COMPARISON OF TWO COMPUTER PROGRAMS FOR VOLUME-WEIGHTED AVERAGING OF LIMNOLOGICAL DATA

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SUMMARY

This report presents the results of a study in which two computer codes designed for volume-weighted averaging of limnological data were evaluated and compared. Codes such as the two evaluated here, Averaging Lake Data by Regions (ALDAR) produced by Canada's National Water Research Institute, and Volume-Weighted Averaging (VWA) produced by the United States Environmental Protection Agency's Large Lakes Research Station, are most valuable when it is desirable or necessary to compensate for any spatial bias in sampling that may affect the calculation of summary statistics. This is often the case in limnological surveys. The report includes a discussion of the basic features of the codes and their implementation as well as an evaluation of the spatial interpolation algorithms upon which the codes are based.

Both codes use sample data to estimate the value of the limnological variable in every cell of a gridded representation of the lake of interest. ALDAR uses a nearest-neighbor interpolation in which the value assigned to each cell is that of the sampled station nearest the cell. VWA estimates the value in a cell by using a weighted average of the station data in which the station weights depend on the distance between the cell and the stations. Neither of these interpolation techniques is optimal, in the sense that the expected interpolation error is minimized as a function of the interpolation parameters. It may not be possible, however, to devise an optimal interpolation for limnological data without making some assumptions about the spatial structure of the variable for which interpolation is desired. Evaluation of alternate methods of spatial interpolation, not represented by either ALDAR or VWA, is beyond the scope of this study.

Estimates of local interpolation accuracy as a function of the interpolation parameters can be made by using sample data. Such an evaluation may be used to decide whether spatial analysis is desirable for analysis of the data. Local interpolation accuracy depends on the size and configuration of the sampling network and on the signal-to-noise ratio of the sampled data.

In most cases the VWA interpolation can be made more accurate than the ALDAR interpolation by appropriate choice of VWA's distance-weighting parameter. A simple analysis of the sample data using the VWA algorithm and a range of interpolation parameters may be used to select a locally best value for the weighting parameter. This value may vary with the variable to be analyzed.

Several coding errors were noted in ALDAR. These errors result in mislocation of stations within the bathymetric grid and in miscalculation of the volumes associated with specified regions of the lake being analyzed. The accuracy of the ALDAR method of mass calculation within layers depends on the assumed vertical structure and may be inaccurate. However, ALDAR, unlike VWA, is generalized so that it may be applied to any lake and gridding system without modification. VWA is coded for only one lake (Michigan) and grid resolution. The measures of variability calculated by VWA are inappropriate for evaluation of the uncertainty associated with the volume-weighted mean.

RECOMMENDATIONS

Limnological survey data should be analyzed with the spatial interpolation algorithm contained in VWA. An initial screening analysis, involving the sample data only, can be conducted to determine whether the data exhibit spatial correlation and would benefit from spatial interpolation. If so, the results of the screening analysis can be used to determine the best value of the weighting parameter required by VWA.

In general, the VWA code should be used in preference to ALDAR. The major advantage of ALDAR is its ease of application to different lakes and grids. The VWA code should be modified so that it too can be applied easily to other lakes and grids. The VWA code also should be modified along the lines of ALDAR to accommodate changes in station locations more easily.

Research into the spatial structure of limnological variables should be encouraged. In particular, the application of optimal analysis techniques to limnological data should be investigated. Studies of the factors contributing to the uncertainty of estimates of volume-weighted means should be conducted as well. Measures of uncertainty analogous to the standard error would make it possible to put error ranges or confidence levels on estimates of the volume-weighted mean. This type of error evaluation is necessary for comparisons between volume-weighted means.

Sampling designs should be evaluated with the tools of spatial analysis. Simulations based on historical data can be used to determine the size and configuration of limnological sampling networks. Spatial analysis also can be used to determine the homogeneity of a sampled region.

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ACKNOWLEGMENTS

This research was sponsored by the Great Lakes National Program Office of the U.S. Environmental Protection Agency (EPA) through IAG DW89931897-01-0 to the U.S. Department of Energy. The two computer codes described in this report were supplied by Mr. Kevin McGunagle and Mr. William Richardson of the EPA's Large Lakes Research Station (LLRS) in Grosse Ile, Michigan. The work was carried out with the advice and guidance of Mr. David C. Rockwell of the Great Lakes National Program Office, who served as project officer.

SECTION 1

INTRODUCTION

Estimation of the mean value of a spatially distributed variable is a goal common to many limnological sampling programs. This mean value may be defined as

$$\langle C\rangle = V^{-1} \int\int\int c(x,y,z)dxdydz \;, \qquad (1)$$

in which V is the volume of integration, and c(x,y,z) is the value of the variable at point x,y,z. If the variable of interest is a mass concentration, then c(x,y,z) may be thought of as the concentration in a control volume centered at point x,y,z, and the integration is taken as a summation over all control volumes. Of course, it is impossible to determine the true mean exactly. Therefore $\langle C\rangle$ must be estimated from sample values, usually collected at discrete locations.

Although the simple average of the sample values is often used to estimate $\langle C\rangle$, this statistic may not be an appropriate estimator of the true mean value because limnological variables are rarely homogeneous (i.e., their expected value is not independent of location). When the variable is nonhomogeneous, for example, the sample average may be biased by the relationship between the sample locations and the underlying spatial distribution of the variable, which is, necessarily, unknown.

Methods are available to compensate for this bias, and these have been incorporated into computer programs that are intended to produce estimates of $\langle C\rangle$ that are more appropriate than the simple sample average. The purpose of the work described in this report was to evaluate and compare two of these programs, Averaging Lake Data by Regions (ALDAR) produced by the Inland Waters Directorate of Environment Canada (Neilson et al. 1984), and Volume-Weighted Averaging (VWA) produced by the Large Lakes Research Station of the U.S. Environmental Protection Agency (Yui 1978; Griesmer and McGunagle 1984).

Because software evaluation is a very subjective undertaking, this report is focused on objective features of the two programs. Included is a discussion of the approach common to the two, as well as an explicit explanation of the differences between them. Details of the steps required to implement and use the codes are discussed. Finally, the absolute accuracy of the algorithms embodied in the programs is examined by evaluation of their local accuracy by using sample data and by comparison with analytical results that may be calculated exactly.

SECTION 2

FEATURES OF VOLUME-WEIGHTED AVERAGING PROGRAMS

General Strategy

The general strategy used to calculate volume-weighted averages is the following:

(1) Spatially interpolate the sample data to estimate the value of the variable of interest at the center of every cell in a gridded representation of the lake.

(2) Weight each estimate by the relative volume of the cell, where the relative volume is defined as the volume of the cell divided by the total volume of the region of interest.

(3) Add the weighted estimates to produce an estimate of the volume-weighted mean.

ALDAR and VWA share this general strategy along with the ability to estimate volume-weighted means in predefined subregions of the lake. Differences exist between the two programs in several key areas, however. Among them are the ways in which the programs treat the vertical distribution of the sample data, the methods used for spatial interpolation of the sample data, the methods used for horizontal integration, and the methods used to calculate volumes. The basic features of the two programs will be outlined below.

ALDAR

Grid:

ALDAR is based on an equal-area-gridded representation of the lake. The grid is made up of square cells typically 2 km, 4 km, or 8 km on a side, depending on the lake to be modeled and the resolution desired. The depth in each cell is given in meters. A 2-km gridded representation of Green Bay, Lake Michigan, is shown in Fig. 1 as an example. Bathymetric grids with this (2-km) resolution are readily available (Schwab and Sellers, 1980). Properties of these grids are listed in Table 1.

Table 1. Properties of bathymetric data files (Schwab and Sellers, 1980).

Lake	Grid Size (km)	East-West Grids	North-South Grids
Superior	2.0	304	147
Michigan	2.0	160	250
Huron	2.0	209	188
St. Clair	1.2	35	36
Erie	2.0	209	57
Ontario	2.0	152	57

Segmentation:

ALDAR allows the user to choose up to 24 separate zones within which volume-weighted means can be calculated. A "whole-lake" volume-weighted mean ("whole-lake" refers to the sum of the zones actually included in the calculation) is produced as well. The zones are based on the gridded representation so that each grid cell is assigned to a zone. Zones may be excluded, in which case no calculations are done for those zones. Data from stations within the excluded zones are not used to estimate the parameter values in the active (i.e., included) zones. The zones are not necessarily contiguous (e.g., nearshore areas separated by other zones may be designated as a single zone). Although individual stations may contribute to estimates in more than one zone, the zones themselves may not overlap.

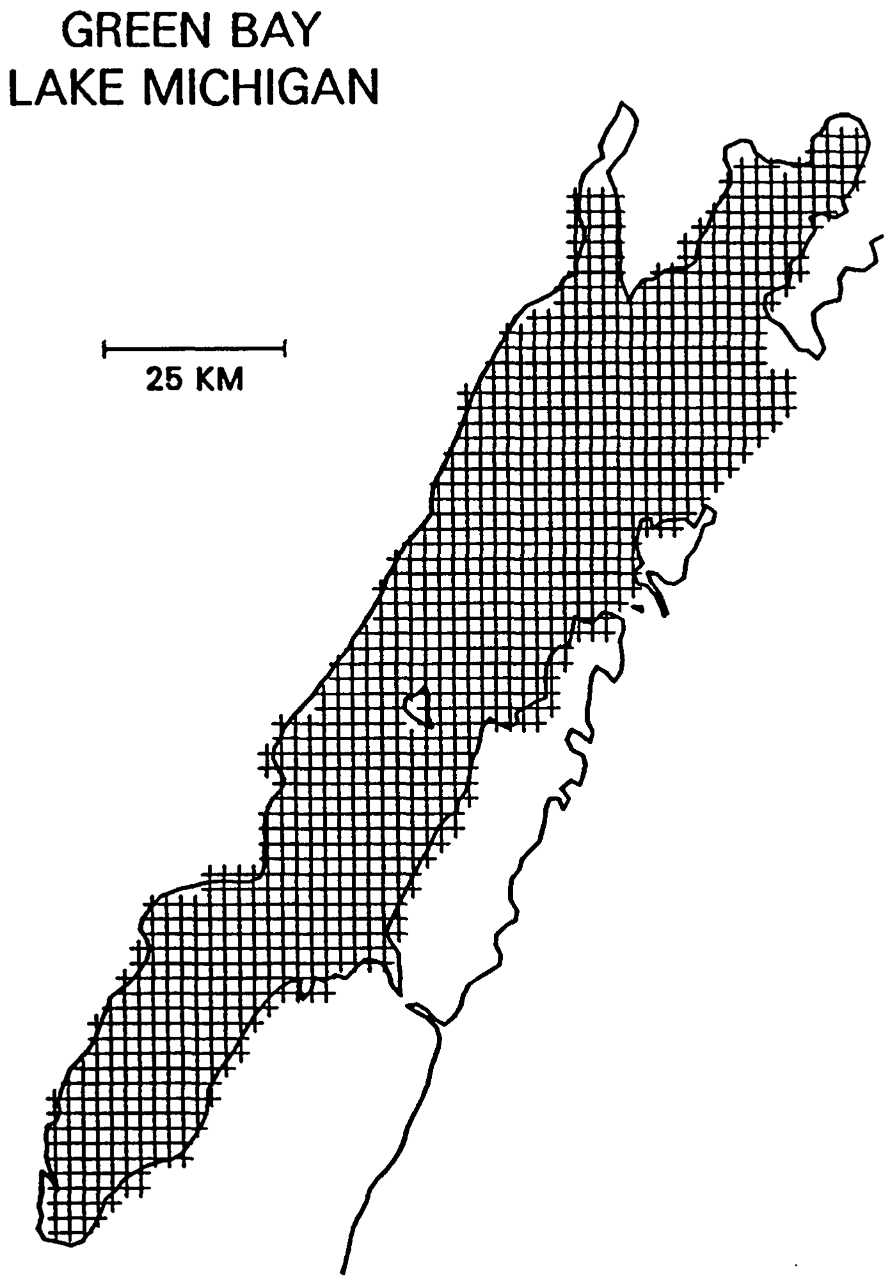

Figure 1. Two-kilometer grid applied to Green Bay, Lake Michigan.

Vertical Structure:

The user may specify up to 20 "standard depths" in ALDAR. These depths are used as the basis for the vertical and horizontal interpolation of the sample data. Data collected at various depths at a station are linearly interpolated to produce estimated values at the standard depths. For example, if samples were collected at 10 m and 20 m, their average would be used as the estimated value of the variable at 15 m if that were a specified standard depth. If a data point is below the last standard depth, it is ignored. If a standard depth is deeper than the bottom sounding at a station, and a data point is located between the next shallower standard depth and the bottom, that data point too is ignored. Horizontal interpolation in ALDAR is based on estimates of the variable at the standard depths.

Horizontal Interpolation:

ALDAR uses a nearest-neighbor (Thiessen) horizontal interpolation scheme. In this method each cell is assigned the value observed at the nearest station. Thus the horizontal distribution of the interpolated values (at the surface) resembles a pattern of tiles or polygons, the centers of which are the station locations. This interpolation holds for each standard depth, although the station associations for each cell are based on the surface locations. That is, cells are associated with the nearest station regardless of the vertical distribution of data at that station. So a deep cell may be associated with a shallow station and, as a result, there will be no estimated value (for the cell) at depths below the deepest standard depth at the station. The area-weighted mean values for each zone are based on summation of the interpolated estimates at each standard depth.

Results:

ALDAR produces estimates for each selected zone of the surface area and the area-weighted mean value at each standard depth, estimates of the volume and integrated variable values for the layers between standard depths, and vertically accumulated estimates (from the surface) of the volume and integrated variable value. These estimates are presented in tabular form.

VWA

Grid:

In contrast to ALDAR, VWA was originally designed to operate on an equal-angle grid in which each cell was formed by parallels of latitude and meridians of longitude. Typical cell sizes were 2° and 4°. In the study reported here, VWA was modified to use the same equal-area grid as was used for ALDAR. This modification simplified the VWA calculation because the area of the cells was no longer dependent on latitude and also made comparison between ALDAR and VWA easier because they could be based on identical bathymetric grids.

Segmentation:

VWA allows the user to identify 25 zones for which volume-weighted means will be calculated. Each grid cell is assigned to a zone.

Vertical Structure:

VWA models the vertical structure of the water column as a series of homogeneous layers. Up to five layers can be specified by the user. Sample data within each layer are averaged and provided to the program as a station average. For example, if data were collected at 1 m, 5 m, and 15 m, their average could be used to represent that station in a layer from the surface to 20 m. Horizontal interpolation in VWA is based on the layering scheme. Each layer can have its own segmentation scheme, so the number and definitions of the zones can change with depth.

Horizontal Interpolation:

VWA uses an inverse distance weighted horizontal interpolation scheme. In this scheme, the value of the variable z at a point not sampled is given by

$$z^*(x_o) = \sum_j w_{oj} z'_j \ , \qquad (2)$$

in which z^* is the estimate at unsampled location x_o, the z'_j are the sampled data ($j = 1,2,\ldots,N$), and the w_{oj} are the weights appropriate for position x_o. These weights are given by

$$w_{oj} = (D_{oj}^{-\alpha})/(\sum_i D_{oi}^{-\alpha}) \ , \qquad (3)$$

where D_{ij} is the Euclidian distance between points i and j. The weights have the properties that $\sum_j w_{oj} = 1$ and $w_{oj} \rightarrow 1$ as $D_{oj} \rightarrow 0$.

Therefore the interpolation is such that the estimated values equal the observed values at the points of observation. This is termed exact interpolation.

The parameter α in Equation (3) affects the amount of influence that distant observations have on the estimated value at a point. The lower this value, the stronger the influence of distant observations and the smoother the resultant estimated field will appear between observation points. Since the interpolation is exact, however, the field will appear spiky at the observation points. On the other hand, a very high value of α will cause nearby observations to have dominant influence on the cell estimates, a situation that approaches the Theissen interpolation used in ALDAR.

VWA uses all the sampled points in the interpolation. Thus sample data collected far away from a point to be estimated will have some influence on that point. Although the early documentation supplied with VWA (Yui 1978) implied that the code has a provision for specifying that sample data used in the interpolation be restricted to a circular region of specified radius around each point to be estimated, this feature was not implemented in the code supplied for this study.

Results:

VWA produces an output listing for each layer. Descriptive statistics based on sample data are calculated. These include the mean, maximum, minimum, standard deviation, and standard error of all the vertically averaged means supplied for the layer. The volume-weighted mean value is calculated for each zone along with standard error, standard deviation, and confidence limits defined by the mean plus and minus the standard error and standard deviation. The maximum and minimum of the estimated values are also calculated for each zone.

In addition to these results, VWA produces a histogram of the estimated values for each layer as well as a printer plot contour map showing the spatial distribution of estimates within the layer. Volume-weighted geometric statistics also are calculated for each zone.

SECTION 3

IMPLEMENTATION OF ALDAR AND VWA

The purpose of this section is to describe the steps required to use the programs ALDAR and VWA. Because the exact details of implementation will differ from computer system to computer system, this description is based on the programs as they were used in this study. In each case it is assumed that a bathymetric data file containing the gridded depth information for the lake in question already exists. This discussion is intended to give the reader an overview of the procedures associated with each program and is not intended to replace their specific documentation.

ALDAR

Creation of the Zoned Bathymetry File:

The first step in using ALDAR is to create a "zoned bathymetry file" that contains both the zone assignment and depth for each cell in the grid. This file is created by using a program called ZONSEL. The user provides the segmentation scheme to ZONSEL by creating a file that lists the zone number and the column numbers of the cells beginning each zone for every row of the bathymetric grid. Each row may include more than one zone (Appendix A). This information is combined with the bathymetric data contained in another file to produce the unformatted, zoned bathymetry file that ALDAR requires. A new zoned bathymetry file is required for every new segmentation scheme. The effort involved in producing a new segmentation scheme depends on the complexity of the scheme and the size of the bathymetric grid. This is not a particularly difficult procedure.

Preparation of the Data File:

In addition to the zoned bathymetry file, ALDAR requires sample data and run control information. The run control information includes the user's choice of parameters to be studied, a choice of whether the actual observations used in the calculation are to be printed, specification of the number and identity of zones that are to be excluded from the analysis, and the standard depths at which the observations are to be interpolated. The sample data are provided for one station at a time (Appendix A). Information about the station itself (name and location) is also provided to ALDAR in the data file. One of ALDAR's notable features is its ability to calculate volume-weighted averages for many variables (up to 50) in one run. A code (STORET2) has been prepared by the Large Lakes Research Station to create an ALDAR data file from a STORET-FCF retrieval. This data file contains the number of stations, the dates of sampling, the station names and locations, and the sample data for all the variables and depths of interest. A listing of this code, as modified for use in this study, is also given in Appendix A.

The above three files (zoned bathymetry, data, and control) are all that is necessary to run ALDAR. ALDAR is sufficiently general so that calculations can be made for any of the lakes or embayments for which bathymetric data are available without modification of the code. Sections from a sample output are shown in Appendix C.

VWA

As supplied, VWA was configured for use with Lake Michigan data on 4° grid. In contrast to ALDAR, application of VWA to a different lake or grid would require modification and recompilation of the code. The basic input requirements for VWA are similar to those of ALDAR. In VWA the bathymetry, segmentation scheme, and layering information for a particular run are contained in a "master file". Control information and the vertically averaged station data are supplied (in one file) separately for each layer. Only one variable can be analyzed in each run. The interpolation parameters and segmentation scheme can vary between layers in the same run. A third input file containing the segmentation scheme is required for the graphic output. Just as the ALDAR system consists of several separate codes (ZONSEL, STORET2, and ALDAR), the VWA system also consists of several separate codes that are needed to produce the files necessary to run VWA. These will be discussed below.

Creation of the Master File:

Several steps are required to create a VWA master file. The user must first decide on a vertical layering scheme. This involves selection of up to five layers in the water column. The layers are specified by their top surface depths (starting with 0.0 for layer 1). The bottom depth of the deepest layer is automatically defined to be the maximum sounding depth in the grid. The layers must be continuous; that is, there can be no gaps in the water column. Layers can be ignored, however, when the actual VWA analysis is conducted.

Once the user has decided on a layering scheme, this information is combined with the bathymetric information in code CHARLAY to produce a file that defines the limits of the grid for each layer. These limits show the transitions between grid cells that are in water and those on land. As the layers become deeper, for example, those cells bordering the grid in which the water is shallower than the top of the layer will appear as "land" cells, and some cells in shallow areas in the lake will appear to be islands. The file produced by CHARLAY (Appendix B), which lists the grid columns at which a transition between land and water occurs for every grid row that has a water cell, is subsequently used as the basis for the horizontal segmentation scheme. CHARLAY also produces a printer map of the lake of interest showing the horizontal extent of the specified layers, and a listing of the geometric characteristics of these layers including their surface areas and volumes.

Editing of the file produced by CHARLAY to create a segmentation scheme is similar to the process required by ALDAR. The segmentation is specified by adding, to each row of the grid, information about the grid columns at which transitions between segments occur. This information consists of a pair of numbers (segment number and column number) for each transition in a row. If only one segment is used, as would be the case if a direct calculation of the whole-lake average were desired, the only editing that would be required would be the insertion of a line after the title line for each layer indicating the layer number, the number of segments in this layer, and their identification numbers. This line also would be required for more complicated segmentation schemes.

Given a segmentation scheme as defined above along with the bathymetric data, code CORSWAIT is used to produce a raw master file. This file contains, for each layer, information about the segmentation scheme, including the volume and area of each segment as well as the location, depth, and relative weighting for every cell within the segment. The raw master file created by CORSWAIT is next merged with information describing the stations in code STARSEG.

One of the differences between VWA and ALDAR is the method by which information about the sample locations is included in the codes. In ALDAR this information is provided in the data file along with the sample data. In VWA, however, the master file contains a prespecified list of all the possible stations that may be sampled. This list gives a unique number to each of the potential stations, and this number is used to associate a sample datum with a particular location. Thus, if sampling is conducted at a new station (i.e., one not already included in the master file), a new master file must be created that includes the description of that station.

Station information required by STARSEG includes the agency designation, the station name, its latitude and longitude, its coordinates in terms of grid units, and a station reference number. These data may be produced in the proper format by using a code STNSC2 (Appendix B) that uses the station name, agency designation, and geographic position (latitude and longitude) to calculate the grid position and reference number.

STARSEG actually has two functions and must be invoked twice in the process of completing the master file. The first use is to compare the positions of the potential stations with the bathymetric grid for each layer and warn the user if a particular station falls on land. This may be the case if a location has been given incorrectly or if the top of a particular layer is deeper than the sounding in the cell occupied by a station. STARSEG produces an output listing that summarizes the station information and, for each layer, lists the segmentation scheme, prints the number of grid cells in each segment, prints a map showing the distribution of grid cells and the locations of the stations, and lists the stations assigned to each segment. In addition to this listing, STARSEG produces for each layer a data file that contains the segment assignment for each station that falls in a water cell. This data file is edited and used as input for the second run of STARSEG, the purpose of which is to complete the definition of the master file by assigning stations to particular segments.

Preparation of the Data File:

A separate set of control information and sample data is required for each layer to be analyzed in VWA. This information is provided to the code PRNTPNCH as successive FORTRAN files read on input unit 5. That is, an end-of-file mark serves as a data delimiter for each layer. The control information required by VWA consists of various descriptive items such as cruise number and dates and parameter code and name, as well as the number of the layer to be analyzed and the value of the weighting factor for the spatial interpolation. Also required are specification of the contour interval to be used in the output contour maps, and flags as to whether the estimated cell values are to be printed and plotted. As in ALDAR, the user may select the number and identity of the segments to be analyzed; however, in contrast to ALDAR, all the data (including those in segments not analyzed) are used in the spatial interpolation. The vertically averaged sample data are provided for each station to be included in the analysis. The stations are identified by their index number as printed by STARSEG.

SECTION 4

GENERAL FEATURES OF ALDAR AND VWA

The purpose of this section is to point out some features of ALDAR and VWA that may not be apparent to the end user of the two codes but may have a significant effect on the interpretation of the results. This discussion does not include evaluation of the accuracy of the spatial interpolation algorithms, which will be discussed in detail in Section 5.

ALDAR

ALDAR is fairly easy to use and is sufficiently general so that it can be applied to the analysis of many different lakes and grids without being modified or recompiled. This generality is reflected in the simple manner in which station data are provided to the code via the run time data file. However, some features of ALDAR are not obvious, and the user should be aware of these before attempting to use the code.

Location of Stations in Grid Coordinates:

The method used to convert the x and y coordinates of the stations to grid coordinates in ALDAR is incorrect. If DLAT is the size of the grid in kilometers and XSTIN and YSTIN are the x and y distances of a station from the grid origin, also in kilometers, the expression used to calculate IS and JS, the indices of the grid cell within which the station falls, is given (for IS) in ALDAR as

```
IS = (XSTIN + DLAT/2.0)/DLAT .
```

This will result in an error of one cell whenever the fractional portion of the quantity XSTIN/DLAT is less than 0.5. This coding problem can be corrected by changing the code to

XS = (XSTIN + DLAT/2.0)/DLAT

IS = IFIX (XS + 0.5) .

Use of Standard Depths to Define Layers:

Vertical layering in ALDAR is based on the definition of standard depths. At each station, parameter values are estimated at these depths, which are selected by the user, by linear interpolation of the sample data. If no sample data are collected at depths equal to or deeper than the standard depth, no parameter estimate is made for that depth. Similarly, because only the sample values closest (on either side) to the standard depth are used in the interpolation, some of the sample data may not be used at all. Thus, the standard depths must be chosen carefully, and it may be desirable to use as many as possible to ensure that all of the sample data are included in the analysis.

If no estimated values exist at the deeper standard depths, these depths are not used in the subsequent volume calculations. Thus volume-weighted values are only calculated for layers that are between standard depths for which estimated values are available.

Stations in Excluded Zones:

The nearest-neighbor interpolation method used in ALDAR assigns to each grid cell the parameter value of the station closest to the cell only if the closest station is in an active zone. Thus, data collected at stations that are in excluded zones are not used at all in the analysis, no matter how close the stations are to cells in active zones. In order to include data from these stations, it may be necessary to do calculations in zones that are not of interest, or to redefine the zones to include the stations of interest. Because the "whole-lake" estimates calculated by ALDAR are based on all of the included zones, the first option may result in meaningless "whole-lake" estimates.

Estimation of Layer Volumes:

ALDAR does not calculate exact volumes for the specified layers. Instead, layer volumes (in zone J) are approximated by using the code

DELV = (DELC/2.0) * (NHYP(M,J) + NHYP(M-1,J)) ,

in which DELV is the volume of the layer between depths M and M-1, DELC is the thickness of the layer, NHYP(M,J) is the number of grid cells at standard depth M, and NHYP(M-1,J) is the number of grid cells at standard depth M-1. Since this formulation assumes a constant rate of areal decrease with depth, the accuracy of the approximation will depend on the configuration of the basin as well as on the selection of the standard depths. The higher the resolution of the standard depths, the better the approximation will be. This may be seen by comparison of ALDAR volume calculations for several different layering schemes with the true layer volumes calculated using VWA (Table 2.) It also should be noted that the quantity DELV, as defined above, does not have units of volume. This can be corrected by multiplying the expression by the square of the grid size, either expressing the units of the layer thickness in kilometers or the units of the grid size in meters.

Calculation of Layer Quantities:

The total quantity of a substance within a layer is also approximated in ALDAR. This approximation is written

DELQ = (DELC/3.0) * [(NHYP(M,J)*THS(M,J) + (NHYP(M-1,J)*THS(M-1,J) +
0.5 * ((NHYP(M,J)*THS(M-1,J) + (NHYP(M-1,J)*THS(M,J))] ,

in which THS(M,J) is the average value of the variable of interest at standard depth M in segment J, and the NHYP terms are as they were defined above. As in the case of the volume calculation, the accuracy of this approximation depends on the configuration of the basin and zone (segment) boundaries as well as on the selection of the standard depths.

Table 2. Comparison of ALDAR and VWA volume calculations with differing vertical resolutions. Example from analysis of Green Bay, Lake Michigan with 2-km grid. Dashed lines indicate layer boundaries.

		Calculated Layer Volume (km^3)				
Depth (m)	Number of Cells	9 Layers*	5 Layers		2 Layers	
		ALDAR	ALDAR	VWA	ALDAR	VWA
0.0	1128	----	----	----	----	----
		4.5				
1.0	1128	----	20.1	19.9		
		16.1				
5.0	880	----	----	----		
		15.6	15.6	15.1		
10.0	675	----	----	----	60.4	55.3
		12.0				
15.0	523	----	21.2	20.3		
		9.1				
20.0	383	----	----	----	----	----
		6.4				
25.0	253	----	9.8	9.4		
		3.6				
30.0	105	----	----	----	16.1	10.2
		1.2				
35.0	13	----	2.3	0.8		
		0.2				
41.0	1	----	----	----	----	----
Total Volume		68.7	69.0	65.5	76.5	65.5

* VWA is limited to five layers, so no comparison is possible.

The quantity THS requires some explanation. This quantity is calculated by summing all of the individual cell values at a standard depth and within a zone, and dividing the total by the number of cells at that depth and within that zone. Thus THS may be considered an areally weighted mean value of the variable at a single depth. The quantity of the variable within a particular layer is then approximated by a function of the areally weighted mean values at the top and bottom of the layer. As was shown above, the approximation function is not a simple linear one (as is the volume approximation), but one that includes an adjustment term, the source of which is unclear. The extent of error in this approximation may be judged by comparing calculations of the vertically integrated quantity (based on a thick layer) with the sum of thinner sublayers within the thick layer. Such a comparison is illustrated in Table 3. Assuming that the approximation based on the thin layers is more accurate, reducing the vertical resolution results in an underestimate of the total mass.

Table 3. Comparison of ALDAR layer quantity and volume-weighted concentration (in parentheses) calculations with differing vertical resolutions. Example from analysis of Green Bay, Lake Michigan, with 2-km grid. Variable is total phosphorus. Dashed lines indicate layer boundaries.

Depth (m)	Number of Cells	Calculated Layer Quantity (Mg) and Volume-Weighted Concentrations (mg/L)		
		9 Layers	5 Layers	2 Layers
0.0	1128	---------------	---------------	---------------
		61.0 (0.0135)		
1.0	1128	---------------	267.0 (0.0133)	
		213.0 (0.0133)		
5.0	880	---------------	---------------	
		198.0 (0.0128)	198.0 (0.0128)	
10.0	675	---------------	---------------	672.0 (0.0111)
		157.0 (0.0131)		
15.0	523	---------------	219.0 (0.0103)	
		98.6 (0.0109)		
20.0	383	---------------	---------------	---------------
		51.5 (0.0081)		
25.0	253	---------------	77.3 (0.0079)	
		29.9 (0.0084)		
30.0	105	---------------	---------------	105.0 (0.0065)
		7.8 (0.0066)		
35.0	13	---------------	15.8 (0.0068)	
		0.7 (0.0040)		
41.0	1	---------------	---------------	---------------
Total		817.5 (0.0119)	777.1 (0.0113)	777.0 (0.0101)

Presentation of Results:

ALDAR output (Appendix C) consists of a repetition of the input control information, a listing of the vertically interpolated station data showing the parameter values estimated at each standard depth at each station, and a zone-by-zone summary of the volume-weighting calculations. For each active zone, the summary shows, for each standard depth, the areally weighted mean value, the area represented by the standard depth, the vertically integrated quantity from the surface to the standard depth, and the vertically integrated volume from the surface to the standard depth. As was pointed out above, the volumes and quantities are approximations and have incorrect units in ALDAR. As coded, the printed area does not have units of area, but actually is the number of grid cells at the standard depth. This error can be corrected by multiplying the listed number by the square of the grid cell length.

In addition to estimates at the standard depths, the zone summary contains estimates of the volume of and the variable quantity within the layers defined by the standard depths. The volume-weighted concentration is also listed for each of these layers. The vertically integrated, volume-weighted concentration is calculated at each standard depth below the surface by dividing the integrated quantity by the integrated volume.

The zone summary also contains a listing of the actual observations that have affected the calculation for that zone. This listing includes the station number, the depth and value of the observation, and an indicator as to whether the station is inside the zone. This indicator will be wrong in some cases because of the error in the original ALDAR code relating station position to grid location. The calculations, however, will not be affected.

ALDAR produces a "whole-lake" estimate that is really the combination of the estimates made for the included zones. The combined data are accumulated in a phantom zone, number 25. The summary listing for zone 25 follows the format of the other zone summaries.

Finally, ALDAR prints a "summary report" that lists, for each selected zone and zone 25, the areally weighted mean parameter value at the surface and, for specified zones and zone 25, the areally weighted mean parameter value at selected standard depths and the "bottom" or deepest standard depth. A total integrated quantity of the variable in question is also printed. This quantity is not the total mass of the variable in the lake (assuming that the original data are given as concentrations) but is the product of the spatially averaged, "whole-lake" concentration at the deepest standard depth at which an estimate has been made, and the estimated volume of the lake. It is not clear what this number is intended to represent; but unless the code is modified, it is best ignored.

VWA

VWA is somewhat more cumbersome to use than is ALDAR. A major shortcoming is its specificity to a single lake. Modifications to the original code would be required in order to make VWA as general as ALDAR. Although a new master file is needed for every change in segmentation and layering, it should be possible to create a library of master files that can be reused as necessary. This would simplify application of VWA in exploratory data analysis. Some other features of VWA that require comment are discussed below.

Use of Vertical Averages to Define Station Data:

VWA is based on analysis of predefined vertical layers. Station data are provided as a single number representing the mean value for each layer. Although it is assumed that this mean value is the simple average of sample data within the layer, this need not be the case. The user can select any representative value. Thus, the user can correct for any perceived bias in the vertical location of the station data within the layer. The use of single values as representatives of the layers tends to reduce the effect of noisy sample data. There is no implicit assumption (as there is in ALDAR) that the sample data are exact. However, vertical resolution in VWA is limited to five layers. It may be desirable to increase the number of vertical layers from the five currently allowed, but this would increase the complexity of both the master files and the data files.

Use of All Stations in Horizontal Interpolation:

As currently configured, VWA uses data from all stations to calculate estimated values at each grid cell. Information from distant stations is damped, however, by the choice of the smoothing parameter in the distance-weighting algorithm. The fact that all stations are used may affect the choice for the value of this parameter. An alternate method would restrict the selection of stations contributing to the estimate at a cell to those within some fixed distance of the cell. Although this method is mentioned in the documentation of VWA, it does not seem to have been implemented in the production version. Given the use of all stations, estimates made outside (e.g., shoreward) of the domain of the sampled locations will tend toward the arithmetic mean values of the sample data. The distance at which this will occur depends on the geometry of the sampling network and on the choice of the smoothing parameter. In no case, however, will an estimated value be outside the range of the observed values.

Presentation of Results:

The results of a VWA analysis (Appendix D) are produced by three of the codes that make up the VWA system (CHARLAY, STARSEG, and PRNTPNCH). The basic geometric conditions of the analysis, including the area and volume of the zones and layers, are calculated and printed in CHARLAY. CHARLAY also produces a printer map showing the bathymetric distribution of the selected layers. Details of the segmentation scheme are printed by STARSEG. This output includes a cross-referenced listing of the stations in the master file that shows their reference number, latitude and longitude, and grid coordinates. Printer maps showing the spatial boundaries of the chosen segments are printed for each layer by STARSEG. These maps also show the locations of the available stations.

Output from PRNTPNCH is presented by layer. This output consists of a repetition of the input control data, a listing of the stations actually selected for the analysis (including the data values used for the layer), a summary of simple statistics of the input data (mean, high and low values, standard deviation, and standard error), the volume-weighted statistics (mean, standard error, standard deviation, and estimated maximum and minimum values), a histogram of the cell estimates, and a contour map showing the spatial distribution of the variable.

The measures of dispersion (standard deviation and standard error) calculated for the volume-weighted statistics are based on the deviations of the station data from the volume-weighted mean. It is not clear what this statistic actually represents, however, because the volume-weighted mean is a complicated function of the basin configuration, station values, and station locations. These dispersion statistics should not be used as estimates of the accuracy of the mean value. Because parametric statistical estimators are inappropriate as measures of the dispersion of the volume-weighted mean, it may be desirable to use a nonparametric estimator such as that described by Lesht (1988).

SECTION 5

INTRINSIC ACCURACY OF THE SPATIAL INTERPOLATION ALGORITHMS

Because both ALDAR and VWA depend on spatial interpolation algorithms, it is of interest to examine these algorithms in terms of accuracy. Two types of accuracy, which may be termed local (or point) and integrated, may be considered. Local accuracy is a measure of how well the interpolation algorithm can be expected to predict the value of a variable at an unsampled point, and integrated accuracy is a measure of how well the algorithm reproduces the summed value of the sampled field. Because integration in both algorithms is based on summation of values estimated at points, this discussion begins with the question of local accuracy.

Local Accuracy:

For the purposes of this study, local estimation error (e_i) is defined as the difference between the true value of a variable at some point (z_i) and the estimated value at that same point (z^*_i). Estimators such as the algorithms used in ALDAR and VWA are termed linear estimators and may be evaluated on the basis of the average value (bias) and the variance of the errors. Linear estimators as defined in Eq. (2), repeated below, may be expressed as

$$z^*_i = \sum_j w_{ij} z_j \, , \qquad (4)$$

where the w_{ij} are the weights appropriate for estimated location i and sample j. It is easy to see that the spatial interpolation algorthims used in ALDAR and VWA belong to this class of estimators. In ALDAR the weights w_{ij} are defined so that $w_{ij} = 1$ if station j is closest to point i, and $w_{ij} = 0$ otherwise. Later in this discussion, the value of the variable at station j closest to point i will be designated $z_{i|j}$.

In VWA the weights are defined in Eq. (3) above. If, as is the case for both ALDAR and VWA,

$$\sum_j w_{ij} = 1 ,$$

the estimator is unbiased, because $E[z^*_i] = E[z_j]$, and the expected value of the local estimation error is zero.

A general expression for the variance of the local estimation error (s^2_e) when the estimates are based on a weighted average of the sample data can be written (Tabios and Salas 1985) as

$$s^2_e = s^2 - 2 \sum_j w_{ij} \operatorname{cov}(z_i z_j) + \sum_j \sum_i w_{ij} w_{ik} \operatorname{cov}(z_j z_k) , \qquad (5)$$

where s^2 is the variance of the sample data, the w_{ij} are the weights for location i and sample j, and $\operatorname{cov}(z_i z_j)$ represents the spatial covariance between z_i and z_j.

This expression requires knowledge of the spatial covariance function which, in general, is unknown. Some methods of spatial interpolation that have been developed make use of estimates of this function [e.g., Gandin's (1965) optimal interpolation or Matheron's (1971) Kriging], but these are beyond the scope of the analysis presented here.

In the case of sampled systems for which the spatial covariance function is unknown, the bias and variance of an interpolation procedure can be estimated from the sample data by using all but one of the samples to interpolate the value at the last point. Thus for a sample network of n stations, we define the error at station i to be

$$e_i = z_i - z^*_i , \qquad (6)$$

where z_i is the sampled value at the station and z^*_i is the value estimated using the interpolation procedure.

Given n stations, there will be n values of e_i, and the statistics of these values (e.g., their mean and standard deviation) provide some estimate of the overall accuracy of the interpolation. If the mean and standard deviation of the errors are given as

$$\langle e\rangle = E[e_i] \tag{7}$$

and

$$s^2_e = E[(e_i - \langle e\rangle)^2] \tag{8}$$

where E[ ] designates expected value, then the combined or RMS error may be calculated by

$$RMS_e = [\langle e\rangle^2 + s^2_e]^{0.5} \ . \tag{9}$$

This combination of bias ($\langle e\rangle$) and precision (s^2_e) will be used as the basic measure of the accuracy of the local estimates.

Many factors will affect the accuracy of an interpolation procedure. Among them are the configuration and size of the sampling network and the structure of the spatial distribution being sampled. For ALDAR and for one special case of VWA it is possible to derive an analytical expression for the sample estimates of both the bias [Eq. (7)] and variance [Eq. (8)] of the errors.

Since, in ALDAR, the estimated value of a variable at location i (written z^*_i) is the value observed at location j ($z_{j|i}$) closest to location i, we can write

$$\langle e\rangle = 1/N \sum_i (z_i - z_{j|i}) \tag{10}$$

or

$$\langle e\rangle = \langle z\rangle - 1/N \sum_i (z_{j|i}) \ . \tag{11}$$

The first term in Eq. (11) is the simple average of the sample values. The second term is the simple average of the values at those stations that are nearest to the sampled stations. Since a station may be nearest to more than one (or to none) of the other stations, this term, which will be referred to as z'', will not, in general, be equal to $\langle z \rangle$.

The expression for the variance of the interpolation errors [Eq. (8)] may be expanded by using Eq. (11).

$$
\begin{aligned}
(N - 1)\ s^2{}_e &= \sum (e_i - \langle e \rangle)^2 \qquad (12) \\
&= \sum_i [(z_i - z_{j|i}) - (\langle z \rangle - z'')]^2 \\
&= \sum_i [(z_i - \langle z \rangle) - (z_{j|i} - z'')]^2 \\
&= s^2{}_z + s^2{}_{z*} - 2s_{zz*}\ .
\end{aligned}
$$

Thus, in ALDAR, the local error variance may be estimated by the sum of the sample variance and the variance of the estimated values (which are a subset of the sampled values) minus twice the covariance of the samples and estimates. As would be expected, the more highly correlated the estimated values are with the samples, the lower will be the error variance.

Similar estimators can be constructed for the special case of VWA when the smoothing parameter α equals zero. This is equivalent to the interpolation procedure of estimating the value at each point by the mean value of the other N - 1 points. If we let

$$w_{ij} = (N - 1)^{-1}\ ,$$

then

$$z^*_i = \sum_j (N - 1)^{-1} z_j \qquad (j \neq i) \tag{13}$$

and

$$\langle e_i \rangle = (N)^{-1} \left[\sum_i z_i - \sum_j \sum_i (N - 1)^{-1} z_j \right] \qquad (j \neq i)$$

$$= (N)^{-1} \sum_i z_i - \sum_i (N - 1)^{-1} \left(\sum_j z_j \right) + \sum_i (N - 1)^{-1} z_i$$

$$= 0 \ .$$

So the average error for this case will be zero.

By substituting Eq. (13) into the expression for the local estimation variance [Eq. (8)], we obtain the simple expression

$$s^2_e = [N/(N - 1)]^2 \, s^2_z \ . \tag{14}$$

The local estimation variance obtained for this case (sample value estimated by the mean of the remaining samples) approaches the variance of the sample data. It is impossible to derive a similar relationship for the case $\alpha \neq 0$ without making assumptions about the spatial structure of the sampled variable.

Numerical Examination of Factors Affecting Local Accuracy:

One of the objectives of this study was to gain some insight into the effects of different factors on the analysis of spatially distributed data. Among the factors we consider are the number and location of the samples, the spatial structure of the sampled variable, and the parameters required to apply the interpolation algorithms ALDAR and VWA. In this section synthetic data drawn from known distributions are analyzed first. The results of these analyses are then applied to limnological data.

Random Data

We consider first the case in which the sampled variable has no spatial structure. This case is modeled by drawing samples from a normal distribution with known mean and variance and assigning them randomly to a preselected number of locations in a model domain. For the purpose of illustration we will use a square model domain with sides 100 units long. Although selection of a domain is arbitrary, the use of a square domain simplifies some of the following calculations. Since the mean value is the best estimator of sample values drawn from a normal distribution, we would expect that the VWA interpolation with parameter α set to zero would result in the lowest RMS estimation error. This is indeed the case (Fig. 2), with the RMS error equaling the theoretical value

$$s_e = [N/(N - 1)] \; s_z$$

when α is zero.

The RMS error increases as a function of α in this case, approaching the value obtained by using the ALDAR-type interpolation. This is due to the fact that as α increases, the influence of nearby stations increases, and VWA interpolation approaches the nearest-neighbor interpolation used in ALDAR. As is shown in Eq. (12), the asymptotic value will depend on the configuration of the stations and on the covariance of the data at the stations and their nearest neighboring stations.

The configuration of the station locations will influence the interpolation results. If instead of randomly locating the stations (Fig. 3a) within the model domain as was done above, we use a regular rectangular grid of the same number of stations (Fig. 3b), we find that the asymptotic value of the RMS error is considerably lower than for the purely random case. This is a result of the regularity of the grid in which each interior station is equidistant from four other stations. With the distance-weighting algorithm

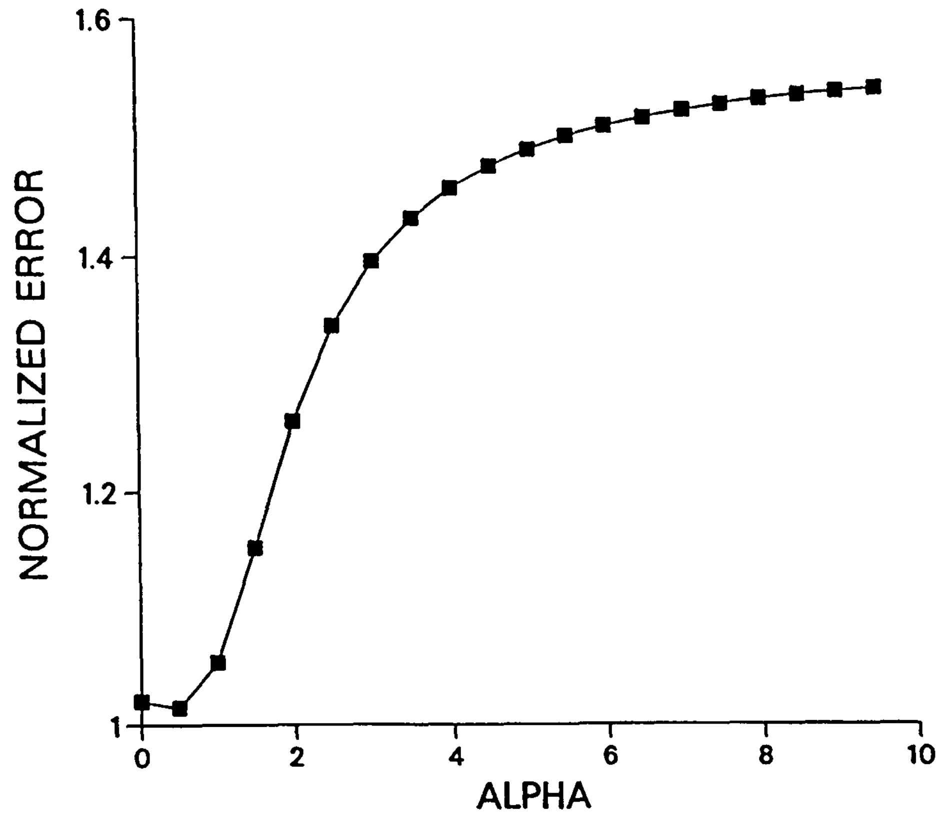

Figure 2. Normalized error (RMS error divided by sample standard deviation) as a function of α for data selected from a normal distribution and assigned to randomly located stations.

of VWA (and, in its limit, ALDAR), using a regular grid results in a point estimate that is dominated by the mean of the surrounding stations. This dominance increases with α. If the grid is made hexagonal (Fig. 3c), then interior points are equidistant from six other points, and the RMS error is reduced further at most values of α. At high values of α, small differences in the calculated distances of the hexagonal grid, resulting from numerical truncation, tend to dominate. If the grid is regular with some degree of randomness (Fig. 3d), as is generally the case in limnological sampling, the RMS errors fall between those of the regular case and the purely random case (Fig. 4). The proximity of this curve to the extremes (i.e., the random case and the regular case) depends on the degree of randomness in the grid. Results from networks based on random spacing of 25%, 50%, and 75% of the grid size also are shown in Fig. 4.

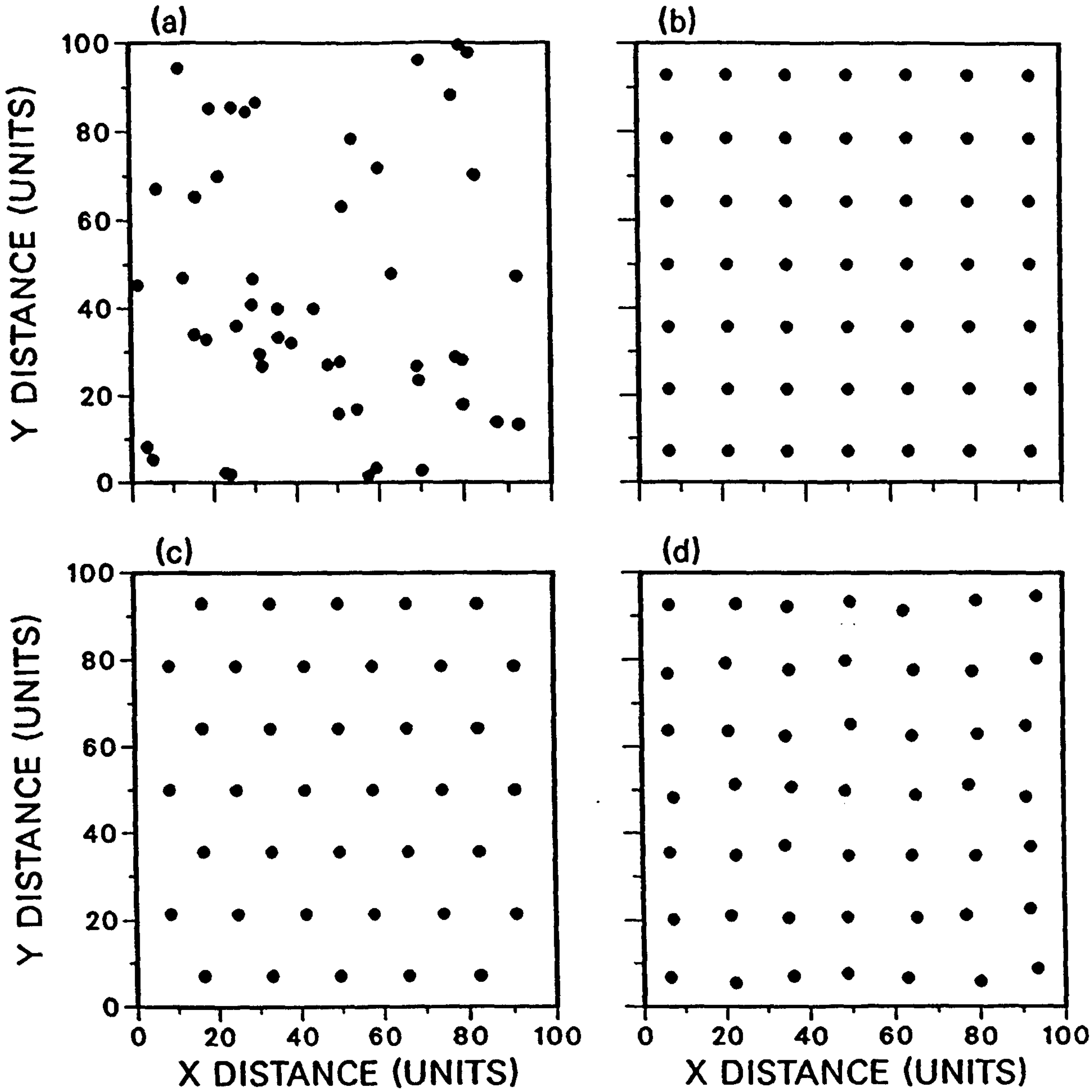

Figure 3. Station configurations in the square model domain with sides 100 units long. (a) Random network of 49 stations. (b) Regular rectangular network. (c) Regular hexagonal network. (d) Regular rectangular network with station positions moved randomly within a radius of 50% of the grid spacing.

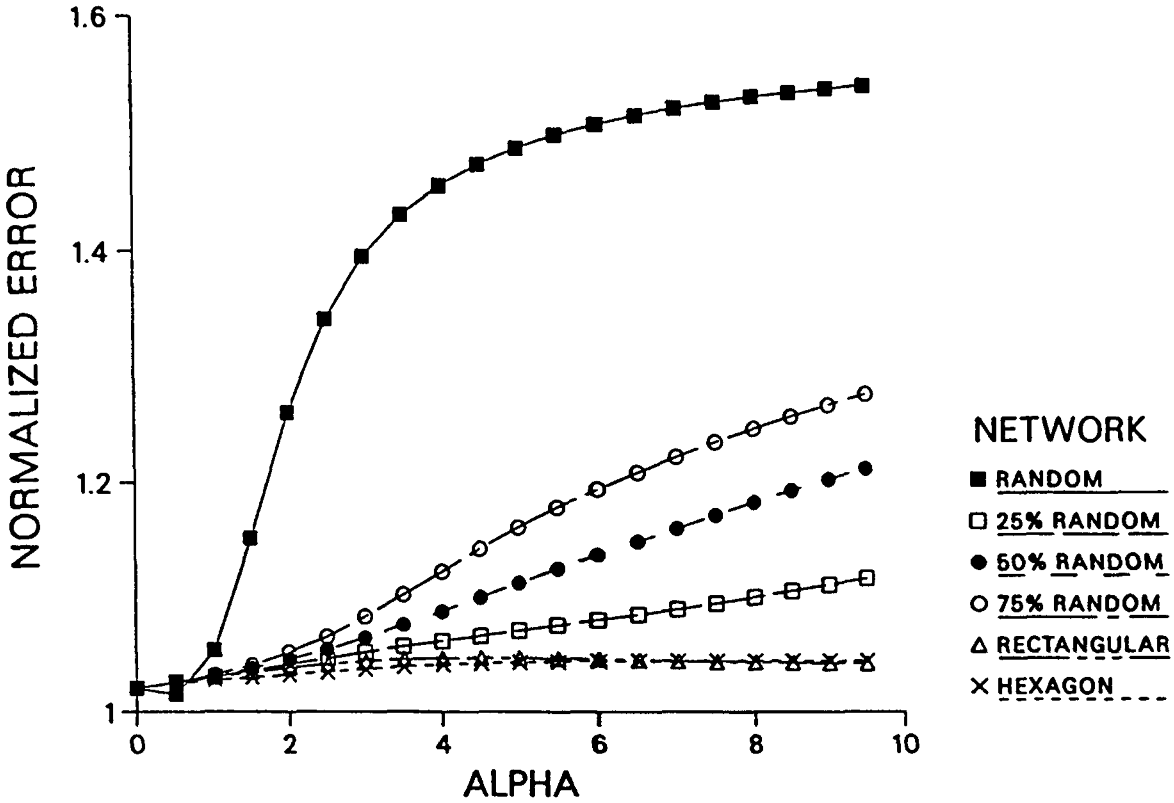

Figure 4. Normalized error as a function of α for data selected from a normal distribution and assigned randomly to networks of differing configuration.

Deterministic Data

The most important feature of the random data used above is the lack of spatial correlation. This would be the case if the sampled variable were homogeneous. The case to be considered next involves variables that have some deterministic spatial structure. Such a variable can be modeled by any number of functions. The simple function used here,

$$z(x,y) = A\,[\sin\,(xn\pi/X)\,\sin\,(ym\pi/Y)]\ , \qquad (15)$$

in which X and Y are the limits of the domain in the x and y directions, A is the peak value of the function, and n and m are wave numbers, is shown for one case (A = 10, m = n = 1, X = Y = 100) in Fig. 5.

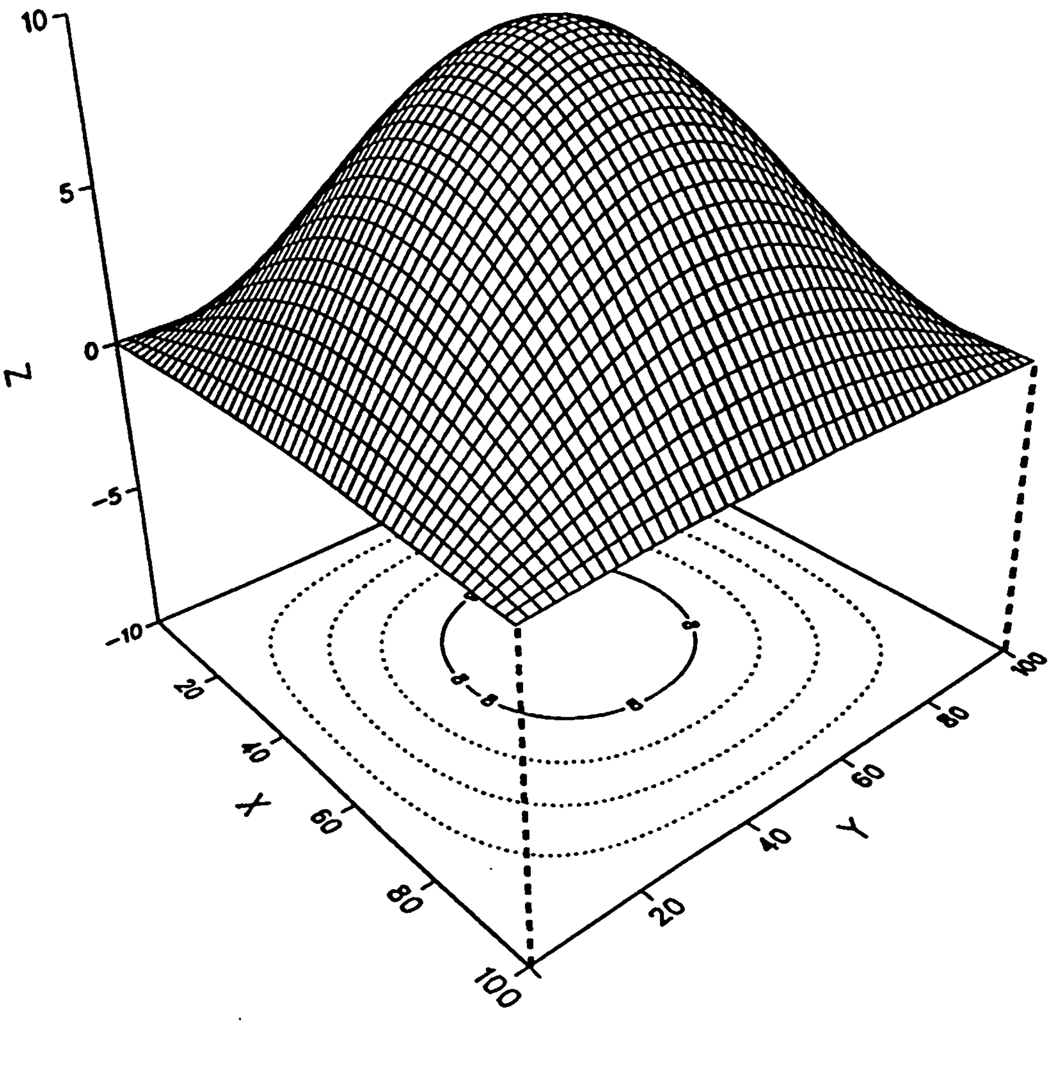

Figure 5. Deterministic function described by Eq. (15) shown in the model domain.

Considering again the results of simulated sampling from networks of differing configurations, we find that the dependence of the estimated RMS error on the parameter α is opposite that shown in Fig. 6 for the purely random data. In the case of deterministic data [as represented by the simple function defined in Eq. (15)], the mean value of the data (i.e., $\alpha = 0$) is the poorest estimator of the sample values. When the locations of the stations in the sampling network are randomly chosen, the minimum RMS error occurs when $\alpha = 5.5$. As the station grid becomes more regular, the location of the minimum error moves toward higher and higher values of α. In the limit of the rectangular grid, the minimum error is found at the highest value of α tested.

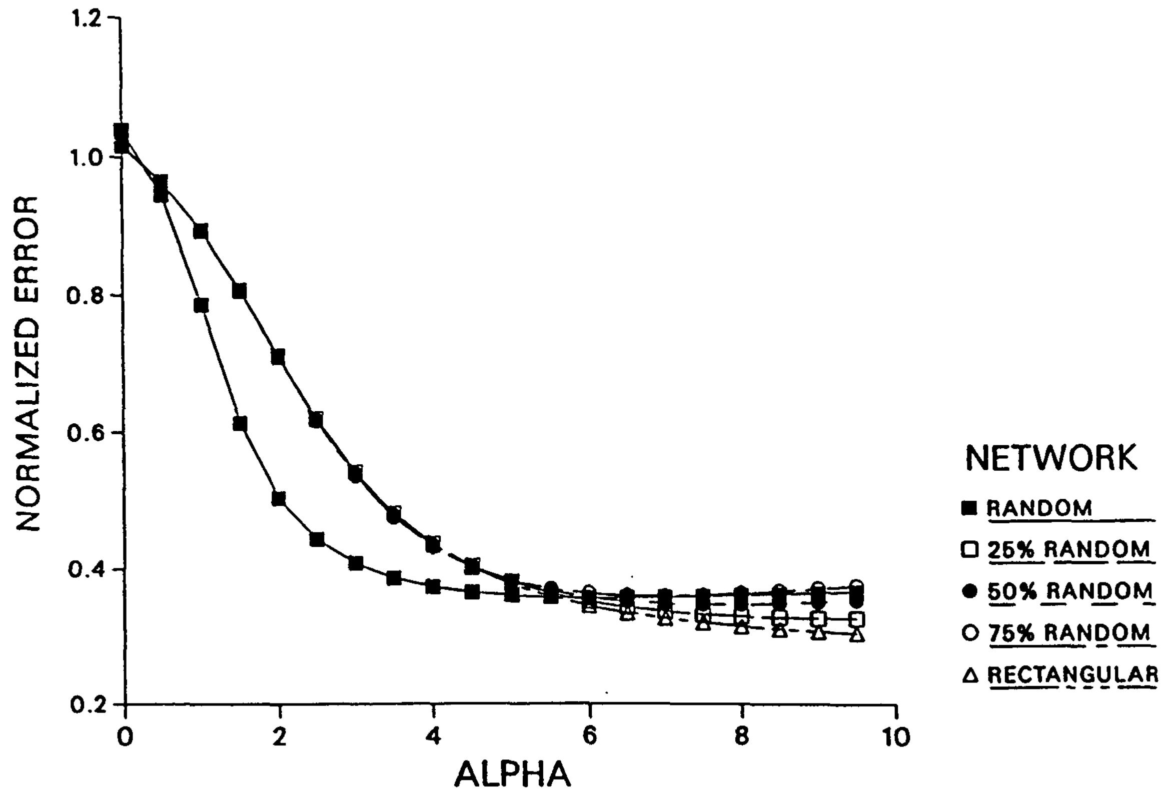

Figure 6. Normalized error as a function of α for data selected from the deterministic function described by Eq. (15) at stations defined by different network configurations.

Deterministic Data With Uncorrelated Noise

The relationship between local RMS error, network configuration, and the weighting parameter α changes again if noise is added to the deterministic signal given in Eq. (15). Figure 7 shows the result of simulations in which the data are given by Eq. (15) plus a random component drawn from a normal distribution with a mean of zero and a standard deviation of one. Since the amplitude of the signal ranges from zero to ten, this represents a noise level of less than 10 percent. As would be expected, the magnitude of the errors is higher than was the case for the purely regular function. This is a reflection of the higher variability in the input signal. Similarly, the relative reduction in the local error is smaller for the case of the noisy signal than for the case of the regular function. We find that the network in which the stations are located randomly has its minimum error at a lower value of the parameter α when the data are noisy and that the minimum error again occurs at higher values of α as the grid becomes more regular.

Figure 8 shows the effect of the signal-to-noise ratio on the relationship between the local RMS error and the parameter α for one network configuration. As the data become more noisy, the optimal value of α approaches zero. When the data have noise levels similar to those inferred for limnological variables (between 25 and 50 percent), the RMS error has a definite minimum between $\alpha = 2$ and $\alpha = 4$. This, of course, depends on the nature of the deterministic signal.

Effects of Network Size

All of the previous examples have been based on a 49-station sampling network in a domain 10,000 square units in area. This is equivalent to a sampling density of one station per 200 square units. Typical limnological sampling networks are more sparse, ranging downward toward one station per 1000 square kilometers. Obviously, reducing the number of stations in a network will increase the absolute magnitude of the local estimation errors.

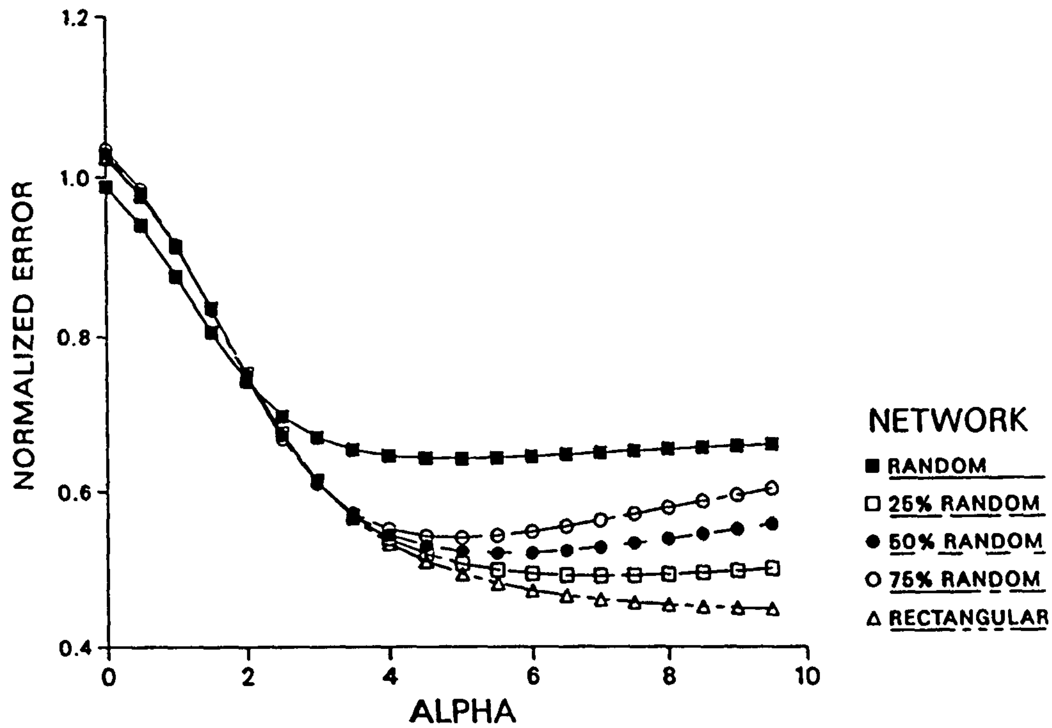

Figure 7. Effect of adding noise (10%) to a deterministic signal on the relationship between normalized estimation error and α for for several network configurations.

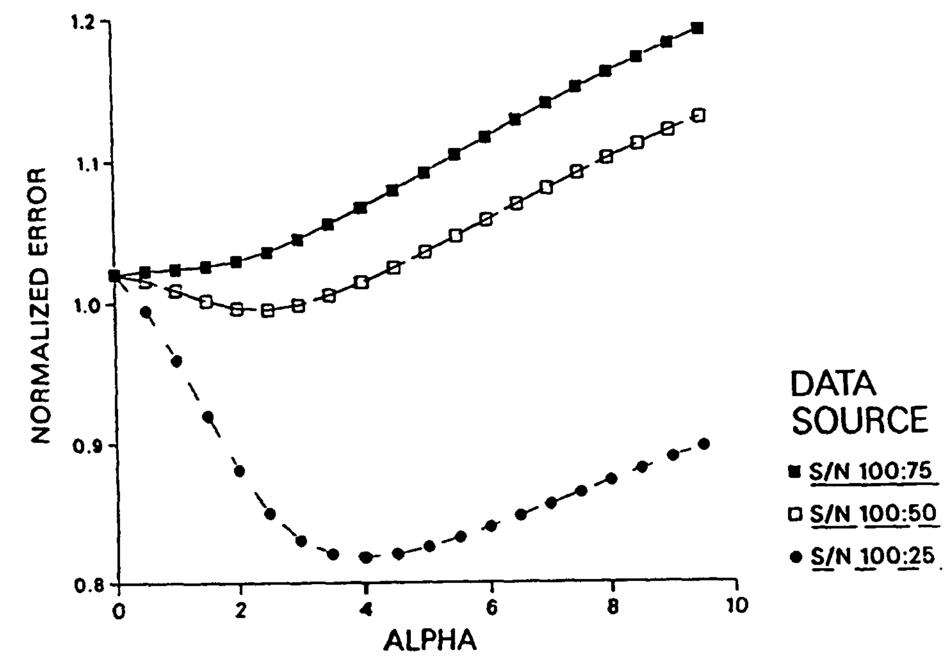

Figure 8. Effect of signal-to-noise ratio on the relationship between normalized estimation error and α for a randomized (50%) sampling network.

Qualitatively, the dependence of the errors normalized by the sample standard deviation on the weighting parameter α and the network size (Fig. 9) is similar to the dependence of the normalized errors on signal-to-noise ratio. As the number of stations in the network is reduced, the normalized error curve moves closer to that for the purely random case. This is a result of the tendency for highly separated stations to have low spatial correlations, especially when the data have some noise. It should be recalled that the basis of spatial interpolation is the assumption that some spatial structure exists in the variable and is reflected in the sample data. Sparse networks will have some difficulty in representing any spatial structure in the presence of noise.

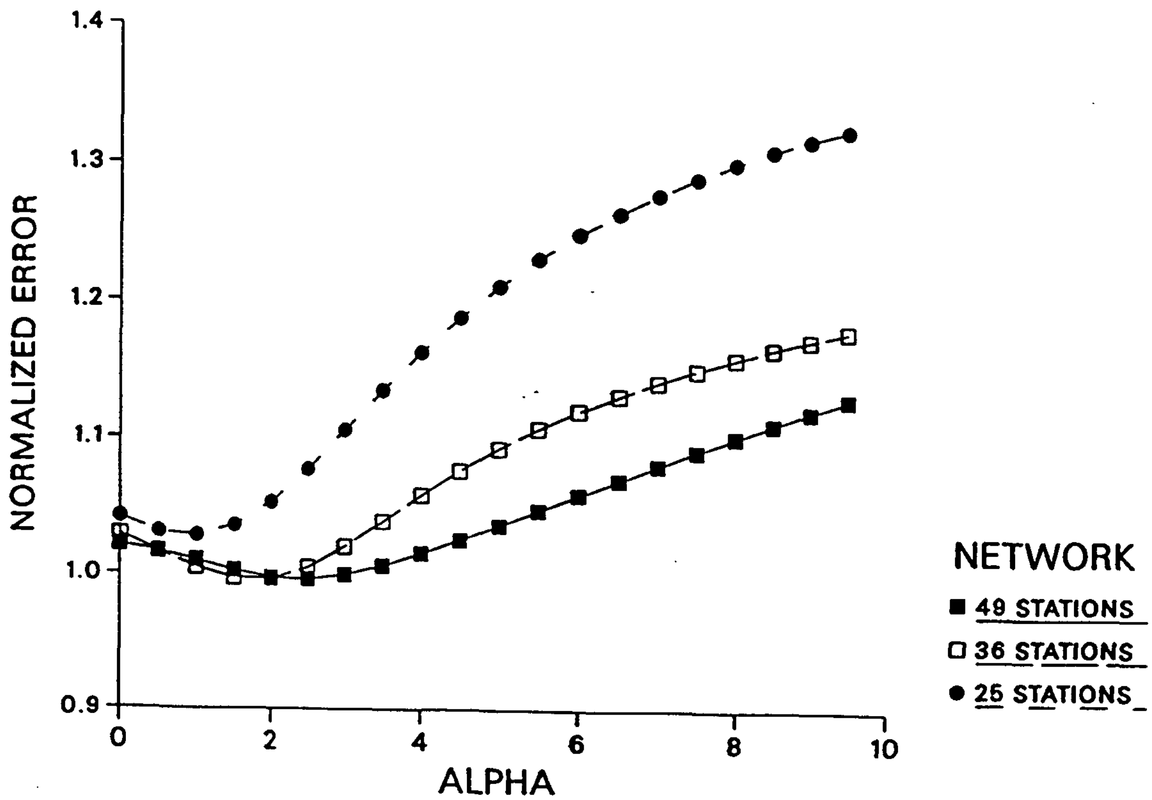

Figure 9. Effect of station density on the relationship between normalized estimation error and α for a randomized regular network and a deterministic signal with noise (50%).

Actual Limnological Sampling

Figure 10 shows the location of sampling stations occupied by the U.S. Environmental Protection Agency in southern Lake Michigan during lakewide surveys conducted in 1976 and 1977. The network was composed of 39 stations, and the approximate density was one station per 550 square kilometers. Two of the variables (total phosphorus and chloride) sampled during one of the 1977 surveys were used for analysis of local estimation errors. These variables were chosen because they should have similar spatial distributions (with primary sources along the coasts and at tributaries), but quite different signal-to-noise ratios; total phosphorus has a much more noisy signal in general than does chloride. The results of this analysis, shown in Fig. 11, are consistent with this expectation. Spatial interpolation of both variables is very dependent on the value of the weighting parameter α. Because the signal-to-noise ratio is lower (or equivalently the network is more sparse) for total phosphorus, the lowest normalized error is found at a low value (α = 1) of this parameter. The improvement over the purely random case, however, is very small. In contrast, local estimation of chloride values is improved by about 20 percent with the use of the weighting parameter (α = 2). In both cases the local error calculated by using the weighted averaging algorithm of VWA is lower than the local error that would be calculated by using the nearest-neighbor algorithm of ALDAR.

These spatial interpolation procedures may be used to estimate the size of the smallest network that is not too sparse to resolve any spatial structure in the sampled variable. This may be done by repeatedly selecting random subsets of a test sampling network and examining the average dependence of the local estimation error on α. Fig. 12 shows the results of such an analysis using the 1977 Lake Michigan southern basin total phosphorus and chloride data. In this example, randomly selected networks of 26, 21, 16, 11, and 6 stations were chosen from the original 39 stations, and the average estimation errors for 1000 realizations were calculated for each. As would be expected, reducing the number of stations increases the average absolute

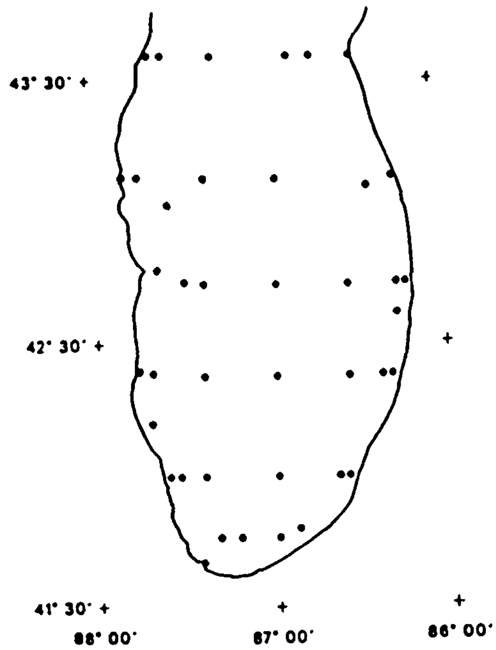

Figure 10. U.S. Environmental Protection Agency sampling stations in the southern basin of Lake Michigan during 1977.

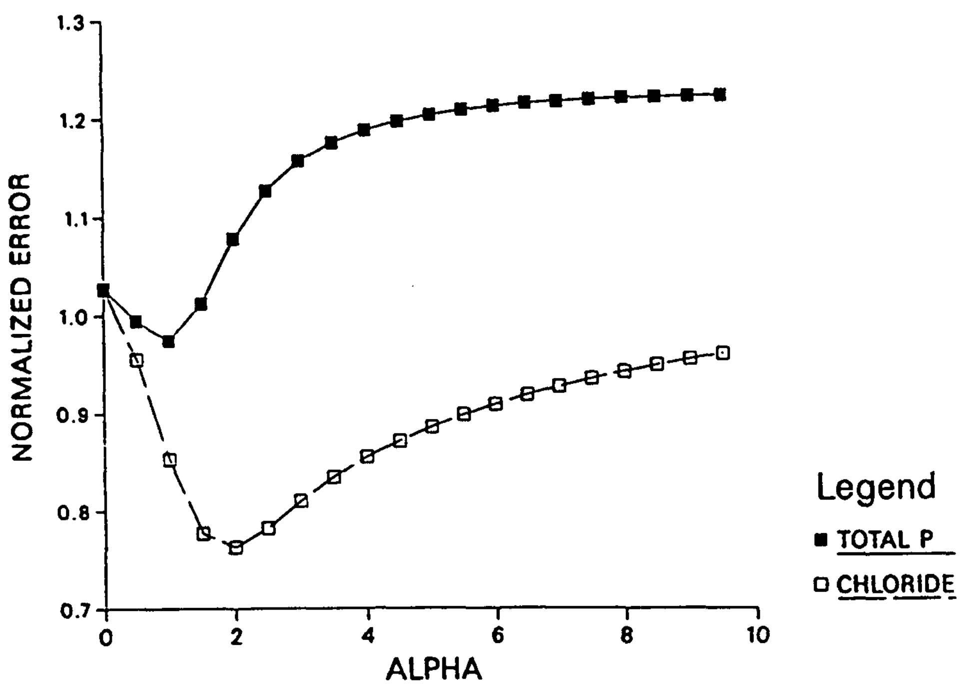

Figure 11. Normalized error as a function of α for total phosphorus and chloride concentrations in southern Lake Michigan. Data are from 39 surface samples collected during the intensive survey of June 1977.

estimation error and shifts the optimal value of α toward zero. In the case of total phosphorus, information about spatial structure, as evidenced by a definite minimum error value as a function of α, is lost for networks of less than 11 stations. Chloride, on the other hand, shows some spatial structure even when the network size is reduced to six stations.

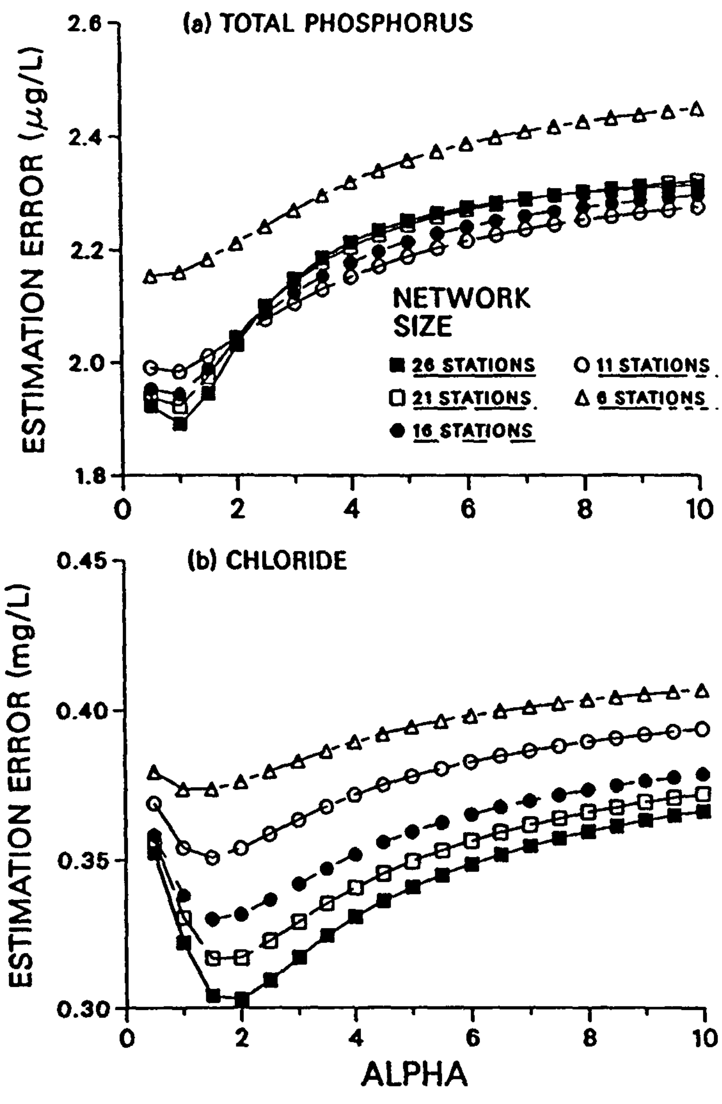

Figure 12. Average estimation error for total phosphorus (a) and chloride (b) as a function of α for five network sizes. Data are taken from 1977 EPA sampling in southern Lake Michigan. Each curve shows the average of 1000 realizations, in which stations for the different-sized networks were chosen at random from the original 39 stations.

In recent years the Environmental Protection Agency has reduced its sampling network in Lake Michigan to 11 stations. This reduction was predicated on the assumption that the stations would be located within a homogeneous region of the lake. The reduced network that has been used since 1985 is shown in Fig. 13. In terms of the surface area of Lake Michigan (approximately 55,000 km^2) this represents an extremely low sampling density of 1 station per 5000 km^2. This value is somewhat misleading because the network was intended to be representative of the open lake (roughly defined as waters greater than 90 m deep). Spatial analysis of total phosphorus and chloride concentrations measured at the surface in June 1976 at these stations (Fig. 14) showed no spatial structure in total phosphorus, although the sampling has detected structure in the chloride distribution. This indicates that, unlike total phosphorus, the scale of the chloride distribution is still greater than the scale of sampling.

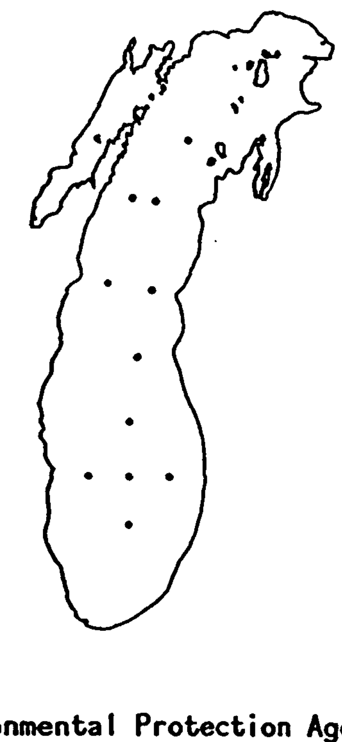

Figure 13. U.S. Environmental Protection Agency sampling stations in Lake Michigan during 1985.

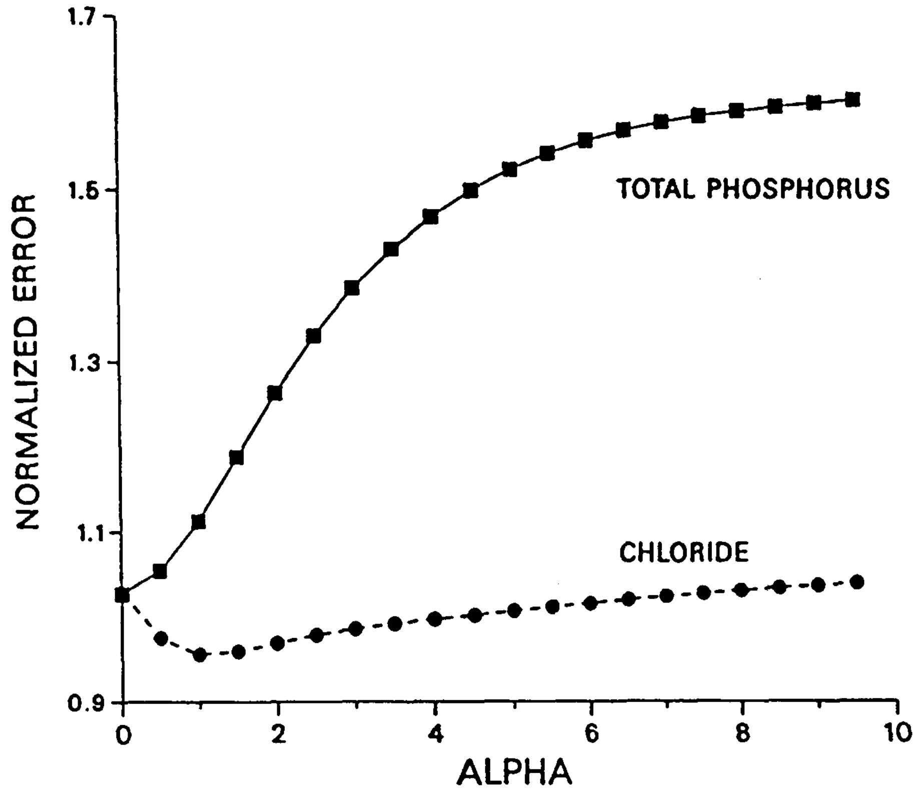

Figure 14. Normalized error as a function of α for total phosphorus and chloride concentrations in Lake Michigan. Data are from surface samples collected at stations shown in Fig. 13 during intensive the survey of June 1976.

Although the existence of a minimum estimation error for chloride concentration ($\alpha = 1$) implies a spatial dependence, this dependence is weak. The improvement in the normalized error is less than 10% and does not vary substantially over the range of α tested. It should be recalled that little variation exists in chloride concentrations measured in the open waters of Lake Michigan. In fact, the data that were used in the analysis shown in Fig. 14 ranged from 8.0 mg/L to 7.7 mg/L. Thus, if one were to consider the hypothetical situation in which the highest and lowest observations were nearest neighbors, estimation using high values of α, equivalent to the ALDAR interpolation, would result in an error at either point of only 4 percent.

SECTION 6

CONCLUSIONS

Two computer codes for volume-weighted averaging of limnological data (ALDAR and VWA) have been evaluated in terms of their generality, ease of use, and accuracy. Although ALDAR is more general than VWA and somewhat easier to apply and implement, it includes inaccurate algorithms for location of stations within the numerical grid and for computation of lake volumes and integrated quantities.

Vertical variations are treated differently in ALDAR and VWA. ALDAR linearly interpolates between sample values in the water column to produce estimated values at preselected standard depths. VWA, on the other hand, uses the average of sample values within preselected layers of the water column to represent the variable value within that layer. ALDAR allows finer vertical resolution than does VWA, but this resolution is based on the assumption that the sampled data are exact, and that the vertical linear interpolation produces representative variable values at the standard depths. The use of averages in VWA implicitly accounts for uncertainty in the sample values and tends to reduce the influence of noisy data on the subsequent calculations. Both methods require the judgement of the analyst for specification of the vertical structure.

The spatial interpolation algorithms in both ALDAR and VWA belong to the family of exact linear interpolators. In ALDAR the weighting function is such that only the datum from the observation point nearest the point of estimation is used. VWA uses an inverse-power distance-weighting algorithm involving a single parameter α that is applied to all of the observed data. The two weighting functions are equivalent when α is very high and there are no observation points equidistant from an estimation point. For most cases of real data the VWA interpolator can be made more accurate than the ALDAR interpolator by selection of a locally optimal value of α. This selection can be based on a simple analysis of the sample data.

When the data are homogeneous or purely random, the sample mean is the best estimator of the true mean value for all sampling network configurations. When the data are purely deterministic, with no noise, the ALDAR interpolation will produce the best estimator when used with a regular sampling network. If the data are noisy or the sampling network is irregular, the VWA interpolator produce the best estimator. The optimum value of the VWA weighting parameter α will vary with the signal-to-noise ratio of the data and with the irregularity of the grid. Reducing the density of an irregular sampling network is roughly equivalent to decreasing the signal-to-noise ratio and has the effect of limiting the utility of spatial analysis.

Limited simulations using limnological data show that choice of the most desirable interpolation procedure depends on the variable to be analyzed and the size and configuration of the sampling network. Spatial analysis, as provided by ALDAR and VWA, may or may not be beneficial. Exploratory analysis of sample data using the methods of spatial statistics should be a regular part of limonological surveillance programs.

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APPENDIX A

INPUT FILES AND AUXILIARY CODE USED WITH ALDAR

Example Segmentation Scheme

In this example the 2-km Lake Michigan grid is segmented into seven zones. The first two lines of the file contain descriptive information, and each succeeding line defines the segmentation scheme for a grid row, starting from the south. Only the first 33 rows are shown.

```
LAKE MICHIGAN 2KM GRID 7 ZONES                                    0000
   4  250  160    7   2.                                          0000
  3 160                                                           00001
  3 160                                                           00002
  3 160                                                           00003
  3 160                                                           00004
  3 160                                                           00005
  3 160                                                           00006
  3 160                                                           00007
  3 160                                                           00008
  3  30   1  44   3 160                                           00009
  3  30   1  45   3 160                                           00010
  3  30   1  46   3 160                                           00011
  3  29   1  46   3 160                                           00012
  3  28   1  47   3 160                                           00013
  3  27   1  47   3 160                                           00014
  3  26   1  48   3 160                                           00015
  3  26   1  49   3 160                                           00016
  3  25   1  49   3 160                                           00017
  3  24   1  49   3 160                                           00018
  3  24   1  50   3 160                                           00019
  3  23   1  50   3 160                                           00020
  3  22   1  50   3 160                                           00021
  3  22   1  50   3 160                                           00022
  3  22   1  50   3 160                                           00023
  3  21   1  51   3 160                                           00024
  3  20   1  52   3 160                                           00025
  3  20   1  53   3 160                                           00026
  3  19   1  53   3 160                                           00027
  3  18   1  54   3 160                                           00028
  3  17   1  54   3 160                                           00029
  3  16   1  54   3 160                                           00030
  3  15   1  55   3 160                                           00031
  3  14   1  55   3 160                                           00032
  3  13   1  55   3 160                                           00033
```

Example Input Data File

The following file is an example of an ALDAR input data file. The data shown here come from 25 stations in Green Bay, Lake Michigan, that were sampled between 5 October and 8 October 1977. Only one variable (STORET code 665, Total Phosphorus) is included in this example. Data from five stations are shown. Sample depths are in feet, and concentrations are in mg/L.

```
 25  771005  771008
 01 4554000  8657000
NULL
  665          6 0.200E-01
  665         22 0.230E-01
    0
 02 4549000  8703000
NULL
  665          6 0.120E-01
  665         22 0.180E-01
  665         32 0.170E-01
    0
 03 4547000  8704000
NULL
  665          6 0.120E-01
  665         22 0.140E-01
  665         32 0.150E-01
    0
 04 4543000  8704000
NULL
  665          6 0.110E-01
  665         29 0.800E-02
  665         55 0.700E-02
    0
 05 4543000  8702000
NULL
  665          6 0.110E-01
  665         19 0.100E-01
  665         32 0.100E-01
    0
```

Listing of Code STORET2

The code listed below was written to convert a STORET "Further Computation File" (FCF) into the form required by the LLRS modification of ALDAR. This version was written to extract data taken in Green Bay, Lake Michigan, from the Lake Michigan Intensive Study 1976-1977 database.

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                              C
C   STORET2:  MODIFICATION OF LLRS CODE STORET2.PGM            C
C             FOR USE WITH GREEN BAY DATA IN 1976-77 DATABASE  C
C                                                              C
C   PURPOSE:  CREATE ALDAR DATA FILE FROM STORET FCF FILE      C
C                                                              C
C   INPUT:    CONTROL INFORMATION ON UNIT 5                    C
C             STORET FCF FILE ON UNIT 8                        C
C                                                              C
C   OUTPUT:   PRINTER OUTPUT ON UNIT 6                         C
C             SCRATCH FILE ON UNIT 9                           C
C             DATA FILE ON UNIT 10                             C
C                                                              C
C   WRITTEN:  BARRY LESHT                                      C
C             BEM/CER                                          C
C             ARGONNE NATIONAL LAB                             C
C             AUGUST 20, 1987                                  C
C                                                              C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                              C
C   VAL IS AN ARRAY OF PARAMETER VALUES
C   PCODE IS AN ARRAY OF PARAMETER NAMES
C
      REAL*4 VAL(50)
      INTEGER*4 PCODE(50),BDATE,EDATE,SDATE
C
C   FORMAT STATEMENTS TO READ FROM STORET FCF
C
    1 FORMAT(I2,2I7)
    2 FORMAT(25X,I6,4X,50A4,64X,I5)
    3 FORMAT(I5,I10,E10.3)
    4 FORMAT(I3,2I8)
    5 FORMAT(A1)
C
      IZ=0
      NST=0
C
C   READ IB AND BEGINNING AND ENDING DATE FROM UNIT 5
C   WRITE FIRST RECORD TO SCRATCH OUTPUT FILE ON UNIT 9
C
```

```
      READ(5,1) IB, BDATE, EDATE
      WRITE(9,4) NST, BDATE, EDATE
      WRITE(6,4) NST, BDATE, EDATE
C
C   IE AND IB REFER TO POSITIONS WITHIN THE STATION NAME STRING
C   IN THIS CASE THE NUMBER OF THE STATION
C
      IE=IB+2
C
C   CODES IS A SUBROUTINE THAT READS THE PARAMETER HEADER RECORD
C   FROM THE STORET FCF AND RETURNS THE NUMBER OF PARAMETERS
C   AND THEIR ID CODES
C
      CALL CODES(PCODE,NCODE)
      WRITE(6,420) NCODE
  420 FORMAT(' NOCODE = ',I3)
C
C   UNIT 8 IS THE STORET FCF - FIRST READ THE DELIMITER RECORD
C   BETWEEN THE PARAMETER HEADER CARDS AND THE STATION HEADER
C   CARDS
C
      READ(8,5) DUMMY
C
C   SUBROUTINE STNIFN RETURNS THE STATION NUMBER (NST) AND A
C   FLAG ON ENCOUNTERING THE END OF FILE
C
 1000 CALL STNINF(NST,IB,IE,IRC,ISFLG)
      WRITE(6,521) NST,ISFLG
  521 FORMAT(' NST,ISFLG = ',2I4)
C
C   FINISH UP IF IRC IS SET
C
      IF (IRC.EQ.1) GOTO 300
C
C   CHECK TO SEE IF THIS IS A GREEN BAY RECORD
C   IF NOT SKIP TO DELIMETER AND TRY AGAIN
C
      IF (ISFLG.EQ.0) THEN
       CALL FNDDEL
       GOTO 1000
      END IF
C
C   START READING DATA RECORDS FROM THE FCF
C
      DO 200 INS=1,10000
       READ(8,2,END=300) SDATE,VAL,IDEP
C
C   CHECK FOR END OF DATA RECORDS
C
       IF(SDATE.LT.9999 .OR. SDATE.GT.990000) THEN
```

```
C
C   WRITE ZERO AND READ NEXT STATION
C
       WRITE(9,3)IZ
       CALL STNIFN(NST,IB,IE,IRC,ISFLG)
C
C   IF WE'VE HIT THE EOF THEN FINISH UP
C   IF WE'RE NO LONGER IN GREEN BAY QUIT
C
       IF (IRC.EQ.1 .OR. ISFLG.EQ.0) GOTO 300
C
      ELSE
C
C   SAMPLE IS WITHIN DATE LIMITS - CHECK FOR MISSING DATA
C   CHECK FOR PROPER CRUISE DATES
C
       IF (SDATE.LT.BDATE. OR. SDATE.GT.EDATE) GOTO 200
C
       DO 100 I=1, NCODE
        IF (VAL(I).NE.0.1E-20) THEN
         WRITE(9,3) PCODE(I),IDEP,VAL(I)
        ELSE
C
C   DON'T WRITE ANYTHING IF DATA ARE MISSING
C
       ENDIF
  100  CONTINUE
      ENDIF
  200 CONTINUE
C
C   RESET WRITE DATA FROM SCRATCH FILE TO OUTPUT FILE
C
  300 CALL RESET (NST)
      STOP
      END
C
      SUBROUTINE RESET (NST)
      CHARACTER*80 LINE
C
C  REWIND SCRATCH FILE
C
      REWIND 9
C
      READ(9,1) I1,I2,I3
    1 FORMAT(I3,2I8)
      WRITE(10,1)N,I2,I3
C
```

```
      DO 100 I=1,320000
       READ(9,2,END=200)LINE
    2  FORMAT(A80)
       WRITE(10,2) LINE
  100 CONTINUE
  200 RETURN
      END
C
      SUBROUTINE CODES(PCODE,NCODE)
      INTEGER*4 PCODE (50)
      CHARACTER*1 DUMMY
    1 FORMAT(42X,10(5X,I5))
    2 FORMAT(A1)
    3 FORMAT(' NO PARAMETERS RETRIEVED')
C
      DO 200 I=1,5
       JE=10*I
       JB=JE-9
       READ(8,1)  (PCODE(J),J=JB,JE)
       DO 100 J=1,3
        READ(I,2) DUMMY
  100  CONTINUE
  200 CONTINUE
      DO 300 I=50,I,-1
       IF(PCODE(I).GT.0) THEN
        NCODE=I
        RETURN
       ELSE
       ENDIF
  300 CONTINUE
      WRITE(6,3)
      STOP
      END
C
      SUBROUTINE STNINF(N,IB,IE,IRC,ISFLG)
      CHARACTER*15 STN
      CHARACTER*1 DUMMY
      CHARACTER*4 GBAY
      DATA GBAY/'GBAY'/
C
    1 FORMAT(A1)
    2 FORMAT(8X,A15,67X,3(I2,1X),I1,1X,I3,2(IX,I2),1X,I1)
    3 FORMAT(A3,I8,I9/'NULL')
      IRC=0
C
      READ(8,1,END=900)DUMMY
      READ(8,2,END=900) STN,LT1,LT2,LT3,LT4,LG1,LG2,LG3,LG4
C
      DO 100 I=1,7
       READ(I,1,END=900)DUMMY
  100 CONTINUE
```

```
C
      ISFLG=0
      IF (STN(1:4).EQ.GBAY)ISFLG=1
      IF (ISFLG.EQ.0) RETURN
C
      N=N+1
      LAT=((LT1*100+LT2)*100+LT3)*10+LT4
      LON=((LG1*100+LG2)*100+LG3)*10+LG4
      WRITE(9,3) STN(IB:IE),LAT,LON
      RETURN
  900 IRC=1
      RETURN
      END
C
      SUBROUTINE FNDDEL
      CHARACTER*8 DELIM
      CHARACTER*305 RECORD
      DATA DELIM/'99999999'/
    1 READ(8,10,END=99) RECORD
   10 FORMAT(A305)
      IF(RECORD(24:31).EQ.DELIM) RETURN
      GOTO 1
   99 WRITE(6,100)
  100 FORMAT(' NO DELIMITER FOUND')
      STOP
      END
```

APPENDIX B

INPUT FILES USED WITH VWA

Example of Output of Code CHARLAY

The file listed below shows a simple segmentation scheme for Green Bay, Lake Michigan, based on a 2-km grid. The first row of the file defines the layer number (1) and the number of segments in the layer (1). The succeeding rows identify, for each grid row, the number of transitions and the grid columns at which a transition from land to water (-1) or from water to land (1) occurs. The Green Bay grid has 77 rows. Those shown here range from the most northern (76) to row 46.

```
1 1
76  2  -1  56  1  58
75  2  -1  55  1  59
74  4  -1  50  1  52  -1  55  1  59
73  4  -1  49  1  53  -1  54  1  59
72  4  -1  38  1  41  -1  49  1  59
71  4  -1  38  1  42  -1  49  1  58
70  4  -1  38  1  42  -1  48  1  57
69  4  -1  38  1  42  -1  47  1  56
68  4  -1  38  1  42  -1  46  1  55
67  4  -1  38  1  42  -1  46  1  55
66  4  -1  37  1  42  -1  44  1  55
65  4  -1  37  1  42  -1  43  1  54
64  2  -1  35  1  53
63  2  -1  33  1  52
62  2  -1  33  1  52
61  2  -1  32  1  52
60  2  -1  32  1  52
59  2  -1  30  1  54
58  2  -1  30  1  54
57  2  -1  30  1  54
56  2  -1  30  1  53
55  2  -1  29  1  52
54  2  -1  29  1  51
53  2  -1  28  1  50
52  2  -1  28  1  49
51  2  -1  28  1  48
50  2  -1  27  1  47
49  2  -1  26  1  46
48  2  -1  25  1  43
47  2  -1  25  1  43
46  2  -1  24  1  43
```

Example of VWA Input Data File

The file listed below is an example of a VWA input file. This example is for a one-layer analysis of Green Bay, Lake Michigan.

```
CRUISE=0001
BD=805015
ED=800517
ENDCRUISE=YES
PARMCODE=00076
PARMNAME=TURBIDITY (FTU)
POWER=02.000
LAYER=1
CONTOUR=000.200
MATRIX=NO
PLOTMATRIX=YES
      GREEN BAY WHOLE BAY MODEL
1     1
    2          7.2   E+00         ANLTEST  CONL  2
    3          1.9   E+00         ANLTEST  CONL  3
    4          6.5   E+00         ANLTEST  CONL  4
    5          1.2   E+00         ANLTEST  CONL  5
    6          1.6   E+00         ANLTEST  CONL  6
    7          3.3   E+00         ANLTEST  CONL  7
    8          1.95  E+00         ANLTEST  CONL  8
    9          1.2   E+00         ANLTEST  CONL  9
   10          1.2   E+00         ANLTEST  CONL 10
   11          0.6   E+00         ANLTEST  CONL 11
   12          1.4   E+00         ANLTEST  CONL 12
   13          1.3   E+00         ANLTEST  CONL 13
   14          0.9   E+00         ANLTEST  CONL 14
   15          0.93  E+00         ANLTEST  CONL 15
   16          0.92  E+00         ANLTEST  CONL 16
   17          0.75  E+00         ANLTEST  CONL 17
   18          0.95  E+00         ANLTEST  CONL 18
   19          0.88  E+00         ANLTEST  CONL 19
   20          0.78  E+00         ANLTEST  CONL 20
   21          0.79  E+00         ANLTEST  CONL 21
   22          0.76  E+00         ANLTEST  CONL 22
   23          0.68  E+00         ANLTEST  CONL 23
   24          0.88  E+00         ANLTEST  CONL 24
   25          0.81  E+00         ANLTEST  CONL 25
   26          0.67  E+00         ANLTEST  CONL 26
   27          0.84  E+00         ANLTEST  CONL 27
   28          0.93  E+00         ANLTEST  CONL 28
   29          1.2   E+00         ANLTEST  CONL 29
   30          1.2   E+00         ANLTEST  CONL 30
   31          0.78  E+00         ANLTEST  CONL 31
   32          0.82  E+00         ANLTEST  CONL 32
   33          1.2   E+00         ANLTEST  CONL 33
```

Listing of Code STNSC2

The code listed below was written to convert station identification data into the form required by VWA. This version was written for data collected in Lake Michigan applied to a 2-km grid.

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                     C
C   STNSC2:  PRODUCE STATION LISTING COMPATIBLE WITH INPUT FILE       C
C            REQUIRED BY VWA                                          C
C                                                                     C
C   INPUT:   STATION DATA ON UNIT 10                                  C
C                                                                     C
C   OUTPUT:  OUTPUT FILE ON UNIT 8                                    C
C                                                                     C
C   WRITTEN: BARRY LESHT                                              C
C            BEM/CER                                                  C
C            ARGONNE NATIONAL LAB                                     C
C            JULY 14, 1987                                            C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                     C
      CHARACTER*8 AGENCY
      CHARACTER*12 NAME
      CHARACTER*2 NUM
      REAL A(5), B(5)
C
C   PARAMETERS FOR THE LAKE MICHIGAN GRID
C
      PHIM=41.60766
      GM=87.94260
      A(1)=83.1831
      A(2)=1.90171
      A(3)=-1.31825
      B(1)=-2.07627
      B(2)=111.
      B(4)=0.958685
      DLAT=2.0
C
C   DATA COME FROM JOHN CONLEY'S THESIS
C
      DATA AGENCY/' ANLTEST'/
      NAME(1:5)='CONL '
      KNT=0
      NAME(8:12)='     '
C
```

```
  100 READ(10,1000,END=200)NUM,LATD,ALAMIN,LOND,ALOMIN
 1000 FORMAT(A2,2(I3,F6.2))
      NAME(6:7)=NUM
C
      LAMIN=INT(ALAMIN)
      LOMIN=INT(ALOMIN)
C
      ALAS=(ALAMIN-LAMIN)*60.0
      ALOS=(ALOMIN-LOMIN)*60.0
C
C   CONVERT TO GRID COORDINATES
C
      XLAT=FLOAT(LATD)+FLOAT(LAMIN)/60.+ALAS/3600.
      XLONG=FLOAT(LOND)+FLOAT(LOMIN)/60.+ALOS/3600.
      G = GM-XLONG
      P = XLAT-PHIM
      XSTIN = G*A(1)+P*A(2)+P*G*A(3)
      YSTIN = G*B(1)+P*B(2)+(G**2)*B(4)
      YSTIN = YSTIN-324.
C
      BLONG=(XSTIN+DLAT/2.)/DLAT
      BLAT =(YSTIN+DLAT/2.)/DLAT
      IS=IFIX(BLONG+0.5)
      JS=IFIX(BLAT+0.5)
      KNT=KNT+1
C
      IF(FLOAT(IS).EQ.BLONG.AND.FLOAT(JS).EQ.BLAT) THEN
       BLONG=BLONG+0.0001
       BLAT =BLAT+0.0001
      END IF
C
C  USE FORMAT REQUIRED BY VWA
C
      WRITE(8,9100)AGENCY,NAME,LATD,LAMIN,ALAS,LOND,LOMIN,ALOS,
     +              BLAT,BLONG,JS,IS,KNT
      GOTO 100
  200 STOP
 9100 FORMAT(A8,1X,A12,1X,2(I4,I3,F5.1),2(1X,F10.4),3(1X,I3))
      END
```

APPENDIX C

EXAMPLE OF ALDAR OUTPUT

The following example output is from an ALDAR analysis of total phosphorus (variable code 665) and turbidity (variable code 76) in Green Bay, Lake Michigan. The analysis was done by using the 2-km Lake Michigan grid and a two-layer model of Green Bay, with standard depths at 0 m, 20 m, and 41 m. Green Bay is identified in the Lake Michigan grid as zone 6. Zone 4 is also included in the analysis to ensure that stations located outside of, but close to, zone 6 are included in the calculation. The output in this appendix is representative of that produced by ALDAR as supplied. Some additional output has been added in the Argonne version of the code.

Page	Description
C-2	First page of ALDAR output showing job parameters. The station location listing was added to the Argonne version.
C-3	Vertical interpolation of input data at the standard depths. Shown are station identifiers and values that are used in the horizontal interpolation.
C-4	Grid map of Green Bay showing cells and stations that influence those cells. The grid is 60 columns wide and 77 rows high. Cells with zero values are land. This map was added to the Argonne version of ALDAR.
C-5	Southern portion of Green Bay grid map.
C-6	ALDAR calculations for the two-layer model in Green Bay (zone 6).

ALDAR

```
NUMBER OF PARAMETER CODES =  2
ACTUAL OBSERVATIONS IN EACH ZONE WILL BE PRINTED
THE FOLLOWING  5 ZONES ARE EXCLUDED:   1  2  3  5  7
 3 STANDARD DEPTHS:
                                  Ø.ØØ     2Ø.ØØ     41.ØØ
CRUISE       1
PARAMETER CODES:
   665    76
DEPTH NUMBERS FOR ZONE  6 IN SUMMARY REPORT ARE    1  2
DEPTH NUMBERS FOR ZONE 25 IN SUMMARY REPORT ARE    1  2
```

LAKE MICHIGAN(2KM.) IS BEING STUDIED

GEOGRAPHIC AND GRID LOCATIONS

STATION	Ø1	POSITIONS	45.9ØØ	86.95Ø	85.114	475.334	43.Ø57	238.167	43	238
STATION	Ø2	POSITIONS	45.817	87.Ø5Ø	77.3ØØ	466.11Ø	39.15Ø	233.555	39	234
STATION	Ø3	POSITIONS	45.783	87.Ø67	75.982	462.417	38.491	231.7Ø8	38	232
STATION	Ø4	POSITIONS	45.717	87.Ø67	75.932	455.Ø17	38.466	228.ØØ8	38	228
STATION	Ø5	POSITIONS	45.717	87.Ø33	78.524	455.ØØ5	39.762	228.ØØ2	4Ø	228
STATION	Ø6	POSITIONS	45.55Ø	87.117	71.9Ø8	436.539	36.454	218.769	36	219
STATION	Ø7	POSITIONS	45.45Ø	87.133	7Ø.525	425.448	35.763	213.224	36	213
STATION	Ø8	POSITIONS	45.5ØØ	87.283	58.859	431.Ø98	29.929	216.Ø49	3Ø	216
STATION	Ø9	POSITIONS	45.333	87.25Ø	61.296	412.572	31.148	2Ø6.786	31	207
STATION	1Ø	POSITIONS	45.2ØØ	87.467	44.167	397.979	22.584	199.49Ø	23	199
STATION	11	POSITIONS	45.133	87.55Ø	37.537	39Ø.683	19.269	195.841	19	196
STATION	12	POSITIONS	45.Ø83	87.55Ø	37.468	385.132	19.234	193.Ø66	19	193
STATION	13	POSITIONS	45.Ø67	87.517	4Ø.Ø66	383.239	2Ø.533	192.12Ø	21	192
STATION	14	POSITIONS	45.Ø33	87.55Ø	37.399	379.583	19.199	19Ø.291	19	19Ø
STATION	15	POSITIONS	44.95Ø	87.55Ø	37.284	37Ø.333	19.142	185.666	19	186
STATION	16	POSITIONS	44.85Ø	87.683	26.624	359.426	13.812	18Ø.213	14	18Ø
STATION	17	POSITIONS	44.883	87.417	47.7Ø7	362.773	24.354	181.887	24	182
STATION	18	POSITIONS	45.133	87.35Ø	53.245	39Ø.456	27.122	195.728	27	196
STATION	19	POSITIONS	45.3ØØ	86.967	83.452	4Ø8.737	42.226	2Ø4.868	42	2Ø5
STATION	2Ø	POSITIONS	45.45Ø	86.8ØØ	96.564	425.379	48.782	213.19Ø	49	213
STATION	21	POSITIONS	45.483	86.733	1Ø1.783	429.Ø91	51.391	215.Ø46	51	215
STATION	22	POSITIONS	45.517	86.7ØØ	1Ø4.394	432.8ØØ	52.697	216.9ØØ	53	217
STATION	23	POSITIONS	45.533	86.883	9Ø.Ø97	434.626	45.548	217.813	46	218
STATION	24	POSITIONS	45.717	86.767	99.262	454.984	5Ø.131	227.992	5Ø	228
STATION	25	POSITIONS	45.783	86.65Ø	1Ø8.348	462.418	54.674	231.7Ø9	55	232

PARAMETER (665)
STANDARD DEPTHS:

PSN	0.	20.	41.
02	.12E-01		
04	.11E-01		
05	.11E-01		
06	.10E-01		
07	.12E-01	.94E-02	
08	.10E-01		
09	.80E-02	.83E-02	
10	.90E-02	.94E-02	
11	.10E-01		
12	.90E-02		
13	.10E-01		
14	.15E-01		
15	.16E-01		
16	.27E-01		
17	.21E-01		
18	.15E-01		
19	.90E-02	.83E-02	
20	.70E-02	.53E-02	.40E-02
21	.50E-02	.50E-02	
22	.50E-02	.49E-02	
23	.70E-02	.60E-02	
24	.90E-02		
25	.80E-02		

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CRUISE 1 ZONE NUMBER 6
PARAMETER (665)

DEPTH	AREA WEIGHTED MEAN VALUE	AREA	LAYER QUANTITY	INTEGRATED QUANTITY	LAYER VOLUME	INTEGRATED VOLUME	VOLUME WEIGHTED VALUES LAYER	COLUMN
0.00	0.0135	1128		0.000E+00		0.000E+00		
			0.672E+03		0.604E+05		0.0111	
20.00	0.0077	383		0.6716E+03		0.6044E+05		0.0111
			0.105E+03		0.161E+05		0.0065	
41.00	0.0040	1		0.7764E+03		0.7657E+05		0.0101

APPENDIX D

EXAMPLE OF VWA OUTPUT

The following example output is from a VWA analysis of turbidity (parameter code 76) in Green Bay, Lake Michigan. Output from three of the codes (CHARLAY, STARSEG, and PRNTPNCH) are shown.

Pages	Description
D-2/D-4	Output from CHARLAY for a five-layer model of Green Bay. CHARLAY produces a printer map of the grid showing the areal extent of the layers and a table of layer volumes and areas.
D-5/D-13	Output from STARSEG for a two-layer model of Green Bay. STARSEG produces a table of station positions, a listing of the segmentation scheme for each layer, and printer maps of each layer showing the areal extent of the segments and the location of the stations.
D-14/D-21	Output from PRNTPNCH for a two-layer model of Green Bay (with only one layer printed). PRNTPNCH lists the control information for the job and prints a table of the stations that are to be used in the anlaysis (a subset of those stations listed by STARSEG). The sample statistics of the data are printed as well as the volume-weighted statistics. PRNTPNCH produces histograms of the interploted values and a printer map showing the areal distribution of the interpolated values.

MAXIMUM DEPTH FOUND FROM BATHYMETRIC DATA IS: 41.00

```
*********************************************
*     GREEN BAY VOLUME-WEIGHTED STATISTICS *
*********************************************
```

BATHYMETRIC MAP OF GREEN BAY

GREEN BAY STRATIFIED AT METER-DEPTHS   0.0   5.0   10.0   20.0   30.0   41.0

```
    0         1         2         3         4         5         6
77 0----*----0----*----0----*----0----*----0----*----0----*----0
76 0----*----0----*----0----*----0----*----0----*----0----* AA 0
75 0----*----0----*----0----*----0----*----0----*----0---- AAAA
74 0----*----0----*----0----*----0----*----0----*---- AA - AAAA
73 0----*----0----*----0----*----0----*----0----*--- AAAA AAAAA
72 0----*----0----*----0----*----0----*-- AAA --*--- AAAAAABAAA
71 0----*----0----*----0----*----0----*-- ABAA -*--- AAAAABBAA 0
70 0----*----0----*----0----*----0----*-- ABAA -*-- AABBABBAA -0
69 0----*----0----*----0----*----0----*-- ABBA -*- AABBBBBAA --0
68 0----*----0----*----0----*----0----*-- ABBA -* AABBBCBBA ---0
67 0----*----0----*----0----*----0----*-- ABBA -* ABCCCCCBA ---0
66 0----*----0----*----0----*----0----*- ABCBA  AAABCCCCBBA ---0
65 0----*----0----*----0----*----0----*- ABCCA AAABBCCCCBA ----0
64 0----*----0----*----0----*----0---- AABCCCAAAABBCCCCCA *----0
63 0----*----0----*----0----*----0-- AAAABCDCBABBBBCCCCB -*----0
62 0----*----0----*----0----*----0-- AABBBCDCBBBBBBCCCCC -*----0
61 0----*----0----*----0----*----0- AABBBCCDCCCCCCCCCCDC -*----0
60 0----*----0----*----0----*----0- ABBBBCDDCCCCCCCCCDDC -*----0
59 0----*----0----*----0----*---- AABCCCCCDDCCCCCCCCCDDCBA ----0
58 0----*----0----*----0----*---- ABCCCCCDEDCCCCDDDDDDDDCA ----0
57 0----*----0----*----0----*---- ACCCCCCDEDCCCCDDDDDDDCCB ----0
56 0----*----0----*----0----*---- ACCCDCCDEDCCCCDDDDDDDCC *----0
55 0----*----0----*----0----*--- ABCDDDDDDEDCCCDDDDDDDDC -*----0
54 0----*----0----*----0----*--- BCDDDDDDDEDCCCDDDDEEDD --*----0
53 0----*----0----*----0----*-- ACCDDDDDDEEEDDDDDDDEDC ---*----0
52 0----*----0----*----0----*-- ACDDDDDDDEEEDDDDDDDED ----*----0
51 0----*----0----*----0----*-- BCDDDDDDDEEEEEEEEEEE 0----*----0
50 0----*----0----*----0----*- ACCDDEEEEDEEEEEEEDDDE -0----*----0
49 0----*----0----*----0----* ABCDDDEEEEDEEEEEEDBBB --0----*----0
48 0----*----0----*----0---- ABCDDDEDDDEEEEEEEEC *----0----*----0
47 0----*----0----*----0---- ABCDDEDDCDDEEEEEEDC *----0----*----0
46 0----*----0----*----0--- ABCDDDEDCCDDEEEEEEDC *----0----*----0
45 0----*----0----*----0--- ACDDEEEDCCDDDEEEEEDC *----0----*----0
44 0----*----0----*----0--- BCDDEEDDDDDDDDDDDDD -*----0----*----0
43 0----*----0----*----0-- ACDDEEEDDDDDEDCCCB --*----0----*----0
42 0----*----0----*----0- ABCDEEEDDDDDEEDBBBA --*----0----*----0
41 0----*----0----*----0 AACDEEEDDDDDDDDDB 0----*----0----*----0
40 0----*----0----*----0 ACDDEDCDDDDCDDCBA 0----*----0----*----0
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39 0----*----0----*---- ABCDDDCCCDDDCCCCA -0----*----0----*----0
38 0----*----0----*---- BCDDDCBACCCCCCCBA -0----*----0----*----0
37 0----*----0----*- AAACCDDDB ACCCBCBBAA -0----*----0----*----0
36 0----*----0----*- AABCDDDCB ACCBAAAAA --0----*----0----*----0
35 0----*----0----* AABCCDDDCCBBCCB --*----0----*----0----*----0
34 0----*----0----* ABCCDDDDDDDCCCB --*----0----*----0----*----0
33 0----*----0----* ABCCDDDDDDDCCCB --*----0----*----0----*----0
32 0----*----0----*- ACCDDDEDDDCCCB --*----0----*----0----*----0
31 0----*----0----*- ABCCDEEEDDCCBA --*----0----*----0----*----0
30 0----*----0----* AABCCDEEEDDCCB ---*----0----*----0----*----0
29 0----*----0----* ABCCCDEEEDCCBA ---*----0----*----0----*----0
28 0----*----0----* ABCDDDEEEDCBA ----*----0----*----0----*----0
27 0----*----0----* ABCDDDEEDCBA 0----*----0----*----0----*----0
26 0----*----0- AAAAABCDDDEEDCA -0----*----0----*----0----*----0
25 0----*----0- AAAAABCDDDDDDBA -0----*----0----*----0----*----0
24 0----*-- AAAAABBBBCCDDDDDCB --0----*----0----*----0----*----0
23 0----*-- AAABBCCCCCDDDDDDCA --0----*----0----*----0----*----0
22 0----*-- ABBBBCCCCDDDDCCCBA --0----*----0----*----0----*----0
21 0----*- AABBCCCCDDDDDCCCCA ---0----*----0----*----0----*----0
20 0----*- AABBCCCCDDCCCBBBBA ---0----*----0----*----0----*----0
19 0----* AAABCCCCCCCCCCA --*----0----*----0----*----0----*----0
18 0----* AABBCCCCCCBBBAA --*----0----*----0----*----0----*----0
17 0---- AAABBCCCCCBA -0----*----0----*----0----*----0----*----0
16 0--- AAABBCCCCCBA --0----*----0----*----0----*----0----*----0
15 0--- AABBCCCCCBA ---0----*----0----*----0----*----0----*----0
14 0--- ABBBCCCCBAA ---0----*----0----*----0----*----0----*----0
13 0-- AABBCCCCBBA ----0----*----0----*----0----*----0----*----0
12 0- AABBBCCCBBA *----0----*----0----*----0----*----0----*----0
11 0 AAABBBBBBBAA *----0----*----0----*----0----*----0----*----0
10 0 AABBBBBBBBA -*----0----*----0----*----0----*----0----*----0
 9 0 AABBBBBBBAA -*----0----*----0----*----0----*----0----*----0
 8 0 AABBBBBBBA --*----0----*----0----*----0----*----0----*----0
 7 0 ABBBBBBAAA --*----0----*----0----*----0----*----0----*----0
 6 0 ABBBBAA 0----*----0----*----0----*----0----*----0----*----0
 5 0 AABAAAA 0----*----0----*----0----*----0----*----0----*----0
 4 0 AAAAA --0----*----0----*----0----*----0----*----0----*----0
 3 0 AAAA ---0----*----0----*----0----*----0----*----0----*----0
 2 0 AAA ----0----*----0----*----0----*----0----*----0----*----0
 1 0----*----0----*----0----*----0----*----0----*----0----*----0
```

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*************************************************
*     GREEN BAY VOLUME-WEIGHTED STATISTICS *
*************************************************

                    *********************************************
                    * GEOMETRICAL CHARACTERISTICS OF LAYERS *
                    *********************************************
```

LAYER NUMBER	MAP CODE	DEPTH IN METER TOP	DEPTH IN METER BOTTOM	TOP AREA (KM)**2	LAYER VOLUME (KM)**3
1	A	0.0	5.0	0.4512E+04	0.1990E+02
2	B	5.0	10.0	0.3520E+04	0.1511E+02
3	C	10.0	20.0	0.2700E+04	0.2032E+02
4	D	20.0	30.0	0.1532E+04	0.9432E+01
5	E	30.0	41.0	0.4200E+03	0.7520E+00

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*********************************************
* GREEN BAY VOLUME-WEIGHTED STATISTICS      *
*********************************************
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CROSS REFERENCE LISTING OF ALL STATIONS OF INTEREST

STATION REFERENCE NUMBER	STATION DESIGNATION	COORDINATES (X)	(Y)	LATITUDE			LONGITUDE			AGENCY
1	CONL 1	0.87	1.27	44	32	21.6	88	0	12.6	ANLTEST
2	CONL 2	1.88	3.28	44	34	33.6	87	58	44.4	ANLTEST
3	CONL 3	2.17	5.60	44	37	4.2	87	58	21.6	ANLTEST
4	CONL 4	3.56	3.46	44	34	48.0	87	56	12.0	ANLTEST
5	CONL 5	2.94	8.82	44	40	34.8	87	57	16.8	ANLTEST
6	CONL 6	4.72	7.18	44	38	51.0	87	54	32.4	ANLTEST
7	CONL 7	6.20	6.32	44	37	57.6	87	52	16.2	ANLTEST
8	CONL 8	7.46	11.55	44	43	39.0	87	50	30.0	ANLTEST
9	CONL 9	9.75	16.04	44	48	33.6	87	47	7.2	ANLTEST
10	CONL 10	10.13	21.10	44	54	2.4	87	46	39.6	ANLTEST
11	CONL 11	12.12	19.64	44	52	30.0	87	43	36.6	ANLTEST
12	CONL 12	13.73	18.17	44	50	57.0	87	41	7.8	ANLTEST
13	CONL 13	14.78	17.56	44	50	18.6	87	39	30.6	ANLTEST
14	CONL 14	17.63	21.10	44	54	12.0	87	35	15.0	ANLTEST
15	CONL 15	20.67	24.33	44	57	44.4	87	30	40.8	ANLTEST
16	CONL 16	18.87	29.58	45	3	23.4	87	33	31.2	ANLTEST
17	CONL 17	20.92	28.15	45	1	52.8	87	30	22.8	ANLTEST
18	CONL 18	22.93	26.88	45	0	32.4	87	27	17.4	ANLTEST
19	CONL 19	24.96	25.25	44	58	48.6	87	24	10.2	ANLTEST
20	CONL 20	23.76	31.94	45	6	1.2	87	26	6.6	ANLTEST
21	CONL 21	26.31	42.39	45	17	21.0	87	22	22.8	ANLTEST
22	CONL 22	28.35	41.66	45	16	35.4	87	19	15.0	ANLTEST
23	CONL 23	30.36	40.36	45	15	12.6	87	16	8.4	ANLTEST
24	CONL 24	32.06	40.17	45	15	1.2	87	13	32.4	ANLTEST
25	CONL 25	37.18	50.22	45	25	55.2	87	5	48.6	ANLTEST
26	CONL 26	38.46	57.74	45	34	3.6	87	3	55.2	ANLTEST
27	CONL 27	42.72	53.76	45	29	46.8	86	57	20.4	ANLTEST
28	CONL 28	48.17	50.63	45	26	17.4	86	48	56.4	ANLTEST
29	CONL 29	39.89	67.48	45	44	36.0	87	1	49.2	ANLTEST
30	CONL 30	40.67	72.25	45	49	45.6	87	0	39.6	ANLTEST
31	CONL 31	49.76	64.46	45	41	21.0	86	46	34.2	ANLTEST
32	CONL 32	51.31	68.16	45	45	20.4	86	44	11.4	ANLTEST
33	CONL 33	54.85	68.52	45	45	42.6	86	38	43.8	ANLTEST

TOTAL STATION-COUNT = 33

****

* GREEN BAY VOLUME-WEIGHTED STATISTICS *

****

SEGMENTATION SCHEME FOR LAYER NO. 1

BETWEEN METER-DEPTHS 0.00 AND 20.00

76	2	-1	56	1	58				
75	2	-1	55	1	59				
74	4	-1	50	1	52	-1	55	1	59
73	4	-1	49	1	53	-1	54	1	59
72	4	-1	38	1	41	-1	49	1	59
71	4	-1	38	1	42	-1	49	1	58
70	4	-1	38	1	42	-1	48	1	57
69	4	-1	38	1	42	-1	47	1	56
68	4	-1	38	1	42	-1	46	1	55
67	4	-1	38	1	42	-1	46	1	55
66	4	-1	37	1	42	-1	44	1	55
65	4	-1	37	1	42	-1	43	1	54
64	2	-1	35	1	53				
63	2	-1	33	1	52				
62	2	-1	33	1	52				
61	2	-1	32	1	52				
60	2	-1	32	1	52				
59	2	-1	30	1	54				
58	2	-1	30	1	54				
57	2	-1	30	1	54				
56	2	-1	30	1	53				
55	2	-1	29	1	52				
54	2	-1	29	1	51				
53	2	-1	28	1	50				
52	2	-1	28	1	49				
51	2	-1	28	1	48				
50	2	-1	27	1	47				
49	2	-1	26	1	46				
48	2	-1	25	1	43				
47	2	-1	25	1	43				
46	2	-1	24	1	43				
45	2	-1	24	1	43				
44	2	-1	24	1	42				
43	2	-1	23	1	41				
42	2	-1	22	1	41				
41	2	-1	21	1	38				
40	2	-1	21	1	38				
39	2	-1	20	1	37				
38	2	-1	20	1	37				
37	4	-1	17	1	26	-1	27	1	37
36	4	-1	17	1	26	-1	27	1	36
35	2	-1	16	1	31				
34	2	-1	16	1	31				

33	2	-1	16	1	31
32	2	-1	17	1	31
31	2	-1	17	1	31
30	2	-1	16	1	30
29	2	-1	16	1	30
28	2	-1	16	1	29
27	2	-1	16	1	28
26	2	-1	12	1	27
25	2	-1	12	1	27
24	2	-1	8	1	26
23	2	-1	8	1	26
22	2	-1	8	1	26
21	2	-1	7	1	25
20	2	-1	7	1	25
19	2	-1	6	1	21
18	2	-1	6	1	21
17	2	-1	5	1	17
16	2	-1	4	1	16
15	2	-1	4	1	15
14	2	-1	4	1	15
13	2	-1	3	1	14
12	2	-1	2	1	13
11	2	-1	1	1	13
10	2	-1	1	1	12
9	2	-1	1	1	12
8	2	-1	1	1	11
7	2	-1	1	1	11
6	2	-1	1	1	8
5	2	-1	1	1	8
4	2	-1	1	1	6
3	2	-1	1	1	5
2	2	-1	1	1	4

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* GREEN BAY VOLUME-WEIGHTED STATISTICS *
****

MAP CODE AND SEGMENT GRID-COUNTS FOR LAYER NO. 1

BETWEEN METER-DEPTHS 0.00 AND 20.00

SEGMENT NUMBER	MAP CODE	NUMBER OF GRIDS
1	A	1128

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**********************************************
* GREEN BAY VOLUME-WEIGHTED STATISTICS       *
**********************************************

                    STATION & SEGMENTATION MAP FOR LAYER NO.   1

                    BETWEEN METER-DEPTHS   0.00 AND  20.00


                    GREEN BAY MAP NO.  100

    0         1         2         3         4         5         6
77  0----*----0----*----0----*----0----*----0----*----0----*----0
76  0----*----0----*----0----*----0----*----0----*----0----* AA 0
75  0----*----0----*----0----*----0----*----0----*----0---- AAAA
74  0----*----0----*----0----*----0----*----0----*---- AA - AAAA
73  0----*----0----*----0----*----0----*----0----*--- AAAA AAAAA
72  0----*----0----*----0----*----0----*-- AA+ --*--- AAAAAAAAAA  ( 1)  30
71  0----*----0----*----0----*----0----*-- AAAA -*--- AAAAAAAAA 0
70  0----*----0----*----0----*----0----*-- AAAA -*-- AAAAAAAAA -0
69  0----*----0----*----0----*----0----*-- AAAA -*- AAAAAAA+A --0 ( 1)  33
68  0----*----0----*----0----*----0----*-- AAAA -* AAAA+AAAA ---0 ( 1)  32
67  0----*----0----*----0----*----0----*-- A+AA -* AAAAAAAAA ---0 ( 1)  29
66  0----*----0----*----0----*----0----*- AAAAA  AAAAAAAAAAA ---0
65  0----*----0----*----0----*----0----*- AAAAA AAAAAAAAAAA ----0
64  0----*----0----*----0----*----0---- AAAAAAAAAAAAAA+AAA *----0 ( 1)  31
63  0----*----0----*----0----*----0-- AAAAAAAAAAAAAAAAAAA -*----0
62  0----*----0----*----0----*----0-- AAAAAAAAAAAAAAAAAAA -*----0
61  0----*----0----*----0----*----0- AAAAAAAAAAAAAAAAAAAA -*----0
60  0----*----0----*----0----*----0- AAAAAAAAAAAAAAAAAAAA -*----0
59  0----*----0----*----0----*---- AAAAAAAAAAAAAAAAAAAAAAAA ----0
58  0----*----0----*----0----*---- AAAAAAA+AAAAAAAAAAAAAAAA ----0 ( 1)  26
57  0----*----0----*----0----*---- AAAAAAAAAAAAAAAAAAAAAAAA ----0
56  0----*----0----*----0----*---- AAAAAAAAAAAAAAAAAAAAAAA *----0
55  0----*----0----*----0----*--- AAAAAAAAAAAAAAAAAAAAAAA -*----0
54  0----*----0----*----0----*--- AAAAAAAAAAAAA+AAAAAAAA --*----0 ( 1)  27
53  0----*----0----*----0----*-- AAAAAAAAAAAAAAAAAAAAAA ---*----0
52  0----*----0----*----0----*-- AAAAAAAAAAAAAAAAAAAAA ----*----0
51  0----*----0----*----0----*-- AAAAAAAAAAAAAAAAAAA+ 0----*----0 ( 1)  28
50  0----*----0----*----0----*- AAAAAAAAA+AAAAAAAAAA -0----*----0 ( 1)  25
49  0----*----0----*----0----* AAAAAAAAAAAAAAAAAAAA --0----*----0
48  0----*----0----*----0---- AAAAAAAAAAAAAAAAAA *----0----*----0
47  0----*----0----*----0---- AAAAAAAAAAAAAAAAAA *----0----*----0
46  0----*----0----*----0--- AAAAAAAAAAAAAAAAAAA *----0----*----0
45  0----*----0----*----0--- AAAAAAAAAAAAAAAAAAA *----0----*----0
44  0----*----0----*----0--- AAAAAAAAAAAAAAAAAA -*----0----*----0
43  0----*----0----*----0-- AAAAAAAAAAAAAAAAAA --*----0----*----0
42  0----*----0----*----0- AAA+A+AAAAAAAAAAAAA --*----0----*----0 ( 2)  21  22
41  0----*----0----*----0 AAAAAAAAAAAAAAAAA 0----*----0----*----0
40  0----*----0----*----0 AAAAAAAA+A+AAAAAA 0----*----0----*----0 ( 2)  23  24
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39  0----*----0----*---- AAAAAAAAAAAAAAAAA -0----*----0----*----0
38  0----*----0----*---- AAAAAAAAAAAAAAAAA -0----*----0----*----0
37  0----*----0----*- AAAAAAAAA AAAAAAAAAA -0----*----0----*----0
36  0----*----0----*- AAAAAAAAA AAAAAAAAA --0----*----0----*----0
35  0----*----0----* AAAAAAAAAAAAAAA --*----0----*----0----*----0
34  0----*----0----* AAAAAAAAAAAAAAA --*----0----*----0----*----0
33  0----*----0----* AAAAAAAAAAAAAAA --*----0----*----0----*----0
32  0----*----0----*- AAAAAA+AAAAAAA --*----0----*----0----*----0 ( 1)  20
31  0----*----0----*- AAAAAAAAAAAAAA --*----0----*----0----*----0
30  0----*----0----* AA+AAAAAAAAAAA ---*----0----*----0----*----0 ( 1)  16
29  0----*----0----* AAAAAAAAAAAAAA ---*----0----*----0----*----0
28  0----*----0----* AAAA+AAAAAAAA ----*----0----*----0----*----0 ( 1)  17
27  0----*----0----* AAAAAA+AAAAA 0----*----0----*----0----*----0 ( 1)  18
26  0----*----0- AAAAAAAAAAAAAAA -0----*----0----*----0----*----0
25  0----*----0- AAAAAAAAAAAA+AA -0----*----0----*----0----*----0 ( 1)  19
24  0----*-- AAAAAAAAAAAA+AAAAA --0----*----0----*----0----*----0 ( 1)  15
23  0----*-- AAAAAAAAAAAAAAAAAA --0----*----0----*----0----*----0
22  0----*-- AAAAAAAAAAAAAAAAAA --0----*----0----*----0----*----0
21  0----*- AA+AAAAAAA+AAAAAAA ---0----*----0----*----0----*----0 ( 2)  10  14
20  0----*- AAAA+AAAAAAAAAAAAA ---0----*----0----*----0----*----0 ( 1)  11
19  0----* AAAAAAAAAAAAAAA --*----0----*----0----*----0----*----0
18  0----* AAAAAAA++AAAAAA --*----0----*----0----*----0----*----0 ( 2)  12  13
17  0---- AAAAAAAAAAAA -0----*----0----*----0----*----0----*----0
16  0--- AAAAA+AAAAAA --0----*----0----*----0----*----0----*----0 ( 1)   9
15  0--- AAAAAAAAAAA ---0----*----0----*----0----*----0----*----0
14  0--- AAAAAAAAAAA ---0----*----0----*----0----*----0----*----0
13  0-- AAAAAAAAAAA ----0----*----0----*----0----*----0----*----0
12  0- AAAA+AAAAAA *----0----*----0----*----0----*----0----*----0 ( 1)   8
11  0 AAAAAAAAAAAA *----0----*----0----*----0----*----0----*----0
10  0 AAAAAAAAAAA -*----0----*----0----*----0----*----0----*----0
 9  0 A+AAAAAAAAA -*----0----*----0----*----0----*----0----*----0 ( 1)   5
 8  0 AAAAAAAAAA --*----0----*----0----*----0----*----0----*----0
 7  0 AAA+AAAAAA --*----0----*----0----*----0----*----0----*----0 ( 1)   6
 6  0 +AAA+AA 0----*----0----*----0----*----0----*----0----*----0 ( 2)   3   7
 5  0 AAAAAAA 0----*----0----*----0----*----0----*----0----*----0
 4  0 AAAAA --0----*----0----*----0----*----0----*----0----*----0
 3  0 +A+A ---0----*----0----*----0----*----0----*----0----*----0 ( 2)   2   4
 2  0 AAA ----0----*----0----*----0----*----0----*----0----*----0
 1  0----*----0----*----0----*----0----*----0----*----0----*----0
    0         1         2         3         4         5         6
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GREEN BAY MAP NO. 100

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**********************************************
* GREEN BAY VOLUME-WEIGHTED STATISTICS       *
**********************************************
```

SEGMENTATION SCHEME FOR LAYER NO. 2

BETWEEN METER-DEPTHS 20.00 AND 41.00

62	2	-1	39	1	40								
61	2	-1	39	1	40								
60	2	-1	39	1	40								
59	4	-1	38	1	40	-1	49	1	51				
58	6	-1	37	1	40	-1	44	1	46	-1	48	1	51
57	4	-1	37	1	40	-1	44	1	51				
56	4	-1	37	1	40	-1	44	1	51				
55	4	-1	33	1	40	-1	44	1	51				
54	4	-1	32	1	40	-1	43	1	50				
53	2	-1	31	1	49								
52	2	-1	30	1	49								
51	2	-1	30	1	48								
50	2	-1	30	1	47								
49	2	-1	29	1	43								
48	2	-1	29	1	42								
47	4	-1	28	1	32	-1	34	1	42				
46	4	-1	27	1	32	-1	34	1	42				
45	4	-1	27	1	32	-1	34	1	42				
44	6	-1	26	1	32	-1	33	1	40	-1	41	1	42
43	2	-1	25	1	37								
42	2	-1	25	1	37								
41	2	-1	24	1	37								

40	6	-1	23	1	27	-1	29	1	32	-1	33	1	35
39	4	-1	23	1	26	-1	30	1	32				
38	2	-1	22	1	25								
37	2	-1	22	1	25								
36	2	-1	21	1	24								
35	2	-1	21	1	24								
34	2	-1	21	1	26								
33	2	-1	20	1	27								
32	2	-1	20	1	27								
31	2	-1	21	1	27								
30	2	-1	21	1	27								
29	2	-1	21	1	26								
28	2	-1	19	1	26								
27	2	-1	19	1	25								
26	2	-1	19	1	25								
25	2	-1	19	1	24								
24	2	-1	19	1	24								
23	2	-1	18	1	24								
22	2	-1	17	1	21								
21	2	-1	15	1	20								

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***********************************************
* GREEN BAY VOLUME-WEIGHTED STATISTICS        *
***********************************************
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MAP CODE AND SEGMENT GRID-COUNTS FOR LAYER NO. 2

BETWEEN METER-DEPTHS 20.00 AND 41.00

SEGMENT NUMBER	MAP CODE	NUMBER OF GRIDS
1	A	358

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*********************************************
* GREEN BAY VOLUME-WEIGHTED STATISTICS      *
*********************************************

                     STATION & SEGMENTATION MAP FOR LAYER NO.   2

                     BETWEEN METER-DEPTHS  20.00 AND  41.00


                     GREEN BAY MAP NO.  101

    0         1         2         3         4         5         6
77  0----*----0----*----0----*----0----*----0----*----0----*----0
76  0----*----0----*----0----*----0----*----0----*----0----*    0
75  0----*----0----*----0----*----0----*----0----*----0----
74  0----*----0----*----0----*----0----*----0----*----    -
73  0----*----0----*----0----*----0----*----0----*---
72  0----*----0----*----0----*----0----*--     --*---
71  0----*----0----*----0----*----0----*--      -*---           0
70  0----*----0----*----0----*----0----*--      -*--           -0
69  0----*----0----*----0----*----0----*--      -*-           --0
68  0----*----0----*----0----*----0----*--      -*           ---0
67  0----*----0----*----0----*----0----*--      -*           ---0
66  0----*----0----*----0----*----0----*-                    ---0
65  0----*----0----*----0----*----0----*-                   ----0
64  0----*----0----*----0----*----0----                    *----0
63  0----*----0----*----0----*----0--                     -*----0
62  0----*----0----*----0----*----0--       A             -*----0
61  0----*----0----*----0----*----0-        A             -*----0
60  0----*----0----*----0----*----0-        A             -*----0
59  0----*----0----*----0----*----         AA        AA    ----0
58  0----*----0----*----0----*----        +AA    AA  AAA   ----0 ( 1)   26
57  0----*----0----*----0----*----        AAA    AAAAAAA   ----0
56  0----*----0----*----0----*----        AAA    AAAAAAA  *----0
55  0----*----0----*----0----*---    AAAAAAA    AAAAAAA  -*----0
54  0----*----0----*----0----*---   AAAAAAAA   AAAAAAA  --*----0
53  0----*----0----*----0----*--   AAAAAAAAAAAAAAAAAA  ---*----0
52  0----*----0----*----0----*--  AAAAAAAAAAAAAAAAAAA ----*----0
51  0----*----0----*----0----*--  AAAAAAAAAAAAAAAAA+ 0----*----0 ( 1)   28
50  0----*----0----*----0----*-   AAAAAA+AAAAAAAAA -0----*----0 ( 1)   25
49  0----*----0----*----0----*   AAAAAAAAAAAAAA    --0----*----0
48  0----*----0----*----0----    AAAAAAAAAAAAA  *----0----*----0
47  0----*----0----*----0----   AAAA  AAAAAAAA  *----0----*----0
46  0----*----0----*----0---   AAAAA  AAAAAAAA  *----0----*----0
45  0----*----0----*----0---   AAAAA  AAAAAAAA  *----0----*----0
44  0----*----0----*----0---  AAAAAA AAAAAAA A -*----0----*----0
43  0----*----0----*----0--  AAAAAAAAAAAA     --*----0----*----0
42  0----*----0----*----0-   +A+AAAAAAAAA     --*----0----*----0 ( 2)   21   22
41  0----*----0----*----0   AAAAAAAAAAAAA  0----*----0----*----0
40  0----*----0----*----0  AAAA  +A+ AA    0----*----0----*----0 ( 2)   23   24
```

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39 0----*----0----*----    AAA    AA      -0----*----0----*----0
38 0----*----0----*----   AAA             -0----*----0----*----0
37 0----*----0----*-      AAA             -0----*----0----*----0
36 0----*----0----*-     AAA             --0----*----0----*----0
35 0----*----0----*      AAA        --*----0----*----0----*----0
34 0----*----0----*      AAAAA      --*----0----*----0----*----0
33 0----*----0----*     AAAAAAA     --*----0----*----0----*----0
32 0----*----0----*-    AAA+AAA     --*----0----*----0----*----0 ( 1)  20
31 0----*----0----*-     AAAAAA     --*----0----*----0----*----0
30 0----*----0----*      AAAAAA    ---*----0----*----0----*----0
29 0----*----0----*      AAAAA     ---*----0----*----0----*----0
28 0----*----0----*    A+AAAAA    ----*----0----*----0----*----0 ( 1)  17
27 0----*----0----*    AAA+AA    0----*----0----*----0----*----0 ( 1)  18
26 0----*----0-        AAAAAA   -0----*----0----*----0----*----0
25 0----*----0-        AAAAA    -0----*----0----*----0----*----0
24 0----*--            A+AAA   --0----*----0----*----0----*----0 ( 1)  15
23 0----*--           AAAAAA   --0----*----0----*----0----*----0
22 0----*--          AAAA      --0----*----0----*----0----*----0
21 0----*-         AA+AA      ---0----*----0----*----0----*----0 ( 1)  14
20 0----*-                    ---0----*----0----*----0----*----0
19 0----*                 --*----0----*----0----*----0----*----0
18 0----*                 --*----0----*----0----*----0----*----0
17 0----              -0----*----0----*----0----*----0----*----0
16 0---              --0----*----0----*----0----*----0----*----0
15 0---             ---0----*----0----*----0----*----0----*----0
14 0---             ---0----*----0----*----0----*----0----*----0
13 0--             ----0----*----0----*----0----*----0----*----0
12 0-             *----0----*----0----*----0----*----0----*----0
11 0              *----0----*----0----*----0----*----0----*----0
10 0             -*----0----*----0----*----0----*----0----*----0
 9 0             -*----0----*----0----*----0----*----0----*----0
 8 0            --*----0----*----0----*----0----*----0----*----0
 7 0            --*----0----*----0----*----0----*----0----*----0
 6 0         0----*----0----*----0----*----0----*----0----*----0
 5 0         0----*----0----*----0----*----0----*----0----*----0
 4 0       --0----*----0----*----0----*----0----*----0----*----0
 3 0      ---0----*----0----*----0----*----0----*----0----*----0
 2 0     ----0----*----0----*----0----*----0----*----0----*----0
 1 0----*----0----*----0----*----0----*----0----*----0----*----0
   0         1         2         3         4         5         6
```

GREEN BAY MAP NO. 101

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*********************************************
* GREEN BAY VOLUME-WEIGHTED STATISTICS      *
*********************************************

                                *********************************************
                                *  SUMMARY OF INPUT DATA FOR USER OPTIONS  *
                                *********************************************

 CRUISE NO.    1   DATED:  805015 - 800517

 LAYER NO.   1     DEFINED BY DEPTHS BETWEEN    0.00 M AND   20.00 M

 PARAMETER CODE     76  TURBIDITY (FTU)

 INVERSE POWER=    2.000

 MAP WANTED USING    0.200  CONTOUR INCREMENT

 MATRIX ELEMENTS ARE TO BE PUNCHED

      SEGMENT(S) SELECTED BY THE USER FOR THIS LAYER :

                        1
121-DEC-87      11:32:09

0
*********************************************
* GREEN BAY VOLUME-WEIGHTED STATISTICS *
*********************************************

 CRUISE NO.    1   DATED:  805015 - 800517

 LAYER NO.   1     DEFINED BY DEPTHS BETWEEN    0.00 M AND   20.00 M

 PARAMETER CODE     76  TURBIDITY (FTU)

 INVERSE POWER=    2.000
```

****
* CHARACTERISTICS OF USER-SELECTED STATIONS *
****

STATION REFERENCE NUMBER	VERTICALLY AVERAGED MEAN	COORDINATES IN UNITS OF GRID (X)	(Y)	SEGMENT ASSIGNMENT	STATION DESIGNATION	AGENCY CODE
2	7.200	1.88	3.28	1	CONL 2	ANLTEST
3	1.900	2.17	5.60	1	CONL 3	ANLTEST
4	6.500	3.56	3.46	1	CONL 4	ANLTEST
5	1.200	2.94	8.82	1	CONL 5	ANLTEST
6	1.600	4.72	7.18	1	CONL 6	ANLTEST
7	3.300	6.20	6.32	1	CONL 7	ANLTEST
8	1.950	7.46	11.55	1	CONL 8	ANLTEST
9	1.200	9.75	16.04	1	CONL 9	ANLTEST
10	1.200	10.13	21.10	1	CONL 10	ANLTEST
11	0.6000	12.12	19.64	1	CONL 11	ANLTEST
12	1.400	13.73	18.17	1	CONL 12	ANLTEST
13	1.300	14.78	17.56	1	CONL 13	ANLTEST
14	0.9000	17.63	21.10	1	CONL 14	ANLTEST
15	0.9300	20.67	24.33	1	CONL 15	ANLTEST
16	0.9200	18.87	29.58	1	CONL 16	ANLTEST
17	0.7500	20.92	28.15	1	CONL 17	ANLTEST
18	0.9500	22.93	26.88	1	CONL 18	ANLTEST
19	0.8800	24.96	25.25	1	CONL 19	ANLTEST
20	0.7800	23.76	31.94	1	CONL 20	ANLTEST
21	0.7900	26.31	42.39	1	CONL 21	ANLTEST
22	0.7600	28.35	41.66	1	CONL 22	ANLTEST
23	0.6800	30.36	40.36	1	CONL 23	ANLTEST
24	0.8800	32.06	40.17	1	CONL 24	ANLTEST
25	0.8100	37.18	50.22	1	CONL 25	ANLTEST
26	0.6700	38.46	57.74	1	CONL 26	ANLTEST
27	0.8400	42.72	53.76	1	CONL 27	ANLTEST
28	0.9300	48.17	50.53	1	CONL 28	ANLTEST
29	1.200	39.89	67.48	1	CONL 29	ANLTEST
30	1.200	40.67	72.25	1	CONL 30	ANLTEST
31	0.7800	49.76	64.46	1	CONL 31	ANLTEST

TO BE CONTINUED ON NEXT PAGE

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*********************************************
* GREEN BAY VOLUME-WEIGHTED STATISTICS      *
*********************************************
```

CRUISE NO. 1 DATED: 8Ø5Ø15 - 8ØØ517

LAYER NO. 1 DEFINED BY DEPTHS BETWEEN Ø.ØØ M AND 2Ø.ØØ M

PARAMETER CODE 76 TURBIDITY (FTU)

INVERSE POWER= 2.ØØØ

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***********************************************
*  CHARACTERISTICS OF USER-SELECTED STATIONS  *
***********************************************
```

STATION REFERENCE NUMBER	VERTICALLY AVERAGED MEAN	COORDINATES IN UNITS OF GRID (X)	(Y)	SEGMENT ASSIGNMENT	STATION DESIGNATION	AGENCY CODE
32	Ø.82ØØ	51.31	68.16	1	CONL 32	ANLTEST
33	1.2ØØ	54.85	68.52	1	CONL 33	ANLTEST

TOTAL STATION-COUNT= 32

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**********************************************
* GREEN BAY VOLUME-WEIGHTED STATISTICS      *
**********************************************
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CRUISE NO. 1 DATED: 805015 - 800517

LAYER NO. 1 DEFINED BY DEPTHS BETWEEN 0.00 M AND 20.00 M

PARAMETER CODE 76 TURBIDITY (FTU)

INVERSE POWER= 2.000

GREEN BAY WHOLE BAY MODEL

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****************************************************
* STATISTICS OF VERTICALLY AVERAGED STATION MEANS *
****************************************************
```

STATION COUNT	AVERAGE OF STATION MEANS	HIGH	LOW	STANDARD DEVIATION	STANDARD ERROR
32	1.4694	7.2000	0.60000	1.5056	0.26616

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********************************************
* GREEN BAY VOLUME-WEIGHTED STATISTICS     *
********************************************
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CRUISE NO. 1 DATED: 805015 - 800517

LAYER NO. 1 DEFINED BY DEPTHS BETWEEN 0.00 M AND 20.00 M

PARAMETER CODE 76 TURBIDITY (FTU)

INVERSE POWER= 2.000

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****************************
*  ARITHMETIC  STATISTICS  *
****************************
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SEG		STANDARD ERROR			STANDARD DEVIATION		
NO.	M=MEAN	E=ST.ERR.	M+E	M-E	D=ST.DEV.	M+D	M-D
1	0.9550	0.2817	1.237	0.6733	1.594	2.549	-0.6388

SEG NO.	GRID COUNT	STATION COUNT	PARAMETER ESTIMATED MAXIMUM	MINIMUM
1	1128	32	7.042	0.6576

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**********************************************
* GREEN BAY VOLUME-WEIGHTED STATISTICS       *
**********************************************
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CRUISE NO. 1 DATED: 805015 - 800517

LAYER NO. 1 DEFINED BY DEPTHS BETWEEN 0.00 M AND 20.00 M

PARAMETER CODE 76 TURBIDITY (FTU)

INVERSE POWER= 2.000

GREEN BAY WHOLE BAY MODEL

HISTOGRAM FOR LAYER NO. 1 AND CONTOUR MAP NO. 100

INTERVAL RANGE (SYMBOL)			0.000E+00 200. 400. 600. 800. 1.000E+03 I....*....I....*....I....*....I....*....I....*....I	CENTER	FREQUENCY	PERCENT
0.0000E+00	(A)	0.8000	.XXX	0.4000	63.00	5.59
0.8000	(B)	1.600	.XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX	1.200	959.0	85.02
1.600	(C)	2.400	.XXX	2.000	71.00	6.29
2.400	(D)	3.200	.	2.800	17.00	1.51
3.200	(E)	4.000	.	3.600	7.000	0.62
4.000	(F)	4.800	.	4.400	1.000	0.09
4.800	(G)	5.600	.	5.200	2.000	0.18
5.600	(H)	6.400	.	6.000	7.000	0.62
6.400	(J)	7.200	.	6.800	1.000	0.09

PARAMETER MINIMUM IN THIS LAYER: 0.6576

PARAMETER MAXIMUM IN THIS LAYER: 7.042

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*********************************************
* GREEN BAY VOLUME-WEIGHTED STATISTICS      *
*********************************************

 CRUISE NO.     1   DATED:  805015 - 800517

 LAYER NO.   1      DEFINED BY DEPTHS BETWEEN     0.00 M AND    20.00 M

 PARAMETER CODE      76  TURBIDITY (FTU)

 INVERSE POWER=     2.000

                      GREEN BAY MAP NO.  100

                 GREEN BAY WHOLE BAY MODEL

    0         1         2         3         4         5         6
77  0----*----0----*----0----*----0----*----0----*----0----*----0
76  0----*----0----*----0----*----0----*----0----*----0----* BB 0
75  0----*----0----*----0----*----0----*----0----*----0---- BBBB
74  0----*----0----*----0----*----0----*----0----*---- BB - BBBB
73  0----*----0----*----0----*----0----*----0----*--- BBBB BBBBB
72  0----*----0----*----0----*----0----*-- BB+ --*--- BBBBBBBBBB  ( 1)   30
71  0----*----0----*----0----*----0----*-- BBBB -*--- BBBBBBBBB 0
70  0----*----0----*----0----*----0----*-- BBBB -*-- BBBBBBBBB -0
69  0----*----0----*----0----*----0----*-- BBBB -*- BBBBBBB+B --0 ( 1)   33
68  0----*----0----*----0----*----0----*-- BBBB -* BBBB+BBBB ---0 ( 1)   32
67  0----*----0----*----0----*----0----*-- B+BB -* BBBBBBBBB ---0 ( 1)   29
66  0----*----0----*----0----*----0----*- BBBBB  BBBBBBBBBBB ---0
65  0----*----0----*----0----*----0----*- BBBBB BBBBBAABBBB ----0
64  0----*----0----*----0----*----0---- BBBBBBBBBBBBA+BBB *----0 ( 1)   31
63  0----*----0----*----0----*----0-- BBBBBBBBBBBBBBBBBBB -*----0
62  0----*----0----*----0----*----0-- BBBBBBBBBBBBBBBBBBB -*----0
61  0----*----0----*----0----*----0- BBBBBBBBBBBBBBBBBBBB -*----0
60  0----*----0----*----0----*----0- BBBBAAABBBBBBBBBBBBB -*----0
59  0----*----0----*----0----*---- BBBBBAAAAABBBBBBBBBBBBBB ----0
58  0----*----0----*----0----*---- BBBBBAA+AAABBBBBBBBBBBBB ----0 ( 1)   26
57  0----*----0----*----0----*---- BBBBBAAAAAABBBBBBBBBBBBB ----0
56  0----*----0----*----0----*---- BBBBBAAAAABBBBBBBBBBBBB *----0
55  0----*----0----*----0----*--- BBBBBBBAAABBBBBBBBBBBBB -*----0
54  0----*----0----*----0----*--- BBBBBBBBBBBBB+BBBBBBBB --*----0 ( 1)   27
53  0----*----0----*----0----*-- BBBBBBBBBBBBBBBBBBBBBBB ---*----0
52  0----*----0----*----0----*-- BBBBBBBBBBBBBBBBBBBBBB ----*----0
51  0----*----0----*----0----*-- BBBBBBBBBBBBBBBBBBBB+ 0----*----0 ( 1)   28
50  0----*----0----*----0----*- BBBBBBBBB+BBBBBBBBBB -0----*----0 ( 1)   25
49  0----*----0----*----0----* BBBBBBBBBBBBBBBBBBBBB --0----*----0
48  0----*----0----*----0---- BBBBBBBBBBBBBBBBBBB *----0----*----0
47  0----*----0----*----0---- BBBBBBBBBBBBBBBBBBB *----0----*----0
46  0----*----0----*----0--- BBBBBBBBBBBBBBBBBBBB *----0----*----0
45  0----*----0----*----0--- BBBBBBBBBBBBBBBBBBBB *----0----*----0
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44  0----*----0----*----0---  BBBBBBBBBBBBBBBBBB -*----0----*----0
43  0----*----0----*----0--  BBAAAAABBBBBBBBBBB --*----0----*----0
42  0----*----0----*----0-  BBB+A+AAABBBBBBBBBB --*----0----*----0  ( 2)  21  22
41  0----*----0----*----0  BBBBAAAAAABBBBBB 0----*----0----*----0
40  0----*----0----*----0  BBBBBAAA+A+BBBBBB 0----*----0----*----0  ( 2)  23  24
39  0----*----0----*----  BBBBBBBAAAABBBBBB -0----*----0----*----0
38  0----*----0----*----  BBBBBBBBBBBBBBBBB -0----*----0----*----0
37  0----*----0----*-  BBBBBBBBB BBBBBBBBB -0----*----0----*----0
36  0----*----0----*-  BBBBBBBBB BBBBBBBB --0----*----0----*----0
35  0----*----0----*  BBBBBBBBBBBBBBB --*----0----*----0----*----0
34  0----*----0----*  BBBBBBBBBBBBBBB --*----0----*----0----*----0
33  0----*----0----*  BBBBBBBBBBBBBBB --*----0----*----0----*----0
32  0----*----0----*-  BBBBBA+BBBBBBB --*----0----*----0----*----0  ( 1)  20
31  0----*----0----*-  BBBBBBBBBBBBBB --*----0----*----0----*----0
30  0----*----0----*  BB+BBBBBBBBBBB ---*----0----*----0----*----0  ( 1)  16
29  0----*----0----*  BBBBBBBBBBBBBB ---*----0----*----0----*----0
28  0----*----0----*  BBBB+BBBBBBBB ----*----0----*----0----*----0  ( 1)  17
27  0----*----0----*  BBBBBB+BBBBB 0----*----0----*----0----*----0  ( 1)  18
26  0----*----0-  BBBBBBBBBBBBBBB -0----*----0----*----0----*----0
25  0----*----0-  BBBBBBBBBBBB+BB -0----*----0----*----0----*----0  ( 1)  19
24  0----*--  BBBBBBBBBBBB+BBBBB --0----*----0----*----0----*----0  ( 1)  15
23  0----*--  BBBBBBBBBBBBBBBBBB --0----*----0----*----0----*----0
22  0----*--  BBBBBBBBBBBBBBBBBB --0----*----0----*----0----*----0
21  0----*-  BB+BBBBBBB+BBBBBBB ---0----*----0----*----0----*----0  ( 2)  10  14
20  0----*-  BBBB+BBBBBBBBBBBBB ---0----*----0----*----0----*----0  ( 1)  11
19  0----*  BBBBBABBBBBBBBBB --*----0----*----0----*----0----*----0
18  0----*  BBBBBBB++BBBBBB --*----0----*----0----*----0----*----0  ( 2)  12  13
17  0----  BBBBBBBBBBBB -0----*----0----*----0----*----0----*----0
16  0---  CCBBB+BBBBBB --0----*----0----*----0----*----0----*----0  ( 1)   9
15  0---  CCCBBBBBBBB ---0----*----0----*----0----*----0----*----0
14  0---  CCCCBBBBBBB ---0----*----0----*----0----*----0----*----0
13  0--  CCCCCCCCBBB ----0----*----0----*----0----*----0----*----0
12  0-  CCCC+CCCCCC *----0----*----0----*----0----*----0----*----0  ( 1)   8
11  0 CCCCCCCCCCCC *----0----*----0----*----0----*----0----*----0
10  0 CCCCCCCCCCC -*----0----*----0----*----0----*----0----*----0
 9  0 B+CCCCCCCCC -*----0----*----0----*----0----*----0----*----0  ( 1)   5
 8  0 CCCCCDDDDC --*----0----*----0----*----0----*----0----*----0
 7  0 CCC+DDDDDD --*----0----*----0----*----0----*----0----*----0  ( 1)   6
 6  0 +DDD+DD 0----*----0----*----0----*----0----*----0----*----0  ( 2)   3   7
 5  0 DEEEEED 0----*----0----*----0----*----0----*----0----*----0
 4  0 HHHFE --0----*----0----*----0----*----0----*----0----*----0
 3  0 +H+G ---0----*----0----*----0----*----0----*----0----*----0  ( 2)   2   4
 2  0 HHG ----0----*----0----*----0----*----0----*----0----*----0
 1  0----*----0----*----0----*----0----*----0----*----0----*----0
    0         1         2         3         4         5         6
```

GREEN BAY MAP NO. 100