DICK PERREAULT

Project No. 876191
Rio Salado Channel Improvements
Mill Avenue Reach

Final Report

CHANNEL IMPROVEMENT STUDY

MILL AVENUE REACH

Prepared for

RIO SALADO TASK FORCE
CITY OF TEMPE
Tempe, Arizona

by
CRSS, INC.
4041 North Central, Suite 650
Phoenix, Arizona 85012-3306

October 1989

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1.0 INTRODUCTION

1.1 Background

The development of the Rio Salado Park within the City of Tempe offers a unique opportunity to enhance and reclaim areas of the Salt River Floodplain. The essential components of the project include flood control structures, transportation improvements, utility relocation and land reclamation. A conceptual plan for river channel improvements was prepared in August 1988 (SLA, 1988) which showed the configuration of the Rio Salado channelization through Tempe. This plan continued the 1,000-foot wide channel planned by ADOT from downstream of the Southern Pacific Railroad bridge east to the Tempe city limit. The channelization plan was subsequently incorporated into the Rio Salado masterplan along with other planning studies undertaken by the Rio Salado Task Force.

The conceptual study pointed out a conflict between the proposed channel configuration and the existing at-grade northbound Mill Avenue roadway. Relocation of the roadway and potentially Rio Salado Parkway in the vicinity of the bridge was anticipated. The concept report showed the channelization in conflict with the tri-city sanitary sewer line on the north bank of the river. Also, it was recognized that the hydraulics of the Mill Avenue bridge were more complex than previous analysis had defined. The 30 degree skew of the bridge and the close proximity of the two downstream bridges were a

concern. The concept study proposed to narrow the channel to 1,000 feet from the 2,000 foot floodplain width which might also increase hydraulic losses at the bridges. It was not known if the skew of the Mill Avenue bridge would result in any adverse flow conditions in the narrowed channel. There was interest in understanding the full hydraulic impact to the bridges upstream of the ADOT channelization and guidebanks. The combination of the utility and transportation conflicts and the complicated hydraulic conditions indicated a need for a more detailed study of the river reach in the vicinity of Mill Avenue and the development of alternative channelization schemes.

1.2 Study Objectives

The purpose of this study is to evaluate alternative river design concepts for the reach of the Salt River through the three existing bridges near Mill Avenue. This reach of the Salt River connects the eastern and western portions of the Tempe Rio Salado Project. It is a critical reach because of planned land use improvements on the south bank and the planned addition of a bridge near the existing Mill Avenue Bridge. The study area is defined as the reach of the Salt River beginning 1,000 feet upstream of Hardy Drive (upstream limit of the ADOT Salt River channelization) and ending approximately 2,000 feet upstream of the Mill Avenue Bridge.

This interim working paper discusses the existing flood conditions for the Salt River through the study reach and presents alternative alignments

and profiles for the north and south channel levees. The general advantage/disadvantage of each alternative are discussed from the standpoint of flood control, transportation and land development. Further hydraulic analysis is currently underway for each alternative and will develop the hydraulic performance of each alternative. Additional scoping of transportation and land development issues are to be conducted prior to selection of a preferred alternative.

1.3 Description of the Study Reach

The Tempe buttes form the narrowest unchannelized reach of the Salt River below Granite Reef Dam to the confluence with the Gila River. Historically, this location in the river provided the best opportunity for a crossing of the Salt River. The close proximity of bed rock provided an excellent foundation for bridge piers and abutment, and the narrow channel width reduced the required bridge length. As shown in Figure 1, three bridges have been constructed in this reach of the Salt River beginning with the Southern Pacific Railroad bridge (c. 1890), followed by the Ash Avenue bridge (c. 1912), and finally, the Mill Avenue bridge (c. 1930). The bridges are supplemented by two at-grade crossings of the river. Northbound Mill Avenue traffic is carried on a two lane at-grade crossing that is located immediately east of the Mill Avenue bridge. West of the bridge is a southbound ramp from the north approach to Rio Salado Parkway. During flooding of the Salt River, the Mill Avenue bridge carries both north and southbound traffic, and Rio Salado Parkway is typically closed.

TEMPE RIO SALADO PARK

Figure 1

STUDY AREA

RIO SALADO DATABASE

DEPARTMENT OF PUBLIC WORKS

CITY OF TEMPE

DIVISION OF ENGINEERING

P.O. BOX 5002 TEMPE, ARIZONA

SURVEYED: HHC	CRSS	DATE: AUGUST 1989
DESIGNED: DKC		PROJECT NO. 876189B
DRAWN: BRR		
SCALE: 1:200		

Hydraulically, this reach of the river is complex due to the close proximity of the three existing bridges, the existing condition of the Salt River as it approaches the Mill Avenue bridge, and the planned addition of channelization and control structures downstream of the railroad bridge. The three bridges are located within 800 feet of each other with the railroad crossing about 350 feet downstream of the Ash Avenue bridge, and Ash Avenue about 400 feet downstream of Mill Avenue. The alignment of the Mill avenue bridge is skewed about 25 degrees relative to the alignment of the Ash Avenue bridge. The north abutment of the Mill Avenue bridge is 80 feet east of the Ash Avenue abutment, while the south abutment is 620 feet east of the Ash Avenue abutment. The alignment of the Ash Avenue bridge is essentially north/south.

The approach flow to the Mill Avenue bridge is conveyed in a main channel and two adjacent overbank areas. The main channel is approximately 800 feet wide and is flanked by overbank areas that are each about 60 feet wide. A contraction of the overbank flow areas is caused by the Mill Avenue bridge abutments and creates a backwater condition in the approach reach. The skew of the bridge, which is about 65 degrees relative to the approach flow, results in a more complex contraction with flow at the south abutment contracting through the bridge ahead of flow at the north abutment. This effect and the massive pier configuration for the bridge combine to alter the flow direction near the bridge.

The lower reach of channelization of the Salt River being constructed by ADOT ends about 1,450 feet downstream of the Southern Pacific railroad bridge. The channel ends at this location with a grade control structure which is 860 feet long from bank to bank. Guide banks contract the flow in the reach from the railroad bridge to the grade control structure from a width of over 1,500 feet to 860 feet. This results in higher flow velocities and a steep water surface gradient as flow is accelerated. In addition, to avoid landfills on the south bank, the alignment of the ADOT channel was directed adverse to the existing Salt River alignment through the bridges.

2.0 DATABASE

The Rio Salado Project has compiled a comprehensive computer database which consists of 14 data sets including a variety of topographic and planimetric information. Data acquisition for this study was done largely from this computer database. Similarly, alternative channel alignments have been developed and then included in the database during the course of the study.

2.1 Terrain Data

The Rio Salado District was aerially surveyed in December 1988 and data sets of digitized planimetric features and terrain elevations were prepared by April of 1989. The terrain data set consists of an approximately uniform grid of spot elevations taken at 50-foot intervals. The approximate limits of aerial mapping data for the project are as follows:

West: 48th Street
East: Evergreen Road
(1/2 mile east of Price Road)
North: Curry Road
South: First Street

Accuracy of terrain data is such that 90 percent data points have a vertical accuracy of ± 0.25 feet and a horizontal accuracy of ± 5 feet.

2.2 Hydrology

The project hydrology is based on the revised analysis of Central Arizona Project features by the U. S. Army Corps of Engineers, Los Angeles District. This analysis was initiated in November of 1987, after it was determined that Plan 6 (one of nine alternatives to Orme Dam) would not include Cliff Dam (one of four structures which comprised Plan 6) or similar water conservation storage features on the Verde River as an element of the recommended plan. The analysis was conducted in three parts; the future without project conditions were developed, alternatives for upstream storage were developed, and the benefits for upstream alternatives were evaluated.

The future without project condition was the current condition from which the feasibility of flood control was measured. Currently there is no flood control storage on either the Salt or Verde Rivers. Under Plan 6, flood control storage would have been provided on two dams; 565,000 acre-feet of storage on the Salt River from a modified Roosevelt Dam, and 465,000 acre-feet of storage on the Verde River from the new Cliff Dam. The future without project in the Corps analysis assumes Plan 6 will be constructed, but without Cliff Dam.

The future without project condition, Plan 6 minus Cliff Dam, was evaluated in the original CAWCS study as Plan 9. During the revised analysis, the Corps reevaluated the discharge-frequency relationships developed for Plan 9 and found that

the results supported most of the original CAWCS Plan 9 discharges, but found that there would be a greater peak flow reduction for floods exceeding a 50-year event. Discharge- frequency results for existing conditions (i.e. no flood control), Plan 6, the original CAWCS Plan 9, and the new Plan 9 values are given in Table 1. Under existing conditions, the 100-year flow at the Mill Avenue bridge is 215,000 cfs. The new Plan 9, without project condition, reduces the 100-year flow to 160,000 cfs.

TABLE 1
Discharge-Frequency Values
Salt River at Mill Avenue Bridge

Frequency (year)	Existing	Plan 6	CAWCS Plan 9	New Plan 9
5	40,000	40,000	44,000	44,000
10	93,000	50,000	84,000	84,000
20	135,000	50,000	110,000	110,000
50	160,000	50,000	140,000	135,000
100	215,000	55,000	170,000	160,000
200	275,000	92,000	215,000	190,000
500	330,000	170,000	265,000	250,000

The 300-year flood (215,000 cfs) was selected as the appropriate design discharge for Rio Salado Project. The risk to life, property, and floodplain improvements is considered typical of urban areas where the Corps of Engineers sets the Standard Project Flood (SPF) in excess of the 100-year event as the design flood. For the existing conditions (i.e. no flood control), the SPF discharge is 300,000 cfs which also corresponds to the 300-year flood.

There are several other considerations for selecting a design discharge at the SPF level. First, the developed floodway of the Salt River through the Rio Salado Park will need to convey all large magnitude flood flows. The floodway will need to be able to handle such a flood surcharge in an acceptable manner. Since highly valued commercial and recreational development is planned adjacent to the floodway, a lower risk of flooding for these properties is warranted. Next, review of the Corps' discharge-frequency values upstream of Mill Avenue indicates that there is a potential for increase in flood discharge due to upstream channelization of the Salt River. For example, the 100-year new Plan 9 discharge is 175,000 cfs at Granite Reef Dam, compared to 160,000 cfs at Mill Avenue. If plans for channelization are implemented by the Indian community, flood discharges could approach 175,000 cfs in the Rio Salado Project.

Finally, results from the Corps and CAWCS analysis of Plan 9 indicates that the accuracy the flood study is at best on the order of ± ten percent. Use of the SPF discharge, therefore, provides a prudent design discharge that takes into consideration the value of the project, potential changes in the upstream floodways and the accuracy of the synthesized discharge-frequency values.

2.3 Other Planimetric Information

The Rio Salado Database (CRSS, 1989) includes the following general categories of data:

1. Survey Control - reference framework
2. Parcel Identification
3. Street and Road - centerline
4. Utility Network - water, sewer, power, gas, storm drainage.
5. Physical Geography - soil geology, hydrography
6. Environmental - vegetation, habitat, air quality, water quality, noise
7. Planimetric Details - building outlines, road features, etc.
8. Topography
9. Administrative - zoning, land use, tax districts, etc.

A set of reference files for various planimetric information are included in the database based on the above thematic categories. These files can be combined to display and combination of plainmetric information in the Rio Salado Park project area.

TABLE 2
Rio Salado Database Files

Extension	Contents	Thematic Type
LND	Control framework & parcel description	Control & Parcel
PLN	Planimetric features	Planimetric
TOP	Digital terrain data	Topography
TRN	Street, road & freeway	Transportation
WAT	Water transmission	Utility
SAN	Sanitary sewer	Utility
POW	Electrical power transmissions	Utility
GAS	Natural gas transmissions	Utility
TEL	Telephone	Utility
DRN	River control & storm drainage structures	Utility
GEO	Soil, geology & hydrography	Physical Geography
ENV	Vegetation types wildlife habitat boundaries	Environmental
ZON	Zoning boundaries	Administration
USE	Land use boundaries	Administration

3.0 BASELINE CONDITION

This section describes the results of the modeling approach used to analyze the existing condition (including ADOT planned channel construction features) which serves as the baseline condition for this study. Model input data consists of digitized terrain data, the design discharge, and hydraulic parameters. Each of these datasets is briefly reviewed in this report. The baseline condition has been analyzed using a two-dimensional modeling system developed by the U. S. Geological Survey for the Federal Highway Administration, known as "Finite Element Surface Water Model System," or simply "FESWMS" (see Appendix A for description of the program). This modeling approach was chosen because of the complexity of the river conditions, which involve multiple and skewed bridges across the Salt River floodplain.

3.1 Input Dataset

Input data can be classified broadly as 1) program control data, 2) network data, or 3) initial boundary condition data.

Program control data govern the overall operation of a program. These data include parameters that define routines to be performed, and constant values that are used as coefficients in equations and apply to the entire finite element network.

Network data describe the finite element network (grid). These data include element connectivity lists, element property type codes, node point

coordinates, and node point ground-surface elevations. Also included as network data are sets of empirical coefficients that apply to a particular element property type.

All coordinate and elevation data for the model network of the Salt River were obtained with the aid of Intergraph's digital terrain modeling software. These programs extract terrain values from a terrain dataset which consists of a semi-uniform grid of coordinate/elevation points. The programs operate in an interactive graphics environment which permit the finite element network to be drawn and refined while viewing a representation of the underlying terrain information. Plate 1 shows the terrain contours which are derived from the coordinate/elevation data in the model input data. The terrain for the finite element network is an approximation of the underlying digital terrain model (DTM) as can be seen by comparing contours on Plates 1 and 4. The model terrain is designed to represent the significant terrain features.

The finite element network for the study reach is shown in Plate 2. The network shown is actually a composite of three separate models. The need for three separate models arises from the maximum array size permitted by the program, which is in turn a function of the microcomputer hardware and the DOS operating system. Each of the three models approaches the maximum size of 500 elements and 1,500 nodes. In general, the finite element network describes the terrain conditions in the

reach. Because of the alignment of the Mill Avenue bridge and the size and type of piers, this bridge was also included in the network.

The waterway through each span of the bridge is described by six elements. The bridge piers are described as a single diamond-shaped element which is set to a no-flow condition. The waterways of the two downstream bridges are not modeled with the same level of detail because it was found that the approach flow to these bridges is properly aligned to the bridge openings. To provide hydraulic information, the network is aligned to each waterway opening which provides a detailed computation of depth and velocity across each waterway. Separate computation of drag and friction losses for piers at these bridges also indicated that detailed modeling of waterway conditions would not be necessary. Also, because of the large size of the model network, it was necessary to simplify the analysis of the lower two bridges.

Initial condition data are starting values of the dependent variables and their time derivatives at each node point in the finite element network. Boundary condition data are values of dependent variables that are prescribed at particular node points along the boundary of the network. The design discharge is the upstream boundary condition and a known computed water surface elevation is the downstream boundary condition. The initial conditions are established by successive approximation. A zero velocity field is first assumed using a downstream stage which is

high enough to submerge the entire river reach. The resulting flow field is assumed to be the initial condition for the model using a lower downstream stage. The process is repeated until the known downstream boundary condition is obtained.

3.2 Model Output

Printed output from the modeling system consists of processed network data and computed flow data (depth-averaged velocities, and water depth at each node point).

Graphic output from FESWMS-2DH is written in a specified format to a data file that is called a plotfile. A plotfile is read by a utility program that displays the graphic output on a specific graphic device (either graphics terminal or pen plotter).

Plate 3 shows the water surface contours and the corresponding velocity field for the baseline condition.

3.3 Interpretation of Baseline Conditions

The two-dimensional modeling of hydraulic conditions in the Salt River near the Mill Avenue bridge shows a number of interesting river conditions. Beginning at the downstream end of the study reach, the influence of the ADOT channelization can be clearly seen. The velocities at the grade control structure are in the range of 14 fps, which exceeds by about 50

percent the 8 to 10 fps velocities that are typical of the approach reach above the guide banks. Within the river section that is bounded by the guide banks, there is an abrupt acceleration of the flow. Acceleration of the flow creates a steep water surface gradient which is steepest against the south guidebank. This condition results in increased shear stress on the channel boundary at this location, which is several times greater than the boundary shear conditions in the approach reach above the guidebanks. The scour rate immediately upstream of the grade control structure and near the south guidebank will locally increase to several times the upstream rates because of the increased boundary shear stress. This indicates that a local scour zone is likely at the south guide bank. ADOT plans a 8.0 foot toe down for the bank protection below the channel bed to protect against the general scour. The ADOT scour analysis did not explicitly consider the increased local scour at the guide bank.

In the reach above the guidebanks, there are two bridges, the SPRR bridge and the Ash Avenue bridge. Flow is aligned nearly perpendicular to the waterway openings of the bridges. However, the water surface is not level through either bridge waterway. There is a lateral gradient of about 0.15 percent across the river which results in a 2.0 to 2.5 foot drop in the water surface from north bank to south bank. Flow is more concentrated in the southern portion of the channel where the longitudinal water surface gradient is greater. Maximum velocities through the two bridges are in the range of 8 to 9 fps.

The hydraulics of the Mill Avenue bridge are much more complicated compared to the two adjacent downstream bridges. The bridge skew is probably the most significant factor in the hydraulic performance of the bridge waterway. The southern approach embankment projects into the south overbank area. Flow conveyed in this overbank is forced to make an abrupt turn north, travel around the abutment and then merge with the main flow. This motion creates a high pressure zone upstream of the south abutment with a water surface about four feet higher than the water surface elevation through the bridge opening. A steep hydraulic gradient of nearly 2.0 percent forms at the south abutment. This area would be a zone of high local scour during a major flood event.

The nine large piers that support the bridge are another important factor in the bridge hydraulics. Collectively, the piers redirect the flow perpendicular to the Mill Avenue bridge. This redirection persists for about 200 feet downstream of the bridge. The northern 200-300 feet of the Ash Avenue bridge is most effected by this flow redirection. However, the effect is offset by the lower flow concentration in the northern portion of the river channel.

The maximum surface elevation immediately upstream of the Mill Avenue bridge opening is about 1,161. This elevation is 11 feet above the springline of the bridge arches. To account for the additional wetted perimeter associated with an arch, the friction coefficient through the bridge openings were increased slightly. The water surface

elevation is sufficiently below the top of arch elevation of 1170 that no pressure flow condition will result. Velocities through the bridge opening are locally higher and can reach 12 to 13 fps.

In the channel section above the Mill Avenue bridge, flow is concentrated in the main channel and south overbank. Flow in the north overbank is relatively shallow (three to four feet). The south overbank flow is partially separated from the main channel by a remnant of a flood control levee. This levee is submerged but may contribute to a higher flow concentration in the south overbank. The levee height decreases in the downstream direction, and the flow field can be seen to bend slightly north as the levee ends and the south overbank flows back to the main channel.

Finally, there is a sloping water surface across the Mill Avenue bridge waterway and a non-uniform distribution of flow. The water surface drops about three feet from the south bank to the north bank. Flow is concentrated in the main channel and near the south abutment. The elevation of the north overbank and the profile of northbound Mill Avenue restrict flow near the north abutment. In fact, there is negligible conveyance through the most northern span of the Mill Avenue bridge.

4.0 CHANNELIZATION ALTERNATIVES

From the standpoint of channel design, it would be desirable to improve the Mill Avenue bridge hydraulics. This could be accomplished by eliminating the south bank encroachment and improving the alignment of the approach channel which would significantly reduce the locally high gradients near the bridge. Also, it would be desirable to develop a channel section which more uniformly distributes the flow through all three bridges. It is also necessary to provide for roadway routes and development options for lands on the south bank of the channel.

Considering these objectives, a set of channel alignment and cross section alternatives were formulated. Five alternative channel alignments were developed which consist of the original proposed channel alignment which is currently part of the Rio Salado Masterplan, and two sets of two channel alignments which shift the channel either north or south of the masterplan alignment and provide alternative south bank alignments. The four alternative channel sections are variations on a compound trapezoidal section in which overbank terraces are included in the channel section. The combination of the five channel alignments and four channel sections result in twenty potential channelization alternatives. These alternatives have been screened against a set of known conflicts and constraints to arrive at an initial set of channelization alternatives.

4.1 Channel Alignment Alternatives

Masterplan Alignment Alternative MP (Plate 4). This alignment connects the proposed Rio Salado channel improvements which begin about 2,000 feet upstream of Mill Avenue to the planned ADOT channelization of the Salt River, which ends about 2,100 feet downstream of Mill Avenue. The channel alignment consists of a tangent reach which begins at grade control number 4 in the ADOT channelization (2,115 feet west of the center line of the Mill Avenue bridge) and ends 1,220 feet east of the Mill Avenue bridge center line. The center line of this alignment deflects 7.5 degrees north of the ADOT center line at grade control number 4. This results in a channel with a bearing of 92° east. The skew angles at the SPRR, Ash Avenue, and Mill Avenue bridges are 7, 7, and 29 degrees respectively.

The masterplan alignment does not affect the existing alignment of Rio Salado Parkway. This would allow the parkway to become an all-weather roadway that would be operational during major flood events (greater than the ten-year flood).

Finally, the masterplan alignment includes the tri-city sanitary sewer line within the channelization limits. The line parallels the north bank of the channel and extends as much as 100 feet into the proposed channel. It is unlikely that this utility would be relocated, because of the cost (the line is 54 inches RCP). Instead, the utility will be accommodated by the inclusion of a terrace in the channel section.

Land development options are improved with this alternative since the floodplain is narrowed by about 600 feet on the south bank. The alternative provides for adequate land for a flood control levee that would upgrade Rio Salado Parkway to 100-year flow service level.

Channel Alignment Alternatives A1 and A2 (Plate 5) The "A" set of channel alternatives pivots the main channel center line to improve the angle of attack at the Mill Avenue bridge. The north bank of the channel is aligned about 50 feet to the north of the masterplan alignment east of the Mill Avenue bridge (note Station 35+00 north levee control line). This brings the alignment of the north bank to within 75 feet of the centerline of the East Papago Freeway. The typical section for the freeway is 80 feet from centerline to back of curb. The alignment of the main channel is skewed 22 degrees to the Mill Avenue bridge piers. The main channel alignment connects the ADOT and Rio Salado channels by a set of reverse curves. The western curve is tangent to the ADOT channel control line and does not require a deflection angle as in the case of alternative MP. The north bank alignment coincides with the location of the first pier south of the north Mill Avenue bridge abutment.

There are two south bank alignments which result in Alternatives A1 and A2. Alternative A1 has a south bank alignment which coincides with the location of the second pier north of the south Mill Avenue bridge abutment. Alternative A2 has a south bank alignment that coincides with the first pier north of the south bridge abutment.

Alternative A1 has a south bank alignment that is similar to Alternative MP west of the Mill Avenue bridge, but bends about 130 feet north of that alignment east of Mill Avenue. This alternative provides the narrowest channel width (950 feet) of all channelization alternatives, and as a result, would not affect the existing Rio Salado Parkway and would provide the largest increase in land area on the south bank. As with Alternative MP, Alternative A1 includes the tri-city sanitary trunk line within the channel section and would, therefore, require a terraced channel section.

Alternative A2 has a south bank alignment that is about 150 feet south of Alternative MP west of the Mill Avenue bridge and converges to the MP alignment 1,500 feet east of the Mill Avenue bridge. This alternative provides a 1,100-foot channel width, which is similar to the existing condition. Because of the channel width, it would be necessary to relocate the Rio Salado Parkway onto a terraced channel section. The parkway would be protected from minor flood events (less than ten-year flood) but would be closed by major floods. This alternative would reduce the developable land area on the south bank relative to Alternative MP. As with Alternative A1, a terraced channel section would be required at the north bank to provide for the tri-city sanitary sewer trunk line.

Channel Alignment Alternatives B1 and B2 (Plate 6) The "B" set of channel alternatives also pivots the main channel center line to improve the angle of attack at the Mill Avenue bridge. The north bank of the channel is located south of the north bank alignment of Alternative MP. Near the Mill Avenue bridge, the north bank alignment coincides with the second pier located south of the north abutment of the bridge. The alignment of the main channel is skewed 22 degrees to the Mill Avenue bridge piers. The main channel alignment is deflected five degrees to the south of the ADOT control line at grade control number 4.

There are two south bank alignments which result in Alternatives B1 and B2. Alternative B1 is the northern most alignment, and coincides with the first pier to the north of the south Mill Avenue bridge abutment. Alternative B2 is further south, and coincides with the south Mill Avenue bridge abutment.

Alternative B1 is about 150 feet further south of the original MP south bank alignment. This alternative has a minimum channel width of about 970 feet, but more typically, is about 1,000 feet wide. This alternative affects the existing Rio Salado Parkway alignment, and would require either relocation of the roadway onto a channel terrace. The parkway would be protected from minor floods (less than ten-year flood) but would be closed by major floods. This alternative would reduce the amount of developable land on the south bank relative to the original MP alternative. However,

it would be possible to protect the tri-city sanitary sewer trunk line within the north bank without adding a terrace section to the main channel.

Alternative B2 is about 300 feet further south, compared to the original MP alignment. It would require that the alignment of Rio Salado Parkway move away from the river onto First Street. This would further reduce the developable land area on the south bank relative to the MP alternative. The channel top width is over 1,100 feet. As with Alternative B1, there would be no need for a channel terrace for the tri-city sanitary sewer trunk line.

4.2 Channel Cross Section Alternatives

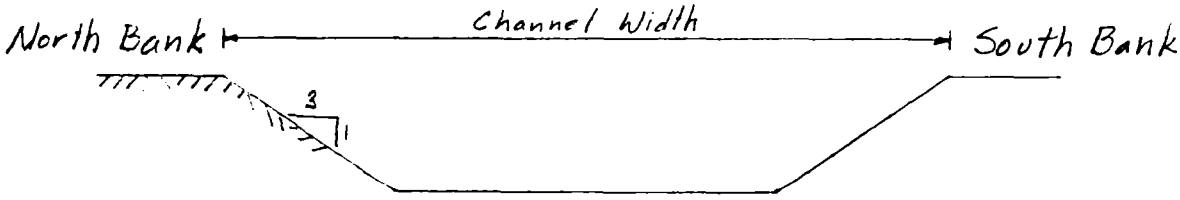
There are four types of channel sections that will be considered in conjunction with the various channel alignment alternatives. These include:

- S1 - Single trapezoidal channel
- S2 - Compound channel with south bank terrace only
- S3 - Compound channel with north bank terrace only
- S4 - Compound channel with both north and south bank terraces

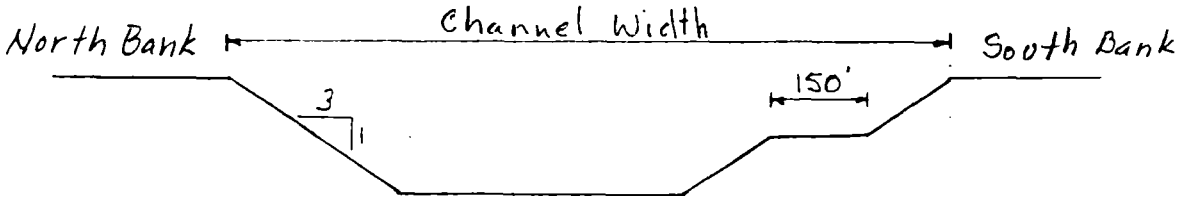
Figure 2 shows the typical sections for each alternative. The terrace width is set to 100 feet for the north bank and 150 feet for the south bank. These widths are sufficient to accommodate the tri-city sanitary trunk line and the Rio

CRS SIRRINE	PROJECT: Rio Salado Channelization	JOB NO. R10CH	NO.
	CLIENT: City of Tempe	DESIGNED BY: GKC / DATE	
	SUBJECT	CHECKED BY / DATE	OF

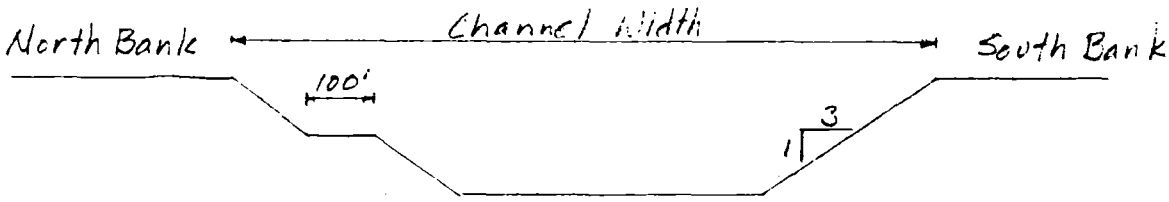
Figure 2.
Alternative Channel Cross Sections



Alternative S1: Trapezoidal Channel



Alternative S2: Compound Channel w/ South Terrace



Alternative S3: Compound Channel w/ North Terrace

Alternative S4: Compound Channel w/ North & South Terraces

Salado Parkway, respectively. The channel section has not been modified to include lake excavation. Such excavation will be below the channel bed and will add waterway area. Neglecting this area is conservative in the evaluation of the hydraulic performance of each alternative.

4.3 Selected Alternatives

A total of twenty combinations of alignment and cross section alternatives are possible. The number of alternatives was reduced by limiting the use of a terraced section to only those cases where it is necessary to provide for Rio Salado Parkway or the tri-city sanitary trunk line. Table 1 summarizes the selected alternatives.

Table 3
SELECTED ALTERNATIVES

Cross Section	Channel Alignments				
	MP	A1	A2	B1	B2
S1					X
S2				X	
S3	X	X			
S4			X		

The resulting five alternatives are:

MPS3: Masterplan alignment with a north bank terrace.

A1S3: North channel alignment with the northern south bank alignment and a north bank terrace.

A2S4: North channel alignment with the southern south bank alignment and a north and south bank terrace.

B1S2: South channel alignment with the northern south bank alignment and a south bank terrace.

B2S1: South channel alignment with a southern south bank alignment and a trapezoidal channel section.

The selected alternatives represent the full range of channelization conditions that might occur in this reach of the Rio Salado. It should be possible, based on the analysis of these alternatives, to select a preferred alternative that best meets the following needs:

1. Improved hydraulic performance at the Mill Avenue bridge.
2. All weather Rio Salado Parkway.
3. Reclamation of adjacent floodplain lands.

The next phase of this study will evaluate the ability of each of these selected alternatives to meet the project needs. The analysis will be supplemented by scoping sessions which include Tempe staff and other interested parties.

5.0 EVALUATION OF ALTERNATIVES

The five channel alternatives were compared on the basis of hydraulic conditions, Rio Salado Parkway location and land reclamation.

5.1 Hydraulic Conditions

The hydraulic conditions for the alternative channel alignments were compared to baseline conditions. In general, all the alternatives will improve the hydraulic performance of the Mill Avenue bridge or reach compared to the existing condition. Construction of levees upstream of the bridge permits the flow to be controlled as it approaches the bridge. This prevents the formation of a high pressure zone near the south abutment where flow contracts from the south overbank to the bridge opening.

The modeled water surface elevations and velocity fields for each alternative are shown on Plates 7 - 10. Table 4 summarizes a set of key hydraulic conditions for each alternative.

TABLE 4
Summary of Hydraulic Conditions

Alt	Vup (fps)	Vbr (fps)	Vdn (fps)	Vtr (fps)	Zup (ft)	Sup (ft)	Sdn (ft)	Abr (degrs)	Ach (degrs)
BL	7-8	11-13	13-14	--	1163.2	--	--	17	--
MP	9-10	12	12	6-7	1160.0	0.25	--	11	7.5
A1	9-10	13	12-13	6-7	1160.4	0.38	0.30	6	0
A2	9-10	12	12-13	5-6	1160.4	0.47	0.40	5	0
B1	10-11	13	12-13	6-8	1160.7	0.53	0.80	5	5
B2	8-9	9-10	11-12	--	1159.5	0.50	0.53	5	5

BL: Baseline, MP: Master Plan

Where Vup: typical velocity in approach reach to bridge

Vbr: typical velocity in bridge reach

Vdn: typical velocity reach below bridge

Vtr: typical velocity in terrace

Zup: average water surface 1,000 feet upstream of bridge

Sup: maximum superelevation in approach reach to bridge

Sdn: maximum superelevation downstream of the bridge

Abr: flow deflection through the bridge

Ach: flow deflection at ADOT channel.

Relative to the baseline condition, Alternative B2 provides the largest improvement in hydraulic conditions in the study reach. Flow velocity is reduced in the vicinity of the bridge and in the downstream reach. The water surface is the lowest of any alternative. The flow through the Mill Avenue bridge is well aligned with the bridge as indicated by the relatively small flow deflection at the bridge piers. The only area of relatively poor performance is the degree of superelevation above and below the bridge, and the deflection angle where the channel meets the planned ADOT channel. The reason for Alternative B2's better performance is that it provides the largest waterway area compared to any alternative.

Alternatives A1 and A2 have similar hydraulic characteristics which result in a higher main channel velocity and a larger backwater upstream of the Mill Avenue bridge. The amount of superelevation occurring upstream and downstream

of the bridge is slightly less than for Alternative B2. While the main channel velocity is higher, these alternatives each have an overbank terrace area where the velocity is lower. The flow is well aligned to the Mill Avenue bridge with only a slight deflection at the piers. The channel alignment coincides with ADOT's channel alignment.

Alternative B1 has a slightly higher backwater compared to Alternatives A1 and A2 and the highest superelevation of the flow both above and below the Mill Avenue bridge of any alternative. The flow is well aligned to the bridge piers.

The initial Master Plan alignment, Alternative MP, has hydraulic conditions comparable to Alternatives A1 and A2 but with a lower backwater affect and little superelevation. However, the flow at the bridge has a relatively large deflection at the piers. This points out a likely trade-off that occurs in the channel alternatives between flow direction and superelevation. Alternatives with good flow alignment at the Mill Avenue bridge will have higher superelevation in the approach reach, and a reach without superelevation will have a poor angle of attack at the bridge pier. The poor angle of attack at the bridge piers will increase scour depths at the piers and directly affects the stability of the bridge foundation. Superelevation alters the lateral distribution of general scour and will have a less direct affect on the bridge foundation. Finally, the Master Plan alignment has the largest deflection to the ADOT channel alignment.

Although Alternative B2 has the best hydraulics during the design flood, alternatives such as A1 and A2 have the desirable feature of a terrace. This area of the channel would be flooded less frequently and would permit in-channel uses. During the design flood, the overbank velocity would be lower, which reduces the chance of damage to facilities placed on the overbank. The overbank also serves to dampen the superelevation of the flow.

Comparing Alternatives A1 farthest north and A2 shows that the addition of a second overbank does not greatly change the hydraulics of the channel during the design flood. This indicates that the south overbank area could be used intermittently along the channel without adversely affecting the main channel flow. The Rio Salado Master Plan proposes this type of encroachment to accommodate commercial development along the Rio Salado Parkway, and it appears from this analysis, that these plan features are hydraulically acceptable.

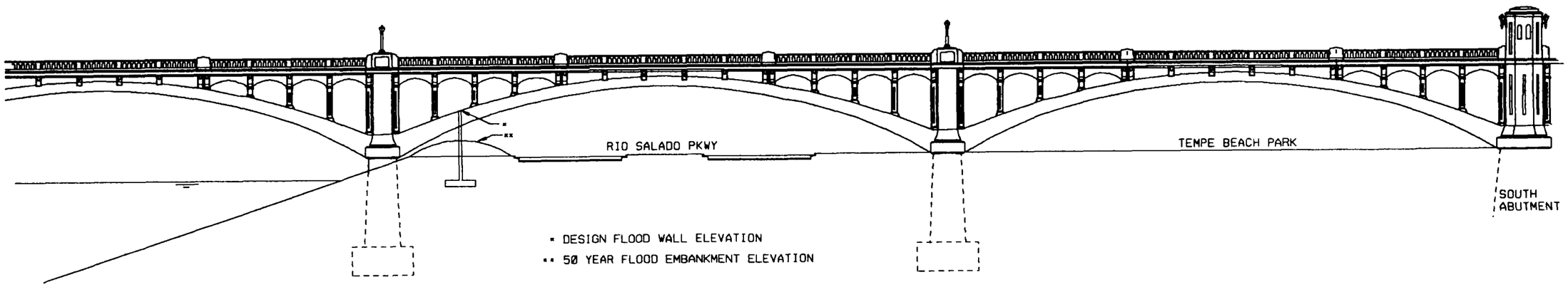
5.2 Rio Salado Parkway

The original Master Plan Alternative, MP, and Alternative A1 provide a location for the south bank of channelization which would completely protect the present alignment of the Rio Salado Parkway from the design flood (215,000 cfs). Alternatives A2 and B1 would provide protection of the existing parkway alignment up to the ten-year flood event (84,000 cfs). During the design flood, the parkway would be submerged for about

three days as the flood peak was released from upstream reservoirs. Alternative B2 would require that an alternative route be established for Rio Salado Parkway.

For Alternatives MP and A1, it would be necessary to protect the roadway from the main channel using a levee or floodwall structure. If the parkway profile were raised to the spring line of the Mill Avenue bridge, the floodwall would have a crest height of about 12 feet above the roadway profile. Figure 3 shows the approximate elevation of a new parkway and floodwall relative to the existing Mill Avenue bridge.

The use of a floodwall to provide a level of protection less than the design flood for the parkway may also be practical, since the parkway is the only facility at risk on the overbank of the channel. A levee or floodwall constructed to protect the parkway up to a 50-year flood elevation coincides more closely with the value of the route as a transportation link. However, it is likely that the structure would be partially damaged during the design flood. Given that such damages would be very infrequent, the use of an internal parkway levee has a distinct advantage. A lower levee or floodway would be a less prominent feature and would have less of an effect on views from adjacent areas on the south bank of the channel.



TEMPE RIO SALADO PARK

RIO SALADO PARKWAY
CROSS-SECTION AT MILL AVENUE
FIGURE 3

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DRAWN:		
SCALE:		

5.3 Land Reclamation

Alternative A1 provides the most reclaimed land on the south bank of the channel. It improves on the original Master Plan alignment by providing more land area on the south bank of the channel east of the Mill Avenue bridge and roughly the same land area to the west.

Alternative A2 provides an overbank area which could be developed for in-channel recreational uses and could be encroached upon intermittently for development of commercial areas.

Alternatives B1 and B2 align the channelization furthest to the south, and as a result, provide the least reclaimed land on the south bank of the channel.

5.4 Summary Evaluation

The following matrix qualitatively evaluates the set of five channel alternatives according to their relative impact compared to the baseline condition. The alternatives are reviewed for the effect on river and bridge hydraulics, Rio Salado Parkway location, and land reclamation.

Weighing all conditions equally results in the following ranking of alternatives: (1) A1, (2) A2, (3) MP, (4) B2, (5) B1.

TABLE 5
Evaluation Matrix

Alternative	Hydraulic	Parkway	Land
MP	0	2	1
A1	1	2	2
A2	2	1	1
B1	0	1	0
B2	2	0	0

0 - slight improvement
1 - improved
2 - much improved

There are numerus other factors that must enter into the final selection of a channel alignment. However, this initial ranking, based on the evaluation of a limited set of conditions, can be used to guide in the selection of the preferred alternative. In this regard, Alternatives A1 and A2 show the largest benefit to the Rio Salado project. A combination of the relative advantages of both alternatives could result in a better alternative which provides both improved hydraulic conditions as with A2 and the parkway and land reclamation options associated with A1.

6.0 RECOMMENDED ALTERNATIVE

The recommended alternative is a combination of the A1 and A2 alternatives presented earlier in this report. This alternative takes advantage of the overbank area provided by Alternative A2 to locate project features such as the Rio Salado Parkway, recreation facilities and parks in this area. Since the overbank alignment can be varied without adversely affecting main channel flow conditions, encroachments for parkway and commercial development can be included in the channel design. Specific features of the recommended alternative are as follows:

1. Locate the main channel banks along the A1 alignments. Use the compound channel section (S4) with north and south overbank terraces where the inside of the south overbank is defined by the A1 alignment. Establish the terrace elevation at the elevation of the water surface profile for the ten-year flood (84,000 cfs).

2. Locate the Rio Salado Parkway on the south overbank near its present alignment. Provide a flood control embankment between the parkway and the main channel at the elevation of the water surface profile for the 50-year flood (135,000 sfs) plus freeboard. This embankment will be about three to five feet above the overbank terrace.

3. Identify overbank encroachments and park areas based on planned land uses. Set the alignment of the south bank to meet these development plans.

The recommended alternative achieves several important results for the channelization of the Salt River. First, it provides a floodway capable of conveying a major flood event on the order of the 300-year flood (215,000 cfs). The hydraulic performance of the Mill Avenue bridge is substantially improved over the conditions in the existing channel. This improvement will facilitate the construction of a second Mill Avenue bridge near the existing structure. Second, substantial flood protection is provided for the Rio Salado Parkway which will result in an essentially all-weather parkway adjacent to the Salt River channel improvements. Finally, an opportunity for an area of varied land use is provided by the addition of a south overbank terrace.

The recommended alternative provides the necessary flexibility for future development on the south bank of Rio Salado Park. It does this while maintaining a high degree of protection against damages from future floods on the Salt River.

7.0 REFERENCES

Froehlich, D. C., 1989, "Finite Element Surface-Water Modeling System: Two-Dimensional Flow in a Horizontal Plane", publication No. FHWA-RD-88-177, U. S. Department of Transportation, Federal Highway Administration.

U. S. Army Corps of Engineers, 1988, "Study for Flood Control Alternatives to Cliff Dam", Los Angeles District.

Simon, Li & Associates, Inc., 1988, "Rio Salado Channel Improvement, Mill Avenue to Hayden Road", submitted to City of Tempe.

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A P P E N D I X A

HYDRAULIC MODELING SYSTEM

The following description of the FESWMS is extracted from the program Users Manual, and is included here for the sake of completeness.

FESWMS is a modular set of computer programs developed to simulate surface water flow where the flow is essentially two-dimensional in a horizontal plane. The programs that comprise the modeling system have been designed specifically to analyze flow at bridge crossings where complicated hydraulic conditions exist, although the programs can be used to model many other types of steady and unsteady surface water flows. Three separate, but interrelated, programs form the core of the modeling system: 1) The Data Input Module (DINMOD), 2) the Depth-Averaged Flow Module (FLOMOD), and 3) the Analysis of Output Module (ANOMOD).

The primary purpose of DINMOD is to generate a two-dimensional finite element network (grid). Functions performed by this program include editing of input data, automatic generation of all or part of the finite element network, refinement of an existing network, ordering of elements to enable an efficient equation solution, and graphic display of the finite element network. As such, DINMOD acts as a preprocessor of the finite element network (grid) data. Processed network data can be stored in a data file for use by other FESWMS-2DH programs.

FLOMOD simulates both steady and unsteady (time-dependent) two-dimensional (in a horizontal plane) surface water flow. The program numerically solves the vertically integrated equations of motion and continuity, using the finite element method of analysis, to obtain depth-averaged velocities and flow depths. The effects of bed friction and turbulent stresses are considered, as are, optionally,

surface wind stresses and the Coriolis force. Flow over weirs, or weir-type structures (such as highway embankments), and flow through culverts can also be modeled. The computed two-dimensional flow data can be written to a data file and stored for future use.

Results of flow simulations are presented graphically and in the form of reports by ANOMOD. Plots of velocity and unit-flow vectors; ground surface and water surface elevation contours; and time history graphs of velocity, unit flow or stage (water surface elevation) at a computation point can be produced. As such, ANOMOD acts as a post-processor in the modeling system.

FESWMS is a numerical model which provides a quantitative description of the physical processes that affect the system two-dimensional flow. The partial differential equations that govern two-dimensional surface water flow in a horizontal plane are derived from the full three-dimensional flow equations.

FESWMS-2DH calculates depth-averaged horizontal velocities and water depth and the time derivatives of these quantities, if a time- dependent flow is modeled. The equations that govern depth-averaged surface water flow account for the effects of bed friction, wind-induced stress at the water surface, fluid stresses caused by turbulence, and the effect of the Earth's rotation. Because velocity in the vertical direction is not modeled, evaluation of phenomena such as stratified flow is beyond the scope of the modeling system. Also, because water density is assumed constant, flows resulting from horizontal density gradients cannot be evaluated.

The numerical technique used to solve the governing equations is based on the Galerkin finite element method. Application of the finite element method causes the water body being modeled to be divided into small regions called elements. An element can be either triangular or quadrangular in shape; shapes that can easily be arranged to fit complex boundaries. The elements are defined by a series of node points located at the element vertices, mid-side points, and, in the cause of nine-node quadrilateral elements, at their centers. Values of dependent variables area approximated within each element using the nodal values and a set of interpolation functions (also called shape functions).

Approximations of the dependent variables are substituted into the governing equations, which generally will not be satisfied exactly, thus forming a residual. The residual is weighted over the entire solution region. The weighted residuals, which are defined by equations, are set to zero, and the resulting equations are solved for the dependent variables. In Galerkin's method, the weighting functions are chosen to be the same as those used to interpolate values of the dependent variables within each element.

The Galerkin finite element method requires the governing equations to be weighted over the entire solution domain. The weighting process requires integration, which is performed numerically using Gaussian quadrature on a single element. Repetition of the integration for all elements that comprise a solution region produces a system of nonlinear algebraic equations when the time derivatives are discretized. Because the system of equations is nonlinear, an interactive solution procedure is needed. Newton iteration, or a variation of this technique, is used, and the resulting system of equations is solved using an efficient frontal solution scheme.

100 0 200 400 600 800 FEET

SCALE: 1"=200'

TEMPE RIO SALADO PARK
SALT RIVER CHANNEL STUDY
TOPOGRAPHY
RIO SALADO DATABASE

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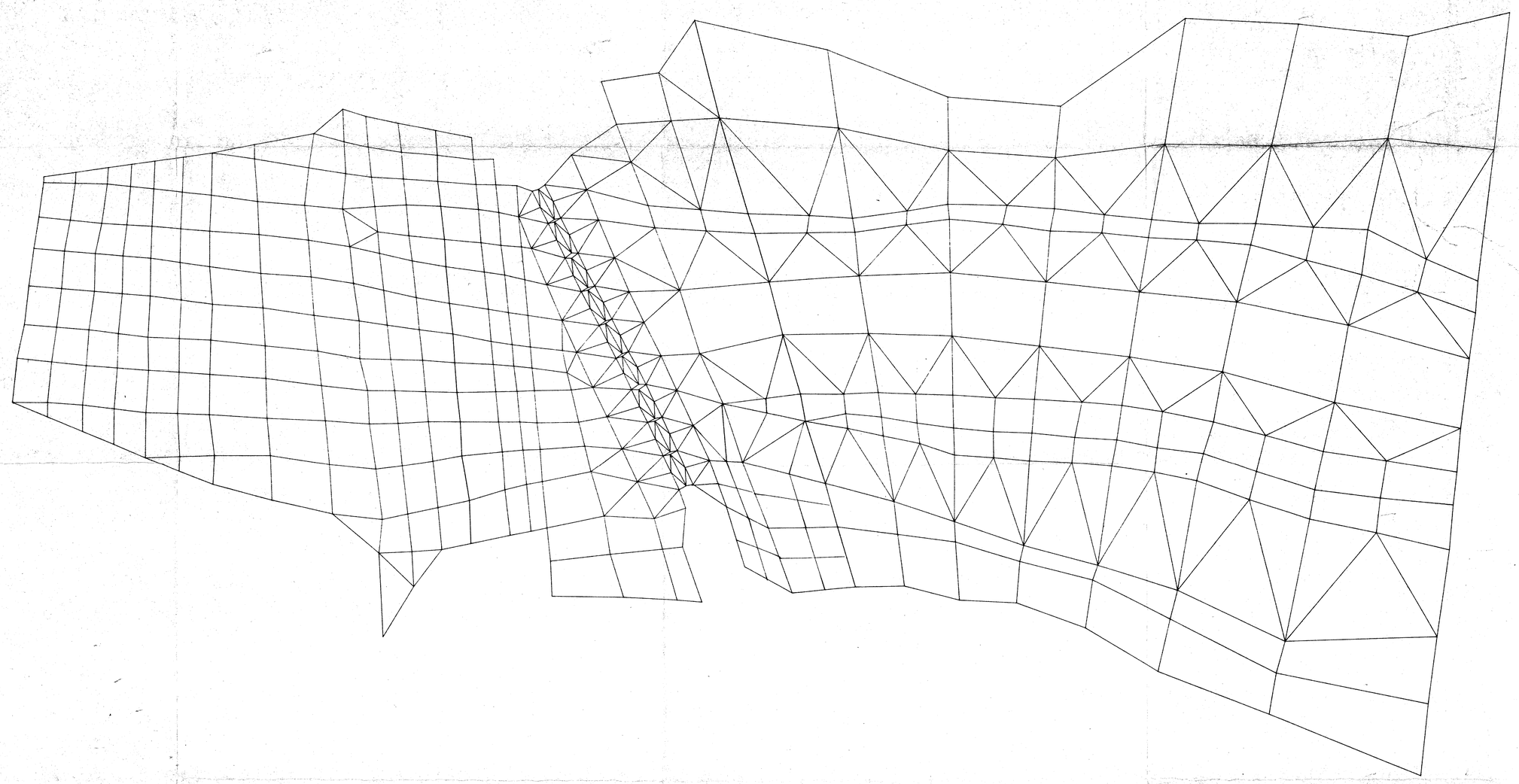
SURVEYED: MHC	CRSS	DATE: AUGUST 1989
DESIGNED: GKC		PROJECT NO. 876189B
DRAWN: SRK		
SCALE: 1:200		PLATE 1 OF 6



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SCALE: 1"=200'

TEMPE RIO SALADO PARK
SALT RIVER CHANNEL STUDY
GRID
RIO SALADO DATABASE

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DESIGNED: GKC		PROJECT NO. 876189B
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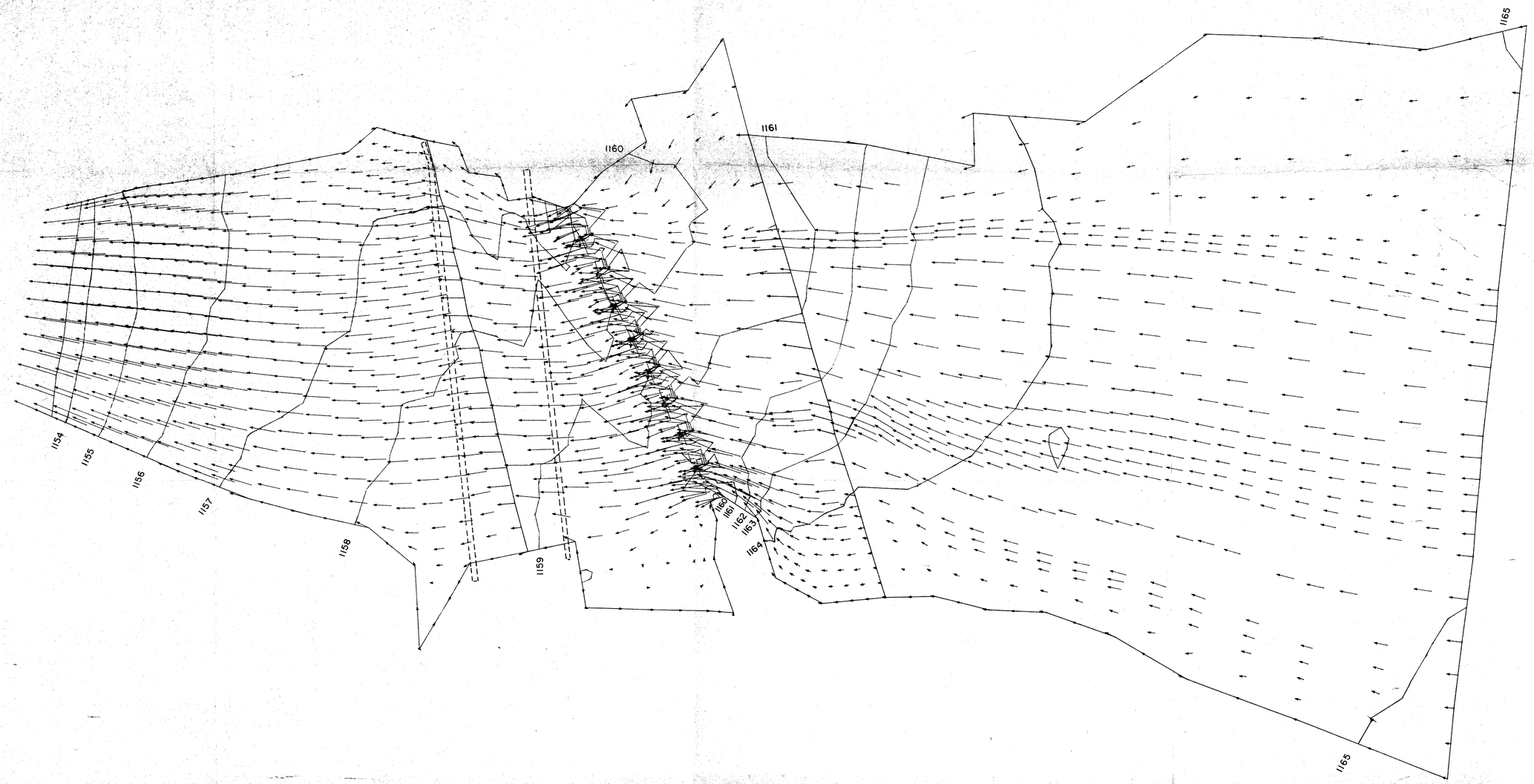
SCALE: 1:200		PLATE 2 OF 6



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SCALE: 1"=200'

TEMPE RIO SALADO PARK
SALT RIVER CHANNEL STUDY
WATER SURFACE CONTOURS
RIO SALADO DATABASE

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DRAWN: PHP		
SCALE: 1:200		PLATE 3 OF 6

SCALE: 1"=200'
CONTOUR INTERVAL 5 FEET

100 0 200 400 600 800 FEET

TEMPE RIO SALADO PARK

MASTER PLAN
CHANNEL ALIGNMENT
RIO SALADO DATABASE

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DESIGNED: GKC		PROJECT NO. 876189B
DRAWN: BMP		
SCALE: 1:200		PLATE 4 OF 6

TEMPE RIO SALADO PARK

CHANNEL ALIGNMENT A1 & A2
RIO SALADO DATABASE

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SURVEYED: MHC	CRSS	DATE: AUGUST 1989
DESIGNED: GKC		PROJECT NO. 876189B
DRAWN: BRR		
SCALE: 1:200		PLATE 5 OF 6

TEMPE RIO SALADO PARK

CHANNEL ALIGNMENT B1 & B2
RIO SALADO DATABASE

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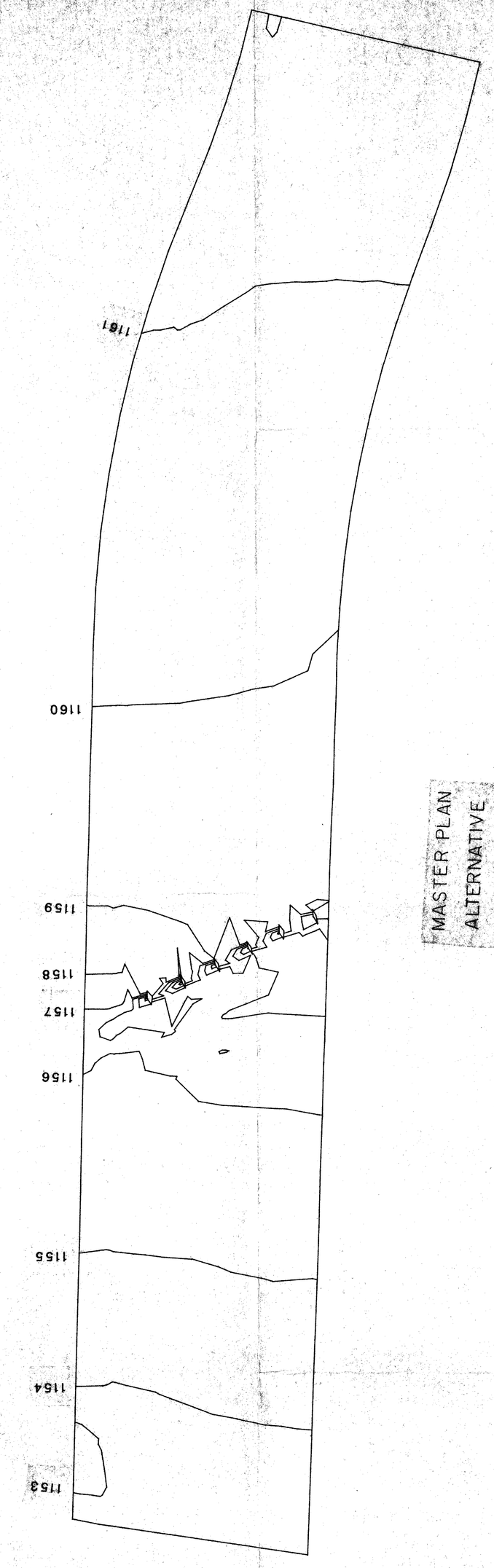
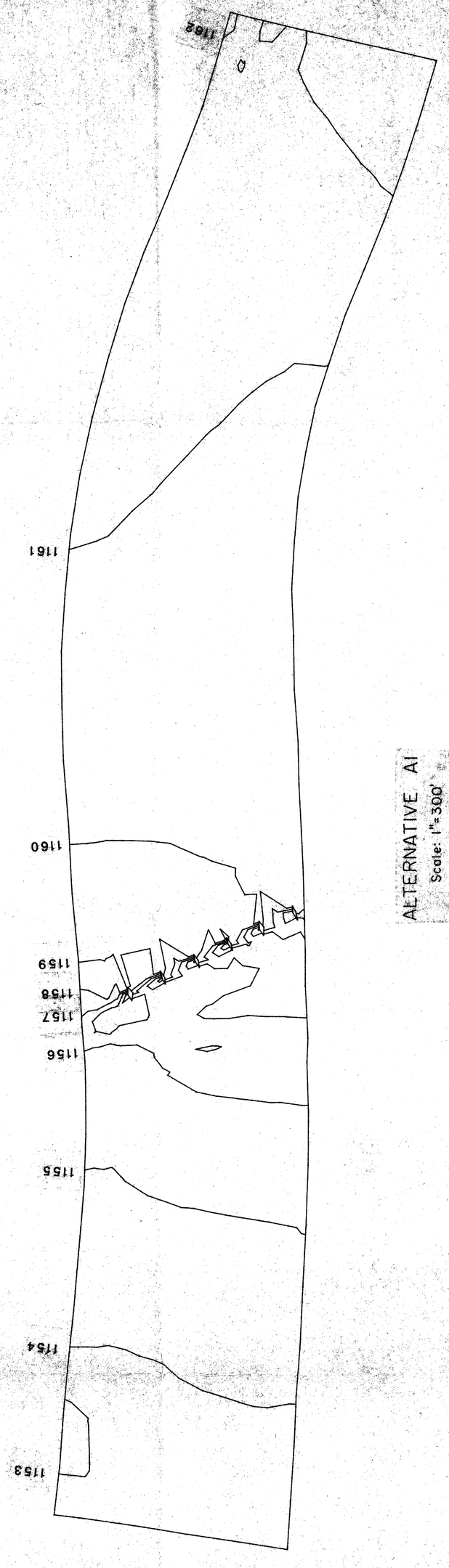


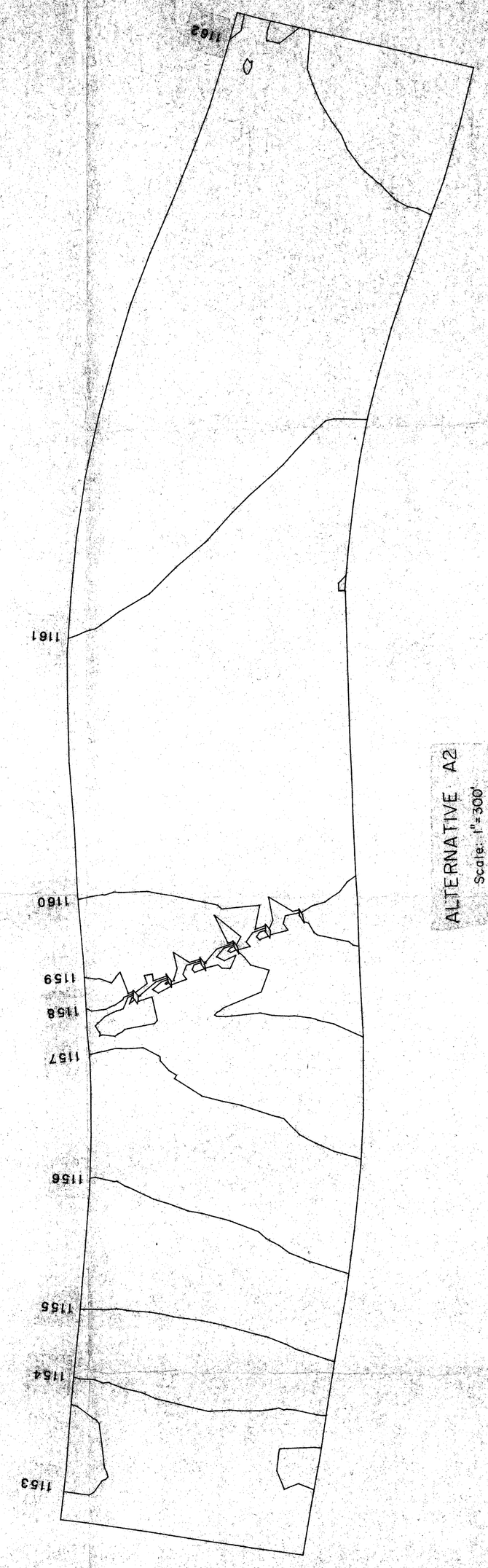
MASTER PLAN
ALTERNATIVE
Scale: 1"=300'

WATER-SURFACE CONTOURS



ALTERNATIVE A1
Scale: 1"=300'

WATER-SURFACE CONTOURS



ALTERNATIVE A2
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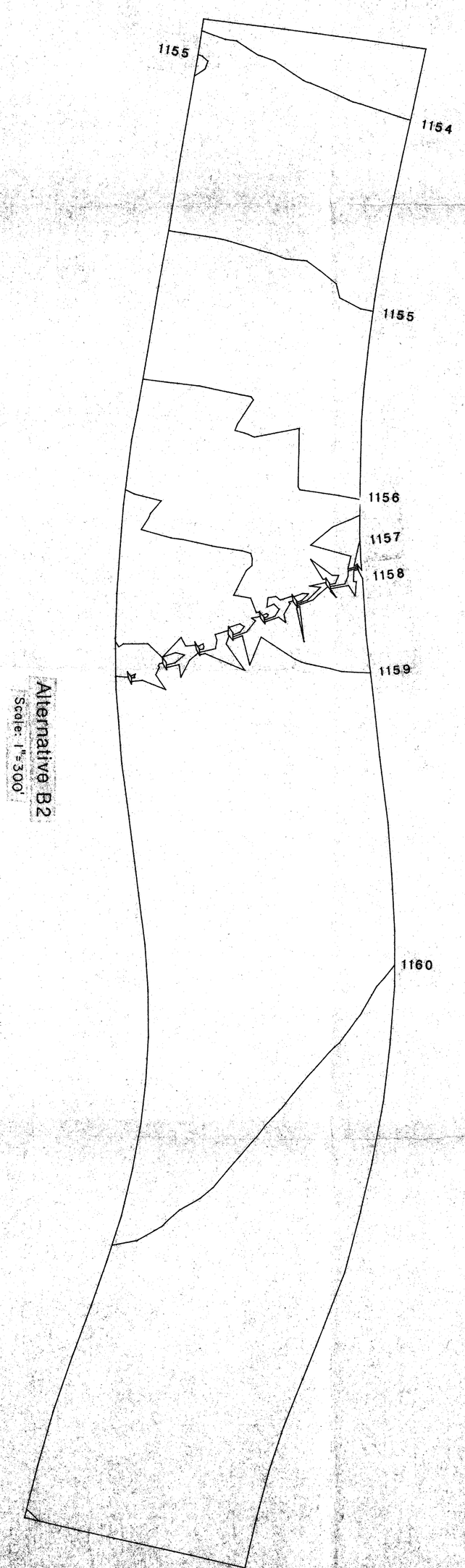
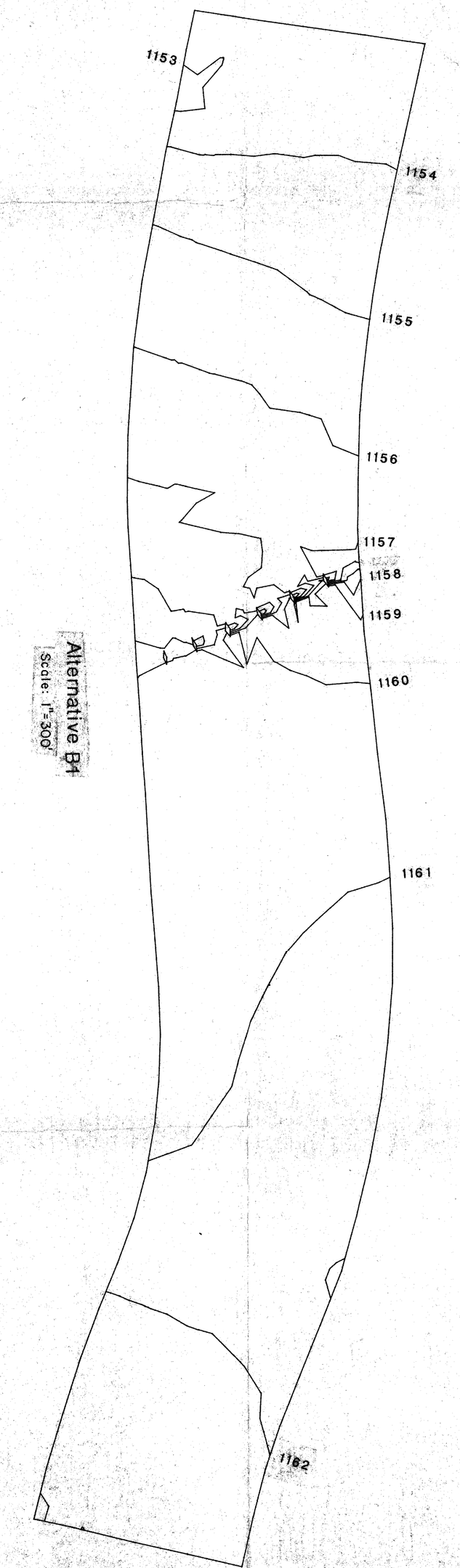
WATER-SURFACE CONTOURS

WATER-SURFACE CONTOURS



Alternative B2
Scale: 1"=300'

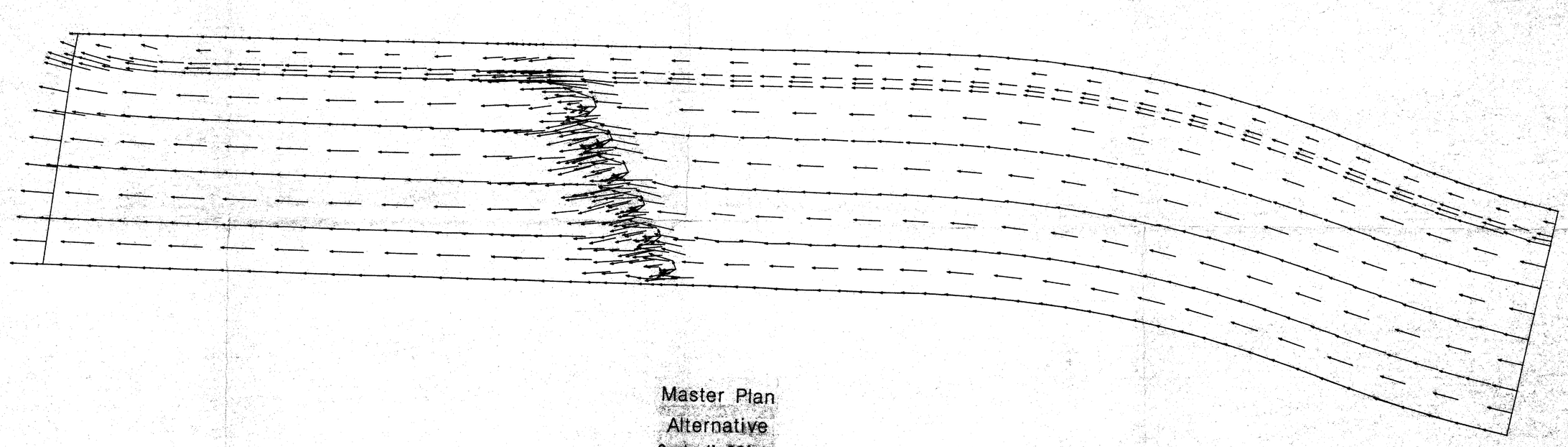
WATER-SURFACE CONTOURS



Alternative B4
Scale: 1"=300'

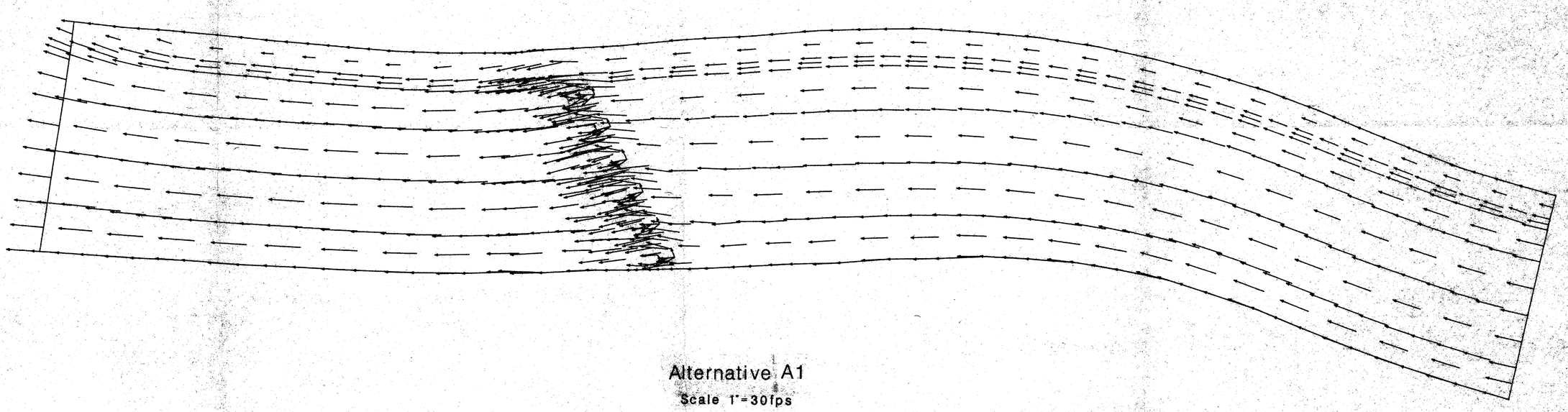
PLATE 8

VELOCITY FIELD



Master Plan
Alternative
Scale 1"=30fps

VELOCITY FIELD



Alternative A1
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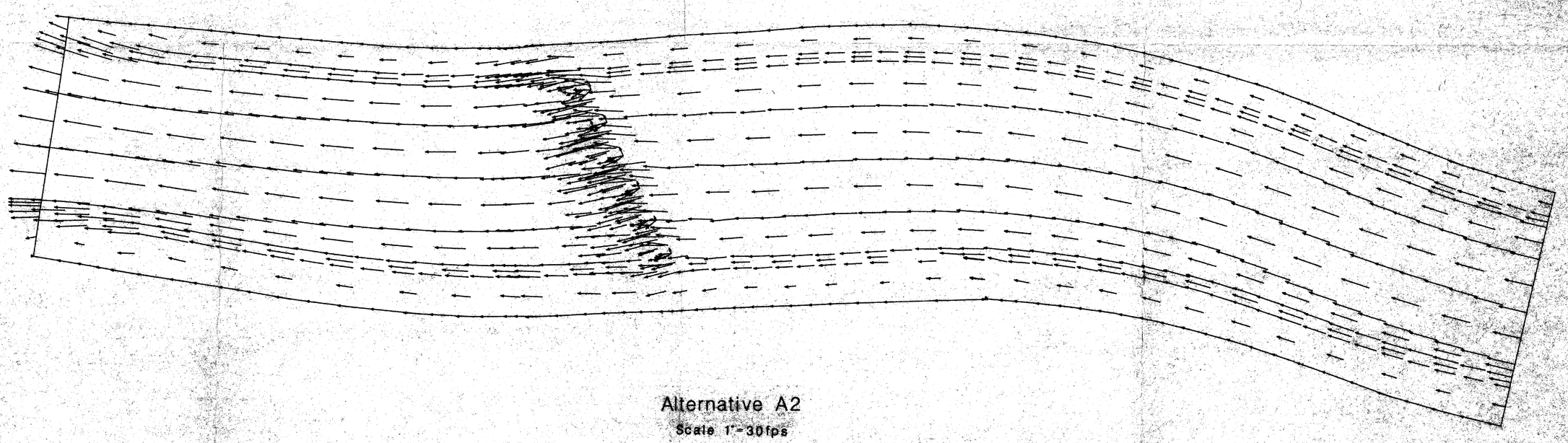
VELOCITY FIELD



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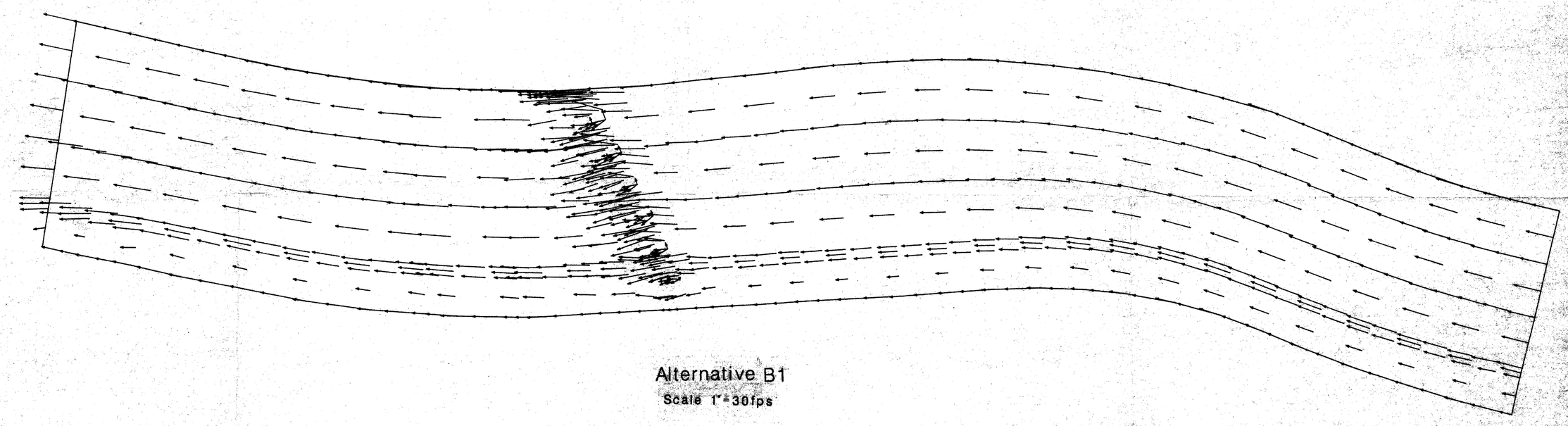

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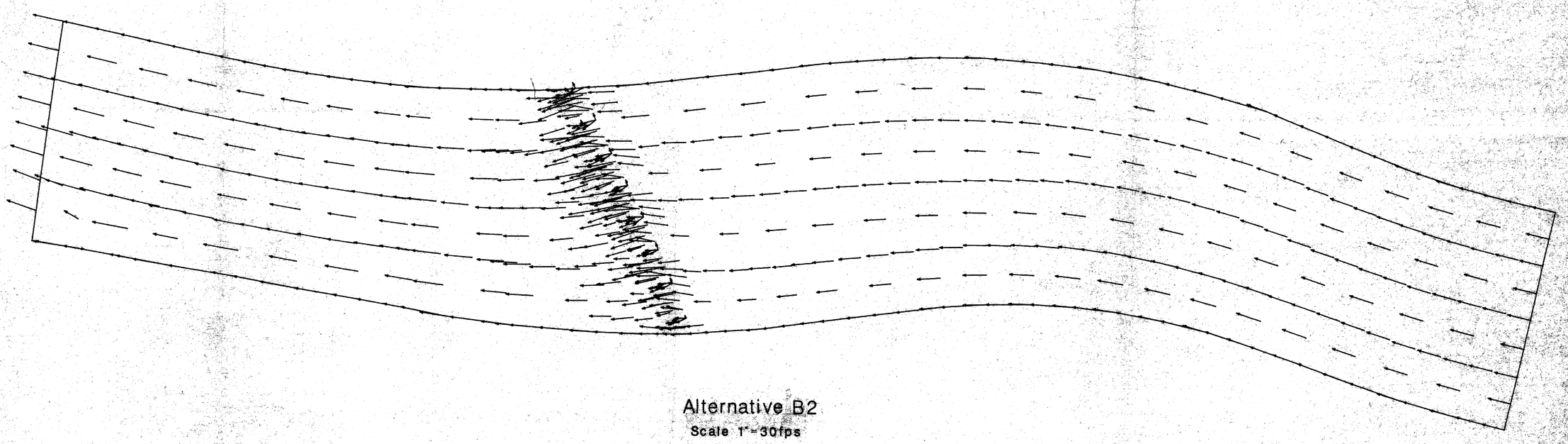

Alternative B2
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