REVIEW OF LAKE WINNIPEG WATER LEVEL REPORTING PROCEDURES

FINAL REPORT

Prepared for:

LAKE WINNIPEG SHORELINE EROSION ADVISORY GROUP

Prepared by:

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EXECUTIVE SUMMARY

Baird & Associates was selected by the Lake Winnipeg Shoreline Erosion Advisory Group to carry out a third party assessment of the accuracy of Manitoba Hydro's water level determinations and reporting for Lake Winnipeg. Water levels on Lake Winnipeg are regulated by Manitoba Hydro at the Nelson River outlet to the lake. To assist in regulating the water level control systems, a representative water level is established based on the recorded water levels around the lake. This representative water level is intended to eliminate the effects of wind, and is known as the "wind-eliminated water level". A key element of the study was a detailed evaluation of the methodology used by Manitoba Hydro to derive the wind-eliminated water level.

The study involved a review of technical literature which addresses water levels and gauges on Lake Winnipeg, and the review and analysis of historical water level data provided by both Manitoba Hydro and the Water Survey of Canada. In order to better understand the effect of wind on lake levels and the validity of the method used to calculate the "wind-eliminated water level", a numerical model was developed that simulated storm surge effects on the lake.

From the analyses carried out, it was determined that there are no significant irregularities in how the water level information is being determined and reported by Manitoba Hydro (Hydro).

Analyses, conducted with the numerical model, demonstrated that the method presently used by Hydro to compute the wind-eliminated water level is slightly biased towards the south basin of Lake Winnipeg because of the larger number of water level gauges per surface area of the lake in the south basin. Lake Winnipeg is susceptible to significant storm surge during wind storm events due to its shallow water depths. When two or more storm surge events occur in succession, use of the existing methodology results in a bias of a few centimetres from the true wind-eliminated water level. It was also shown in the study that the existing procedure can only provide a wind-eliminated water level that is ten days in the past. It is possible to improve the current methodology to provide more up-to-date information. An example of such a method is discussed in this report.

Analysis of historical data from the various water level gauges distributed around the lake showed slight differences in the observed monthly water levels even during periods of ice cover. The largest difference was observed at the Victoria Beach station where the level appears to be about 5 cm higher than that at Berens River. Further analyses may be required at this and other stations, and a review of the station datums should be completed.

The existing water level stations are not situated in ideal locations for the computation of an average lake level. In particular, there are more stations on the east side of the lake as compared to the west, and the smaller water volume of the south basin is over-represented. However, despite the inequitable distribution of the water level stations, a wind-eliminated water level can be computed from the data provided by the existing stations, using suitable weighting factors that vary from station to station. This is currently done in the methodology used by Manitoba Hydro.

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1.0 INTRODUCTION

Lake Winnipeg is the seventh largest lake in North America, with a surface area of about 23,700 km^2 and a drainage basin of about 147,000 km^2 (Adhoc Committee, 1982). The length of the lake is about 430 km from north to south and the maximum width is about 100 km. The lake consists of a large north basin (with maximum depths of about 16 m) connected to a smaller south basin (with maximum depths of about 11 m) through a constricted passage known as the "narrows".

A consequence of the large size, complex shape and relative shallow water is that the lake levels vary significantly from location to location during periods of significant wind. These fluctuations are in addition to longer period changes as a result of precipitation, inflow and outflow from the lake.

The water levels on Lake Winnipeg are regulated by Manitoba Hydro (Hydro). To assist in regulating the water level control systems, a representative water level is established based on the recorded water levels around the lake. The representative water level is intended to eliminate the effects of wind, and is known as the "wind eliminated water level".

In the summer of 1999, Baird & Associates (Baird) was selected by the Lake Winnipeg Shoreline Erosion Advisory Group (LWSEAG) to carry out a third party assessment of the accuracy of Manitoba Hydro's water level determinations and reporting for Lake Winnipeg.

The work described within this report consists of analyses of the water level data from the various Lake Winnipeg gauging sites as well as a review of the method used to determine the "wind eliminated water level" on Lake Winnipeg. This work involved an extensive review of past documents addressing water levels and gauges on Lake Winnipeg, in addition to a review of the large amounts of both raw and processed data. In order to better understand the effect of wind on lake levels and the validity of the method used to calculate the "wind eliminated water level", a finite element computer model of the lake was employed.

1.1 Regulation of Lake Winnipeg

Regulation of Lake Winnipeg by Hydro considers the present and predicted water levels in the lake, in addition to industry based issues. When asked to describe the regulation procedure used to determine the outlet control, the following response was provided by Hydro (1999):

"Manitoba Hydro continually evaluates its need to store or release water from Lake Winnipeg based upon expected power demands in Manitoba and on the export market, long term water supply forecasts and current flow and storage conditions in all rivers and reservoirs across the entire Nelson-Churchill drainage system, maintenance plans at generating stations, and the capabilities of the transmission system. As long as Lake Winnipeg is kept within the range 711 to 715, outflows from the lake are set based upon this evaluation.

The level used to determine whether the lake is within the range 711 to 715 is the wind eliminated level."

The full correspondence from Hydro is included in Appendix A.

1.2 Units of Measurement

All horizontal positions are described with respect to NAD 1927 either as latitude and longitude, or as UTM coordinates (metres) in zone 14N.

Datums for elevations are either Geodetic Survey of Canada (GSC) or Lake Winnipeg Datum (LWD) as noted. Water surface elevations published by Hydro are typically in feet, and thus many of the values within this report are in feet in order to be in agreement with these values. Water level values that are not to a specific datum, such as differences in lake level due to wind are typically reported in metres.

1.3 Limitations of the Present Study

The present study examines water levels as reported by the array of gauges that are maintained by the Water Survey of Canada (WSC) and Manitoba Hydro. For the purpose of this study, it is assumed that values that are published by the WSC as "approved" data are indicative of the water level at the location of the gauge. Checks of the actual gauge mechanisms and levelling accuracy has not been carried out as part of this study. Further details on the water level data collection and transmission are provided in Section 2.0.

2.0 LAKE WINNIPEG WATER LEVEL GAUGES AND DATUMS

2.1 Water Level Gauges on Lake Winnipeg

There are presently eight water level gauges in operation on Lake Winnipeg, as shown in Figure 2.1. All of these gauges, with the exception of Montreal Point near the entrance to the Nelson River, are maintained by the WSC. The Montreal Point gauge is maintained by Hydro.

It may be noted that the gauges are not spread equally around the lake and, in particular, there are more gauges on the east side of the lake than on the west side. If the primary use of the water level data is to establish a wind-eliminated water level on Lake Winnipeg through averaging of the measured water levels then the gauges should be more evenly distributed around the lake perimeter.

It is important to recognize that since the early 1980's the water level measurements at the gauges are relayed by two different means: electronic transmission and strip chart recordings.

Water level gauges on Lake Winnipeg make use of a real time data link via either satellite telemetry or overland connection to transmit the real time water level to a central location maintained by the U.S. National Oceanic and Atmospheric Administration (NOAA) in Wallace Island, New York. Data from the gauges are not in a consistent format as a result of the different instrumentation that exists in the field. For example, some of the older instrumentation may only transmit four digits for the water level so that a level of 217.123 m would be transmitted as 7.123 m. An adjustment of 210 m would have to be made for such an example.

Depending on the user of the data, different *standard* adjustments are made to adjust each gauge reading to the appropriate datum. Data used by Hydro and Water Survey of Canada are adjusted to Lake Winnipeg Datum (LWD) (as discussed later). *Data collected from the real time system are considered to be "provisional" data, even after the standard adjustments have been made.*

The "approved" water level data that are published by the WSC are not based on the data from the real time data links. Instead, the analogue recording device at each gauge (typically a strip chart) is used as the primary data source for publishing the "approved" water level data. In the event that the analogue recording device failed, then the real time data may be inserted into the data set. Indication from the WSC is that they are slowly changing systems and procedures such that the real time data will be considered the primary data source for generating the approved data, and the analogue record will be the secondary data set.

An important distinction between provisional and approved data is the application of non-standard corrections to the approved data. WSC conducts periodic visits to each of the gauge sites. The timing of these visits depends on site location. Accessible gauge sites, such as Gimili, may be visited on a monthly basis while less accessible locations may be visited much less frequently. During a typical site visit, the WSC representative makes a direct measurement of the water surface elevation. In processing of the analogue recordings (strip charts), if it is noted that the recorded water level deviates from that measured by the WSC representative, a correction may be applied. These deviations between the actual water level and the chart recordings may be the result of chart slippage, or similar mechanical problems.

A key point to note is that all data published to date by Water Survey of Canada is "approved" data generated from analogue recording devices. Manitoba Hydro obtains and utilizes "provisional" data from the electronic data stream by downloading from the NOAA site at Wallace Island, New York. There can, at times, be differences between these two data sets. This is investigated in further detail in Section 4.0.

2.2 Water Level Data Acquired for this Study

Water level data for this study were obtained from the WSC, Hydro, and previous reports, as described below.

2.2.1 Water Survey of Canada Data

The WSC publishes data from inland water level gauges throughout Canada, in the form of average daily and average monthly water levels. The following data were obtained:

- **Daily Data** – Daily data were obtained for the period of record for seven of the Lake Winnipeg water gauges by means of the HYDAT CD-ROM produced for the WSC.

- **Monthly Data** – Monthly average water levels were also obtained from the HYDAT CD for each of the available stations.

- **Hourly Data** - Hourly water level data were obtained from the WSC for the fall of 1997 for seven of the eight gauges around the lake. These hourly data are not normally distributed to the public and required special processing by the WSC.

These WSC data provided an independent check of the water levels supplied and utilized by Manitoba Hydro.

2.2.2 *Manitoba Hydro Data*

- **Hourly Data** - Water level data were obtained from Hydro for all eight gauges around the lake for the period of 1986 to 1999. These values were raw data that has been processed to Lake Winnipeg Datum. Any gaps in the original data sets, based on "provisional" data, were filled by Manitoba Hydro with "approved" data supplied by WSC.

- **Daily Data** - Daily water level data were provided by Hydro for a variety of periods, typically covering 1980 to the present, with some data sets going back further. Data were provided in three different forms:

  - Raw data as collected by the real time system for each of the eight gauges.
  - Calculated data which is based on the raw data but with various corrections made for each of the eight gauges.
  - Smoothed data, which is the daily wind eliminated water level value for the lake after the weighted average, limited rate of change, and smoothing algorithms have been applied to the calculated data.

- **Monthly Water Level** - Monthly mean water levels for the lake from the period of May 1913 to August 1999 were obtained from Hydro.

2.3 History of Datums

Water level datums at the various gauges around Lake Winnipeg have undergone a series of changes over the years as a result of different levelling techniques and different vertical control datums.

The first hydrometric station on Lake Winnipeg was established at Winnipeg Beach (Station 05SB001) in 1913. The station at Berens River was established in October 1914, with the datum determined by water level transfer from Winnipeg Beach. It was not until the summer of 1976 that the GSC completed a land survey which tied Berens River to their vertical control network. According to this 1976 survey, the datum in use till 1978 at Berens River was high by 0.07 m (0.23 ft). Other water level gauges around the lake had various discrepancies between the GSC surveyed datum and the water level transfer datum.

The various manners in which reference elevations may be established for water level gauges caused a great deal of debate, and lead to a study by the Ad Hoc Committee on Lake Winnipeg Datums. One of the primary recommendations of their study was that since water levels on Lake Winnipeg are primarily used to manage the resource, it shall be assumed that the surface of Lake Winnipeg is, on average, flat. Therefore, water level transfer should be used to determine the gauge datums rather than land based level loops.

This flat water level datum on Lake Winnipeg is referred to as Lake Winnipeg Datum (LWD).

The benchmark at Berens River Hydrometric Station (Benchmark 78M079) was recommended to be the master benchmark for LWD. This benchmark is fixed at 233.159 m (732.15 ft) 1960 Geodetic Survey of Canada (GSC) Datum. All other datums of the various water level gauges on the lake are referenced to this station. Table 2.1 presents the adjustment that must be made to convert from LWD to GSC at the eight active water level stations.

The elevation difference at Berens River determined in the 1978 GSC survey was not incorporated in the benchmark designation as the 1960 GSC datum was in use at the time the Interim Licence for the Regulation of Lake Winnipeg was signed. In addition, it was noted that all of Manitoba Hydro's designs and simulated lake levels in hydraulic analyses were based on the 1960 GSC datum at Berens River (Ad Hoc Committee, 1982).

Certainly a key factor in the definition of datum for the water level gauges on Lake Winnipeg has been the use of water level transfer and its assumption of a "flat" lake. When wind stress is not present, the flat lake assumption should be reasonably valid except for the near-negligible effects of coriolis forces (due to the rotation of the earth) and local water level variations in the immediate vicinity of river inflows and outflows.

A water level transfer of datum that is carefully performed during a period of near-zero wind stress (such as in the winter when ice cover exists) should give an accuracy comparable or better than running a ground-based level loop to all of the water level gauges. The highest order level survey specified in Canada has an accuracy of 3 mm per 1000 metres.

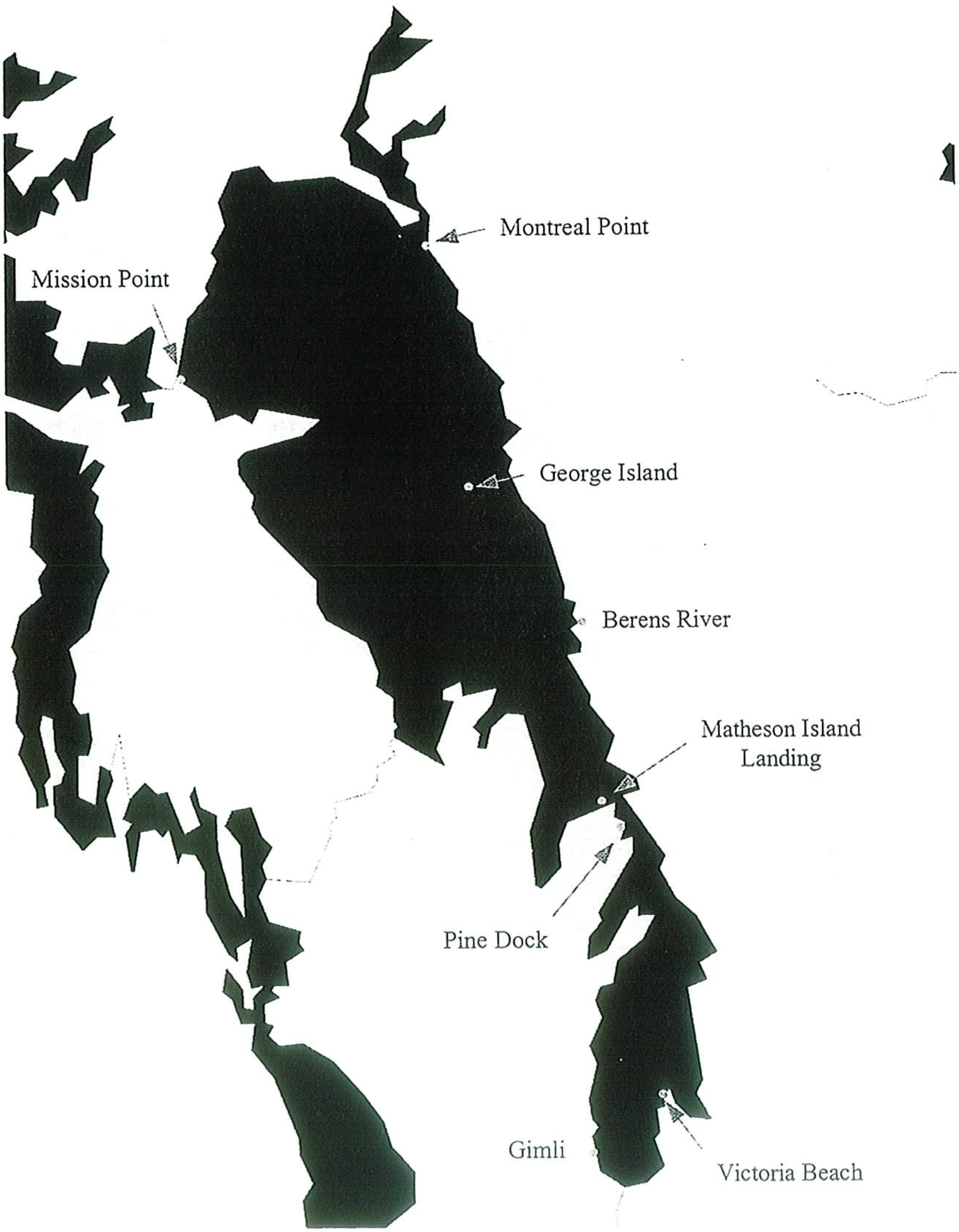
It is important to note that use of the water level transfer with its inherent assumption of a flat lake means that any possible spatial variation in the Lake Winnipeg water surface cannot be assessed as the gauge datums are no longer independent of one another.

Table 2.1
Summary of Datums on Lake Winnipeg
(Based on Environment Canada, 1996)

Station	Data Duration	Datum Correction to GSC from LWD
Berens River	1914-1999	Apply 0.043 m adjustment to convert to GSC Datum (Local 1976 Adj.)
George Island	1983-1999	Apply 0.043 m adjustment to convert to GSC Datum (Local 1976 Adj.)
Gimli	1966-1999	Apply 0.043 m adjustment to convert to GSC datum (1968 Adj.)
Matheson Island Landing	1959-1999	Apply 0.043 m adjustment to convert to GSC datum (local 1964 Adj.)
Mission Point	1953-1999	Apply 0.064 m adjustment to convert to GSC datum (Local 1969 Adj.)
Montreal Point	1969-1999	Apply 0.043 m adjustment to convert to GSC datum (Local 1968 Adj.)
Pine Dock	1958 – 1999	Apply 0.024 m adjustment to convert to GSC datum (Local 1964 Adj.)
Victoria Beach	1959 – 1999	Apply 0.043 m adjustment to convert to GSC Datum (Local 1962 Adj.)

LWD: Lake Winnipeg Datum

GSC: Geodetic Survey of Canada Datum (with different adjustments)



Active Water Level Gauges on Lake Winnipeg

Figure 2.1

3.0 WATER LEVELS ON LAKE WINNIPEG

3.1 Short Duration Fluctuations in Water Level

Short term fluctuations in water level on Lake Winnipeg are typically variations that occur locally on the lake in response to atmospheric stress. While an increase in water level occurs in one location, a corresponding lowering of the water level occurs elsewhere.

It is important to note that local fluctuations in the water level occur rapidly, and are of such magnitude, that regulation of the lake on a day to day basis cannot offset these variations. Water levels in the south basin may change by more than one metre over the course of a few days as a result of atmospheric stress, while the actual control on the level of the lake is a fraction of this.

The maximum daily outflow from Lake Winnipeg averaged over many years is about 3230 m^3/s, while monthly mean flow rates for all of the gauged tributaries varies by month but is in the range of about 1600 to 2800 m^3/s. Therefore, the maximum flow rate in the Nelson River is about 1600 to 400 m^3/s higher than the range of monthly mean inflows. Using an average of these values as an example would effect Lake Winnipeg water levels as follows: If the outlet from the lake is flowing at a rate of 1000 m^3/s greater then the sum of all the inflows to the lake, the lake level would increase by only 3 mm per day.

3.1.1 Wind Setup

Wind setup describes an increase in water level that is caused by winds blowing in an onshore direction. On a lake such as Lake Winnipeg, a wind setup in one location must be accompanied by a wind set-down in another location. When wind blows over a water body, the surface water moves in the direction of the wind, while the water at depth typically moves in the opposite direction. In shallow regions, this "return flow" is hampered, causing greater setup than would occur in deeper water bodies. Figure 3.1 illustrates this principle.

The process of wind setup is affected by water levels in the same manner as the depth of the water body. If the same wind storm occurred with two different mean lake levels, the wind setup would be fractionally larger for the low water level scenario than the high water scenario. This implies that mean lake level differences are not amplified during wind events.

Wind is undoubtedly the largest factor causing short duration water level fluctuations on Lake Winnipeg. Wind forcing, and the impact on water level fluctuation is an aspect that was studied in greater detail through the use of a computer model. This is described in Section 4.

3.1.2 Pressure Setup

Pressure setup is a phenomena whereby differences in atmospheric pressure over a water body cause a difference in water levels to occur. Pressure setup is most evident in deep ocean waters where the water may move easily to compensate for the pressure difference. Hurricanes and tropical storms with low central pressures may result in a pressure setup of one metre or more, while on an enclosed water body, the pressure setup is much less due to the typically shallow water depths and smaller spatial extent over which the pressure difference may occur.

Atmospheric pressure differences over Lake Winnipeg cause pressure setup values that are much smaller in magnitude than the wind setup. A review of atmospheric pressures from the north to the south end of the lake over a period of 34 years revealed that the largest pressure differences are in the order of about 1.5 kPa. If this pressure difference was held constant for long enough for the water level to respond to this pressure difference, the result would be a difference of about 15 cm from one end of the lake to the other. In reality, there is friction that opposes the movement of water to adjust to the pressure imbalance, and time required to do so. As a result, only a fraction of the possible pressure setup is realized. Given that wind setup values are sometimes one metre or more, one may thus conclude that the pressure effect on water level setup is likely well below ten per cent of the effect that wind has on water level setup. Pressure setup will not be further considered in this report.

3.2 Medium Duration Fluctuations in Water Level

Over the time scale of weeks or seasons, tributaries to the lake, including the Saskatchewan River, Winnipeg River, Red River, Berens River and many other rivers and streams affect the level of the lake. Large scale weather patterns affect the amount of rainfall in the watershed, in addition to the amount of evaporation from the lake.

Regulation of medium duration events is possible to a degree, although some of these events are impossible to control. The freshet each year results in large volumes of water entering the lake that have historically resulted in a rise in Lake Winnipeg as the water was stored and later released.

3.3 Long Duration Fluctuations in Water Level

Long duration fluctuations in water level are variations that occur over a number of years. Lake Winnipeg is subject to long duration variations in the water level as a result of climatic variations in the watershed, and a slow rise in the level of the lake because of the greater rate of post-glacial rebound at the north end of the lake where the outlet is located. Based on radiocarbon dating of marsh facies, peat and drowned trees, Nielsen (1998) estimated that the water level at the south end of the lake has been rising on the average about 20 cm/century for the last three centuries. A simple linear regression of the annual mean water levels for the period 1914 to 1998 indicates a rise of about 50 cm per century on average. However, a linear regression for the period of 1950 to 1998 indicates a drop of about 50 cm per century on average. Clearly, the water level data from the period of record on the lake is not long enough to assess any long term variations in the lake level due to post glacial rebound.

3.4 Discussion of Recorded Water Levels

Prior to 1976 Lake Winnipeg was unregulated. However, water level records prior to 1976 cannot be considered as totally natural because starting in about 1892, water control projects in Ontario, Manitoba, Saskatchewan, Alberta, Minnesota and North Dakota affected natural inflows into the lake.

Hydro's license for regulation of the lake requires that the lake be maintained between elevations 216.7 and 217.9 meters (711.0 and 715.0 ft) in so far as is possible. During the period of regulation, the monthly mean water level has never been below the target minimum level (minimum of 711.4 ft in January 1989), while the target maximum level has been exceeded during three periods (June & July 1976, May 1986, and May to July of 1997)

Figure 3.2 presents the monthly mean water levels for Lake Winnipeg at Berens River. This plot clearly shows the naturally large variation in the water level during the period of 1913 to 1975 when the lake was essentially unregulated. During the period of 1977 to the present, the lake level has shown less variation, as illustrated in Figure 3.3 which presents the difference between the highest monthly mean and the lowest monthly mean for each full year of data on record. Note that this plot depicts data from Manitoba Hydro since their data set was more complete (fewer missing months). Comparison of Hydro data and WSC data is presented in the following section.

The long-term average lake level for the periods before and after regulation is almost identical, with both at about 713.5 ft; however this can vary depending on the period , over which water levels are averaged. Table 3.1 provides a comparison of average long-term lake levels for different averaging periods from the WSC data which were only available to 1995. Note that water levels since 1995 have been higher than the average from 1977 to 1995, thus the value for 1977 to 1999 would be higher than that in Table 3.1. Figure 3.4 presents the average levels in each month before and after regulation. This figure indicates that on average, the levels are similar, with a slightly higher value in the winter and early spring months since regulation started (although ice cover exists for much of this period).

Table 3.1
Long-Term Water Levels on Lake Winnipeg
Berens River Station, WSC Data

Averaging Period	Lake Level (ft LWD)
1917-1936	712.744
1937-1956	713.182
1957-1976	714.614
1917-1976	713.513
1977-95	713.272

3.5 Comparisons of WSC and Manitoba Hydro Water Level Data

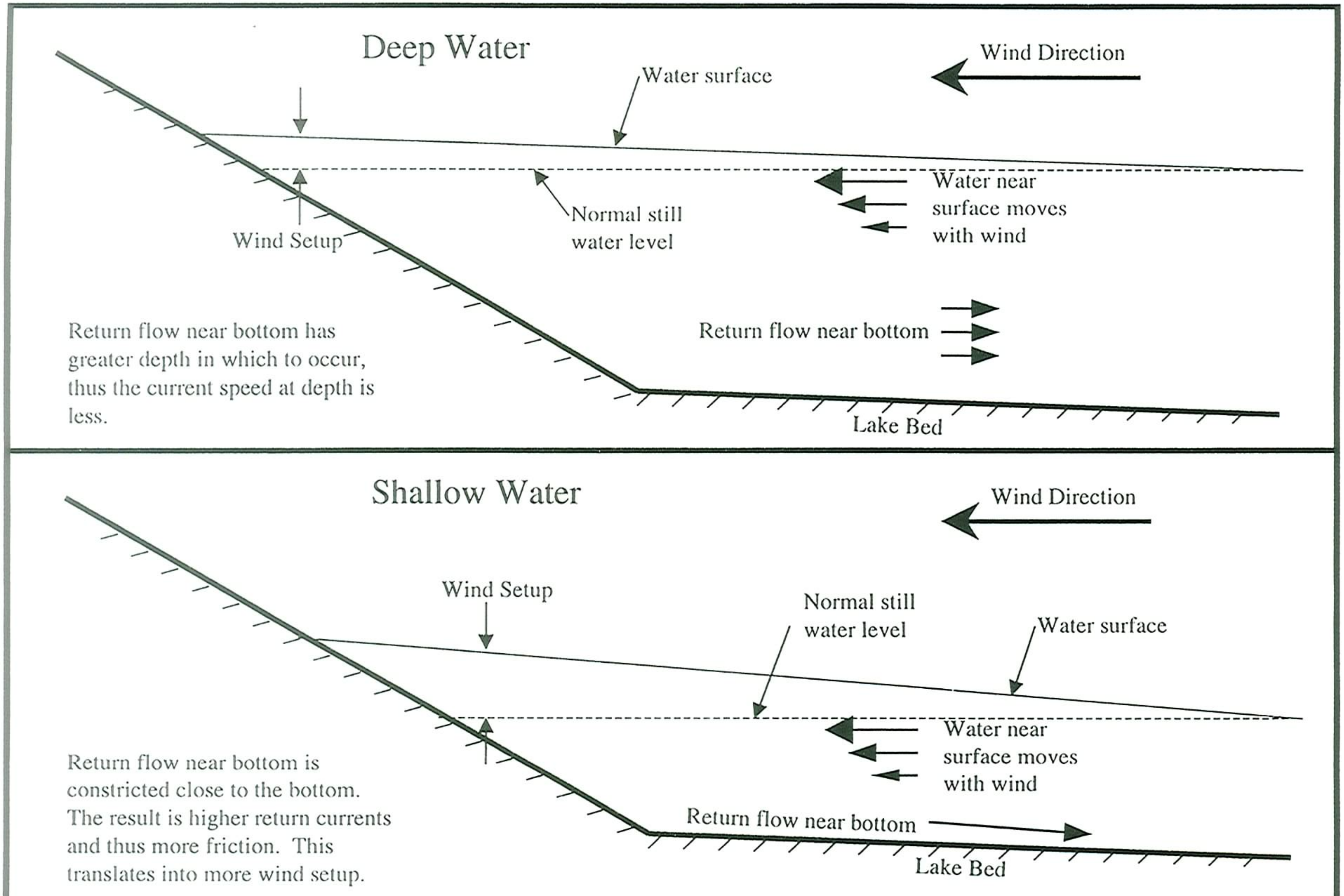
A comparison was also made of long term data provided in the form of monthly wind eliminated water levels from Hydro with WSC data from Berens River. Slight variations did exist between the data sets, probably as a result of the treatment of missing data or data recovery percentages in order to consider the data acceptable. In general, the values compared very well as may be seen in Figure 3.5.

Comparisons were also conducted between the hourly data supplied by both Manitoba Hydro and the WSC. In general, the data sets compared closely, however, at times there were differences of up to 8 cm at individual stations and there could be differences in excess of 20 cm for a single hour. Figure 3.6 shows an example of a typical comparison between the data sets at Berens River. These differences likely exist due to the differences between the "provisional" water level data used by Hydro and the "approved" data developed by the WSC. The WSC does perform quality control on the data and undertake some post-correction of the data if problems with gauge performance (such as gauge drift) have been noted.

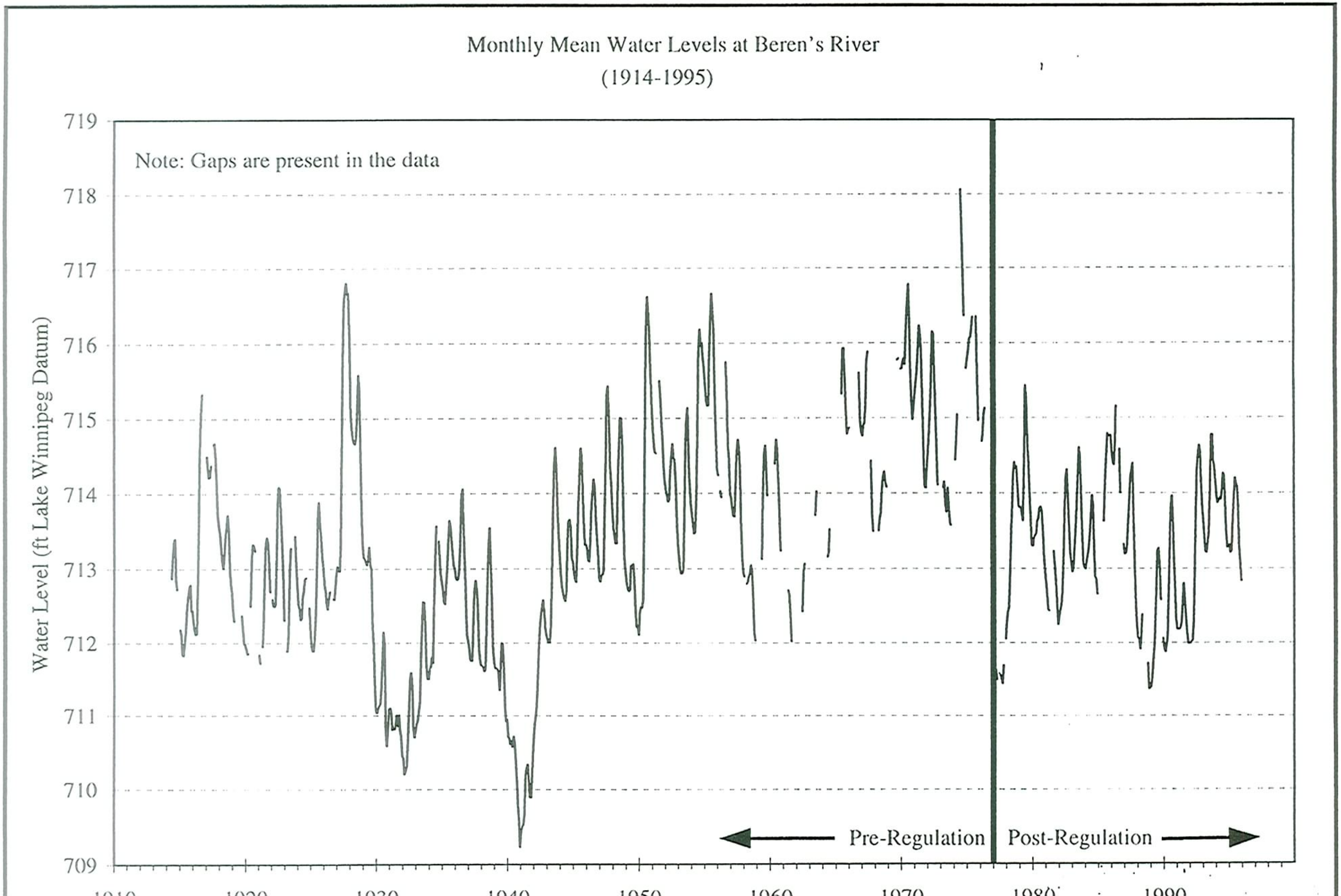
3.6 Spatial Comparison of WSC Water Level Data

In order to assess potential differences in water level at different locations on the lake, monthly average water levels from the WSC were obtained for the gauges' period of record up to 1995. A comparison of the active gauge locations for the years 1990 to 1995 is presented in Figure 3.7 along with the wind-eliminated water level provided by Manitoba Hydro. It may be noted that there are some notable long-term differences between the monthly lake levels at the various gauges. The average monthly level should provide a reasonable estimate of the wind-eliminated water level except for months where there has been a strong wind of extended duration from one particular direction. The consistent differences between the gauges indicates a possible variation in datum definition.

In order to better assess the differences among the various water level gauges, a comparison of the monthly water levels was carried out for the winter months in which Lake Winnipeg was covered with ice (in order to eliminate the effects of ice cover). This comparison showed that the Victoria Beach gauge was consistently reading 5 cm higher than Berens River. Similarly, the Gimli gauge was on average 2.4 cm higher than Berens River. There are likely some minor differences in the gauge datums and this should likely be re-visited through a more precise water level transfer of datum.



The Effect of Water Level on Wind Setup — Figure 3.1


Monthly Mean Water Levels at Beren's River
(1914-1995)
Note: Gaps are present in the data
Water Level (ft Lake Winnipeg Datum)
719
718
717
716
715
714
713
712
711
710
709
1910
1920
1930
1940
1950
1960
1970
1980
1990
Pre-Regulation
Post-Regulation
Figure 3.2

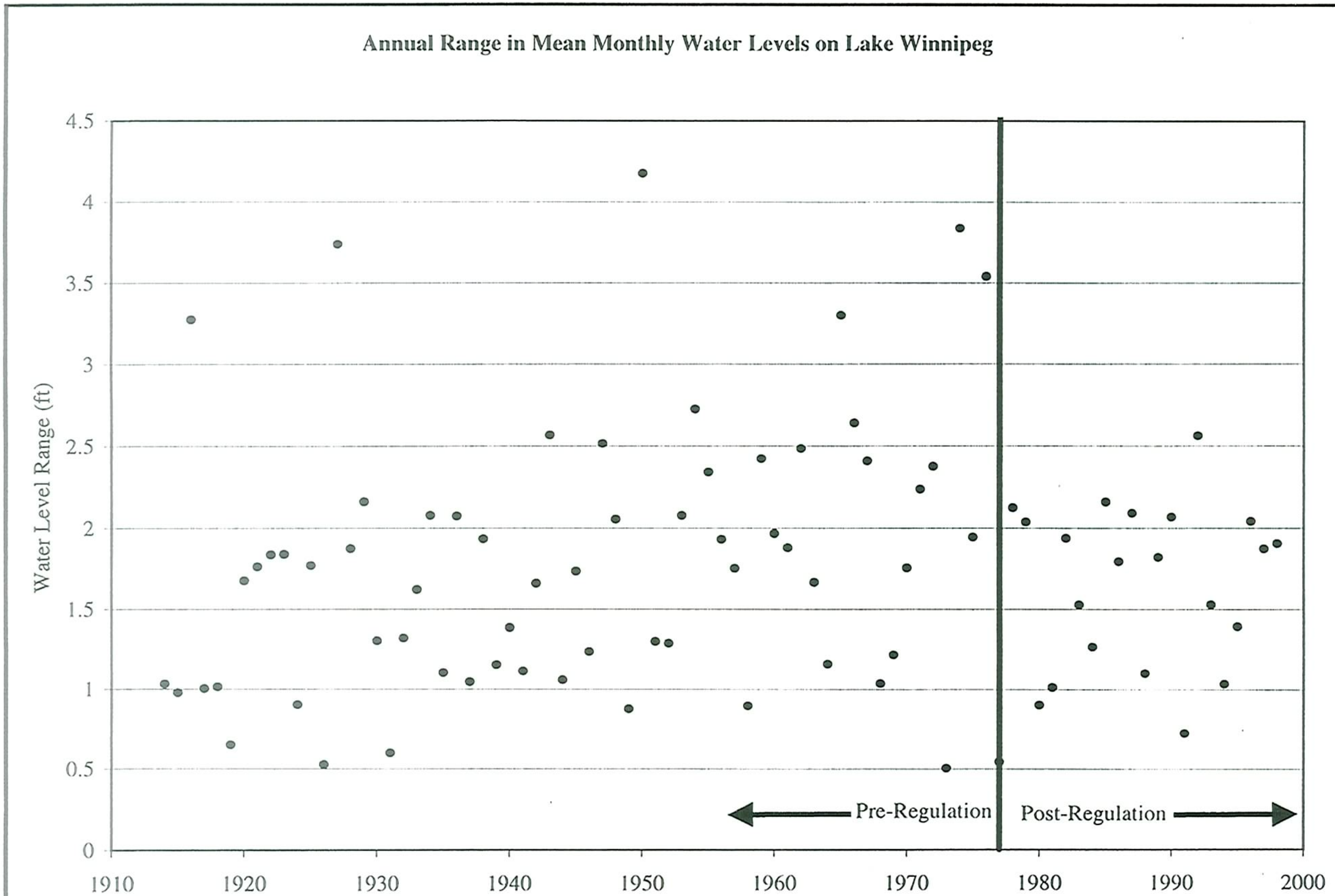
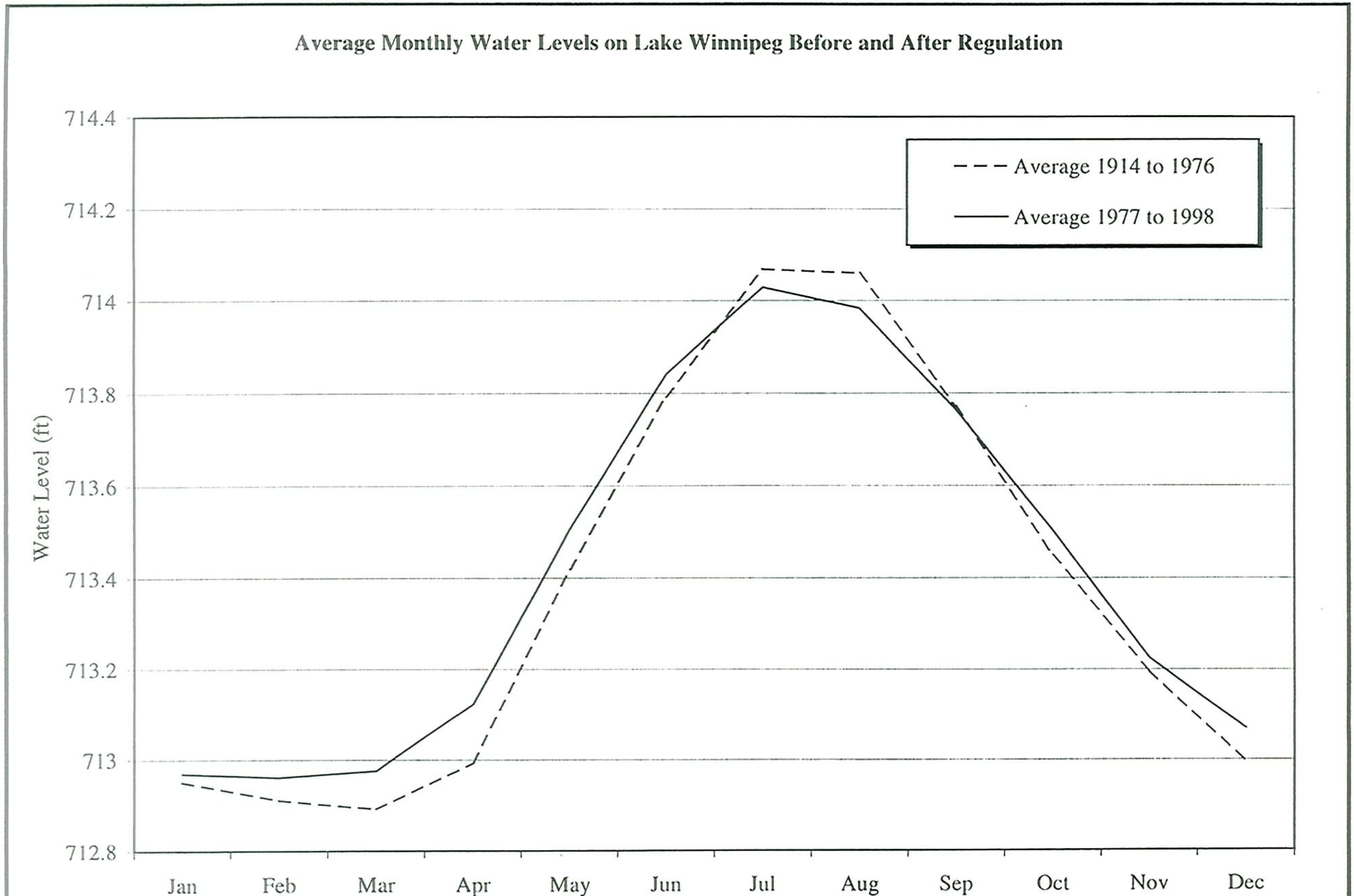

Annual Range in Mean Monthly Water Levels on Lake Winnipeg
Water Level Range (ft)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
Pre-Regulation
Post-Regulation

Figure 3.3


Average Monthly Water Levels on Lake Winnipeg Before and After Regulation
714.4
714.2
714
713.8
713.6
713.4
713.2
713
712.8
Water Level (ft)
Average 1914 to 1976
Average 1977 to 1998
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Figure 3.4

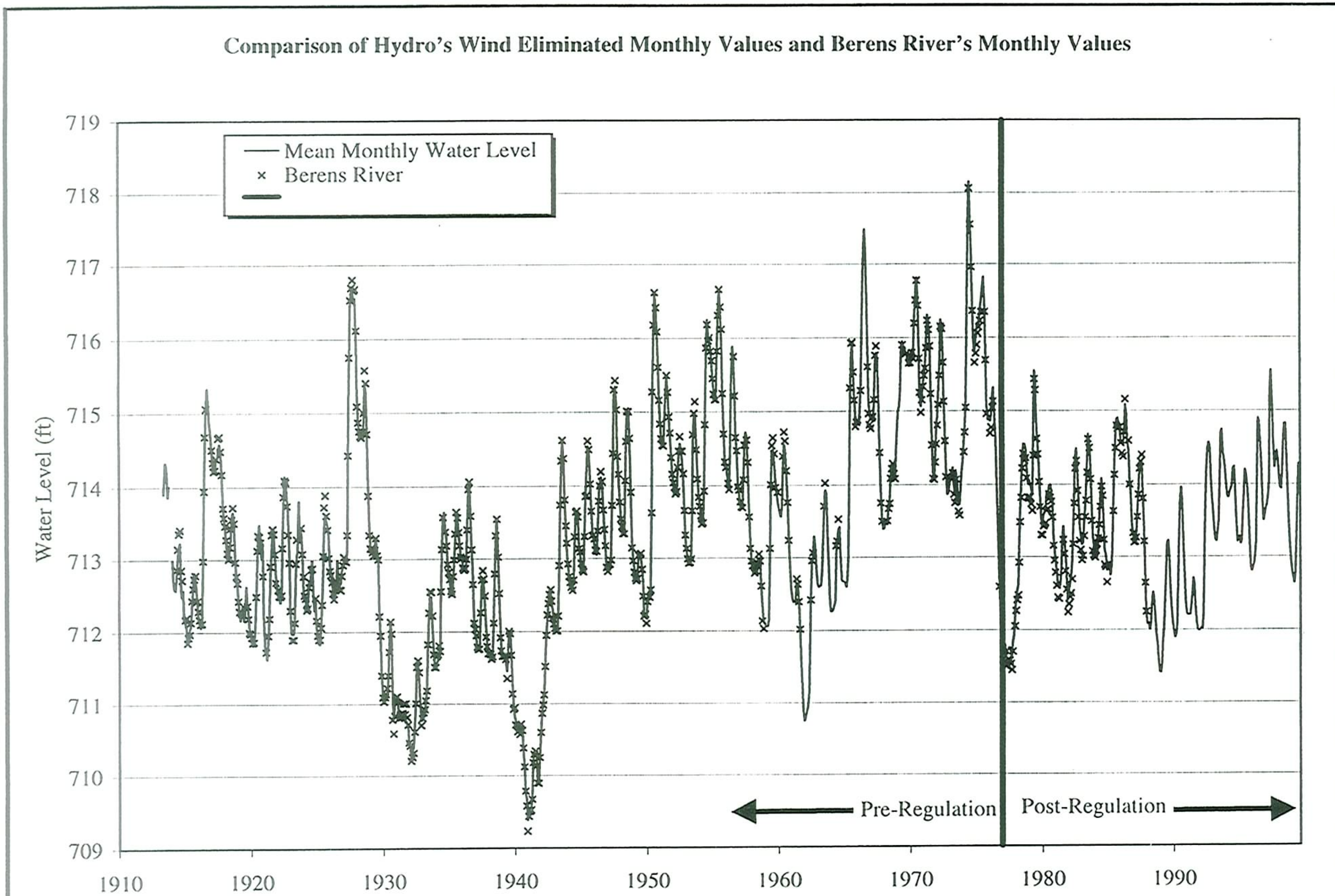

Comparison of Hydro's Wind Eliminated Monthly Values and Berens River's Monthly Values
Mean Monthly Water Level
Berens River
Water Level (ft)
719
718
717
716
715
714
713
712
711
710
709
1910
1920
1930
1940
1950
1960
1970
1980
1990
Pre-Regulation
Post-Regulation

Figure 3.5

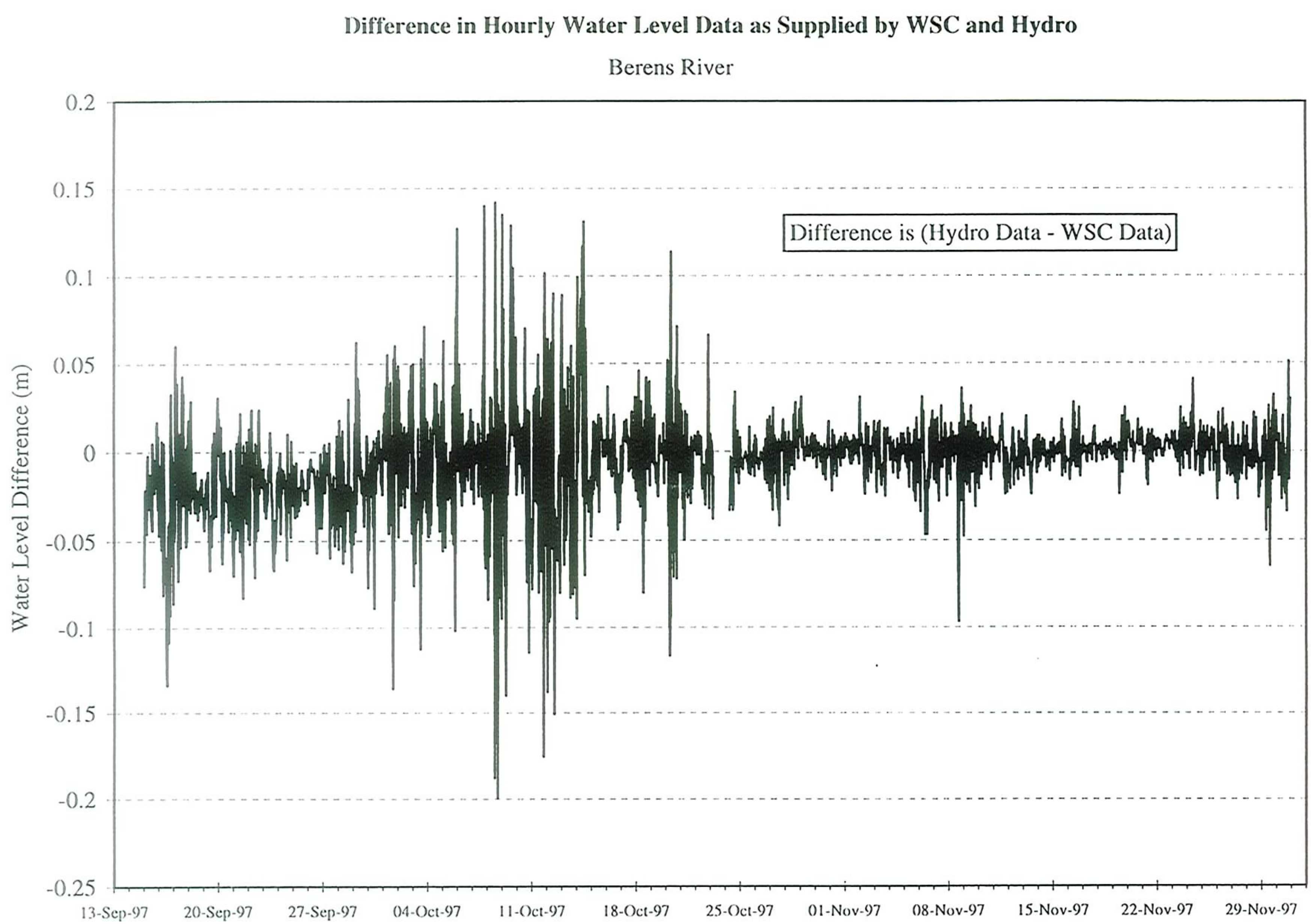
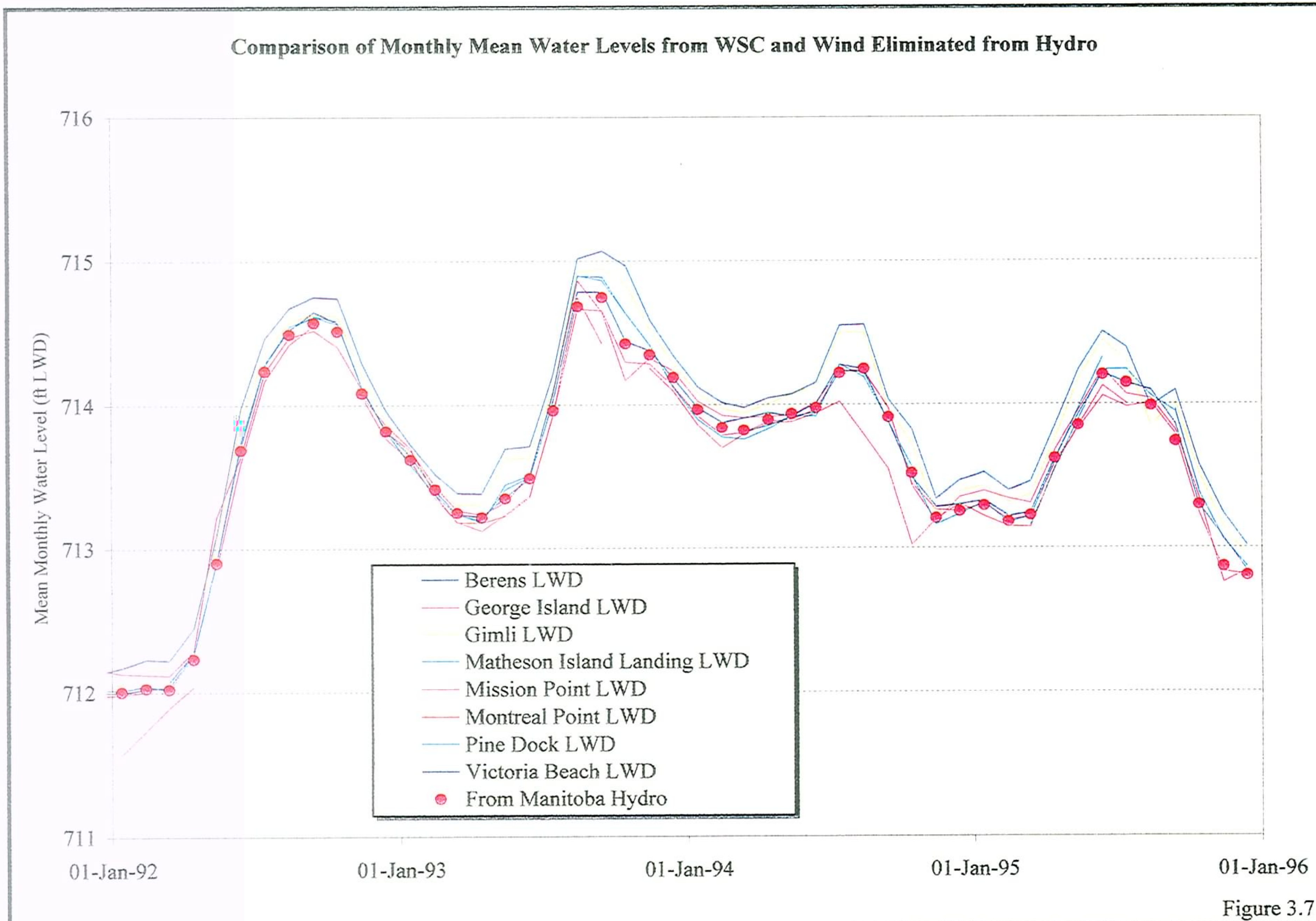

Difference in Hourly Water Level Data as Supplied by WSC and Hydro
Berens River
Difference is (Hydro Data - WSC Data)
Water Level Difference (m)
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
13-Sep-97
20-Sep-97
27-Sep-97
04-Oct-97
11-Oct-97
18-Oct-97
25-Oct-97
01-Nov-97
08-Nov-97
15-Nov-97
22-Nov-97
29-Nov-97

Figure 3.6



Comparison of Monthly Mean Water Levels from WSC and Wind Eliminated from Hydro
Mean Monthly Water Level (ft LWD)
716
715
714
713
712
711
01-Jan-92
01-Jan-93
01-Jan-94
01-Jan-95
01-Jan-96
Berens LWD
George Island LWD
Gimli LWD
Matheson Island Landing LWD
Mission Point LWD
Montreal Point LWD
Pine Dock LWD
Victoria Beach LWD
From Manitoba Hydro

Figure 3.7

4.0 MODELLING LAKE WINNIPEG WATER LEVELS

4.1 Introduction

The wind eliminated water level may simply be described as the water level on the lake that would occur if wind had no impact on the water levels throughout the lake. The wind eliminated water level on Lake Winnipeg is difficult to determine as a result of the highly irregular bathymetry of the lake, and the shallow water depths that make the lake more prone to variations in the water level due to wind.

The use of a numerical model for such an investigation provides a controlled environment for assessing water levels. The numerical model has the advantage that if it is used correctly, the volume of water in Lake Winnipeg is precisely known, as is the wind eliminated water level. This allowed for an assessment of the accuracy of various techniques for determining the wind eliminated water level. Assessments that are carried out based on recorded data alone are complicated with changing lake levels as a result of:

- gauged and ungauged tributary inflows
- outflows
- rainfall (which is spatially and temporally variable)
- evaporation (which is spatially and temporally variable)

Use of a numerical model has the advantage of eliminating all of the above variables, although one must be aware that the water levels in the model are now simulated rather than recorded. If the simulated water levels can be shown to be similar to the recorded water levels, then the model is a powerful tool for examining the determination of the wind eliminated water level.

4.2 Numerical Model Description

The numerical model that was chosen for carrying out the simulations of water level on Lake Winnipeg is RMA2; a model that is maintained by the U.S. Army Corps of Engineers. RMA2, which is a two-dimensional finite element model, has been used extensively in North America and other parts of the world, and has the ability to simulate:

- steady state conditions
- time varying conditions
- wind stresses and the resulting setup of the water level,
- flooding and drying of low-lying areas

RMA2 runs fairly quickly on today's PC's, and is also in the public domain, permitting more economical distribution of the software.

The first step in developing a finite element model of Lake Winnipeg is to generate the finite element mesh. The shoreline position and depths throughout Lake Winnipeg were determined based on navigation charts obtained from the Canadian Hydrographic Service (CHS). These charts provide good coverage throughout most of the lake; however, certain regions such as Kinwow Bay, Washow Bay, Sturgeon Bay and regions southwest of Reindeer Island have poor or no soundings. In these regions, water depths were estimated based on surrounding areas and any notes that exist on the hydrographic charts.

A finite element mesh was generated which included a total of about 5000 nodes and 2250 elements to represent the lake. The mesh was structured in such a manner as to provide high resolution in regions such as the narrows, and lower resolution in the large open parts of the lake. This provides a good balance between computational speed and accuracy. A plot of the finite element mesh and associated bathymetry is provided in Figure 4.1.

4.3 River Flow Simulations

Prior to carrying out simulations with winds on Lake Winnipeg, a study was carried out in order to determine the effect that tributary flow rates could play in varying the water levels on Lake Winnipeg. A simulation was carried out in which all of the recorded tributaries were flowing at a rate equal to the mean June flow rate. The water level at the outflow from the lake was then held constant and the resulting spatial variation in water level over the lake was documented. This is clearly a very artificial situation (the outflow would never remain at constant elevation); however, the model simulation provides an indication of the possible maximum spatial changes in water level due to river inflow only.

The result of these simulations is presented in Figure 4.2. From this figure it is evident that tributary inflows into the lake will cause only very minor fluctuations in the water level. In fact, most of these variations are less than the accuracy of most water level gauges.

4.4 Calibration/Verification of Model Performance

Carrying out a detailed calibration of wind induced surges on Lake Winnipeg is an enormous task due to the large spatial extent and the number of variables that must be considered. However, as outlined in the proposal, the intent of the present model is to provide a reasonable representation of the Lake Winnipeg water levels. Comparison of measured data to recorded data was used to establish confidence in the model's performance.

One of the key inputs to a model of storm surge is the wind field. For all of the numerical model simulations of storm surge conducted in this study, the input wind field was based on historical wind conditions at Gimli. Thus, the wind field over the model was spatially constant. Appendix B provides a statistical summary of the Gimli wind data for the period of record. Other wind stations had been obtained (eg. Grand Rapids) and additional data could have been sought from other sources, such as the Manitoba Government. However, the creation of spatially-varying wind fields based on wind data blended from various stations was well beyond the scope of this study and was not necessary in order to assess Manitoba Hydro's water level reporting procedures.

Calibration of a model is the process whereby parameters in the model, such as the bed friction, are adjusted in order to match the output from the model with recorded data. Following the calibration, a comparison is then made with a different data set in order to assess the model's performance on data for which it was not specifically calibrated. For the present modeling exercise, only the verification procedures were carried out.

The parameters that would normally be varied during the calibration process for a model of storm surge include the bottom friction, wind friction, time step and the wind field itself. For the verification procedure, two bottom friction values were tested, and two time steps were tested. The wind field was based on the wind conditions recorded at Gimli, while default wind friction values were used.

Time steps of one half hour and one hour produced virtually identical results, and thus a time step of one hour was adopted for the simulations. The fall of 1995 and 1996 were selected for assessing the model's performance.

Comparison of time series of various gauges around the lake shows a strong resemblance between the measured and simulated data, especially considering the fact that wind over the entire lake is simulated in the model based on the hourly readings from Gimli. Figures 4.3 and 4.4 show the water level at a number of the gauges for simulations with Manning's n friction values of 0.035 (higher friction) and 0.028 (lower friction) respectively. Figure 4.5 shows the water levels from the fall 1995 simulation.

From these figures, it is evident that the model is producing a reasonable representation of the water levels on Lake Winnipeg. Therefore, the data from these model simulations should provide a reasonable database from which to assess various techniques for assessing the wind eliminated water level. A final bottom friction value of 0.035 was assumed for all subsequent simulations.

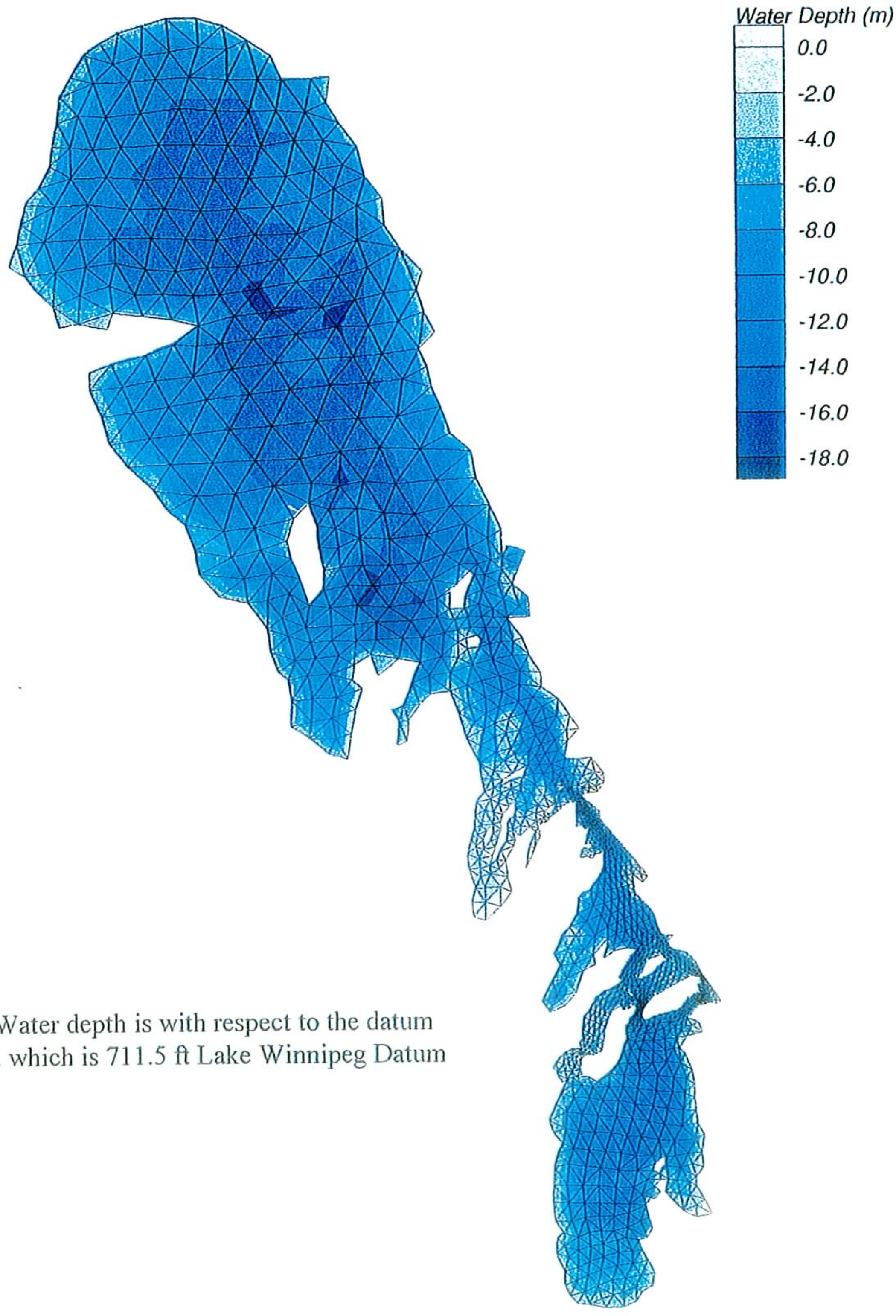
4.5 Steady State Wind Simulations

In order to assess the accuracy of the Hydro method for computing the wind eliminated water level, some simple simulations were carried out in which the wind conditions were held constant and a steady state simulation of the resulting wind setup was determined.

These simulations were carried out for a wind speed of 50 km/h for eight points of the compass. A value of 50 km/h was chosen since this wind speed is one that is fairly strong and may occur for a duration of one day or more. A 50 km/h wind occurs approximately 1% of the time during the open water season, as indicated by statistical analysis of the Gimli wind data. The resulting wind setup is depicted in Figure 4.6, which shows contours of water level in the lake, while Figure 4.7 shows the gauge readings for the eight gauges around the Lake that are used by Hydro.

4.6 Oscillation of the North and South Basins

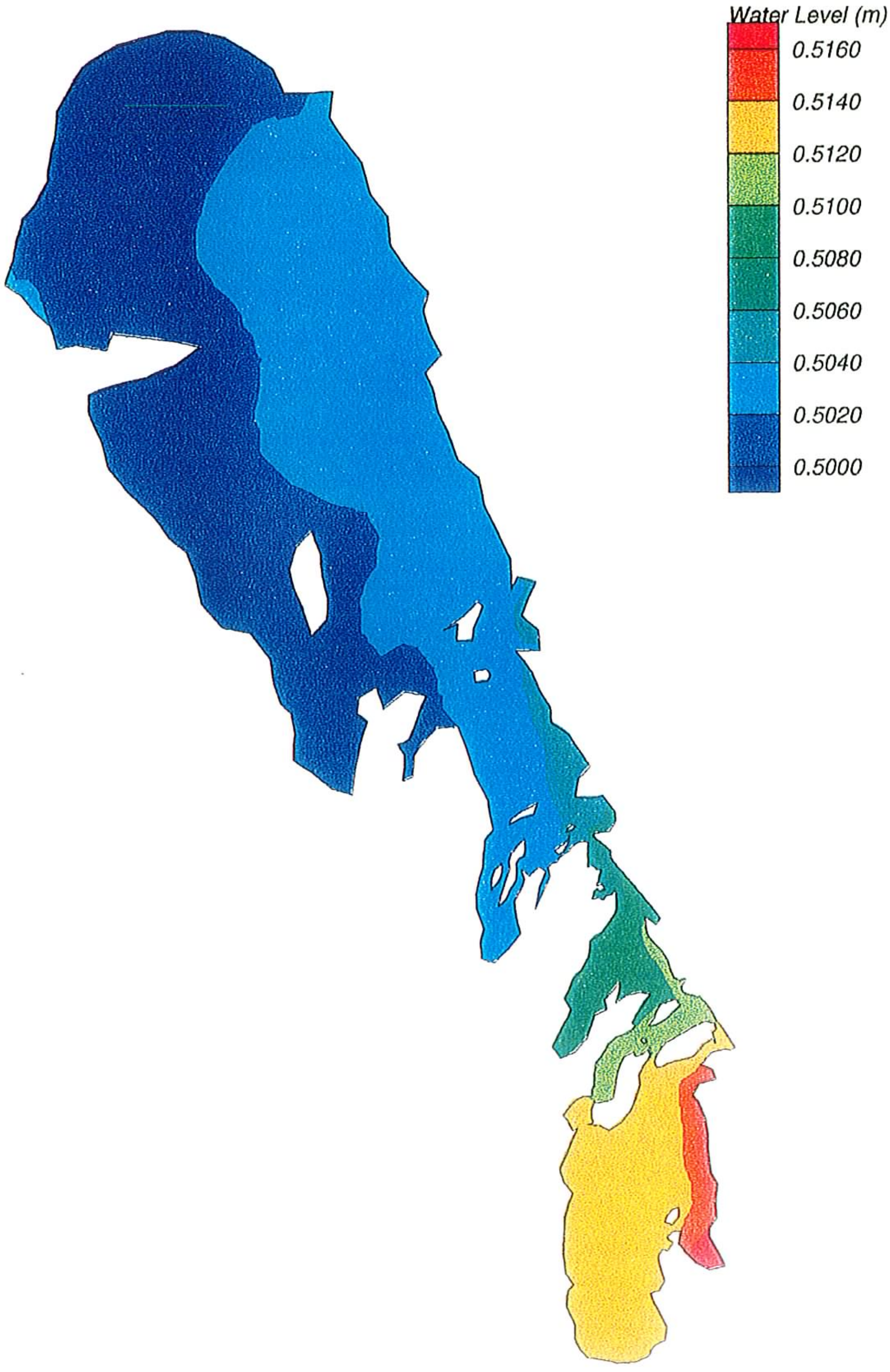
One of the interesting phenomena noted during the numerical model simulations was that surge in the Lake Winnipeg basins sets up much more rapidly than it dissipates. For example, a wind from the NNW (for example) will cause both the north and south basins to setup towards the SSE. The result is that the difference in water level across the narrows region is very large since it is going from a region of set-up to set-down. When the wind subsides, there is a smaller difference in water level across the narrows than there was when the wind started to blow. For this reason, the time required for the water level to return to normal is much longer than the time over which the change occurred. These processes are illustrated by Figure 4.8.



Note: Water depth is with respect to the datum for grid which is 711.5 ft Lake Winnipeg Datum

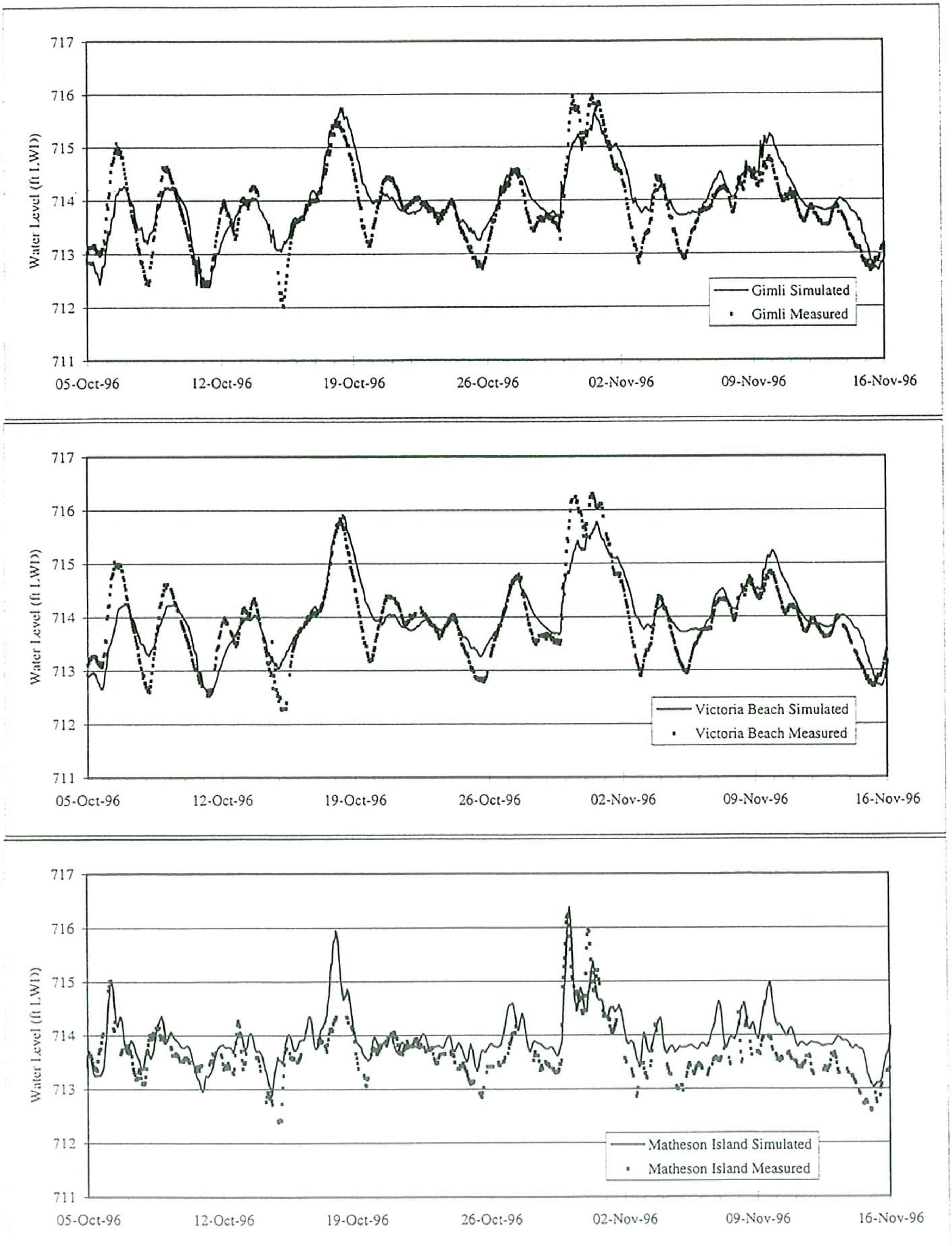
Finite Element Mesh for Numerical Model of Lake Winnipeg

Figure 4.1



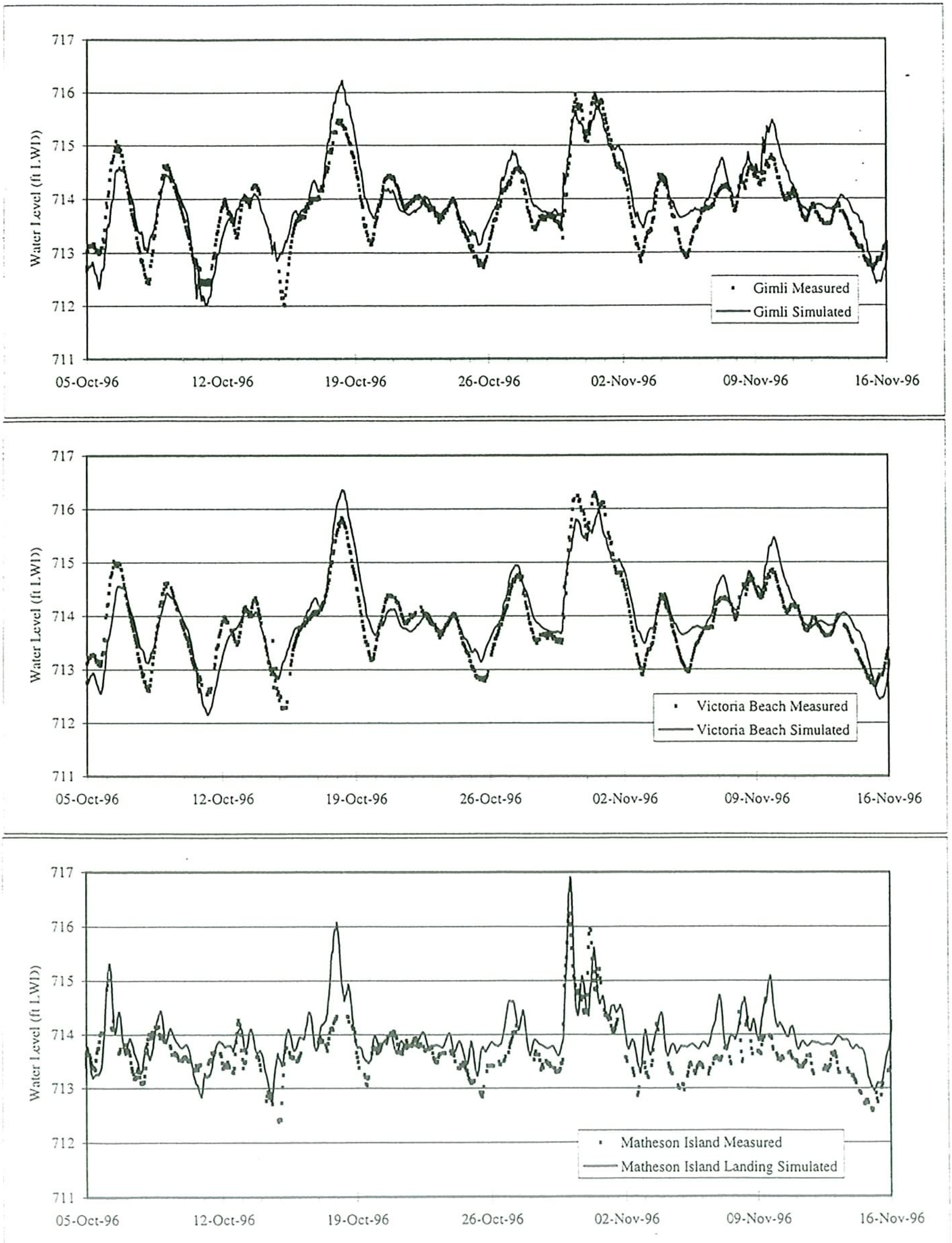
Lake Level Contours With High River Discharge

Figure 4.2

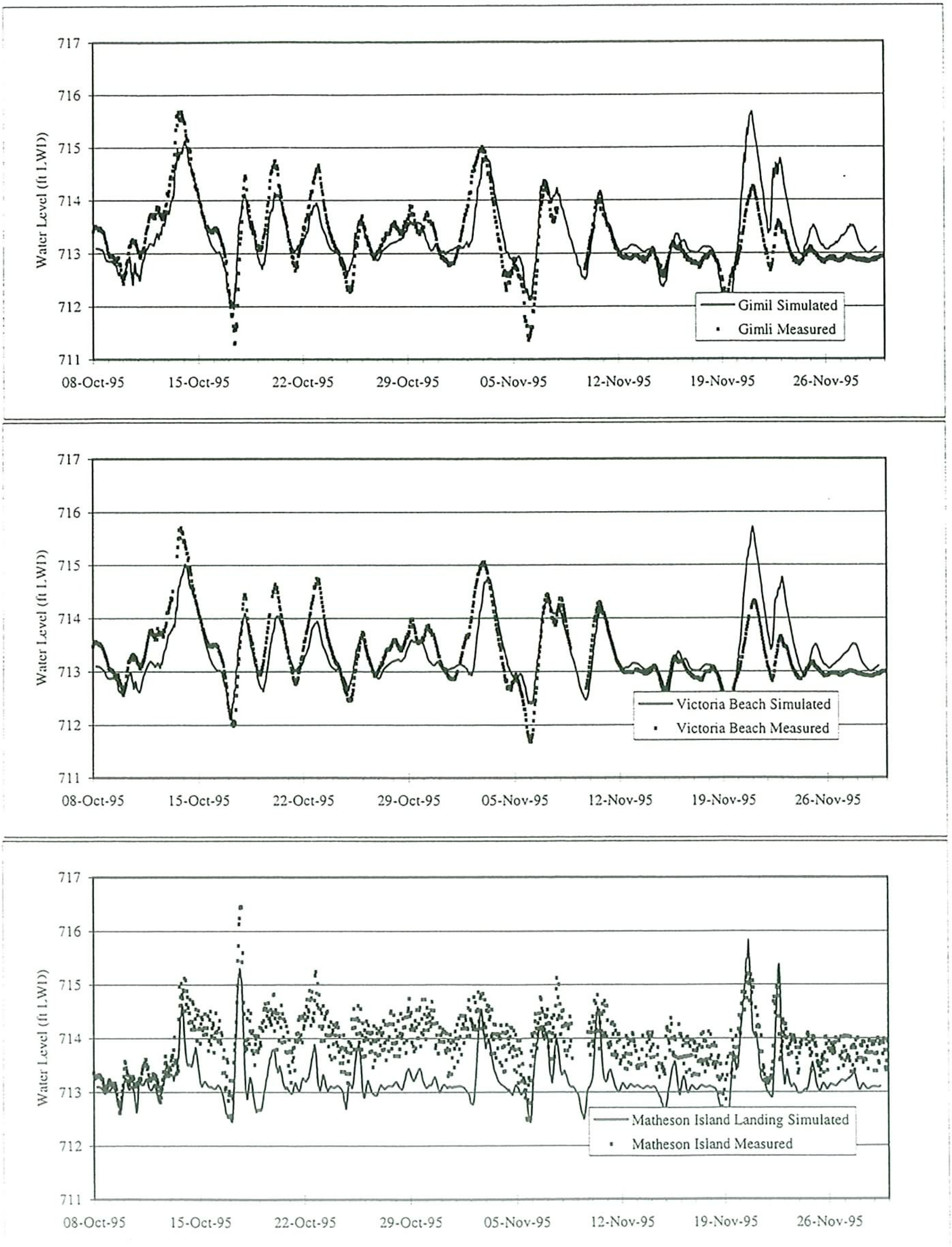


Comparison of Measured and Simulated Water Level - High Friction

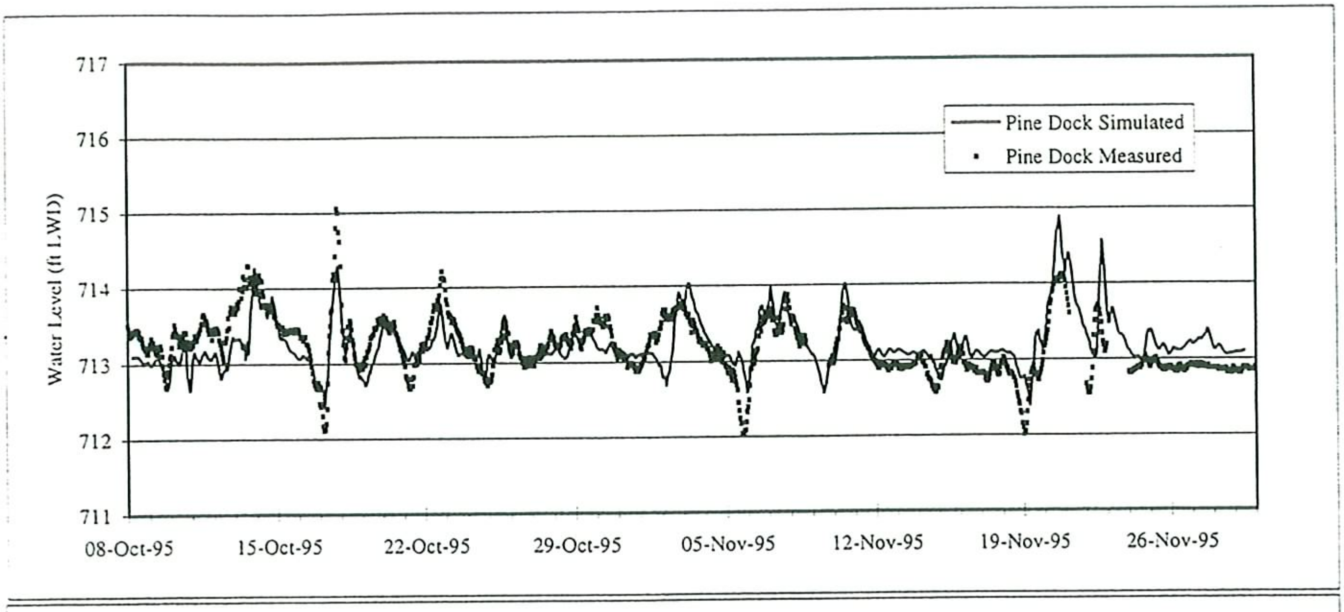
Figure 4.3

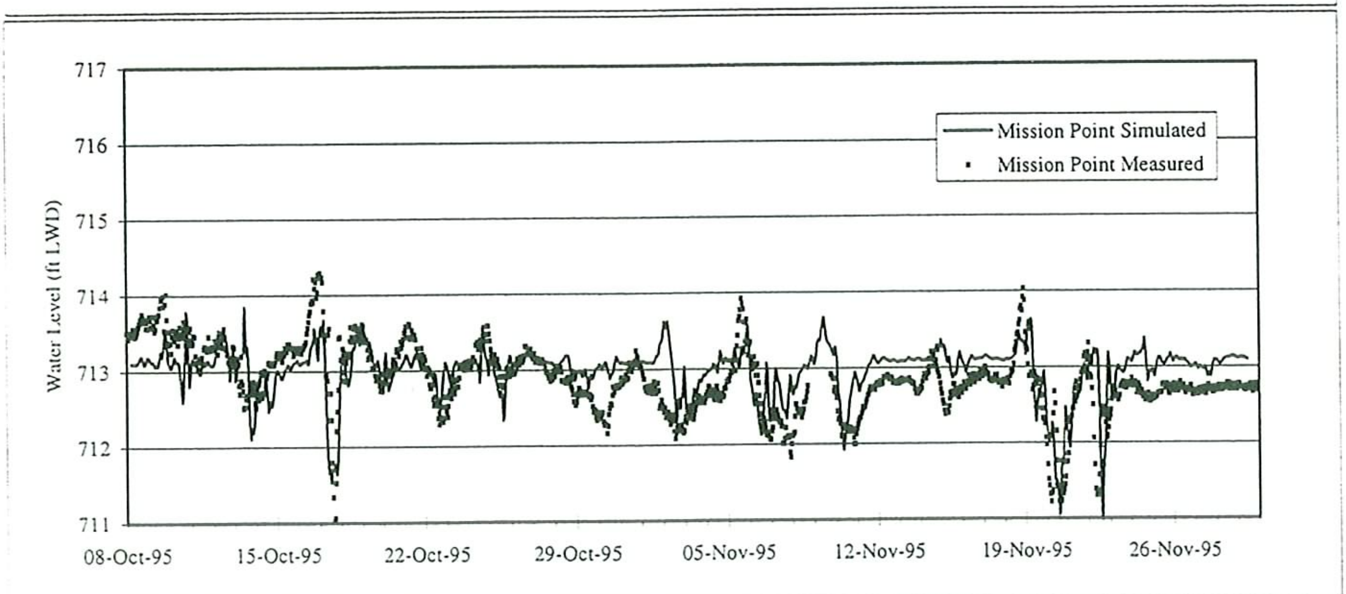


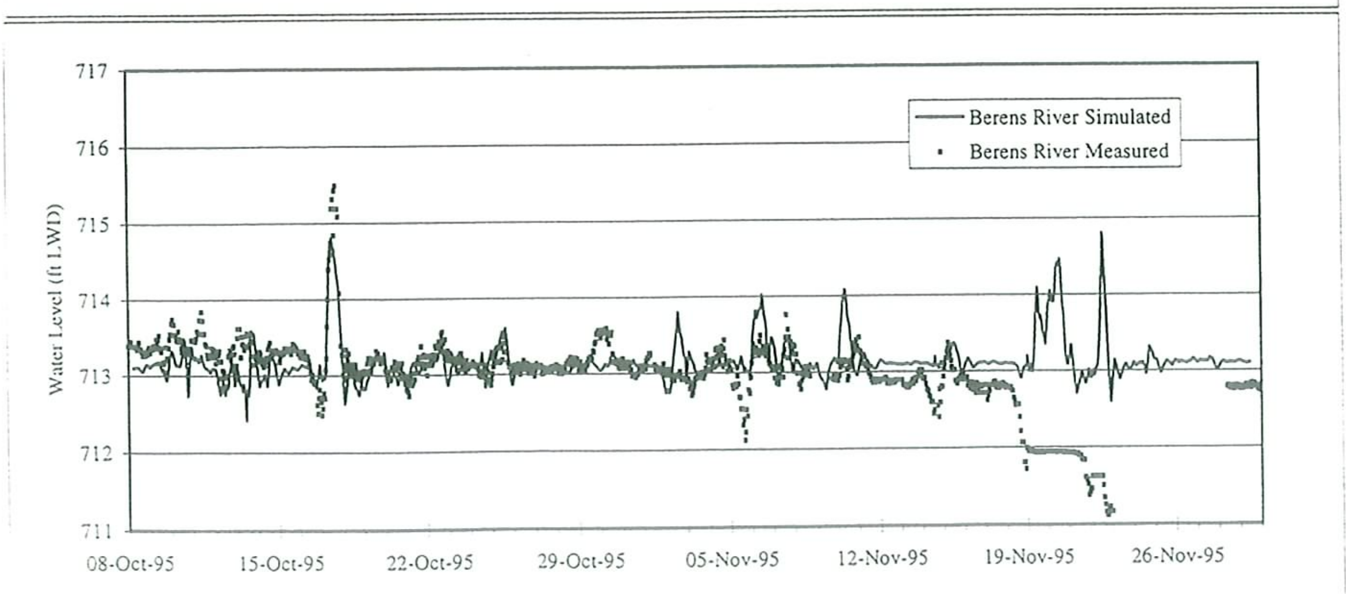
Comparison of Measured and Simulated Water Level - Low Friction Figure 4.4



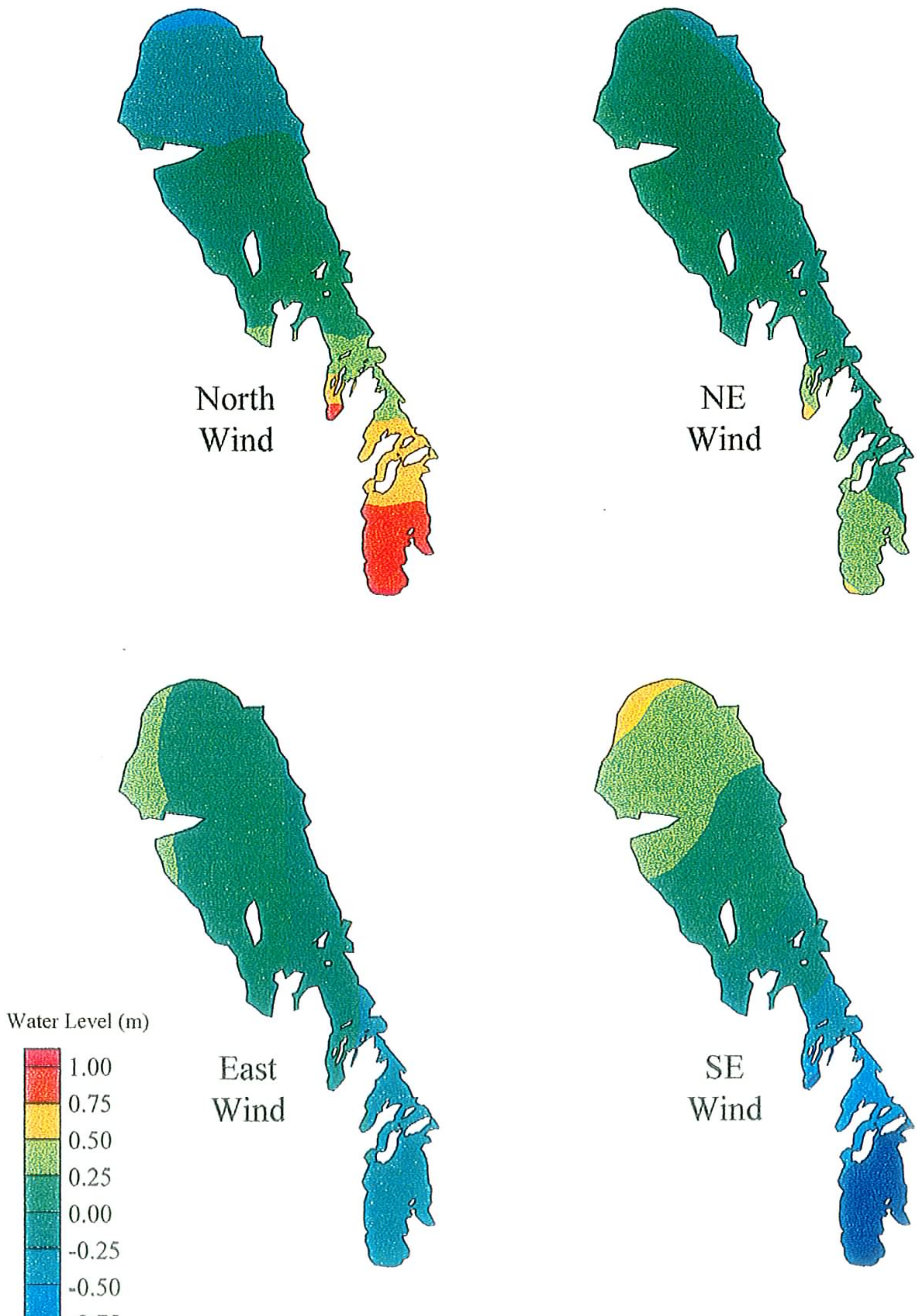
Comparison of Measured and Simulated Water Level - Fall 1995 Figure 4.5a





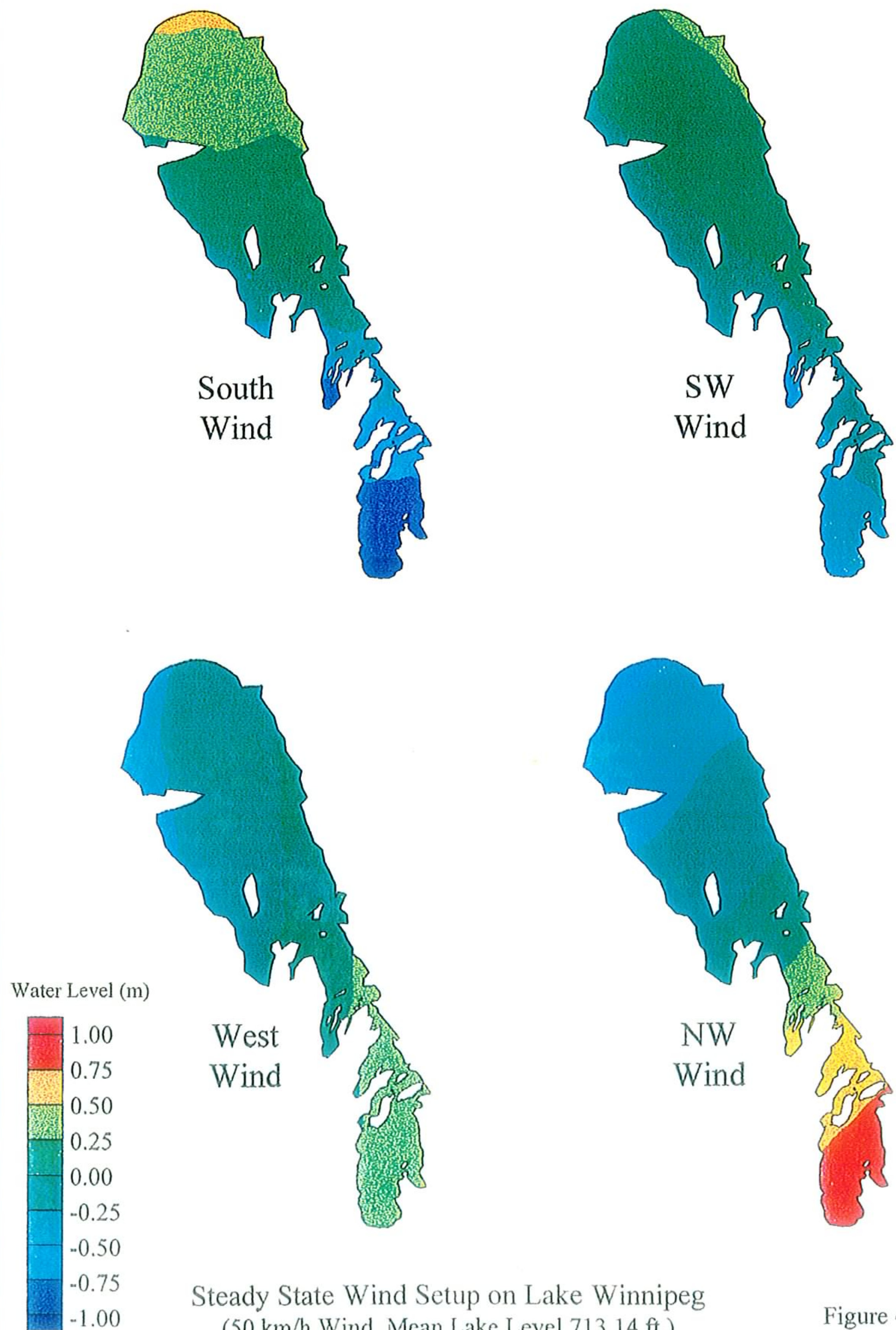


Comparison of Measured and Simulated Water Level - Fall 1995 Figure 4.5b



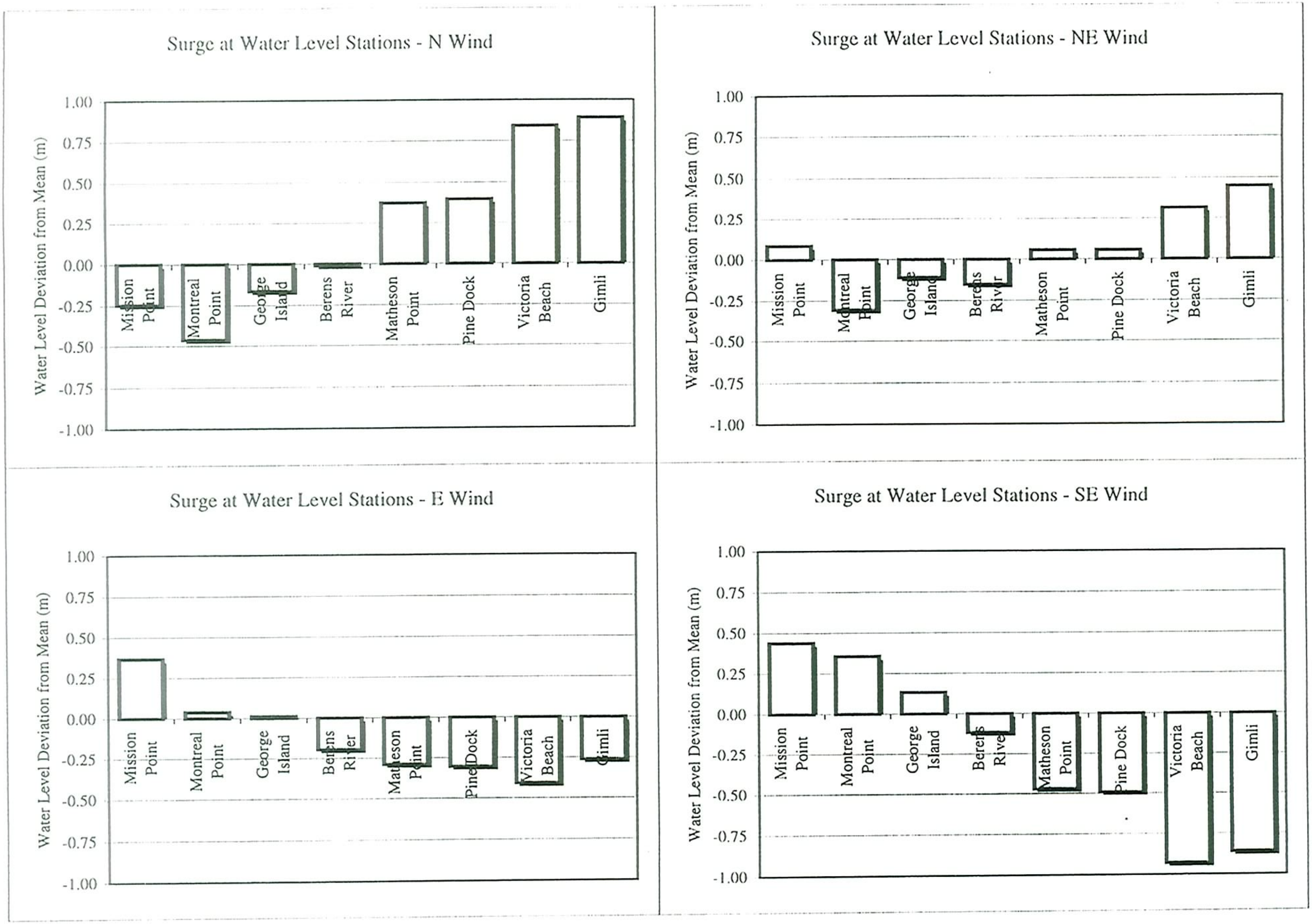
Steady State Wind Setup on Lake Winnipeg
(50 km/h Wind , Mean Lake Level 713.14 ft.)

Figure 4.6a



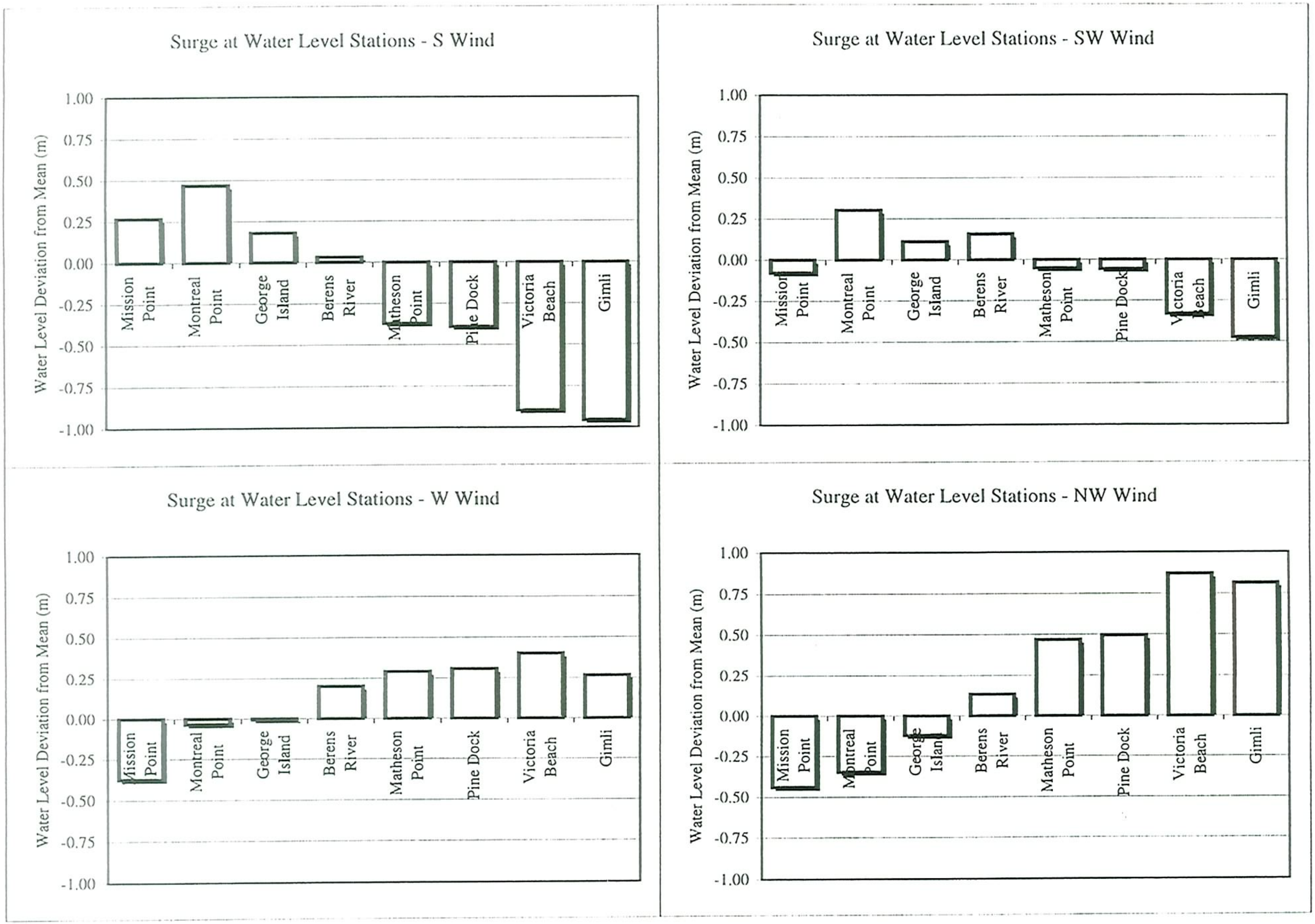
Steady State Wind Setup on Lake Winnipeg
(50 km/h Wind, Mean Lake Level 713.14 ft.)

Figure 4.6b



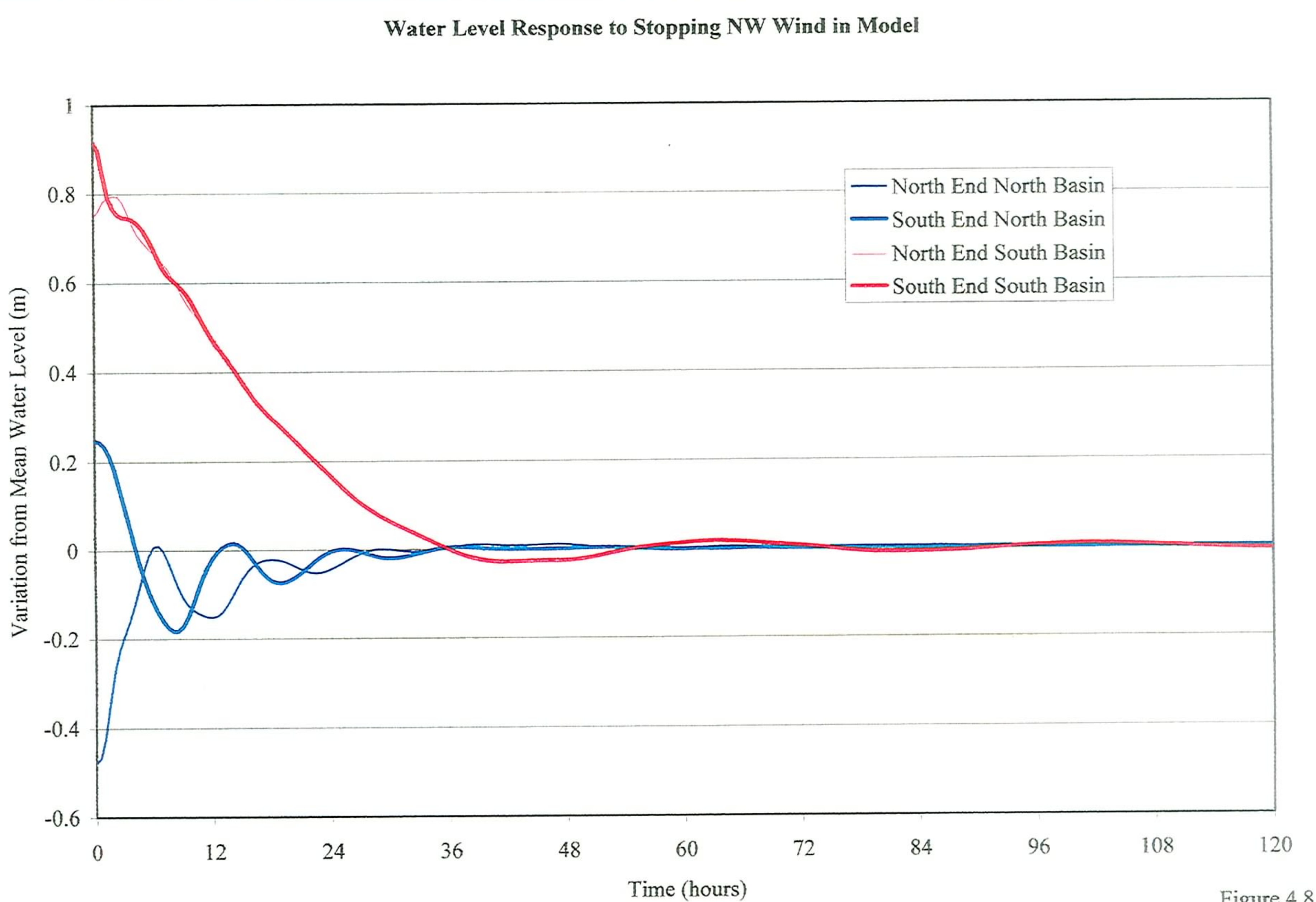
Water Level at Gauge Locations for Different Wind Directions

Figure 4.7a



Water Level at Gauge Locations for Different Wind Directions

Figure 4.7b



Water Level Response to Stopping NW Wind in Model
North End North Basin
South End North Basin
North End South Basin
South End South Basin
Variation from Mean Water Level (m)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0
12
24
36
48
60
72
84
96
108
120
Time (hours)

Figure 4.8

5.0 ESTIMATION OF A WIND ELIMINATED WATER LEVEL

5.1 Working Data

In order to assess the performance of various methods for computing the wind eliminated water level, numerical model simulations of Lake Winnipeg hydraulics were carried out for two different historical time periods: the fall of 1995 and the fall of 1996. Data from the eight gauges are presented in Figures 5.1, 5.2 and 5.3 for 1995, 1996 and 1997, respectively. Recorded data were not used for making this assessment due to the difficulty in determining what the correct wind eliminated water level should be.

The data from 1995 and 1996 are used for detailed analyses in this chapter, while the 1997 data is presented further in Appendix C.

5.2 Manitoba Hydro's Technique

Manitoba Hydro's method for determining the "wind eliminated water level" starts with the calculation of the weighted average of daily average water level values from eight stations (or however many are available) around the lake. The weighting procedure is based on the standard deviation (or the "noise") in the water level reading from each station based on historical data. It is the reciprocal of the station's noise that is used as the weighting factor for the computation.

After computing the daily average water level for the lake, a process is used which limits the amount which the level may vary from the previous day to 18.2 mm (0.06 ft). The resulting values are referred to as the Rate Of Change Limited Elevation or ROCLE. This eliminates some of the large peaks in the data as may be seen in Figure 5.4; however, the resulting line is still far from a smooth line. A two mode filter is then applied to the data depending on the trend in the data, as follows:

- If, over a three day period, the water level is unchanged, increasing each day, or decreasing each day, the ROLCE value is used for the middle of the three days.
- If the middle of the three day period is higher or lower than both of its neighbors, a five day central average is applied.

This averaging filter is applied five times in order to smooth the water level to the desired level. The result of this is that there is a 10 day period at the start and end of the record for which the wind eliminated water level may not be computed. This value is referred to as the wind eliminated water level, and is shown in Figure 5.5

5.3 Application of Manitoba Hydro's Technique to Model Data

As outlined in Section 4, the numerical model of wind setup and seiching on Lake Winnipeg provides an excellent manner in which to assess the accuracy of the wind eliminated water level calculation due to the controlled environment of the model.

A series of steady state wind simulations were carried out, as described in Section 4.6, for eight compass points. For each simulation, the wind eliminated water level was determined based on Hydro's technique, treating the water level at each gauge as if it were the daily average. The results of these analyses are displayed in Figure 5.6, which shows that the wind eliminated water level on a particular day may be biased by in the order of 15 cm in either direction for a steady wind at 50 km/h. This figure clearly illustrates that although Hydro's technique uses a weighted average, the weighting is biased as a result of the gauges position on the lake. Fewer gauges per surface area of water at the north end of the lake results in an average value that is too low for SE winds, and too high for NW winds.

Hydro's technique was then applied to the data produced from the long duration simulations in the fall of 1995 and 1996. The model simulations included wind stresses, but did not include any inflows, outflows, precipitation or evaporation. As a result, the total volume of water in the lake, and the wind eliminated water level did not change during the simulation. The results of these simulations are displayed in Figures 5.5, 5.7 and 5.8, which show the weighted average, the rate of change limited elevation, and the smoothed line after five smoothing passes for 1995, 1996 and 1997 respectively. Table 5.1 presents statistics for the lines in Figures 5.5 and 5.7.

Table 5.1
Wind Eliminated Water Level Calculation Performance Statistics – Hydro's Technique
[Difference from the static water level in model]

	Weight Average		ROCLE		5 Smoothing Passes	
Fall of Year	1995	1996	1995	1996	1995	1996
Average (cm)	0.926	2.244	0.619	1.443	0.640	1.351
St. Dev. (cm)	0.019	0.040	0.011	0.020	0.005	0.009
Maximum (cm)	5.372	13.909	3.172	6.223	1.409	2.820
Minimum (cm)	-2.329	-4.350	-1.099	-2.770	-0.024	-0.112

Note: Values closer to zero imply greater accuracy

Table 5.1 shows that the Manitoba Hydro technique deviated from the wind eliminated water level by 0.640 cm and 1.351 cm for the 1995 and 1996 simulations, respectively.

5.4 Limitations with Manitoba Hydro's Technique

While the Hydro technique provides reasonable estimates of the wind eliminated water level for a long period of record there are a number of shortcomings with the technique, as listed below.

5.4.1 Present Lake Levels

The technique used by Hydro relies on a series of smoothing passes to produce an estimate of the wind eliminated water level. These smoothing passes require a period of 21 days in total, 10 days previous to the day of interest, and 10 days following the day of interest. As a result, it is not possible to determine the wind eliminated water level for anything in the past 10 days unless the number of smoothing passes is reduced.

5.4.2 Non-physically Based Weighting Factors

The weighting factors used in Hydro's technique are based on the variation in the water levels from a historical set of data. While this method considers the variability of the stations and weights more heavily those with typically less fluctuation, it does not consider the spatial distribution of the gauges. For example, the south basin of Lake Winnipeg has a lower lake area per gauge value than the north basin.

5.4.3 Poor Response to Real Events

Hydro's technique uses two methods to produce a smooth line, both of which affect the ability of the value to respond to changes in the lake. The rate of change limited elevation line assumes that the maximum change in water level from one day to the next is limited to 18.2 mm (0.06 ft), while multiple smoothing passes are also used in order to produce a smooth line. The result of this is that a large rainfall event of about 20 mm or more would be poorly represented since they would be truncated by the ROCLE process (although rainfall events over the entire lake of this magnitude are not too common). Additionally, large rainfall events would tend to get blurred over a period of many days as the multiple smoothing processes were applied. Prior to application of the ROCLE process and the smoothing, the average lake level prior to the smoothing would display this change in elevation. However this change in elevation would be difficult to detect since it is very common that rain events are accompanied by wind that would complicate the gauge readings.

5.4.4 *Effect of Multiple Events*

One disadvantage of using a long smoothing window or multiple smoothing passes is that when there are multiple events that are a few days apart, the two events may combine to create an apparent small but long duration increase in the water level. An example of this "hump" may be seen in Figure 5.5

5.5 Weighted Average Using Optimized Coefficients

In order to check the assumption that different weighting factors would provide better weighted average values, a simple test was carried out in which the weighting factor for Mission Point was doubled since this gauge is in a region of the lake with a large expanse of water and relatively fewer gauges. The result of this was that the standard deviation of the weighted average water level was reduced by an average of 42 per cent and 45 per cent for the 1995 and 1996 examples respectively. Following this, investigations were carried out to determine optimum weighting values for the gauges on Lake Winnipeg.

The gauge values from the steady state wind simulations were used as input to a FORTRAN program that computed the weighted average water level for each simulated wind direction. Weighting factors from 1 to 10 were applied for each of the eight stations, and all one hundred million (10^8) combinations of these weighting factors were assessed. The weighting factors that produced the lowest average error for all wind directions were selected, and applied to the model time series data as described in Section 5.1. The results of this analysis are presented in Figures 5.9, 5.10 and 5.11, and Table 5.2.

Table 5.2
Comparison of Hydro's Technique and Optimized Weights Technique
[Difference from the static water level in model]

	Optimized Weighted Average		Hydro's Weighted Average		Hydro's Technique 5 Smoothing Passes	
Fall of Year	1995	1996	1995	1996	1995	1996
Average (cm)	-0.056	-0.125	0.926	2.244	0.640	1.351
St. Dev. (cm)	0.009	0.013	0.019	0.040	0.005	0.009
Maximum (cm)	1.082	1.861	5.372	13.909	1.409	2.820
Minimum (cm)	-2.984	-5.849	-2.329	-4.350	-0.024	-0.112

Note: Values closer to zero imply greater accuracy

As may be seen from this table and figure, maximum and minimum values are generally best for the optimized method, except for a few single day events. The average water level for the entire period is best from the optimized weights method, while Hydro's average and smoothed values are much less accurate. The standard deviation indicates the amount of "noise" in the line, with the optimized weights method being only slightly noisier than the 20 day average from Hydro.

Clearly, the optimized weights method provides a better estimate of the wind eliminated water level, and does so for an individual day rather than after a series of smoothing passes. It is likely that an un-smoothed optimized weights method, with a knowledge of recent wind conditions, would be a superior method for calculating the wind eliminated water level for operational decisions.

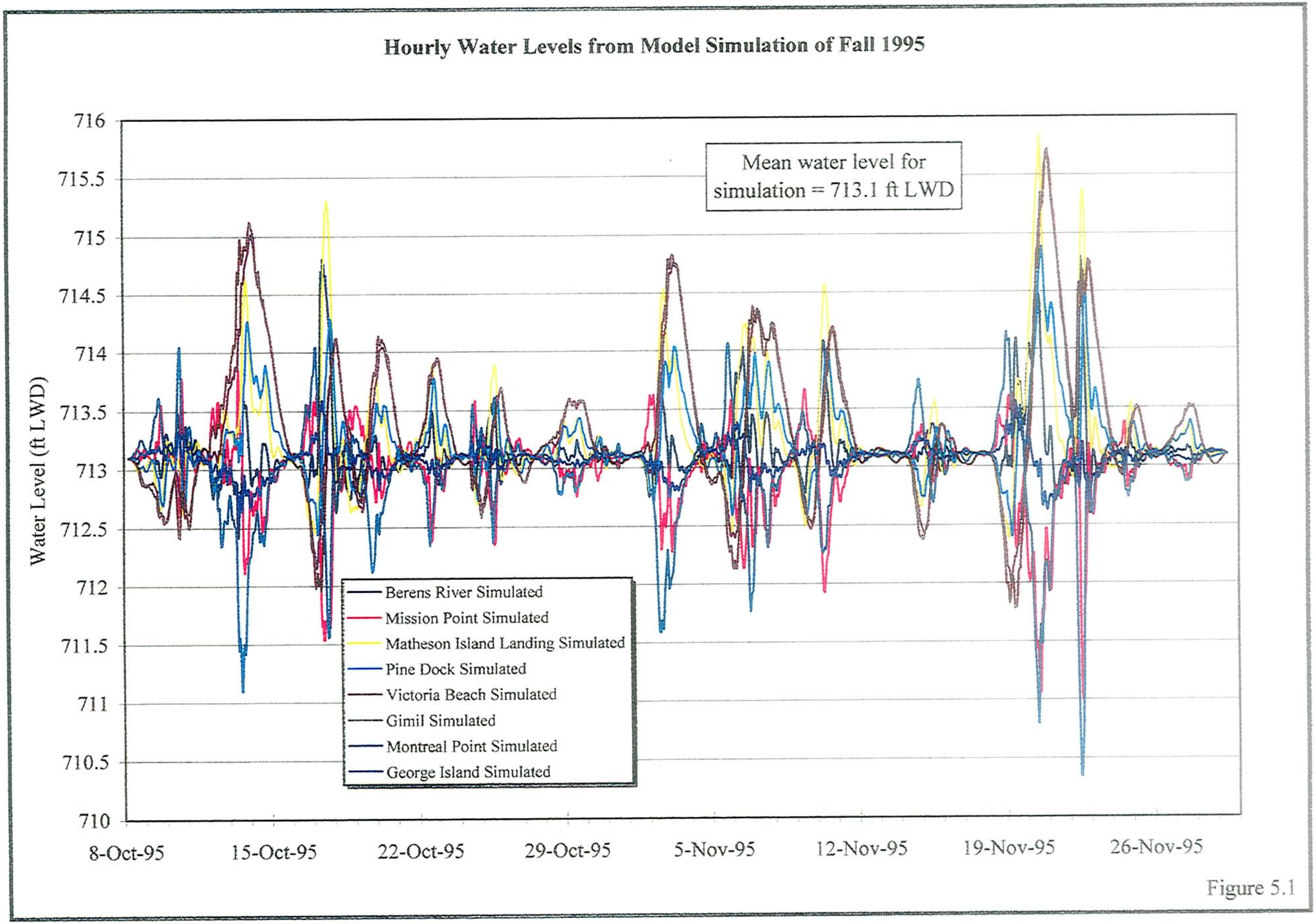

Hourly Water Levels from Model Simulation of Fall 1995
Mean water level for simulation = 713.1 ft LWD
Water Level (ft LWD)
716
715.5
715
714.5
714
713.5
713
712.5
712
711.5
711
710.5
710
8-Oct-95
15-Oct-95
22-Oct-95
29-Oct-95
5-Nov-95
12-Nov-95
19-Nov-95
26-Nov-95
Berens River Simulated
Mission Point Simulated
Matheson Island Landing Simulated
Pine Dock Simulated
Victoria Beach Simulated
Gimil Simulated
Montreal Point Simulated
George Island Simulated

Figure 5.1

Hourly Water Levels from Model Simulation of Fall 1996

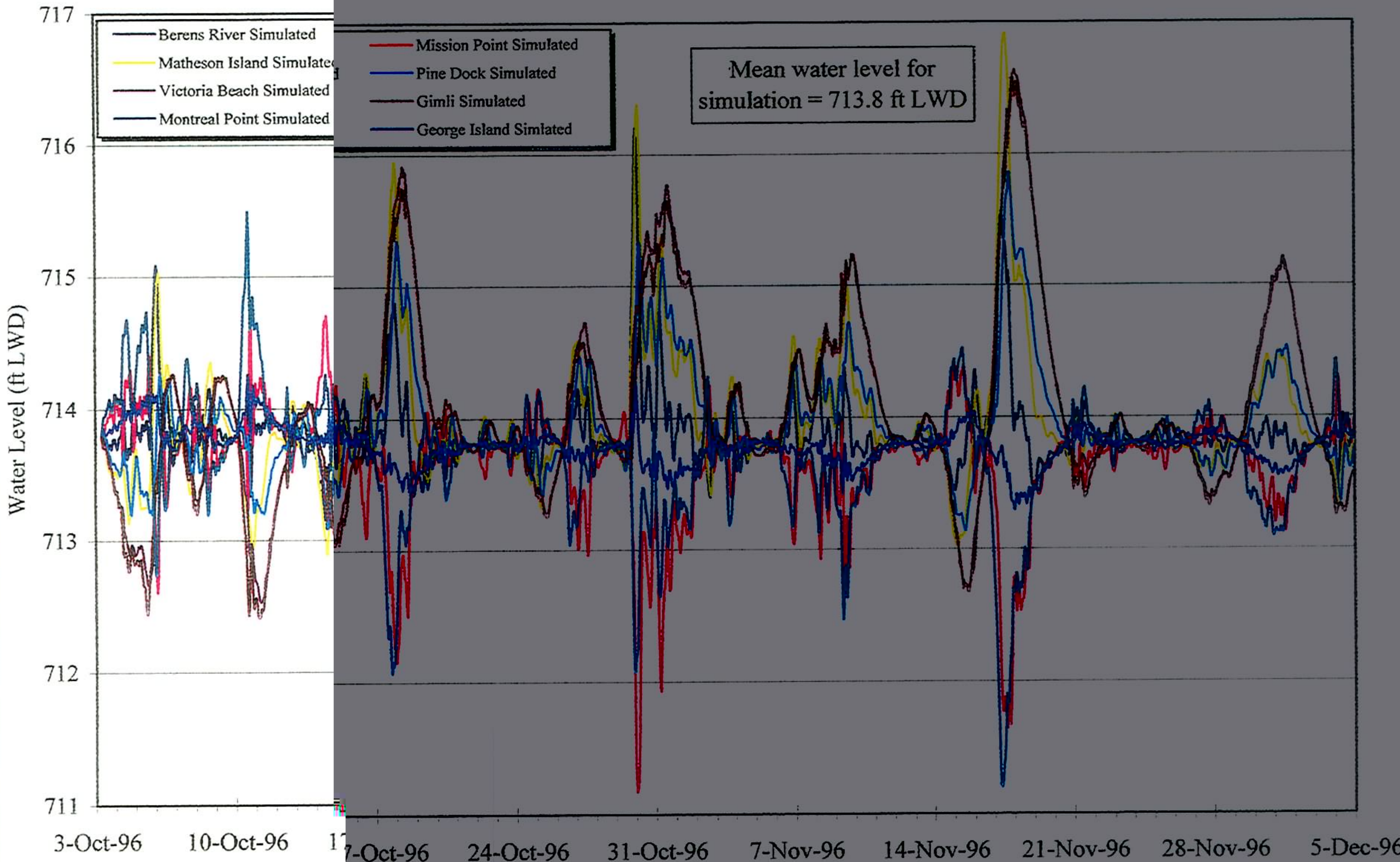
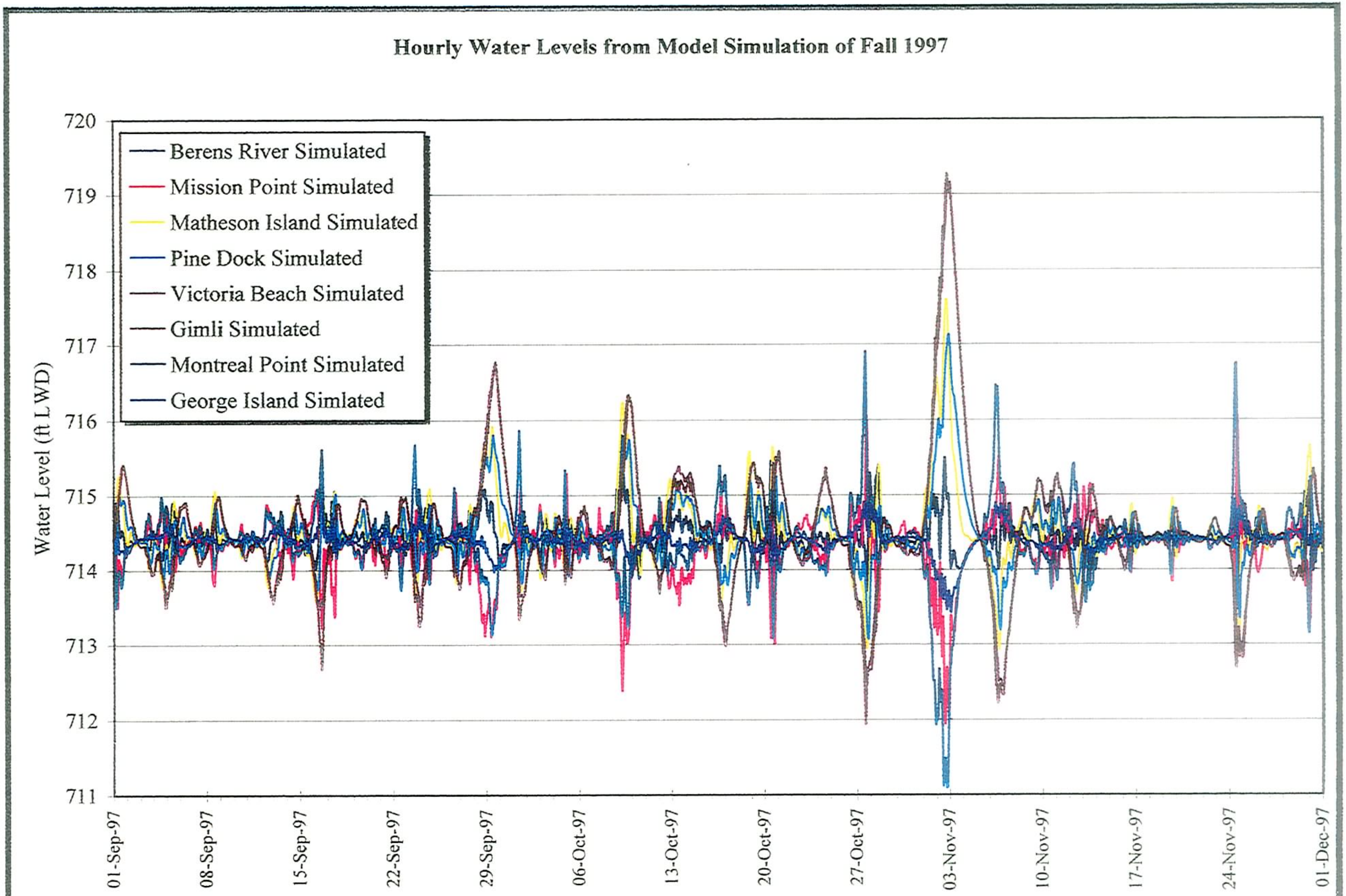
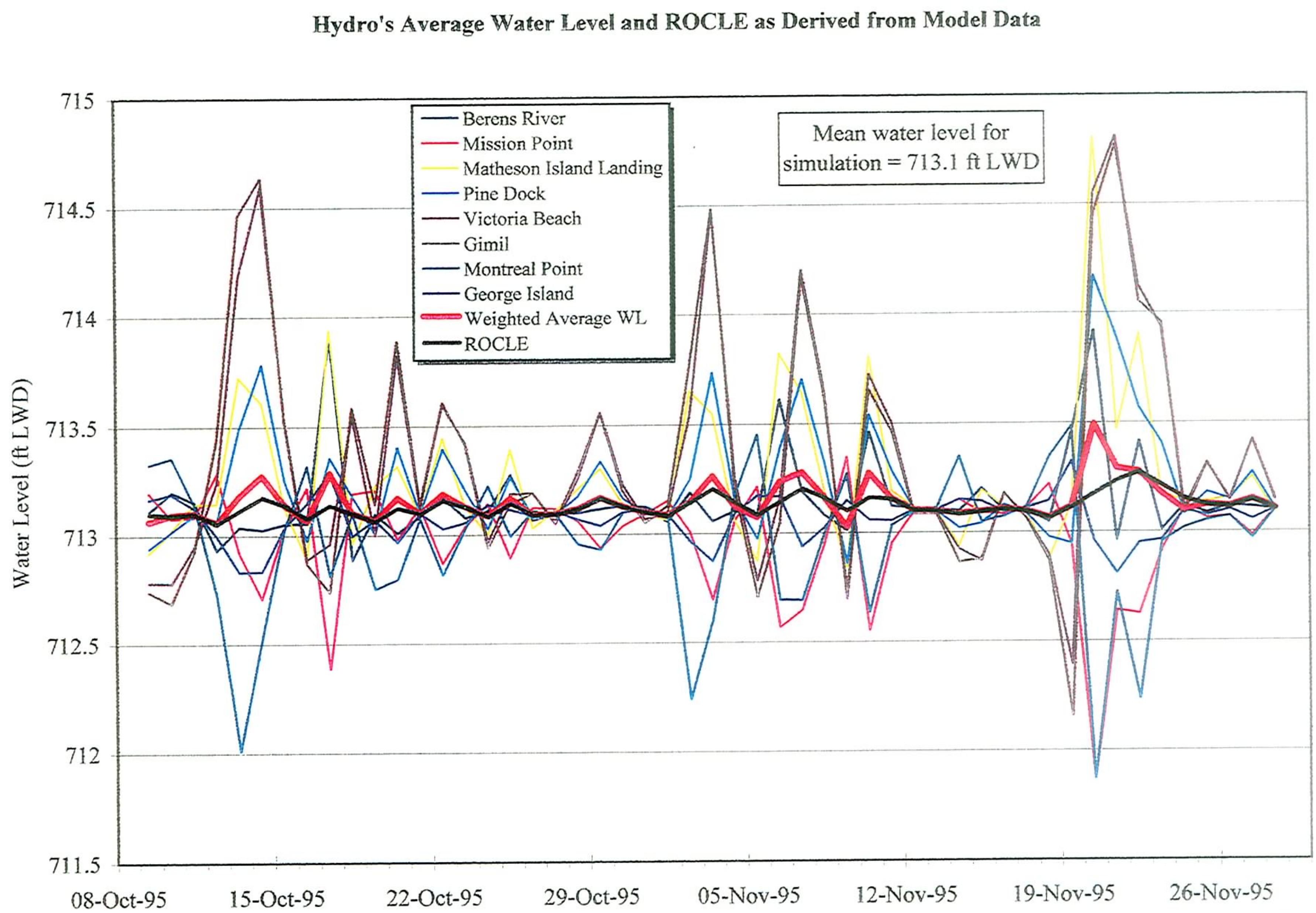


Figure 5.2



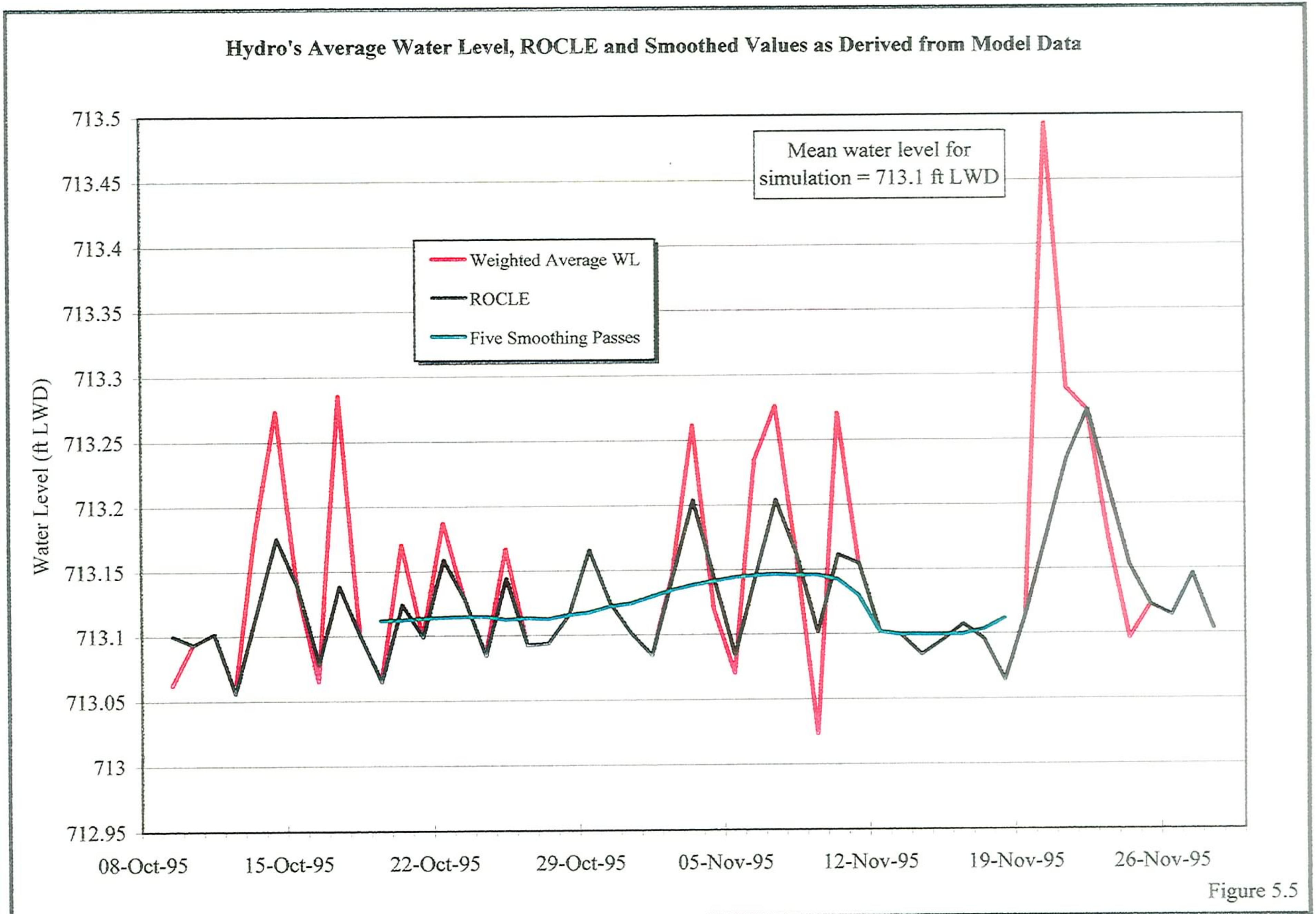
Hourly Water Levels from Model Simulation of Fall 1997
720
719
718
717
716
715
714
713
712
711
Water Level (ft L WD)
Berens River Simulated
Mission Point Simulated
Matheson Island Simulated
Pine Dock Simulated
Victoria Beach Simulated
Gimli Simulated
Montreal Point Simulated
George Island Simlated
01-Sep-97
08-Sep-97
15-Sep-97
22-Sep-97
29-Sep-97
06-Oct-97
13-Oct-97
20-Oct-97
27-Oct-97
03-Nov-97
10-Nov-97
17-Nov-97
24-Nov-97
01-Dec-97

Figure 5.3



Hydro's Average Water Level and ROCLE as Derived from Model Data
Berens River
Mission Point
Matheson Island Landing
Pine Dock
Victoria Beach
Gimil
Montreal Point
George Island
Weighted Average WL
ROCLE
Mean water level for simulation = 713.1 ft LWD
Water Level (ft LWD)
715
714.5
714
713.5
713
712.5
712
711.5
08-Oct-95
15-Oct-95
22-Oct-95
29-Oct-95
05-Nov-95
12-Nov-95
19-Nov-95
26-Nov-95

Figure 5.4



Hydro's Average Water Level, ROCLE and Smoothed Values as Derived from Model Data
Mean water level for simulation = 713.1 ft LWD
Weighted Average WL
ROCLE
Five Smoothing Passes
Water Level (ft LWD)
713.5
713.45
713.4
713.35
713.3
713.25
713.2
713.15
713.1
713.05
713
712.95
08-Oct-95
15-Oct-95
22-Oct-95
29-Oct-95
05-Nov-95
12-Nov-95
19-Nov-95
26-Nov-95

Figure 5.5

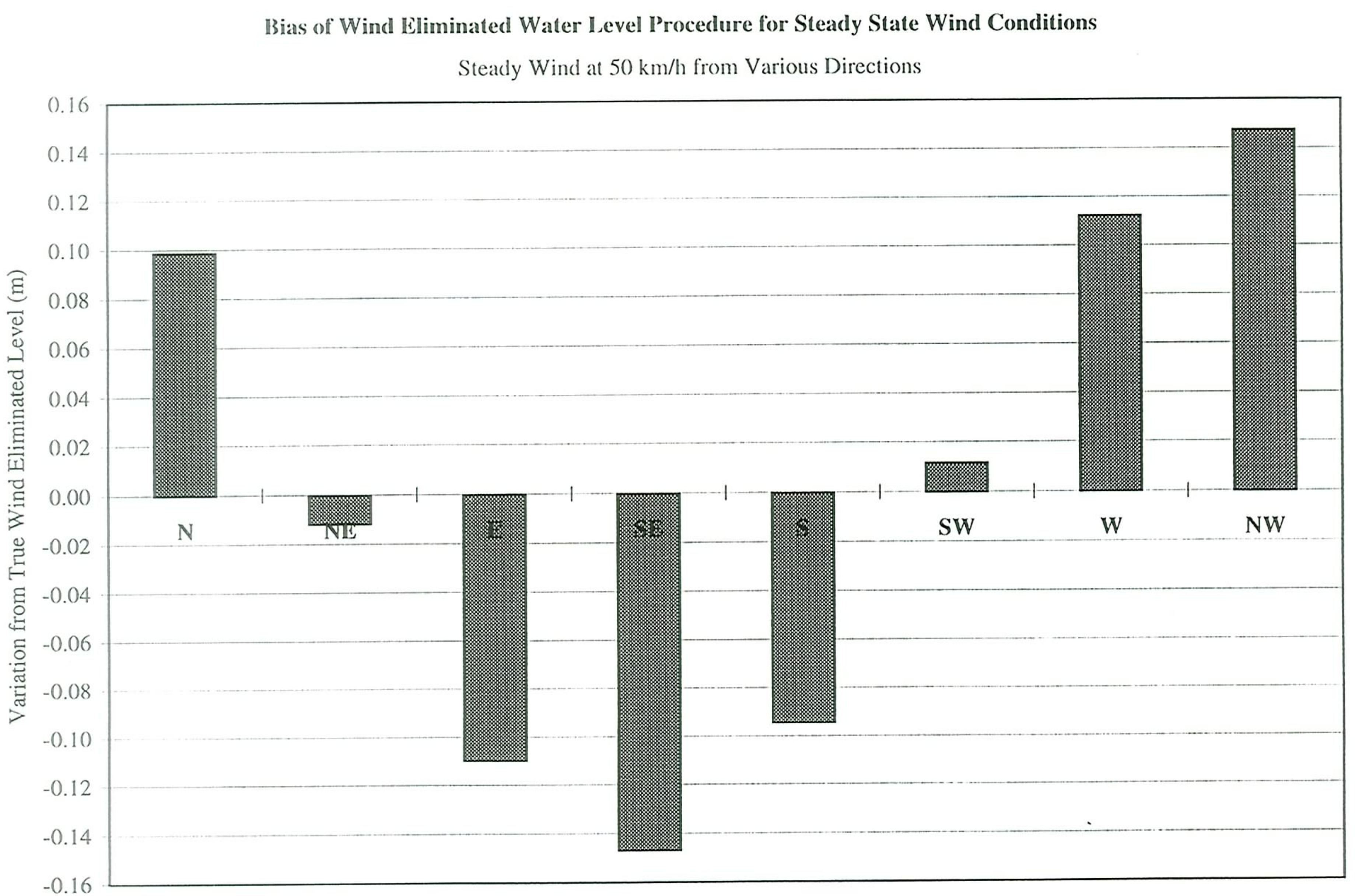
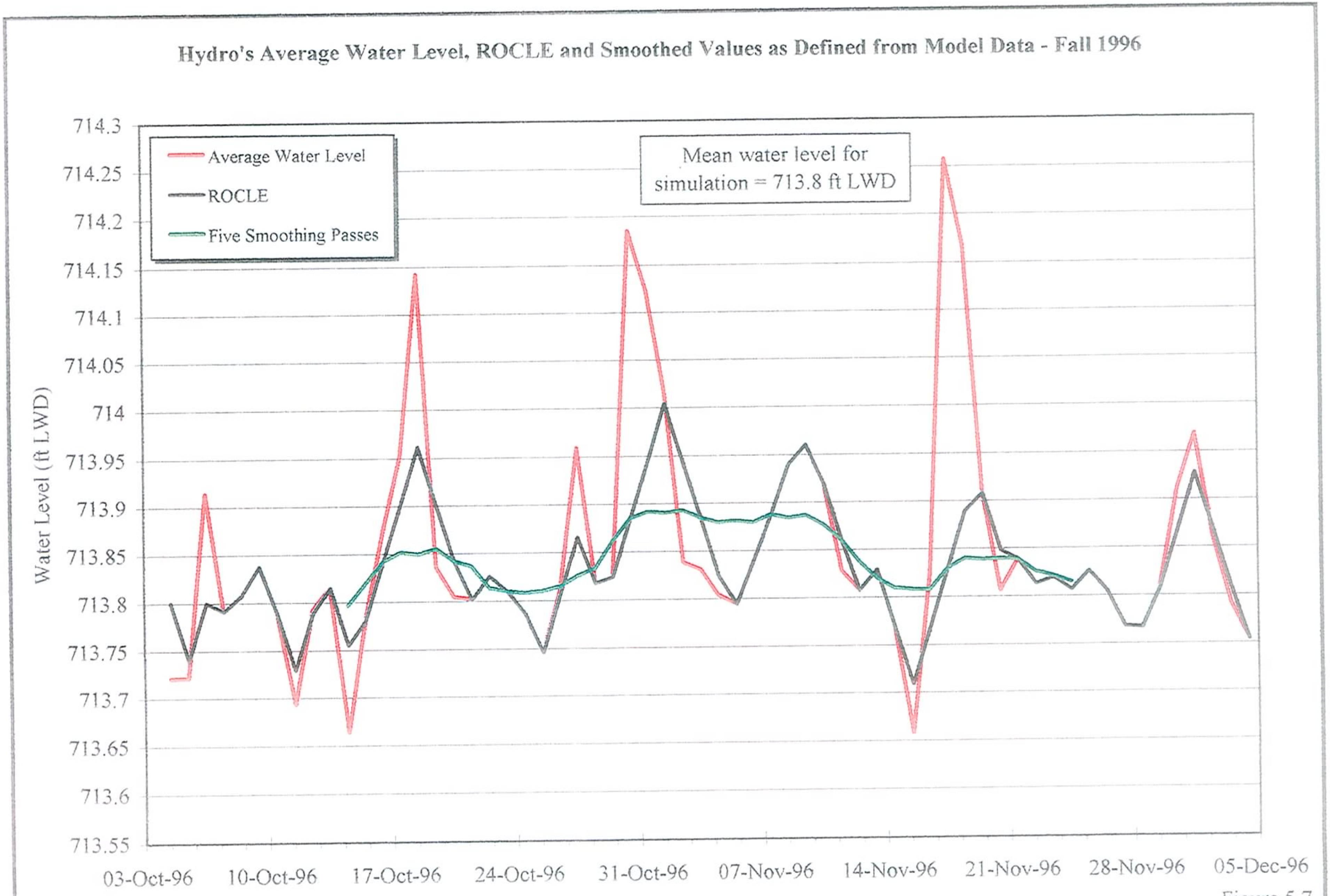

Bias of Wind Eliminated Water Level Procedure for Steady State Wind Conditions
Steady Wind at 50 km/h from Various Directions
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
-0.10
-0.12
-0.14
-0.16
Variation from True Wind Eliminated Level (m)
N
NE
E
SE
S
SW
W
NW

Figure 5.6



Hydro's Average Water Level, ROCLE and Smoothed Values as Defined from Model Data - Fall 1996
Average Water Level
ROCLE
Five Smoothing Passes
Mean water level for simulation = 713.8 ft LWD
Water Level (ft LWD)
714.3
714.25
714.2
714.15
714.1
714.05
714
713.95
713.9
713.85
713.8
713.75
713.7
713.65
713.6
713.55
03-Oct-96
10-Oct-96
17-Oct-96
24-Oct-96
31-Oct-96
07-Nov-96
14-Nov-96
21-Nov-96
28-Nov-96
05-Dec-96

Figure 5.7

Hydro's Average Water Level, ROCLE and Smoothed Values as Derived from Model Data

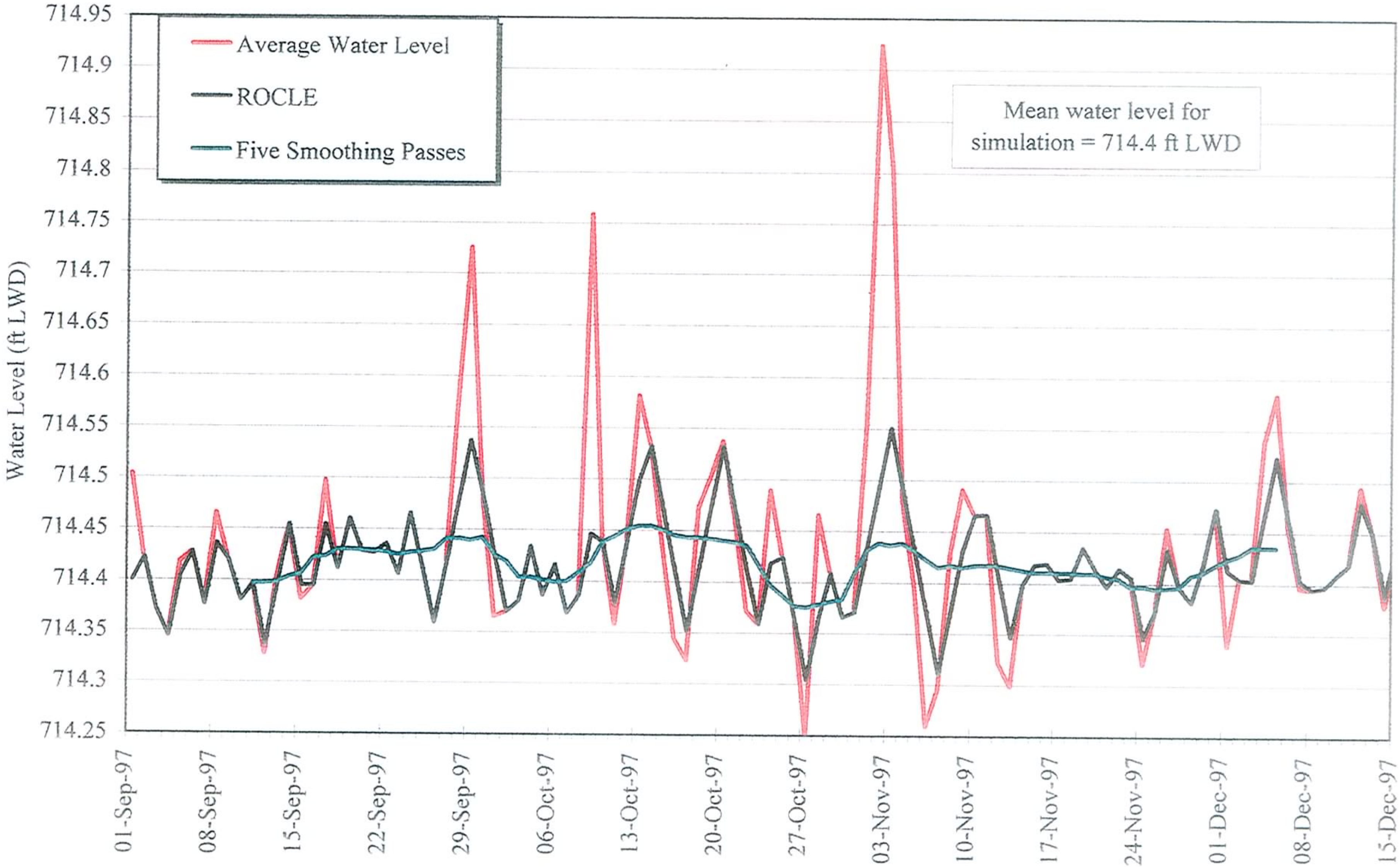
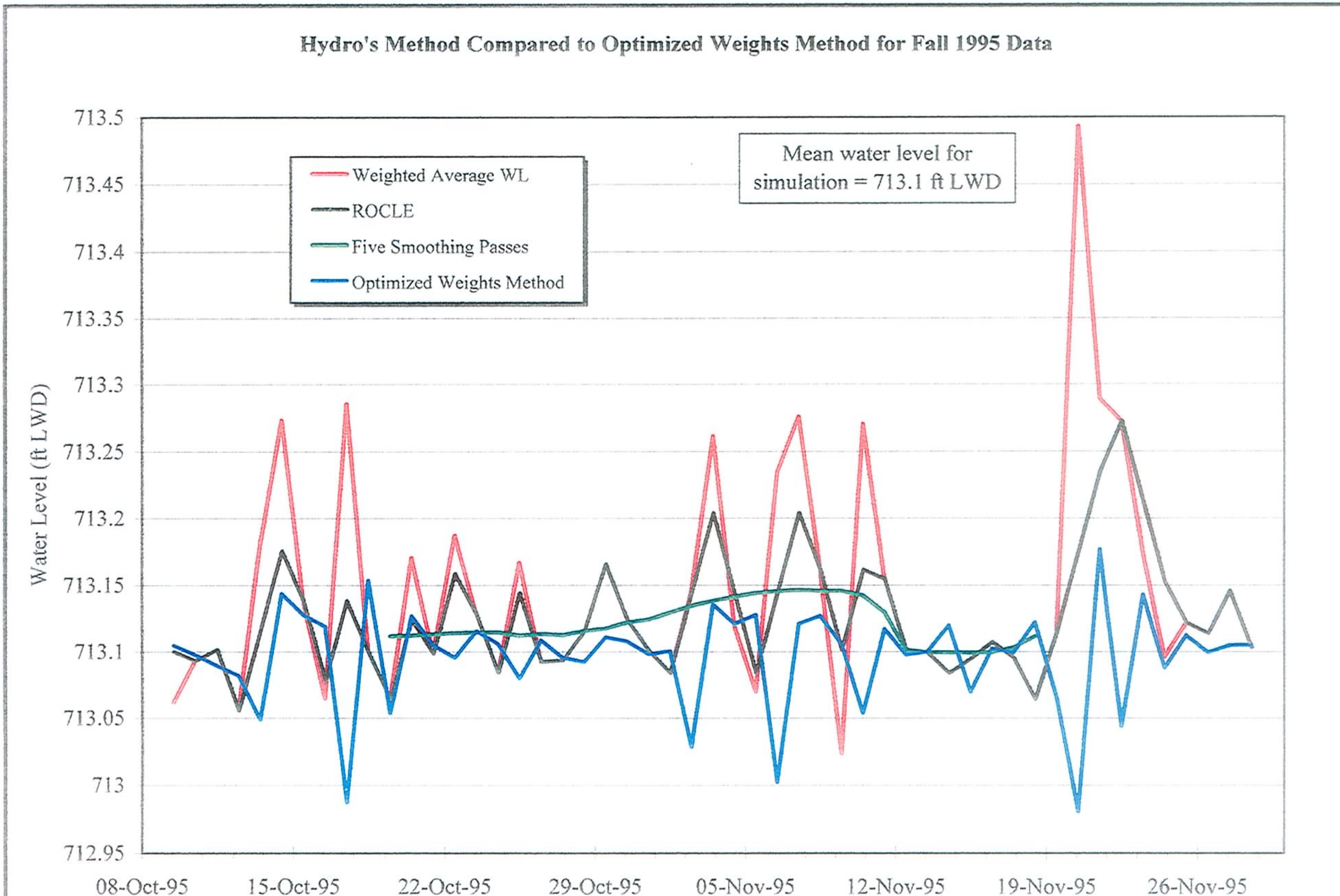
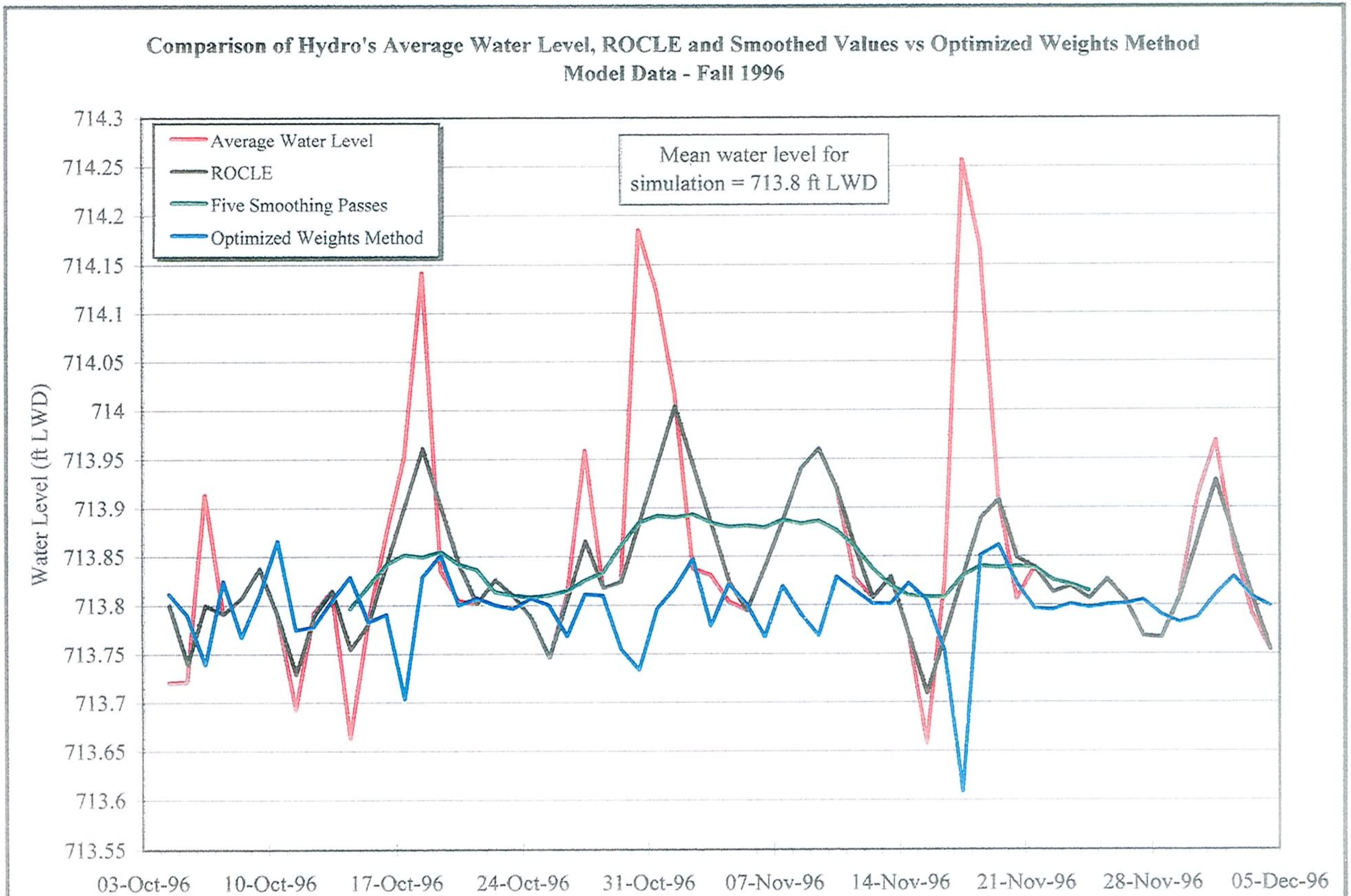


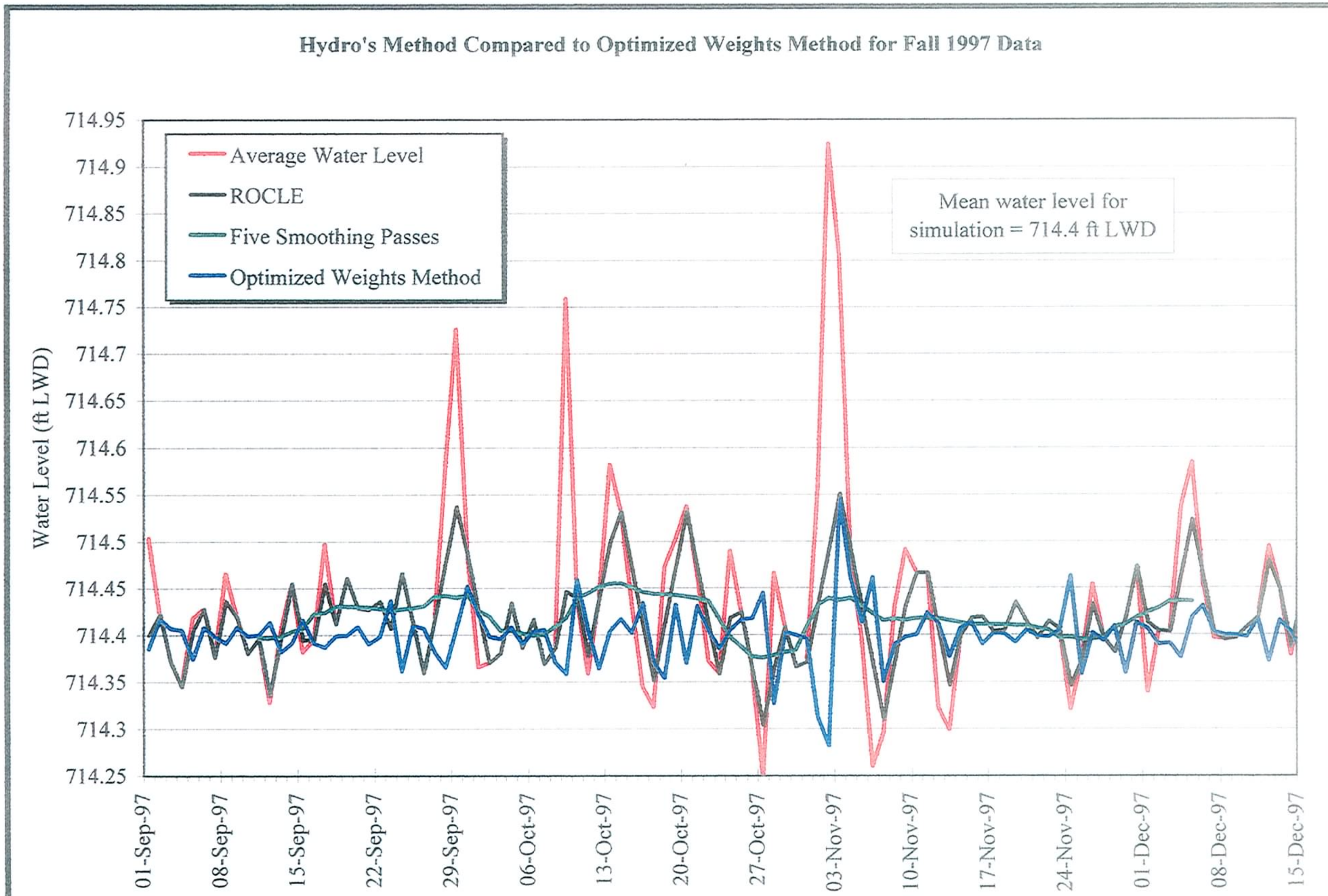
Figure 5.8



Hydro's Method Compared to Optimized Weights Method for Fall 1995 Data
Weighted Average WL
ROCLE
Five Smoothing Passes
Optimized Weights Method
Mean water level for simulation = 713.1 ft LWD
Water Level (ft LWD)
713.5
713.45
713.4
713.35
713.3
713.25
713.2
713.15
713.1
713.05
713
712.95
08-Oct-95
15-Oct-95
22-Oct-95
29-Oct-95
05-Nov-95
12-Nov-95
19-Nov-95
26-Nov-95

Figure 5.9


Comparison of Hydro's Average Water Level, ROCLE and Smoothed Values vs Optimized Weights Method
Model Data - Fall 1996
Average Water Level
ROCLE
Five Smoothing Passes
Optimized Weights Method
Mean water level for simulation = 713.8 ft LWD
Water Level (ft LWD)
714.3
714.25
714.2
714.15
714.1
714.05
714
713.95
713.9
713.85
713.8
713.75
713.7
713.65
713.6
713.55
03-Oct-96
10-Oct-96
17-Oct-96
24-Oct-96
31-Oct-96
07-Nov-96
14-Nov-96
21-Nov-96
28-Nov-96
05-Dec-96
Figure 5.10



Hydro's Method Compared to Optimized Weights Method for Fall 1997 Data
Average Water Level
ROCLE
Five Smoothing Passes
Optimized Weights Method
Mean water level for simulation = 714.4 ft LWD
Water Level (ft LWD)
714.95
714.9
714.85
714.8
714.75
714.7
714.65
714.6
714.55
714.5
714.45
714.4
714.35
714.3
714.25
01-Sep-97
08-Sep-97
15-Sep-97
22-Sep-97
29-Sep-97
06-Oct-97
13-Oct-97
20-Oct-97
27-Oct-97
03-Nov-97
10-Nov-97
17-Nov-97
24-Nov-97
01-Dec-97
08-Dec-97
15-Dec-97

Figure 5.11

6.0 DISCUSSION

6.1 Other Regulated Waterbodies - Lake Ontario Procedures

Lake Ontario is a similar lake to Lake Winnipeg in that the lake is regulated at its outflow. Water levels on Lake Ontario are less affected by wind stress, and thus a straight average of six gauges is used to determine the water level on the lake.

The International Joint Commission (IJC) developed criteria for Lake Ontario water level regulation, and developed a plan for operation of the St. Lawrence River control structures. This plan may be simply described as a series of stage-discharge relationships for different times of the year.

One requirement in the IJC's criteria was to regulate Lake Ontario within a target range from 74.2 to 75.4 metres (243.3 to 247.3 feet) above sea level. The project must also be operated to provide no less protection for navigation and shoreline interests downstream than would exist without the project. Another provision, known as criterion (k), was included because water supplies would inevitably be more extreme at some time in the future than in the past (1860-1954). When supplies exceed those of the past, shoreline property owners upstream and downstream are to be given all possible relief. When water supplies are less than those of the past, all possible relief is to be provided to navigation and power interests.

Water level policy and general targets are determined by the International St. Lawrence River Board of Control (the Board). The Board meets at least twice a year and provides semi-annual reports to the Commission, and holds meetings with the public annually. The Board may deviate from planned flows under emergency conditions or winter operations. It may also use its limited discretionary authority when a change from the planned flow can be made to provide benefits or relief to one or more interests without appreciably harming others, and without breaching the requirements of the order.

Carrying out the weekly regulation of the outflow is the Operations Advisory Group (OAG) who are responsible to the Board. The OAG consists of Ontario Hydro, Hydro Quebec, the New York Power Authority, the Canadian Coast Guard, and the Seaway Development Corporation, while members from the U.S. Army Corps of Engineers and Environment Canada are present for the meetings (typically a conference call) as regulatory representatives. There are other interests such as recreational boaters and environmental groups who are not part of the process, and are lobbying to be included in regulatory decisions.

Lake Ontario outflow strategy press releases are periodically published on the Board's web site (www.islrbc.org), in addition to the past week's water levels, and the past and predicted outflows.

6.2 Public Communication of Wind Eliminated Water Levels

The Manitoba Hydro web site (as it existed in October 1999) provides a plot of daily wind-eliminated water levels for the past year, lists monthly wind eliminated water levels for the past year, and gives a two month forecast of daily water levels. There are no explanations of the presented values, the wind eliminated calculation or the forecasting procedures.

The wind eliminated monthly mean data published on the Hydro web site was found to be representative of the conditions that were recorded on the lake by the WSC. The forecast values are provided in tabular form in feet, with two values after the decimal point. The format of the forecast values implies far more accuracy than is actually contained within the forecast. A better format for the predictions would be to provide a chart with the best prediction, and a confidence interval that indicates, for example, 95 per cent confidence levels.

There are a number of steps that Manitoba Hydro could undertake to better communicate the water level changes in Lake Winnipeg on their web site, such as:

- Discussion of wind eliminated water levels and forecasting procedures.

- Display recent daily water levels for various water level gauges around the lake. This would allow the public to be aware of differences in the water levels that occur around the lake. During periods of sustained N to NW winds, for example, the general public will encounter an increase in the water level if they are adjacent to the south basin. These surges, which may be significant in both height and duration, will cause water level readings in the area to be different from published forecast values.

- Charts illustrating the outflow from Lake Winnipeg. The chart could also display historical values such as the mean and extremes. Along with the outflow data, there could be a discussion of some of the various factors that must be considered when selecting an outflow rate from the lake.

6.3 Improvements to Wind Eliminated Water Level Calculation Procedure

The scheme that is currently used by Hydro to determine the weighted average water level for the lake is biased towards the water levels that are occurring at the south end of the lake. Some of this bias is removed in the ROCLE and smoothing process; however, a slight bias remains after these processes have been applied. The current procedure cannot produce a wind eliminated water level that is more recent than 10 days in the past.

One possibility for an improved procedure is to use the optimized weighting method that was discussed in this report. Further work would have to be done on this procedure to determine optimized weighting factors for situations where one or more gauges are not reporting. Some basic error checking would also have to be built into such a system so that erroneous data were not considered in the calculations.

6.4 Independent Monitoring and Verification

If the LWSEAG would like to have a more direct assessment of the wind eliminated water level on Lake Winnipeg, then a system may be developed that would allow the LWSEAG to monitor the gauges and calculate the wind eliminated water level independent of Hydro.

This may be achieved by accessing the same real time data that is accessed by Hydro from the WSC gauges through the Atmospheric Meteorological Information Service (AMIS). Data obtained from the AMIS system would be in raw format, and would require standard corrections to go from the datum of the gauge to Lake Winnipeg Datum. Error checking, and a procedure such as the optimized weighting method could then be used to determine the wind eliminated lake level.

An independent monitoring system would require development, in addition to annual data fees in the order of $2000 per year (based on very preliminary discussions with the Water Survey of Canada).

7.0 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations were developed from this study:

1. No significant irregularities were found in the reporting of water levels by Manitoba Hydro. Past wind eliminated water levels are approximately representative of the amount of water in the lake.

2. It was noted when comparing monthly water level data provided by the Water Survey of Canada that there were consistent differences between various stations during the months when Lake Winnipeg is covered with ice and subject to limited or no wind stress. The monthly water level at such times should provide a reasonable indication of the wind-eliminated water level in the lake. The largest difference occurred at the Victoria Beach station, which had an average water level that was approximately 5 cm higher than that measured at Berens River. It is recommended that the datum adjustments for the various water level stations be reviewed and, if necessary, a water level transfer of datum be performed and verified by means of level loops to the most accessible water level stations.

3. The water level stations are not situated in ideal locations for the computation of an average lake level. In particular, there are more stations on the east side of the lake as compared to the west, and the smaller water volume of the south basin is over-represented. However, despite the inequitable distribution of the water level stations, a wind-eliminated water level can be computed from the data provided by the existing stations using suitable weighting factors that vary from station to station. This is currently done in the Manitoba Hydro methodology.

4. There are limitations to the methodology used by Manitoba Hydro to compute the wind-eliminated water level on Lake Winnipeg. Specifically, the technique employed:

   - can only provide a wind-eliminated water level that is ten days old,
   - applies a weighting factor to the water levels measured at each station that is based on a statistical assessment and not on consideration of physical processes, and
   - shows a bias of a few centimetres in water level when there are two or more surge events that occur sequentially.

5. The method used to compute the wind eliminated water level is slightly biased towards the water levels in the south basin. These short periods of bias are typically smoothed out during the averaging process.

6. Due to the considerable data smoothing that is applied, the current methodology used by Manitoba Hydro can only compute the wind-eliminated water level that occurred ten days in the past. A more quantitative method for assessing near-present (day before) water level's on the lake could provide Hydro with a better value for making regulation decisions. This would require use of a different technique to compute wind eliminated water levels than that which is presently employed.

7. An improved procedure for developing the station weighting factors was briefly explored in this study through use of the numerical modelling results. This initial investigation provided better estimates of the wind-eliminated water levels than the current Manitoba Hydro procedure. This technique also provided an estimate of wind-eliminated water levels for the previous day rather than ten days in the past as with the existing Hydro procedures.

8. Manitoba Hydro could better communicate the issue of Lake Winnipeg water levels to the public on their web site. Suggested changes include explanations of the water level regulation and forecasting procedures, and the presentation of data from the individual gauges. Past and predicted outflows from the lake, in addition to strategies concerning lake level regulation, would also help keep the public informed on how Hydro is operating.

9. The forecast wind eliminated water level on Hydro's web site should have some indication of probable accuracy. Presently two month water level forecasts are shown to have an accuracy of ±0.01 feet which is clearly not realistic.

8.0 REFERENCES

Adhoc Committee on Lake Winnipeg Datum (1982). Report on Lake Winnipeg Levels, Dec. 1982, 15 p + appendices.

Environment Canada (1988). Historical Water Levels Summary, Manitoba to 1987, Inland Waters Directorate, Water Resources Branch, Water Survey of Canada, Ottawa, 123 p.

Environment Canada (1996). HYDAT CD-ROM. Inland Waters Directorate, Water Resources Branch, Water Survey of Canada, Ottawa.

International St. Lawrence River Board of Control (1999). http://www.islrbc.org

Lord, Stephen, Waterways Development Branch of the Canadian Coast Guard (1999). Personal communication.

Manitoba Hydro (1999), Letter dated October 7 from H.S. Zbigniewicz to Mr. David Farlinger.

Nielsen, E. (1998). Lake Winnipeg Coastal Submergence Over the Last Three Centuries, Journal of Paleolimnology, Vol. 19, 335-342.

APPENDIX A
CORRESPONDENCE FROM MANITOBA HYDRO

Manitoba Hydro

PO Box 815 • Winnipeg MANITOBA CANADA • R3C 2P4
Telephone / N° de téléphone : (204) 474-3018
Fax / N° de télécopieur : (204) 452-5639
hszbigniewicz@hydro.mb.ca

1999 10 07

Attn: Mr. David Farlinger, P. Eng.
Lake Winnipeg Shoreline Erosion Advisory Group
200-905 Waverley Street
Winnipeg MB R3T 5P4

Dear Mr. Farlinger:

On 1999 08 26 and 1999 09 07 Manitoba Hydro received copies of faxes from Baird and Associates to the Lake Winnipeg Shoreline Erosion Advisory Group (LWAG) requesting Lake Winnipeg information. We understand that the information will be used in their " … assessment of Manitoba Hydro's methodology for determining and reporting Lake Winnipeg water levels as well as the accuracy and integrity of such water level data and reporting."

The following is a point-by-point response to their request:

1. "Hourly water level data from the stations that are maintained throughout Lake Winnipeg. These data should include recent as well as historical data, and would ideally be the complete set of digital data that is available."

   Fourteen Excel files of hourly water level data for the period 1986 to 1999 have been forwarded to ftp.Baird.com. These contained the hourly levels received from the real-time equipment at George Island, Montreal Point, Berens River, Victoria Beach, Gimli, Pine Dock, Matheson Island and Mission Point.

   Three Excel files "raw data.xls", "calculated.xls" and "smooth.xls" containing daily average levels were forwarded to ftp.Baird.com. The "raw data.xls" file contains the raw daily average levels derived from the hourly real-time information for each of the eight gauges. The "calculated.xls" file contains the best estimate of the daily averages at the same gauges. The "smooth.xls" file contains the calculated Lake Winnipeg wind eliminated daily level for 1970-1999. Also forwarded to ftp.Baird.com was a separate Excel file "LWpg Monthly Mean Levels.xls" listing of the monthly mean levels for the period 1913 to 1999 based on the wind-eliminated levels.

   Published historical level data may be obtained from Water Survey of Canada.

2. "Wind data that are recorded at the various stations around the lake by Manitoba Hydro."

Manitoba Hydro does not archive wind data.

3. "Is the current calculation procedure used by Manitoba Hydro to derive the wind-eliminated water level identical to that outlined in the December 1982 Report on Lake Winnipeg Levels? In particular, are the weighting factors and temporal averaging procedure the same?"

Attached are the four pages (faxed to Baird and Associates 1999/09/28) from our database manual (OHG166 - Lake Winnipeg Rate of Change Limited Elevation (ROCLE) and OHG168 - Lake Winnipeg Smoothed Elevation) which describe the factors and calculation procedure used in our determination of Lake Winnipeg wind eliminated levels.

4. "What is the operational procedure followed by Manitoba Hydro in regulating water levels on Lake Winnipeg? We would like to understand the details of the relationship between the reported wind-eliminated water levels and the lake outlet control."

Manitoba Hydro continually evaluates its need to store or release water from Lake Winnipeg based upon expected power demands in Manitoba and on the export market, long term water supply forecasts and current flow and storage conditions in all rivers and reservoirs across the entire Nelson-Churchill drainage system, maintenance plans at generating stations, and the capabilities of the transmission system. As long as the level of Lake Winnipeg is kept within the range 711 to 715, outflows from the lake are set based upon this evaluation.

The level used to determine whether the lake is within the range 711 to 715 is the wind eliminated level.

Yours truly,

Original signed by: Halina Zbigniewicz

H.S. Zbigniewicz
Manager
Hydraulic Eng. & Ops.

MJD/ljm/991007-1.w61
Att.

cc: D. Williamson, W.F. Baird & Associates Coastal Engineer Ltd.

66.0 CALCULATION NO. 66

66.1 FLD#(170) - ROCLE OF L. WPG

PROGRAM NAME : OHG166

REFERENCE FIELDS :

(1) YESTERDAY'S "RATE OF CHANGE LIMITATED ELEVATION OF LAKE WINNIPEG(ROCLE)" = FLD #(170)

(2) ELEVATIONS (FEET) :

```
    GIMLI (REAL TIME)             ELEV = FLD #(156)
    GIMLI (OFFICIAL)              ELEV = FLD #(155)
    VICTORIA BEACH (REAL TIME)    ELEV = FLD #(161)
    VICTORIA BEACH (OFFICIAL)     ELEV = FLD #(154)
    BERENS RIVER (REAL TIME)      ELEV = FLD #(163)
    BERENS RIVER (OFFICIAL)       ELEV = FLD #(157)
    GEORGE ISLAND (REAL TIME)     ELEV = FLD #(115) <-- DCP
    GEORGE ISLAND (OFFICIAL)      ELEV = FLD #(267)
  ~ SANDY BEACH (OFFICIAL)        ELEV = FLD #(162)
    MISSION POINT(REAL TIME)      ELEV = FLD #(137) <-- DCP
    MISSION POINT(OFFICIAL)       ELEV = FLD #(158)
    PINE DECK (REAL TIME)         ELEV = FLD #(153)
    MATHESON ISLAND (REAL TIME)ELEV = FLD #(144)
    MONTREAL POINT  (IWP)         ELEV = FLD #(159)
```

(3) NOISE LEVEL TABLE (IN SAME SEQUENCE AS (2))

```
    (100.00,  84.72,  89.61,  97.91,   49.12,  26.66,
      21.27,  44.40,  43.66,  38.67,   46.25,  47.74,
      42.39,  45.50)
```

NOTE : IF THERE IS ANY CHANGE IN NOISE LEVEL TABLE THEN PROGRAM(OHG166) IS REQUIRED TO BE RECOMPILE

EQUATIONS :

(1) Y = 1 / EACH NOISE LEVEL

(2) X = 1 / SUM OF Y

(3) WF (WEIGHTING FACTORS) = X / EACH NOISE LEVEL

(4) AWL (AVERAGE WATER LEVEL) = SUM OF (WF * EACH ELEVATION)

(5) DELTA = TODAY'S AWL - YESTERDAY'S ROCLE

(6) ROCLE = YESTERDAY'S ROCLE +
SIGN(DELTA) * MIN(ABS(DELTA),0.06)

METHOD OF CALCULATION :

(1) CALCULATE TODAY'S LAKE WINNIPEG'S AVERAGE WATER LEVEL (AWL) BY USING EQUATIONS (1) TO (4)

** NOTE : IF BOTH "REAL TIME" & "OFFICIAL" DATA ARE AVAILABLE THEN ONLY THE "OFFICIAL" DATA IS TO BE USED FOR EQUATIONS (2) & (4)

(2) CALCULATE TODAY'S ROCLE BY USING EQUATION (5) AND (6)

68.0 CALCULATION NO. 68

68.1 FLD#(165) - L. WPG SMOOTHED ELEVATION

PROGRAM NAME : OHG168

REFERENCE FIELDS :

CURRENT DAY'S AND PAST 20 DAYS' ROCLE = FLD # (170)

EQUATIONS :

(1) SMOOTHED ELEV(DAY3) = ROCLE(DAY3)

OR

(2) SMOOTHED ELEV(DAY3) = FIVE DAYS' MEAN
<< (SUM OF DAY 1 TO DAY 5) / 5 >>

(2) COMPARE EVERY FIVE DAYS' ROCLE

METHOD OF CALCULATION:

(1) GET TODAY'S AND PAST 20 DAYS' ROCLE
<< ROCLE(N), ROCLE(N-1), ... , ROCLE(N-20) >>

IF DAY2=DAY3=DAY4 OR DAY2>DAY3>DAY4 OR
DAY2<DAY3<DAY4
THEN USE EQUATION(1) OTHERWISE USE EQUATION(2) TO CALCULATE SMOOTHED ELEVATION OF DAY3.

(3) APPLY A TOTAL OF FIVE SUCH PASSES, WHICH ARE BASED ON THE PRECEDING NEW FIELDS.

(4) AFTER ALL 5 PASSES, SAVE THE FINAL RESULT OF
'ROCLE(N-11)' IN FILE 'FLD(165)(N-11)'

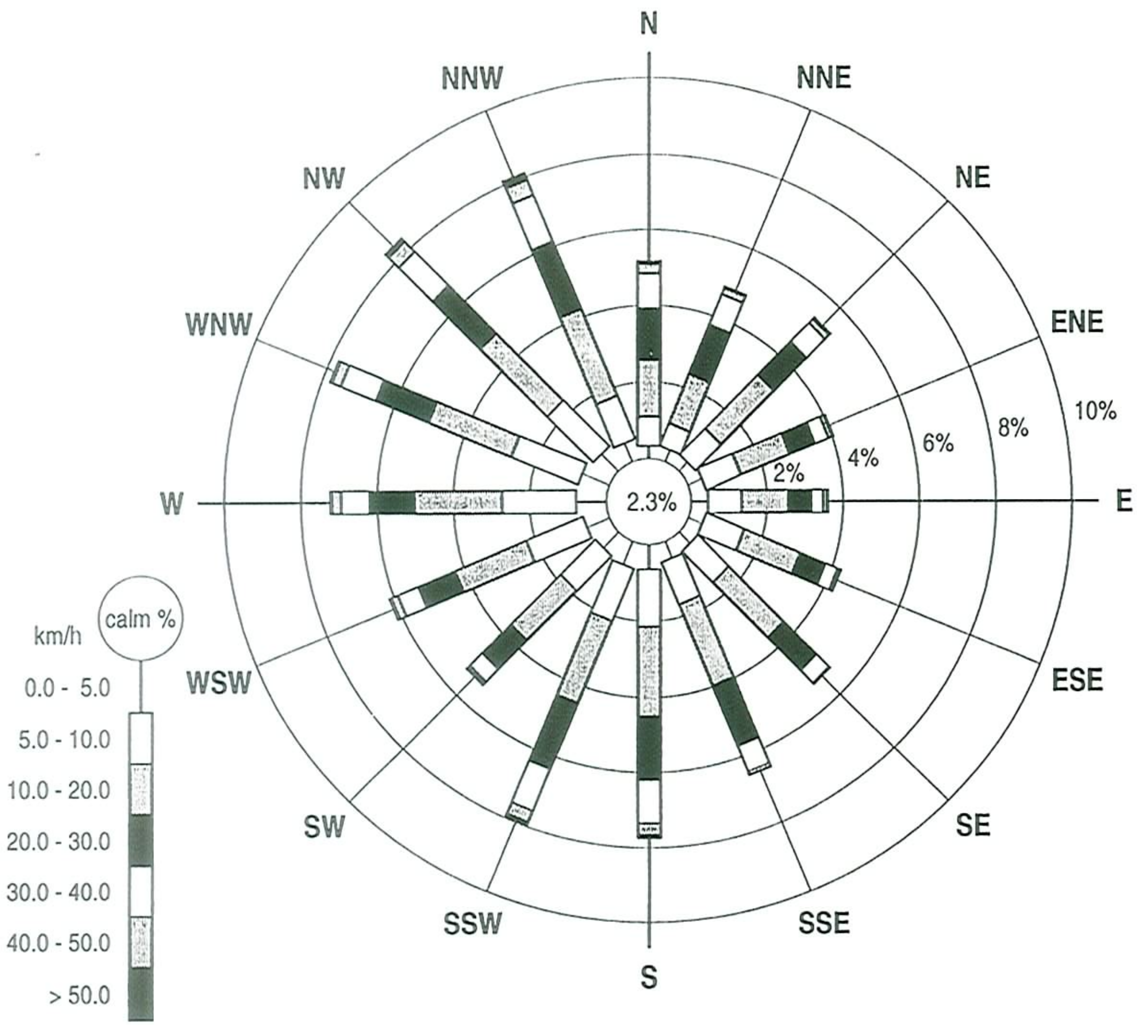
```
                    (N-20) .  .  .   (N-11)    .  .  .   N
                      |                |                 |
BEFORE 1ST            |                |                 |
  PASS (ROCLE)        X X X X X X X X X X X X X X X X X X X X X
```

```
AFTER 1ST PASS     X X X X X X X X X X X X X X X X X

AFTER 2ND PASS         X X X X X X X X X X X X X

AFTER 3RD PASS             X X X X X X X X X

AFTER 4TH PASS                 X X X X X

AFTER 5TH PASS                     X
```

APPENDIX B
STATISTICAL SUMMARY OF GIMLI WIND DATA

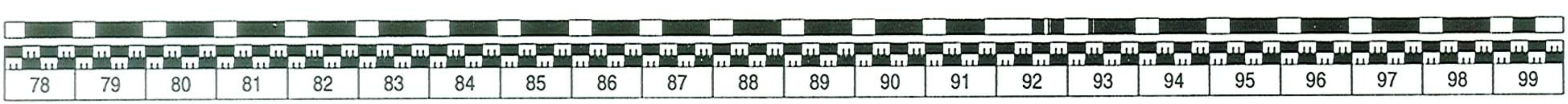
Wind Rose

Wind Station: Gimli



Cumulative Distribution (%)

	0.0	5.0	10.0	20.0	30.0	40.0	50.0 km/h
NNE	0.3	1.0	2.4	3.8	4.6	4.8	4.8
NE	0.3	1.3	3.2	4.5	5.1	5.3	5.4
ENE	0.4	1.4	2.8	3.5	3.9	4.0	4.0
E	0.4	1.3	2.6	3.2	3.5	3.6	3.6
ESE	0.4	1.5	3.1	3.8	4.1	4.2	4.2
SE	0.4	1.5	3.6	4.8	5.3	5.3	
SSE	0.5	1.6	4.0	5.7	6.4	6.5	
S	0.6	2.1	4.5	6.2	7.3	7.7	7.7
SSW	0.6	2.1	4.4	6.3	7.5	7.9	8.0
SW	0.6	1.8	3.7	4.7	5.2	5.3	5.3
WSW	0.6	2.2	4.3	5.3	5.9	6.1	6.1
W	0.8	2.7	5.0	6.2	6.9	7.2	7.2
WNW	0.8	2.6	5.0	6.5	7.5	7.7	7.8
NW	0.6	2.3	4.8	6.6	7.8	8.2	8.3
NNW	0.5	1.7	4.2	6.1	7.5	7.9	8.1
N	0.3	1.1	2.6	3.9	4.8	5.1	5.2



wind velocity threshold = 53.00 max Dip Length = 48 min Storm Length = 6

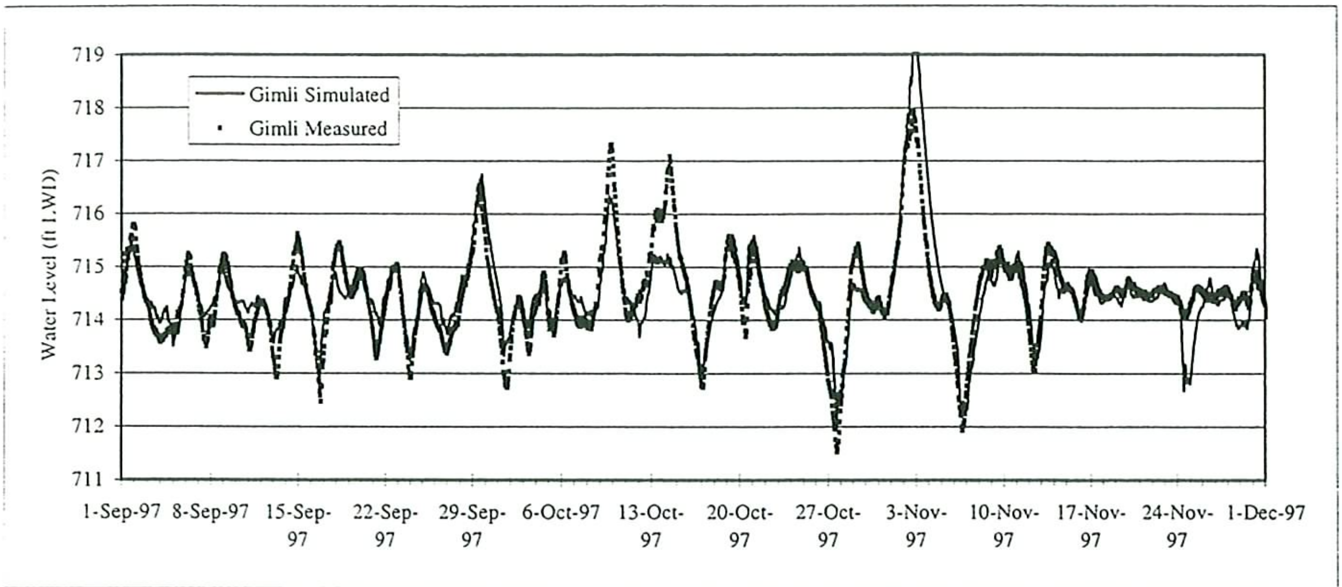
Rank	Storm	Start	End	Peak	Dur	vel	Dir	F->S	P->P
1	17	08OCT87:13	08OCT87:23	08OCT87:21	11	86	29	8043	8028
2	59	01MAY99:11	02MAY99:19	02MAY99:16	33	75	192	5404	5380
3	48	08MAY97:04	11MAY97:15	11MAY97:13	84	75	334	154	143
4	40	04DEC95:24	05DEC95:15	05DEC95:02	16	75	278	367	301
5	54	01NOV97:17	03NOV97:01	02NOV97:13	33	72	347	157	142
6	39	20NOV95:07	22NOV95:16	22NOV95:12	58	71	354	483	479
7	43	29OCT96:20	31OCT96:04	29OCT96:20	33	71	317	325	286
8	44	17NOV96:04	17NOV96:19	17NOV96:07	16	71	341	454	442
9	16	07NOV86:19	08NOV86:17	08NOV86:08	23	70	18	1065	1053
10	2	05NOV78:03	05NOV78:12	05NOV78:12	10	69	272	1315	1310
11	37	17OCT95:10	17OCT95:18	17OCT95:13	9	69	300	102	93
12	8	16OCT84:05	16OCT84:11	16OCT84:07	7	69	170	597	587
13	56	04MAY98:13	04MAY98:20	04MAY98:15	8	68	323	4305	4297
14	22	18APR94:07	19APR94:11	18APR94:14	29	68	328	4163	4126
15	62	04JUN99:11	04JUN99:18	04JUN99:11	8	68	192	609	595
16	63	22JUN99:12	22JUN99:17	22JUN99:16	6	66	187	437	436
17	14	12JUN86:10	13JUN86:15	13JUN86:15	30	65	275	4964	4964
18	29	16NOV94:12	22NOV94:06	16NOV94:12	139	64	187	714	426
19	53	27OCT97:11	27OCT97:17	27OCT97:14	7	64	193	445	442
20	41	08DEC95:09	09DEC95:04	08DEC95:20	20	64	336	99	89
21	6	26SEP81:21	27SEP81:09	27SEP81:02	13	64	326	2440	2419
22	15	25SEP86:07	25SEP86:22	25SEP86:10	16	64	88	2531	2490
23	19	12JUN89:17	13JUN89:06	13JUN89:01	14	64	55	5016	5011
24	34	19AUG95:14	22AUG95:05	22AUG95:05	64	64	12	305	304
25	33	09AUG95:11	09AUG95:23	09AUG95:12	13	64	240	298	286
26	28	23OCT94:11	29OCT94:17	29OCT94:17	151	63	285	459	457
27	57	16MAY98:05	16MAY98:17	16MAY98:06	13	63	314	291	278
28	23	26APR94:10	26APR94:19	26APR94:12	10	63	19	203	189
29	45	15APR97:02	15APR97:11	15APR97:03	10	63	326	3582	3571
30	49	14MAY97:06	14MAY97:19	14MAY97:09	14	63	324	158	67
31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	63	87		
32	55	06NOV97:10	06NOV97:16	06NOV97:13	7	62	192	118	95
33	42	17OCT96:14	18OCT96:01	17OCT96:21	12	62	337	7551	7536
34	5	17JUN81:16	18JUN81:11	18JUN81:06	20	62	302	5542	5537
35	36	13OCT95:11	13OCT95:18	13OCT95:15	8	62	24	896	893
36	32	28JUL95:12	01AUG95:16	28JUL95:13	101	62	296	1103	981
37	60	06MAY99:15	07MAY99:19	06MAY99:17	29	62	326	151	96
38	31	16JUN95:16	18JUN95:17	17JUN95:15	50	61	196	703	676
39	27	10OCT94:13	10OCT94:18	10OCT94:15	6	61	193	323	314
40	25	10JUL94:10	11JUL94:16	11JUL94:16	31	61	312	1561	1532
41	24	07MAY94:14	08MAY94:19	08MAY94:19	30	61	344	296	294
42	9	19OCT84:09	19OCT84:18	19OCT84:10	10	61	59	84	74
43	61	10MAY99:08	10MAY99:21	10MAY99:15	14	60	69	101	93
44	7	21SEP84:13	21SEP84:22	21SEP84:19	10	60	74	26184	26176
45	3	27JUN80:12	27JUN80:20	27JUN80:12	9	60	98	14416	14399
46	12	07OCT85:24	08OCT85:11	07OCT85:24	12	60	42	1254	1237
47	47	05MAY97:04	05MAY97:13	05MAY97:13	10	60	343	168	168
48	46	28APR97:12	29APR97:12	28APR97:12	25	60	193	345	320
49	10	08JUN85:15	08JUN85:24	08JUN85:17	10	60	254	5582	5574
50	35	06SEP95:09	06SEP95:17	06SEP95:09	9	60	42	434	363
51	30	20MAY95:09	20MAY95:14	20MAY95:10	6	59	327	4441	4437
52	26	27SEP94:06	27SEP94:18	27SEP94:12	13	59	331	1903	1867
53	21	27OCT93:23	28OCT93:19	28OCT93:15	21	59	345	35945	35941
54	52	09OCT97:03	09OCT97:13	09OCT97:03	11	57	323	380	370
55	50	09JUN97:11	09JUN97:18	09JUN97:15	8	57	194	635	629
56	18	16NOV88:05	16NOV88:17	16NOV88:05	13	57	317	9723	9703
57	58	19SEP98:14	20SEP98:12	20SEP98:11	23	56	351	3054	3052
58	13	18NOV85:18	19NOV85:02	18NOV85:18	9	56	29	1009	1001
59	11	17AUG85:04	17AUG85:11	17AUG85:10	8	56	33	1675	1672
60	38	02NOV95:12	02NOV95:23	02NOV95:12	12	56	358	396	382
61	4	30OCT80:12	30OCT80:17	30OCT80:12	6	56	289	3004	2999
62	51	23SEP97:16	24SEP97:16	23SEP97:16	25	54	208	2572	2544
63	20	22SEP89:01	23SEP89:24	22SEP89:01	48	54	1	2478	2423

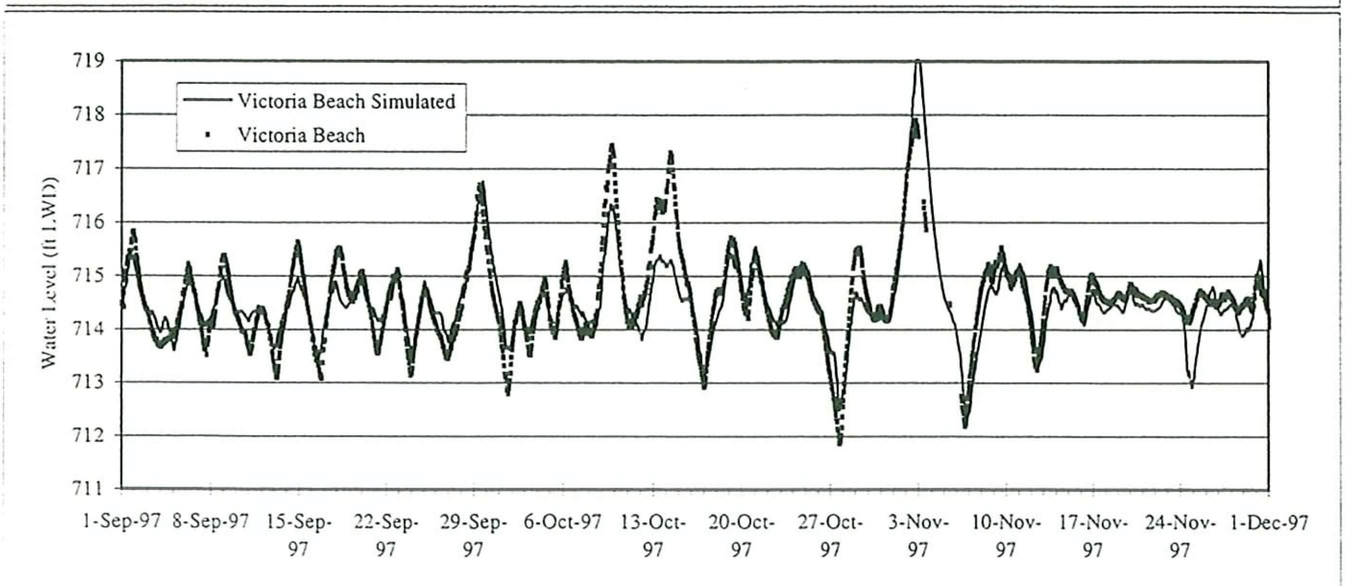
```
11Aug99 11:27  "REFAES" v2m0
Station name : Gimli
Vmin =    0.10   :   Vmax = 150.00
Conversion parameters:
START  -31DEC70 (mph  0) (------) (km/h 0)  16 pt
01JAN71-28FEB75 (mph  0) (------) (km/h 0)  36 pt
01MAR75-31DEC76 (kts  0) (mph  0) (km/h 0)  36 pt
01JAN77-END     (kts  0) (------) (km/h 0)  36 pt
11Aug99 11:27  "REPAIR" v2m0
Maxgap = 12     Repair type = LI
11Aug99 13:18  "WNDCVT" v3m0
Wind data modified from  START  to  END
 There is no anemometer height correction
 There is no over water / over land correction
 Transformation file =  C:\data\winnipeg\trfn_bb
 Directional validity
   From     To
   0.0  360.0
 Transformation function
   0.0000     1.0000
   7.0000     1.1000
  10.0000     1.2000
  12.0000     1.3000
  15.5000     1.4000
  20.0000     1.4500
  27.5000     1.4000
  30.0000     1.3800
  40.0000     1.3200
  43.0000     1.3000
  50.0000     1.2700
  60.0000     1.2300
  70.0000     1.2100
  80.0000     1.2000
  90.0000     1.2000
 100.0000     1.2000
 125.0000     1.2000
 150.0000     1.2000
 There are no additional correction factors
11Aug99 15:46  "SELECT" v2m0
        Selected from START   to END
        Season from 15APR to 15DEC
        There is no directional selection
        There are no exception intervals
```

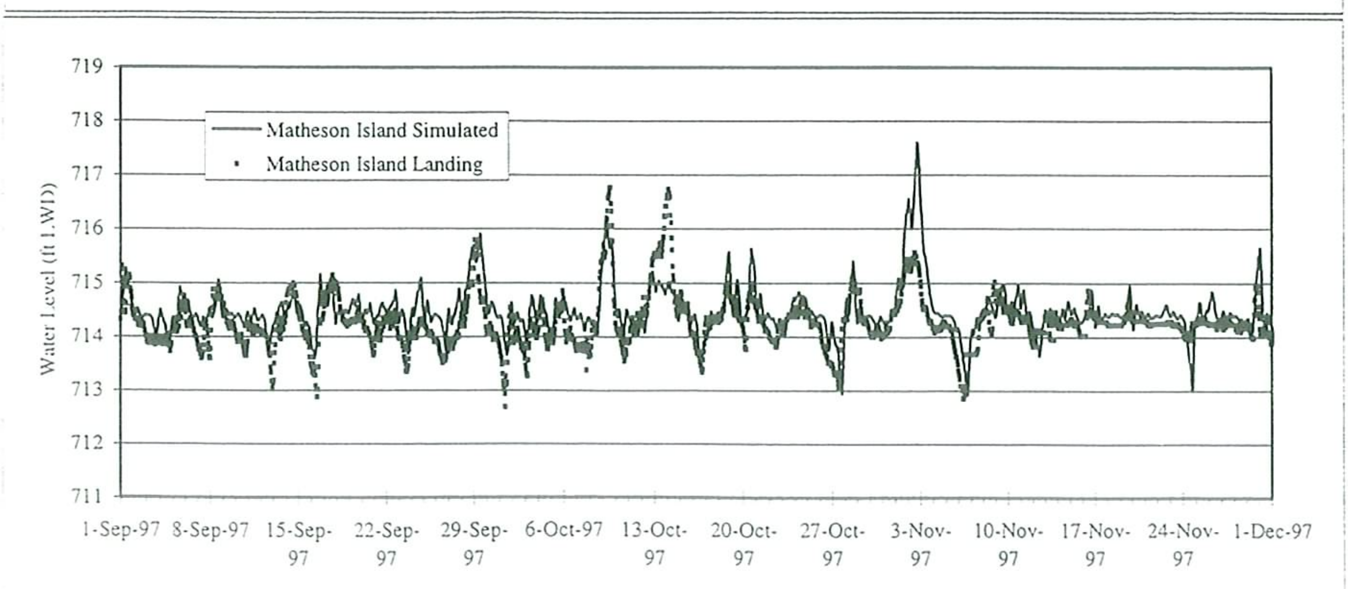
SELECTED 15 APR - 15 DEC

MIN STORM DURATION = 6 hrs.

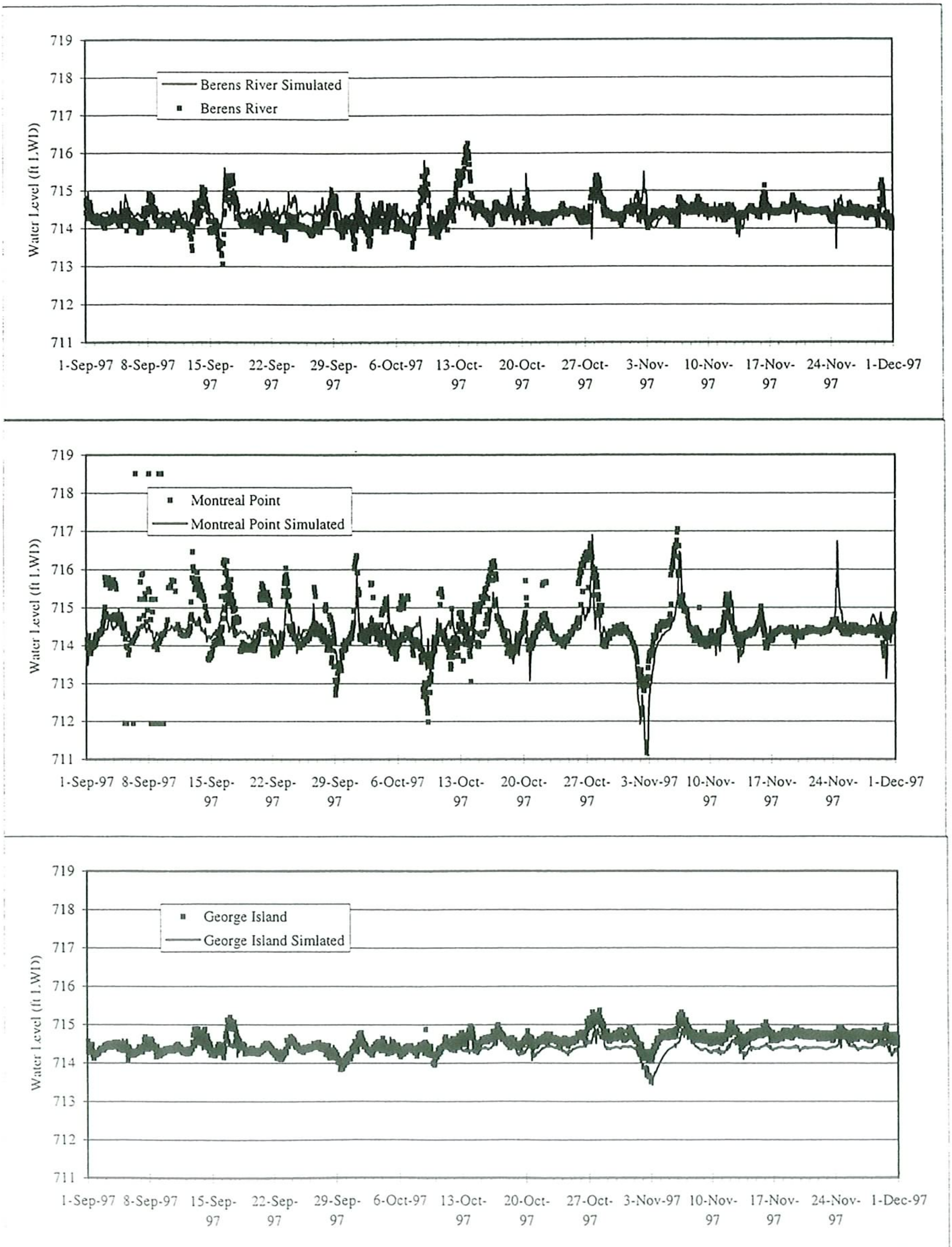
APPENDIX C
TIME SERIES DATA FROM MODEL SIMULATIONS



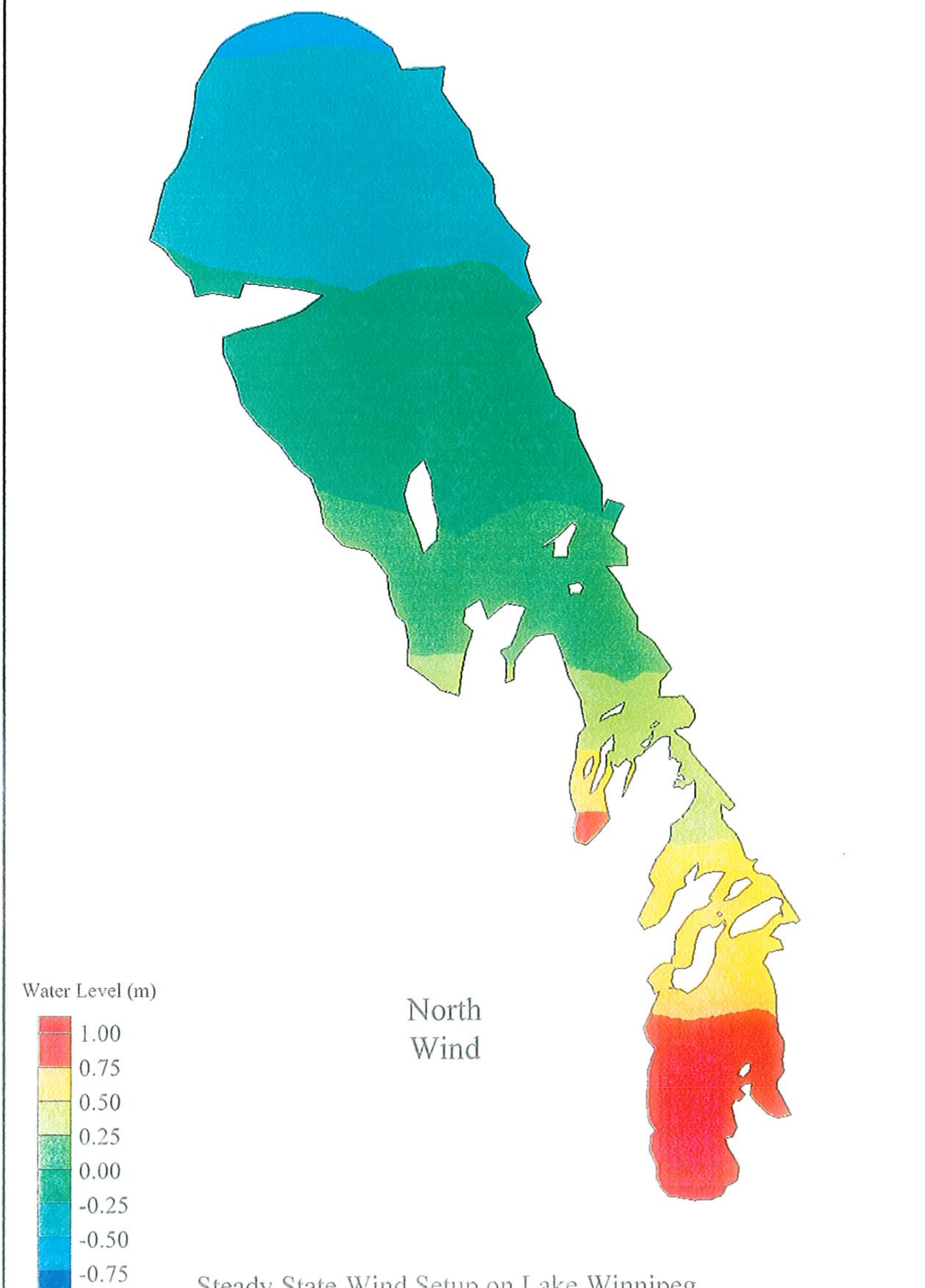




Comparison of Measured and Simulated Water Level - Fall 1997

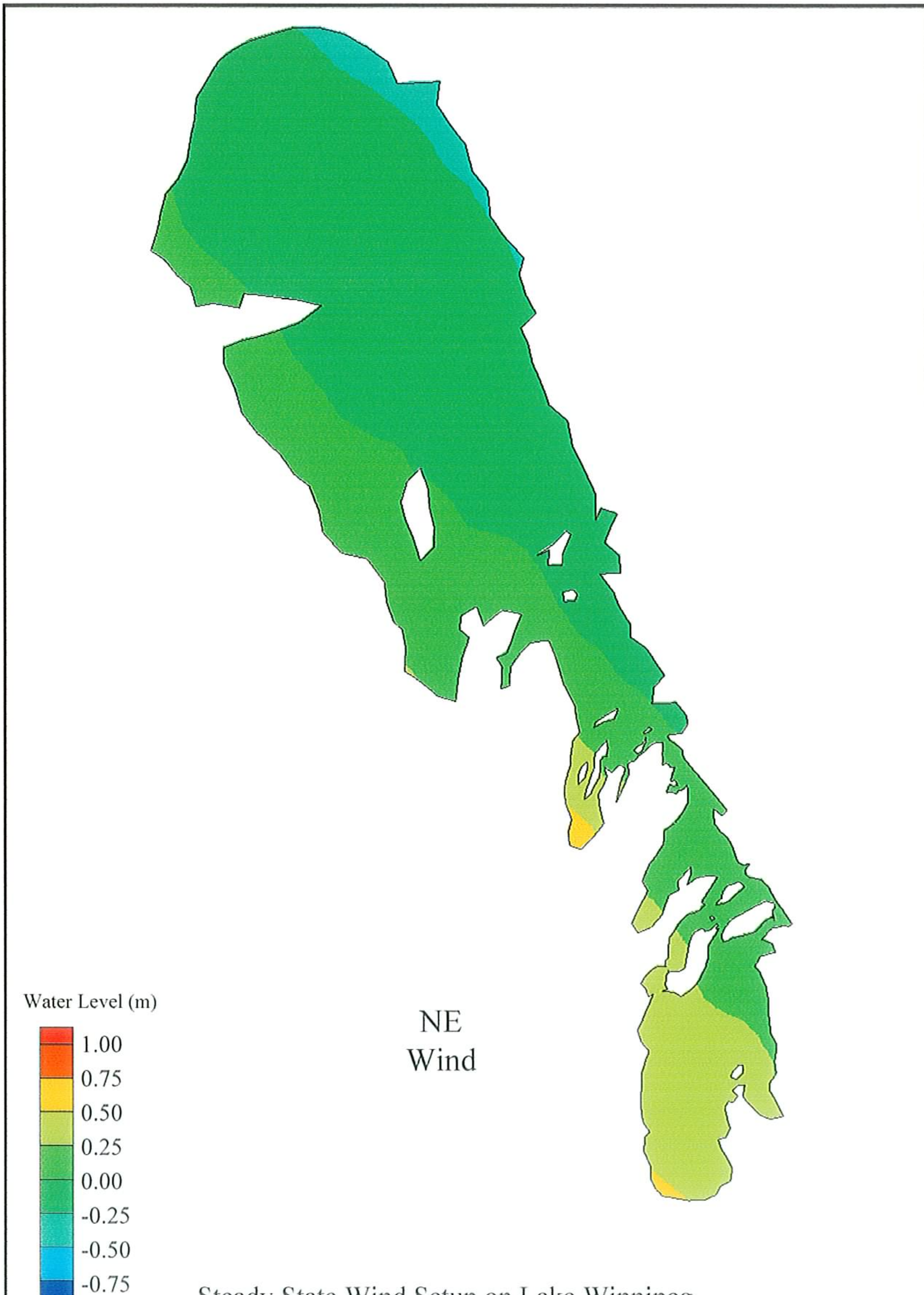


Comparison of Measured and Simulated Water Level - Fall 1997



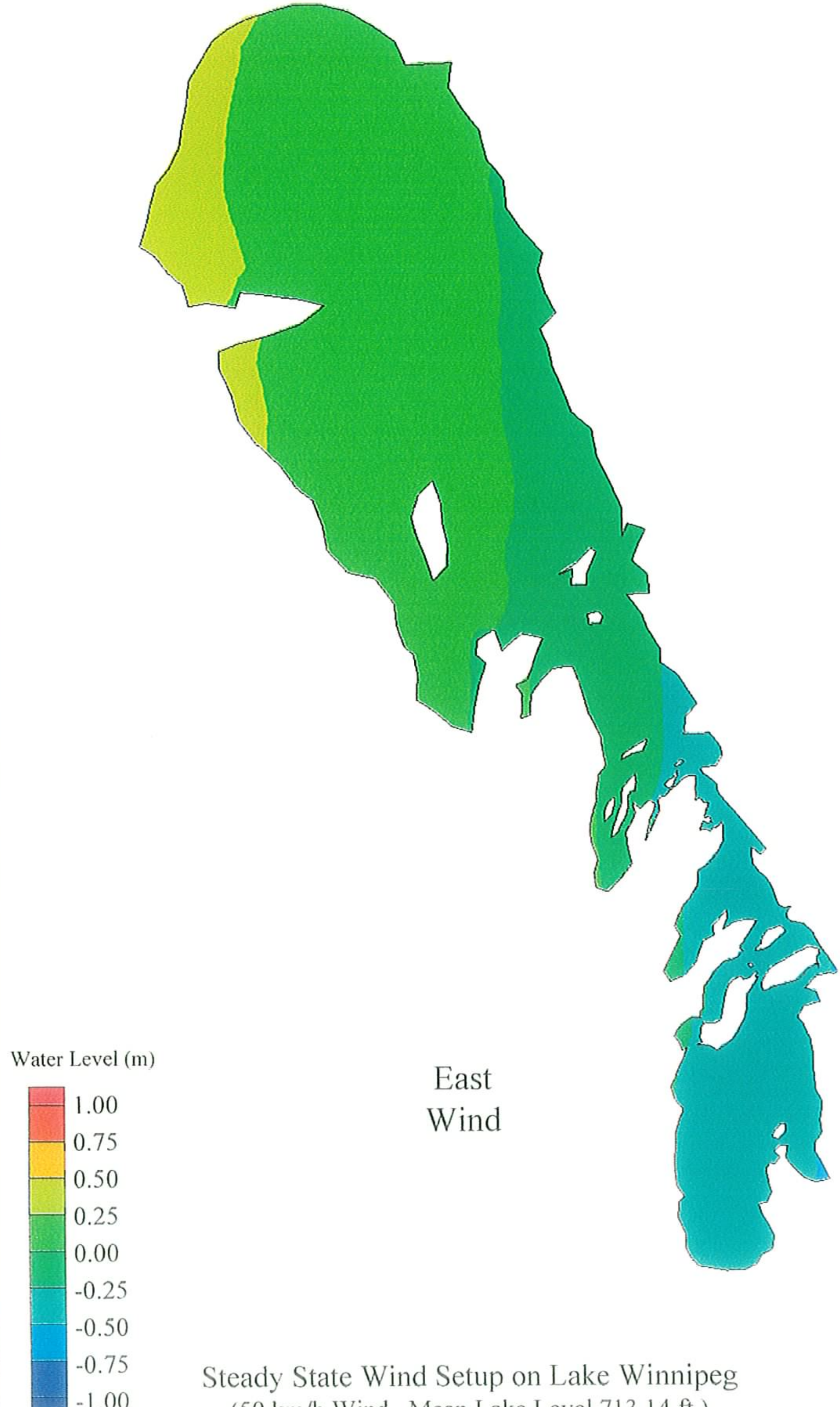
Steady State Wind Setup on Lake Winnipeg
(50 km/h Wind , Mean Lake Level 713.14 ft.)

Figure 4.6a



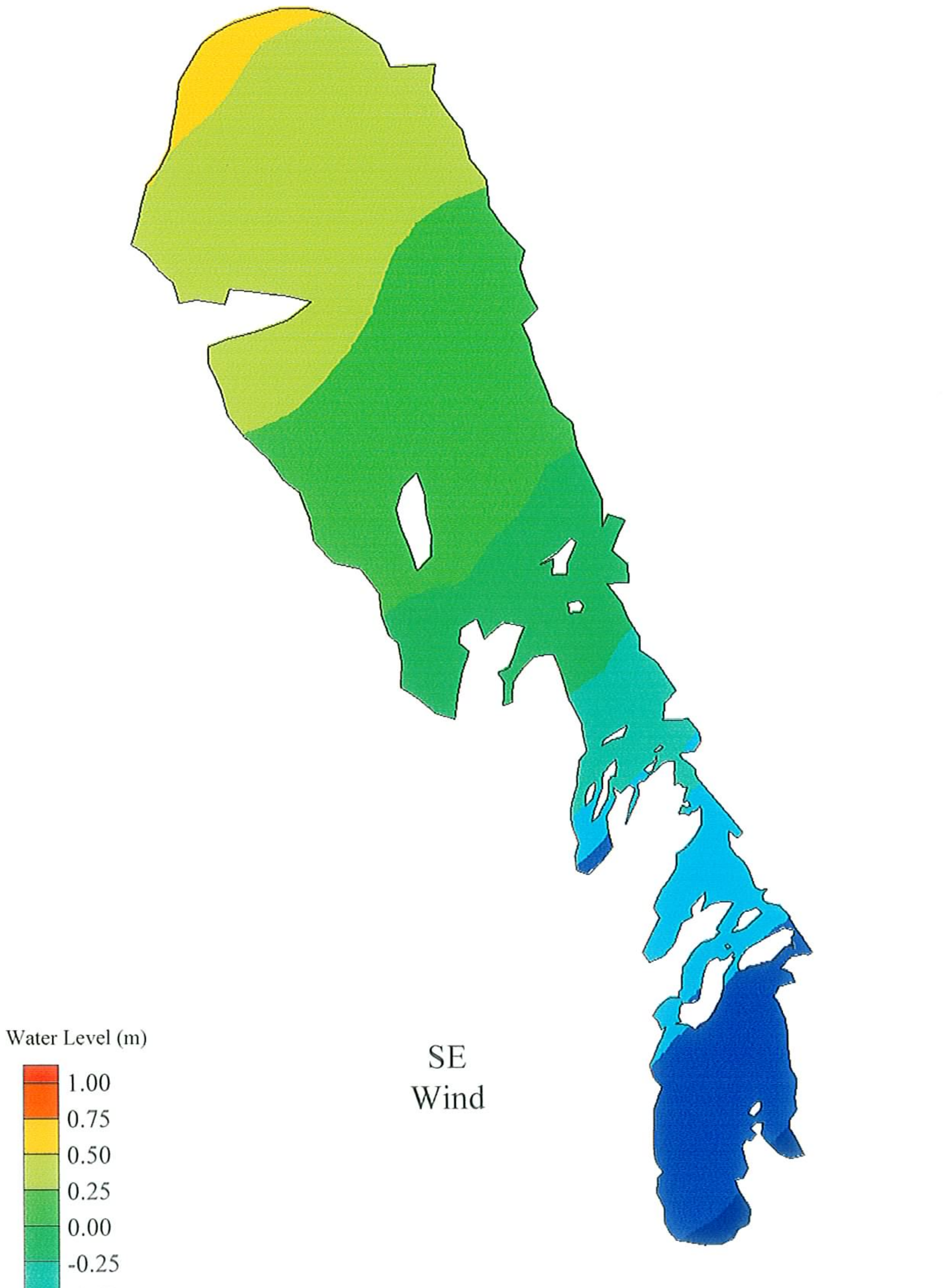
Steady State Wind Setup on Lake Winnipeg
(50 km/h Wind , Mean Lake Level 713.14 ft.)

Figure 4.6b



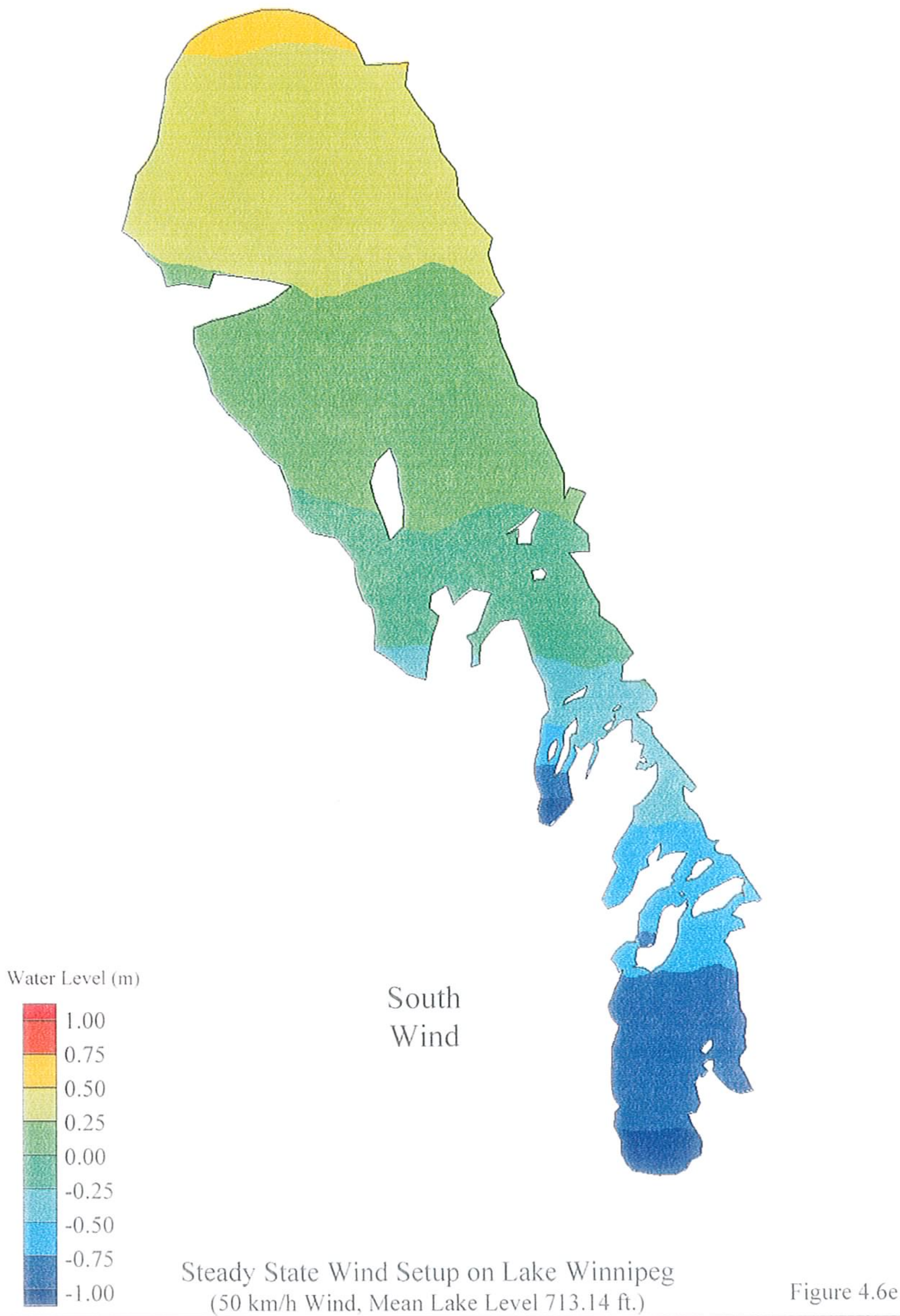
Steady State Wind Setup on Lake Winnipeg
(50 km/h Wind , Mean Lake Level 713.14 ft.)

Figure 4.6c



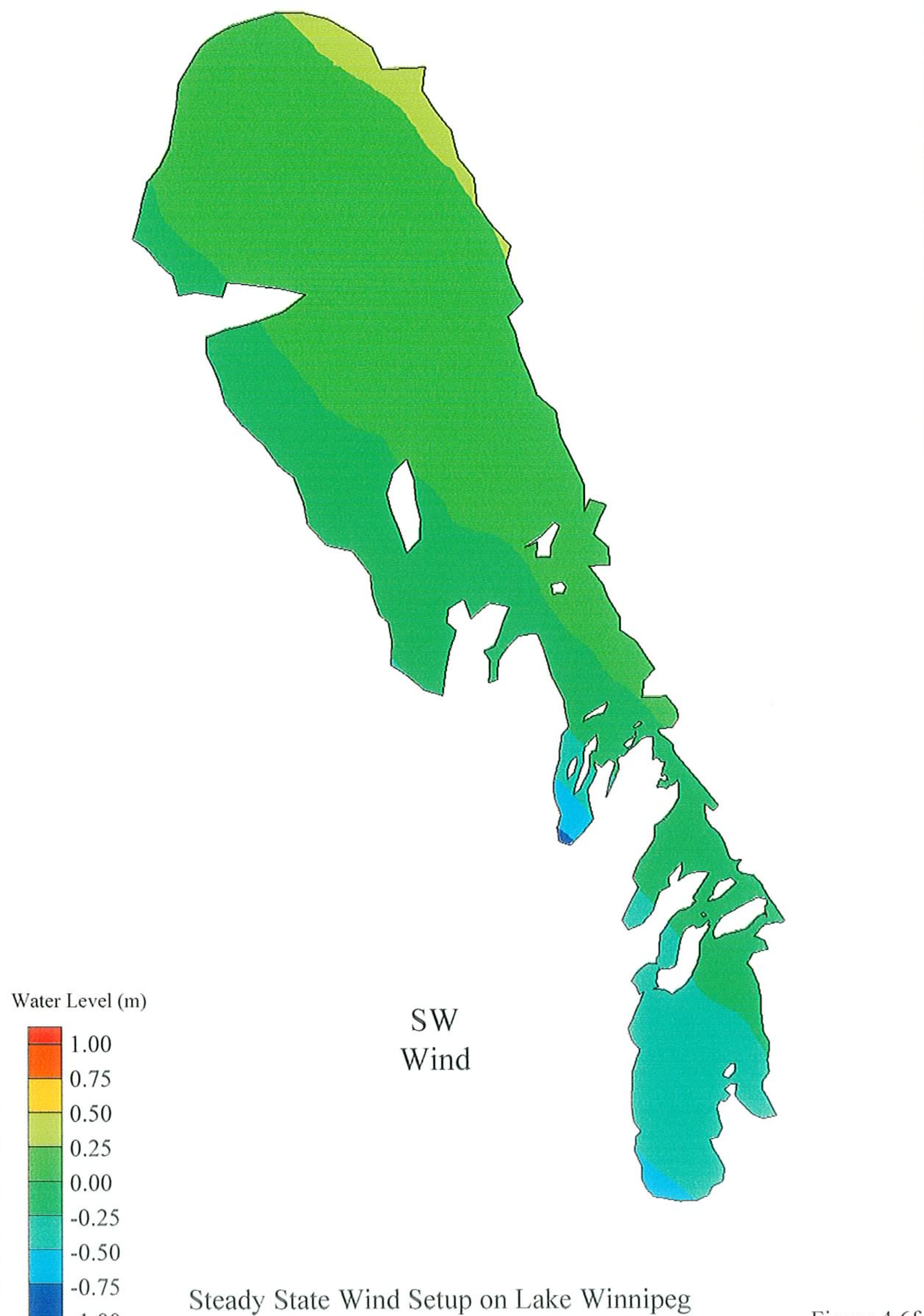
Steady State Wind Setup on Lake Winnipeg
(50 km/h Wind , Mean Lake Level 713.14 ft.)

Figure 4.6d



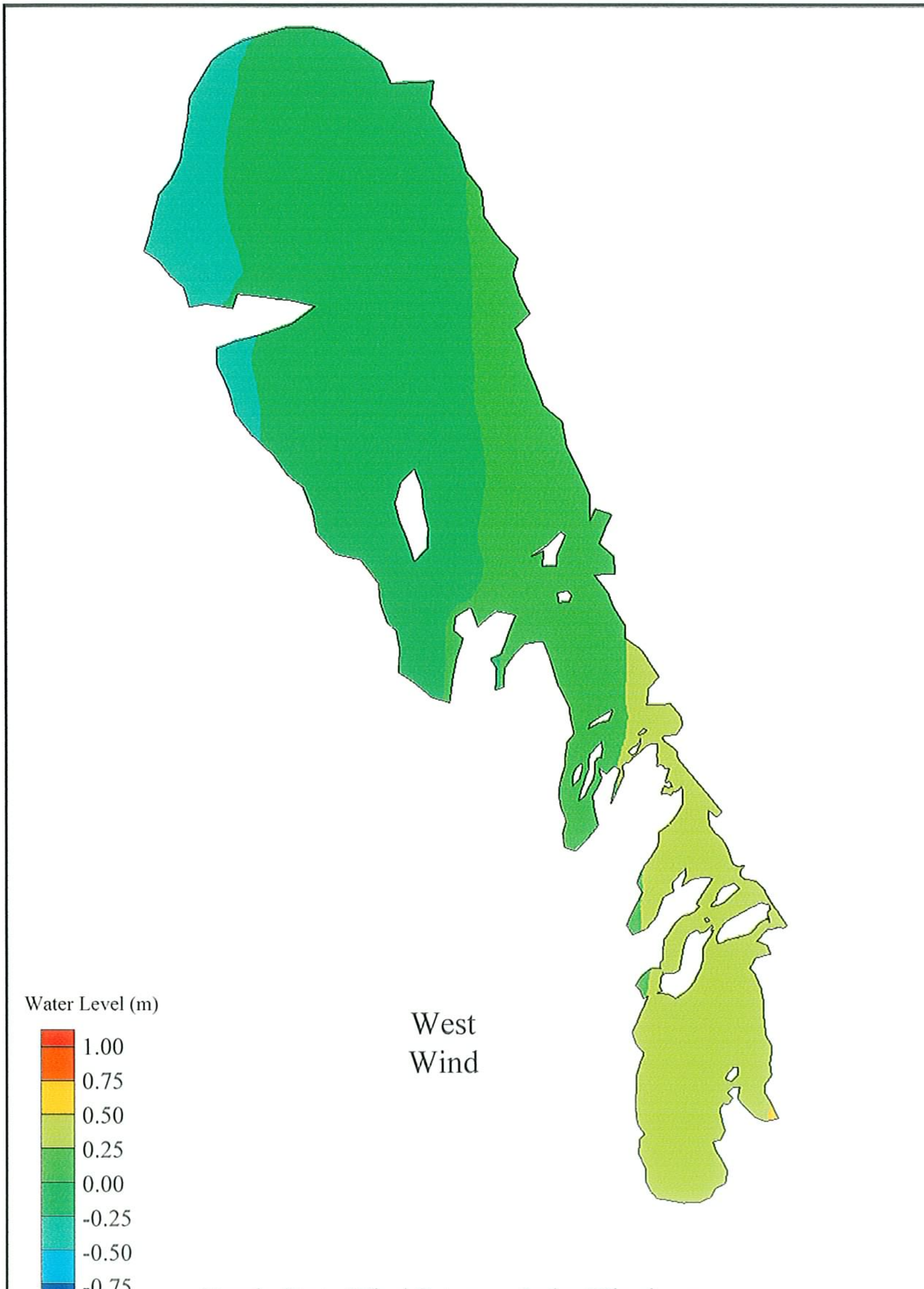
Steady State Wind Setup on Lake Winnipeg
(50 km/h Wind, Mean Lake Level 713.14 ft.)

Figure 4.6e



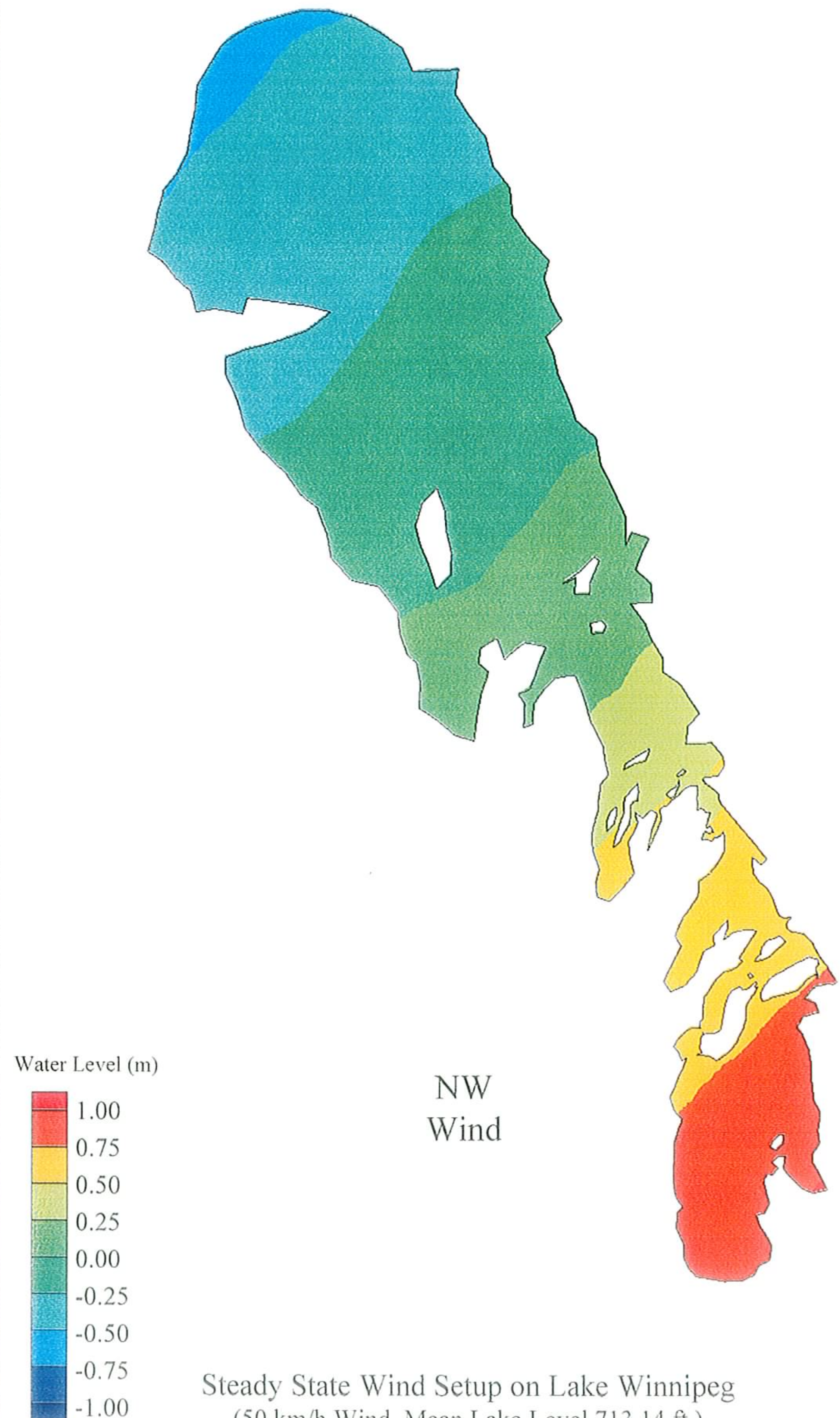
Steady State Wind Setup on Lake Winnipeg
(50 km/h Wind, Mean Lake Level 713.14 ft.)

Figure 4.6f



Steady State Wind Setup on Lake Winnipeg
(50 km/h Wind, Mean Lake Level 713.14 ft.)

Figure 4.6g



Steady State Wind Setup on Lake Winnipeg
(50 km/h Wind, Mean Lake Level 713.14 ft.)

Figure 4.6h