Appendix A

KCM Hydraulic Modeling Memoranda

Technical Memorandum **KCM**

Date:	June 19, 1997
To:	David Davidson City of Sumas 433 Cherry Street Sumas, WA 98295
c:	*Tony Melone (KCM)* *Central Files*
From:	Greg Gaasland
Project No.:	2640040-001
Subject:	Hydraulic Modeling Technical Memorandum

This Technical Memorandum summarizes the hydraulic modeling performed by KCM as part of a floodplain management investigation for the City of Sumas. The modeling was conducted for existing conditions in the City and for a flood with a return period of 100-years. The 100-year flood analysis included the effect of landfill associated with industrial development located to the west of the city center and the Burlington Northern Railroad (BNRR). This is discussed in greater detail later in this memo.

MODEL DESCRIPTION

Flood flows through the City of Sumas were analyzed using a numerical model referred to as FESWMS. This model is a Finite Element Surface Water Modeling System for two-dimensional flow in a horizontal plane. Version 2.0c of the model was used in conjunction with the pre- and post-processor software called the "Surface water Management System" (SMS) developed and supported by Brigham Young University (BYU). The FESWMS software is in the public domain and is available from the Federal Highway Administration. The SMS software is proprietary and is available for purchase from BYU.

The FESWMS model requires a three-dimensional representation of the topography of the study area. This information was gathered from topographic mapping with 2-foot contours prepared for Whatcom County by Walker and Associates in 1993. Using the topographic information, the study area in the model was represented by a grid of rectangles and triangles that creates a surface over which the numerical calculations are based. The grid initially developed as part of the Nooksack River Comprehensive Flood Hazard Management Plan (Nooksack River CFHMP) was used as a starting point for the City of Sumas model. The grid generated as part the Nooksack River CFHMP was further refined to provide greater detail within the City limits and the surrounding area.

The size of the grid elements are governed by the rate of change of topography, the level of detail that is required for a particular area, the anticipated flow paths, and unique features that require special considerations. The model for the City of Sumas was complicated by the numerous creeks and river (Sumas Creek, Johnson Creek, Bone Creek, and the Sumas River), the sinuosity of these drainages, and the numerous railroad embankments. The railroad embankments are critical features affecting how flood flows are conveyed to and through the City of Sumas. Also, the model must be structured to properly represent the potential overtopping of the embankments.

The grid developed for the City of Sumas consists of 7,180 nodes and 2,094 elements. Figure 1 depicts the grid used in this analysis.

THE FLOOD EVENTS

Two flood events were analyzed in this project. These include the November 10, 1990 flood (approximately a 50-year flood) and the 100-year flood (FEMA 1984[1]). To model these events require "boundary conditions". In FESWMS modeling, these boundary conditions are the incoming flow rate in the creeks and rivers at the upstream end of the model and water surface elevation for the downstream end of the model. The downstream end of the model for this analysis is about 800-feet beyond the United States/Canadian international border.

Model Calibration

Calibration is a standard procedure in model development in which input parameters are adjusted until model results reproduce flood levels that have actually occurred in the past. Once a model is calibrated it can be applied to predict flood levels for other floods. The City of Sumas model was calibrated to flood levels that occurred during the November 10, 1990 flood.

During that flood, the City recorded over a dozen high water marks in and around town. With this information and the overflow flow rate estimated from the Nooksack River at Everson, adjustments were made to the model so that the model closely duplicated the November 10, 1990 flood. Typical adjustments during calibration include modifying the surface roughness of the land over which the water flows during the flood. For example, a surface such as forested land has a greater roughness than farmland lying fallow. The calibration involves changes to the roughness of these surfaces to represent the local situation.

Flood Flows

Flood flows reaching the City of Sumas are based on the overflow of the Nooksack River at Everson and to a lesser extent by the flow contributions of local creeks and the Sumas River. Due to flow attenuation that occurs as the flood wave travels from Everson to Sumas, the peak overflow rate at Everson is greater than the peak flow that reaches the City of Sumas. A separate one-dimensional unsteady flow model (FEQ) was developed for the City that estimated the peak flow rate reaching Sumas (Linsley, Kraeger Associates, Ltd., 1997[2]). The FEQ model predicted that the peak overflow reaching Sumas for the 1990 flood was

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[1] Federal Emergency Management Agency, Flood Insurance Study, City of Sumas, Washington, Whatcom County, November 15, 1984

[2] Dr. Delbert D. Franz, Modeling of the Nooksack-Fraser Overflow Corridor, Linsley, Kraeger Associates, Ltd., June 11, 1997

approximately 6,560 cfs. The total overflow at Everson from the Nooksack River, including flow in Johnson Creek, was estimated at 7,450 cfs.

The FEQ model was also used to estimate the effect of the hay bale partial blockage and the subsequent railroad embankment failure on the Sumas Creek crossing near Third Street. The effect of this blockage is estimated to be about a 0.5-foot increase in flood depth on the upstream side of the railroad embankment. Once the embankment failed, the resulting flood surge raised flood elevations in town by approximately 0.15-feet. The FESWMS model was calibrated to the adjusted high water elevations during the November 10, 1990 flood in order to eliminate the effects of the blockage.

The 100-year flood flows at Sumas were based upon the adopted FEMA Flood Insurance Study value of 8,520 cfs (including Johnson Creek).

Flood Elevations

The water surface elevation near the U.S./Canadian border is another critical element in the modeling. This water surface elevation is termed the downstream boundary condition. The 1990 flood produced high water marks in Sumas; additional high water information was obtained from B.C. Environment for high water marks in the Huntingdon vicinity. Flood elevations for the 100-year flood were based upon the adopted November 15, 1984 FEMA Flood Insurance Study values.

The flood elevation at the border is controlled by numerous factors. These include the shape and magnitude of the flood wave, the pumping capacity of the Barrowtown pump station which is used to pump flood water into the Fraser River, and the flow rate in the Sumas River and its tributaries (including Johnson and Sumas Creek). The Canadians are performing an hydraulic/hydrologic analysis of the Nooksack River overflow as it exits Sumas and enters and impacts Canada. Their analysis will use information from the one-dimensional unsteady flow model that was developed for the City. The unsteady flow model provides an estimate of the flood peak reaching Sumas and the flood peak at the U.S./Canadian border.

Another ongoing task currently underway in Canada affecting selection of boundary condition water levels at the U.S./Canadian border is revision of the flood-frequency relationship for the Sumas River at Huntingdon. This relationship provides both the magnitude of flood flows in the Sumas River and the corresponding flood level at the border. With the existing flood-frequency relationship, there is uncertainty in the magnitude of flow in the Sumas River for the large magnitude (less frequent) flood flows. To further compound the uncertainty, the Sumas River bank-full flow contains only about the 2-year flood prior to overtopping its banks. This analysis is currently ongoing in Canada and may eventually revise the Sumas River 100-year flood adopted by FEMA.

The recorded water surface elevation near the U.S./Canadian border during the November 10, 1990 flood was 33.14 feet. The 100-year flood boundary elevation was established from the existing FEMA maps for the Sumas area. An elevation of 37.0 feet was taken and used for modeling the 100-year flood.

A summary of the boundary conditions of the major inflows and outflow water surface elevations are provided in Table 1 below.

Table 1
Summary of Boundary Conditions

Flood Event	Everson Overflow at Sumas	Water surface elevation at the U.S./Canadian border
1990 (LKA, 1997)	6,560 cfs	33.14 feet
100-year (FEMA, 1984)	8,520 cfs	37.0 feet

In addition to these major flows from the Everson overflow are the minor inflows due to the Sumas River, Johnson Creek, Sumas Creek, and Bone Creek. The Sumas River inflow can be estimated from the Canadian flood-frequency analysis. However, the Canadian frequency analysis does not include Nooksack River overflow effects and it is currently under revision. The frequency analysis is based only on the normal tributary watershed of the Sumas River. Consequently, the adopted 1984 FEMA value was used for the 100-year flood (3,225 cfs upstream of the confluence with Johnson Creek) and the flow predicted by the 1-D modeling for the 1990 flood (1,140 cfs). Sumas Creek was assigned a flood flow near Kneuman Road west of Sumas of 100 and 120 cfs for the 1990 and 100-year floods, respectively.

Base flows into Johnson Creek and Bone Creek were assumed to be a minor component of the total Everson overflow flood flow. The Everson overflow flood flow enters both the Johnson Creek and Bone Creek drainage systems which passes through Sumas (in the case of Johnson Creek) or south of Sumas (in the case of Bone Creek). The apportionment of the Everson flood flow into these drainages were calculated internally by the model for the floods.

CALIBRATION

The 2-D FESWMS model was calibrated using sixteen high water marks which were recorded following the November 10, 1990 flood. Three of these points are located west of the Burlington Northern Railroad embankment and the remainder are located east of the tracks to the Sumas River and between Front Street and the Canadian border. Table 2 summarizes these calibration points.

The 1990 flood created a unique situation at the Sumas Creek crossing of the BNRR embankment. The flood waters carried hay bales and lumber from upstream property and created a partial blockage of this passage forcing additional ponding of flood water behind the embankment. Ultimately, the railroad embankment failed which created a surge of flood water that entered the business district. The effect of this condition, based upon estimated degree of blockage and time and rate of the embankment failure, was about 0.5-foot increased depth upstream of the embankment and 0.15-foot increased depth downstream of the embankment following the embankment failure. These values were estimated from the 1-D unstready flow analysis using the FEQ model with anecdotal information and photos of the flood.

The 2-D FESWMS steady flow model calibration was based upon a stable embankment without blockage of any of the crossings. This was done in order to assure that representative physical conditions would be utilized in the analysis of the 100-year flood. Therefore, during the 1990 flood, in order to compare the recorded high water marks with the predicted elevation from the FESWMS model, it is necessary to adjust the predicted water surface elevations by the values discussed above.

Table 2
Calibration Points

Identifier	Recorded Water Elevation (ft)	Description/Location
S-1	39.6	Middle of the block bounded by Front St./Morton St. and Cherry St./Sumas Ave.
S-2	43.5	On Johnson St. 200 feet north of Halverstick Road
S-3	43.5	Mid-field on the projected alignment of Johnson St. and the mid-point of the projection of Columbia St. and Vancouver St.
S-4	40.2	On Sumas Ave. between Mitchell St. and Vancouver St.
S-5	43.6	At the intersection of Third St. and Johnson St.
S-6	40.8	At the intersection of Second St. and Sumas Ave.
S-7	40.4	On Garfield St. mid-block between Railroad St. and Cherry St.
S-8	37.4	At the intersection of Sumas Ave. and Harrison Ave.
S-9	38.5	At the intersection of Gough St. and Garfield St.
S-10	37.8	On First St. 300 feet east of Gough St.
S-11	38.9	On Third St. 400 feet east of Lawson St.
S-12	38.7	180 feet west of Victoria St. between Morton St. and Mitchell St.
S-13	39.0	At the intersection of Gough St. and Mitchell St.
S-14	40.6	At the intersection of Lawson St. and Front St.
S-15	36.7	At the intersection of Harrison Ave. and Gough St.
S-16	33.14	Sumas River gauging station in B.C.

The calibration process typically involves adjustment to the surface roughness characteristics of the land over which the flood waters pass. The results of the calibration process are summarized in Table 3 below. A difference between predicted and observed water surface elevation of 0.1 feet corresponds to 1.2-inches.

With the exception of points S-6, S-7, S-9 and S-14, the calibration results are very good. These four points, however, are surrounded by other points which were predicted by the FESWMS model much more accurately. For these four points, it is possible since each observed water surface elevation was higher than the predicted value, that local conditions (such as a wave set-up that may occur as the flood waters strike a building) occurred which would result in an elevation not representative of the surrounding water surface. Therefore, these four values are suspect and the model was not forced to duplicate these apparent outliers which would be at the expense of decreased accuracy for the remaining 12 points.

Table 3
Calibration Results
Elevation in Feet

Identifier	Observed WSE*	Model Prediction (No Blockage) WSE	Blockage Correction	Model Prediction (with Blockage) WSE	Difference (predicted (w/blockage) - observed)
S-1	39.6	39.9**	0.15	40.05	0.45
S-2	43.5	43.0	0.50	43.5	0.00
S-3	43.5	42.9	0.50	43.4	-0.10
S-4	40.2	39.8	0.15	39.95	-0.25
S-5	43.6	42.9	0.50	43.4	-0.20
S-6	40.8	39.2	0.15	39.35	-1.45
S-7	40.4	39.1**	0.15	39.25	-1.15
S-8	37.4	37.8	0.15	37.95	0.55
S-9	38.5	36.7	0.15	36.85	-1.65
S-10	37.8	37.0	0.15	37.15	-0.65
S-11	38.9	38.6	0.15	38.75	-0.15
S-12	38.7	38.5	0.15	38.65	-0.05
S-13	39.0	38.7	0.15	38.85	-0.15
S-14	40.6	39.2	0.15	39.35	-1.25
S-15	36.7	36.1	0.15	36.25	-0.45
S-16	33.14	33.15	0.00	33.15	0.01

*WSE = water surface elevation

**Observed point located in inactive model cell, value estimated from nearby results.

SUMMARY OF MODEL RESULTS

Modeling results are presented in terms of isolines depicting contours of water surface elevation and velocity vectors that depict the magnitude and direction of the flood flows. Velocity vectors are arrows that point in the direction of flow, and the length of the arrow represents the speed of the flow.

Flood elevations and velocity vectors are presented for the 1990 and 100-year flood flows. This is one type of graphical representation of the computer output from the FESWMS model. Large scale (1"=200') color graphics of model results were also developed and are on file with the City of Sumas.

November 10, 1990 Flood

The results for the November 10, 1990 flood are shown in Figures 2 and 3. The Burlington Northern Railroad embankment is not overtopped although in many locations, especially near the Canadian border and at Second Street crossing, it is within about 1-foot. No railroad overtopping is occurring at the Bone Creek crossing although overtopping is close to occurring. Higher velocity flooding occurs west of the BNRR embankment to Johnson Creek and once in the City, generally in a northeastern direction east of Gough Street across the border.

Isolated dry islands are scattered both east and west of the Burlington Northern Railroad embankment. In general, the driest area is south of Front Street between the BNRR embankment and the Sumas River.

100-Year Flood

The analysis of the 100-year flood included the effect of anticipated filling of the industrial zoned areas west of the business district, generally between Garrison Road (SR 9) and the BNRR on both the north and south sides of Halverstick Road. Figure 4 identifies this area. The anticipated filling will raise the ground elevations to above the level predicted for the 100-year flood. Consequently, this removes this area from the flood flow path and the model was modified to represent this effect.

The results for the 100-year flood are shown in Figures 5 and 6. Some overtopping of the BNRR embankment is predicted. BNRR embankment overtopping is predicted near the Canadian border to north of the Front Street crossing. Overtopping was not predicted in the vicinity of the Bone Creek crossing but was at the threshold of overtopping.

Higher velocity flow paths are similar to those seen during the 1990 flood. However, due to the high boundary conditions imposed near the Canadian border for the 100 year flood, the flood depths are higher, resulting in a reduction of velocity close to the border.

Few dry islands are predicted for the existing developed portions of downtown Sumas. The driest area is again south of Front Street between the BNRR embankment and the Sumas River. However, bank overtopping from the Sumas River has reduced the total dry area that occurred during the 1990 flood.

List of Figures

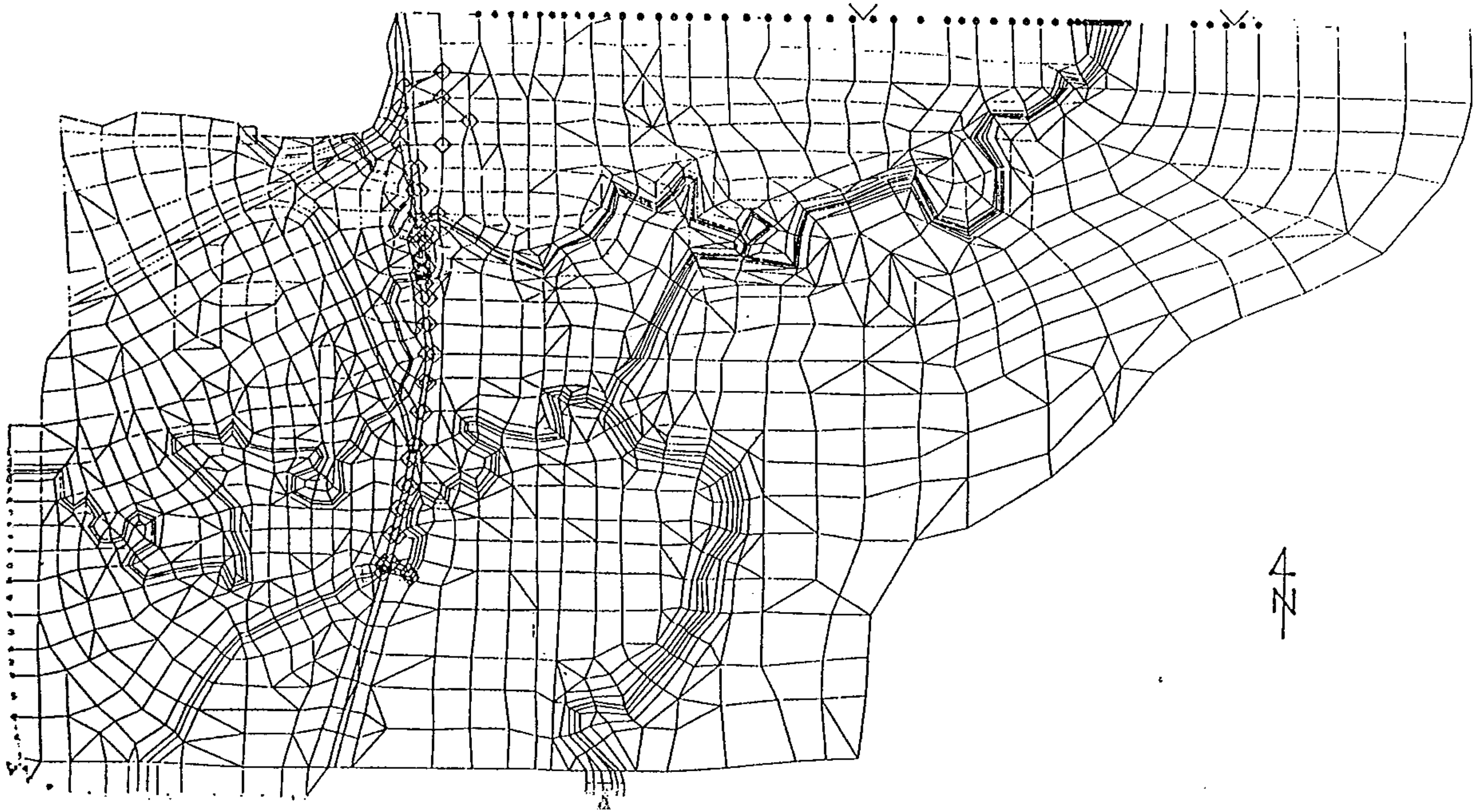

Figure 1
Grid Elements for the FESWMS Model

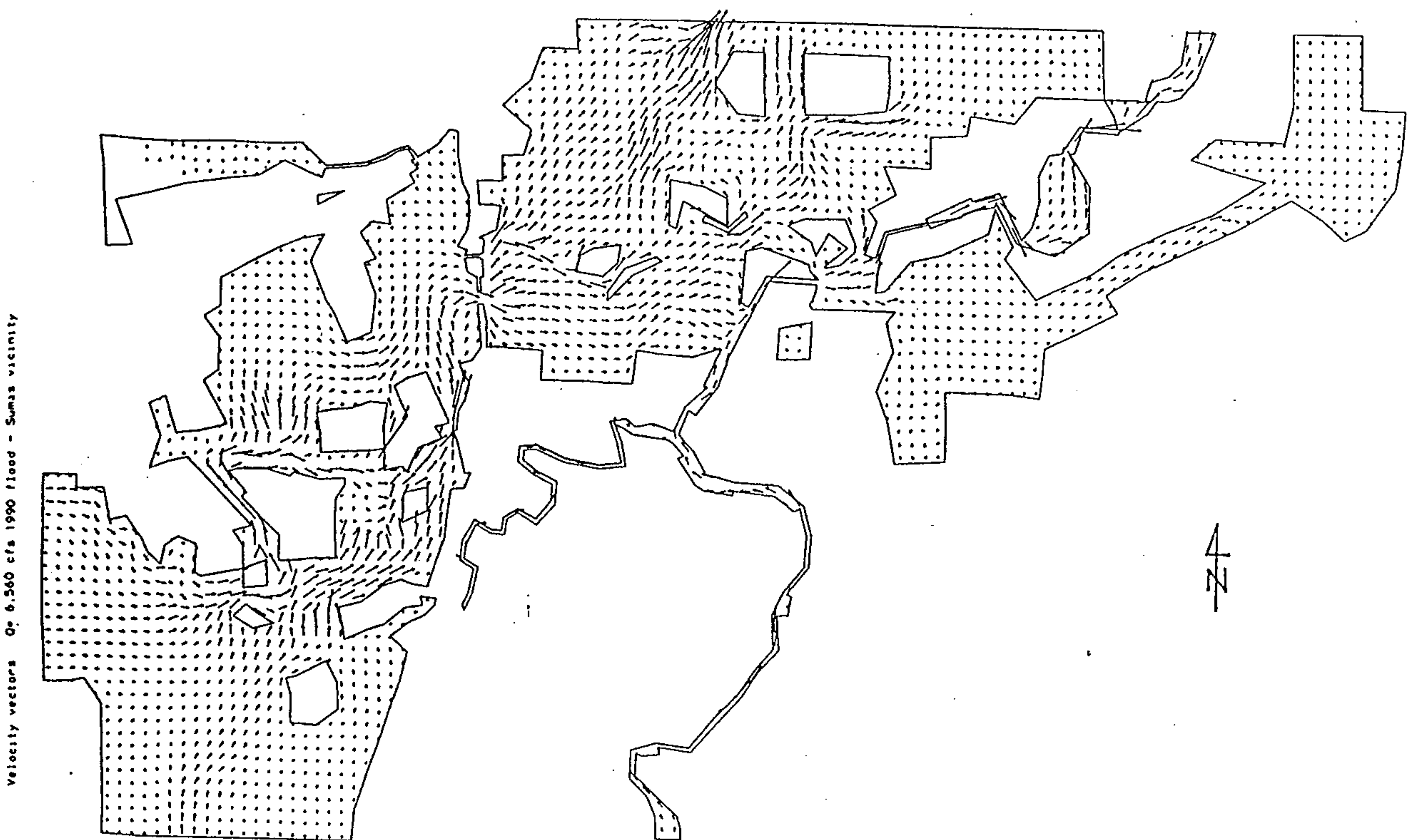

Figure 2
Velocity Vectors for the November 10, 1990 Flood

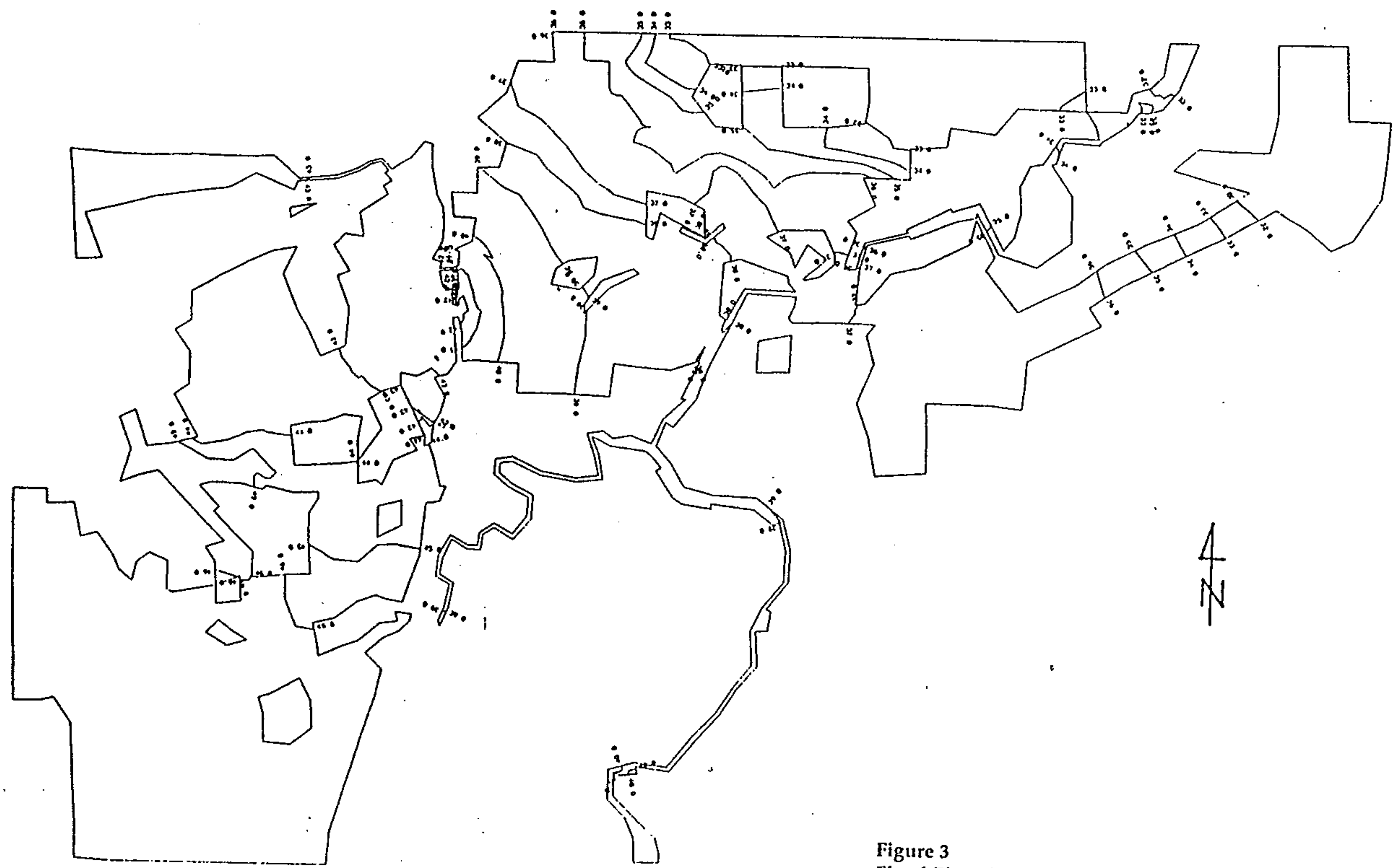

Figure 3
Flood Elevations for the November 10, 1990 Flood

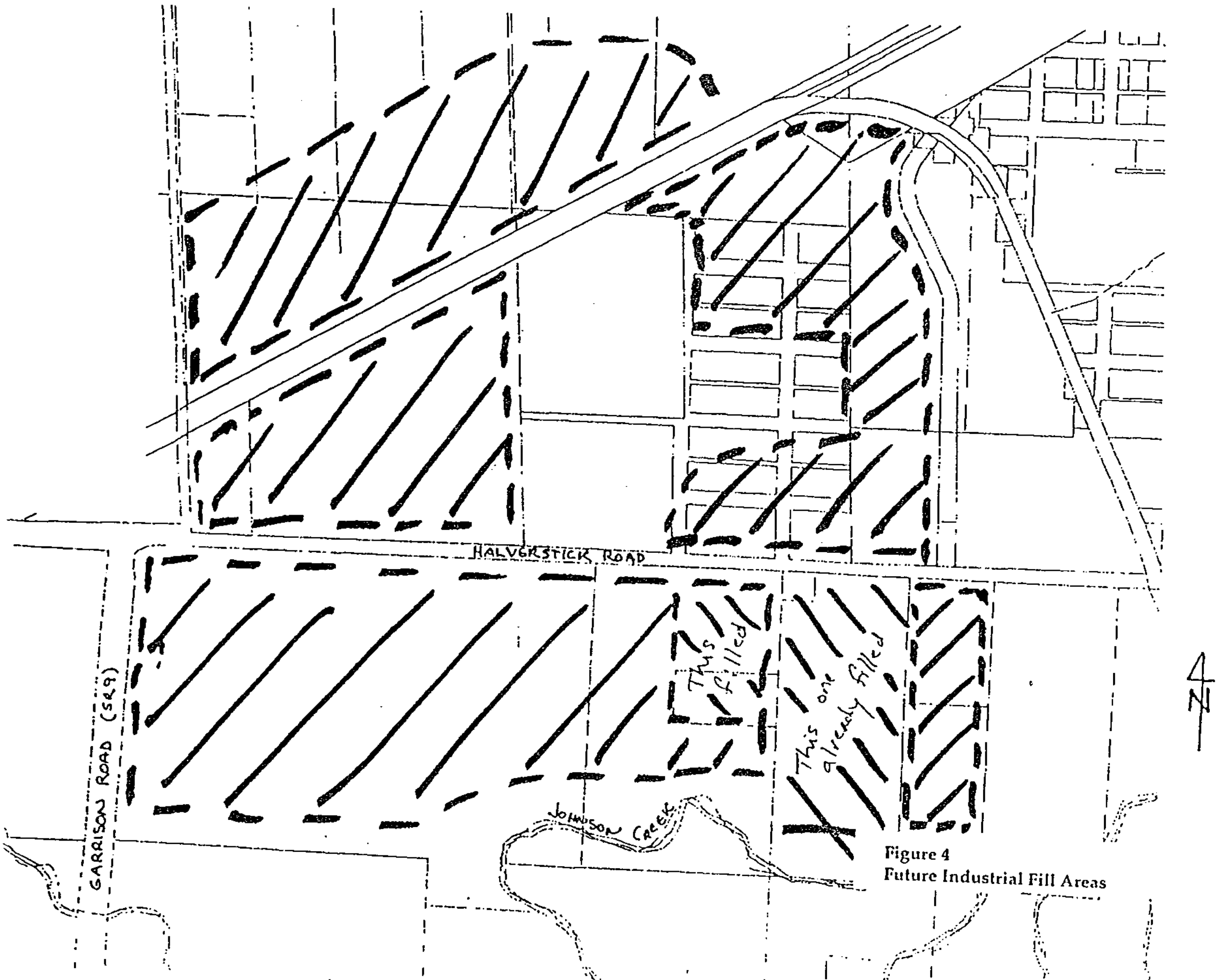

Figure 4
Future Industrial Fill Areas

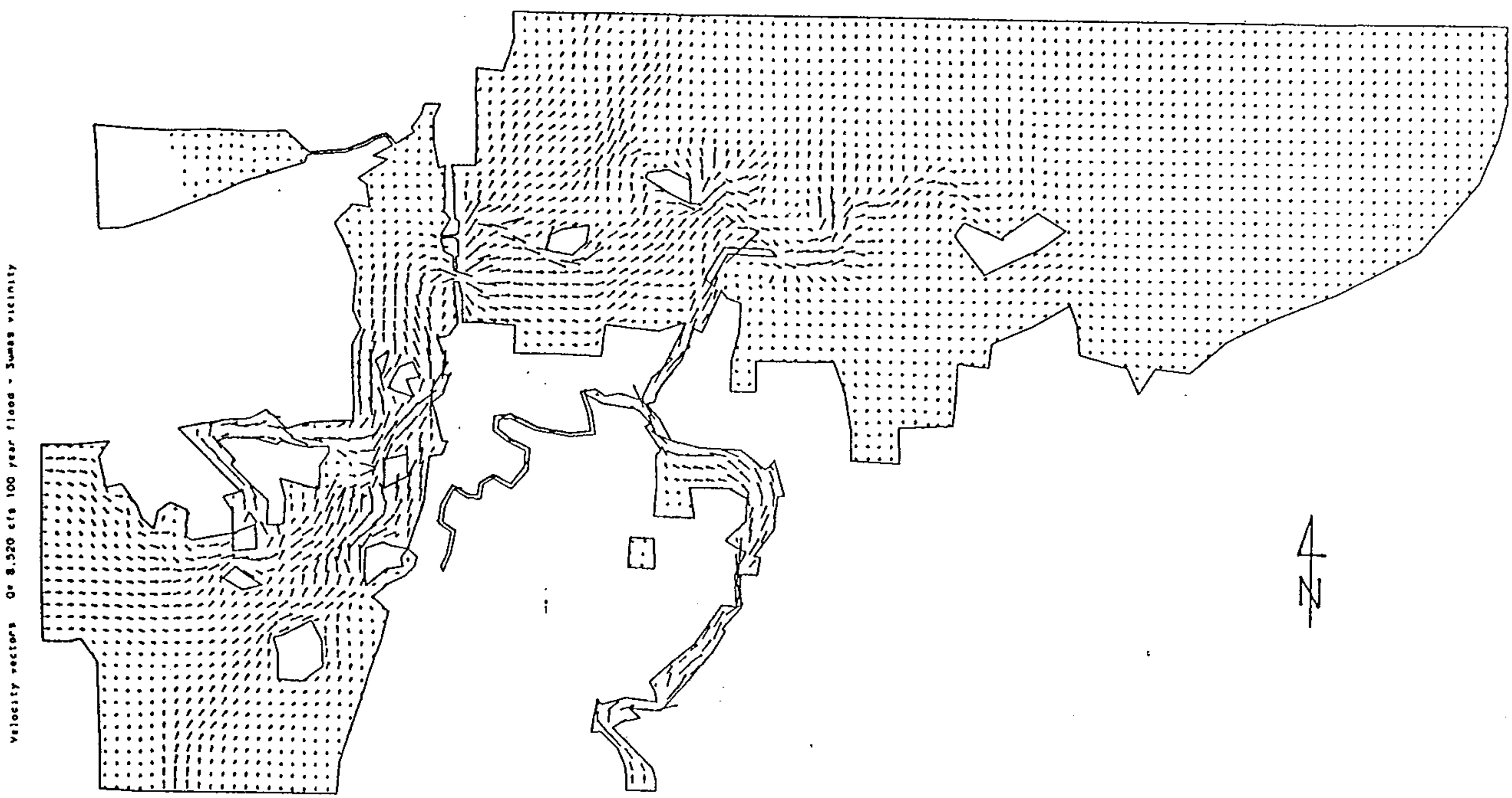

Figure 5
Velocity Vectors for the 100-Year Flood

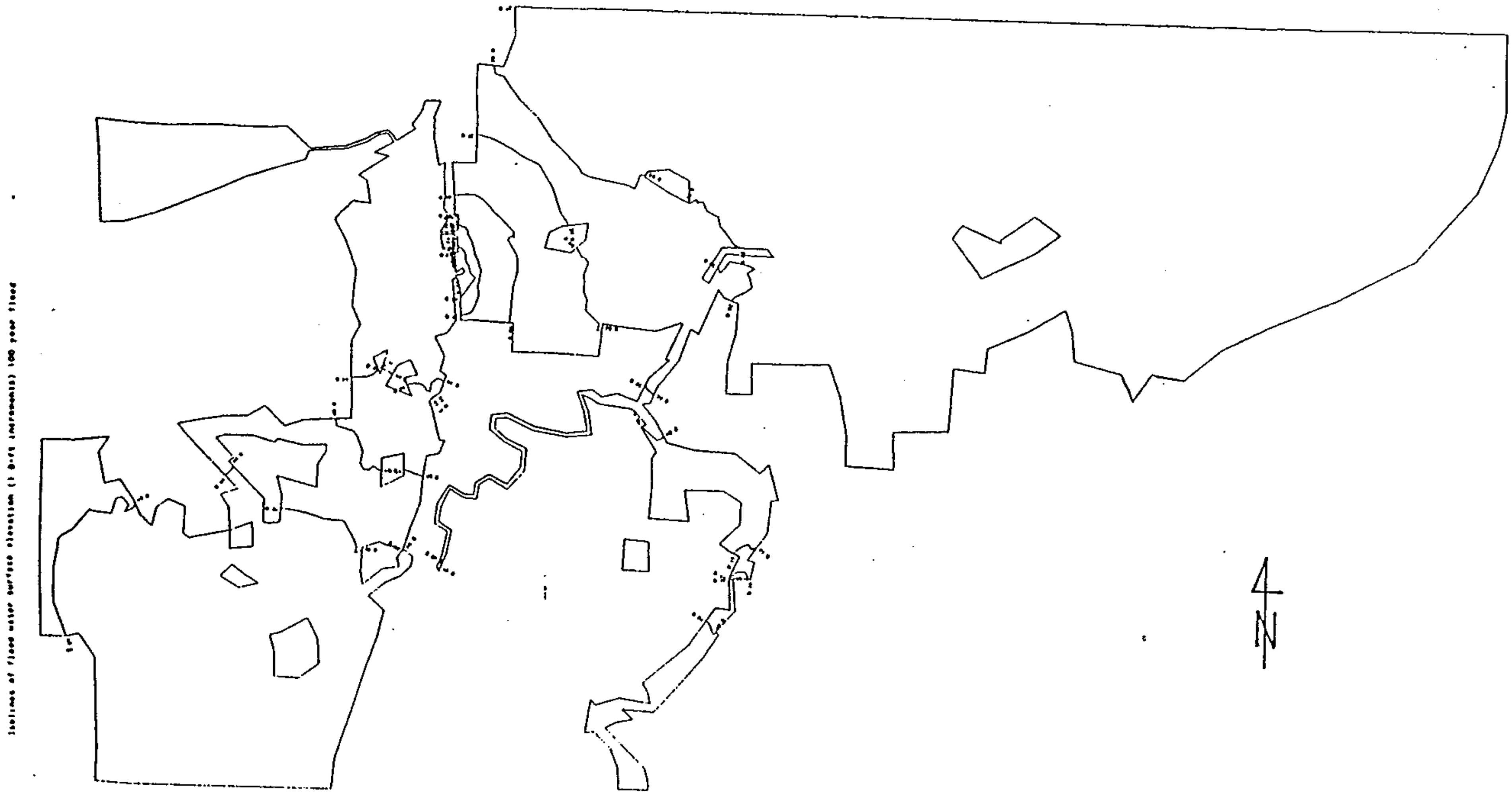

Figure 6
Flood Elevations for the 100-Year Flood

Memo

KCM

Date:	July 8, 1997
To:	Project File
c:	*Tony Melone, David Davidson (Sumas), Central Files*
From:	Greg Gaasland
Project No.:	2640040-001
Subject:	Comparison of industrial area blockage versus no blockage

To observe the influence of the proposed industrial block-out area (west of the railroad around Halverstick Road) to the condition of no industrial block-out, the 100-year flood was run using FESWMS v2c for these two conditions. Both model runs used the same inflow (overflow from Everson and Sumas River flow) and the same tailwater elevation (FEMA, WSE 37'). The only difference was removing a large portion of the northwest quadrant of the model grid from an active status to disabled which effectively represents the anticipated filling of the industrial area above the flood level.

Figure 1, attached, represents the difference in flood elevations between the no block-out and the industrial block-out conditions. These results are generated via SMS v5.03 using the results in 100yr-3 and noblock, both stored in the project directory. The data set containing this calculated difference is stored as wsediff.dat.

The results indicated that the impact on water surface elevations was less than 1-foot throughout the City. The most noticeable difference was south of the cogen facility in the vicinity of Johnson Creek. This area experienced up to about 1-foot increase in flood level. However, further upstream, this difference decreased to near zero. There were no significant differences in the developed City area.

Note that Figure 1 only depicts water surface elevation differences in mutually active elements. Consequently, the no block-out area for the industrial area doesn't appear in the figure since it was inactive in the block-out analysis.

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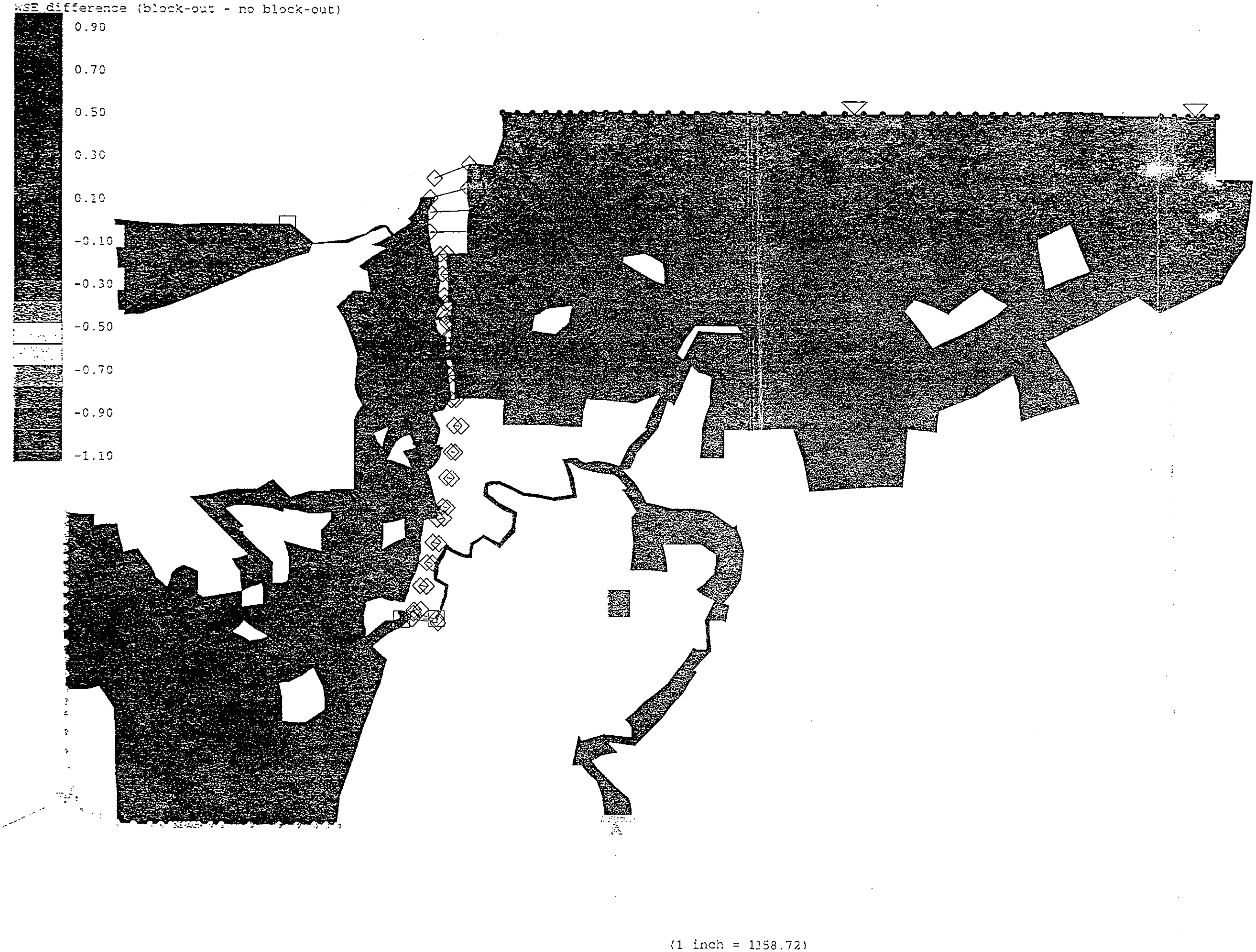

Figure 1 of KCM Memo