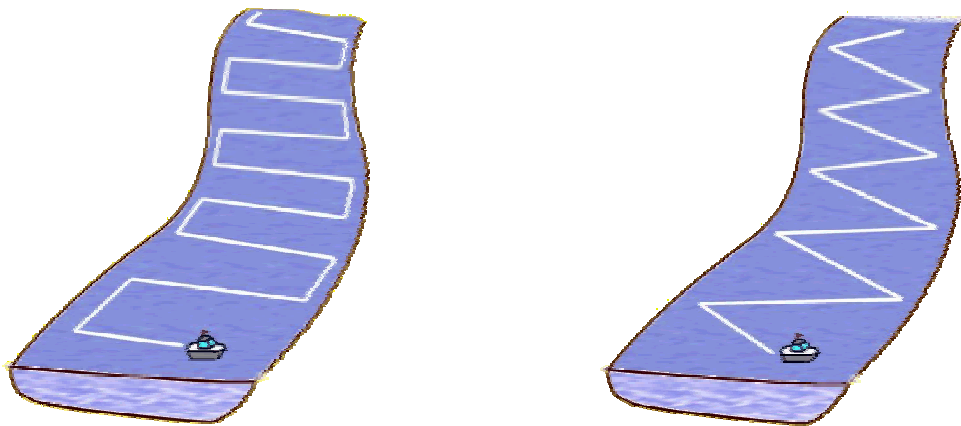


**GIST 6120**  
**Project Final Report**

**Optimal Survey Configuration Analysis  
for  
Fraser River Bathymetric Mapping**



By

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May 2001

BCIT GIS Advanced Diploma Program

## **ABSTRACT**

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This project used GIS as a tool to study the effect of survey configurations on the accuracy of DEM that maps the bathymetry of the Fraser River. The industry sponsor of this project was the Fraser River Project Group at UBC Department of Geography. River bathymetry is a good tool for the study of river morphological changes over time. In this project, two study areas with different channel morphologies were chosen — the Mission reach and Chilliwack reach of the lower Fraser River. Reference bathymetric surfaces were created from a set of densely distributed survey points collected in 1991. For each study area, DEM surfaces were then created using 40 different sets of data points that had different survey configurations (sample pattern, line and point density). In general, two survey configurations were under consideration in this project: cross-sections and diagonals. Linear regression was performed to assess the accuracy of the DEMs relative to the reference bathymetric surfaces that were created with the complete set of data. The results of the statistical analysis suggested that the optimal survey configuration had a transect line spacing of 100 m, and the cross-section survey pattern was superior to the diagonal pattern. This project started on January 3, 2001 and ended on May 17, 2001, and a total of 273 hours of work was devoted to complete this project.

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## **1. INTRODUCTION**

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This report consists of 11 sections that describe the GIS project Optimal Survey Configuration Analysis for Fraser River Bathymetric Mapping . The project was sponsored by Dr. Michael Church and Darren Ham of the UBC Department of Geography to facilitate their research work on sediment transport in the lower Fraser River. This section provides an introduction, and it briefly outlines the contents of the rest of the sections in this report. Project statement, sponsor details, project deliverables and project background are then given. The technical details of the project were described in the project data and tools, project methodology, and results and recommendations sections. A conclusion on the project is then given, and references are included. Supplementary materials are attached to the appendices section at the end of the report.

## **2. PROJECT STATEMENT**

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Use GIS as a tool to find the most efficient survey configuration for collecting echo-sounding bathymetric data and the most appropriate interpolation algorithms for building accurate and representative digital elevation model (DEM) of the Fraser River.

## **3. PROJECT SPONSOR DETAILS**

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## **4. PROJECT OBJECTIVES**

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### **4.1. Project objectives**

- § Find the most efficient survey configuration, in terms of sampling pattern and data density, to collect bathymetric data of the Fraser River.
- § Find the most suitable interpolation algorithms and digital elevation modeling routines to construct reasonably accurate bathymetric surfaces that can provide enough details for river morphology study, using various surface generating modules.
- § Quantify the error of the bathymetric DEM surfaces using linear regression statistics.
- § Customize the procedures to automate survey transect generation

### **4.2. Project deliverables**

- § A presentation on the technical component of the project.
- § A project report with details on the methodology and result of the analysis.
- § A customized ArcInfo application program to automate survey transect and DEM generation and error analysis.

## **5. PROJECT BACKGROUND**

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### **5.1. Mapping topography under water**

Topography is an important factor in any geography-related studies. Geoscientists, environmental engineers, planners and designers often start their work by consulting topographic maps. Before the advancement of mathematical interpolation algorithms and reliable computer numerical modeling programs, topographic maps were mostly in the form of contour lines hand-drawn by experienced cartographers. With the development of geographic information systems (GIS) and the science of digital terrain modeling (DTM), topographic maps are no longer restricted to 2D contour lines but 3D continuous surfaces that enhance the visualization of topography and computation of terrain-related properties such as slope and aspect.



Field surveys, stereo aerial photographs and satellite images are all common data sources of topographic mapping. Yet, topographic measurement under water relies heavily on echo-sounding data. Single-track echo-sounding data are the most commonly available resources for oceanographers, marine geologists and biologists to portray the bathymetry of the ocean floor. Such data usually have very closely spaced points distributed along widely separated lines. Such a sampling pattern makes interpolation of data values in areas between the lines very tricky. Various attempts have been made to automate the process of contouring bathymetric data using different methods of interpolation. The accuracy and precision of the interpolation methods, the optimal track line orientation and data spacing interval have also been investigated (David *et al.* 1986; Gambolati and Galeati 1989). Mapping the bathymetry of rivers using echo-sounding or cross-section survey-line data is in the same situation. However, there is very little in the literature about river bathymetry. The characteristics of a river bottom could be quite different than those of the ocean floor. It is necessary to deal with not only the widely spaced lines of data, but also the sharp break of slope along the banks.

## **5.2. River morphology and DEM**

Fluvial geomorphology — the study of river forms and processes — is a key in river engineering and management planning. The form (or morphology) of a river is best described by means of bathymetry, which is the measurement of water depth in a water body (UMESC 2000). The study of river morphology is helpful in understanding the processes and behaviour, hence the stability of a river.

Managing large river systems such as the Fraser River is always challenging. Good river management decisions, such as dredge site selection, fish habitat management and bank erosion control, could be made only when we have a sound knowledge of the historical changes of the river and its sediment transport budget. Geographic information system (GIS) is a potential tool for mapping and analysing such changes.

## **5.3. GIS application on river bathymetry**

The application of GIS in river processes flourishes in regional-scale hydrological modeling (e.g. watershed delineation and floodplain mapping), but there is little attention



given on mapping the river in the reach scale (Milne and Sear 1997). Although computerized hydrographic surveying using GPS and echo-sounding technologies is quite well developed (Rogala 1999), there is room for research on how to make the best use of the bathymetric data collected in terms of digital elevation modeling (DEM). Collecting bathymetric data of larger river systems is often very costly, but money and time could be saved if we know how to sample the river bed efficiently while being able to ensure the accuracy of data and the bathymetric surfaces generated.

In this project, the effect on DEM accuracy of two survey configuration patterns, cross-section and diagonal, was examined. Accuracy assessment was based on linear regression test.

## **6. PROJECT DATA AND TOOLS**

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### **6.1. Data sets and data dictionary**

#### River morphology (MAP91)

*MAP91* is a polygon coverage that maps the morphology (water, island, bar, back channel and floodplain) of the Fraser River. The morphology of the river was interpreted from 1991 air photos, and the mapped polygons were digitized by the sponsor.

#### River bathymetry point data (SURVEY91)

*SURVEY91* (Figure 1, left) is a point coverage that contains bathymetric survey sample points collected in 1991, and this set of data was used to create the reference bathymetric surfaces. Bathymetric data were also collected in other years but the 1991 data was chosen for this project because it had the most even distribution and the highest sampling density compared to other data sets — the average point spacing was about 50 m. Elevation was stored in the *Z\_VALUE* column in meters above sea level (accuracy – 20 cm).

#### Floodplain and island elevation data (HELI\_LASER)

*HELI\_LASER* (Figure 1, right) is a point coverage that contains elevations of areas that were above water, i.e. islands, bars, banks and floodplains along the river and not



covered by the 1991 bathymetric survey. The data were collected by helicopter altimetry in 1999.

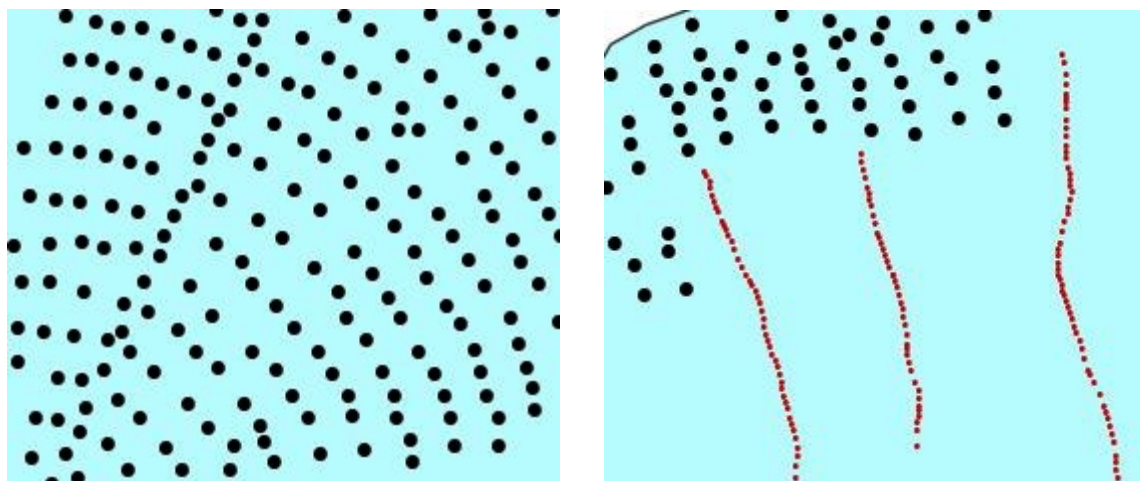


Figure 1. Elevation data. Large-sized symbols represent *SURVEY91* and small symbols represent *HELI\_LASER*. (Scale 1:8500)

Table 1a. Data dictionary of input data.

Data	Description	Attribute	Value
MAP91 (polygon)	Air photo interpretive map of river morphology	CHANNEL-ID	0 - bedrock 100 - water 200 - island 250 - floodplain 300 - exposed bar 350 - submerged bar 400 - back channel 600 - dyke
SURVEY91 (point)	Echo-sounding data; sample spacing was about 50 m	Z_VALUE	Elevation
HELI_LASER (point)	Elevation collected along banks and islands of the river	Z_VALUE	Elevation

Table 1b. Data dictionary of manipulated data.

Data	Description	Attribute	Value
CENLN (arc)	River centerline	--	--
RIVER (polygon)	River boundary polygon; interpolation extent	--	--
ELEV (point)	Elevation points from SURVEY91 and HELI_LASER	Z_VALUE SOURCE	Elevation H - helicopter S - survey





All data were in UTM Zone 10 projection (Spheroid GRS1980).

## 6.2. Study area description

### 6.2.1. Fraser River

Fraser River drains about one-quarter of British Columbia, and it is a significant salmon habitat. Sourced at Mount Robson in the Rocky Mountains, the river passes through the rock canyon between the Coast Mountain and Cascade Mountains. The main alluvial reach of the river starts from near Hope in the Lower Mainland and then flows west to the sea. The river changes its morphology from an irregular single channel near Hope to a wandering or anastomosed pattern with frequent mid-channel bars between Laidlaw and Vedder River (Church and McLean 1994). It changes from a gravel- to sand-bed channel near Mission. The river near Mission is heavily riprapped at its natural width and part of it flows along erosion resistant, non-alluvial material (e.g. Sumas Mountain). Church *et al.* (1991) recognized this uniform section of the river as the ideal site for conducting sediment observations.



Figure 2. River morphology map (Mission to Chilliwack), 1991.

### 6.2.2. Study area

The study area is a section of the lower Fraser River from near Chilliwack to Mission of the Southwest British Columbia (Figure 2). This section of the river undergoes several changes in morphology, from gravelly anastomosed (multi-threaded with frequent bars and islands) near Agassiz to sandy single-threaded near Mission. This



project will use two subsets of bathymetric data, one set from near Mission (study area 1) and the other from near Chilliwack (study area 2), to compare the effects of survey configurations on DEM accuracy in different river morphology.

### **6.3. Tools and languages**

ArcInfo 8 workstation was the primary GIS tool used for data analysis in this project. An application program was developed in AML (Arc Macro Language). ArcView 3.2 and Spatial Analyst were used to display grid data for visual examination. Linear regression analysis was performed in S-PLUS.

## **7. PROJECT METHODOLOGY**

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### **7.1. Methodology**

This section describes the steps taken to complete the project — data input, data manipulation, reference surface creation, survey configuration analysis, and customization.

#### **7.1.1. Data input**

The original data were in ArcInfo coverage format, and they were located in the sponsor's computer that used ArcInfo 7 and ran under Solaris. Data were exported into E00 format and compressed into zip files before sending to the author via email. Data were then uncompressed and imported back to ArcInfo 8 coverage format.

#### **7.1.2. Data manipulation**

A flow chart on p.27 shows the steps taken in the data manipulation stage of the project. The first step was to combine *SURVEY91* and *HELI\_LASER* to create a new point coverage called *ELEV*. It contained elevation points that covered the entire study area (i.e. included mid-channel island and bar). Prior to combining the two point coverages, data cleanup was performed on *HELI\_LASER*, and the reasons were as follows.


1. Some of the data points in the *HELI\_LASER* coverage overlapped with the *SURVEY91* data, and it was necessary to remove these redundant data points before building the reference bathymetric surface.




2. Since the two sets of data were collected in different years (1991 and 1999), there were slight discrepancies in elevation between the two data sets in the same area as the river changed its morphology over time.

The following diagrams showed the steps used to combine *HELI\_LASER* and *SURVEY91*.

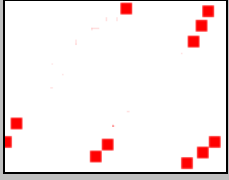
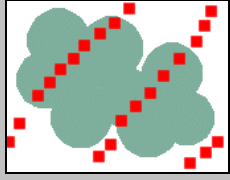
§ Point **BUFFER** was performed on the *SURVEY91* points with a distance of 30 m (slightly larger than half the average spacing between the points).



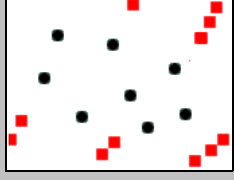
§ Sliver polygons were removed using the **ELIMINATE** command to create polygon coverage *SURVEYAREA*.



§ *HELI\_LASER* points that fell outside *SURVEYAREA* was selected and a new coverage *DRYELEV* (right) was created using the **ERASE** command.



§ *DRYELEV* was then combined with *SURVEY91* to create *ELEV* using the **APPEND** command.



The second step was to create a river polygon from *MAP91* to define the extent of the region for bathymetric surface generation. Polygons that were mid-channel islands and bars were merged with the adjacent water polygons (the **DISSOLVE** command was used). The resultant coverage was *RIVER*.

The third step was to create a centerline from the *RIVER* polygon. The ArcInfo **CENTERLINE** command was used but it gave unsatisfactory results because the bank line



of the *RIVER* polygon was too irregular and complex. Therefore, on-screen digitizing in ArcEdit was done to create the centerline coverage (*CENLN*).

The last step was to extract data for the two study areas — Mission and Chilliwack. The *RIVER* coverage was edited to create *RPOLY\_S1* and *RPOLY\_S2*. Using the `CLIP` command, a subset of data, *WELEV\_S1*, *WELEV\_S2*, *CENLN\_S1* and *CENLN\_S2* were extracted from *ELEV* and *CENLN* with *RPOLY\_S1* and *RPOLY\_S2* polygons.

### **7.1.3. Reference surface creation**

Two reference surfaces, one for each study area, were interpolated and created from the elevation data points assembled in the data manipulation stage. In this project, we assumed that these two reference surfaces represented the "true" elevation of the river bed. Although the elevation data used in this project had a relatively high density, extra attention was still needed on the choice of interpolation method. Some manual surface edition was done to make the reference surfaces as realistic as possible.

Several interpolation methods were attempted to create a reference surface from the original data points: Inverse Distance Weighting (IDW), TOPOGRID, Kriging and TIN. In general, universal kriging and TOPOGRID performed better than TIN and IDW. Since TOPOGRID ran faster and required less user interaction (e.g. geostatistical variogram analysis), it was used as the primary interpolation method to generate the reference surfaces. However, it was obvious that TOPOGRID, upon close examination to its derived contour, did not automatically create highly satisfactory DEMs to be used as reference surfaces. For example, the "bull's eye" pattern shown in Figure 3 (left) reveals that some manual edition to the contours was required. Manual edition of the contours included the digitizing of new contour lines and the removal the "bull's eye" pattern. The thicker contour line in Figure 3 (right) shows the result of such manual adjustment. The edited contour coverage was then used as an input to TOPOGRID to create the reference surfaces.

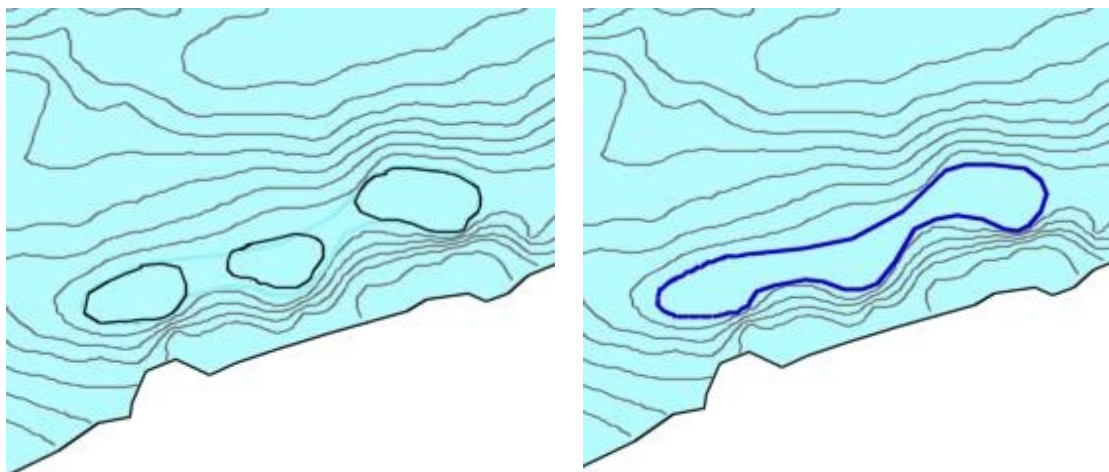


Figure 3. Contours derived from surface interpolated by TOPOGRID (left). Bull's eye pattern was removed by manual contour edition (right).

#### Example TOPOGRID command

```
topogrid mygrid 10  
boundary rpoly_s1  
datatype contour  
enforce off  
line ctour1 spot  
point welev_s1 spot
```

#### **7.1.4. Survey configuration analysis**

The purpose of the survey configuration analysis was to find the optimal survey configuration that could generate the most accurate bathymetric surface. The accuracy of the generated surface from one particular survey configuration was assessed by comparing it with the reference surface. In this project, two survey track line patterns were under consideration (cross-section and diagonal transects), as well as different line offset distances and data point separations (Table 2 and Figure 4).

Table 2. Survey configurations tested (line spacing and point separation).

Line spacing (m)	Point separation along line (m)
75	10, 20, 40, 60
100	10, 20, 40, 60
150	10, 20, 40, 60
200	10, 20, 40, 60
300	10, 20, 40, 60

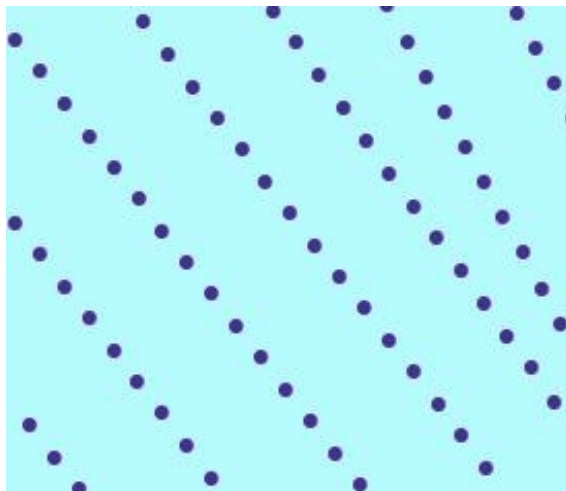


Figure 4. One of the 40 survey configurations tested in this project: Cross-section with 100 m line offset and 40 m data points separation along each line.

Survey configuration analysis started with the creation of arc coverages that contained survey track lines with different survey patterns and offset distances. These survey track lines were then densified with vertices at a constant interval that represented the data point separation along the line. Sample point coverages were then created. Elevation values were then extracted from the reference surfaces and attached to the SPOT item of the sample point coverages. The automation of track line and sampling point generation was performed with a customized AML program (see next section).

Once the sample point coverage was created, interpolation was run to generate DEMs. In this project, three types of surface generation methods were used for each of the survey configuration data sets — IDW (number of points = 12 and power = 2), TOPOGRID (stream enforce off) and TIN (convert to lattice with the quintic option).

<code>idwgrd = IDW (samplepnt, SPOT, #, 2, SAMPLE, 12)</code>	
<code>topogrid tpgrid 10 boundary rpoly_s1 datatype SPOT enforce OFF point samplepnt SPOT</code>	<code>CREATETIN mytin cover samplepnt points spot cover rpoly_s1 poly -9999 7 END TINLATTICE mytin tingrd quintic &lt;CR&gt; &lt;CR&gt; &lt;CR&gt; 10</code>



The effect of survey configuration on DEM accuracy was then performed. DEM created was compared with the reference surface using linear regression. The equation for testing was:

$$y = a + mx$$

where,

$y$  = grid cell value of DEM generated from one set of the sample points

$x$  = grid cell value of reference surface

$a$  = y-intercept of the regression line

$m$  = slope of the regression line

In addition, the coefficient of determination ( $R^2$ ) was useful to describe the variance of data from the linear regression equation. The value of  $R^2$  ranges from 0 to 1, and it reaches 1 if the fit to the regression is tight (i.e. low variance).

The ideal case is that the DEM generated has the same  $z$  value as the reference surface.

So,

$$y = x$$

$$a = 0$$

$$m = 1$$

$$R^2 = 1$$

Linear regression statistics ( $a$ ,  $m$  and  $R^2$ ) was calculated in S-PLUS. Before importing the data to S-PLUS, the ArcInfo grids were converted into xyz ACSII format. The GRID command SAMPLE was used to generate the text files:

```
sample.txt = SAMPLE (model_s1, grid1, grid2, grid3)
```

The values of  $a$ ,  $m$  and  $R^2$  for each of the survey configurations tested were then compared. The optimal survey configuration was the one with the value of  $a$  closest to 0 and the values of  $m$  and  $R^2$  closest to 1.



### **7.1.5. Customization**

Most of the procedures taken to run the survey configuration analysis were automated with an application that was written in AML. Example source code was provided in the appendices section (11.2) at the end of this report. The application menus and dialogs were also provided in the appendix (11.4).

## **7.2. Project management techniques**

This project started on January 3, 2001 and ended on May 17, 2001, and it consisted of two components — technical and management. The technical component consisted of 205 hours of work and ended on April 30, 2001. Workload per week ranged from 14 to 20 hours. Time accounting table was set up to track project progress, and ten progress reports (weekly or bi-weekly) were submitted to project supervisor to summarize tasks performed since the last reporting period. Problems encountered and unresolved were discussed with the project supervisor and sponsor during project meetings.

## **7.3. Resources used**

Below is a list of resources used in this project:

<b>Research</b> Journal articles and books	BCIT and UBC libraries
<b>Solution to technical problems</b>	WWW and online help
<b>Operating system</b> Windows NT	UBC GIS Lab
<b>GIS</b> ArcInfo 8 (GRID) and ArcView 3.2 (Spatial Analyst)	UBC GIS Lab
<b>Customization</b> AML script writing and testing	BCIT GIS Labs
<b>Statistical analysis</b> S-PLUS 4.5	UBC GIS Lab
<b>Project management</b> MS Excel, Word	Author's home





## 8. PROJECT RESULTS AND RECOMMENDATIONS

### 8.1. Results

#### 8.1.1. Reference surfaces

Figure 5 shows the two reference surfaces created in this project. These bathymetric surfaces revealed the difference in river morphology: the river morphology of the Mission reach is more regular and the Chilliwack reach is more complex. However, the range of elevation values of the Mission reach (-24 to 14 m) was larger than that of the Chilliwack reach (-10 to 8 m). This suggests that different survey configurations may be required to map the bathymetry accurately for the two reaches.

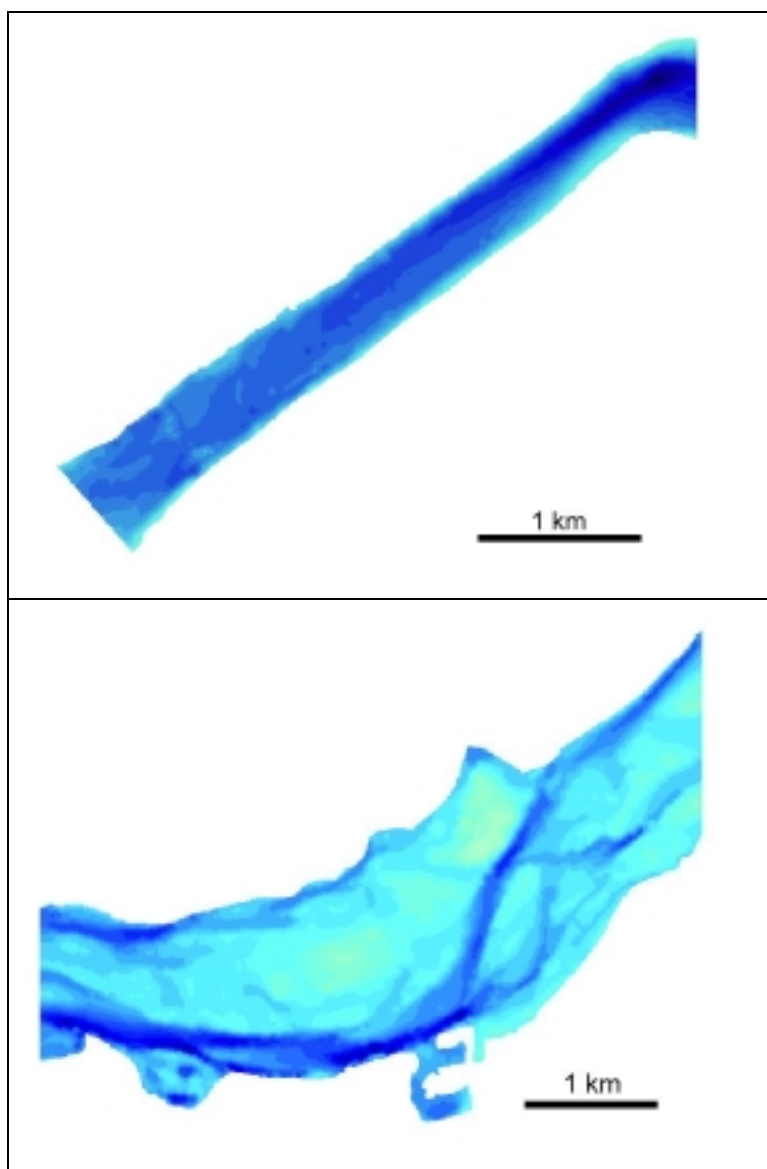
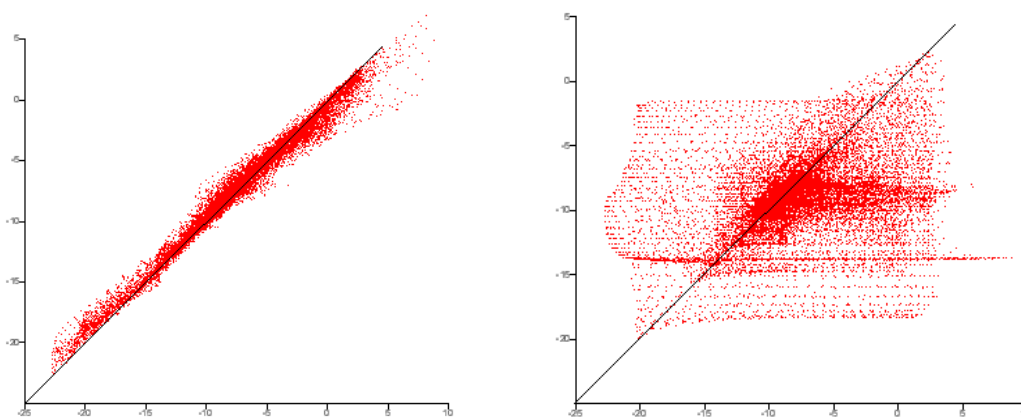


Figure 5. The reference surfaces - Mission reach (top), Chilliwack reach (bottom)



### **8.1.2. Optimal survey configuration**

Linear regression analysis on all of 40 survey configurations tested for each of the study areas was performed. For both of the study areas, the cross-section survey pattern was superior to the diagonal pattern, especially when the offset spacing between lines was large (e.g. > 200 m). Figure 6 shows two extreme cases of the regression plots created in this project. By comparing the trends and extents of the data cloud, it was very obvious that the plot on the left represented a more accurate DEM and the plot on the right was a poor representation of the reference surface.



a) Best case

b) Worst case

Figure 6. Example linear regression plots. The x-axis represents the elevation value of the reference surface and the y-axis represents the DEM created from sample points of a particular kind survey configuration — survey pattern, line spacing and point density.

Figure 7 plots the trend of values  $a$  (circles),  $m$  (square) and  $R^2$  (triangles) calculated from the regression analysis of the DEMs created from different survey configurations (line spacing). Below is a list of the parameters of the linear regression equation of the optimal survey configuration found in this project: cross-section lines with 100 m offset and 10 m data point separation along a transect line. Both sets of points were interpolated using the TOPOGRID method.

	$a$	$m$	$R^2$
Study area 1	-0.6642	0.9121	0.9819
Study area 2	0.1594	0.9083	0.9557

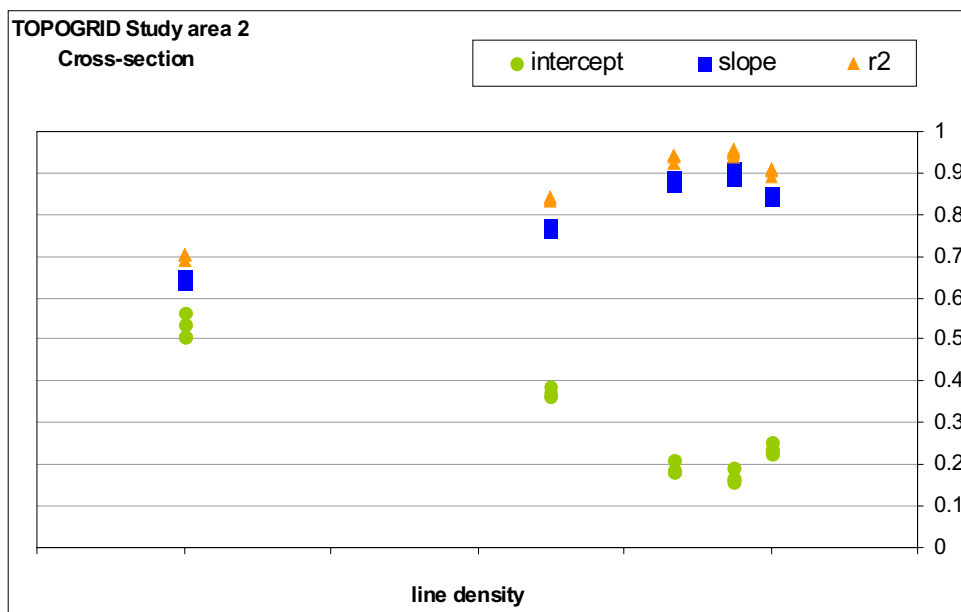
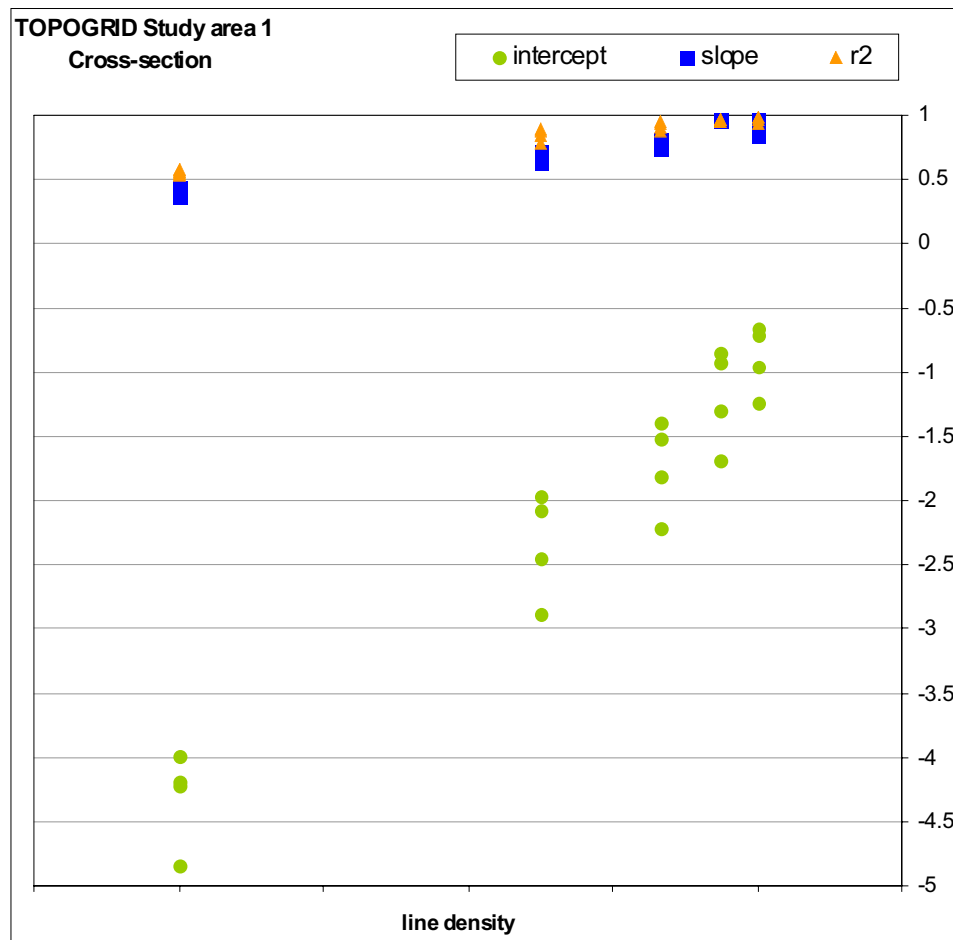


Figure 7. Linear regression statistics of different survey configurations for study area 1, Mission reach (top), and study area 2, Chilliwack reach (bottom).



## 8.2. Recommendations

Below is a list of recommendations for further research on river bathymetry and survey configuration analysis.

- § Use different methods of interpolation to further test the appropriateness of the optimal survey configuration found in this project. For example, we can use the newly released ArcGIS Geostatistical Analysis Extension to create kriged surfaces.
- § Stochastic simulation can be run for alternative sets of data points of the same survey configuration (i.e. the line and point spacing remains the same but the position of the points and lines shifts).
- § Run spatial correlation analysis to examine the relation of DEM accuracy to river morphology. For example, is DEM accuracy lower in certain areas, such as banks along river where there are sharp change of slope and elevation?

## 9. CONCLUSION

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This project examined the effect of survey configuration on DEM accuracy for mapping the bathymetry of the Fraser River. Reference surfaces were created and were compared with DEMs interpolated from sample points generated from different survey configuration considerations. The optimal survey configuration for the study area was found. The principles behind this project, its application program and procedures have provided a good insight on further investigations on finding the optimal sampling pattern in other projects like soil sampling, altimetry and geophysical surveying.

The project started on January 3 and ended on May 17. GIS software and tools, programming languages and statistical package were used to complete the technical component of this project. Planned tasks were completed after 205 hours of technical work and 68 hours of management work.



## 10. REFERENCES

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- Church, M. and D.G. McLean, 1994, Sedimentation in Lower Fraser River, British Columbia: implications for management. In, Schumm, S.A. and B.R. Winkley, editors, *The Variability of Large Alluvial Rivers*, American Society of Civil Engineers, pp. 221-241.
- Church, M., D.G. McLean, R. Kostaschuk, S. Macfarlane, B. Tassone, and D. Walton, 1991, Channel stability and management of Lower Fraser River field excursion guide. Report, Environment Canada, Inland Waters Directorate, Vancouver.
- David, M., D. Crozel and J.M. Robb, 1996, Automated mapping of the ocean floor using the theory of intrinsic random functions of order k. *Marine Geophysical Researches*, **8**, pp. 49-74.
- Gambolati, G. and G. Galeati, 1989, Optimal interpolation of bathymetry in the Thyrrehnian Sea. *Proceedings of the 1989 National Conference on Hydraulic Engineering*, pp. 813-819.
- Martin, Y. and M. Church, 1995, Bed-material transport estimated from channel surveys: Vedder River, British Columbia. *Earth Surface Processes and Landforms*, **20**, pp. 347-361.
- Milne, J.A., and Sear, D.A., 1997, Modelling river channel topography using GIS. *International Journal of Geographical Information Science*, **11**, pp. 499-519.
- Rogala, J.T., 1999, Bathymetry, URL:  
[ftp://ftp.umesc.er.usgs.gov/pub/media\\_archives/documents/bathymetry/methods.pdf](ftp://ftp.umesc.er.usgs.gov/pub/media_archives/documents/bathymetry/methods.pdf)
- UMESC, 2000, Bathymetry - Frequently asked questions, URL:  
<http://www.emtc.er.usgs.gov/aquatic/bathymetry/faqs.html>



## 11. APPENDICES

### 11.1. Final time accounting table

Task No.	Task	Original Estimate	Revised Estimate	Hrs. to Date	% Complete	Est. +/-
<b>1.0</b>	<b>Data and software familiarization</b>	<b>11</b>	<b>16</b>	<b>16</b>	<b>100</b>	<b>5</b>
1.1	Data acquisition	1	1	1	100	--
1.2	Data import and conversion	2	2	2	100	--
1.3	Review ArcView Spatial and 3D Analyst	1	1	1	100	--
1.4	Learn ArcInfo surface modeling commands	3	8	8	100	5
1.5	Review interpolation algorithms	4	4	4	100	--
1.6	Learning STATISTICA / S-PLUS	0	5	5	100	5
<b>2.0</b>	<b>Reference surface creation</b>	<b>49</b>	<b>64</b>	<b>64</b>	<b>100</b>	<b>15</b>
2.1	Extract data for the 2 study sites	2	3	3	100	1
2.2	Build topology of river banks and islands	1	5	5	100	4
2.3	Integrate bathymetric and island elevation data	5	5	5	100	--
2.4	Interpolate to build reference surface	20	25	25	100	5
2.5	Learn SURFER	5	7	7	100	2
2.6	Build reference surface using SURFER	7	7	7	100	--
2.7	Surface modeling design	9	12	12	100	3
<b>3.0</b>	<b>Survey configuration analysis</b>	<b>103</b>	<b>125</b>	<b>125</b>	<b>100</b>	<b>22</b>
3.1	Develop algorithm for the analysis	10	30	30	100	20
3.2	Interpolate with different survey configurations	50	50	50	100	--
3.3	Surface "goodness-of-fit" analysis	28	20	20	100	-8
3.4	Correlation statistical analysis	15	25	25	100	10
<b>4.0</b>	<b>Bathymetric map preparation</b>	<b>32</b>	<b>0</b>	<b>0</b>	<b>N/A</b>	<b>-32</b>
<b>5.0</b>	<b>Project Management</b>	<b>66</b>	<b>68</b>	<b>68</b>	<b>100</b>	<b>2</b>
5.1	Meet with sponsor / supervisor	10	7	7	100	-3
5.2	Progress reports	5	5	5	100	--
5.3	Resume	1	1	1	100	--
5.4	GIS Conference poster	10	10	10	100	--
5.5	Cartographic poster	10	10	10	100	--
5.6	Final written report	20	25	25	100	5
5.7	Final presentation	10	10	10	100	--
	<b>Totals</b>	<b>261</b>	<b>273</b>	<b>273</b>	<b>100</b>	<b>12</b>



## 11.2. Sample programs

```

/*****
/* Program:      transect2.aml
/* Description:  Split input arc cover at equal interval specifies by user
/*              Create a line cover with perpendicular lines to the input arc
/*              Clip transects to the polygon
/*              NOTE: only works for coverage with ONE single arc
/*              Modified from transect.aml created by Eager Ip (29/3/2001)
/* Author:      Eager Ip
/* Created:     25/4/2001
*****/

&args incov bndcov outcov offset l
&sv usgmsg = Usage: &r transect <centerline> <bound_cov> <out_cover> /& ~
                <offset> <length>

&if [NULL %incov%] or [NULL %outcov%] or [NULL %bndcov%] ~
    or [NULL %offset%] or [NULL %l%] &then
    &return %usgmsg%
/*****
/* check existence of centerline coverage
*****/
&if ^ [exists %incov% -COVER] &then
    &return ERROR: Coverage %incov% does not exist in this workspace.

/*****
/* check if arc topology and number or arcs
*****/
&describe %incov%
&if %DSC$ARCS% = 0 &then
    &return ERROR: Coverage %incov% does not contain arcs.

&if %DSC$ARCS% > 1 &then
    &return This AML script only works for coverages with a single line.

/*****
/* check existence of bounding coverage
*****/
&if ^ [exists %bndcov% -COVER] &then
    &return ERROR: Coverage %bndcov% does not exist in this workspace.

/*****
/* check if the coverage has polygon topology
*****/
&describe %bndcov%
&if %DSC$POLYGONS% = 0 &then
    &return ERROR: Coverage %bndcov% does not contain polygons.

/*****
/* check output coverage existence
*****/
&if [exists %outcov% -COVER] &then
    &return ERROR: Coverage %outcov% exists in this workspace.

/*****
/* check integer type of variable offset
*****/
&if [type %offset%] > -1 &then
&do
    &ty You must enter a numeric value for <offset>
    &ty %usgmsg%
```



```
&return
&end
/*****
/* check numeric type of variable l
*****/
&if [type %l%] > -1 &then
&do
    &ty You must enter a numeric value for <length>
    &ty %usgmsg%
    &return
&end

/*****
/* change double precision to single precision
*****/
&sv oldincov
&if [translate %DSC$PRECISION%] = DOUBLE &then
&do
    &if ^ [exists oo%incov% -cover] &then
        copy %incov% oo%incov% single
    &sv oldincov = %incov%
    &sv incov = oo%incov%
&end

/*****
/* calculate number of profiles to make
/* use cursor to get the length of the arc and
/* divide length by offset distance and truncate to integer
*****/
cursor len_cur declare %incov%.aat info RO
cursor len_cur open
&do &while %:len_cur.aaml$next%
    &sv n = [truncate [calc %:len_cur.length% / %offset%]]
    &sv final = %:len_cur.length%
    cursor len_cur next
&end
cursor len_cur remove

/*****
/* create and open ungenerate file
*****/
&sv ungenfile = %incov%.ung
&if [exists %ungenfile% -file] &then
    &sv delfile = [delete %ungenfile% -file]
ungenerate line %incov% %ungenfile%
&sv readu = [open %ungenfile% openstatu -READ]
&if %openstatu% NE 0 &then
    &return Error opening file, error code: %openstatu%

/*****
/* reading ungenerate file
/* output lineid and xy coordinate of vertices
/* calculate segment length between vertices
*****/
&sv record = [read %readu% readstat]
&do &while %readstat% = 0 /* not End of File
    &if [translate %record%] NE END &then /* not End of file
        &do
            &sv lineid = %record% /* line id
            &sv record = [read %readu% readstat] /* start reading xy
            &sv num = 0 /* xy index
            &sv x%num% = [extract 1 [unquote %record%]] /* read x0
            &sv y%num% = [extract 2 [unquote %record%]] /* read y0
```





```
&sv length%num% = 0 /* length of current segment
&sv record = [read %readu% readstat] /* read next xy

&do &while [translate %record%] NE END /* not End of Line
  &sv num = %num% + 1
  &sv x%num% = [extract 1 [unquote %record%]]
  &sv y%num% = [extract 2 [unquote %record%]]
  &sv delx = [calc [value x%num%] - [value x[calc %num% - 1]]]
  &sv dely = [calc [value y%num%] - [value y[calc %num% - 1]]]
  &sv length%num% = [sqrt [calc %delx% * %delx% + %dely% * %dely%]]
  &sv record = [read %readu% readstat] /* read next xy
&end
&end
&sv record = [read %readu% readstat]
&end
/*****
/* close and delete ungenerate file
/*****
&sv clsfile = [close %readu%]
&sv delfile = [delete %ungenfile% -FILE]

/*****
/* calculate xy value of the points along centerline
/*****
&sv px0 = %x0%
&sv py0 = %y0%
&sv dx0 = [calc %x1% - %x0%]
&sv dy0 = [calc %y1% - %y0%]

&do pnt = 1 &to %n% &by 1
  &sv offset1 = [calc %pnt% * %offset%]
  &sv totlen = 0
  &sv i = 0
  &do &while %totlen% <= %offset1%
    &sv i = %i% + 1
    &sv totlen = [calc %totlen% + [value length%i%]]
  &end

  &sv ratio = [calc [value length%i%] - %totlen% + %offset1%]
  &sv ratio = [calc %ratio% / [value length%i%]]
  &sv dx%pnt% = [calc [value x%i%] - [value x[calc %i% - 1]]]
  &sv dx%pnt% = [calc [value dx%pnt%] * %ratio%]
  &sv dy%pnt% = [calc [value y%i%] - [value y[calc %i% - 1]]]
  &sv dy%pnt% = [calc [value dy%pnt%] * %ratio%]
  &sv px%pnt% = [calc [value x[calc %i% - 1]] + [value dx%pnt%]]
  &sv py%pnt% = [calc [value y[calc %i% - 1]] + [value dy%pnt%]]
&end

/*****
/* make perpendicular line from the points
/* - trigonometry is used to make the transects
/* - "Right hand rule" is used for the transect direction
/* write to temporary generate file, perpen.tmp
/*****
&sv genfile = perpen.tmp
&if [exists %genfile% -file] &then
  &sv delfile = [delete %genfile% -FILE]

&sv readp = [open %genfile% openstatp -WRITE]
&if %openstatp% NE 0 &then
  &return Error opening file, error code: %openstatp%

&do pnt = 0 &to %n% &by 1
```



```
&sv writestat = [write %readp% [calc %pnt% + 1]]
&sv dx = [abs [value dx%pnt%]]
&sv dy = [abs [value dy%pnt%]]
&if %dx% NE 0 &then
&do
  &sv a = [atan [calc %dy% / %dx%]]
  &sv qdx%pnt% = [calc %l% * [sin %a%]]
  &sv qdy%pnt% = [calc %l% * [cos %a%]]

  &if [value dx%pnt%] > 0 and [value dy%pnt%] > 0 &then
  &do
    &sv qdx%pnt% = [abs [value qdx%pnt%]]
    &sv qdy%pnt% = [calc -1 * [abs [value qdy%pnt%]] ]
  &end

  &if [value dx%pnt%] < 0 and [value dy%pnt%] < 0 &then
  &do
    &sv qdy%pnt% = [abs [value qdy%pnt%]]
    &sv qdx%pnt% = [calc -1 * [abs [value qdx%pnt%]] ]
  &end

  &if [value dx%pnt%] < 0 and [value dy%pnt%] > 0 &then
  &do
    &sv qdx%pnt% = [abs [value qdx%pnt%] ]
    &sv qdy%pnt% = [abs [value qdy%pnt%] ]
  &end

  &if [value dx%pnt%] > 0 and [value dy%pnt%] < 0 &then
  &do
    &sv qdx%pnt% = [calc -1 * [abs [value qdx%pnt%]] ]
    &sv qdy%pnt% = [calc -1 * [abs [value qdy%pnt%]] ]
  &end
&end

&if %dx% = 0 and %dy% > 0 &then
&do
  &sv qdy%pnt% = 0
  &sv qdx%pnt% = %l%
&end

&if %dx% = 0 and %dy% < 0 &then
&do
  &sv qdy%pnt% = 0
  &sv qdx%pnt% = [calc -1 * %l%]
&end

&sv qx%pnt% = [calc [value px%pnt%] + [value qdx%pnt%] ]
&sv qy%pnt% = [calc [value py%pnt%] + [value qdy%pnt%] ]
&sv writestat = [write %readp% [value qx%pnt%],[value qy%pnt%]]
&sv qx%pnt% = [calc [value px%pnt%] - [value qdx%pnt%] ]
&sv qy%pnt% = [calc [value py%pnt%] - [value qdy%pnt%] ]
&sv writestat = [write %readp% [value qx%pnt%],[value qy%pnt%]]

  &sv writestat = [write %readp% END] /* end of line
&end

&sv writestat = [write %readp% END]
&sv clsfile = [close %readp%]

/*****
/* generate transect line from file and build arc topology
*****/
generate xx%outcov%
```



```
input %genfile%
lines
q

&sv delfile = [delete %genfile% -FILE]
build xx%outcov% line

/*****
/* clip cover to the polygon boundary
/*****
clip xx%outcov% %bndcov% %outcov% LINE

/*****
/* clean up intermediate coverages and files
/*****
kill xx%outcov% all
&if ^ [NULL %oldincov%] &then
&do
    kill oo%oldincov% all
    &sv %incov% = %oldincov%
&end

&sv close = [close -all]
&return
```



```
/* *****
/* Program: diagonals.aml
/* Description : create diagonal transects from a line coverage containing
/*               parallel transect lines
/* Author: Eager Ip
/* Started: 4/4/2001
/* Modified: 19/4/2001 ei
/*           - add variable %% to count the number of vertex
/*           - code to handle intersecting perpendicular lines
/* *****
&args incov outcov
&sv errmsg = Usage: diagonals <transect_cover> <out_cover>

/* *****
/* check validity of input arguments
/* *****
&if [NULL %incov%] or [NULL %outcov%] &then
    &return %errmsg%

&if ^ [exists %incov% -COVER] &then
    &return ERROR: Coverage %incov% does not exist in this workspace.

/* check if the coverage has arcs
&describe %incov%
&if %DSC$ARCS% = 0 &then
    &return ERROR: Coverage %incov% does not contain arcs.

/* check output coverage existence
&if [exists %outcov% -COVER] &then
    &return ERROR: Coverage %outcov% exists in this workspace.

/* *****
/* ungenerate input file
/* *****
&sv ungenfile = %incov%.tmp
&if [exists %ungenfile% -FILE] &then
    &sv delfile = [delete %ungenfile% -FILE]
ungenerate line %incov% %ungenfile%

/* *****
/* open file to read and write
/* *****
&sv readr = [open %ungenfile% openstatr -READ]
&if %openstatr% NE 0 &then
    &return Error in opening file

&sv tmpfile = xx%outcov%.tmp
&if [exists %tmpfile% -FILE] &then
    &sv delfile = [delete %tmpfile% -FILE]
&sv readw = [open %tmpfile% openstatw -WRITE]
&if %openstatw% NE 0 &then
    &return Error in opening file

/* *****
/* storing the xy coordinates of nodes into variables
/* *****
&sv n = 0
&sv record = [read %readr% readstat]
&do &while %readstat% = 0
    &if [translate %record%] NE END &then
        &do
            &sv n = %n% + 2
            &sv lineid = [unquote %record%]
```



```
&sv record = [read %readr% readstat]

/*****
/* renumbering nodes by lineid
/*****
&sv id = [calc %lineid% * 2 - 1]
&sv x%id% = [extract 1 [unquote %record%]]
&sv y%id% = [extract 2 [unquote %record%]]

/*****
/* only extract the xy of the end points
/*****
&sv next = [read %readr% readstat]
&do &while [translate %next%] NE END
    &sv record = %next%
    &sv next = [read %readr% readstat]
&end
&sv id = [calc %lineid% * 2]
&sv x%id% = [extract 1 [unquote %record%]]
&sv y%id% = [extract 2 [unquote %record%]]
&sv record = %next%
&end
&else
    &sv record = [read %readr% readstat]
&end
&sv clsfile = [close %readr%]

&sv w = [write %readw% 1] /* line id of diagonal transect
&sv i = 0

/*****
/* join nodes to form diagonals (+1, +3)
/* and write to generate file
/*****
&do &while %i% <= %n%
    &sv i = %i% + 1
    &if %i% <= %n% &then
        &sv w = [write %readw% [value x%i%],[value y%i%]]
        &sv i = %i% + 3
    &if %i% <= %n% &then
        &sv w = [write %readw% [value x%i%],[value y%i%]]
&end

&sv w = [write %readw% END]
&sv w = [write %readw% END]
&sv clsfile = [close %readw%]

/*****
/* generate diagonal line files
/*****
generate %outcov%
input %tmpfile%
lines
q
build %outcov% lines

/*****
/* CLEAN UP
/*****
&sv delfile = [delete %ungenfile% -FILE]
&sv delfile = [delete %tmpfile% -FILE]
&sv delvar *
&return
```



```
/* *****  
/* Program:          samplepnt.aml  
/* Description:      Densify arcs and convert vertex to point  
/*                  Create a sampling point coverage along transects  
/*                  User specifies distance between sampling points  
/* Author:          Eager Ip  
/* Created:         5/4/2001  
/* *****  
  
&args incov outcov interval  
  
&sv errmsg = Usage: samplepnt <transect_cover> <out_cover> <interval>  
  
&if [NULL %incov%] or [NULL %outcov%] or [NULL %interval%] &then  
&do  
    &ty %errmsg%  
    &return  
&end  
  
&if ^ [exists %incov% -COVER] &then      /* check coverage existence  
&do  
    &ty ERROR: Coverage %incov% does not exist in this workspace.  
    &return  
&end  
  
&describe %incov%  
&if %DSC$ARCS% = 0 &then      /* check if the in_cover has arcs  
&do  
    &ty ERROR: Coverage %incov% does not contain arcs.  
    &return  
&end  
  
&if [exists %outcov% -COVER] &then      /* check coverage existence  
&do  
    &ty ERROR: Coverage %outcov% exists in this workspace.  
    &return  
&end  
  
&if [type %interval%] > -1 &then  
&do  
    &ty You must enter a numeric value for <interval>  
    &ty %errmsg%  
    &return  
&end  
  
&sv tempcov = xx%incov%  
&if [exists %tempcov% -COVER] &then  
    kill %tempcov% all  
  
/* *****  
/* densify arcs  
/* *****  
densifyarc %incov% %tempcov% %interval%  
  
/* *****  
/* create pointcover from arc  
/* ungenerate arcs  
/* *****  
&sv ungenfile = %incov%.vtx  
&if [exists %ungenfile% -file] &then  
    &sv delfile = [delete %ungenfile% -FILE]  
  
ungenerate line %tempcov% %ungenfile%
```



```
/* open ungenerate file
****
&sv readu = [open %ungenfile% openstatu -READ]
&if %openstatu% NE 0 &then
    &return Error opening file to read

/* open generate file for writing point id, xy
****
&sv genfile = %incov%.pnt
&if [exists %genfile% -file] &then
    &sv delfile = [delete %genfile% -FILE]

&sv readg = [open %genfile% openstatg -WRITE]
&if %openstatg% NE 0 &then
    &return Error opening file to write

/* convert vertex to point and write to a generate file
****
&sv record = [read %readu% readstat]
&sv id = 0

&do &while %readstat% = 0
    &if [translate %record%] NE END &then
        &do
            &if [type [extract 1 [unquote %record%]]] = -2 &then
                &do
                    &sv id = %id% + 1
                    &sv x = [extract 1 [unquote %record%]]
                    &sv y = [extract 2 [unquote %record%]]
                    &sv writestat = [write %readg% %id%,%x%,%y%]
                &end
            &end
            &sv record = [read %readu% readstat]
        &end

&sv writestat = [write %readg% END]

&sv closef = [close %readu%]
&sv closef = [close %readg%]

generate %outcov%
input %genfile%
points
q

build %outcov% point

****
/* clean up temporary files and coverages
****
&sv delfile = [delete %genfile% -FILE]
&sv delfile = [delete %ungenfile% -FILE]
kill %tempcov% all

&return
```