Central Arizona Water Control Study

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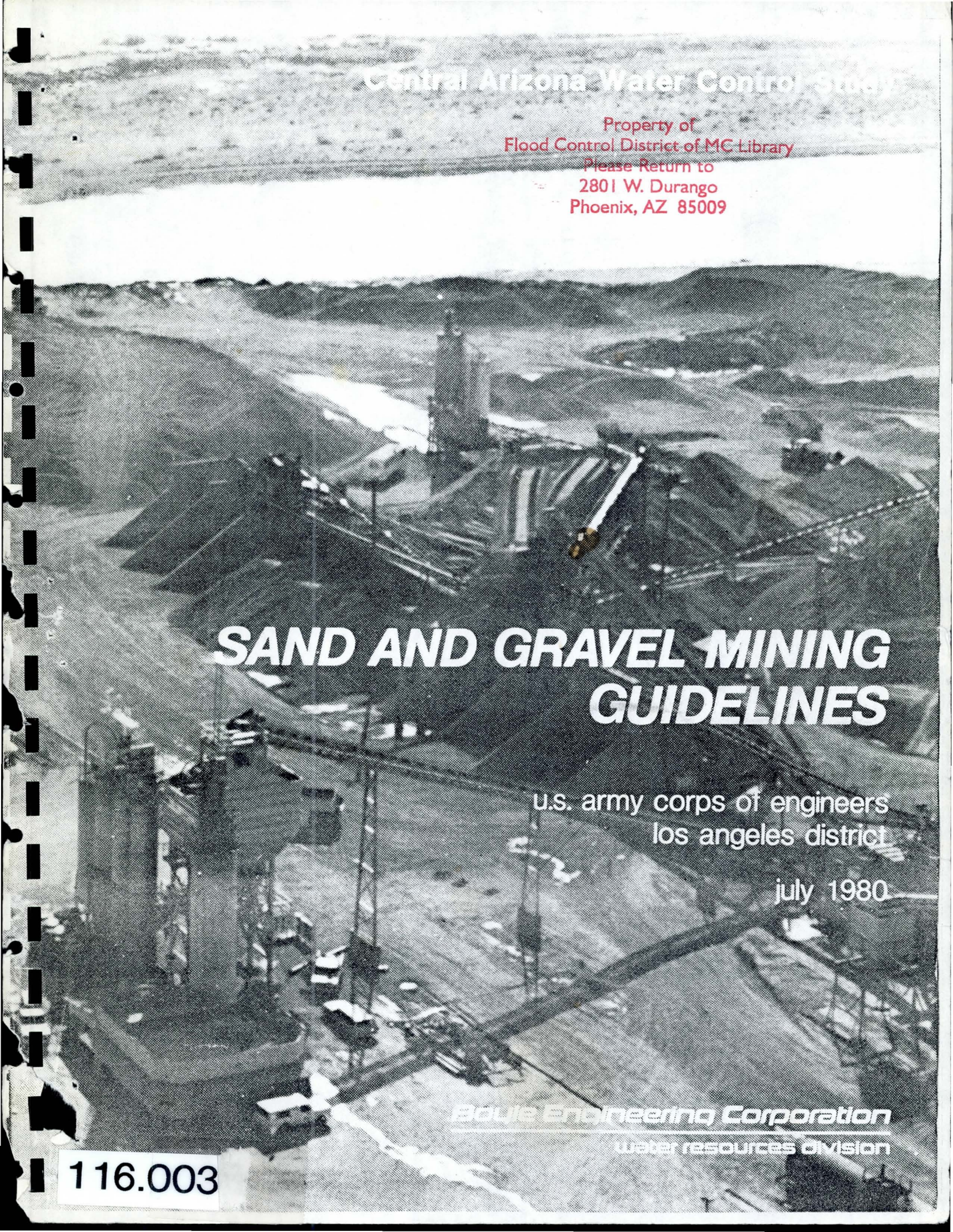

SAND AND GRAVEL MINING GUIDELINES

u.s. army corps of engineers
los angeles district

july 1980

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water resources division

116.003

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August 8, 1980

Central Arizona Water Control Study
Sand and Gravel Mining Guidelines

We are pleased to submit the accompanying report concerning sand and gravel mining guidelines on the Salt and Gila Rivers, Maricopa County, Arizona. In accordance with Contract DACW09-80-C-0002, the report includes the following elements:

1. hydraulic effects of in-stream sand and gravel mining;
2. flooding problems associated with sand and gravel mining; and
3. mitigation measures, including sand and gravel mining guidelines, to reduce flood-related problems.

During the preparation of this report we had the pleasure of working closely with members of your staff, all of whom were very cooperative. We have appreciated the opportunity to study this important problem, and to prepare the report.

BOYLE ENGINEERING CORPORATION
Water Resources Division

Young S. Yoon, Ph.D.
Senior Hydrologist

blc

Enclosure

X-C38-100-02

CENTRAL ARIZONA WATER CONTROL STUDY

SAND AND GRAVEL MINING GUIDELINES

PREPARED FOR

U.S. ARMY CORPS OF ENGINEERS

LOS ANGELES DISTRICT

BY

BOYLE ENGINEERING CORPORATION

WATER RESOURCES DIVISION

JULY 1980

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1.0 INTRODUCTION

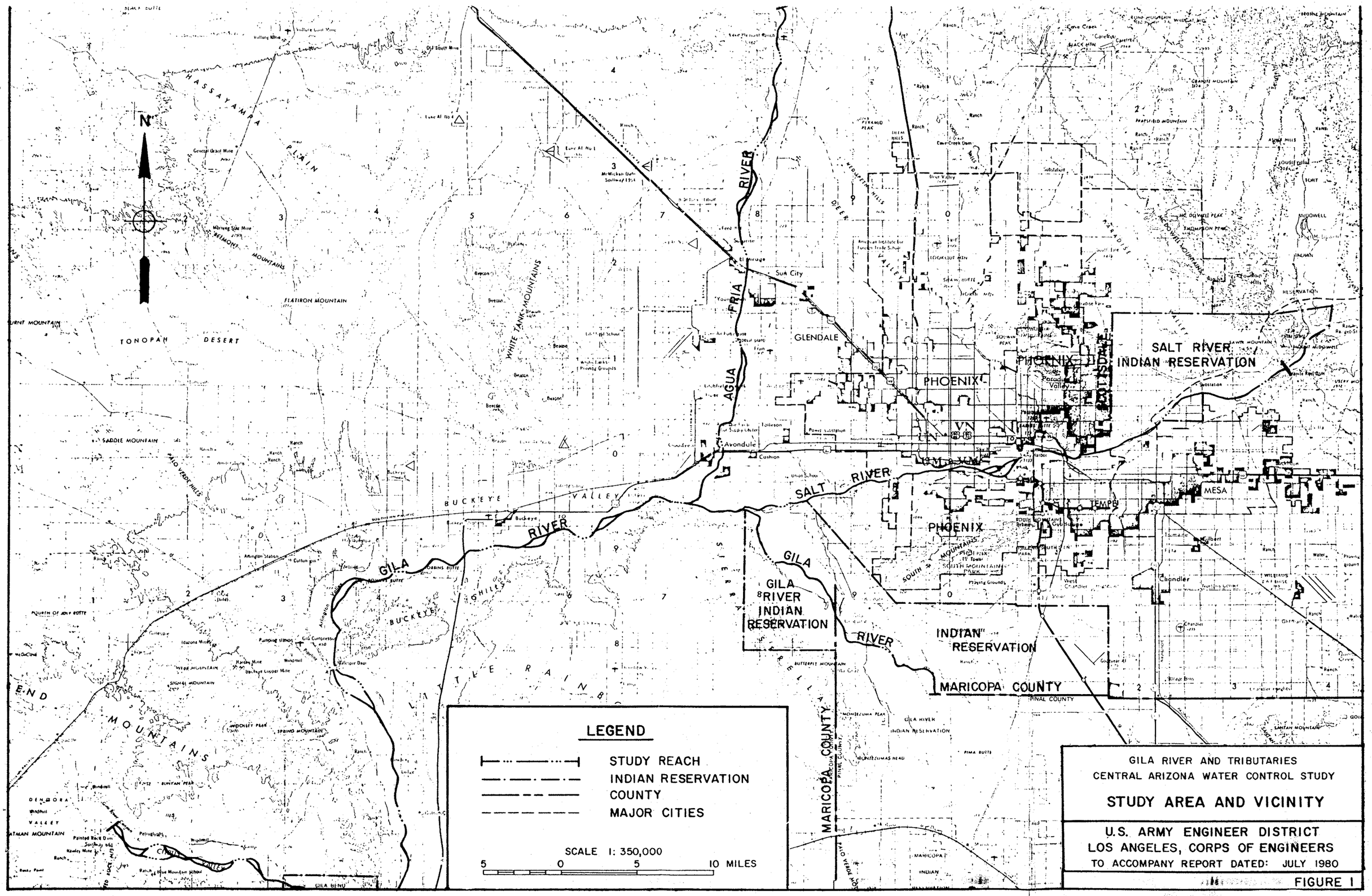
1.1 Background

The purpose of this study is to develop guidelines for sand and gravel extraction from the Salt and Gila Rivers that would reduce flood damages associated with sand and gravel mining. The study reach extends from Granite Reef Dam to Painted Rock Dam, Maricopa County, Arizona (Figure 1). The report is based on data obtained from field investigations, informal interviews, a literature review, and computer modeling. The report discusses impacts of sand and gravel mining activities, especially on the hydraulic processes of degradation/aggradation, headward erosion, and lateral migration. It outlines mitigation measures that may reduce the adverse hydraulic impacts of extraction activities, and proposes guidelines for management of future in-channel mining of sand and gravel. These guidelines are developed as part of the nonstructural measures under study by the Central Arizona Water Control Study.

1.2 Definition of the Problem

Private and public property has been damaged during recent, severe floods on the Salt and Gila Rivers. An undetermined portion of that damage resulted from in-channel sand and gravel mining. Mining activities change the pattern of flow in the flood plain. These changes can cause damages to structures adjacent to mining operations.

The problem of regulating sand and gravel mining is twofold. The current flood plain ordinances of Phoenix and Maricopa County could reduce some flood damages resulting from mining. However, most mining operations are not subject to the ordinances because a state law exempts from regulation all



GILA RIVER AND TRIBUTARIES
CENTRAL ARIZONA WATER CONTROL STUDY

STUDY AREA AND VICINITY

U.S. ARMY ENGINEER DISTRICT
LOS ANGELES, CORPS OF ENGINEERS
TO ACCOMPANY REPORT DATED: JULY 1980

FIGURE 1

flood plain uses existing prior to enactment. Another hindrance to uniform enforcement of regulations is the presence of multiple jurisdictions. City, county and federal governments have authority in different areas of the Salt River Valley flood plains.

The guidelines in this report are based on engineering analyses of the hydraulic effects of sand and gravel mining. A comparative analysis was made of existing and proposed regulations in other areas. The purpose of the guidelines is to reduce flood damages sustained and caused by in-channel mining operations. The proposed provisions are more comprehensive and more specific than the existing flood plain regulations. The effect of the guidelines on the industry itself depends on the method of enactment, and the specific provisions and their enforcement. The governments involved should develop among themselves the most effective and equitable strategy for implementation.

1.3 Conclusions and Recommendations

-- Sand and gravel mining in the Salt and Gila Rivers has caused hydraulic changes in the channels. As a result of these changes, nearby lands and structures have been threatened or damaged during floods.

-- The most severe problem caused by in-channel extraction in the study area is headward erosion upstream of a pit. In addition, the presence of dikes and stockpiles in the floodplain may divert flood flows, causing erosion of the opposite bank and lateral migration of the channel.

-- Sand and gravel mining can be managed so that it enhances the capacity of the river system and reduces flooding, while accomplishing the objective of mineral extraction. However, this process requires the adoption of a river basin management plan.

-- The guidelines proposed in this report should be considered for adoption whether or not a basinwide plan is implemented.

-- The appropriate agencies should commit more resources to the enforcement of the existing regulations that apply to sand and gravel mining, and to the bringing of all existing operations under the regulations.

1.4 Acknowledgments

We acknowledge with appreciation the information and cooperation we received from the following groups during this study: Arizona Department of Transportation, Maricopa County, City of Phoenix, Salt River Pima-Maricopa Indian Community, Sonoma County Planning Department, Dames & Moore, Arthur Beard Engineering, Natelson Company, and CDM, Inc. Special thanks go to Dr. Daryl B. Simons and Dr. Ruh-Ming Li of Colorado State University, who provided material used throughout the report.

2.0 GUIDELINES

The guidelines developed in this section are based on the engineering analyses and references discussed in the following chapters. The guidelines are considered to be minimum acceptable practices that, if followed, will reduce flood and erosion damages associated with sand and gravel mining operations on the Salt and Gila Rivers. The guidelines do not consider the other potential environmental impacts of sand and gravel mining.

Any guidelines that are adopted should acknowledge the economic importance of sand and gravel mining, while protecting other values and activities in the flood plain. The guidelines could be implemented through a permit process applying to existing, as well as new, operations. Sand and gravel operations would be liable for damages resulting from failure to adhere to permit requirements.

Operation

-- All extraction should be conducted in accordance with plans that have received prior, official approval of regulatory agencies.

-- All excavation operations should be conducted in such a manner as to cause no obstruction of the natural flow in waterways, and cause no damage to adjacent structures or properties. No excavations, no stockpiling of any kind, and no other obstructions should be permitted in the floodway during the months of highest flood risk.

-- Excavations should be located so that the grade cannot exceed one percent between the midpoint elevation of the upstream pit face and the nearest point in the streambed 200 feet downstream of an existing structure or utility crossing (see Figure 2), unless it is shown that the excavations would have no effect on the upstream structure or utility crossing.

-- Excavations within a strip extending 100 feet streamward from the toe of river banks, or below a plane extending streamward at a 10 to 1 slope (horizontal to vertical), should not be permitted if there is a potential for such excavations to cause significant bank sloughing that would endanger structures or property within or adjacent to the flood plain.

-- No excavation should be permitted below the existing elevation of the flow line of the channel unless it is shown that the excavation would not cause significant damage to bank stability or to nearby structures.

-- All extraction operations should be performed on the basis of a continuous pit within the property of any one operation. Leapfrog operations should not be permitted; and a continuous pit should not be sinuous with respect to either the line or grade of the stream.

-- In cases where there are potential adverse hydraulic effects from an extraction operation, the owner should provide the regulatory agency with the necessary engineering analysis, performed by a qualified engineer, showing that there are no significant adverse effects, or if there are, that they can be mitigated.

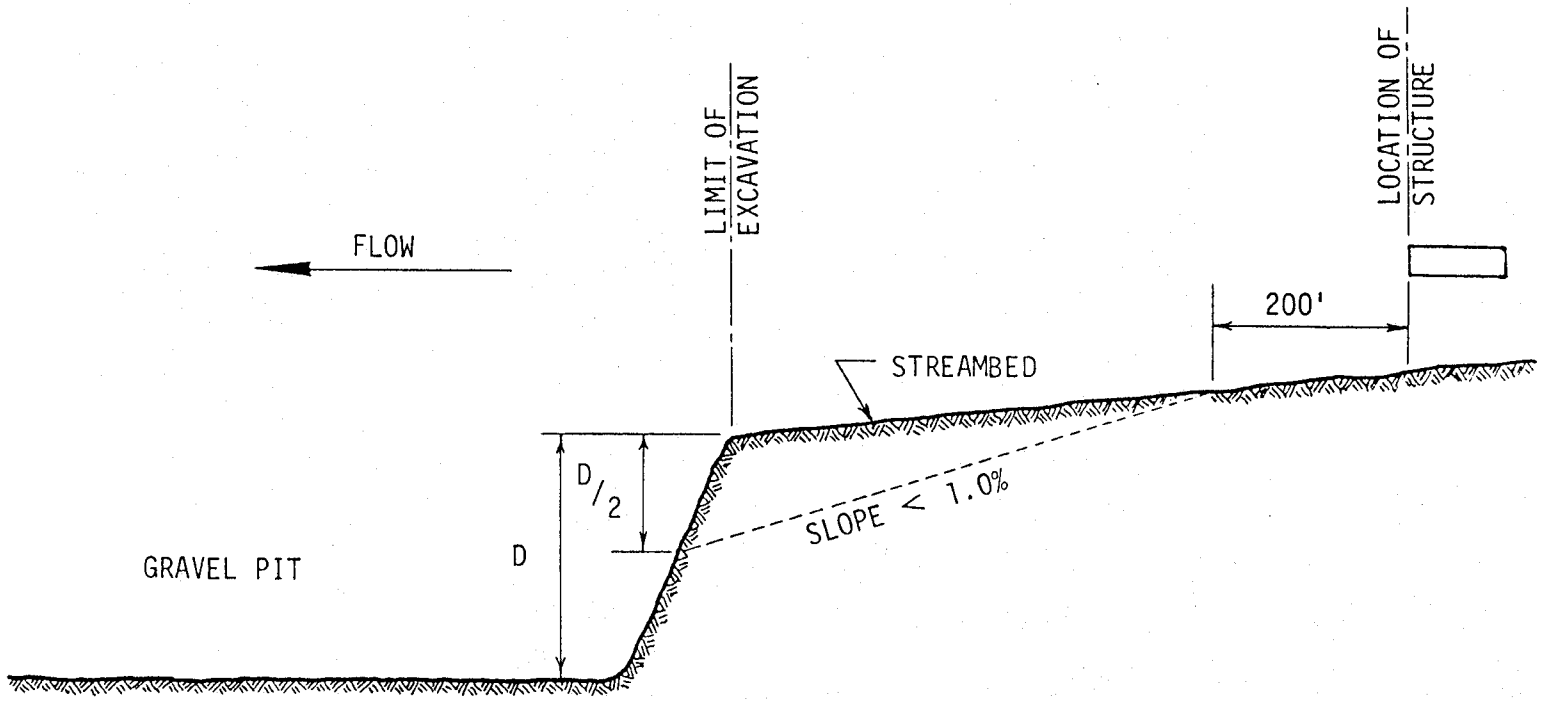


Figure 2 Limit of Excavation Downstream of a Hydraulic Structure.

Reclamation

-- Streambanks affected by a sand and gravel mining operation should be rehabilitated according to the standard procedures acceptable to the regulatory agencies.

-- Any piles of mining waste, and any equipment should be removed from the flood plain after excavation is completed. Certain materials may be used for the backfilling of the excavated pits provided that there is no adverse environmental effect. No toxic materials or solid waste will be allowed for the backfilling. Fill material or weathered waste should be graded and covered with coarse hard material, where practical, to prevent scouring.

-- The final side slopes of the pits should take into consideration slope stability and the effects of river hydraulics. In all cases, the slopes should be flatter than the critical gradient (angle of repose) for the type of soil involved.

-- All streambanks that have been disturbed by mining operations should be stabilized to prevent erosion and sloughing.

-- Access to abandoned pits should be prevented by structures such as fences or berms constructed outside the floodway.

Administration

-- The regulatory agency should establish and maintain in-house measures

and procedures to ensure organized record keeping, monitoring of gravel mining operations, and reclamation under its jurisdiction.

-- The regulatory agency should have authority to suspend sand and gravel mining operations when significant adverse effects are likely to occur as a result of such operations.

-- The regulatory agency should assure that the objectives of the operation and reclamation plan will be accomplished. This may include provisions for liens, performance bonds, or other security to guarantee reclamation in accordance with the approved reclamation plan.

-- The regulatory agency should act with diligence in reviewing and ruling on applications for extraction permits, and on proposed reclamation plans for existing pits. The agency should integrate the requirements of these guidelines with other planning, and institute environmental review procedures required by law and administrative practice.

3.0 SAND AND GRAVEL MINING ACTIVITIES

3.1 Resources

The quality of aggregate is measured in terms of size and shape distributions, flexibility, durability, chemical stability, and cleanness. Specifications in each category may vary with aggregate use. Such uses include concrete, asphaltic concrete, road base and subbase, trench backfill and pipeline bedding, riprap, and road surfaces (Sonoma County, 1980).

There are three major sources of aggregate: hardrock quarries, terrace (out-of-channel alluvium) excavations, and in-channel excavations. Processing and transportation are the two major costs associated with aggregate materials. Therefore, the source of supply that is exploited depends on minimizing total costs. A high quality source that is farther from the potential market may be competitive with a poorer source closer in. However, a distant, low-quality source will not be competitive with either.

Although no data are available for Maricopa County, it is generally accepted that in-channel operations on the Salt River are the most important sources of aggregate (Hollingsworth, 1970). There are four reasons for this preeminence. First, in-channel sources have no overburden and, therefore, are cheaper to extract. Second, the sand and gravel deposits in the Salt River are of excellent quality for all purposes. Third, the river sites are close to major urban markets and transportation routes. The fourth advantage results from the arid climate of the region. Because the Salt River flows intermittently, sand and gravel operators have access to the entire riverbed

for most of the year. In addition, the lack of groundwater close to the surface increases the depth to which pits may be dug.

In 1970, Hollingsworth estimated the volume of available sand and gravel from Granite Reef Dam to 67th Avenue to be 368,000,000 cubic yards. Approximately half of that has been reserved by the Water and Power Resources Service for use in constructing the Central Arizona Project (Mariscal, 1973). Aggregate resources downstream of 67th Avenue are estimated to be approximately the same as in the upstream reach. Hollingsworth estimated the reserves of the Agua Fria River channel to be approximately 8,500,000 cubic yards. Other in-channel sources currently are not as important as the Salt and Agua Fria Rivers because of quality, quantity, or distance constraints.

Since Hollingsworth's study, there have been no estimates of the annual extraction and renewal rates. Both figures are necessary to estimate the existing in-channel reserves.

Empirical information suggests that not all of the in-channel resources are renewable. The sand portion of recently deposited aggregate is too fine to be used for ready-mix concrete (Bureau of Indian Affairs, undated). Further changes in size distribution are likely if additional upstream dams are built.

3.2 Historical and Present Patterns of Extraction

Sand and gravel extraction has followed the patterns of urbanization in the Salt River Valley. Extensive excavation activities near central Phoenix and near Tempe have expanded upstream and downstream with development. There are not as yet any major extraction operations downstream of the confluence

of the Salt and Gila Rivers (see Plate 1). The location of gravel pits shown on Plates 1 through 3 was identified from USGS 1:24,000 topographic maps, and from photos taken before the 1978 floods (information provided by Natelson Company, Inc.). Also shown on the sheets is the 100-year flood boundary determined by the U.S. Army Corps of Engineers in 1979.

The streambeds of the Salt and Gila Rivers, and their tributaries, are in both public and private ownership. Jurisdictional authority in the study area is fragmented. Federal law and tribal regulations apply in the Indian reservations. The municipalities have control over the area within their corporate boundaries. Maricopa County has jurisdiction in all non-federal, unincorporated areas. State-owned land is not a significant factor in the study area.

Sand and gravel operations can be divided into three major categories: (1) those producing only sand and gravel; (2) those producing sand and gravel, and ready-mix concrete; and (3) those producing sand and gravel, and ready-mix and asphaltic concrete (Mariscal, 1973). The four largest companies in the greater Phoenix area fall into the third category, and have approximately 71 percent of the market (Mariscal, 1973). It was estimated in 1970 that each of the four companies had production capacities of at least 1,000 tons per hour; whereas the smaller companies had capacities of less than 200 tons per hour (Hollingsworth, 1970).

3.3 Flood Damages

Historically, sand and gravel operations have experienced the greatest industrial losses from flooding in Maricopa County, because they are situated in or near the riverbeds (U.S. Army Corps of Engineers, Feb. & Sept. 1979).

Damages to sand and gravel operations are mainly in the form of damaged conveyors, flooded materials, water-filled pits, and interrupted business. In the February-March 1978 floods, sand and gravel industrial losses were estimated to be $2.5 million (U.S. Army Corps of Engineers, Feb. 1979). This loss is about eight percent of the total flood damages. Floods in the following year caused damage to sand and gravel operations estimated at $5.2 million, about 10 percent of the total damages.

While the sand and gravel industry has incurred flood damages, it also has been accused of causing, or extending, damage to adjacent property and structures. In the most recent floods a main pier footing of the 1,500-foot, Maricopa freeway (I-10) bridge over the Salt River was undercut as a result of riverbed shifting and scouring. Part of the problem was caused by sand and gravel operations excavating large areas in the riverbed, both upstream and downstream of the bridge. It is alleged that both the downstream and upstream excavations caused the shifting of the main channel, creating scouring at the piers. It also is alleged that the problem was aggravated by the headcutting of the downstream excavation. (Bishop 1980)

Erosion problems similar to those of the I-10 bridge were noted on the old Oak Street crossing on the Salt River Reservation (Bureau of Indian Affairs, undated). Presence of an abandoned gravel pit located about 200 feet from the road caused undercutting of the road foundations, and collapse of the paved roadway.

Another problem related to in-channel sand and gravel operations has been the obstruction of the floodway by stockpiles, or by levees and dikes built to

protect equipment and pits. These obstructions can divert runoff and change the course of streams, thereby endangering adjacent property. In addition, the constriction of flow increases velocity, which increases erosive capacity, endangering streambed and banks.

Mining-related damages were also observed in earlier floods (Aldridge, 1970). However, interviews with local agency personnel indicate that flood-related complaints against sand and gravel operators are increasing. Examples include damage to the south bank of the Salt River between 16th and 24th Streets and to the southeast corner of 19th Avenue. The extent to which sand and gravel mining is responsible for these damages has not been determined and quantified. However, the potential damages are severe enough that the present pattern of extraction is considered to be a flood-related problem (U.S. Dept. of Interior, Nov. 1979).

4.0 POTENTIAL IMPACTS OF SAND AND GRAVEL MINING

Any consumptive use of resources will cause impacts on natural and cultural systems. Some effects are direct and relatively easy to quantify, predict, and assess. Other impacts may be indirect or may affect dynamic processes that are either poorly understood or, in turn, are affected by random events outside human control. The following discussion of potential effects of in-stream sand and gravel mining indicates that the least understood and least predictable impacts may be the most severe. Consequently, the discussion focuses on hydraulic impacts of extraction. Although not within the scope of this study, other potential impacts are summarized in section 3.2 for general reference.

4.1 Hydraulics

A characteristic of flowing water is to seek and maintain an even gradient (thalweg) of flow. A stream in this condition is said to be in equilibrium. Natural or human-related forces can disturb this equilibrium by creating a knickpoint, or sudden change in gradient. The stream will respond with various processes which tend to return it to equilibrium--in effect making a stair-step into a ramp. A knickpoint may develop indirectly as a result of stream disturbances such as a sudden increase in flow at a particular point or in erosive capacity by removal of sediment.

The hydraulic processes that tend to recover and maintain equilibrium are sedimentation (aggradation), erosion (degradation), and lateral migration. Because equilibrium is a dynamic process, not a steady state, these hydraulic processes are present to some degree in every stream. However, their dominance

and potential adverse effects increase as the amount of disturbance increases. Sand and gravel mining inevitably affects stream hydraulics by removing material from the streambed. The impact, however, need not be negative. In deepening a channel, the capacity is increased, thus reducing the amount of overbank flow during floods. On the other hand, with all other factors remaining the same, velocity is also increased, so that actual damage caused by flooding may not be reduced. The natural replenishment rate of extracted material will also affect the extent of impacts. The higher the replenishment rate, the faster equilibrium will be restored. In watersheds where dams and storage reservoirs exist upstream of mining operations, replenishment will be limited, and the channel may be subject to severe instability. In addition, the rate and amount of extraction will affect the duration of impacts.

Some impacts of sand and gravel mining are related to the creation of a knick-point. Examples are headcutting upstream of a pit, and aggradation at the pit and downstream. Headcutting is the erosive process by which a drop in gradient moves upstream. Field investigations revealed that headcutting of a pit is one of the most severe threats to hydraulic structures on the Salt River. Mechanisms causing headcutting, and typical examples, are illustrated in the appendix. In addition if a pit is extensive, it may cause water to slow and drop its sediment load, giving the stream increased erosive capacity below the pit. This process ceases when the pit fills with sediment.

To analyze the extent of headcutting associated with gravel pits, a computer model (Simons and Li, 1979) was applied to a reach of the Salt River. The model uses the Meyer-Peter, Muller bed load equation, coupled with an adaptation of Einstein's suspended sediment integration method. This integrated procedure

determines the total bed material load by size fractions, based on the hydraulic parameters determined from HEC-2 analysis, and the measured bed material size distribution. The reach that was modeled extended 2.8 miles upstream of the I-10 bridge and 3.2 miles downstream of the bridge. This study reach was chosen because of readily available information. The gravel pit was assumed to be located downstream of the bridge with a surface area of 60 acres (1,200 feet wide and 2,200 feet long). The analysis used an 11-day, synthesized hydrograph with a peak flow of 176,000 cubic feet per second, approximately the 100-year flood (Figure 3). The maximum headcut distances and associated bed slopes for pits 15-feet, 30-feet and 50-feet deep are presented in Table 1. When the maximum headcut distance occurs, the depth at the upstream pit face is about half of the pit depth, and the bed slope is approximately one percent. This pattern has been used in the proposed guidelines as a standard for protecting upstream structures.

Additional hydraulic impacts are related to other aspects of mining operations, such as the creation of stockpiles, or the building of levees and dikes to protect equipment and active pits. These obstructions may deflect a stream during high flows and cause it to alter course. This can be a particularly serious problem if urban lands or high-value agricultural land is threatened by channel encroachment. Heavy economic losses will be sustained if channel migration undermines and destroys buildings, roads or bridges. If flood protection structures, such as levees, are breached by channel migration during floods, then loss of life may occur as well as property loss. However, lateral migration is a natural process among braided streams of the Southwest. The extent that sand and gravel mining may increase or accelerate this process is difficult to determine, especially because of the random element present in the natural migration process.

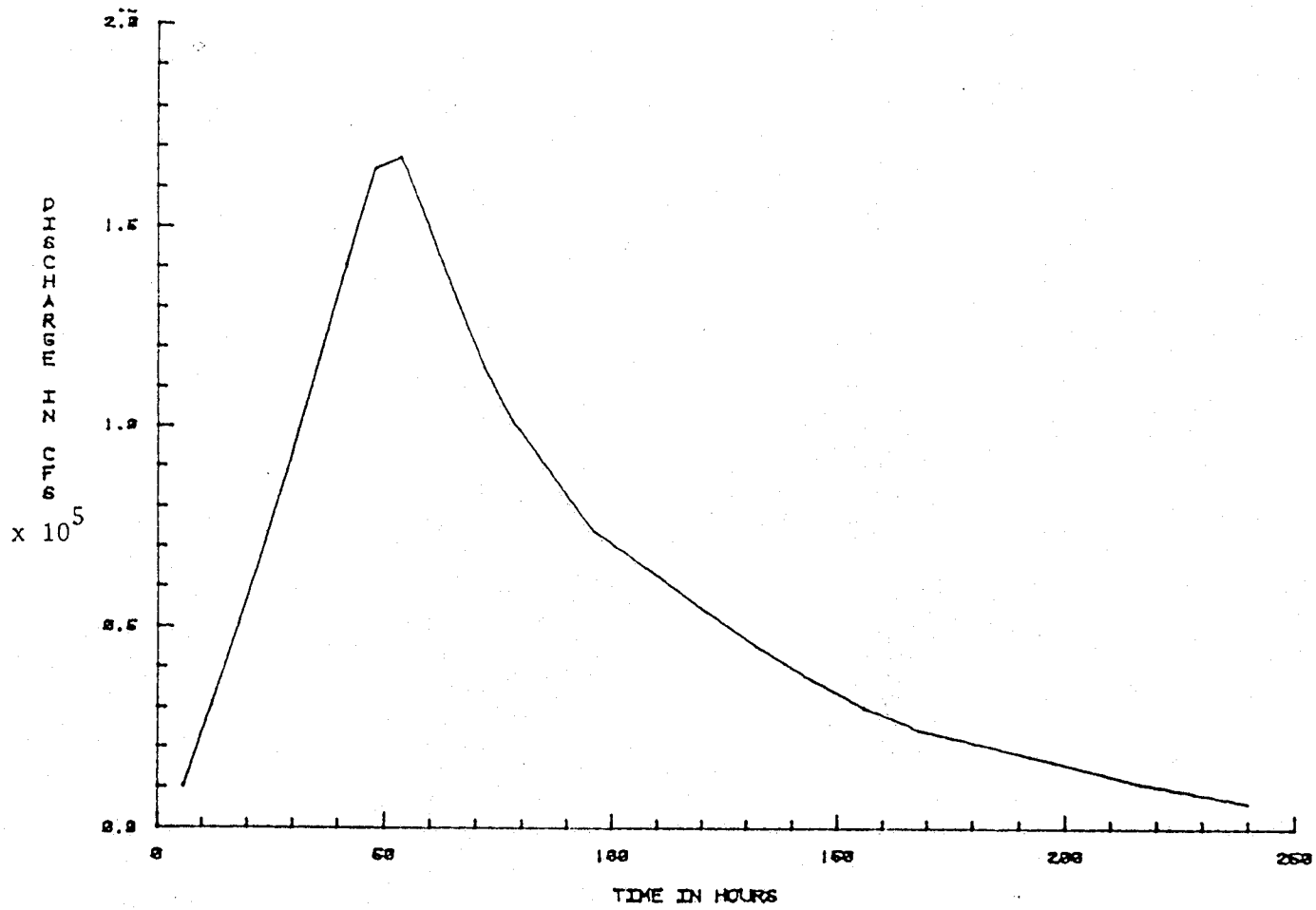


Figure 3 Synthetic Hydrograph, Salt River

Table 1. Computed Maximum Headcut Distance and the Associated Bed Slope for Various Assumed Pit Sizes in the Salt River.

Depth of Pit (ft)	Volume of Pit (Acre-ft)	Maximum Headcut Distance (ft)	Depth of Headcut at the Pit Boundary Associated With Maximum Headcut Distance (ft)	Bed Slope Associated With Maximum Headcut Distance (ft/ft)
15	900	940	9	0.0121
30	1,800	1,300	11	0.0105
50	3,000	2,500	20	0.0100

Finally, gravel pit location and alignment can affect channel location. For example, if a long, deep pit is excavated parallel to the natural channel, the stream may begin eroding a new channel through the pit, and eventually abandon its old channel (Bureau of Indian Affairs, undated). This may cause adverse impacts if the new channel is close to the bank or to a flood control structure such as a levee. In another case, if the pits are deep and "leapfrog," then increased velocity results, in turn causing increased erosion and channel instability downstream (Sonoma County, 1980).

Studies of other areas confirm that channel degradation has occurred as a result of sand and gravel operations (Envicom, 1979). Although not a negative impact in itself, degradation indicates instability which may cause problems in the stream and adjacent flood plain. The long-term effects of sand and gravel mining on the Salt and Gila Rivers cannot be determined from the inadequate data currently available. However, the channel has exhibited extreme local fluctuations in gradient. As an example, the profiles shown in Figure 4 are based on measurements taken before and after the 1980 floods. The profiles extend from 2.8 miles downstream of the I-10 bridge to 2.3 miles upstream of the bridge. Conclusions about the effect of mining operations on lateral migration must await additional data and studies.

4.2 Other Impacts

4.2.1 Groundwater. Groundwater recharge may be enhanced by gravel pits which retain flood waters and allow infiltration over a longer period of time (Dames & Moore, 1979). However, finer sediments often replace permeable river gravel after extraction, thereby reducing infiltration through the streambed. Groundwater quality may be degraded by the reduction of this permeable layer

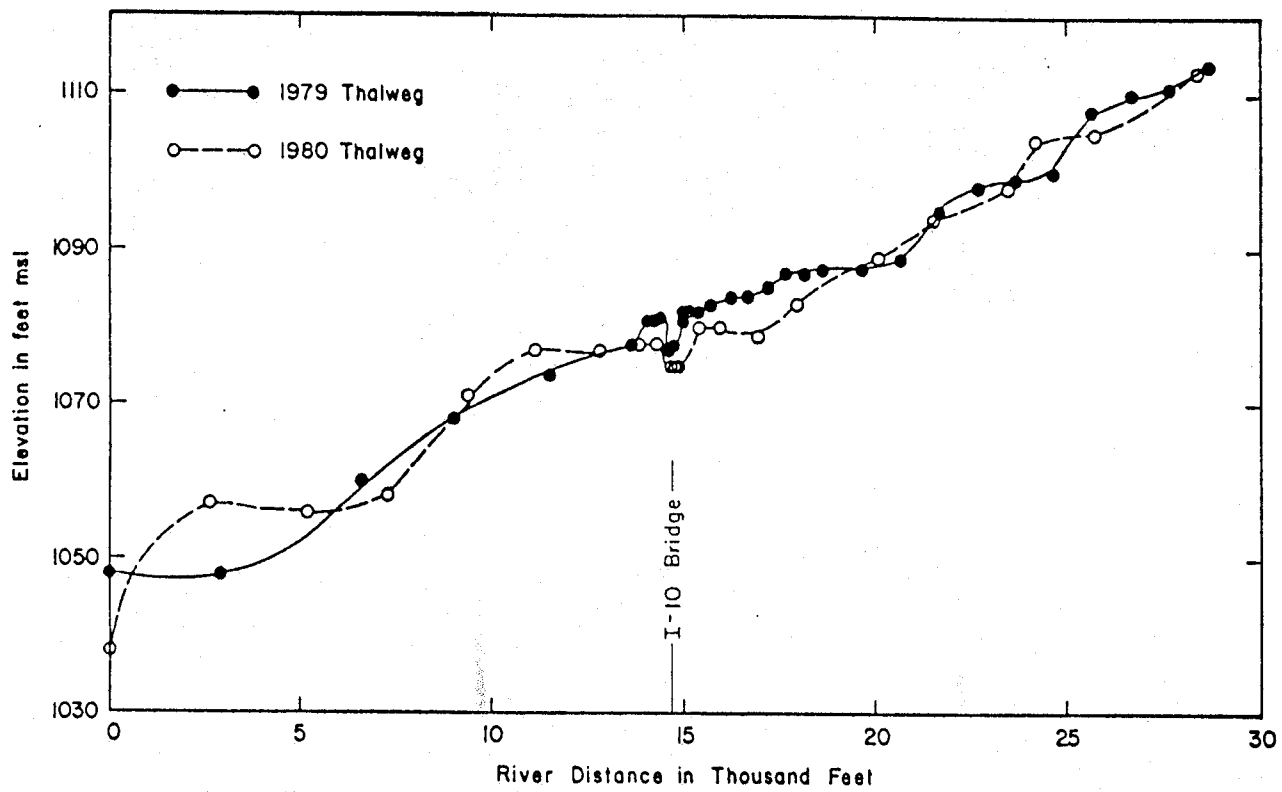


Figure 4 Salt River Thalweg Profile.

and its filtering qualities, or by exposure of the water table. This impact may be more important on smaller tributaries than on the Salt River where the groundwater table is at least 100 feet below the surface (U.S. Army Corps of Engineers, Sept. 1979, Draft Technical Appendix). Finally, a small negative effect on groundwater will occur if it is used for processing the aggregate.

4.2.2 Surface Water Quality. Turbidity and downstream sedimentation increase when mining operations disturb silts and sediments trapped among river gravels, or when water from washing operations is released into the stream. However, this is a relatively minor problem on intermittent streams such as those in the study area. A more important impact on water quality in the Salt River occurs when abandoned pits, filled with landfill, have been exposed, creating a public nuisance and health hazard.

4.2.3 Air Quality. Both stationary and mobile emissions occur during mining and processing operations. In an urban setting, the impacts of these emissions have been judged to be relatively minor (Dames & Moore, 1979). Dust can be a nuisance to adjacent property and will degrade habitat by coating vegetation with dust particles.

4.2.4 Acoustic. The major effects of noise associated with sand and gravel extraction and processing are lessening of aesthetics and recreational value of the area, and disruption of animal use of the riparian zone. The longer the diurnal period of operations, the more severe are these impacts.

4.2.5 Biologic. Removal of riparian vegetation reduces aquatic and terrestrial habitat by reducing cover and feeding areas for animals, and by reducing diversity of vegetation (Sonoma County, 1980).

4.2.6 Economic. The economic benefits of sand and gravel mining are employment and income generation, and lower costs of supplying aggregates over alternative sources. However, public costs are increased by the need for additional access routes and road maintenance required by heavy vehicles used to transport aggregate. In addition, mining extraction can cause irretrievable loss of the resource if extraction exceeds replenishment.

4.2.7 Recreation. Sand and gravel operations may temporarily interfere with some recreational uses of a stream and the riparian zone. However, it is possible to reclaim abandoned sites in such a way as to make them more attractive to recreation than before mining. Visual and aesthetic qualities are affected negatively during operations. Negative impacts may continue after termination if sites are not reclaimed.

4.2.8 Archaeological. In the Phoenix area, the development of access roads and processing locations may disturb archaeological sites.

4.2.9 Additional Impacts. Other impacts may occur as a result of sand and gravel mining, but are considered negligible in the Phoenix area. These impacts are alterations of topography, loss of topsoil, reduction of beach-sand formation, and reduction of aquatic habitat quality.

5.0 MITIGATION MEASURES AND MANAGEMENT PLAN

Mitigation measures are aimed at reducing either the temporal or spatial extent of adverse impacts. Such measures can be structural, non-structural, or a combination of both. Their cost may be borne by public agencies or private sources. The following discussion presents various mitigation measures related to flooding and erosion problems that may apply to the study area.

5.1 Structural Measures

5.1.1 Grade-Control Structures. A grade control structure can be an effective means of controlling general scour. Such structures can prevent headward erosion if the gravel pit initiating the headcut is shallow. The structure can be placed upstream of the gravel pit or downstream of the threatened structure (bridge, road, utility crossing).

Considering the use of control structures to limit headward erosion, two types are feasible: (1) a relatively economical structure formed of rock riprap reinforced with steel rods that will require minimum maintenance, or (2) a conventional reinforced concrete drop structure which can more effectively accommodate large differences in head, but is much more expensive to construct and maintain.

The rock riprap control structure should be constructed in a trapezoidal form with a downstream slope of approximately 1:4 with a stilling basin formed of adequate-size riprap extending approximately 15 feet downstream for a 2- to 3-foot differential in head. The top width of the structure would be approximately 10 feet and the upstream slope should be approximately 1:2. To improve

the stability of the structure, reinforcing rods can be placed strategically in the rock riprap as construction proceeds. After the base layer of rock riprap is laid, steel rods can be laid horizontally and parallel to the direction of flow. These rods should extend through the rock riprap on the upstream and downstream faces of the structure. This procedure should be repeated at approximately each 4-foot change in elevation. Simultaneously with the placement of the first layer of rock riprap, vertical rods with large washers would be installed extending upward through the rock riprap. These reinforcing rods terminate in a steel bolt with a thread diameter of approximately 1-1/2 inches. Upon completion of the rock structure, longitudinal steel members would be welded to those rods extending through the structure parallel to the flow. Subsequently, as the structure settles, these longitudinal and horizontal rods are stressed by this settling action. Continuous steel elements would be drilled and placed over the steel rods extending through the top of the rock riprap and nuts would be tightened to stress these steel elements, compressing the rock and simultaneously increasing the tension in the horizontal steel members. The vertical rods extending through the top of the structure should be spaced at approximately 10-foot intervals along the axis of the control structure (see Figure 5). Constructing a rock riprap control using this methodology adds to the stability of the structure without adding significantly to its cost.

If a reinforced concrete retaining wall is built, a typical dimension for a single drop is as shown in Figure 6a. The riprap placed downstream should be designed to resist the forces exerted on the surface by the flowing water.

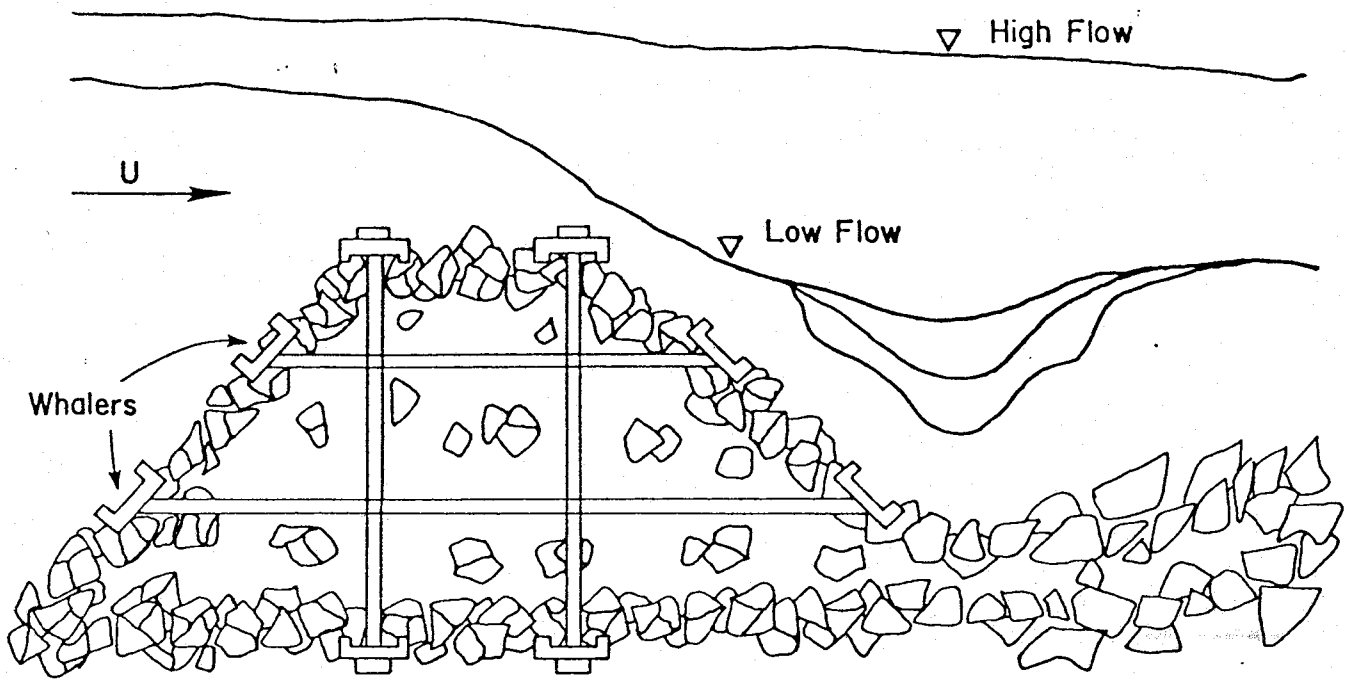
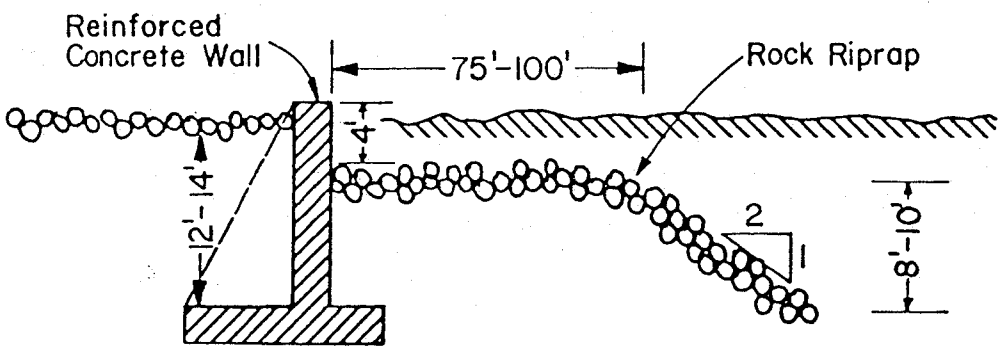
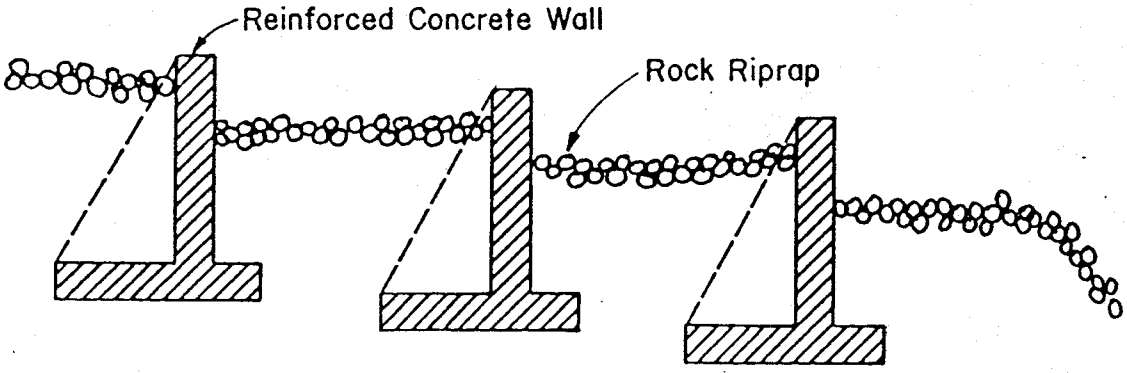


Figure 5 A Proposed Grade-Control Structure.



(a) Single Drop



(b) Multiple Drop

Figure 6 Reinforced Concrete Wall Drop Structure.

The riprap control structure can be effective if the potential drop across the structure is on the order of two to three feet. It is usually impractical to use a dumped riprap drop structure for a potential head drop equal to or greater than 4 feet. Another restriction is that a grade-control structure must extend across the full width of the channel to be effective. In many sections of the Salt and Gila Rivers, such a structure would be a half mile or more in length, greatly increasing its cost. Additional costs are incurred in maintaining the structure. Maintenance is required even after mining activities have ceased.

5.1.2 Flow Control Structure. The effects of dynamic scour during the storm, and the acceleration of lateral channel migration are major problems associated with sand and gravel mining. The shifting of the river thalweg is a major problem in the Salt River. Many existing bridges were designed without taking channel migration into consideration. An appropriate measure to mitigate the problems is implementation of a channelization scheme that controls the location and direction of the flow.

Guide banks have often been used to guide the flow of water through a bridge opening, and to control the position of scour and protect the abutments. Guide banks have been used effectively on both sand- and gravel-bed streams. Principal factors that must be included in the design of guide banks include controlled convergence of the flow normal to the opening, plan shape, upstream and downstream lengths, cross section, crest elevation, scour, and riprap protection. A common practice in the United States is to give the guide banks an elliptical form convergent to the opening; whereas in Pakistan and India the banks are straight and parallel to the opening, with a curved section at the upstream

and downstream ends. The form of the short, elliptical guide bank was illustrated by Karaki (1959). The design layout for straight guide banks is given in Figure 7 (from Control Board, 1956).

Guide banks require specialized engineering experience in design and construction. Guide banks can be effective in protecting existing bridges, but their cost would prohibit use at every river crossing.

5.1.3 Additional Structural Measures. Riprap may be used in emergencies to prevent immediate collapse of bridges, levees or banks. The failure of the I-10 bridge across the Salt River was prevented during the February 1980 flood by placing 3,000 cubic yards of boulders in the channel (Bishop, 1980). However, such measures are temporary and do not solve the problems of erosion and lateral migration.

The effects of sand and gravel extraction may be lessened by reducing flood peaks. Existing dams on the Salt River were constructed for the purpose of water supply, not flood control. Construction of a flood control dam upstream will change design requirements of downstream structures, and may reduce lateral migration.

Structural measures are limited in their effectiveness by engineering and economic considerations. The wider the channel, the deeper and more extensive the excavation, the larger the flows, or the higher their velocities, then the less effective the structure. In addition, there must be a minimum working distance between the excavation and threatened structure in which to

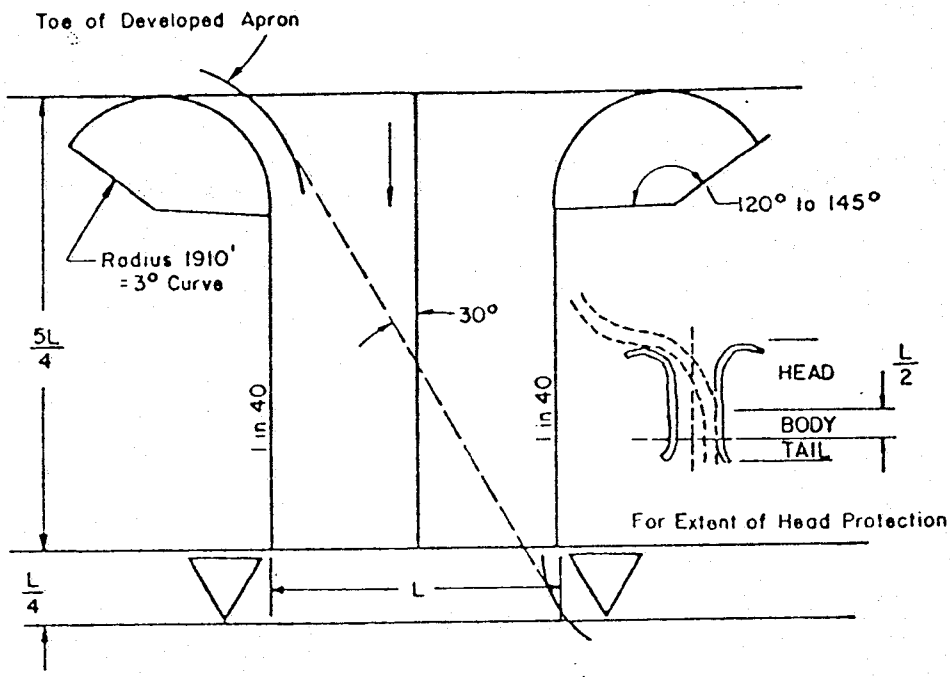


Figure 7 Straight Guide Bank Design to Protect Bridge From Misalignment of the Flow.

construct protection works. Clearly, the cost of and need for mitigating structures can be reduced by implementing non-structural mitigation measures.

5.2 Non-Structural Measures

5.2.1 Operation Standards. Operation standards would regulate the manner in which sand and gravel are mined. These standards could be enacted and enforced under the authority of zoning, flood control, or surface mining regulations. The standard would require that a permit be obtained before excavation begins. The permit process would include considerations of the effects of the particular excavation plan, and a review by public agencies and utilities that could be affected by these impacts. The degree of scrutiny applied to each permit request would depend on the extent of the proposed excavation and on its additive effect in relation to existing sand and gravel mining.

Possible operation standards include: restrictions as to rate and extent of extraction; setback and slope restrictions; limitations on pit location, phasing and configuration; separation of mining and processing phases; wetting requirements to reduce dust; and seasonal and diurnal shutdown requirements (Envicom, 1979).

The advantages of operation standards are that they reduce adverse impacts of in-stream sand and gravel mining while allowing continued use of the resource. They also can reduce the size and cost of necessary structural mitigation measures. However, for standards to be effective, they must be applied uniformly along an extensive reach of river. Operation standards that could be applied to sand and gravel mining on the Salt and Gila Rivers are suggested in Chapter 2 of this report. It is emphasized that these standards should be

enacted so as to apply to existing sand and gravel operations, as well as to those established after enactment.

If enacted, the guidelines would have a number of effects. Slope and setback restrictions would reduce the area that otherwise could be excavated for sand and gravel mining purposes, thereby reducing the available resource. Restrictions on stockpiling, and requirements for reclamation may increase operational cost of sand and gravel mining.

As previously mentioned, the damages associated with sand and gravel operations accompany the natural processes of flooding and erosion which are random in nature. There are no quantitative data that indicate how much sand and gravel mining increases damage. Therefore, it is extremely difficult, if not impossible, to quantify the degree to which the proposed guidelines would reduce flood and erosion damage to public and private property. However, the guidelines are considered to be minimum acceptable practices that will reduce flood and erosion damages associated with sand and gravel mining operations.

5.2.2 Reclamation Standards. Reclamation standards could be enacted and enforced in a similar manner to operation standards. The reclamation standards would apply when an excavation was abandoned permanently. Such standards might require that all stockpiles, equipment, or waste heaps be removed or leveled; that the low flow channel be excavated to the depth of the pit, reducing the chance of channel migration; that side slopes be graded to at least five degrees less than the angle of repose for the remaining bed material; and that access to an abandoned pit be restricted by berms, fences, or other structures, reducing the chance of unauthorized dumping into the pit.

5.2.3 Right-of-Way Acquisition. When public right-of-way is acquired in the stream channel for a bridge or utility crossing, an additional area downstream could be obtained. Within that area, sand and gravel mining would be prohibited or severely restricted, thus reducing headward erosion problems. However, the right-of-way required to protect a structure, such as a bridge, is dependent on the location, size, and depth of the pit, and on the flow rates and sequences of flow. Right-of-way requirements for various assumed gravel pit depths and sizes can be estimated using a technique presented in Section 4.1. For example, the headcut distance for a pit 50 feet deep may be as much as 2,500 feet. If a safety factor of 500 feet is added, the right-of-way requirements would be 3,000 feet. The economic and legal problems of acquiring as much as 3,000 feet of riverbed could be extraordinary for agencies in the study area.

5.2.4 Extraction Fee. If prevention of headcutting or lateral migration is not feasible, then a jurisdiction may choose to impose an extraction fee. The fees would be set aside in a fund to finance repair or replacement of structures damaged by mining-related impacts. The advantage of this approach is that the cost of repairing public facilities is paid by those responsible. However, the cost will be passed on to consumers. In addition, the timing of destructive flows cannot be predicted. On one extreme, the fund could remain unused for many years. On the other hand, it could be depleted in less than one year.

5.2.5 Monitoring and Modeling Programs. Programs such as annual topographic mapping, aerial surveillance, and aggregate sampling would provide a better understanding of the effects of aggregate extraction. With increased understanding, better predictive models could be developed and applied to specific situations.

An accurate inventory of quantity, quality, and replenishment rate of sand and gravel resources in the study area is necessary. This base information, combined with improved information about extraction quantities and a refined model, would provide data about resource availability required by planners and private enterprise.

5.2.6 Moratorium of In-Stream Extraction. Some effects of gravel extraction, such as resource depletion and channel alterations, are long term and irreversible. Termination of in-stream extraction would be the only way to avoid these impacts. However, such a moratorium would undoubtedly increase costs of aggregates to consumers, and might create severe market disruptions. Therefore, it is assumed in the proposed guidelines that in-channel sand and gravel mining will continue in Maricopa County, and that its adverse effects can be reduced significantly.

5.2.7 Enforcement of Existing Flood Plain Regulations. The existing flood plain regulations for the unincorporated area of Maricopa County (1977) permit extraction of sand, gravel, and other materials from the flood plain on the condition that such activities

> do not require permanent structures, fill or other obstructions to the flow of flood water in the Floodway District, and provided that they do not adversely affect the capacity of the channels or floodways of any tributary to the main stream, drainage ditch, or any other drainage facility or system.

In addition, permitted activities are allowed only after the issuance of a flood plain use permit issued by the county flood plain administrator. A similar regulation in the Phoenix city ordinance prevents stockpiling in the floodway.

The county regulations divide the flood plain into two districts, following Federal Emergency Management Agency guidelines. Development is allowed at the edge of the flood plain until the cumulative effect of the structures raises the flood elevation by one foot. At that point no additional development is allowed. This area of limited development is called the Floodway Fringe District. The area in the center of the flood plain, where no development is allowed, is called the Floodway District.

Flood damages incurred and caused by sand and gravel operations would be reduced if the appropriate jurisdictions in the study area adopted and enforced regulations suggested by the federal guidelines. An obstacle to enforcing such regulations is the state requirement that they not apply to existing land uses or facilities installed or constructed prior to enactment. However, it may be possible to develop use permit requirements that would bring existing operations within the flood plain guidelines.

5.2.8 Existing Regulations in Other Areas. In 1939 Virginia became the first state to enact a surface mining law applicable to the sand and gravel industry (Newport & Moyer, 1974). In 1974, Newport and Moyer reported that 21 states had enacted similar legislation. Most state laws address the quality of water runoff from mining sites, and the reclamation of sites. Many states require periodic reports by the mining operator, and the posting of a performance bond. Some states impose criminal penalties for failure to comply.

At the local level, sand and gravel operators may be required to obtain use permits which are issued on a case-by-case basis. This is the policy in San Diego and San Bernardino Counties, California. Some jurisdictions, such

as Sonoma County, California, are now considering ordinances that formally regulate many aspects of sand and gravel mining. The proposed Sonoma County ordinance includes requirements of in-stream operations relating to setbacks, extraction volumes, processing, seasonal operations, in-stream crossings, erosion, and sedimentation.

5.3 Management and Channelization Plans

The dynamic nature of river and watershed systems requires that local problems and their solutions be considered in terms of the entire system. Natural and man-induced changes in a river frequently initiate responses that can be propagated for long distances both upstream and downstream. Sand and gravel mining activities affect the sediment movement and supply in a channel system. Such operations can be beneficial or detrimental depending on watershed and river characteristics, and the mining and management practices followed. Therefore, a thorough understanding of the river system is necessary to evaluate the effects of mining activities.

In many rivers sand and gravel bars, formed by the natural processes of moving water and sediment, force the subsequent flows to meander around them. Consequently, rapid bank erosion can be expected opposite these large deposits. These features move slowly downstream, resulting in continued attack to opposite banks. With managed removal of excess sediments by sand and gravel mining, an adequate channel can be maintained, flooding can be reduced, bank erosion can be reduced, and an extremely valuable renewable resource can continue to be utilized.

The sand and gravel mining industry can assist local agencies in development of a flood control channel. It was estimated that construction of a flood

control channel on the Salt River capable of carrying the 100-year flood (approximately 200,000 cfs) would require excavation of approximately 2.7 million tons per mile on the average. This estimate is based on a trapezoidal channel having a side slope of 3 to 1 with the depth of 15 feet, a bottom width of 1,000 feet, and an average channel slope of 0.0024. The apparent specific weight of the channel material is assumed to be 93 pounds per cubic foot. It is assumed that about 70 percent of the trapozoidal cross-sectional area would have to be excavated given the existing channel area.

A construction plan for such a channel that relies solely on sand and gravel operators may encounter problems. Annual demand for sand and gravel in Maricopa County during 1978 was estimated to be 10 million tons (Buehler & Best, 1979). Assuming that 20 river miles would be channelized through the urban area, the total volume excavated would be more than 5 year's demand. More importantly, not all excavated material would be of market quality. Fine materials, composed of silt or clay, are typically deposited on the gravel and sand bars in the middle of the wash or in the downstream river reaches. These materials may not be suitable for concrete aggregate.

Other problems that may discourage commercial excavation of a channel are access to public roads, proximity to aggregate markets, difficulty in shaping the channel, existence of impermeable layers, and shallow water tables causing pit flooding during excavation. Other considerations are land ownership of the reach to be channelized, continuity of the channel, administration of construction, and problems of maintenance.

Although problems may be encountered in developing a plan, nevertheless opportunities may exist for the sand and gravel mining industry to excavate a channel while fulfilling its aggregate extraction objectives. Currently, the Salt River Pima-Maricopa Indian Community is planning to have sand and gravel operators excavate a trapezoidal channel with a capacity of 150,000 cfs. If the outcome is successful, downstream jurisdictions may implement similar plans.

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APPENDIX

SEDIMENT TRANSPORT ANALYSIS OF GRAVEL PITS

A.1.1 General Sediment Transport Theory And Its Application To Sand And Gravel Mining. The amount of material transported, eroded, or deposited in a channel is a function of sediment supply and channel transport capacity. Sediment supply includes the quality and quantity of sediment brought to a given reach. Transport capacity involves the size of bed material, flow rate, and geometric and hydraulic properties of the channel. Both the supply rate and the transport capacity may limit the actual sediment transport rate in a given reach.

The total sediment load in a stream is the sum of bed material load and wash load. The bed material load is that part of the total sediment discharge which is composed of grain sizes found in the bed. The wash load is that part composed of particle sizes finer than those found in appreciable quantities in the bed (Simons and Senturk, 1977). Wash load can increase bank stability, reduce seepage and increase bed material transport, and can be transported easily in large quantities by the stream, but is usually limited by availability from the watershed and banks. The bed material load is more difficult for the stream to move, and is limited in quantity by the transport capacity of the channel.

Sediment particles are transported by the flow in one or more of the following ways: (1) surface creep, (2) saltation, and (3) suspension. Surface creep is the rolling or sliding of particles along the bed. Saltation is the cycle of motion above the bed with resting periods on the bed. Suspension involves the sediment particle being supported by the water during its entire motion. Sediments transported by surface creep, sliding, rolling and saltation are referred to as bed load, and those transported by suspension are called

suspended load. The suspended load consists of sands, silts, and clays. The bed material load is the sum of bed load and suspended bed material load.

Under proper management, sand and gravel removal can increase the stability of a river system that is overloaded with sediment (supply greater than transport capacity). The overloaded condition can exist as a result of the natural characteristics of the watershed, or from abnormal events. These events could include land conversion changes in the watershed, construction, seismic activities, climatic conditions, and wildfire. The overload of sands and gravels can form large gravel bars and also provide material to form an armored layer of coarse particles on the streambed. Armoring encourages lateral migration due to the shifting of the thalweg in response to the development and movement of the bars and the relatively erodible bank material. With this condition, controlled removal of gravel bars by extraction and limited mining may actually enhance channel bank stability. Hence, careful river management is required to maintain equilibrium between excess production of sand and gravel, and extraction of sand and gravel.

Excessive sand and gravel removal (removal greater than supply in any given reach) can endanger the stability of the river system and bridges by inducing general degradation and headcutting. For example, during recent floods several bridges over the Salt, Gila and Agua Fria were endangered by significant bed erosion and/or lateral migration of channels. Sand and gravel mining in the river system has been identified as one of the major causes of bridge instability and/or failure. Analysis of the effects of sand and gravel mining activities on the stability of a river system and bridges is important. Protection of the bridges may be required where the sand and gravel mining activities of significant magnitude.

A.1.2 Physical Processes Governing the Mechanisms of a Gravel Pit. The extent of damage to the system that can result from the potential headcut induced by the sand and gravel mining activities is a function of volume and depth of the gravel pit, location of the pit, bed material size, flood hydrographs, and sediment inflow rates and volume. During a low flow period the sediment supply to the river and to any given reach is generally less than the transporting capacity. Under these conditions the flow in that reach is capable of producing degradation by picking up additional sediment from the bed. The presence of a gravel pit can add energy to the system by increasing the water surface slope, or energy slope, just upstream of the pit. The steeper slope has greater erosive power and can initiate bank erosion and headcutting. These processes supply additional sediment to the river in quantities greater than it is capable of carrying locally. In contrast, at high flows the river is generally already transporting near capacity, and the influence of an increased water surface slope near the gravel pit is relatively smaller due to backwater effects and channel control. In addition, the velocity in the scoured portion may be reduced because of the increased depth when the pit is filled with water. Therefore, low flows can cause significant erosion and may even have a higher erosion potential than high flows for local situations involving gravel pits.

The significance of this unexpected situation, where low flows are potentially more destructive than high flows, depends on the size and volume of the gravel pit and the characteristics of the inflow hydrograph. For a small pit the increased water surface slope would not be nearly as significant as for a large pit. In a low flow event, the pit will not fill or reach equilibrium as soon as it will for a high flow event. During a high flow event the rising limb of the hydrograph fills the pit with water rapidly, and quickly drowns out the effect of a steeper energy slope. This concept is illustrated

in Figure A-1 for representative low and high flow hydrographs. The cross-hatching indicates the relative times required to fill the pits to the level where channel hydraulics control the flow conditions.

The depth of scour occurring at bridge crossings as a result of a headcut changes as the hydrograph passes through the river system. During the rising limb of the hydrograph scour occurs and potentially endangers the structural stability of the bridge by undermining the bridge footings. After the peak has passed (during the falling limb), the scour hole partially refills as sediments drop out. Therefore, the critical time for the structural stability of the bridge is during the storm, near the peak flow (see Figure A-2). Soundings made of scour holes after the storm do not indicate the potentially dangerous situation that might have existed during the storm.

A.1.3 Problem Solving Techniques and Examples of Gravel Pit Analysis. The degradation and aggradation problems associated with sand and gravel mining are very complicated. Simplifying assumptions are needed to obtain a practical and economical solution. The dominant physical processes include water runoff, sediment transport, sediment routing by size fractions, degradation, aggradation, and breaking and forming of the armor layer. These processes are unsteady and complicated in nature.

Recently, a number of computer models have been developed to analyze sediment and erosion problems associated with gravel mining operations occurring along rivers. A water and sediment routing method developed by Simons and Li (1979) has been applied to analyze headcutting problems associated with the Consolidated Rock (Conrock) gravel mining operation in San Juan Creek and Bell Canyon of Orange County, California. The model evaluated the erosional and depositional

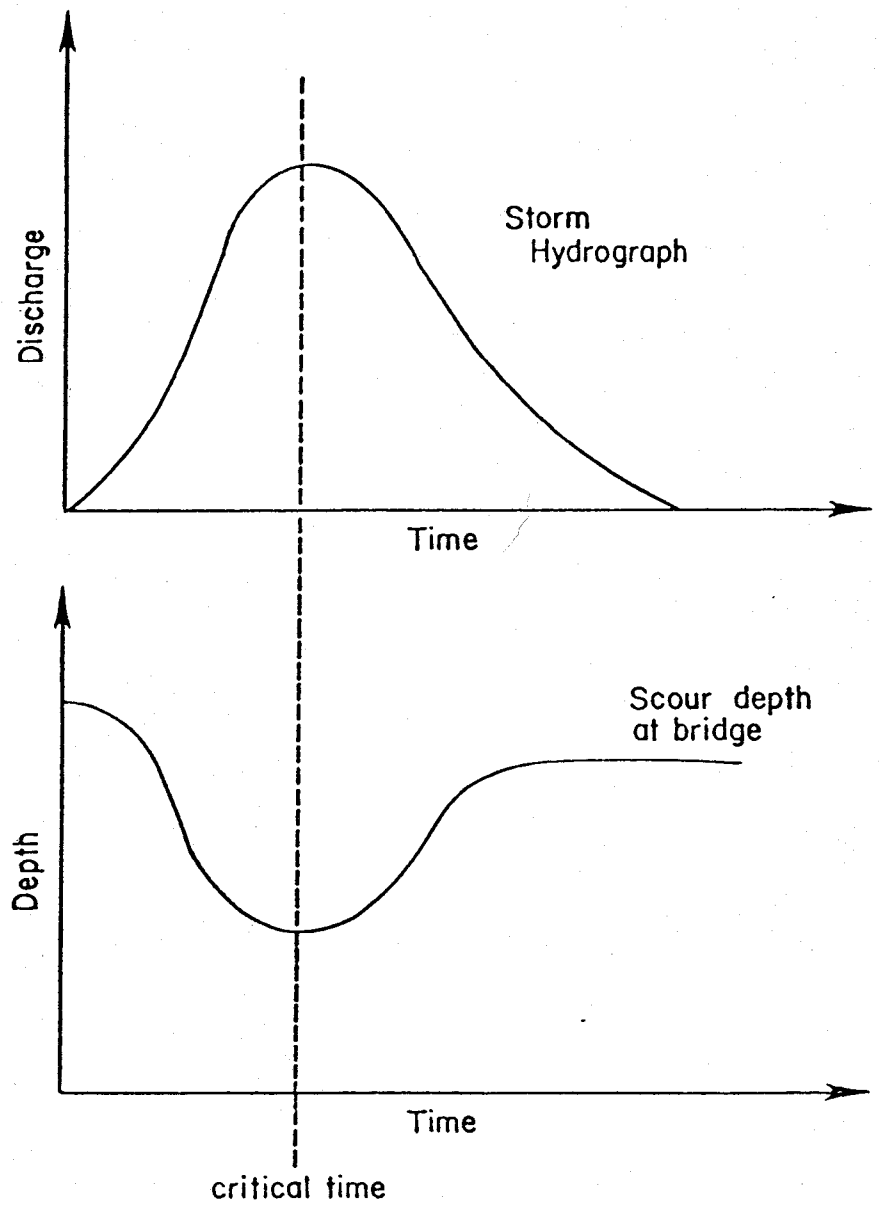


Figure A-2. Temporal change of scour hole depth at a bridge during a storm.

responses of the stream when subjected to different hydrologic inputs. In order to simplify the analysis, a known discharge water routing approach is used. The known discharge solution utilizes the data base developed for the HEC-2 flood level analysis. This method is feasible for gravel pit problems because of the short distances involved in the analysis. Three storms in January, February and March 1978 induced significant degradation and headcutting, and provided an excellent test for the model. The evaluation was made using time steps of four hours. The time lapse change of bed elevation at the original gravel pit boundary (Station 16+00) is given in Figure A-3.

A second example involves sand and gravel mining activities just downstream of the Oracle Highway bridge over Rillito Creek in Tucson, Arizona. The reach length studied was approximately 2 miles (river mile 4.00 to 6.1). The bridge is located at river mile 5.05, and a gravel pit extends from river mile 4.65 to 5.03. The assumed dimensions of the pit for computer modeling were 10 feet deep by 400 feet wide by approximately 2000 feet long. Upstream of the bridge, the channel is 350 feet wide. Five cross sections were used within the pit during the analysis to define the geometric conditions.

The hydrograph used for testing was the 2-year flood event with a peak discharge of 7000 cfs. The 18-hour duration was divided into six time steps of three hours each. The changes occurring in the geometry of the upstream edge of the pit were defined at each of these time increments.

The initial condition was for a dry riverbed and an empty gravel pit. Prior to filling the pit with water or sediment, a normal depth approximation is used, rather than the HEC-2 analysis, to determine the hydraulic conditions and sediment transport rate. After the pit fills with water, the HEC-2

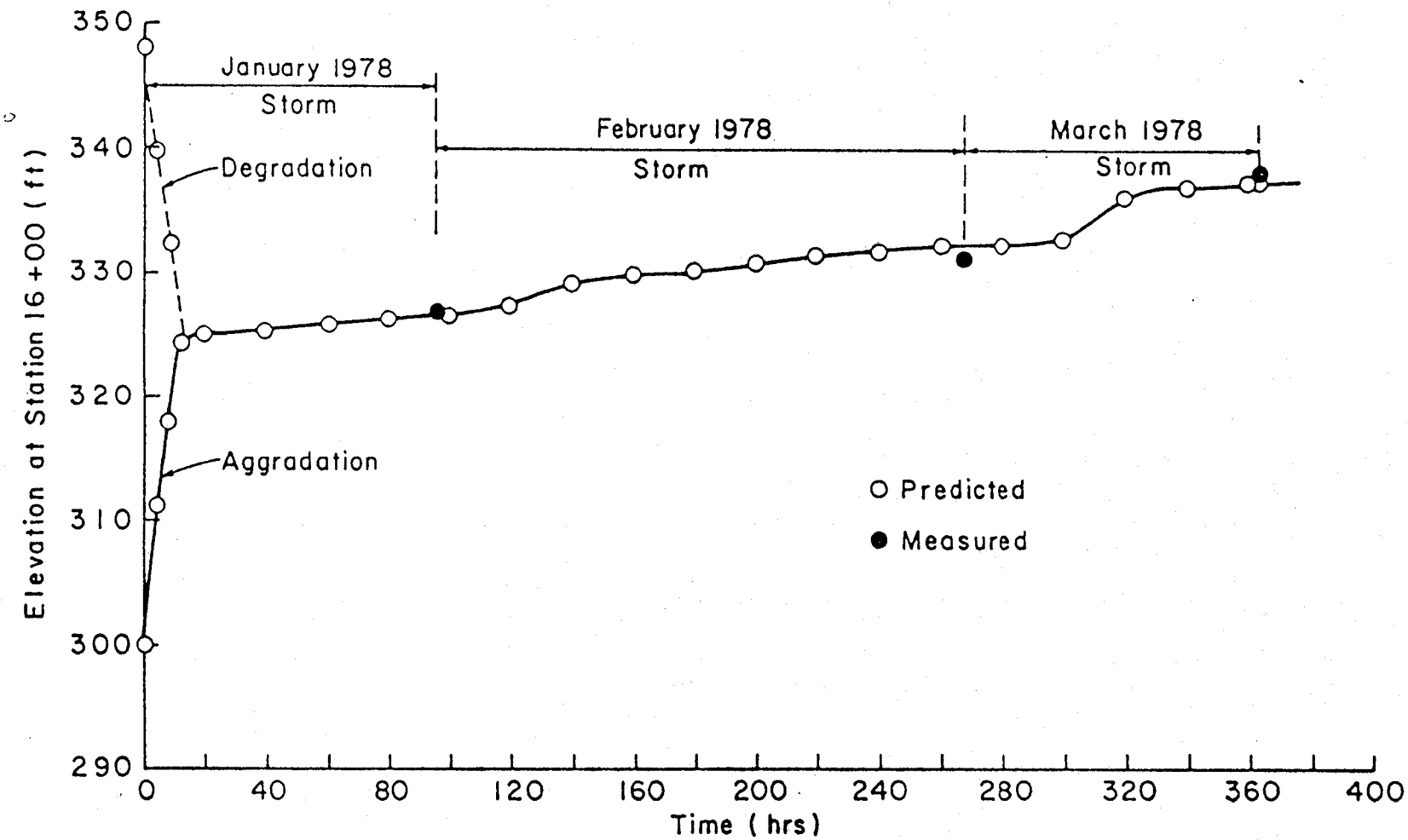


Figure A-3. Time lapse changes of elevation at the original gravel pit boundary (Station 16+00).

analysis is used to define the hydraulic conditions. The inflow occurring in the first time step (3 hours) initiates the headcut by eroding the corner off the upstream edge of the pit and depositing sediment in the bottom of the pit at the upstream end (see Figure A-4). The slope of the headcut and deposited material is 0.050; however, a discontinuity of 2.40 feet exists. At time 5.20 hours the discontinuity between the headcut and deposition slope disappears, and a continuous slope of 0.050 exists. Table A-1 summarizes the changes occurring throughout the hydrograph. The pivot point actually shifts upstream 18 feet, although the resolution on the figure does not illustrate this. The calculated degradation (scour) occurring at the bridge as a result of the headcut is 4.66 feet at the end of the storm, which agrees with actual soundings that indicated approximately 5 feet of scour for this event.

The U.S. Army Corps of Engineers developed the HEC-6 computer model to simulate scour and deposition in rivers and reservoirs. The model has been revised to simulate the effects of sand and gravel mining operations, and tested on the Kansas River in Missouri (U.S. Army Corps of Engineers, 1980). The results indicate that the model may be useful in future predictions of changes in bed load movement resulting from instream extraction.

Another computer program that may be used for simulation of sand and gravel mining operations is that developed by Chang for San Diego County (1976). The model has been applied a number of times to analyze erosion and sedimentation problems associated with sand and gravel mining operations as part of the requirements for a county use permit.

The models mentioned above, as well as other models, may be useful tools to evaluate river management practices or special problems, resulting from sand

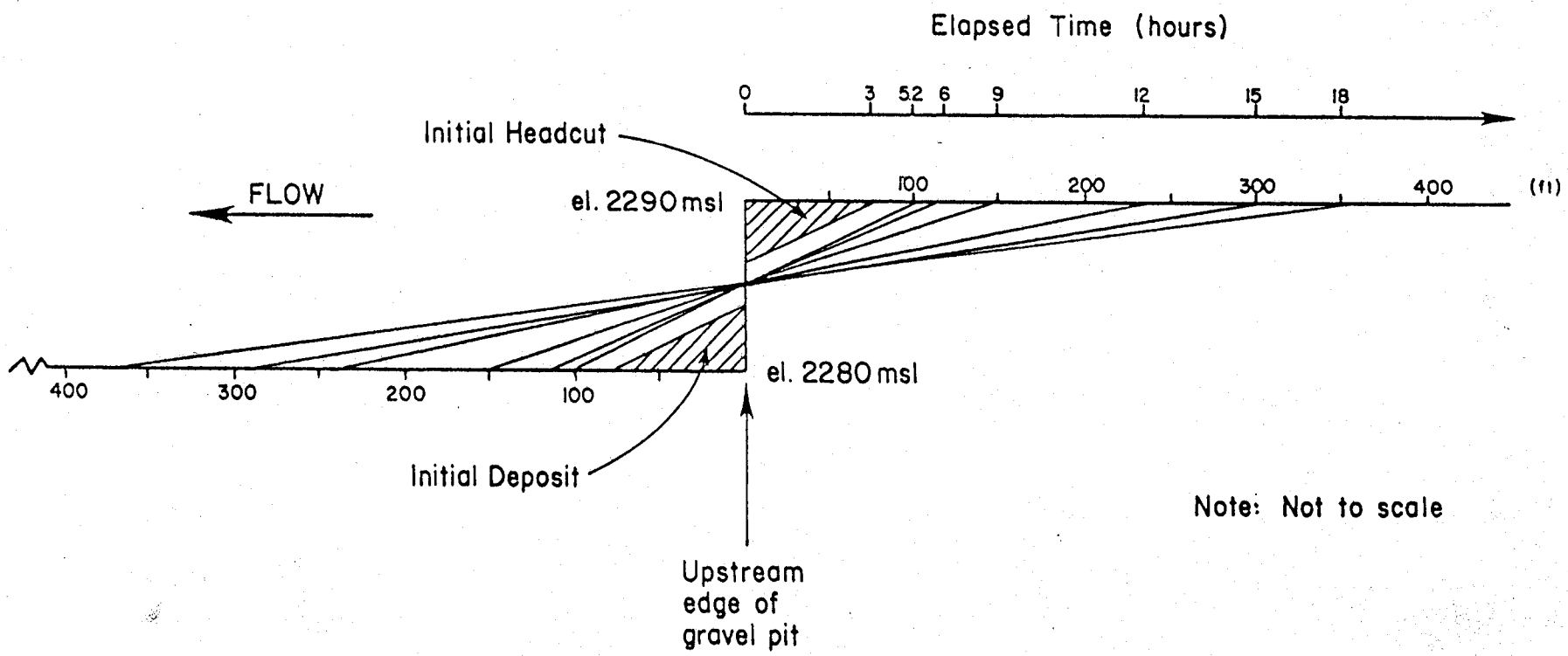


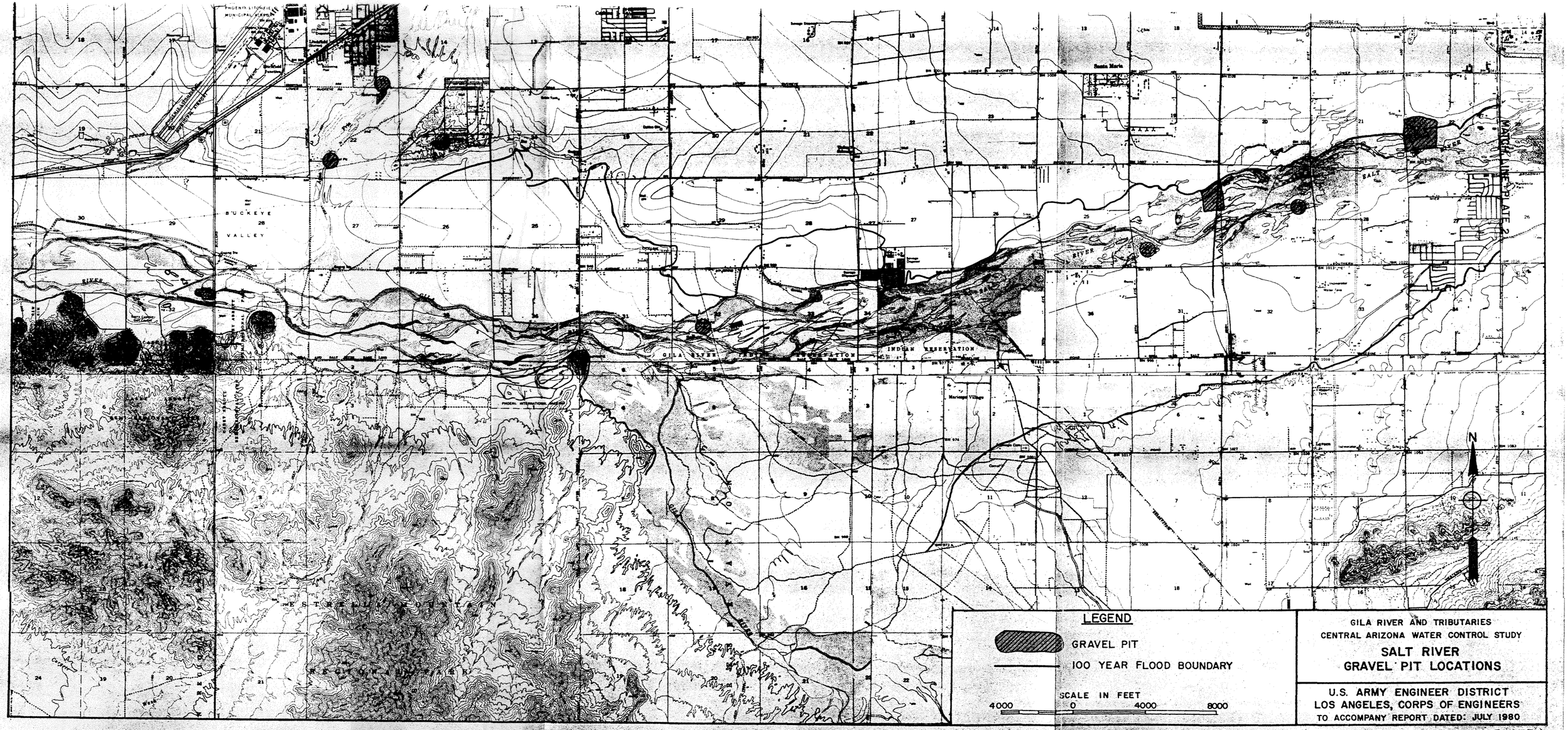
Figure A-4. Definition sketch of the temporal changes at the upstream edge of a gravel pit.

Table A-1. Calculated Headcut Distance and Slope.

Time (hrs)	Headcut Distance (ft)	Headcut Slope
3	76	0.050
5.2	100	0.050
6	116	0.044
9	176	0.029
12	237	0.022
15	299	0.018
18	363	0.015

and gravel mining operations. Selection of an approprdiate model should be based on the quantity and quality of available data, stream characteristics, and the special problems to be analyzed. Some of the models may be complex and expensive. If sufficient information is not available, the results could be misleading and the cost of using those models may not be warranted.

PLATES



GILA RIVER AND TRIBUTARIES
CENTRAL ARIZONA WATER CONTROL STUDY

SALT RIVER
GRAVEL PIT LOCATIONS

U.S. ARMY ENGINEER DISTRICT
LOS ANGELES, CORPS OF ENGINEERS
TO ACCOMPANY REPORT DATED: JULY 1980

PLATE I

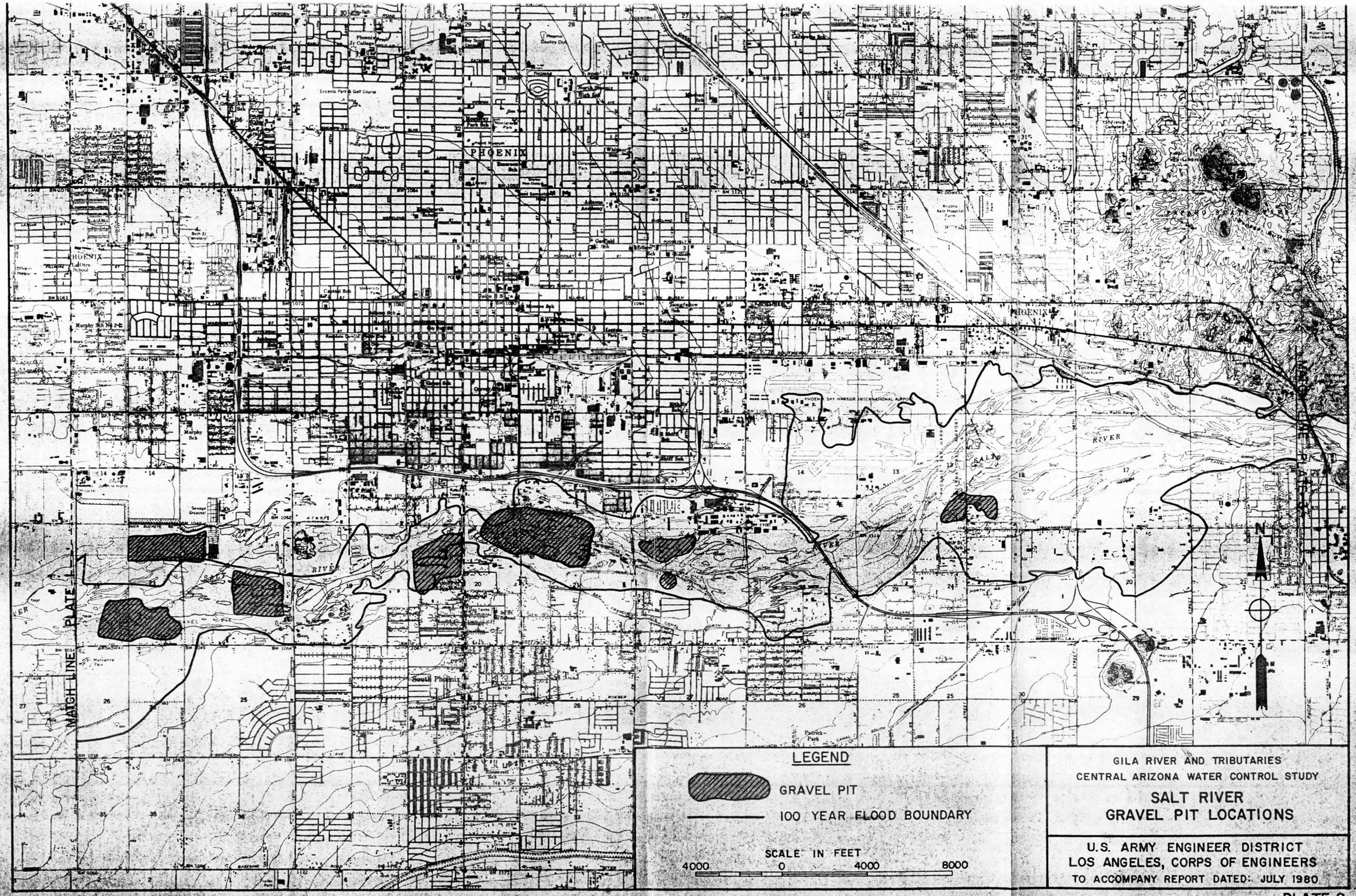
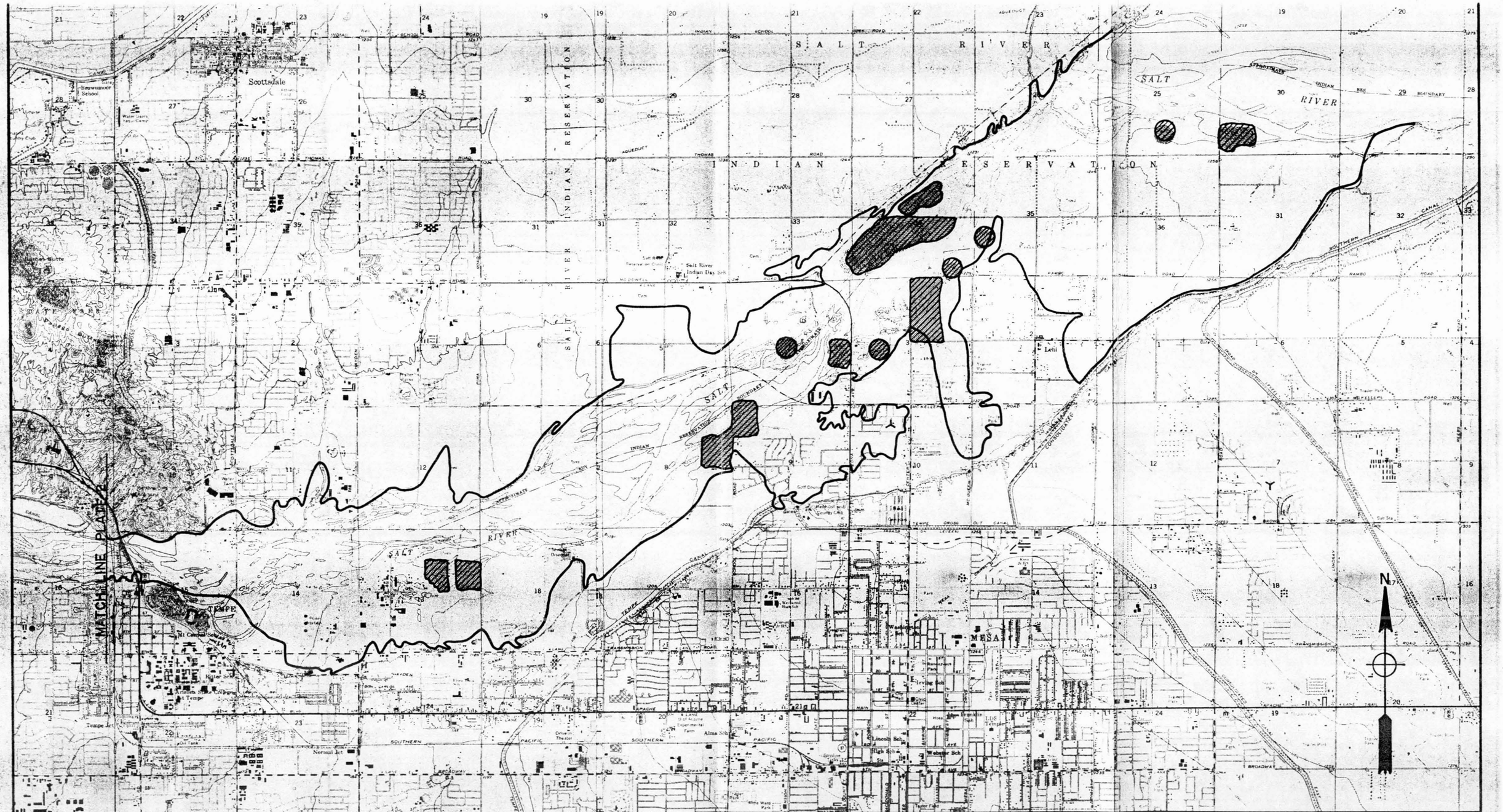

PHOENIX
MATCH LINE
PLATE
RIVER
LEGEND
GRAVEL PIT
100 YEAR FLOOD BOUNDARY
SCALE IN FEET
4000 0 4000 8000
GILA RIVER AND TRIBUTARIES
CENTRAL ARIZONA WATER CONTROL STUDY
SALT RIVER
GRAVEL PIT LOCATIONS
U.S. ARMY ENGINEER DISTRICT
LOS ANGELES, CORPS OF ENGINEERS
TO ACCOMPANY REPORT DATED: JULY 1980

PLATE 2



LEGEND

GRAVEL PIT

100 YEAR FLOOD BOUNDARY

SCALE IN FEET

4000 0 4000 8000

GILA RIVER AND TRIBUTARIES
CENTRAL ARIZONA WATER CONTROL STUDY

SALT RIVER
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PLATE 3