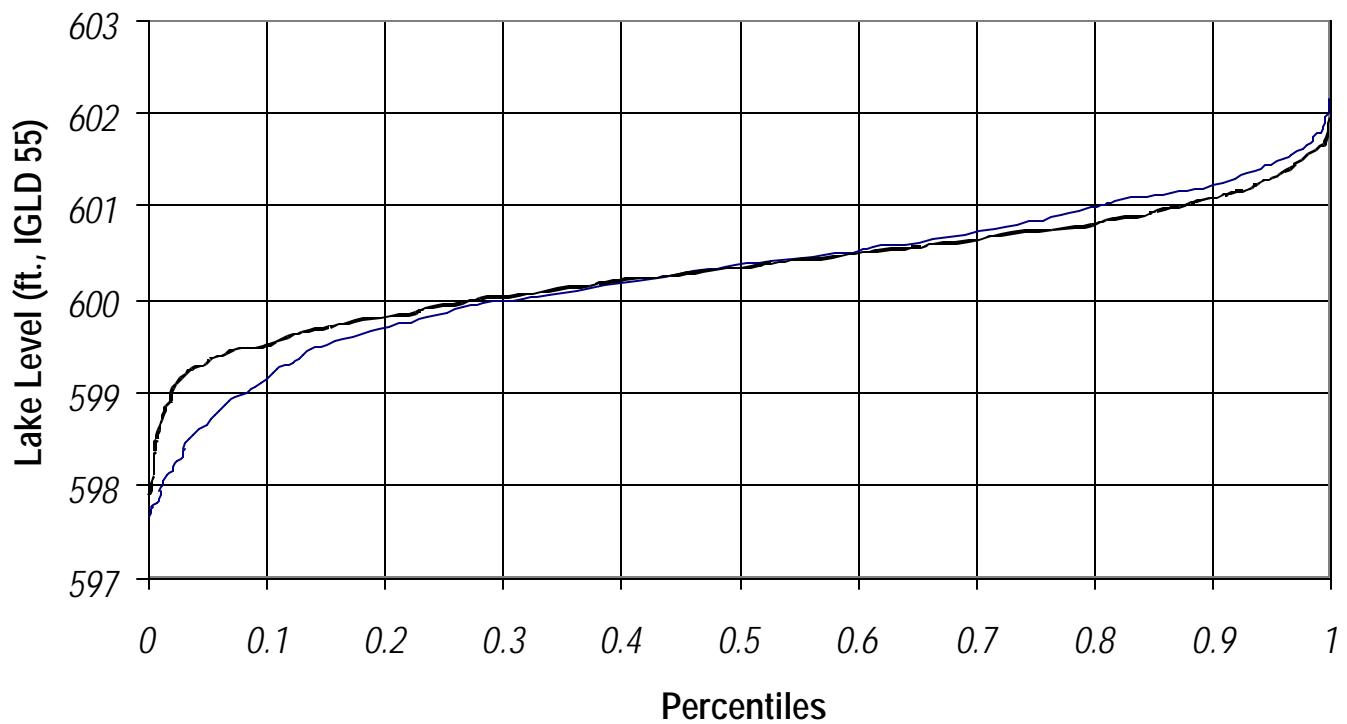


Figure 19 - Scenario 3 for Lake Ontario

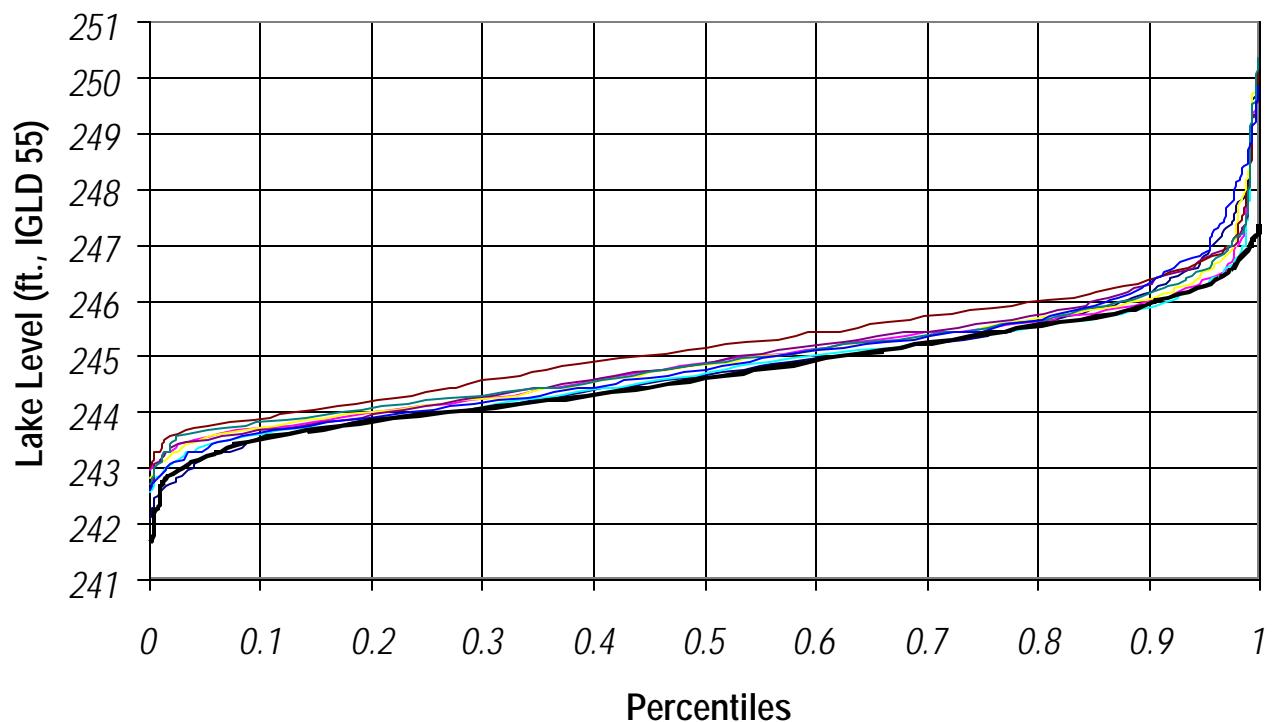


Figure 20 - Scenario 4 for Lake Ontario

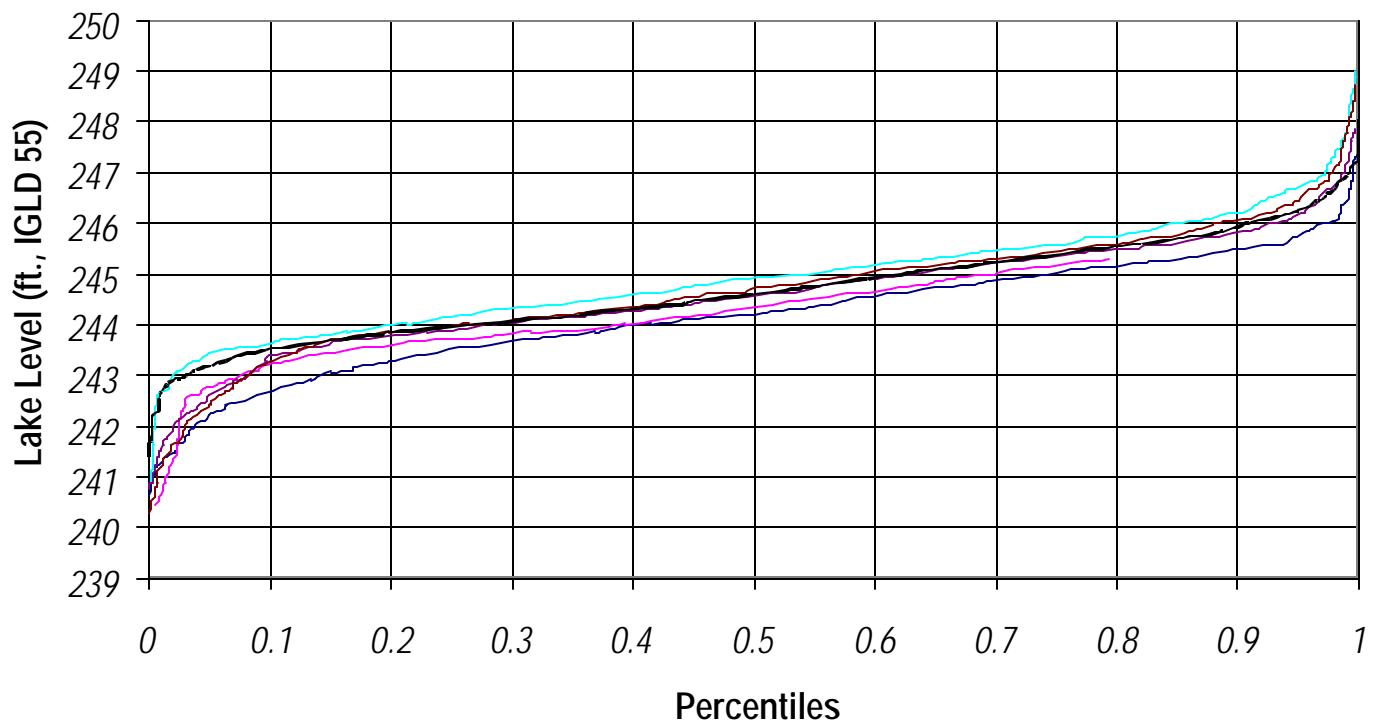


Figure 21 - Scenario 5 for Lake Ontario

