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An improved anisotropic scheme for interpolating scattered bathymetric data points in sinuous river channels

by

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Abstract

This paper presents an improved technique for applying three-dimensional bathymetric (bed form) scatter point data of a sinuous, meandering, low-gradient river to a three-dimensional Finite Element grid. A standard inverse distance weighted interpolation scheme (Franke and Nielson, 1980) is used to apply the bathymetric data to each node (interpolant) of the triangular Finite Element mesh. A unique search space algorithm is presented which geospatially limits scatter point input data by utilizing the known anisotropic shape of a river cross-section. Unlike widely distributed interpolation algorithms (ESRI, 2001; SMS, 2002) generally used for interpolating scatter data in similar situations, the new algorithm is capable of rotating the anisotropy coincident with the natural, sinuous curves of the river plan form. In tests using filtered field data, the new algorithm accurately represents natural bathymetry and does so more reliably in areas of sparse field data than the other tested interpolation methods.

Introduction

The increasing importance of and the legislative mandate for Instream Flow studies in the state of Texas has allowed emphasis to be placed on refinement of the existing methods of analysis. Instream Flow studies are performed in riverine environs to determine the optimum quantity, timing, and quality of water that sustains ecological health while also making water available for beneficial uses. The effects of water uses like diversions and impoundments are studied in a multidisciplinary framework involving engineers, biologists, and geomorphologists.

At least two components of a typical Instream Flow study, hydrodynamic modeling and fish habitat utilization modeling, require an accurate bathymetric representation of the active river channel on a discrete reach. Recognizing that bathymetry data is collected at the finest scale allowed by contemporary technology and by available resources, the resolution of bathymetric data is still either too coarse or too irregular to be used directly for modeling. Improvements to standard interpolation algorithms will allow reasonable representation of channel bed form at both a resolution finer than the source data and at regular locations that may have poor scatter data coverage.

The goal of hydrodynamic modeling is to provide the analyst with continuous water velocity and depth information over the entire domain of the river reach that is being studied (Leclerc, et al, 1995). Local perturbations in bed form like boulders, slumps, scour holes, and submerged sand bars all have an effect on both local velocity fields and the overall hydraulic conditions (Crowder and Diplas, 2000); using an accurate surface representation of the three-dimensional river bed results in more accurate model output.

Fish habitat utilization modeling is performed by combining the velocity and depth output of the hydrodynamic model with spatial knowledge of other river features like substrate and structure (stumps, root wads, cut banks, bars, etc.) then applying knowledge of fish species habitat utilization. These data allow the spatial extent of suitable habitat for a particular species to be quantified (Leclerc and Lefleur, 1997; Wentzel and Austin, 2000; Vadas and Orth, 1998). Changes observed in the available habitat area at different flow rates are used to generate a minimum sustainable flow regime that optimizes available habitat area to all fish species, thus maintaining diversity of the fish population. As a surrogate indicator for the overall health of the ecosystem, a healthy and diverse fish population indicates a healthy and sustainable ecosystem.

Thus, sustainable limits on the amount of water that users can withdraw from the river should be set with reference to the optimum instream flow regime that promotes overall ecological health. Since the instream flow determination has serious effects on water users, permit holders, and overall riverine ecology, and since the determination depends in large part on the bathymetric representation of the channel bed, it is very important that the bathymetry be as accurate as possible.

Collection of bathymetry data is a resource-intensive component of a typical instream flow project that involves deployment of a highly-trained field crew who utilize global positioning and echosounding equipment for durations as long as a week.

Available resources are generally at a premium, and while every effort is made to collect bathymetry data at the finest resolution possible, expense is often minimized by collecting bathymetric data at resolutions more coarse than ideal.

This paper presents a technique that improves standard interpolation techniques to allow bathymetric scatter point data to be utilized for creating regular grid surfaces on a scale finer than the bathymetric source data in situations where the surface anisotropy varies over the domain. Methods and software packages exist (ESRI, 2001; SMS, 2002) that allow for directionally static, anisotropic search spaces; however, no methods exist that adequately account for situations where the directional surface anisotropy varies across the domain as is exhibited in any sinuous river channel.

A suite of software entitled Mesh Elevating and Bathymetry Adjusting Algorithms (MEBAA) was developed in FORTRAN to implement the new interpolation routine, and was developed to support a project conducted at the Texas Water Development Board (TWDB). A literature review describing applicable research is included herein and is followed by a description of the source data and physical setting, the spatial and mathematical interpolation methods, methods of verification, and a discussion of the final results.

1. Literature Review

Research loosely related to this project has been performed in many disparate fields including biology, marine geology, hydraulics, and mathematics; however, no research relating directly to fine-scale interpolation of riverbed surfaces is found. For ocean and estuary models where two-dimensional hydraulic models are most often applied, resolution is often stated on the scale of hundreds or thousands of meters (Li, et al, 2000) so bathymetric accuracy is not paramount; river modeling studies have traditionally been performed using one-dimensional models that require only cross-sectional channel information for input (USGS, 2001). The need for three-dimensional bathymetric surfaces of fine scale in a river has been, until now, very slight.

With the increasing importance of two-dimensional modeling in rivers for purposes of Instream Flow projects (Leclerc and Lafleur, 1997), accurate representation of channel morphology is much more important because of the necessity to model flow effects on the small, centimeter scales of ecological importance (Crowder and Diplas, 2000). While the centimeter resolution is far too dense for either two-dimensional hydraulic modeling or for efficient data collection activities, one-meter horizontal resolution with existing hydraulic models and data-collection technology is possible as long as the horizontal positioning device is capable of measuring position at the sub-meter level. The introduction of differential Global Positioning Systems (DGPS) has allowed that positional accuracy to be achieved (Trimble, 2001), and combining the DGPS with a marine echosounder, three-dimensional points that represent discrete locations of the riverbed can be measured relatively easily.

Positional accuracy creates its own problems. The bathymetric data is collected at a particular time with regard to the evolution of the bed surface; in dynamic systems like sand-bed channels, the bed forms change with changing flow and with changing flow regimes (Julien and Wargadalam, 1995; Chang and Yen, 2002). Plant, et al (2002), discuss error scales of bathymetric source data sets and note that the resolution of the data is a function of the natural variability of not only the surface, but also the temporal conditions that produced the surface. Natural variability is adequately resolved by the TWDB's current data collection methods because of the high local density of data points. The local density is high enough to resolve small bed forms like ripples, but the overall density only resolves larger bed forms with wavelengths larger than approximately 2 meters. Additionally, temporal variability is not considered in this analysis; rather, the bed forms present at the time of the survey are assumed to have the same average occurrence at all points in time. The methods of interpolation can be used on future data sets to study the temporal variability of the bed forms.

Scattered data interpolation methods have been studied for many years and have been proposed for many different purposes including (but certainly not limited to) submerged surfaces, topographic surfaces, Digital Terrain Modeling (DTM), and visually rendered computer graphics. The most common methods, Linear, Inverse Distance Weighted, Kriging, and Natural Neighbor, are easily applied using standard tools present in common GIS frameworks (ESRI, 2001; SMS, 2002) but often perform poorly when surface discontinuities exist. Interpolation parameters include the option to weight scatter data based upon Cartesian position relative to the interpolant. The weighting can be applied anisotropically, but the limitation is that the anisotropy must remain constant over the entire horizontal domain. In the river channel, the anisotropy varies with respect to the direction of flow; since the flow direction changes with respect to the Cartesian coordinate system (meandering), the weightings must be based upon the direction of flow rather than on the Cartesian coordinate system.

MEBAA transforms the Cartesian coordinate domain of the input data into a domain based upon the direction of flow represented by a hand-digitized, linear channel centerline. The coordinate transformation gives MEBAA knowledge of the direction of anisotropy that allows definition of a search space and selection of a subset of scatter points. The subset is consists of scatter points that are most applicable to the interpolant based upon distance perpendicular to and parallel to the channel centerline. Since bed forms evolve in the direction of flow, less variability of the surface is expected longitudinally than laterally (Julien and Wargadalam, 1995; Allen, et al, 1994).

After choosing the appropriate subset of the source scatter set, MEBAA utilizes the Shepard's (1968) Inverse Distance Weighted (IDW) interpolation method, as modified and presented by Franke and Nielson (1980). This method is termed the Modified Quadratic Shepard's Method and was shown to perform well in a comparison of 29 interpolation methods (Franke, 1982).

Outside of the GIS frameworks described above, many complex surface interpolation methods have been recently studied like Bezier surfaces (Park and Kim, 1995), Finite Element surface modeling (Xiao and Ziebarth, 2000), and basis functions (Chaturvedi and Piegl, 1996) that are more suitable for surface interpolations that contain discontinuities and spatially varying break lines. The more complex methods are worth further investigation and incorporation into MEBAA; however, high computing overhead and difficulties encountered while programming the complex numerical techniques prevent simple implementation. These complex methods also appear to be dependant on data that lies outside of the river channel in order to resolve discontinuities near the bank;

since data collection activities are performed in a boat at the water surface, collection of land topographic data would prove to be a cost-prohibitive addition to the data collection regimen. In fact, MEBAA's transformed coordinate system takes advantage of the bank discontinuity and interpolates along the flow lines.

CRWR-UT is in the midst of a project that improves upon the coordinate transformation ideas utilized by MEBAA. Where MEBAA employs a rather simple linear centerline, CRWR-UT is working on a scheme that uses a curvilinear centerline. Inherent to the curvilinear coordinate system is a continuous centerline that uses radius of curvature and tangent length data to provide smoother transitions in tight curves and, presumably, a more accurately interpolated surface. A comparison of the methods will be performed as soon as output from the curvilinear scheme is available.

Evaluation of the final surface is one of the main objectives of this project. The interpolated surface must be compared to measured surface data and the errors must be quantified. Many methods have been proposed to detect errors in bathymetry data ranging from simple surface visualization (Basu and Malhotra, 2002), to spectral analysis (Plant, et al, 2001). Chaturvedi and Peigl (1996) describe five general requirements of a terrain surface modeling system, three of which are applicable to MEBAA: shape fidelity, domain independence, and locality. Shape fidelity describes the ability of the final surface to follow the terrain even when scatter data is unevenly spaced. Domain independence states that the surface can be defined over arbitrary domains that can contain holes. Locality is basically a computing requirement, stating that subsets of data should be used to avoid using large datasets with every operation. These three applicable conditions all appear to be satisfied by MEBAA.

To evaluate the output surface generated by MEBAA, a total of eight surfaces are generated and four discrete points on each of those surfaces are examined and compared. Six surfaces are generated using the interpolation algorithms available in the Surface Water Modeling System (SMS): Linear, Natural Neighbor, and Inverse Distance Weighted (EMSI, 2002). Two surfaces are generated for each of the methods above; the first surface is generated using the entire available scatter data set and the second surface is generated using a reduced data set. Similarly, two surfaces are generated using the MEBAA algorithm, one surface using the complete data set and one surface using the reduced data set. A complete description of the analysis follows.

2. Physical Setting

An Instream Flow study is currently being conducted on the Lower Brazos River to assess the effects of a proposed off-channel reservoir project. A discrete study reach approximately 6.9-km long has been identified near Simonton, Texas (see Figure 1, location in Texas, Figure 2). Data that has already been collected for the purposes of the Instream Flow study is to be used for this project.

With headwaters located in northern New Mexico, the Brazos River flows southeast across the entire state of Texas and discharges into the Gulf of Mexico. Approximately 72,000 square kilometers drain to the designated study site that is located near the bottom of the basin, approximately 100 miles upstream of the Gulf of Mexico. The site is located in the Western Gulf Coastal Plain, along the border of Austin and Fort Bend counties (29`40'N, 96`01'W). Low-gradient and sinuous (sinuosity index of 2), point bars and pools are the dominant bed forms and the substrate is composed of a relatively homogeneous combination of fine sand and silt. The river's free surface width is approximately 100m at median flow. Some limited sandstone outcrops exist as well as one very limited area of coarse sand, gravel, and cobbles. Land use in the vicinity is predominated by rangeland and crop production.

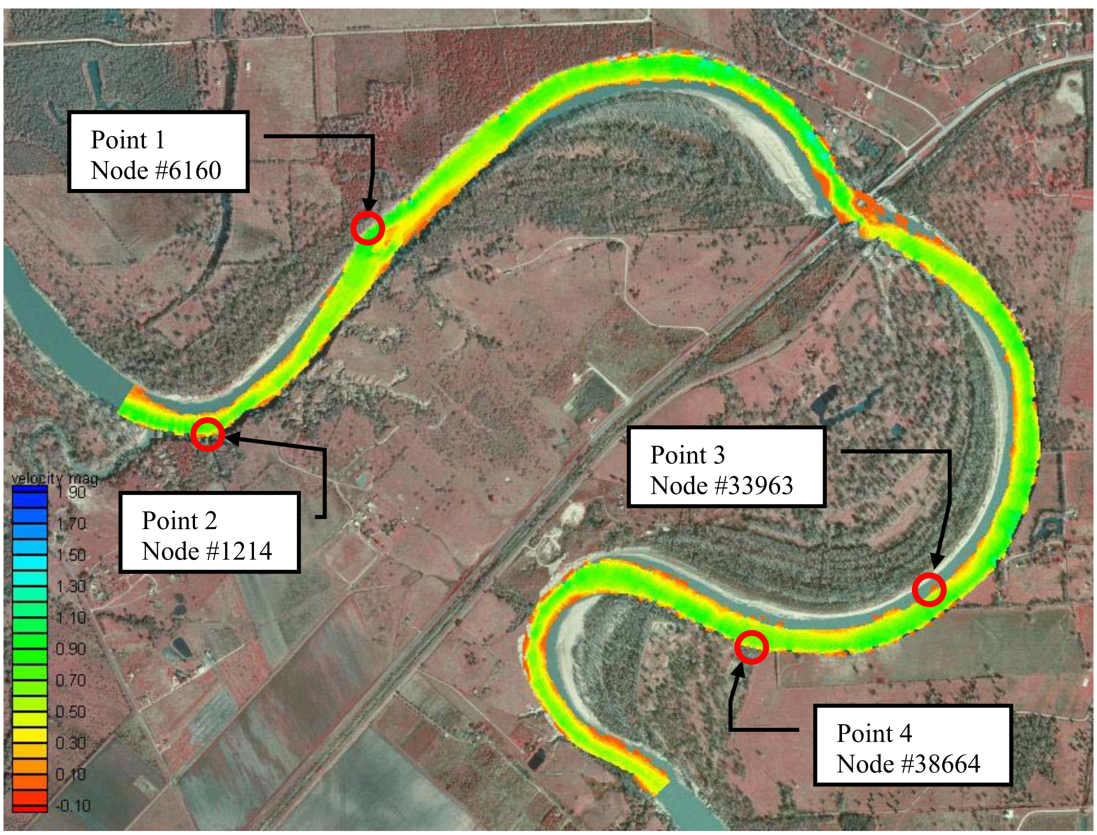

Figure 1. Brazos River study reach near Simonton, Texas. Color contours depict velocity contours (m/s) of hydraulic model output. Points of evaluation are annotated. Flow shown in aerial photo is ~4,000 cfs, flow depicted by velocity contours is 1,456 cfs.

Anthropogenic influences on sediment transport in this segment include reservoir construction, changes in land use, and instream sand and gravel mining. While changes in land use may have affected changes in sediment load, the accurate quantification of those changes is not possible. Similarly, quantification of change in transport caused by sand and gravel mining is not possible on the river segment scale since annual sand and gravel removal accounts for less than 25% of total annual transported sediment and the mining operations are widely dispersed along the river (Dunn and Raines, 2001). Intuitively, the number of in-channel impoundments on the Brazos River should result in drastically decreased amounts of sediment transported; however, post-impoundment sediment transport has not varied considerably from pre-impoundment transport. Sediment levels are presumably sustained by tributary sedimentary inputs and increased local bank erosion. The primary quantifiable effect that reservoir construction has had on the Brazos River is the reduction in frequency of higher flows capable of transporting larger sediment downstream (Dunn and Raines, 2001).

The study reach was chosen for the Instream Flow study after careful consideration and extensive reconnaissance of the entire Lower Brazos River segment that stretches from Sealy, TX, downstream to the Gulf of Mexico. River plan form is fairly homogeneous along this lower segment and all major riverbed forms found in the segment are encompassed in the study reach.

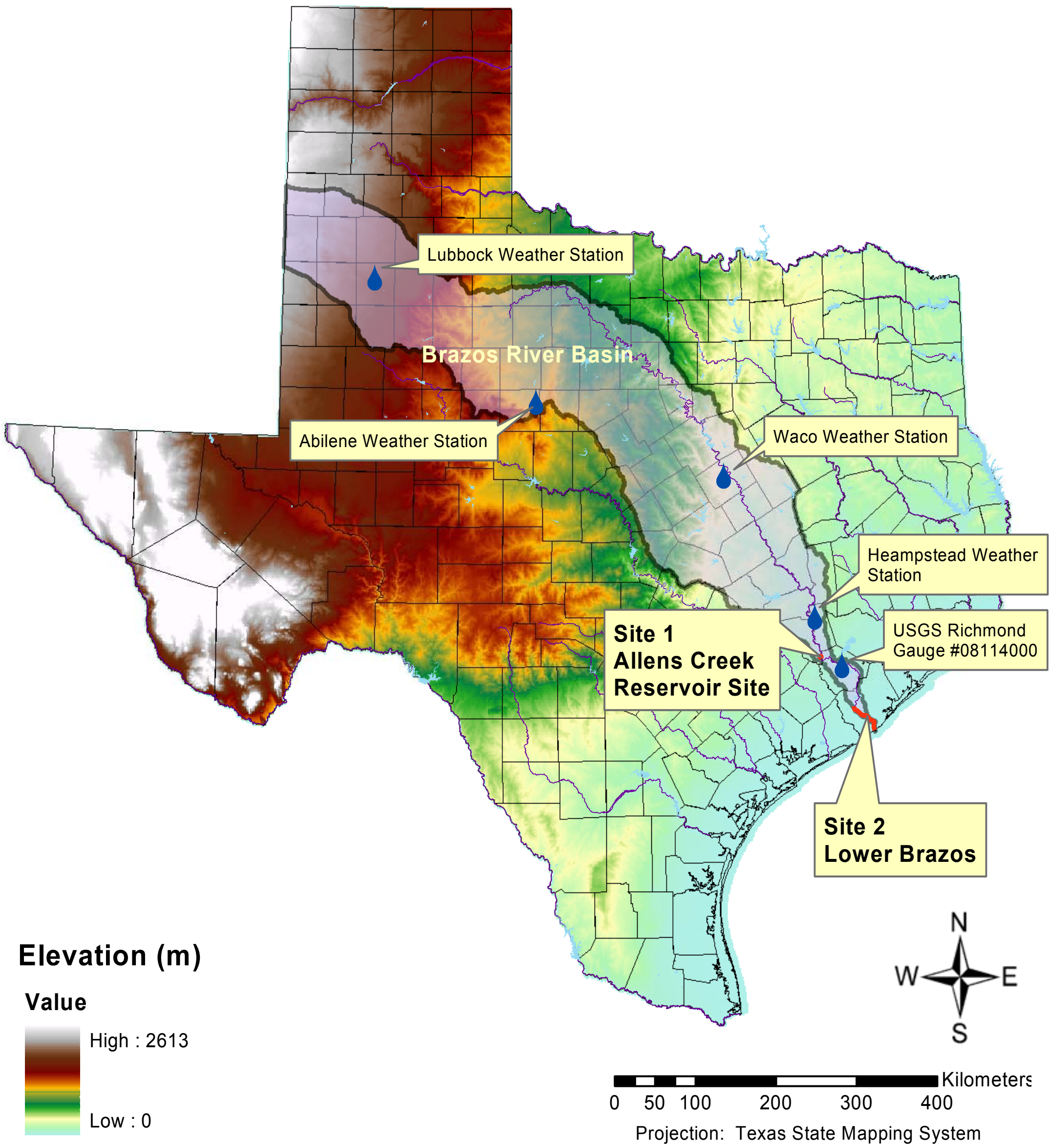

Figure 2. Area map of Texas. Project site is annotated as "Site 1."

3. Background and Data

One scattered data set (source data) and one Finite Element grid (interpolants) will be used for this project. The scattered data set is composed of 39,496 unique data points; data at each point consists of x,y position (projected to UTM14N, WGS84 in meters) and z elevation (assumed datum in meters). To generate the scatter dataset, a differential GPS with absolute accuracy of near 1m (relative accuracy +/-10cm) measured the position and a marine echosounder measured the depth from water surface (+/- 5cm). The measured echosounder depth is converted to elevation by subtracting the measured depth from a known water surface elevation at the time of survey. A sample of depth sounder data for a small 200m section of the 4.3 km reach is shown below in Figure 3.

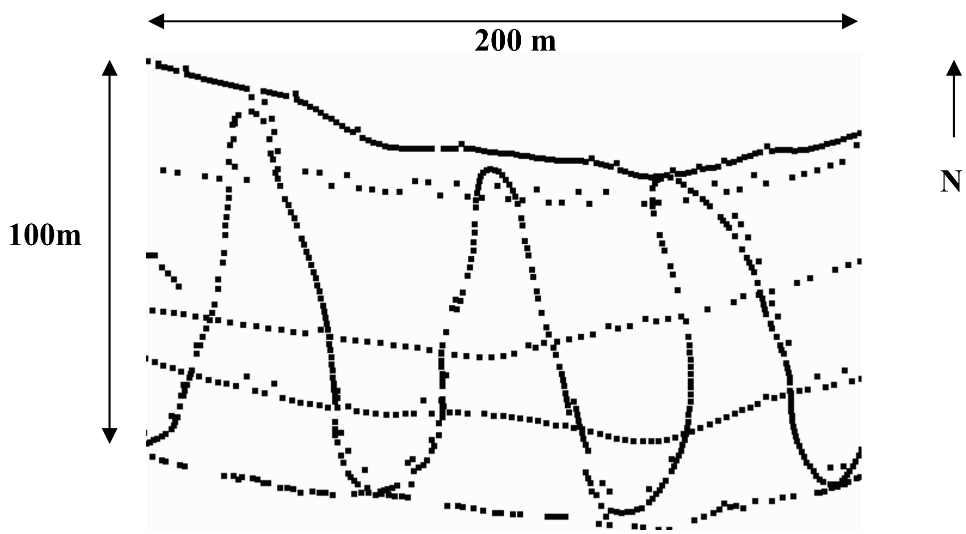

Figure 3. Scatter point bathymetric data. Each point represents elevation at a particular horizontal position. Flow in the river is from west to east. Reach length shown is approximately 200m, channel width approximately 100m. This reach is located on the Brazos River, just downstream of the Allens Creek confluence, near Simonton, TX. Point 2 is located within this small reach.

The regular grid data set is composed of the vertices of triangular elements of the Finite Element mesh used in the hydrodynamic model. As shown in Figure 4, below, each element is approximately 25 m long and 10 m wide.

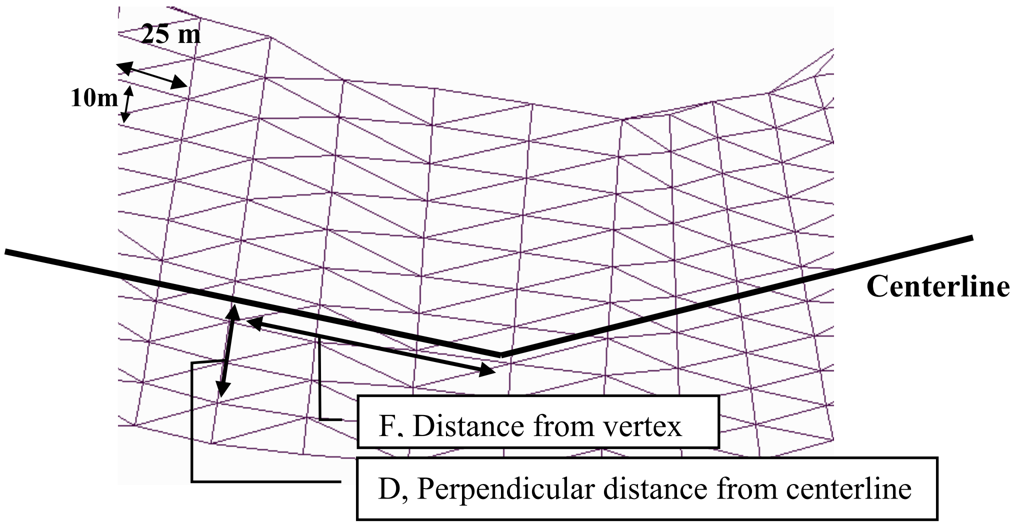

Figure 4. Small sample of the Finite Element mesh at same location as Figure 2.

Also shown in Figure 4 is a centerline, digitized by hand, that is used to perform a coordinate transformation whereby each scatter point and each mesh node is assigned a coordinate relative to the centerline. The traditional x,y,z Cartesian coordinates are transformed to d,f,z coordinates, where d is the perpendicular distance of the point to the centerline and f is the distance of the point from the downstream centerline vertex, parallel to the centerline. The z coordinate is not transformed.

A hand-digitized centerline will be replaced in future versions with an automatically generated flow streamline. Since flow direction (not the line's exact location within the reach) is of primary importance, the position of the hand-digitized centerline does not significantly affect accuracy.

Coordinate transformation with respect to the channel centerline allows the natural cross-sectional shape of the river to be exploited in the interpolation. Recognizing that elevation gradients parallel to the direction of flow are small compared to elevation gradients perpendicular to flow, scatter points found upstream or downstream of an interpolant are given more importance than those scatter points found to either side of the interpolant (Chang and Yen, 2002; Julien and Wargadalam, 1995).

After transforming coordinates of each scatter point and mesh node, the MEBAA program performs the interpolation. Each mesh node is individually interpolated and a subset of bathymetry scatter points within a user-defined region near that current mesh node is generated. The MEBAA algorithm looks for a user-specifiable, minimum number of bathymetry points within successively larger user-specifiable bounding regions. When the minimum number of points is found, the mesh node elevation is calculated using an Inverse Distance Weighted average of the elevations of only the selected bathymetry points. The bounding regions are shown below in Figure 5.

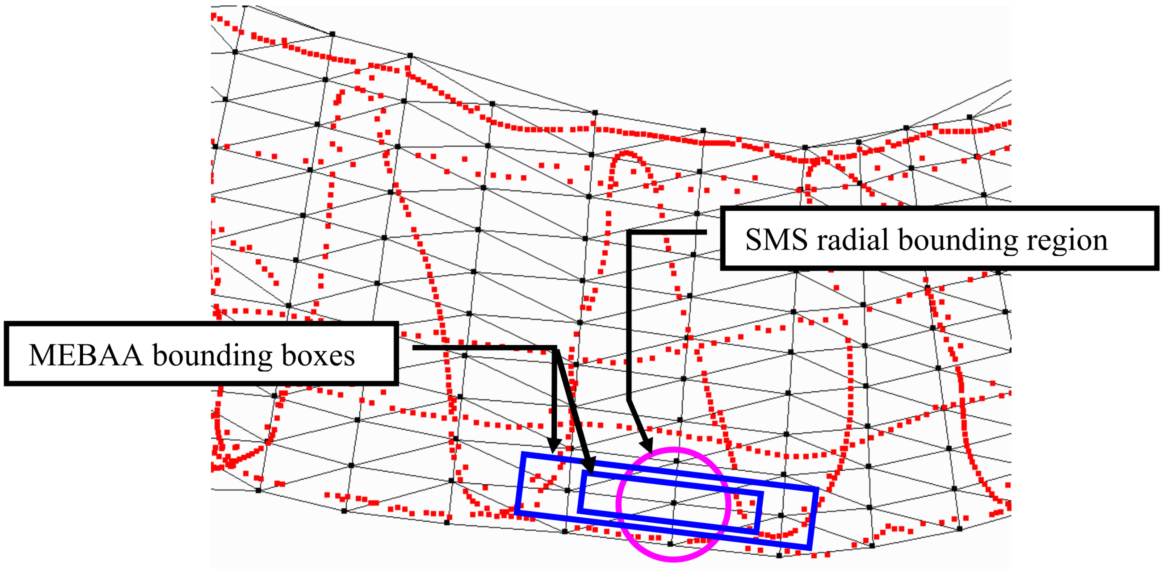

Figure 5. Combination of Figures 3 and 4 showing relationship of scatter points to mesh nodes.

The directional search pattern allows the mesh elevation routine to account for geomorphic processes. As shown, the rectangles are dimensioned to be longer in the flow direction and shorter in the direction perpendicular to flow; generally, bathymetry points located along the same streamline as the mesh node will have a more representative elevation than those bathymetry points collected on distant, parallel streamlines since bed processes act in the direction of flow. For example, a mesh node located in the center of a steep bank will have an elevation more similar to a second point 5m directly downstream than to a third point located 5m down the slope, closer to the center of the channel.

4. Methods and Results

Four different scatter point interpolation techniques are used on two scatter point sets to generate a total of eight surfaces. Three scatter point interpolation techniques are readily available for use inside SMS software: Linear, Natural Neighbor, and Inverse Distance Weighted (EMSI, 2002). These techniques are implemented inside SMS similarly to the implementation within ESRI's ArcGIS (ESRI, 2001), so the results of this analysis are equally applicable to surfaces generated in ArcGIS. Adequate mathematical description of each interpolation technique is included in the references given so further discussion is not presented as part of this paper; however, the fact that none of the techniques are capable of varying anisotropy over the spatial domain shall be noted. The fourth scatter point interpolation technique is the MEBAA technique that is the subject of this paper.

Two scatter point data sets are used for the analysis. The first set contains 39,496 unique data points that consist of position data (x and y projected to UTM zone 14N, WGS84 ellipsoid, in meters) and bed elevation data (z in meters above assumed datum). The bathymetric (bed elevation) scatter data was reduced from DGPS positions and marine echosounder depths collected on December 4 and 5, 2001 by two teams consisting of TWDB and Texas Parks and Wildlife Department personnel. The second scatter point set is identical to the first set, but has been reduced by 2 data points near Point 1, and 46 data points near Point 4, containing a total of 39,448 unique data points. These scatter data are removed to test the response of the output of each of the interpolation techniques.

The basis for each interpolated surface is a Finite Element mesh that is applied to a depth-averaged hydrodynamic model. The mesh consists of 48,283 nodes defining 23,368 triangular quadratic elements. Each node of each element is individually assigned an elevation by using an interpolation technique and the scatter point data.

Linear interpolation and Natural Neighbor interpolation do not have user-specifiable settings to control the interpolation technique. The only settings are those for extrapolation outside the bounds of the available scatter data set. Since the only two options given in SMS for extrapolation are fixed elevation and inverse distance weighted interpolation, the extrapolation function is ignored by setting the fixed out-of-bounds elevation at zero. These interpolation techniques do not allow for interpolation outside the bounds of available scatter point data and this shortcoming is illustrated in the following examples.

For the inverse distance weighted interpolation a fixed number of source points is required for each interpolant. The six scatter points nearest the interpolant are used for the interpolation. An anisotropic option available in ArcGIS is ignored because, as mentioned in the problem statement, anisotropy varies over the domain. An appropriate anisotropy in one area with flow in a particular direction is grossly inappropriate in another area where flow is in another direction. Options to find a specified number of points in each quadrant and to use all data points are not used.

Settings used in the MEBAA interpolation are shown in Table 1, below. A minimum of six scatter data points is used to determine the elevation for each interpolant. As many as 10 bounding regions are used to find the minimum of six points. Each region, whose size is described below in Table 1, is searched in succession. If at least six scattered data points are located inside a bounding region, the search stops and all located points are used to assign an elevation to the interpolant.

Number of Nodes	6
	Dimensions in meters
	width x length = dD x dF
Region 1	1.5 radius
Region 2	1.5 x 3.0
Region 3	1.5 x 5.0
Region 4	1.75 x 7.0
Region 5	3.06 x 12.25
Region 6	3.5 x 14
Region 7	5.25 x 21
Region 8	8.75 x 35
Region 9	12.25 x 49
Region 10	17.5 x 70

Table 1. Parameter settings for MEBAA interpolation algorithm.

Four mesh nodes are chosen for individual evaluation: Point 1, Point 2, Point 3, and Point 4. One point is chosen from each quadrant of flow direction; Point 1 is chosen in an area that flows north east, Point 2 is in an area that flows south east, Point 3 is in an area that flows south west, and Point four is in an area that flows north west. Testing one point in each quadrant ensures that the algorithm is functioning properly in each quadrant. The relative location of each point is shown in Figure 1.

Point 1 is located on the edge of the mesh in an area with good coverage of scatter point data. Figure 6 shows the point in relation to the surrounding Finite Element grid and to the scatter point data. Two interpolation scenarios are presented for this point: one scenario using all available data, and a second scenario that removes the two nearest scatter points (highlighted in Figure 7).

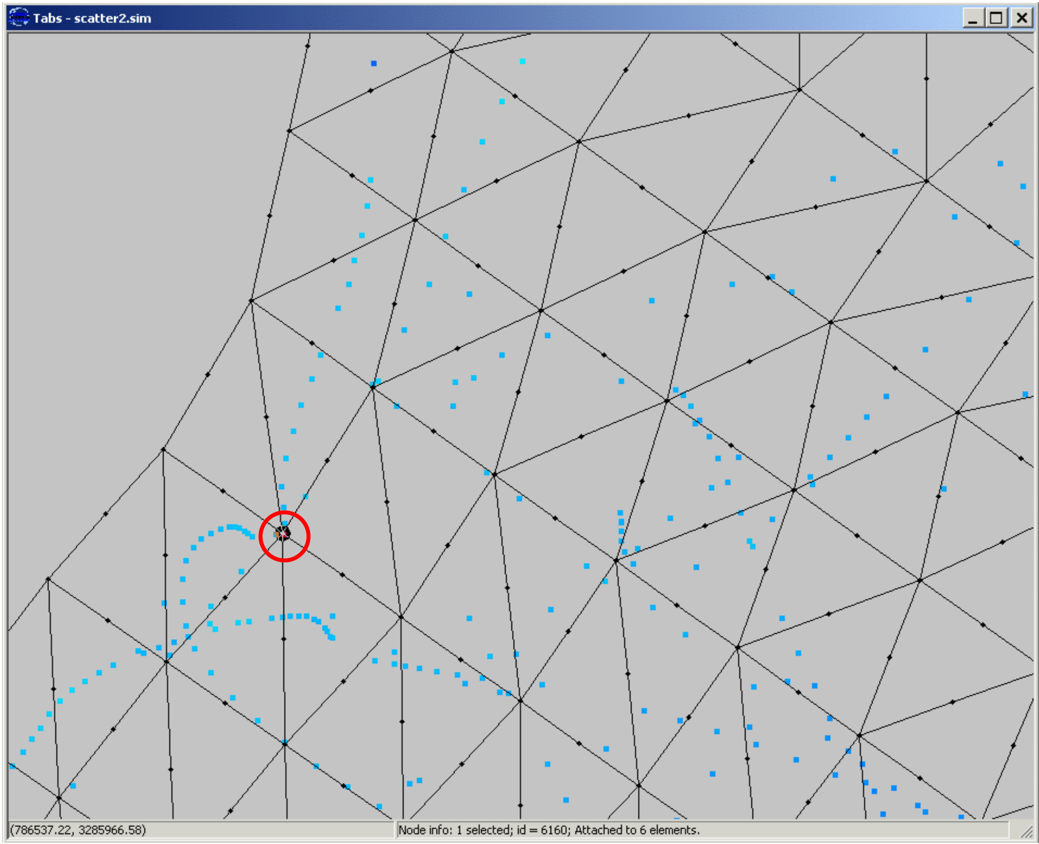

Figure 6. Point 1 area map, point 1 is circled. Scattered data points are shown in blue.

All four interpolation algorithms are applied to both the completed data set and the reduced data set. Resulting interpolant elevation for all points for all interpolation methods are shown in Table 2.

Point 2 best illustrates the utility of the MEBAA algorithm for areas of scarce data, as illustrated in Figure 8. Figure 9a shows elevation contours in the vicinity of Point 2 that have been generated by SMS inverse distance weighted interpolation. Figure 9b shows elevation contours generated using MEBAA; note the smooth contours and absence of artificial humps that follow areas of scarce data.

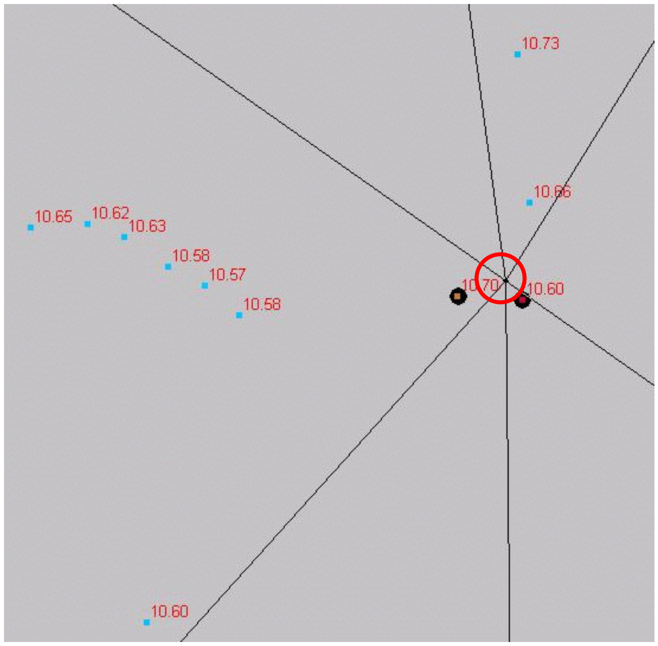

Figure 7. Point 1 closeup map. The two high-lighted scatter points are removed from the scatter set 2 and point 1 is circled.

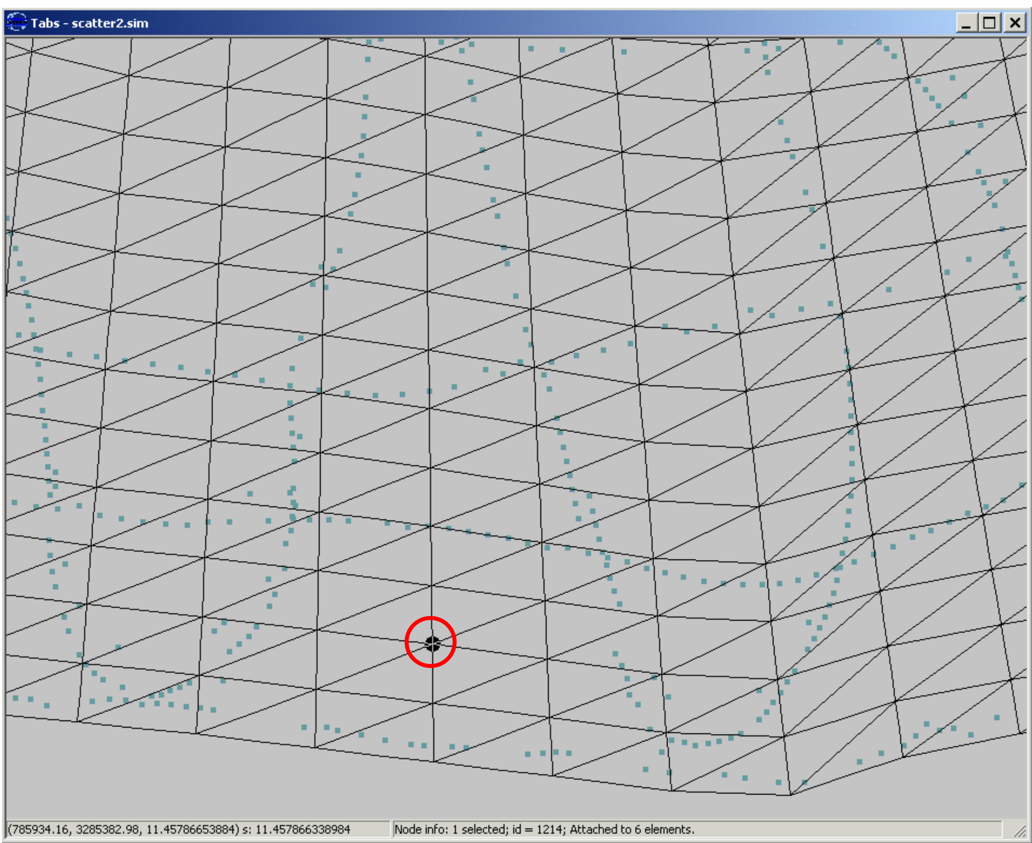

Figure 8. Point 2 closeup map, note the sparse scatter data near point 2 (circled).

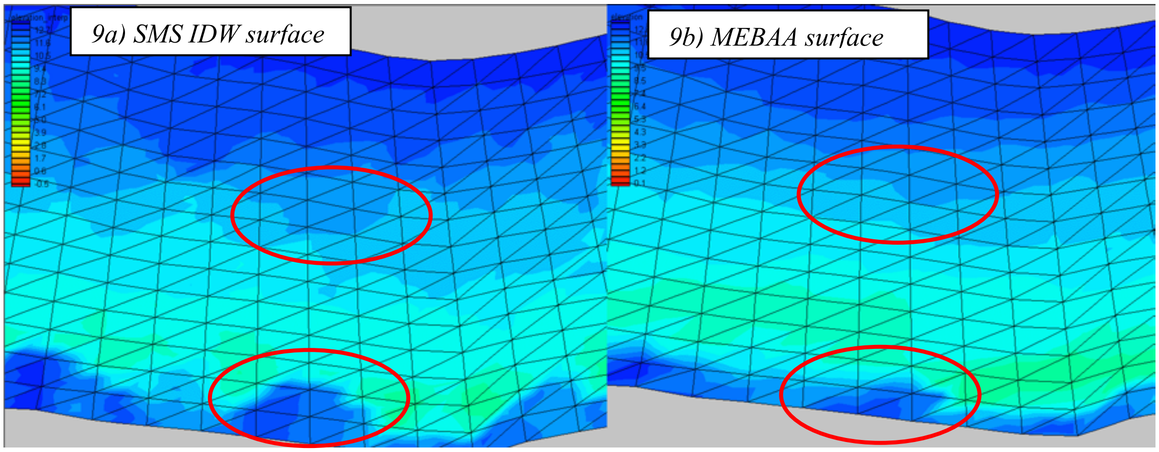

Figure 9. a) Surface generated by SMS IDW interpolation. b) Surface generated with MEBAA.

Point 3 was chosen at random in an area where flow direction is south west. The point lies on the edge of the mesh outside of the range of the scattered data, so the Linear and Natural Neighbor algorithms are not able to assign an elevation. SMS IDW and MEBAA perform similarly and both assign reasonable elevations.

Point 4 elevation is evaluated with both a complete data set and with a reduced data set. The complete data set evaluation allows comparison of interpolant elevation under ideal conditions for all interpolation algorithms. Reduction of scatter data allows comparison of each interpolation algorithm's reaction to the reduction as well as evaluation of each algorithm's utility with sparse data. Figure 10 shows Point 4 and all of the data points that are removed from the second scatter set.

Table 2 contains the resulting elevation at each point as interpolated by each algorithm. Point 1 shows that all interpolation algorithms do an adequate job of assigning a reasonable elevation in areas with adequate scatter data. All elevations are within the tolerance of the measurement instruments, and for the reduced data set, the SMS IDW and MEBAA interpolated elevation is approximately the same as the average of the elevation of the scatter points that were removed (see Figure 7). Linear and Natural Neighbor interpolations break down since the interpolant lies outside of the domain of the reduced scatter data set.

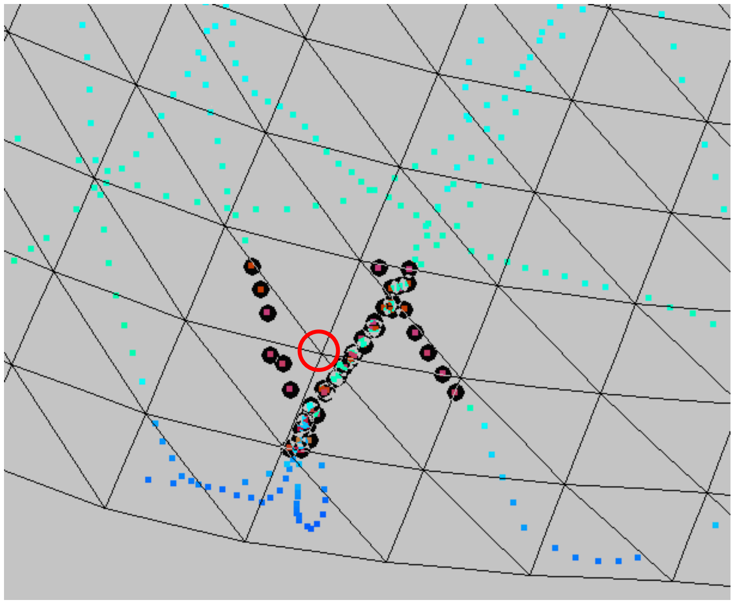

Figure 10. Scatter data near Point 4. Highlighted data points are removed from second set and Point 4 is circled in red.

			Elevation (meters above assumed datum)							
			IDW		Linear		NN		MEBAA	
Point	Quadrant	Mesh Node	complete	reduced	complete	reduced	complete	reduced	complete	reduced
1	1	6160	10.6353	10.6648	10.6411	0	10.6305	0	10.6207	10.661
2	2	1214	12.062	x	10.9213	x	10.8638	x	9.0091	x
3	3	33963	11.5799	x	0	x	0	x	11.4716	x
4	4	38664	8.7135	10.9235	8.724	0	8.6344	0	8.7215	9.2558

Table 2. RESULTS: Interpolant elevations for each algorithm at each Point.

Elevations shown for Point 2 vary widely between the data sets. Linear and natural neighbor agree, but both SMS IDW and MEBAA are significantly different. The MEBAA elevation is deemed quite a bit more reasonable by applying a priori knowledge of the bathymetry. SMS IDW assigns an elevation as high as the surrounding bank, whereas MEBAA assigns an elevation more representative of the bottom of the channel.

All schemes assign a similar elevation to Point 4 using the complete data set; however, the reduced data set shows that Linear and Natural Neighbor are not able to assign an elevation. SMS IDW assigns an elevation that is much higher (more than 2m) than the elevation assigned using the complete set and appears to be heavily influenced by point that lie near the bank. Using the reduced data set, MEBAA assigns an elevation that is higher than that for the complete set, but the difference is only ½ meter higher.

5. Discussion and Conclusions

Use of MEBAA has clearly shown the utility of (1) using coordinate systems that coincide with river planform and (2) anisotropic search spaces for bathymetric scatter point interpolation. The MEBAA routine performed better than the three other interpolation algorithms tested in this paper. For situations where fine resolution scatter point data is available, all interpolation routines performed equally well and assigned a similar elevation. SMS IDW and MEBAA outperformed both Linear and Natural Neighbor algorithms in situations where an interpolant is not surrounded by scatter data. MEBAA, utilizing an anisotropic search space based upon flow direction, outperforms the Cartesian-fixed SMS IDW interpolation in regions where scatter data is sparse. More validation and verification of the MEBAA algorithm is required before widespread use, and more refined search space techniques can further improve the elevation assignment of MEBAA.

The ability to use sparse data sets for interpolating fine-scale meshes is important because it reduces resources required to collect accurate bathymetric data and improves the accuracy of any analysis that requires use of bathymetric data. More work is needed that illustrates the importance of coordinate systems that follow natural river plan forms and that streamlines the use of such coordinate systems; their use is beneficial for channel hydraulic studies, sediment transport studies (Chang and Yen, 2002; Merigliano, 1997), and even planning-level models (Allen, et al, 1994). The power, popularity, and ease-of-use of GIS software enable users to further develop the understanding of geospatial systems.

References

P. M. Allen, J. G. Arnold, and B. W. Byars. "Downstream channel geometry for use in planning-level models," *Water Resources Bulletin*, 30 (4), 663-671 (1994).

A. Basu and S. Malhotra. "Error detection of bathymetry data by visualization using GIS," *Journal of Marine Science* 59, 226-234 (2002).

A. K. Chaturvedi and L. A. Piegl. "Procedural method for terrain surface interpolation," *Computers and Graphics* 20 (4), 541-566 (1996).

S. Chang and C. Yen. "Simulation of Bed-Load Dispersion Process," *Journal of Hydraulic Engineering*, 128 (3), 331-342 (2002).

D. W. Crowder and P. Diplas. "Using two-dimensional hydrodynamic models at scales of ecological importance," *Journal of Hydrology* 230, 172-191 (2000).

D. D. Dunn, and T. H. Raines. "Indications and Potential Sources of Change in Sand Transport in the Brazos River, Texas," U.S. Geological Survey, Water-Resources Investigations Report 01-4057, Austin, Texas (2001).

Environmental Modeling Systems, Inc. "Online help reference for Surface Water Modeling System" (2002).

ESRI, Inc. "Online help for ArcGIS 8.1" (2001).

B. Donnell, et al. "Users Guide to RMA2 WES version 4.3," United States Army Corps of Engineers-Waterways Experimentation Station (1997).

R. Franke and G.M. Nielson. "Smooth interpolation of large sets of scattered data," *International Journal for Numerical Methods in Engineering* 15, 1691-1704 (1980).

R. Franke. "Scattered Data Interpolation: Tests of Some Methods," *Mathematics of Computation* 38 (157), 181-200 (1982).

P. Y. Julien and J. Wargadalam. "Alluvial Channel Geometry: Theory and Applications," *Journal of Hydraulic Engineering*, 121 (4), 312-325 (1995).

M. Leclerc, A. Boudreault, J. A. Bechara, and G. Corfa. "Two-Dimensional Hydrodynamic Modeling: A neglected Tool in the Instream Flow Incremental Methodology," *Transactions of the American Fisheries Society* 124 (5), 645-661 (1995).

M. Leclerc, and J. Lefleur. "The Fish Habitat Modeling with Two-Dimensional Hydraulic Tools: a Worthwhile Approach for Setting Minimum Flow Requirements?" Presented at *Instream & Environmental Flow Symposium, Houston, Texas* (1997).

L. B. Leopold. Water, Rivers and Creeks. University Science Books, Sausalito, 1997.

Y. Li, A. J. Brimicombe, and M. P. Ralphs. "Spatial data quality and sensitivity analysis in GIS and environmental modeling: the case of coastal oil spills," *Computers, Environment, and Urban Systems* 24, 95-108 (2000).

M. F. Merigliano. "Hydraulic Geometry and stream channel behavior: An uncertain link," *Journal of American Water Resources Association*, 33 (6), 1327-1336 (1997).

H. Park and K. Kim. "An adaptive method for smooth surface approximations to scattered 3D points," *Computer-Aided Design* 27 (12), 929-939 (1995).

N. G. Plant, K. T. Holland, and J. A. Puleo. "Analysis of the scale of errors in nearshore bathymetric data," *Marine Geology* 191, 71-86 (2002).

D. Shepard. "A two-dimensional interpolation for irregularly spaced data," In *Proceedings 23rd ACM National Conference*, 517-524 (1968).

Trimble, Inc. "GPS Pathfinder Office 2.90, online help" (2001).

United States Geological Survey. "PHABSIM for Windows, Users Manual and Exercises; Mid-continent Ecological Science Center, Open File Report 01-340" (2001).

R. L. Vadas and D. J. Orth. "Use of physical variables to discriminate visually determined mesohabitat types in North American Streams," *Rivers* 6 (3), 143-159 (1998).

M. W. Wentzel and B. N. Austin. "Fish Habitat Modeling for Instream Flow Assessment, combining 2-D hydrodynamic and GIS modeling," In *Proceedings 4th International Conference on Integrating GIS and Environmental Modeling (GIS/EM4)* (2000).

Y. Xiao, J. P. Ziebarth. "FEM-based scattered data modeling and visualization," *Computers and Graphics* 24, 775-789 (2000).