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# IMPROVED COMMUNICATION OF GREAT LAKES WATER LEVEL INFORMATION

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# IMPROVED COMMUNICATION OF GREAT LAKES WATER LEVEL INFORMATION

Anne H. Clites, Editor

ABSTRACT. This report outlines a strategy for improving the content and communication of Great Lakes water level information. It is hoped that by providing decision-makers with more helpful information, the social and economic disruptions caused by fluctuating lake levels can be mitigated. To define the water level information needs of the decision-makers, an assessment of user needs was conducted by phone interview. This was not a scientific survey, but an attempt to interview as many informed representatives of different water level information user groups as time allowed. Sixty-five interviews were completed during the fall of 199 1. The user needs assessment revealed that unmet needs seem to be concentrated in certain user groups: coastal engineers emergency government workers, recreational boaters and marina operators, and riparians. Some of the needs expressed included better extreme level statistics, more storm surge information, better access to historical and real-time data, and a more understandable water level bulletin. According to our small sampling, there are many user groups that are satisfied with the water level information they now receive. The water level bulletins prepared monthly by the governments of Canada and the United States proved to be the most widely used decision-making tools. As effective as they are, it was also apparent that, even among frequent users, the bulletins are not completely understood. This suggested strategy for improving the quality and communication ofwater level information involves (1) developing better extreme level statistical decision-making tools, (2) proposing to the relevant agencies that subtle changes be made to the water level bulletins to increase their understanding, and (3) tailoring existing forecast and statistical information so that users can take better advantage of the wealth of Great Lakes water level information generated by governments. Authors of this report included J. Philip Keillor, Charles F. Southam, Murray Clamen, and Deborah H. Lee.

## 1. INTRODUCTION

Anne H. Clites and Deborah H. Lee

The high Great Lakes water levels of 1985 and 1986, followed by extreme drought and an unprecedented decline in levels, adversely affected the public's confidence in water level information products and methods. Efforts under Phase I of the International Joint Commission's (IJC) Levels Reference Study made it clear that the water level forecasts and statistics now available are not as useful or as easily understood as they need to be. Annex C of the Phase I progress report discussed the prospects for managing water level issues within the Great Lakes and concluded that "there is an urgent need for improvement in information about the probabilistic nature of lake levels" (IJC, 1989b). The report further recommended that "governments develop improved information on the probabilistic nature of levels and storms." Likewise, Annex A, which discussed past and future water level fluctuations, concluded "serial correlation of annual lake levels requires modification of the traditional probability analyses of lake level data" (IJC, 1989a).

The scientific community responded to these needs and to the public's frustration with a symposium in 1990. The symposium, entitled "Great Lakes Water Level Forecasting and Statistics for Decision-Making," was sponsored by the National Oceanic and Atmospheric Administration's Great Lakes Environmental Research Laboratory (NOAA/GLERL), the Great Lakes Commission, and the U.S. Army Corps of Engineers, and was held in May 1990 in Windsor, Ontario. The sym-

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posium had two objectives: to assess the strengths and weaknesses of current water level forecasting techniques, and to explore innovative approaches for developing and communicating statistics that would best serve the wide range of user groups in the Great Lakes basin. The event was attended by more than 70 interested professionals. The two-day symposium provided a unique opportunity for meaningful dialogue between resource managers, statisticians, and a wide variety of people who use lake level information in either personal or business decisions. Papers were presented on various aspects of forecasts and statistics from both the providers' and the users' points of view.

One of the recurrent themes of the symposium was the need for technical experts to reach a consensus on statistics generated to describe the fluctuating levels of the Great Lakes. Water level information users are confused by conflicting forecasts and the varied statistical approaches employed by the different information products they receive. There is an apparent lack of understanding of the products currently available, leading to possible misinterpretation or misuse of the information. At the same time, there is a prevailing feeling in the scientific community that these products could be improved.

Phase II of the IJC Levels Reference Study got underway in 199 1. The study had specific objectives to develop improved statistical techniques and better ways to communicate those techniques to decision-makers. This report is the result of efforts under Phase II to strengthen the link between water level information providers and users. It was written by a committee of five people. Authorship in indicated at the beginning of each section. The report summarizes the results of three distinct, but extremely interdependent topics relating to the goal of improving the content and communication of water level information in the Great Lakes basin:

1. Assessment of water level information user needs (Section 3.0);

2. Examination of the content and complexities of the U.S. and Canadian water level bulletins (Section 4.0);

3. Discussion of how existing forecast and statistical products, as well as products that could be developed by government agencies, can be used more effectively to enhance decision-making (Section 5.0).

## 2. BACKGROUND

Anne H. Clites and Deborah H. Lee

In 1964, record low levels were set on Lakes Michigan and Huron, and near record lows were experienced on Lakes St. Clair and Erie. Some people who were adversely affected by the low levels speculated that the lakes were being kept low artificially. In 1986, record high levels were experienced on the Great Lakes. Navigation and hydropower profited from the high water, and some of those who were adversely affected suspected the lakes were being regulated to keep the levels high. The drought of 1987-1988 caught everyone by surprise. The precipitous drop in lake levels affected many people. Even those who weren't directly affected by the abrupt reversal in lake levels lost confidence in governments' ability to predict water levels in the Great Lakes basin.

Great Lakes basin residents in the United States and Canada whose property or livelihood is critically affected by lake level fluctuations rely on forecast and statistical information provided by government. The amount and quality of that information have greatly increased in recent years. However, there are still problems that stem from a lack of public awareness of the complexities of the information and of the natural system itself. The myth that the levels of the Great Lakes are controlled to benefit certain interests over others still persists.

What can be done? The focus of this effort was to find the decision-makers and to ascertain their water level information needs. The decision-makers, those people who, either once or frequently, base personal or business decisions on water levels or water level information, need to be the primary recipients of improved statistical tools and more easily understood forecasts. These decision-makers are a very diverse group. They include (in no particular order) shoreline property owners, marina operators and boaters, investors and insurance agents, public utility employees, shippers, power authorities, coastal engineers and marine contractors, and many government employees at various levels.

Presumably, there are some groups of decision-makers who are more in need of improved information than others. Finding those groups who are most in need of improvements in the communication of water level information and recommending steps to be taken to meet those needs were the goals of this study.

## 3. ASSESSMENT OF WATER LEVEL INFORMATION USER NEEDS

Anne H. Clites

When the symposium, "Great Lakes Water Level Forecasting and Statistics for Decision-Making," held in Windsor on May 17- 18, 1990, came to a close, several conclusions had been reached on future needs. There was a strong sentiment, voiced often throughout the symposium, that the forecast and statistics generators need to reach a consensus on some forecast and statistical products. It was believed that only through a multi-agency effort would the water level information that is disseminated gain any real readability.

In February 199 1, NOAA/GLERL formed the Advisory Task Force on Great Lakes Water Level Statistics. The task force is comprised of experts in water level statistics from the United States and Canada, from academia as well as government:

Dr. Steven Buchberger, University of Cincinnati
Dr. Murray Clamen, Environment Canada
Ms. Anne Clites, NOAA/Great Lakes Environmental Research Laboratory
Dr. Timothy Cohn, U.S. Geological Survey
Mr. David Fay, Environment Canada
Mr. Lynn Herche, NOAA/Great Lakes Environmental Research Laboratory
Mr. Philip Keillor, University of Wisconsin Sea Grant Institute
Dr. Geoffrey Kite, *Environment Canada
Ms. Deborah Lee, NOAA/Great Lakes Environmental Research Laboratory
Ms. Gail Monds, U.S. Army Corps of Engineers, Detroit District
Dr. Kenneth Potter, University of Wisconsin
Mr. Charles Southam, Environment Canada

The goal of the task force was to develop a strategy for improving the content and communication of water level forecasts and statistics in support of the IJC Levels Reference Study, Phase II. During the first meeting of the task force in April 1991, discussion centered on what type of information is really needed. The technical experts had well-developed ideas on where improvements could be made in existing statistical products. That group embarked on a study to outline the steps that need to be taken to improve statistical tools used to make Great Lakes water level-related decisions. The results of that effort are reported in a NOAA Technical Memorandum entitled "Great Lakes Water Level Statistical Techniques" (Lee, 1992). The specific information needs of the public were less well defined. A subgroup of the task force set out to define those needs.

The User Needs Subgroup felt that the most efficient way to collect information about water level information user needs in the short time remaining in the Levels Reference was to conduct phone interviews with a selected list of users. The goal was to reach informed users of water level information from all different interest groups. This was not a random or scientific sample. The interviewees were selected because they are known to be personally or professionally affected by the fluctuating levels of the Great Lakes. The selections were made in an attempt to reach representatives from all interest group types. It was not feasible in the short time allowed to sample all geographic regions. Many of the people interviewed have a lot of experience in dealing with water level information. The goal of the interviews was to draw on the collective experience of this diverse group of water levei information users; to delineate their unmet needs, and to record their ideas for meeting those needs.

Sixty-five interviews were conducted during the summer and fall of 199 1. The interview consisted of six questions. The sixth question asked the interviewee to examine and react to a series of graphs of water level forecast and statistical information. The interview packet, consisting of cover letter, questions, and graphs, was sent out to potential interviewees. The interviews were conducted over the phone, a week or more later. The content and format of the questionnaire were reviewed and approved by the appropriate agencies in Canada and the United States.

The interview consisted of the following questions:

1. Do you use Great Lakes level forecasts and/or statistics to make decisions?

Our goal is to highlight the needs of the people who use water level information to make decisions. This question was also used to determine what types of decisions are being made with this information.

2. Where do you get the information you use?

It is important to know what types of information, from what agency, etc., are now being used to make these decisions.

3. What is your planning time frame?

Existing water level information products are used for many different purposes. Some are interested primarily in the forecast levels for next month. Others are concerned with the trend in levels and what it might mean for the next year or more. The type of information desired is dictated by the planning needs of the decision-makers.

4. Are your forecast or statistical needs being met? If not, what else do you need?

This question was an attempt to gather ideas from users on specific improvements needed in current products, and new products needed. It was also intended to help discriminate between user groups that need improvements in water level information, and those who are relatively satisfied with the status quo.

5. How would you like to receive water level information (mail, radio, TV, newspaper, fax, dial-up computer, other )?

The focus of this question was the means of information transmittal. It was, in part, an attempt to get users to speculate about how agencies can better serve their water level information needs, both specific and general.

6. Attached are some examples of different ways to portray forecast or statistics about water levels. Do any of these appear to be more helpful than others?

Which one best or least suits your needs? This question refers to a set of eight graphs developed to depict water level information in different ways. These graphs are included as Figures 1 through 8. Figures 1 through 4 are variations on the present 6-month Great Lakes level forecasts distributed in the U.S. and Canada. Figures 5 through 7 are variations showing probabilities of future extreme water levels. Figures 5 (based on Potter, 1990) and 6 (based on Buchberger, 199 1) introduce the concept of conditional probability-the probability of future levels being dependent on the present water level. Figure 7 is based on a 1987 Southeastern Wisconsin Regional Planning Commission report. Figure 8 depicts a different concept-duration. Instead of giving information on the extent of extreme levels, this curve is an attempt, based on water level statistics, to predict the duration of any one occurrence of an extreme level.

Figure 1.-- Deterministic 6 month water level forecast.

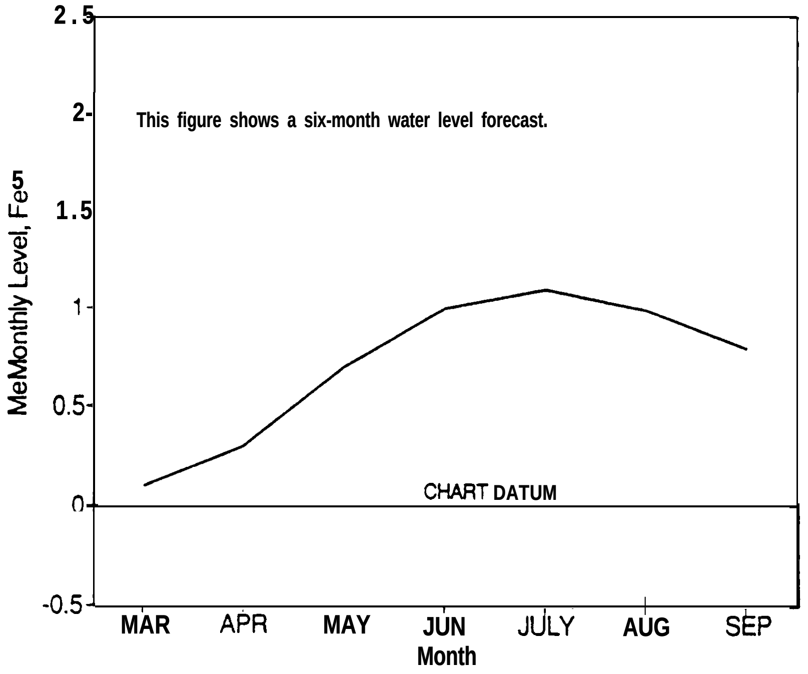


Figure 2.-- Six month water level forecast shown as a probable range of levels.

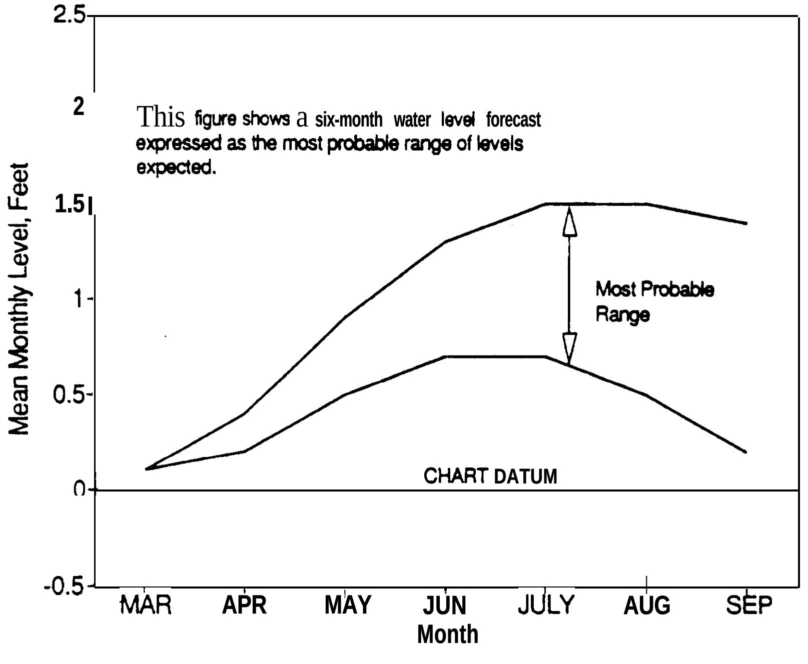


Figure 3.-- One year water level forecast based on historical statistics.

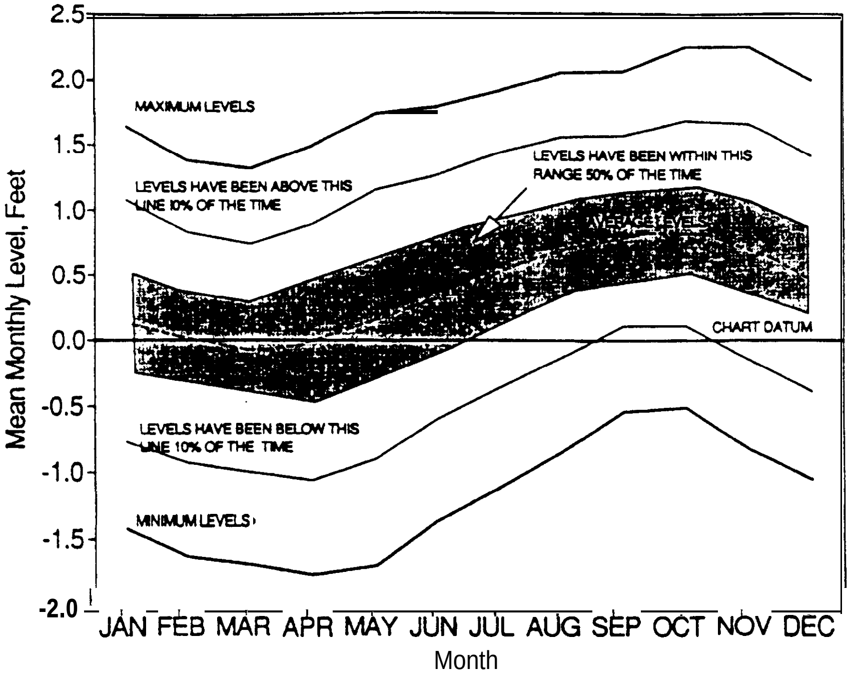


Figure 4.-- Six month forecast shown in terms of non-exceedance probabilities.

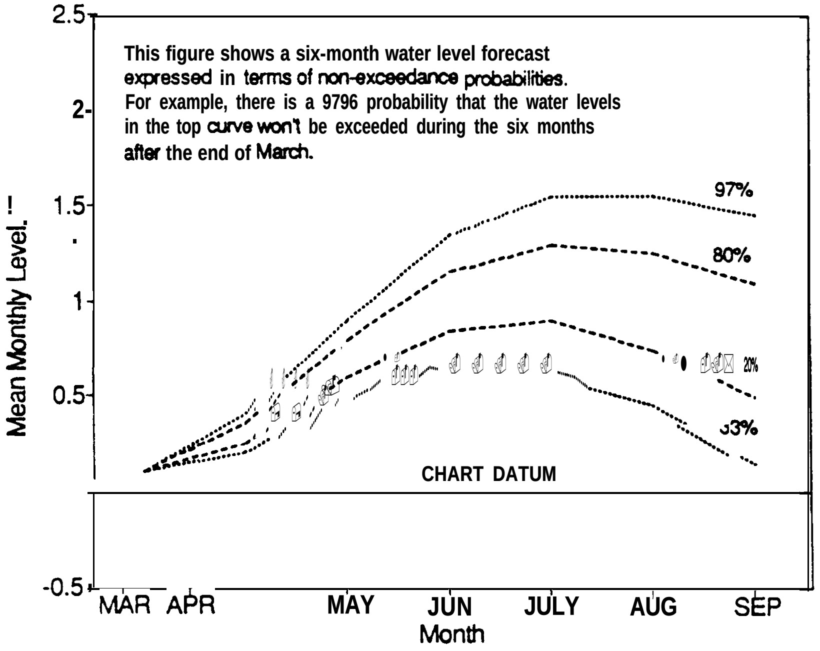

This figure shows a six-month water level forecast expressed in terms of non-exceedance probabilities. For example, there is a 9796 probability that the water levels in the top curve won't be exceeded during the six months after the end of March.

Figure 5a.--Conditional probabilities - Year 1 - from Potter (1990).

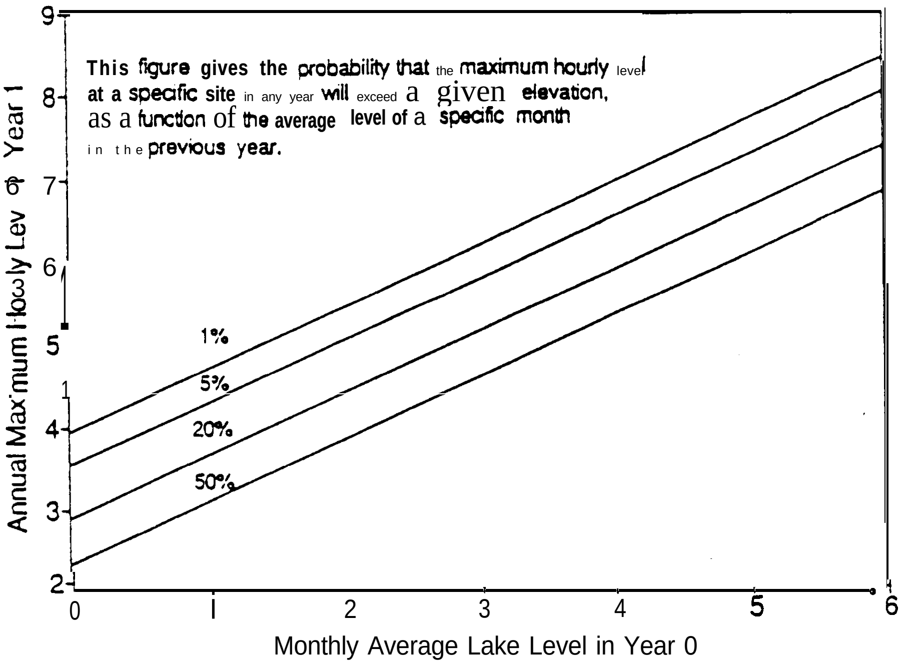


Figure 5b.--Conditional probabilities - Year 5 - from Potter (1990).

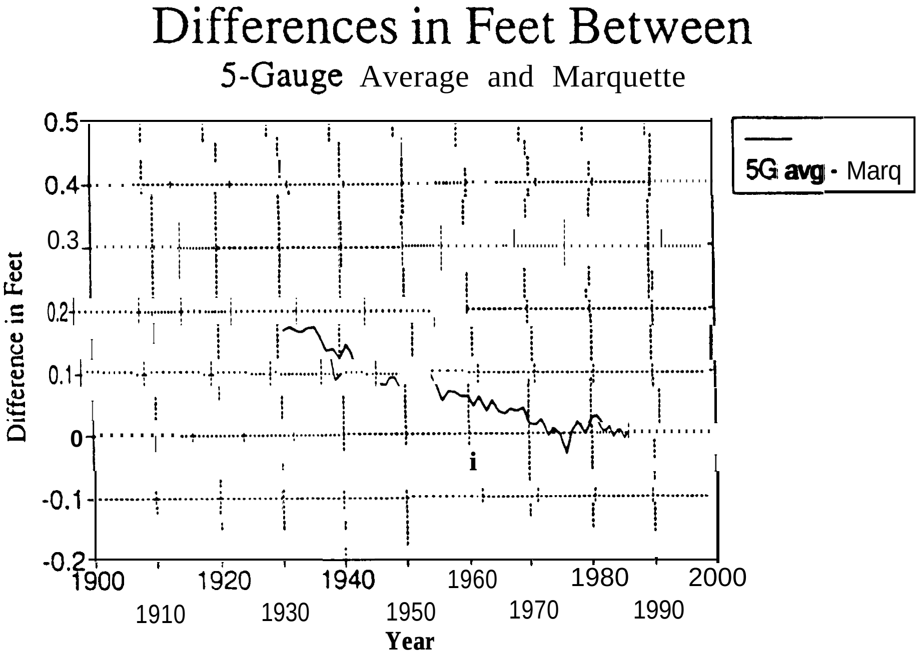
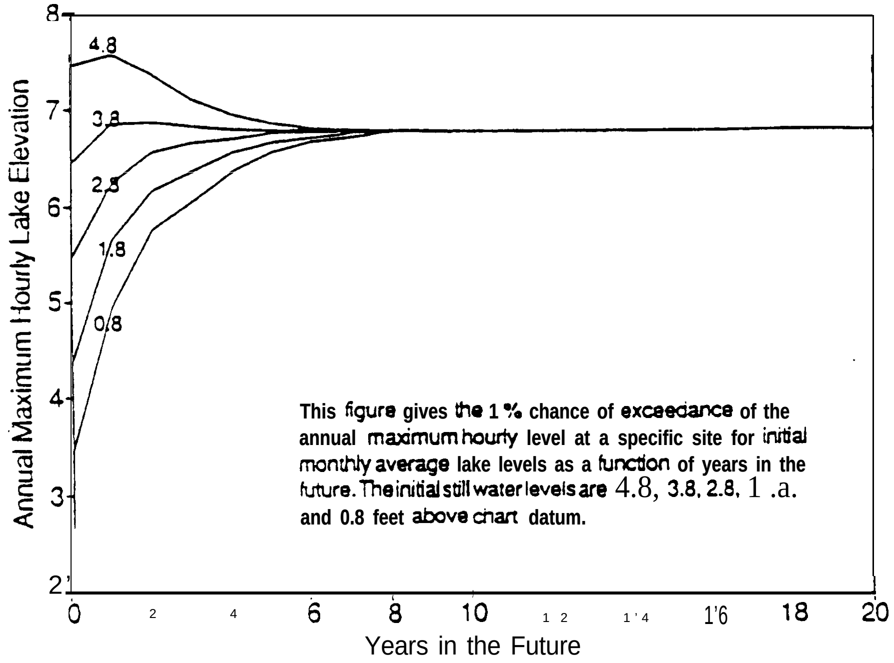
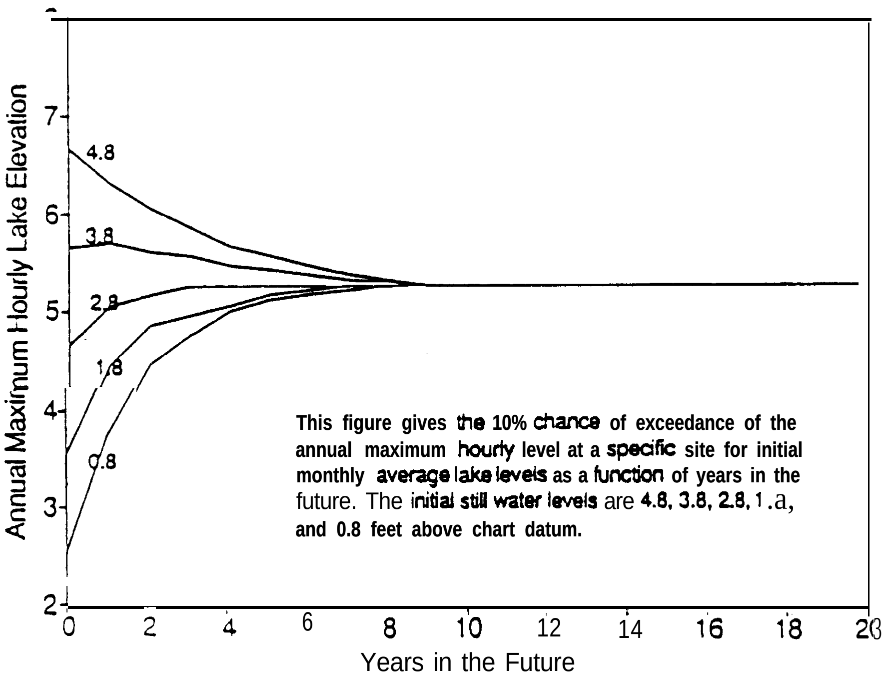


Figure 6a.--Conditional probabilities - 1% chance of exceedance (Buchberger, 1991).



This figure gives the 1 % chance of exceedance of the annual maximum hourly level at a specific site for initial monthly average lake levels as a function of years in the future. The initial still water levels are 4.8, 3.8, 2.8, 1.8, and 0.8 feet above chart datum.

Figure 6b.--Conditional probabilities - 10% chance of exceedance (Buchberger, 1991).



This figure gives the 10% chance of exceedance of the annual maximum hourly level at a specific site for initial monthly average lake levels as a function of years in the future. The initial still water levels are 4.8, 3.8, 2.8, 1.8, and 0.8 feet above chart datum.

Figure 7a.--Exceedance probabilities (SEWRPC, 1987).

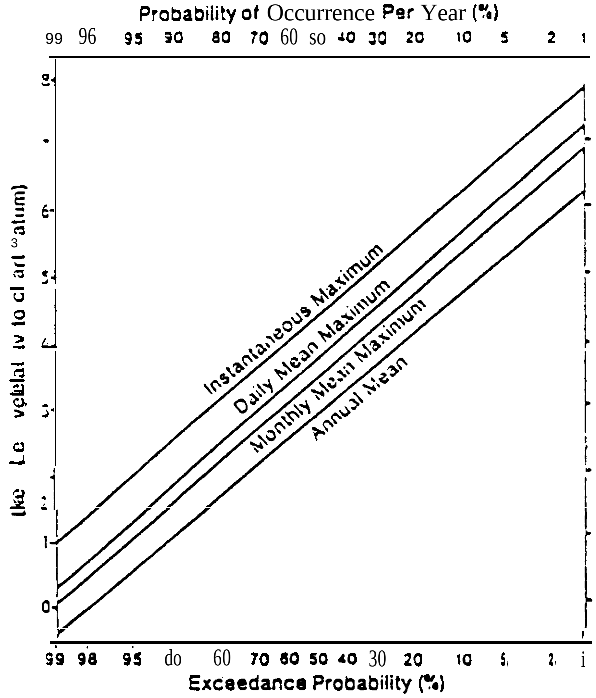


Figure 7b.--Non-exceedance probabilities (SEWRPC, 1987)

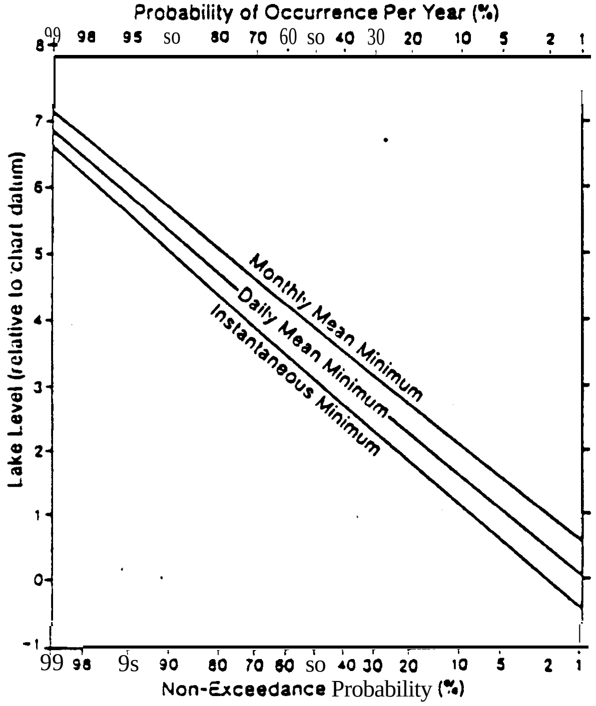
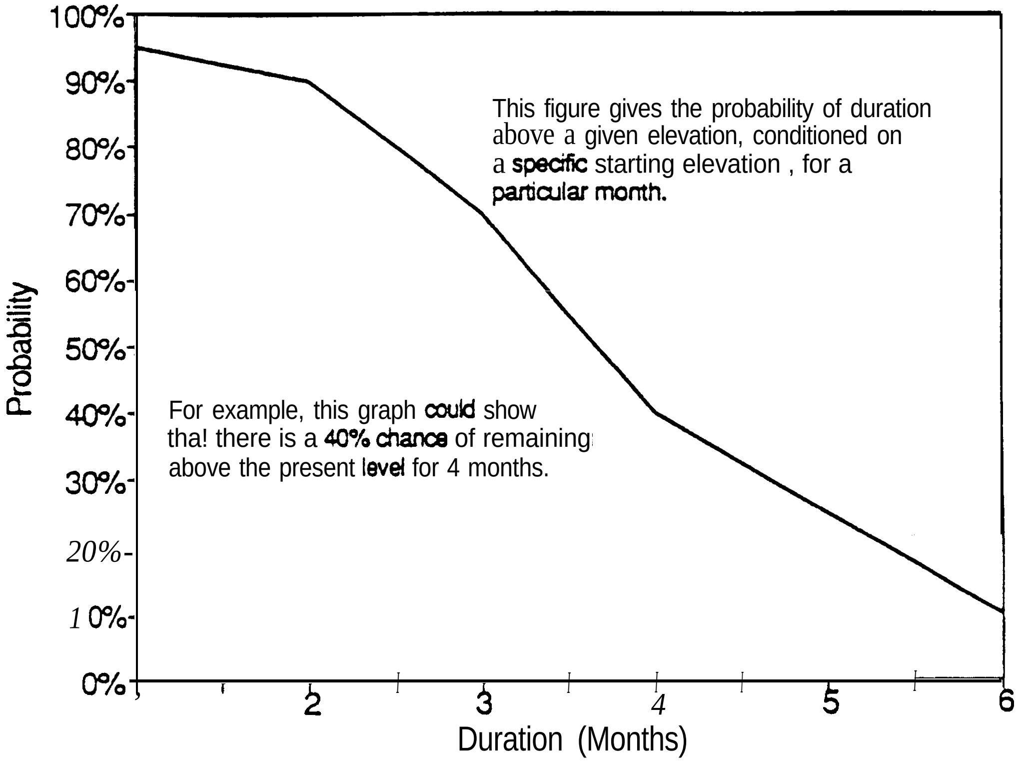


Figure &--Probability of duration curve.



This figure gives the probability of duration above a given elevation, conditioned on a specific starting elevation , for a particular month.

For example, this graph could show tha! there is a 40% chance of remaining above the present level for 4 months.

The results of the 65 interviews are summarized by interest group. In some cases this was difficult because there was little consensus between members of some groups. In summarizing the remarks, the emphasis is on defining unmet needs and highlighting users' ideas for improving the content and communication of water level information. The User Needs Subgroup did not embark on this exercise in an attempt to meet every need. It was hoped that this effort would outline a few specific areas in which some changes in information content or delivery could really make a difference for people. The number interviewed in each group is in parentheses. As stated earlier, this was not a random or scientific sample of users. It was an attempt to reach as many informed users as possible in a very short time span. It was not possible to sample all geographic regions or points of view. Despite these drawbacks, the authors felt the interview results were revealing. These results are presented by user group in alphabetical order:

Coastal Engineers (6)
Environmental Interests (2)
Government: City/Regional (11)
Government: Emergency (4)
Government: State/Provincial (6)
Government: Federal (7)
Marine Contractors (2)
Native North Americans (3)
Navigation/Shipping (8)
Power (4)
Recreational Boating (6)
Riparians (6)

### 3.1 Coastal Engineers

Coastal engineers design coastal structures such as harbor breakwaters, marina docks, commercial harbor docks, seawalls, and revetments. Some also advise clients on construction and operations as well as precautionary measures. All six respondents use both water level forecasts and statistics in their professional decision-making. Forecasts are used to advise clients on what levels to expect for planning construction, making operational decisions, and taking precautionary measures. Statistics are used in designing structures, modeling coastal processes, and demonstrating to clients the history of lake levels.

Forecasts are obtained from the monthly lake levels bulletins of the U.S. Army Corps of Engineers and the Canadian Hydrographic Service (CHS), Department of Fisheries and Oceans. (Many people incorrectly refer to the Canadian bulletin as the “Environment Canada bulletin.” The forecast is generated by the Inland Waters Directorate (IWD) of Environment Canada, but the bulletin is prepared and distributed by the Canadian Hydrographic Service.) The coastal engineers interviewed retrieve statistical information from several sources: U.S. Army Corps of Engineers open-coast flood levels reports, NOAA water level gauge historical data for specific sites, and NOAA National Weather Service (NWS) weather data from Asheville, North Carolina for hindcasting storm wave conditions. Each respondent has a particular approach to assembling extreme value statistics for combinations of still water levels, storm surges, and storm wave conditions. Some use in-house programs that calculate extreme-value statistics. Others use their professional judgment to select separate reoccurrence intervals for combinations of highest instantaneous water level (that includes storm surge) and storm wave conditions. One engineer said that the historical record of instantaneous annual maximum lake levels was his preferred measure of water levels for use in design.

Planning times vary from a few months to decades. To plan construction projects and advise clients, the approximate time frame is from 6 to 18 months. For construction design life, the coastal engineer must consider the possible range in lake levels for the next 10 to 50 years. Twenty years is a common value used in construction design planning.

When asked if their forecast and statistical needs are being met, only one of six coastal engineers answered yes. Inadequacies in the available data were cited, and the need for better information was voiced:

Forecasts aren’t reliable beyond 1 month. There is a need for better long-term forecasts (6 months to 1 year or more) and the ability to predict changes in climatic regimes.

It is sometimes difficult to get needed information for extreme “worst-case” water levels. One engineer said that he used multiple approaches to get design water levels: crude estimates of worst-case storm surges combined with guesses about future higher-than-record water levels and instantaneous peak water levels from historical gauge records. He would like to have storm surge data in terms of probabilities.

There is evidence that extreme water level statistics severely underestimate highest storm water levels in some locations. One engineer mentioned studying a post-storm aerial photo of the Lake Huron shore at the south end of the lake near Samia. All shore protection structures were severely overtopped. Joint probability analysis of storm wave run-up, storm surge, and high water levels gave results different from the 100-year flood elevation, which also could not have predicted the overtopping. There is a need to develop some competency to statistically determine the joint probabilities of storm waves, storm surge, and high water levels.

One engineer mentioned that it is a problem for coastal engineers that NOAA doesn't have 5-minute interval water level data available from all gauging stations. This interval is needed to record highest storm surge elevations.

Most of those interviewed prefer to receive the forecast and historical hydrograph of past levels as they do now-paper copy by mail. When obtaining historical levels data from particular gauges, most would like to be able to use a dial-up computer link. One person added that this should include provisions for data transfer of historic water levels so that the engineer can make his or her own data analysis. Other suggested means of information transfer included computer tape (or disk) of basic water level data by courier, phone call to an agency person when lake levels are very high or low, and fax response to requests.

The following comments were reactions to the sample graphs (Figures 1-S) included in the interview packet.

Most of the engineers preferred Figure 2, or a combination of 1 and 2, similar to the current monthly forecast bulletin format used by CHS and the Corps. One engineer would like to have a computer-interactive version of Figure 2 so that he could do his own sensitivity analysis, selecting his own definition of "probable." Most engineers appreciated the information content of Figures 3 and 4 but didn't think the graphs were particularly useful.

One engineer has used the type of information contained in Figure 5 on major construction projects, like harbor breakwaters. Two others liked the statistical look ahead for 5 years (relevant time frame), but preferred the format of Figure 6. One person suggested that Figure 5 be published annually in the end-of-the-year update summary accompanying the monthly lake level forecast bulletin. Another engineer said this figure is appropriate for an old structure or for looking at the duration of a Super-fund clean-up project (e.g., what is the prospect for a dike being breached?), but has too short a time frame for new construction.

Figure 6 was described as "a neat plot...gives the worst you can expect...suitable for an industrial site." It would be most useful when a large rise in mean monthly lake levels has occurred, to help emergency governments prepare. Another engineer said that the longer time frame makes this figure more useful than Figure 5 for design purposes. He also said that many of his projects have greater than 20 year design lives, but that extending probabilities of lake levels further than 20 years into the future would be "a flat lie." Another engineer thinks that it would be useful to have a plot like this for lake levels during boating season as well as ice-cover season. One engineer said he thought he could explain this figure to a client.

One engineer said that Figure 7 shows the type of output he currently gets from his firm's in-house method. Another respondent liked the emphasis on the difference between the monthly mean level (which is in the monthly forecast) and the daily or instantaneous maximum levels. He thinks that this figure is suitable for a technical audience and experienced lake observers. Another engineer said that his firm has used this information in the past but not recently because of their concern about joint probabilities of storm surges and water levels. This figure may not be conservative enough for design. Designers need to apply record high water levels and a 20-year storm surge, he claimed. Another engineer said that he likes this figure. It has lots of information for him. It is not "client-friendly,'* and need not be.

One engineer wasn't sure whether Figure 8 showed the duration of a monthly or a daily mean level, but thought it useful to know what the duration of a water level is likely to be during a storm seiche (a matter of hours). Another engineer looked at this figure for quite awhile and didn't see how it would be useful by itself. One person said that it would be interesting to have some peak-over-threshold curves of duration, to give some idea of a base water level to which a storm surge could be added. How long an exposure would there be to high water levels? What is the probability of occurrence of storms during a period of high water levels? Another engineer said that duration information would be relevant only in reference to storm surge and storm waves. One engineer said that he produces similar statistics on duration of waves. If he were designing a marina, he could use this information for operational considerations. Another engineer found this figure not useful because it is for still water level and doesn't include storm surge and wave action. He is skeptical about duration data, remembering the surprise late in 1986 when high water levels did not continue as expected, but, in his words, "fell through the floor." He uses the actual historical record to demonstrate that unanticipated lake levels can and do occur.

### 3.1.1 Conclusions

The major unmet needs of coastal engineers are (1) some ways to anticipate the occasional episodes when a climatic shift brings a major and unexpected change in lake levels, and (2) a better way to anticipate and deal with the probabilities of a combination of very high lake level, extreme storm surge, and extreme storm wave conditions. The latter need is greatest in the coastal areas, particularly bays, where there are no water level records available and simple data interpolation between records of adjacent gaging stations is inadequate.

Coastal engineers seek more credible methods for extreme-value analysis of still water levels, storm surges, and storm waves. These statistics are of critical importance for the short-term (6-18 months) for planning construction as well as long-term (20 years or more) for design. They find merit in most of the sample' figures because there is a specific application for most of them. This suggests that a menu of statistical graphic programs be developed and made available to engineers along with computer access to the water level data base.

The coastal engineers are also a group that can use a credible, longer range lake level forecast. They were not shown a probabilistic 1 year forecast of the type demonstrated by Hartmann and Croley (1987), but they would most likely find it useful, judging by their use of probabilities in water level data. The quality and utility of such a forecast could be tested with the unprecedented sequence of water level changes from 1984 to 1989.

## 3.2 Environmental Interests

The two people interviewed for the environmental interests group are very well-informed representatives of environmental concerns in the Great Lakes basin. They are well acquainted with lake level issues. They have filled leadership roles in Great Lakes advocacy groups.

These people are very familiar with sources of water level information. They do not necessarily use the information to make decisions, but are very interested in following trends and understanding the current status of the lake levels. Information sources mentioned included the Corps and CHS water level bulletins and LJC mailings.

In general, this group is satisfied with the content and quality of the forecast bulletins. However, they had very specific suggestions for improving the bulletins. One person said the bulletin needs further explanation in order to be clearly understood He reported there is some confusion interpreting the graph and distinguishing between the “real” versus “projected” lines. They believe the bulletins should include additional precipitation information to help people understand the link between precipitation and water levels.

One respondent expressed a need for a table highlighting environmentally sensitive areas in the basin (wetlands, etc.) and the corresponding water levels that must be “maintained” to protect those areas. More research is needed on the relationship between lake levels and wildlife propagation and habitat.

In the area of communication needs, they thought more exposure of water level information to the public through radio, TV, or newspaper would help people accept the reality of fluctuating lake levels. One person said environmental groups need access to more current information, preferably by dial-up computer, so that they can feel more confident when communicating with state or federal agency officials.

### 3.2.1 Figures

One person preferred Figure 4 and thought it could be quite useful for marinas and other users. The other interviewee likes Figure 2, but wants the “probable” band to be narrowed and very well defined. Both respondents expressed their dislike of Figure 1, the deterministic forecast. Figures 3 and 8 also sparked some interest. The remainder of the figures (5, 6, and 7) were felt to be “too complicated,” or, “only for the professional.” One person would like to see actual elevations on each graph, not just “feet above datum.”

### 3.2.2 Conclusions

The people interviewed are generally satisfied with the content and quality of the forecast bulletins. Of primary interest is the current status of lake levels in relation to the historical range of levels. Their chief unmet need is for information that interprets the meaning and significance of lake level data and forecasts. Some of their suggestions for improvement will make good topics for future Lake Level Updates (published by the U.S. Army Corps of Engineers in conjunction with their water level bulletin):

* identify environmentally sensitive areas in the basin where water level changes pose a critical threat;

* explain features of the forecast bulletin graphs more clearly;

* define the band width of uncertainty in the forecast;

* define and describe "Chart Datum"—its physical meaning, and how those important reference numbers are established.

The people interviewed saw a real need for increasing the public's awareness of water level issues by encouraging the inclusion of this information in radio, TV, or newspaper weather reports.

### 3.3 Government: City/Regional

This rather diverse group of 11 interviews focuses on local concerns associated with water levels. The group includes two city engineers, two managers in city public works departments, one county parks director, and one senior engineer for a coastal regional planning commission (RPC). These people are responsible for planning major investments in or operation of major lakeside facilities. Also included in this group are a mayor, a representative of a port authority, a water supply provider, and two Ontario Conservation Authority employees.

Some people responsible for major lakeside facilities don't want more information on lake levels. One engineer for a major metropolitan sanitary district showed the questionnaire and figures to other staff. He then wrote, "We have concluded that we do not need to receive this type of information. Therefore, in order to save time and paper, please remove us from your mailing list." During the follow-up phone call, he added that their people pay attention to lake levels only when they reach a high level that poses a threat to operations or structures. The employee of a municipal water supply agency also indicated they had no need for Great Lakes water level information. He indicated that since Lake Ontario is regulated, they feel perfectly secure.

In the U.S., two public works people and one city engineer said they use water level forecasts and statistics only when lake levels rise to elevations that cause concern for facility safety and operations. The other city engineer and the parks director use forecasts and statistics for shore protection projects and for marina operations. The mayor indicated that water level information is used for shore development and other long-term plans. The RPC engineer uses forecasts to assist local governments and statistics to help with planning of shore protection, flood/land management, and water quality improvement.

Land use in Canada is managed based on 100-year flood levels determined by Environment Canada (EC) and the Ontario Ministry of Natural Resources (OMNR) in concert with wave run-up and erosion data. Conservation Authority employees use weekly and hourly level information for site inspections and to check private survey results. They use the 6-month forecast combined with wind data to anticipate flood potential. Required storm surge watches and warnings are issued by the Ontario Weather Centre of Atmospheric Environment Service/EC. Warnings are forwarded to the Conservation Authority through the OMNR. These watches and warnings are also provided to the general public over the Weatheradio Canada network as well as commercial radio and TV.

Forecasts are obtained from the U.S. Army Corps of Engineers and the Canadian Hydrographic Service's monthly bulletins. Other information sources mentioned include the OMNR, the Canadian Department of Fisheries and Oceans/CHS, and the IJC "Focus" newsletter. Statistics on 100-year flood levels from the U.S. Federal Emergency Management Agency (FEMA) are also used. In some cases, statistical analysis of NOAA water level gauge records is performed in-house. One person mentioned that reports of damage from property owners are his indicator that lake levels are high.

These interviewees are diverse in their application of water level data as well as their planning needs, which range from hours to many years. For setting county marina pier elevations, there is a need to know in March what levels to expect in May, and whether or not big changes in levels are expected for the summer. There is a similar need for seasonal forecasts to aid in making decisions to reinforce manholes in a major sewer interceptor located beneath the beach of one city. A 6 month to 1 year forecast is needed for shore protection projects in one city. A 6 month forecast is adequate for projects in another city. Construction projects with major costs (millions of dollars) need 18 months to several years of lead time. Twenty years is required for typical regional planning commission projects. In general, when levels are extreme, especially on the high end, there is a greater need for very current information.

The two city engineers and the RPC engineer answered "yes" when asked if their water level information needs are being met. Two people answered "no," citing the inadequate warning of rising lake levels in 1985 and subsequent drop, and a need to know more in advance when such changes in trends are going to occur. Storm surge forecasting is a need identified by several people in this group. One public works official said that his department needs the occurrence of a damaging storm event to justify a request for major shore protection expenditures. One person believed that a lot of lake level information is generated, but it is of limited use to him since it is not tailored for specific geographic regions.

Everyone prefers to receive the forecast bulletins through the mail. Several people also would like dial-up computer access to water level data or storm surge forecasts. Fax access to real-time information during critical periods was also suggested. One person thought the 800-number that was available for public water level information requests in Canada during the high levels of the 1980s should be revived. Another respondent said that his local newspaper prints water level information several times each week. He would like to see agencies encourage more media coverage (radio, TV, newspapers) of lake level information to heighten people's awareness that the levels of the Great Lakes do fluctuate.

### 3.3.1 Figures

All the interviewees who commented on the graphs preferred the presentations that are similar to the forecast bulletins. The county parks director stressed the importance of timeliness and reliability for lake level forecasts. If the range of likely levels is to be given in the forecast, the probability represented by the range must be included. An engineer thought Figures 2 and 4 would be useful for advising people to take action. The Conservation Authority employees preferred Figures 3 and 4. One said that only the extreme levels are really important to him.

Reactions to the last four figures were mixed. Several people said they were too complex, and that what the public needs is the simplest possible picture. Others found some of the more complex figures to be potentially useful. The probability information contained in Figures 5 and 6 would be helpful in long-range planning, according to a city engineer. The county parks director found Figure 7 to be very useful. Several people thought it could be helpful in land use planning and safety applications. Figure 8, the duration curve, was intriguing to many, though some were skeptical. It was pointed out that had this type of graph been available in the fall of 1986, it would have turned out to be very wrong. One person said it would be helpful "if true."

### 3.3.2 Conclusions

This group's needs are being met only marginally. The chief unmet need of this group is adequate warning when lake levels are expected to reach the limits of the "comfort zone." Water levels within the range of comfortable levels do not threaten structures or operational activities, and so do not merit attention from these officials. However, this group needs more information when levels are extreme. Storm surge warnings need to be included in the NWS weather and nearshore marine forecasts. There also is a need for lake level information at specific geographic sites not served by a lake level gauging station.

In general, the group's comments suggest improvements in the way that users are alerted when forecasts indicate levels that reach the limits of the comfort zone. Fax access to real-time water level data or transmission of high/low warnings may be needed. Reactivation of the Canadian toll-free water level information hotline during critical periods was also recommended.

Some members of this group were very interested in the variety of statistical information demonstrated in the figures. Some even do their own statistical analysis. This group could profit from some new statistical presentations of lake level data, thoroughly explained with sufficient background information.

## 3.4 Government: Emergency

Four interviews are reported here. One person interviewed in this group is active in managing emergency government at the state level. Two other people are involved with emergency government at the county level. These three people swing into action when lake levels rise to an elevation where flooding and major shore property damage are imminent. Because of emergency government's dependence on weather forecasts, added to this group was information gamed in an interview with two staff people at the NWS office responsible for making land and marine forecasts for western Lake Michigan. Conservation Authority and OMNR staff, who play an important role in emergency response in Canada, were included in the previous section.

All three emergency government people and the two NWS forecasters said, "yes," they do use Great Lakes water level forecasts, but only reactively, when water levels rise to dangerous levels. One person was aware of lake level statistics but didn't use them.

All respondents mentioned the U.S. Army Cop of Engineers monthly lake level bulletin and update as their source of water level information. TWO persons mentioned NWS marine forecasts. Another person mentioned the Wisconsin Sea Grant lake level updates, which were produced from information supplied by the people who prepare the U.S. bulletin. The Sea Grant updates were produced monthly from the beginning of the high water level problems in the spring of 1985 until the rapid decline of lake levels ended after the 1988 drought. The U.S. Coast Guard was also mentioned as an information source.

The person from the state office mentioned that the typical time of response to a high water level emergency or other crisis is from a few weeks to three months after the crisis occurs. One county official, a captain in the sheriffs department, said that they need hours to days of advance warning of an impending crisis. They need time to locate and assemble stocks of sandbags and other emergency supplies and gear. The other county official mentioned a need for 24 hours of advance notice. The NWS forecasters need lake level information more than a day in advance so that they can issue statements warning of lakeshore flooding as supplements to the 24-hour weather forecast.

The two NWS forecasters felt that their lake level information needs are already being met. They find the present U.S. Army Corps of Engineers monthly lake level bulletin to be “perfectly adequate.” They have NOAA/GLERL’s Storm Surge Planning Program (SSPP) loaded on their personal computers to help them estimate storm surges and flooding potential. The Chicago NWS office is the only other office they know of that uses the SSPP for issuing storm surge warnings. Storm surge information for Lake Erie (Toledo and Buffalo) is provided on a regular basis to local forecast offices by the NWS National Meteorologic Center. In Canada, AES uses an in-house model, originally developed at the Canada Centre for Inland Waters, to forecast storm surges for the Canadian portion of the shoreline.

All three emergency government people said their water level information needs are not being met at present. The state office person said it would be “extremely helpful” to have information about the probabilities of future very high lake levels. One county official complained that he didn’t have enough warning of rising lake levels in 1985. He said it was unclear how much lake level reduction could be achieved at times of high water levels by increased flow out of Lake Superior, determined by the Lake Superior Lake Level Board of Control. The other county official (from the southern end of Green Bay) said he would like to get advance warning of storm surge flooding and flooding potential. He appeared unaware that the NWS office near Milwaukee provides such warnings (see comments above). He mentioned the flash flood and storm surge that hit the City of Green Bay on June 2 1, 1989. Local officials were surprised by it. They had difficulty in quickly locating barricades. Spectators in four-wheel-drive vehicles created damaging wakes on flooded streets and roads.

### 3.4.1 Figures

Figures 1 and 2 were preferred over others. One county official thought Figure 3 would be helpful when levels become critical. One county official thought Figures 5 and 6 could be useful during periods of high water levels. Figure 8, the duration curve, was very interesting to county and state officials. The state official felt that this figure would help emergency government employees convince local people of the seriousness of situations such as that experienced in 1986.

The two NWS forecasters said they had no interest in longer-range lake level outlooks other than those now available in the U.S. bulletin. They were unaware of any talk in the NWS about making longer-range lake level outlooks, similar to the 30, 60, and 90 day temperature and precipitation outlooks that the NWS produces.

### 3.4.2 Conclusions

Since most of the people in this group are in city and county government, their uses of water level information and their unmet needs are similar to those of the preceding group. This group has an urgent need for better advance warning of extreme lake levels and better communication of those warnings by fax, phone, or radio. Their planning time is very short: from a few hours to a few months. Even in areas where the NOAA Storm Surge Planning Program is being used, the warnings do not always get to the local emergency government officials that need them. The SSPP also needs to be applied to weather forecasts in more Great Lakes localities. This group does not use water level statistics.

## 3.5 Government: State/Provincial

Three of the six people interviewed here work for the Wisconsin Department of Natural Resources (WISDNR); two are design engineers in the central offices and one is a district staff person. A coastal engineer with the New York Department of Environmental Conservation (NYDEC) and an environmental planner on the staff of the Pennsylvania Coastal Zone Management Program were interviewed. An interview with a staffer from the OMNR was also included here.

All six people use water level forecasts on the job. One WISDNR design engineer uses statistics in the design of launch ramps and docks. The OMNR official uses lake level statistics in flood line mapping. The others don’t use water level statistics: The Pennsylvania Coastal Zone Management Program staff members don’t use statistics because of the character of their shoreline (bluffs averaging 60 feet in height). Several people use the forecast bulletin to monitor trends in lake levels and to compare current levels with the historical range of lake levels.

Four people use the U.S. Army Corps of Engineers monthly lake level bulletin. Two of the three WISDNR staff also used the Wisconsin Sea Grant lake level update bulletin and call on local Sea Grant staff for lake levels on a particular day or for other information. OMNR uses water level information from the IWD of Environment Canada, CHS, as well as the U.S. Army Corps of Engineers. Storm surge warnings are received from AES, and distributed to the local Conservation Authority or acted upon in-house.

The planning time for these people is from months to years. The two WISDNR design engineers said that months are required for a project to go through the approval process, and 6 months to several years are required to complete construction. Structure design life ranges from 12 to 20 years. In WISDNR district permitting activities, staff are concerned about time frames ranging from construction periods (months) to structure life (years). In their determination of Ordinary High Water Mark (OHWM), they consider a 100 year time period. The NYDEC engineer said his department used a 50 year design life for structures. The 1 in 100 year combined probability levels serve as the basis for flood zone delineation in Canada.

Four people felt that their water level information needs are currently being met. Two others did not, because they would like to be able to know what the water level is at a particular gauge, day, and time for advising property owners or for reviewing permit applications on site. One person added a need for historical water level statistics in helping to determine an OHWM.

Interviewees gave multiple choices in response to the question about different means of distributing water level information. Four people mentioned their preference for the current system of receiving monthly forecast bulletins through the mail. All six would like to have dial-up computer access to information to get current water levels during a project or in times of critical levels. One person wishes to get current levels by mobile cellular phone when visiting and advising property owners. Two people liked the fax option.

### 3.5.1 Figures

There was no consensus of choice on the figures. One person preferred Figure 1, two preferred Figure 2, and some liked both. Someone else preferred Figures 3 and 4. One of the design engineers mentioned that the historical multi-year hydrograph in the U.S. bulletin was more helpful than the 6 month time frame in Figures 1 through 4.

Two people found Figure 5 to be somewhat useful, and one person liked Figure 7. One person indicated that Figure 8 would be helpful for permitting and erosion control projects. Three others said it would not be helpful. One person thought Figures 6 through 8 would be good file information.

### 3.5.2 Conclusions

Most of this group feels their needs are being met by current forecast products. One person needs historical water level statistics and another wants access to water level data at a particular gauge and time. The primary need, once again, is better access to extreme water level statistics for hazard area delineation (long-term, 100 years), planning (20 years), and emergency response (immediate) by fax, phone, or computer. All of these people would like dial-up computer access to water level information during critical periods or during a project.

## 3.6 Government: Federal

This group of seven interviews includes government workers from the U.S. and Canada who depend on water level information for a wide variety of applications: planning for future flood control or flood insurance administration, other public works projects, small craft needs, and weather service and water resources research.

All interviewees use Great Lakes level forecasts and statistics to some degree. For example, the 6-month forecast is used to follow trends and make comparisons with past levels to determine flooding potential and plan future dredging projects. Many of the users of water level data in this group are concerned only when water levels approach historic maximum or minimum levels. Water level conditions are used to advise provincial governments on fish harvest levels. In Canada, hazard lands are defined using 100-year combined probability levels based on water level statistics. In the U.S., statistics are used to designate 100-year flood levels to set flood insurance rates. These statistics are also used to determine which still water level/wind condition combinations could cause flooding.

The planning time needs and information sources vary as widely as the applications. Most people are familiar with the CHS and/or Corps of Engineers monthly water level bulletins. Real time data are obtained from Canada's Great Lakes Water Level Communication Centre, CHS, and direct access water gauges. Responses to the question about planning time ranged from hours, for surveying and storm events, to many years, for public works and flood level planning. Most respondents like to compare the current month's conditions with long-term lake level maximums and minimums.

In general, the people interviewed in this group feel their water level information needs are adequately met. Most are generally pleased with the 6 month forecast. One planner would like an 18 month forecast, but only if it were accurate. One user would like to see more physical information included in the forecast bulletin, such as precipitation and evaporation. Another person would like to see more real time storm surge forecasting. Someone else requested wave hindcasts.

Everyone interviewed was content with receiving the monthly forecast and other basic information through the mail. Many people mentioned the need during critical levels to obtain real-time data by fax or computer dial-up. Most people also mentioned thatone-to-one communication over the phone is essential to their understanding and use of water level information. It was not surprising that everyone interviewed knew who to contact for more detailed information. This group is obviously comfortable using the phone to obtain water level information. This is not the case for many other groups.

### 3.6.1 Figures

Most people preferred some combination of Figures 1 through 4. In Figure 2, the term "probable range" should be defined very precisely. One user suggested that a figure like Figure 3 using the actual year-by-year levels would be better than a simple summary plot of annual values. The annual summary doesn't show the long-term ups and downs.

Most people quickly dismissed Figures 5 through 8 as "too complicated" or "of no interest." After some discussion and explanation, several users could see that the information contained in these graphs could be useful for reference or for specific applications.

One respondent suggested that an interpretation guide be prepared to help users understand the forecast bulletins. He would like to see the forecast bulletin include an explanation of the chances of levels being outside the band. It would be helpful if bulletin preparers could identify whether these occurrences outside the band are concentrated during certain times of the year. It was also suggested that more use be made of the monthly water level plots, rather than relying on the forecast bulletins' average plot.

### 3.6.2 Conclusions

It is not surprising that this group generally feels that their water level information needs are adequately met. These people are closer to the providers of forecasts and statistics than most other user groups. They know who to call when they have a specific need.

Two suggestions for improvement from this group were also mentioned as unmet needs by state/provincial government workers: longer range forecasts, and more real-time storm surge forecasting. One new suggestion surfaced here: wave hindcasts. Another suggestion was for the agencies involved to produce a forecast bulletin interpretation guide.

It was somewhat surprising that most of this group quickly dismissed the more complicated figures as "of no interest" until the figures were explained and discussed. Apparently, this type of graphical information is unfamiliar to many of these people.

## 3.7 Marine Contractors

The two contractors interviewed are with major firms having a long history of coastal construction on the shores of Lake Michigan. Both people indicated that lake level information is important in design and in estimating costs. Since their concern with lake levels extends to the duration of any one construction project, marine contractors are interested in water level information from one month to one year in the future. Both contractors use the Corps of Engineers monthly bulletin. Lake level forecasts are consulted when planning construction projects.

One contractor said that his water level information needs are being met. The other said it would be helpful if future lake levels could be forecast up to one year ahead, but only if there was a reasonable degree of accuracy. They found current means of receiving the information (mail) to be adequate for their needs.

Marine contractors have trouble finding conversions between the local datums used in many construction plans, the International Great Lakes Datum (IGLD) for lake levels, and the National Geodetic Vertical Datum (NGVD) in the U.S. or Canadian Geodetic Datum (CGD) in Canada for land elevations. It was suggested that some agency should publish and distribute a set of conversions for datums.

### 3.7.1 Figures

Both contractors preferred Figure 2 over all others. One person said that Figure 3 would be of value to consulting engineers who are not used to working on marine projects and, as a result, design permanent structures that are either too high or too low. The rest of the graphs are not seen as useful by these marine contractors.

### 3.7.2 Conclusions

These people need to know what the lake level will be during any one construction project. They would like to have an accurate forecast that looks a year in the future. They also need help to convert local datum-based elevations to IGLD and NGVD datums. Aside from these needs, the two U.S. marine contractors interviewed are comfortable with current products.

## 3.8 Native North Americans

The environmental coordinator of the Walpole Island Indian Reservation, a representative from the Great Lakes Indian Fish and Wildlife Commission, and a member of the Keweenaw Bay Indian Community were interviewed. One respondent said that water level information is sometimes used to make decisions about the timing of the spring spawning run. The other two said they do not use water level forecasts. They are affected by changes in water levels, for instance, the harvest of wild rice is certainly affected, but they have learned to live with the fluctuations.

Information sources mentioned included the 6 month water level bulletins produced by CHS and the Corps of Engineers. These are used for monitoring trends. One person would like to see the bulletins include information on snow pack and runoff.

All three people mentioned a need for more warning of extreme lake levels. One person said an early warning of expected extreme levels would be helpful to tribal members engaged in fishing or wild rice harvesting. Another interviewee participates in planning for shore erosion abatement, so is interested in high levels forecast. One respondent would like to see water level information included in the local newspaper.

### 3.8.1 Figures

Two people commented on the graphs. Both liked and understood Figures 2 and 4. One person especially liked Figure 3 and the other found it “too busy.” The rest of the figures were seen as only marginally useful, if at all.

### 3.8.2 Conclusions

This group, like many others, could benefit from earlier warnings of extreme levels. Native American people using the lakes have learned to adapt to their fluctuating levels. They were somewhat interested in increased media coverage of local water level conditions.

## 3.9 Navigation/Shipping

This group consists of eight people whose prime interest in Great Lakes levels is their impact on navigation. Interviewees included a representative from an association of Great Lakes shippers, representatives from the U.S. and Canadian St. Lawrence Seaway Authorities, and members of the Canadian and U.S. Coast Guards.

The planning time for this group is shorter than many groups-often on the order of days to weeks. Decisions concerning St. Lawrence outflow regulation are made weekly, based on real-time gauge information and past history to determine minimum water levels required for allowable maximum vessel draft. Great Lakes shippers need information on the levels expected for the next 2-5 days. At the long end of the planning spectrum, dredging plans are often made 10 years in advance.

The U.S. Coast Guard operational people do not use water level information for decision-making, but they are interested in levels. Some offices are familiar with the Corps 6-month forecast, but most use primarily real-time information from local gauges or over phone lines from the Corps. Some Coast Guard offices report local water level information to the NWS regularly. Others said they really didn't know how they would find out about a forecast predicting a dramatic increase or decrease in levels. They would like to have lake level information somehow included in weather forecasts, because they scrutinize those.

The Canadian Coast Guard uses statistics and forecasts to formally advise shippers on conditions in the Montreal to Three Rivers reach of the St. Lawrence, and on an ad hoc basis in other parts of the basin. They also get involved in planning for dredging projects and shore protection in harbors and shipping channels. They use information obtained from the Marine Environmental Data Services Branch (MEDS) of the Department of Fisheries and Oceans, the Great Lakes-St. Lawrence Study Office, the St. Lawrence Seaway Authority records, the Corps, NOAA, Port of Montreal, and direct readings from gauges.

The water level information sources mentioned by the rest include the Corps, CHS, direct access to water level gauges, and St. Lawrence Seaway Authority and Port of Montreal records. The information is received daily or weekly by phone, fax, or dial-up computer. Monthly records are received through the mail.

Most of the people interviewed would like a more accurate long-term weather forecast on which to base lake level forecasts, but realize this is not currently available. Some reported that they receive too much lake level information and have a hard time sorting it out. One interviewee indicated that basing lake level forecasts on single gauges can be misleading. For instance, does the water level gauge at Kingston, Ontario fairly represent the level of Lake Ontario?

The shippers' association representative said shippers are happy with the accuracy and timeliness of the Corps forecast but wish storm surge information could be included in the forecasts. They would also benefit by having current and forecast water level information available by fax. Association members currently can get weather information, updated four times daily, by fax from the NWS Cleveland office. They would like to have water level information included in those weather updates.

The Canadian Coast Guard representative said there is a demand for more accurate and more frequent forecasts for the lower St. Lawrence (downstream of Montreal). He said it is sometimes a problem to quickly obtain data on current or recent (past few weeks) water levels. They would like computer access to real-time information.

### 3.9.1 Figures

There was very little reaction to the graphs from most of this group. Several people said they are comfortable with the forecast bulletin type of presentation, similar to a combination of Figures 1, 2, and 4. All others were rejected by most people for being “too long-term,” “too general,” or “too technical.” The Canadian Coast Guard respondent preferred Figure 3. They would like to have the “average” line removed and “actual” level with a “probable range” forecast superimposed.

### 3.9.2 Conclusions

Many of these people are more dependent on very near-term forecasts (usually several days) than most other groups. Computer access to real-time level data by fax or computer was mentioned as a need. Inclusion of real-time water level information in the local weather forecasts would help shippers. On the other end of the time scale, a lo-year lake level forecast would help determine long-range dredging plans.

## 3.10 Power

Representatives from four large power companies were interviewed. Three companies have large hydroelectric power plants on the connecting channels. The other company has coal-fired power plants along the shoreline of Lake Michigan. The hydroelectric power companies use water level information extensively in their work. Information is used to forecast future hydroelectric power generation and power purchases, to set rates, and to do long-range planning for new power generation facilities. The other power company does not have a regular need for water level information unless lake levels approach the limits of the power plants’ design parameters.

The information used is drawn from a variety of sources, including, in several cases, extensive in-house expertise. Data from the monthly U.S. and Canadian bulletins are used, in some cases, mainly to compare with in-house forecasts. Computer models from NOAA/GLERL and AES are used. Basic data are also obtained from government-maintained gauges. The Great Lakes-St. Lawrence Study Office in Cornwall and the Lake Superior Board of Control Regulation Letter and Tables were also mentioned as information sources.

The planning time needs for these individuals is basically 6 to 12 months, though shorter and longer term information is used. Projections of power production must be made regularly; these may be looking 1, 6, or 12 months in the future.

In general, the power company scientists interviewed feel their water level information needs are currently being met. All expressed a wish for more accurate long-range forecasts (12 months and longer). One power representative mentioned that a more accurate preliminary forecast just before month's end would help them anticipate expected outflows. They are also satisfied with the way they receive water level information, through various combinations of mail, phone, and fax.

### 3.10.1 Figures

There was no consensus among power company scientists on the graphs. Several people preferred Figure 3, possibly combined with Figure 2 and including current and future data ("like the Lake of the Woods graph"). One person found the exceedance probability graphs to be very relevant. One scientist found the duration information contained in Figure 8 to be potentially very useful.

### 3.10.2 Conclusions

Power company scientists generally expressed no unmet needs. Most hydroelectric power companies have extensive in-house expertise to provide them with the water level information needed for power production projections. Like many others, they would like to have longer-range forecasts of 1 or more years. One person suggested that a more accurate preliminary forecast be released just before the end of the month.

## 3.11 Recreational Boating

This group of six interviews includes one marina owner/designer, two marina operators, two Sea Grant agents, the bulk of whose comments were applicable to this category, and one commercial fisherman. One of the Sea Grant agents interviewed, Frank Lichtkoppler of Ohio, recently completed a survey of marina owners and boaters from the U.S. side of Lake Erie. (Lichtkoppler, 1990). His survey was very similar in content to the interviews reported here, minus the graphs. At Mr. Lichtkoppler's suggestion, his results are also included here. There were 108 responses to the marina operators survey and 204 responses to a survey of recreational boaters and fishermen.

Most of the people interviewed in this group use lake level information regularly. The U.S. Army Corps of Engineers, Environment Canada, direct-dial link to water level gauges, and personal gauges were all mentioned as information sources. The Sea Grant agents also use water level updates published by Sea Grant offices in New York and Wisconsin. From the Lichtkoppler survey, all marina operators said they use lake level information in some form. About half of the boaters said they use it.

The information is used by many in this group to explain lake level conditions to others. They are interested in the very near-term (hours-days-weeks) forecast, but are just as concerned with longer-term trends. Sea Grant agents advise people on water level matters as part of their job. Marina owners are called upon in a less formal way to advise local boaters on changes in the lake level. The diversity in the types of information used and passed on is great. One marina owner receives forecast information from the Corps, but doesn't use it because it's "too technical." Instead, he uses his own personal water level gauge to make his own guess as to future conditions. Another marina owner has a direct hook-up to the government-maintained gauges nearest his business. About half of the Lake Erie (U.S. side) marina operators surveyed by Lichtkoppler indicated that their main source of lake level information is the Corps water level bulletin or the NOAA marine weather forecasts. Other sources are newspapers, TV, and radio. More than half of the marina operators reported sharing lake level forecasts with, on average, 88 people. Of the boaters surveyed, only about 9% reported using the Corps forecast bulletin.

The commercial fisherman interviewed indicated that water levels really don't matter to him, unless they get so extreme that docking facilities are impaired. Commercial fishermen's mobile nets are moved in response to changing water levels. He has no need for water level information.

Responses to the question about whether or not needs are being met were mixed. One Sea Grant agent and one marina owner are satisfied with the information currently received. The other Sea Grant agent asked for more water budget information, including groundwater inflow to the lakes. One marina owner feels fairly well-equipped, but would like to have a better forecast for the next few weeks' levels, based on real-time precipitation information. Another marina owner feels there must be information somewhere that could help, but he doesn't know where to get it. All the information he has seen is too technical. Marina owners would like forecast information in text and percentages, more like the weather forecasts, rather than "complicated mathematical descriptions." They also need "fresher" information - maybe with a turn-around time of a week. The owners of a St. Lawrence River marina feel frustrated by the sudden changes in water levels that affect them and their business. They feel some of the frustration could be alleviated if they could receive information regularly from the Lake Ontario Board of Control. More than 63% of the marina operators and 83% of the boaters surveyed by Lichtkoppler said their water level forecast needs are currently being met. The others mentioned a need for more accurate, more timely forecasts. Some of the boaters want more weather and wind information.

This group saw a real need to explore new types of media for the communication of water level information. Fax and dial-up computer access to current water levels were attractive ideas to both marina operators. One marina owner thought that a boating information association could belong to some sort of fax weather/lake level forecast service. One Sea Grant agent also said that type of real-time information could be helpful to marinas. This Sea Grant agent, who works in western Lake Erie where storm surges play a big role, would also like to see extreme storm surge and marine wave forecast information available by phone, fax, TV, radio, and newspaper. One marina owner also would like to see very simple lake level forecasts included in the weather reports on TV, radio, and newspaper. He would like it to include the current level and projection as well as how both current and forecast levels compare with the same time last year.

### 3.11.1 Figures

Reactions to the graphs also varied quite a bit. One marina owner understood Figure 4. The rest of the figures drew labels such as "gobbledy-gook," and "mumbo-jumbo." Another marina owner has no use for any of the graphs because they are all too long-term for his interest (he would like a two-week forecast). A third marina owner liked Figure 3, but found Figure 4 to be confusing. He suggested making the forecast level darkest where it is most probable, continuously fading in intensity towards least probable limits. On the same graph, he would also like to see actual levels up to one and one-half years ago. Several people were interested in the concept of the duration curve, Figure 8. A Sea Grant agent thought this could be helpful for marina owners.

### 3.11.2 Conclusions

Marina operators and boaters, like coastal engineers, use lake level information regularly. Both groups use the information to explain lake level conditions to others. More than half of the marina operators in the Lichtkoppler (1990) survey reported sharing lake level forecasts with an average of 88 people.

A majority of marina operators and boaters surveyed by Lichtkoppler are satisfied with present lake level information. The stated unmet needs have a greater sense of immediacy than those stated by preceding groups: better forecasts for the next few weeks, based on real-time precipitation data, fresher information with a turn-around time of a week, and more weather and wind information. This group also has a greater need for new types of timely communication of water level, storm surge, and marine wave forecasts via radio, TV, or newspaper. Some new ideas surfaced: forecast bulletins containing actual levels (not average) for the past 18 months, and two-week forecasts.

## 3.12 Riparians

The six riparians that were interviewed include lakeshore home and small business owners. Some represent riparian organizations in different parts of the Great Lakes basin. Most of the people in this group have been involved in the lake level issue for many years and are quite well informed about its intricacies.

Riparians, as a group, are well connected in the water level information loop. The riparians interviewed use water level forecasts and other information for a variety of purposes - from making personal household or business decisions, to counseling others on timing of dock or shore protection work. One stated that although he finds the lake level forecasts interesting, he does not base any decisions on them because he feels they are unreliable, based on personal experience.

The riparians interviewed use primarily the monthly bulletins from the Corps of Engineers or CHS. One Canadian riparian admitted to preferring the U.S. bulletin because it is in English units rather than metric. Most found receiving the bulletin through the mail to be acceptable for normal water level conditions. Several would like to see water level information weekly or biweekly in the local newspaper. During periods of extreme levels, they would appreciate more coverage of water level information on local radio and TV, with access to a computer dial-up or fax in response to specific requests.

Riparians have a broad range of planning time needs, ranging from days or weeks during crisis conditions (in case of the need for re-siting a house, for example) to months or years when planning dock siting or shore protection features. Like everyone else, riparians would greatly benefit from better long-term forecasting of trends, but most understand this is not currently possible. Two of the respondents find the forecast bulletins to be of no real use to them because they don't contain long-term information.

Responses to the question regarding whether or not water level needs are being met included both "Yes" and "No, because no reliable forecasts are available." One riparian would like to see the monthly forecast bulletin include information on average monthly flows in connecting channels, monthly evaporation, and amounts of water used by hydroelectric plants. They would also like to see a comprehensive annual review with a projection for the coming year. Several people found Environment Canada's toll free number to be very useful during the critical levels of 198586 and would like to have that available on a continuing basis. They also suggested that some agency should have a Fax request number for specific needs. One respondent made a plea for information dissemination on a more local level. He feels that until water level information gets into township newsletters, 4-H bulletins, and similar publications, it will not really be available to most people.

### 3.12.1 Figures

Most riparians preferred the first few graphs which most resemble the water level bulletins. Several people liked Figure 3; one person would like to see it made site-specific and combined with erosion potential information. One riparian, an engineer, thought that Figures 5 through 8 could be extremely useful in times of high water, although they would have to be explained more thoroughly. One respondent would like to see more actual data (weekly lake levels) disseminated so that he can make his own projections. He would also like to see precipitation included in the forecast bulletin as a curve paired with the level curve so that people become better informed about the relationship between precipitation and lake levels.

### 3.12.2 Conclusions

This group of people is representative of those riparians who have been involved with lake level issues for years, are well informed, and use available lake level information. The principal unmet need identified is more reliable forecasts. Like other groups, riparians want more information in forecast bulletins and ready access to more timely information during periods of extreme levels. Most of the people interviewed are comfortable with the graphic display of lake level forecasts that exists in current forecast bulletins. This group also recognizes the need for more media coverage of water level conditions.

## 3.13 User Needs Assessment Conclusions

This group of 65 people who agreed to be interviewed for the assessment of water level information user needs includes a substantial number of people who are satisfied and an equally significant number of people who are not satisfied with the water level information they now use.

The people who are dissatisfied with forecasts want a better "early warning" system when there appears to be a precipitation trend that will bring critically high or low lake levels. They also want longer range forecasts, up to 18 months in the future.

The people who are dissatisfied with statistics want credible methods for estimating the joint probabilities of extreme lake levels, storm surges, and storm wave runup. They want access to water level data. The responses indicate decidedly mixed opinions about whether the currently available water level information is satisfactory or not.

Participants in the various groups surveyed appear to have one or more distinctly perceived information needs. They want the information for long-range planning and structure design, for daily operational activities, and for emergency response. Each item on the following list of water level information needs is followed by the groups who feel that need. A group is listed in more than one category when there were indications of each type of need.

* Early warning of a climatic shift that is likely to result in a significant change in lake levels.
    - Coastal Engineers
    - Local/Regional Government
    - Navigation/Shipping
    - Power Companies
    - Ripalians

* Real-time water levels available on request. Storm surge warnings with marine weather forecasts for operational decisions.
    - Emergency/Local Government
    - Federal Government
    - Marina Operators/Boaters
    - Navigation/Shipping

* Water level information and storm surge warnings only when storm water levels threaten to move outside the “comfort zone.”
    - Commercial Fishermen
    - Emergency Government
    - Environmental groups
    - Federal Government
    - Native Americans
    - Riparians
    - State/Provincial/Local Government

* Water level information available upon request.
    - Environmental groups
    - Government (all levels)
    - Marina Operators/Boaters
    - Navigation/Shipping
    - Power Companies
    - Riparians

* Water level data, statistical methods, and graphics available upon request.
    - Coastal Engineers
    - Government (all levels)

The existing lake level forecast bulletins are appreciated and used by many. There are many indications, based on interview responses, that they are not fully understood. Many interviewees want more information to help them understand why lake levels are changing. They want the type of information that has become available in the U.S. Army Corps of Engineers Lake Level Update supplement to the monthly bulletin. This Update supplement has greatly benefited bulletin readers by supplying important background information. Respondents want to see lake level forecast bulletins that explain how to interpret the forecast graph. They need to understand what "probable" means for the projected range of levels. Information on precipitation, evaporation, connecting channel flows, groundwater inflows, consumptive use, lake level control actions, and how all these factors influence lake levels is needed. They want to see an annual review of the past year and a projection for lake levels in the coming year. They want identification of areas that are environmentally sensitive to extreme water level changes and explanations for this sensitivity. Some people would like to see the forecast in text, rather than graphical format, "more like the weather forecast.*' Others would like to see the average lake level line removed from the bulletin graphs and the most likely future level line replaced with the band representing the probable range.

During times of very high or very low water levels, respondents would like to have a toll-free phone line available for information requests, as was done by Environment Canada during the most recent high water crisis. A surprising number of people want access to present water level information by phone, fax, or computer link during times of extreme levels.

Although advance warning of climatic shifts and longer-range lake level forecasts are currently unavailable, other commonly requested measures can be implemented. These include expansion of the storm surge warning program to more nearshore marine weather forecasting centers in the Great Lakes and larger portions of the shorelines. Similarly, it should be possible to develop software and companion graphics to help engineers perform probability analyses of extreme water levels at any coastal site of interest. It should also be possible to provide read-only access to water level data banks for those professionals who need the information for planning and design. Addressing these unmet needs will require modest changes in the lake level forecast bulletins, enlarged access to water level data banks, and greater public access to present water levels when lake levels leave the comfort zone.

## 4. FURTHER COORDINATION OF THE WATER LEVEL BULLETINS

Charles F. Southam

The user needs interviews affirmed that the Great Lakes water level bulletins published monthly in Canada (Figure 9) and the United States (Figure 10) are the primary source of water level information for a large percentage of the respondents.

Initially, commercial interests such as navigation and power entities were the major users of the bulletins. Today, about 2,600 copies of the Canadian bulletin and 10,000 copies of the U.S. bulletin are distributed monthly to a much wider audience, including government agencies, commercial interests, media, recreational boaters, and riparians. As was reflected by the needs assessment interviews, and summarized in Table 1, each user group has a different knowledge base and use for the information contained in the bulletins. This makes production of the bulletins an even greater challenge.

# Table l.--Summary of user needs interviews

| Question<br>Group | 1 Do you use water level statistics or forecasts? | 2 what are your info sources? | 3 What is your time frame? | 4 Are your needs being met?/Unmet needs: | 5 How would you like to receive info? | 6 Which graphs do you prefer? |
|---|---|---|---|---|---|---|
| Coastal Engineers | Yes | bulletins, gauges, published data | 6 mos. to 20 years | No; storm surge, extreme level statistics, longterm forecast | dial-up computer, fax, phone | 2 |
| Environmental Interests | not regularly | bulletins<br>IJC | long term | Yes: more info on areas sensitive to level changes; more understandable bulletin | radio, TV news-paper, dial-up access | 2,4 |
| Local Government | Yes | bulletins<br>OMNR<br>IJC | hours to years | No (yes); more storm surge, better early warning | fax, phone, 800 #, dial-up | 2,3,4 |
| Emergency Government | Yes; when levels are extreme | bulletins, marine forecasts: Sea Grant Updates | hours to months | No, (yes); extreme level stats, better early warning | fax, phone, radio | 1,2,8 |
| State/ Provincial Government | Yes | bulletins<br>Sea Grant updates | months to years | Yes, (no) would like access to specific gauges | dial-up access, fax | 1,2,3,4 |
| Federal Government | Yes | bulletins, phone requests | hours to years | Yes; longer range forecast, surge forecasts, wave hindcasts | phone, fax, dial-up | 1,2,3,4 |
| Marine Contractor | Yes | bulletins | 1 month to 1 year | Yes; U.S. side needs datum conversions | mail | 2 |
| Native Americans | not regularly | bulletins | hours to months | Yes: better warning of extremes | local news media | 2,4 |
| Navigation/ Shipping | Yes | real-time info from gauges or corps, bulletins | days to weeks | Yes; more storm surge information | local weather forecast, fax | 1,2,4 |
| Power | Yes | mostly in-house expertise, bulletins | 6-12 months | Yes; more accurate forecasts, longterm forecasts | mail, phone, fax | 2,3 |
| Recreational Boating | Yes | bulletins, gauges, Sea Grant Updates | both near and long-term | No, (yes); more understandable bulletins, more timely, accurate forecasts | fax, dial-up, local news media | 3,4 |
| Riparians | Yes | bulletins | both near and long-term | No, (yes); more reliable forecasts | fax, 800 #, local news media | 3 |

Figure 9.--Canadian monthly water levels bulletin, prepared by Canadian Hydrographic Service (January, 1992).

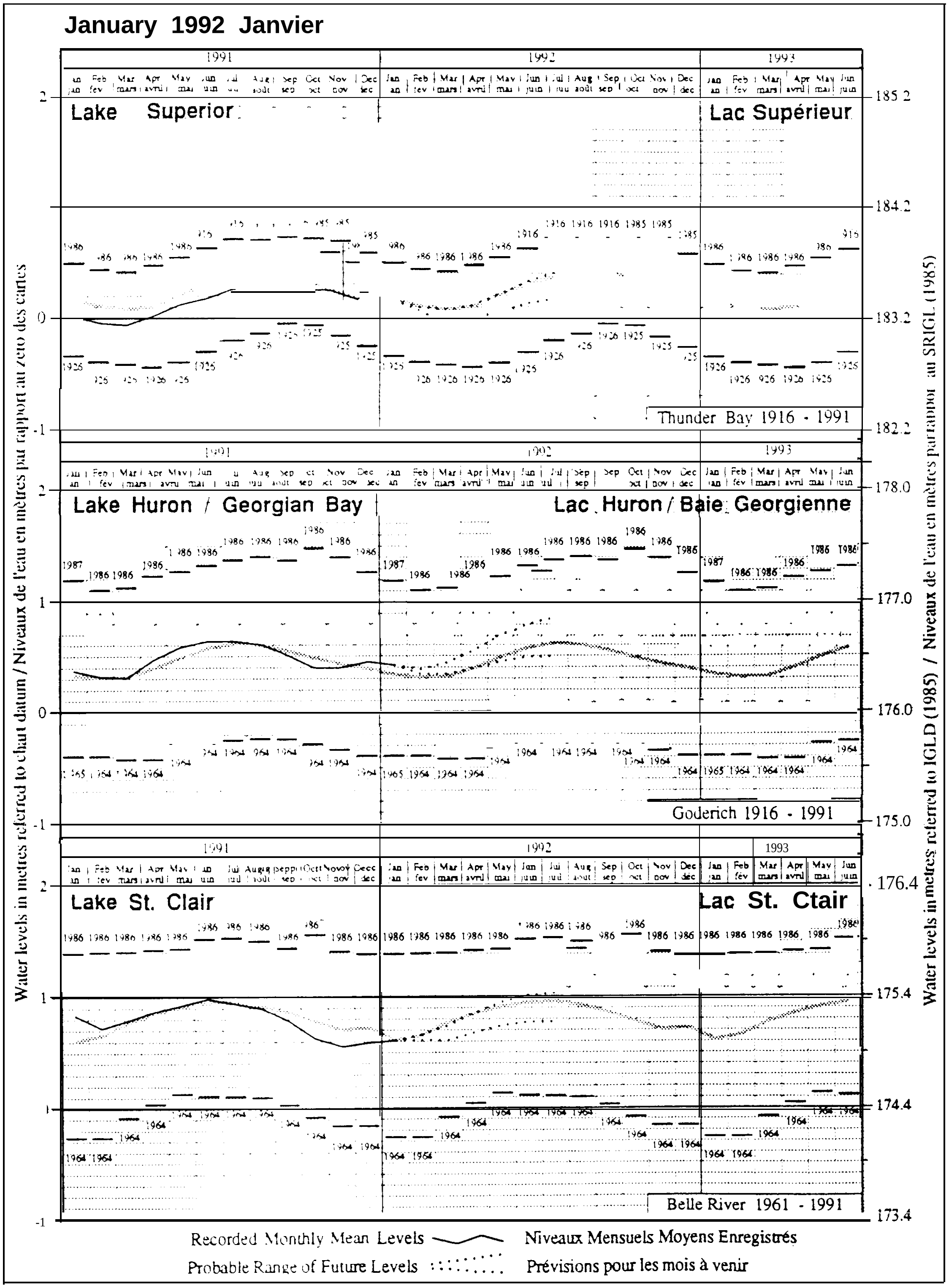
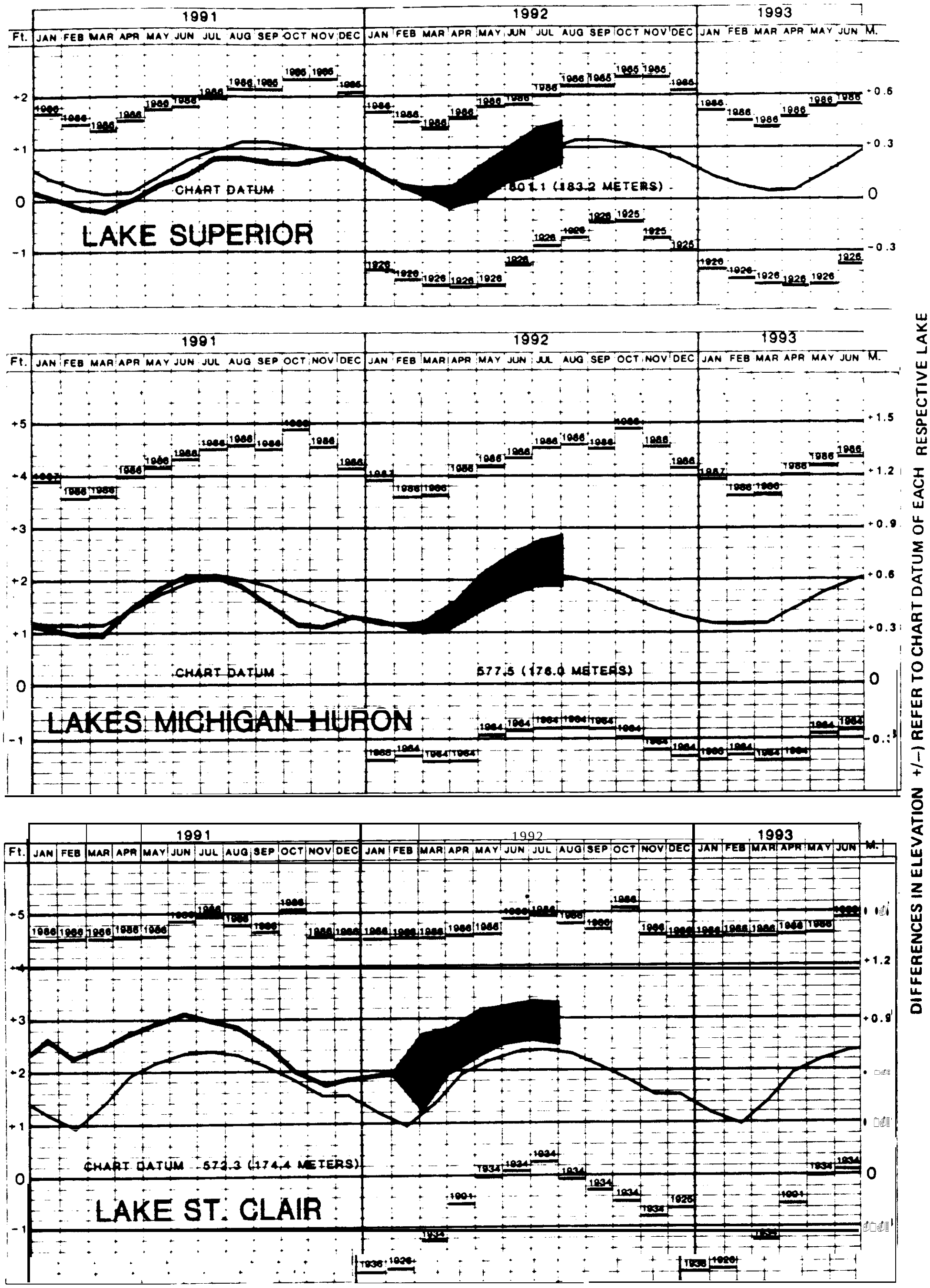


Figure 10.--U.S. monthly water level bulletin, prepared by the U.S. Army Corps of Engineers (January, 1992).



## 4.1 Description of the Current Bulletins

Three basic types of water level data are presented in the monthly bulletins: 1) historical data in the form of long-term means and historical extremes, 2) current conditions defined by a plot of the levels recorded over the past several months, and, 3) possible future levels in the form of a 6-month forecast. The data presented are based on monthly means. Recently, both bulletins have undergone some layout changes, but the basic data are similar to bulletins published before 1992.

Each month, under the auspices of the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data, the U.S. Army Corps of Engineers' Detroit District office and Environment Canada's Great Lakes-St. Lawrence Study Office in Cornwall produce a 6-month forecast of Great Lakes water levels. In the U.S., the 6-month forecast, the water level bulletin, and a monthly newsletter are prepared and distributed by the U.S. Army Corps of Engineers-Detroit District. In Canada, the forecast is prepared by Environment Canada, and preparation and primary distribution of the water level bulletin is the responsibility of the Canadian Hydrographic Service, Department of Fisheries and Oceans. Although the forecast portion is prepared under the auspices of the Coordinating Committee, the bulletin's base data and layout are not. Environment Canada prepares a news release and provides it along with the bulletin to a much smaller group, primarily the media and others such as International Joint Commission staff, who may be called upon to discuss current and future water level conditions.

The two bulletins are similar in many ways, containing the same type of data presented in similar formats. There are, however, several subtle differences between them. Although these differences are probably not important most of the time, they can lead to discrepancies between the two during extreme lake level conditions. These differences have caused confusion and misunderstanding of the hydrologic conditions of the Great Lakes, primarily among those who receive both versions of the bulletin.

The differences between the Canadian and U.S. bulletins, as outlined in government correspondence (Yee, personal communication), are primarily a result of:

1. different forecast methodologies,
2. different master gauge stations on each lake,
3. different periods of record for historical data.

Differences 2 and 3 are further complicated by the effect of apparent differential crustal movement within the basin on recorded water level data. The following sections review the cause and effect of these differences and explore how further coordination of the bulletins might help alleviate confusion in the future.

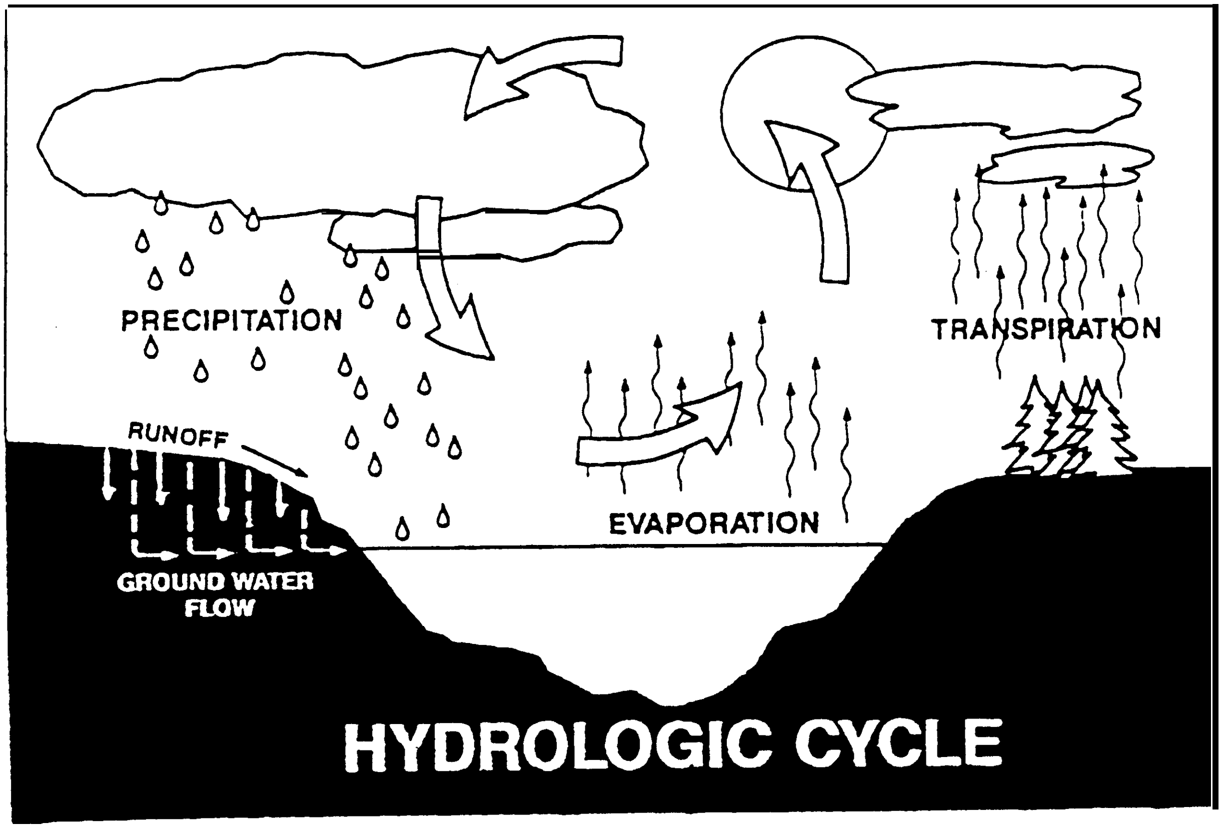
## 4.2 Different Forecast Methodologies

Initial efforts to forecast water levels of the Great Lakes date back to the early 1950s with the publication of a monthly bulletin of lake levels by the U.S. Lake Survey (DeCooke and Megerian, 1967). In Canada, the publication of a monthly bulletin began in 1966, and the first 6-month water level forecast appeared in the Canadian bulletin in 1973. This discussion will concentrate only on forecasting as related to the water level bulletins.

Forecasts of Great Lakes water levels are based on estimates of future supplies of water to the lakes, which are called net basin supplies. Net basin supply is defined as the net amount of water that is added to or taken from a lake as a result of the integration of the various factors of the hydrologic cycle (Figure 11).

Environment Canada generates a 6-month forecast of levels for three net basin supply scenarios — those having 5%, 50%, and 95% exceedance probabilities. These three scenarios represent wet, average, and dry basin hydrologic conditions, respectively. Each of the selected supplies are routed through the Great Lakes hydrologic model to produce forecasts of water levels.

Figure 1 l.--The Hydrologic Cycle (Noorbakhsh and Wilshaw, 1990).



The U.S. Army Corps of Engineers combines two statistical techniques to forecast the net basin supplies. The first technique uses equations derived for linear regression of precipitation, air temperature, and net basin supplies. Given these values for the previous months, and forecasted air temperature and precipitation, the regression equations are used to compute net basin supplies 1 month into the future. The second technique uses time series analysis of historical net basin supplies (trend). This is used to produce a forecast 6-months into the future. The forecaster then selects one or the other, or a combination of the net basin supply forecasts for the first month, and uses the trend forecast for the second through sixth month, optionally weighting these to reflect the choice of net basin supply for the first month. These decisions are based on the forecaster's judgement and experience. The selected supplies are routed through a computer model of the Great Lakes to produce the forecasted water levels. The forecasted levels are then coordinated with the levels predicted for the 50% exceedance supply scenario by the Canadian method to produce a most probable 6 month forecast. Coordination generally involves averaging the two forecasts. However, since the two methods are different, forecaster judgment is sometimes required to arrive at the coordinated values.

The coordinated probable levels forecast is published in the U.S. bulletin as a dashed line. The U.S. Army Corps of Engineers also includes a shaded area defining a probable range of water levels based on one standard deviation of the long-term predictive error. In preparing the Canadian bulletin, the Canadian Hydrographic Service plots two dashed lines based on the levels resulting from the 5% and 95% supply scenarios prepared by Environment Canada. These lines defined the envelope of probable levels over the forecast period. Before the mid-1980s, CHS included the "coordinated most probable levels" forecast—a dashed line in the middle of the forecast band. The user public tended to focus on the line as the forecast, although other information such as weather reports suggested levels would tend towards the wet or dry end of the forecast range. The decision to remove that line was based on the desire to highlight the possible range in levels that could be expected. The most probable levels forecast is used by Environment Canada in its news release, which accompanies the bulletin.

Record high water levels occurred in 1985 and 1986, after which the lake levels experienced an unprecedented rapid drop starting in late 1986. According to Keillor (1990), the actual levels did fall outside the range of probable levels forecast by the U.S. Army Corps of Engineers in 30% of the 125 forecasts. This caused the user public to question government's ability to provide a meaningful 6-month forecast. In May 1990, staff from both Environment Canada and the U.S. Army Corps of Engineers participated in the Great Lakes Water Level Forecasting and Statistics Symposium held in Windsor, Ontario (Hartmann and Donahue, 1990). Both forecasting techniques were discussed and their accuracy was evaluated. Analysis of the two methods (Lee and Noorbakhsh, 1990; Southam and Yee, 1990) concluded that both the U.S. and Canadian methods provide reasonable estimates of water level conditions. Although both techniques are valid, the fact that the bulletins use different forecast methods will continue to be a source of confusion to the public.

### 4.3 Differences Related to Base Data

Water level bulletin users who have access to both the Canadian and the U.S. versions are frustrated by the differences. It is not just the forecasts that differ; the current levels indicated are also often different. Much of these discrepancies are caused by the use of different data sets on opposite sides of the border. Neither bulletin is incorrect. The use of different gauging stations, the assumption that the master gauge level can represent the lake-wide level, and crustal movement are prime reasons for the differences.

Tables 2-6 (adapted from Yee, personal communication) provide a comparison of the published monthly average readings for the bulletin master gauges on each lake for a 6-month period ending in December 1990. Since the data have been extracted from bulletins published in 1990, the water levels provided are referred to a new datum, IGLD 1955. This datum replaced IGLD 1955 in January 1992. The need for this change and its impact on the bulletins are addressed in section 4.3.2.

On Lake Superior (Table 2), the Marquette readings were consistently higher than those of Thunder Bay (0.10-0.21 feet or 0.03-0.06 meters). This can become a critical issue because, depending on the station used, a reader concludes that either Lake Superior is above or below chart datum, and either the lake is above or below the elevation of 602.0 feet (183.5 meters) IGLD 1955, the target upper limit of regulation.

On Lake Huron (Table 3), the Harbor Beach readings were as much as 0.13 feet (0.04 meters) lower than those of Goderich. Readings from St. Clair Shores and Belle River (Table 4) are quite similar, but Lake St. Clair data have caused a much bigger problem, which is discussed in section 4.4.1. On Lake Erie (Table 5), readings were higher at Cleveland, about 0.11 feet (0.03 meters) in the summer months but were lower by up to 0.30 feet (0.09 meters) in December.

Table 2.--Comparison of published Lake Superior water levels (in feet, IGLD 1955).

| 1990 | Marquette | Thunder Bay | Difference | Average of 5 Stations* | Maximum Departure |
|---|---|---|---|---|---|
| Dec | 600.33 | 600.12 | 0.21 | 600.22 | 0.11 |
| Nov | 600.52 | 600.35 | 0.17 | 600.43 | 0.09 |
| Oct | 600.57 | 600.40 | 0.17 | 600.47 | 0.10 |
| Sep | 600.49 | 600.35 | 0.14 | 600.42 | 0.07 |
| Aug | 600.46 | 600.33 | 0.13 | 600.38 | 0.08 |
| Jul | 600.40 | 600.30 | 0.1-0 | 600.33 | 0.07 |

* Marquette, Thunder Bay, Duluth, Michipicoten Harbour, and Point Iroquois.

Table 3.--Comparison of published Lakes Michigan-Huron water levels (in feet, IGLD 1955).

| 1990 | Harbor Beach | Goderich | Difference | Average of 6 Stations* | Maximum Departure |
|---|---|---|---|---|---|
| Dec | 577.99 | 578.10 | -0.09 | 578.04 | 0.06 |
| Nov | 578.02 | 578.15 | -0.13 | 578.04 | 0.11 |
| Oct | 578.07 | 578.17 | -0.10 | 578.12 | 0.05 |
| Sep | 578.23 | 578.30 | -0.07 | 578.25 | 0.05 |
| Aug | 578.32 | 578.36 | -0.04 | 578.37 | 0.05 |
| Jul | 578.38 | 578.41 | -0.03 | 578.43 | 0.05 |

* Harbor Beach, Goderich, Ludington, Mackinac City, Milwaukee, and Thessalon.

Table 4.--Comparison of published Lake St. Clair water levels (in feet, IGLD 1955).

| 1990 | St. Clair Shores | Belle River | Difference | Average of 2 Stations* | Maximum Departure |
|---|---|---|---|---|---|
| Dec | 573.86 | 573.78 | 0.08 | 573.82 | 0.04 |
| Nov | 573.82 | 573.74 | 0.08 | 573.78 | 0.04 |
| Oct | 574.02 | 573.95 | 0.07 | 573.99 | 0.04 |
| Sep | 574.28 | 574.22 | 0.06 | 574.25 | 0.03 |
| Aug | 574.33 | 574.24 | 0.09 | 574.29 | 0.05 |
| Jul | 574.35 | 574.28 | 0.07 | 574.32 | 0.04 |

*St. Clair Shores and Belle Rivers

Table 5.--Comparison of published Lake Erie water levels (in feet, IGLD 1955).

| 1990 | Cleveland | Port Colborne | Difference | Port Stanley | Maximum Departure | Average of 2 Stations* | Maximum Departure |
|---|---|---|---|---|---|---|---|
| Dec | 570.98 | 571.28 | -0.30 | 571.10 | 0.12 | 571.04 | 0.24 |
| Nov | 570.91 | 571.14 | -0.23 | 570.99 | 0.08 | 570.95 | 0.19 |
| Oct | 571.18 | 571.30 | -0.12 | 571.24 | 0.06 | 571.21 | 0.09 |
| Sep | 571.48 | 571.53 | -0.05 | 571.48 | 0.00 | 571.48 | 0.05 |
| Aug | 571.54 | 571.43 | 0.11 | 571.49 | 0.06 | 571.52 | 0.09 |
| Jul | 571.60 | 571.49 | 0.11 | 571.55 | 0.05 | 571.57 | 0.08 |

* Cleveland and Port Stanley.

Table 6.--Comparison of published Lake Ontario water levels (in feet, IGLD 1955).

| 1990 | Oswego | Kingston | Difference | Average of 6 Stations* | Maximum Departure |
|---|---|---|---|---|---|
| Dec | 244.40 | 244.34 | 0.06 | 244.43 | 0.09 |
| Nov | 244.34 | 244.25 | 0.09 | 244.33 | 0.08 |
| Oct | 244.40 | 244.32 | 0.08 | 244.41 | 0.09 |
| Sep | 244.57 | 244.51 | 0.06 | 244.61 | 0.10 |
| Aug | 245.11 | 245.04 | 0.07 | 245.16 | 0.12 |
| Jul | 245.56 | 245.52 | 0.06 | 245.61 | 0.09 |

* Oswego, Kingston, Cobourg, Port Weller, Rochester, and Toronto.

On Lake Ontario (Table 6), the Oswego readings were consistently higher than those of Kingston by 0.06-0.09 feet (0.02-0.03 meters). Although these differences are small in comparison to the lake's range of high to low levels of about 4 feet (1.2 meters), the different readings can cause problems because the present target range of operation, as specified in the IJC's Orders of Approval, is between about 242.8 and 246.8 feet (74.0 and 75.2 meters) IGLD 1955.

These small but important differences are not caused by errors in recording or presentation but are the result of a number of factors. The following sections present a brief explanation of each.

### 4.3.1 Use of different water level stations

A close review of the Canadian and U.S. bulletins reveals that although they both provide a water level chart (or hydrograph) for each Great Lake, a single gauge site is specified on each lake. This gauge is referred to as the lake's master gauge. The U.S. bulletin uses Marquette for Lake Superior, Harbor Beach for Lakes Michigan-Huron, St. Clair Shores for Lake St. Clair, Fairport (replacing Cleveland as of January 1992) for Lake Erie, and Oswego on Lake Ontario. The Canadian bulletin uses Thunder Bay, Goderich, Belle River, Port Colbome, and Kingston for each of the lakes, respectively. These individual gauges have been chosen for many reasons. Each site serves as the reference port in each country for each lake. This is reflected on all navigation charts by a water level hydrograph. The datum note and the hydrograph on the lake charts are referred to these master gauge stations. These gauges have a long, continuous period of record and were key in the definition of IGLD 1955. The gauges are at major ports throughout the system and are in keeping with CHS and NOAA responsibilities for supplying data to mariners. Many of the differences between the U.S. and Canadian forecast bulletins can be traced to the use of different master gauges.

### 4.3.2 Impact of crustal movement on recent data

When water levels recorded at one bulletin's master gauge site are consistently higher or lower than the other master gauge on the lake, the cause can often be traced to the impact of differential crustal movement on recorded water levels. Water level data for Lakes Superior, Michigan-Huron, and Ontario demonstrate this characteristic.

Geologists studying the Great Lakes basin have discovered that uplift of several hundred feet has occurred in some places in the Great Lakes area during the thousands of years since the retreat of the last glacier. About the turn of the century, the late Dr. G.K. Gilbert, U.S. Geological Survey, was convinced that this uplift of the earth's crust was continuing, that it was measurable, and that it should be considered in any study of levels in the area. The effects of this phenomenon on the water level regime of the Great Lakes have been documented in reports of the Coordinating Committee (1957, 1977), among others. The effects of differential crustal movement are not uniform. The rates around Lake Superior, the northern portions of Lakes Michigan-Huron, and Lake Ontario are greater than those around lower Lakes Michigan-Huron and Lake Erie. Since vertical movement studies are usually carried out by water level record comparisons, factors that can affect the accuracy of computed movement rates include changes in gauging sites, unstable vertical survey control points, limitations of gauging and vertical measuring instruments and procedures, and local subsidence. Larsen (1987) shows that modem rates of tilting are consistent with the historical geological record. Sophisticated measurement equipment and computer modeling of the earth's crust are currently being applied to further refine the rates of movement (Tushingham, 1992). Figure 12 shows estimated rates of upward differential movement in the Great Lakes basin.

For this review of the impact of crustal movement on the water level bulletins, Lake Superior has been chosen as the sample lake. Lake Superior, like the other Great Lakes, is subject to crustal movement or isostatic rebound from the last Ice Age, which causes relative changes in water level elevations between various sites around the lake. Figure 13 shows early estimates of apparent vertical movement rates between Point Iroquois (which represents the lake level at the location of the outflow) and selected sites around the lake as determined by the Coordinating Committee (1977).

It is sometimes hard to take the rates of vertical movement as presented in reports by the Coordinating Committee and others and visualize how water levels will change over time and what effect this could have on the monthly bulletin. The effects of differential crustal movement on Lake Superior water levels may be better understood if the lake is visualized as a basin being rotated about an axis running across the lake from Point Iroquois, Michigan, to a point south of Thunder Bay, Ontario by a gradual raising of its northeastern rim. The surface of the lake remains level, but as time progresses, water levels along shores that are situated north of the axis are receding with respect to the land for a given water level elevation. Similarly, water levels long shores south of the axis are rising with respect to land. This presents an interesting situation, since for the most part, conditions experienced in the two countries are the exact opposite. As water levels fall over time with respect to the Canadian shoreline, they are increasing on the U.S. side.

To explain the effect of crustal movement on current (or historical) data, the use of IGLDs and the significance of their reference years must be addressed. The Great Lakes-St. Lawrence River system, one of the world's greatest fresh water resources, is shared by Canada and the U.S. The harmonious use of these waters requires international coordination of many aspects of their management. The most basic requirement for coordinated management is a common elevation reference or "datum" by which water levels can be measured. This datum or vertical reference system must be adjusted every 25 to 35 years because of movement of the earth's surface or crust. This movement is very gradual and has been occurring since the retreat of the glaciers. This movement causes the bench marks to shift with respect to the reference zero and also with respect to each other. This causes the levels recorded at sites around a lake to depart from one another over time.

Although the differences in levels amount to only a fraction of a foot per century, the changes are sufficient to require periodic reestablishment of bench mark elevations so that water levels measured at all sites on the lake will be the same. The establishment of a new datum brings the elevations of all bench marks in the system into harmony; that is, the assigned elevations are measurements of their respective places in the vertical. Because crustal movement causes these positions to shift, it becomes very important to show the year in which the assigned elevations were true. The first internationally coordinated datum is known as IGLD 1955, for which 1955 is the "reference year." As of the beginning of 1992, a new datum, IGLD 1985, has replaced IGLD 1955. The most significant change between IGLD 1955 and IGLD 1985 is in the elevations assigned to water levels.

Figure 12.--Estimated rates of upward differential crustal movement in the basin (adapted from Clark and Persoage, 1970; Larsen, 1987).

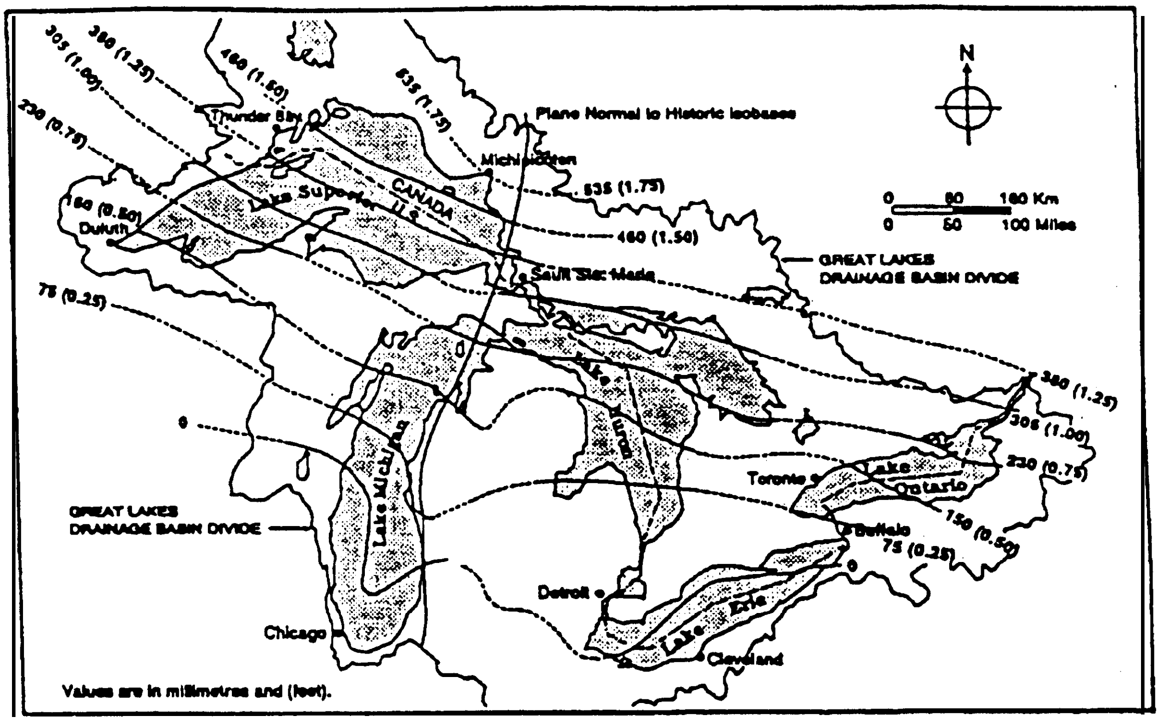
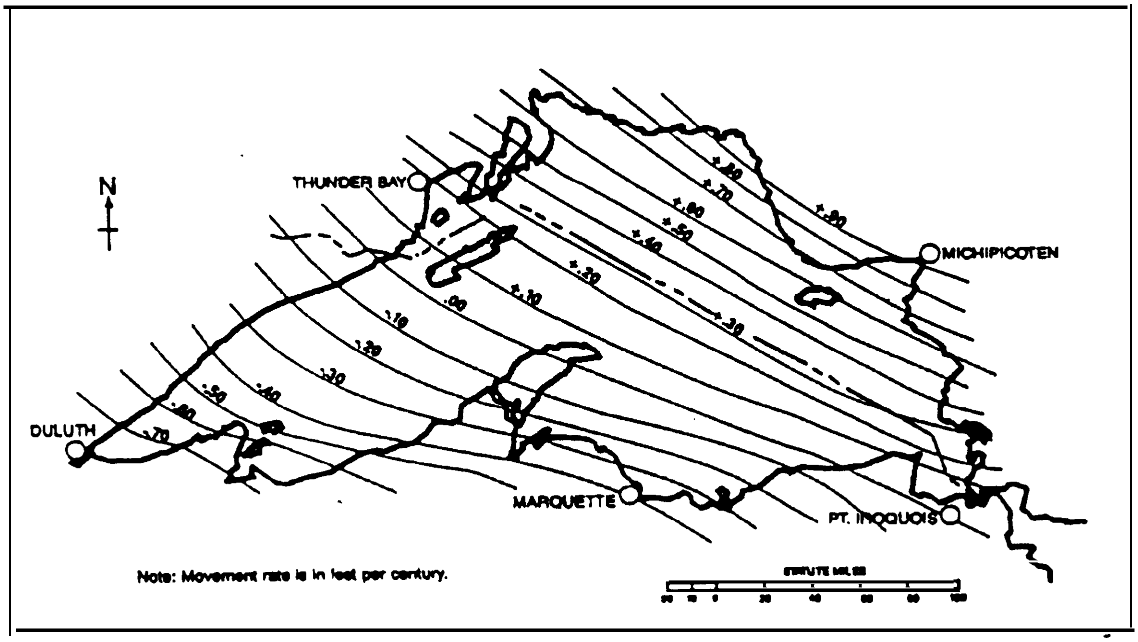


Figure 13.--Estimates of apparent vertical movement rates between Point Iroquois and selected other sites (Coordinating Committee, 1977).



To establish the rates of movement shown in Figure 13, the Coordinating Committee established the apparent vertical movement rates between Point Iroquois and selected sites around the lake. The rate of apparent vertical movement between each pair of stations was determined by linear regression of the differences between the 4 month (June-September) mean levels recorded at the stations each year with respect to time over the period 1931-1974. Thus, the rate of movement is given by the slope of the linear equation through the plot of the differences each year. Positive values signify that the second station is rising with respect to the first station.

Given the apparent crustal movement trends and gauge distribution around the lake, the average land-to-water relationship around the lake does not appear to be changing. The regulation of Lake Superior is based on its monthly mean level. At present the elevation of the mean is ascertained by taking the mean of the readings of five automatic water level gauges. From Figure 13 it appears that the gauges are reasonably balanced around the lake.

Figures 14a through 14e (Southam, unpublished) have been produced using the same methodology employed by the Coordinating Committee. For these plots, however, the individual gauge readings have been subtracted from the five-gauge average as opposed to using Point Iroquois alone. The differences shown in Figure 14a indicate that water levels recorded at Point Iroquois do not differ significantly from the five-gauge average over time. Since the plots in Figures 14b and 14c have negative slopes, Marquette and Duluth are falling with respect to the average land-to-water relationship around the lake and water levels recorded at both sites are rising with time compared to the five-gauge average. Conversely, positive slopes in Figures 14d and 14e indicate that Thunder Bay and Michipicoten are rising, and water levels recorded at these two sites are falling over time relative to the five-gauge average. From Figures 14b and 14d we can see that in 1990, the average summer time levels recorded at Marquette are about 0.10 feet (0.03 meters) higher, and Thunder Bay is about 0.05 feet (0.02 meters) lower than the five-gauge lake wide average, respectively. Marquette and Thunder Bay levels therefore differ by about 0.15 feet (0.05 meters), consistent with the values in Table 2. Similar trends can be found in the recorded data of all the Great Lakes, but it is most pronounced on Lakes Superior and Michigan-Huron.

Differences Between

5-Gauge Average and Point Iroquois

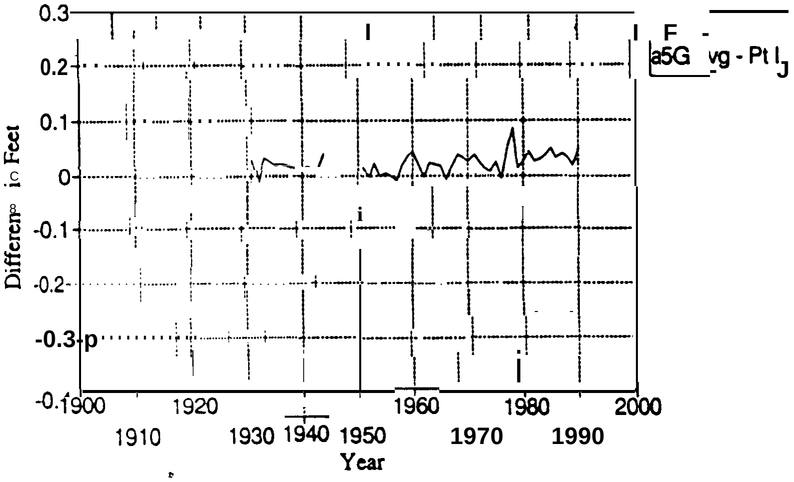


Figure 14a.

Differences Between

5-Gauge Average and Marquette

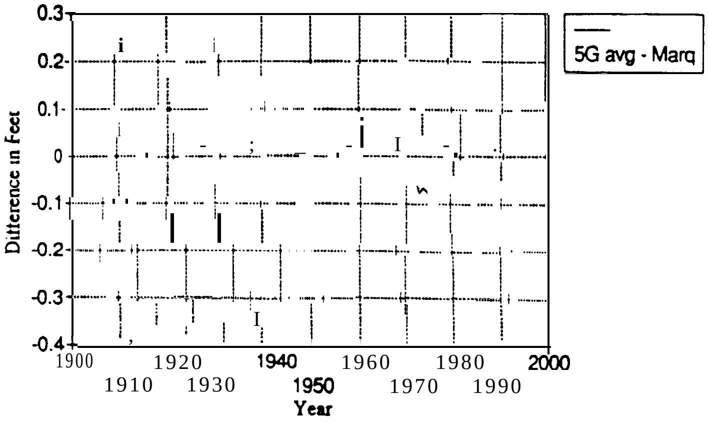


Figure 14b.

Differences Between

5-Gauge Average and Duluth

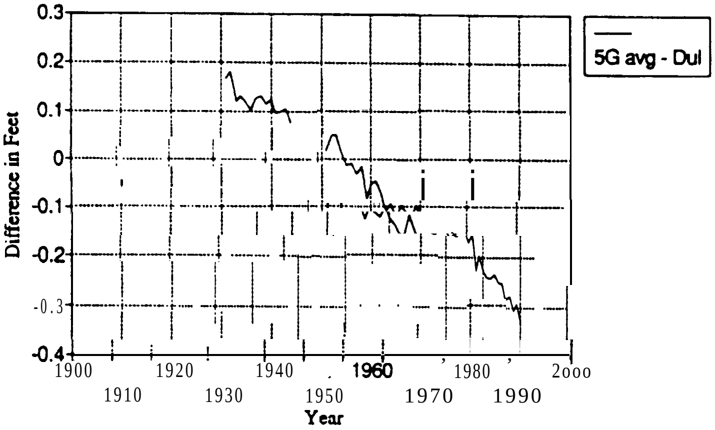


Figure 14c.

Differences Between

5-Gauge Average and Thunder Bay

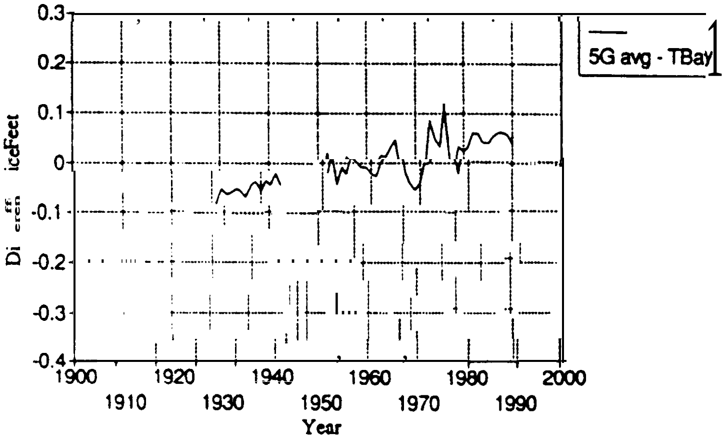
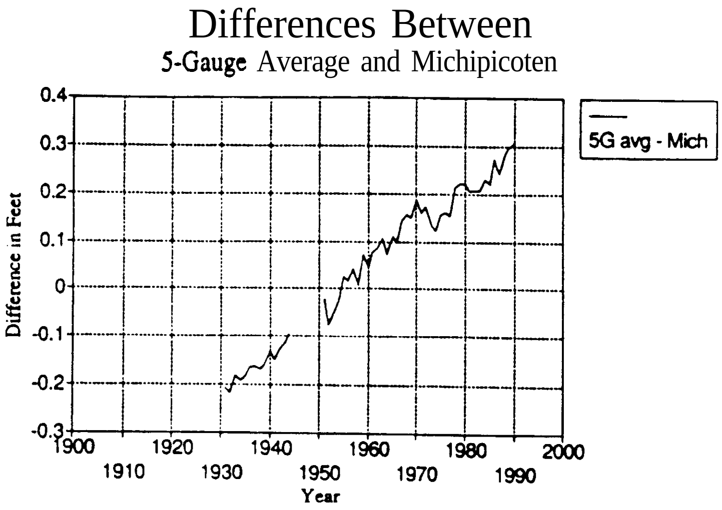


Figure 14d.

Figure 14e.



### 4.3.3 Other factors

Published water level records generally consist of peak instantaneous water levels, mean daily water levels, and mean monthly water levels. Peak instantaneous values reflect fluctuations in water level due to wind setup and seiches. Variations in water levels caused by wave action are not recorded because levels are measured within an enclosed well and, in spite of wave action, the water surface within the well is the same as the stillwater (or setup) level without wave action. Wind setup and seiches have a lesser influence on the mean daily levels and the least effect on the mean monthly level, which is assumed to be unaffected by seiches or wind setup.

Since the water level data published in both the Canadian and U.S. bulletins are based on mean monthly water level data, one would not expect a problem using levels recorded at a master gauge (crustal movement impacts aside) to represent the lake-wide average. As illustrated by Lake Erie, this may not always be the case. The problem stems from the fact that Port Colbome (the Canadian master gauge) is near the eastern end of the lake where water levels fluctuate more frequently due to winds and storms. Winds over Lake Erie are predominately from the southwest over the winter months. Since Port Colbome readings are not representative of the mean Lake Erie levels, inclusion of the Environment Canada 6-month forecasts can sometimes give a rather strange picture. Cleveland (or, similarly, Fairport) appears to provide a better representation of the mean lake level. Port Stanley, which is more centrally located and is less sensitive to storms, may be a better choice on the Canadian side. Readings taken at Port Stanley are closer to those at Cleveland.

## 4.4 Historical Data

So far, we have addressed differences related to the current and estimated future information presented in the bulletin. The last component, historical data, is equally important when examining the differences between and intricacies of the U.S. and Canadian forecast bulletins.

### 4.4.1 Use of different periods of record for statistics generation

When it is stated that a certain level represents a record high or low level or the long-term mean on a lake, it is critical to know the period of record upon which that value was based. The period of record from which long-term average and extreme levels are drawn for comparison to recent data and forecasts is clearly stated on both the Canadian and U.S. bulletins. The U.S. bulletin seems to have one advantage in that all its master gauging stations have records back to 1900. In fact, one of the reasons for selecting a master gauge is an extended period of sound record. The Canadian data start in 1916 except for Lake St. Clair data, which start in 1961, and Montreal Harbour data, which start in 1967. A slightly shorter period of record doesn't generally cause difficulties, but the Lake St. Clair and Montreal Harbour charts in the Canadian bulletin have caused confusion.

Table 7.--Comparison of historical summary for St. Clair Shores (1900-1990) and Belle River (1961-1989), in feet, IGLD 1955.

| | Minimum | | | Mean | | | Maximum | | |
|---|---|---|---|---|---|---|---|---|---|
| Month | St. Clair Shores | Belle River | Diff | St. Clair Shores | Belle River | Diff | St.Clair Shores | Belle River | Diff |
| Jan | 569.86 | 570.60 | -0.74 | 572.84 | 573.69 | -0.85 | 576.13 | 576.02 | 0.11 |
| Feb | 569.88 | 570.60 | -0.72 | 572.60 | 573.62 | -1.02 | 576.17 | 576.08 | 0.09 |
| Mar | 570.41 | 571.20 | -0.79 | 573.01 | 574.02 | -1.01 | 576.17 | 576.08 | 0.09 |
| Apr | 571.09 | 571.61 | -0.52 | 573.54 | 574.28 | -0.74 | 576.21 | 576.15 | 0.06 |
| May | 571.64 | 571.91 | -0.27 | 573.82 | 574.48 | -0.66 | 576.25 | 576.18 | 0.07 |
| Jun | 571.74 | 571.85 | -0.11 | 573.99 | 574.57 | -0.58 | 576.51 | 576.48 | 0.03 |
| Jul | 571.88 | 571.83 | -0.05 | 574.06 | 574.61 | -0.55 | 576.56 | 576.48 | 0.08 |
| Aug | 571.60 | 571.79 | -0.19 | 573.95 | 574.48 | -0.53 | 576.45 | 576.38 | 0.07 |
| Sep | 571.36 | 571.57 | -0.21 | 573.73 | 574.28 | -0.55 | 576.31 | 576.21 | 0.10 |
| Oct | 571.13 | 571.20 | -0.07 | 573.45 | 574.02 | -0.57 | 576.69 | 576.61 | 0.08 |
| Nov | 570.83 | 570.94 | -0.11 | 573.17 | 573.82 | -0.65 | 576.20 | 576.12 | 0.08 |
| Dec | 571.05 | 570.94 | 0.11 | 573.18 | 573.85 | -0.67 | 576.14 | 576.02 | 0.12 |

Lake St. Clair provides an example where differences between the two bulletins are quite dramatic and can be traced to the use of different periods of record. Although Table 4 indicated that the gauges record similar levels, Table 7 shows that the difference between the two long-term means is as much as 1.02 feet (0.31 meters). The very short period of record for Belle River

(1961-1990) includes the low period of the early 1960s, but is dominated by the high level years of much of the 1970s and 1980s. The shorter period of record is not representative of the long-term average conditions on the lake. Therefore, although the gauge readings at the U.S. and Canadian gauges differ only slightly, when the U.S. bulletin shows that the lake is well above average, the Canadian bulletin can show it is below average. Since the period of record used at Belle River doesn't start until 1961, many of the record lows of the 1920s and 1930s experienced on Lake St. Clair are not included. As a result, the period of record minimums at Belle River are up to 0.79 feet (0.24 meters) higher than those at St. Clair Shores. Since period of record highs were recorded at both sites throughout 1986, the period of record maximums differ by a maximum of only 0.11 feet (0.03 meters), consistent with the gauge reading differences. Therefore, depending on which bulletin readers see and/or choose to believe, they might arrive at opposite conclusions. This can be particularly troublesome given the location of Lake St. Clair and the high concentration of bulletin users from both the public and media who may receive both bulletins.

The very short period of record for Montreal Harbour coincides with a high water level period. The average curve shown in the bulletin is not representative of the long-term average conditions of the harbour. Canadian officials have to explain on many occasions why levels are below the average line printed on the bulletin when Lake Ontario outflows are consistently well above average. Since Montreal Harbour is located below the International Section of the St. Lawrence River in the Province of Quebec, the U.S. bulletin does not contain a chart for this area. Although comparisons between the two bulletins are not made for this area, a representative historical data set is certainly needed.

### 4.4.2 Impact of crustal movement on historic data

Until this point we have restricted our discussion on crustal movement impacts to recently recorded data. We have emphasized that water levels recorded at an individual site may be rising or falling when compared to another gauge or the lake-wide average. This can in turn cause the bulletins to present a different view of the water level situation on the lakes. Crustal movement also affects the historical water level data provided in the bulletins for comparison purposes.

One of the key features of Figures 14a through 14e is that there is a zero difference calculated between the five-gauge average and the individual gauge readings around 1955. This coincides with the reference year for IGLD 1955. The plots also show that if water levels at a site, such as Marquette, increase with time when compared to the lake-wide average (shown by negative differences following the reference year) the historical data will be numerically low, represented by the positive differences before 1955. Conversely, if over time, water levels fall at a particular site, such as Thunder Bay, the historical data will be numerically high compared to the five-gauge average. This change is a by-product of establishing a new datum.

When a new datum is adopted, water level data recorded on the old datum at each site must be converted to the new datum. Understanding the effect of this adjustment is very important when utilizing historical water level data. This adjustment maintains the historical measured difference between the bench mark and the water surface. Since bench marks are moving at different rates with respect to the reference zero (sea level), adjustments vary from site to site around the lake.

It must be stressed that the historical data presented in each bulletin are correct for the site specified. Problems can occur when the individual gauge data are used to represent the lake as a whole. For many users, it is important to have a lake-wide perspective when discussing water levels. Although the data may be stronger from a measurement point of view at an individual gauge, such as Marquette or Thunder Bay, it may not represent the lake-wide average. For example, examine years 1930 and 1990 on the five-gauge average minus Marquette data plot in Figure 14b. For the same average lake level, the recorded value in 1930 at Marquette would be about 0.2 feet less than the value recorded in 1990. In other words, although the 1930 value would be numerically lower than the 1990 number, the lake would be at the same elevation. It is quite possible to have a numerically low level appearing early in the Marquette data set that in fact reflects a higher average lake level than a numerically higher level appearing later on. Differences can also exist between the two bulletins. For a specific example, consider the maximum level for August indicated in the Canadian and U.S. bulletins, Figures 9 and 10. The bulletins indicate the maximums occurred in 1916 at Thunder Bay (602.09 feet) and 1986 at Marquette (602.04 feet). At each location, and for the period of record used, the highest level relative to the land near the gauge did occur in these different years. However, when discussing record highs or lows, we should again try to look at the lake-wide average, filling in missing data if possible.

The adoption of IGLD 1985 eliminates (at least for the present) some of the problems discussed here regarding current data. The IGLD 1985 update will not eliminate the problems related to historical data. Figures 15a through 15e (Southam, unpublished) have been produced using Lake Superior water level data referenced to IGLD 1985. As they show, with the adoption of IGLD 1985, the zero difference (or reference) year moves to 1985 and the positive or negative differences calculated in earlier years are increased. These figures also show the amount of departure between readings that has already taken place since 1985.

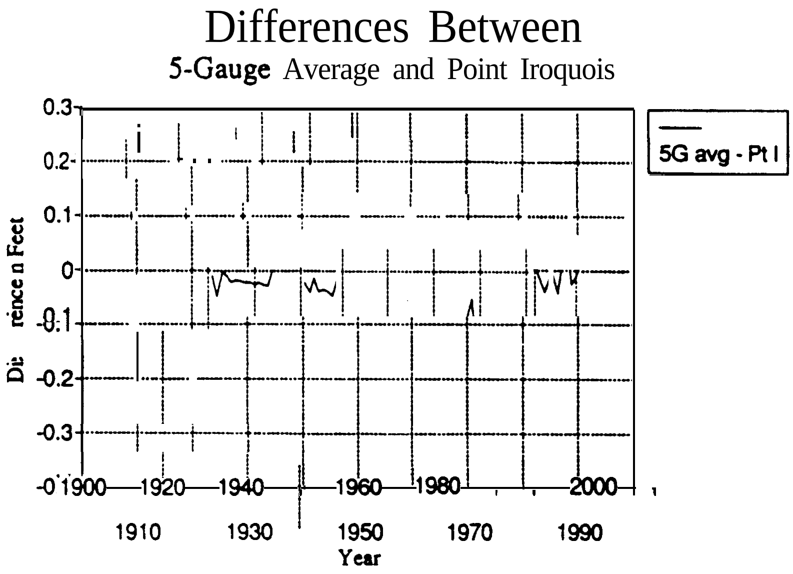


Figure 15a.

Figure 15b.

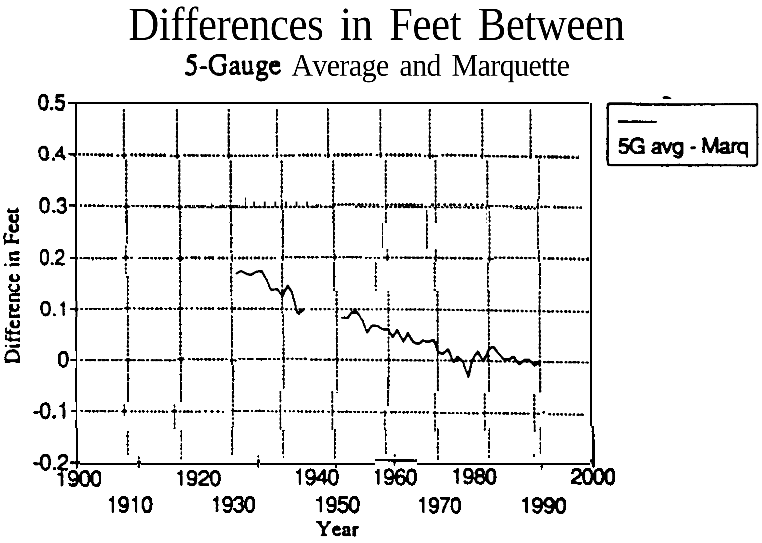


Figure 15c.

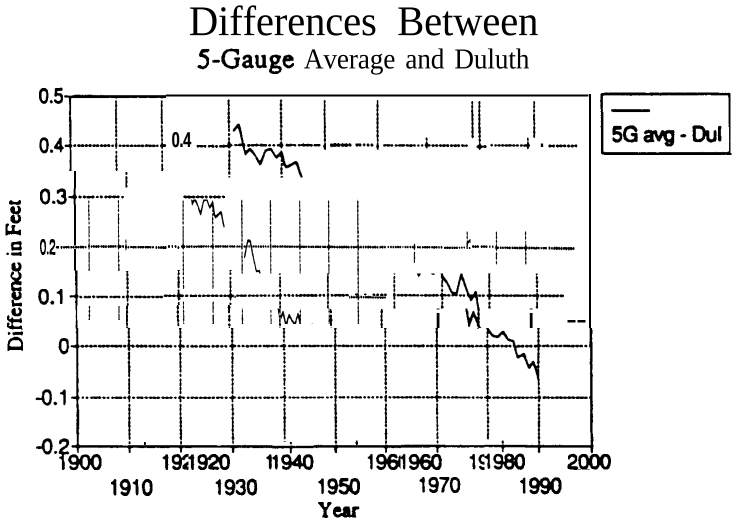
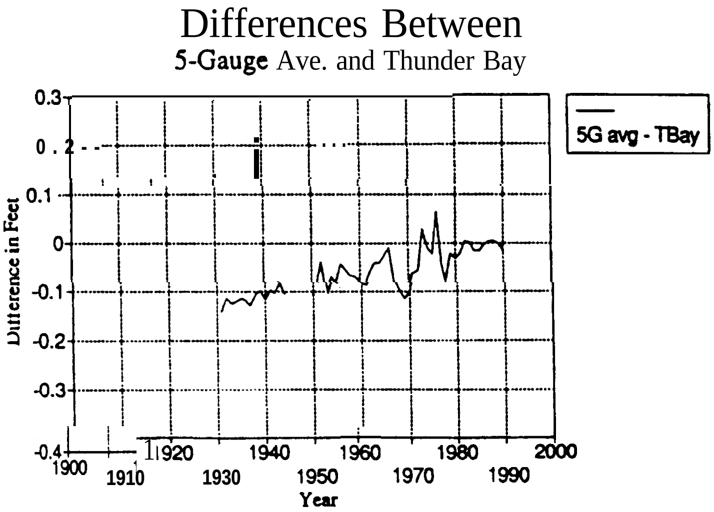


Figure 15d.



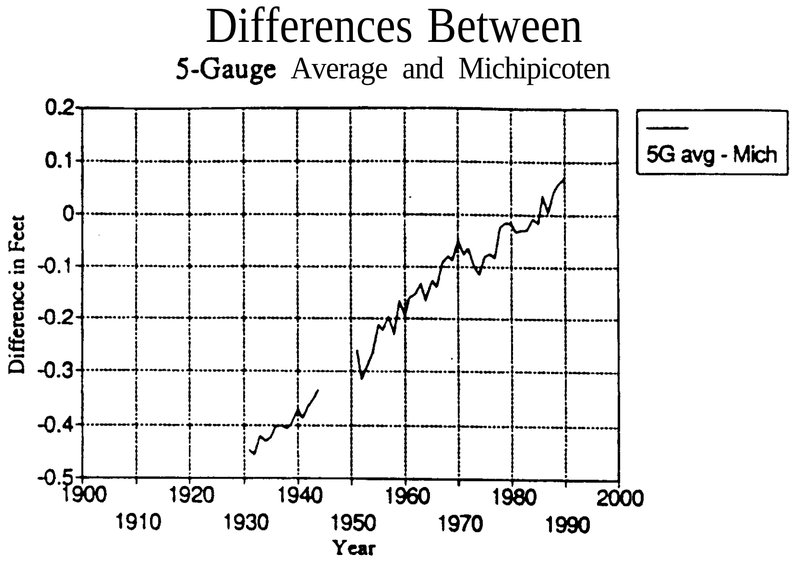


Figure 15e.

## 4.5 Strategies for Improvement

The information presented in both the Canadian and the U.S. bulletins is accurate. However, the fact that they are different will continue to cause confusion. The differences between them can and should be explained regularly by technical experts. The user interviews show that the monthly water level bulletins are, by far, the preferred information tool used by the many diverse groups in the Great Lakes basin whose decisions are affected by fluctuating water levels. It is expected that the bulletins will remain the primary means of communication about water levels in the future.

Problems have arisen as the bulletins' audience has grown in recent years. Although both bulletins are prepared for a broad spectrum of users, they are still very technical documents. Many bulletin readers do not sufficiently understand the technical and presentation differences required to properly interpret the wealth of information contained in the bulletins. The agencies responsible for producing the monthly bulletins are to be commended for their recent efforts to improve formats and highlight pertinent information. The U.S. Army Corps of Engineers' Update letter, an insert to the monthly bulletin, is an excellent example of such efforts. However, it is the opinion of this group that more can be done to avoid confusion and improve understanding.

It would be politically as well as logistically difficult for the United States and Canada to produce one joint forecast bulletin. However, coordination of certain basic data would help minimize the differences between the two. Forecasting techniques and base data are two areas in which better coordination could result in improved products on both sides of the border.

### 4.5.1 Coordination of forecasting techniques and base data

The improvement of forecasting capabilities is an ongoing process. This issue is being addressed as part of the current IJC Levels Reference under Task 19.3, Lake Levels Analysis. Although consensus on a single methodology might be the ultimate goal, it is probably not achievable any time soon. Work toward this goal should continue under the auspices of the Coordinating Committee.

Meanwhile, the U.S. Army Corps of Engineers should consider removing the dashed line from the probable forecast band, as the Canadian bulletin did in 1990. Such a change would help the user public consider the uncertainties related to future level forecasts.

Better coordination of base data could have a profound positive effect on both bulletins. Several small but important differences between the U.S. and Canadian bulletins can be traced to the use of different current and historical data based on individual gauges. The use of coordinated information in the bulletins needs to be promoted. Table 10 in Section 7 gives specific recommendations.

A network approach is now used by the International Lake Superior and the International St. Lawrence River Boards of Control in the regulation of Lakes Superior and Ontario. The calculation of water supplies to the lakes also uses change in lake storage data based on this network of stations. Tables 2-6 show how the use of the network approach will differ from the present bulletins. Adopting a network approach to establish current levels published in the bulletin would help minimize the effect of using individual site data.

Table &--Comparison of Lake Superior Maximums Thunder Bay (1916-1990)

| Thunder Bay (1916-1990) | | Marquette (1900-1990) | Network Average* (1900-1990) |
|---|---|---|---|
| Jan | 601.41 (1986) | 601.64 (1986) | 601.50 (1986) |
| Feb | 601.22 (1986) | 601.38 (1986) | 601.28 (1986) |
| Mar | 601.16 (1986) | 601.31 (1986) | 601.21 (1986) |
| Apr | 601.35 (1986) | 601.49 (1986) | 601.41 (1986) |
| May | 601.58 (1986) | 601.72 (1986) | 601.64 (1986) |
| Jun | 601.84 (1916) | 601.77 (1986) | 601.74 (1916) |
| Jul | 602.12 (1916) | 601.91 (1986) | 601.93 (1916) |
| Aug | 602.09 (1916) | 602.04 (1986) | 602.02 (1950) |
| Sep | 602.17 (1916) | 602.06 (1985) | 602.07 (1916) |
| **Oct** | 602.13 (1985) | 602.24 (1985) | 602.17 (1985) |
| Nov | 602.04 (1985) | 602.24 (1985) | 602.13 (1985) |
| **Dec** | 601.71 (1985) | 601.99 (1985) | 601.85 (1985) |

*Based on available gauge information

A properly defined network would also eliminate some of the problems related to historic data. Recall the example comparing the years of maximum levels for August indicated in the Canadian and U.S. bulletins: in 1916 at Thunder Bay and 1986 at Marquette. Preliminary values shown in Table 8 based on the network of five gauges (as available) suggest the lake-wide August maximum may have occurred in 1950. The network averages in Table 8 are referred to as preliminary because the values presented are based on simple averaging of all network gauges available in the specific year. Because of differing periods of record at each site, the full network is not available for every year. This can create additional problems. Before 1915, for example, data are available for Duluth and Marquette only. Given our understanding of crustal movement impacts on recorded data, we know that the historical data for both these gauges will be numerically low compared to the lake-wide average. Simple averaging of these two gauges will produce a level lower than the true lake-wide average. After 19 18, data are available at Duluth, Marquette, Thunder Bay, and Michipicoten. Point Iroquois data are available starting in 193 1 with the exception of 1945- 1950. If all gauges were available for estimating the network maximums in Table 8, the values would be changed somewhat.

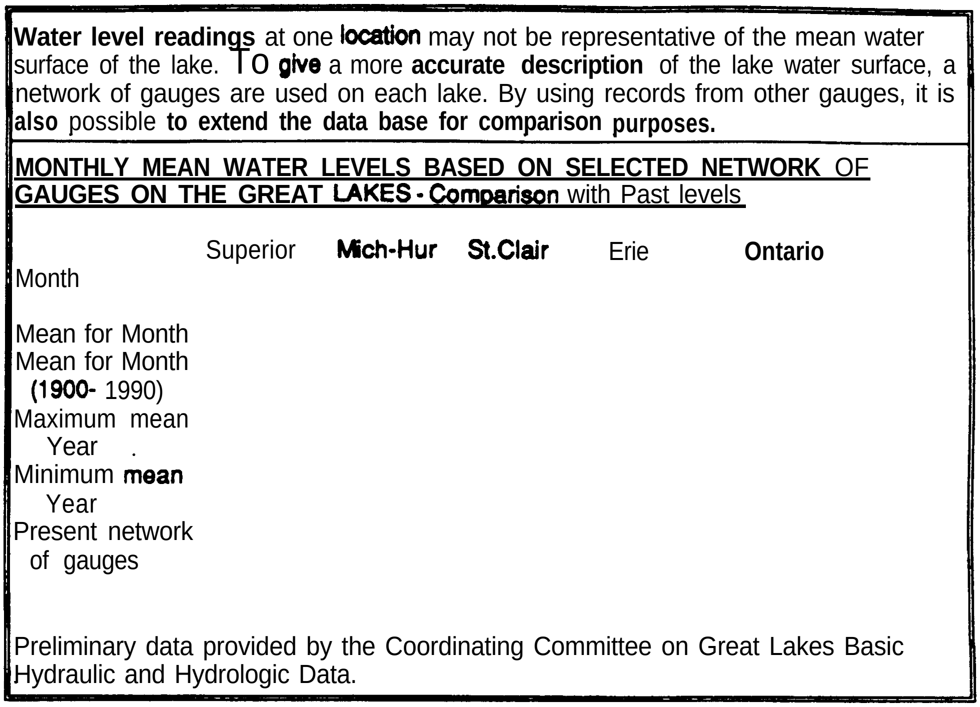
If the network approach is desirable, we will need to address the issue of missing data. Otherwise, period of record long-term averages and extreme values may be incorrectly defined. It may be possible to adequately estimate missing data using the calculated rates of vertical movement. Certainly, the estimated values will not be as accurate as a true network average, but the benefits of using an estimate representing the lake as a whole would seem to outweigh the costs. Alternatively, periods of record could be standardized to eliminate periods of biased results. The period of record for Lake Superior could be reduced to the 19 18- 1990 period, for example, because the four gauges available after 19 18 will produce a reasonable lake-wide average.

The Coordinating Committee should be encouraged to examine the following:

1. The benefits and problems of publishing average lake levels using a gauge network instead of a single master gauge;
2. A comparison of different lengths of record, such as 1900 to present and 1955 to the present of the most recent 30 or 40 year periods;
3. The question of whether (and how) current and historical data should be adjusted for crustal movement;
4. A strategy for dealing with missing data.

If the network approach cannot be adopted in place of the single gauge presentations, perhaps some additional coordinated information could be included on the bulletins that will not contradict or take away from any existing information, as suggested by Yee (personal communication). A table like the prototype shown in Figure 16 listing the mean monthly lake level for each lake based on the averages of a network of gauges could be added.

Figure 16.--
Prototype Table



**Water level readings** at one **location** may not be representative of the mean water surface of the lake. **TO give** a more **accurate description** of the lake water surface, a network of gauges are used on each lake. By using records from other gauges, it is **also** possible **to extend the data base for comparison purposes.**

**MONTHLY MEAN WATER LEVELS BASED ON SELECTED NETWORK** OF **GAUGES ON THE GREAT LAKES - Comparison** with Past levels

| Month | Superior | **Mich-Hur** | **St.Clair** | Erie | **Ontario** |
|---|---|---|---|---|---|
| Mean for Month | | | | | |
| Mean for Month (**1900-** 1990) | | | | | |
| Maximum mean | | | | | |
| Year | | | | | |
| Minimum **mean** | | | | | |
| Year | | | | | |
| Present network of gauges | | | | | |

Preliminary data provided by the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data.

Whether a network approach is adopted or not, it is important to ensure that the user public knows the period of record upon which any set of historical data is based. Given the varying period of records used in the preparation of the Canadian bulletin, in a recent format change, CHS chose to specify the gauge period of record right on the lake hydrograph (see Figure 9). In the case of the U.S. bulletin, where the period of record is the same for all gauges, the period of record is specified in the supporting text (see Figure 10). The Corps of Engineers could consider adding the period of record information to the hydrograph similar to the Canadian bulletin. Although this might seem redundant, such a modification would serve as an aid when explaining differences between the two bulletins. It would also protect against the loss of this information if a hydrograph was extracted from the bulletin for another purpose.

### 4.5.2 Other information

Each month, the Corps' Update letter contains a discussion of basin precipitation. Some Canadian bulletin users, both government and nongovernment, expressed a desire to see some climatic information included on the bulletin. This request is currently being explored by CHS staff. Some users requested information on short-term storm surge. Although some historical data such as peak instantaneous levels, for example, could be added, the monthly bulletin would not be appropriate for storm surge forecasts. Adding just information on historical surges or current risks could easily overcrowd the bulletins. It would be more effective to improve the contents of the bulletins as they are today and make them easier to understand.

During the high water period of 1986, CHS, in cooperation with Environment Canada, added an information block to the front page of the bulletin. This block was updated each month to highlight the current high level conditions and inform the user of the increased risk of flooding. Once levels fell below critical, use of the notice was suspended. Continued use of this information block could have helped bulletin readers recognize the falling water level trend throughout 1987. A number of users commented in the user survey that they had inadequate warning of the rising levels in 1985, and the subsequent drop. An information block could be used to highlight basin conditions or trends in an effort to help the user public correctly interpret the bulletin and the 6-month forecast. Starting with the January 1992 edition of the bulletin, the CHS reintroduced the information block as a continuing feature. A similar feature could be considered for the U.S. bulletin.

## 4.6 Improved Communication

To this point we have restricted ourselves to the existing bulletins and their distribution. As the user needs assessment indicated, almost all respondents use lake level forecasts and receive them as a mailed monthly bulletin. They prefer this means of information transfer in the future. Even though they were not specifically asked to comment on the current bulletin format, a significant number of users noted they want the present format continued.

Although most users like and use the bulletins, the user interviews indicate that some of the information provided is being misunderstood. Both bulletins contain many terms that have specific meanings. As we have already noted, when the bulletin identifies a historical extreme maximum or minimum, it is referring to the extreme monthly average level, not the peak instantaneous high or low. We also know that a specific period of record is used when determining these values. It is just not possible to describe each term on the bulletin. Given the wide audience, it may be time to consider developing a user's guide.

Instead of producing a user's guide as a separate publication with its own coordination, printing and distribution problems, it may be better to produce a user's guide version of the bulletin. Once a year, a photoreduced version of the respective bulletins could be printed on standard bulletin size paper. Specific items on the bulletins could be highlighted and an explanation provided in the surrounding blank area. Preparing an annual user's guide version of the bulletin would help ensure that new bulletin users (as well as old) receive an explanation of the bulletin content. The guide could easily be kept current. Future changes to the bulletins would not be delayed by the preparation of the guide. Changes to bulletin formats could be timed to coincide with the annual user's guide version. Since both bulletins contain basically the same information, development of the user's guide format could be a joint effort. The user's guide format could be prepared with or without any further coordination of the bulletins' basic data.

For select users, for example, media writers in areas where both bulletins are routinely received such as around Lake St. Clair, a workshop on the bulletins' content and interpretation might be appropriate. A workshop might be sparsely attended unless water level conditions were causing heightened awareness. As time passes and media staff change, the benefits of even the most successful workshop would diminish. A professionally prepared videotape explaining the bulletin content may be a suitable alternative.

Although the bulletin may remain the primary means of mass distribution, it seems appropriate to explore additional means. The public can get up-to-date information by contacting the responsible agency or, in some cases, direct dial water level gauges. Weekly water level bulletins are also available free of charge. Nevertheless, several users specifically asked for this type of data, apparently unaware that it already exists. One frustrated user said, “There must be information somewhere that could help, but (I) don’t know where to get it.” From some users’ statements and reactions to the sample figures provided in the survey, it is apparent that too much or too technical data are no better than none. Targeting occasional special mailings for the groups who seem to feel most overlooked in terms of water level information (riparians, marina owners, emergency government workers, etc.) may help alleviate some of this frustration.

Improved access to water level information, recognizing the different levels of user needs and confidence, must be promoted. Although phone numbers are publicized, non-government bulletin readers are often not comfortable seeking assistance over the phone from agency technical staff. Not surprisingly, they feel very differently than the government workers for whom over-the-phone communication about water level information is “essential.” A number of the nongovernment people expressed a desire to see lake level forecasts included in the weather reports on television, radio, and newspaper. One respondent felt that until the information gets into township newsletters, 4-H bulletins, and similar publications, it will not really be available to most people. Special access channels must be provided for special circumstances. Many people found Environment Canada’s toll free number to be very useful during the critical levels of 1985-86. People need easy access to forecast information, either through toll-free phone lines or a fax request system, when water levels are approaching the limits of the comfort zone.

The suggestion of including water level information/forecasts in weather reports seems worth pursuing. This would facilitate demonstrating and explaining the connection between climate and water levels. This may be more effective than including summary climate tables with the monthly bulletins. Including short-term storm and surge information would be easier at this level. Including the forecast and real-time data in a weather report would also help the user track conditions. If conditions were either extremely wet or dry, the trends in daily water levels would be recognizable. Including water level information in weather reports would also help inform the public of changes in level trends as occurred in 1987-88. Efforts should be made to inform the user if a trend toward extreme levels appears to be developing. This would also enable a wider audience to be exposed to the topics of Great Lakes water levels and climate regimes.

Many local and regional newspapers already carry regular features on water levels. Some use the Environment Canada news release as is; others modify it. This can help bring the bulletin down to a regional level. It is suggested that a “Lake Level Index” be designed for inclusion on television and newspaper weather maps. This index would at a glance provide the user public with current conditions-high, low, or about average. Color coding the Great Lakes shorelines on weather maps to reflect current flood risks could also be considered.

Initial informal contact with the media suggests a willingness to consider these ideas. Further contact is required to produce a well designed, coordinated product. Although this will take time and effort, the wide distribution of information might make it desirable. This market research/ product development work could be carried out as one of the functions of the proposed water levels communication clearinghouse.

Finally, we can’t expect to satisfy all users. Much of the data requested are already available. The old Canadian bulletin format contained directions on receiving additional data. These instructions were dropped because the limited requests did not justify the space required for the directions. In the users survey, some boaters expressed a desire for more weather and wind information. Given the degree of coverage both these topics receive, it is apparent that we cannot expect to satisfy everyone

## 5. APPLICATIONS TO DECISION-MAKING

J. Philip Keillor

To live more harmoniously with the ever-changing Great Lakes, we must empower decision-makers with the proper information. Great Lakes water level records are one of the longest continuous physical data sets in North America. But to the average person making decisions affected by lake levels, the data itself will be of no use. Only the most technical users wish to do their own statistical analysis. Most others want to know the conclusions based on the collective wisdom of experts. They need decision-making tools. In Section 3, the information needs of the users were explored. Section 4 took a very close look at the preeminent decision-making tool in use today: the monthly forecast bulletins prepared by the governments of Canada and the United States. Section 5 illustrates, using a series of detailed examples, how decisions based on Great Lakes water levels could be greatly enhanced through the informed use of forecasts and statistics.

There are water level information products currently available that are not used enough, or are used incorrectly. Some existing products could be modified to improve their effectiveness. Possibilities for new decision-making tools abound. However, no decision-making tool can be effective unless it is used, and used properly. This section demonstrates the use of many decision-making tools, both those currently available and those that could be made available.

The user interviews provide insight into the key decisions that are based, in part, on available water level information. These decisions can be divided into the following categories: design and build decisions made by engineers and contractors; investment decisions by owners; operational decisions by contractors, owners, and managers; and emergency action decisions by owners and emergency management officials.

For each of the four types of decisions, an example is given to show how the decision process can be improved by providing the decision-maker with new water level information tools. The improvements utilized are based on new types of forecast and statistical products, which were provided for comments in the user interviews. The examples also use improvements suggested by the users themselves. Although these examples refer to some information products that are not currently available, they also illustrate how existing water level information could be used more effectively by decision-makers today.

### 5.1 Design and Build Decisions

Design and build decisions are made by engineers, marine contractors, and owners and managers of coastal property. Design decisions involve consideration of either most-probable water level scenarios or “worst-case” combinations of water levels and storm conditions under which structures will function adequately and survive with minimal damage. Information on the probabilities of extreme levels is needed in making deliberate trade-offs between construction costs and risks of damage. When worst-case water level scenarios are chosen, it is because of a perceived need to exercise reasonable engineering prudence and minimize liability risk in the aftermath of record-breaking high water levels and major property damage.

Build decisions are primarily decisions on how to advise owners when, whether or not, and how extensively to build new structures or strengthen and repair existing structures. Build decisions often require a long-term look at future water levels, from a year to many decades. The long-term probabilities of high lake levels can influence the long-range planning decisions of a county parks director, the owner of a harbor-side industrial plant, a marina operator, or a city engineer. Marina operators report using lake level information to make decisions about installation of permanent docks, marina facility development, and marina design (Lichtkoppler, 1990).

The following example of a build decision illustrates how an engineer might use water level forecasts and statistics to maximal advantage.

### 51.1 Example: build decision

It is January 1998. In their new, year-end lake level reviews, Environment Canada and the U.S. Army Corps of Engineers issue advisories that unusually high lake levels can be expected in 1998 as a result of present high levels and a prediction of continued above average precipitation. The agencies also offer a set of conditional probabilistic statistics for each lake (Figures 5 through 7). By March, their new, simplified 6-month lake level forecasts show the range of lake levels expected through the summer (Figure 2). The forecast bulletins include an invitation to request a probabilistic l-year forecast to be sent by fax or mail (Figure 4).

A Lake Erie engineering firm receives the lake level review and promptly notifies all of their coastal clients of the high water warning. They recommend that planned repair, renovation, or new construction of shoreline protection structures should be done as quickly as possible. Marine contracting firms in the area also receive the review document and move to secure commitments from local quarries for riprap stone in anticipation of increased demand by spring.

The lake level review arrives as the engineering firm is developing design criteria for a new seawall to protect a lakeside water filtration plant in the city from which the data came to produce Figures 5 through 7. The project design engineer needs lake level statistics to estimate the maximum storm wave height and wave period likely to occur at the wall. From this information, the engineer can design the wall to withstand impact forces and provide an adequate drainage structure to handle overtopping water from breaking storm waves. Worst-case conditions are sought because an effort to balance cost and risk of damage is not appropriate in this situation. The engineer requests and receives by fax (from the U.S. Army Corps of Engineers or Environment Canada) the set of graphs showing lake level statistics (Figures 5 through 7).

These graphs are used to answer the following questions:

* What is the near-term (5-year) probability of high storm water levels?

Figure 5 gives probability information on maximum hourly lake level in each of the next 5 years. These data are based on monthly average lake level for a specific month in Year 0. Since the engineer is interested in extremes, the maximum monthly average lake level will be used. Last year (1997), it was 4.9 feet (1.5 meters) above chart datum.

From Figure 5a, there is a 1% probability that the maximum hourly water level at the design site next year will exceed 7.7 feet (2.3 meters) above chart datum. From Figure 5b, there is a 1% probability that the maximum hourly water level during 1998-2002 will exceed 7.2 feet (2.2 meters) above chart datum in the next 5 years.

* What is the long-term (20-year) probability of high storm water levels?

Figure 6 gives probability information on maximum hourly lake levels for a longer time frame than found in Figure 5. This graph is based on initial still water levels. In this case, the initial still water level is assumed to be the mean lake level at the end of 1997, which is 3.8 feet (1.2 meters) above chart datum.

Figure 6a shows that beyond the next 5 years and over the next two decades, there is a 1% probability that the annual maximum hourly water level will exceed 6.8 feet (2.1 meters). Thus, over the next 20 years, a maximum hourly lake level of 7.7 (2.3 meters) feet has only a 1% probability of being exceeded, and only in the next few years. This value will be rounded up to 8 feet (2.4 meters) and used as the design maximum storm water level for calculating the maximum storm water depth on the lakeside of the seawall. Using this storm water depth, the engineer will calculate the parameters of the largest waves that can reach the seawall before breaking and during breaking.

* A maximum hourly water level of 8 feet (2.4 meters) is going to be used in this design. What is the probability of this water level occurring at all?

Figure 7a shows probabilities for maximum instantaneous, daily mean, monthly, and annual mean water levels at this location. There is less than a 1% probability that a water level of 8 feet (2.4 meters) above chart datum will be reached (or exceeded) instantaneously at this site during any given year.

* How "realistic" is the design water level of 8 feet (2.4 meters) above chart datum that was chosen from the statistics?

"Reality checks" are needed for placing in context the chosen value of 8 feet above chart datum for a design maximum hourly water level. The engineer accesses the U.S. or Canadian water level database containing lake levels recorded at 5-minute intervals and searches for dates and values of all water level data at or above 8 feet (2.4 meters) above chart datum at the gauge location closest to the proposed seawall construction site. The engineer also has a hydrograph of historic mean monthly lake levels from 1860 to the present. This hydrograph shows the highest monthly mean lake level of 5 feet (1.5 meters) above present chart datum occurred in 1986.

Another source suggests a "probable upper bound" of maximum monthly mean water levels on Lake Erie of 175 meters, 5.6 feet (1.7 meters) above chart datum (Bishop, 1987). This conclusion was based on historical data as well as the author's review of model simulations of lake level response to hypothetical scenarios of several years of high net basin supplies (Hartmann, 1988). The engineer goes to the source of these model simulations and finds that the-scenarios included persistent (decade-long) high net basin supplies (NBS) that were 25%, 50%, 75% above the 1900-1986 long-term average values.

The engineer extracts from the U.S. or Canadian water level database a series of lo-year moving averages for Lake Erie NBS in the 20th century. There is a sequence of nine lo-year averages that range from 45 to 58% above the long-term mean. A decadal average net basin supply of 50% above average appears to be a reasonable high NBS scenario for the Lake Erie basin. Features of the actual Lake Erie data have been compared to the Hartmann 1988 scenario in Table 9.

Table 9.--Features of the actual Lake Erie data are compared with data used in the Hartmann (1988) scenario.

| Feature | Scenario | Actual |
|---|---|---|
| Starting lake level (feet, IGLD 1955) | 572.4 | 572.4 |
| Starting month/year | Jan. 1986 | Jan. 1973 |
| Ending year | 2006 | 1982 |
| Net Basin Supplies | 50% above long-term mean | 53% above long-term mean |
| Interval for long-term mean | 1900-1986 | 1900-1987 |
| Highest mean monthly level feet above IGLD 1955 | 575.3 | 573.5 |
| Highest mean monthly level feet above chart datum | 6.7 | 4.9 |
| Year of highest level | 2006 | 1973 |
| Mean St. Marys' River flow | 50% above long-term mean | 11% above long-term mean |

The engineer draws the following conclusion about the "realism" of the chosen design water elevation value:

A maximum hourly average water elevation of 8 feet (2.4 meters) above chart datum could occur as a result of:

( 1) a combination of an extraordinarily high (but credible) lake level (6.7 feet / 2.0 meters) and a common storm surge (1.3 feet / 0.4 meters), or,

(2) a combination of a historic high monthly mean lake level (5 feet / 1.5 meters) and a rare high storm surge (3 feet / 0.9 meters).

At this point, the engineer has sufficient information to understand and explain to a client the physical combinations resulting from lake levels and storms that would bring the chosen maximum hourly average water level with the statistical property of a 1% chance of occurring and possibly being exceeded.

The engineer's lack of confidence in available design methods for determining wave impact forces on walls and the minor additional cost of overdesigning adequate drainage of overtopping water justifies the use of the extreme design water level value. If there were a need for cost optimization and design/cost trade-offs, the engineer would again access the water level database and a new program for determining the joint probability of lake level, storm surge, and storm wave conditions. Development of this program began at the University of Wisconsin (Potter and Green, 1990).

In the preceding example, Figures 5, 6, and 8 are not yet available. Without them, the engineer cannot answer the probability questions with confidence. There is also no existing direct access by an engineer to a government database of lake level and net basin supply data. The engineer can get the needed information on extreme lake level events with a letter of request. The engineer cannot check the realism of the Hartmann (1988) scenarios. With the new tools mentioned in this example, the analysis could be done more quickly and with more confidence.

## 5.2 Investment Decisions

Investment decisions are decisions made to either directly or indirectly invest in coastal property. People debate whether or not to buy a particular coastal property, because the property may be vulnerable to flooding and buildings on the property could be damaged by flooding or lost to erosion. Marina owners decide whether or not to expand their facilities. Like the build decisions, investment decisions are based on a long-term time horizon. The indirect investment decisions are made by bankers in both countries and insurers on the U.S. side, when they must quantify the risks to sell flood insurance policies. This is a distinctly U.S. quandary; flood insurance is not available in Canada. In both countries, investment decisions are complicated by uncertainty about the risks of flooding and erosion.

There have been few Great Lakes studies to determine how investment decisions about coastal property differ from investment decisions about non-coastal property. Armstrong and Denuyl (1977) developed an investment decision model that shows how the proximity of a coastal home to the edge of a receding bluff influenced Michigan coastal property values during times of well-publicized high levels and erosion damage. Further work on this model was published by Braden and Rideout (1980). Kriesel (1988) examined the benefits of erosion control for Ohio properties on Lake Erie where erosion damage occurred principally during periods of high water levels. Kim (1992) followed up this work and included an examination of the influence that expectations about lake levels has on coastal home values. These studies typically focus on the coastal real estate markets in one or several counties and do not attempt to generalize the study results to other locales. Lake inundation damage (stage-damage) studies have been make by government agencies following high water level periods. The most recent of these studies was done by the U.S. Army Corps of Engineers for the Lake Level Reference Study (DeCooke, 1991).

The following example uses both current and futuristic decision tools to help evaluate the risks involved with purchasing a house on the lakeshore. Much more detail is provided in a workbook developed by Wisconsin Sea Grant for insurers and investors (Keillor and Miller, 1987a and 1987b). The elevations and flood levels in this example are based on a Lake Michigan site, but the methods apply to any of the Great Lakes.

### 5.2.1 Example: investment decision

You are interested in purchasing a lake front home. The house has no basement. The lakeside yard in front of the house slopes to a beach of reasonable width. If you live in Canada, your local conservation authority agent will be your best source of information about flood risk for this property. The OMNR has published a report, Great Lakes System Flood Levels and Water Related Hazards (1989), containing tables on flood risk on a reach-by-reach basis. In the U.S., you would probably seek advice from a NOAA Sea Grant agency, regional planning commission, county extension agent, or FEMA. The figures and agencies referred to in this example are for a U.S. site. Similar results were obtained for a Canadian site by translating National Geodetic Vertical Datum (NGVD) elevations to Canadian Geodetic Datum (CGD) elevations and using the appropriate Canadian government look-up tables.

You need to answer a number of questions about the property before you invest:

* What is the risk of flooding of the land at the house elevation?

By consulting local topographic maps, you determine that the house is on the 590 feet (NGVD 1929) contour line, ñ 2.5 feet (0.76 meters). The latest U.S. Federal Insurance Administration flood table, which the Sea Grant agent is familiar with, shows that a flood level of 584.3 feet ( 178.1 meters) above Mean Sea Level ( 1929) is expected, on the average, to be equalled or exceeded once in every 100 years (FEMA, 1991). Mean Sea Level 1929 (MSL 1929) is the same datum as NGVD 1929. An accompanying flood plain map shows that this “100-year” flood level has been rounded up to 585 feet (178.3 meters) MSL 1929 and adopted as the elevation delineating the 100-year flood plain in which federal flood insurance is available and applicable. The house is above and outside of this flood plain. The actual risk of flooding is unknown since there has been no effort to adopt an additional wave-runup value in your area, as has been done in some regions.

With the aid of your technical expert, you can proceed to determine the risk of the house being flooded:

> Step 1. Estimate highest future still water level, using the Sea Grant workbook mentioned above (or the most recent Great Lakes hydrograph), rounding up to the nearest whole number. Highest still water level based on record monthly mean level for Lake Michigan: 5.0 feet (1.5 meters) above chart datum.

Step 2. From a map in the workbook (or a new Environment Canada/NOAA/Corps of Engineers directory) add a typical local storm surge: 1.2 feet (0.37 meters)

Step 3. From a table in the Sea Grant workbook, add an estimated minimum wave run-up value for the beach: 2.0 feet (0.61 meters).

Step 4. Convert the chart datum elevation to an NGVD 1929 elevation: 578.1 feet, NGVD 1929 (176.2 meters).

Step 5. Calculate the storm water elevation on this property by summing the values in Steps 1 through 4: 586.3 feet (178.7 meters), NGVD 1929.

Step 6. Compare the storm water elevation with the elevation of the building site. The building appears to be on land at an elevation of 590 feet, NGVD (plus or minus 2.5 feet). At the storm water elevation, the house is at least 590.0 - 2.5 - 586.3 = 1.2 feet (0.37 meters) above the water elevation.

You conclude from this exercise that the house is not in obvious risk of flooding from the lake.

* Is this house apparently safe from flooding under reasonably “worst-case” combinations of highest water levels, highest storm surge, and extreme wave runup?

Step 1. Use the same highest still water level of 5.0 feet (1.5 meters) above chart datum.

Step 2. Access a new U.S./Canadian database that includes automatically updated statistics on recorded storm surges. Select a storm surge of 2.5 feet (0.76 meters) as a highest storm surge value for this portion of the open coast.

Step 3. Look up the ranges of maximum wave runup values that are listed in the Sea Grant manual mentioned above. You decide to use the maximum value of 8.0 feet (for a beach slope of 10: 1) since you are not inclined to go to the site or to use the manual description of how to measure beach slope (horizontal:vertical distances).

Step 4. Add the numbers determined in Steps 1 through 3 to the NGVD 1929 elevation of chart datum, 578.1 feet (176.2 meters), to estimate the highest storm water elevation, 593.6 feet (180.9 meters), NGVD 1929.

Step 5. Compare the highest storm water elevation with the elevation of the land surrounding the house. Even if the land elevation around the house is actually 590 + 2.5 = 592.5 feet (180.6 meters) NGVD 1929, the house is not apparently safe from flooding under the extreme combination of high water and storm conditions used.

Since the results are not conclusive, you still have a decision to make. If you live in Canada, where there is no flood insurance, you take the risk upon yourself if you choose to buy. In the U.S., you can try to get flood insurance. Based on the fact that there is risk of flooding in extreme conditions, you may have a hard time insuring the house. An insurance company could offer insurance if you are willing to pay for an engineer's analysis, providing the engineer can state in Writing that the chance of flooding is very small.

You decide to hire an engineer to better define the risk. The engineer measures the present beach surface elevations and slope, probes and measures the underlying beachform and nearshore lakebed. Standard survey techniques and equipment are used to obtain the elevation of the property. The engineer accesses the government water level database and the new program for determining the joint probabilities of high lake levels, storm surge, and storm wave conditions. Extreme wave runup values are computed using the most commonly accepted coastal engineering methods, which require the best judgment of wave shoaling, beach slope, and nearshore lakebed slopes under these extreme conditions. The engineer may decide to use primary sources or the methodology for wave runup used in the FEMA's federal flood insurance program (U.S. Army Corps of Engineers, 1989).

Several iterations are required along with a simple sensitivity to error analysis before the engineer concludes that the house elevation meets the conditions required to purchase a flood insurance policy in the U.S. The engineer's analysis will give the Canadian investor added confidence in his purchase decision.

This example can be carried out without the futuristic access to a government data base and software for computing joint probabilities. The engineer can use conventional methods and best judgment for assembling a combination of extreme lake level, storm surge, and wave runup. There are published methods for determining joint probabilities, but it is unlikely that the individual probabilities of levels, surge, and waves will be known at the site. The analysis could be done more quickly and with some confidence in the probabilities of joint occurrence if the futuristic products were available.

## 5.3 Operational Decisions

Operational decisions do not require building, modifying, or repairing structures. They affect only operations. Operational decisions generally have a short-term time horizon, about 1 to 6 months. Examples of operational decisions that must be based inpart on water level information include:

* When to schedule maintenance dredging in order to maintain adequate vessel access to a marina (Lichtkoppler, 1990).

* Whether or not to contract for a coal trans-shipment operation from an outer harbor deeper-draft slip to a power plant storage yard on a nearby river with a shallower navigation channel.

* The expected range of power generation during the next 6 months at a Great Lakes hydroelectric power plant.

One example of how water level information can be used in making operational decisions follows. This example refers to high water level conditions. The same information tools would also be useful in the case of extreme low water levels.

### 5.3.1 Example: operational decision

It is January 1998. A marina operator needs to decide the most likely range of water levels during the boating season for the annual spring installation of fixed docks at an elevation convenient to boaters. In their new, year-end lake level reviews, Environment Canada and the U.S. Army Corps of Engineers issue advisories that unusually high lake levels can be expected in 1998 as a result of present high levels and a prediction of above average precipitation for the season.

By mid-March, the marina owner receives the U.S. or Canadian 6-month lake level forecast bulletin, showing an expected range of lake levels through September that is likely to reach 0.7 to 1.5 feet (0.2-0.5 meters) above chart datum (Figure 2). The forecast bulletin includes an invitation to request a probabilistic forecast to be sent by fax or mail (Figure 4). The marina owner requests it.

Years of experience in making small decisions based on daily probabilistic weather forecasts provide the familiarity needed to use this information. The owner decides to set the docks at an optimum height for boat owners with the lake level assumed to beat the 80% July peak level: 1.3 feet (0.4 meters). This means that there is an 80% probability that the water level won't exceed that elevation. The owner knows from experience that even if lake levels reached the 97% probability level (1.55 feet / 0.5 meters), it would take a rare storm surge to flood the finger piers and such flooding would last for only a few hours.

Two futuristic elements were included in the above example. There was a prognosis for very high lake levels in the coming year because of a long-term precipitation forecast. This capability is not available now. The marina owner used the probabilistic forecast offered by the U.S. Army Corps of Engineers and Environment Canada, which is also not currently available. Without either element, the decision to select a dock height would probably be put off as long as possible if the owner sees troubling monthly revisions in the forecast levels. Exercising caution, the owner may have elected to set the docks at an elevation near the upper limit of the forecast range, resulting in an inconvenient dock height.

## 5.4 Emergency Action Decisions

Emergency action decisions are made in the face of a perceived threat to public safety, possible destruction of public or private property, or an unacceptable disruption of normal activities. The time horizon involved in these situations is very short: hours to days. The following threats can be posed from high or low water levels:

* injury or loss of life,

* interruption of electrical power, water supply, heat, sewage treatment, or other essential service,

* interruption of transportation, and,

* damage to, or loss of, stored raw materials or finished products, machinery, furniture, and fixtures.

The following example illustrates the mechanics behind an emergency action decision.

### 5.4.1 Example: emergency action decision.

It is January 1998. The state or provincial emergency preparedness agency receives a faxed notice issued by Environment Canada and the Army Corps of Engineers. The advisory states that unusually high lake levels can be expected in 1998 as a result of present high levels and a prediction of above average precipitation for the season. The notice points out that at the forecast higher lake levels, 100-year flood levels can be exceeded on any Great Lakes bay with a severe storm surge.

The agency forwards the high water notice to the regional or local government office responsible for emergency preparedness. Upon receiving the notice, local agencies locate stored stocks of street barricades and arrange for the rapid procurement of sandbags.

In the U.S., the nearby office of the U.S. Army Corps of Engineers also receives the faxed high water level warning from their District office. The local Corps engineer uses the upper limit of the forecasted lake level (Figure 2) in running a new NOAA Storm Surge Planning Program computer model, based on an earlier model by Schwab and Lynn (1987). The model estimates storm surge values in municipalities along the shores and small bays. The model runs with three "typical" historical storm conditions: an intense, rapidly moving storm front; a strong, slow-moving storm system; and a strong, stalled storm system. The model provides detailed maps of storm surge elevations and storm breaking-wave conditions at the bay shore with sufficient detail for local governments to identify most vulnerable areas in need of emergency attention. The Corps office mails the relevant three model printout maps to each local government agency. Also sent with these storm surge/storm wave maps are Corps fact sheets on construction of temporary dikes and temporary shore protection structures.

The NOAA Weather Service forecast office in the area also uses the NOAA Storm Surge Planning Program to forecast and issue a shoreline storm surge/storm wave warning as part of their neat-shore marine storm warnings. The new model allows the forecasters to list in any storm warning the communities and bays most likely to receive the most severe flooding and storm damage.

In Canada, storm surge/storm wave watches and warnings are issued by the AES on a reach-by-reach basis. These warnings are transmitted to the OMNR Flood Forecast Office, who distributes them to local Conservation Authorities over an interactive computer network.

In this example, there are four futuristic elements that affect the decision-making process: accurate long-range weather forecasts, faxed warnings of very high lake levels, storm surge modeling in small bays, and mapping of storm surge elevations and breaking storm wave conditions along the bay shore. A fifth element, typical or extreme historical storm conditions, can be easily developed now. Both the Corps and CHS provide notices on the fronts of their monthly bulletins that highlight extreme levels. But, without the futuristic elements, the emergency response will be slower and some communities will not get a timely warning (as was indicated in the survey responses in Section 3). The storm surge/storm wave damage forecast warnings will be generalized. Local community officials will rely on their judgment and their experience with past storms to make preparedness decisions.

## 6. CONCLUSIONS

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The following conclusions about the "status quo" of lake level forecasts and statistics in the Great Lakes were based primarily on needs assessment responses:

### 6.1 Forecasts

1. The monthly water level bulletin is widely used and relied upon.

2. A few simple changes to the format and content of the monthly water level bulletins could greatly increase their usefulness.

3. Many people are interested in lake level forecasts only when levels approach very high or low limits (move outside of their comfort zone).

4. When levels are extreme, users need greater access to forecast information by fax request or toll free phone line.

5. Many users want better forecasts (longer term, shorter term, more accurate) and better early warnings of major changes in lake levels caused by changing climate regimes. When such warnings are issued, they will pay more attention to lake level forecasts.

6. Many forecast users do not fully understand how to interpret the information contained in the current water level bulletin.

7. Some users want more information on the forecast for special uses with clients (as in Figures 3 and 4).

### 6.2 Statistics

1. About one-third of the people interviewed use water level statistics and get them from data published for flood insurance purposes, from water level gauge records, or from their own data analysis.

2. There is no single approach that coastal engineers now use to develop worst-case combinations of lake level, storm surge levels, and storm waves.

3. Engineers want a credible statistical methodology and computer access to water level data to determine extreme, "worst-case" combinations of lake levels, storm surges, and storm wave conditions along with the joint probabilities of their occurrence or exceedance.

4. The historical record of lake levels as currently published in hydrograph form, contains the information that many users requested, but only the coastal engineers mentioned it. Its availability needs to be publicized.

5. Figures 5, 6, and 7 each had significant groups of proponents. Users would like to have graphical displays of this statistical information available upon request, either by fax or mail.

6. Engineers and non-technical users responded to Figure 8 with both interest and skepticism. The unfamiliar element of "duration" in water level statistics has potential value. There are doubts that experts can address this issue with any credibility.

## 7. RECOMMENDATIONS

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A number of unmet needs were identified during the assessment of user needs. Some of the needs expressed are not yet attainable; for example, there is no method currently available for accurately predicting long-term climate regimes or resulting lake levels. However, many of the needs voiced during the interviews can and should be addressed. The following "Action Items," in no particular order, are recommended by this Task Force. They constitute a reasonable strategy for improving the content and communication of Great Lakes water level forecasts and statistics.

### Tailor forecast and statistical information products for specific groups.

The assessment of water level information user needs has confirmed that some interest groups are much more in need of improvements in forecasts, statistics, and the means of their communication than other groups. Initial attempts at improvement should be directed at those groups with the clearest needs: engineers, emergency government workers, recreational boaters, and riparians. The needs expressed range widely from additional technical information to a better explanation of forecast information for non-technical audiences. Information tailored for each group's needs should be developed, perhaps through the activities of the Great Lakes Water Levels Clearinghouse recommended by the Communications Task Group.

### Make modest improvements to the water level bulletins.

In both the United States and Canada, the water level bulletins are the best known, most used tools for the communication of lake level conditions and forecasts. The needs assessment has shown that many regular bulletin users do not fully understand this valuable tool. Some subtle improvements to the content and presentation of the bulletins could increase their credibility and usefulness. A user's guide should be published annually to increase understanding of this valuable tool. Changes to the bulletins and production of the user's guide could be overseen by the Coordinating Committee. Specific recommendations for changes to the bulletins are found in Table 10.

Table lO.--Recommendations to Improve the Lake Level Forecast Bulletins.

| Recommendation | **Participating** Agencies |
|---|---|
| The Coordinating Committee should be the lead agency for all of these recommendations. | Coordinating Committee |
| Conditional probability statistics:<br>Governments must support further research toward developing and distributing conditional probability statistics for Great Lakes water levels. | IWD, GLERL |
| Improved access to data:<br>Engineers and others with special information needs should be able to access the database of historic water levels to perform their own analyses. | **CHS,** NOS<br>**IWD,** GLERL,<br>MEDS |
| Storm surge forecasts:<br>Further the use of storm surge forecasting tools to cover more of the Great Lakes basin. Forecast users should be **encouraged** to provide feedback to forecast generators. | AES, NWS<br>IWD, GLERL |
| Extreme level statistics:<br>A methodology needs to be developed to help engineers, government workers, and others with the computation of joint probabilities of storm waves, storm surge, and high water levels at specific sites. | IWD, GLERL<br>Sea Grant |
| Datum conversions:<br>A conversion table to relate **IGLD** to local datums should be developed for use by marine contractors (U.S. side). | Corps, GLERL<br>USGS |
| Statistics for special uses:<br>A menu of statistical graphics should be made available to engineers, and other interested persons, along with access to the statistical data base, to aid in decision-making. | IWD, GLERL |
| Probable future levels:<br>The Canadian bulletin has removed the “most probable” line from the “Probable Future Levels” band. The U.S. bulletin should consider doing the same, since this line can be misleading to the user public. The meaning of “probable” should be frequently defined in both bulletins. | **Corps** |
| Special-use bulletins:<br>The bulletins could be tailored for special user groups relatively easily. These could be available by fax, by request. User fees should be considered. | CHS, Corps,<br>IWD, GLERL |

### Increase access to historic/real-time water level data.

Some people interviewed expressed a need for access to water level data. Only a small portion of those interviewed knew how to go about requesting such data from the appropriate agency. Technical users want access to historical levels so they can perform their own statistical analyses. Others (marina owners, riparians, emergency officials, etc.) could benefit from access to local gauge information, particularly during extreme levels.

### Provide statistical forecast graphics on request.

Some users would like more probabilistic information included in the water level bulletin, similar to Figures 3 and 4. Both governments have the capability to supply these products to interested parties, by fax.

### Develop extreme level statistics methodology.

Scientists need to develop a credible methodology for combining the effects of high water levels, storm surge, and waves. Areas that are not currently covered by storm surge forecasts need to be included. Where surge forecasts do exist, efforts to improve their accuracy and their distribution should be continued. Local government agency staff should be encouraged to provide forecasters with feedback. Some specific recommendations for new statistical products are included in Table 11.

### Develop and distribute conditional probability statistics.

Governments need to fund efforts by scientists and statisticians to develop state-of-the-art conditional probability statistics for Great Lakes water levels. The technical experts need to continue their pursuit of better decision-making tools for the millions of people affected by water level fluctuations in the Great Lakes. The closer the binational technical community can come to a consensus on statistical methods, data problems, and information presentation, the more credibility these tools will attain.

### Hold periodic workshops for scientists and users.

If progress is being made in the above areas, workshops for users (local government staff, engineers, others who serve in an advisory or communication capacity, etc.) will be essential.

### Improve public awareness of existing products.

A lot of very useful information about the fluctuating levels of the Great Lakes is not used because the people who need it are not aware of it. The agencies involved in the technical aspects of generating lake level forecasts and statistics need to take a more active role in more effectively disseminating the information, perhaps through the Communications Task Group's recommended Water Levels Communications Clearinghouse. Some specific items for improving communication of water level information are listed in Table 12.

### Expand role of the Coordinating Committee.

To facilitate implementation of these recommendations, the Coordinating Committee should assume the role of lead agency. Most of these recommendations will require input from multiple agencies in both countries. The Coordinating Committee, whose members are drawn from all of the appropriate agencies, seems to be the logical vehicle to ensure the implementation of these recommendations.

Table 1 l.--Recommended new water level forecast and/or statistical products.

| **Recommendation** | **Participating Agencies** |
|---|---|
| The Coordinating Committee should be the lead agency for all of these recommendations. | Coordinating Committee |
| Conditional probability statistics:<br>Governments must support further research toward developing and distributing conditional probability statistics for Great Lakes water levels. | IWD, GLERL |
| Improved access to data:<br>Engineers and others with special information needs should be able to access the database of historic water levels to perform their own analyses. | CHS, NOS<br>IWD, GLERL,<br>MEDS |
| Storm surge forecasts:<br>Further the use of storm surge forecasting tools to cover more of the Great Lakes basin. Forecast users should be encouraged to provide feedback to forecast generators. | AES, NWS<br>IWD, GLERL |
| Extreme level statistics:<br>A methodology needs to be developed to help engineers, government workers, and others with the computation of joint probabilities of storm waves, storm surge, and high water levels at specific sites. | IWD, GLERL<br>Sea Grant |
| Datum conversions:<br>A conversion table to relate IGLD to local datums should be developed for use by marine contractors (U.S. side). | Corps, GLERL,<br>USGS |
| Statistics for special uses:<br>A menu of statistical graphics should be made available to engineers, and other interested persons, along with access to the statistical data base, to aid in decision-making. | IWD, GLERL |

Table 12.--Recommendations to improve communication of water level information.

| Recommendation | Participating Agencies |
|---|---|
| The Coordinating Committee should be the lead agency for all of these recommendations. | Coordinating Committee |
| Media involvement:<br>Encourage inclusion of water level information in local weather forecasts on TV, radio, newspapers. | IWD, GLERL, corps |
| Forecast bulletins:<br>Encourage responsible agencies to make needed improvements in the existing forecast bulletins. | IWD, GLERL |
| Great Lakes hydrograph:<br>Make this more available through wider distribution. | CHS, Corps, GLERL |
| Forecast quality assurance:<br>Periodically, demonstrate the accuracy of the forecasts by distributing a figure showing forecast levels superimposed on actual levels. This may restore some faith in the forecasts while helping the user understand their uncertainty. | CHS, Corps |
| Special-use mailings:<br>Much of the information that user groups need exists, but remains undiscovered. Targetted mailings to different user groups summarizing the information available could increase the use of some of these valuable products. | IWD, GLERL, CHS, Corps |

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