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UPPER EAST FORK CAVE CREEK BENEFIT COST ANALYSIS

INDEX NO. ST-896829

TECHNICAL SUBMITTAL #1

NBS LOWRY

ENGINEERS & PLANNERS

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BENEFIT COST ANALYSIS

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TECHNICAL SUBMITTAL #1

PREPARED FOR:

CITY OF PHOENIX
AND
FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

-DRAFT-

PREPARED BY:

NBS/LOWRY ENGINEERS & PLANNERS
2600 N. 44th Street, Phoenix, AZ 85008

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CHAPTER 1
BACKGROUND

This report presents the results of the Upper East Fork Cave Creek Benefit Cost Anlaysis. The computed benefit to cost ratio is __. The procedures and assumptions used in the study are presented in this report.

I. SCOPE OF WORK

This Benefit Cost Analysis has been prepared for the City of Phoenix and the Flood Control District of Maricopa County to assist in allocating project funding for the Upper East Fork Cave Creek flood control improvements beginning at the outfall to the Greenway Channel and continuing upstream to Detention Basin One at Beardsley Road. The Benefit Cost Analysis consists of an economic comparison of estimated average annual project benefits to average annual flood control costs over the life of the project, using a 3 percent discount rate. The results of the comparison are expressed as a benefit to cost ratio. The primary project benefit is reduced flood damages resulting from the project.

The proposed improvements were first identified in the Upper East Fork Cave Creek Area Drainage Master Plan. Design development for Detention Basins One and Three has been documented in the Upper East Fork Cave Creek Detention Area Sizing Study prepared in February, 1989 and the Engineering Design Descriptions dated June, 1989. Preliminary design for the 18th and 20th Street stormdrains is documented in Update of the North Central Area Master Storm Drainage Study (East Half), September, 1989.

A benefit cost ratio has been computed for the proposed flood control improvements following procedures outlined in the Economic Analysis Procedure developed by the Flood Control District of Maricopa County. This report summarizes the procedures followed.

II. PROJECT DESCRIPTION

A. Project Location

Figure 1.1 shows the location of the Upper East Fork Cave Creek watershed, the benefit cost study area, and the proposed flood control improvements included in the study. The proposed facilities included in the analysis are:

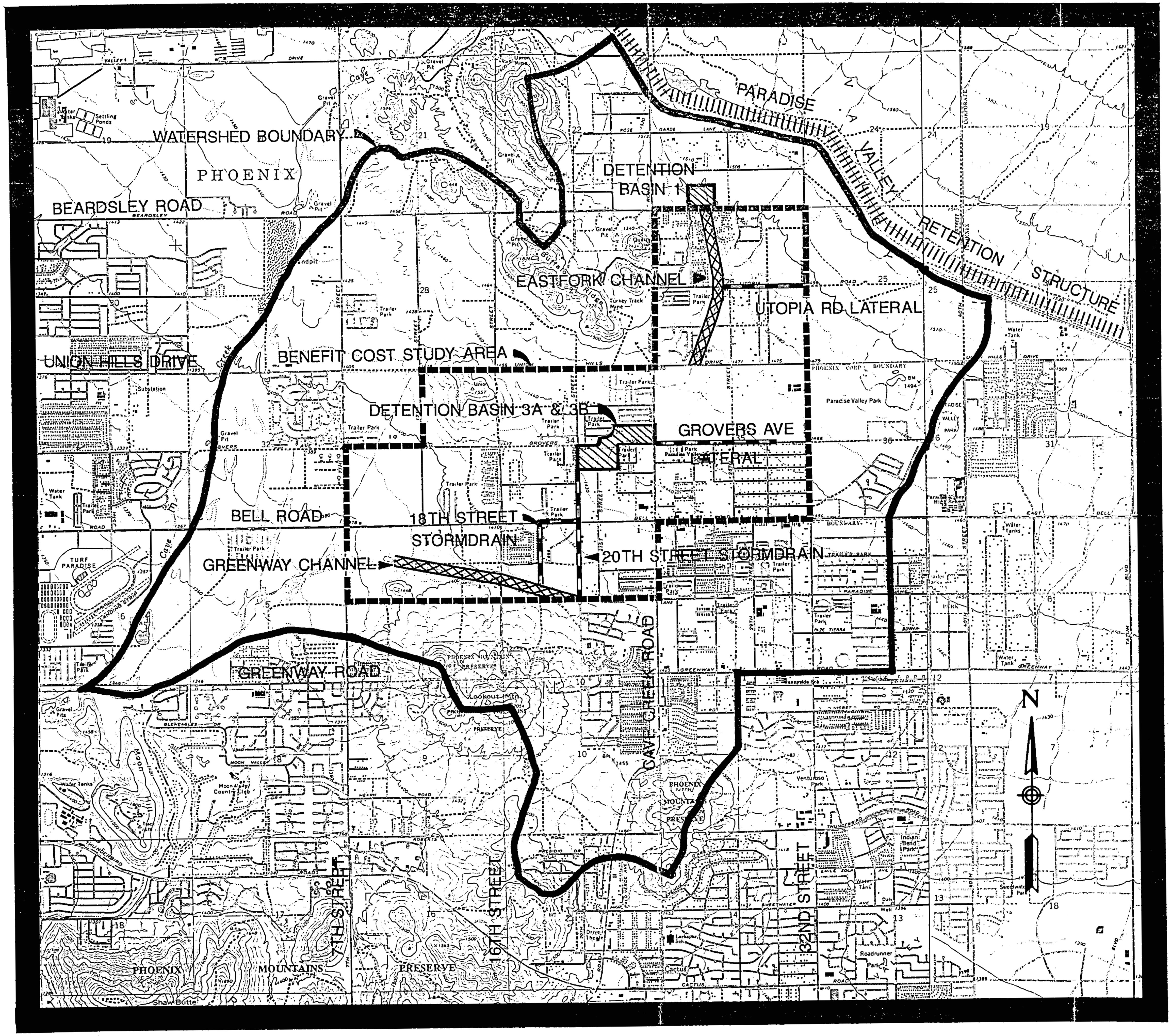
1. The 18th and 20th Street stormdrains from the Greenway Channel to Bell Road and 20th Street.
2. The 20th Street stormdrain from Bell Road to Detention Basin Three.
3. Detention Basin Three.
4. (2) The Grovers Avenue lateral.
5. The East Fork Channel from Union Hills Drive to Beardsley Road.
6. (2) The Utopia Road lateral, and
7. Detention Basin One, north of Beardsley Road.

The upstream study limit for computing project benefits is Beardsley Road. The downstream study limit is the system outlet to the Greenway Channel.

B. Flood Control Elements

The 18th and 20th Street stormdrain system drains Detention Basin Three with a 108 inch pipe extending to Bell Road, where the flow is split. A portion of the flow is diverted west on Bell Road to 18th Street, then south to the Greenway Channel in an 84 inch pipe. The remaining flow continues south in 20th Street in an 84 inch pipe which upsizes to a 96 inch pipe near the Greenway Channel.

Detention Basin Three is planned as a multi-use detention basin. It will be used as a City park with amenities including baseball diamonds, basketball and volleyball courts, a tot lot, and equestrian riding



WATERSHED BOUNDARY
PHOENIX
BEARDSLEY ROAD
DETENTION BASIN 1
PARADISE VALLEY RETENTION STRUCTURE
EASTFORK CHANNEL
UTOPIA RD LATERAL
BENEFIT COST STUDY AREA
UNION HILLS DRIVE
DETENTION BASIN 3A & 3B
GROVERS AVE LATERAL
BELL ROAD
18TH STREET STORMDRAIN
20TH STREET STORMDRAIN
GREENWAY CHANNEL
GREENWAY ROAD
CAVE CREEK ROAD
7TH STREET
16TH STREET
32ND STREET
N

FIGURE 1.1

trails. The basin is divided by Grovers Avenue with 15 acres north of Grovers Avenue and 20 acres south of Grovers Avenue. The basin will have a volume of 275 acre feet. A low flow pipe system will be installed to convey low flows beneath the basin to minimize public inconvenience and increased maintenance caused by frequent flooding.

The Grovers Avenue Lateral will divert runoff generated east of Cave Creek Road into Detention Basin Three, preventing it from flowing directly to Bell Road.

The East Fork Channel from Union Hills Drive to Beardsley Road will be an earth-lined channel with drop structures for grade control. The channel will be landscaped and will include an equestrian trail system connecting Detention Basin Three to Detention Basin One.

The Utopia Road Lateral drains into the East Fork Channel and extends upstream to 32nd Street, intercepting runoff from the north, and diverting it from reaching an existing subdivision south of Utopia Road.

III. FLOODING

A. Flooded Area

The study area is within a FEMA designated floodplain. In the upper reaches of the watershed, the flow is channelized in a small natural channel. The channel has capacity for a 1 or 2-year storm. At Cave Creek Road the defined channel disappears. The runoff spreads in an overland flow condition, eventually making its way to the Greenway Channel. The Greenway Channel drains to Cave Creek Wash which is the ultimate outfall for the Upper East Fork. Development has taken place in the floodplain prior to the Flood Control District of Maricopa County or FEMA regulation of the floodplain. This results in many existing structures in the floodplain.

Under existing conditions, runoff breaks out of the designated floodplain, making its way south through streets and overland to the Greenway Channel. The older structures in the floodplain are at natural ground level and experience frequent flooding. New development has been built on elevated pads above the flood elevation. This backs up water, aggravating the flooding of existing structures. Most of the street crossings are overland dip crossings resulting in traffic congestion whenever it rains.

Figure 1.2 shows the flooded area expected for a 100-year storm.

B. Land Use

Land use in the study area consists of mostly single family residential structures, most of which are mobile homes. There are a few apartment complexes as well as a strip of commercial buildings along Bell Road. The existing structures in the area are as follows:

Structure Type	No. of Structures
Single Family Homes	641
Mobile Homes	1205
Apartments	1172 units
Commercial	786,000 sf

IV. METHODOLOGY

The Benefit Cost Analysis requires a specific sequence of computations, which are accomplished for this study, using several computer analysis programs supported by government agencies. **Table 1.1** outlines the basic steps in the analysis and the computer applications used.

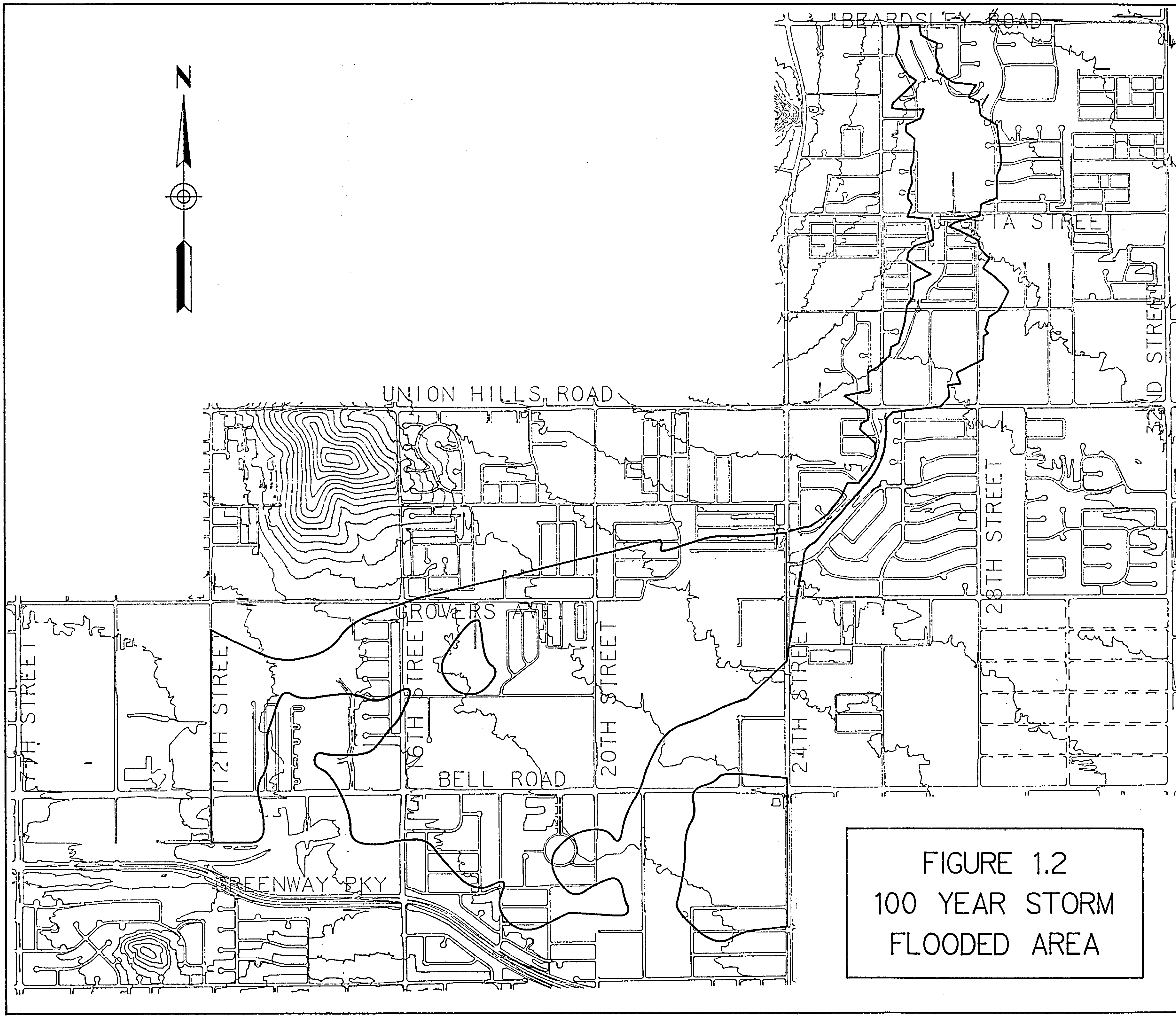


FIGURE 1.2
100 YEAR STORM
FLOODED AREA

	Analysis Type	Computer Program / Sponsoring agency
1.	Hydrology	TR-20 Project Formulation Hydrology Soil Conservation Service (SCS).
2.	Hydraulics	HEC-2 Water Surface Profiles U.S. Army Corps of Engineers.
		DHM-21 Diffusion Hydrodynamic Model U.S. Geological Survey (USGS)
3.	Inventory	SID Structure Inventory for Damage Analysis U.S. Army Corps of Engineers.
4.	Economics	EAD Expected Annual Damage Analysis U.S. Army Corps of Engineers.

Table 1.1
Sequence of Computations and Computer Programs Used

V. ACKNOWLEDGMENTS

The completion of this Engineering Report was made possible by the assistance and data furnished by many individuals whose valuable assistance is gratefully acknowledged.

We especially wish to thank Mr. Chris Cornell, P.E., Engineering Supervisor, Mr. Art Glover, P.E., CE III, and Mr. John Fincel, P.E., CE III of the City of Phoenix, and Mr. John Berghian, P.E., Project Management Engineer, of the Flood Control District of Maricopa County for their close involvement and assistance in the preparation of this report.

Those individuals on the NBS/Lowry staff who contributed to this report are as follows: Mr. Richard Perry, P.E. served as principal in charge. Mr. Brian Fry, P.E. served as project manager. Mr. Andrew Spear, P.E. served as project engineer, graphics were prepared by Mr. Bill Parrot, and typing and proofreading were done by Ms. Linda Moritz.

CHAPTER 2
DAMAGE CALCULATIONS

I. EXISTING CONDITION WITHOUT PROJECT

A. General

Flood damages for existing conditions are expressed as "expected annual damages." Expected annual damages are defined as the monetary value of physical loss that can be expected in any given year based on the magnitude and probability of losses from all possible flood events. The expected annual flood damages for the existing condition without the flood control improvements in place have been computed following the eight steps itemized in the Economic Analysis Procedure of the Flood Control District of Maricopa County. These procedures have been taken from the National Economic Development Procedures Manual - Urban Flood Damage with minor changes to reflect District policies.

The specific application of each of these steps to estimate flood damages are discussed below.

B. Step 1 - Delineate The Affected Area

The affected area is considered to be the area within the existing and future 500 year floodplain which is affected by the proposed improvements. The affected area has been defined considering; a) The existing FEMA designated floodplain, b) Reports of historic flooding, and c) Hydraulic modeling of the predicted 10-, 25-, 50-, 100-, and 500-year storms. **Figure 2.1** shows the 2 square mile study area for which flood damage calculations were done along with the FEMA designated 100-year floodplain and the 500-year floodplain derived from hydraulic calculations. The area is bounded on the North by Beardsley Road, on the East by 29th Street, on the South by Paradise Lane and the Greenway Channel, and on the West by 12th Street. Outflow from this area drains to the Greenway Channel. Existing flood control works that affect the floodplain are described below.

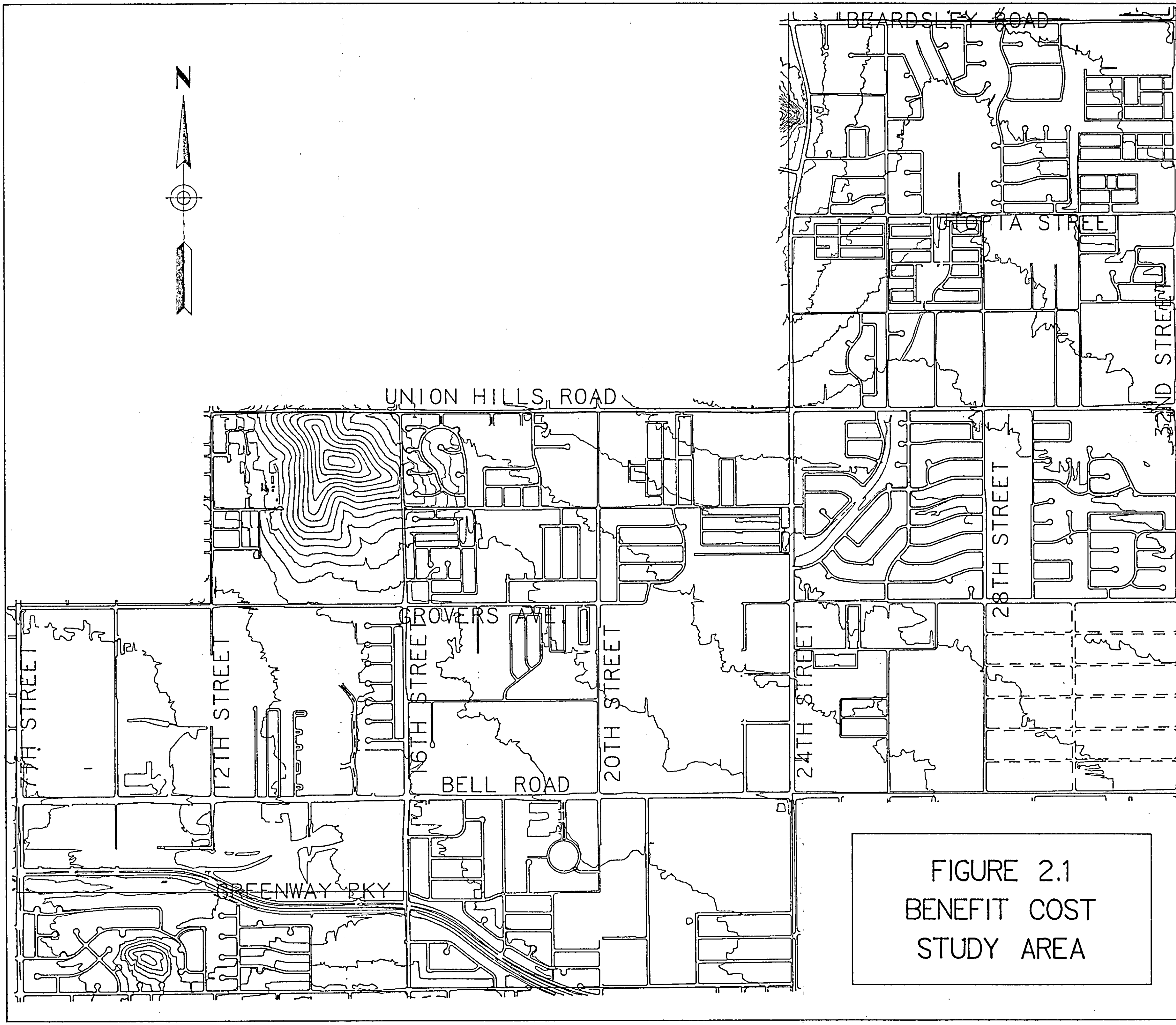


FIGURE 2.1
BENEFIT COST
STUDY AREA

1. **Existing Flood Control Works**

The Paradise Valley Retention Structure (see **Figure 1.1**) consists of a series of dikes constructed north (upstream) of the Central Arizona Project (CAP) Granite Reef Aqueduct to retain runoff and prevent it from flowing into the CAP aqueduct. Mr. Rich Dent of the Construction and Design Section of the United States Bureau of Reclamation (USBR) was contacted regarding the level of protection provided and the structural integrity of the dikes.

Dike number one intercepts runoff that historically flowed to the East Fork of Cave Creek. The structure was designed for the probable maximum flood (PMF), which is defined by the USBR as "the maximum runoff condition resulting from the most severe combination of hydrologic and meteorologic conditions that are considered reasonably possible for the drainage basin under study." Mr. Dent indicated that the PMF is greater than the 500 year event, which is the most extreme event considered in this study. The hydrology for the area contributing to Dike number one was recomputed by the cities of Phoenix and Scottsdale after the dike was constructed. The newer hydrology predicted a PMF that was higher than the design PMF. However, it was still beleived that the structure had capacity for an event greater than the 500-year event.

There have been problems with cracking and differential settlement within the dike which require repair. The USBR plans to complete the repairs as soon as funding is available. The effect of the damage in a large storm such as the 100- or 500-year event is uncertain. For purposes of this study it will be assumed that the dike will retain all flows up to and including the 500-year event without overtopping or structural failure.

The Greenway Channel is the outfall for the proposed improvements. The Greenway Channel is designed for the 100-year event. A 36-inch low flow pipe under the channel carries nuisance flows. The channel is constructed with gabion sideslope protection and a combination of concrete and earth-bottom lining. Although it is recognized that damage to downstream structures may occur in storms in excess of the 100-year storm, that damage is not considered in this study.

2. History of Flooding

Records at the City of Phoenix and Flood Control District of Maricopa County were searched for post flood damage surveys and other records depicting the extent of historical flooding. No such reports were found. Therefore, the available history of flooding is limited to the experience of the project team members and discussions with local residents as they are encountered in the field.

C. Step 2 - Select Planning Reaches

Reaches are the primary geographic unit for planning. The entire study area is subdivided into planning reaches that are relatively homogeneous from a hydraulic and land use perspective. The hydraulic, structure inventory, and damage data are compiled for each reach and then aggregated to form the frequency-damage relationship for the entire area.

The floodplain is well channelized at the upper reaches from Cave Creek Road and John Cabot Road to the headwaters at Beardsley Road. Planning reaches in this area were established along the channel from the HEC-2 water surface profile calculations. Downstream from Cave Creek Road the floodplain is not channelized. Flooding is characterized by overland spreading of flows that meander through existing development. The HEC-2 program assumes channelized flow, and has therefore not been used. Instead, a finite element diffusion model (DHM-21) has been used. This model portrays the nonchannelized nature of flooding characteristic of this alluvial fan area. The finite element diffusion model computes the depth of flooding expected within each 10-acre (660 feet x 660 feet) square cell within the modeled area. For this study, each 10-acre square cell has been modeled as a planning reach. **Figure 2.2** shows the planning reaches (cells) and numbering used.

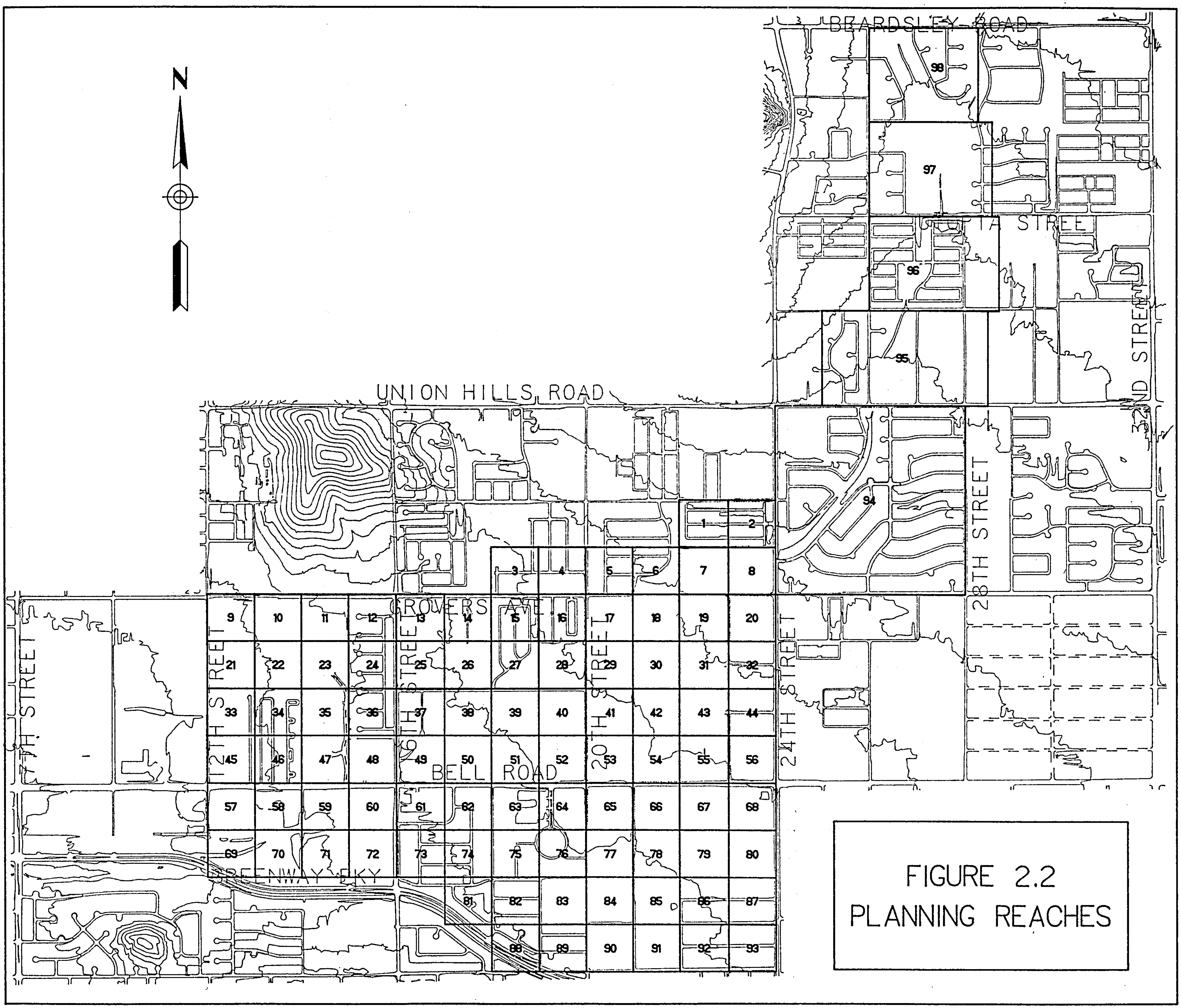


FIGURE 2.2
PLANNING REACHES

D. Step 3 - Establish Elevation Frequency

Step three is a series of three elements involving the primary portion of the hydrologic and hydraulic studies required in establishing the existing conditions. This step includes development of the frequency-discharge relationship, which is the basic hydrologic relationship; and the stage-discharge relationship, which is the basic hydraulic relationship. The elevation-frequency (or stage-frequency) relationship is the function derived by combining these two basic relationships. The three elements are accomplished in two steps by using the discharges derived for the selected return periods from the frequency-discharge relationship in the hydraulic analysis of the stage-discharge relationship.

1. Discharge-Frequency Relationship

Discharge-frequency relationships were determined from a series of TR-20 runs for the 10-, 25-, 50-, 100-, and 500-year storms using the existing condition model and routing developed in the "Upper East Fork Cave Creek Area Drainage Master Study." A summary description of the development of the TR-20 model is contained in **Appendix A**.

2. Elevation-Frequency Relationship

The runoff hydrographs generated by TR-20 for the 10-, 25-, 50-, 100-, and 500-year events were input into the hydraulic models to generate the elevation-frequency relationship.

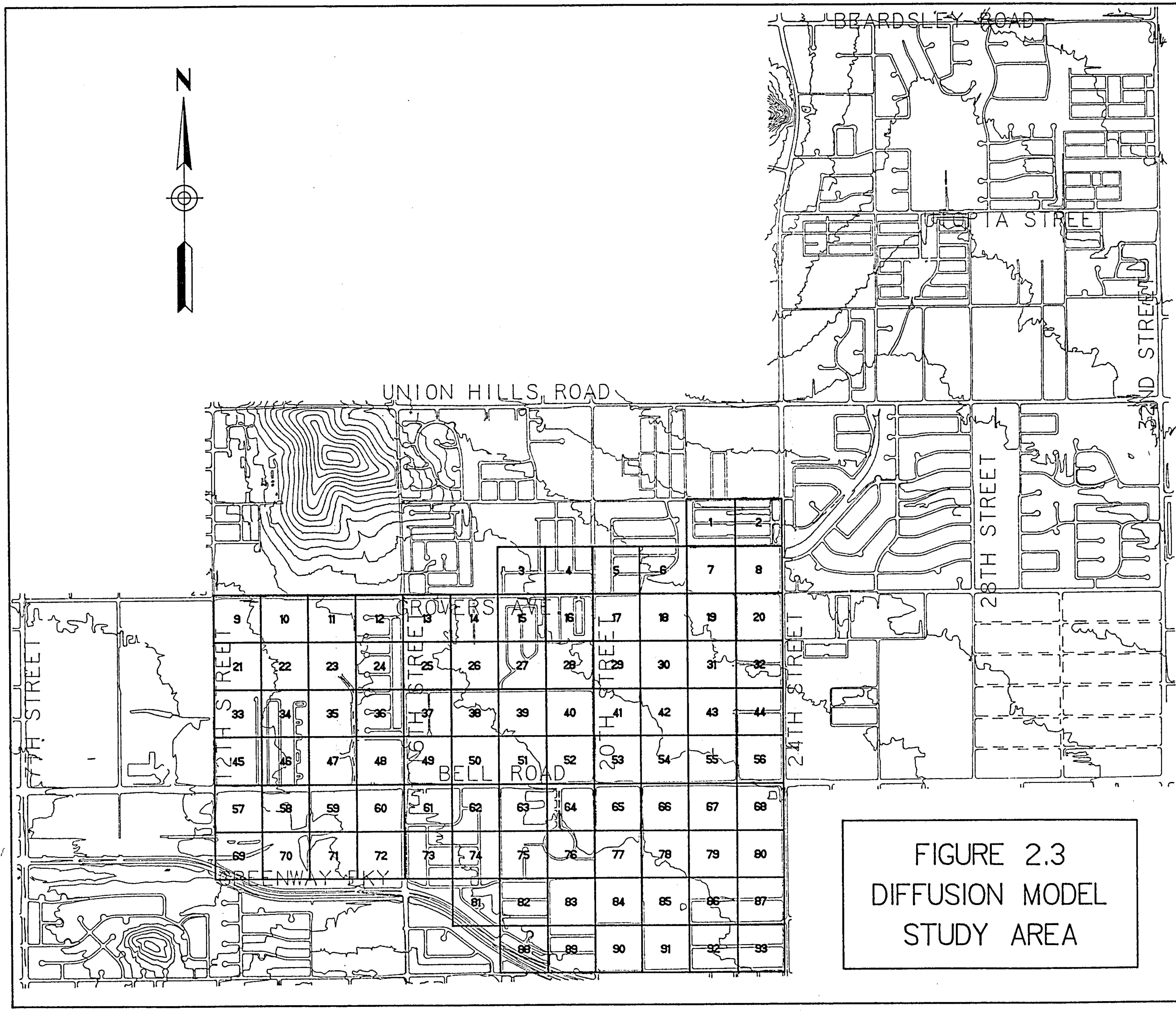
For the channelized area, upstream from Cave Creek Road, the U.S. Army Corps of Engineers, HEC-2 Water Surface Profile computer program was used to establish the elevation-frequency relationship. The discharges from the TR-20 analysis for the 10-, 25-, 50-, 100-, and 500-year events were input into the model. Cross sections were taken at 100 foot intervals from aerial mapping. A detailed description of the development of the HEC-2 model is contained in **Appendix B**.

For the overland flow area, downstream from Cave Creek Road, the U.S. Geological Survey, DHM-21 Diffusion Hydrodynamic computer model was used to establish the elevation-frequency relationship. The DHM-21 model develops hydraulic equations for two-dimensional flow for each cell within the user specified grid that covers the modeling area. Diffusion equations are developed for each cell and solved using as many simultaneous equations as the sum of the number of grid cells and the number of grid boundaries. The solution gives the magnitude, velocity, and depth of flow across each of the four sides of each cell. Inflow hydrographs were specified at cells where runoff enters the modeling area. Critical depth outflows were specified where flow leaves the modeling area. If the external boundary of the grid is not specified as critical depth outflow, it is treated as a no flow boundary, which means no flow can cross that boundary. Effective rainfall was also modeled over the grid area by specifying an effective rainfall hyetograph. The effective rainfall amount is the total rainfall minus losses. The area modeled with DHM-21 is shown in **Figure 2.3** with the cell numbering and hydrograph inflow points. The diffusion model was used to compute the maximum flood depths in each reach (cell) for the 10-, 25-, 50-, 100-, and 500-year events. A detailed description of the development of the DHM-21 model is contained in **Appendix C.**

As a point of clarification about the differences between the two hydraulic models used, the HEC-2 model is a one-dimensional, steady state model which means that the flow is in one direction (parallel stream lines) and that a single flow rate is modeled. Therefore, the peak discharges were used in the HEC-2 model. The DHM-21 model is a two-dimensional, unsteady flow model, which means that the flow is in more than one direction (x- and y-direction) and that an entire hydrograph is modeled.

E. Step 4 - Outline Flooded Area

The limits of flooding are shown on **Figure 2.4** for the 10-, 25-, 50-, 100-, and 500-year floods for the existing conditions, with no


N
BEARDSLEY ROAD
UTOPIA STREET
32ND STREET
UNION HILLS ROAD
28TH STREET
GROVERS AVE
24TH STREET
20TH STREET
16TH STREET
12TH STREET
7TH STREET
BELL ROAD
GREENWAY PKY
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93
FIGURE 2.3
DIFFUSION MODEL
STUDY AREA

improvements. The limits shown are the results of the elevation-frequency analysis of Step 3. Flooding is also shown in **Figures 2.5, 2.6, 2.7, 2.8** and **2.9** with flooded depth contours for the 10-, 25-, 50-, 100-, and 500-year floods, respectively.

F. Step 5 - Inventory Existing Floodplain

An inventory of existing structures within the flooded area was completed using 1-inch = 200 feet scale aerial photographs flown November 15, 1990, prepared by Kenney Aerial Mapping Inc. Supplemental information on existing structures was gathered by driving through the study area and conducting a "windshield survey."

Copy Available?

Structures were counted and inventoried by planning reach from the aerial photograph and classified according to the structure types shown in **Table 2.1.**

Table 2.1

Structure Types and Values

Designation	Structure Type	Class	Structure Value
MHA	Mobile Home	A	$20,000.
MHB	Mobile Home	B	$15,000.
MHC	Mobile Home	C	$ 8,000.
SFA	Single-family residential	A	$80,000.
SFB	Single-family residential	B	$60,000.
SFC	Single-family residential	C	$40,000.
MF1	Multi-family residential	1-story	$25,000./unit
MF2	Multi-family residential	2-story	$25,000./unit
COM	Commercial		per appraisal.

Class A is above average condition, class B is average condition, and class C is below average condition.

A sampling approach was used to estimate structure values. Structure value for benefit cost is the estimated depreciated replacement value of the structure. Structure values were estimated by identifying areas of similar and representative structure type, size, and quality, such as subdivisions that were built at one time and have a uniform type and

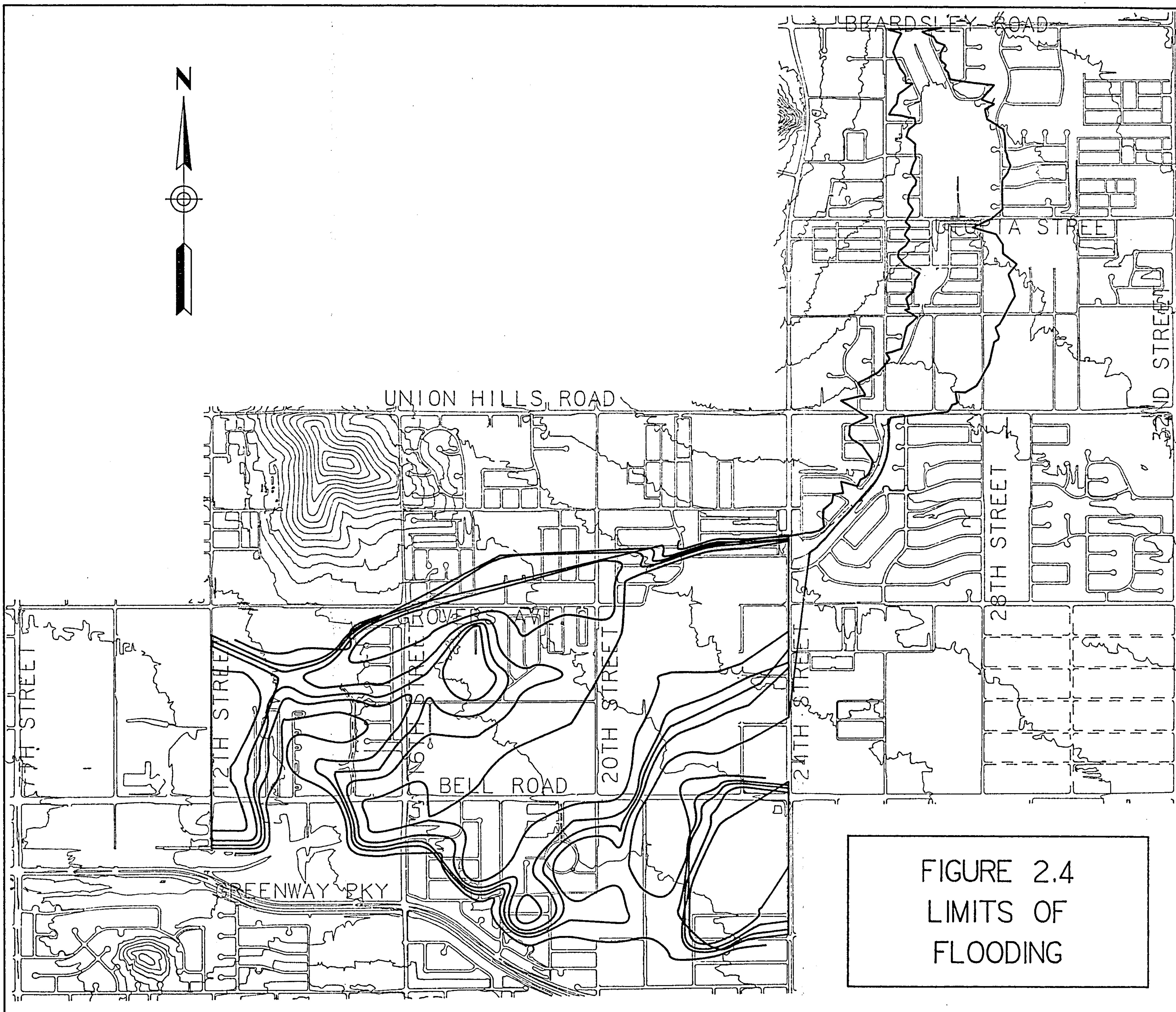


FIGURE 2.4
LIMITS OF
FLOODING

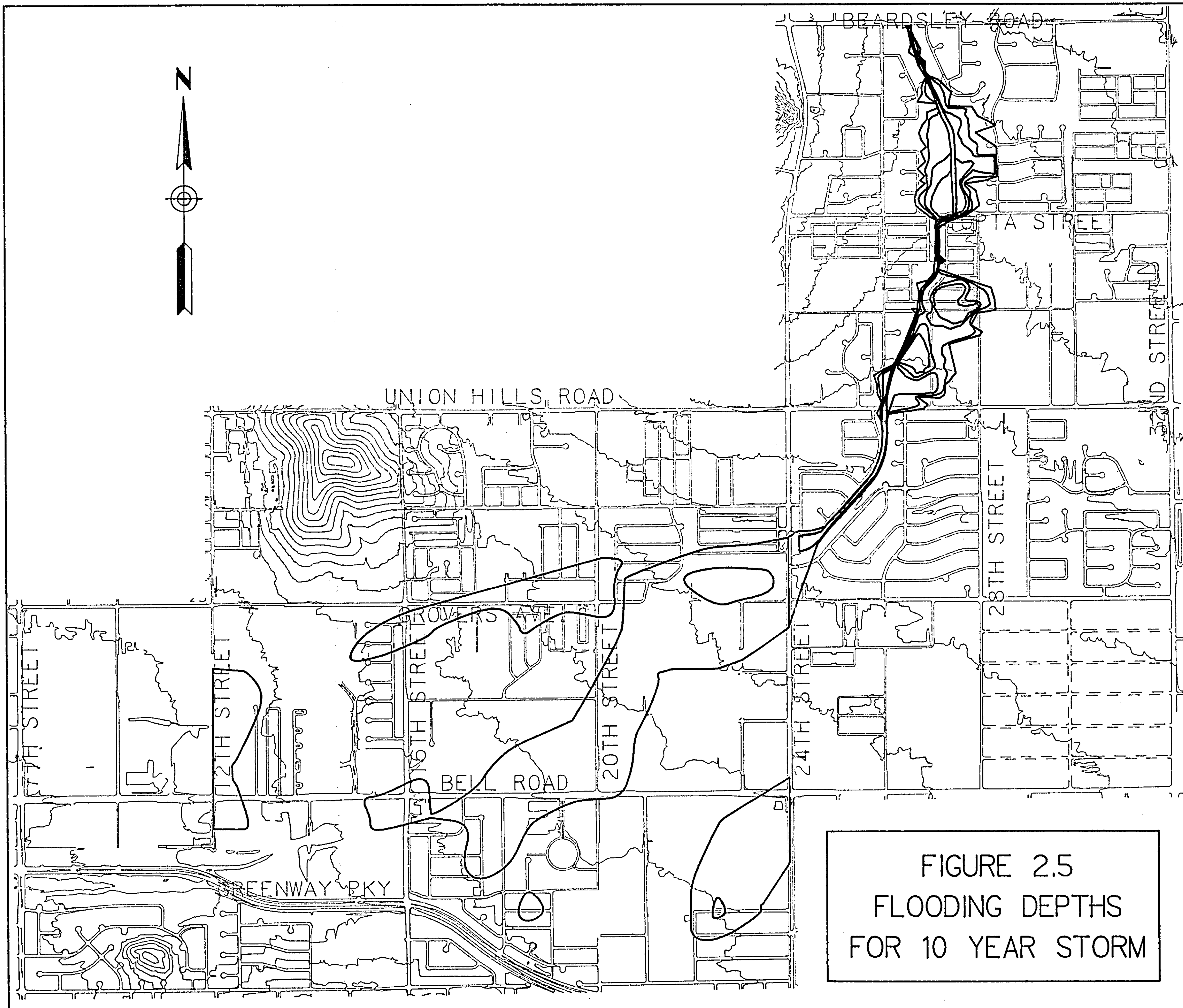


FIGURE 2.5
FLOODING DEPTHS
FOR 10 YEAR STORM

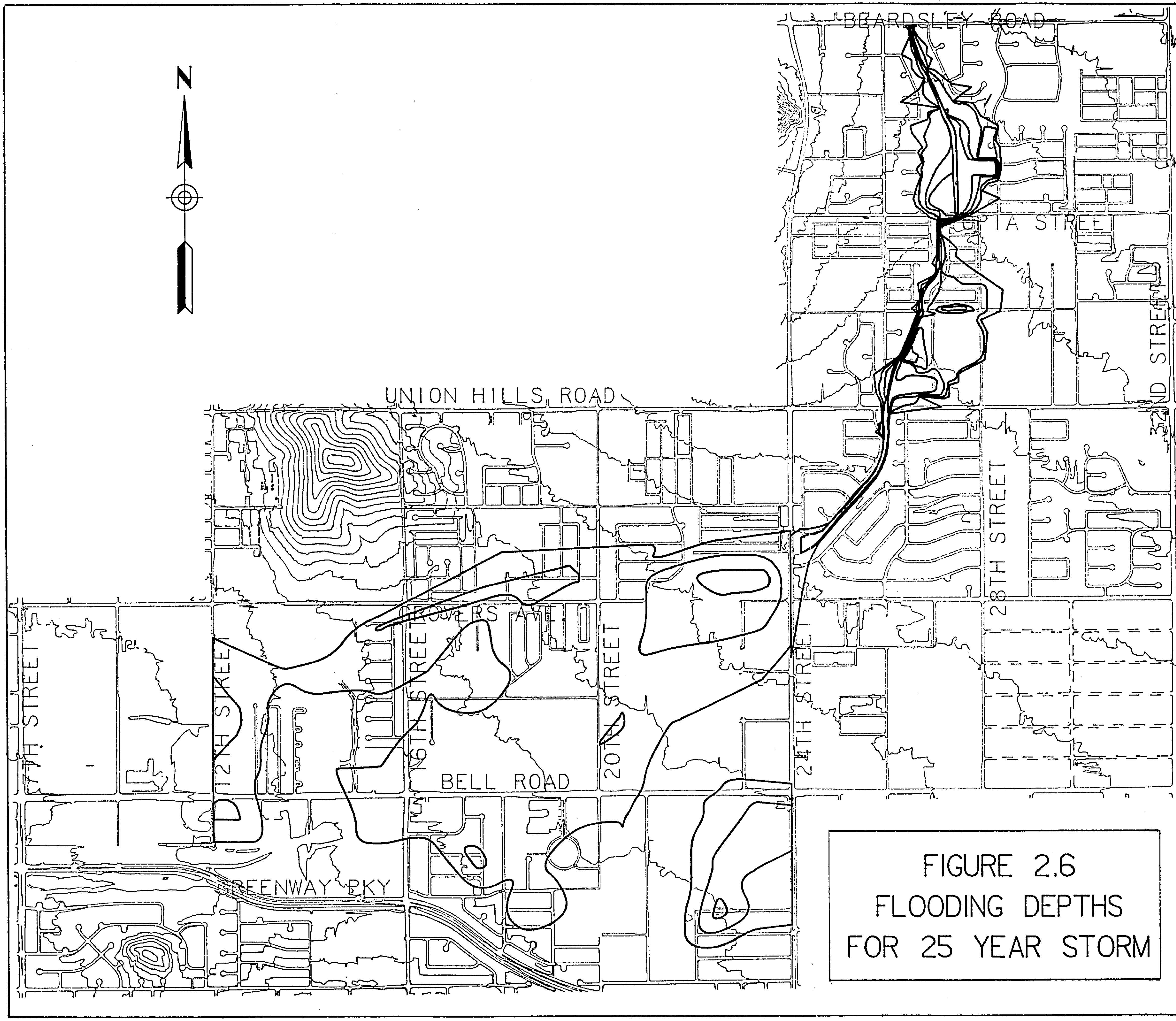


FIGURE 2.6
FLOODING DEPTHS
FOR 25 YEAR STORM

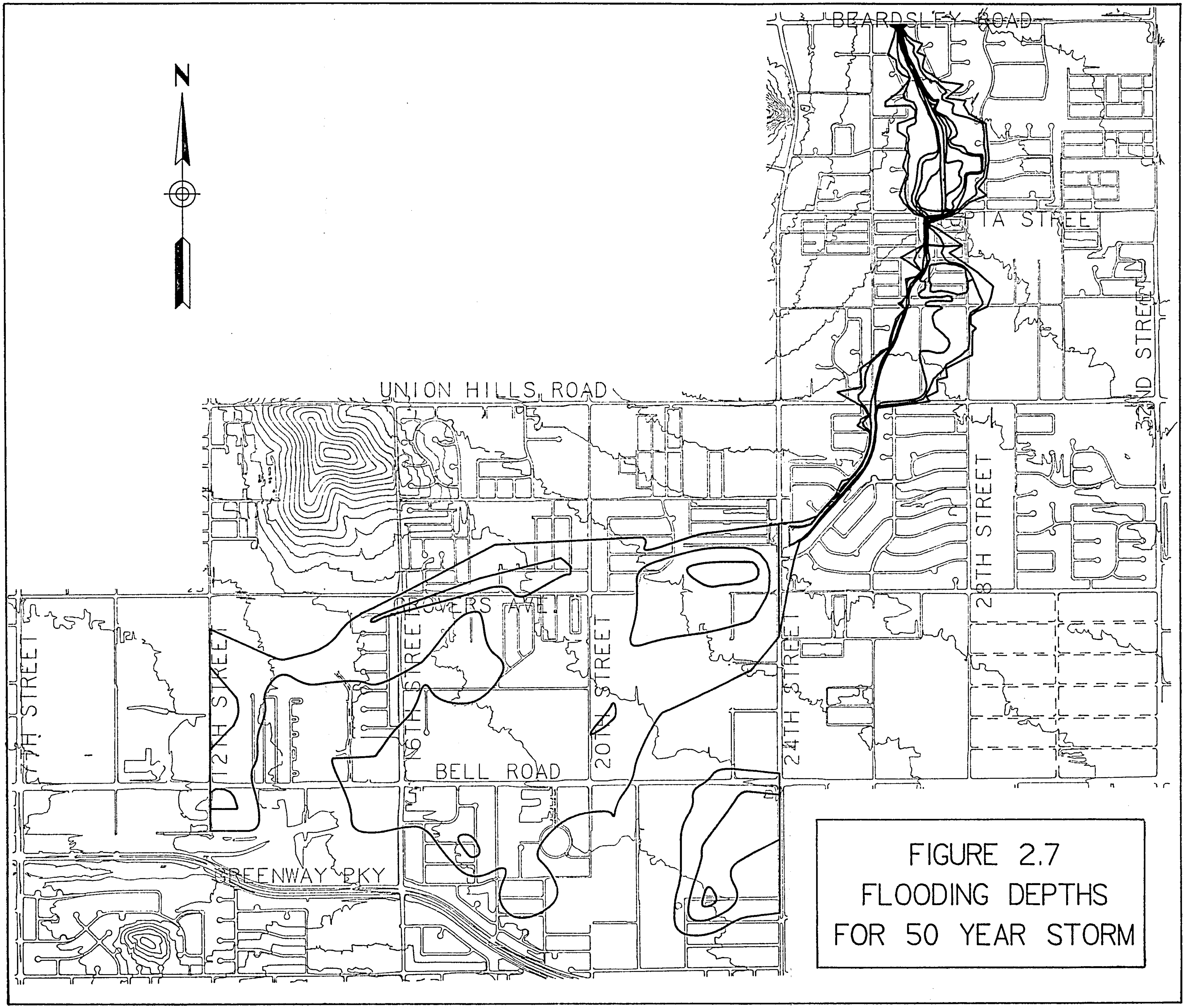


FIGURE 2.7
FLOODING DEPTHS
FOR 50 YEAR STORM

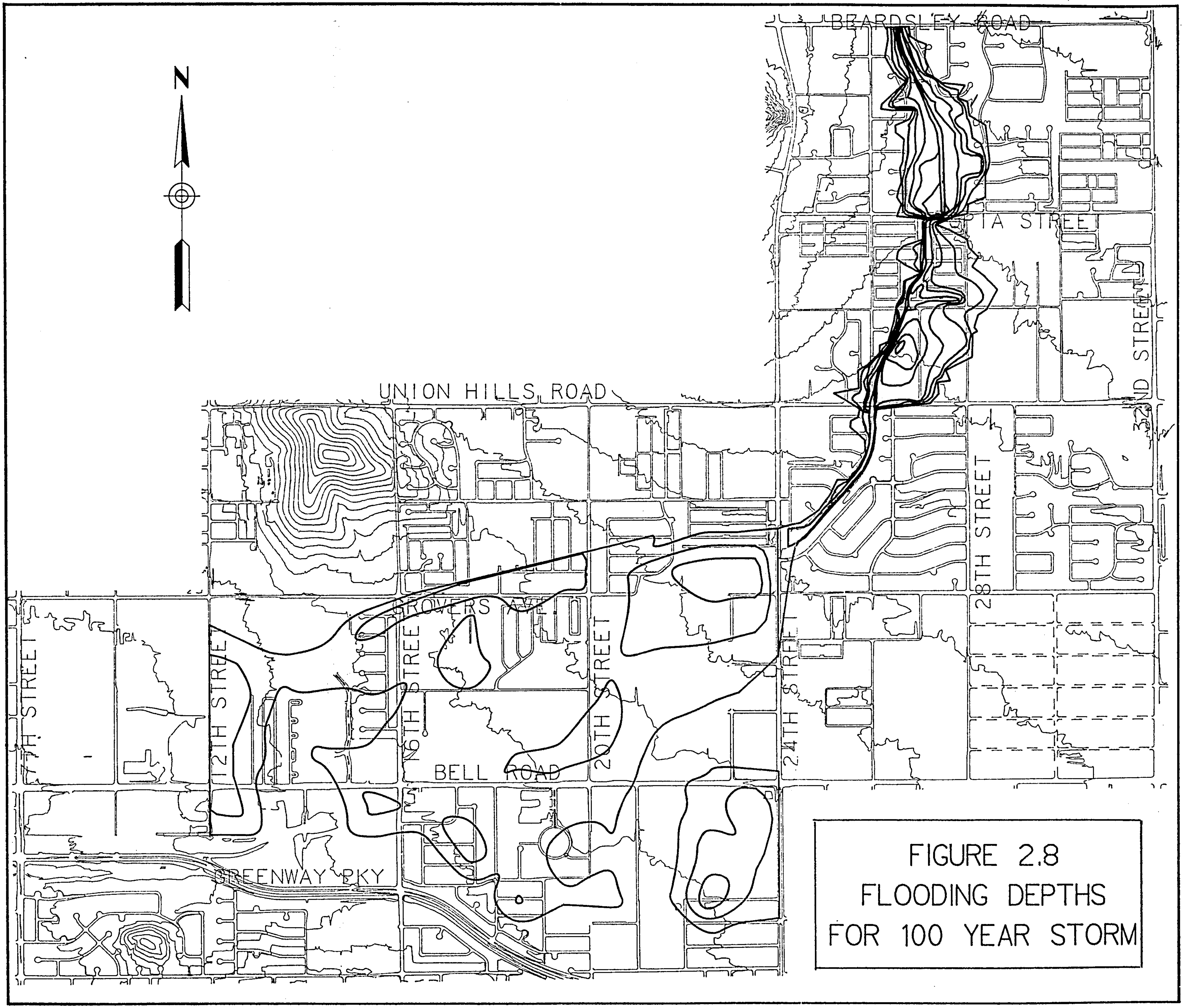


FIGURE 2.8
FLOODING DEPTHS
FOR 100 YEAR STORM

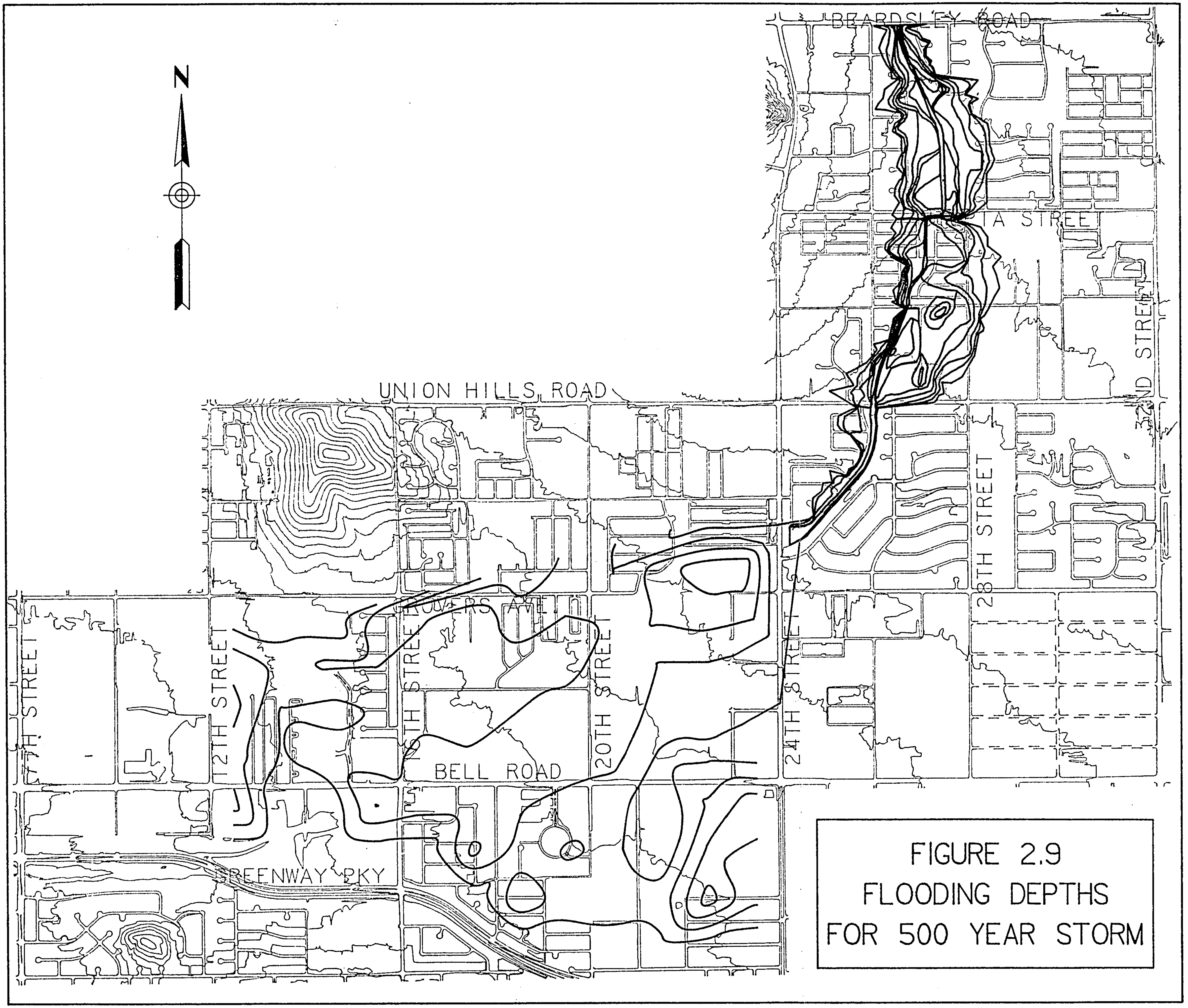


FIGURE 2.9
FLOODING DEPTHS
FOR 500 YEAR STORM

quality of home. An estimate was then made of the market value of a typical improvement located within the area that would be representative of an average value of the improvements located within the subdivision. The estimates were established using recent comparable sales located within the subdivision whenever possible. A vacant land value was then estimated based on vacant land sales of similar properties. This land value estimate was then subtracted from the market value of the property to estimate the value of the improvements.

The structure values from the representative areas were then assumed to be representative of the remaining areas within the study area that were judged to be similar in type, size, and quality to those appraised. **Table 2.1** contains the representative structure types and values used.

The commercial improvements along Bell Road between 12th Street and 24th Street were estimated separately based on comparable sales, whenever possible, or based on a reproduction cost, new, less depreciation (RCNLD). The major source of information to arrive at RCNLD was the 1991 Marshall and Swift Valuation Service Manual.

The documentation supporting the derivation of the estimates for each representative area are presented in "Improvement Value Estimate Report," prepared by Mike Chierighino, A.S.A., November 4, 1991 for the Flood Control District of Maricopa County.

Based on the windshield survey, mobile homes were assumed to lie 1 foot in elevation above the ground surface. All other structures were assumed to lie 6 inches above the ground surface. This allows for the fact that grid cells are modeled by the DHM-21 program as flat planes, with no allowance for onsite grading to prevent ponding.

The value of the contents of buildings were estimated as a percentage of structure value as follows:

Structure Type	Content Value
Single Family	60% of structure value
Multi-Family	60% of structure value
Mobile Home	60% of structure value
Commercial	100% of structure value

Value for outside property was included in the structure value estimates. Value for public utilities has been neglected.

G. Step 6 - Depth Damage Relationships

The depth-damage relationship relates the structure damage in dollars to the depth of flooding at the structure. Flooding depths were computed in step 3 for the various return period storms. The damage estimate is based on a percent of total structure value dependent on the depth of flooding. Generalized depth vs percent damage relationships were used from the FEMA 1990 Flood Insurance Rate Report which is based on a statistical analysis of flood insurance claims. **Figure 2.10** shows damages as a percentage of total value used for the following structure types;

a) one floor, no basement,
b) two floor, no basement, and
c) mobile home, no basement.

Figure 2.11 shows expected content damages as a percentage of total contents value for structure types;

a) residential, first floor only,
b) residential, mobile home, and
c) commercial, first floor only.

H. Step 7 - Damage Frequency Relationships

The U.S. Army Corps of Engineers Structure Inventory for Damage Analysis (SID) computer program was used to compute the damage frequency relationships. Input to this program includes the elevation vs frequency data for each reach as computed in steps 2 and 3; the inventory data of structure type, percent sample, and structure and content values for each reach as developed in step 5, plus the depth vs

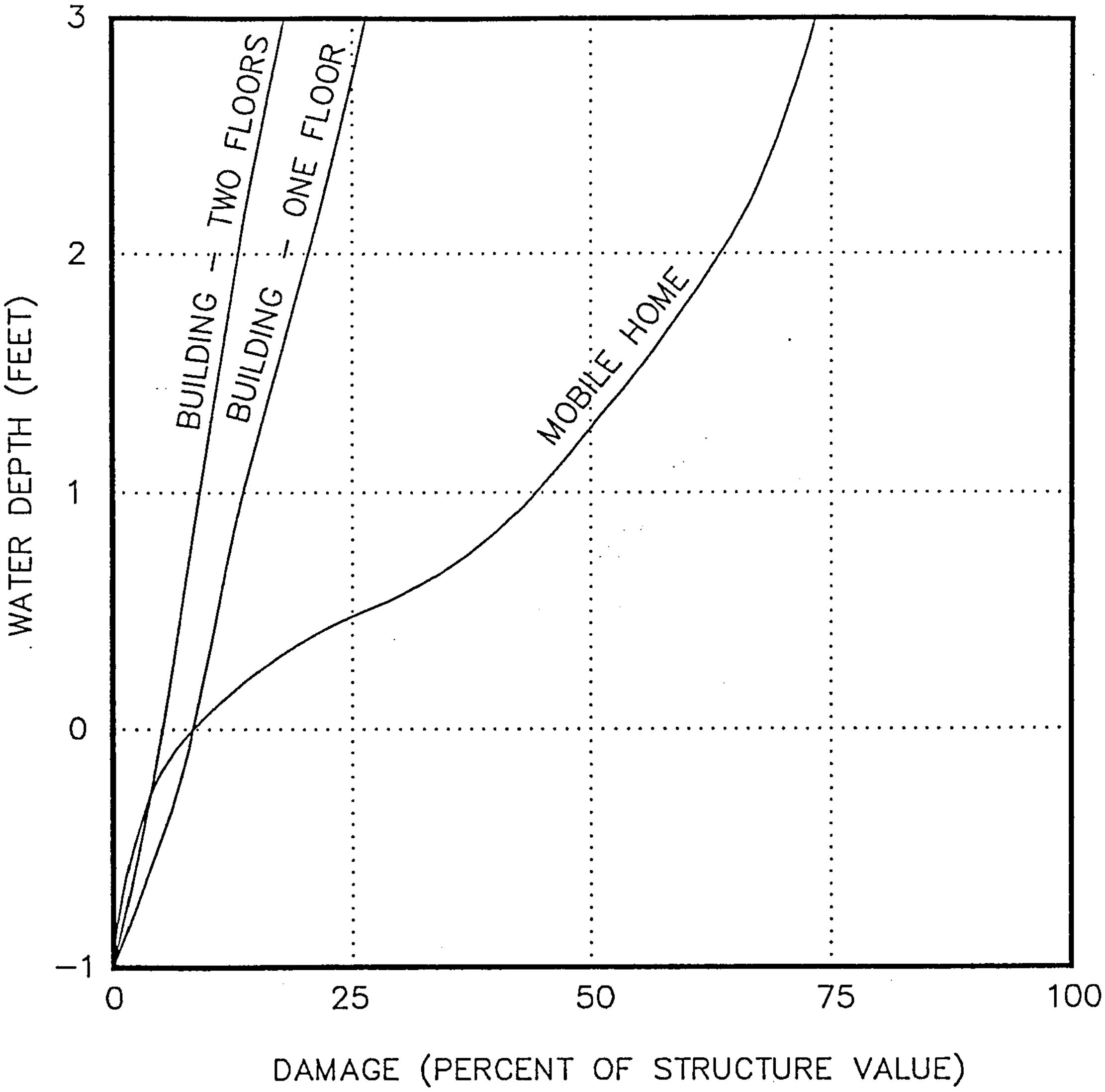


Figure 2.10
Depth vs. Percent Damage (Structure)

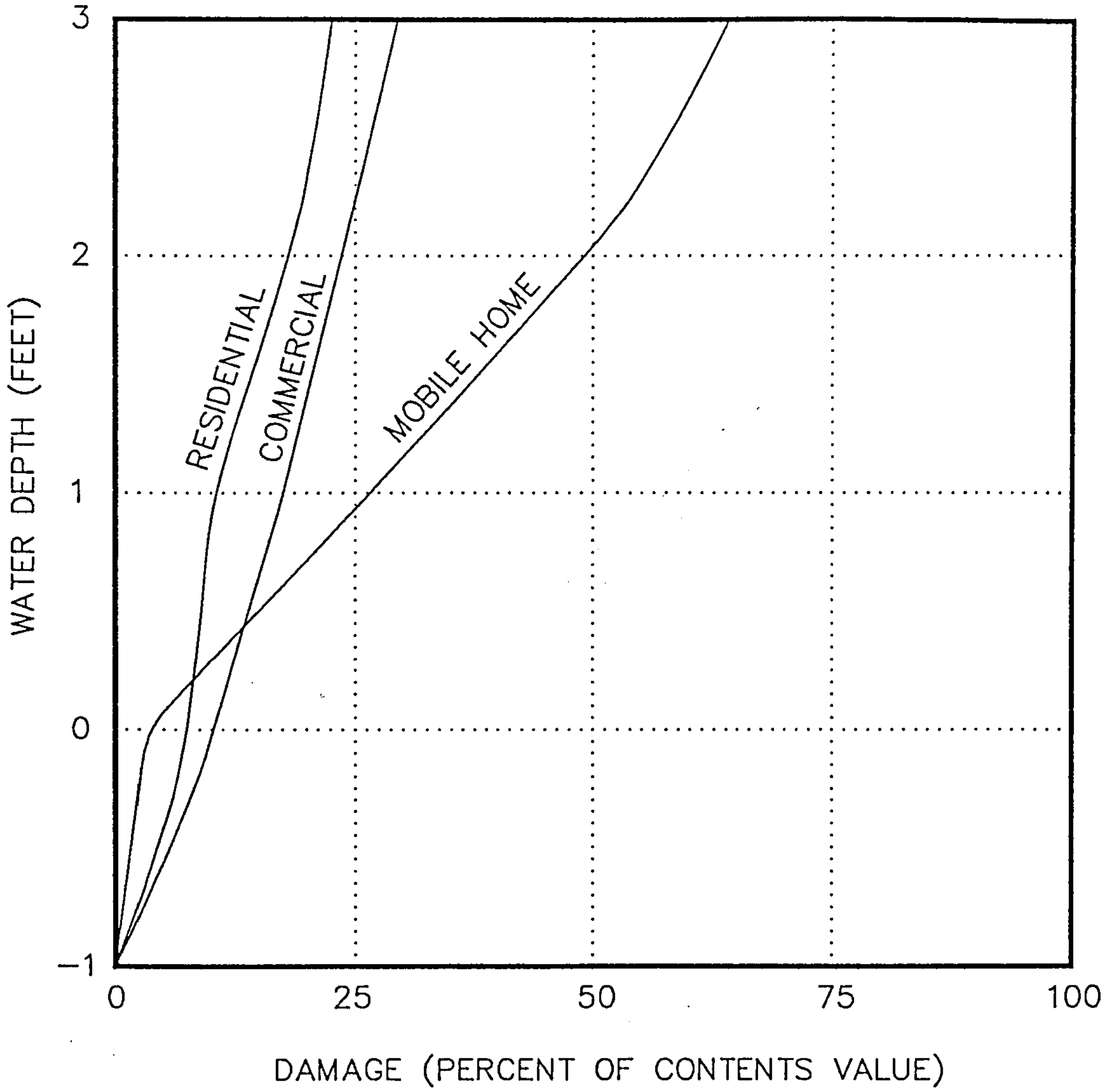


Figure 2.11
Depth vs. Percent Damage (Contents)

damage relationships from step 6. The SID model then computes the damage vs frequency relationship for each reach. The results are then aggregated to produce a single representative damage vs. frequency relationship for the entire flooded area. The damage vs. frequency relationship for existing conditions without improvements are estimated as follows.

Frequency	Damage ($1000)
10-year	13,803.2
25-year	15,488.8
50-year	16,651.6
100-year	18,269.1
500-year	22,402.0

I. Step 8 - Calculate Expected Annual Damages

The U.S. Army Corps of Engineers Expected Annual Flood Damage Computation (EAD) computer program was used to compute expected annual damages. The frequency vs. damage relationship ~~from~~ is entered from the SID output generated in step 7, the EAD program then sums or "integrates" the damages for each event after weighting them for the probability of occurrence in any one year. The result is a single value computed for the expected annual damages per year for the entire flooded area.

Expected annual damages for the existing condition without improvements in place were computed to be $4,422,020.

II. FUTURE CONDITION WITHOUT PROJECT

A. General

After computing expected annual damages for the existing condition, it is necessary to address the impacts of changes expected to occur within the study area over the project life.

B. Step 1 - Establish Economic and Demographic Base

C. Step 2 - Project Land Use Changes

D. Step 3 - New Floodplain Inventory

E. Step 4 - New Damage Frequency Relationships

F. Step 5 - Calculate Expected Annual Damages

III. NON-PHYSICAL COSTS

A. General

B. Income Loss

C. Emergency Costs

D. Traffic Rerouting

E. Floodproofing Costs

F. Temporary Relocation and Reoccupation Costs

G. Modified Use of Flood Prone Property

H. Restoration of Land Market Values

CHAPTER 3
CALCULATION OF BENEFITS

I. REDUCTION IN FLOOD DAMAGES

A. Existing and Future Condition With Project

B. Calculation of Equivalent Annual Flood Damages

II. REDUCTION IN NON-PHYSICAL COSTS

III. NET BENEFIT

CHAPTER 4

CALCULATION OF COSTS

I. CONSTRUCTION AND RIGHT-OF-WAY COSTS

II. OPERATION AND MAINTENANCE COSTS

III. DISCOUNTING PROCEDURES

CHAPTER 5
BENEFIT COST RATIO

I. TOTAL PROJECT BENEFITS

II. TOTAL PROJECT COSTS

III. BENEFIT COST RATIO

APPENDIX A
TR-20 HYDROLOGIC ANALYSIS

I. GENERAL

The existing conditions hydrology was originally developed using the U.S. Soil Conservation Service (SCS) TR-20 Project Formulation - Hydrology computer package as part of the Upper East Fork Cave Creek Area Drainage Master Study, in October 1987. The development of the TR-20 model is described in detail in that report. Parameters used in preparing TR-20 model for this study are identical to those used in preparing the Area Master Drainage Study, and are summarized below.

II. INPUT PARAMETERS

A. Rainfall

The City of Phoenix design rainfall criteria was used, which consists of rainfall frequency-depth-duration values and a 24-hour time distribution of rainfall. The point rainfall is assumed to apply to the entire subarea. The frequency-depth-duration criteria is shown in **Table A.1**. The 24 hour values for the 10-, 25-, 50-, and 100-year frequency storms were used. The 500-year depth was extrapolated using Gumbel's extreme value method in accordance with guidelines adopted by the National Weather Service. The City of Phoenix 24-hour rainfall distribution is shown in **Table A.2**.

B. Losses

Losses are estimated by use of the curve number which is a variable that indicates the runoff potential for a subwatershed based on the hydrologic soil cover complex. The soil cover complex is a combination of the soil type and the land use and treatment classes. Procedures for estimating curve numbers are contained in the SCS National Engineering Handbook, Section 4 - Hydrology for natural watersheds and in SCS TR-55 Urban Hydrology for Small Watersheds for urban watersheds. Soils in the East Fork of Cave Creek are primarily type D in the higher elevations and type B in the lower alluvial floodplain areas. Soil types were determined from the SCS Soil Survey of Maricopa County, Arizona.

Curve numbers were assigned to each soil cover complex. In areas with mixed land use, a composite curve number was developed based on the percentage of the total area made up of each land use. A minimum curve number of 95 was used in areas having slopes in excess of 10%. Future condition curve numbers were developed based on zoning information.

C. Unit Hydrograph

The SCS dimensionless unit hydrograph is used in TR-20 which requires the time of concentration as the only input parameter to develop the unit hydrograph. Time of concentration is defined as the time it takes for runoff to travel from the hydraulically most distant part of the storm area to the watershed outlet or other point of reference downstream. Times of concentration were estimated using the Upland method for overland flow conditions and gutter flow times from the City of Phoenix Stormdrain Design Manual for channelized flow conditions. A minimum time of concentration of 10 minutes was used. Subarea characteristics of area, curve number, and time of concentration are tabulated in **Table A.3**.

D. Reach Routing

The Modified Attenuated Kinematic (Att-Kin) routing method was used which takes into account channel storage and hydrograph attenuation as the hydrograph is routed through the reach. With the Att-Kin method the discharge-flow area relationship for simple cross sections (rectangular, triangular, trapezoidal) is fit by a power curve function of the form $Q=XA^m$, where Q and A are the discharge and area at any distance and time. The coefficient X and the exponent m are specified by the user based on the channel dimensions, roughness, and slope.

III. RESULTS

The TR-20 subarea map is attached as **Figure A.1**, showing the drainage subarea boundaries and points of concentration as well as the reach routing paths used. The TR-20 modeling area was limited to the area outside the diffusion modeling area because the hydrologic routing is accomplished within the DHM-21 model with hydrograph inputs from TR-20 at the model boundary (see Appendix C for a description of DHM-21).

The computed peak discharges for the 10-, 25-, 50-, 100-, and 500-year runs, designated as storm numbers 1, 2, 3, 4, and 5 respectively, are shown in the TR-20 output Summary Table 3. The computer input and output listings are contained in **Appendix AA**, bound under separate cover.

Current City of Phoenix Engineering Department Frequency-Depth-Duration Data (Kangieser, 1969) From U.S. Weather Bureau Technical Paper 40 (Hershfield, 1961) Isohyetal Maps

Duration	Return Period, in Years						
	1	2	5	10	25	50	100
	Rainfall Depth, in Inches						
5 min.	0.17	0.26	0.38	0.47	0.59	0.68	0.77
10 min.	0.27	0.40	0.59	0.72	0.91	1.06	1.20
15 min.	0.34	0.50	0.74	0.92	1.15	1.34	1.52
30 min.	0.47	0.70	1.03	1.27	1.60	1.86	2.10
1 hr.	0.60	0.88	1.30	1.61	2.02	2.35	2.66
2 hr.	0.65	0.94	1.39	1.72	2.15	2.49	2.82
3 hr.	0.69	1.01	1.48	1.82	2.27	2.62	2.97
6 hr.	0.81	1.16	1.70	2.07	2.57	2.96	3.35
12 hr.	0.91	1.30	1.90	2.30	2.84	3.26	3.69
24 hr.	1.02	1.44	2.10	2.53	3.12	3.57	4.04

TABLE A.1

City of Phoenix Frequency-Depth-Duration Data

Current City of Phoenix Engineering Department
24-Hour Rainfall Distribution

Time (hours)	Total Rainfall %	Time (hours)	Total Rainfall %
0	0.0	12.5	83.0
.5	0.4	13.0	86.0
1.0	0.8	13.5	88.0
1.5	1.3	14.0	89.3
2.0	1.8	14.5	90.7
2.5	2.2	15.0	92.0
3.0	2.6	15.5	92.4
3.5	3.1	16.0	92.8
4.0	3.5	16.5	93.3
4.5	4.0	17.0	93.7
5.0	4.4	17.5	94.2
5.5	4.8	18.0	94.7
6.0	5.3	18.5	95.1
6.5	5.7	19.0	95.6
7.0	6.2	19.5	96.0
7.5	6.6	20.0	96.4
8.0	7.1	20.5	96.9
8.5	7.5	21.0	97.3
9.0	8.0	21.5	97.8
9.5	9.3	22.0	98.2
10.0	10.7	22.5	98.7
10.5	12.0	23.0	99.1
11.0	14.0	23.5	99.5
11.5	17.0	24.0	1.0
12.0	50.0		

TABLE A.2
City of Phoenix 24-Hour Rainfall Distribution

DRAINAGE AREA NO.	AREA [SQ. MI.]	RUNOFF CURVE NO.	TIME OF CONCENT. [HRS.]
1	0.148	95	0.30
2	0.097	95	0.19
3	0.047	77	0.36
4	0.195	95	0.22
5	0.125	77	0.56
6	0.109	81	0.82
7	0.117	77	0.69
8	0.131	78	0.75
9	0.198	77	0.93
10	0.095	77	0.56
11	0.234	77	0.84
12	0.07	77	0.42
13	0.125	82	0.61
14	0.177	83	0.39
15	0.073	82	0.89
16	0.119	86	0.54
17	0.059	95	0.17
18	0.184	78	0.72
19	0.022	95	0.17
20	0.064	95	0.17
21	0.189	83	0.58
22	0.153	83	0.47
23	0.091	95	0.23
24	0.198	81	0.46
25	0.089	83	0.43
26	0.067	85	0.31
27	0.188	80	1.20
28	0.156	79	0.93
29	0.25	78	1.03
30	0.25	79	0.97
31	0.084	77	0.58
32	0.18	77	0.93
33	0.234	77	1.14
34	0.125	84	0.73
35	0.125	83	0.49
36	0.125	83	0.48
37	0.125	83	0.25
38	0.125	79	0.44
39	0.125	85	0.53
40	0.094	82	0.51
41	0.172	84	0.38
42	0.078	83	0.22
43	0.047	86	0.17
44	0.125	83	0.30
45	0.125	86	0.51
46	0.125	82	0.29
47	0.125	82	0.31

TABLE A.3

TR-20 Subarea Characteristics

DRAINAGE AREA NO.	AREA [SQ. MI.]	RUNOFF CURVE NO.	TIME OF CONCENT. [HRS.]
48	0.125	79	0.60
49	0.086	95	0.19
50	0.134	77	0.57
51	0.063	83	0.18
52	0.063	79	0.56
53	0.084	84	0.31
54	0.061	79	0.23
55	0.063	83	0.25
56	0.063	82	0.25
57	0.063	82	0.25
58	0.063	84	0.25
59	0.063	82	0.25
60	0.063	81	0.49
61	0.102	83	0.25
62	0.13	79	0.88
63	0.141	84	0.34
64	0.25	82	0.33
65	0.063	77	0.49
66	0.063	83	0.46
67	0.063	88	0.25
68	0.063	85	0.25
69	0.063	81	0.62
70	0.063	86	0.25
71	0.125	85	0.49
72	0.125	83	0.49
73	0.197	80	0.79
74	0.063	90	0.24
75	0.063	95	0.52
76	0.063	86	0.25
77	0.063	77	0.38
78	0.063	86	0.27
79	0.063	88	0.25
80	0.063	83	0.45
81	0.063	77	0.52
82	0.063	84	0.27
83	0.063	81	0.52
84	0.063	78	0.52
85	0.063	80	0.52
86	0.063	86	0.27
87	0.063	83	0.52
88	0.094	87	0.75
89	0.047	84	0.39
90	0.109	85	0.63
91	0.125	86	0.47
92	0.125	86	0.47
93	0.195	84	0.45
94	0.139	84	0.34
95	0.125	86	0.98

TABLE A.3 (Cont.)

TR-20 Subarea Characteristics

UPPER EAST FORK - CAVE CREEK ADMS

DRAINAGE AREA NO.	AREA [SQ. MI.]	RUNOFF CURVE NO.	TIME OF CONCENT. [HRS.]
96	0.125	82	0.51
97	0.188	87	0.53
98	0.094	86	0.37
99	0.094	86	0.49
100	0.078	86	0.39
101	0.047	89	0.52
102	0.063	82	0.63
103	0.081	84	0.26
104	0.069	78	0.67
105	0.063	78	0.63
106	0.063	79	0.56
107	0.059	82	0.42
108	0.025	79	0.28
109	0.063	84	0.29
110	0.073	78	0.56
111	0.07	77	0.56
112	0.061	77	0.46
113	0.053	86	0.52
114	0.128	77	1.19
115	0.094	82	0.45
116	0.094	79	0.77
117	0.313	77	2.38
118	0.231	81	1.59
119	0.231	81	1.05
120	0.231	87	0.30
121	0.25	95	0.17
122	0.355	85	0.29
123	0.213	95	0.25
124	0.219	84	0.25
125	0.117	95	0.17
126	0.158	95	0.28
127	0.159	82	0.21
128	0.036	80	0.17
129	0.108	82	0.17
13	0.031	91	0.17
131	0.119	86	0.27
132	0.145	88	0.27
133	0.08	95	0.17
134	0.197	85	0.31
135	0.042	95	0.17
136	0.066	95	0.17
137	0.078	79	0.49
138	0.203	84	0.24
139	0.188	87	0.43
140	0.125	86	0.44
141	0.188	87	0.53
142	0.25	83	1.39
TOTAL	16.46		

TABLE A.3 (Cont.)

TR-20 Subarea Characteristics

APPENDIX B
HEC-2 WATER SURFACE PROFILE ANALYSIS

I. GENERAL

The U.S. Army Corps of Engineers HEC-2 Water Surface Profile computer program was used for the water surface profile analysis for the channelized area east of Cave Creek Road. The area modeled is contained within planning reaches 94 through 98 and extends from Cave Creek Road on the southwest to Beardsley Road on the north. The HEC-2 model area is shown on the attached **Figure B.1** which shows the channel centerline and 100 foot stations. The channel centerline and stationing is the same for the existing and improved conditions. The centerline is assigned station 1000 in the cross sections, and the centerline stationing corresponds to the stationing on the channel construction plans.

II. INPUT PARAMETERS

A. Cross-sections

Existing condition cross sections were developed from a digital terrain model generated from aerial mapping data using the McDonnell Douglas "Graphic Design System" (GDS) computer package. The GDS system develops a surface by triangulating between data points supplied by the aerial mapping company. Cross sections were then cut through the triangulation network at every 100 foot station and any intermediate stations required.

The design cross sections were developed using the three dimensional digital terrain modelling and design software MOSS. The channel design was incorporated into the three dimensional model. Cross sections were then cut at every 25 foot station.

B. Manning's n

Manning's n values were determined based on field inspections of the channel reaches with consideration of vegetation and soil types. N values in the overbank areas are affected by the presence of structures that impede the flow. Manning's n values for the overbank areas were adjusted to account for obstructions using the adjusted urban roughness coefficient, n_u, described in Drainage Design Manual for Maricopa County, Arizona, Volume II Hydraulics, (Draft dated November, 1991).

C. Downstream Conditions

Downstream control for starting water surface profiles is the road crossing at Cave Creek Road. The road acts as a weir and backs up the flow into the Pepperidge channel to the east. Critical flow across Cave Creek Road was assumed as the control condition for backwater calculations.

D. Road Crossings

Dip section crossings were modeled at Cave Creek Road, Bell Road, and Siesta Lane. Dip crossings were modeled by inputting the road profile at the upstream and downstream edges of pavement using the GR ground cross section records.

Culvert crossings were modeled at B Street and Utopia Road. The B Street crossing is a box culvert and was modeled using the normal bridge option within HEC-2. The Utopia Road crossing consists of six pipe culverts of varying size, material, invert elevation, and slope. Because of limitations within the HEC-2 program for modeling circular culverts, a separate calculation was performed to generate a composite stage discharge rating curve that included flow through the 6 culverts as well as roadway overtopping for the range of flows modeled. The rating curve was input using the RC records. The water surface profile for the reach upstream from Utopia Road was based on the water surface profile elevation from the rating curve, not the backwater computed downstream. The stage discharge rating curve used is shown on **Figure B.2**.

III. RESULTS

The results of the HEC-2 water surface profile analysis are shown on **Figure 2.4** as the limits of flooding for the 10-, 25-, 50-, 100-, and 500-year flows. Results are also shown in **Figures 2.5, 2.6, 2.7, 2.8,** and **2.9** with flooding depth contours. The computer input and output listings are contained in **Appendix BB**, bound under separate cover.

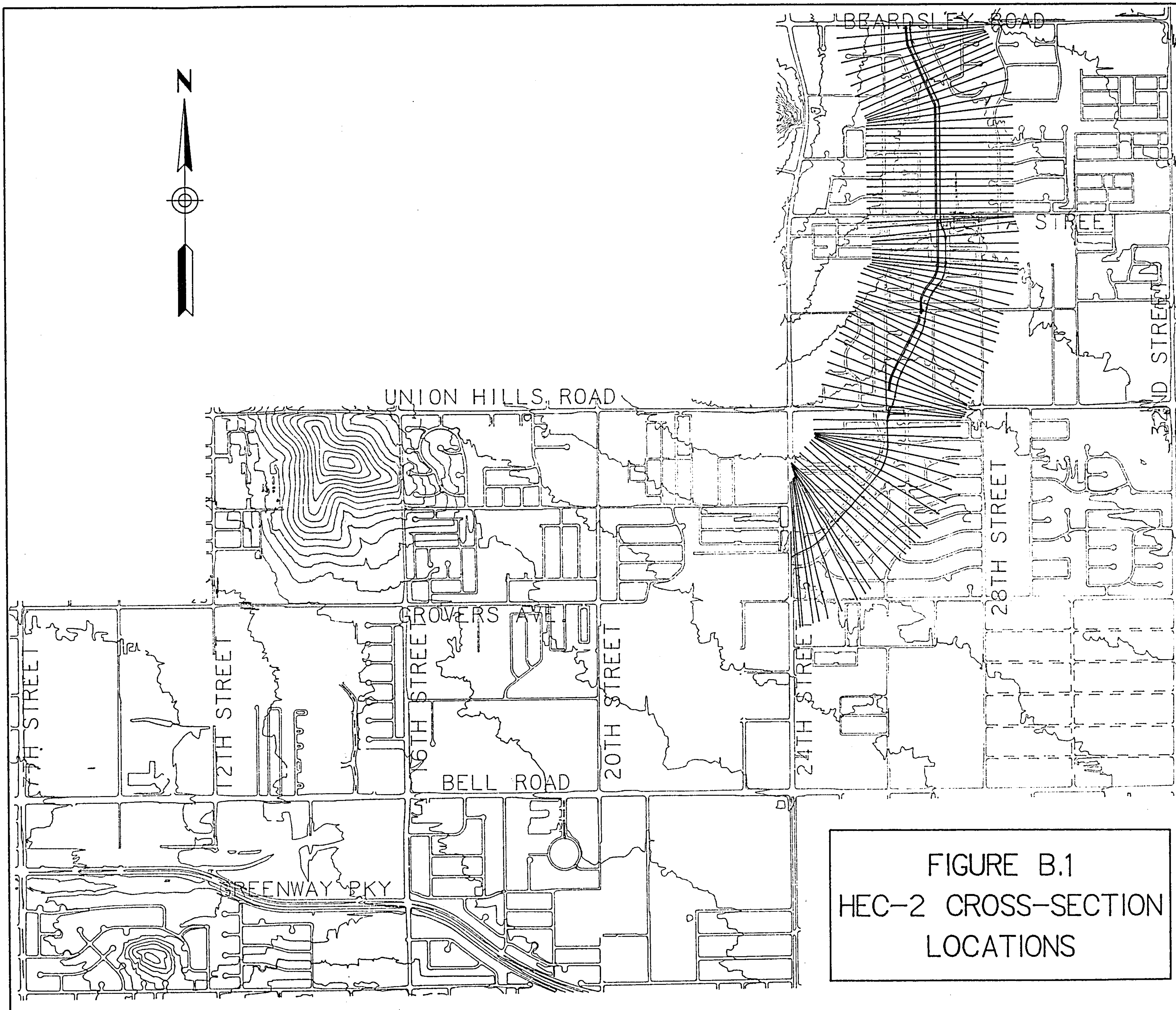


FIGURE B.1
HEC-2 CROSS-SECTION
LOCATIONS

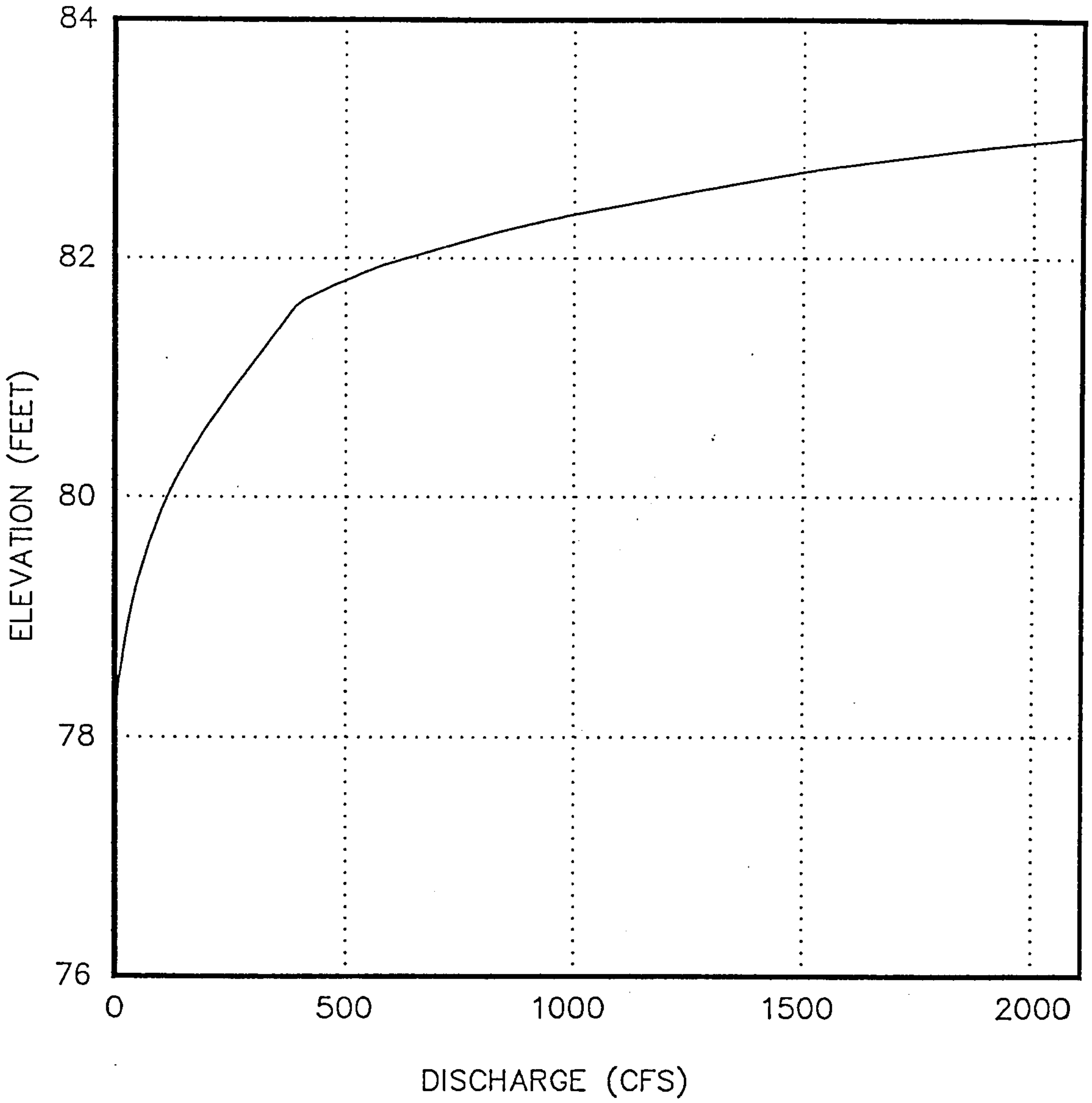


Figure B.2
Utopia Road Crossing - Rating Curve

APPENDIX C
DHM-21 DIFFUSION HYDRODYNAMIC MODEL ANALYSIS

I. GENERAL

The U.S. Geological Survey DHM-21 Diffusion Hydrodynamic Model computer program was used for the flooding depth analysis for the non channelized area west of Cave Creek Road. The area modeled is contained within planning reaches 1 through 93 and extends from 12th Street on the west to Cave Creek Road on the east and from Michigan Avenue on the north to the Greenway Channel on the south. The DHM-21 model area is shown on **Figure 2.3** which shows the grid used with the cell numbering, channel reaches, and points of hydrograph inflow along the grid boundary.

II. INPUT PARAMETERS

A. Physical Description of Cell

The input required to describe the physical characteristics of the cell is the adjoining cell numbers for the cells located on the north, east, south, and west sides of the current cell, the length of the side of each cell, the mannings n value for the cell, and the average elevation for the cell. Cells are effectively modeled as flat planes with the specified roughness.

Mannings n values for overland flow are affected by the presence of structures that impede the flow. Manning's n values were determined based on the natural ground n value, adjusted to account for obstructions using the adjusted urban roughness coefficient, n_u, described in Drainage Design Manual for Maricopa County, Arizona, Volume II Hydraulics, (Draft dated November, 1991). The physical input data is tabulated in **Table C.1**.

B. Boundary Conditions

The flow conditions at the grid boundaries are specified as either critical depth outflow boundaries or as impervious no-flow boundaries.

Additionally, hydrograph inflows may be specified at any cell.

Runoff hydrographs from the TR-20 analysis were input at the grid boundaries where they enter the DHM-21 modeling area. The hydrograph input is limited to ten data points. Intermediate data points from the TR-20 output hydrograph were deleted to reduce the number of points to ten. The ten points were selected so that the peak discharge and runoff volume were maintained within an acceptable error. This was done by selecting various combinations of 10 points and computing the volume for comparison with the volume output from TR-20 until the optimal combination was found. Errors in volume were within 8 percent in all cases and were generally within 5 percent. The Hydrograph values used along with the error in volume are shown in **Table C.2**

C. Rainfall

The model has the capability to add rainfall to the inflow at each cell based on a user input rainfall hyetograph. Rainfall losses due to infiltration and ground surface interception are not computed, therefore, the effective rainfall values are input. The effective rainfall hyetograph was input by computing a composite curve number for the entire modeled area and computing the total runoff depth for the 24 hour rainfall using the SCS runoff equation. The City of Phoenix rainfall distribution was used to distribute the effective rainfall over the 24 hour period of rainfall. The rainfall hyetographs used are shown in **Table C.3**

D. Channels

The model has the capability of modeling rectangular shaped channel reaches within the grid. The water surface elevation in the channel is balanced with the water surface elevation in the cell to determine the amount of flow contained in the channel. The required channel input data is the depth, width, and manning's n for the reach. Four channel reaches were modeled. The channel input parameters used are tabulated in **Table C.4.**

20th and 21st Streets divert a significant amount of runoff to the south. During larger storms, the street capacity is exceeded and the overflow proceeds to the west. 20th and 21st Streets were modeled as channels to account for this diversion. 20th Street was modeled as a channel from Bell Road to Grovers Avenue and 21st Street was modeled as a channel from Paradise Lane to Contention Lane.

There is an existing channel that drains into the Greenway Channel at 12th Street. The channel extends from 12th Street at the Greenway channel to about 14th Street, south of Bell Road at the Cadillac dealership. This channel was input into the model.

There is a channel at 15th Street that drains south from Grovers at an apartment complex. The channel intercepts runoff from Grovers Avenue and from the Mobile Home Park to the east and directs it to an open field at 14th Street at the apartment complex boundary. This channel was modeled but was found to be out of the affected area of flooding for the proposed improvements. The channel reaches modeled are shown on **Figure 2.3**.

III. RESULTS

The results of the DHM-21 diffusion modeling analysis are shown on **Figure 2.4** as the limits of flooding for the 10-, 25-, 50-, 100-, and 500-year flows. Results are also shown in **Figures 2.5, 2.6, 2.7, 2.8,** and **2.9** with flooding depth contours. The computer input and output listings are contained in **Appendix CC**, bound under separate cover.

Cell No.	NN	NE	NS	NW	Adj. n nu	Elev. (Ft.)
1	0.0	2.0	7.0	0.0	0.482	1446.7
2	0.0	0.0	8.0	1.0	0.482	1449.0
3	0.0	4.0	15.0	0.0	0.341	1429.3
4	0.0	5.0	16.0	3.0	0.341	1433.9
5	0.0	6.0	17.0	4.0	0.341	1437.2
6	0.0	7.0	18.0	5.0	0.279	1439.9
7	1.0	8.0	19.0	6.0	0.173	1442.4
8	2.0	0.0	20.0	7.0	0.170	1445.7
9	0.0	10.0	21.0	0.0	0.170	1399.0
10	0.0	11.0	22.0	9.0	0.170	1404.0
11	0.0	12.0	23.0	10.0	0.230	1409.0
12	0.0	13.0	24.0	11.0	0.414	1413.0
13	0.0	14.0	25.0	12.0	0.193	1417.8
14	0.0	15.0	26.0	13.0	0.174	1422.8
15	3.0	16.0	27.0	14.0	0.389	1427.8
16	4.0	17.0	28.0	15.0	0.389	1432.3
17	5.0	18.0	29.0	16.0	0.170	1435.3
18	6.0	19.0	30.0	17.0	0.170	1438.0
19	7.0	20.0	31.0	18.0	0.301	1441.0
20	8.0	0.0	32.0	19.0	0.435	1443.9
21	9.0	22.0	33.0	0.0	0.170	1397.0
22	10.0	23.0	34.0	21.0	0.170	1401.5
23	11.0	24.0	35.0	22.0	0.230	1406.5
24	12.0	25.0	36.0	23.0	0.414	1411.2
25	13.0	26.0	37.0	24.0	0.170	1416.2
26	14.0	27.0	38.0	25.0	0.170	1421.5
27	15.0	28.0	39.0	26.0	0.223	1425.6
28	16.0	29.0	40.0	27.0	0.254	1429.4
29	17.0	30.0	41.0	28.0	0.173	1432.1
30	18.0	31.0	42.0	29.0	0.173	1434.9
31	19.0	32.0	43.0	30.0	0.227	1438.3
32	20.0	0.0	44.0	31.0	0.262	1440.0
33	21.0	34.0	45.0	0.0	0.182	1396.3
34	22.0	35.0	46.0	33.0	0.397	1401.3
35	23.0	36.0	47.0	34.0	0.230	1407.0
36	24.0	37.0	48.0	35.0	0.414	1411.3
37	25.0	38.0	49.0	36.0	0.338	1414.4
38	26.0	39.0	50.0	37.0	0.170	1418.4
39	27.0	40.0	51.0	38.0	0.188	1422.2
40	28.0	41.0	52.0	39.0	0.190	1425.6
41	29.0	42.0	53.0	40.0	0.171	1428.2
42	30.0	43.0	54.0	41.0	0.171	1431.4
43	31.0	44.0	55.0	42.0	0.216	1434.5
44	32.0	0.0	56.0	43.0	0.204	1435.5
45	33.0	46.0	57.0	0.0	0.182	1396.0
46	34.0	47.0	58.0	45.0	0.397	1401.3
47	35.0	48.0	59.0	46.0	0.230	1406.0
48	36.0	49.0	60.0	47.0	0.153	1409.0
49	37.0	50.0	61.0	48.0	0.136	1411.7
50	38.0	51.0	62.0	49.0	0.173	1415.4
51	39.0	52.0	63.0	50.0	0.188	1419.4

Table C.1

DHM-21 Input Data Summary

Cell No.	NN	NE	NS	NW	Adj. n nu	Elev. (Ft.)
52	40.0	53.0	64.0	51.0	0.186	1423.3
53	41.0	54.0	65.0	52.0	0.162	1426.1
54	42.0	55.0	66.0	53.0	0.170	1428.4
55	43.0	56.0	67.0	54.0	0.170	1430.4
56	44.0	0.0	68.0	55.0	0.136	1431.9
57	45.0	58.0	69.0	0.0	0.176	1393.8
58	46.0	59.0	70.0	57.0	0.141	1397.5
59	47.0	60.0	71.0	58.0	0.173	1401.5
60	48.0	61.0	72.0	59.0	0.170	1405.5
61	49.0	62.0	73.0	60.0	0.327	1410.0
62	50.0	63.0	74.0	61.0	0.213	1413.7
63	51.0	64.0	75.0	62.0	0.168	1417.0
64	52.0	65.0	76.0	63.0	0.280	1421.5
65	53.0	66.0	77.0	64.0	0.164	1423.5
66	54.0	67.0	78.0	65.0	0.170	1424.3
67	55.0	68.0	79.0	66.0	0.170	1426.4
68	56.0	0.0	80.0	67.0	0.253	1428.4
69	57.0	70.0	0.0	0.0	0.170	1390.0
70	58.0	71.0	0.0	69.0	0.170	1395.0
71	59.0	72.0	0.0	70.0	0.183	1398.8
72	60.0	73.0	0.0	71.0	0.170	1403.3
73	61.0	74.0	0.0	72.0	0.364	1407.3
74	62.0	75.0	81.0	73.0	0.364	1410.8
75	63.0	76.0	82.0	74.0	0.191	1414.3
76	64.0	77.0	83.0	75.0	0.166	1418.1
77	65.0	78.0	84.0	76.0	0.170	1418.8
78	66.0	79.0	85.0	77.0	0.205	1420.0
79	67.0	80.0	86.0	78.0	0.170	1422.8
80	68.0	0.0	87.0	79.0	0.170	1425.0
81	74.0	82.0	0.0	0.0	0.364	1408.4
82	75.0	83.0	88.0	81.0	0.364	1411.4
83	76.0	84.0	89.0	82.0	0.170	1414.0
84	77.0	85.0	90.0	83.0	0.263	1414.6
85	78.0	86.0	91.0	84.0	0.203	1416.8
86	79.0	87.0	92.0	85.0	0.332	1419.0
87	80.0	0.0	93.0	86.0	0.332	1422.7
88	82.0	89.0	0.0	0.0	0.374	1410.0
89	83.0	90.0	0.0	88.0	0.364	1412.0
90	84.0	91.0	0.0	89.0	0.185	1412.3
91	85.0	92.0	0.0	90.0	0.208	1414.3
92	86.0	93.0	0.0	91.0	0.332	1417.9
93	87.0	0.0	0.0	92.0	0.332	1421.7

Table C.1

DHM-21 Input Data Summary

Table C.2

Boundary Conditions - Input Hydrographs

	8 (2) Area 37			68 (5) Area 88			80 (6) Area 101			4 (1) Area 40			13 (4) Area 41			12 (3) Area 42		
No.	Time Hrs.	Q CFS	Vol. AF	Time Hrs.	Q CFS	Vol. AF	Time Hrs.	Q CFS	Vol. AF	Time Hrs.	Q CFS	Vol. AF	Time Hrs.	Q CFS	Vol. AF	Time Hrs.	Q CFS	Vol. AF
1	0	0		0	0		0	0		0	0		0	0		0	0	
2	10.4	0.01	0.00	10.72	0.01	0.00	9.84	0	0.00	9.28	0.38	0.15	11.44	0.14	0.07	9.04	0	0.00
3	11.84	5.17	0.31	11.84	16.11	0.75	11.6	1.65	0.12	11.76	8.4	0.90	11.76	18.39	0.25	10.48	0	0.00
4	12.64	494.65	16.52	12.64	343.18	11.88	12.24	29.16	0.81	12.48	154.14	4.84	12.48	172.01	5.66	11.52	0.16	0.01
5	13.04	620.83	18.44	12.88	393.47	7.31	12.56	36.51	0.87	12.72	177.81	3.29	12.56	181.51	1.17	12	33.02	0.66
6	13.52	716.07	26.52	13.6	210.93	17.98	12.8	25.46	0.61	12.8	172.5	1.16	13.36	40.15	7.33	12.48	53.98	1.73
7	14.24	457.55	34.92	15.84	58.71	24.96	13.12	8.88	0.45	13.36	56.63	5.30	13.92	15.2	1.28	12.8	9.64	0.84
8	15.2	154.61	24.28	17.28	23.36	4.88	13.84	2.38	0.34	14.08	16.22	2.17	15.04	10.38	1.18	13.12	4.73	0.19
9	16.96	38.76	14.06	19.6	14.85	3.66	15.76	0.62	0.24	16.16	3.61	1.70	16	3.6	0.55	16	0.75	0.65
10	23.92	26.78	18.85	23.92	13.98	5.15	23.92	0.63	0.42	23.92	3.43	2.26	23.92	3.72	2.40	23.92	0.96	0.56
		Vol (AF)	153.90		Vol (AF)	76.57		Vol (AF)	3.87		Vol (AF)	21.76		Vol (AF)	19.89		Vol (AF)	4.63
		TR-20	146.38		TR-20	72.35		TR-20	3.68		TR-20	20.27		TR-20	19.06		TR-20	4.47
		ERROR	5.14%		ERROR	5.83%		ERROR	5.06%		ERROR	7.37%		ERROR	4.34%		ERROR	3.66%

Boundary Conditions - Input Hydrographs

Table C.2

18-Apr-91 DHM-21 Inflow Hydrographs - 25 Year Flows

No.	Area 37 (8 (2)✓) Time Hrs.	Area 37 Q CFS	Area 37 Vol. AF	Area 88 (68 (5)✓) Time Hrs.	Area 88 Q CFS	Area 88 Vol. AF	Area 101 (80 (6)✓) Time Hrs.	Area 101 Q CFS	Area 101 Vol. AF	Area 40 (4 (1)✓) Time Hrs.	Area 40 Q CFS	Area 40 Vol. AF	Area 41 (13 (4)✓) Time Hrs.	Area 41 Q CFS	Area 41 Vol. AF	Area 42 (12 (3)✓) Time Hrs.	Area 42 Q CFS	Area 42 Vol. AF
1	0	0		0	0		0	0		0	0		0	0		0	0	
2	10.4	0.03	0.01	10	0.02	0.01	9.2	0.01	0.00	9.36	0.64	0.25	10.88	0.16	0.07	9.04	0	0.00
3	11.76	20.26	1.14	11.76	19.02	1.38	11.52	1.68	0.16	11.76	14.69	1.52	11.68	19.3	0.64	10.48	0	0.00
4	12.88	986.99	46.62	12.64	501.81	18.94	12.32	43.19	1.48	12.56	233.54	8.21	12.48	259.44	9.21	11.52	1.24	0.05
5	13.28	1109.33	34.65	12.8	553.97	6.98	12.56	48.43	0.91	12.72	245.74	3.17	12.56	268.9	1.75	12	50.29	1.02
6	13.52	1057.24	21.49	13.6	329.59	29.21	12.8	33.4	0.81	12.8	239.56	1.60	13.2	65.63	8.85	12.48	74.11	2.47
7	14.24	513.8	46.74	15.68	83.24	35.48	13.12	11.59	0.59	13.36	77.27	7.33	13.84	19.95	2.26	12.8	13.04	1.15
8	15.12	174.19	25.02	17.12	29.76	6.72	13.84	3.07	0.44	14.08	20.77	2.92	15.04	13.74	1.67	13.12	6.36	0.26
9	16.96	44.59	16.63	19.6	19.52	5.05	15.76	0.79	0.31	16.16	4.68	2.19	16	4.55	0.73	16	1.01	0.88
10	23.92	35.14	22.93	23.92	18.75	6.83	23.92	0.8	0.54	23.92	4.47	2.93	23.92	4.98	3.12	23.92	1.28	0.75
		Vol (AF)	215.23		Vol (AF)	110.61		Vol (AF)	5.24		Vol (AF)	30.12		Vol (AF)	28.30		Vol (AF)	6.58
		TR-20	206.66		TR-20	104.56		TR-20	5		TR-20	28.06		TR-20	27.19		TR-20	6.4
		ERROR	4.15%		ERROR	5.79%		ERROR	4.85%		ERROR	7.33%		ERROR	4.09%		ERROR	2.79%

Table C.2

Boundary Conditions - Input Hydrographs

	8 (2) ✓			68 (5) ✓			80 (6) ✓			4 (1) ✓			13 (4) ✓			12 (3) ✓		
	Area 37			Area 88			Area 101			Area 40			Area 41			Area 42		
No.	Time Hrs.	Q CFS	Vol. AF	Time Hrs.	Q CFS	Vol. AF	Time Hrs.	Q CFS	Vol. AF	Time Hrs.	Q CFS	Vol. AF	Time Hrs.	Q CFS	Vol. AF	Time Hrs.	Q CFS	Vol. AF
1	0	0		0	0		0	0		0	0		0	0		0	0	
2	10.4	0.05	0.02	10.64	1.47	0.65	9.2	0.08	0.03	9.44	1.01	0.39	10.88	1.09	0.49	9.04	0	0.00
3	11.76	73.47	4.13	11.84	55.11	2.81	11.52	2.33	0.23	11.76	21.16	2.13	11.68	29.29	1.00	10.48	0.02	0.00
4	12.88	1212.17	59.50	12.56	621.74	20.14	12.32	52.09	1.80	12.56	290.18	10.29	12.48	321.79	11.61	11.52	2.27	0.10
5	13.28	1347.04	42.30	12.8	746.76	13.57	12.56	57.56	1.09	12.72	301.53	3.91	12.56	331.29	2.16	12	64.28	1.32
6	13.52	1303.93	26.29	13.6	444.78	39.39	12.8	39.46	0.96	12.8	292.14	1.96	13.2	76.72	10.79	12.48	89.7	3.05
7	14.24	617.44	57.16	14.88	164.48	32.23	13.12	13.65	0.70	13.36	88.26	8.80	13.84	23.33	2.65	12.8	15.66	1.39
8	15.12	201.1	29.77	16.48	42.25	13.67	13.84	3.59	0.51	14.08	23.5	3.33	15.04	16.34	1.97	13.12	7.62	0.31
9	16.96	52.3	19.27	20	22.16	9.37	15.76	0.92	0.36	16.16	5.45	2.49	16	5.37	0.86	16	1.2	1.05
10	23.92	41.77	27.05	23.92	22.3	7.20	23.92	0.94	0.63	23.92	5.28	3.44	23.92	5.91	3.69	23.92	1.51	0.89
		Vol (AF)	265.50		Vol (AF)	139.02		Vol (AF)	6.31		Vol (AF)	36.74		Vol (AF)	35.22		Vol (AF)	8.11
		TR-20	254.86		TR-20	130.79		TR-20	6.03		TR-20	34.28		TR-20	33.69		TR-20	7.95
		ERROR	4.17%		ERROR	6.29%		ERROR	4.65%		ERROR	7.18%		ERROR	4.53%		ERROR	2.03%

Table C.2

Boundary Conditions - Input Hydrographs

	Area 37 (8 (2) ✓)			Area 88 (68 (5) ✓)			Area 101 (80 (6) ✓)			Area 40 (4 (1) ✓)			Area 41 (13 (4) ✓)			Area 42 (12 (3) ✓)		
No.	Time Hrs.	Q CFS	Vol. AF	Time Hrs.	Q CFS	Vol. AF	Time Hrs.	Q CFS	Vol. AF	Time Hrs.	Q CFS	Vol. AF	Time Hrs.	Q CFS	Vol. AF	Time Hrs.	Q CFS	Vol. AF
1	0	0		0	0		0	0		0	0		0	0		0	0	
2	10.4	0.07	0.03	10.64	3.44	1.51	9.2	0.17	0.06	9.44	1.63	0.64	10.88	2.51	1.13	9.04	0	0.00
3	11.76	103.66	5.83	11.84	73.03	3.79	11.52	3.07	0.31	11.68	20.27	2.03	11.6	17.35	0.59	10.48	0.28	0.02
4	12.88	1519.92	75.14	12.56	758.82	24.75	12.32	61.43	2.13	12.56	365.97	14.05	12.48	374.83	14.26	11.52	3.48	0.16
5	13.28	1651.19	52.42	12.8	901.81	16.47	12.56	67.1	1.27	12.72	365.32	4.83	12.56	385.99	2.52	12	79.4	1.64
6	13.52	1566.45	31.91	13.6	545.92	47.86	12.8	45.78	1.12	12.8	339.3	2.33	13.2	104.32	12.97	12.48	106.11	3.68
7	14.24	687.51	67.06	14.88	197.59	39.33	13.12	15.8	0.81	13.36	83.36	9.78	13.76	32.16	3.16	12.8	18.41	1.65
8	15.12	222.09	33.08	16.48	48.59	16.28	13.84	4.13	0.59	14.08	24.36	3.20	15.04	19.15	2.71	13.12	8.93	0.36
9	16.96	59.33	21.40	20	25.91	10.84	15.76	1.06	0.41	16.16	6.1	2.62	16	6.39	1.01	16	1.4	1.23
10	23.92	48.58	31.04	23.92	26.09	8.42	23.92	1.07	0.72	23.92	6.28	3.97	23.92	6.78	4.31	23.92	1.76	1.03
		Vol (AF)	317.89		Vol (AF)	169.24		Vol (AF)	7.44		Vol (AF)	43.45		Vol (AF)	42.66		Vol (AF)	9.77
		TR-20	306.94		TR-20	158.97		TR-20	7.12		TR-20	41		TR-20	40.68		TR-20	9.62
		ERROR	3.57%		ERROR	6.46%		ERROR	4.48%		ERROR	5.96%		ERROR	4.86%		ERROR	1.59%

Boundary Conditions - Input Hydrographs

Table C.2

	8			68			80			4			13			12		
	Area 37			Area 88			Area 101			Area 40			Area 41			Area 42		
No.	Time Hrs.	Q CFS	Vol. AF	Time Hrs.	Q CFS	Vol. AF	Time Hrs.	Q CFS	Vol. AF	Time Hrs.	Q CFS	Vol. AF	Time Hrs.	Q CFS	Vol. AF	Time Hrs.	Q CFS	Vol. AF
1	0	0		0	0		0	0		0	0		0	0		0	0	
2	9.68	0.37	0.15	9.68	3.14	1.26	8.96	0.28	0.10	9.28	1.7	0.65	8.72	0.01	0.00	9.04	0	0.00
3	11.68	119.89	9.94	11.76	77.17	6.90	11.52	4.79	0.54	11.68	32.49	3.39	11.52	18.24	2.11	10.48	1.01	0.06
4	12.72	2279.34	103.11	12.64	1248.81	48.22	12.24	77.88	2.46	12.48	471.73	16.67	12.48	520.16	21.36	11.52	6.49	0.32
5	13.04	2490.81	63.08	12.8	1367.77	17.30	12.56	87.95	2.19	12.64	502.1	6.44	12.56	530.87	3.47	12	113.72	2.38
6	13.44	2212.4	77.74	13.04	1238.6	25.85	12.8	59.56	1.46	12.8	466.79	6.41	13.36	86.24	20.40	12.48	142.17	5.08
7	14.08	928.68	83.07	14.16	452.89	78.28	13.12	20.47	1.06	13.28	137.91	11.99	13.92	33.71	2.78	12.88	17.86	2.65
8	14.8	325.18	37.30	15.12	167.84	24.62	13.76	5.92	0.70	14	34.33	5.12	15.04	25.11	2.72	13.12	11.79	0.29
9	16.64	84.13	31.12	17.12	40.21	17.19	15.52	1.77	0.56	16.08	8.08	3.65	16	8.28	1.32	16	1.84	1.62
10	23.92	63.01	44.26	23.92	34.15	20.89	23.92	1.37	1.09	23.92	8.12	5.25	23.92	8.87	5.61	23.92	2.31	1.36
		Vol (AF)	449.77		Vol (AF)	240.52		Vol (AF)	10.16		Vol (AF)	59.57		Vol (AF)	59.78		Vol (AF)	13.76
		TR-20	425.59		TR-20	223.65		TR-20	9.56		TR-20	56.13		TR-20	56.57		TR-20	13.42
		ERROR	5.68%		ERROR	7.54%		ERROR	6.28%		ERROR	6.12%		ERROR	5.68%		ERROR	2.55%

Point	Time	10 Yr		25 Yr		50 Yr		100 Yr		500 Yr	
No.	(Hrs.)	(in/hr)	(in)	(in/hr)	(in)	(in/hr)	(in)	(in/hr)	(in)	(in/hr)	(in)
1	0	0		0		0		0		0	
2	9	0.01	0.05	0.01	0.05	0.02	0.09	0.02	0.09	0.03	0.14
3	9.5	0.03	0.01	0.04	0.01	0.05	0.02	0.06	0.02	0.08	0.03
4	11.5	0.06	0.09	0.09	0.13	0.11	0.16	0.13	0.19	0.19	0.27
5	12	0.67	0.18	0.97	0.27	1.21	0.33	1.48	0.40	2.07	0.57
6	12.5	0.67	0.34	0.97	0.49	1.21	0.61	1.48	0.74	2.07	1.04
7	13	0.06	0.18	0.09	0.27	0.11	0.33	0.13	0.40	0.19	0.57
8	14	0.03	0.05	0.04	0.07	0.05	0.08	0.06	0.10	0.08	0.14
9	19	0.01	0.10	0.01	0.13	0.02	0.18	0.02	0.20	0.03	0.28
10	24	0.01	0.05	0.01	0.05	0.02	0.10	0.02	0.10	0.03	0.15
24 hour Rain (in)			1.04		1.44		1.89	3.4	2.24	4.77	3.16
Calc'd by CN (in)			1.02		1.47		1.84		2.24		3.14
Error			1.96%		-1.87%		2.58%		0.00%		0.56%

Table C.3

Boundary Conditions - Input Rainfall Hyetographs

Cell No.	Channel Data: Max Depth (Ft)	Width (Ft)	Slope (Ft/Ft)	Mann n	Alpha	Description
11	2	10	0.0043	0.013	75	Apt Complex
17	0.5	15	0.0034	0.016	81	20th Street
23	2	10	0.0043	0.013	75	Apt Complex
29	0.5	15	0.0034	0.016	81	20th Street
30	0.5	15	0.004	0.016	88	21st Street
41	0.5	15	0.0034	0.016	81	20th Street
42	0.5	15	0.004	0.016	88	21st Street
53	0.5	15	0.0034	0.016	81	20th Street
54	0.5	15	0.004	0.016	88	21st Street
59	2	200	0.0114	0.018	1768	12th St. - Bell Rd.
66	2	30	0.0045	0.016	187	21st Street
69	4	50	0.0038	0.018	255	12th St. - Bell Rd.
70	4	50	0.0038	0.018	255	12th St. - Bell Rd.
78	2	30	0.0045	0.016	187	21st Street
85	2	30	0.0045	0.016	187	21st Street
91	2	30	0.0045	0.016	187	21st Street
58	4	90	0.05	0.018	1666	12th St. - Bell Rd.

Table C.4

Channel Input Data Summary

APPENDIX D
SID STRUCTURE INVENTORY FOR DAMAGE ANALYSIS

I. GENERAL

The frequency-damage relationship was derived using the Structure Inventory For Damage Analysis (SID) computer program. The input required is the depth-percent damage functions, the planning reach data, and the structure inventory data. The input parameters are described below.

II. INPUT PARAMETERS

A. Damage Functions

The six damage functions described in Chapter 2 under step 6 of the existing conditions without project analysis were input into the SID model. The six functions are shown on **Figures 2.10** and **2.11**. Zero stage is the finished floor elevation. It should be noted that the program interpolates between the data points as it computes damages. Stage -1 has zero damage, but damage is computed for depths between -1 and zero feet to account for damage that occurs when water is below the finished floor elevation. The ground elevation was input into SID and a difference of one foot for mobile homes and 0.5 feet for all other structures was input between the ground level and the finished floor. Therefore, damage begins when the flood elevation is at ground level for mobile homes and 0.5 feet below ground for all other structures.

B. Planning Reach data

The flood elevations for each of the 5 storms were input for each reach. The program computes the damage to structures in each reach for the flooding depths specified. Additionally, the percent of structures sampled is input for each structure type. In the diffusion modeling area, one structure of each type that occurs in the reach was input. The damage for that structure was adjusted to account for the actual number of structures based on the percentage of structures sampled for the reach. In the HEC-2 modeling area, a complete inventory was made and each structure entered individually.

C. Structure data

Each structure sampled is specified with a unique identifier and described by the type of structure and the damage functions to be used for the structure and contents. Additionally, the structure value and contents value (percentage of the structure value) is input.

III. RESULTS

Separate SID models were prepared for the DHM-21 area and the HEC-2 area. The frequency damage values were computed for each reach and aggregated into a single value for the entire area. The values for the DHM-21 run and the HEC-2 run were added together for the Expected Annual Damage analysis. The frequency damage results are presented in Chapter 2 of the report. The SID input and output listings are contained in **Appendix DD**.

APPENDIX E
EAD EXPECTED ANNUAL DAMAGE ANALYSIS

I. GENERAL

The expected annual damage for existing conditions without project was computed by inputting the frequency damage data from the SID output into the Expected Annual Damage Analysis (EAD) computer program. The input parameters are described below.

II. INPUT PARAMETERS

A. Floodplain Management Plans

The EAD program has the capability of evaluating several alternative floodplain management plans. For the existing conditions with no project, only one plan was specified. As the future conditions are analyzed, two plans will be specified, future conditions, no project, and future conditions, with project. The expected annual damages will be easily compared between the two plans, yielding the flood damage benefit from the project.

B. Input data years

No future input data years were specified because the analysis is for existing conditions. Input data years will be specified during the next phase of the project.

C. Economic Data

The period of analysis is 100 years and the discount rate is three percent.

D. Frequency-Damage Relationship

The frequency damage relationship is input from the SID output. The frequency damage relationship is presented in Chapter 2, as an aggregate value for the entire flooded area.

III. RESULTS

The expected annual damage for the existing conditions without project is $4,422,020. The EAD computer input and output listings are contained in **Appendix EE.**

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