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PRELIMINARY EROSION ANALYSIS OF THE NORTH BANK OF THE SALT RIVER FOR THE EAST PAPAGO FREEWAY AND RED MOUNTAIN INTERCHANGE

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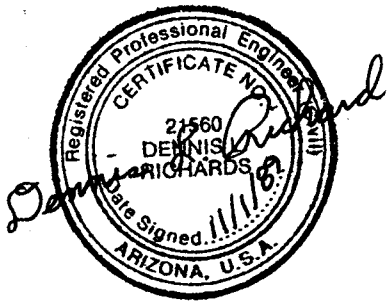


PREFACE

The results presented in this report are based on state-of-the-art techniques for river mechanics and scour analysis. However, the state-of-the-art of river mechanics is such that flow depths on the order of those which exist within the Salt River cannot realistically be predicted more accurately than plus or minus 10%. In addition, the state-of-the-art for scour analysis is such that predictions may vary by as much as 50% to 100%. The results obtained depend on the data base used, assumptions made, engineering computer models utilized, engineering judgement exercised, etc. Some of the assumptions made in conjunction with this study effort include: 1) hydrology (flood peaks) for the Salt River is correct; 2) the 1986 topographic mapping is sufficient to accurately depict topographic conditions; 3) sediment sampling adequately represents the existing sediment distributions in the stream bed; and 4) one-dimensional hydraulic modeling is appropriate to apply to the study reach. Consequently, the results obtained by different investigators could vary widely. Because the results presented within this report are considered to be conservative, based on the assumptions made, they can be used to give a relative measure of the maximum impacts associated with the proposed project. However, the results are only preliminary and not to be used for final design.

I. INTRODUCTION

The following report is to serve as an addendum to the report entitled "Preliminary Analysis of the Salt River for the East Papago Freeway and Red Mountain Interchange" prepared by Simons, Li & Associates. The items addressed within this Addendum were prepared in direct response to comments posed by Evans Kuhn & Associates, acting as consulting engineers for the Salt River Pima Maricopa Indian Community. The following items are addressed herein:

- The stability of the north bank of the Salt River in the vicinity of the Red Mountain Interchange.

- The effects that the proposed concept highway alignments may have on the Indian Communities gravel-mining operations.

- The effect that the proposed concept highway alignments may have on the extent of the floodplain on Indian lands.

II. NORTH BANK STABILITY

A preliminary erosion analysis of the north bank of the Salt River, located between the limits of Hayden Road and the Outer Loop freeway alignment, was undertaken to determine what effect, if any, alternative alignments of the East Papago Freeway might have upon bank stability. Several types of analysis techniques and methodologies were utilized for this effort, including 1) simple regime relationships, based upon an assumption of constant stream power to predict channel widening; 2) permissible tractive stress and permissible velocity approaches, in order to assess bank erosion potential; 3) a sediment-continuity approach, in order to attempt to quantify the extent of bank erosion; and 4) local-scour calculations to determine the effect that pier columns, associated with a proposed northern alignment, might have upon the subject bank.

The data utilized for these various analyses were taken from the hydraulic computer models and sediment-routing computer models which have previously been performed by SLA for this project. No additional modeling was performed. Generalized relationships, utilizing average hydraulic conditions, were used to compute sediment-transport volumes, as opposed to performing detailed, mobile-bed sediment routing. Therefore, the results obtained from this study effort are considered as approximate, although conservative--especially those obtained using the sediment-continuity approach.

The following paragraphs are a presentation of the results of the analyses, and a discussion of each approach. It should be noted that the four reach

designations (i.e., reaches #1 through #4) referenced herein are the same reaches which are defined within SLA's report entitled "Preliminary Hydraulic Analysis of the Salt River for the East Papago Freeway and Red Mountain Interchange". Figure 6 from that report, which delineates these reach designations, is provided herein as Figure 1 for the readers reference.

1) Several simple relationships are available, as well as a computer program developed by SLA, to predict the equilibrium width of an alluvial channel based upon the assumption that the channel will attempt to adjust its geometry so as to flow with minimum stream-power expenditure. In these relationships, it is also assumed that the channel is formed within unconsolidated alluvium, and is therefore free to widen and deepen accordingly. The equilibrium width is computed as a function of various combinations of the following parameters: discharge, sediment concentration, channel slope, and Froude Number, among others. For a 100-year flood, the resulting equilibrium channel widths obtained from these relationships ranged from about 500 to 1300 feet, depending upon the equation used and the assumptions made. Table 1 provides a comparison of the channel widths for the baseline condition, the southern alignment, and the northern alignment for the four reaches being considered. By making the assumption that all of the widening would occur on the north bank for the baseline condition as well as for concept conditions for both alignments, and by assuming that the channel would widen to 1300 feet for equilibrium-width conditions, the maximum predicted distances that a stable

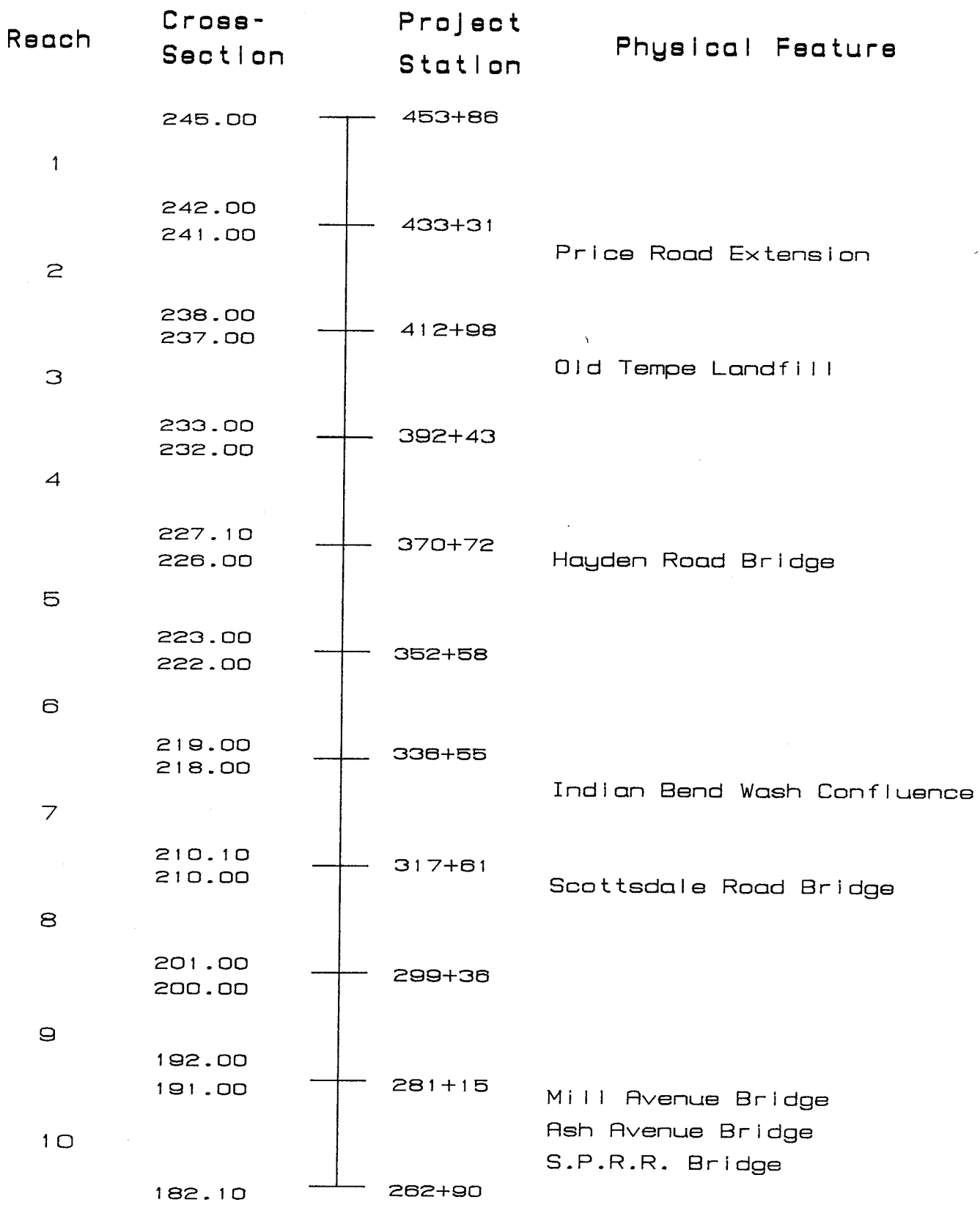


Figure 1. Reach Delineation for Hydraulic and Sediment-Transport Analysis

TABLE 1. CHANNEL WIDTHS

Reach No.	Baseline (Existing)	Southern Alignment (Proposed)	Northern Alignment (Proposed)
1	2268	2135	2134
2	1233	1494	1428
3	1033	728	932
4	978	1125	1157

TABLE 2. MAXIMUM PREDICTED DISTANCE OF STABLE BANK LINE NORTH OF EXISTING NORTH BANK (feet), EQUILIBRIUM-WIDTH CONDITIONS

Reach No.	Baseline (Existing)	Southern Alignment (Proposed)	Northern Alignment (Proposed)
1	0	0	0
2	70	0	0
3	270	570	370
4	320	180	140

north bank would be located north of the existing north bank for the imposed conditions would be as indicated within Table 2.

2) As previously stated, simple relationships for equilibrium channel width do not directly account for the ability of the channel banks to withstand the erosive forces of the flowing water. Therefore, the erosion potential of the north channel bank along the study reach was evaluated utilizing the permissible-shear-stress and permissible-velocity approach, as outlined by the Federal Highway Administration. Since detailed, quantitative information on the soil conditions present along the north bank was unavailable, a field trip was conducted to visually inspect the in-situ material. Soil conditions observed during the field trip can be generally characterized as consisting of mostly unconsolidated alluvial deposits which are easily erodible. However, it would be desirable if a more detailed soils investigation were undertaken in the future in order to verify the composition of subsurface soils, and to provide a basis for a more thorough permissible-shear-stress and permissible-velocity analysis.

The methods of permissible shear stress and velocity are normally used to determine if a channel is stable, in the sense that the boundaries should remain immobile. Under the permissible-velocity approach, the channel is assumed stable if the calculated mean velocity is less than the maximum permissible velocity. The permissible-shear-stress (tractive-force) approach focuses on stresses which develop at the interface between flowing water and the materials which constitute the channel boundary. The

permissible shear stress is defined as the maximum unit tractive force that will not cause serious erosion of natural channel materials.

The permissible shear stress is a function of the type of material which comprises the bed or banks of the channel. Based upon the soils observed, a permissible shear stress of 0.05 lbs/ft^2 was estimated for the study reach of the Salt River. This permissible shear stress is based upon the recommended value in the literature for non-cohesive, medium, sand-sized material. The permissible velocity for this material is dependent on the permissible shear stress, the roughness of the material (i.e., Manning's n-value) and, to a lesser degree, the hydraulic radius of flow. The permissible velocity determined for the bank materials and the flow conditions existing along the study reach of the Salt River ranges between 1.8 and 2.0 feet per second (fps). The actual shear stresses and flow velocities which will occur during a 100-year flood along the study reach are approximately 0.3 to 1.7 lb/ft^2 and 5.0 to 12.0 fps, respectively. The large difference between the permissible shear stress and the permissible velocities compared with the calculated values indicates that the existing material at the project site is <u>highly susceptible</u> to erosion during a 100-year flood. While the results of this analysis cannot be used to estimate the actual distance a bank may erode during a particular flow event, it can be used to determine if the bank-erosion distances determined from other analysis techniques are potentially attainable.

3) The sediment-continuity analysis examines the sediment-transport capacity of a particular reach in comparison to the sediment being supplied to the reach from upstream flow. If sediment supply exceeds transport capacity, sedimentation is expected to occur along the reach. If transport capacity exceeds sediment supply, erosion of the channel bed and/or channel banks is expected to occur. For this analysis, sediment transport was calculated by the Meyer-Peter/Muller equation for bed-load transport, while suspended load was estimated from the Einstein procedure for computation of suspended sediment.

The results of this analysis indicate that sediment-transport capacity increases dramatically from reach 1 to 2 and from reach 2 to 3, then drops off somewhat from reach 3 to 4. This pattern is true for the baseline condition as well as for the proposed southern and the northern alignments. However, the greatest increase in sediment-transport capacity occurs within reach 3 of the proposed southern alignment, due to the constriction caused by this alignment encroaching into the channel as it avoids the old Tempe landfill. The constriction causes the average flow velocity within the reach to increase from 9.2 fps (baseline conditions) to 12.5 fps for concept conditions. Note that the average flow velocities just upstream (within reaches 1 and 2) are 4.8 fps and 6.5 fps, respectively. Since sediment-transport capacity is proportional to flow velocity to approximately the fourth power, this increase in velocity correspondingly causes a much larger increase in sediment-transport capacity.

This increased sediment-transport capacity in the downstream direction indicates that scour is very likely to occur within reaches 2, 3, and 4. This scour can occur on the bed or the banks of the channel. However, it has already been demonstrated, through previous analyses, that scour of the bed of the channel will be halted by an armoring process at a depth of approximately six and one-half feet. At that point, the channel will most likely begin to widen, if further adjustment is to occur. If the channel widens, its sediment-transport capacity will reduce until it approaches that of the upstream supply, at which point it will reach a state of equilibrium. Due to the large differences between the upstream and downstream sediment-transport capacity and the long duration of flow for the design flood, it is possible that reaches 2, 3, and 4 could widen to the same width as reach 1 during a single flow event. As listed on Table 1, this width is approximately 2300 feet. Although this magnitude of widening is potentially achievable for the baseline condition as well as for concept conditions for both alignments, it is likely to occur more rapidly with the proposed southern alignment, due to the constriction previously mentioned and the fact that bank stabilization is proposed for only the south bank of the channel.

4) An analysis of pier scour was conducted for the northern alignment, due to the proximity of pier columns along the north bank of the channel. A column diameter of seven feet was used, with an additional seven feet assumed for debris buildup. Local-scour relationships indicate that, for a 100-year flood, the maximum scour depth could be up to 28 feet below the

channel invert. The horizontal zone of influence of such a scour depth is found by adding the 28-foot scour depth to the existing 20-foot bank height, and then multiplying this sum times the cotangent of a natural angle of repose of 30 degrees for the in-situ soils, and then adding one pier diameter to this value. On this basis, the horizontal zone of influence of pier scour into the north bank would be approximately 90 feet (i.e., [28 + 20] x 1.73 + 7). Therefore, regardless of whether or not the channel will widen, as predicted by the previous analyses, the northern alignment could cause the north bank to be unstable for a distance of approximately 90 feet north of its present bank line, just as the result of local scour alone.

In summary, it can be concluded that the north bank along the study reach should be considered unstable during a 100-year flow for the baseline condition as well as for concept conditions for both alignments. Without the benefit of a more detailed analysis, the location of a stable north bank should be determined by conservative results obtained from the analyses performed. In this case, the most conservative results are obtained from a sediment-continuity analysis; and they indicate that the channel could widen to approximately 2,300 feet through reaches 2, 3, and 4. By making the assumption that all of the widening would occur on the north bank for the baseline condition as well as for concept conditions for both alignments, the maximum predicted distances that a stable north bank would be located north of the existing north bank for the imposed conditions would be as indicated within Table 3. It should again be noted that these estimates are conservative, and that they are based upon

TABLE 3. MAXIMUM PREDICTED DISTANCE OF STABLE BANK LINE NORTH OF EXISTING NORTH BANK (feet), SEDIMENT-CONTINUITY ANALYSIS

Reach No.	Baseline (Existing)	Southern Alignment (Proposed)	Northern Alignment (Proposed)
1	0	0	0
2	1070	800	870
3	1270	1570	1370
4	1320	1180	1140

generalized relationships and assumptions which may or may not be strictly applicable to the study reach of the Salt River. A more definitive evaluation of the stability of the north channel bank along the study reach of the Salt River would require thorough soils testing and a much more detailed river-mechanics analysis.

III. MINING IMPACTS

3.1 Flow Velocities

Velocities during the 100-year flood in the vicinity of the gravel mining (i.e., reaches 1 and 2) range between 4.0 and 8.0 fps for the baseline condition and between 5.0 and 7.0 fps for both the proposed southern and northern alignments. Velocities will increase slightly at certain sections, and will actually decrease at other sections. For the baseline condition, the gravel-mining activities will always be in serious jeopardy during times of flooding within the Salt River. The change in flow velocities caused by either of the proposed roadway alignments would be insignificant with regard to affecting the already existing flood hazards to which the gravel-mining operations are presently exposed under the baseline condition.

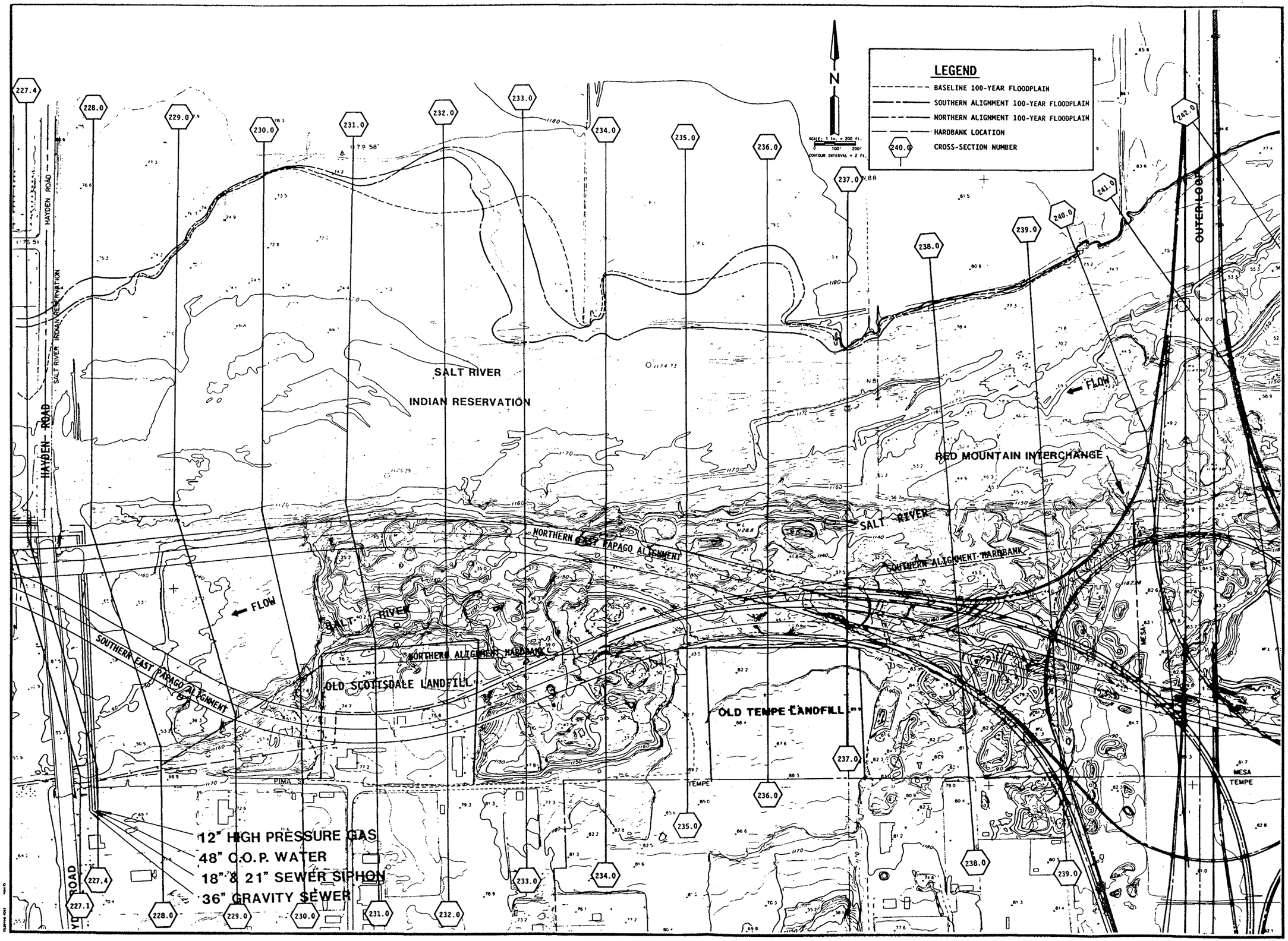
3.2 Setback Impacts on Mining

In-stream sand and gravel mining activities located in close proximity to highway crossings can potentially create serious hazards for structures which are founded within the channel bed. In order to provide for a highway crossing of the Salt River which would have a stable foundation during it's design life, some limitations on the extent of gravel mining in the vicinity of the highway would be necessary. These restrictions should consist of some combination of minimum setbacks and maximum excavation depths, combined with possible realignment of low flows. The exact limitations for mining activities would need

to be determined through a detailed channel scour analysis which would take into account both the long-term and single-event scour, as well as the specific type and depth of the roadway-crossing foundation.

IV. FLOODPLAIN IMPACTS

Water-surface profiles were computed for the 100-year peak discharge for 1) baseline conditions, 2) concept conditions for the proposed southern alignment of the East Papago freeway, and 3) concept conditions for the proposed northern alignment of the East Papago freeway. The effects of gravel pits were removed for concept conditions, as they were for baseline conditions, to provide a conservative estimate of impacts resulting from the proposed project. Concept conditions included bank protection along the south bank of the Salt River from Hayden Road to upstream of the Outer Loop highway. No protection was included along the north bank of the river. Figure 2 shows the 100-year floodplain delineation north of the Salt River for the three conditions described above.



SIMONS, LI & ASSOCIATES, INC.
NEWPORT BEACH, CA., FORT COLLINS, CO., TUCSON, AZ., PHOENIX, AZ.

NORTH BANK OF THE SALT RIVER
100 - YEAR FLOODPLAIN DELINEATION

Project No.	
Date:	10/27/89
Design:	
Drawn:	JRM
Check:	
Revisions:	

FIGURE 2

V. MITIGATION OF POTENTIAL IMPACTS

Several techniques have been identified for mitigating the potential adverse impacts which have been discussed herein. The most effective of these would be a channelization and bank-protection project that could extend from Hayden Road to some point upstream of the proposed Red Mountain Interchange. This alternative would establish a stable north bank by eliminating the possibility of channel widening or bank erosion. Although gravel mining should still be restricted in the vicinity of the highway crossing, this option would provide the greatest flexibility for continued operation. One option may be to provide bank stabilization along the historic bank alignment, which would also establish a stable north bank. However, with this option the existing gravel mining would still be located within the streambed, and greater restriction of the operations would be recommended. Another possible option would be to channel the river in such a manner that future gravel mining could continue outside of the new channel alignment--thereby not posing a hazard to bridge foundations.

Without some form of bank stabilization, the location of the north bank cannot be insured, even without the existence of the highway or the interchange. Should the gravel mining continue to operate without restriction in this area, the only option available for mitigating the hazards to the highway would be to design its foundation for the total scour which is expected along this reach (as documented within the previously referenced SLA report).