THE UNIVERSITY OF MANITOBA

SURFACE WATER LEVEL ESTIMATION USING THE KRIGING METHOD

by

ZOLT ZRINJI

A Thesis

Submitted to the Faculty of Graduate Studies in Partial

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ABSTRACT

In many fields it is necessary to make use of some form of an interpolation technique. Most frequently, this is the method used to spread the point measurements over some observation domain of interest. Which interpolation technique will be most appropriate for a given problem application will depend on the number and the spatial location of the point estimates of the data.

A selection of interpolation methods are presented and discussed in this work. However, the major emphasis of this thesis is on the presentation of the Kriging technique. A description of the previous application of this technique in various fields, of the theoretical development of the algorithm, and finally of the application of this method to the Winnipeg Lake water level estimation is given.

Following presentation and comparison of results from using alternative estimation techniques, some benefits and recommendations resulting from experience gained in the course of the research project described, are given at the end of this work.

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1 INTRODUCTION

In most practical scientific problems, measured data are collected at point locations, but the desired knowledge about the measured property is related to a continuous field or a space. Furthermore, the number of point locations where data are collected is quite limited. To spread the sparse observation records, one of the available interpolation methods is usually used. In that way, it is possible to obtain a map of the desired property, or the average value, over the observed domain.

This type of problem arises in several fields. Some problems in the water resources area are: determination of average rainfall, estimation of groundwater level, in mining: mineral concentration in an orebody; in environmental engineering: pollution concentration over an observed domain; and in agriculture: corn production control.

For different types of problems different interpolation methods will be preferred. There are many known interpolation methods for the estimation of the spatial characteristics of a property over a domain based on point measurements of the property. Some of these methods are very simple and are widely used in different fields of science, while some of the new techniques have been used only in specific fields. The different methods not only require different amount of input data, but also have different interpolation characteristics.

1.1 PROBLEM STATEMENT

In this work, the Kriging interpolation method will be investigated for application

to surface water level estimation. This is an unique field for the application of Kriging technique.

The Kriging method is applied to Lake Winnipeg, which is a very large lake (surface area of roughly 23700 square kilometers) with a limited number of water level gauge stations. The measured data are collected at discrete points but the operation of Manitoba Hydro system relies on average lake water level. The problem is more complicated by the wind set-up and the earth's rotation effects on lake water surface. Furthermore, the water level data collected at point locations are not necessarily reliable.

The Kriging technique is also capable of providing useful information for investigation of a new gauge network. Data collection network design issues such as preferred new station locations, optimal relocation of existing stations, and identification of nearly redundant gauges, can all be addressed using Kriging.

For a successful application of the Kriging interpolation technique, an historical record of the desired property is needed. This record is used to create an auxiliary function, called the semivariogram, which represents the fundamental part of this interpolation method. Using the experimental semivariogram, the theoretical semivariogram can be developed and used to calculate the weighting coefficients for each measuring point.

A major advantage of the Kriging method is its capability of calculating the reliability of the prediction, (i.e. it can provide an estimation plus a confidence interval). This capability can be used in the interpolation process to evaluate the reliability of the source data from the point measurement locations. This way, it is possible to identify which source data are likely in error and repeat the interpolation

process without that record.

Since the above mentioned reliability is calculated on the basis of the geometrical dispersion of the observation points, (i.e., it is independent of the observed records), it is possible to use this information in the planning process of implementing new observation locations.

1.2 SCOPE OF WORK

The major objective of the work reported in this thesis is to apply the Kriging interpolation technique to surface water level estimation. The case study is for the water level estimation on Lake Winnipeg.

Chapter 2 gives a general review of previous work. This includes interpolation methods such as Lagrange interpolation, least squares; weighted methods such as inverse distance, polygons; and Kriging. The chapter continues with a review of the successful applications of the Kriging method in the mining and the hydrosciences fields. At the end of this section, the problem of the Lake Winnipeg water level estimation from the Manitoba Hydro point of view as well as the summary of current estimation methods used in Manitoba Hydro are presented.

Theory of the Kriging technique is given in Chapter 3. The theoretical report includes an explanation of the semivariogram, the calculation of the weighting coefficients and the calculation of the standard error. At the end of the Chapter, difficulties in the semivariogram, and Kriging system development are discussed.

The application of the Kriging technique to Lake Winnipeg is described in Chapter 4. It contains a description of practical experience gained through the model

implementation. At the end of this chapter, the algorithm is presented and recommendations for the case study are given.

In Chapter 5 is a presentation of results obtained from Kriging and from other methods used to estimate Lake Winnipeg water levels. Comparison of the results and some conclusions are also given in this chapter.

Chapter 6 gives a summary of the merits of the Kriging technique and its application to Lake Winnipeg water level estimation.

2 REVIEW OF PREVIOUS WORK

This chapter contains a review of previous work related to the different interpolation methods, a summary of applications of the Kriging technique in different subject areas, and finally, description of several models developed in order to obtain water level estimates for Lake Winnipeg.

2.1 INTERPOLATION METHODS

Suppose that there are N observed points $x_1, x_2, ..., x_N$, with respective measured properties $Z_1, Z_2, ..., Z_N$, and we want to interpolate the value Z^* at the point x. One possible way of estimating Z^* is as follows:

$$Z^*(x) = \sum_{i=1}^{N} \alpha_i(x) * Z_i(x) \qquad (2.1)$$

where $Z_i(x)$ represents the measured properties in the point x_i and the α_i are coefficients with $\Sigma\ \alpha_i = 1$ a common characteristic. This is a linear combination of the observed data.

Different determinations of the α coefficients leads to different interpolation methods.

2.1.1 LAGRANGE INTERPOLATION

This method belongs to the group of analytical methods. The modified formula

for estimation is:

$$Z^*(x) = \sum_{k=1}^{M} a_k * f_k(x) \qquad (2.2)$$

where the $\mathbf{a_k}$ are constant, the $\mathbf{f_k(x)}$ are known and in most applications are polynomial functions. If the number of observation points is small (<10), then **M** is equal to the total number of observed points **N**. However, if the total number of observation points is too large, the solution becomes the moving neighbourhood process with $\mathbf{M < N}$. Solution for $\mathbf{Z^*}$ involves the solution for the coefficients $\mathbf{a_k}$ (Gambolati 1979).

This method is acceptable if the observed data are tolerably smooth, but it can lead to unrealistic gradients when the surface is very chaotic. If values in the observation field are smooth the functions $\mathbf{f_k(x)}$ have a low degree polynomial function and the field modelled with these $\mathbf{f_k(x)}$ functions has the same characteristics. If the observed values in the field have a high variability then the mathematical function is forced to interpolate the data and this results in contorsions and 'wriggles' quite unrelated to the actual phenomena.

2.1.2 LEAST SQUARES

This method assumes that the estimated value of the desired property is the sum of a deterministic component and an error term.

$$Z^*(x) = \sum_{k=1}^{N} a_k * f_k(x) + e(x) \qquad (2.3)$$

where the coefficients $\mathbf{a_k}$ and the functions $\mathbf{f_k(x)}$ are defined the same way as previously. The error term $\mathbf{e(x)}$ has zero mean, constant variance and no autocorrelation (i.e., a white noise process). The solution of this method, unlike the Lagrange interpolation, does not provide definite interpolation. It gives estimated values at the observation point which may differ from the observed value. That implies that this method is not designed to solve problems of local phenomena (Delfiner 1976).

2.1.3 WEIGHTED INTERPOLATION TECHNIQUES

a. Weighting as a function of distance

In this method, it is assumed that the weighting coefficients depend only on the distance between observed points $\mathbf{x_i}$ and the desired point of estimation, $\mathbf{x}$.

$$u_j(x) = \frac{w(d_j)}{\sum_{i=1}^{N} w(d_i)} \qquad j=1,N \qquad (2.4)$$

$$\alpha_j(x) = \frac{1/u_j(x)}{\sum_{i=1}^{N} u_i(x)} \qquad j=1,N \qquad (2.5)$$

where $\mathbf{N}$ is the number of observation points, $\mathbf{w(d_j)} = | \mathbf{x} - \mathbf{x_j} |$ is the distance between desired and observed point, and $\mathbf{u_j}$ is the auxiliary function defined in equation (2.4) and used in equation (2.5) in order to obtain weighting coefficients α_j. Points

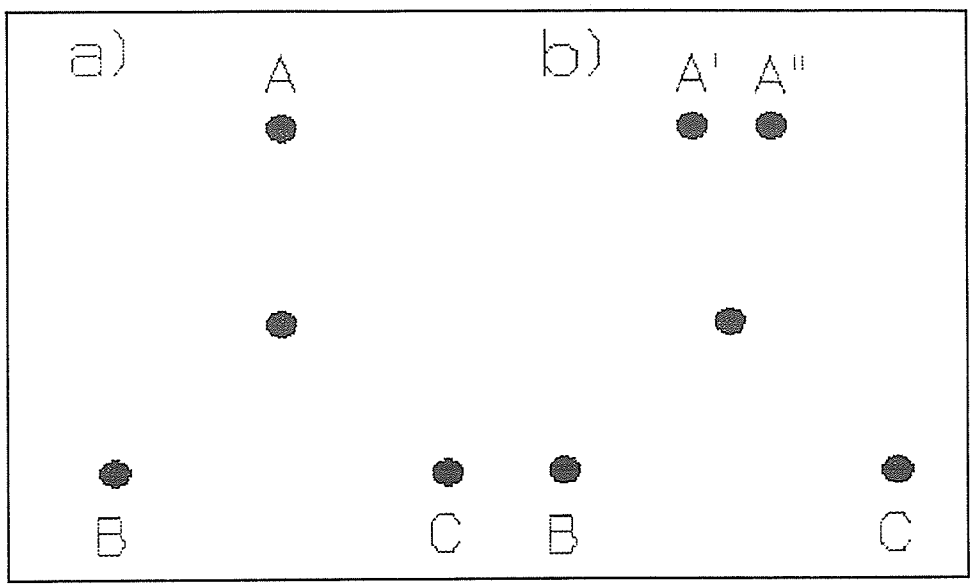


Figure 2.1 Disadvantage of Inverse Distance method

further from the point where the information is required may be more penalized by squaring the distance as follows $\mathbf{w(d_j)=|\ x - x_j\ |^2}$ or $\mathbf{w(d_j)=exp(\ k\ |\ x - x_j\ |\ )}$ where the smoothing effect depends on the parameter **k**. The weighting coefficient α_i approaches zero when the distance between the observed point and desired point is relatively large.

The major shortcoming of this method is that the relative positioning of observation points is not included into calculation of weighting coefficients. If we have three experimental points, situated at equal distance from the point to be estimated (Figure 2.1.a), the weights will be 1/3 for each. But if point **A** is replaced by two points very close to each other, **A'** and **A"** (Figure 2.1.b), an inverse distance weighting method will assign to each of them again an equal weight as 1/4. The influence of the two points **B** and **C** on the estimation point would decrease. However, the information they contain remains the same, and their weights should also

remain unchanged. In the new formation of the experimental points the weights should be 1/3 for points B and C and 1/6 for points A' and A". The distance weighting method cannot handle this situation. (Gambolati 1979)

b. Thiessen polygons

Weighting coefficients in this method are related to a subarea. The complete area of interest is divided into subareas so that the center of each of them lies close to a point where the value is measured. The assumption is that the observed property is uniformly distributed in each subarea. The weighting coefficient for observation i is then:

$$\alpha_i = \frac{s_i}{S} \qquad (2.6)$$

where $S = \sum_{i=1}^{N} s_i$, s_i is the size of the i-th subarea and N is the number of the subareas.

The first drawback of this model is that the calculation of weighting coefficients is only for one configuration of the observation points. In case of any change in the observation map, a new map of subareas must be constructed.

The second disadvantage of the method is that it does not take into consideration other factors, such as in the case of rainfall measurements, where the orographic influence is important. For the estimation of surface water levels, this is not a major issue however.

c. Kriging method

For a successful application of this model, it is necessary to have historic record of the desired property. From this record, it is possible to estimate an auxiliary function called the semivariogram. The semivariogram is half of the variance of two observed points which are equally distanced. The presentation of semivariogram is a diagram Γ versus h. The value of the semivariogram depends only on the distance between two points. The weighting coefficients can be determined from the solution of a system of **N+1** linear equations, where **N** is the number of observation points.

When the weighting coefficients are calculated, it is possible to calculate a confidence interval for the estimate at the same location. This reliability level depends only on the relative distance between the observation points and on the desired location. This capability is a major advantage of the Kriging interpolation method relative to the above-mentioned methods.

For detailed description of Kriging method see Chapter 3.

2.2 PREVIOUS USE OF KRIGING

The Kriging technique is a member of the class of stochastic interpolation methods. The general formulation of the theory was provided by Matheron (1969) but the theory is named after D.R. Krige who first applied some of the basic concepts of this theory to the estimation of gold content in the South African mines. Many other applications were made in the mining field. Also, the Kriging technique has been applied successfully for analyzing hydrological data.

The theory about 'Regionalized Variable' provided by Matheron is intended to provide a successful tool for the reconstruction of a natural variable based on a set of arbitrarily distributed observations. As note in the previous section the important improvement over the interpolation techniques is that the algorithm gives an estimate of reliability of the estimated value.

2.2.1 APPLICATION IN MINING FIELD

For mining engineers, it is important to know the concentration of a mineral in a given volume of ore. However, this concentration is highly dependent on the position of the ore in the orebody. Mining engineers have realized the inadequacy of having a large number of samples at one ore exposure, which may occur in a poor or rich zone, because they tell little about the nature of the ore elsewhere in the deposit. Therefore, mining technicians try to take samples at regular intervals rather than at randomly selected sites.

Traditional methods like polygonal and triangular weighting, rectangular zones of influence and inverse distance methods attempted to combine data on the sample position with an intuitive notion of the area of influence to produce usable results. Some of these techniques show good results, but, without providing confidence limits. These methods are based on the random observations of independent samples in a given population without respect for spatial position.

Introducing the theory of 'Regionalized variables' provides a framework suited to handle problems related to estimation of spatial variables. 'Regionalized variables' means variables whose values are related in some way to their position.

More information about the mineral volume in the ore can be obtained from the variance between equally distanced observation points. Distance in a regular mesh increases with the unit length. If the sampled data are more randomly distributed, not in a regular shape, then a classification of distance is needed to obtain a sufficient number of pairs of observations for a reliable point on the experimental semivariogram. This is very often the case in the mining industry.

The experimental semivariogram is one half of the average of squared difference between the above defined two observations. On the basis of the experimental semivariogram, a theoretical semivariogram can be obtained. Experimental semivariogram consist of discrete values for various separation distances, however the theoretical semivariogram is a fitted function to the experimental points. This is the basis for establishment of the estimated property.

The semivariogram is related not only to the two measurements, but also to a single sample itself. This is the case when the sample is sufficiently big enough so that the mineral concentration is not uniformly distributed in it. In that case, the nugget effect, or the discontinuity at the zero distance on the Γ versus h diagram, has more influence than when the sample is treated as uniform data. In the uniform sample the variation will be zero. The non-uniformity of the observed property means that not only the geometry of the field with the place of the samples but also the relative geometrical relationship between samples and the estimated fields and the geometrical configuration of the samples have effect on the solution.

In some cases, the inverse distance, or inverse distance squared methods might give close results to those obtained by Kriging, but the Kriging might define the places where further sampling is necessary for better estimation. The biggest advantage of

the Kriging technique is that it provides a reliability level of the estimated concentration of mineral in the orebody.

2.2.2 APPLICATION IN THE HYDROSCIENCES

One use of Kriging in hydrosciences is the calculation of the average rainfall depth over a given region (Delhome 1978). It is often the case that some measurements are missing or measurements at desired locations are not available. The main assumption in such a case is that different storms are proportional to each other in the intensity while the spatial dispersion of the events is the same. In that way it is possible to collect enough data pairs to obtain an experimental semivariogram. After that, the theoretical semivariogram can be drawn. The Kriging system (see Chapter 3.2) will be solved for every storm to obtain optimal weighting coefficients for each storm. This will be the solution for one configuration of gauge stations. For other raingage networks, other weighting coefficients are needed.

If the interest is to know the point by point value in the observed domain, like a groundwater level estimation, the approach is slightly different. Theoretical semivariogram can include some of the physical phenomena, such as a transmissivity of the soil. The Kriging system will then be solved for each grid mesh. On the basis of the obtained values in the desired points, it is possible to draw a map of the complete observed field. This approach is reasonable to use for the average value over a domain, if this field has an irregular shape. The first step is to obtain a value at all of nodes of the mesh and then calculate a mean value of these values which will be the estimated value of observed property on the domain of interest.

In both cases it is possible to use a Kriging technique for the optimization of the measurement network with the objective of obtaining a more accurate estimated value.

When the purpose is to estimate an average value over a given domain, the aim is to find the location for a new gauge in order to get the smallest Kriging error, or the confidence interval (see Chapter 3.2), over the domain. The fictitious point can be moved over an observed domain and the new location of the gauge will be found where the Kriging error has the smallest value.

When the purpose is to obtain local estimates of the property the problem is somewhat different because there are the same number of Kriging errors as the number of the node points. An additional measurement point will influence the Kriging error of any grid node in the neighbourhood of the location of this new point. In that case, the new station will be located at that point where the local maxima of the Kriging error existed.

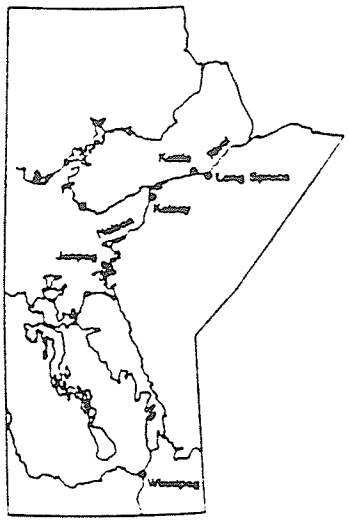
In both of the above cases it is possible not only to find the location of the new station, but also to find which station would be preferable to relocate. In the first case, the tendency will be that each gauge has equal weight. The gauge with the highest weight will be moved. In the second one, the tendency is that the Kriging error has an uniform level over the observed field. The gauge in the lowest Kriging error area will relocate somewhere in the highest Kriging error area.

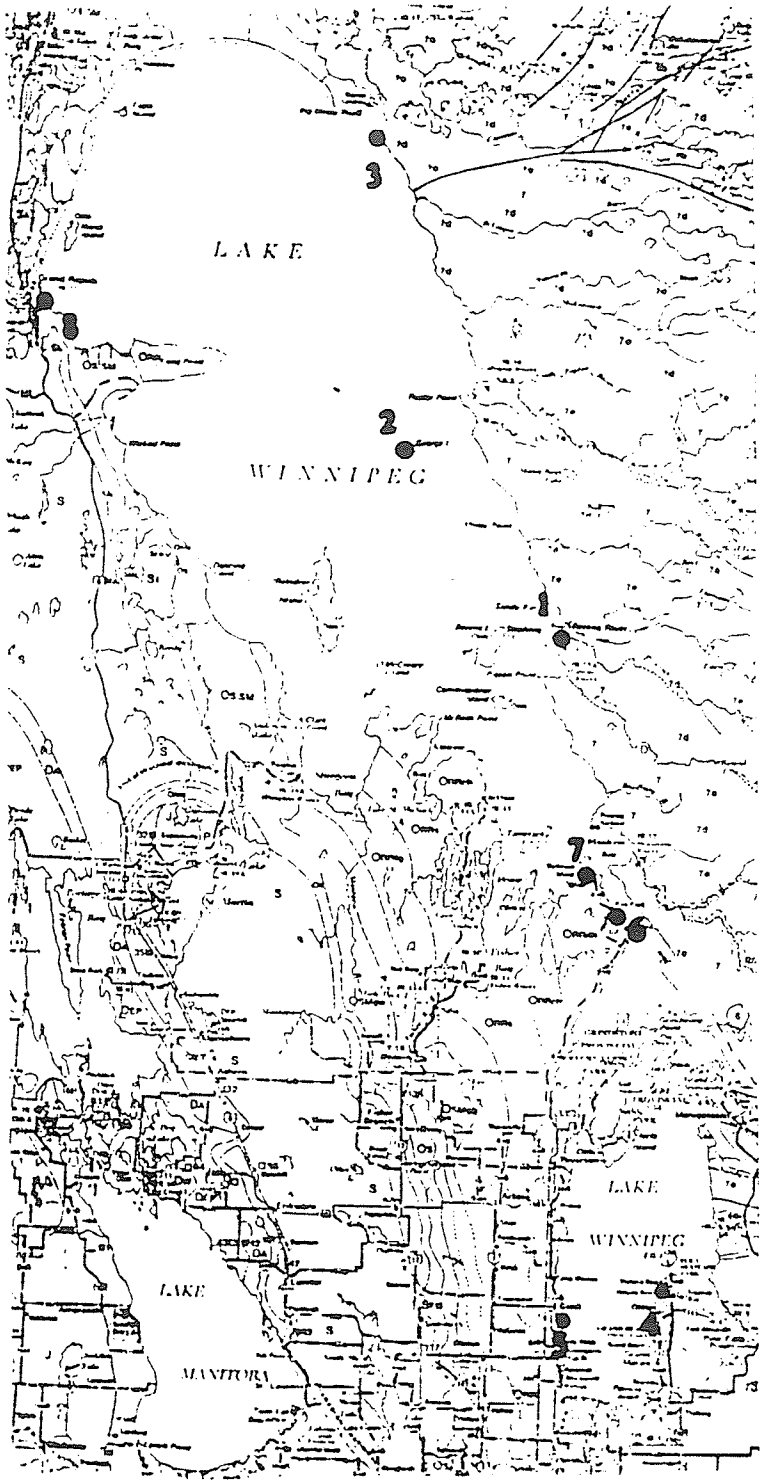
2.3 TECHNIQUES USED FOR ESTIMATING WATER LEVELS ON LAKE WINNIPEG

Lake Winnipeg is a large shallow lake, thirteenth largest surface area in the world, seventh largest in North America and the largest 'reservoir' of the Manitoba Hydro system. The average depth is less than 15 m and its surface area is approximately 23700 square kilometers (km^2). The lake can be divided into three sections. The small south basin, the large north basin and the narrow section between these two basins. The waters flowing into the lake come from Saskatchewan River, Red River, Winnipeg River and Berens River, mentioning just those rivers with a significant inflow. Outlet of Lake Winnipeg is the Nelson River at the north east corner of the lake. The outflow is partially controlled at the Jenpeg Generating Station about 100 km north of the lake.

Since November 18, 1970 Manitoba Hydro has had a licence to regulate the level of Lake Winnipeg. The plan specified that the level of Lake Winnipeg would be maintained between 216.7 and 217.9 meters above sea level.

From the establishment of the first gauge station at Winnipeg Beach in 1913 until the establishment of the gauge station at George Island in 1983, there were several changes in the stations locations and their elevation adjustments, that now in the measured levels incorporate the water level difference caused by the earth's rotation. Since the last changes in 1983, there are eight gauge stations with the daily records on Lake Winnipeg. The gauage network is operated by Water Survey of Canada. Figure 2.2 shows the location of the stations.





LAKE WINNIPEG
GAUGE STATIONS:

1 Berens River
2 George Island
3 Montreal Piont
4 Victoria Beach
5 Gimli
6 Pine Dock
7 Matheson Island
8 Mission Point

Figure 2.2 Gauge stations on Lake Winnipeg

The surface of the lake is not flat. The wind action is the most important cause of the non-uniform lake level. This set-up can result in water level differences of as much as 0.6 m from one side of the lake to the other. The effect of the rotation of the earth, that the water tends to rise near the earth's equator, also results in nonuniform water level. Furthermore the gauge stations are also constantly breaking down. Since most of the time they are not completely broken, it is difficult to say whether or not the recorded level is correct. Therefore, a good method to use the daily recorded levels and provide an accurate estimate of the 'official average' lake level is required. In the past, many techniques were used. First, a hand drawn method was used with daily data at Gimli as a guide. The subsequent methods included theoretical determination of wind effects and numerous mathematical smoothing techniques. These are briefly described below.

Theoretical Determination of Wind Effects

A model developed by Dr. E.J. Fee, which incorporates wind effects, was successfully used on Green Bay of Lake Michigan. Model application on Lake Winnipeg did not perform satisfactory, because of the complexity of the geometry, the size of the lake and the presence of thermal stratification (ad hoc Committee on Lake Winnipeg Datum 1982).

Lake Ontario Model

The model developed by The Advisory Committee of the International St.

Lawrence Board of Control for Lake Ontario has a capability for eliminating the wind effect. In spite of the fact that the model is based on a simple arithmetic process, the application to Lake Winnipeg was impossible because of an insufficient number of gauging stations (ad hoc Committee on Lake Winnipeg Datum 1982).

Lake Erie Model

A model developed by Ontario Hydro for Lake Erie was considered possible for successful application on Lake Winnipeg, because of the similar complexity in geometry, and similarity in the size and depth of the two lakes. The cause of the unsuccessful application was an insufficient number of real time meteorological stations available to provide input for the model (ad hoc Committee on Lake Winnipeg Datum 1982).

Empirical Mathematical Smoothing

Many models, from straight arithmetic average of all recorded levels, to three, five, seven days moving average model for stations Berens River and Gimli to the recommended procedure now in active use have all been used for water level estimation on Lake Winnipeg.

The procedure presently used is a three step smoothing process. The weighting coefficients are in inverse proportion to standard deviation of each station's successively measured level. In the second step the obtained level is further refined in the sense that the maximum daily water level change is ± 0.0183 meters. This is a

maximum possible water level changes caused by large outflow and low inflow in the lake or vice versa. In the third step, the sawtooth shape of the daily calculated water level from the second approximation is further smoothed. In the particular day the water level is averaged with the two previous and two following days (ad hoc Committee on Lake Winnipeg Datum 1982).

A second method, currently used in Manitoba Hydro, is called the rational model and is based on the water mass balance. This method gives a weekly water level estimation and can be formulated in the following form:

$$S_{i+1} = S_i - \delta S_P + (I_R + I_P + I_L - Q_R) * T \qquad (2.7)$$

where: S_i is the stored water volume in the Lake Winnipeg in week **i**, I_R is the regulated, known, inflow (such as Red River, Winnipeg River and Saskatchewan River), I_P is the significant precipitation occurring on Lake Winnipeg, I_L is the unregulated, unknown, inflow, Q_R is the Nelson River outflow, δS_P is the storage change in the Playgreen Lake and Jenpeg forbay, and **T** is the time step.

The water volume in Lake Winnipeg is estimated by Thiessen polygons using seven day averaged water level records for each gauge station. The water volume change in the Jenpeg forbay is estimated by Jenpeg forbay water level record. In the inflow-outflow part of Equation (2.7) for unregulated inflow, I_L, a two step averaging procedure is used.

Weekly unregulated	First step averaging	Second step averaging	inflow
.	.	.	
.	.	.	
[i-5]	a_{15} = {1/3 * ([i-6]+[1-5]+[i-4]}	{1/3 * (a_{16}+a_{15}+a_{14})}	
[i-4]	a_{14} = {1/3 * ([i-5]+[i-4]+[i-3]}	{1/3 * (a_{15}+a_{14}+a_{13})}	
[i-3]	a_{13} = {1/3 * ([i-4]+[i-3]+[i-2]}	{1/3 * (a_{14}+a_{13}+a_{12})}	
[i-2]	a_{12} = {1/3 * ([i-3]+[i-2]+[i-1]}	{1/3 * (a_{13}+a_{12}+a_{11})}	
[i-1]	a_{11} = {1/3 * ([i-2]+[i-1]+[i]}	{1/3 * (a_{12}+a_{11}+a_{10})}	
[i]	a_{10} = {1/2 * ([i-1]+[i]}	{1/2 * (a_{11}+a_{10})}	

This calculation is made in a spreadsheet and the obtained result, S_i is easy to compare with the measured water levels. If a weekly water volume change shows unrealistic value then further investigation of the input data set is needed (ad hoc Committee on Lake Winnipeg Datum 1982).

3 THEORETICAL DEVELOPMENT OF THE KRIGING INTERPOLATION METHOD

The theoretical basis of the Kriging interpolation method will be presented in this chapter. The first section describes the empirical and theoretical semivariogram. In the second section the Kriging system is presented together with the discussion related to the determination of the weighting coefficients and the reliability of the estimated value.

3.1 SEMIVARIOGRAM

Before defining a semivariogram some basic assumptions should be established. It is assumed that the field of measurements represents a statistically stationary field. That means, that the difference in registered data between any two points in the field depends only on the distance between these two points (and possibly on the relative orientation in the field), but not on the location in the field. If different orientations have no effect on the property difference between two points at the same distance, then this represents an isotropic case. For most real-world problems the assumption of an isotropic case is made, although this is seldom actually true. A shortage of data necessary to quantify the anisotropy leads to this assumption.

Recall the assumptions from Section 2.1 that there are **N** observation points $\mathbf{x}_1, \mathbf{x}_2, \ldots, \mathbf{x}_N$ with respective measured properties of $\mathbf{Z}_1, \mathbf{Z}_2, \ldots, \mathbf{Z}_N$. For any sample point $\mathbf{x}_i$ which is separated from another sample point by distance h denoted by $\mathbf{x}_i+\mathbf{h}$

it is possible to define the average sum of squares of the difference in sample magnitude as:

$$2\Gamma^*(h) = \frac{1}{n} \sum_{i=1}^{n} [\ Z_i(x) - Z_i(x+h)\ ]^2 \qquad (3.1)$$

where: **n** is the number of data pairs used in the calculation, $2\Gamma^*(\mathbf{h})$ is the empirical variogram value for separation distance **h**, and $\Gamma^*(\mathbf{h})$ is the semivariogram value. Both the variogram and semivariogram are just a function of separation distance **h**. The units of $2\Gamma^*(\mathbf{h})$ and $\Gamma^*(\mathbf{h})$ are the same and equal to the square of the units $\mathbf{Z}_i$. The semivariogram is defined as a calculated value of $\Gamma^*(\mathbf{h})$ for various distances and is plotted as a diagram of Γ^* versus **h**. On this graph are as many points as number of separation distances between two points.

For a rectangular, regular mesh of measurements points where the samples were taken at distance $\delta\mathbf{h}$ the semivariogram has a value at every distance step of $\delta\mathbf{h}$. However, this type of measurement network is very rare in the real world, because for most cases the distances are not equal between two measured points. In those cases, distances can be classified to obtain a reasonable number of pairs for each distance class. In both cases, in regular mesh and in random sampled points, as the distance increases between points, less pairs of points are included in the calculation. It follows that points on the semivariogram graph closer to the origin (for small distance **h**) will be more reliable than those with greater distances. This is an important consideration when interpreting the empirical sample variograms.

In addition to the above mentioned semivariogram as defined in Equation (3.1), there are some other definitions.

Semivariogram defined by Huber (1964)

$$2\Gamma^*_q(h) = Q_q \; [\; Z_i(x) - Z_i(x+h) \;]^2 \qquad (3.2)$$

where Q_q is the **q**th quantile of the squared differences for distance **h**. This is an optimal estimator for contaminated normal distributions.

Definition by Cressie and Hawkins (1980) is:

$$2\Gamma^*(h) = \frac{1}{0.457} \{\text{median}[(Z_i(x) - Z_i(x+h))^2]^{1/4}\}^4 \qquad (3.3)$$

Other scale estimators of the variogram are Dowd (1984):

$$2\Gamma^*(h) = \{ \frac{1}{n} \sum_{i=1}^{n} | \; Z_i(x) - Z_i(x+h) \; | \; \}^2 \qquad (3.4)$$

and

$$2\Gamma^*(h) = 2.198 \; \{\text{median} \; | \; Z_i(x) - Z_i(x+h) \; | \}^2 \qquad (3.5)$$

In general the quantile variogram does not give good results when used in an interpolation model. Others give fairly good and similar results. The only difference is the complexity of calculation required. Which calculation method will be used depends on the user calculation capability and the nature of the observed property as well.

At the separation distance of zero, $\mathbf{Z_i(x)=Z_i(x+h)}$ so $\mathbf{\Gamma^*(h)=0}$. The semivariogram passes through the origin on the Γ^* versus **h** diagram. However, it is possible that two distinct points, even very close to each other, show a difference with a variance equal

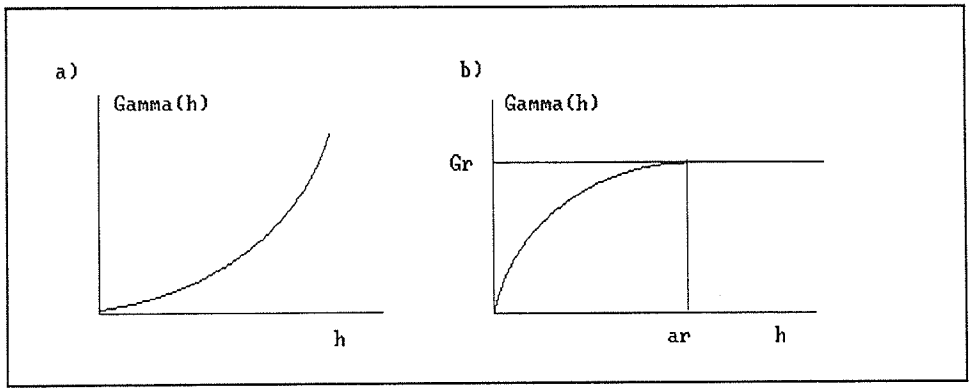


Figure 3.1 Behaviour of smivariogram near the origin

to the so-called nugget effect.

The term "nugget effect" gets its name from the gold nugget deposits, where the gold grade varies a great deal, depending on whether the point is inside or outside a nugget. The term has been kept to describe the discontinuity of the variogram which may be due to a distance on a scale much smaller than the spacing of the data points.

In that case the semivariogram does not pass through the origin, but has a discontinuity at the origin. This can be explained by the fact that the observed property is very irregular at small separation distances. As the separation distance increases the value of $\Gamma^*(\mathbf{h})$ must be non-zero and because of the definition of the variogram, the $\Gamma^*(\mathbf{h})$ value is always positive. The semivariogram near the origin can have several different shapes. Mostly it is linear as in Figure 3.1.a, parabolic as in Figure 3.1.b, or flat, (i.e., a pure nugget effect) as in Figure 3.1.c. The value of Γ^* increases as separation distance rises, as shown in Figure 3.2.a, except in the pure nugget effect case. In some cases, the value of Γ^* variance increases until some point where a further increase in the separation distance does not lead to increased value of

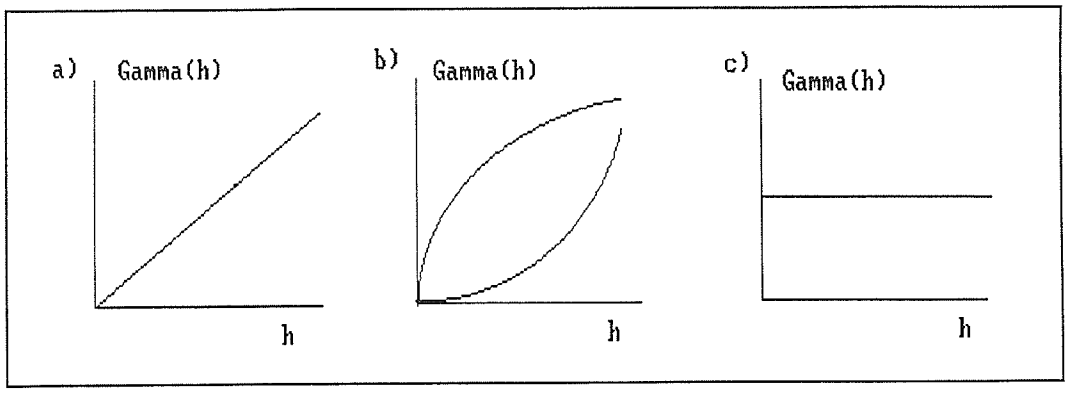


Figure 3.2 General shape of semivariogram

Γ^* variance. In such a case, the variogram has a sill and a radius of influence, as shown in Figure 3.2.b. At the separation distance **h** when the variogram approaches a constant value Γ^*_r, called the sill the separation distance **h** is called the radius of influence $\mathbf{a}_r$. Radius of influence and at that certain point the sill-value of semivariogram is important to define because if the semivariogram has a decreasing slope after a certain point (radius of influence), the influence of these far away points will be higher than they should be. In that case the value of semivariogram will be equal to the sill for separation distances greater then the radius of influence. In this way, it is possible to avoid large weighting coefficients for these points further than the radius of influence. In other case, if the semivariogram has a constantly increasing slope, the radius of influence has an equally important role as in the previous case now to avoid a relative big difference between semivariogram value for small and for large separation distances. This is important in order to avoid negative weighting coefficients for distant points.

In practice it is impossible to use the experimental semivariogram directly. It is

necessary to fit a theoretical model to the experimental semivariogram. There are many different approaches for finding a suitable model for the experimental semivariogram.

The simplest theoretical model is the pure nugget effect as:

$$\Gamma(h) = C \tag{3.6}$$

This model has a constant value **C** which is independent of the separation distance **h** and equal to the nugget effect.

The linear theoretical semivariogram model is the next simplest and has the form:

$$\Gamma(h) = b * h \tag{3.7}$$

where **b** is the slope of the line and **h** is the separation distance. This model has no sill and no radius of influence, however the value of $\Gamma(\mathbf{h})$ rises as separation distance increases.

The nonlinear power model, used very often in hydrology and has the following form (McCuen 1986):

$$\Gamma(h) = b * h^c \tag{3.8}$$

where **c** is the power coefficient. When **c** is equal to 1 the power model becomes the linear model. Only in the case when **c** is less than 0 does the model have a radius of influence and a sill (Figure 3.2.b).

The extension of the power model is a linear combination of separation distances raised to a power as:

$$\Gamma(h) = \sum_{i=1}^{m} b_i * h^i \qquad (3.9)$$

The summation is usually made for three terms, (i.e., m=3). A large number of terms gives a better fit to the experimental model but it is always a question, how closely should the theoretical model follow the experimental model's fluctuation, which could be a nonphysical nature.

The logarithmic or deWijsian model (McCuen 1986) has the following form:

$$\Gamma(h) = b * \ln(h) \qquad (3.10)$$

This model also has no sill. If the separation distance scale is logarithmic the semivariogram model plot will be a straight line.

The exponential model provides coefficients which control the sill and radius of influence. The form of the model is:

$$\Gamma(h) = \Gamma_r \, [\, 1- \exp(-h/a_r) \,] \qquad (3.11)$$

where the $\mathbf{a_r}$ controls the rate at which $\Gamma(\mathbf{h})$ approaches the sill and Γ_r is a sill value. This model has a fixed shape (McCuen 1986).

Most physical processes can be modelled by a spherical model given as:

$$\Gamma(h) = \begin{cases} \Gamma_r & \text{when } h > a_r \\ \Gamma_r(3h/2a_r - h^3/2a_r^2) & \text{when } h =< a_r \end{cases} \qquad (3.12)$$

The above mentioned forms of theoretical semivariogram can be used in combination. The most common combination is a pure nugget effect plus one of the

above mentioned theoretical models (McCuen 1986).

The method used to fit the theoretical model to the experimental semivariogram can be selected by the user. The fit of theoretical model to the experimental semivariogram must be tested. If the selected theoretical model does not reproduce the sampled property in the Kriging model, then another model needs to be selected and tested again. Note that in the development process of the theoretical semivariogram, the emphasis is more on the general shape and behaviour near the origin of the semivariogram than on the theoretical model strictly following every fluctuation of the experimental semivariogram.

The semivariogram has an important role in the Kriging interpolation method. On the basis of the theoretical semivariogram, the weighting coefficients for each of the measured points are determined. The weighting coefficients are inversely related to the $\Gamma(\mathbf{h})$ value from the semivariogram model. In a number of situations, it may be possible to avoid calculating a semivariogram, or simply, there may not be enough available data to calculate the semivariogram. However, the disadvantages involved (that the real behaviour of the observed property is not presented), are not always worth the trouble they can save. In that case it is necessary to choose one of the theoretical semivariogram models. For most hydroscience problems, especially in case of groundwater estimation, the spherical model gives a fairly good results. It is necessary to estimate parameters $\mathbf{a}_r$ and Γ_r for this model and to test them by the Kriging model.

3.2 KRIGING SYSTEM

In order to be able to deal with phenomena where the hypothesis of constant expectation is not acceptable one more assumptions will be introduced. This non constant mean situation could happen in the case of hydraulic head or thickness of mineral layer in an orebody.

The expectation of the studied variable $\mathbf{Z_i(x)}$ is a function $\mathbf{m(x) = E\ [Z_i(x)]}$. This function, $\mathbf{m(x)}$, is used to deal with drift and it is assumed that it is regular enough to be expressed locally as:

$$m(x) = \sum_{l=1}^{k} a_l\ f_l(x) \qquad (3.13)$$

where $\mathbf{f_l}$ is a given basic function and the $\mathbf{a_l}$ are unknown coefficients. In a case without a drift it is also possible to express $\mathbf{m(x)}$, where the basic functions will be identically equal to one and:

$$m(x) = a_1 \qquad (3.14)$$

For the estimated value of the $\mathbf{Z_0}$, where $\mathbf{0}$ indicate a point, it is considered to be a weighted average of the available collected data:

$$Z_0^* = \sum_{i=1}^{N} \alpha_i\ Z_i(x) \qquad (3.15)$$

where the asterisk indicates the estimated value.

The problem is to find the set of weights α_i which will give the best estimated value

of Z_0^*. The best estimate is one for which the weights α_i are unbiased, giving non systematic over- or under-estimate, and optimal, minimum mean square error. These conditions can be mathematically expressed as:

$$E[Z_0^* - Z_0] = 0 \tag{3.16}$$

$$\mathrm{var}[Z_0^* - Z_0] = \text{minimum} \tag{3.17}$$

With the combination of Equations (3.16) and (3.13), the unbiasedness condition becomes:

$$E[Z_0^* - Z_0] = E[\sum_{i=1}^{N} \alpha_i Z_i(x) - Z_0]$$

$$= \sum_{i=1}^{N} \alpha_i \left(\sum_{l=1}^{k} a_l f_{li} \right) - \sum_{l=1}^{k} a_l f_{lS}$$

$$= \sum_{l=1}^{k} a_l \left(\sum_{i=1}^{N} \alpha_i f_{li} - f_{lS} \right) = 0 \tag{3.18}$$

where $\mathbf{f_{li}} = \mathbf{f_l(x_i)}$ and

$$f_{lS} = \frac{1}{S} \int_S f_l(x)\, dx$$

where S indicate the domain of interest, and the integration is made over the domain of interest.

Equation (3.18) which express the unbiasedness, must be fulfilled, which results in:

$$\sum_{i=1}^{N} \alpha_i f_{li} - f_{iS} = 0 \qquad l=1,k \tag{3.19}$$

Taking that $f_1 = 1$, (i.e., there is no drift) and the function which describes the drift becomes constant, then the first constraint will come out as:

$$\sum_{i=1}^{N} \alpha_i - 1 = 0 \tag{3.20}$$

The error term can be written in a form as a linear combination of differences between observed and real values:

$$Z_0^* - Z_0 = \sum_{i=1}^{N} \alpha_i Z_i(x) - Z_0 = \sum_{i=1}^{N} \alpha_i (Z_i(x) - Z_0) \tag{3.21}$$

The variance of this error can be expressed in terms of the variogram:

$$\mathrm{var}[Z_0^* - Z_0] = E[(Z_0^* - Z_0)^2]$$

$$= E[(\sum_{i=1}^{N} \alpha_i Z_i(x) - Z_0)^2]$$

$$= -\sum_{i=1}^{N} \sum_{j=1}^{N} \alpha_i \alpha_j \Gamma_{ij} + 2 \sum_{i=1}^{N} \alpha_i \Gamma_{is} - \Gamma_{ss} \tag{3.22}$$

where: $\Gamma_{ij} = \Gamma(x_i - x_j)$ - is the value of the variogram between two experimental points x_i and x_j

$\Gamma_{is} = \frac{1}{S} \int_S \Gamma(x_i - x)dx$ - is the mean value of the variogram between the point x_i and a point describing the domain S

$$\Gamma_{SS} = \frac{1}{S^2} \int_S \int_S \Gamma(x-x')dxdx'$$ - is the mean value of the variogram between two points independently located within the domain S.

Minimizing the quadratic form of α_i in Equation (3.22) under the constraint set in Equation (3.19), which expresses the unbiased condition, the following linear system, called the **Kriging System**, is obtained:

$$\sum_{j=1}^{N} \alpha_i \Gamma_{ij} + \sum_{l=1}^{k} \mu_l f_{li} = \Gamma_{iS} \qquad i=1,N \qquad (3.23.a)$$

$$\sum_{j=1}^{N} \alpha_j f_{lj} = f_{lS} \qquad l=1,k \qquad (3.23.b)$$

For the case to estimate the property at point, i.e. the domain is reduced to a point, it is necessary to substitute:

f_{lS} by $f_{l0} = f_l(x_0)$

Γ_{iS} by $\Gamma_{i0} = \Gamma(x_i - x_0)$

Γ_{SS} by $\Gamma_{00} = \Gamma(x_0 - x_0) = 0$

The solution of this system of **n+k** linear equations with **n+k** unknowns gives **n** weights α_i and **k** Lagrange multipliers μ_l.

When the weighting coefficients are obtained, at the optimum, it is possible to substitute:

$$\sum_{j=1}^{N} \alpha_j \Gamma_{ij} = \Gamma_{is} - \sum_{l=1}^{k} \mu_l f_{ls} \tag{3.24}$$

and calculate the estimation variance as:

$$\sigma^2_K = \text{var}\,[Z^*_0 - Z_0] = \sum_{i=1}^{N} \alpha_i \Gamma_{is} + \sum_{l=1}^{k} \mu_l f_{ls} - \Gamma_{ss} \tag{3.25}$$

(Derivation of Kriging System and Kriging Error is based on Delhome 1978)

For the case of a point estimation, like finding the average value over mesh, there are as many Kriging systems as there are nodes for which the estimates are required. If the system has the property that all the experimental points are taken into consideration, then only the right hand side of the Kriging system changes. Thus, it is necessary to invert the basic matrix of the Kriging system only once. However, if the number of experimental points is large (greater than 15 or 20) then it is the case of a moving neighbourhood. In such a case only 15 - 20 observations will be taken in the computation, and the whole Kriging system must be solved for each node. This remark is related to saving computation time.

In applying the Kriging system for estimation, the distances between the estimation points, between the estimation point (domain) and the experimental points, and finally the semivariogram (Γ versus **h** diagram) shape are taken into account. The Kriging system gives higher weights to the closer points when the semivariogram has a regular form. Regular form is defined as the one when the theoretical semivariogram passes through the origin and has a continuously rising shape. If the point where estimate is required is identical with the experimental one, the solution of the Kriging

system gives:

$$\alpha_i = 1 \qquad \text{for} \quad i = j$$

$$\alpha_i = 0 \qquad \text{for} \quad i \neq j$$

the case is that $\mathbf{Z}^*_0 = \mathbf{Z}_i(\mathbf{x})$, i.e., that the Kriging is an exact interpolator. The Kriging variance in the case has zero value.

If the semivariogram is a pure nugget effect, the Kriging system will give an average weighting coefficient for each of the experimental points. A difficulty may arise if a nugget effect combines with a rising shape for the semivariogram. At an experimental point, the Kriging system will remain the exact interpolator, but outside of those points, the Kriging system leads to an estimate where the chaotic component is filtered out. This case is characterized with a local discontinuity around the measurement points.

For the optimization of the measurement networks it is meritorious that the Kriging system takes into account, especially in the calculation of the variance, only the structure and the geometric configuration of the data collection points and the estimation point (or domain). The optimal network configuration does not depend on the actual measured value.

3.2.1 SOME RECOMMENDATIONS IN THE CALCULATION OF THE KRIGING SYSTEM

Negative weights

In some situations it is possible that negative weights may be obtained. This

happens mostly when the theoretical semivariogram does not have a sill and radius of influence. The difference between the Γ value for close and for the point far away is relatively large. Therefore, the Kriging system will be weighted with negative weight for the farther measured points. If this negative weight is not significant, (i.e., absolute value of all negative weighting coefficients must be less than any positive weighting coefficient), a rough solution can be obtain by replacing the weights as:

$$\alpha_i = \frac{|\alpha_i|}{\Sigma |\alpha_i|} \qquad (3.26)$$

In the case of significant negative weights, it is necessary to recompose the theoretical semivariogram. In some cases it is sufficient just to reduce the radius of influence. This will reduce the difference of the Γ value for different points and as a result the weights will be more uniform. There will still be some difference in the weights for the close and for the far away points, but all the weights will be positive. In other cases, the whole process of the development of the theoretical semivariogram must be repeated. The new theoretical semivariogram requires a smaller slope, increased discontinuity (nugget effect) at the origin and a defined radius of influence at a certain point, in order to avoid negative weights in the solution of the Kriging system.

Outliers

It is also possible using Kriging variance to find which measured point is out of the acceptable estimation range. This is a comparison between squared difference of estimated value $\mathbf{Z}^*_i(\mathbf{x})$ and the measured value $\mathbf{Z}_i(\mathbf{x})$ and the Kriging variance σ^2_K

multiplied by coefficient **k** as:

$$[Z_i(x) - Z^*_i(x)]^2 > k\sigma^2_K \qquad (3.27)$$

where σ^2_K is a Kriging variance and **k** is a coefficient which usually has a value between 2 and 9. For each case the value of coefficient **k** must be determined. For the higher value of **k** coefficient there are more significant the influence of every measured value on the estimated value, however, for the small value of **k** coefficient the criteria that the measurement is outlier will be considered even for the small non-uniformity in the measured data. If the statement in Equation (3.27) is true the S^2_i value needs to be calculated as:

$$S^2_i = \frac{[Z_i(x) - Z^*_i(x)]^2}{c\ \sigma^2_K} \qquad (3.28)$$

where the coefficient **c** is between 0.5 and 1. The S^2_i value represents the normalized variance. As the S^2_i value is bigger, i.e. the difference between estimated and measured value is large, the effect of reduced weight for the outlier data will be more significant. In this process, it is also necessary to chose the **c** coefficient. For small values of the **c** coefficient, the penalization is more significant. Therefore, the Kriging system of Equation (3.23) will be modified and recalculated as:

$$\begin{aligned} &\sum_{j=1}^{N} \alpha_i\, \Gamma_{ij} - \alpha_i S^2_i + \sum_{l=1}^{k} \mu_l\, f_{li} = \Gamma_{is} \qquad i=1,N \\ &\sum_{j=1}^{N} \alpha_j\, f_{lj} = f_{ls} \qquad l=1,k \end{aligned} \qquad (3.29)$$

In this way the calculated weights for measured points which were found as outliers will be reduced and these points are filtered out from the interpolation process.

In summary, the process of Kriging interpolation method could be summarized as:

i) Use historical data to obtain an experimental semivariogram,

ii) Fit the theoretical semivariogram model to the experimental one,

iii) Test the theoretical model with the Kriging System, Equation (3.23), if not satisfied, go back to ii)

iv) Use the Kriging system of Equation (3.23) to obtain the weights and later the Kriging variance by Equation (3.24),

v) Check for possible outliers and if there are some, calculate the S^2_i values and solve the modified Kriging system of Equation (3.29),

vi) Repeat the steps iv) and v) for all estimation points.

The flowchart of the algorithm is shown in Figure 3.3

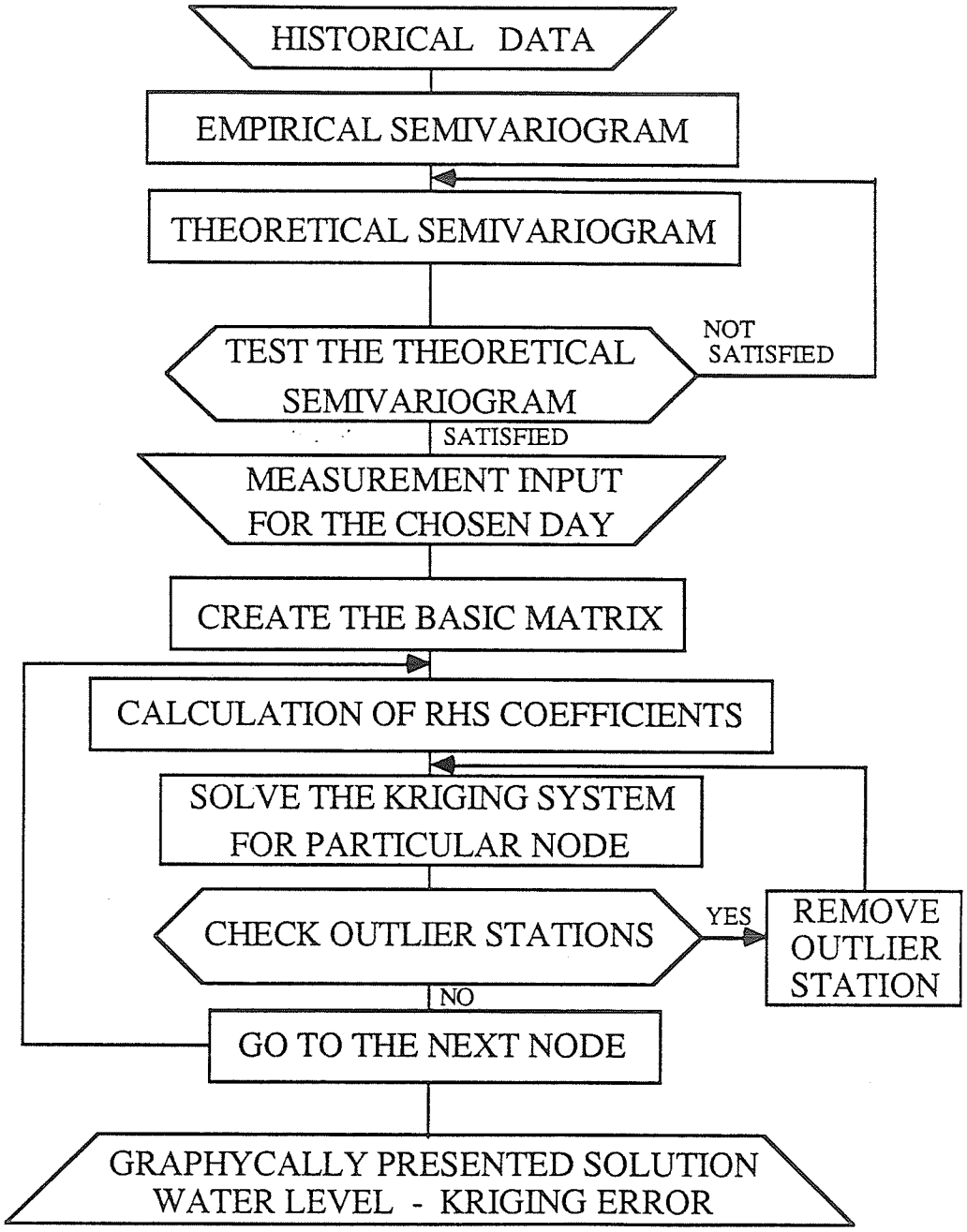


Figure 3.3 Flowchart of the Kriging algorithm

4 APPLICATION OF KRIGING FOR LAKE WINNIPEG WATER LEVEL ESTIMATION

In this chapter, the application of the Kriging technique for the Lake Winnipeg water level estimation is presented. In the first section, the semivariogram model for Lake Winnipeg with special characteristics identified through the development phase will be described. Following section reports the application of Kriging system to the Lake Winnipeg water level data. The last section of this chapter summarizes the algorithm for the Kriging method and makes recommendations for its use for the Lake Winnipeg water level estimation.

4.1 SEMIVARIOGRAM

Currently, eight gauge stations are located on the Lake Winnipeg. Two of them are in the south basin, two are in the narrow section between the south and north basins and four stations are in the northern basin (see Figure 2.2). The selected semivariogram is, after discussion in Section 3.1, as Equation (3.1) and calculated by computer program presented in Appendix B.

$$2\Gamma^*(h) = \frac{1}{n} \sum_{i=1}^{n} [\, Z_i(x) - Z_i(x+h) \,]^2 \qquad (4.1)$$

The assumption is that the water level difference between two points does not depend on the direction, just on the separation distance. It was necessary to introduce the

assumption, because there are a limited number of experimental points in a random location (not on the regular grid nodes). With these location of experimental points, it was impossible to develop a directional experimental variogram to take into account a measurement difference as a function of the direction. Thus the case study is considered as an isotropic case.

Since in this case there are eight gauge stations, the combination of eight by two gives 28 pairs of points. Each pair corresponds to a different separation distance. Classification in distance classes in this case is not useful, since the number of experimental points is small. Instead of the unit step, the actual distance is used on the semivariogram distance scale. In that way the continuity in the semivariogram shape is preserved, but on the other hand for each distance only one pair of points is available. In order to avoid this, one more assumption is introduced. The problem will be not considered to just exhibit spatial stationarity, but also time stationarity will be introduced. This assumption means, that the expected difference between two points will be the same, and is independent of the date used for calculation. Thus, in Equation (4.1) **n** represents the number of days when in both observed stations there are recorded water levels. If for some reason, even one observation is missing, this day will be skipped and not taken into account for experimental variogram calculation. In Appendix A, where the raw input data are presented, the zero value means that at that day no measured data were available for that gauge station.

The data (daily recorded water level) were provided by Manitoba Hydro. On the basis of these data, it was possible to calculate the experimental semivariogram. The calculation was made for one year (1987) separately for each month. The year 1987 was chosen, because this year shows an average "behaviour", without a large

irregularity in the recorded levels. Irregularity, in this context would imply that the recorded water level jumps at some station in an unrealistically high amount. An additional irregularity would arise from many interruptions in the recorded data.

The obtained monthly experimental semivariograms are very inconsistent among themselves, meaning that some of them have a different shape and also a different maximum, sill value. In order to avoid the fluctuation of the monthly semivariogram shape, 5 and 10 days averaging of the recorded levels was made. The data prepared in that way were used for experimental variograms calculation. This, however, did not lead to an acceptable solution. Smoothing effect of the averaging process did not change the shape of monthly semivariograms. They remained inconsistent.

In the following analysis, the data base was extended from year 1982 to 1988. Additional daily water level records were provided by Manitoba Hydro for each of the eight gauge stations. Further monthly semivariograms were calculated for years from 1982 to 1986 and for 1988 year. So the comparison of monthly semivariograms for different years finally was possible. Also, yearly semivariograms were computed, but results were not acceptable. Calculated values for experimental semivariogram showed a large dispersion on the Γ^* versus **h** diagram. Finally, it was concluded, that two distinct seasons can be distinguished in a year, namely; the winter, or lake with ice cover, and the summer, or lake without ice cover season. The winter season consists of December, January, February, March and April and the summer season of May, June, July, August, September, October and November. The difference between these two seasons is that during the winter season, the difference between two measured data at different measured points is less, even for a big separation distance, than the nugget effect in the summer season. This observation is possible to explain by physical

phenomena, that in the winter season the wind effect is essentially completely eliminated by ice covering. Thus, the fluctuation caused by wind is filtered out. The remaining difference between the recorded level is primarily a measurement error.

The next step was the development of a theoretical semivariogram. The chosen form of the theoretical semivariogram has been described in the Section 3.1 in Equation (3.9). This kind of theoretical semivariogram is very easy to determine and there are many software packages which can easily fit the regression model to the experimental points by the least squares method.

The final decision for the winter semivariogram was the three term polynomial regression model:

$$\Gamma(h)=0.00064+0.00009*h-1.36*10^{-6}*h^2 \qquad (4.2)$$

where distance **h** is in the 10 of kilometres. In that way, the theoretical semivariogram for winter season has a nugget effect value **c=0.00064 [m²]** and a sill value of Γ_r**=0.00213 [m²]** at the radius of influence of $\mathbf{a_r}$**=330 [km]**. This radius of influence has been selected as the maximum value of the Γ**(h)** function Equation (4.2). This feature is important in order to avoid unrealistically high weighting coefficient for distant experimental points. The winter season theoretical semivariogram shown in Figure 4.1 is very flat. This flatness also indicates the ratio of sill Γ_r and the nugget effect value **c** as a value of **R=3.3**. This ratio gives an indication of relative importance of weighting coefficients. If this **R** value is close to unity, the more significant is the tendency of averaging, and less significant is the influence of separation distances between stations themselves, distances between estimated point and

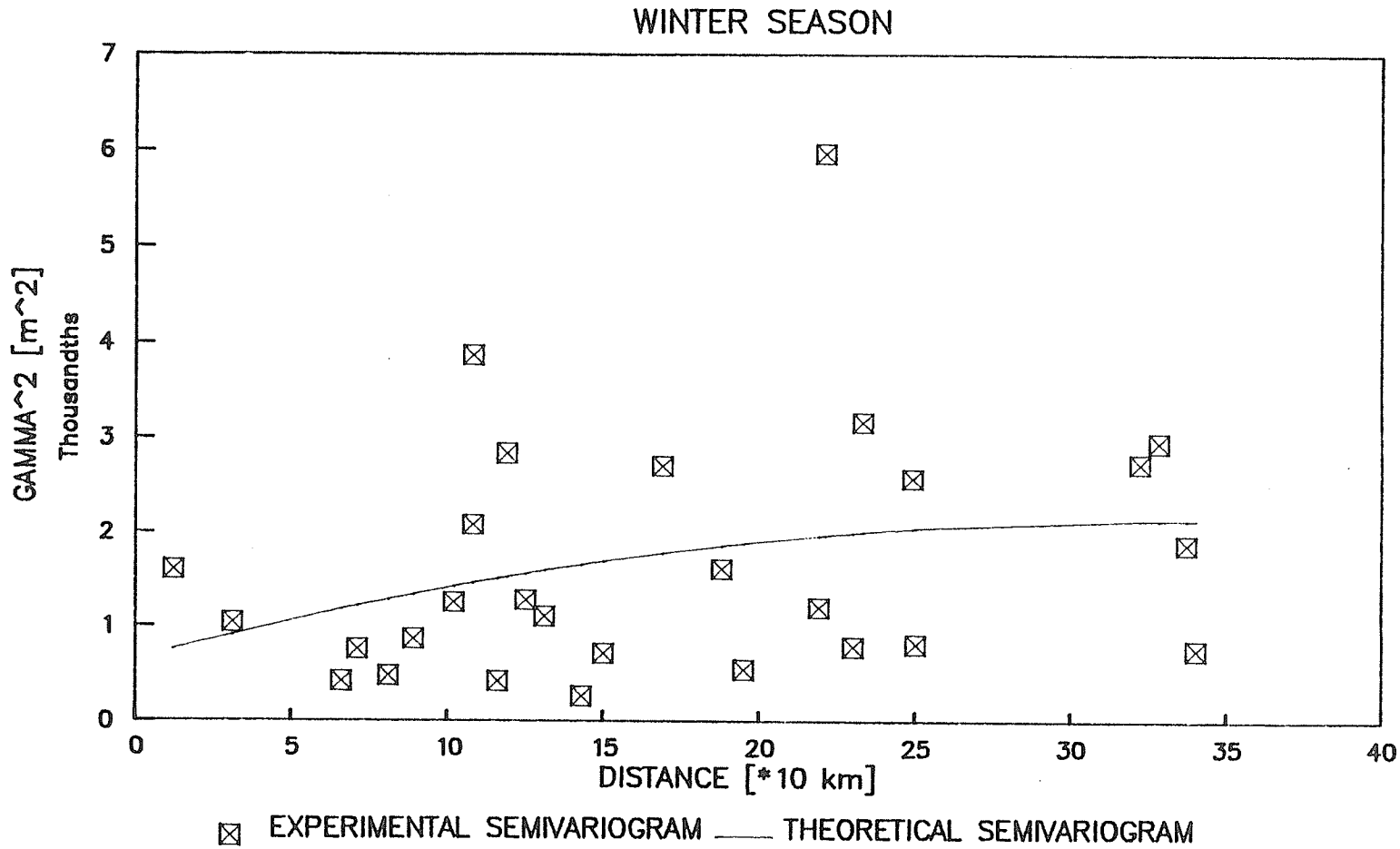


Figure 4.1 Semivariogram for Winter Season

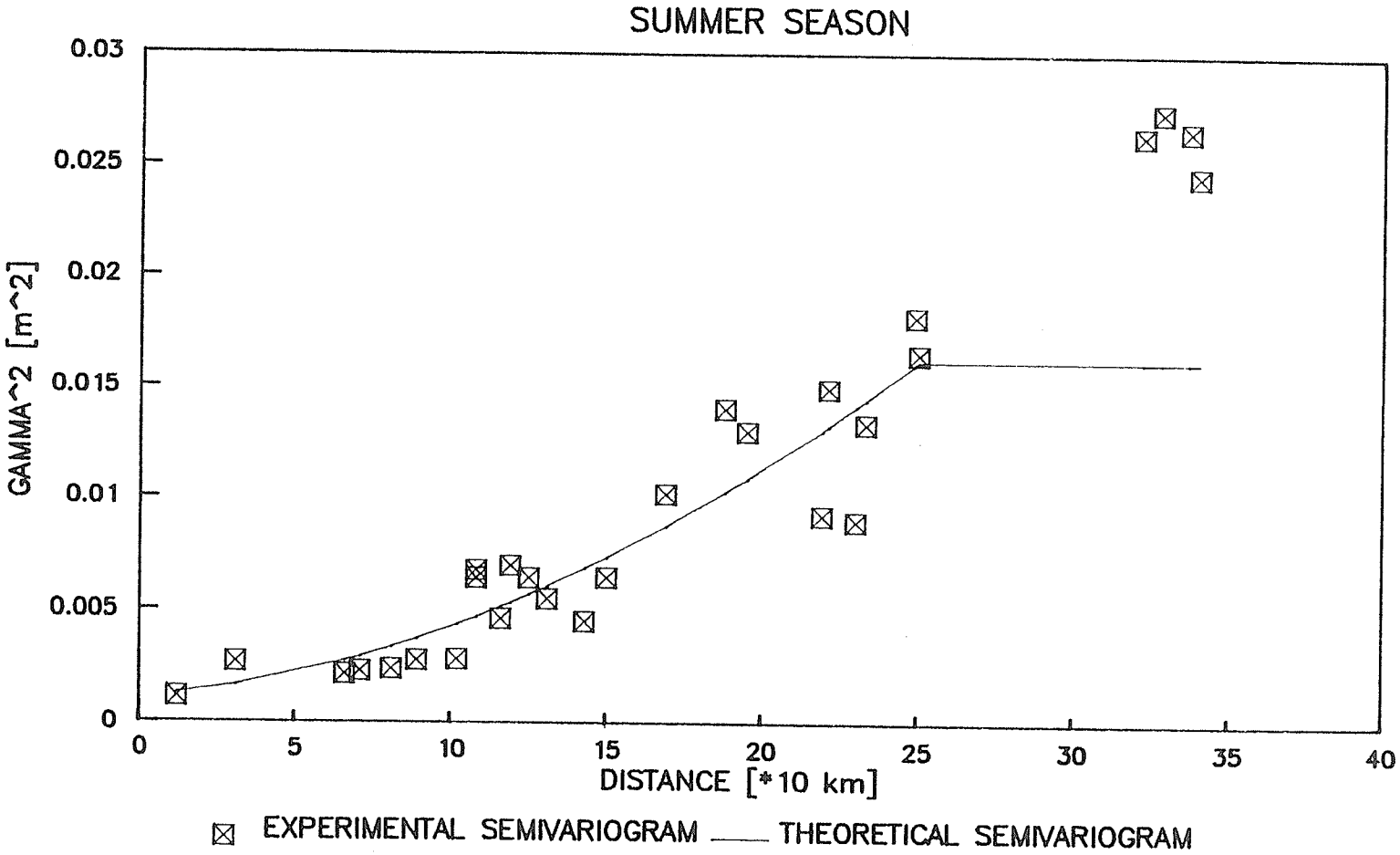


Figure 4.2 Semivariogram for Summer Season

experimental points, and vice versa. Another effect which can be indicate by ratio **R** is the Kriging error. By increasing the ratio **R** the Kriging error will also be increased.

The summer theoretical semivariogram shown in Figure 4.2 also has the form of Equation (3.1) with following four terms:

$$\Gamma(h)=0.00106+0.00012*h+0.00002*h^2-4.6*10^{-8}*h^3 \qquad (4.3)$$

The nugget effect for the theoretical semivariogram for summer season is **c=0.00106 [m²]**. The sill of Γ_r**=0.01619 [m²]** at the radius of influence of a_r**=250 [km]** is selected after several tests performing by the Kriging system in order to avoid high (in the sense of absolute value) negative weights solutions for experimental points. In this way, the theoretical semivariogram is somewhat truncated, but the solution obtained by the Kriging system shows reasonable weighting coefficients. The break point at the distance of radius of influence means that the effect of experimental points further then a_r have the same influence, and is independent of the actual separation distance.

4.2 KRIGING SYSTEM

Because of the very irregular configuration of the Lake Winnipeg, the punctual Kriging method has been used for water level estimation. The name "punctual" means that the water level is estimated at many points over the lake area. The estimated average lake level is the mean value of the point estimations.

For the sake of simplicity, the estimated points will be located on a regular mesh. The grid size is 41 X 78 [*10 km]. The Lake Winnipeg area with the eight gauge stations is fitted in this grid system. The nodes which are covered by the lake area

will be the points of interest for estimation. In this case there are 234 nodes. In the later phase of the analysis, for the graphical presentation of the results, the previously mentioned resolution was insufficient. Therefore, the number of nodes for estimation was doubled in both X and Y direction so that total number has been increased to 962. The difference in estimated mean water levels was in the range of 1 to 2 cm with low and high density grids. This establishment is important for the reason that: if the goal is just to obtain the mean water level with the average confidence interval, then it is sufficient to make a calculation for a low density grid system, because the calculation is much faster. However, if besides the mean water level the user is interested in additional information, such as a water level distribution on the lake or the local confidence level, then it is worth spending the additional computer time to make a calculation with the high density grid system.

$$[A] = \begin{bmatrix} a_{11} & a_{12} & a_{13} & \cdot & \cdot & \cdot & \cdot & a_{1N} & a_{1N+1} \\ a_{21} & a_{22} & a_{23} & \cdot & \cdot & \cdot & \cdot & a_{2N} & a_{2N+1} \\ a_{31} & a_{32} & a_{33} & \cdot & \cdot & \cdot & \cdot & a_{3N} & a_{3N+1} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \\ a_{i1} & a_{i2} & a_{i3} & \cdot & \cdot & \cdot & \cdot & a_{iN} & a_{iN+1} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \\ a_{N1} & a_{N2} & a_{N3} & \cdot & \cdot & \cdot & \cdot & a_{NN} & a_{NN+1} \\ a_{N+11} & a_{N+12} & a_{N+13} & \cdot & \cdot & \cdot & \cdot & a_{N+1N} & a_{N+1N+1} \end{bmatrix} \quad [X] = \begin{bmatrix} \mu \\ \alpha_1 \\ \alpha_2 \\ \cdot \\ \alpha_{i-1} \\ \cdot \\ \alpha_{N-1} \\ \alpha_N \end{bmatrix} \quad [B] = \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ \cdot \\ b_i \\ \cdot \\ b_N \\ b_{N+1} \end{bmatrix}$$

In the Kriging system, [A] * [X] = [B] as described in Section 3.2, all of the experimental points were always included into the system for water level estimation. Therefore, it was sufficient to define the basic matrix once, which is the function of the gauge station locations within the lake area. This is the first step of the calculation in the Kriging system. The size of this matrix depends on the number of available records. If for some gauge stations, data are not available for the day chosen for

estimation, this gauge has been eliminated from the calculation. The size of the basic quadratic matrix [A] will be **N+1**, where **N** is the number of available recorded water level for the particular day. Due to the assumption that there will only be one Lagrange multiplier, the assumption implies the water level is flat as in ideal case. Therefore the constraint set explained in Section 3.2 as Equation (3.19) is reduced to the one constraint as it is shown in Equation (3.20).

The coefficients in the basic matrix are the values of the semivariogram for different separation distances. The coefficients $\mathbf{a_{1,2}}$, $\mathbf{a_{2,3}}$, ... , $\mathbf{a_{8,9}}$, in general $\mathbf{a_{i,i+1}}$, have a zero value, because these coefficients represents the $\Gamma(\mathbf{h})$ value at the separation distance zero, in other words the distance between the stations themselves. The zero values are denoted on the basis of the definition of the semivariogram, although for both the winter and summer season, there is a nugget effect value for **h=0** distance. Coefficient $\mathbf{a_{i,j}}$ (i>1, j<N+1 and j is not equal i+1) is the $\Gamma(\mathbf{h})$ value at the separation distance between gauge station **i** and **j**. The minor matrix from $\mathbf{a_{2,1}}$ to $\mathbf{a_{N,N+1}}$ is symmetrical, because the distance between the station **i** and **j** is the same as between **j** and **i**. Coefficients $\mathbf{a_{i,1}}$ where **i=1,N** are equal to unity. These are coefficients for Lagrange multiplier. In this case, there will only be one Lagrange multiplier, because the assumption is that there is no drift on the lake, because the water level is flat in an ideal case. Coefficients $\mathbf{a_{N+1,i}}$ where **i=2,N+1** have a value of unity. This describes Equation (3.20) which is the only constraint in this case. The coefficient $\mathbf{a_{N+1,1}}$ has a zero value.

The next step is the calculation of the right hand side of the Kriging system. These coefficients must be defined for each estimation point. The right hand side coefficients **b(i) i=1,N** have values of semivariogram for separation distances between

point of estimation and the gauge station **i**. The coefficients **b(n+1)** have a value of unity in order to satisfy the constraint defined by the equation (3.20). Coefficients on the right hand side should be developed for each of the estimation points.

In the next step, the above defined Kriging system has been solved. This is a system of N+1 linear equations with N+1 unknown variables. **N** weights for weighting **N** observation points and one Lagrange multiplier have been determined. The system is solved by Gauss-Jordan elimination and the obtained results are used for further calculation.

The weighting coefficients obtained from this process are examined for negative values. If there are some negative weights, then the weighting coefficients should be recalculated following the recommendation of Equation (3.26). If in the solution of the system of linear equations, all weighting coefficients have a non-negative value, then the correctional calculation as in Equation (3.26) should be skipped.

Further, weighting coefficients are used for calculation of the Kriging error. Kriging error can be calculated as a square root of Kriging variance defined by Equation (3.25). Using the Kriging error, it was possible to check which gauge station is out of the estimation range. To perform this task some judgement was necessary. A multiplier **k** needs to be defined. Selecting the value of this coefficient **k**, determines decided how large the estimation range will be. The estimation range is defined as:

$$ER = \sigma_K * k \qquad (4.4)$$

where: **ER** is the estimation range, σ is the Kriging error, and **k** is the multiplier coefficient. The estimation range also depends on the Kriging error and Kriging error

depends on the weighting coefficients. Going further, the weighting coefficients depend on the parameters of the system of linear equations, which are nothing else than the value of $\Gamma(\mathbf{h})$ function. In that way, there leads back to the basic, historical data. If the slope of the semivariogram function is steep, then the Kriging error will be greater than when the slope is less steep. If the slope of the semivariogram is less steep, then the historical data were more uniform than in the case when the slope of the semivariogram is steep. The physical explanation of this is, if water level records are uniform then the Kriging error will be less, and if water level records are less uniform, this means less reliability.

The above mentioned statement faithfully illustrates the observed semivariograms for Lake Winnipeg, for both the winter and for the summer seasons. The winter season semivariogram is very flat (the ratio of the sill and the nugget effect is **R=3.3**). However, in the summer season this ratio is **R=15.2**. Thus the Kriging error for winter season is about one half of the Kriging error for the summer season.

In this case, for Lake Winnipeg water level estimation, the **k** coefficient is set to **2**. This establishment is done on the basis of the test with different **k** values. The best results for the filtering of the known outlier data is achieved with the small **k** value. Then if some of the measured water level are wrong, the effect of this measurement is located just in the limited radius around the questionable station. If some of the gauge station measurements fall out of the range which is defined as an estimated value +/- ER, then the S_i coefficients are calculated for each outlier station. These S_i values are placed in the basic Kriging system, as described in the Section 3.2. The new system (3.29) is then solved again to obtain new weighting coefficients. The purpose of these S_i coefficients is to decrease weights related to these outlier measured

records. In that way, the effect of suspect recorded data could be filtered out.

The Kriging error changes from estimation point to estimation point. It is possible that for some region of estimation points the **i**-th recorded level will be an outlier. It is also possible, that around this **i**-th gauge station only this recorded level will be found in the estimation range, while all others will be found as outliers, because the close gauge station have a high weighting coefficient and to the point estimation this close station have the greatest effect. This could happen only in the small region around the **i**-th experimental point, because of the nugget effect, which decreases weights for the closest measured point, or in other words, allows higher influence on the estimation from the rest of gauge stations compare with the case that there are no nugget effect. In this case the Kriging error will have a peak value at that suspect experimental point, because in the estimation process the influence of other measurements will be decreased and the estimation in that way will be less reliable.

4.3 KRIGING ALGORITHM AND SOME RECOMMENDATIONS FOR THE ESTIMATION PROCESS

The first step in the application of Kriging technique is the semivariogram development. It is beneficial to have sufficient data which may give a good characterization of the variable for estimation, in this case Lake Winnipeg water levels. In the phase of fitting the theoretical semivariogram to the experimental one, the major effort should be on preserving the shape of the experimental semivariogram. The

theoretical semivariogram should be tested, using the Kriging system, to justify the selection of the proper semivariogram. The weighting coefficients obtained by Kriging system, should be positive. If this is not the case, recalculation by Equation (3.26) is required. However, this correction is only possible if these negative weighting coefficients have smaller absolute values than any of the positive weighting coefficients. If not, then a revision of the semivariogram structure is necessary. The negative impact of the negative weights is not just on the estimated value but also a wrong Kriging error determination as well. It is recommended to test the semivariogram for different combination of the available data. Tests should be done for cases where recorded data are available at each station, and also when data exist on some stations only. Comparing these results will help in deciding if the theoretical semivariogram satisfies the required conditions or not. Once the semivariogram satisfies the criteria of the estimated property, the Kriging system may be used for estimation.

The actual use of the Kriging estimation system starts by making decision for which day the water level will be estimated. The program constructs (computer program listing is presented in Appendix B) the basic matrix for Kriging system. The size of this matrix depends on how many recorded measurements are available for that day. After that, the water level estimation and Kriging error are calculated for every node. At every node every measured value is checked for possibility of being out of the estimation range. If some of the measured records are found as outliers then the S_i value is calculated and the modified Kriging system described by Equation (3.29) is resolved. In the meantime, the outlier stations will be counted for later evidence. When the calculation is finished for every node, the mean estimated water level and the mean Kriging error are calculated. Both values are presented on the screen with

the number of outlier occurrences for each gauge station. This way, it is possible to decide which measured record is not reliable. At that point, there are two possible ways to continue the estimation process. One option is to finish the calculation, and other to increase the value of **k** coefficient, which controls the estimation range, and repeat the calculation. If the second option is used, the number of times some experimental records were found out of estimation range should decrease. At the end of the repeated calculation, the mean water level and the mean Kriging error should be compared with the results of previous calculations. If the mean water level does not change significantly, then the estimation process could be terminated. If the water level change significantly, then further investigation of the recorded level which is most frequently considered as an outlier is necessary. It may be useful to repeat the whole Kriging estimation process without that suspect data location and compare the obtained result with the results obtained with that experimental record included.

It is also possible to get some useful information from graphically presented results. In this case the graphical package **DRACON**, developed by **ENERGODATA - Yugoslavia**, was used . This graphical package is used to draw isolines and fill with colour the area between them. Using graphics and presenting results day after day, it is possible to observe the recorded water level fluctuation at each gauge station. It is useful to graphically present the Kriging error map also. The point error information is more valuable than the mean kriging error. The graphically presented Kriging error map is more convenient then the raw output as presented in the Appendix C. There are less chance to overview some data.

5 RESULTS

In this chapter, the daily water level estimations obtained by Kriging, Rational (Thiessen) and Inverse Weight methods (last two methods are described in the Section 2.3 as Empirical Mathematical Smoothing methods) are presented. The comparison of methods is made using results obtained for the years 1987 and 1988. In addition, sequential daily water level maps together with Kriging error are presented.

5.1 PRESENTATION OF RESULTS

In Figures 5.1.1-4 and 5.2.1-4, the daily water level estimation obtained by Kriging and Inverse Weight methods are presented for year 1987 and 1988 respectively. The Thiessen method, as described in Chapter 2, gives a weekly water estimate. Thus, the daily water level estimates for this method, also presented in the Figures 5.1.1-4 and 5.2.1-4, were obtained by interpolation between weekly values. This approach of linear interpolation is acceptable since the increase in water level, caused by precipitation events, is smoothed during one week. In other words, the effect of a significant precipitation event will be counted in the actual week, without any smoothing effect on the previous or later weeks. Note that there is only one estimated water level in the week and for the rest of the days in the week the water levels are interpolated. This does not have the same effect as a moving average process which is used in the Inverse Weight and Kriging method. All figures contain the presentation of the Kriging error. However, values for Kriging error shows always the daily

obtained values, these values are not averaged.

In Figures 5.3.1a - 5.3.9a the water level maps and in the Figures 5.3.1b - 5.3.9b the Kriging error maps are shown for a sequence of days. These figures contain mean water level and mean Kriging error as well as the spatial pattern of both quantities.

In Appendix A Tables 1.1 - 1.8 contains the official water level records for year 1987 and Tables 2.1 - 2.8 for year 1988. Official records are measurements with removed obvious outlier stations. Where a zero value occurs in the records, the interpretation is that the water level record is not available. It is possible that absolutely no information was available at that particular gauge station for that particular day, or the recorded level may be considered not available because the gauge station was out of order.

5.2 COMPARISON AND EXPLANATION OF RESULTS

Daily water levels obtained by all three methods give fairly consistent results. This is particularly true for the winter season when the ice cover prevents large water level fluctuations. For the summer season, the water level estimation by the Kriging method shows a larger daily fluctuation then the other two methods as shown on the Figure 5.1.1 and 5.2.1. This result can be explained by the fact that the Kriging method uses only the chosen daily data, without any smoothing through the use of a moving average incorporating previous and subsequent day or days. This is contrary to the other techniques, which both involve some form of a smoothing process. Large fluctuation obtained by Kriging for the period from October 1st 1988 to October 10th 1988, or for days 275 to 284 is unacceptable. This is the time period when water

level records were available only at Victoria Beach and Gimli gauge stations, both in the south basin. Thus, the resulting fluctuation is not a water level fluctuation of the whole lake, but rather just of the south basin. Since this fluctuation has nearly a daily period, a smoothing, or averaging process could successfully alleviate the consequences of this data shortage. Figures 5.1.2-4 and 5.2.2-4 shows a results obtained using three, five and seven days moving average smoothing process for results obtained by Kriging method. With the smoothing process, the results are essentially the same. The reasonable comparison between results obtained by Kriging method alone and later through the use of a moving average smoothing process, with the Inverse Weighting method, which also used a moving average process, can be made. Thiessen method gives one water level estimation in a week which is based on the averaged water level measurement. Thus, this method gives a more smoothing day by day water level estimation than the other two methods.

The Kriging error, or the confidence level, shown in Figures 5.1.1-4 and 5.2.1-4 shows very high values for some days. It should be noted that this confidence level is not a confidence level in the sense that is usually used in statistical analysis. Rather, this indicates existence of some unacceptable records in the input data. For the winter season, the Kriging error is normally in the range of 0.03 to 0.05 m, and in the summer season, it is roughly doubled in magnitude because of the different semivariogram structure, and has values of 0.07 to 0.10 m. If the average Kriging error exceeds the above mentioned ranges, it means that some of the input records are likely in error. The measurements that are suspected to be wrong, are indicated in the output from the Kriging computation by the number of times the particular gauge station is out of the estimation range. In such a case it is recommended to repeat the

Kriging estimation process without this measurement. Results obtained and presented in Figures 5.1.1-4 and 5.2.1-4, are obtained without removing outlier stations. These are the first calculated water level estimations with the coefficient **k=2** for estimation range (see Equation (4.4)). In this case the wrong records are not removed from the estimation process in the procedure to correct the problem. Instead their influence is decreased through assigning lower weights to these.

For example, for October 15th and 16th 1987 (288th and 289th day on Figure 5.1), data recorded at Mission Point cause the high Kriging error. These records are considered as outliers at every estimated point on the lake, and the weights related to this gauge station record were always decreased by resolving the Kriging system (as explained in Section 3.2). In that way, the reliability of Mission Point records is decreased, or in other words, the Kriging error increased rapidly around this gauge station. This happened throughout December 1987. At the Mission Point gauge station, the measured level is about 0.3 m higher than the other measurements. Only for a few days, December 12 - 13 and 26 - 27, when water level records are not available at Mission Point are the Kriging errors in the normal range. The high Kriging error on January 3rd and 26th 1988, is also caused by unreliable data record at Mission Point.

The high Kriging error characteristic can be better visualized with the sequentially presented daily spatial water level distribution. Figure 5.3.2b for August 21st 1988 shows high error around the Mission Point gauge station. This happens because the measured water level at Mission Point is higher than any other by 0.4 m for this day. The point estimation process around the Mission Point gauge station results in every other measured data being out of the estimation range. Then, by recalculation, weights

for these outlier stations were decreased, but also, the Kriging error increased, because of many unreliable outlier data. This effect, in this case, is more significant, because water level records at Mission Point only were available for the north basin. Measurements are missing at George Island and at Montreal Point. Information about the north basin would thus be completely excluded if the recorded measurements at Mission Point were removed from the repeated calculation.

On August 25th 1988, high Kriging error occurs between the south basin and the narrow section between the two basins. This is the place where the high south basin measurements and lower measurement at Matheson Island also fall out of the estimation range. The water level were estimated in the middle of this measured range, but these records will be found as outliers and the Kriging error in that area will increase.

For August 27th 1988, the high Kriging error area is shifted a little to the north basin. A high Kriging error area also occurs around Mission Point. This is the area where the influence of this station starts to decrease. On the water elevation map, unrealistic water level estimations for the north end of the lake can be seen. This is the consequence of the extrapolation for that area. Thus, the Kriging method better handles the estimation for the points between observation points, instead of extrapolation which is for any procedure always an unreliable process.

It can be seen, that the Kriging error provides useful information in the Kriging estimation process. By the spatial distribution of the Kriging error, it can be determined which measured data could be an outlier. If in some area the Kriging error exceeds the normal (acceptable) range, this gives an indication of the need for a further investigation. The observed records from the areas with high Kriging error should be examined and in the normal case they should be removed from the repeated estimation

process. However, if there are a limited number of observed records, especially if only one data represents a big area, (e.g., the north basin of Lake Winnipeg), then it is better to leave this record in. In that way it is better to have any information, than no information at all. In that case Kriging error is a warning that the estimated result should be considered potentially unreliable.

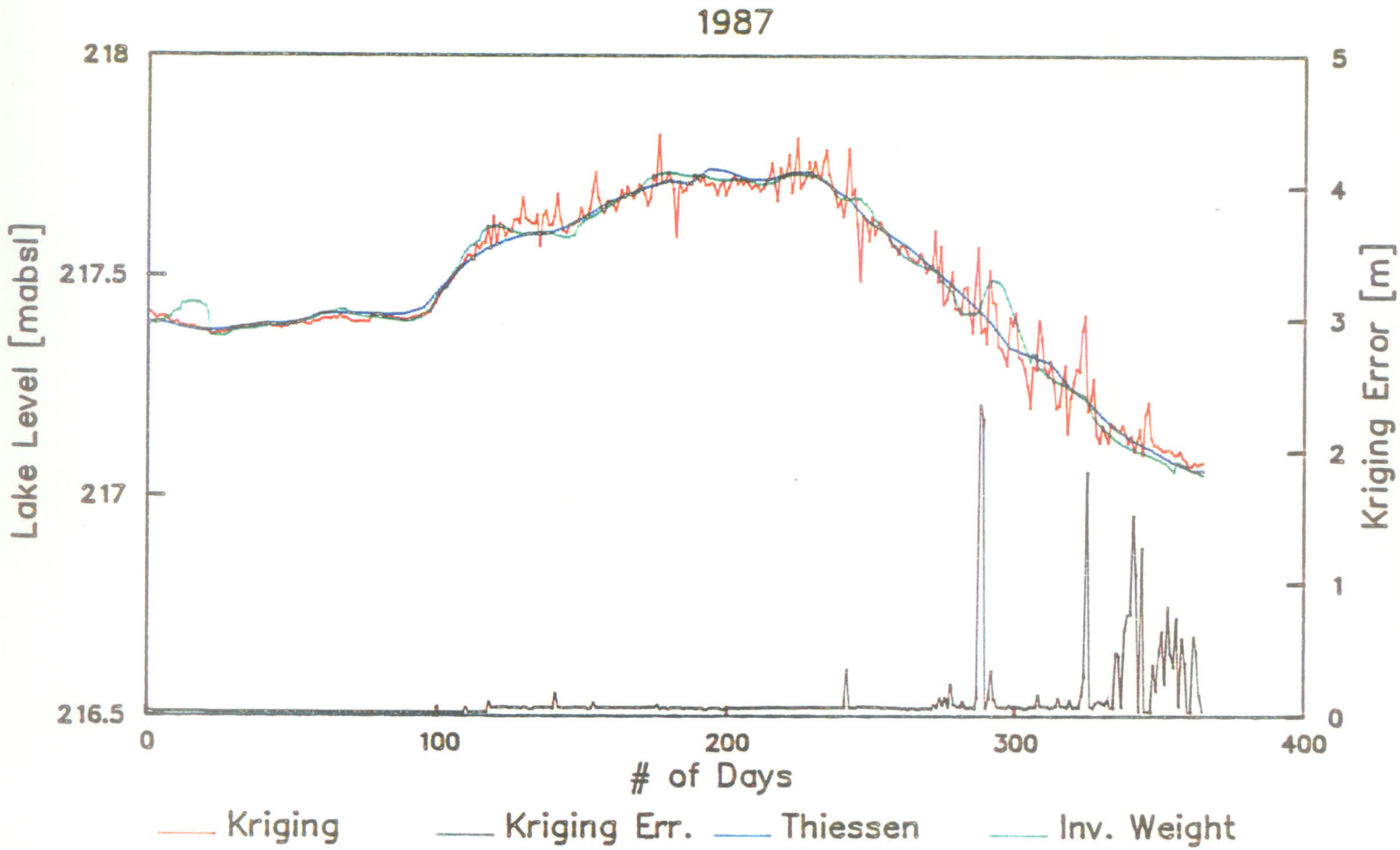


Figure 5.1.1 Results comparison - Kriging with daily data

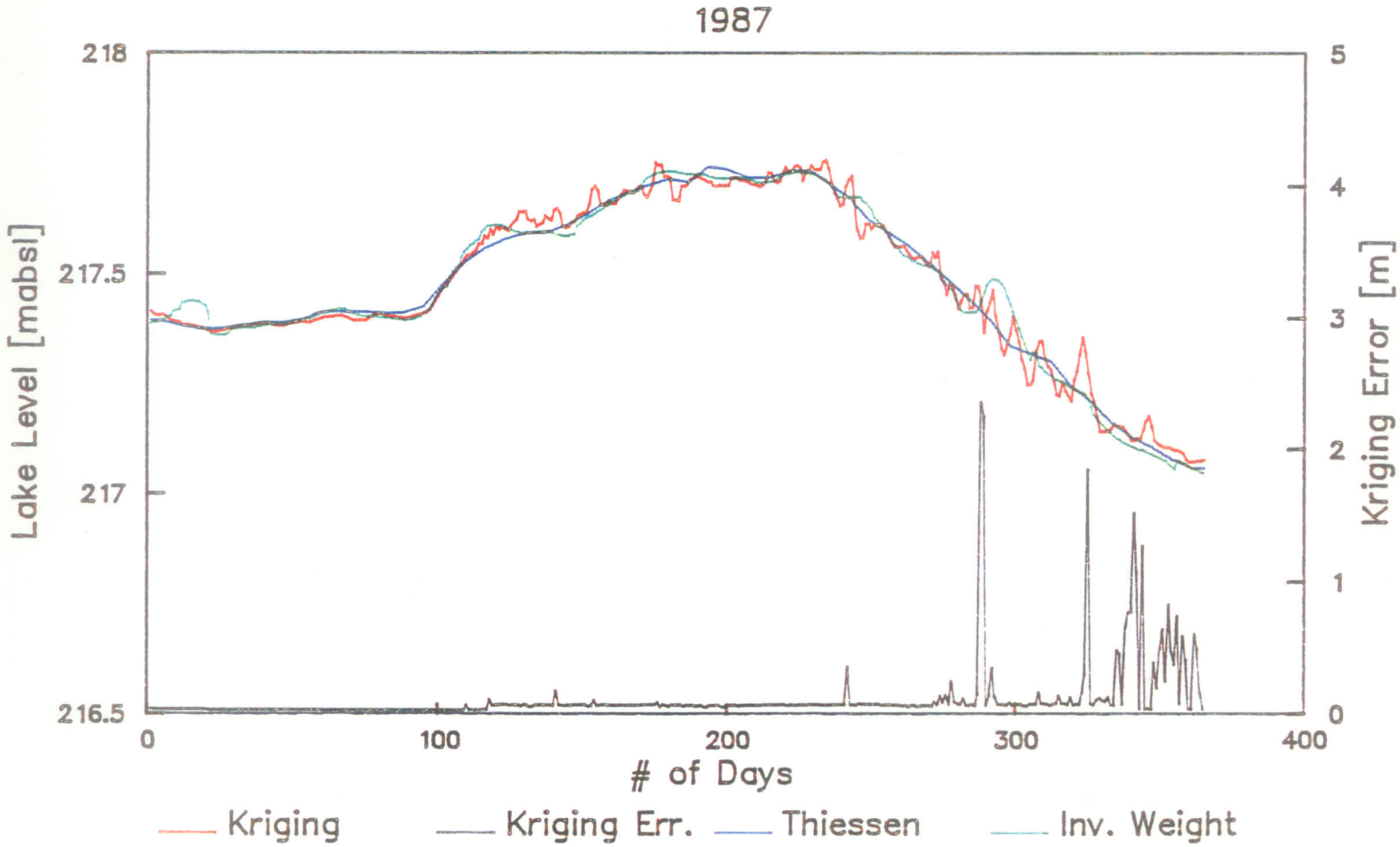


Figure 5.1.2 Results comparison - Kriging with 3 days moving average smoothing process

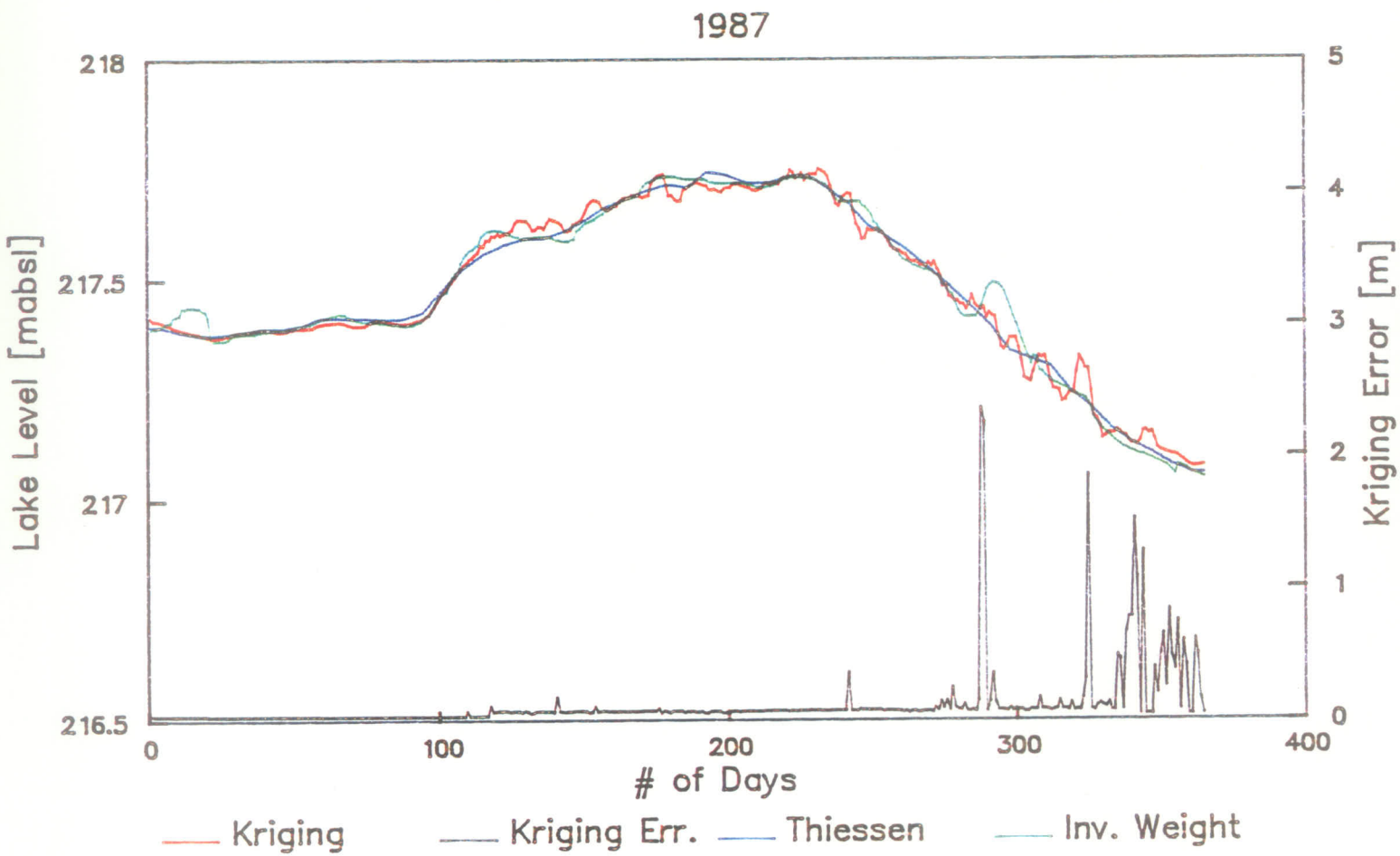


Figure 5.1.3 Results comparison - Kriging with 5 days moving average smoothing process

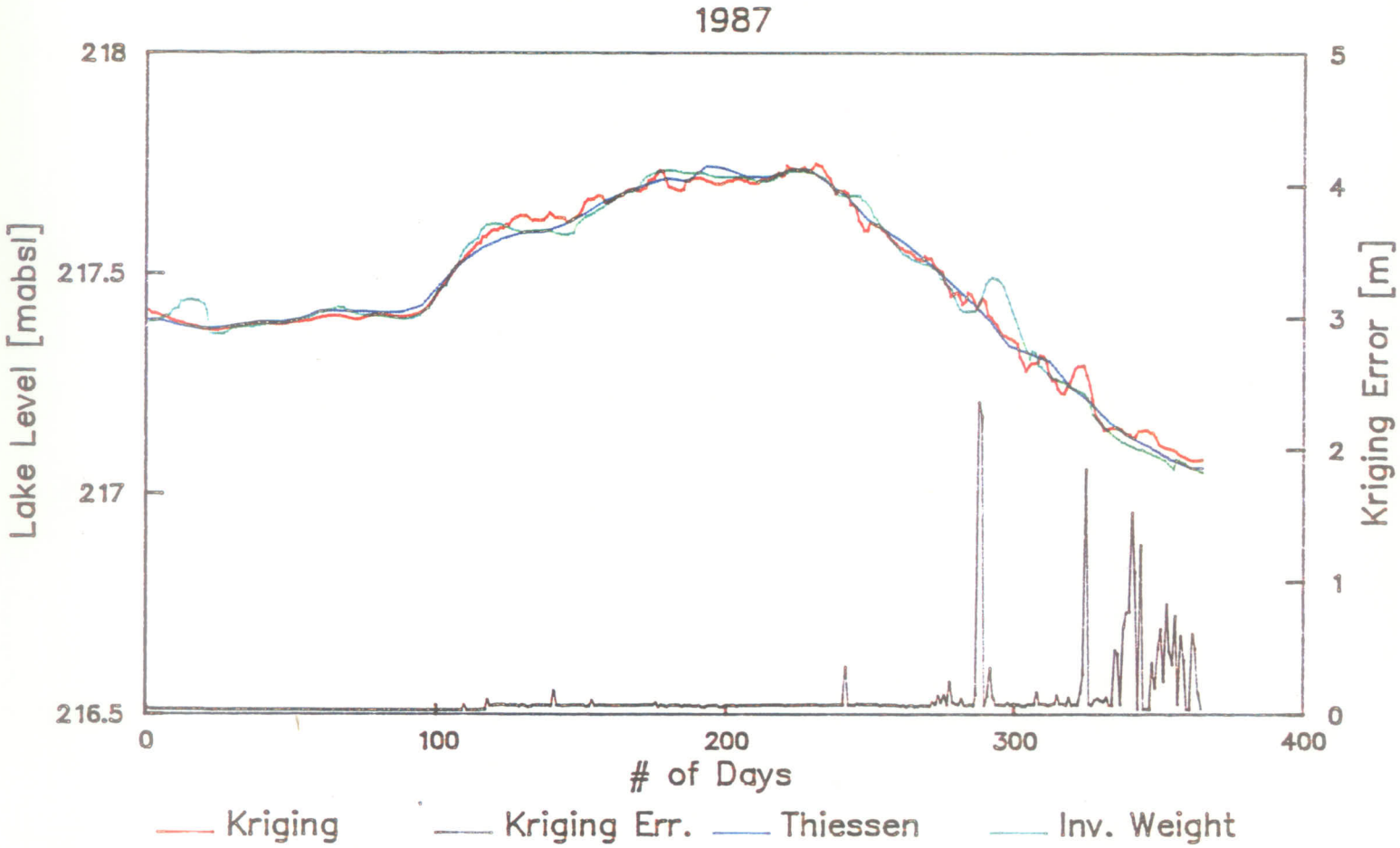


Figure 5.1.4 Results comparison - Kriging with 7 days moving average smoothing process

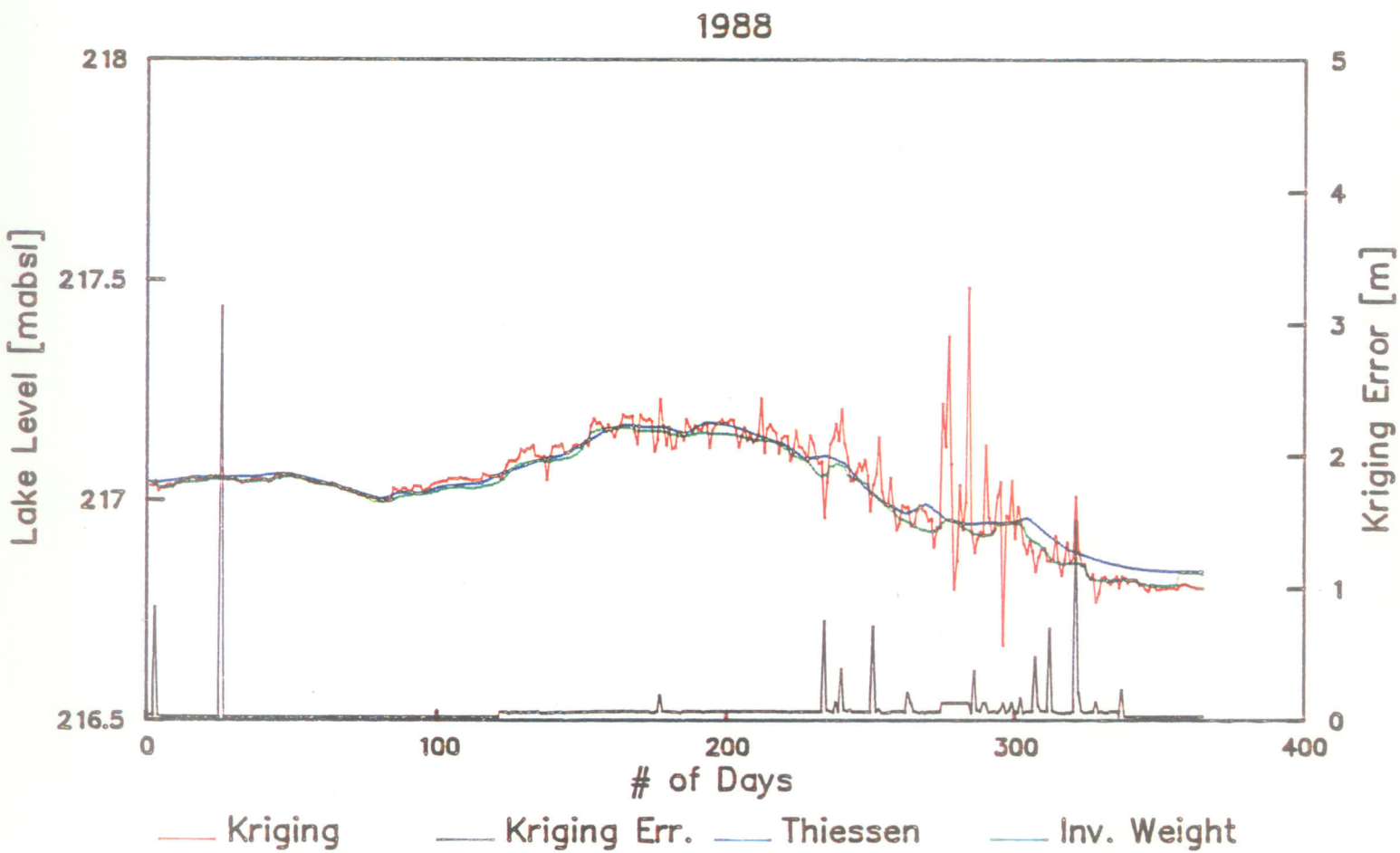


Figure 5.2.1 Results comparison - Kriging with daily data

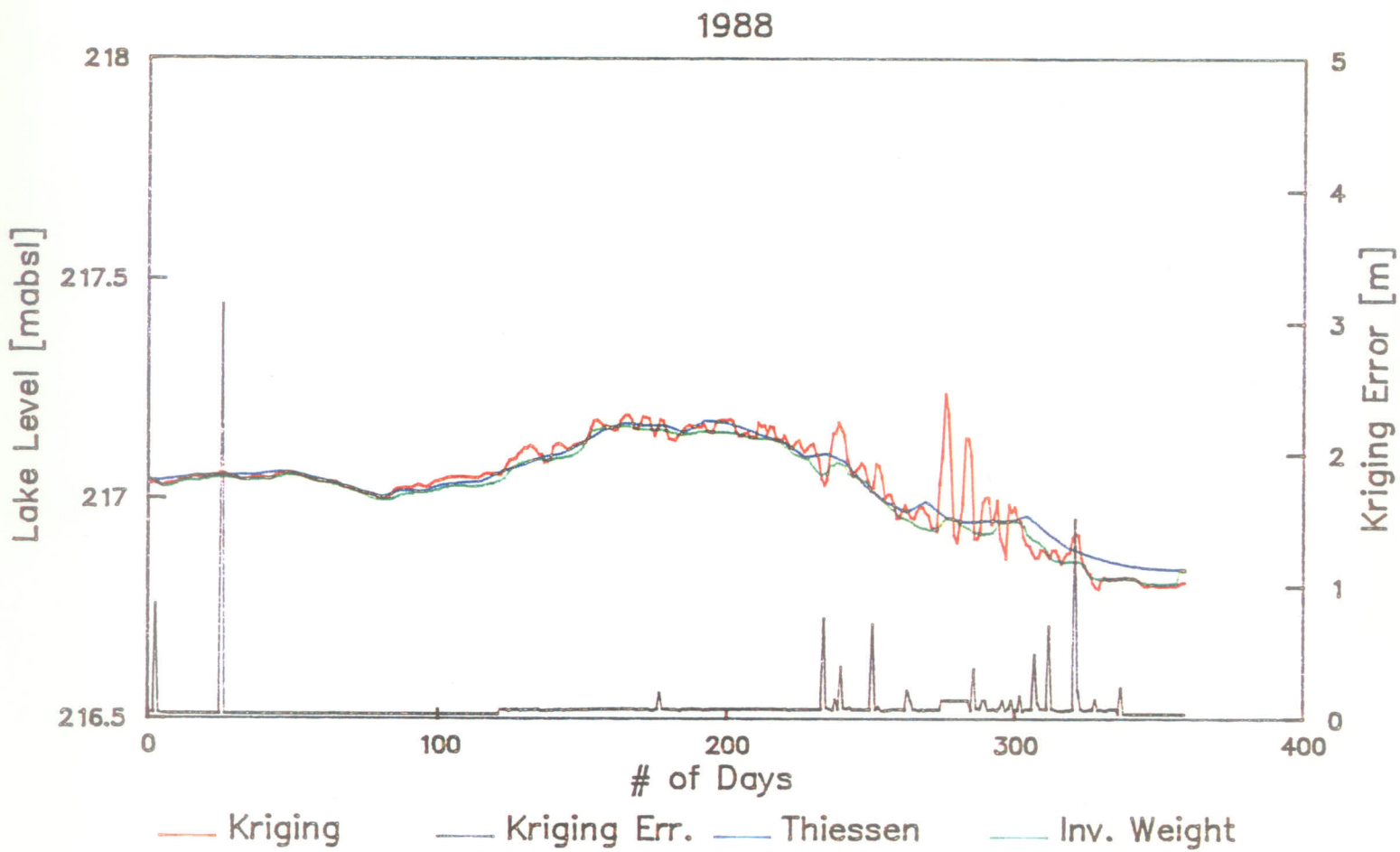


Figure 5.2.2 Results comparison - Kriging with 3 days moving average smoothing process

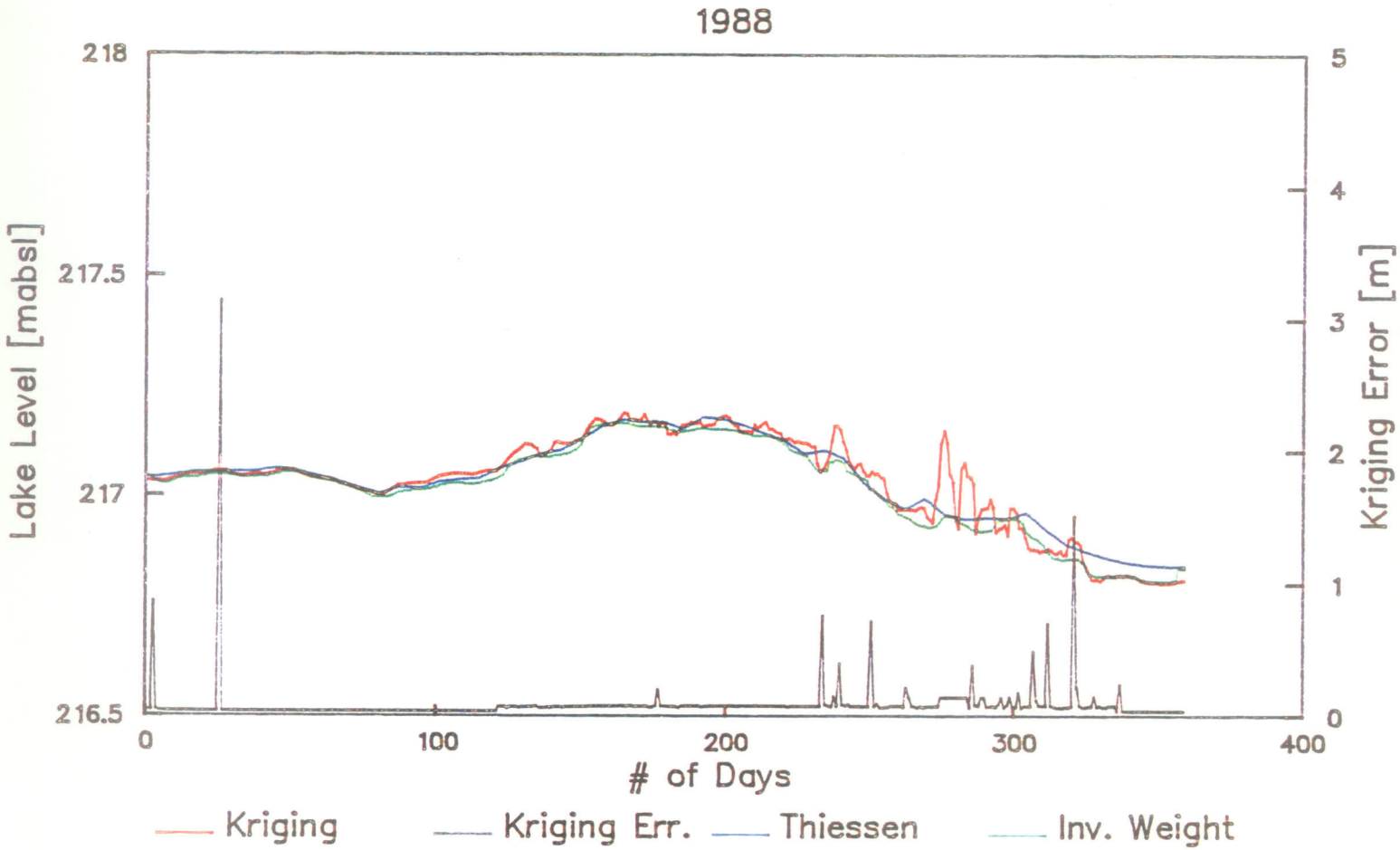


Figure 5.2.3 Results comparison - Kriging with 5 days moving average smoothing process

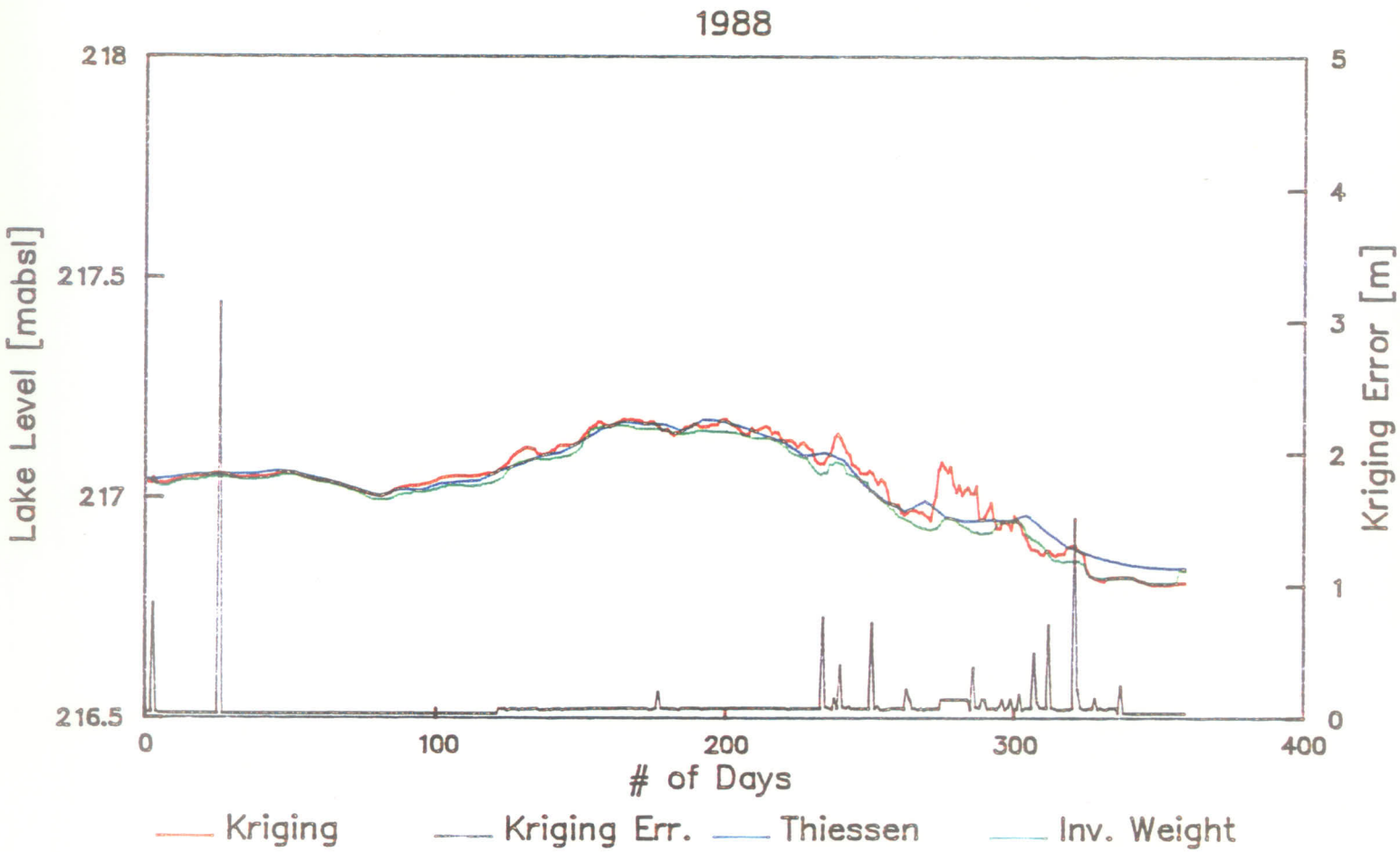
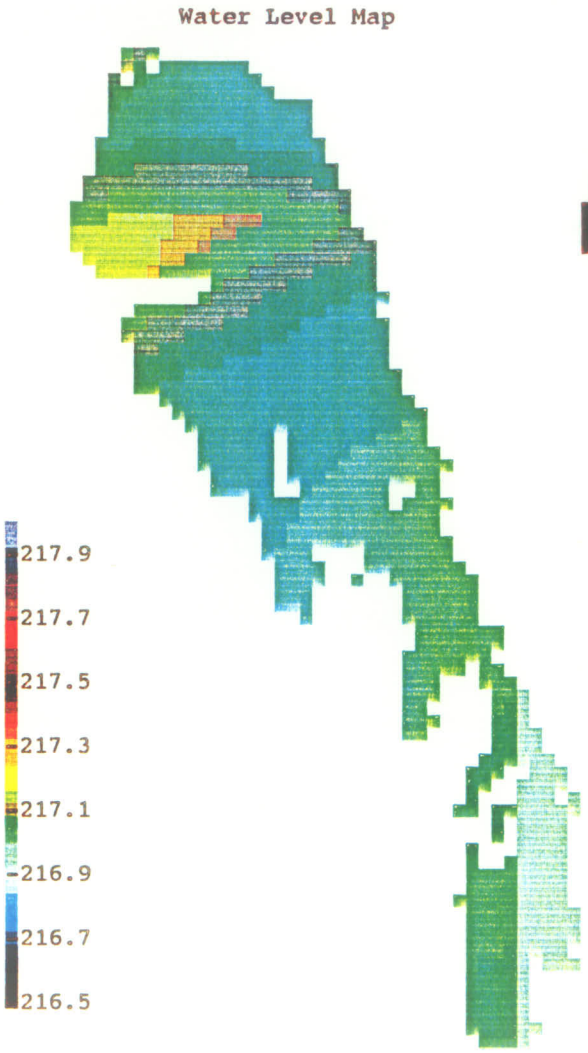


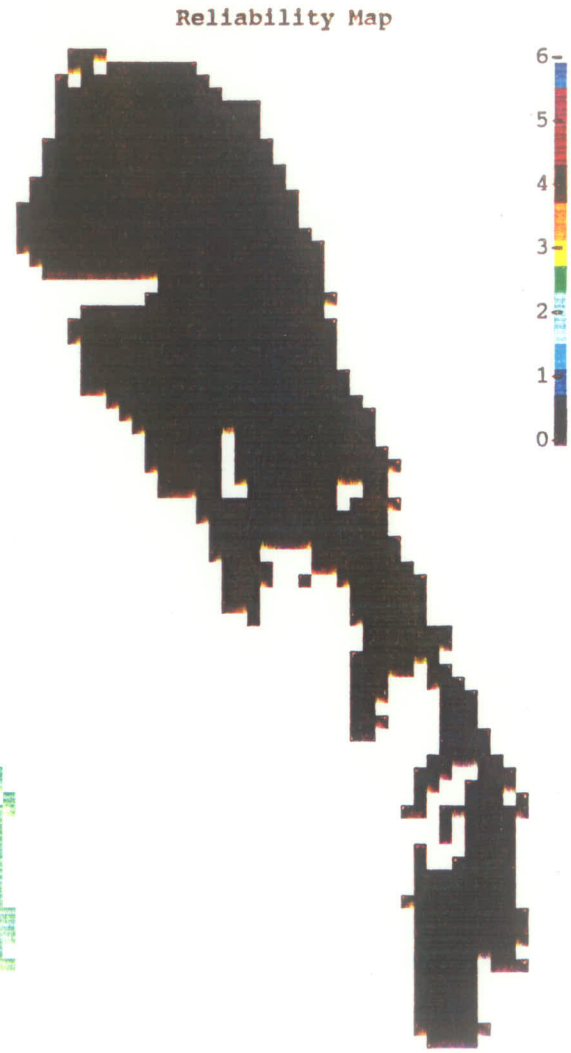
Figure 5.2.4 Results comparison - Kriging with 7 days moving average smoothing process

DATE = AUGUST 20, 1988



Mean Level = 217.090m

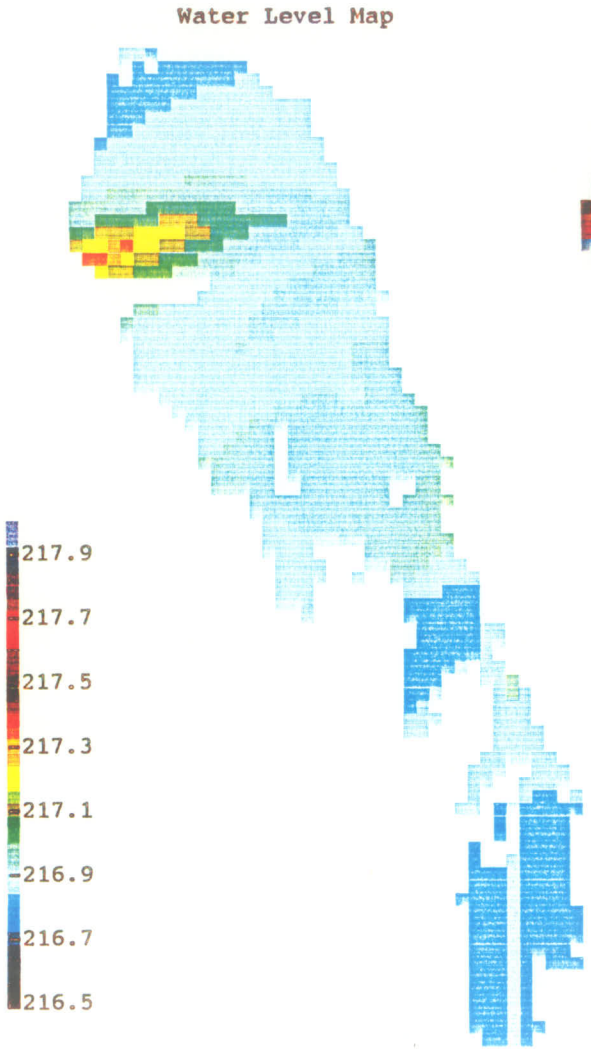
Figure 5.3.1a



Mean Error = 0.078m

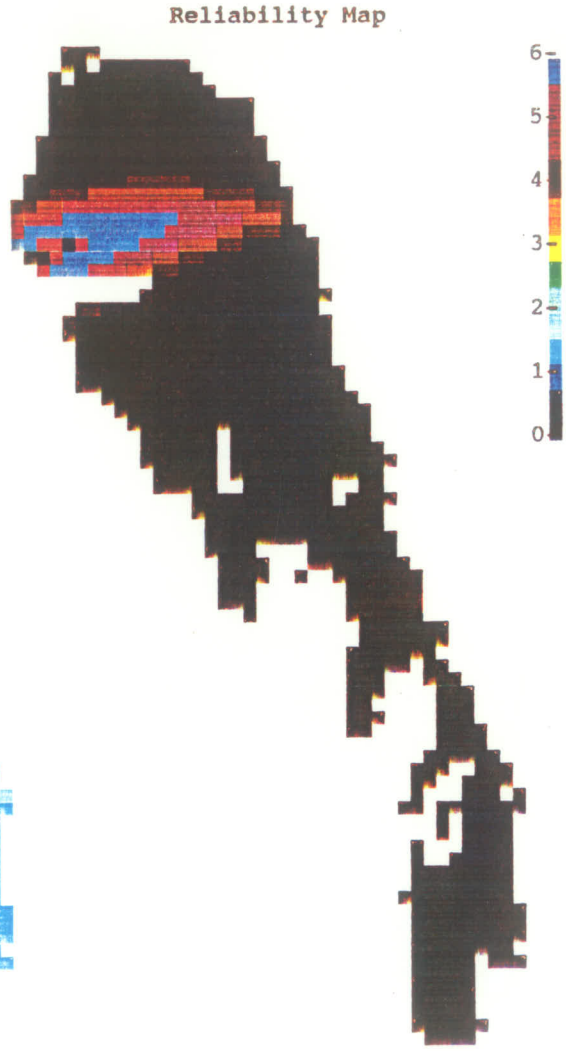
Figure 5.3.1b

DATE = AUGUST 21, 1988



Mean Level = 216.962m

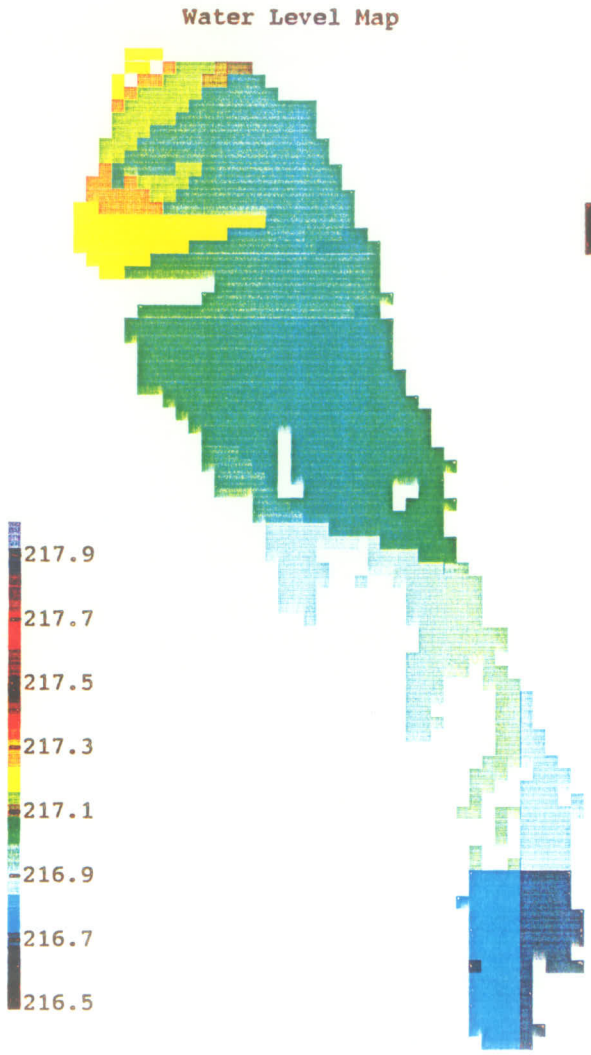
Figure 5.3.2a



Mean Error = 0.767m

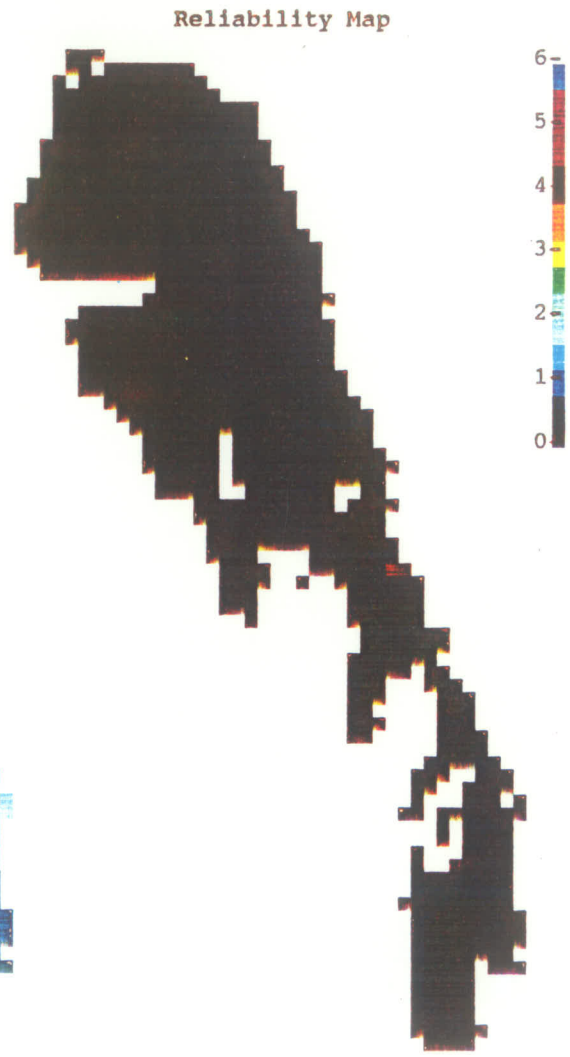
Figure 5.3.2b

DATE = AUGUST 22, 1988



Mean Level = 217.041m

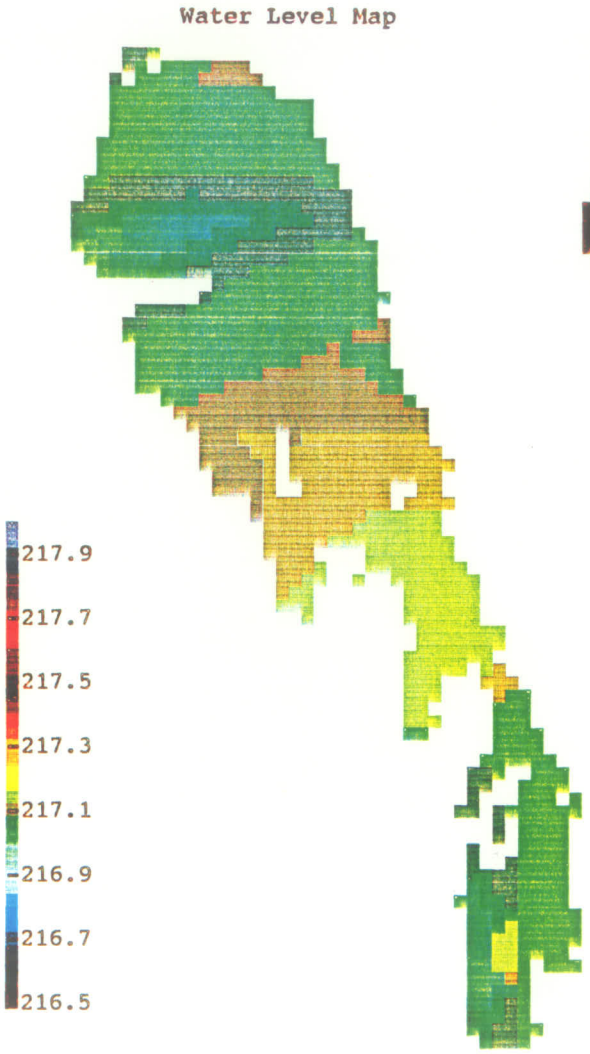
Figure 5.3.3a



Mean Error = 0.091m

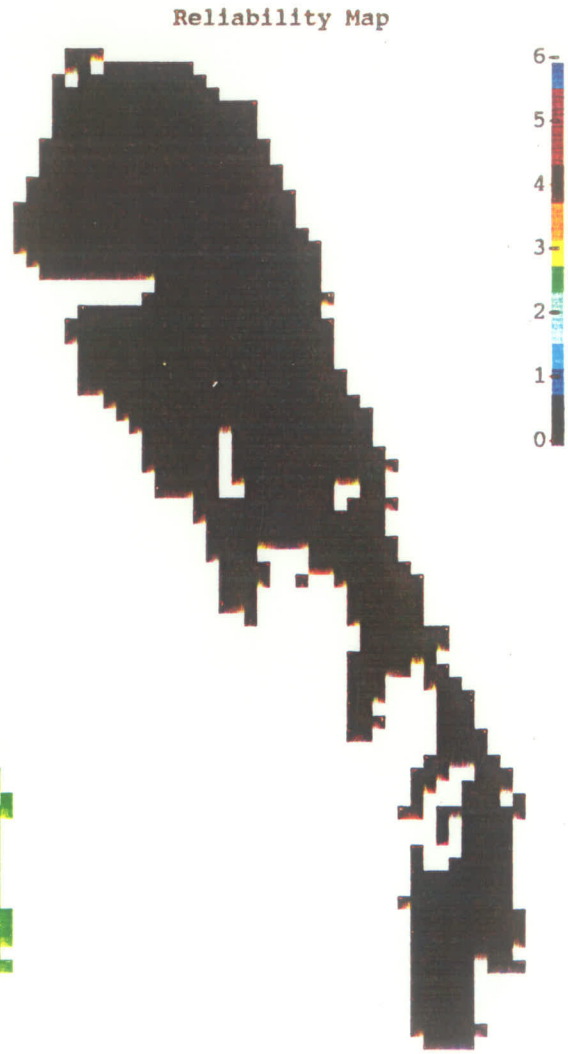
Figure 5.3.3b

DATE = AUGUST 23, 1988



Mean Level = 217.129m

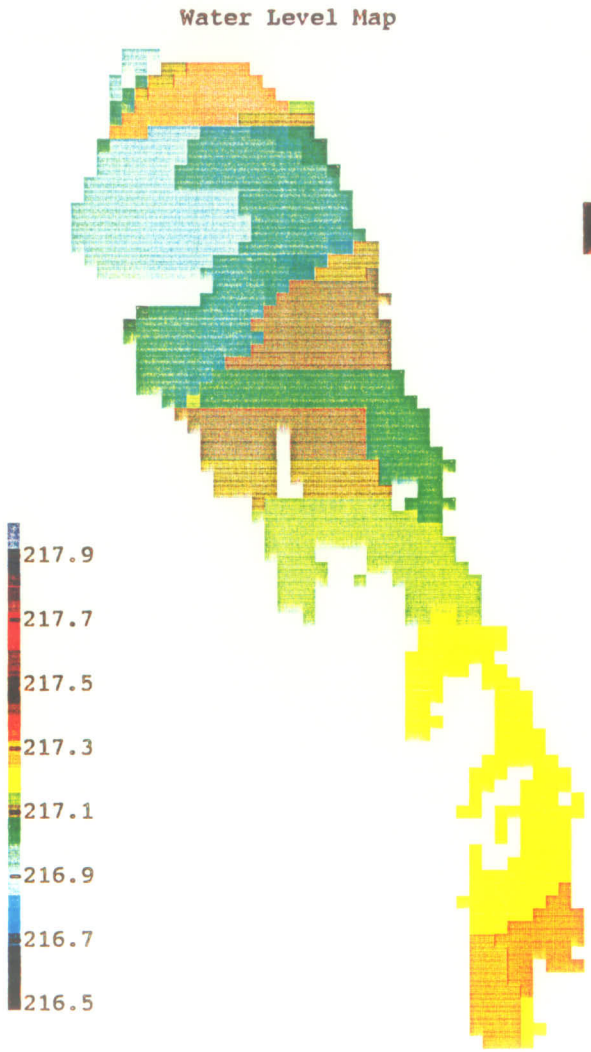
Figure 5.3.4a



Mean Error = 0.079m

Figure 5.3.4b

DATE = AUGUST 24, 1988



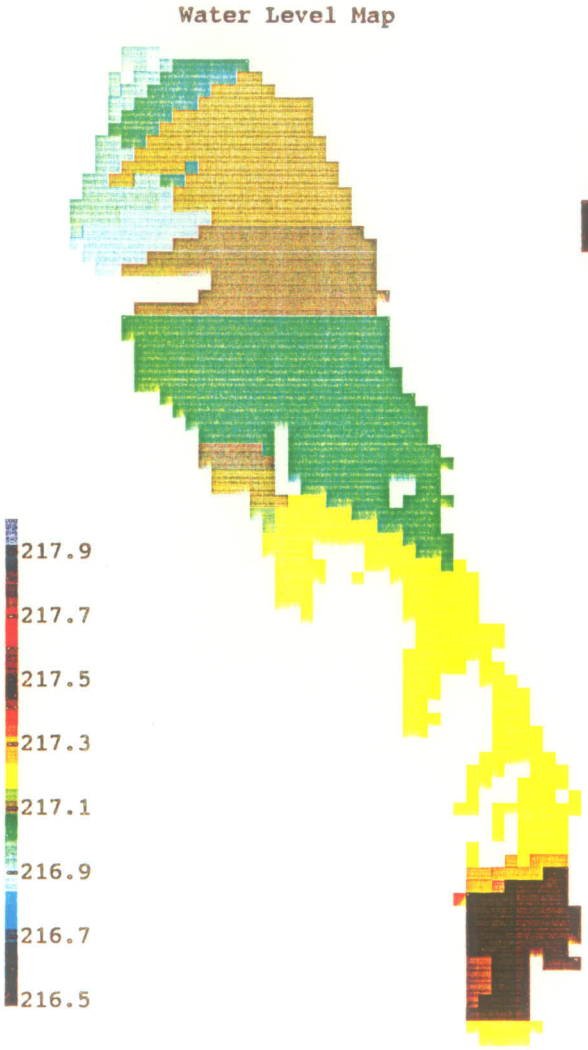
Mean Level = 217.143m

Figure 5.3.5a

Mean Error = 0.067m

Figure 5.3.5b

DATE = AUGUST 25, 1988



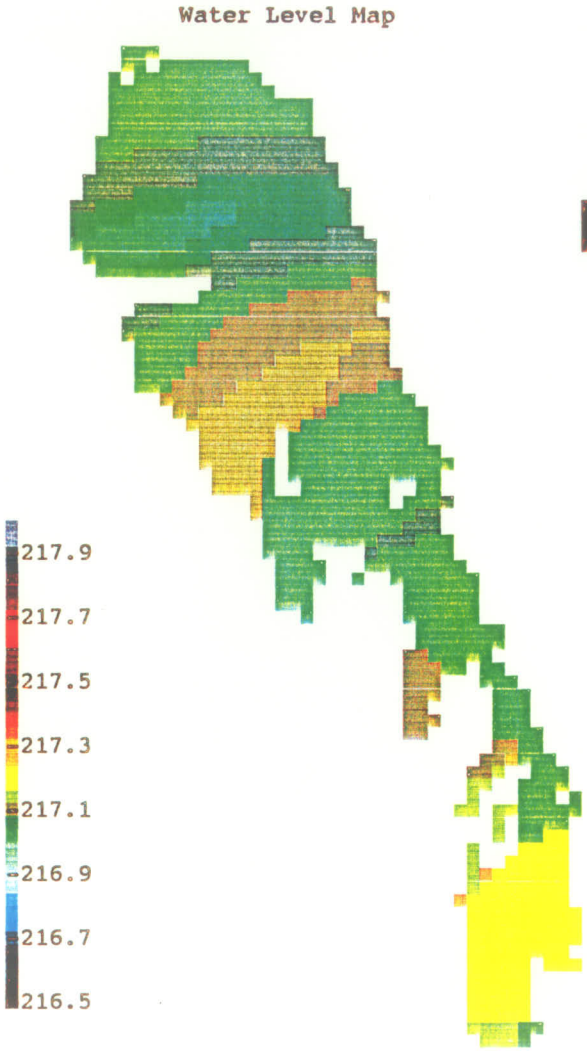
Mean Level = 217.175m

Figure 5.3.6a

Mean Error = 0.150m

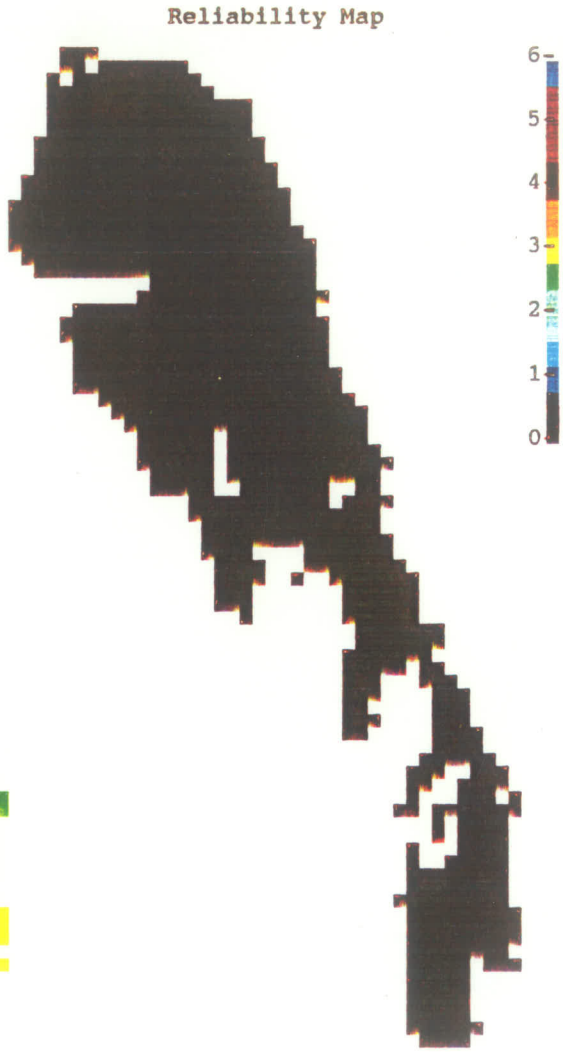
Figure 5.3.6b

DATE = AUGUST 26, 1988



Mean Level = 217.136m

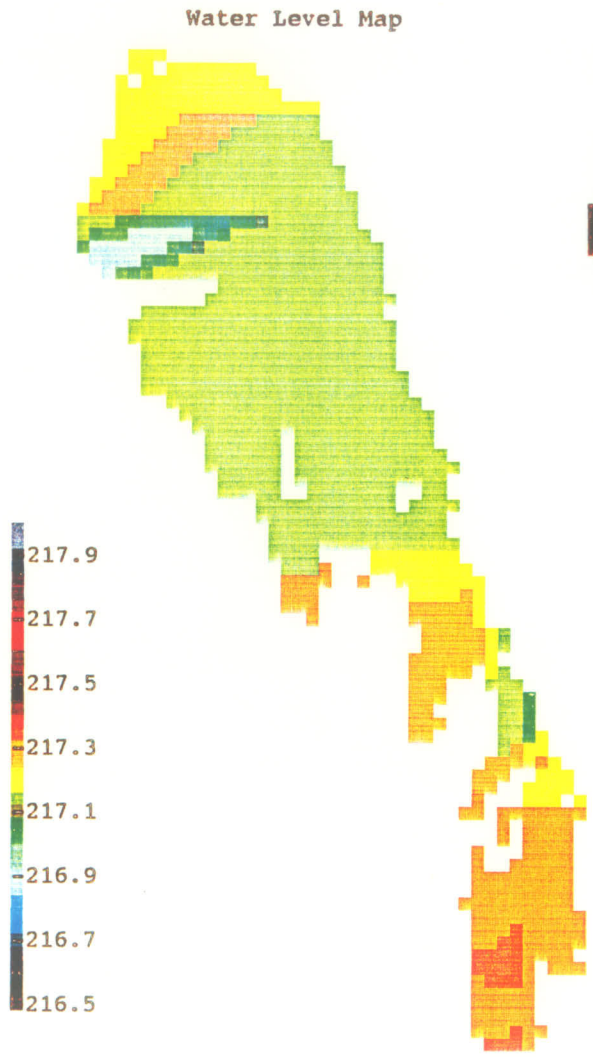
Figure 5.3.7a



Mean Error = 0.077m

Figure 5.3.7b

DATE = AUGUST 27, 1988



Mean Level = 217.208m

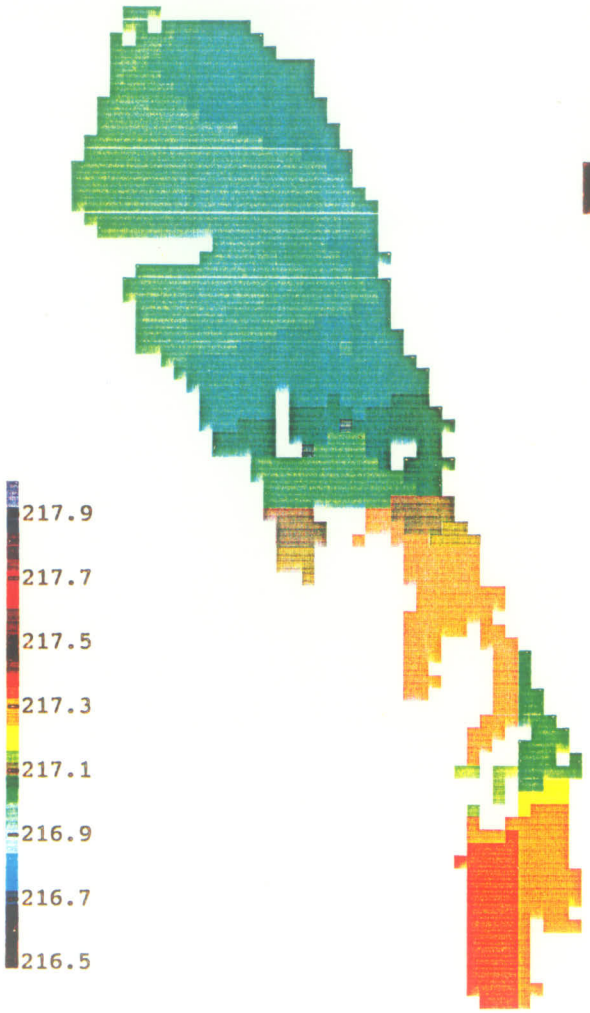
Figure 5.3.8a

Mean Error = 0.404m

Figure 5.3.8b

DATE = AUGUST 28, 1988

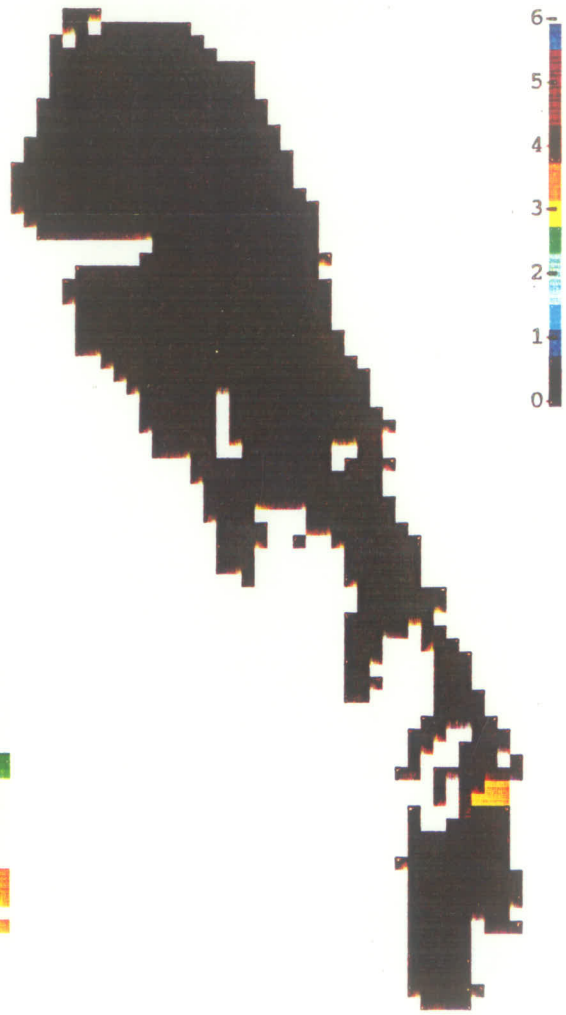
Water Level Map



Mean Level = 217.130m

Figure 5.3.9a

Reliability Map



Mean Error = 0.088m

Figure 5.3.9b

6 CONCLUSIONS

The application of the Kriging method as a new method of surface water level estimation gives satisfactory results. It can be seen that results obtained by all of the discussed methods (Kriging, Thiessen, Inverse Weight) are fairly consistent. All three methods are based on the same input data, but the use of the data differs for the three methods. The Kriging method without a moving average smoothing process shows larger daily fluctuations than the other two methods. By the averaging the obtained results, the day by day estimated level will be smoothed. Therefore, the averaged Kriging results could compare with two methods, which are currently used in Manitoba Hydro for water level estimation. The Kriging error remain unchanged, since the moving average smoothing process were applied for the daily mean water level. There is no reason to use a moving average smoothing process to average them, because the Kriging error gives useful information in a form of a high value for days when the input data set is less reliable.

In some cases, when the available input data are radically reduced, especially if that shortage of data is related to particular whole area, the estimated mean water level by Kriging could be less accurate. This could have an effect on the daily mean water level fluctuation, or it may be reflected in high Kriging error in some area. During periods of extreme data shortage, when the smoothing, and averaging methods could not provide a good results, further investigation is needed.

A useful capability of the Kriging method is that it can provide punctual, or point estimation. This is useful for obtaining an overview of the estimated variable in terms of the spatial distribution over the observation domain. Through the graphical

presentation of the spatial water level distribution, it is easy to find the physical explanation for obtained results. Beside the estimated water level the Kriging error could be obtained at each point as well. The Kriging error gives useful information about the reliable estimation range. The Kriging error is not a confidence interval in a sense that it is usually used in the statistical analysis, however this is a relative measurement of the reliability of the estimated property (in this case water level). If in some estimation area the Kriging error shows a large value, this indicates a poor reliability of estimated property, however it also indicates the area where there is a wrong input data which caused the high Kriging error level. If besides the graphically presented estimated property, the graphically presented Kriging errors are also displayed, one could very easily conclude which input data are less reliable and should possibly be removed from the repeated calculation. Graphically presented water levels and Kriging errors do not provide additional information, but it provides considerably easier handling. For example, compare the typical computer output presented in Appendix C, and one of the Figures 5.3.1-8.

For the development of the Kriging method, some expertise is needed. An element of decision making or judgement is required during semivariogram development for deciding a type of theoretical model and also determination of parameters like the range of influence ($\mathbf{a}_r$) and sill value (Γ_r). Also, it is necessary to select the coefficient **k** which controls the estimation range. After these parameters have been established, the estimation process is very convenient, and can be completed with minimal, if any, expert input.

For the further development or refinement of a data collection network of some property, the Kriging error can be very useful. The Kriging error distribution on the

observation domain provides beneficial information about advantageous locations for new observation points, or relocation of some existing observation locations.

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Report on Lake Winnipeg Levels, Prepared by ad hoc Committee on Lake Winnipeg Datum, December 1982

APPENDIX A

Table 1.1 Raw measured water level

05RD005 LAKE WINNIPEG AT BERENS RIVER

		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1987	1	217.412	217.384	217.403	217.420	217.552	217.649	217.615	217.720	217.700	217.605	217.172	217.116
1987	2	217.398	217.385	217.407	217.416	217.557	217.760	217.746	217.770	217.620	217.417	217.318	217.122
1987	3	217.379	217.382	217.393	217.414	217.548	217.683	217.690	217.730	217.500	217.477	217.258	217.134
1987	4	217.400	217.375	217.398	217.416	217.566	217.632	217.736	217.720	217.720	217.471	217.423	217.114
1987	5	217.410	217.381	217.401	217.414	217.596	217.639	217.778	217.770	217.650	217.480	217.361	217.065
1987	6	217.411	217.385	217.408	217.421	217.580	217.638	217.719	217.770	217.600	217.402	217.269	217.115
1987	7	217.399	217.394	217.411	217.423	217.584	217.627	217.819	217.760	217.740	217.397	217.260	217.040
1987	8	217.388	217.373	217.396	217.432	217.592	217.655	217.740	217.780	217.600	217.337	217.288	217.109
1987	9	217.388	217.385	217.392	217.452	217.598	217.669	217.739	217.820	217.610	217.482	217.211	217.136
1987	10	217.390	217.380	217.386	217.470	217.587	217.658	217.756	217.630	217.620	217.478	217.209	217.043
1987	11	217.383	217.389	217.397	217.462	217.565	217.684	217.727	217.800	217.610	217.414	217.226	217.191
1987	12	217.372	217.383	217.387	217.469	217.586	217.675	217.708	217.860	217.580	217.344	217.250	217.193
1987	13	217.374	217.389	217.390	217.479	217.629	217.692	217.716	217.830	217.610	217.603	217.211	217.125
1987	14	217.373	217.377	217.391	217.472	217.579	217.695	217.718	217.670	217.600	217.460	217.102	217.101
1987	15	217.382	217.372	217.378	217.488	217.553	217.706	217.693	217.680	217.520	217.335	217.249	217.097
1987	16	217.374	217.378	217.384	217.498	217.594	217.662	217.736	217.850	217.532	217.342	217.209	217.091
1987	17	217.366	217.378	217.390	217.499	217.564	217.728	217.741	217.690	217.585	217.379	217.211	217.084
1987	18	217.374	217.384	217.407	217.507	217.572	217.706	217.663	217.780	217.577	217.494	217.341	217.091
1987	19	217.367	217.384	217.411	217.538	217.580	217.695	217.698	217.800	217.526	217.399	217.370	217.086
1987	20	217.367	217.384	217.417	217.534	217.639	217.694	217.760	217.790	217.526	217.336	217.140	217.084
1987	21	217.389	217.387	217.417	217.521	217.550	217.682	217.740	217.840	217.524	217.303	217.145	217.080
1987	22	217.384	217.392	217.417	217.555	217.560	217.724	217.737	217.780	217.546	217.301	217.204	217.082
1987	23	217.381	217.395	217.418	217.535	217.575	217.739	217.710	217.770	217.523	217.283	217.137	217.075
1987	24	217.377	217.396	217.420	217.543	217.584	217.773	217.720	217.780	217.520	217.291	217.081	217.070
1987	25	217.367	217.400	217.417	217.546	217.568	217.808	217.720	217.650	217.530	217.322	217.096	217.062
1987	26	217.376	217.410	217.408	217.566	217.578	217.698	217.730	217.670	217.480	217.425	217.164	217.072
1987	27	217.382	217.397	217.431	217.541	217.579	217.723	217.680	217.690	217.487	217.326	217.089	217.058
1987	28	217.376	217.393	217.420	217.584	217.607	217.719	217.720	217.690	217.485	217.270	217.119	217.064
1987	29	217.386		217.410	217.558	217.646	217.700	217.700	217.800	217.548	217.354	217.149	217.047
1987	30	217.377		217.407	217.563	217.624	217.689	217.670	217.760	217.413	217.250	217.141	217.070
1987	31	217.385		217.413		217.601		217.730	217.600		217.265		217.051

Table 1.2 Raw measured water level

05RE003 LAKE WINNIPEG AT GEORGE ISLAND

		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1987	1	0.000	0.000	0.000	217.403	217.673	217.717	0.000	217.704	217.733	217.469	217.289	217.133
1987	2	0.000	0.000	0.000	217.414	217.676	217.717	0.000	217.705	217.669	217.446	217.290	217.127
1987	3	0.000	0.000	0.000	217.418	217.695	217.717	217.669	217.688	217.701	217.531	217.276	217.124
1987	4	0.000	0.000	0.000	217.418	217.694	217.717	217.718	217.692	217.641	217.509	217.273	217.126
1987	5	0.000	0.000	0.000	217.427	217.713	217.717	217.708	217.730	217.585	217.373	217.232	217.116
1987	6	0.000	0.000	0.000	217.426	217.710	0.000	217.676	217.742	217.625	217.401	217.259	217.124
1987	7	0.000	0.000	0.000	217.435	217.702	217.717	217.725	217.710	217.607	217.443	217.253	217.119
1987	8	0.000	0.000	0.000	217.439	217.711	217.650	217.687	217.750	217.597	217.405	217.226	217.116
1987	9	0.000	0.000	0.000	217.460	217.717	217.680	217.751	217.719	217.591	217.408	217.225	217.114
1987	10	0.000	0.000	0.000	217.465	217.717	217.688	217.699	217.713	217.571	217.449	217.292	217.098
1987	11	0.000	0.000	0.000	217.462	217.717	217.721	217.670	217.783	217.561	217.425	217.244	217.114
1987	12	0.000	0.000	0.000	217.483	217.717	217.717	217.672	217.766	217.572	217.402	217.234	217.103
1987	13	0.000	0.000	0.000	217.495	217.717	217.723	217.691	217.773	217.574	217.532	217.200	217.106
1987	14	0.000	0.000	0.000	217.504	217.717	217.700	217.700	217.770	217.582	217.388	217.200	217.104
1987	15	0.000	0.000	0.000	217.523	0.000	217.728	217.708	217.744	217.551	217.375	217.268	217.096
1987	16	0.000	0.000	0.000	217.538	217.717	217.714	217.741	217.722	217.565	217.381	217.195	217.091
1987	17	0.000	0.000	0.000	217.540	217.717	217.744	217.693	217.722	217.565	217.393	217.181	217.091
1987	18	0.000	0.000	217.412	217.546	217.717	217.717	217.690	217.743	217.556	217.399	217.244	217.088
1987	19	0.000	0.000	217.409	217.580	217.717	217.728	217.701	217.739	217.545	217.362	217.164	217.093
1987	20	0.000	0.000	217.414	217.545	217.717	0.000	217.760	217.739	217.530	217.341	217.119	217.087
1987	21	217.340	0.000	217.410	217.579	217.717	0.000	217.748	217.757	217.551	217.332	217.216	217.077
1987	22	217.335	0.000	217.406	217.636	217.717	0.000	217.700	217.680	217.565	217.330	217.169	217.079
1987	23	217.338	0.000	217.409	217.603	217.717	0.000	217.701	217.684	217.516	217.345	217.121	217.063
1987	24	217.332	0.000	217.404	217.628	217.717	0.000	217.707	217.693	217.520	217.374	217.142	217.067
1987	25	217.341	0.000	217.402	217.633	217.717	0.000	217.725	217.683	217.538	217.476	217.171	217.062
1987	26	217.352	0.000	217.401	217.663	217.717	0.000	217.699	217.670	217.527	217.400	217.187	217.067
1987	27	217.339	0.000	217.405	217.632	217.717	0.000	217.703	217.675	217.534	217.310	217.151	217.057
1987	28	217.345	0.000	217.398	217.699	217.717	0.000	217.701	217.676	217.507	217.307	217.176	217.062
1987	29	217.357		217.398	217.649	217.717	0.000	217.687	217.713	217.548	217.344	217.147	217.053
1987	30	217.358		217.399	217.692	0.000	0.000	217.690	217.743	217.522	217.272	217.136	217.056
1987	31			217.404		217.717		217.692	217.743		217.298		217.042

Table 1.3 Raw measured water level

05RF001 LAKE WINNIPEG AT MONTREAL POINT

		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1987	1	217.427	217.364	217.386	217.368	0.000	217.666	217.673	0.000	0.000	0.000	0.000	0.000
1987	2	217.437	217.362	217.384	217.378	0.000	217.588	217.615	0.000	0.000	0.000	0.000	0.000
1987	3	217.408	217.372	217.379	217.383	0.000	217.448	217.653	0.000	0.000	0.000	0.000	0.000
1987	4	217.432	217.388	217.382	217.351	217.568	217.595	217.689	0.000	0.000	0.000	0.000	0.000
1987	5	217.424	217.382	217.396	217.373	217.600	217.659	217.622	0.000	0.000	0.000	0.000	0.000
1987	6	217.411	217.387	217.376	217.363	217.552	217.600	217.620	0.000	0.000	0.000	0.000	0.000
1987	7	217.429	217.359	217.397	217.379	217.560	217.603	217.684	0.000	0.000	0.000	0.000	0.000
1987	8	217.415	217.391	217.385	217.377	217.626	217.622	217.681	0.000	0.000	0.000	0.000	0.000
1987	9	217.388	217.391	217.412	217.388	217.516	217.646	217.774	0.000	0.000	0.000	0.000	0.000
1987	10	217.416	217.385	217.406	217.404	217.537	217.675	217.646	0.000	0.000	0.000	0.000	0.000
1987	11	217.409	217.386	217.384	217.430	217.569	217.660	217.604	0.000	0.000	0.000	0.000	0.000
1987	12	217.399	217.351	217.386	217.470	217.669	217.612	217.656	0.000	0.000	0.000	0.000	0.000
1987	13	217.410	217.346	217.383	217.460	217.588	217.676	217.670	0.000	0.000	0.000	0.000	0.000
1987	14	217.389	217.361	217.380	217.470	217.556	217.643	217.689	0.000	0.000	0.000	0.000	0.000
1987	15	217.395	217.366	217.394	217.470	217.632	217.666	217.701	0.000	217.540	0.000	0.000	0.000
1987	16	217.400	217.368	217.392	217.474	217.544	217.667	217.679	0.000	217.544	0.000	0.000	0.000
1987	17	217.393	217.373	217.379	217.498	217.531	217.688	217.601	0.000	217.472	0.000	0.000	0.000
1987	18	217.377	217.371	217.391	217.495	217.604	217.672	217.626	0.000	217.484	0.000	0.000	0.000
1987	19	217.368	217.384	217.403	217.477	217.578	217.692	217.623	0.000	217.515	0.000	0.000	0.000
1987	20	217.385	217.378	217.404	217.456	217.487	217.664	217.710	0.000	217.480	0.000	0.000	0.000
1987	21	217.369	217.374	217.399	217.498	217.432	217.659	217.668	0.000	217.534	0.000	0.000	0.000
1987	22	217.368	217.378	217.380	0.000	217.574	217.681	217.681	0.000	217.504	0.000	0.000	0.000
1987	23	217.371	217.364	217.374	0.000	217.611	217.664	217.625	0.000	217.393	0.000	0.000	0.000
1987	24	217.378	217.353	217.366	0.000	217.600	217.699	217.667	0.000	0.000	0.000	0.000	0.000
1987	25	217.382	217.339	217.359	0.000	217.594	217.559	217.667	0.000	0.000	0.000	0.000	0.000
1987	26	217.393	217.363	217.367	0.000	217.575	217.596	217.655	0.000	0.000	0.000	0.000	0.000
1987	27	217.385	217.364	217.342	0.000	217.548	217.674	217.682	0.000	0.000	0.000	0.000	0.000
1987	28	217.389	217.357	217.368	0.000	217.538	217.588	217.676	0.000	0.000	0.000	0.000	0.000
1987	29	217.389		217.357	0.000	217.616	217.555	217.649	0.000	0.000	0.000	0.000	0.000
1987	30	217.379		217.368	0.000	217.582	217.641	217.652	0.000	0.000	0.000	0.000	0.000
1987	31	217.373		217.342		217.629		217.644	0.000		0.000		0.000

Table 1.4 Raw measured water level

05SA003 LAKE WINNIPEG AT VICTORIA BEACH

		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1987	1	217.409	217.438	217.447	217.500	217.639	217.500	217.487	217.753	217.755	0.000	217.175	217.201
1987	2	217.366	217.446	217.462	217.442	217.607	217.651	217.747	217.747	217.573	0.000	217.280	217.196
1987	3	217.434	217.415	217.433	217.426	217.555	218.009	217.792	217.908	217.233	0.000	217.335	217.247
1987	4	217.396	217.396	217.452	217.455	217.559	217.771	217.572	217.774	217.631	0.000	217.574	217.179
1987	5	217.417	217.408	217.424	217.420	217.524	217.598	217.680	217.586	217.721	0.000	217.751	217.165
1987	6	217.441	217.403	217.471	217.465	217.670	217.672	217.830	217.769	217.493	0.000	217.414	217.158
1987	7	217.391	217.449	217.477	217.438	217.650	217.737	217.734	217.776	217.711	0.000	217.324	217.109
1987	8	217.403	217.426	217.497	217.476	217.575	217.791	217.876	217.707	217.621	0.000	217.565	217.134
1987	9	217.446	217.397	217.436	217.488	217.771	217.645	217.623	217.927	217.685	0.000	217.410	217.240
1987	10	217.387	217.425	217.425	217.527	217.675	217.571	217.803	217.747	217.740	0.000	217.020	217.121
1987	11	217.389	217.408	217.451	217.540	217.782	217.585	217.951	217.603	217.797	0.000	217.113	217.261
1987	12	217.401	217.454	217.448	217.499	217.402	217.770	217.904	217.947	217.683	0.000	217.316	217.359
1987	13	217.386	217.466	217.448	217.515	217.534	217.636	217.803	217.614	217.631	0.000	217.424	217.226
1987	14	217.433	217.437	217.463	217.502	217.713	217.803	217.729	217.734	217.536	0.000	217.156	217.161
1987	15	217.398	217.404	217.428	217.501	217.517	217.633	217.661	217.770	217.688	0.000	217.020	217.183
1987	16	217.390	217.429	217.423	217.542	217.701	217.674	217.654	217.831	217.563	0.000	217.423	217.148
1987	17	217.399	217.420	217.442	217.545	217.747	217.601	217.893	217.833	217.646	0.000	217.457	217.139
1987	18	217.418	217.435	217.463	217.582	217.583	217.767	217.828	217.806	217.700	0.000	217.288	217.171
1987	19	217.448	217.417	217.464	217.605	217.583	217.685	217.764	217.802	217.658	0.000	217.749	217.126
1987	20	217.386	217.410	217.459	217.764	217.604	217.703	217.707	217.750	217.738	217.575	217.686	217.142
1987	21	217.427	217.454	217.482	217.622	218.005	217.647	217.795	217.751	217.600	217.388	217.965	217.145
1987	22	217.438	217.437	217.471	217.449	217.663	217.628	217.739	218.062	217.522	217.356	217.449	217.117
1987	23	217.416	217.461	217.449	217.641	217.520	217.801	217.873	217.875	217.734	217.323	217.524	217.179
1987	24	217.414	217.459	217.472	217.565	217.520	217.699	217.768	217.755	217.726	217.099	217.189	217.124
1987	25	217.391	217.476	217.484	217.609	217.562	217.946	217.743	217.771	217.609	217.874	217.139	217.130
1987	26	217.378	217.464	217.441	217.628	217.577	218.036	217.773	217.701	217.560	217.358	217.177	217.102
1987	27	217.418	217.460	217.483	217.742	217.635	217.753	217.730	217.700	217.560	217.917	217.214	217.132
1987	28	217.392	217.473	217.455	217.512	217.603	217.865	217.737	217.578	217.726	217.351	217.124	217.106
1987	29	217.410		217.466	217.793	217.614	217.967	217.783	217.617	217.789	217.242	217.242	217.117
1987	30	217.430		217.435	217.577	217.673	217.771	217.751	218.181	0.000	217.523	217.246	217.133
1987	31	217.403		217.469		217.567		217.746	217.868		217.225		217.160

Table 1.5 Raw measured water level

05SB006 LAKE WINNIPEG AT GIMLI

		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
1987	1	217.373	217.397	217.406	217.444	217.624	217.448	217.475	217.706	217.730	217.698	217.121	217.154	
1987	2	217.332	217.407	217.418	217.391	217.591	217.534	217.730	217.693	217.545	217.727	217.226	217.145	
1987	3	217.394	217.382	217.397	217.378	217.529	217.941	217.748	217.847	217.199	217.161	217.264	217.189	
1987	4	217.359	217.360	217.413	217.407	217.535	217.741	217.528	217.721	217.591	217.448	217.481	217.128	
1987	5	217.387	217.372	217.379	217.372	217.488	217.565	217.643	217.540	217.683	218.024	217.647	217.111	
1987	6	217.404	217.357	217.435	217.419	217.638	217.652	217.794	217.699	217.452	217.759	217.345	217.114	
1987	7	217.352	217.411	217.429	217.400	217.622	217.723	217.676	217.716	217.661	217.429	217.278	217.051	
1987	8	217.371	217.388	217.446	217.439	217.526	217.763	217.832	217.655	217.573	217.491	217.485	217.079	
1987	9	217.412	217.361	217.393	217.446	217.746	217.610	217.581	217.887	217.643	217.759	217.340	217.177	
1987	10	217.352	217.385	217.383	217.487	217.641	217.545	217.771	217.711	217.704	217.513	216.893	217.061	
1987	11	217.358	217.367	217.410	217.500	217.742	217.555	217.913	217.544	217.753	217.390	217.123	217.194	
1987	12	217.371	217.411	217.401	217.460	217.359	217.742	217.871	217.881	217.645	217.378	217.258	217.291	
1987	13	217.351	217.418	217.407	217.476	217.492	217.605	217.751	217.551	217.592	217.279	217.364	217.156	
1987	14	217.399	217.393	217.422	217.466	217.679	217.768	217.690	217.728	217.497	217.705	217.115	217.102	
1987	15	217.362	217.367	217.388	217.469	217.481	217.596	217.633	217.722	217.659	217.383	216.979	217.122	
1987	16	217.351	217.385	217.389	217.505	217.678	217.649	217.626	217.773	217.532	217.394	217.371	217.100	
1987	17	217.361	217.381	217.402	217.507	217.729	217.566	217.854	217.781	217.609	217.276	217.392	217.078	
1987	18	217.379	217.389	217.421	217.544	217.562	217.731	217.846	217.756	217.665	217.553	217.163	217.103	
1987	19	217.402	217.373	217.424	217.565	217.553	217.654	217.728	217.742	217.631	217.514	217.646	217.062	
1987	20	217.343	217.364	217.410	217.736	217.592	217.672	217.648	217.707	217.705	217.551	217.581	217.073	
1987	21	217.378	217.411	217.435	217.574	218.042	217.616	217.751	217.677	217.563	217.344	216.875	217.080	
1987	22	217.385	217.395	217.424	217.409	217.655	217.589	217.708	217.991	217.468	217.313	217.247	217.058	
1987	23	217.372	217.417	217.407	217.608	217.501	217.743	217.832	217.807	217.726	217.289	217.467	217.115	
1987	24	217.373	217.419	217.423	217.538	217.502	217.631	217.724	217.695	217.673	217.267	217.192	217.064	
1987	25	217.353	217.442	217.433	217.578	217.547	217.872	217.701	217.727	217.539	216.779	217.086	217.071	
1987	26	217.340	217.424	217.393	217.588	217.573	217.986	217.730	217.663	217.498	217.269	217.095	217.045	
1987	27	217.376	217.420	217.436	217.708	217.629	217.709	217.685	217.658	217.531	217.623	217.155	217.072	
1987	28	217.355	217.432	217.402	217.484	217.583	217.827	217.698	217.528	217.664	217.293	217.074	217.051	
1987	29	217.371		217.414	217.766	217.594	217.935	217.740	217.552	217.695	217.172	217.191	217.060	
1987	30	217.391		217.388	217.546	217.654	217.736	217.711	218.105	217.590	217.463	217.190	217.080	
1987	31	217.370		217.422		217.543		217.725	217.817		217.170		217.085	

Table 1.6 Raw measured water level

05SD001 LAKE WINNIPEG AT PINE DOCK

		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1987	1	0.000	0.000	0.000	0.000	0.000	0.000	217.548	217.722	217.689	217.689	217.126	217.133
1987	2	0.000	0.000	0.000	0.000	0.000	217.740	217.740	217.726	217.501	217.509	217.314	217.137
1987	3	0.000	0.000	0.000	0.000	0.000	217.848	217.702	217.793	217.432	217.365	217.282	217.162
1987	4	0.000	0.000	0.000	0.000	0.000	217.688	217.644	217.706	217.671	217.523	217.502	217.123
1987	5	0.000	0.000	0.000	0.000	0.000	217.622	217.755	217.629	217.632	217.719	217.538	217.073
1987	6	0.000	0.000	0.000	0.000	0.000	217.657	217.739	217.772	217.549	217.529	217.320	217.118
1987	7	0.000	0.000	0.000	0.000	0.000	217.654	217.764	217.715	217.649	217.405	217.296	217.041
1987	8	0.000	0.000	0.000	0.000	0.000	217.701	217.760	217.736	217.602	217.363	217.406	217.093
1987	9	0.000	0.000	0.000	0.000	0.000	217.654	217.643	217.799	217.626	217.592	217.284	217.163
1987	10	0.000	0.000	0.000	0.000	0.000	217.604	217.774	217.651	217.657	217.500	217.081	217.052
1987	11	0.000	0.000	0.000	0.000	0.000	217.636	217.792	217.713	217.651	217.430	217.204	217.165
1987	12	0.000	0.000	0.000	0.000	0.000	217.703	217.780	217.823	217.590	217.343	217.272	217.231
1987	13	0.000	0.000	0.000	0.000	0.000	217.645	217.737	217.686	217.566	217.478	217.311	217.143
1987	14	0.000	0.000	0.000	0.000	0.000	217.728	217.716	217.653	217.555	217.598	217.098	217.099
1987	15	0.000	0.000	0.000	0.000	0.000	217.664	217.652	217.707	217.582	217.352	217.130	217.108
1987	16	0.000	0.000	0.000	0.000	0.000	217.635	217.697	217.770	217.525	217.367	217.277	217.096
1987	17	0.000	0.000	0.000	0.000	0.000	217.663	217.802	217.718	217.615	217.328	217.319	217.072
1987	18	0.000	0.000	217.385	0.000	0.000	217.711	217.698	217.778	217.621	217.576	217.269	0.000
1987	19	0.000	0.000	217.389	0.000	0.000	217.671	217.731	217.731	217.563	217.478	217.597	0.000
1987	20	0.000	0.000	217.380	0.000	0.000	217.682	217.711	217.715	217.610	217.441	217.393	0.000
1987	21	0.000	0.000	217.375	0.000	0.000	217.642	217.743	217.760	217.536	217.315	217.028	0.000
1987	22	217.349	0.000	217.355	0.000	0.000	217.674	217.713	217.884	217.538	217.314	217.221	0.000
1987	23	217.297	0.000	0.000	0.000	0.000	217.761	217.787	217.751	217.623	217.292	217.280	0.000
1987	24	217.265	0.000	0.000	0.000	0.000	217.715	217.705	217.714	217.582	217.285	217.144	0.000
1987	25	217.213	0.000	0.000	0.000	0.000	217.882	217.733	217.667	217.534	217.114	217.101	0.000
1987	26	217.196	0.000	0.000	0.000	0.000	217.801	217.709	217.644	217.487	217.391	217.151	0.000
1987	27	0.000	0.000	0.000	0.000	0.000	217.725	217.690	217.658	217.511	217.503	217.127	0.000
1987	28	0.000	0.000	0.000	0.000	0.000	217.787	217.718	217.604	217.549	217.295	217.099	0.000
1987	29	0.000		0.000	0.000	0.000	217.807	217.723	217.688	217.648	217.312	217.166	0.000
1987	30	0.000		0.000	0.000	0.000	217.704	217.704	217.989	217.448	217.346	217.157	0.000
1987	31	0.000		0.000		0.000		217.715	217.683		217.250		0.000

Table 1.7 Raw measured water level

05SD002 LAKE WINNIPEG AT MATHESON ISLAND LANDING

		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1987	1	0.000	0.000	217.397	217.415	217.599	217.609	217.565	217.713	217.679	217.718	217.068	217.114
1987	2	0.000	0.000	217.400	217.401	217.583	217.751	217.770	217.731	217.465	217.460	217.330	217.131
1987	3	0.000	0.000	217.402	217.396	217.538	217.806	217.695	217.790	217.474	217.378	217.254	217.137
1987	4	0.000	0.000	217.390	217.408	217.579	217.683	217.669	217.698	217.677	217.525	217.503	217.111
1987	5	0.000	0.000	217.403	217.400	217.587	217.640	217.775	217.635	217.617	217.676	217.473	217.094
1987	6	0.000	0.000	217.390	217.418	217.614	217.660	217.733	217.792	217.563	217.501	217.286	217.107
1987	7	0.000	0.000	217.415	217.409	217.622	217.654	217.780	217.712	217.641	217.407	217.236	217.035
1987	8	0.000	0.000	217.411	217.429	217.588	217.692	217.746	217.750	217.594	217.367	217.375	217.096
1987	9	0.000	0.000	217.400	217.446	217.679	217.666	217.662	217.788	217.624	217.553	217.248	217.148
1987	10	0.000	0.000	217.376	217.473	217.631	217.614	217.779	217.611	217.651	217.479	217.071	217.044
1987	11	0.000	0.000	217.387	217.466	217.613	217.660	217.784	217.743	217.638	217.434	217.210	217.124
1987	12	0.000	0.000	217.389	217.461	217.534	217.706	217.774	217.792	217.589	217.331	217.259	0.000
1987	13	0.000	0.000	217.390	217.471	217.626	217.665	217.734	217.691	217.563	217.497	217.314	0.000
1987	14	0.000	0.000	217.390	217.466	217.625	217.727	217.720	217.651	217.569	217.577	0.000	217.096
1987	15	0.000	0.000	217.376	217.481	217.545	217.682	217.651	217.704	217.575	217.348	217.184	217.099
1987	16	0.000	0.000	217.380	217.498	217.630	217.640	217.717	217.780	217.532	217.357	217.253	217.084
1987	17	0.000	0.000	217.387	217.504	217.633	217.687	217.795	217.700	217.613	217.332	217.289	217.080
1987	18	0.000	0.000	217.401	217.522	217.569	217.712	217.686	217.781	217.617	217.560	217.289	217.082
1987	19	0.000	0.000	217.407	217.553	217.588	217.677	217.726	217.713	217.565	217.459	217.601	217.078
1987	20	0.000	0.000	217.411	217.612	217.678	217.695	217.712	217.709	217.601	217.416	217.565	217.073
1987	21	0.000	0.000	217.415	217.531	217.692	217.652	217.736	217.798	217.535	217.306	0.000	217.070
1987	22	0.000	0.000	217.410	217.533	217.583	217.692	217.722	217.861	217.542	217.308	217.265	217.063
1987	23	0.000	0.000	217.410	217.566	217.574	217.760	217.784	217.735	217.616	217.290	217.226	217.072
1987	24	0.000	0.000	217.409	217.557	217.571	217.727	217.704	217.719	217.575	217.250	217.084	217.051
1987	25	0.000	0.000	217.414	217.581	217.582	217.880	217.739	217.658	217.532	217.137	217.093	217.051
1987	26	0.000	0.000	217.394	217.585	217.593	217.773	217.708	217.645	217.491	217.421	217.151	0.000
1987	27	0.000	0.000	217.417	217.606	217.606	217.732	217.694	217.655	217.510	217.457	217.101	0.000
1987	28	0.000	0.000	217.400	217.571	217.612	217.788	217.725	217.609	217.541	217.286	217.044	217.049
1987	29	0.000		217.402	217.641	217.641	217.794	217.727	217.711	217.636	217.326	217.159	217.035
1987	30	0.000		217.391	217.569	217.648	217.699	217.706	217.952	217.403	217.303	217.148	217.059
1987	31	0.000		217.415		217.588		217.715	217.630		217.241		217.054

Table 1.8 Raw measured water level

05SG001 LAKE WINNIPEG AT MISSION POINT

		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1987	1	217.429	217.374	217.409	217.390	217.571	217.667	217.864	217.724	217.597	217.209	217.514	217.411
1987	2	217.435	217.370	217.405	217.412	217.590	217.495	217.657	217.723	217.745	217.326	217.286	217.400
1987	3	217.410	217.381	217.432	217.430	217.623	217.482	217.704	217.649	217.768	0.000	217.347	217.380
1987	4	217.425	217.393	217.417	217.427	217.609	217.592	217.759	217.688	217.562	217.365	217.055	217.407
1987	5	217.403	217.391	217.430	217.440	217.601	217.664	217.727	217.787	217.608	217.148	217.081	217.418
1987	6	217.381	217.390	217.399	217.420	217.577	217.644	217.730	217.670	217.656	217.331	217.253	217.394
1987	7	217.398	217.375	217.393	217.441	217.580	217.645	217.675	217.726	217.524	217.450	217.329	217.487
1987	8	217.383	217.394	217.379	217.431	217.573	217.624	217.691	217.709	217.590	217.472	217.141	217.418
1987	9	217.369	217.403	217.406	217.422	217.538	217.684	217.785	217.653	217.583	217.185	217.264	217.345
1987	10	217.406	217.399	217.412	217.415	217.572	217.719	217.709	217.797	217.539	0.000	217.523	217.453
1987	11	217.388	217.392	217.389	217.450	217.559	217.704	217.667	217.713	217.544	0.000	217.638	217.368
1987	12	217.396	217.374	217.402	217.479	217.685	217.664	217.673	217.591	217.600	217.408	217.531	0.000
1987	13	217.388	217.364	217.395	217.481	217.589	217.686	217.702	217.710	217.606	217.405	217.498	0.000
1987	14	217.358	217.387	217.393	217.514	217.587	217.638	217.723	217.715	217.604	218.104	0.000	217.347
1987	15	217.381	217.403	217.417	217.509	217.649	217.699	217.750	217.715	217.571	218.194	217.601	217.347
1987	16	217.391	217.389	217.412	217.500	217.566	217.724	217.723	217.645	217.621	218.176	217.530	217.350
1987	17	217.373	217.391	217.404	217.511	217.565	217.702	217.671	217.685	217.467	0.000	217.510	217.362
1987	18	217.369	217.396	217.421	217.503	217.610	217.676	217.698	217.623	217.469	217.916	217.419	217.339
1987	19	217.358	217.402	217.418	217.490	217.606	217.714	217.713	217.665	0.000	218.045	217.120	217.357
1987	20	217.389	217.410	217.423	217.458	217.502	217.705	217.703	217.671	217.454	218.061	217.146	217.332
1987	21	217.357	217.387	217.410	217.546	217.461	217.734	217.695	217.598	217.491	217.390	0.000	217.326
1987	22	217.352	217.392	217.406	217.554	217.598	217.727	217.719	217.514	217.485	217.388	217.459	217.336
1987	23	217.369	217.376	217.404	217.528	217.626	217.662	217.674	217.604	217.405	217.460	217.365	217.308
1987	24	217.382	217.370	217.399	217.546	217.620	217.683	217.738	217.652	217.417	0.000	217.512	217.333
1987	25	217.394	217.367	217.395	217.535	217.626	217.580	217.738	217.669	217.398	217.485	217.516	217.318
1987	26	217.391	217.375	217.421	217.508	217.603	217.628	217.744	217.642	0.000	217.205	217.458	0.000
1987	27	217.369	217.391	217.376	217.530	217.592	217.689	217.750	217.667	0.000	217.225	217.466	0.000
1987	28	217.391	217.397	217.398	217.561	217.628	217.651	217.720	217.691	217.393	217.391	217.543	217.308
1987	29	217.390		217.402	217.503	217.638	217.618	217.708	217.550	217.293	217.319	217.414	217.316
1987	30	217.382		217.417	217.589	217.641	217.693	217.721	217.352	217.494	217.269	217.410	217.279
1987	31	217.386		217.394		217.695		217.718	217.614		0.000		217.257

Table 2.1 Raw measured water level

05RD005 LAKE WINNIPEG AT BERENS RIVER ** PROVISIONAL

		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1988	1	217.030	217.031	217.024	217.007	217.094	217.140	217.134	217.120	217.054	0.000	216.827	216.789
1988	2	217.027	217.030	217.015	217.006	217.122	217.140	217.141	217.124	217.055	0.000	216.821	216.613
1988	3	217.044	217.032	217.011	216.997	217.136	217.110	217.142	217.136	217.043	0.000	216.842	216.896
1988	4	217.033	217.036	217.006	217.003	217.119	0.000	217.139	217.122	217.060	0.000	216.820	216.791
1988	5	217.028	217.039	217.004	217.012	217.130	0.000	217.118	217.120	217.030	0.000	216.841	216.792
1988	6	217.014	217.036	217.007	217.016	217.129	217.110	217.128	217.116	217.027	0.000	216.803	216.846
1988	7	217.035	217.035	217.001	217.031	217.147	217.060	217.157	217.178	217.052	0.000	216.740	216.800
1988	8	217.034	217.041	216.994	217.052	217.139	217.040	217.152	217.109	217.123	0.000	216.885	216.811
1988	9	217.029	217.033	217.001	217.045	217.172	217.080	0.000	217.112	217.144	0.000	216.921	216.805
1988	10	217.034	217.035	217.006	217.041	217.154	217.140	217.142	217.105	217.033	0.000	216.849	216.799
1988	11	217.040	217.019	216.998	217.037	217.167	0.000	217.129	217.109	216.998	216.892	216.802	216.767
1988	12	217.040	217.028	216.995	217.046	217.178	0.000	217.121	217.096	216.997	216.823	216.838	216.796
1988	13	217.032	217.040	216.986	217.063	217.096	217.132	217.128	217.085	217.056	216.899	216.873	216.798
1988	14	217.033	217.051	216.983	217.056	217.104	217.131	217.128	217.084	217.005	216.873	216.859	216.804
1988	15	217.037	217.035	216.978	217.045	217.129	217.137	217.141	217.102	216.999	0.000	216.829	216.791
1988	16	217.049	217.046	216.957	217.058	217.086	217.131	217.152	217.092	216.998	0.000	216.823	216.799
1988	17	217.045	217.038	216.960	217.056	217.068	217.123	217.140	217.068	217.019	0.000	216.822	216.798
1988	18	217.038	217.042	216.965	217.060	217.125	0.000	217.141	217.080	216.999	216.875	216.810	216.796
1988	19	217.047	217.055	216.967	217.067	217.137	217.162	217.142	217.071	216.859	216.859	216.803	216.799
1988	20	217.039	217.035	216.962	217.057	217.122	217.144	217.134	217.069	216.914	217.013	216.736	216.797
1988	21	217.044	217.041	216.956	217.063	217.121	217.152	217.130	216.994	216.911	216.989	216.790	216.787
1988	22	217.046	217.044	216.965	217.060	217.139	217.135	217.134	217.090	217.066	0.000	216.759	216.791
1988	23	217.034	217.041	216.966	217.056	217.147	217.073	217.166	217.137	216.996	217.014	216.540	216.816
1988	24	217.048	217.032	216.971	217.073	217.117	217.141	217.128	217.131	216.961	216.972	216.734	216.818
1988	25	217.031	217.024	217.027	217.089	217.151	0.000	217.138	217.121	216.966	217.039	216.834	216.807
1988	26	217.034	217.025	217.014	217.078	217.146	217.133	217.125	217.107	216.901	216.897	216.808	216.795
1988	27	217.031	217.019	217.003	217.068	217.152	217.118	217.122	217.158	216.913	216.954	216.853	216.807
1988	28	217.027	217.026	217.013	217.077	217.146	217.124	217.130	217.098	216.868	216.969	216.758	216.805
1988	29	217.041	217.012	217.015	217.071	217.161	217.000	217.118	217.077	216.920	216.887	216.844	216.800
1988	30	217.045		217.005	217.070	217.163	217.121	0.000	217.121	216.954	216.888	216.810	216.802
1988	31	217.048		216.993		217.050		0.000	217.019		216.848		0.000

Table 2.2 Raw measured water level

05RE003 LAKE WINNIPEG AT GEORGE ISLAND

		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1988	1	0.000	217.026	217.007	0.000	217.030	217.167	217.147	0.000	217.029	0.000	216.894	216.794
1988	2	0.000	217.020	217.003	0.000	217.040	217.168	217.156	0.000	217.006	0.000	217.029	216.803
1988	3	216.979	217.023	217.006	0.000	217.052	217.173	217.157	0.000	216.990	0.000	216.889	216.800
1988	4	216.967	217.031	0.000	217.006	217.023	0.000	217.132	0.000	216.991	0.000	216.834	216.803
1988	5	216.969	217.031	0.000	217.010	217.042	217.176	217.129	0.000	216.987	0.000	216.845	216.801
1988	6	216.967	217.031	216.994	217.004	217.053	217.183	217.143	0.000	217.002	0.000	216.837	216.817
1988	7	216.978	217.027	216.991	216.997	217.072	217.159	217.165	0.000	217.130	0.000	216.934	216.798
1988	8	216.970	217.033	216.985	217.010	217.043	217.172	217.156	0.000	217.101	0.000	216.878	216.782
1988	9	216.967	217.027	216.995	217.016	217.071	217.174	0.000	0.000	216.969	0.000	216.838	216.774
1988	10	216.968	217.032	216.982	217.020	217.060	217.176	217.099	0.000	216.951	0.000	216.834	216.775
1988	11	216.974	217.025	216.971	217.012	217.077	217.176	217.137	0.000	216.948	216.897	216.911	216.787
1988	12	216.972	217.027	216.972	217.027	217.065	217.155	217.147	0.000	216.947	217.020	216.870	216.789
1988	13	216.968	217.035	216.971	217.023	217.068	217.148	217.152	0.000	217.011	217.057	216.840	216.780
1988	14	216.971	217.026	216.969	217.022	217.103	217.144	217.138	0.000	216.962	216.967	216.806	216.768
1988	15	216.967	217.033	216.976	217.019	217.041	217.157	217.146	0.000	216.980	0.000	216.822	216.778
1988	16	216.976	217.037	216.994	217.036	217.064	217.169	217.142	0.000	216.961	0.000	216.735	216.774
1988	17	216.969	217.034	216.994	217.012	217.097	217.195	217.141	0.000	216.968	216.923	216.769	216.773
1988	18	216.964	217.033	216.991	217.020	217.105	0.000	217.137	0.000	216.898	216.923	216.840	216.776
1988	19	216.997	217.037	216.981	217.023	217.073	217.165	217.132	0.000	216.826	216.923	216.859	216.771
1988	20	217.035	217.025	216.977	217.016	217.100	217.174	217.127	0.000	216.864	217.094	216.840	216.775
1988	21	217.046	217.032	216.981	217.018	217.096	217.164	217.141	0.000	216.948	217.003	216.849	216.775
1988	22	217.025	217.027	216.985	217.019	217.105	217.128	217.149	0.000	217.031	0.000	216.810	216.792
1988	23	217.030	217.031	216.987	217.015	217.074	217.149	217.165	0.000	216.922	216.889	216.800	216.793
1988	24	217.026	217.022	216.986	217.011	217.088	217.204	217.104	0.000	216.946	216.865	216.823	216.795
1988	25	217.029	217.019	216.999	217.020	217.120	0.000	217.136	0.000	216.915	216.841	216.808	216.792
1988	26	217.031	217.017	216.994	217.031	217.097	217.161	217.112	0.000	216.941	216.862	216.819	216.787
1988	27	217.024	217.015	216.993	217.024	217.096	217.162	217.117	0.000	216.930	216.888	216.792	216.779
1988	28	217.030	217.012	216.996	217.027	217.101	217.158	217.118	0.000	216.992	216.865	216.761	216.780
1988	29	217.025	216.998	217.013	217.020	217.110	217.154	217.109	0.000	216.989	216.874	216.785	216.768
1988	30	217.010		217.008	217.025	217.145	217.147	0.000	217.066	217.049	216.910	216.769	216.762
1988	31	217.034		217.001		217.146		0.000	217.088		216.883		0.000

Table 2.3 Raw measured water level

05RF001 LAKE WINNIPEG AT MONTREAL POINT

		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1988	1	0.000	217.042	217.047	217.078	217.102	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	2	0.000	217.040	217.055	217.068	217.101	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	3	0.000	217.037	217.048	217.063	217.104	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	4	0.000	217.045	217.045	217.066	217.094	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	5	217.067	217.055	217.041	217.076	217.108	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	6	217.075	217.057	217.040	217.065	217.116	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	7	217.072	217.055	217.036	217.060	217.125	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	8	217.074	217.043	217.036	217.058	217.117	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	9	217.088	217.041	217.041	217.065	217.139	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	10	217.077	217.048	217.025	217.075	217.127	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	11	217.081	217.051	217.030	217.078	217.142	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	12	217.081	217.048	217.042	217.078	217.098	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	13	217.084	217.043	217.046	217.074	217.140	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	14	217.079	217.045	217.043	217.079	217.143	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	15	217.067	217.051	217.042	217.081	217.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	16	217.069	217.047	217.047	217.100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	17	217.068	217.066	217.044	217.083	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	18	217.068	217.063	217.047	217.089	217.178	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	19	217.070	217.050	217.039	217.083	217.099	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	20	217.064	217.052	217.039	217.080	217.123	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	21	217.075	217.049	217.046	217.065	217.125	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	22	217.053	217.055	217.048	217.071	217.122	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	23	217.062	217.062	217.040	217.070	217.063	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	24	217.058	217.053	217.044	217.060	217.147	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	25	217.080	217.049	217.029	217.070	217.181	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	26	217.070	217.049	217.045	217.087	217.139	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	27	217.063	217.047	217.039	217.085	217.129	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	28	217.057	217.036	217.034	217.092	217.136	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	29	217.049	217.041	217.059	217.093	217.134	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	30	217.036		217.063	217.102	217.124	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	31	217.035		217.063		217.195		0.000	0.000		0.000		0.000

Table 2.4 Raw measured water level

05SA003 LAKE WINNIPEG AT VICTORIA BEACH

		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
1988	1	0.000	217.080	217.100	217.023	217.079	217.192	217.131	217.208	217.103	217.252	216.939		0.000
1988	2	0.000	217.070	217.107	217.057	217.114	217.249	217.079	217.222	217.241	217.160	216.600		0.000
1988	3	0.000	217.104	217.072	217.073	217.176	217.229	217.080	217.184	217.208	217.398	216.844		0.000
1988	4	0.000	217.079	217.080	217.045	217.295	217.196	217.253	217.196	217.246	217.115	216.998		0.000
1988	5	0.000	217.085	217.062	217.046	217.191	217.161	217.232	217.033	217.197	216.837	217.016		0.000
1988	6	0.000	217.081	217.104	217.065	217.144	217.127	217.153	217.129	216.945	216.891	216.941		0.000
1988	7	0.000	217.094	217.079	217.099	217.130	217.203	217.203	217.128	216.671	217.062	216.675		0.000
1988	8	0.000	217.081	217.094	217.117	217.322	217.166	217.160	217.263	216.999	216.960	216.846		0.000
1988	9	0.000	217.118	217.046	217.111	217.175	217.131	217.352	216.955	217.431	217.019	217.083		0.000
1988	10	0.000	217.079	217.108	217.071	217.266	217.114	217.527	217.093	217.270	217.503	217.059		0.000
1988	11	0.000	217.077	217.140	217.091	217.177	217.164	217.246	217.243	217.157	217.208	216.706		0.000
1988	12	0.000	217.064	217.108	217.064	217.256	217.287	217.110	217.172	217.206	216.834	216.698		0.000
1988	13	0.000	217.092	217.082	217.106	217.251	217.335	217.146	217.188	217.105	216.645	217.027		0.000
1988	14	0.000	217.165	217.066	217.104	217.054	217.353	217.226	217.163	217.079	216.910	217.144		0.000
1988	15	0.000	217.095	217.080	217.096	217.382	217.291	217.212	217.036	216.877	216.943	216.974		0.000
1988	16	0.000	217.111	217.042	217.046	217.281	217.177	217.266	217.204	216.901	217.155	217.498		0.000
1988	17	0.000	217.099	217.060	217.145	217.029	216.909	217.252	217.232	217.038	217.098	217.401		0.000
1988	18	0.000	217.106	217.054	217.088	216.997	217.179	217.244	217.108	217.237	216.987	0.000		0.000
1988	19	0.000	217.119	217.069	217.093	217.291	217.240	217.249	217.079	217.443	217.061	0.000		0.000
1988	20	0.000	217.122	217.056	217.105	217.208	217.227	217.280	217.084	217.375	216.747	0.000		0.000
1988	21	0.000	217.081	217.030	217.091	217.205	217.202	217.195	216.888	216.982	217.216	0.000		0.000
1988	22	217.140	217.125	217.037	217.096	217.183	217.392	217.055	216.783	216.842	216.728	0.000		0.000
1988	23	217.094	217.082	217.034	217.080	217.276	217.124	217.033	217.155	217.219	217.057	0.000		0.000
1988	24	217.128	217.090	217.036	217.122	217.190	217.067	217.301	217.384	217.051	217.330	0.000		0.000
1988	25	217.106	217.068	217.131	217.178	217.020	217.493	217.098	217.538	217.225	217.516	0.000		0.000
1988	26	217.075	217.089	217.136	217.084	217.184	217.212	217.198	217.265	216.967	217.300	0.000		0.000
1988	27	217.103	217.069	217.070	217.086	217.196	217.098	217.152	217.428	217.093	217.152	0.000		0.000
1988	28	217.071	217.079	217.101	217.049	217.173	217.164	217.123	217.434	216.852	217.448	0.000		0.000
1988	29	217.117	217.114	217.066	217.075	217.164	217.092	217.274	217.140	216.903	217.167	0.000		0.000
1988	30	217.153		217.044	217.057	217.173	217.101	217.262	216.873	216.871	216.814	0.000		0.000
1988	31	217.114		217.052		217.082		217.050	216.848		216.951			0.000

Table 2.5 Raw measured water level

05SB006 LAKE WINNIPEG AT GIMLI ** PROVISIONAL TELEMAR

		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1988	1	217.027	217.029	217.062	216.961	217.037	217.153	217.070	217.170	217.063	217.188	216.900	216.770
1988	2	217.032	217.028	217.047	217.022	217.084	217.205	217.018	217.183	217.204	217.081	216.470	216.850
1988	3	217.039	217.060	217.032	217.018	217.143	217.183	217.020	217.111	217.175	217.348	216.790	0.000
1988	4	217.034	217.039	217.025	216.993	217.254	217.161	217.213	217.145	217.228	217.055	217.020	0.000
1988	5	217.037	217.033	217.015	217.000	217.146	217.121	217.194	216.982	217.162	216.765	0.000	216.850
1988	6	217.028	217.035	217.050	217.028	217.118	217.077	217.106	217.092	216.892	216.839	0.000	216.870
1988	7	217.019	217.051	217.031	217.052	217.101	217.181	217.117	217.062	216.589	217.012	216.620	216.900
1988	8	217.061	217.034	217.037	217.069	217.293	217.160	217.087	217.208	216.882	216.902	216.740	216.830
1988	9	216.996	217.069	217.003	217.061	217.118	217.084	217.284	216.893	217.322	216.972	217.010	216.840
1988	10	217.051	217.035	217.071	217.029	217.218	217.067	217.471	217.060	217.212	217.467	217.040	0.000
1988	11	217.036	217.022	217.087	217.040	217.129	217.122	217.186	217.207	217.168	217.154	0.000	0.000
1988	12	217.058	217.030	217.051	217.024	217.197	217.237	217.056	217.151	217.130	216.770	0.000	216.820
1988	13	217.063	217.047	217.020	217.058	217.191	217.306	217.054	217.153	217.039	216.590	0.000	216.840
1988	14	217.026	217.120	217.018	217.054	216.998	217.315	217.175	217.118	217.008	216.862	217.160	0.000
1988	15	217.056	217.035	217.024	217.043	217.342	217.246	217.150	216.986	216.821	216.895	216.900	0.000
1988	16	217.043	217.072	216.988	217.005	217.227	217.109	217.197	217.181	216.854	217.098	217.420	0.000
1988	17	217.055	217.041	217.017	217.100	216.973	216.857	217.179	217.227	216.979	217.033	217.370	0.000
1988	18	217.059	217.063	217.000	217.038	216.953	217.133	217.184	217.075	217.227	216.934	216.890	0.000
1988	19	217.063	217.075	217.025	217.051	217.246	217.179	217.193	217.036	217.436	216.996	0.000	0.000
1988	20	217.060	217.065	217.002	217.053	217.157	217.166	217.232	217.077	217.326	216.660	0.000	0.000
1988	21	217.017	217.036	216.984	217.045	217.155	217.163	217.138	216.865	216.908	217.153	216.750	0.000
1988	22	217.094	217.080	216.998	217.045	217.134	217.351	216.996	216.691	216.766	216.614	216.900	0.000
1988	23	217.034	217.030	216.983	217.036	217.241	217.107	216.974	217.029	217.145	216.995	216.740	0.000
1988	24	217.097	217.049	217.000	217.090	217.154	217.027	217.243	217.306	217.008	217.227	216.680	0.000
1988	25	217.043	217.019	217.094	217.126	216.970	217.418	217.046	217.468	217.173	217.404	216.800	0.000
1988	26	217.034	217.059	217.071	217.036	217.139	217.152	217.147	217.195	216.954	217.215	0.000	0.000
1988	27	217.048	217.011	217.029	217.037	217.158	217.095	217.101	217.352	217.064	217.109	0.000	0.000
1988	28	217.027	217.047	217.056	217.017	217.129	217.147	217.083	217.370	216.807	217.337	216.880	0.000
1988	29	217.086	217.067	217.015	217.035	217.126	217.057	217.224	217.090	216.843	217.073	216.830	0.000
1988	30	217.100		217.002	217.023	217.135	217.045	217.208	216.836	216.807	216.750	216.910	0.000
1988	31	217.051		217.010		217.038		217.003	216.827		216.914		0.000

Table 2.6 Raw measured water level

05SD001 LAKE WINNIPEG AT PINE DOCK

		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1988	1	0.000	217.044	0.000	216.964	217.029	217.152	0.000	0.000	0.000	0.000	0.000	0.000
1988	2	0.000	217.036	0.000	217.001	217.077	217.151	0.000	0.000	0.000	0.000	0.000	0.000
1988	3	0.000	217.056	0.000	216.989	217.092	217.130	0.000	0.000	0.000	0.000	0.000	0.000
1988	4	0.000	217.045	0.000	216.977	217.119	217.117	0.000	0.000	0.000	0.000	0.000	0.000
1988	5	0.000	217.048	0.000	216.993	217.097	217.100	0.000	0.000	0.000	0.000	0.000	0.000
1988	6	0.000	217.043	0.000	217.002	217.080	217.141	0.000	0.000	0.000	0.000	0.000	0.000
1988	7	0.000	217.056	0.000	217.012	217.095	217.105	0.000	0.000	0.000	0.000	0.000	0.000
1988	8	0.000	217.047	0.000	217.035	217.149	217.099	0.000	0.000	0.000	0.000	0.000	0.000
1988	9	0.000	217.059	0.000	217.021	217.117	217.126	0.000	0.000	0.000	0.000	0.000	0.000
1988	10	0.000	217.045	0.000	217.018	217.118	217.120	0.000	0.000	0.000	0.000	0.000	0.000
1988	11	0.000	217.025	0.000	217.007	217.130	217.186	0.000	0.000	0.000	0.000	0.000	0.000
1988	12	0.000	217.037	0.000	217.019	217.092	217.183	0.000	0.000	0.000	0.000	0.000	0.000
1988	13	0.000	0.000	0.000	217.031	217.041	217.194	0.000	0.000	0.000	0.000	0.000	0.000
1988	14	0.000	0.000	0.000	217.036	217.217	217.188	0.000	0.000	0.000	0.000	0.000	0.000
1988	15	0.000	0.000	0.000	217.021	217.101	217.102	0.000	0.000	0.000	0.000	0.000	0.000
1988	16	0.000	0.000	0.000	217.012	216.993	217.049	0.000	0.000	0.000	0.000	0.000	0.000
1988	17	0.000	0.000	216.997	217.052	217.021	217.124	0.000	0.000	0.000	0.000	0.000	0.000
1988	18	0.000	0.000	216.988	217.026	217.147	217.187	0.000	0.000	0.000	0.000	0.000	0.000
1988	19	0.000	0.000	216.999	217.032	217.107	217.143	0.000	0.000	0.000	0.000	0.000	0.000
1988	20	0.000	0.000	216.979	217.029	217.108	217.155	0.000	0.000	0.000	0.000	0.000	0.000
1988	21	0.000	0.000	216.962	217.034	217.109	217.219	0.000	0.000	0.000	0.000	0.000	0.000
1988	22	217.082	0.000	216.975	217.030	217.173	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	23	217.043	0.000	216.968	217.019	217.067	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	24	217.075	0.000	216.973	217.040	217.054	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	25	217.042	0.000	217.049	217.069	217.100	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	26	217.043	0.000	217.020	217.027	217.126	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	27	217.047	0.000	216.994	217.019	217.089	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	28	217.035	0.000	217.013	217.008	217.110	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	29	217.074	0.000	217.006	217.014	217.115	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	30	217.077		216.994	217.006	217.074	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1988	31	217.065		216.988		217.142		0.000	0.000		0.000		0.000

Table 2.7 Raw measured water level

05SD002 LAKE WINNIPEG AT MATHESON ISLAND LANDING

		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1988	1	0.000	217.027	217.042	0.000	216.997	217.173	0.000	217.135	217.057	0.000	216.827	216.790
1988	2	0.000	217.018	217.026	0.000	217.004	217.169	0.000	217.168	217.117	0.000	216.718	216.831
1988	3	217.033	217.033	217.017	0.000	217.008	217.155	217.127	217.158	217.090	0.000	216.901	216.910
1988	4	217.032	217.027	0.000	217.004	217.067	0.000	217.196	217.114	217.146	0.000	216.877	216.793
1988	5	217.018	217.032	0.000	217.003	217.055	217.136	217.136	217.055	217.043	0.000	216.893	216.810
1988	6	217.002	217.030	217.026	217.004	217.064	217.136	217.141	217.116	216.955	0.000	216.830	216.848
1988	7	217.022	217.038	217.016	217.004	217.072	217.157	217.167	217.209	216.861	0.000	216.712	216.825
1988	8	217.025	217.037	217.012	217.004	217.097	217.122	217.169	217.124	217.077	0.000	216.901	216.800
1988	9	217.004	217.038	217.010	217.004	217.086	217.118	0.000	217.025	217.303	0.000	216.989	216.806
1988	10	217.018	217.032	217.035	217.003	217.093	217.161	217.253	217.102	217.088	0.000	216.890	216.792
1988	11	217.016	217.012	217.023	217.004	217.103	217.146	217.168	217.158	216.988	216.940	216.718	216.770
1988	12	217.027	217.028	217.011	217.003	217.170	217.199	217.091	217.081	216.988	216.768	216.859	216.788
1988	13	217.017	217.041	216.999	217.004	217.086	217.205	217.161	217.079	217.102	216.833	216.974	216.804
1988	14	217.012	217.068	217.000	217.004	217.072	217.208	217.142	217.043	216.952	216.899	216.944	216.802
1988	15	217.018	217.029	216.997	217.004	217.222	217.212	217.183	217.069	216.898	0.000	216.890	216.781
1988	16	217.019	217.052	216.984	217.003	217.104	217.116	217.196	217.121	216.927	0.000	217.076	216.797
1988	17	217.016	217.039	216.986	217.003	217.017	217.015	217.176	217.062	216.998	0.000	216.979	216.785
1988	18	217.020	217.049	216.978	217.007	217.065	0.000	217.175	217.055	217.043	216.907	216.831	216.795
1988	19	217.024	217.055	216.986	217.010	217.153	217.223	217.199	217.022	217.033	216.890	216.833	216.805
1988	20	217.014	217.039	216.973	217.011	217.128	217.154	217.190	217.027	217.026	216.964	216.751	216.804
1988	21	217.016	217.041	216.963	217.014	217.124	217.194	217.134	216.800	216.894	217.142	216.804	216.782
1988	22	217.058	217.050	216.975	217.011	217.129	217.229	217.112	216.955	216.981	0.000	216.785	216.809
1988	23	217.030	217.034	216.968	217.011	217.175	217.014	217.155	217.196	217.070	217.141	216.601	216.819
1988	24	217.054	217.037	216.974	217.010	217.076	217.094	217.171	217.224	216.986	217.150	216.786	216.810
1988	25	217.028	217.024	217.041	217.007	217.105	0.000	217.132	217.247	217.051	217.255	216.854	216.802
1988	26	217.030	217.037	217.002	217.008	217.118	217.140	217.149	217.135	216.925	216.994	216.854	216.791
1988	27	217.032	217.022	216.989	217.007	217.150	217.086	217.108	217.339	216.957	217.061	216.887	216.813
1988	28	217.024	217.040	217.005	217.008	217.113	217.142	217.142	217.197	216.836	217.148	216.772	216.793
1988	29	217.055	217.029	216.996	217.004	217.137	217.099	217.132	217.043	216.908	216.936	216.848	216.798
1988	30	217.064		216.987	216.996	217.140	217.098	0.000	216.896	216.886	216.863	216.824	216.811
1988	31	217.041		216.989		217.108		0.000	216.977		216.897		0.000

Table 2.8 Raw measured water level

05SG001 LAKE WINNIPEG AT MISSION POINT

		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1988	1	217.031	217.060	217.046	217.077	217.076	217.165	217.227	217.195	217.096	0.000	217.018	216.885
1988	2	0.000	217.066	217.055	217.036	217.080	217.203	217.232	217.183	217.054	0.000	217.321	216.852
1988	3	217.288	217.053	217.060	217.047	217.103	217.201	217.230	217.184	217.053	0.000	217.179	216.755
1988	4	217.139	217.060	217.062	217.060	217.086	217.225	217.193	217.199	217.062	0.000	217.203	216.860
1988	5	217.042	217.061	217.067	217.041	217.128	217.246	217.238	217.249	217.079	0.000	216.906	216.849
1988	6	217.078	217.070	217.051	217.045	217.133	217.256	217.248	217.216	217.161	0.000	217.013	216.770
1988	7	217.065	217.061	217.056	217.054	0.000	217.254	217.184	217.101	217.195	0.000	217.218	216.823
1988	8	217.041	217.070	217.057	217.028	0.000	217.244	217.199	217.120	216.893	0.000	216.838	216.830
1988	9	217.065	217.049	217.060	217.042	0.000	217.254	217.089	217.215	216.756	0.000	216.772	216.837
1988	10	217.054	217.070	217.033	217.060	0.000	217.225	217.133	217.139	216.926	0.000	216.841	216.830
1988	11	217.061	217.097	217.014	217.079	0.000	217.224	217.204	217.134	216.997	216.946	217.044	216.862
1988	12	217.061	217.094	217.022	217.065	0.000	217.177	217.257	217.151	216.972	217.073	216.921	216.850
1988	13	217.058	217.092	217.032	217.062	0.000	217.167	217.231	217.139	216.895	217.050	216.794	216.832
1988	14	217.093	217.053	217.033	217.055	0.000	217.169	217.263	217.161	216.999	216.981	216.823	216.818
1988	15	217.090	217.115	217.036	217.079	0.000	217.174	217.218	217.171	217.056	0.000	216.868	216.846
1988	16	217.096	217.093	217.044	217.071	0.000	217.231	217.183	217.177	217.041	0.000	216.685	216.837
1988	17	217.066	217.107	217.024	217.042	0.000	217.295	217.183	217.170	216.986	0.000	216.759	216.849
1988	18	217.074	217.090	217.019	217.059	0.000	217.231	217.199	217.160	216.965	216.936	216.894	216.847
1988	19	217.060	217.072	217.008	217.049	0.000	217.130	217.202	217.192	216.949	216.972	216.909	216.837
1988	20	217.065	217.081	217.026	217.045	0.000	217.224	217.194	217.187	216.913	217.014	216.958	216.832
1988	21	217.081	217.087	217.041	217.047	0.000	217.201	217.224	217.383	217.034	216.764	216.912	216.863
1988	22	217.041	217.057	217.029	217.054	0.000	217.168	217.272	217.266	216.941	0.000	216.932	216.836
1988	23	217.083	217.073	217.043	217.065	0.000	217.339	217.181	217.063	216.878	216.776	217.124	216.820
1988	24	217.041	217.066	217.030	217.039	0.000	217.213	217.173	217.006	216.953	216.761	216.915	216.827
1988	25	217.059	217.090	216.971	217.041	0.000	217.129	217.218	216.944	216.892	216.741	216.828	216.830
1988	26	218.073	217.065	217.018	217.083	0.000	217.220	217.198	217.077	217.033	216.849	216.826	216.840
1988	27	217.068	217.079	217.048	217.082	0.000	217.293	217.240	216.912	216.930	216.890	216.757	216.818
1988	28	217.077	217.055	217.055	217.094	0.000	217.250	217.235	217.029	217.056	216.696	216.907	216.829
1988	29	217.035	217.057	217.038	217.094	0.000	217.285	217.156	217.152	216.990	216.862	216.821	216.842
1988	30	217.027		217.042	217.094	0.000	217.266	217.226	217.282	217.004	216.972	216.845	216.831
1988	31	217.035		217.052		0.000		217.151	217.201		216.952		0.000

APPENDIX B

B1.1 PROGRAM STRUCTURE OF CONVERT FORTRAN PROGRAM

The CONVERT algorithm is programmed in FORTRAN IV language. The program is used for convert the raw measured data at each gauge station for one year from the condensed form to the readable form, presented in Appendix A.

The program has 31 lines. The executable version takes 31 kB of memory on the hard disk of a personal computer. The execution time is about 20 seconds on an IBM/AT personal computer with a mathematical coprocessor.

The sample input is presented in Section B1.4 and the output file are presented in Appendix A. The program reads an input file with a name ACTUALS.DAT and create the output file with name MABSL.DAT. When no measurements is occur in the input file it is presented as a blanc space, however, in the output file it is noted as zero.

B1.2 VARIABLES

The following section describes the variables existing in the CONV program.

D(I) - measured water level in converted form

DAY - number of day in month

I - index for month

ID - measured water level in condensed form

J - index for days

K - index for gauge stations

NAME - name of gauge station

NO - code number for gauge station

YEAR - year indicator

B1.3 PROGRAM LISTING

```
C*********************************************************************** C*
C*
C*        PROGRAM FOR CONVERSION OF THE ROW MEASURED DATA
C*
C***********************************************************************
      DIMENSION ID(12),D(12)
      INTEGER DAY,YEAR
      CHARACTER NO*10,NAME*45
      OPEN(1,FILE='ACTUALS.DAT')
      OPEN(2,FILE='MABSL.DAT')
      DO 3 K=1,8
      READ(1,101) NO,NAME
      WRITE(2,102) NO,NAME
      DO 1 J=1,31
      READ(1,110)DAY,YEAR, (ID(I),I=1,12)
      DO 2 I=1,12
      D(I)=ID(I)
      IF (D(I) .EQ. 0.) GOTO 2
      D(I)=D(I)/1000+200
 2    CONTINUE
 1    WRITE(2,120)YEAR,DAY, (D(I),I=1,12)
 3    CONTINUE
      CLOSE (1)
      CLOSE (2)
 100  FORMAT(12(I2,1X))
 101  FORMAT(5X,A7,A45,/)
 102  FORMAT(//,5X,A7,5X,A45,/)
 110  FORMAT(14X,I2,I4,12(I5))
 120  FORMAT(2X,I4,5X,I2,5X,12(F7.3,2X))
      END
```

B1.4 INPUT FILE "ACTUALS.DAT"

```
1211105RD005LAKE WINNIPEG AT BERENS RIVER
1211105RD005Provisional Data collected by Water Resources Branch (29-SEP-87)
1205RD005112-3 119871741217384174031742017552176491761517720177001760517172171 16
1205RD005112-3 219871739817385174071741617557177601774617770176201741717318171 22
1205RD005112-3 319871737917382173931741417548176831769017730175001747717258171 34
1205RD005112-3 419871740017375173981741617566176321773617720177201747117423171 14
1205RD005112-3 519871741017381174011741417596176391777817770176501748017361170 65
1205RD005112-3 619871741117385174081742117580176381771917770176001740217269171 15
1205RD005112-3 719871739917394174111742317584176271781917760177401739717260170 40
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1205RD005112-3 919871738817385173921745217598176691773917820176101748217211171 36
1205RD005112-310198717390173801738617470175871765817756176301762017478172091704 3
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1205RD005112-318198717374173841740717507175721770617663177801757717494173411709 1
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1211105RE003PROVISIONAL DCP DATA
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1205RE003112-3 21987 174141767617717 17705176691744617290171 27
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1205RE003112-3161987 175381771717714177411772217565173811719517091
1205RE003112-3171987 175401771717744176931772217565173931718117091
1205RE003112-3181987 174121754617717177171769017743175561739917244170 88
1205RE003112-3191987 174091758017717177281770117739175451736217164170 93
1205RE003112-3201987 174141754517717 177601773917530173411711917087
1205RE003112-321198717340 174101757917717 177481775717551173321721617077
1205RE003112-322198717335 174061763617717 177001768017565173301716917079
1205RE003112-323198717338 174091760317717 177011768417516173451712117063
1205RE003112-324198717332 174041762817717 177071769317520173741714217067
1205RE003112-325198717341 174021763317717 177251768317538174761717117062
1205RE003112-326198717352 174011766317717 176991767017527174001718717067
1205RE003112-327198717339 174051763217717 177031767517534173101715117057
1205RE003112-328198717345 173981769917717 177011767617507173071717617062
1205RE003112-329198717357 173981764917717 176871771317548173441714717053
1205RE003112-330198717358 1739917692 176901774317522172721713617056
1205RE003112-3311987 17404 17717 1769217743 17298 17042
1211105RF001LAKE WINNIPEG AT MONTREAL POINT
1211105RF001******* PROVISIONAL WATER SURVEY OF CANADA DATA *******
1205RF001112-3 119871742717364173861736 8 1766617673

1205RF001112-3 2198717437173621738417378 1758817615
1205RF001112-3 3198717408173721737917383 1744817653
1205RF001112-3 4198717432173881738217351175681759517689
1205RF001112-3 5198717424173821739617373176001765917622
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1205RF001112-3141987173891736117380174701755617643176 89
1205RF001112-3151987173951736617394174701763217666177 01 17540
1205RF001112-3161987174001736817392174741754417667176 79 17544
1205RF001112-3171987173931737317379174981753117688176 01 17472
1205RF001112-3181987173771737117391174951760417672176 26 17484
1205RF001112-3191987173681738417403174771757817692176 23 17515
1205RF001112-3201987173851737817404174561748717664177 10 17480
1205RF001112-3211987173691737417399174981743217659176 68 17534
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1205RF001112-3231987173711736417374 176111766417625 17393
1205RF001112-3241987173781735317366 176001769917667
1205RF001112-3251987173821733917359 175941755917667
1205RF001112-3261987173931736317367 175751759617655
1205RF001112-3271987173851736417342 175481767417682
1205RF001112-3281987173891735717368 175381758817676
1205RF001112-329198717389 17357 176161755517649
1205RF001112-330198717379 17368 175821764117652
1205RF001112-331198717373 17342 17629 17644
1211105SA003LAKE WINNIPEG AT VICTORIA BEACH
1211105SA0031211105LK002Provisional Data collected by Water Resources Branch (29
1205SA003112-3 1198717409174381744717500176391750017487177531775 5 1717517201
1205SA003112-3 2198717366174461746217442176071765117747177471757 3 1728017196
1205SA003112-3 3198717434174151743317426175551800917792179081723 3 1733517247
1205SA003112-3 4198717396173961745217455175591777117572177741763 1 1757417179
1205SA003112-3 5198717417174081742417420175241759817680175861772 1 1775117165
1205SA003112-3 6198717441174031747117465176701767217830177691749 3 1741417158
1205SA003112-3 7198717391174491747717438176501773717734177761771 1 1732417109
1205SA003112-3 8198717403174261749717476175751779117876177071762 1 1756517134
1205SA003112-3 9198717446173971743617488177711764517623179271768 5 1741017240
1205SA003112-3101987173871742517425175271767517571178031774717740 1702017121
1205SA003112-3111987173891740817451175401778217585179511760317797 1711317261
1205SA003112-3121987174011745417448174991740217770179041794717683 1731617359
1205SA003112-3131987173861746617448175151753417636178031761417631 1742417226
1205SA003112-3141987174331743717463175021771317803177291773417536 1715617161
1205SA003112-3151987173981740417428175011751717633176611777017688 1702017183
1205SA003112-3161987173901742917423175421770117674176541783117563 1742317148
1205SA003112-3171987173991742017442175451774717601178931783317646 1745717139
1205SA003112-3181987174181743517463175821758317767178281780617700 1728817171
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1205SA003112-3211987174271745417482176221800517647177951775117600173881796517145
1205SA003112-3221987174381743717471174491766317628177391806217522173561744917117
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1205SA003112-3241987174141745917472175651752017699177681775517726170991718917124
1205SA003112-3251987173911747617484176091756217946177431777117609178741713917130

1205SA003112-326198717378174641744117628175771803617773177011756017358171771710 2
1205SA003112-327198717418174601748317742176351775317730177001756017917172141713 2
1205SA003112-328198717392174731745517512176031786517737175781772617351171241710 6
1205SA003112-329198717410 1746617793176141796717783176171778917242172421711 7
1205SA003112-330198717430 174351757717673177711775118181 175231724617133
1205SA003112-331198717403 17469 17567 1774617868 17225 17160
1211105SB006LAKE WINNIPEG AT GIMLI
1211105SB006Provisional Data collected by Water Resources Branch (29-SEP-87)
1205SB006112-3 119871737317397174061744417624174481747517706177301769817121171 54
1205SB006112-3 219871733217407174181739117591175341773017693175451772717226171 45
1205SB006112-3 319871739417382173971737817529179411774817847171991716117264171 89
1205SB006112-3 419871735917360174131740717535177411752817721175911744817481171 28
1205SB006112-3 519871738717372173791737217488175651764317540176831802417647171 11
1205SB006112-3 619871740417357174351741917638176521779417699174521775917345171 14
1205SB006112-3 719871735217411174291740017622177231767617716176611742917278170 51
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1205SB006112-313198717351174181740717476174921760517751175511759217279173641715 6
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1205SB006112-330198717391 1738817546176541773617711181051759017463171901708 0
1205SB006112-331198717370 17422 17543 1772517817 17170 17085
1211105SD001LAKE WINNIPEG AT PINE DOCK
1211105SD0011211105LK0031211105LH001Provisional Data collected by Water Resource
1205SD001112-3 11987 175481772217689176891712617133
1205SD001112-3 21987 177401774017726175011750917314171 37
1205SD001112-3 31987 178481770217793174321736517282171 62
1205SD001112-3 41987 176881764417706176711752317502171 23
1205SD001112-3 51987 176221775517629176321771917538170 73
1205SD001112-3 61987 176571773917772175491752917320171 18
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1205SD001112-3 81987 177011776017736176021736317406170 93
1205SD001112-3 91987 176541764317799176261759217284171 63
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1205SD001112-3151987 176641765217707175821735217130171 08
1205SD001112-3161987 176351769717770175251736717277170 96

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1205SD001112-323198717297 17761177871775117623172921728 0
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1205SD001112-3311987 1771517683 17250
1211105SD002 LAKE WINNIPEG AT MATHESON ISLAND LANDING
1211105SD002PROVISIONAL DCP DATA
1205SD002112-3 11987 17397174151759917609175651771317679177181706817114
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1205SD002112-3121987 17389174611753417706177741779217589173311725 9
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1205SD002112-3151987 17376174811754517682176511770417575173481718417099
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1205SD002112-3171987 17387175041763317687177951770017613173321728917080
1205SD002112-3181987 17401175221756917712176861778117617175601728917082
1205SD002112-3191987 17407175531758817677177261771317565174591760117078
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1205SD002112-3221987 17410175331758317692177221786117542173081726517063
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1205SD002112-3261987 17394175851759317773177081764517491174211715 1
1205SD002112-3271987 17417176061760617732176941765517510174571710 1
1205SD002112-3281987 17400175711761217788177251760917541172861704417049
1205SD002112-3291987 17402176411764117794177271771117636173261715917035
1205SD002112-3301987 17391175691764817699177061795217403173031714817059
1205SD002112-3311987 17415 17588 1771517630 17241 17054
1211105SG001 LAKE WINNIPEG AT MISSION POINT
1211105SG001PROVISIONAL DCP DATA
1205SG001112-3 11987174291737417409173901757117667178641772417597172091751417411
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1205SG001112-3 819871738317394173791743117573176241769117709175901747217141174 18
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1205SG001112-317198717373173911740417511175651770217671176851746 7 1751017362
1205SG001112-318198717369173961742117503176101767617698176231746917916174191 7339
1205SG001112-319198717358174021741817490176061771417713176 65 180451712017357
1205SG001112-320198717389174101742317458175021770517703176711745418061171461 7332
1205SG001112-321198717357173871741017546174611773417695175981749117390 17326
1205SG001112-322198717352173921740617554175981772717719175141748517388174591 7336
1205SG001112-323198717369173761740417528176261766217674176041740517460173651 7308
1205SG001112-324198717382173701739917546176201768317738176521741 7 1751217333
1205SG001112-325198717394173671739517535176261758017738176691739817485175161 7318
1205SG001112-326198717391173751742117508176031762817744176 42 1720517458
1205SG001112-327198717369173911737617530175921768917750176 67 1722517466
1205SG001112-328198717391173971739817561176281765117720176911739317391175431 7308
1205SG001112-329198717390 174021750317638176181770817550172931731917414173 16
1205SG001112-330198717382 174171758917641176931772117352174941726917410172 79
1205SG001112-331198717386 17394 17695 1771817614 17257

B2.1 PROGRAM STRUCTURE OF SVS FORTRAN PROGRAM

The SVS algorithm is programmed in FORTRAN IV language. The program is used to calculate the seasonal semivariogram values for different separation distances.

The program has 70 lines. The executable version takes 156 kB of memory on the hard disk of a personal computer. The execution times is two minutes on the IBM/AT personal computer with a mathematical coprocessor.

The input data are the converted raw measured data for years from 1982 to 1988. The output file is presented in the Section B2.3 as a two column, one for the winter and one for the summer season as well.

B2.2 VARIABLES

The following section describes the variables existing in the SVS program.

D(L,K,J,I) - measured water level in converted form

DAY - number of day in month

I - index for month

II - index for season

IN(L) - names of input files

J - index for days

K - index for gauge stations

KK - index for the second gauge station in pair

L - index for year

LK - counter for combination of gauge stations

M - the number of pairs in calculation

NAME - name of gauge station

NO - code number for gauge station

S - variable for summation

SV(LK,II) - semivariogram values

YEAR - year indicator

B2.3 PROGRAM LISTING

```
C*********************************************************************
C
C       SEASONAL SEMIVARIOGRAM CALCULATION
C
C       D(L=YEAR,K=GAGE STATION,J=DAY,I=MONTH)
C
C*********************************************************************

        CHARACTER IN*11,NO*10,NAME*45
        DIMENSION D(10,8,32,12),SV(28,2),IN(7)
        INTEGER DAY,YEAR
        DATA IN/11HMABSL82.DAT,11HMABSL83.DAT,11HMABSL84.DAT,
     *11HMABSL85.DAT,11HMABSL86.DAT,11HMABSL87.DAT,11HMABSL88.DAT/
        DO 10 L=1,7
        OPEN(2,FILE=IN(L))
        DO 1 K=1,8
        READ (2,102) NO,NAME
        DO 1 J=1,31
  1     READ (2,120)YEAR,DAY, (D(L,K,J,I),I=1,12)
        CLOSE (2)
  10    CONTINUE
  102   FORMAT(//,5X,A7,5X,A45,/)
  120   FORMAT(2X,I4,5X,I2,5X,12(F7.3,2X))
        DO 7 II=1,2
        LK=0
        DO 7 KK=1,7
        DO 7 K=KK+1,8
        LK=LK+1
        S=0
        M=0
        IF (II .EQ. 2) GOTO 21

C-------------------------------------
C        FIRST SEASON
C-------------------------------------
```

```
      DO 5 I=1,4
      DO 5 L=1,7
      DO 5 J=1,31
      IF ((D(L,KK,J,I) .EQ. 0.) .OR. (D(L,K,J,I) .EQ. 0. )) GOTO 5
      M=M+1
      S=S+(D(L,KK,J,I)-D(L,K,J,I))**2
 5    CONTINUE
      I=12
      DO 6 L=1,6
      DO 6 J=1,31
      IF ((D(L,KK,J,I) .EQ. 0.) .OR. (D(L,K,J,I) .EQ. 0. )) GOTO 6
      M=M+1
      S=S+(D(L,KK,J,I)-D(L,K,J,I))**2
 6    CONTINUE
      GOTO 24

C-----------------------------------------
C        SECOND SEASON
C-----------------------------------------

 21   DO 23 I=5,11
      DO 23 L=1,7
      DO 23 J=1,31
      IF ((D(L,KK,J,I) .EQ. 0.) .OR. (D(L,K,J,I) .EQ. 0. )) GOTO 23
      M=M+1
      S=S+(D(L,KK,J,I)-D(L,K,J,I))**2
 23   CONTINUE
 24   IF (M .EQ. 0 ) GOTO 9
      SV(LK,II)=S/M/2
      GOTO 7
 9    SV(LK,II)=0.
 7    CONTINUE
      OPEN(3,FILE='SVS.')
      DO 8 LK=1,28
 8    WRITE(3,110) (SV(LK,II),II=1,2)
 110  FORMAT(2E16.6)
      CLOSE (3)
      END
```

B2.4 OUTPUT FILE SVS.

```
0.713143E-03    0.211766E-02
0.123229E-02    0.708019E-02
0.165415E-02    0.131766E-01
0.972820E-03    0.125835E-01
0.101599E-02    0.257251E-02
0.954040E-03    0.234034E-02
0.198028E-02    0.968946E-02
0.682223E-03    0.327295E-02
0.298083E-02    0.163783E-01
0.136479E-02    0.150834E-01
0.561873E-03    0.476370E-02
0.166178E-02    0.561291E-02
0.287664E-02    0.652940E-02
0.304891E-02    0.272122E-01
0.175724E-02    0.250272E-01
```

0.140247E-02	0.106615E-01
0.110587E-02	0.105204E-01
0.688225E-03	0.347067E-02
0.102334E-02	0.263616E-02
0.216205E-02	0.609855E-02
0.257712E-02	0.672927E-02
0.221735E-02	0.261690E-01
0.530742E-03	0.441693E-02
0.162127E-02	0.650647E-02
0.222412E-02	0.253319E-01
0.215814E-02	0.137137E-02
0.245336E-02	0.135689E-01
0.588981E-02	0.148808E-01

B3.1 PROGRAM STRUCTURE OF KRIGING FORTRAN PROGRAM

The KRIGING algorithm is programmed in FORTRAN IV language. The program is composed of a main routine and of a subroutine GAUSS for solving system of linear equations. The program is used for calculation of water level in each of the defined point. The program used input data from the data set presented in the Section B1.4 and additional three input files KRI1.DAT, KRI2.DAT and GSNAME.DAT presented in the Section B3.4. Furthermore, the program produces three output files, namely OUT.OUT, KRI.OUT and ERR.OUT presented in the Appendix C.

The main program has about 300 lines and the subroutine has 50 lines. The executable version of the program takes 165 kB of the memory on the hard disk of personal computer. The execution time varies depending on the number of available data and the number of point where some of the measured data found as an outlier, but the typical values are three to five minutes on the IBM/AT personal computer with mathematical coprocessor.

The program first read the measured water level for each gauge station and on the basis of available data create the basic matrix. In the second step for each estimation point calculates the RHS coefficients and solve the system of linear equations. The obtained coefficients are checked for negative sign and if there are some there is corrected. The next check is for the outlier stations and if there are some the modified system is solved. In the last part of the program the results and documentation of calculation process are printed in three different files.

B3.2 VARIABLES

The following section describes the variables existing in the KRIGING program.

A - modified basic matrix

AC - basic matrix

B - modified RHS coefficients

BC - RHS coefficients

D - separation distance

DAY - number of day in month

DD - desired day

DX - step in the X direction

DY - step in the Y direction

E - estimated water level

EL- average Kriging error

ER - estimated Kriging error

FLAG - decision variable indicator

GSD - converted reading from source file

GSN - name of gauge stations

GSX - X coordinates of gauge stations

GSY - Y coordinates of gauge stations

ID - condensed form of measured water level

INPUT - input data files

IT - maximum number of iteration

JX - index for X scale

KK - K coefficient

KO - counter for stations without records

KON - control index

KON1 - counter for iteration

M - indicator for number of points at Y value

MK - index for counter for stations without records

MM - desired month

MMM - season indicator

MABSL - input files with measured water level

NAME - name of gauge station

NGS - number of gauge stations

NO - code number for gauge station

NOD - counter for nodes

NX - number of discrete points on X axis

NY - number of discrete points on Y axis

OUT - counter to being outlier

POUT - OUT presented in percentage form

RI - radius of influence

S1 - component of Kriging error

S2 - component of Kriging error

S3 - S_i coefficients

SVR - sill value of semivariogram

SV0 - 3 - coefficients of theoretical semivariogram

VL - mean water level

X - X coordinates

Y - Y coordinates

YEAR - year indicator

YY - desired year

W - weighting coefficients

B3.3 PROGRAM LISTING

```
C*************************************************************
C
C                    KRIGING INTERPOLATION METHOD
C
C     autor: Zolt Zrinji
C            University of Manitoba
C            Faculty of Engineering
C            Department of Civil Engineering
C            342 Engineering Building
C            Winnipeg, Manitoba
C            Canada R3T 2N2
C
C*************************************************************

      INTEGER YY,DD,DAY,YEAR,FLAG
      CHARACTER MABSL*6,INPUT*8,NO*10,NAME*45,GSN*19
      DIMENSION A(10,10),AC(10,10),B(10),BC(10),W(10),GSX(10),GSY(10),
     +M(100),E(100,100),ER(100,100),GSD(10),KO(10),Y(100),X(100,60),
     +S3(10),OUT(10),MABSL(8),INPUT(2),ID(9,32,13),GSN(8)
      DATA MABSL/6h81.DAT,6h82.DAT,6h83.DAT,6h84.DAT,6h85.DAT,6h86.DAT,
     +6h87.DAT,6h88.DAT/
      DATA INPUT/8HKRI1.DAT,8HKRI2.DAT/
      OPEN(7,FILE='OUT.OUT')
      WRITE(*,*) 'Please enter the desired date (Available from Jan 1st
     +1982 to Dec 31st 1988)'
      WRITE(*,*) 'Year = '
      READ(*,*) YY
      WRITE(*,*) 'Month = '
      READ(*,*) MM
      WRITE(*,*) 'Day = '
      READ(*,*) DD
      YY=YY-1980
      IF(MM .GT. 4 .AND. MM .LT. 12) THEN
         MMM=2
         ELSE
         MMM=1
         END IF
      OPEN(1,FILE=INPUT(MMM))
      READ(1,*) SV0,SV1,SV2,SV3
      READ(1,*) RI,IT,KK
           SVR=SV0+SV1*RI+SV2*RI*RI+SV3*RI*RI*RI
      READ(1,*) NGS
```

```
      DO 2 I=1,NGS
 2    READ(1,*) GSX(I),GSY(I)
      READ(1,*)NY,NX,DY,DX
      DO 1 I=1,NY
 1    READ(1,*) Y(I),M(I),(X(I,J),J=1,M(I))
      close (1)
      OPEN(1,FILE='GSNAME.DAT')
      DO 8 I=1,NGS
 8    READ(1,126) GSN(I)
      CLOSE (1)
 126  FORMAT(A19)
      OPEN(2,FILE=MABSL(YY))
       DO 7 K=1,NGS
       READ(2,121) NO,NAME
       DO 7 J=1,31
       READ(2,122)DAY,YEAR, (ID(K,J,I),I=1,12)
 7     CONTINUE
       CLOSE (2)
 121    FORMAT(5X,A7,A45)
 122    FORMAT(14X,I2,I4,12(I5))
      MK=1
      DO 3 K=1,NGS
      IF (ID(K,DD,MM) .EQ. 0) THEN
          GSD(K)=0.
          KO(MK)=K
          MK=MK+1
          ELSE
          GSD(K)=ID(K,DD,MM)
          GSD(K)=GSD(K)/1000+200
          END IF
 3    CONTINUE
      WRITE(*,123) 'Measured data at the date of: ',MM,DD,1980+YY
      WRITE(7,123) 'Measured data at the date of: ',MM,DD,1980+YY
 123   FORMAT(A31,I2,'.',I2,'.',I4,//)
      DO 47 I=1,NGS
      WRITE(7,124) GSN(I),GSD(I)
 47    WRITE(*,124) GSN(I),GSD(I)
 124   FORMAT(A20,F7.3)
      IF ( MK .EQ. 1) GOTO 9
        DO 4 J=1,MK-1
          DO 5 I=KO(J),NGS-1
          GSN(I)=GSN(I+1)
          GSX(I)=GSX(I+1)
          GSY(I)=GSY(I+1)
 5         GSD(I)=GSD(I+1)
        DO 6 L=J,MK-1
 6         KO(L)=KO(L)-1
 4       NGS=NGS-1

C-------------------------------------------------------------
C
C        Coefficients of the basic matrix
C
C-------------------------------------------------------------

  9   DO 10 I=1,NGS
      DO 10 J=I,NGS
```

```
      IF(I .EQ. J) THEN
         AC(I,J)=0.
       ELSE
         D=((GSX(I)-GSX(J))**2+(GSY(I)-GSY(J))**2)**0.5
           IF(D .GE. RI) THEN
           AC(I,J)=SVR
           ELSE
         AC(I,J)=SV0+SV1*D+SV2*D*D+SV3*D*D*D
           END IF
       END IF
 10   AC(J,I)=AC(I,J)
      DO 12 I=1,NGS
      DO 11 J=NGS+1,2,-1
 11   AC(I,J)=AC(I,J-1)
 12   AC(I,1)=1.
      AC(NGS+1,1)=0.
      DO 13 J=2,NGS+1
 13   AC(NGS+1,J)=1.

C-----------------------------------------------------------
C
C     RHS coefficients
C
C-----------------------------------------------------------

 14   WRITE(*,*)'      Please wait...      '
      VL=0.
      EL=0.
      LN=0
      DO 25 I=1,NY
      DO 25 J=1,M(I)
      IF(X(I,J) .EQ. 999) GOTO 25
      NOD=NOD+1
      DO 20 L=1,NGS
      D=((X(I,J)-GSX(L))**2+(Y(I)-GSY(L))**2)**0.5
            IF(D .GE. RI) THEN
               B(L)=SVR
            ELSE
               B(L)=SV0+SV1*D+SV2*D*D+SV3*D*D*D
            END IF
 20   BC(L)=B(L)
      B(NGS+1)=1.
      BC(NGS+1)=1.

C-----------------------------------------------------------
C
C     Weighting coefficients
C
C-----------------------------------------------------------

      DO 22 II=1,NGS+1
      DO 22 JJ=1,NGS+1
 22   A(II,JJ)=AC(II,JJ)
 29   CALL GAUSS(NGS+1,A,B,W)

C-----------------------------------------------------------
C
```

```
C       Checking and modification of the weighting coefficient
c
c-----------------------------------------------------------

        KON=0
        DO 41 II=2,NGS+1
        IF (W(II) .GE. 0.) GOTO 41
           KON=KON+1
  41    CONTINUE
        IF (KON .EQ. 0) GOTO 42
        S=0.
           DO 43 II=2,NGS+1
  43       S=S+ABS(W(II))
           DO 44 II=2,NGS+1
  44       W(II)=ABS(W(II))/S
  42    CONTINUE

C-----------------------------------------------------------
C
C       Calculation of the water level and
C       St.Error in nodes
C
C-----------------------------------------------------------
        KON=0
        DO 45 L=1,NGS+1
  45    S3(L)=0.
        S1=0.
        S2=0.
        JX=X(I,J)/DX
        E(I,JX)=0.
        DO 21 L=1,NGS
        S1=S1+W(L+1)*BC(L)
  21    E(I,JX)=E(I,JX)+W(L+1)*GSD(L)
        DO 23 II=2,NGS+1
        DO 23 JJ=2,NGS+1
  23    S2=S2+W(II)*W(JJ)*AC(II-1,JJ)
        ER(I,JX)=SQRT(S1+W(1))

C-----------------------------------------------------------
C
C       Checking outliers
C
C-----------------------------------------------------------

           DO 24 L=1,NGS
           IF((E(I,JX)-GSD(L))**2 .LE. KK*ER(I,JX)**2) GOTO 24
           IF(KON1 .NE. 0) GOTO 46
           OUT(L)=OUT(L)+1
  46       KON=KON+1
           S3(L)=((E(I,JX)-GSD(L))**2)/(SV0/SVR)/ER(I,JX)**2
  24       CONTINUE
        IF(KON .EQ. 0) GOTO 26
           DO 27 II=1,NGS+1
           DO 27 JJ=1,NGS+1
  27       A(II,JJ)=AC(II,JJ)
           DO 28 II=1,NGS
           B(II)=BC(II)
```

```
 28        A(II,II+1)=0.-S3(II)
           B(NGS+1)=1.
           KON1=KON1+1
           IF(KON1 .EQ. IT) GOTO 26
           GOTO 29
 26    VL=VL+E(I,JX)
       EL=EL+ER(I,JX)
       KON1=0
 25    CONTINUE
      DO 40 I=1,NY
      DO 40 JX=1,NX/DX
         IF(E(I,JX) .NE. 0.) GOTO 40
         E(I,JX)=-999.
         ER(I,JX)=-999.
 40   CONTINUE

C-----------------------------------------------------------
C
C      Printing of results
C
C-----------------------------------------------------------

      VL=VL/NOD
      EL=EL/NOD
 1004  continue
      WRITE(*,128) 'The estimated mean water level is = ',VL
      WRITE(*,128) 'The estimated mean error level is = ',EL
      WRITE(7,128) 'The estimated mean water level is = ',VL
      WRITE(7,128) 'The estimated mean error level is = ',EL
 128  FORMAT(A37,F7.3)
      WRITE(7,107) KK,NOD
      write(*,107) KK,NOD
      DO 33 I=1,NGS
      POUT=OUT(I)/NOD*100
      WRITE(*,106) GSN(I),OUT(I),POUT
33    WRITE(7,106) GSN(I),OUT(I),POUT
35    WRITE(*,*)'Do you want to repeat the calculation with the'
      WRITE(*,125)'coef.  K =  ',KK,'+ 1  (Y=1/N=0)  '
125   FORMAT(A13,I1,A17,/)
      READ(*,150) FLAG
150   FORMAT(i1)
      IF(FLAG .EQ. 1 ) THEN
          KK=KK+1
          NOD=0
          DO 36 I=1,NGS
36         OUT(I)=0.
          GOTO 14
      ELSE
          IF( FLAG .EQ. 0 ) THEN
          GOTO 37
          ELSE
             GOTO 35
          END IF
     END IF
106   FORMAT(A20,2X,F6.0,2X,F8.3)
107  FORMAT(5X,'Coef k = ',I2,/,7X,' # of nodes ',I3,/,10X,'GST',9X,
    +'# out.',2X,'  % out')
```

```
 37   OPEN(3,FILE='KRI.OUT')
      OPEN(4,FILE='ERR.OUT')
      WRITE(3,105) 'RE',NY,NX,-999.,1.,1.,VL
      WRITE(4,105) 'RE',NY,NX,-999.,1.,1.,EL
        DO 30 I=1,NX
 30       WRITE(3,110)(E(J,I),J=1,NY)
        DO 31 I=1,NX
 31       WRITE(4,111) (ER(J,I),J=1,NY)
 105      FORMAT(A2,I6,I8,3F8.0,F8.3)
 110      FORMAT(10F8.2)
 111      FORMAT(10F8.2)
      END
```

B3.4.1 INPUT FILE KRI1.DAT

```
0.0006426548  0.0000904191 -0.0000013671   0.0000000000   ! sv0,sv1,sv2,sv3
33.0  3  2            ! radius of influence, # of itteration, coef. K
8                     ! # of gage stations
15.5  22.8            ! Berens River          ! x & y cordinates
11.5  28              ! George Island
10    36.8            ! Montreal Point
19.2  4.3             ! Victoria Beach
16.2  3.4             ! Gimli
7.3   14.9            ! Pine Dock
16.5  15.9            ! Matheson Island
1.2   31.8            ! Mission Point
78 41 0.5 0.5                              ! # of Y & X coordinates (from 1.)
1 4 17 17.5 18 18.5                        ! # of X in one row, X coordinates
1.5 6 16.5 17 17.5 18 18.5 19
2 5 16.5 17 17.5 18 18.5
2.5 5 16.5 17 17.5 18 18.5
3 5 16.5 17 17.5 18 18.5
3.5 5 16.5 17 17.5 18 18.5
4 9 16.5 17 17.5 18 18.5 999 19.5 20 20.5
4.5 8 16.5 17 17.5 18 18.5 19 19.5 20
5 9 16.5 17 17.5 18 18.5 19 19.5 20 20.5
5.5 9 16.5 17 17.5 18 18.5 19 19.5 20 20.5
6 9 16.5 17 17.5 18 18.5 19 19.5 20 20.5
6.5 9 16. 16.5 17 17.5 18 18.5 19 19.5 20
7 8 16.5 17 17.5 18 18.5 19 19.5 20
7.5 8 16.5 17 17.5 18 18.5 19 19.5 20
8 8 16.5 999 999 18 18.5 19 19.5 20
8.5 8 16.5 999 999 999 18.5 19 19.5 20
9 6 17.5 999 18.5 19 19.5 20
9.5 6 17.5 999 18.5 19 19.5 20
10 10 16 16.5 999 17.5 18 18.5 19 19.5 20 20.5
10.5 9 16.5 999 999 999 18.5 19 19.5 999 20.5
11 8 16.5 17 999 999 18.5 19 19.5 20
11.5 8 16.5  17 17.5 999 999 19 19.5 20
12 6 17 17.5 18 18.5 19 19.5
12.5 4 17.5 18 18.5 19
13 11 14 14.5 999 999 999 999 999 17.5 18 18.5 19
13.5 10 14 14.5 15 999 999 999 999 17.5 18 18.5
14 10 14 14.5 999 999 999 999 999 17.5 18 18.5
14.5 10 14 14.5 15 999 999 999 999 17.5 18 18.5
15 9 14 14.5 15 999 999 999 17 17.5 18
```

15.5 8 14 14.5 15 15.5 16 999 17 17.5
16 7 14 14.5 15 15.5 16 16.5 17
16.5 7 14.5 15 15.5 16 16.5 17 17.5
17 7 14.5 15 15.5 16 16.5 17 17.5
17.5 14 10 999 999 999 999 999 999 999 14 14.5 15 15.5 16 16.5
18 16 9 9.5 10 999 999 999 999 999 999 999 14 14.5 15 15.5 16 16.5
18.5 16 9 9.5 10 999 999 999 999 999 999 999 14. 14.5 15 15.5 16 16.5
19 16 9 9.5 10 10.5 999 999 12 999 999 13.5 14 14.5 15 15.5 16 16.5
19.5 15 9 9.5 10 10.5 999 999 999 999 12.5 13 13.5 14 14.5 15 15.5 16
20 15 8.5 9 9.5 10 999 999 999 999 12.5 13 13.5 14 14.5 15 15.5
20.5 15 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15 15.5
21 14 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15
21.5 15 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15
22 16 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 999 14 14.5 15 15.5
22.5 18 6.5 7 7.5 8 8.5 999 999 10 10.5 11 11.5 12 12.5 13 999 999 14.5 15
23 18 6.5 7 7.5 8 8.5 999 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15
23.5 20 6 6.5 7 7.5 8 8.5 999 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15 15.5
24 19 6 6.5 7 7.5 8 8.5 999 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15
24.5 18 6 6.5 7 7.5 8 8.5 999 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5
25 19 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5
25.5 20 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5
26 20 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14
26.5 21 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14
27 21 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5
27.5 20 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13
28 20 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13
28.5 21 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13
29 21 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13
29.5 19 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5
30 15 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13
30.5 13 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5
31 22 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5
31.5 23 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12
12.5
32 24 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12
12.5
32.5 23 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12
33 22 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5
33.5 22 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5
34 21 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5
34.5 20 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11
35 19 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11
35.5 18 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5
36 18 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5
36.5 16 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
37 16 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
37.5 16 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
38 13 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 39 10 3 3.5 999 4.5 5 5.5 6 6.5 7 7.5
38.5 12 2.5 999 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8
39 10 3 3.5 999 4.5 5 5.5 6 6.5 7 7.5
39.5 3 3 3.5 4

B3.4.2 INPUT FILE KRI2.DAT

0.001064887 0.0001203889 0.0000205516 -0.0000000461 ! sv0,sv1,sv2,sv3
25.0 3 2 ! radius of influence, # of itteration, coef K

```
8                    ! # of gage stations
15.5  22.8           ! Berens River          ! x & y cordinates
11.5  28             ! George Island
10     36.8          ! Montreal Point
19.2  4.3            ! Victoria Beach
16.2  3.4            ! Gimli
7.3  14.9            ! Pine Dock
16.5  15.9           ! Matheson Island
1.2   31.8           ! Mission Point
78 41 0.5 0.5                          ! # of Y & X coordinates (from 1.)
1 4 17 17.5 18 18.5                     ! # of X in one row, X coordinates
1.5 6 16.5 17 17.5 18 18.5 19
2 5 16.5 17 17.5 18 18.5
2.5 5 16.5 17 17.5 18 18.5
3 5 16.5 17 17.5 18 18.5
3.5 5 16.5 17 17.5 18 18.5
4 9 16.5 17 17.5 18 18.5 999 19.5 20 20.5
4.5 8 16.5 17 17.5 18 18.5 19 19.5 20
5 9 16.5 17 17.5 18 18.5 19 19.5 20 20.5
5.5 9 16.5 17 17.5 18 18.5 19 19.5 20 20.5
6 9 16.5 17 17.5 18 18.5 19 19.5 20 20.5
6.5 9 16. 16.5 17 17.5 18 18.5 19 19.5 20
7 8 16.5 17 17.5 18 18.5 19 19.5 20
7.5 8 16.5 17 17.5 18 18.5 19 19.5 20
8 8 16.5 999 999 18 18.5 19 19.5 20
8.5 8 16.5 999 999 999 18.5 19 19.5 20
9 6 17.5 999 18.5 19 19.5 20
9.5 6 17.5 999 18.5 19 19.5 20
10 10 16 16.5 999 17.5 18 18.5 19 19.5 20 20.5
10.5 9 16.5 999 999 999 18.5 19 19.5 999 20.5
11 8 16.5 17 999 999 18.5 19 19.5 20
11.5 8 16.5  17 17.5 999 999 19 19.5 20
12 6 17 17.5 18 18.5 19 19.5
12.5 4 17.5 18 18.5 19
13 11 14 14.5 999 999 999 999 999 17.5 18 18.5 19
13.5 10 14 14.5 15 999 999 999 999 17.5 18 18.5
14 10 14 14.5 999 999 999 999 999 17.5 18 18.5
14.5 10 14 14.5 15 999 999 999 999 17.5 18 18.5
15 9 14 14.5 15 999 999 999 17 17.5 18
15.5 8 14 14.5 15 15.5 16 999 17 17.5
16 7 14 14.5 15 15.5 16 16.5 17
16.5 7 14.5 15 15.5 16 16.5 17 17.5
17 7 14.5 15 15.5 16 16.5 17 17.5
17.5 14 10 999 999 999 999 999 999 999 14 14.5 15 15.5 16 16.5
18 16 9 9.5 10 999 999 999 999 999 999 999 14 14.5 15 15.5 16 16.5
18.5 16 9 9.5 10 999 999 999 999 999 999 999 14. 14.5 15 15.5 16 16.5
19 16 9 9.5 10 10.5 999 999 12 999 999 13.5 14 14.5 15 15.5 16 16.5
19.5 15 9 9.5 10 10.5 999 999 999 12.5 13 13.5 14 14.5 15 15.5 16
20 15 8.5 9 9.5 10 999 999 999 999 12.5 13 13.5 14 14.5 15 15.5
20.5 15 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15 15.5
21 14 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15
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22 16 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 999 14 14.5 15 15.5
22.5 18 6.5 7 7.5 8 8.5 999 999 10 10.5 11 11.5 12 12.5 13 999 999 14.5 15
23 18 6.5 7 7.5 8 8.5 999 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15
23.5 20 6 6.5 7 7.5 8 8.5 999 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15 15.5
24 19 6 6.5 7 7.5 8 8.5 999 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15
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24.5 18 6 6.5 7 7.5 8 8.5 999 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5
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26 20 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14
26.5 21 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14
27 21 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5
27.5 20 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13
28 20 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13
28.5 21 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13
29 21 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13
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31 22 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5
31.5 23 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12
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32 24 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12
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32.5 23 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12
33 22 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5
33.5 22 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5
34 21 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5
34.5 20 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11
35 19 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11
35.5 18 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5
36 18 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5
36.5 16 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
37 16 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
37.5 16 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
38 13 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 39 10 3 3.5 999 4.5 5 5.5 6 6.5 7 7.5
38.5 12 2.5 999 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8
39 10 3 3.5 999 4.5 5 5.5 6 6.5 7 7.5
39.5 3 3 3.5 4

B3.4.3 INPUT FILE GSNAME.DAT

Berens River
George Island
Montreal Piont
Victoria Beach
Gimli
Pine Dock
Matheson Island
Mission Point

B4.1 PROGRAM STRUCTURE FOR SUBROUTINE GAUSS FORTRAN PROGRAM

The subroutine GAUSS is programmed in FORTRAN IV language. The program is used to solved the system of linear equations by Gauss elimination system. Subroutine is used in the KRIGING program.

The program has 50 lines. The input and output is directly to the main program.

B4.2 VARIABLES

The following section describes the variables existing in the GAUSS subroutine.

A - basic matrix

B - RHS coefficients

C - comparison coefficient

D - comparison coefficient

E - coefficient for normalization

N - number of equation

TOL - tolerance limit

X - unknown variables

B4.3 PROGRAM LISTING

```
SUBROUTINE GAUSS(N,A,B,X)
DIMENSION A(10,10),B(10),X(10)
TOL=1.E-10
DO 500 I=1,N-1
K=I
D=ABS(A(I,I))
DO 20 J=I+1,N
C=ABS(A(J,I))
IF(C .LE. D) GO TO 20
K=J
```

```
      D=C
20    CONTINUE
      IF (K .EQ. I) GO TO 40
      DO 30 J=I,N
      C=A(I,J)
      A(I,J)=A(K,J)
30    A(K,J)=C
      C=B(I)
      B(I)=B(K)
      B(K)=C
40    IF(ABS(A(I,I)) .GT. TOL) GO TO 50
45    WRITE(11,*) 'SOLUTION IS IMPOSSIBLE'
      STOP
50    E=A(I,I)
      DO 60 J=I,N
60    A(I,J)=A(I,J)/E
      B(I)=B(I)/E
      DO 100 J=I+1,N
      E=-A(J,I)
      DO 80 K=I,N
80    A(J,K)=A(J,K)+E*A(I,K)
100   B(J)=B(J)+E*B(I)
500   CONTINUE
      IF(ABS(A(N,N)) .LE. TOL) GO TO 450
      B(N)=B(N)/A(N,N)
      A(N,N)=1.
      DO 1000 I=N,2,-1
      DO 700  J=I-1,1,-1
      E=-A(J,I)
700   B(J)=B(J)+E*B(I)
1000  CONTINUE
      DO 850 I=1,N
850   X(I)=B(I)
      RETURN
450   WRITE(11,*) 'SOLUTION IS IMPOSSIBLE'
      RETURN
      END
```

APPENDIX C

C1 OUTPUT FILE OUT.OUT

Measured data at the date of: 8.21.1988

```
Berens River        216.994
George Island         0.000
Montreal Piont        0.000
Victoria Beach      216.888
Gimli               216.865
Pine Dock             0.000
Matheson Island     216.800
Mission Point       217.383
The estimated mean water level is = 216.962
The estimated mean error level is =    0.767
    Coef k =  2
       # of nodes 962
         GST          # out.     % out
Berens River           232.     24.116
Victoria Beach         332.     34.511
Gimli                  618.     64.241
Matheson Island        962.    100.000
Mission Point          959.     99.688
The estimated mean water level is = 216.950
The estimated mean error level is =    0.604
    Coef k =  3
       # of nodes 962
         GST          # out.     % out
Berens River           168.     17.464
Victoria Beach         267.     27.755
Gimli                  319.     33.160
Matheson Island        884.     91.892
Mission Point          954.     99.168
The estimated mean water level is = 216.942
The estimated mean error level is =    0.425
    Coef k =  4
       # of nodes 962
         GST          # out.     % out
Berens River           120.     12.474
Victoria Beach         214.     22.245
Gimli                  260.     27.027
Matheson Island        785.     81.601
Mission Point          944.     98.129
The estimated mean water level is = 216.936
The estimated mean error level is =    0.311
    Coef k =  5
       # of nodes 962
         GST          # out.     % out
Berens River            92.      9.563
Victoria Beach         176.     18.295
Gimli                  218.     22.661
Matheson Island        587.     61.019
Mission Point          935.     97.193
The estimated mean water level is = 216.933
```

The estimated mean error level is = 0.124

Coef k = 6

# of nodes 962

GST	# out.	% out
Berens River	65.	6.757
Victoria Beach	150.	15.593
Gimli	188.	19.543
Matheson Island	386.	40.125
Mission Point	916.	95.218

C2 OUTPUT FILE KRI.OUT

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0.11	0.11	0.12	0.07	0.07	0.12	0.12	0.12	0.13	0.13
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0.11	0.11	0.11	0.07	0.07	0.12	0.12	0.12	0.12	0.13
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0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.09
0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10
0.10	0.11	0.11	0.11	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00
-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00		
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-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	0.06	0.06	0.06
0.06	0.06	0.06	0.07	0.07	0.07	0.08	0.08	0.08	0.08
0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10
0.10	0.10	0.11	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00
-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00		
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0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.08	0.08	0.08
0.08	0.09	0.09	0.09	0.10	0.10	0.10	-999.00	0.10	-999.00
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0.05	0.06	-999.00	-999.00	0.06	0.06	0.06	0.07	0.07	0.08
0.08	0.09	0.09	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00
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0.06	-999.00	-999.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05
0.05	0.05	0.05	-999.00	0.06	0.06	0.06	0.07	0.07	0.08
0.08	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00
-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00

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0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.07	0.07	0.08
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0.05	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.05
0.05	0.05	0.05	0.05	0.05	0.05	0.05	-999.00	-999.00	-999.00
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-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00		
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-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00
-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	0.05
0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.05	0.05	0.05
-999.00	-999.00	0.05	-999.00	-999.00	0.05	-999.00	-999.00	-999.00	-999.00
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-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00		
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-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	0.05
0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.05	-999.00	-999.00
-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00
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-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00
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0.05	0.05	0.05	0.05	0.04	0.04	0.04	-999.00	-999.00	-999.00
-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00
-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00
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-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00		
0.07	0.06	0.06	0.05	0.05	0.04	0.04	0.04	0.04	0.04
0.04	0.04	0.04	0.04	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00
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-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00		
0.07	0.06	0.06	0.05	0.05	0.04	0.04	0.04	0.04	0.04
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-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00
-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00
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-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00
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-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00
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0.07	0.06	0.06	0.06	0.05	0.05	0.04	0.04	0.04	0.04
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0.05	-999.00	0.05	0.05	0.05	0.05	0.05	0.05	-999.00	-999.00
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-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00
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-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00		
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0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
0.05	0.05	0.05	0.05	0.05	-999.00	-999.00	-999.00	-999.00	-999.00
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0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
0.05	0.05	0.05	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00
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-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00
-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00
-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00
-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00		
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0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	-999.00
0.05	0.05	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00
-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00
-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00
-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00
-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00
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0.05	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	0.05	0.05
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-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00	-999.00
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