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EFFECTS OF IN-STREAM MINING ON CHANNEL STABILITY

Volume I - Executive Summary

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16. Abstract

This report presents a comprehensive treatment of the technical and non-technical issues related to the impacts of in-stream sand and gravel mining upon the stability of river systems in Arizona. All major categories are addressed, including such areas as: regulatory practices, structural hazards, economic value, social and environmental factors, statewide classification of streams, review of methodologies, mitigation measures, engineering parameters, long-term procedures, short-term procedures, river response simulation procedure, case histories, justification for regulation, implementation plan, and recommendation for further monitoring and data collection. The physical processes associated with sand and gravel mining and the impacts of sand and gravel mining on the streams, rivers, and riverine structures are documented. The concepts, theory, and experience of the team have been incorporated in this report in the form of written material and mathematical models. Methods have been formulated and presented for evaluating both short-term and long-term response of sand and gravel mining on river behavior, bridges, and associated river control structures. The necessity for sand and gravel mining, the impacts of sand and gravel mining, regulatory procedures adopted by other states, the short- and long-term interests of the sand and gravel mining industry, and recognition of the fact that the sand and gravel mining industry is vital to the well-being of the State of Arizona all contribute to the justification for regulation. The final section of the study deals with the strategy and formulation of legislative action that could be implemented to better control sand and gravel mining in the State of Arizona.

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FOREWORD

This is to report that I have worked closely with Simons, Li & Associates, Inc. in their effort to achieve the objectives outlined by the contract awarded by the Arizona Transportation Research Center through the total period of investigation and analysis. I have been involved with and have carefully reviewed their work considering all major categories including such areas as: regulatory practices, structural hazards, economic value, social and environmental factors, statewide classification of streams, review of methodologies, mitigation measures, engineering parameters, long-term procedures, short-term procedures, justification for regulation and model legislation. The quality of the effort leading to preparation of the final report, in my opinion, has been excellent. The report is based upon many years of experience by a group of professionals that have worked diligently with watersheds, rivers and mining to better understand the physical process, the necessity for sand and gravel mining, the impacts of sand and gravel mining, regulatory procedures as adopted by other states, the short and long-term interests of the sand and gravel mining industry, and recognition of the fact that the sand and gravel industry is vital to the well-being of the State of Arizona. Also, the project benefitted from other past related work done in the sand and gravel mining area by Simons, Li & Associates, Inc. and by D.B. Simons of Simons & Associates.

It is obvious from the review of past work and the final report submitted by Simons, Li & Associates, that the physical processes associated with sand and gravel mining and the impacts of sand and gravel mining on the streams, rivers and riverine structures are well understood. The concepts, theory and experience of the team have been incorporated in this report in the form of written material and mathematical models. In my opinion, excellent methods have been formulated and presented for evaluating both short-term and long-term response of sand and gravel mining on river behavior and associated river control structures - bridges and so forth.

Looking at current demands upon the sand and gravel industry, it is obvious that certain volumes of sand and gravel must be produced on an annual basis to meet current and future needs. A most important issue is the identification of guidelines from which regulatory statutes can be formulated. The needs of the sand and gravel industry, as well as the needs for their product, must be evaluated, formulated and integrated into any final regulatory procedure that is adopted by the State of Arizona.

It does appear that if regulatory procedures are to be developed and followed that a monitoring plan must be adopted and implemented that will require monitoring of the removal of sand and gravel. From these data, responses of the system can also be documented and utilized to identify the volume of sand and gravel mining that can be mined from various reaches of the river systems. It may be essential to develop a red-line concept below which mining is not allowed to proceed. However, it is emphasized that if such a regulatory procedure is adopted, it must be recognized that rivers have a long memory and the regulatory body should not be surprised if there is additional degradation that will occur below the red-line simply because the river is slowly responding to past activities in the river. However, utilizing the red-line concept and limiting sand and gravel mining in the areas where there has been a drop below the red-line, the river will again develop a new bed profile at or above the hypothetical red-line. As materials accumulate above the red-line, mining may be initiated again under careful control and in accordance with regulatory statutes.

The most complicated aspect of the study deals with the formulation of legislative action that could be implemented to better control sand and gravel mining in the State of Arizona. As stated in the preceding paragraph, the processes and the impacts of sand and gravel mining on the environment and upon various related industries is well understood. Guidelines for better controlling sand and gravel mining can be formulated in the technical sense. The problem of refining the proposed methodologies for regulating sand and gravel mining and selling these concepts to the legislative bodies that must review and adopt such procedures is a much more difficult task. It does appear to be inevitable that some form of guidelines and regulatory laws will be passed to guide the future actions of the sand and gravel mining industry. In refining the materials presented by Simons, Li & Associates and in attempting to implement and adopt guidelines, it is suggested that the experienced engineers and the sand and gravel industry must work closely with those regulatory agencies if workable regulations are to be formulated and adopted to govern future sand and gravel mining in Arizona.

In conclusion, it has been a pleasure, as usual, working with Simons, Li & Associates, Inc., and I have appreciated the opportunity to interact with the highway staff and other participants in the task force and other bodies that have had a direct role in critiquing and helping to formulate this study.

Daryl B. Simons, Ph.D., P.E.
April, 1988

I. INTRODUCTION

Sand and gravel constitute one of the primary natural materials used in construction of the roads, bridges, and buildings required to support the needs of our society. The source of these materials, and the mining practices employed for harvesting them, can create problems for the very society that they serve. This is especially true in arid regions of the country where gravel mining operations are frequently located in the channel and overbank areas of floodplains historically known to be unstable during floods.

The alluvial river systems of the southwestern United States are typically ephemeral streams, flowing only in response to significant amounts of rainfall. As such, they are easily accessible and economical sources of sand and gravel. However, continual removal of these natural materials from a river system changes the hydraulic and sediment transport characteristics of the system. The river's response to such changes includes accelerated degradation, aggradation, headcutting and lateral migration. The occurrence of these phenomena can endanger adjacent property, highways, bridges, or other structures located in the floodplain environment.

The State of Arizona experienced several large floods during recent years. The presence of in-stream gravel pits fueled speculation that such operations contributed to river instability problems and may have been partly responsible for flood-related damage to roads/bridges and nearby riverbank property. The concern and speculation arising from this issue prompted the Arizona Department of Transportation to undertake this research project to study the problem, with the goals of developing technical procedures for analyzing the impacts of in-stream mining upon the river system, and of recommending legislative approaches to regulating the sand and gravel mining industry.

The study found that with the rapid population growth occurring in Arizona, the construction industry will place an even larger demand on the need for economical sources of sand and gravel materials. Development of aggregate resources will change the river environments, and planning for these changes will be essential in reducing the risk to river crossings, mitigating channel stability problems, and minimizing economic, social and environmental impacts, while at the same time providing needed aggregate products economically.

This study was structured to provide the basis for establishing prudent technical procedures and regulatory guidelines for in-stream sand and gravel extraction. The primary study objectives are summarized below. This final report is organized to coincide with the logical progression of these study objectives.

* Research laws and regulations used by other agencies, both within and outside of Arizona, to control in-stream sand and gravel mining. The objective of this review was to compare the status of in-stream mining regulation in Arizona to that in other states.

* Research historical problems associated with in-stream mining. Case histories of existing gravel pits and bridge sites within the study reaches were compiled during this review. The purpose was to obtain a better understanding of the interaction of mining operations, bridge structures and channel behavior.

* Investigate design criteria used by other agencies, both within and outside of Arizona, for the construction of bridge and highway projects within a river system influenced by sand and gravel extraction. A data set was compiled on the structural characteristics of bridges in the study reaches. This dataset was derived from as-built plans, inspection reports, and damage surveys.

* Determine present and future regional demand for aggregate products within Arizona. The market potential and market value for sand and gravel products was assessed for the regional economy.

* Establish a classification system for use in assessing, at a state-wide level, the river reaches which are currently, and will in the future, be resource areas for the sand and gravel mining industry. The classification system was structured to identify river reaches that have both acceptable quality and quantity of sand and gravel reserves, and identified incentives and constraints to the development of those reserves, including regional market potential, in-stream structures, and social/environmental conditions.

* Formulate engineering parameters to provide a quantitative description of river characteristics. The engineering parameters required for the compilation of four data sets for each of the study reaches consisted of river topography, bed material gradation, hydrologic conditions, and mining activity. These data sets provided the factual basis for the development of technical procedures.

* Develop technical procedures for quantifying river system impacts due to in-stream sand and gravel mining. Procedures were developed to assess both short-term and long-term impacts to the river stability. Emphasis was placed on developing procedures that are practical and easily implementable, while yielding prudent estimates of the response of a river channel to mining activity.

* Determine the justification for the regulation of in-stream mining from both a technical and non-technical perspective.

* As justified by the findings of previous study objectives, develop model legislation and guidelines for adoption by regulatory agencies.

II. REVIEW OF LEGISLATION & REGULATORY PRACTICES RELATED TO IN-STREAM MINING

2.1 Introduction

This review covers literature supplied by federal, state, and local agencies responsible for the regulation of sand and gravel mining operations. The bulk of the literature was gathered by Mr. Ottozawa Chatupron in the period from February and March of 1986 and has been supplemented by SLA staff during the course of preparation for this report.

The literature was divided into four categories: (1) federal programs, (2) California state programs, (3) state programs other than California, and (4) Arizona programs. A large amount of regulatory information is associated with the state of California, in conjunction with the Surface Mining and Regulation Act (SMARA). Policy guidelines have been established for in-stream sand and gravel mining operations as a result of the enactment of SMARA. Counties have primary jurisdiction over sand and gravel mining operations in California.

2.2 Federal Programs

2.2.1 General

A paper by Mossa (1983) provides an overview of the general regulatory environment for sand and gravel mining operators in the United States. At this time, there is no federal regulation of in-stream sand and gravel mining. Some federal laws could be interpreted as having an indirect affect on sand and gravel mining activities. These include the Rivers and Harbors Act of 1899 (Section 10), the Federal Water Pollution Control Act (FWPCA) Amendments of 1972 (Section 404), the National Environmental Policy Act, the Federal Land Policy and Management Act, and the National Flood Insurance Policy Act. Because federal law does not directly control in-stream mining operations, most of the responsibility is at the state and local government level. Local control takes the form of zoning ordinances, permits, plans, and variances. The focus of this regulation is primarily on operation and reclamation plans, not on planned resource development or environmental management. Mossa identifies the following issues related to in-stream sand and gravel mining:

- A decrease in channel stability with regard to position and gradient
- Impacts on flood rates and the flood boundary
- Impact on water quality
- Loss of floodplain habitat with impacts to fisheries and wildlife

The following general guidelines are put forth for in-stream sand and gravel development:

- Avoid removal of riparian vegetation.
- Excavation should not be permitted in channel bottoms or point bars.

- Post mining landscape should be left in a stable, non-hazardous, and useful condition.
- Encourage sand and gravel industry development in locations that will benefit (for example, where flood-control channelization is needed).

2.2.2 Corps of Engineers Policies and Guidelines

The Corps of Engineers (COE) studied sand and gravel mining operations in the Phoenix/Tempe area (Los Angeles District, 1981), and found that extensive mining is taking place. Most of the mining is not subject to floodplain regulations because state law exempts floodplain users prior to enactment. However, additions or changes are subject to regulation. COE also noted that multi-jurisdictional responsibilities hinder enforcement of existing regulations. They propose minimum guidelines for sand and gravel operations based on a report by Boyle Engineering (1980) (see discussion in Section 7.5.2). Defining the problem in the Phoenix metropolitan area, the COE notes that sand and gravel operations have followed the pattern of expanding urbanization. Streambed lands are under both public and private ownership. There is fragmented jurisdictional authority with involvement on the part of separate governments representing the Indian reservation, Maricopa County, and municipalities. Federal laws are not applicable to Indian reservations, but are followed on federal lands, or when federal grant monies to Indian tribes are involved. Maricopa County administers all unincorporated areas, and the municipalities administer within their corporate boundaries.

The current pattern of excavation is essentially random and has taken place in a leapfrog fashion. The COE estimated that planned excavation of the Salt River floodway could provide improved flood control. They recommend a channel excavated at a grade of 0.10% (approximately half the existing gradient), with 3:1 side-slopes to a depth of 30 to 40 feet below the floodplain. Maintenance of the channel grade will require grade control. Five structures are proposed: Central Avenue, 16th Avenue, 24th Street, I-10, and Scottsdale Road.

The Federal Water Pollution Control Act, Section 404 is administered by the Corps of Engineers. Barnett (1982) reviews the legislative history and the Crops administration of the permit process as it relates to the arid west. Barnett reviews the legislative history of Section 404, addressing the legislative intent related to several key issues in the Act. The 1972 amendments to the FWPCA adopted a broad definition of navigable waters, as follows: "waters of the United States, including the territorial seas". Barnett states that the 1972 legislative history shows that Section 404 was created to protect the Corps of Engineers and private dredging operations from the more comprehensive water quality program (Section 402). Section 404 was intended to put pressure on the Corps to end the practice when alternatives to open water disposal were available. Barnett quotes Senator Muskie as saying that the use of the word "fill" was to make clear that if the specific disposal site agreed upon by the Corps and the Environmental Protection Agency (EPA) was on land in the form of a fill, that there would be no ambiguity on the question of whether or not it also was covered by Section 404. Implementation of Section 404 by the Corps required substantial clarification of the term "navigable water". The Corps initially published regulations in 1974 that limited the scope of jurisdiction to "traditional" navigable waters. After a great deal of public controversy and congressional review, interim final regulations were published in July 1975 based on the expanded definition of navigable waters. The 1977 regulation threw out the term "navigable waters" altogether in favor of exclusive reference to "waters of the United States" for jurisdictional purposes. The Corps implemented the concept of a nationwide permit at this time that permitted, by regulation, many routine activities not specifically exempted by definition. Exempted activities included agriculture, silviculture, and construction.

According to Barnett, the 1977 Amendments to the FWPCA did not change the broad definition of navigable waters for the purpose of water quality, but did make the following key changes: 1) the ability to issue general permits; 2) exemption for routine activities considered to be of insignificant impact; 3) exemption from regulation any discharge of dredged material which is determined to be a "best management practice" under an approved Section 208 plan; 4) procedures for the states to assume administration of the Section 404 program; 5) procedures to expedite permit processing; 6) exemption of Federal projects if the impacts were addressed in an EIS submitted to Congress prior to authorization; 7) procedures for handling violations; and 8) recognition of the state's authority to control discharges of dredged or fill material within its jurisdiction (including the activity of any Federal agency).

According to Barnett, the Corps revised their regulations in September 1980; the regulations were not promulgated by the Reagan administration. The Reagan administration felt that the Section 404 program had gone far beyond its originally intended scope. The Reagan administration issued their revised regulations in July 1982. The Presidential Task Force on Regulatory Relief directed EPA to revise its regulations under Section 404(g)-(1) to provide increased incentives and simplified procedures for state assumption of the 404 program.

Barnett states that the debate over the appropriateness of the current section of 404 program has focused on four major issues. Those issues involve: 1) whether the program, as administered, is clearly what Congress intended; 2) whether administrative authority for the program should be with the Federal government, or delegated to the individual states; 3) whether the program represents Federal interference with state water allocations; and 4) whether the benefits derived from the program are worth the cost.

2.2.3 Federal Emergency Management Agency Policies and Guidelines

In their guidelines (1985), the Federal Emergency Management Agency (FEMA) does not specifically establish standards for sand and gravel mining within designated flood-hazard areas. The National Flood Insurance Program does require a floodplain-development permit. The standard for a floodplain-development permit prohibits development that will increase flood heights. A new sand and gravel operation would have to show that their operation would not have any significant adverse impact on flood elevations. If sand and gravel operations cause an alteration in a watercourse, modify the base (100-year) flood elevation, or alter the designated floodway, approval of any revision is required from FEMA. Revisions are in the form of either a Physical Map Revision (where selected map panels of the FHBW or the FIRM are modified to show the change), or a Letter of Map Revision (LOMR), which describes the changes made and officially states that corrections to maps have been accepted by FEMA.

2.3 Regulation in California

The State of California has passed a fairly comprehensive piece of legislation that regulates surface mining (1979). The Surface Mining and Regulatory Act of 1975 (SMARA) is administered by the Department of Conservation, Division of Mines, and the Geology Reclamation Board. The actual implementation of the act is a function of individual city or county governments in which the mining operations are located. The Reclamation Board reviews local actions and can intervene if they feel the act is not being enforced. The act set standards for mining practice and reclamation. The act also seeks to classify mineral lands, and provides guidelines for mineral-resource management.

The Reclamation Board has a special policy for sand and gravel operations in floodways. The Board found that sand and gravel extraction near a levee can be detrimental to the integrity of the levee and/or can result in channel changes. The need to clear riparian vegetation during mining was found to be detrimental to flood management and wildlife habitat. Permit approval by the Reclamation Board is required before mining is allowed in a designated floodway. The following requirements must be met in order to obtain a permit.

General Requirements:

1. Excavated material cannot be stockpiled within the limits of the designated floodway during the flood season.
2. Debris has to be completely cleared from the floodway.
3. Damage to levees or access ramps must be promptly repaired.
4. Excavation will not take place within 100 feet of the edge of a streambank.
5. Replanting of specified vegetation.
6. Extraction operations will not entrap fish or cause siltation of spawning gravels.

Specific Requirements:

1. Excavation will not take place within 100 feet of the toe of a levee, toe of a streambank, or an adjacent property line.
2. Side-slopes less than 3:1 (5:1 if excavation by dredge).
3. Excavation depth no lower than bottom of the low-water channel of the streambank adjacent to the excavation area (or not to exceed approved limit for excavation by dredge).
4. Uniform bottom excavation and, if in the floodway, clear and uniform excavation prior to flood season.

Examples of county implementation of SMARA associated with sand and gravel regulation are given by Orange County (1986, undated), Sonoma County (1978), Riverside County (Edwards, 1986), and Sacramento County (Aggregate Resource Management Technical Advisory Committee, 1974). Orange County has both zoning and mining regulations. The zoning ordinance (1986) is administered by the county Environmental Management Agency, and has the following requirements:

- Limits pit depth to 150 feet from existing grade
- Requires reclamation of mined areas
- Requires a drainage and erosion-control plan
- Requires a plan of operations, including depth of all proposed excavation

The county ordinance (undated) requires that all sand and gravel operations have a permit obtained from the county Department of Building and Safety. Standards are provided for inactive and active (or planned) operations. The following requirements are of interest:

- Setbacks - 50 feet, or as determined by the administrator based on the preservation of an adjacent flood-control channel.

- Slopes - inactive, 1.5:1
  Active, if seepage problems exist (i.e., the pit is below the existing water table) a perimeter slope of 2.5:1, if not, then 1.5:1. In addressing more complex problems, Orange County contracted for detailed studies to assess the impacts of sand and gravel operations at the basin level. A study of San Juan Creek and Trabuco Creek in Orange County (SLA, 1984) was conducted to assess aggradation/degradation along river reaches in the basin. The study applied hydrologic, geologic, geomorphic, hydraulic and sediment transport analysis.

Methodologies used included:

- Hydrologic - at-gage statistical analysis (Log-Pearson III and Pearson III), and watershed modeling using programs HEC-1 and SWMM
- Geomorphic analysis - detailed geologic description of the basin, description of channel reaches, bank-erosion history, aggradation/degradation history, evaluation of man's activity
- Hydraulic - water-surface profile determination using program HEC-2
- Watershed sediment yield - use of programs MUSLE and PSIAC
- Sedimentation - estimation of bed material transport, coarse-sediment yield, estimation of the dominant discharge, incipient-motion analysis (static equilibrium), equilibrium-slope analysis (dynamic equilibrium), and local scour at bridges
- Sediment transport - use of QUASED model, transport by size fractions, and determination of bed armoring.

The Sonoma County ordinance (1978) regulates surface mining and was adopted June 1978. The following standards in Section 26A-6 pertain to gravel-mining operations:

- In-stream operations - required to avoid modification of the hydraulic capacity of the channel that would cause upstream or downstream erosion, or that would modify the streamflow (magnitude or direction) that would cause upstream or downstream erosion.
- Setbacks - 25-feet to property lines or public streets; may be required to submit a geotechnical report investigating the stability of excavation and the effect on adjacent property.

Substantial litigation over the effects of in-stream sand and gravel mining on river stability occurred in Sonoma County in the late 1970s. Newspaper articles (Healdburg Tribune, 1980) describe the outcome of this litigation and proposals for more restrictive regulation of sand and gravel operators. The litigation between sand and gravel companies and adjacent property owners along the Russian River and Dry Creek was settled out-of-court. The total settlement was $705,000. The proposed aggregate-resource management plan would curtail sand and gravel operations in in-stream and floodplain-terrace locations. Farmers and property owners were in favor of the plan. Gravel miners were opposed, saying the plan would result in unacceptable economic impacts.

One of the reports produced on the above litigation was by Slosson and Associates (1980), which evaluated the impact of in-stream and terrace sand and gravel mining operations on bed and bank stability of the middle reach of the Russian River and Dry Creek in Sonoma County, California. The report presents data on gravel extractions volumes, topographic data (field surveys, including measured cross-sections and river profiles), aerial photos (1940-1979), field investigations (soil types, existing erosion-control measures, types of riparian vegetation, locations of rock outcropping, and man-made structures such as dams and levees), existing reports and publications, and documentation of meetings with local, state, and federal agencies. The study concludes, based on a sediment bed-material mass balance, that sand and gravel extraction has caused a significant deficit in the sediment balance, resulting in property damage in these river reaches. Slosson estimated a replenishment rate of 0.27 Mtons/-year. Another estimate of the replenishment rate was given in a report by D.B. Simons of 1.0 Mtons/year. Slosson considered their estimate more reliable than Simons, since it was based largely on actual measurements. However, Slosson does not include any estimate of the measurement error for this data. It is interesting to note that a measurement error of -25% for sand and gravel extraction and +25% for streambed volume change greatly reduces the difference between the two estimates. This error would revise estimated recharge based on a sediment balance to .71 Mtons/year. An error of ±25 percent is typical of many fluvial measurements, and bias in selection of river cross-section locations.

Riverside County has addressed regulation of gravel mining on a pit-by-pit basis. Information on Riverside County's regulatory program was provided by the Chief Engineer for the Flood Control and Water Conservation District, Kennith Edwards (1986). An example of the type of review given a large gravel-mining operation is given in intergovernmental correspondence regarding an operation on the San Gorgonio River located just south and west of I-10. Edwards stated the issues related to granting a permit for this operation in a letter to Carolyn Luna of the Riverside County Planning Department as: 1) the existing levee cannot be assumed to be sufficient to prevent the river from flowing into the proposed pits, the resulting erosion could undermine upstream railroad and highway bridges (it was assumed that headcutting erosion would occur at a grade twice that of the existing natural channel); 2) that pipelines are at risk due to potential headcutting; and 3) mining operations had caused local drainage problems. A letter from Norman Arno, Chief Engineer LACOE, stated the following COE guidelines: 1) on the excavated landward side of a levee, the excavation should not extend below a plane passing through the present ground surface at a point 60-feet from the levee, and dropping at a ten percent slope; 2) on the floodway side of a levee, the excavation should not extend below a plane passing through the present ground surface at a point 200-feet from the levee and dropping at a slope of five percent, excavation should be made with a length to width ratio of about five (downstream length to cross channel width); and 3) headcutting is assumed to start at half the depth of excavation and to proceed upstream at twice the slope of the existing natural ground. Riverside County implemented SMARA with Ordinance No. 555, which requires the operator to submit mining and reclamation plans. Public hearings are held prior to granting a permit. Edwards, in a letter to the County Planning Director, Patricia Nemeth, proposed revisions to Ordinance No. 555 to incorporate COE guidelines and to restrict operations in the floodway that might increase flood damage.

Sacramento County conducted an aggregate resource study (Aggregate Resource Management Technical Advisory Committee, 1974) that estimated sand and gravel demand based on population growth and per capita consumption. The study reviewed standard specifications for aggregate products, noting that emphasis on good quality products from the construction industry has increased in recent years. The potential locations and geologic sources of aggregate materials is presented. Areas where land-use conflicts are likely are noted. An estimate is made of the number of square miles that will need to be set aside to meet aggregate resource demand for 25 years. Areas were identified within the county that can be set aside for this land use without conflict. Land-use management is determined to be the best alternative for meeting aggregate resource demand and avoiding adverse impacts to adjacent land uses. Regulations were proposed that would require: 1) a mining plan, 2) a reclamation plan, and 3) property-line setbacks. Regarding runoff and flood control, proposed regulation would require that mining operations compliment the design and purpose of drainage-basin flood-control systems and local drainage improvements. Approval from the Sacramento Division of Water Resources would be required prior to issuance of a permit.

Ventura County (1985) has adopted a resolution establishing a "red-line" profile and width policy for mining and excavation in the Santa Clara River. The policy is comparatively simple and consists of the following requirements:

1. In-river mining will be considered on the basis of a river management strategy which generally limits mining

to the aggradational reaches of the river, with the constraint of protecting structures.

2. Excavation will be limited to the red-line profile and width standards, as determined by the Flood Control District, and be defined by a table of horizontal and vertical control data and excavation widths which have been plotted on drawings on file with the Public Works Agency.

The "red-line" boundaries were defined by a comprehensive engineering analysis of the Santa Clara River. Amendments to the "red-line" boundaries are possible, provided stabilization measurements for the vertical and lateral adjustment of the river are introduced. Adoption of the "red-line" boundary gives a common reference for all users of the river environment. In addition, since the boundaries are defined through a cumulative analysis of the river system both with and without gravel mining, the effect of joint operation of several sand and gravel mines on the river can be assessed.

In California, sand and gravel operations have also been subject to water-quality monitoring and waste-discharge requirements, as implemented by the California Water Quality Board. Issues identified (Luke and Salisbury, 1974) are related to impacts on in-stream biota from sediment deposition or turbidity, reduced ground-water recharge due to sealing of recharge areas by fine sediments, and increased flood potential from sand and gravel operations in the floodway. Water quality permits issued in the San Diego Region (1983, 1978) provide limits on the amount of sand and gravel that can be extracted, and set waste water discharge requirements for settling ponds. The California Division of Mines and Geology works with the various Regional Water Quality Boards to meet water-quality standards, as legislated by the Porter-Cologne Water Quality Control Act, as these relate to mining operations (California Division of Mines and Geology, 1973).

2.4 <u>Regulation in Other States</u>

Several other states, each with a significant coal-mining industry, have adopted legislation for regulation of surface mining. This allows these states to administer parts of the federal program rules implementing the Surface Coal Mining and Reclamation Act. While the federal legislation pertains to coal mining only, state laws tend to regulate all surface-mining activities, which includes sand and gravel extraction. Montana and Colorado's programs are examples of state-level regulation of surface mining. Montana's regulations (Department of State Lands, 1980) require that a detailed permit application be submitted that includes a map of intended operations, a detailed reclamation plan, and a bond of at least $200 per acre. The emphasis in Montana's program is reclamation; no analysis of the impacts of gravel mining on river stability is required or implied. Colorado (Mined Land Reclamation Division, 1978) requires a surface-mining operation to submit a detailed permit application with information on mining plans, reclamation plans, base-line data (water, wildlife, soils, vegetation, and climate), an estimate of reclamation costs, and various legal information (right of entry, property description). Colorado regulations do not specifically address in-stream sand and gravel mining.

States with significant aquatic habitat and/or in-stream recreational resources have adopted regulations on sand and gravel mining to protect those resources. Washington, Oregon, and Idaho have each adopted this type of regulation. Washington's aquatic land management plan (Department of Natural Resources, undated) has a river-management component. The parts pertaining to sand and gravel mining include: 1) protection of braided and meandering channels from mining activity; 2) river channel relocation is permitted only when overriding public benefit can be shown; 3) sand and gravel removals are not permitted beyond the perimeter of navigable rivers, except as authorized under a department of fisheries and game hydraulics permit; 4) sand and gravel removal beyond the wetted perimeter of a navigable river is considered under the following conditions: 1) no alternative upland source is available, b) pit configuration is designed to create improved river floodplain features, c) recreation benefits are provided, d) would reduce sediment deposition in downstream rivers and lakes, and e) would reduce damage to private or public land; and 5) sand and gravel removal beyond the wetted perimeter of a navigable river is not considered under the following conditions: a) below a dam, b) from detached bars and islands, c) if unstable hydraulic conditions will be created, d) if impacts to the esthetics of nearby recreation facilities will occur, and e) if negative water quality will result. Washington's general policy statement for sand and gravel extraction (Department of Natural Resources, 1984) states that upland deposits of sand and gravel are non-renewable and have become less available. The industry is relying more on renewable river gravels than upland deposits. The use of river gravels can cause aquatic habitat damage to fishery and spawning areas and to gravel bars that provide access for various aquatic-land recreational users. The policy is therefore, to allow sand and gravel extraction on aquatic lands, but only when a more preferable upland site is unavailable.

Oregon garners a royalty on sand and gravel extraction (Division of State Lands, undated). The rules for this tax provide uniform methods with which to measure and verify the quantity of material extracted. River beds are owned and controlled by the state. The regulations do not control operational or reclamation aspects of sand and gravel mining.

The lessee is required to file a plan that gives a general volume and rate of extraction for the duration of the lease. A report by the Oregon Water Resources Research Institute (Klingeman, 1979) studied gravel mining practices on the Willamette River and outlined a comprehensive research plan addressing various issues. The report finds that sand and gravel mining is an important industry, but that the lack of quantitative information on sediment transport and erosion processes raise issues of stream-bank stability and potential impacts on recreational usage and fisheries. The objective of the study was to understand the sediment transport regime of the Willamette River, prioritize this information for decision making, and demonstrate how decisions can be made based on this information. Typical gravel mining techniques in Oregon are bar-scalping to the depth of the water surface, or mining in the floodplain to a depth equal to the water level in an adjacent water course. The study proposes a comprehensive attack on the problem, beginning with a thorough understanding of sediment budget and sediment transport rates, and development of river-management tools.

Idaho regulates the removal of sand and gravel below the mean highwater mark (Department of Water Resources, 1985). The Department of Water Resources (DWR) requires the following construction procedures: 1) no construction equipment below the existing water-surface elevation without prior approval; 2) temporary structures should be designed to handle anticipated high flows during construction; 3) only the minimum necessary disturbance to the natural appearance; 4) fill material must be placed in horizontal lifts; and 5) DWR can limit the period of construction to minimize conflicts with fish spawning, migration, or with recreational use.

Contact with the Nevada Department of Transportation (NDOT) and the Nevada Legislative Council Bureau indicated there were no existing statutes regulating in-stream sand and gravel mining. With the exception of an isolated site on the Carson River, NDOT was not aware of any in-stream mining operations within Nevada. At the present time, all sand and gravel extraction is taking place on alluvial fans. The absence of in-stream mining problems in Nevada is, no doubt, largely due to the fact that the two major metropolitan areas (Las Vegas and Reno) are not situated adjacent to major ephemeral rivers as are Phoenix and Tucson.

The New Mexico Department of Transportation (NMDOT) has also experienced very few problems with in-stream sand and gravel mining. As with Nevada, most of the sand and gravel operations in New Mexico are located on alluvial fans, rather than in river floodplains. NMDOT indicated there was no existing or pending legislation which would specifically regulate in-stream sand and gravel operations.

2.5 Regulation in Arizona

Arizona law relative to floodplain management was reviewed. Title 48, Section 3609 of the Arizona Revised Statutes mandates that the board of directors of a flood control district shall adopt and enforce regulations governing floodplains and floodplain management in its area of jurisdiction. This shall include regulations for all development of land; construction of residential, commercial or industrial structures; or a use of any kind which may divert, retard or obstruct floodwater and threaten public health or safety, or the general welfare. The regulations shall also establish minimum flood damage prevention requirements for land uses, structures, and facilities which are vulnerable to flood damage. The regulations shall be in compliance with state and local land-use plans and ordinances, if any.

The law does provide for variances from the regulations that do not result in danger or damage to persons or property in floodplains in the area of jurisdiction. Unless expressly provided, the adopted regulations will not affect existing legal uses of property or the right to continuation of such legal use. However, if a nonconforming use of land or a building or structure is discontinued for twelve months, or destroyed to the extent of 50% of its value, any further use shall comply with the regulations adopted by the district.

ARS Title 48, Section 3610 enables the governing body of an incorporated city or town to assume the responsibility for floodplain management. If the city or town declares by resolution that it no longer wishes to assume the floodplain management and regulation function, then these functions shall be the responsibility of the flood control district.

In general, the regulation of sand and gravel operations in association with floodplain management is based on ARS 48-3613 which addresses the authorization required for construction in watercourses. The law provides that sand and gravel operations which will divert, retard, or obstruct the flow of waters in a watercourse must comply with adopted regulations governing floodplains and floodplain management and that operators shall secure written authorization from the board of the district in which the watercourse is located.

ARS Title 11, Section 251 allows the board of supervisors of a county to adopt and enforce standards for excavation, landfill and grading to prevent unnecessary loss from erosion, flooding and landslides <u>subject to</u> the prohibitions, restrictions and limitations as set forth in ARS 11-830. ARS Title 11, Section 830 addresses restrictions on regulation through zoning ordinances. The law provides that nothing contained in any zoning ordinance shall prevent, restrict or otherwise regulate the use or occupation of land or improvements for "mining purposes", _if_ the tract concerned is five or more contiguous commercial acres. A current court case examines the issue of whether the in-stream sand and gravel mining operation larger than five contiguous acres is exempt from zoning ordinance requirements.

Floodplain regulations for Yuma County, Pima County, the Flood Control District of Maricopa County, the City of Phoenix, and the City of Mesa were reviewed. To obtain a floodplain use permit in Yuma County (Public Works Department, 1984) the sand and gravel operator must submit a permit application containing the following information: 1) excavation limits, location of stock piles, and pit depth; 2) phasing and method of operation; and 3) description of proposed watercourse alterations. The operation is not permitted to store materials within the floodway, nor is the storage of buoyant, flammable, explosive, or injurious materials allowed in areas subjected to flooding.

Pima County (Department of Transportation & Flood Control District, 1985) requires that the sand and gravel operator submit a permit application containing a development plan, a reclamation plan, and assurance for reclamation costs. The development plan requires analyses of hydrologic, hydraulic, and sediment transport issues. The scope of work for the sediment transport analysis is determined on a case-by-case basis. The development plan must show set-back distances, location of structures and equipment, and the phasing of operations. The reclamation plan requires that post excavation slopes be stable and that set-back distances from property lines be established.

The Flood Control District of Maricopa County (1986) excludes certain types of sand and gravel activity from the floodplain. The regulations also require a development plan and a reclamation plan. Guidelines are given in addition to the regulations to assist the sand and gravel operator in preparing a permit application. The exclusions prevent permitting if the sand and gravel operation would be a hazard to life, property, the watercourse, or crossings (i.e., bridges or utility crossings). For sand and gravel operations within the designated floodway, the development plan may require a sediment transport analysis. The reclamation plan addresses the stability of the post-mining floodway. Guidelines help the applicant to identify operation and reclamation issues pertinent to the operation. These guidelines include questions relating to whether the operation is: 1) in the floodway or floodplain; 2) likely to affect channel form; 3) close to property or channel crossings; and 4) in a channel that is known to aggrade or degrade, or in a zone of channel headcutting.

The City of Phoenix ordinance (Floodplain Board, 1981) allows sand and gravel mining within the floodway provided that excavations do not present a hazard to other development and river crossings. The ordinance excludes stockpiling within the designated floodway but permits it within the floodplain.

The City of Mesa ordinance allows gravel mining if the property is zoned for such use. Individual sand and gravel mining operations are subject to stipulations on a case by case basis. An example of such stipulations is the Shill-Biggs zoning case, for a gravel pit on the west side of Mesa Drive, north of Lehi Road. In this case, dikes or levees were not permitted and the excavation depth was limited to 100 feet below natural ground (with 1:1 side-slopes). The direction of excavation was specified as south to north with provisions to carry local runoff around the pit to the river. A requirement was also imposed that the pit be backfilled upon completing sand and gravel extraction.

An industry perspective on the political issues faced by sand and gravel operators was given by the magazine Southwest Contractor, in an August 1985 article entitled "River of Controversy" (1985). The issues discussed relate to sand and gravel mining on the Salt River, and included development of Rio Salado, flooding and flood control, and ownership of river bottom property. The article points out that sand and gravel is a significant but finite resource. The Rio Salado project is considered the number one problem facing sand and gravel operators on the Salt River. The rock producers feel that the project, as proposed, has not properly taken into account their interests. The condemnation of private property owned by mining companies for this project is strongly questioned. Private development of previously mined land has been undertaken by several companies (CALMAT and Tanner). As an alternative to Rio Salado, the rock producers propose channelization of the Salt River with the excavation conducted by the producers. The project would be engineered by the Flood Control District of Maricopa County. The period of construction is estimated at five to eight years.

III. STRUCTURE HAZARD

Arizona is crisscrossed by comprehensive networks of transportation and transmission routes. Transportation facilities include: rail, highway, and air routes; and transmission facilities include: water (domestic and irrigation), gas, electrical and communication lines. These routes interconnect Arizona cities and connect Arizona to the nation as a whole. Crossings of natural and manmade waterways are a frequent occurrence and are at significant risk from potential floods. All of these routes (including air) have been interrupted by periods of severe flooding. Damage to these systems is a significant cost in itself, but the interruption of the service they provide is often far more costly both to the economy and to public safety and welfare.

A general accounting of flood damage to all transportation and transmission routes is not the focus of this study. Of primary interest are the damages that have occurred to the highway system. Highway bridges are probably the most numerous river-crossing structures, and can be assumed to characterize many of the problems of other river-crossing structures in a river reach. Highway-bridge crossings are constructed and maintained by state, county, and local highway departments. The maintenance of these bridges requires periodic inspections, the majority of which are carried out by ADOT bridge inspection staff. All counties in the state with the exception of Maricopa have ADOT conduct this inspection. The computer database maintained by ADOT contains information on the majority of bridges in the state (this may exclude bridges on private land, military bases, forest service roads, and national parks, however).

Data on damage to highway bridge structures was compiled from Flood Damage Reports and Federal/State Damage Survey Reports. Additional data on specific projects that ADOT has conducted on an emergency basis have been compiled from the database for use with this study. Emergency replacement (ER) project funds have been made available to ADOT after disastrous floods. To date, all ER projects in Arizona are associated with flood damage to bridge structures. ADOT also maintains documentation on repair cost associated with scour damage to bridge structures for non-disaster related conditions. This documentation is compiled on an informal basis by ADOT's scour team.

3.1 Existing Bridge Structures Crossing Waterways

ADOT's inventory of Arizona bridges lists 1,514 structures over waterways. ADOT also inspects 95 county bridges and 606 city bridges that are over waterways. Table 3.1 gives a breakdown by county and city of bridge structures over waterways.

TABLE 3.1. Bridge Structure Over Waterways
(Source: Arizona Bridge Inventory)

County/City	ADOT Bridges	County Bridges	City Bridges
Apache	40	18	
Eager			1
Springerville			1
Cochise	67	108	
Bisbee			4
Sierra Vista			12
Coconino	127	28	
Flagstaff			21
Williams			6
Gila	28	7	
Globe			12
Hayden			1
Miami			7
Payson			1
Graham	2	23	
Safford			4
Greenlee	2	15	
Clifton			6
La Paz	23	2	
Maricopa	599	194	
Avondale			1
Buckeye			1
Chandler			2
Gila Bend			1
Gilbert			6
Glendale			11
Goodyear			1
Mesa			51
Paradise Valley			2
Peoria			2
Phoenix			138
Scottsdale			90
Tempe			19
Mohave	65	5	
Kingman			7
Lake Havasu City			1
Navajo	51	21	
Winslow			7
Pima	296	197	
Tucson			143
Pinal	53	74	
Superior			1
Santa Cruz	23	17	
Nogales			11
Yavapai	77	86	
Clarkdale			3
Cottonwood			3
Prescott			23
Yuma	61	100	
Yuma			6

Approximately 80 percent of these structures are less than 100 feet in length and typically span irrigation canals and small washes. Ten percent of structures spanning waterways are 100 to 200 feet in length, and five percent are 200 to 400 feet in length. Structures over 800 feet in length constitute about one percent of all bridge structures over waterways in Arizona.

3.2 Flood Damage to Existing Bridge Structures

Table 3.2 summarizes the frequency and cost of emergency repair and scour repair projects in Arizona. Table 3.3 summarizes flood-damage estimates to transportation systems as reported from COE flood damage reports.

3.3 Transportation Planning

Arizona's highway system has been expanding to keep pace with population growth. In the future, sustained population growth is expected in all areas of the state. The state's highway network will also expand adding road mileage, much of which will occur in metropolitan areas. Three out of four new people moving to Arizona between now and the year 2000 are expected to live in the Phoenix and Tucson metropolitan areas. This will necessitate the early construction of expanded regional transportation systems for these areas. In addition, many of Arizona's midsized urban areas and rural towns are facing growth prospects at least as dynamic as the major metropolitan areas. Without the construction of new roads and the reconstruction and widening of existing roads to higher standards, the cost of congestion will be staggering.

In fiscal year 1986, ADOT invested $370.9 million dollars maintaining and improving the state highway system. Over the next five years, ADOT will invest more than $2.6 billion dollars on the highway system. Table 3.4 identifies the capital investment by counties.

TABLE 3.2. Summary of Emergency Repair Projects
(Source: ADOT Project Expenditures)

Region	River	Reach	Number of Projects	Amount
Basin & Range	Gila	Confluence-Painted Rock	0	NA
		Painted Rock-Salt River	0	NA
		Salt River-Coolidge	14	$ 6,382,556.73
		Coolidge-Safford	5	1,192,334.28
		Safford-headwaters	1	92,637.17
		Hassayampa	2	634,407.85
		Agua Fria	7	5,813,390.29
		New River	4	18,192.76
	Salt	Confluence-Granite Reef	13	26,262,560.62
	Santa Cruz	Confluence-Tucson	4	495,194.06
		Rillito/Pantano	12	683,878.17
		Tucson-Nogales	15	6,445,537.53
	San Pedro		2	112,764.29
	Bill Williams	Confluence-Alamo Lake	0	NA
		Alamo Lake-headwaters	0	NA
	Colorado	Border-Imperial	0	NA
		Imperial-Parker	0	NA
		Parker-Davis	0	NA
		Davis-Hoover	0	NA
		Hoover-Glen Canyon	0	NA
Central Highland	Verde	Confluence-Bartlett	0	NA
		Horseshoe-Camp Verde	1	290,095.97
		Camp Verde-headwaters	0	NA
	Upper Salt	Roosevelt-headwaters	0	NA
Colorado Plateau	Little Colorado	Confluence-Winslow	0	NA
		Winslow-Holbrook	0	NA
		Holbrook-headwaters	0	NA
	Puerco		0	NA

TABLE 3.3. Summary of Flood Damages to Transportation Systems							
RIVER	1/ Dec 1965 Jan 1966	2/ Oct 1972	3/ Oct 1977	4/ Feb-Mar 1978	5/ Dec 1978	6/ Feb 1980	7/ Oct 1983
Salt River Granite Reef Dam to Gila River	$1,686,000						
Gila River to Gillespie Dam	91,000						
Gila River Safford Valley, Graham County		227,000					
Gila River in Duncan & York Valleys, Greenlee Cty		1,000					
San Francisco River at Clifton		184,000					
Nogales Wash Santa Cruz County			69,000				
Santa Cruz River, Santa Cruz County			682,000				
Santa Cruz River, Pima County			784,000				
Santa Cruz River, Pinal County			54,000				
Salt River from Granite Reef Dam to 115th Avenue				11,809,000			
Gila River Maricopa County				340,000			
Salt River, Metro Phoenix					17,985,000	16,339,000	
Gila River, Metro Phoenix					1,526,000	1,360,000	
Agua Fria River, Metro Phoenix					1,999,000	4,242,000	
All rivers within Pima County							28,000,000
All rivers within Greenlee County							4,320,000
All rivers within Santa Cruz County							3,879,586
All rivers within Graham County							1,660,000

REFERENCES FOR TABLE 3.3

1/ Flood Damage Report on Flood of December 1965-January 1966 Salt and Gila Rivers, Granite Reef Dam to Gillespie Dam, Arizona U.S. Army Corps of Engineers, April 1966.

2/ Flood Damage Report, Flood of October 1972 Gila River Basin above San Carlos Reservoir, Arizona and New Mexico, U.S. Army Corps of Engineers, August 1973.

3/ Flood Damage Report on Storm and Floods on 6-10 October 1977 Santa Cruz, Gila, and San Pedro Rivers, Arizona U.S. Army Corps of Engineers, September 1978.

4/ Flood Damage Report, 28 February - 6 March 1978 On the Storm and Floods in Maricopa County, Arizona U.S. Army Corps of Engineers, February 1979.

5/ Flood Damage Report, Phoenix Metropolitan Area, December 1978 Flood, U.S. Army Corps of Engineers, November 1979.

6/ Phoenix Flood Damage Survey, February 1980 U.S. Army Corps of Engineers, April 1981

7/ Federal/State Damage Survey Reports, October 1983 Federal Disaster Declaration Arizona Division of Emergency Services

TABLE 3.4

Planned Road & Bridge Construction by ADOT
Fiscal Year 86-87 Through Fiscal Year 90-91
(Source: Five-Year Transportation Facilities Construction Program, ADOT)

County	Projected Construction Funds
Maricopa	$ 2,032,415,000
Pima	183,320,000
Coconino	119,510,000
Gila	80,590,000
Mohave	51,190,000
Navajo	49,970,000
Yavapai	39,910,000
Pinal	31,985,000
La Paz	28,946,000
Yuma	20,220,000
Apache	14,880,000
Cochise	14,585,000
Santa Cruz	6,720,000
Graham	2,750,000
Greenlee	1,040,000
Total	$ 2,678,031,000

IV. ECONOMIC VALUE

Literature and data on the economic aspects of the sand and gravel industry was gathered and reviewed. Information was available from private and governmental sources. Basic data on resource areas in Arizona, annual production and value of rock products, and transportation costs were compiled from the literature. Sources of economic information included the Arizona Rock Products Association (1986), the Arizona Bureau of Geology and Mineral Technology (formerly the Arizona Bureau of Mines) (Keith, 1969; Williams, 1967), the U.S. Geological Survey (Moore and Varge, 1976), and the U.S. Army Corps of Engineers (Los Angeles District, 1981).

4.1 Resource Identification

Resource information was compiled from data obtained from the U.S. Bureau of Mines, Arizona Bureau of Geology and Mineral Technology (formerly the Arizona Bureau of Mines), and the Arizona Department of Transportation Material Section. The U.S. Bureau of Mines maintains working data files on sand and gravel operations as a part of the Minerals Availability System. The Bureau of Geology and Mineral Technology annually consolidates statewide sand and gravel production statistics from this database, and publishes this information as a part of the Department of the Interior Mineral Yearbook. From 1952 to 1975, the Mineral Yearbook published both state and county production statistics. Since 1975, only statewide statistics have been published.

Sand and gravel deposits derived from stream action occur in all counties of Arizona, but the quantity and quality vary greatly statewide because of different geologic, topographic and climatic conditions. Keith (1969) provides a general description of where sand and gravel deposits occur in the three physiographic regions of Arizona (see Figure 4.1). The geology of these three regions is complex and varied.

* The Basin and Range region includes the deserts of southern and western Arizona; the Gila River and the Colorado River below Hoover Dam are the primary drainages. In the Basin and Range region, the best deposits of sand and gravel occur in alluvial fans along mountain ranges where intermittent streams constantly supply new deposits. Stream channels and dry washes yield a large part of the sand and gravel production.

* The mountainous Central Highlands are drained by the upper tributaries of the Gila River; the Verde and the Salt Rivers. The mountain region has good quality, but generally small, alluvial deposits of sand and gravel along both the stream channels and the terraces along the valley sides.

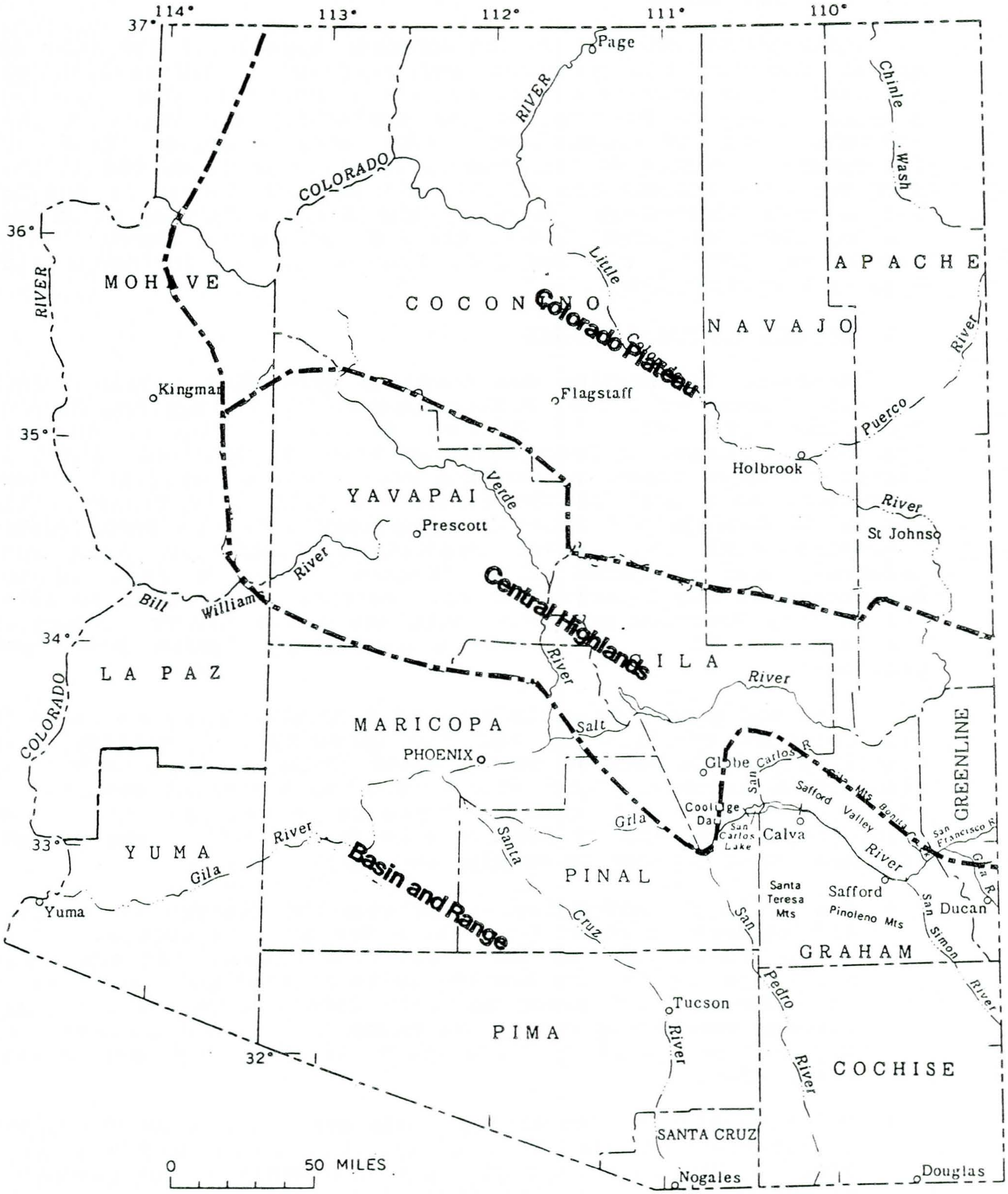


Figure 4.1. Physiographic Regions in Arizona
(Source: Keith, 1969)

* The northern Colorado Plateau region is drained by the Colorado and Little Colorado Rivers. For the Plateau region, the best commercial deposits occur along the streams and washes in local bars and terraces, but they are rather thin and limited in area.

The distribution of sand and gravel in Arizona is the result of natural disintegration and abrasion of rock and the subsequent transport and deposition. The quality of a deposit depends on the parent rock constituents, the duration of weathering and erosion processes, and the transportation and deposition processes. Most rock formations yield sand and/or gravel, but the distribution of sizes and the particle shape can vary greatly. Table 4.1 gives a breakdown of sand and gravel quality by parent rock type. Table 4.2 shows the relationship of sand and gravel quality to transport mechanism. In Arizona, the most important deposits of sand and gravel are formed by stream action.

Stream action can lead to various types of deposits including: basin and valley fills; remnant and active stream channels; stream terraces; and alluvial fans. Overall, the quality of sand and gravel deposits occurring from stream action depends on parent-rock source and the deposition process.

TABLE 4.1. Sand and Gravel Quality by Parent Rock Type (Source: Keith, 1969)

Parent Rock	Quality	Comment
Sandstone	Excellent	Both sand & gravel
Conglomerate	Excellent	Both sand & gravel
Friable sandstone	Excellent	Little or no gravel
Dune and beach sandstone	Excellent	With some beach gravel
Limestone & dolomine	Good	
Shale and Schist	Poor	
Granite and diabase	Good	
Basalt	Excellent	Aggregate sources
Gneiss	Good	Sand
Gneiss	Poor	Gravel

TABLE 4.2. Sand and Gravel Quality by Transport Process (Source: Keith, 1969)

Transport Process	Quality	Comment
In-place	Poor	Chemical alteration, poorly sorted sizes
Talus	Good	Poorly sorted gravel, little sand
Wind	Good	Sand only
Wave	Excellent	Sand, beach gravel
Stream	Excellent	Sand and gravel

Moore, et al (1976) compiled a map showing aggregate deposits in the Phoenix area. The map scale is 1:250,000 and shows contruction material exposed at the ground surface. The map also shows the approximate location of sand and gravel pits, and rock quarries. The COE (Los Angeles District, 1981) estimates in-stream aggregate resources in the Phoenix area to be 368 million cubic yards (490 million tons) over a 33-mile long reach of the Salt River from Granite Reef dam to 67th Avenue. Through the main urban area of Phoenix and Tempe, in-stream aggregate resources are estimated at 120 million cubic yards (160 million tons) for this eleven-mile reach.

The Arizona Department of Transportation Materials Section has compiled inventories, by county, of borrow and aggregate sources from pits which they lease or own. Published inventories exist for twelve Arizona counties: Apache, Cochise, Coconino, Graham, Mohave, Maricopa, Navajo, Pima, Pinal, Santa Cruz, Yavapai, and Yuma. The inventories for Cochise, Graham, Pinal, Pima, Santa Cruz, and Yuma Counties were compiled in the 1960s, and therefore, cannot be considered as a reliable guide to ADOT activity at the present time. Extensive unpublished information is available from files of the Materials Section related to ADOT pits. Assistance was provided by the Materials Section in providing an up-to-date inventory of material pits.

An accurate assessment of sand and gravel resources for the physiographic regions of Arizona requires extensive field investigation. Such investigation has been conducted by the Materials Section of ADOT at over 7,000 pits located throughout the State. The majority of these investigations relate to borrow sources but some 1,000 pits, located in rivers and washes, have been sampled as aggregate sources. Extensive analysis is conducted by the Materials Section on the materials at each site, including tests of the gradation, swell potential, Atterburg limits, abrasion, and R-value. Numerous samples are taken and analyzed prior to opening a pit, and the pit is subsequently resampled throughout its period of use. Published values of test results in the Arizona Materials Inventory represent the average of many samples at a pit. These values are assumed to be representative of the river reaches where the pits occur, and therefore, give an idea of the general quality of sand and gravel materials in Arizona river reaches. Unfortunately, sediment sizes larger than 3-inches are excluded from the sample in ADOT sieve analysis. On cobble-bed channels, this causes a fairly substantial error in estimating the mean bed-material diameter and gradation coefficient. To supplement the ADOT sieve analysis, bed-material gradations reported in sediment transport studies conducted on Arizona rivers were included. These gradations are in close agreement with ADOT gradations on sand-bed rivers but differ significantly on cobble-bed channels. Sediment transport study gradations were used in place of ADOT gradations when they reported coarse fractions of bed material.

Using the published information in the Materials Inventory and with updated information supplied by the Materials Section Staff, an overview of the quality and quantity of sand and gravel resources in Arizona river reaches was compiled. Table 4.3 summarizes this overview of sand and gravel resource by physiographic region and for major river reaches within each region. The quantity estimate assumes single lift mining to a depth of 30 feet for the river width along the reach length.

4.2 Market Potential

In order to identify market potential, information was compiled on the construction industry economy, and on population growth in Arizona. Sources for this information include: Center for Business Research, Arizona State University; U.S. Department of Commerce, Bureau of Census; and the Arizona Department of Economic Security. The Center for Business Research monitors a group of economic indicators which has been published monthly since 1961. Population data from the Bureau of Census is compiled each decade. The Arizona Department of Economic Security has estimated population growth in Arizona for the next 50 years. A broad overview of the Arizona Economy was completed in 1986 by the Arizona Department of Commerce, which analyzed trends in a variety of areas in the economy.

Products derived from sand and gravel mining are utilized in a wide array of building materials such as concrete, asphalt paving, aggregate base coarse, concrete wall blocks, and many others. These building materials are fundamental to the construction industry. Keith (1969) notes that variations in the production of sand and gravel in Arizona are related to the changing levels of economic activity of the construction industry, which includes construction of new homes, city streets, urban arterial streets, freeways, private office and industrial buildings. Production is also influenced by the installation of

TABLE 4.3. Overview of Quality and Quantity of Sand and Gravel in Arizona Rivers (Source: Arizona Materials Inventory, Arizona Department of Transportation, Materials Services)

Region	River	Reach	Volume (million yd^3)	D_{50} (mm)	G	Type
Basin & Range	Gila	Confluence-Painted Rock	3432	3.2	5.8	Fine Gravel
		Painted Rock-Salt River	1783	3.0	6.8	Fine Gravel
		Salt River-Coolidge	3520	5.0	7.5	Fine Gravel
		Coolidge-Safford	2053	2.5	7.5	Fine Gravel
		Safford-headwaters	NI			
		Hassayampa	343	0.71	7.7	Coarse Sand
		Agua Fria	440	1.1	8.5	Coarse Sand
		New River	414	32	6.4	Coarse Gravel
	Salt	Confluence-Granite Reef	1100	96	6.7	Cobbles
	Santa Cruz	Confluence-Tucson	678	0.7	6.1	Coarse Sand
		Rillito/Pantano	281	0.86	5.8	Coarse Sand
		Tucson-Nogales	378	0.58	6.3	Coarse Sand
	San Pedro		718	1.1	8.7	Coarse Sand
	Bill Williams	Confluence-Alamo Lake	246	NP		
		Alamo Lake-headwaters	361[1]	NP		
	Colorado	Border-Imperial	387[2]	NP		
		Imperial-Parker	959	NP		
		Parker-Davis	352[3]	NP		
		Davis-Hoover	(4)	NP		
		Hoover-Glen Canyon	(4)	NP		
Central Highland	Verde	Confluence-Bartlett	183		(5)	
		Horseshoe-Camp Verde	387		(5)	
		Camp Verde-headwaters	493	4.7	22	Fine Gravel
	Upper Salt	Roosevelt-headwaters	NI			
Colorado Plateau	Little Colorado	Confluence-Winslow	748	NP		
		Winslow-Holbrook	867	NP		
		Holbrook-headwaters	950	0.3	16	Fine Sand
	Puerco		1500	0.17	2.6	Fine Sand

NI = Material inventory not available
NP = No ADOT pits located in or near the river in this reach
1 = Exclude section flooded by Alamo Lake
2 = Exclude section flooded by Imperial Dam
3 = Exclude section flooded by Lake Havasu
4 = Within Grand Canyon
5 = Contains cobble sizes not measured in ADOT sieve analysis

major dams, highways, irrigation ditches, air fields, and defense establishments. Important projects that have stimulated sand and gravel production since World War II include the Federal Aid Highways Act of 1956, the Central Arizona Project, and Proposition 300 for freeway expansion in Maricopa County. With the exception of large public works projects, the demand for building materials generally follows the regional trend in population growth. The additional requirements of large public work projects must be estimated separately.

4.2.1 Regional Demand

4.2.1.1 Past Sand & Gravel Production

To obtain a historical perspective of market potential, data on prior sand and gravel production is reviewed along with associated data on construction activity including building permits and population growth. Figure 4.2 shows the historic increase of sand and gravel production for Arizona from 1947 to 1984. Over the 38-year production record, sand and gravel production has increased significantly but at a rate that reflects fluctuating economic cycles in the construction industry.

Production from 1947 to 1954 was fairly uniform but jumped dramatically in 1955 with introduction of the federal aid to highway program. The period from 1956 to 1961 saw steady above-average growth in the sand and gravel production, followed by a period from 1962 to 1970 of uniform or slightly declining production. Production increased rapidly from 1971 to 1973, followed by an equally rapid decline in 1974 and 1975. Production reached its highest level in 1979 but slumped to low levels by 1982, during the last economic recession. Recent production rates have increased rapidly, preliminary records for 1985 production indicate a record production level.

Keith (1969) summarizes statewide production from 1900 through 1966 and provides information on commercial and governmental production. Williams (1967) summarizes production data from the Tucson area from 1952 to 1966 and compares this data to population growth in the area. The Arizona Bureau of Geology and Mineral Technology in cooperation with the U.S. Bureau of Mines, compiles aggregate production data by county on an annual basis. Production data by county was reported in the Mineral yearbooks published from 1957 to 1975. Since 1975, only production data for Pima and Maricopa counties have been intermittently reported (1977, 1978, 1979, 1980 and 1982). Table 4.4 shows the relative portion of sand and gravel production for each county at five-year intervals beginning in 1960 and ending in 1975. During this period, production in Maricopa County consistently ranked the highest, accounting for 34 to 57 percent of total state production. From 1970, Pima County production has ranked second, accounting for 13 to 16 percent of total state

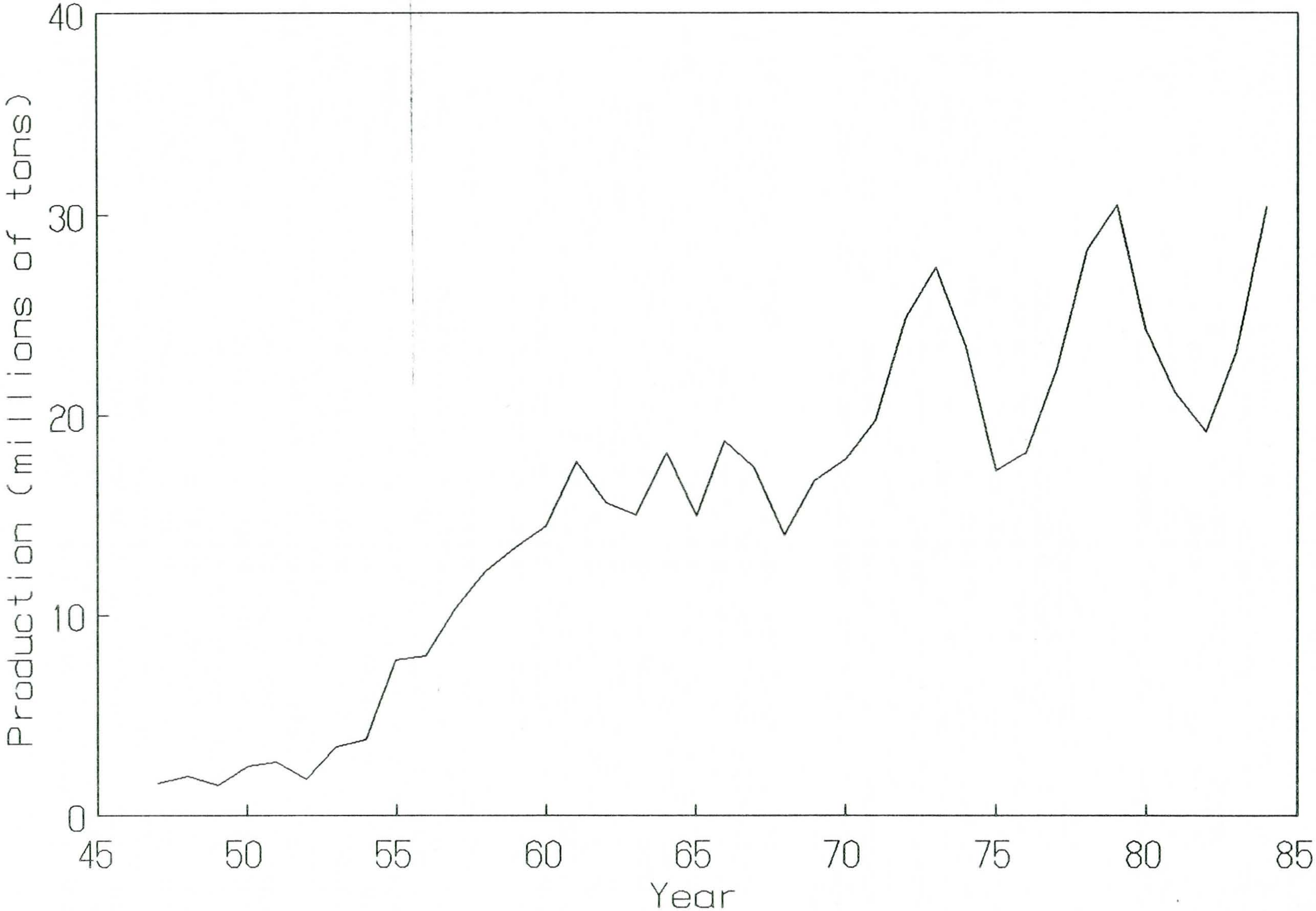


Figure 4.2. Sand and Gravel Production (1947-1984)

Source: Minerals Yearbook, U.S. Department of the Interior

TABLE 4.4. Sand and Gravel Production by County

County	(1960) Production (X 10^3 tons)	%
Santa Cruz	5	0
Undist.	100	1
Graham	121	1
Mohave	139	1
Gila	277	2
Navajo	315	2
Yavapai	363	2
Apache	459	5
Yuma	595	6
Pima	975	9
Cochise	1020	13
Pinal	1278	13
Coconino	2863	14
Maricopa	5980	34
	14490	100

County	(1965) Production (X 10^3 tons)	%
Gila	93	1
Greenlee	104	1
Apache	277	2
Cochise	341	2
Yavapai	680	5
Yuma	868	6
Undist.	1016	7
Navajo	1186	8
Pima	1811	12
Pinal	1824	12
Mohave	1981	13
Maricopa	4737	32
	14918	100

County	(1970) Production (X 10^3 tons)	%
Gila	141	1
Cochise	168	1
Undist.	214	1
Santa Cruz	287	2
Navajo	358	2
Mohave	477	3
Yavapai	756	4
Pinal	1736	10
Coconino	1853	10
Yuma	2546	14
Pima	2923	16
Maricopa	6363	36
	17822	100

County	(1975) Production (X 10^3 tons)	%
Apache	37	1
Santa Cruz	55	1
Greenlee	173	1
Graham	176	1
Gila	294	2
Cochise	312	2
Pinal	482	3
Yavapai	603	4
Mohave	620	4
Navajo	624	4
Yuma	631	4
Coconino	1031	6
Pima	2286	13
Maricopa	9897	57
	17222	100

production. In 1975, Maricopa and Pima counties accounted for 70 percent of total state production and in 1980, the two counties accounted for 76 percent. In 1975, Coconino County's production ranked third at about one-half the production of second ranked Pima County, accounting for six percent of total state production. Yuma, Navajo, Mohave and Yavapai each produced four percent of total state production in 1975. All remaining counties cumulatively had less than eight percent of total state production in 1975.

A gradual increase in Maricopa County production relative to other counties in the state is evident. In the period from 1960 to 1970, Maricopa County accounted for about one-third of total state production. Production levels since 1975 are approaching two-thirds of state production.

Historic data since 1960 indicates that county production of sand and gravel can be grouped into the following catagories:

* Very High Production - Maricopa County (60% of total state production)
* Moderate Production - Pima County (10-15% of total state production)
* Low Production - Coconino, Mohave, Navajo, Pinal, Yavapai and Yuma (3-6% of total state production)
* Very Low Production - Apache, Cochise, Gila, Graham, Greenlee, La Paz and Santa Cruz (less than 3% of total state production).

4.2.1.2 <u>Construction Activity</u>

Data on housing units authorized by building permits is published by the U.S. Department of Commerce, Bureau of Census. This data was reviewed for the period from 1955 to 1985. The historic increase in the number of building permits issued during this period for the State of Arizona is shown in Figure 4.3. There are interesting similarities and differences between sand and gravel production and the issuance of building permits. From 1955 to 1961, there was a 128 percent increase in the production of sand and gravel, but only a 42 percent increase in building permits. As was mentioned previously, a strong demand for sand and gravel was created during this period as a consequence of the initiation of the federal aid highway program. From 1961 to 1970, there was steady or lower demand for sand and gravel. During this time, home building was initially steady, but slumped during the mid and late 1960s. Economic activity accelerated in the early 1970s and both permits issuance and sand and gravel production increased. Building permits peaked in 1972, one year before sand and gravel production, indicating about a one-year lag between the time a permit is issued and actual construction. Building permits and sand and gravel production hit lows in 1975, followed by a period of increased construction activity with

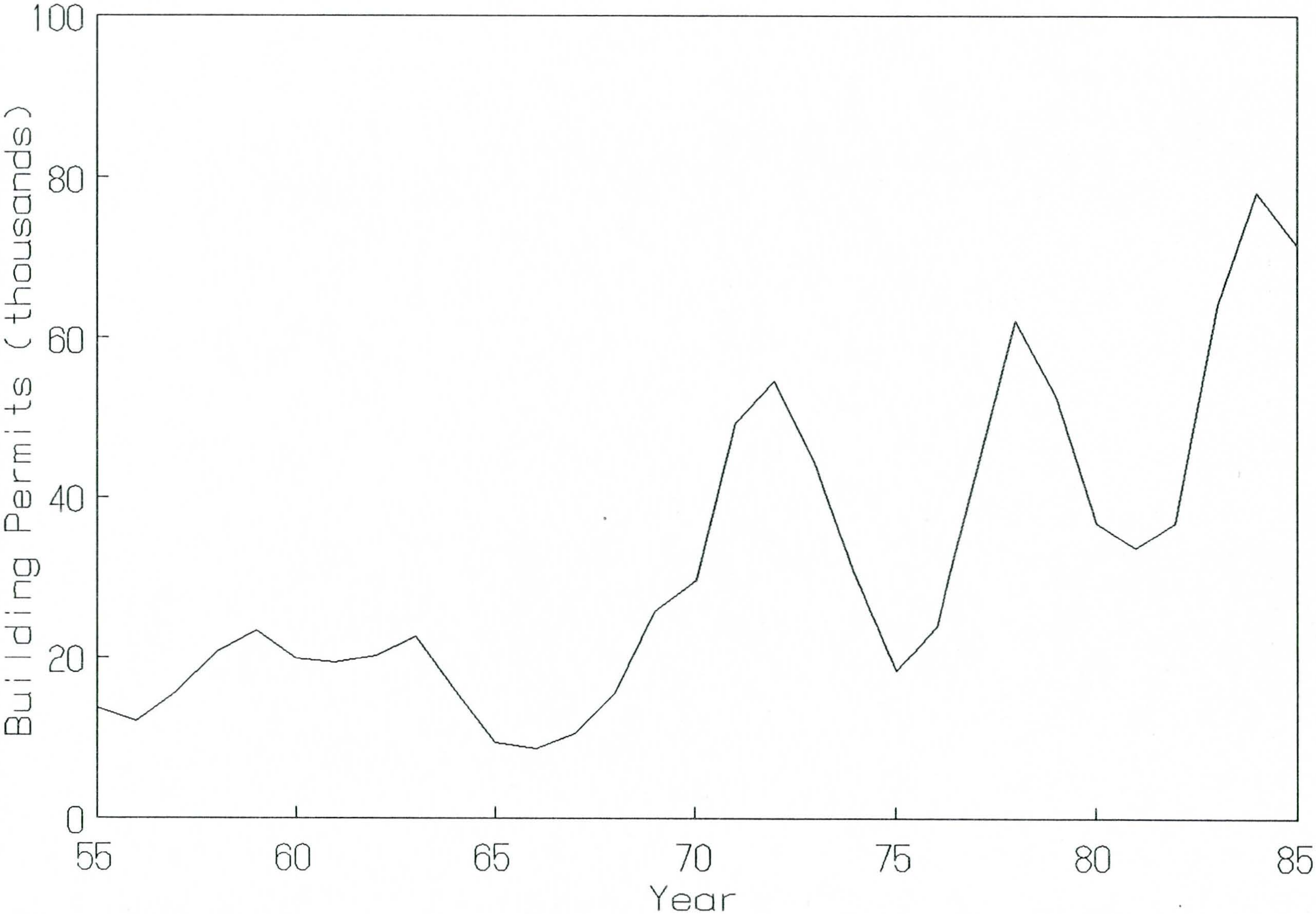


Figure 4.3. Building Permits in Arizona (1955-1985)

Source: U.S. Department of Commerce, Bureau of the Census building permits peaking in 1978 followed one year later by a peak in sand and gravel production. Building permits issuance hit lows in 1980 to 1982, which coincides with low production in the sand and gravel industry in 1982.

This review of construction history indicates that sand and gravel production in Arizona has two primary markets: one being road building; the second being residential, commercial and industrial building. Commercial construction includes construction of apartment, office building, retail and motel/hotel. This sector of the construction industry has been a leading area of activity in recent years, particularly apartments (Ronan, 1986). The economic behavior of commercial and residential construction are similar, with the data on residential home building permits being indicative of the entire commercial/residential construction market. It has been estimated by others (Keith, 1969) that road building consumes approximately one-third of sand and gravel production. Information on the rate of consumption for road building is limited, but is assumed to be more uniform. This implies that the fluctuations in sand and gravel production are associated with residential, commercial, and industrial construction.

Population growth is a primary factor in sand and gravel demand. The demand for new homes, apartments, office buildings, roads, and major infrastructure projects arises from population growth and the ensuing economic activity. Figure 4.4 shows the growth in Arizona population from 1960 to 1985. Two periods in population growth are evident from this graph: in the decade of the 1960s population grew 34 percent, adding 439,000 people; and in the decade of the 1970s population grew at a much faster rate, 49 percent, adding 863,000 people. From 1980 to 1985, Arizona's population has grown at the rate of 82,000 people per year, about the same rate as during the 1970s.

Per capita consumption of sand and gravel for the increase in Arizona population in the 1960s was 105 tons/person, and in the 1970s was 103 tons/person. Consumption in the 1980s is running at 101 tons/person. There was one building permit issued for every 2.6 additional persons during the 1960s and for every 2.1 additional persons during the 1970s. Permitting for residential construction in the 1980s is running at one unit for every 1.6 additional persons. These statistics indicate two countervailing trends in the construction industry: a reduction in the amount of sand and gravel used in construction; and second an increase in the number of housing units per capita. The reduction in the amount of sand and gravel used reflects a wider range of construction methods in addition to the predominant use of concrete block wall. Also, road construction methods have incorporated recycling of pavement which has reduced the demand for aggregate. The increase in housing units per capita indicates a trend toward smaller households.

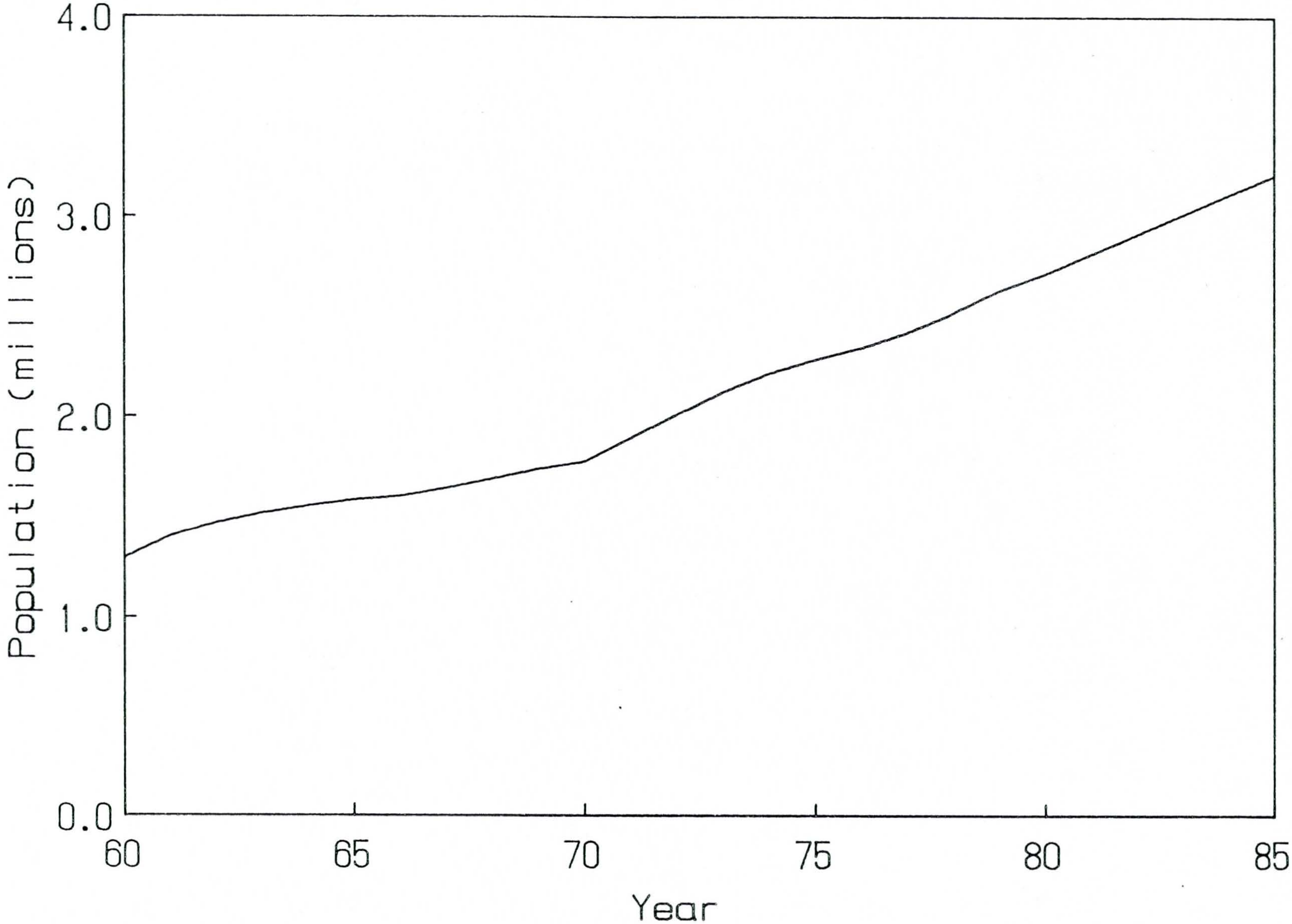


Figure 4.4. Arizona Population Growth (1960-1985)

Source: Arizona Statistical Review

An estimate of future per capita consumption in the face of these trends is somewhat speculative. There is little doubt that sand and gravel will continue to be a basic raw material for road construction and for products used in residential, commercial and industrial construction. The 1980s per capita consumption is considered to provide a reasonable guide to a lower limit of sand and gravel consumption. The 1970s per capita consumption is used as the best estimate of average sand and gravel consumption. The 1960s per capita consumption is taken as an approximate upper limit of sand and gravel consumption. This gives the following bounds for annual per capita consumption of sand and gravel in Arizona:

Lower bound: 10.1 tons/person/year
Mean : 10.3 tons/person/year
Upper bound: 10.5 tons/person/year

In order to account for intensified freeway construction activity within Maricopa County during the twenty-year period beginning in 1985, 1.5 tons/person/year has been added to the mean annual per capita consumption rate for all of Arizona (10.3 tons/person/year). As a result, for Maricopa County only, the mean annual per capita consumption rate is estimated to be 11.8 tons/person/year.

4.2.2 Projected Sand and Gravel Production

The COE (Los Angeles District, 1981) estimated the demand for aggregate resources in the Phoenix area as a function of the following parameters:

$$D = 10.3 + 0.59M + 3.11C + 0.38E$$

where D is the estimated annual demand (tons), M is the annual miles of roads constructed, C is the annual number of commercial-building permits issued, and E is the annual number of workers employed in construction.

The Arizona Rock Products Association (1986) has estimated demand for sand and gravel to the year 2000, (see Figure 4.5). This estimate anticipates that demand for rock products will outpace Arizona population growth through the end of the century. Production of sand and gravel is expected to reach 58 million tons per year by the year 2000, compared to 1985 production of 38 million tons. They also estimate that construction of planned freeways in the Phoenix metropolitan area will require 14.5 million tons of sand and gravel, and 8.8 million cubic yards of concrete.

Using forecasted population growth for the next 50 years for Arizona counties, an estimate of ten-year sand and gravel consumption rates is made. Table 4.5 summarizes sand and gravel consumption by county at ten-year intervals. State production of

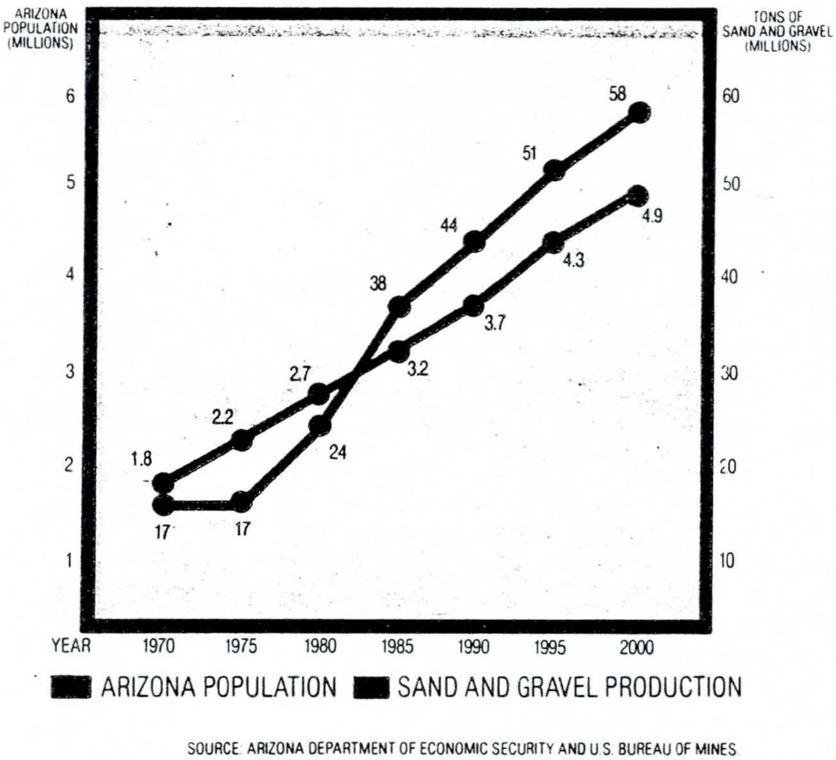


Figure 4.5
Arizona Population and Sand and Gravel
Production:
1970-2000

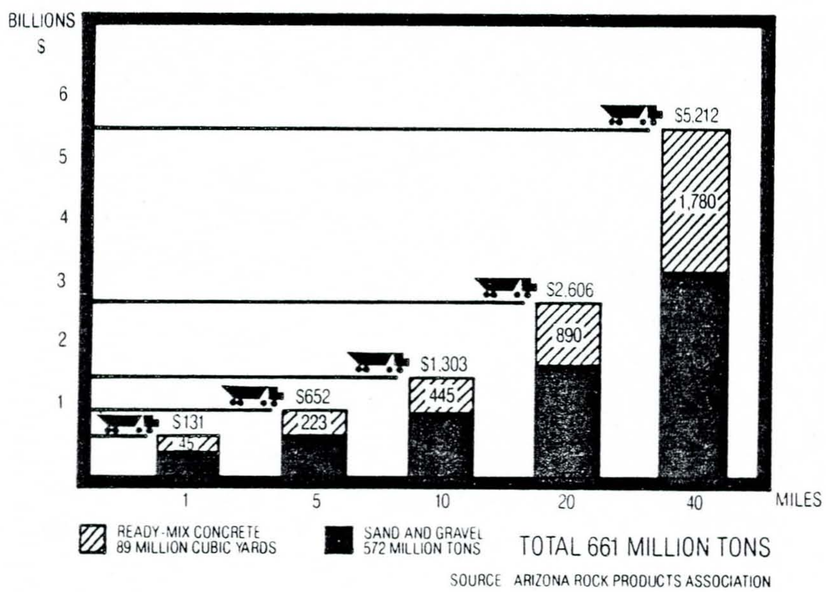


Figure 4.7. Transportation Costs.

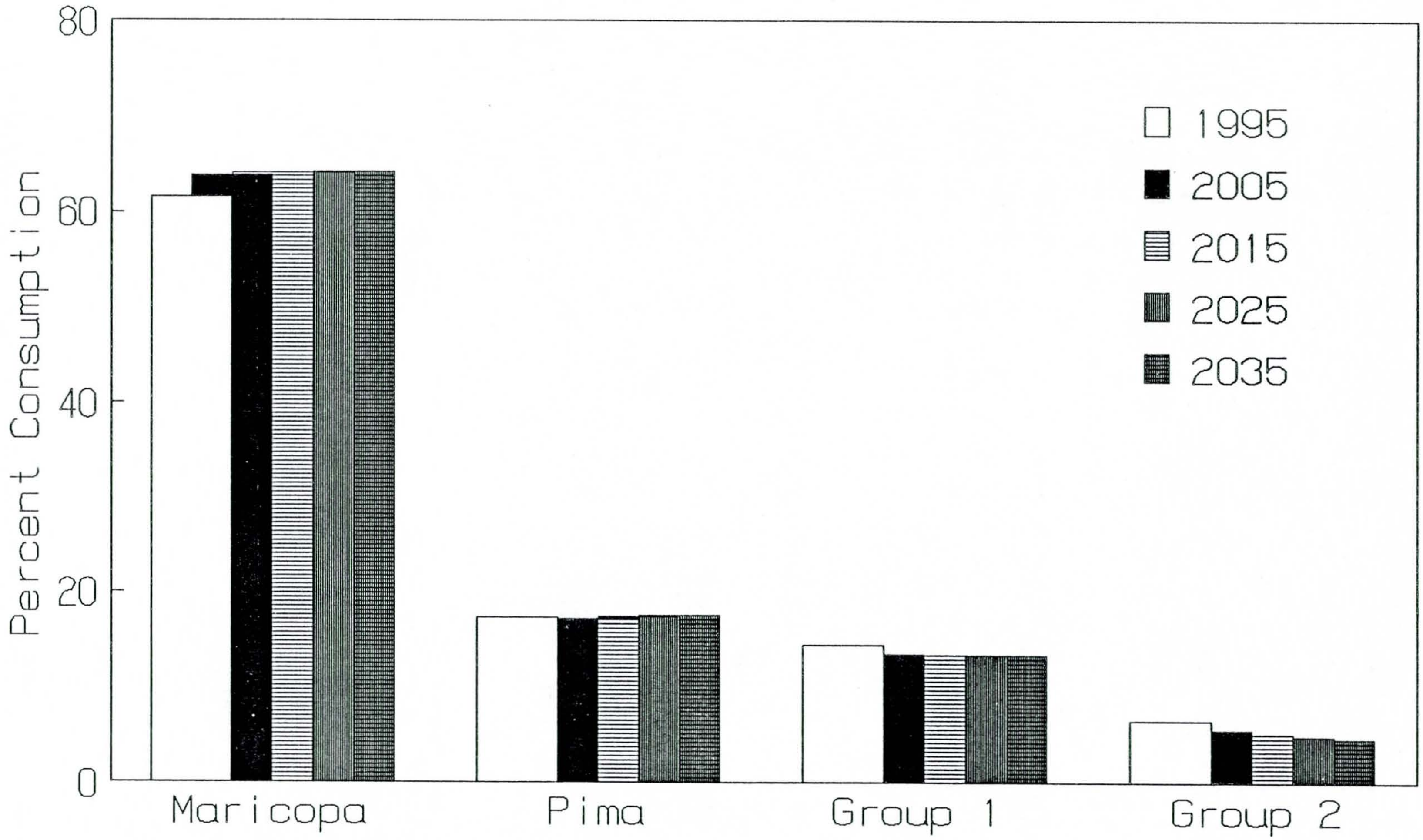
(after Arizona Rock Products Association, 1986) sand and gravel based on forecasted population growth ranges from 440-million tons/decade to 1.1-billion tons/decade. The population forecast anticipates some demographic changes throughout Arizona over the next 50 years. Maricopa County's growth will result in the highest production of sand and gravel. Overall, Maricopa County will result in up to 62 percent for the total state production through 1995, and then average 64 percent through 2035. Pima County's production is expected to reach 17 percent by 1995 and increase to 18 percent through 2035. Together, Maricopa and Pima counties are projected to account for 79 to 82 percent of total state production through 2035. Production rates in Cochise, Coconino, Mohave, Pinal, Yavapai and Yuma are expected to account for fifteen percent of production by 1995 and decrease to 13 percent by 2035. Figure 4.6 graphs the percentage of consumption of sand and gravel by county from 1985 to 2035.

TABLE 4.5. Forecasted Sand and Gravel Production, 1986 to 2035 (Based on population forecasts Arizona Department of Economic Security, 1986)

	Ten-Year Production Rates (thousand tons)				
County	1995	2005	2015	2025	2035
Apache	7056	8683	10305	11984	13601
Cochise	11279	13380	15867	18463	20945
Coconino	10542	13442	16949	20652	24159
Gila	4352	4712	5387	6062	6690
Graham	2786	2750	2961	3198	3414
Greenlee	958	958	979	1009	1030
La Paz	1468	1679	1906	2148	2369
Maricopa	269955	379754	478915	577303	676470
Mohave	8750	11273	14142	17165	20034
Navajo	8786	10254	12082	13957	15790
Pima	76014	100940	128652	157142	184854
Pinal	12123	15445	19189	23046	26785
Santa Cruz	3095	4105	4990	5902	6788
Yavapai	10717	14585	19385	24421	29221
Yuma	10207	12216	14801	17484	20064
Total	438088	594176	746510	899936	1052214

4.3 Market Value

Williams (1967) notes the following about sand and gravel unit prices, and their relation to supply and demand. "When production of sand and gravel is high because of demand, competition among operators is keen and sale prices are usually lower. In addition, higher volume lowers unit production costs and permits profitable operation at a smaller unit profit. Fixed



Group 1: Cochise, Coconino, Mohave, Pinal, Yavapai, Yuma

Group 2: Apache, Gila, Graham, Greenlee, La Paz, Navajo, Santa Cruz

Figure 4.6. Percent Consumption by County (1995-2035)

costs can be spread out and charged to more tons at a lower rate."

The COE (Los Angeles District, 1981) performed a price trend analysis for sand and gravel in the Phoenix area, which gave the following equation:

$$P_t = 1.03 + 0.065t - 0.027t^2 + 0.0029t^3$$

where P_t is the estimated price ($/ton), and t is the cumulative time in years since 1965. The price trend analysis was based on sand and gravel prices from 1965 to 1981. The Corps study reported a 1981 sand and gravel price of $6.80/ton.

The Arizona Rock Products Association (1986) reports a 1985 market value of statewide sand and gravel production of $122.9 million. The value of Arizona production is also reported by the Arizona Bureau of Geology and Mineral Technology in the Mineral Yearbook. The value of output per sand and gravel worker in 1985 was $80,900. This compares to an output of $80,500 per worker in the Arizona electronics industry.

4.3.1 <u>Transportation Costs</u>

Because of the weight of sand and gravel products, and the perishability of concrete, transportation is a major portion of the cost (Arizona Rock Products Association, 1986). Research shows that the additional cost paid for sand and gravel products and ready-mix concrete increases rapidly with transportation distance (Figure 4.7). Most major river reaches in Arizona are paralleled by transportation routes but in some cases, reaches exist that are relatively inaccessible. River reaches that are accessible usually only have a portion of their length that is within a reasonable haul distance of an urban market. Table 4.6 summarizes access and haul distance information for the selected major river reaches in Arizona. Access was considered poor if the river reach was not paralleled by a major transportation route or frequently crossed by a series of routes. The percentage of the reach within reasonable haul distance was determined by measuring a ten-mile radius around all cities in the reach which issued more than 100 residential building permits in 1985.

4.3.2 <u>Employment</u>

Employment statistics compiled by the Arizona Rock Products Association (1986) indicates the very fundamental role that sand and gravel production plays in the construction economy of Arizona. Figure 4.8 shows the relationship between workers in the sand and gravel industry and other workers in the construction industry. The 1,519 sand and gravel workers create essential materials that support an additional 79 jobs (per sand

TABLE 4.6. Access and Haul Distance for Selected River Reaches

Region	River	Reach	Market	Total Length	Marketable Length	Percent Marketable	Percent Urban
Basin & Range	Gila	Confluence-Painted Rock	Yuma	117	6.5	5.5	0
		Painted Rock-Salt River	Yuma/Metro Phx	61	27.5	45.0	0
		Salt River-Coolidge	NM	120	-	-	0
		Coolidge-Safford	NM	70	-	-	0
		Safford-headwaters	NM	LA	LA	-	0
		Hassayampa	Wickenburg	86	18	21	0
		Agua Fria	Avondale	50	24	48	12
		New River	Peoria	47	16.5	35	11
	Salt	Confluence-Granite Reef	Metro Phoenix	38	35	93	43
	Santa Cruz	Confluence-Tucson	Tucson	77	17	22	4
		Rillito/Pantano	Tucson	40	19	48	35
		Tucson-Nogales	Tucson/Nogales	43	27.5	64	7
	San Pedro		Sierra Vista	82	10	12	0
	Bill Williams	Confluence-Alamo Lake	NM	LA	LA	-	0
		Alamo Lake-headwaters	NM	LA	LA	-	0
	Colorado	Border-Imperial	Yuma	35	20	57	9
		Imperial-Parker	NM	LA	LA	-	0
		Parker-Davis	NM	LA	LA	-	0
		Davis-Hoover	NM	LA	LA	-	0
		Hoover-Glen Canyon	NM	LA	LA	-	0
Central Highland	Verde	Confluence-Bartlett	Metro Phoenix	21	12*	60*	0
		Horseshoe-Camp Verde	NM	LA	LA	-	0
		Camp Verde-headwaters	NM	56	-	-	2
	Upper Salt	Roosevelt-headwaters	NM	LA	LA	-	0
Colorado Plateau	Little Colorado	Confluence-Winslow	NM	LA	LA	-	0
		Winslow-Holbrook	NM	-	-	-	2
		Holbrook-headwaters	NM	108	-	-	0
	Puerco		NM	170	-	-	0.6

LA = Limited access
NM = No local market
* = Includes land on Indian Reservation

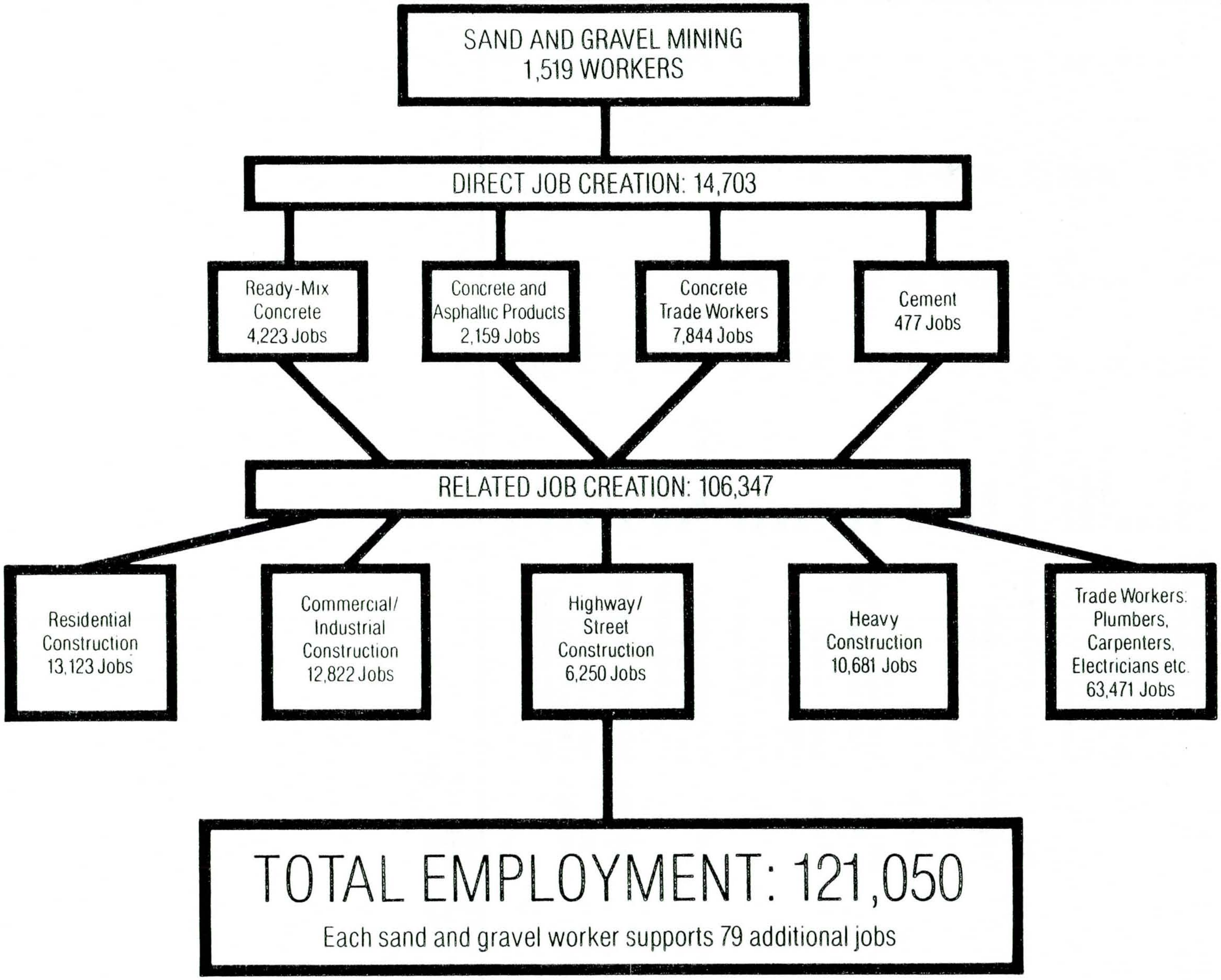


Figure 4.8. Sand and Gravel Employment and Related Construction Industry Jobs.

(after Arizona Rock Products Association, 1986) and gravel worker) in the construction sector of the Arizona economy. The construction industry as a whole results in the creation of other jobs in the service, finance and trade sectors of the economy.

The total 1985 payroll for the sand and gravel industry and various affiliated and related industries approached $2.4 billion. Table 4.7 summaries the 1985 payrolls for these industries.

TABLE 4.7. Payroll in Sand and Gravel and Related Industries (Source: Arizona Rock Products Association, 1986)

Sand and Gravel Mining	$ 28,600,000
Ready-Mix Concrete	98,400,000
Concrete and Asphaltic Products	44,500,000
Concrete Trade Workers	172,600,000
Cement	14,000,000
Residential Construction	231,200,000
Commercial/Industrial Construction	276,000,000
Highway/Street Construction	153,600,000
Heavy Construction	308,200,000
Building Trade Workers	1,063,000,000
TOTAL PAYROLL	$2,390,100,000

4.3.3 Taxes and Fees Paid

The sand and gravel producers are taxed on their investments in land, machinery, and transportation equipment. Property taxes and vehicle fees for 1985 totalled nearly $9 million (Arizona Rock Products Association, 1986). In addition, income, corporation, unemployment and sales taxes amounted to $36.5 million.

V. SOCIAL AND ENVIRONMENTAL FACTORS

5.1 Land Use Conflicts

Sand and gravel mining is an industrial land use and, as such, may conflict with adjacent non-industrial land uses. As with other industrial land uses, sand and gravel mining has operational activities that are considered a nuisance to commercial or residential land uses. Nuisance issues include visual setting, dust in the air, noise of machinery and equipment on site, as well as the effects of truck traffic on flow of local traffic and the frequency of street repairs. Unfortunately, data on these nuisance-level impacts is not generally available.

It is assumed that in areas experiencing urban growth, land-use conflicts will be more likely to occur. These conflicts arise because urban development results in commercial and residential developments on land adjacent to industrial sites. Population growth in urban areas is considered to be a general indicator of potential land-use conflicts. Data on population trends is considered to be the best indicator of social impacts created by sand and gravel mining operations.

It is assumed that river reaches within city boundaries have a strong potential of encountering some conflicts with adjacent land uses. Table 4.6 shows the percentage of a river reach that is within a marketable distance of an urban area that is within urban boundaries. The urban areas associated with metropolitan Phoenix and Tucson have the largest potential for land-use conflicts.

5.2 Proximity to Wildlife Habitat

Data on social and environmental conditions in Arizona are limited. The primary environmental data of interest is the location or riparian and wetland habitat in Arizona. River reaches with perennial and intermittent flows, either natural, regulated or man-induced from waste-water discharges are taken as an indicator of riparian habitat. Sources of data on riparian habitat include the U.S. Fish and Wildlife Service and the Arizona Game and Fish Department. Formal classification and mapping of riparian habitat has not been undertaken for rivers in Arizona. Standards are still under consideration, and actual mapping is probably several years from initiation. The U.S. Fish and Wildlife Service has mapped wetland areas in Arizona at a scale of 1:100,000. In 1981, The Arizona Game and Fish Department published a map of perennial streams and some important wetlands. The perennial-stream information is presented on a U.S.G.S. state base-map at a scale of 1:1,000,000. It was assumed that the amount of riparian and wetland habitats in a river reach provides an indicator of other environmental issues, such as the presence of threatened or endangered species.

It is recognized that habitat resources in the desert environment of Arizona are complex. Ephemeral reaches may provide dynamic habitat that flourishes briefly between dry periods. Likewise, man created habitat may also play a role in providing riparian habitat. Table 5.1 summarizes the relative percentages of perennial and ephemeral reaches of the selected river reaches.

5.3 Noise, Dust, and Visual Pollution

Social impacts to a river reach include air, noise, and water-pollution effects, along with a number of land-use and infrastructure conflicts. A study of the impact of the sand and gravel mining industry on air, noise, and water quality has not been conducted in Arizona. In lieu of such an analysis, it is not known if noise or dust levels at sand and gravel mining operations violate pollution standards. To the extent that noise and dust levels are a nuisance to adjacent property owners, this issue can be classed as a land-use conflict. The same is true of visual resources.

TABLE 5.1. Perennial/Ephemeral Classification of Selected River Reaches (Source: D.E. Brown, Arizona Game and Fish Department)

Region	River	Reach	% Perennial	% Ephemeral	Unclassified
Basin & Range	Gila	Confluence-Painted Rock	0	100	
		Painted Rock-Salt River	0	100	
		Salt River-Coolidge	44	56	
		Coolidge-Safford	24	76	
		Safford-headwaters	46	54	
		Hassayampa	20	-	80
		Agua Fria	24	-	76
		New River	11	-	89
	Salt	Confluence-Granite Reef	0	100	
	Santa Cruz	Confluence-Tucson	0	9	91
		Rillito/Pantano	10	90	
		Tucson-Nogales	0	100	
	San Pedro		0	100	
	Bill Williams	Confluence-Alamo Lake	17	83	
		Alamo Lake-headwaters	46		54
	Colorado	Border-Imperial	100		
		Imperial-Parker	100		
		Parker-Davis	100		
		Davis-Hoover	100		
		Hoover-Glen Canyon	100		
Central Highland	Verde	Confluence-Bartlett	100		
		Horseshoe-Camp Verde	100		
		Camp Verde-headwaters	100		
	Upper Salt	Roosevelt-headwaters	100		
Colorado Plateau	Little Colorado	Confluence-Winslow	8		92
		Winslow-Holbrook	23	77	
		Holbrook-headwaters	65	35	
	Puerco		-	-	100

VI. STATEWIDE CLASSIFICATION OF RIVER REACHES

A classification matrix was developed to facilitate the selection of river reaches for further detailed analysis. See Table 6.1. The river reaches were qualitatively rated according to the following criteria: resource quality/quantity, market demand/access, structure hazard, and social/environmental conditions. The rating was judgemental, based on the information presented in this report.

The weighting of each of these four categories relative to the others is highly dependent upon the objective or purpose of the matrix system analysis. For this study, the goal of the classification matrix was to select river reaches for detailed study of the effects of in-stream mining on channel stability. Consequently, more weight was given to the resource, marketability, and structure hazard factors as compared to the social/environmental criteria. These first three factors were weighted equally relative to each other. A weighting factor of zero was applied to the social/environmental factor. This is not to say that social/environmental criteria are of no importance, but rather it is a reflection of the importance of this factor to the purpose of this classification matrix in this study. Given another study with different goal objectives, the relative weighting of these factors would necessarily be different.

Social/environmental conditions are a very real consideration to be accounted for in the decision of whether or not to pursue a permit for mining a particular reach. The environmental sensitivity of a particular river reach can impact the economic viability of operating there. The compliance requirements of other laws related to wildlife and/or habitat protection and the increased coordination required with the appropriate regulatory agengies must be accounted for where the mining potential of a particular reach is being considered. However, with regard to this study, it was determined that the factors of resource quality/quantity, market demand/access, and structure hazard outweighed the social/environmental conditions in importance relative to the objective of this classification matrix. In addition, the realistic limitation of adequate data availability also impacted the river reach selection.

Ranked according to all factors in the classification matrix except social/environmental conditions, river reaches near the two major metropolitan areas score highest. These river reaches include:

	Matrix Score
Salt River-Confluence to Granite Reef	17
Santa Cruz-Marana to Sahuarita	16
Rillito/Pantano Rivers	16
Gila River-Salt River to Coolidge	15

Agua Fria River	15
New River	15

River reaches which scored in the moderate range include:

	Matrix Score
Santa Cruz-Confluence to Marana	13
Santa Cruz-Sahuarita to Nogales	12
Gila River-Coolidge to Safford	12
Gila River-Confluence to Painted Rock	11
Gila River-Painted Rock to Salt River	11
San Pedro River	11
Verde River-Camp Verde to headwaters	11

These river reaches are a greater distance from the major metropolitan areas, but have local markets and the potential to export to the larger metropolitan areas.

As a result of the evaluation of the statewide classification matrix, the following eight river reaches were selected for detailed study:

1. Salt River-Hayden Road to Country Club Drive
2. Salt River-59th Avenue to 19th Avenue
3. Verde River-2-mile reach near the Dead Horse Ranch Crossing at Cottonwood
4. Verde River-1.5 miles downstream to 1.5 miles upstream of the I-17 bridge
5. Agua Fria River-Buckeye Road to Camelback Road
6. New River-Agua Fria River confluence to Peoria Avenue
7. Santa Cruz River-I-19 bridge to 3-miles downstream
8. Rillito Creek-I-10 bridge to 3-miles upstream

The reaches were selected from the highest ranked river reaches in the classification matrix with the exception of the Verde River. Subreaches were identified within the larger river reaches that had the best information available with which to formulate the engineering parameters database (see Chapter IX). The reaches on the Verde River were included to provide more information on gravel-bed conditions.

TABLE 6.1. Matrix System to Select River Reaches for Detailed Study

River Reach	Resource Quality	Resource Quantity	Marketability Demand	Marketability Access	Structure Hazard Historic	Structure Hazard Future	Social/Environmental Urban	Social/Environmental Wildlife
GILA:								
Confluence-Painted Rock	3	3	1	2	1	1	1	2
Painted Rock-Salt River	3	2	2	2	1	1	1	2
Salt River-Coolidge	3	3	1	2	3	3	1	3
Coolidge-Safford	3	2	1	2	2	2	1	3
Safford-headwaters	NA	NA	1	1	1	1	1	3
Hassayampa	3	1	1	2	1	2	1	3
Agua Fria	3	1	3	3	2	3	3	3
New River	3	1	3	3	2	3	3	3
SALT:								
Confluence-Granite Reef	3	2	3	3	3	3	3	2
SANTA CRUZ:								
Confluence-Marana	3	2	2	1	2	3	1	2
Rillito/Pantano	3	1	3	3	3	3	3	3
Marana-Sahuarita	3	1	3	3	3	3	2	2
Sahuarita-Nogales	3	1	2	1	2	3	2	2
SAN PEDRO:	3	2	1	2	1	2	1	2
BILL WILLIAMS:								
Confluence-Alamo Lake	NA	1	1	1	1	1	1	3
Alamo Lake-headwaters	NA	1	1	1	1	1	1	3
COLORADO:								
Border-Imperial	NA	1	2	3	1	1	2	3
Imperial-Parker	NA	2	1	1	1	1	1	3
Parker-Davis	NA	1	1	1	1	1	1	3
Davis-Hoover	NA	NA	0	0	0	0	1	3
Hoover-Glen Canyon	NA	NA	0	0	0	0	1	3
VERDE:								
Confluence-Bartlett	NA	1	1	2	1	2	1	3
Horseshoe-Camp Verde	NA	1	1	1	1	1	1	3
Camp Verde-headwaters	3	1	2	2	1	2	2	3
UPPER SALT:								
Roosevelt-headwaters	NA	NA	1	1	1	1	1	3
LITTLE COLORADO:								
Confluence-Winslow	NA	2	1	1	1	1	1	2
Winslow-Holbrook	NA	2	1	3	1	1	1	3
Holbrook-headwaters	1	2	1	2	1	1	1	3
PUERCO:	1	3	1	2	1	1	1	2

RANKING SCALE
0 = None
1 = Low
2 = Medium
3 = High
NA = Not Available

VII. REVIEW OF METHODOLOGIES FOR SAND AND GRAVEL MINING IMPACT ANALYSIS

7.1 General

Sand and gravel mining may induce local headcutting, sediment backfill, and clear-water scour upstream, within and downstream of the gravel pit. The scour and fill processes induced by the pit will progress both upstream and downstream. In cases where sand and gravel extraction exceeds replenishment of sediments, net degradation of the river bed will result. The magnitude of river degradation can be analyzed by field measurements, physical models, and analytical methods.

7.2 Methods Using Field Measurements

Using conventional field surveys or topographic mapping, river changes due to sand and gravel mining can be measured by comparing the cross sections and channel profiles before and after mining. This technique has been applied to investigate sand and gravel mining effects in a number of cases.

This method requires a large number of measurements over time and along a river. Accuracy of the method is limited since maximum scour may occur between river sections or between measurement periods. Maximum scour measurements may be critical in assessing the impacts on floodplain structures. The method also requires a long-term commitment of resources to collect, reduce and record the data. The method is probably best suited to monitoring sand and gravel operations. Use of field data alone to predict future river response to mining activity is limited to statistical approximations.

Studies using field data have inferred that sand and gravel mining operations contributed to bank erosion and river degradation. Kira (1972) showed a relationship between data on river degradation and the sand and gravel extraction quantity for the Yasu River, Japan. This relationship indicated that long-term degradation is proportional to the extraction quantities regardless of short-term river-bed fluctuation.

Scott (1973) illustrated the scour and fill phenomenon near a gravel pit located in an inactive channel of Tujunga Wash in Southern California. The old channel was activated by flood water breaking out of the existing main channel. The headcut erosion extended about 3,000 feet from the gravel pit boundary and caused failure of three major highway bridges. In addition, lateral scour damaged the properties lying between the inactive south channel and the existing north channel.

Lagasse et al. (1981) studied the effects of gravel dredging along the lower Mississippi and concluded that historical dredging in this river reach has caused reduction of bed material sizes and an increase in the number of divided-flow reaches, and has affected the overall stability of the river system and structures. Mossa (1983) investigated changes of the channel meander and geometry in the middle Amite River, Louisiana, from 1941 to 1981. The increased channel width, meander cutoff and middle channel bars were attributed to intensive sand and gravel mining over many years. The extraction disrupted riparian vegetation and gravel bars, and increased bank erosion and channel cutoff.

To measure the maximum scour caused by a sand and gravel pit, Bull and Scott (1974) installed a scour chain in the Rillito River, Arizona, in 1973. This technique is more economical than measuring entire cross sections and channel profiles, and can provide critical scour information during the flood. This technique, however, is limited to local application.

7.3 Physical Model Study

Chen (1980) conducted a physical model study to investigate the gravel mining effects on the stability of the Salt River channelization system and the Interstate 10 channel. The physical model was applied to examine the headcut and backfill processes for thirteen hypothetical cases containing various combinations of gravel pit dimensions and flood hydrographs. A rectangular pit was assumed in these cases. Using the model results, the extent of headcut erosion, downstream scour and lateral scour (due to lateral inflow to the pit) were expressed graphically as a function of gravel pit depth. These relationships reveal that the scour depth and length increase proportionally to the depth of the pit.

Although the physical model study can provide valuable information on the potential sand and gravel mining impact, it may not be feasible for general planning and analysis because of the following reasons: (1) physical model facilities and operation are costly; (2) sediment discharge scaling problems; and (3) sediment inflow to the pit is hard to simulate and may affect the accuracy of the model results.

7.4 Analytical Methods Developed for Alluvial River Studies

7.4.1 Sediment Transport Technology

Sediment transport technologies developed for alluvial river studies are applicable to sand and gravel mining impact analysis. Publications by Shen (1971a, 1971b, 1979), Simons and Senturk (1977), Schumm (1977), Simons, Li & Associates (1982a), and Wang et al. (1986) document various methodologies available for studying hydrology, hydraulics, sediment transport and geomorphology of an alluvial river.

Specifically, the unit hydrograph procedure (Sherman, 1932), HEC-1 model (Hydrologic Engineering Center, 1981), and SWMM model (Huber, et al., 1982) are typical methods for hydrologic analysis. Normal depth computations using the flow continuity principle and Manning's equation are applicable if flow depths are nearly uniform throughout a given river reach. The HEC-2 model (Hydrologic Engineering Center, 1976, 1982), developed for solving the energy equation for gradually-varied flow, can be used to obtain the backwater profile. The hydraulic conditions in a river reach can also be assessed using the momentum equation.

Shields' criteria (1936) are frequently referenced in the incipient-motion analysis of a sediment particle. This relationship can be utilized to estimate the armor size of bed materials for a given flow or to size riprap for channel scour protection. Once set in motion, sediment particles are transported by the flow in one or a combination of the following ways: (1) rolling or sliding on the bed (surface creep); (2) jumping into the flow and then resting on the bed (saltation); and (3) supported by the surrounding fluid during its entire motion (suspension). Based on these mechanisms and sources of sediments, bed load, suspended load, wash load, and bed-material load are defined for sediment transport analysis as follows.

The term "bed load" applies to sediments transported by surface creep or saltation. Sediments which are suspended by flow are referred to as "suspended load", "wash load" is the part of the total sediment load which consists of particle sizes finer than those represented in the river bed. Excluding wash load from total load (bed load plus suspended load) leaves the bed-material load. Wash load is mainly determined by watershed production and bank erosion, and may play an important role in changing river morphology. However, for sediment transport analysis and river response evaluation (considering sand and gravel mining impacts), only the bed-material load is of primary consideration.

The mechanism of sediment transport is very complicated. Although previous research work has made the computation of sediment transport capacity possible, improvements in this area are still needed, as each methodology has its limitations. Without a consistent calibration and verification procedure, a large difference may exist in the application of different computational methods. Careful selection and thorough understanding of the methodology may lead to a more successful application.

Of the bed-load equations, those derived by Duboys (1879), Meyer-Peter Muller (1948), Einstein (1952, 1950) and Toffaleti (1968, 1969) are frequently referenced. The Einstein method (1950) also includes the suspended-load equation. Representative theoretical based methods for computing total load include the modified Einstein method (Colby and Hembree, 1955), Toffaleti's method (1969), and the Bishop et al. approach (1965). Regression analysis of existing sediment transport data from flumes and field sites has lead to new formulas for total sediment load. Representative regression based methods include Shen and Hung's approach (1971), Yang's method (1982), Lu and Li (1986), Zeller and Fullerton (1983), and Karim and Kennedy (1981).

7.4.2 Computer Models for River Response Simulations

In 1983, The Federal Emergency Management Agency, in association with the National Research Council conducted an evaluation of flood-level prediction using alluvial river models (Committee on Hydrodynamic Computer Methods for Flood Insurance Studies, 1983). Six computer models developed for alluvial river simulation were evaluated:

1. HEC-2SR, developed by Simons, Li & Associates, Inc. (1980c)
2. KUWASER, developed by Simons, Li and Brown, Colorado State University (1979)
3. UUWSR, developed by Chen and Simons, Colorado State University (1975)
4. HEC-6, developed by Thomas and Prasuhn, U.S. Army Corps of Engineers Hydrologic Engineering Center (1977)
5. FLUVIAL-11, developed by Chang and Hill, San Diego State University (1976), and
6. SEDIMENT-4H, developed by Ariathurai, Resource Management Associates (1980).

Model theories, computational methods, assumptions, data requirements, limitations and applicability were documented, and the results of application to the San Lorenzo River (City of Santa Cruz, California), San Dieguito River (San Diego County, California), and the Salt River (Phoenix, Arizona) were compared. Table 7.1 summarizes the major features of each model. Although none of the alluvial-river models evaluated was found to yield wholly satisfactory results, considerations of the sediment redistribution and bed-armoring effect by HEC-2SR, expression of the sediment transport equation in a simplified power-law function by KUWASER and UUWSR, and simulation of channel widening by FLUVIAL-11 were evaluated favorably.

Since the completion of the NRC study, several new alluvial-river models have been introduced. They include IALLUVIAL, developed at the University of Iowa, and STARS, developed by the U.S. Bureau of Reclamation. Holly and Karim (1985) applied IALLUVIAL to simulate bed degradation in the middle Missouri River as part of an evaluation of downstream environmental consequences due to man-imposed changes to the upper Missouri

TABLE 7.1

Summary of Characteristics of Alluvial-River Simulation Models

Model	Hydraulic Computations	Sediment-Transport Computations	Armoring or Sediment Coarsening	Lateral Migration
HEC-2SR	-Flow continuity eq. (known discharge) -Flow energy eq. -Energy head loss	-Meyer-Peter, Muller (1948) and Einstein (1950) -Sediment continuity eq. -Routing by sediment size	-Sediment redistribution during routing -Simulation of river armoring.	N/A
KUWASER	-Flow continuity eq. (known discharge) -Flow energy eq.	-Power-law function of velocity and depth -Sediment continuity eq.	N/A	N/A
UUWSR	-Flow continuity eq. (unsteady flow) -Flow momentum eq.	-Power-law function of velocity -Sediment continuity	N/A	N/A
HEC-6	-Flow continuity eq. (known discharge) -Flow energy eq.	-Options for Laursen (1958), Toffaleti (1968), Yang (1973), DuBoys (1879), Brown (1950) and a special function of depth and energy slope.	N/A	N/A
FLUVIAL-11	-Flow continuity eq. (unsteady flow) -Flow momentum eq.	Graf (1971) or Engelund-Hansen (1978)	N/A	One-dimensional flow assumption with limited coordination of channel width change.
SEDIMENT-4H	-Flow continuity eq. (unsteady flow) -Flow momentum eq.	Rouse (1937)	N/A	N/A

River basin. The STARS model was applied by the Bureau to describe water and sediment movement on the East Fork near Boulder, Wyoming (Orvis and Randle, 1986).

The major function of the alluvial-river models just presented is large scale simulations of general river response. Assessment of the headcut and backfill processes of a sand and gravel pit requires the spatial and temporal resolution at a smaller scale. The sediment routing model, PIT, simulates headcut, sediment backfill and downstream scour adjacent to a sand and gravel pit. Model PIT was developed by Dr. Ruh-Ming Li and Lan-Yin Li of Simons, Li & Associates. The model was developed for investigating the headcut effect on San Juan Creek and Bell Canyon, Orange County, California, associated with the Consolidated Rock (Conrock) gravel mining operation (Simons and Li, 1978). The model was calibrated for this study using the scour data measured after the January and February, 1969, flood. The applicability of the developed model was validated using the January, February and March, 1978, storm. Simulation of the headcutting process by Model PIT was further verified with physical model observations (Chen, 1980). The Model PIT was applied in the development of qualitative guidelines for sand and gravel mining in the Salt, Gila and Agua Fria Rivers, Arizona. The model was applied to the Rillito River for evaluating the legal responsibilities of sand and gravel mining operators for damage to the Oracle Highway bridge in Tucson, Arizona (SLA, 1980b) and to the Columbia and San Xavier sand and gravel pits on the floodplain of the Santa Cruz river near Cortaro Farm Road, Pima County, Arizona (SLA, 1981). The model has also been applied to assist the authorities of Ventura County, California, in evaluating various sand and gravel mining alternatives proposed along the Santa Clara River, and to develop a sand and gravel mining standard (SLA 1983a, SLA 1980a).

The HEC-6 program was modified in 1980 by MacArthur and Montalvo (1980) to simulate in-stream sand and gravel mining operations. The modifications allow users to specify rates of mining for specific mining locations. Mining activity can also be indicated for different periods in the simulation. Application of the program was made to simulate sediment transport and flow conditions in the Kansas River.

7.4.3 The Three-Level Approach

To date, methodologies for sediment transport computation and simulation of river changes are still in the process of refinement and improvement. Application of the sediment transport equations and sediment routing models presented above requires significant knowledge of the methodologies selected and the physical system and processes of interest. A three-level approach was suggested by Simons and Li (SLA, 1982a) for analysis of a watershed and river system. The three phases or levels for assessing problems relating to a watershed or river system are:

Level I: A qualitative analysis based on general geomorphic parameters.

Level II: A quantitative analysis based on specific geomorphic concepts and basic engineering relationships.

Level III: Mathematical modeling to simulate the physical processes of river response.

The Level I approach is to understand the entire river system, instead of an individual site-specific observation. This approach requires significant data describing the past and present conditions of the river system and the historical changes due to man's activities. In particular, evidence of bank cutting, thalweg shifting, lateral migration, channel down-cutting, sediment deposition, and vegetation changes can be studied based on field investigations and using aerial photographs and channel geometry data for different years.

To quantitatively describe the hydrologic, hydraulic and geomorphic characteristics of a fluvial system, the Level II analysis is applied subsequent to the Level I analysis. The Level II analysis relies mainly on the empirical, theoretical or experimental engineering relations and equations developed for fluvial system analysis, such as rigid boundary water surface profile calculations and the sediment transport equations mentioned previously. This analysis can provide more specific quantitative information to supplement the conclusions from qualitative investigations.

A Level III analysis is employed when more detailed information on river bed changes is needed. This level uses alluvial river models with their calibration based on the Level I and II analyses. The results of a Level II analysis provides a sound engineering base for preparation of model application.

7.5 Procedures for Developing Sand and Gravel Mining Regulations

7.5.1 The "Red-line" Procedure

The technical methods described previously can be applied to develop sand and gravel mining regulations. A procedure recommended by Simons, Li and Associates (1983a), which was applied in the development of an "Optimal Red-line Standard" for the Santa Clara River, Ventura County, California, is as follows:

1. Review sand and gravel mining and channel degradation history;
2. Evaluate qualitatively the stream morphology and identify the erosion or sedimentation pattern;

3. Determine quantitatively the hydraulic, sediment transport and erosion or sedimentation characteristics for the baseline (pre-mining) conditions, including model simulation if necessary;
4. Define specific erosion and sedimentation control objectives for each channel reach, considering the erosion and sedimentation features of the reach and the potential impact on the upstream and downstream reaches;
5. Repeat Step 3 for the proposed mining plans;
6. Estimate the scour potential (including local scour and general degradation) under the proposed mining conditions and compare the results with the available scour protection. Identify the critical structural elevations for sand and gravel mining control;
7. Based on the results of Steps 3, 4, 5, and 6, recommend optimal "red-line" slopes, river control elevations, and lateral limits for sand and gravel extraction;
8. Perform degradation or aggradation analysis for the proposed mining condition based on the optimal "red-line" standard.

The optimal "red-line" standard was determined considering the following major factors:

1. Erosion and sedimentation characteristics of the existing channel;
2. Scour potential under worst mining conditions; and
3. Critical structural elevations.

In the case of Ventura County, stability of critical structures is the foremost of these factors.

7.5.2 U.S. Army Corps of Engineers Sand and Gravel Mining Guidelines

Operation, reclamation, and administrative guidelines for sand and gravel mining were developed by Boyle Engineering for the COE (1980). It was recommended that these guidelines be implemented through a permit process. The operational guidelines call for extraction to be conducted in accordance with approved plans, and that operations not obstruct natural flow or cause damage to adjacent structures. No excavation, stockpiling, or obstruction of the floodway would be permitted during flood-prone months. Excavation should be located far enough downstream of a structure so that a grade of one percent, beginning at the midpoint of the pit depth, would intercept the channel bed at least 200 feet downstream of a structure. Excavation would be set back 100 feet from the riverbank or below a plane at a slope of ten percent from the toe of the streambank, whichever is greater. Excavation would not be permitted below the existing low flow line unless channel stability could be demonstrated. Excavation would be conducted in a continuous manner, not as "leapfrogged" pits. The applicant would be required to assess potential hydraulic effects that might cause loss of property or environmental degradation, using a qualified engineer at the owners expense. Significant impacts would have to be addressed with appropriate mitigation measures.

The guidelines would require approved reclamation plans involving repair of damaged streambanks, removal of waste piles and equipment, stabilization of pit slopes, stabilization of streambanks to prevent erosion, and measures to limit access to abandoned pits. The guidelines would provide administrative procedures for monitoring of gravel operations, and measures to assure compliance with reclamation plans (i.e., performance bonds, liens). The regulating agency would also have the authority to suspend gravel-mining operations.

VIII. MITIGATION MEASURES

The harvesting of aggregate materials from specified study reaches has been quantified, and the subsequent impacts on channel topography analyzed for both short-term and long-term conditions. Chapter X of this report discusses long-term conditions, and Chapter XI covers short-term conditions. The response of river reaches to in-stream mining operations has been determined from the data to include headcut scour, lateral migration, and accelerated degradation within and directly downstream of an actively-mined reach. The purpose of this section of the report is to present a list of mitigation measures that could be implemented to control off-site migration of in-stream scour due to gravel mining.

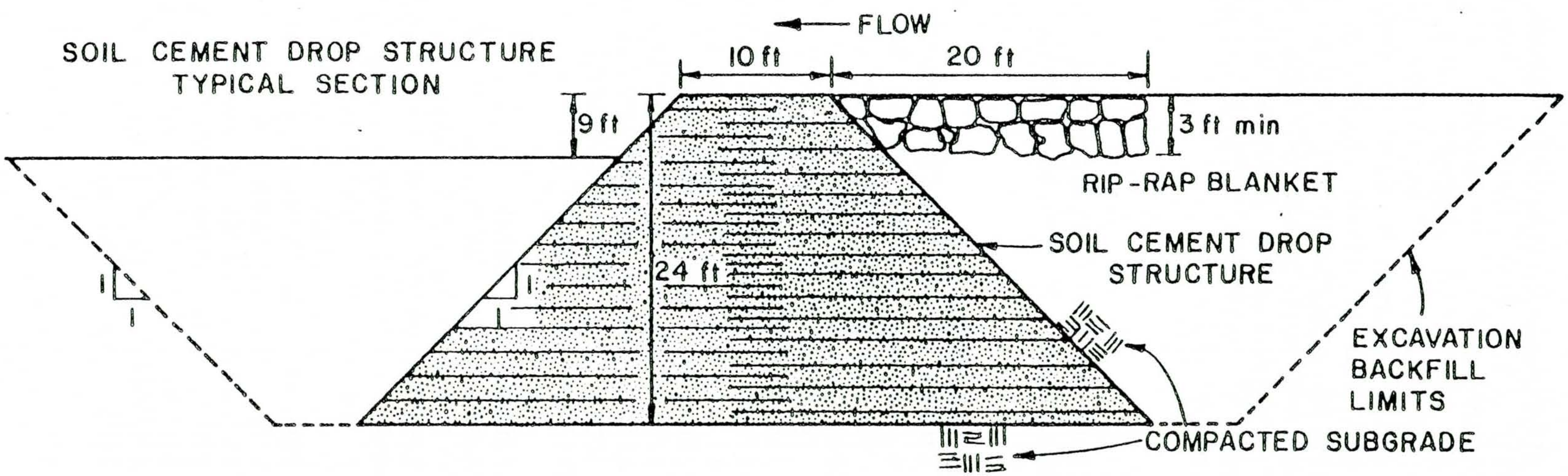
8.1 Structural Measures

Two structural measures for mitigating in-stream mining impacts have been identified as being both functional and effective.

8.1.1 Grade-Control Structures

Grade-control structures are effective channel stabilization measures that may be used either singly or as an integral part of a stabilization plan. The primary function of a grade-control structure is to decrease the gradient of a channel to either create a condition of equilibrium (sediment inflow equal to sediment outflow), or to reduce the protection required from other stabilization measures. Grade-control structures located directly upstream of a gravel pit will protect against the propagation of upstream headcut scour caused by the acceleration of the flow into the excavated area. Locating a grade-control structure directly downstream of a structure (i.e. bridge, road, utility crossing) will serve to control general scour, and reduce the likelihood of failure due to undermining of its foundation.

Grade-control structures can range in complexity from simple rock riprap, to soil-cement drop structures, to large concrete structures with baffled aprons and stilling basins. Depending upon the site-specific requirements, several alternative designs and materials may be appropriate for use in the construction of a grade-control structure. Suitable materials include soil cement, dumped or grouted rock riprap, rock and rail structures, or reinforced concrete. Figures 8.1 through 8.3 show typical cross sections of grade-control structures of various materials. Alternative designs might also include a series of terraces laid back at some stable slope to form the upstream face of a gravel pit. This configuration would act as a multiple-drop grade-control structure, effectively controlling upstream headcutting by reducing the total drop into the gravel pit to a series of stairstep increments.

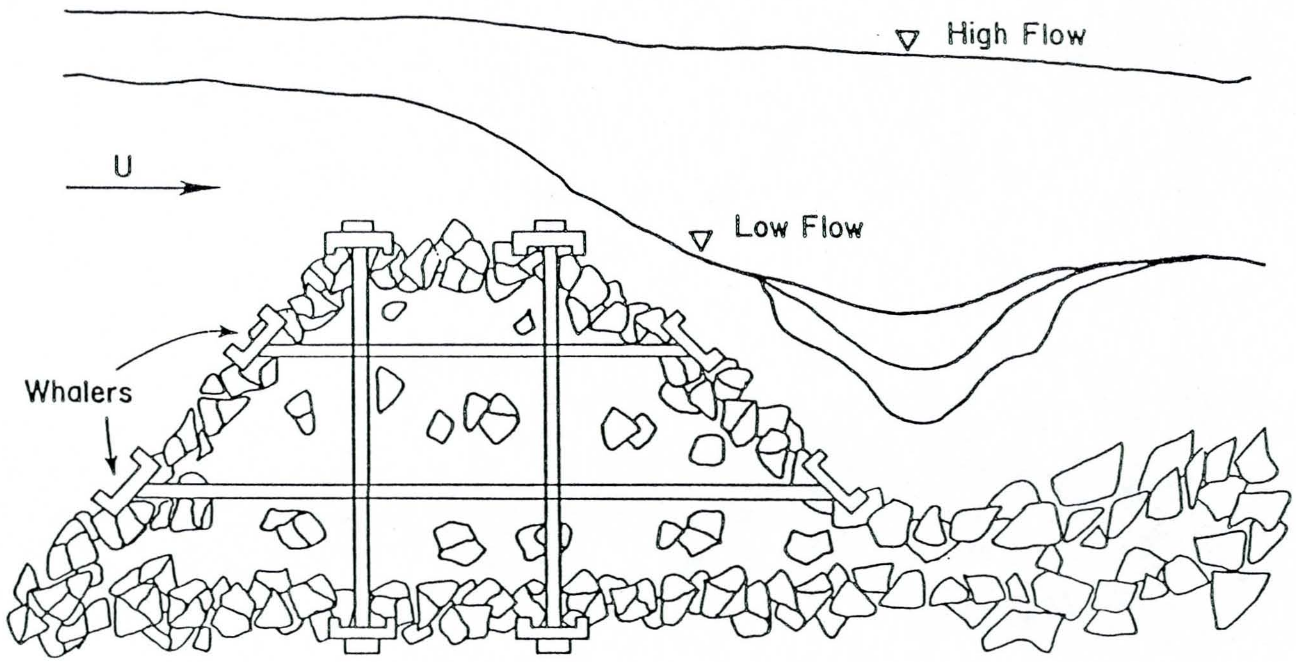


(AFTER RICHARDSON, ET AL, 1987)

sla Simons, Li & Associates, Inc.

SOIL CEMENT GRADE CONTROL STRUCTURE

FIGURE 8.1



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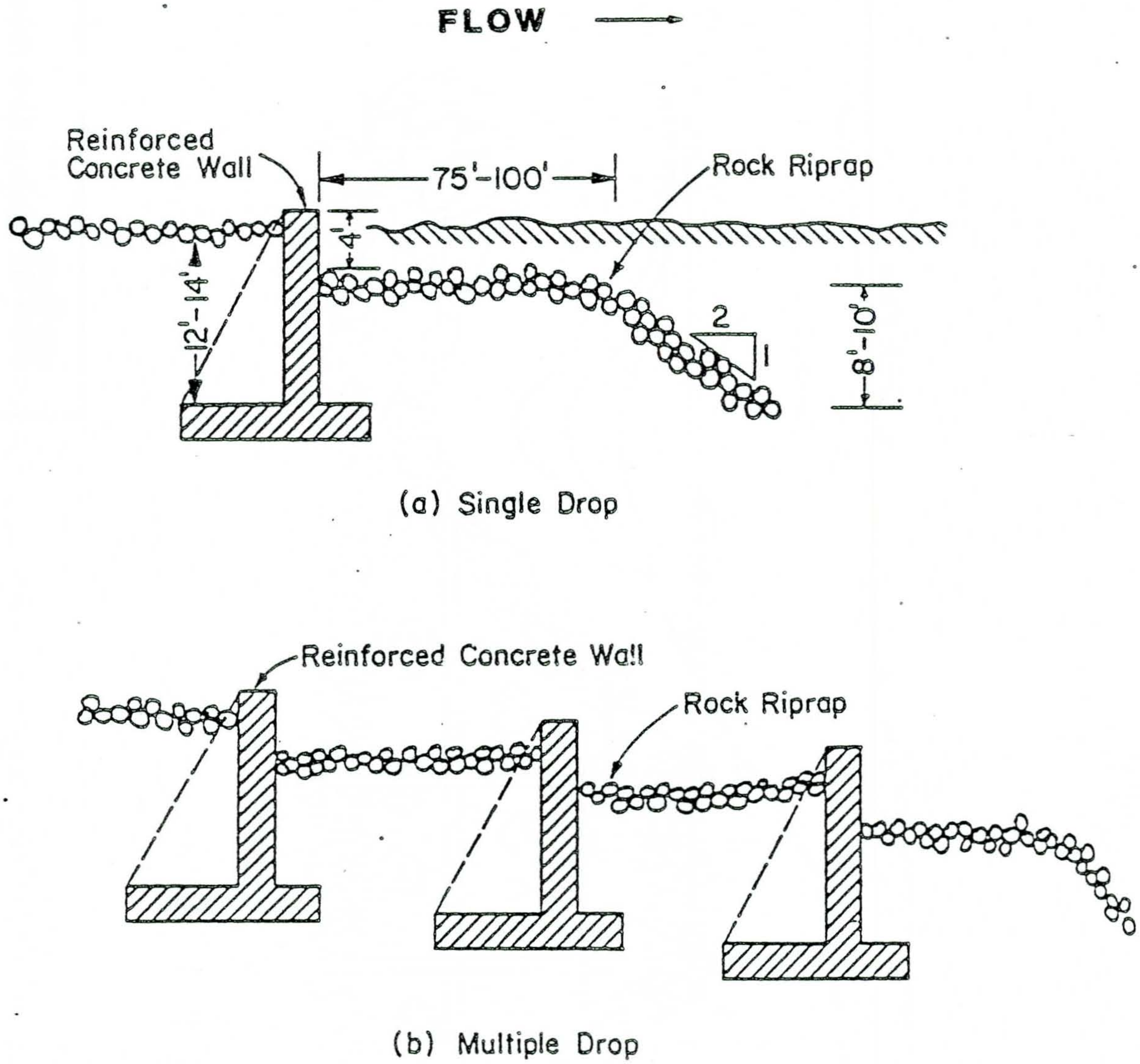
ROCK & RAIL GRADE CONTROL STRUCTURE

FIGURE 8.2



(AFTER SLA, 1980a)

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REINFORCED CONCRETE GRADE CONTROL STRUCTURES

FIGURE 8.3

Outflanking of the grade-control structures can be prevented by maintaining lateral flow control with stable bank protection both upstream and downstream of the grade-control structure. To be most effective, grade-control structures should extend across the full width of the channel such that the ends tie into erosion resistant material to prevent a headcut from by-passing the grade-control structure.

8.1.2 Flow-Control Structures

Flow-control structures involve multiple types of applications of flow regulation and control, which serve several purposes. These include flow-diversion dikes, channelization schemes, and guide banks at bridges.

Properly designed, armored diversion dikes located upstream of gravel pits can eliminate upstream headcutting. The dikes divert low flows away from the upstream pit face, where headcutting normally occurs. To maximize effectiveness, diversion dikes must be properly positioned to efficiently deflect flows away from actively-mined gravel pits. The dikes should constitute a barrier to flows in secondary channels of braided river systems by extending across the full width of the secondary channel thereby protecting the mining operation by diverting flows towards the primary channel. The dike length and positioning should not be constrained by the property boundaries of the mining operation; rather, easements should be obtained, as necessary, to facilitate the proper placement of the diversion dike. In addition, adequately designed bank protection should be provided to stabilize dike slopes, and sufficient toe-down of the bank protection must be provided to ensure structural integrity.

Gravel mining can take place closer to channelization, levees, and transverse dikes if dikes are provided around the pit, or the pit is inundated prior to flooding conditions. If dikes are constructed around the gravel-mining operation, hydraulic computations should be made to assess what effects the dikes will have on the 100-year water-surface elevation in the area. Gravel-mining operations should create no flow obstructions or diversions, other than for headcut prevention, during months of high flood risk.

The implementation of a channelization scheme can control the location and direction of the flow, thus preventing low flows from capturing a gravel pit and minimizing the potential for lateral migration of the main channel and upstream headcut propagation.

Guide banks at bridges control the position of scour, and protect the abutments by guiding the flow of water through the bridge opening. Accelerated scour downstream of a gravel pit or a propagating headcut upstream of a pit face could be directed, by means of guide banks, to occur at a location in the bridged cross-section where such scour was anticipated and provided for in the foundation design.

Flow-control structures should be designed in keeping with the prevailing behavior of the river. Operation and maintenance will be problematic for structures which work counter to river direction, and other flow characteristics. River-training works in large river systems will require more complex analysis and design in the implementation of flow-control strategies.

8.2 Non-Structural Measures

8.2.1 Buffer Zones

Buffer zones which provide for a conservative setback distance between gravel-pit operations and in-stream structures could be established as an alternative to structural stabilization measures, or to work in conjunction with such structural measures. A buffer zone would serve to mitigate the effects of headcut propagation or lateral migration of the channel thereby shielding the structure (i.e., bridge, road, utility crossing) from damage due to these phenomena. The buffer zone would require periodic maintenance following major flows. Setback requirements would be established in conjunction with the right-of-way requirements for the structure, so that adequate right-of-way could be acquired when the bridge/utility crossing was to be built.

8.2.2 Operation Standards

Operation standards, enacted and enforced through county ordinances, would regulate the mining and processing of aggregate materials. These standards would serve to reduce flood and erosion damages associated with sand and gravel mining operations by establishing operational guidelines that specify minimum acceptable practices related to the manner in which sand and gravel is to be mined.

Candidate operation standards pertaining to channel stability would address various aspects of aggregate mining, including, but not limited to, the following:

* Setback requirements between pit location and in-stream structures.

* Slope restrictions for gravel pits (i.e., specify a slope that is flatter than the angle of repose for stability purposes).

* Limitations on pit location, phasing, and configuration (i.e., the pit should be continuous, uniform in shape, and not sinuous with respect to channel grade).

* Requiring continuous backfilling of the pit, with suitable material, to limit the active volume of the pit and keep the duration of headcutting to a minimum prior to pit drown-out.

* Seasonal shutdown requirements (i.e., gravel-mining operations should create no flow obstructions or diversions, other than for headcut prevention, during months of high flood risk).

8.3 Conclusions

The proper approach to the implementation of mitigation measures for a specific river reach would involve the development of a comprehensive plan for aggregate mining in that system from a resource-management perspective. It would include the selection of a cost-effective combination of measures, both structural and non-structural, which would efficiently mitigate impacts to in-stream structures while allowing for the continued use of the aggregate resources in the river system. In addition, closer attention would be paid to the protection of endangered structures, both in a remedial context and in the planning and design of in-stream structures and appurtenances, such that consideration is given to the impacts of existing and impending mining operations upon these structures.

IX. ENGINEERING PARAMETERS

Engineering parameters were formulated to facilitate the development of technical procedures for assessing the effects of in-stream mining on channel stability. The development of engineering parameters required the compilation of four datasets of known physical measurements for each of the eight study reaches. The resulting engineering parameters database provides a quantitative description of river characteristics over time, and the factual basis underlying the technical procedures.

The database is composed of four data sets, each covering a relevant feature of the river system, including: river channel topography, bed material gradations, hydrologic conditions, and mining activity. For the most part, the data sets were derived from existing sources of information. For analysis, the information was encoded into a computer database. The following paragraphs briefly summarize each of the data sets in the engineering parameters database, each of the datasets is described in detail in a separate technical appendix.

The topographic data set (Appendix G) consists of large scale maps prepared for use in flood boundary delineation. For most of the study reaches, two periods of mapping were identified. This permitted a direct comparison of channel and floodplain elevations over a period of years. To facilitate this comparison, the maps were digitized into a two-dimensional matrix of elevations that covered the width and length of each study reach. The location of main channel banks was noted in the matrix, which permitted the identification of in-stream or floodplain activities. In addition to the two dimensional matrix of elevations, the channel thalweg profile was determined.

During the course of the study, an active area of channel erosion in the Salt River study reach near Alma School Road was identified. The erosion occurred during a three-week period of regulatory releases by the Salt River Project in the Spring of 1987. The topographic changes were determined by comparing aerial mapping conducted by ADOT in December 1986, to an aerial map of the same area produced for this study. These measurements provided a topographic data set for calibration of the channel response model.

Information on bed material gradations (Appendix H) in the study reaches was compiled from two sources. The first source was the a database maintained by the ADOT Materials Section containing records of gradation tests conducted on material pits throughout Arizona. Review of the ADOT Material Inventory and files at the Materials Section identified 86 in-stream material pits in the study reaches. Some 3120 records containing gradation information were downloaded from the ADOT database for use with the study. Screening of the records provided 2180 bed material samples to be used in the study, an average of 70 measurements per mile of river in the study. The second source of gradation information was sedimentation studies conducted on river reaches in Arizona. These studies contain the only estimates of bed material larger than 3-inches in diameter, data which is necessary in the analysis of gravel and cobble bed channels. From these two sources, characteristic distributions of bed material samples were prepared for sand and gravel bed channels. It was also possible to determine the typical variation in bed-material characteristics (mean size and gradation coefficients) for the study reaches.

The hydrologic dataset (Appendix I) is a compilation of stream-flow measurements, basin characteristics, and hydraulic data for study reaches. Flood hydrograph measurements were obtained from gaging stations nearest to each study reach. The U.S. Geological Survey and the Salt River Project were the source of this data. Limited hydraulic information was obtained for locations on the Salt River that have been measured by the U.S. Geological Survey. The U.S.G.S. has conducted hydrographic surveys of smaller flood events at these locations, which provides data on flow velocity, depth, and topwidth. Data on hydrologic conditions were used for calibration of the channel response model, and in establishing characteristic ranges of hydrologic conditions.

The mining activity dataset (Appendix J) contains information on the location, and amount of sand and gravel excavation in the study reaches. Pit boundaries and operational activities were identified from aerial photographs over a period of time, roughly concurrent with the period covered by topographic maps. The map collection at the Noble Science and Engineering Library on the campus of Arizona State University was the source of aerial photography for Maricopa County. Photos of river reaches in Pima County were obtained from the Pima County DOT and FCD. Photos of the Verde River near Cottonwood were obtained from Aerial Mapping Company. An interpretation of mined depth was made based on the type of mining operation, available topographic data, and with the assistance of experienced operators. The completed data set provided an estimate of volume of material excavated over time at various location in each study reach.

X. LONG-TERM PROCEDURE

10.1 Database

The long-term procedure is based entirely on measurements of topographic changes and mining activity over a period of time. The procedure was developed from an analysis of the correlation between mining production within the study reach and changes in the bed topography for a given time period. To facilitate the comparison of these two quantities, the topographic maps were digitized into a two-dimensional matrix of cell units that covered the length and width of each study reach. The raw data developed for each cell consists of: 1) the change in mean elevation, in feet, within the cell, and 2) the area of active mining, in acres, for that cell. The measured active mining area was converted to an estimated excavated volume, in tons, by applying an interpreted mined depth and assuming the average unit weight of the material to be 100 lb/ft^3.

Two distinct datasets resulted. The first, for gravel bed channels, consisted of data for the two Salt River study reaches. The second set, for sand-bed channels, included data for the Agua Fria River, New River, and Rillito Creek. The remaining three study reaches (i.e., two on the Verde River and one on the Santa Cruz River) were not included in the analysis, as only limited data for topographic changes and/or mining activity were available. Refer to the technical appendix for database documentation.

Certain limitations on the database were identified. The number of years included in the data window for each study reach ranged from only one year for the Verde River at I-17 to 24 years of available data for the Salt River study reach from Hayden Road to Country Club Drive. The average span of the data window for all study reaches was 11 years. It should be noted that in all cases, the data window encompassed the years during which major hydrologic events caused substantial flooding to occur in the study reaches.

The scale of the topographic mapping used in compiling the database varied from 100 feet to 400 feet to the inch; with 200 foot scale being the most prevalent. The contour interval of the maps was either 2 or 4 feet. Elevations determined from the mapping were not field checked. The scale of the aerial photographs used to determine active mining activity acreage ranged from 200 feet to 1200 feet to the inch.

10.2 Data Analysis

The approach to the analysis of the data was oriented towards developing a very direct and simple procedure for predicting long-term impacts of in-stream mining production upon changes in the channel bed topography. Utilizing a database comprised of limited observed data, a 3-step analysis process based on the basic physical principle of sediment continuity was undertaken.

The sediment continuity principle applied to a given channel reach states that the sediment inflow minus the sediment outflow equals the time rate of change in sediment storage. For a given discharge acting for a given time, the volume of sediment deposited or eroded in a channel reach is simply the difference between the upstream sediment supply rate and the rate at which sediment is removed. If the supply rate is greater than the removal rate, the reach is depositional; if sediment is removed faster than it is supplied to the reach, general scour will occur. An overall sediment balance for each study reach would be achieved when the volume of the sediment supply to the channel reach was equal to the sum of the volume of material being excavated plus the volume of sediment being transported out of the reach.

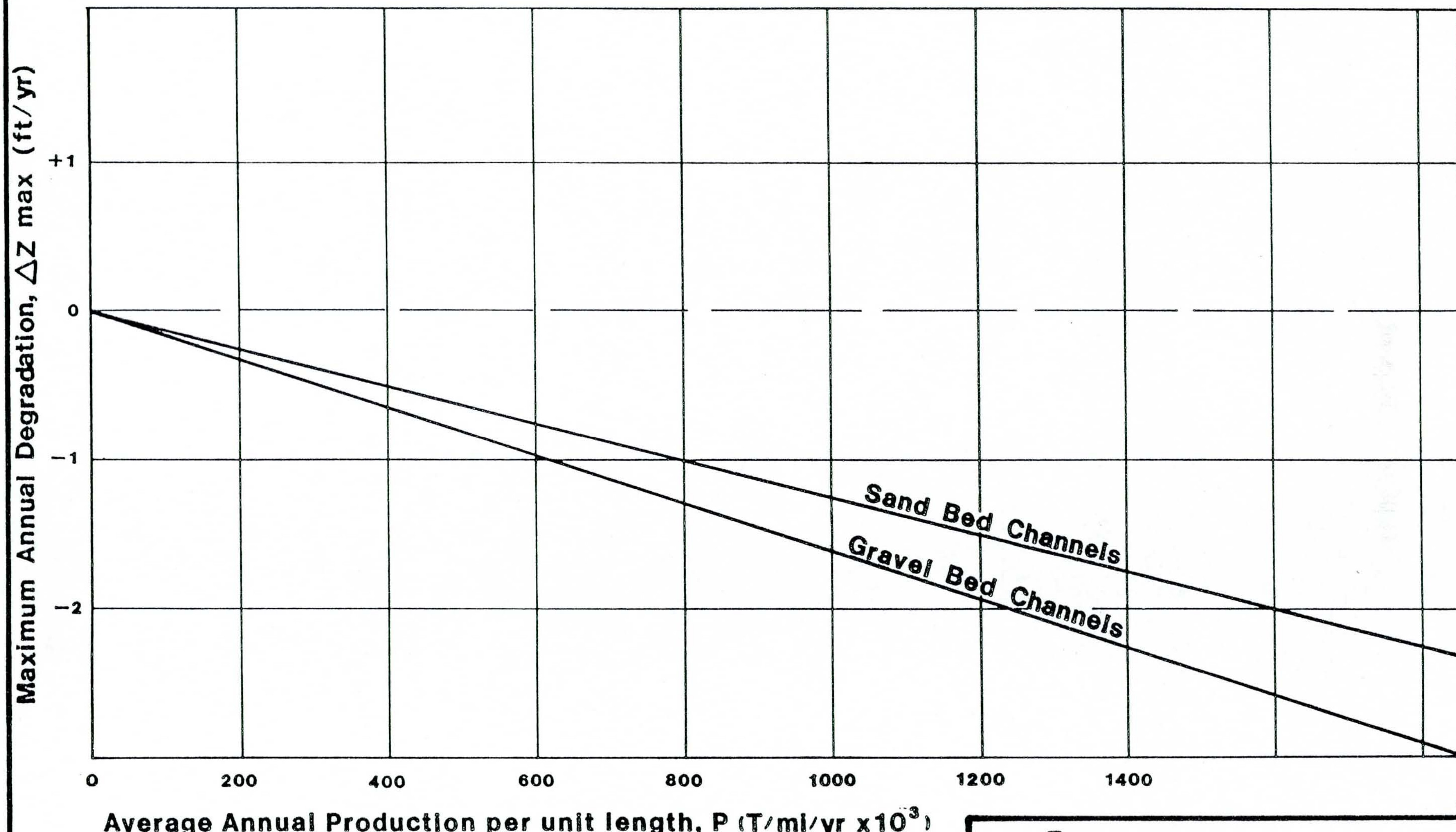
Some assumptions were necessary in applying the continuity principle to the actively mined study reaches. It was assumed that both sediment removal and sediment re-supply was accounted for in the measured data for both elevation changes in the channel bed and concurrent mining activity and, thus, the volume of sediment supply to the study reaches was not directly computed. In all the study reaches, the observation of long-term degradation of the channel bed would indicate that material was being removed at a rate faster than it was being re-supplied. On that basis, it was concluded that the removal of material from the study reaches was the overwhelming factor leading to the observed degradational trend within the system. The volume of sediment transported out of the reach was considered to be a secondary influence. From this analysis, it follows that the volume of the sediment deficit within the reach equals the volume of material mined plus the change in volume of the channel bed due to transport differences.

The purpose of the first step of the analysis process was to develop an envelope curve for the relationship between the change in bed elevation versus mining production within the actively mined reach. The active mining cells were grouped into mining clusters, which encompassed the entire mining operation at a particular location within the study reach. An average of the elevation changes for the actively mined cells comprising the cluster was calculated. The excavated volumes for all cells within the cluster were summed to determine the total volume of production for that mining cluster. The total production volume was divided by the cluster length to yield volume per unit length to account for the different impact on the channel bed resulting from mining the same amount of material over a long, shallow area versus mining deeper over a shorter distance. The mining production per unit length was then plotted versus the average elevation change for each cluster in each study reach. A curve enveloping all data points for each mining cluster resulted, see Chart A. For a given production volume within an actively mined reach, this curve will yield the maximum predicted degradation rate in terms of feet per year distributed laterally across the average width of the active mining cluster.

The observed long-term response of river channels to the influence of sand and gravel mining is a narrowing of channel width, a steepening of bank slope, and an increase in bank height. This process of channel entrenching is limited by the stability of the alluvial material forming the channel bank. The threshold of bank stability varies with the gradation of the bank material, the amount of cohesive soils in that gradation, the size of the material, and the degree of chemical cementing that has occurred over time. If mining depths remain below the threshold of bank stability, then the channel can remain relatively stable. If the mining depths exceed the threshold of bank stability, bank failure will occur resulting in significant lateral instability of the channel.

Observed stable bank heights in gravel bed channels are at a maximum height of 35 feet. Sand bed channels exhibit less bank stability with 25 feet approximating the maximum observed stable bank height. Maximum observed bank slopes are approximately 25 degrees. It is often common for 4 to 5 feet of bank to stand vertically, indicating the presence of cohesive forces in the bank material matrix due either to chemical bonds in the clay fraction of the material or cementing of particles by calcium carbonate. At bank heights greater than 4 to 5 feet, alluvial channel banks should be treated as essentially composed of non-cohesive material.

The next step of analysis sought to evaluate the relationship between the total volume of mining production versus the average change in the channel bed elevation on a subreach basis. The study reaches were divided into subreaches encompassing one or more mining clusters. The sum of the total volume of mining production upstream of each subreach was divided by the average width of the actively mined reach to yield a volume per unit width to address the different impacts resulting from mining the same amount of material over a wide versus a narrow reach. The average change in elevation in all cells, mined and non-mined, upstream of the subreach was computed. The mining production per unit width versus the average elevation change for each subreach was plotted. A curve enveloping all the data points was developed, see Chart B. For a given total production volume of an actively mined reach, this curve yields the average predicted degradation rate, in terms of feet per year, at the downstream limit of the reach, distributed laterally across the width and



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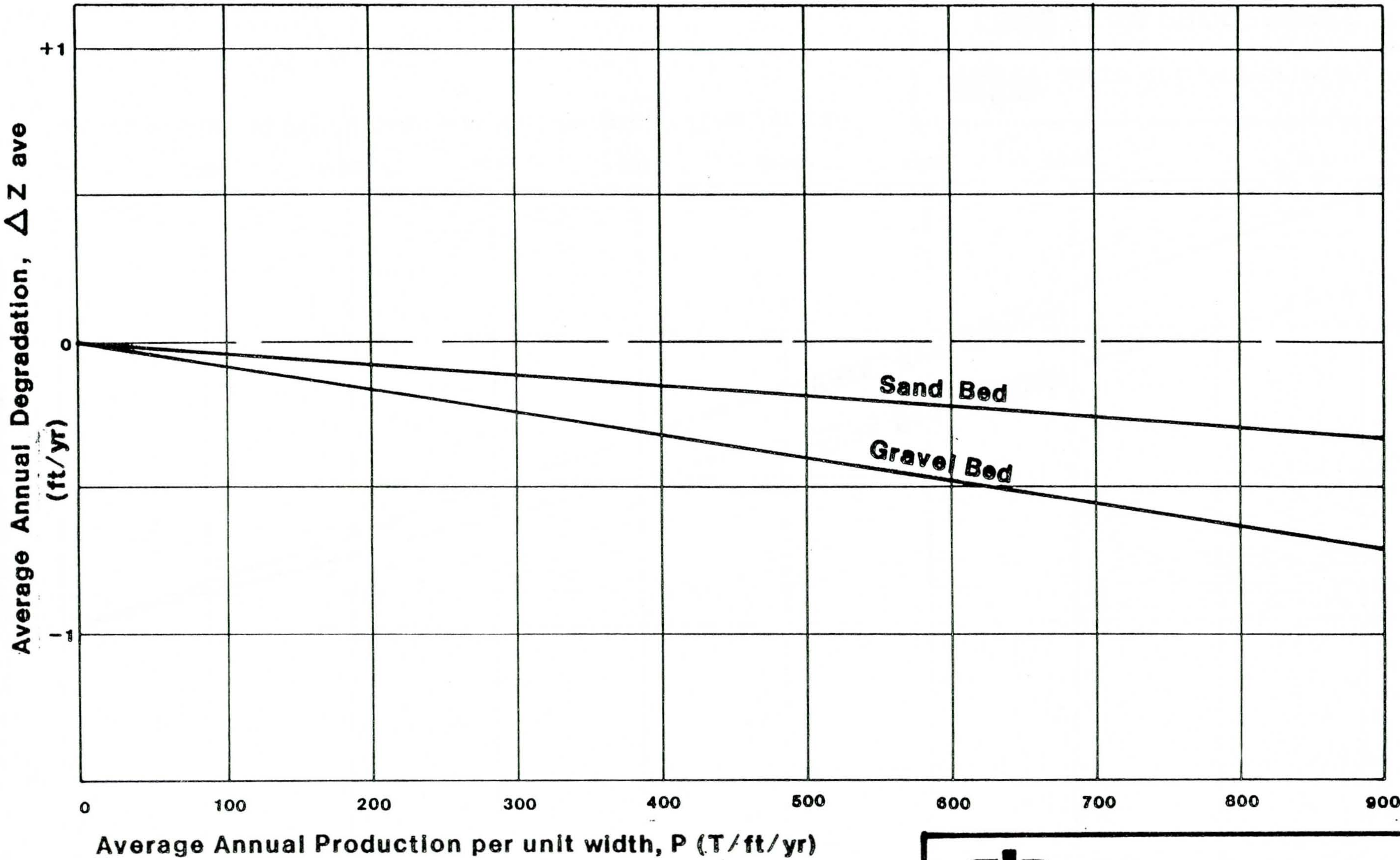
LONG TERM PROCEDURE

CHART A



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LONG TERM PROCEDURE
CHART B

longitudinally along the length of the actively mined reach. This width is defined in geomorphic terms as the main low-flow channel width plus the width of the first overbank terraces on both sides of the channel.

Interestingly, it was noted that for gravel bed channels, the volume of the change in the channel bed distributed over the actively mined reach approximately equals the volume of material removed by sand and gravel mining operations, signifying that sediment supply to the reach and transport out of the reach approach negligible values. In other words, the volume of material mined from gravel bed channels is reflected directly in the volume of the degradation of the channel within that reach. Thus, the average elevation change is simply the mined volume divided by the length times the width of the reach. Further evaluation indicated that the ratio of the average predicted degradation at the downstream limit of the actively mined reach to the maximum predicted degradation in the mining cluster assumed a constant value for both the gravel and sand bed study reaches.

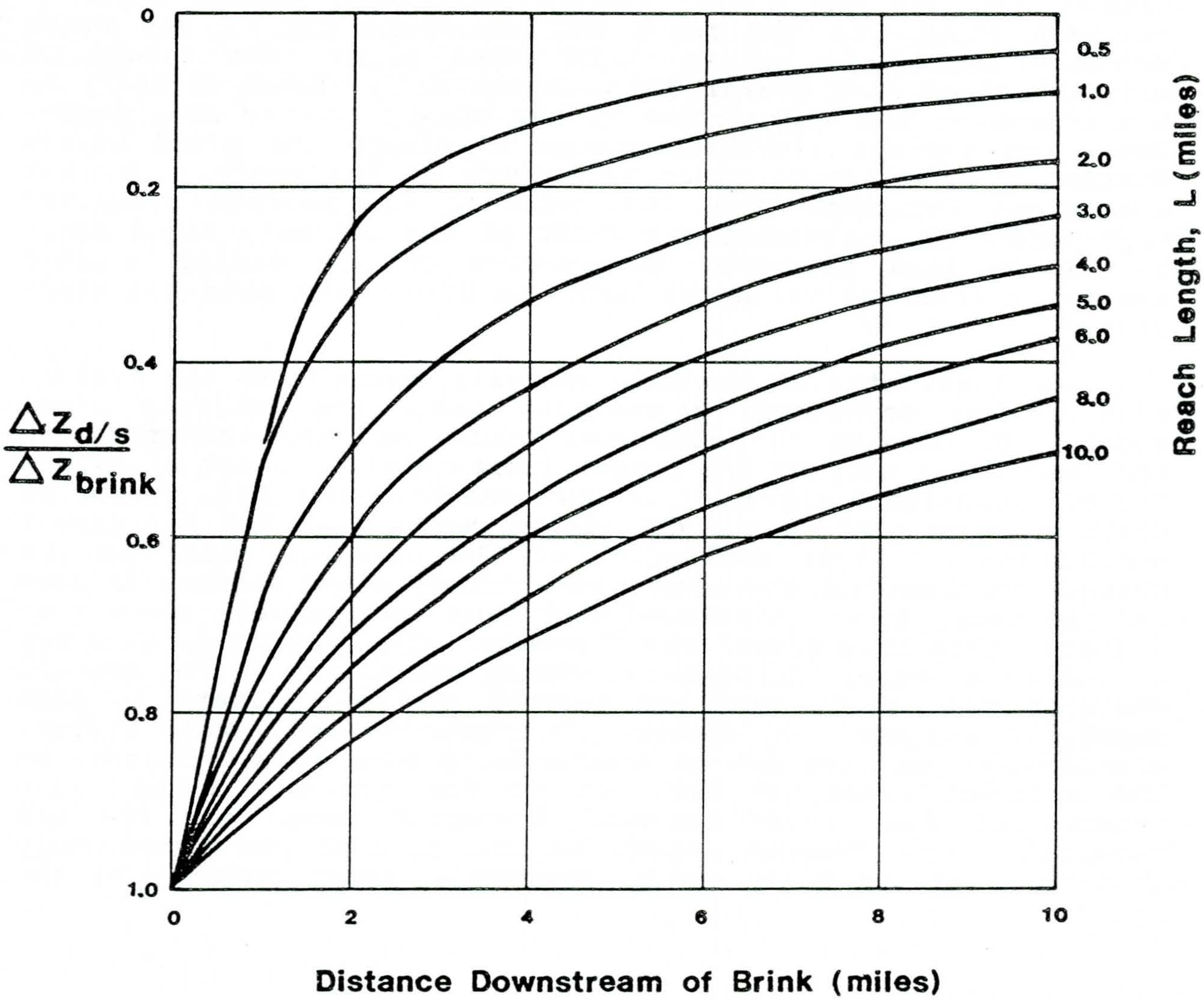
The final step of the data analysis process was the evaluation of the downstream degradation below the actively mined reach. By holding the excavated volume and the average width constant while varying the length incrementally, a set of values for the downstream elevation changes can be determined. Refer to Chart C for a plot of the downstream recovery curves for gravel bed channels. From evaluation of the measured data for the changes in elevation downstream of actively mined reaches in sand bed channels, it was concluded that sand bed channels recover at a faster rate than gravel bed channels. Qualitatively, this may be due to a lesser influence of mining operations on the overall sediment balance in sand bed channel systems. There is more supply to the sand bed system. In channels with larger widths, the mining operation may be accommodated with less influence on the sediment transport rate out of the actively mined reach because of the larger sediment transport rates for the bed material. The reduced impact to the channel bed immediately downstream of the mined reach provides a faster recovery of the system.

10.3 Verification

The actual long-term effects of sand and gravel mining on the channel profile of the study reaches were derived from the measured changes in bed topography for the period of time included in the mapping window. A relative maximum change in elevation for mined and non-mined cells within the actively mined reach was calculated from values in the topographic dataset. This value does not necessarily reflect the deepest pit excavation depth, but rather an average of the pit excavation depths

DOWNSTREAM RECOVERY CURVE

GRAVEL BED CHANNELS



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LONG TERM PROCEDURE

CHART C

occurring in several cells comprising a mining cluster. The measured change in elevation at the downstream brink of the actively mined reach and the actual downstream recovery of the channel bed as a function of length downstream of the brink were also determined.

Using the long-term procedure described in the following subsection, predicted elevation changes were calculated for four of the study reaches where sufficient data was available (i.e., two reaches on the Salt River, the Agua Fria River, and Rillito Creek). Since data from these four reaches was used in the development of the long-term procedure itself, a fifth study reach, the Verde River at Cottonwood, was also included in the verification process in an effort to provide an independent check of the procedure. Data from the Verde River study reach was not included in the development of the procedure. Table 10.1 summarizes the comparison of actual versus predicted channel response. Refer to Figure 10.1 and 10.2 for schematic illustrations of the parameter definition.

Generally speaking, the elevation changes computed using the long-term procedure accurately predicted the actual response measured from the topographic data. The predicted downstream recovery curves approximated the actual values close to the downstream brink of the mined reach, but yielded more conservative values further downstream. The long-term procedure provides a good representation of the observed channel response to sand and gravel mining.

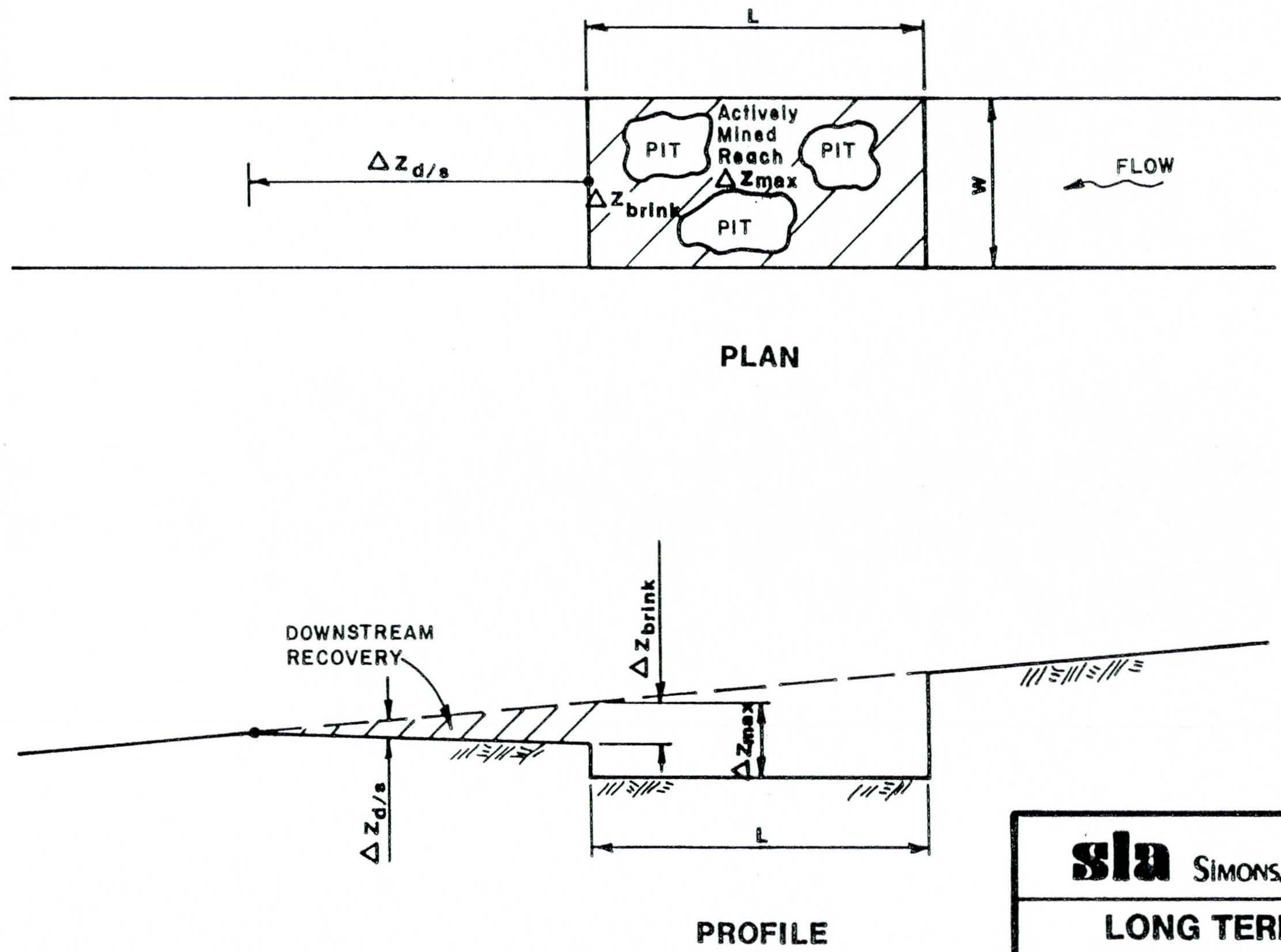
10.4 Procedure

The following procedure estimates the long-term impact of sand and gravel mining production upon changes in the bed topography within and directly downstream of an actively mined river reach. The bed topography changes are a function of production quantified in terms of the number of feet of long-term degradation at three locations: 1) ΔZ max, the maximum predicted degradation within an actively mined pit cluster; 2) ΔZ brink, the average predicted degradation at the downstream limit of the actively mined reach; and 3) ΔZ d/s, the predicted downstream degradation which decreases with increasing cumulative distance downstream of the actively mined reach, eventually daylighting at the original channel invert at some downstream point. Refer to Figure 10.1 for a schematic illustrating these parameter definitions.

1. Determine the Maximum predicted degradation within the actively mined reach, ΔZ max (ft).

TABLE 10.1. Long-Term Procedure - Verification of Parameters

Study Reach	ΔZ max (ft)		ΔZ brink (ft)		Downstream Distance	ΔZ d/s (ft)	
	actual	predicted	actual	predicted	(mi)	actual	predicted
GRAVEL BED CHANNELS:							
Salt River Hayden Rd to Country Club Dr	-22.8	-19.2	-13.5	-11.3	0(brink)	-13.5	-11.3
					0.5	-13.0	
					1	- 9.0	- 9.4
					2	- 6.5	
					3	- 8.0	- 7.2
					4	- 8.0	
					5		- 5.5
Salt River 19 Ave to 59 Ave	-14.1	-12.6	- 5.7	- 4.8	0(brink)	- 5.7	- 4.8
					1	- 6.1	- 3.7
					2	- 1.7	- 2.9
					3		- 2.4
					5		- 1.8
SAND BED CHANNELS:							
Agua Fria River	-10.7	- 9.0	- 2.2	- 2.6	0(brink)	- 2.2	- 2.6
					0.19	- 0.1	
					0.39	+ 0.5	
					0.58	- 0.6	
					0.78	+ 0.1	
					1.00	- 1.1	
					1.14	- 3.2	
					1.37	- 1.8	
					1.57	- 0.5	
					1.87	+ 1.1	
Rillito Creek	- 4.8	- 2.4	- 1.7	- 1.4	0(brink)	- 1.7	- 1.4
					0.12	- 0.5	
					0.23	- 1.5	
					0.33	- 4.8	
					0.42	- 8.1	
					0.52	- 3.7	
					0.62	- 4.6	
					0.73	- 2.3	
					0.83	- 3.6	
Verde River - Cottonwood	N/A	- 1.5	- 1±	- 1.1	0	- 1±	- 1.1
					0.3	- .85	- .89



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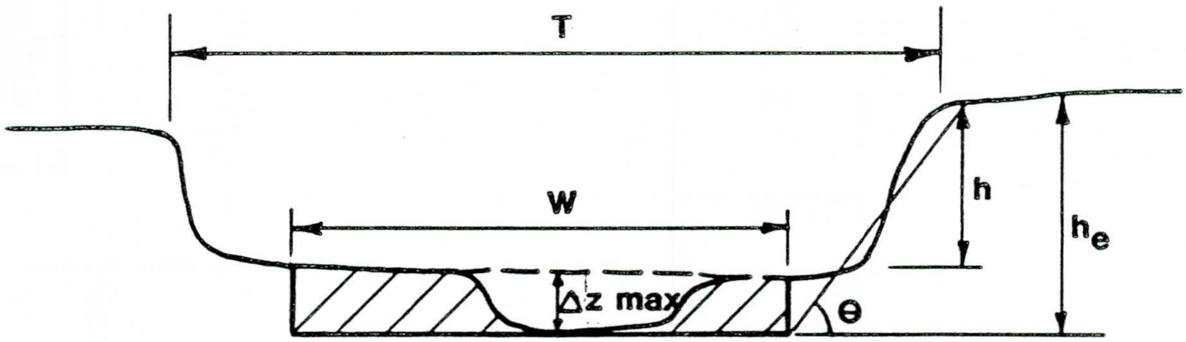
LONG TERM PROCEDURE

PARAMETER DEFINITION

FIGURE 10.1



Definition sketch for channel bank and side slope stability

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LONG TERM PROCEDURE DEFINITION SKETCH

FIGURE 10.2

a. Determine: Reach length, L (miles)
Active Mining Width, W (feet)
Total production, ΣP (tons)
Number of years of production, n (years)
Bed material type (sand or gravel bed)

b. Calculate Average annual production per unit length, P (tons/mile/year)

c. Enter Chart A according to bed material type with Average annual production, P and find corresponding Maximum annual degradation, ΔZ max (ft/yr).

d. Multiply by number of years of production to determine Maximum predicted degradation, ΔZ max (ft).

e. Determine the post mining bank height and side slope. See Figure 10.2.

$$h_e = h + \Delta Z \text{ max}$$

$$\theta = \tan^{-1} (2h_e/(T-W))$$

where h_e is the excavated bank height, h is the maximum existing bank height, ΔZ max is the long-term degradation, θ is the angle of the channel bank, T is the existing channel topwidth, and W is the mining width.

f. Check the resulting bank height and side slope to allowable values.

h_e < 35 feet (Gravel bed)
h_e < 25 feet (Sand bed)
θ < 25 degrees

2. Determine the Average predicted degradation at the downstream limit of the actively mined reach, ΔZ brink (ft).

a. Calculate Average Annual Production per unit width, P (T/ft/yr).

b. Enter Chart B according to bed material type with Average Annual Production per unit width, P and find corresponding Average annual degradation at the downstream limit of the actively mined reach, ΔZ ave (ft/yr).

c. Multiply by the number of years of production to determine Average predicted degradation at the downstream limit of the actively mined reach, ΔZ brink (ft).

3. Determine the Predicted downstream degradation, ΔZ d/s (ft). This quantity will decrease with increasing distance downstream of the actively mined reach thereby approximating a downstream recovery curve.

a. For gravel bed channels:

(1) Enter Chart C according to reach length. Find the ratio ΔZ d/s to ΔZ brink for cumulative distance downstream of the brink.

(2) Multiply each ratio value by ΔZ brink to calculate the Predicted downstream degradation, ΔZ d/s (ft), for each cumulative downstream distance.

b. For sand bed channels, see short-term procedure.

10.5 <u>Limitations</u>

Certain limitations on this methodology should be noted:

1. The following table qualifies the range of topographic and mining activity data used to develop the envelope curves contained in Charts A and B. The user should exercise caution in applying this procedure to conditions outside these limits.

a. Actively mined reach length,
L = 0.8 - 5 miles

b. Actively mined reach width,
W = 2800-5200 ft (gravel)
W = 360-2400 ft (sand)

c. Estimated average excavation depth,
d = 10-35 ft (gravel)
d = 6-35 ft (sand)

d. Estimated total production within the actively mined reach,
P = 22.1-58.5 million tons (gravel)
P = 1.4-9.8 million tons (sand)

2. The methodology considers the impact of a single cluster of pits; therefore, it does not account for the interaction between multiple pit clusters located upstream and/or downstream of the actively mined reach being evaluated.

10.6 Long-Term Procedure - Example

The river reach selected for this example is an actively mined, five-mile long reach of the Salt River between Hayden Road and Country Club Drive. Sand and gravel mining has been underway in this reach since 1962, producing an estimated total of 58.5 million tons of material.

1. Determine the Maximum predicted degradation, ΔZ_{max} (ft).

   a. Actively mined reach length, L = 5 miles.
   Actively mined reach width, W = 4000 feet.
   Total production, ΣP = 58,500,000 tons.
   Number of years of production, n = 24 years.
   Gravel bed material type.

   b. Calculate Average annual production per unit length, P (T/m/yr).

   $P = 58.5 \times 10^6\ T \div 5\ mi. \div 24\ yr.$
   $P = 487{,}500\ T/mi/yr.$

   c. From Chart A: $\Delta Z_{max} = -0.80$ ft/yr.

   d. Determine ΔZ_{max} (ft).

   $\Delta Z_{max} = -0.80$ ft/yr x 24 yr = <u>-19.2 ft</u>.

   e. Determine the post-mining bank height and side-slope.

      1) Maximum existing bank height, h = 15 feet.

      Calculate the excavated bank height, h_e (ft).

      $h_e = h + \Delta Z_{max} = 15 + 19.2$
      $h_e = 34.2$ feet.

      2) Existing channel topwidth, T = 4200 feet.

      Calculate the angle of the channel bank, $\theta°$

      $\theta = \tan^{-1} (2\ h_e/(T-W))$
      $\theta = \tan^{-1} (2x34.2/\ (4200-4000))$
      $\theta = 18.9°$

   f. Check the excavated bank height and side-slope versus allowable values.

1) For gravel bed channels:

Allowable $h_e < 35$ feet.

Calculated $h_e = 34.2$ feet < 35 feet.

2) Allowable $\theta < 25°$.

Calculated $\theta = 18.9° < 25°$ ok.

Since the excavated bank height and the side-slope are within the allowable limits, bank stability is indicated.

2. Determine the Average predicted degradation at the downstream limit of the actively mined reach, ΔZ_{brink} (ft).

a. Calculate Average annual production per unit width, P (T/ft/yr).

$P = 58.5 \times 10^6$ T ÷ 4000 ft ÷ 24 yr.
$P = 609.4$ T/ft/yr.

b. From Chart B: $\Delta Z_{ave.} = -0.47$ ft/yr.

c. Determine ΔZ_{brink} (ft).

$\Delta Z_{brink} = -0.47$ ft/yr x 24 yr = -11.3 ft.

3. Determine Downstream recovery curve.

From Chart C: L = 5 mi.

Downstream Distance (miles)	ΔZ d/s / ΔZbrink	ΔZ d/s (ft)
0 (at brink)	1.0	-11.3
1	0.83	- 9.4
2	0.71	- 8.0
3	0.63	- 7.1
4	0.55	- 6.2
5	0.50	- 5.6

XI. SHORT-TERM PROCEDURE

11.1 Model Description

A computational model was developed for this study for the purpose of simulating several channel-response conditions, characteristic of a river reach with in-stream mining. The model was developed primarily for the purpose of synthesizing additional data for the development of envelope-type relationships for an initial regulatory evaluation of the effects of in-stream mining operations. The program was not configured to serve as a general river simulation model, although the basic design of the program is sufficient to accommodate a future enhancement for this purpose. The simulation procedure was formulated on the hydraulics of a single, unit-width stream-tube for a river channel with differing bed materials, discharge conditions and mining excavation shapes. Multiple simulations were made, which generated synthetic datasets, which were in turn used to develop a series of envelope formulas that are the basis of the analysis procedure. The model is in many respects the mathematical equivalent of a hydraulic laboratory flume, in which the behavior of an alluvial channel bed can be analyzed.

The model is modular in design, meaning that the program relies on various procedures that are organized into separate libraries for specific computational tasks. For convenience, these procedures are grouped into libraries, each library having a general computational function. The model consists of a main program and five libraries, which include: utility procedures, input/output procedures, data structure management procedures, hydraulic procedures, and sediment transport procedures. The model is entitled Channel Response due to In-Stream Mining, or CRISM.

The **utility library** contains a set of general Pascal functions and procedures that facilitate program operation. The input/output library provides the basic procedures that allow the program to access the input data file, and to output results in various specified formats. The data structure and computational procedures are contained in the remaining libraries, that are the technical core of the CRISM model.

One of the most important aspects of the CRISM model is the underlying data structures that has been designed for the program. The **memory library** provides routines to control this data structure. The basic unit of the data structure is a structured variable containing two records: one record containing hydraulic variables, the second record containing sediment transport variables; and three pointer variables which permit the structured variable to be stored in a dynamically allocated portion of computer memory. Each unit of the data structure describes conditions at one cross-section at one time interval. The individual records are linked using the pointer variables to create a dynamic, linked-list data structure. Two of the pointer variables are used to describe the spatial relation, among the cross-section data, and the third is used to describe the temporal relation.

Because data structure is dynamic, no limit on the simulation time is required by the CRISM model. When the limit of computer memory is reached, the previously calculated time intervals are stored on a fixed disk file in an orderly manner. The disk cache is retrieved upon completion of the simulation. The ability to store large amounts of data in computer memory also improves the speed of program, since access to the internal computer memory is a great deal faster than access to a fixed disk.

The <u>hydraulics library</u> contains procedures for calculating hydraulic conditions in the river reach. The library contains a number of procedures that address conditions in an excavated depression in the river reach. These include a mass balance routine to determine the water surface elevation in the depression as the pit fills, and a determination of regions of sub-critical flow and rapidly varied flow in the water surface profile. Other procedures used in hydraulic calculation include a procedure for determination of alluvial channel roughness, and standard step, backwater-computation procedures.

The <u>sediment transport library</u> contains procedures that determine sediment transport capacity for given flow conditions, settling fractions are computed for depositional areas of the reach, and the amount of scour or deposition at a cross-section is determined. The sediment transport capacity is calculated based on the Meyer-Peter Muller bed-load equation and the Einstein suspended bed-load equation. Finally, the amount of elevation change in the channel bed is computed using a finite difference form of the sediment continuity equation.

11.2 <u>Verification</u>

The short-term effects of a mining excavation on a channel profile are difficult to document unless data can be gathered near the time when a flow event occurs. Most of the study reaches evaluated during this research have not had recent flow events. No documentation of channel profile changes, in the vicinity of mining operations for past flow events, is known to exist for these study reaches. Fortunately, during the course of this study, nature provided an opportunity to measure conditions in the vicinity of a mining operation after a flow event.

The study reach located between Hayden Road and Country Club Drive on the Salt River contains a large mining operation located downstream of the Alma School Road bridge. The river was channelized at this location in conjunction with the bridge construction. The mining operation reached the downstream limit of this channelization in 1986. High reservoir levels, behind the dams on the Salt River in the spring of 1987, required that releases be made to maintain safe pool levels. Below Granite Reef Dam, releases were made to the Salt River for a period of 26 days. Figure 11.1 shows the average daily flows for this period of release. The highest flows occurred in the first nine days of the release.

One of the reasons that this reach was valuable for verification of the CRISM model is that detailed mapping of the site was conducted just prior to the spring flow releases. In December 1986, ADOT conducted a survey of the Salt River channel as a part of the planning effort for the Red Mountain Freeway. The condition of the Salt River channel and the extent of mining operations can be clearly ascertained from this survey. During this study, the site was resurveyed and the amount of erosion was determined. This survey identified the volume, depth of scour, and the lateral and longitudinal extent of erosion. The before and after channel profile at the Alma School Road site is shown in Figure 11.2. Figures 11.3 and 11.4 show the channel condition before and after the spring flow in 1987. For the verification simulation, the initial channel profile was averaged to provide a representative profile slope.

The remaining data needed for verification of the model was the gradation of the bed-material layers at the site. The gradation was determined from samples contained in the database that was formulated for this study, and from inspection of the erosion at the site. The bed-material gradations used in the model are considered to be representative of average conditions on the channel surface and within the channel bed. The discretized values of surface and subsurface bed-material gradations are also shown in Figure 11.5.

The CRISM model input consisted of the average daily flow, as recorded at the Granite Reef diversion dam for the first nine days of release, the initial channel-bed profile, and the surface and subsurface bed material gradations. All discharges were converted to a unit discharge based on the average width of erosion in the headcut which was 60 feet. The initial channel-bed profile was discretized into relatively short increments as shown in Figure 11.6. The time interval during simulation was 30 minutes. Results of the simulation are shown in Figure 11.6. The model slightly overestimates the headcut depth, but agrees closely with length of erosion. Overall the simulation is in good agreement with measured erosion.

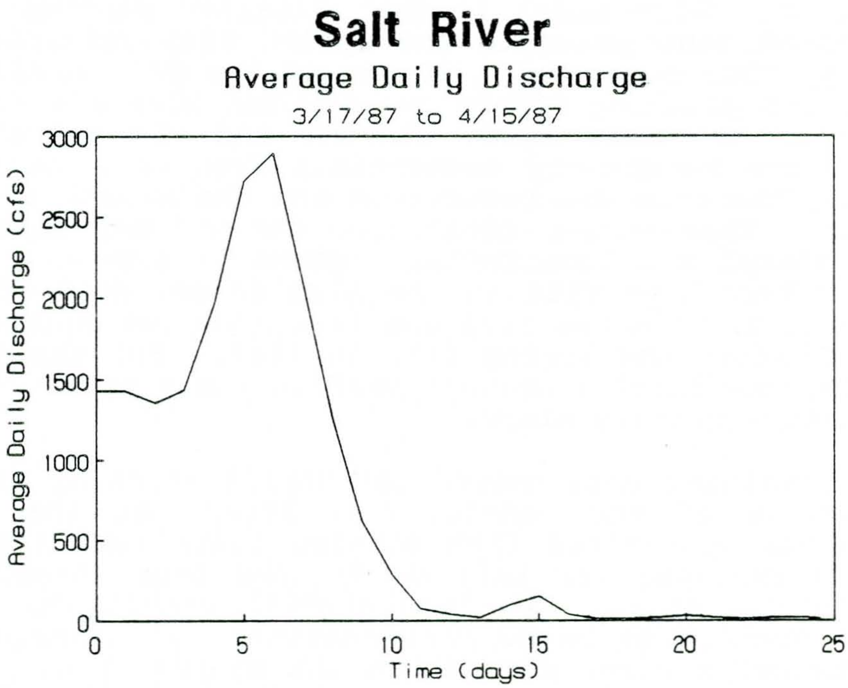

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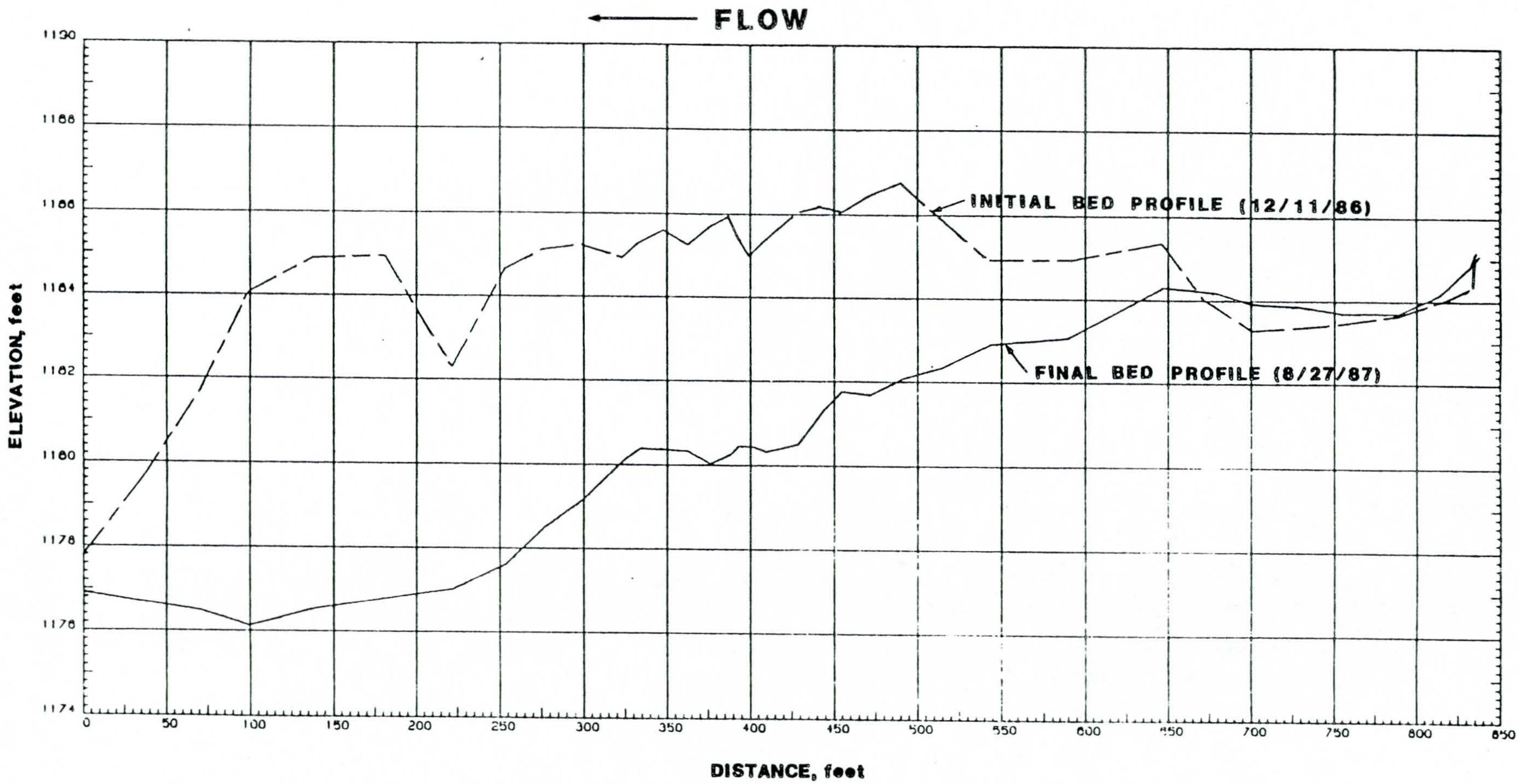
FIGURE 11.1

SALT RIVER AVERAGE DAILY DISCHARGE

MARCH 17, 1987 TO APRIL 15, 1987



SCOUR VOLUME = 15,700 cubic yards

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FIGURE 11.2

SALT RIVER NEAR ALMA SCHOOL ROAD

HEADCUT CHANNEL BED PROFILE

Simons, Li & Associates, Inc.

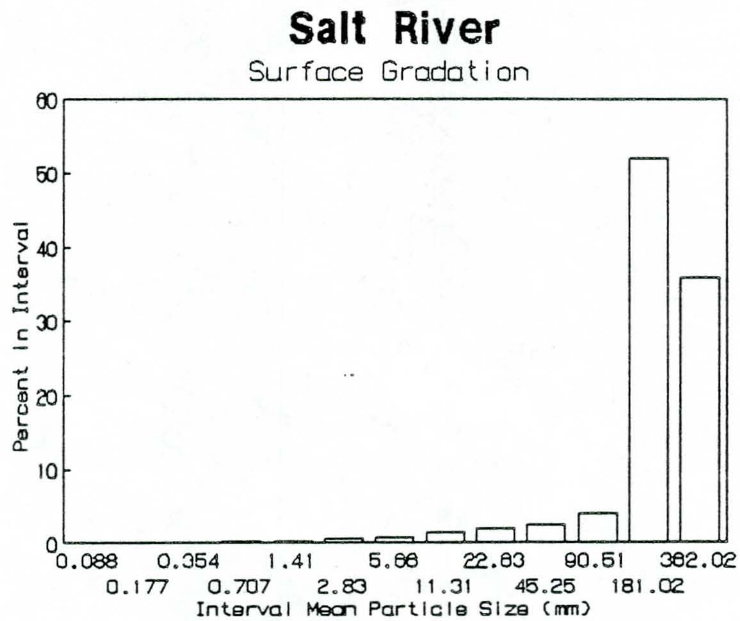
FIGURE 11.3

ALMA SCHOOL ROAD (12/11/86)

sla Simons, Li & Associates, Inc.

FIGURE 11.4

ALMA SCHOOL ROAD (8/27/87)



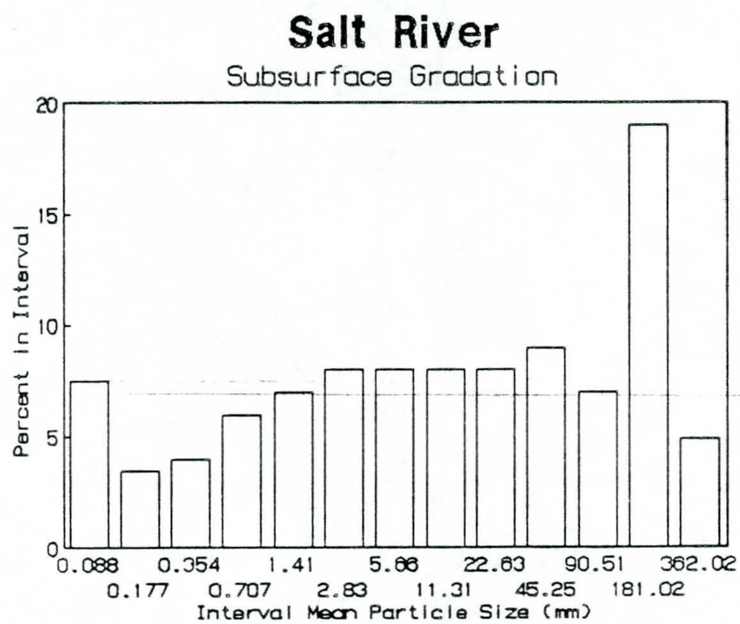


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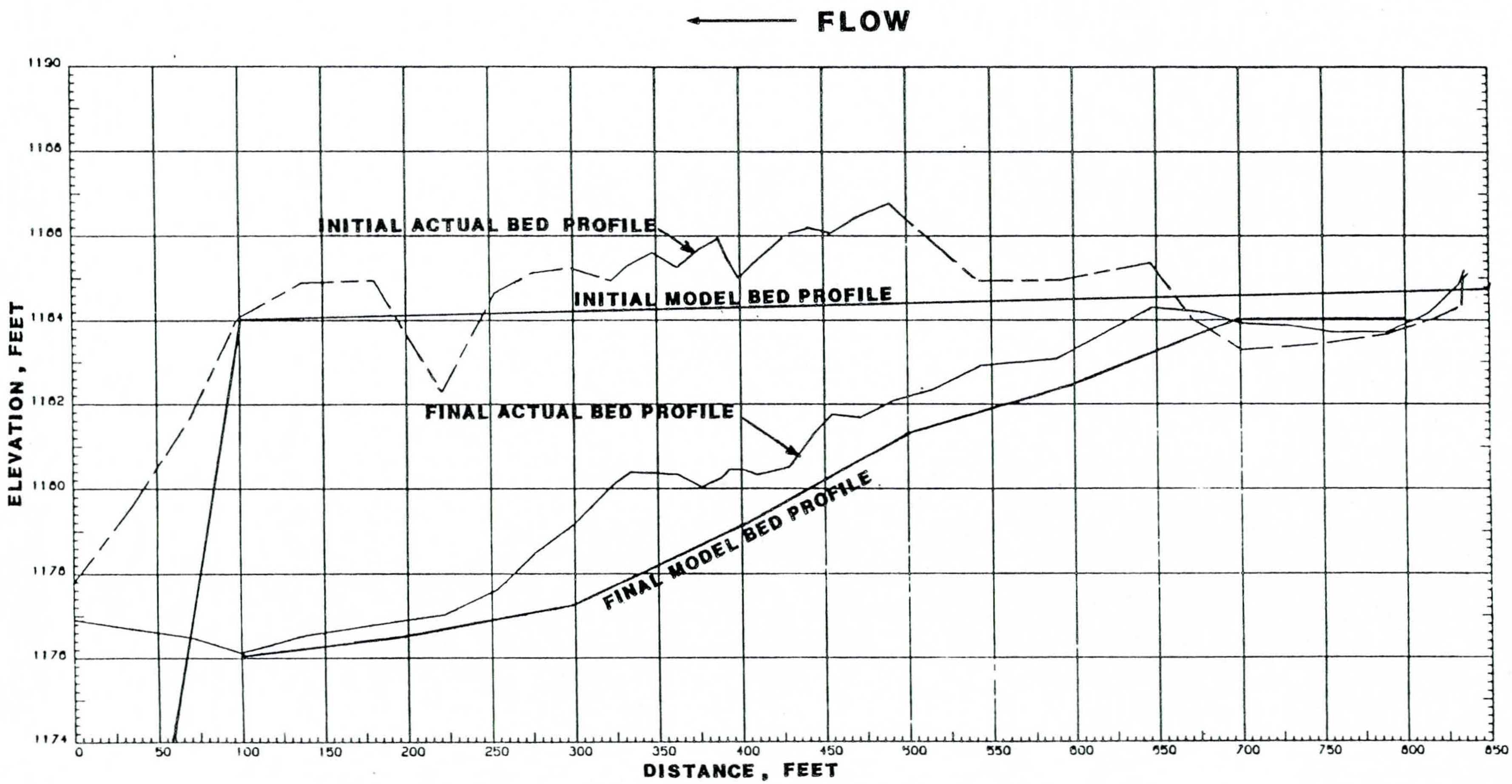
FIGURE 11.5

SALT RIVER BED MATERIAL GRADATION



Q = 1433 CFS
SHIELDS' PARAMETER = 0.054
WEIGHTING FACTOR = 0.40

sla Simons, Li & Associates, Inc.

FIGURE 11.6

BED PROFILE CONFIGURATION FOR CRISM

11.3 Data Synthesis

Due to the lack of measurements on short-term channel response, it was necessary to synthesize a dataset using the CRISM model. This data set was then used to formulate a series of envelope curves covering various aspects of short-term channel response upstream and downstream from an in-stream excavation. Approximately 150 computer runs were necessary to adequately describe the variety of hydraulic and mining conditions found in this study.

The runs selected for use in developing the envelop curves were based on the range of variables observed in the database. A single characteristic gradation was used for sand-bed channels, and dual-gradations were used for gravel-bed channels (one for the surface layer and a second for the underlying parent material). The observed range in channel bed-slope in the study reaches was 0.001 ft/ft to 0.004 ft/ft. The pit shape was varied within the range of observed mining operations in the study reaches. Mining operations on sand-bed channels were observed to be shorter in length and shallower in depth compared to gravel-bed channels. A range of unit discharges were identified from the hydrologic data set

11.4 Overview of Short-Term Scour Processes

The short-term procedure addresses the scour processes in the vicinity of an in-stream mining operation. This will concern structures located in a river reach with active mining immediately upstream or downstream of such a reach. Short-term scour is most pronounced at two locations: near the upstream and downstream brink of an excavation. Figures 11.7 and 11.8 show the simulation of the scour process over the period from initial filling of the excavation through sustained flow.

The upstream scour is caused by the acceleration of the flow into the excavation. The increased velocity near the excavation brink locally increases the transport of sediment and results in a scour of the channel bed. This type of scour is referred to as a headcut. As the headcut progresses upstream, the zone of flow acceleration lengthens resulting in additional scour. The process is arrested when the hydraulic drop created at the headcut brink is submerged by the downstream water-surface profile. For an excavation located in a channel with a mild gradient, this occurs at the approximate time the excavation fills with water. However, if the discharge is insufficient to submerge the hydraulic drop, or if the channel has a relatively steep gradient, the scour process may continue beyond the time it takes the excavation to fill with water.

Scour also develops below the excavation. The scour process is a function of the travel time of a sediment wave through the

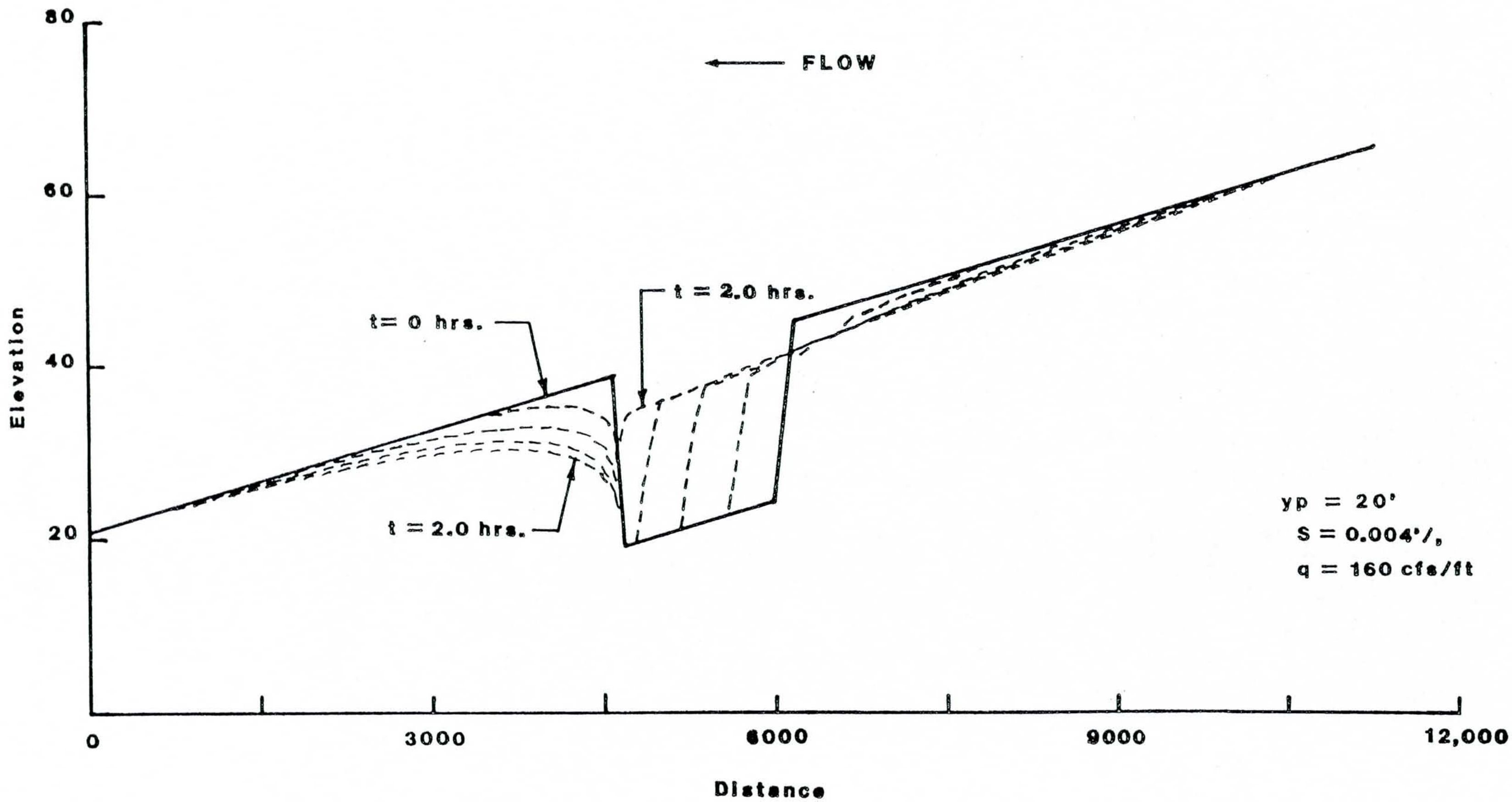


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FIGURE 11.7

SAND—BED PROFILE CHANGES

t =0 hrs. TO t = 2.0 hrs.

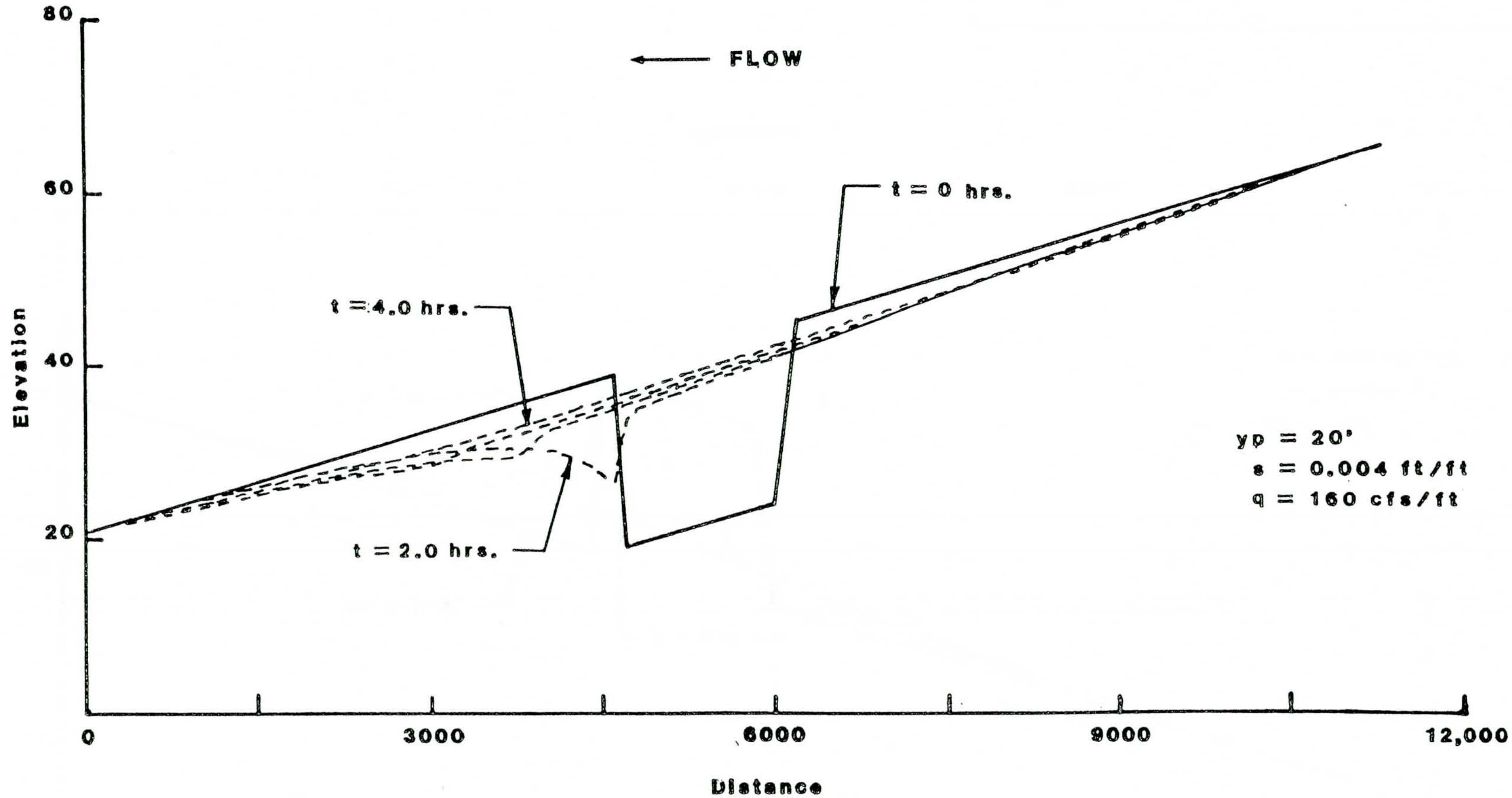

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FIGURE 11.8
SAND—BED PROFILE CHANGES
t = 2.0 hrs. TO t = 4.0 hrs.

excavation (which in turn is a function of the excavation length and sediment-wave celerity) and the depth of the excavation. As sediment is transported into the excavation, it is trapped and deposits near the upstream brink of the excavation. Sediment is subsequently transported further downstream over time creating a sediment wave. As this sediment wave propagates through the excavation, a deficit in sediment supply results which creates a downstream scour. This scour is largest at the downstream brink, and gradually decreases as sediment is re-supplied to the flow. The length and depth of downstream scour increases with increasing excavation length and depth. Increased excavation length increases the time required for the sediment wave to move through the excavation, thus increasing the duration of the downstream sediment deficit. Increased excavation depth permits the downstream scour depths to increase.

Data on headcut scour and downstream scour were synthesized using the CRISM model. The resulting dataset provided scour depths as a function of bed material type (sand or gravel), varying unit discharge, varying channel slope, and varying excavation depth and length.

11.5 Procedure

The following procedure estimates the short-term scour near the upstream and downstream limit of a sand and gravel mining excavation. The changes in bed topography are a function of the shape of the excavation (length, width and depth), the type of alluvial material (sand-bed or gravel-bed), the magnitude and distribution of flow in the channel, and the gradient of the channel. Separate equations are presented for sand-bed and gravel-bed conditions, but the procedure is the same. The procedure involves the solution of set of six equations (Table 11.1 gives the sand-bed equations and Table 11.2 gives the gravel-bed equations). Gravel-bed conditions are considered to exist if a visible armor layer is found in the channel, otherwise the sand-bed condition should be assumed. Regime equations are used to determine the channel width into and exitting the excavation. The complete scour profile can be approximated using the table of profile dimensionless coordinates given in Table 11.3.

The procedure provides the depth, width and length of scour upstream and downstream of an excavation. As a prudent measure, it should be assumed that this scour can be located anywhere across the width of the active channel.

Procedure

1. Acquire the following data:

a. Pit shape: Width
Length
Upstream depth
Downstream depth
b. Design hydrograph
c. Bed-material gradation (sand-bed or gravel-bed)
d. Channel gradient

2. Discretize the inflow hydrograph using approximately uniform time increments. For excavations that are not in the main channel but are within the floodplain, determine the discharge at which the stage in the river reaches the elevation of the excavation. As an initial analysis, only discharge exceeding the brink discharge should be used. (If the resulting headcut length is sufficient to capture the adjacent main channel, the analysis should be repeated using the full hydrograph.)

3. Calculate the time required to fill the excavation with water.

The steps 4 through 9 are repeated for each time increment of the hydrograph.

4. Determine the scoured channel width from the appropriate (sand-bed or gravel-bed) regime equation.

5. Calculate the inflow and outflow unit discharge, and the unit discharge in the excavation. If the excavation fill time has not been reached, there will be no outflow.

6. Calculate the sediment wave celerity in the excavation.

7. Calculate the accumulated dimensionless time. For downstream scour, this is the ratio of the time increment (Δt) to the characteristic sand wave propagation time (excavation length divided by sediment wave celerity), added to the dimensionless time from the previous time step. For upstream scour, this is the ratio of the time increment (Δt) to the excavation fill time. The calculation is only valid for T_* less than 1.0.

8. Calculate the maximum headcut scour.

9. Calculate the scour depths and lengths at the current time.

TABLE 11.1. Sand-Bed Scour Equations	
<u>Regime Width</u>	
$W_c = 2.60\ Q^{0.43}$	(11.1)
<u>Downstream Scour</u>	
$y_s = 0.960 q^{0.25}\ y_p^{0.50}\ T_*^{0.435}$	(11.2)
where $y_s < y_p$ and $T_* < 0.84$	
$L_{s5} = 41.8\ q^{-0.0625}\ (L_p\ y_p)^{0.50}\ T_*^{0.631}$	(11.3)
where $T_* = \dfrac{t}{(L_p/C_s)}$ $\quad C_s = 21.1 q^{1.11}\ S^{1.74}$	
<u>Headcut Scour</u>	
$y_{smax} = a_1\ y_p\ q^{b1}$	(11.4)
where $y_{smax} <= 0.5*y_p$	
$a_1 = 0.120\ W_*^{0.672}$ $\quad b_1 = 0.286\ W_*^{-0.350}$	
$y_s = a_2\ y_p\ T_*^{\ b_2}$	(11.5)
where $y_s <= y_{smax}$	
$a_2 = 1.24\ W_*^{-2.46 q^{-0.451}}$ $\quad b_2 = 0.648$	
$L_{s5} = 0.219\ L_p\ q^{0.262}\ W_*^{-0.624}\ T_*^{b_3}$	(11.6)
where $b_3 = 0.216\ q^{0.155}$	
$T_* = \dfrac{t}{T_f}$ $\quad W_* = W_p/W_c$	

C_s = sediment wave celerity, ft/sec;
L_{s5} = scour length at 5 percent of scour depth, feet;
L_p = excavation length, feet;
q = discharge per unit width of channel, cfs/ft;
Q = main channel discharge, cfs;
t = flow duration, hours;
T_f = excavation fill time, hours;
T_* = dimensionless time;
W_c = channel width, feet;
W_p = excavation width, feet;
W_* = dimensionless excavation width;
y_p = excavation depth, feet; and,
y_s = scour depth, feet.

TABLE 11.2. Gravel-Bed Scour Equations

<u>Regime Width</u>

$$W_c = 1.85\ Q^{0.45} \qquad (11.7)$$

<u>Headcut Scour</u>

$$T_{max} = a_1\ T_f^{\,b_1} \qquad (11.8)$$

where $a_1 = 5.4q^{-0.340}$

$b_1 = 0.54q^{0.112}$

$$y_s = a_2\ t^{b_2}\ y_p \qquad (11.9)$$

where $t <= T_{max}$

$a_2 = 0.0023q^{0.529}$

$b_2 = 1.54q^{-0.162}$

$$L_{s5} = a_3\ t^{b_3} \qquad (11.10)$$

where $t <= T_{max}$

$a_3 = 10^{(1.637+0.0032q)}$

$b_3 = 0.538$

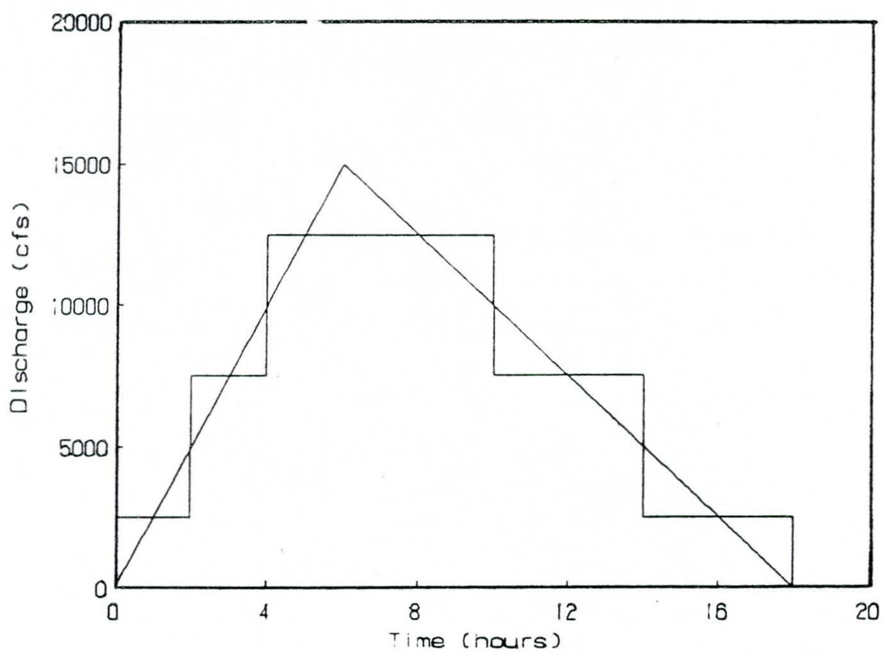
L_{s5} = scour length at 5 percent of scour depth, feet;
q = discharge per unit width of channel, cfs/ft;
Q = main channel discharge, cfs;
t = flow duration, hours;
T_f = excavation fill time, hours;
W_c = channel width, feet;
y_p = excavation depth, feet; and,
y_s = scour depth, feet.

TABLE 11.3. Dimensionless Scour Profiles		
Y_s/Y_{sbrink}	L_s/L_{s5} Downstream	L_s/L_{s5} Upstream
0.05	1.00	1.00
0.25	0.50	0.60
0.50	0.25	0.30
0.75	0.10	0.15
1.00	0.00	0.00

11.6 EXAMPLE

Step 1: a) Pit Shape: Width, W_p = 500'
Length, L_p = 1000'
Depth, Y_p = 10'

b) Design Hydrograph



c) Sand-bed gradation

d) Channel gradient, S = 0.002 ft/ft

Step 2: Discretized Hydrograph

Δt (hrs)	Q (cfs)
2	2500
2	7500
6	12500
4	7500
4	2500

Step 3: Fill Time

$V_f = W_p L_p Y_p = 500 \times 1000 \times 10 = 5 \times 10^6$ cf

Volume of first time step

$V_w = 2 \times 3600 \times 2500 = 18 \times 10^6$ cf
$T_f = 2 \times (5 \times 10^6 / 18 \times 10^6)$
$= 0.56$ hrs.

Steps 4-9: Worksheet: Downstream Scour

Time (hr)	Δt (hr)	Q (cfs)	Step 4 W_c (ft)	Step 5 q_c (cfs/ft)	q_p (cfs/ft)	Step 6 C_s*10^3 (ft/sec)	Step 7 T_*	Step 9 Y_s (ft)	L_s (ft)
2.0	1.4	2500	75	33	5	2.5	.0126	1.09	213
4.0	2.0	7500	121	62	15	8.6	.0745	2.75	627
10.0	6.0	12500	150	83	25	15.1	.401	6.16	1780
14.0	4.0	7500	150	50	15	8.6	.525	6.10	2180
18.0	4.0	2500	150	17	5	2.5	.561	4.79	2430

Steps 4-9: Worksheet: Headcut Scour

Since the volume of the hydrograph exceeds the volume of the excavation, equations 11.4 and 11.5 can be checked without evaluating the complete hydrograph.

$W_c = 2.60\ (2500)^{0.43} = 75$ ft.

$W_* = 13.3$

Equation 11.4 gives

$Y_{smax} = 0.684\ Y_p\ q^{0.116}$

$= 0.684\ (10)\ (2500/75)^{0.116}$

$= 10.3$ ft. Use $Y_{smax} = 5.0$ ft.

Equation 11.5 gives

$Y_s = a_2\ Y_p\ T_*^{b2}$

for $T_* = 1.0$ $\quad Y_s = a_2 Y_p$

$Y_s = 1.24 W_*^{-2.46} q^{-0.451}\ Y_p$

$= 3.4$ feet.

$L_{s5} = 0.219 \times (1000) \times 33.3^{0.262} \times 13.3^{-0.624}$ Eq 11.6

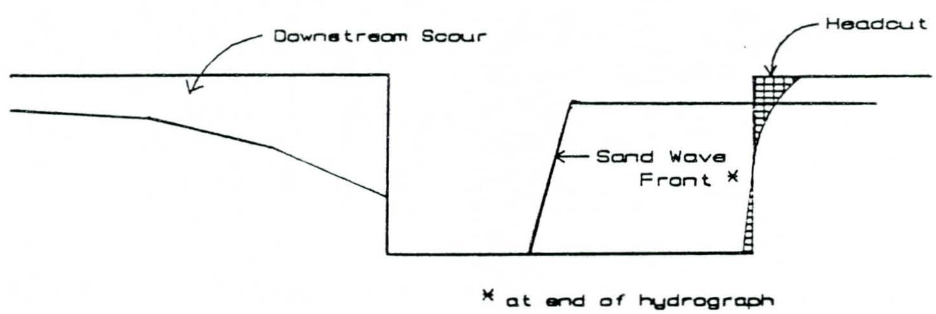
$= 109$ feet

Downstream Scour Profile

Y_s (ft)	L_s (ft)
0.3	1780
1.5	890
3.1	445
4.6	178
6.2	0

Headcut Scour Profile

Y_s (ft)	L_s (ft)
0.2	109
0.9	65
1.7	33
2.6	16
3.4	0



XII. RIVER RESPONSE SIMULATION PROCEDURE

12.1 Model Description

A sediment routing model, Model HEC-2SR, was modified for simulation of general degradation or aggradation after the sand and gravel pit boundaries have been smoothed out through initial headcut, backfill and downstream erosion processes. The simulation reach is not limited to the excavated area, but normally includes the entire study reach where the effects of mining on other structures are to be investigated.

Similar to CRISM, Model HEC-2SR features a modular structure which includes the following major components; data management, hydraulic computations, sediment transport computations, and degradation or aggradation analysis. Model HEC-2SR employs an uncoupled water- and sediment-routing scheme and assumes known-discharge, one-dimensional flow. The HEC-2 water surface profile model (Hydrologic Engineering Center, 1976, 1982) is used to obtain the backwater profiles and hydraulic variables. The HEC-2 output data are scanned to obtain the key hydraulic parameters for sediment transport analysis.

The Meyer-Peter, Muller bed-load function and Einstein suspended-load equation (Appendix F) are employed in this version of Model HEC-2SR for sediment transport computations. The entire study reach is divided into several subreaches, each containing sections with similar hydraulic and bed-material characteristics. Sediment routing by size fractions is performed from upstream to downstream, and changes in bed-material gradation are simulated during each time interval. River armoring effects are considered in estimating the availability of transportable sediments and determining the actual sediment outflow.

Sediment volume changes are determined by applying the principle of continuity, and using the sediment inflow and outflow computed for each subreach (assuming the most upstream reach is a bed-material supply reach). At the end of each routing time step, the channel geometry data are updated to reflect the erosion and sedimentation processes.

In the previous versions, Model HEC-2SR estimates river changes by assuming (1) major changes occur in the form of river-bed degradation or aggradation, and (2) distribution of the degraded or aggraded sediment is uniform in each subreach in both lateral and longitudinal channel directions. Some versions also considered a different lateral distribution of sediment in the overbank areas relative to the main channel.

For joint application with CRISM to sand and gravel mining analysis, the following modifications were made to Model HEC-2SR:

1. Channel erosion is limited to the area within the movable-bed boundaries, which is defined as the area beyond which the flow velocities fall below a nonerodible velocity.

2. The bed-material inflow hydrographs, both from upstream and from a sediment-contributing tributary, are provided as input data. The original version used the sediment transport capacities computed for the most upstream reach as the bed-material supply.

3. Watershed fine-sediment yield computations and correction of sediment transport capacities using the fine sediment concentration in the original model are deleted.

4. Sediment-transport equations are based on either the Zeller-Fullerton equation (a simplified solution of the Meyer-Peter, Muller bed-load, Einstein suspended load equations) for sand-bed conditions or the Meyer-Peter, Muller equation for gravel-bed conditions.

5. As an additional option, sediment transport computations can be performed for every cross section within a sand and gravel pit, instead of for the average hydraulic conditions in the reach.

6. For the option described in Item 5, sediment distribution considers lateral and longitudinal variations instead of uniform changes in both directions.

7. Processes of lateral erosion due to limitation of excessive down-cutting are simulated.

12.2 Definition of Movable-Bed Boundary

In Model HEC-2SR, the extent of the movable-bed boundaries is determined in each time step for all cross sections along the study reach. The movable-bed boundaries are defined as the lines dividing the erodible area with major flow conveyance from the nonerodible area with minor flow conveyance. This concept was introduced to account for the stability offered by vegetation in portions of the river bed. Beyond the movable-bed boundaries, flow velocities are considered not adequate to erode the river bed and to remove the vegetation covers. This concept is particularly important for river response evaluations in wide, braided channels. By limiting erosion within the movable-bed boundaries, degradation depth can be better estimated.

For a given flow discharge, the extent of movable-bed boundaries varies along the channel. For each section, the movable-bed boundaries vary with flow discharge and conveyance distribution across the channel. To apply the concept of movable-bed boundaries to limitation of channel erosion, a basic parameter, the nonerodible velocity, should be defined.

One method of determining the nonerodible velocity is to investigate the flow velocity or conveyance distribution in the areas where vegetation remains after a major flood. Aerial photographs taken before and after the flood are compared to identify the nonerodible areas where vegetation was not removed. Typical cross sections are evaluated to determine the flow velocities outside the movable-bed boundaries. This nonerodible velocity is adopted to define the relations between the flow discharge and movable-bed boundaries for sections along the river. A typical relation between the flow discharge and movable-bed width is illustrated in Figure 12.1. Such relations are required by Model HEC-2SR for defining the bank stations for hydraulic computations and degradation analysis.

12.3 Longitudinal Distribution Along the Channel Reach

Sediment volume changes in Model HEC-2SR are computed using the principle of sediment continuity for each subreach, as in Model PIT. Two options are available in the modified version of HEC-2SR for distribution of the eroded or deposited sediments in the longitudinal direction. The first option assumes uniform sediment distribution along the channel, and the second option assumes distribution based on variation in sediment transport capacity. The first option is recommended for a reach with relatively uniform hydraulic and sediment transport characteristics, and the second option is included for a reach containing a sand and gravel pit. For the second option, sediment transport capacity should be computed for each individual section, and the weighting factor (W_p) for distributing the eroded or deposited sediments to cross section P in reach q can be estimated by

$$Wp = \frac{Q_{s_{q-1}} - Q_{s_p}}{Q_{s_{q-1}} - Q_{s_q}} \qquad (1)$$

where $Q_{s_{q-1}}$ and Q_{s_q} are the average transport capacities in reaches q-1 and q, respectively, and Q_{s_p} is the sediment transport capacity at section P.

12.4 Lateral Distribution Across a Channel Section

Once the change in area at a channel section is computed, the area must be distributed across the channel to determine the river elevation changes. With a one-dimensional model, the exact location of scour or deposition cannot be determined, since the program does not compute lateral flow effects. Therefore, empir-

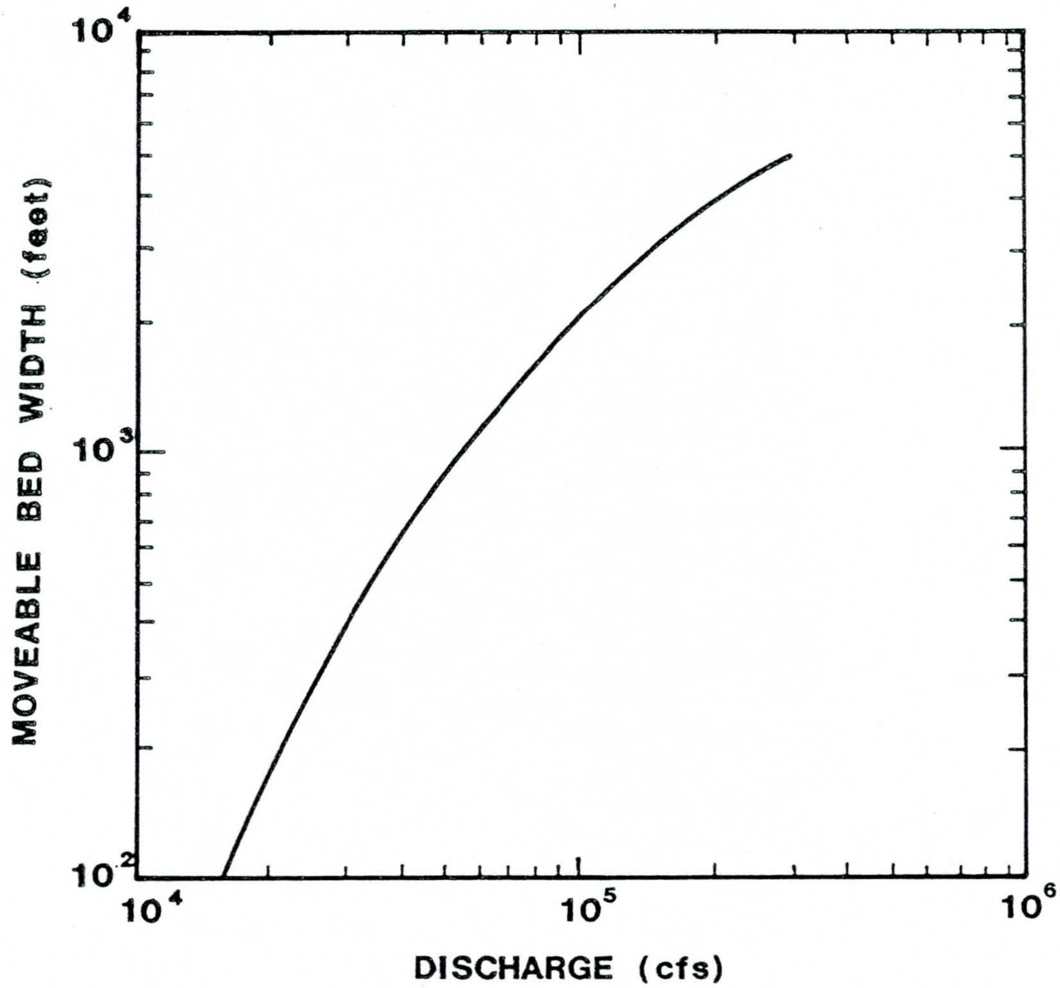


Figure 12.1. Variation of Movable Bed Boundaries with Flow Discharge. (after Li, 1986)

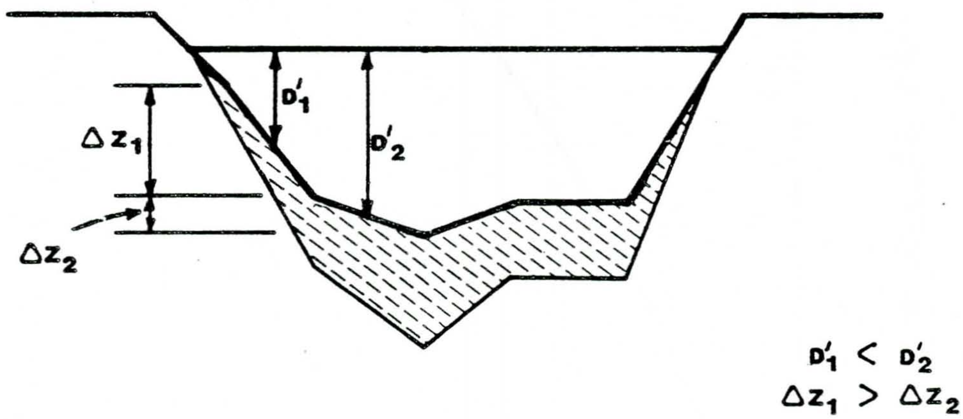


Figure 12.2. Sediment Distribution Based on Conveyance. (after Li, 1986)

ical procedures are used to distribute the bed area change. The method used in Model HEC-2SR to distribute sediment across the cross section relates the change in bed elevation at a point to flow conveyance. This method, as shown in Figure 12.2 is considered appropriate because conveyance is directly proportional to sediment transport.

The conveyance of a channel is defined as

$$K = \frac{Q}{\sqrt{S}} \tag{2}$$

where K is the conveyance, Q is the discharge, and S is the energy slope of the channel. Using Manning's formula, the conveyance can also be expressed as:

$$K = \frac{1.486}{n} A R^{2/3} \tag{3}$$

where A is the cross-sectional area in square feet; R is the hydraulic radius in feet, defined as the area divided by the wetted perimeter; and n is the Manning roughness coefficient.

The cross sections in the HEC-2 input file are defined by a series of (x,z) coordinates. A typical cross section plot is shown in Figure 12.3. For a given water-surface elevation, the incremental area, wetted perimeter and hydraulic radius between successive cross section points can be computed using simple geometry, as shown in Figure 12.4. The incremental area is simply the area of the trapezoid formed by the water surface and the coordinate points on either side of the segment. The wetted perimeter is the length of the line segment connecting the two points.

Using the water-surface elevation for a given cross section from the HEC-2 analysis and the Manning roughness coefficient from the NC or NH cards in the HEC-2 input file (Hydrologic Engineering Center, 1976, 1982), the incremental conveyance between cross section points can be computed using Equation 3. The total conveyance for the cross section is the sum of the incremental conveyances. The conveyance weighting factor for each segment is simply the ratio of its conveyance to the total conveyance of the channel, or

$$Wi = \frac{K_i}{K} = \frac{\left(\frac{A_i R_i{}^{2/3}}{n}\right)}{\left(\frac{A R^{2/3}}{n}\right)_{total}} \tag{4}$$

where W_i is the conveyance weighting factor for the ith segment of the section shown in Figure 12.4.

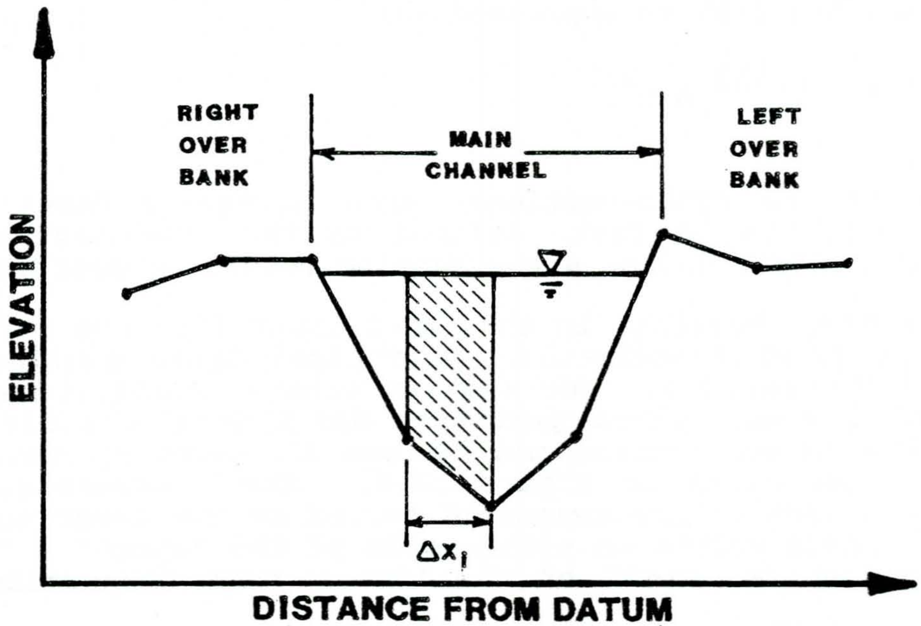


Figure 12.3. Typical Channel Cross Section with Subdivisions. (after Li, 1986)

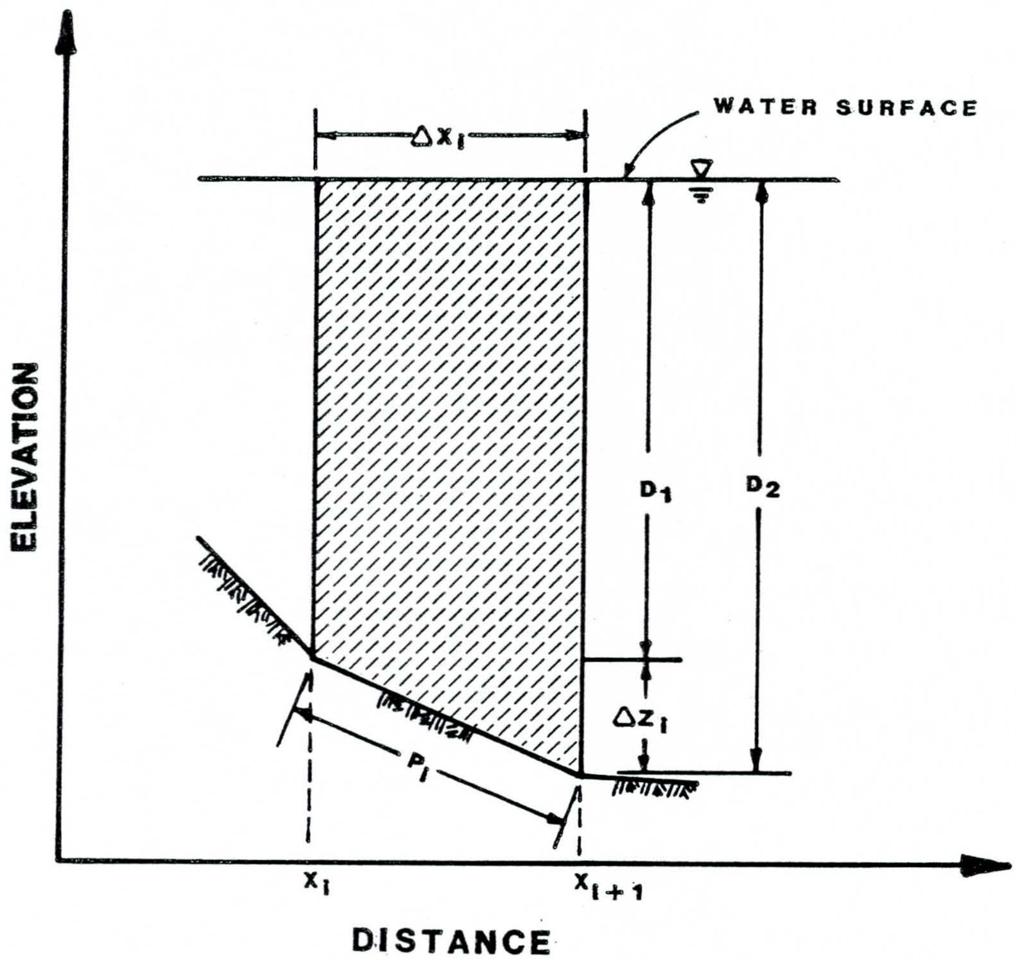


Figure 12.4. Incremental Segment of Typical Cross Section.
(after Li, 1986)

The change in river-bed elevation at a particular point, i, in the given channel section can be computed using the relation

$$\Delta Z_i = \left[\frac{W_i + W_{i+1}}{(x_{i+1} - x_{i-1})} \right] \Delta A_b \qquad (5)$$

where ΔZ_i is the change in elevation at the ith point, W_i and W_{i+1} are the conveyance weighting factors for the segment of cross section on either side of the point, $x_{i+1}-x_{i-1}$ is the distance between the cross section points on either side of the point, and ΔA_b is the total change in bed area for the cross section.

12.5 Limitation of Channel Downcutting

The lateral erosion process is simulated in Model HEC-2SR by considering bank stability in the study area. When continuous degradation causes channel depth to exceed the threshold bank height for a stable bank, further erosion is assumed to occur laterally. Ineffective flow area in the entrenched section and instability of the high bank situation are the basis of this assumption. When increased bank height and slope are caused by channel downcutting to exceed the stable bank condition, lateral erosion takes place instead of continuous downcutting. Figure 12.5 illustrates the typical lateral sediment distribution according to the flow conveyance weighting and modification of the sediment distribution due to the lateral erosion process following significant downcutting.

Although bank stability depends on various factors such as soil composition, bank slope, bank elevation, soil moisture, and hydraulic force, empirical values of 35 feet for gravel-bed channels and 25 feet for sand-bed channels are recommended as the threshold-stable bank height to limit downcutting.

12.6 Model Limitations and Applicability

Application of Model HEC-2SR may be limited due to assumptions made in the development and modifications of this model. Major limitations include:

1. One-dimensional, steady flow is assumed for each routing time increment.
2. Secondary flow is neglected.
3. Lateral distribution of the eroded or deposited sediments is based on flow conveyance variations across the channel sections.
4. Detailed bank erosion processes are not considered, although additional erosion laterally is assumed to limit excessive degradation which may occur in a particular portion of the cross section.

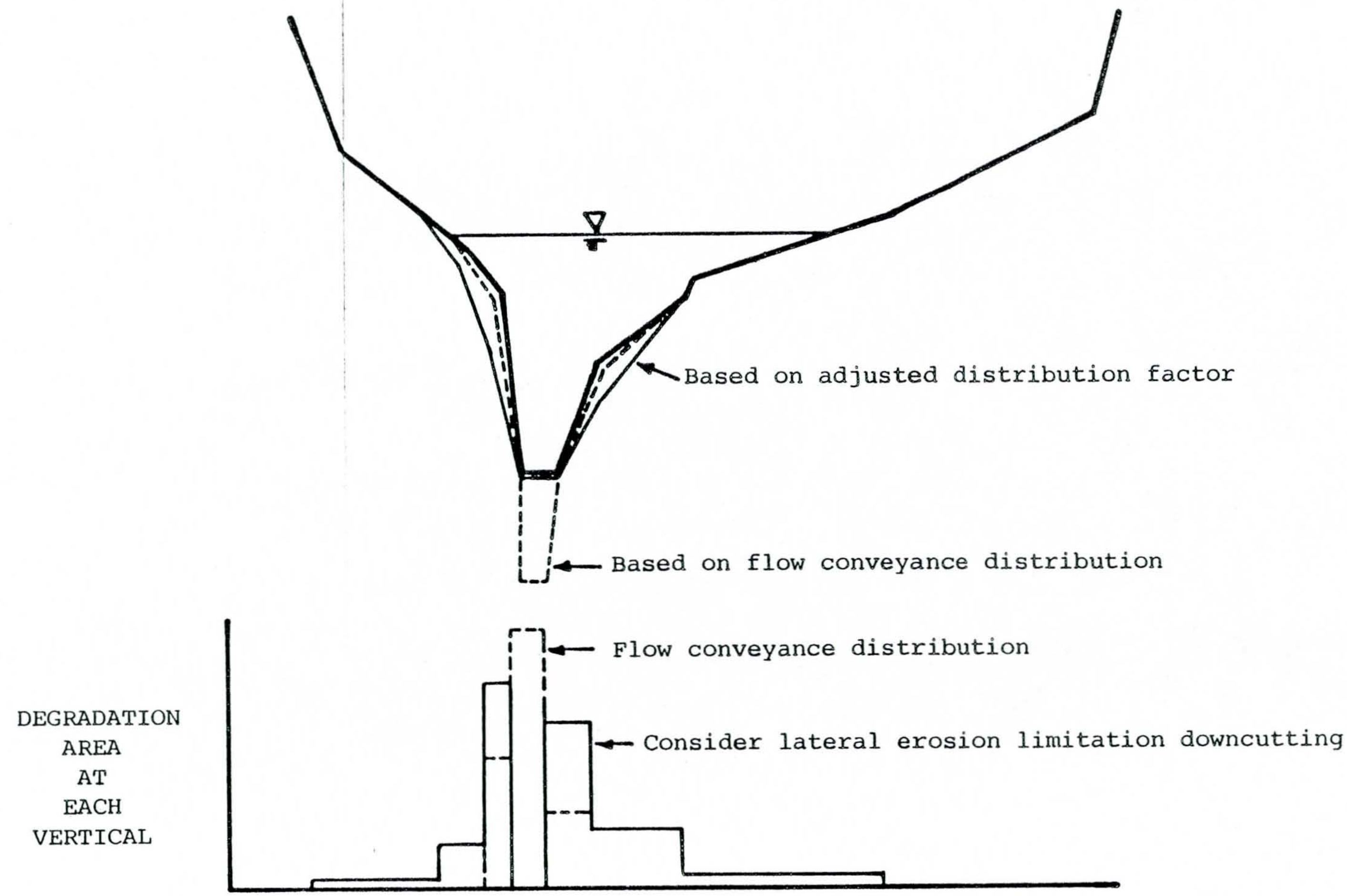


Figure 12.5. Sediment Distribution Across Channel and Lateral Erosion Process (after Li, 1986)

5. Model HEC-2SR can accept bridge information from Model HEC-2, but no computation of the local scour at the bridge is made.

To apply this model, one should be aware of these assumptions, limitations, and special requirements. As with other alluvial river models, long-term simulation of river responses may be limited by computation cost. The spatial and temporal resolutions should be determined in order to minimize computation costs, while reflecting the characteristics of channel geometry and flood hydrographs and achieving the objective of model simulation.

XIII. CASE HISTORIES

13.1 Existing Gravel Pits

This section presents case histories of sand and gravel mining operations within the study reaches. The location and magnitude of these selected mining operations cover a range of aggregate harvesting methods and production capabilities. The case studies are reviewed on a reach-by-reach basis. A historical overview is presented in the first subsection detailing the progress of mining activity, the river response to material extraction, and any channel stability problems identified in the reach. An analysis of trends observed in the case studies is presented in the second subsection.

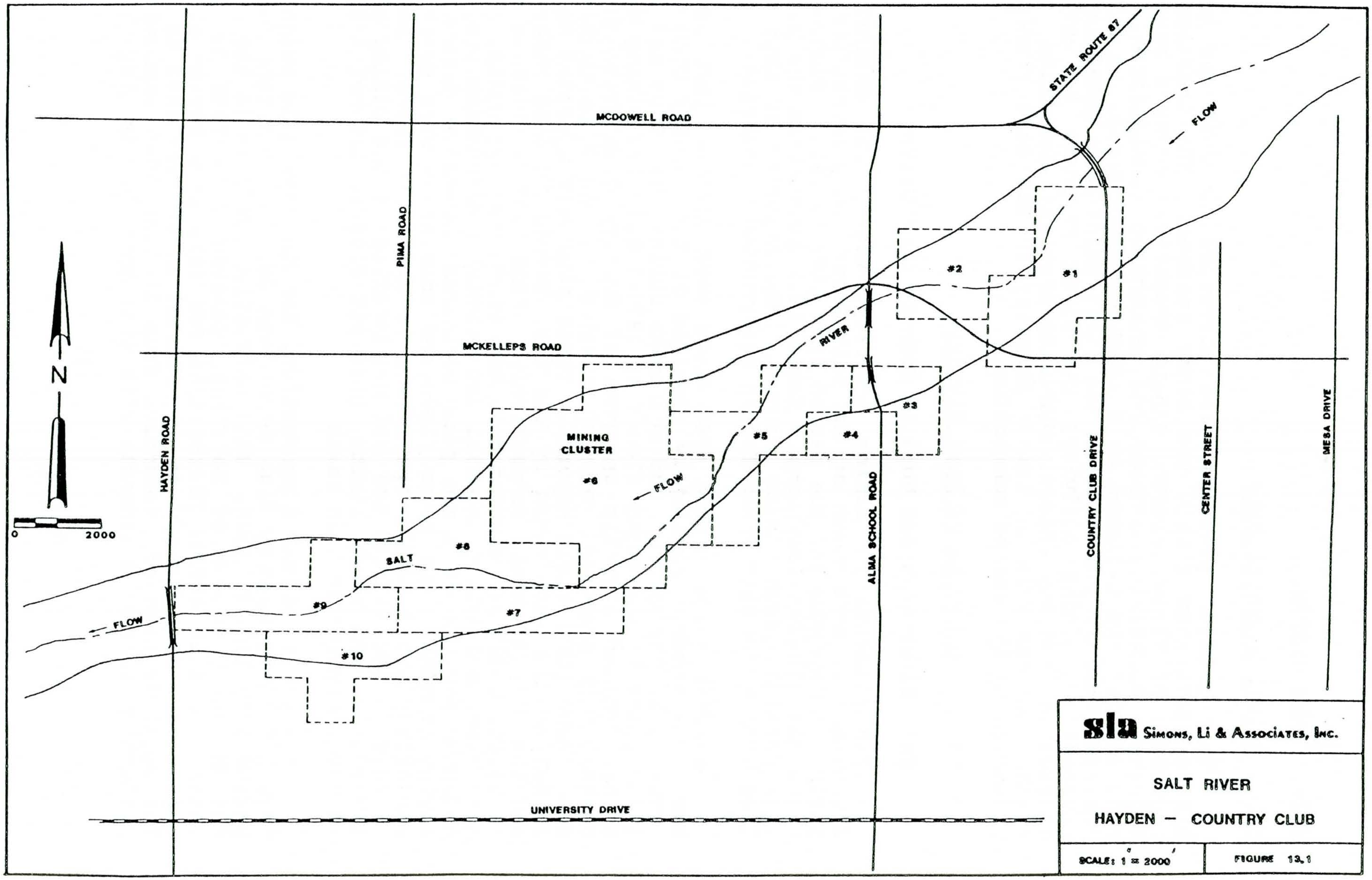
13.1.1 Overview of Past History

Salt River - Hayden Road to Country Club Drive

Ten clusters of mining activity, within the channel and floodplain of this reach of the Salt River, were identified from aerial photographs for the period from 1969 to 1986. Figure 13.1 shows the cluster locations. Table 13.1 summarizes the production data for each mining cluster. The majority of this reach lies within the Salt River Indian Reservation boundaries.

Several large mining operations were located just outside the study reach, immediately upstream of the Country Club Drive crossing in the channel and overbanks during the 1960s and early 1970s prior to the major floods of 1978-1980. Two mining operations, located directly upstream of Country Club Drive in the channel and overbank, were documented in old Arizona Highway Department (AHD) Field Reports. These pits were operated on land leased by the AHD, owned by the U.S. Bureau of Land Management and the City of Mesa, respectively. From 1963 to 1966, a total of 83,000 tons were excavated to use as mineral aggregate, aggregate base, and select material for roadway construction projects. A large portion of these pits sustained extensive damage following inundation by river flows and some areas were eventually converted into landfill operations in the early 1980s. Because of this change in land use and the location of the mining activity outside the study limits, this pit cluster was not included in the analysis for this reach.

The total estimated production, for the five mile reach from Hayden Road to Country Club Drive, was 58.5 million tons for the period from 1962 to 1986. This extraction estimate is the sum of the measured volume of material, removed from 1969 to 1986, determined from aerial photographs for this time period plus an approximation of the volume of material mined from 1962 to 1969. The approximation of production from 1962 to 1969 assumed that production increased linearly with time from zero in 1962 to the



sla Simons, Li & Associates, Inc.

SALT RIVER

HAYDEN — COUNTRY CLUB

SCALE: 1" = 2000'

FIGURE 13.1

Table 13.1 Summary of Sand & Gravel Mining Clusters
SALT RIVER - HAYDEN ROAD TO COUNTRY CLUB DRIVE

Cluster Number	Estimated Excavated Volume (tons)	Mining Period	Comments
#1	5,900,000	1962-1986	This excavation area sustained extensive damage during the 1978 flood which re-filled the pits leaving only the plant intact. The old Country Club Drive bridge and training dike failed during the 1980 flood and work began in 1981 on a new bridge aligned through the upstream end of the pit cluster. The bridge was completed in 1983. In addition, the channel was shaped through the bridge crossing area. Following completion of these channel improvements, production at this site was greatly reduced.
#2	1,000,000	1962-1977	This was a small operation mined from the 1960s to 1977.
#3	3,400,000	1962-1986	Mining was underway at this site in 1969; the plant expanded in 1978. Following the 1980 flood, the main channel was shaped to a uniform width of about 1000 feet for a distance of 3600 feet upstream and downstream of the north Alma School Road bridge. Pits were developed to the south and east of the plant further defining a secondary channel south of the main channel which existed in the pre-mining condition. In 1985, a dike was constructed across the excavated secondary channel to protect the plant area from low flows enabling increased production potential downstream of Alma School Road south of the main channel where the fourth pit cluster is located.
#4	3,600,000	1962-1986	These pits were inundated by the 1980 flood. In 1982, the plant was removed from this site and presumably materials were processed at the plant east of Alma School Road in the third pit cluster. The area formerly occupied by the disassembled plant was mined beginning in 1986.
#5	8,700,000	1975-1986	Operation began in 1975 and steadily increased thereafter. The existing pits were re-filled during the floods of the late 1970s and material re-harvested following that period. The operation greatly expanded in 1985 with large pit development in the main channel.
#6	9,100,000	1962-1986	This pit cluster is located in a braided section of the river. The main low flow channel follows the south bank of the river so that the remainder of the pre-mined floodplain is an open bar with a small secondary channel to the north. The sixth pit cluster has been excavated from the bar beginning in 1982 and greatly expanding since 1983. The pits are of large surface area as compared to shallow excavation depth. Pit development has proceeded radially in a semi-circular fashion from the plant. This mining pattern contrasts with the other mining operations in this reach.

Table 13.1 (continued) SALT RIVER - HAYDEN ROAD TO COUNTRY CLUB DRIVE			
Cluster Number	Estimated Excavated Volume	Mining Period	Comments
	(tons)		
#7	3,700,000	1978-1983	A levee originally constructed in 1975 and subsequently lengthened in 1977 separates the mining area from the active channel. This levee sustained damage during each of the 1978-1980 floods but was repaired as necessary.
#8	5,800,000	1962-1986	Mining activity began in the mid-1970s. The operation was damaged during the major floods of the late 1970s. Since 1981, production has consistently increased to the present day. This pit cluster appears to be operated in conjunction with the large sixth cluster previously described utilizing the same material harvesting procedure.
#9 & 10	17,300,000	1962-1986	The ninth and tenth mining clusters are located adjacent to each other in the main channel and south overbank between Hayden Road and Pima Road. Production began in 1972 and increased through 1978 when flooding altered pit configurations. Mining activity resumed after the floods; at first concentrated in the south overbank and then proceeding into the main channel. The main channel has been excavated back to the south creating a steep bank paralleling Pima Street east of Hayden Road.

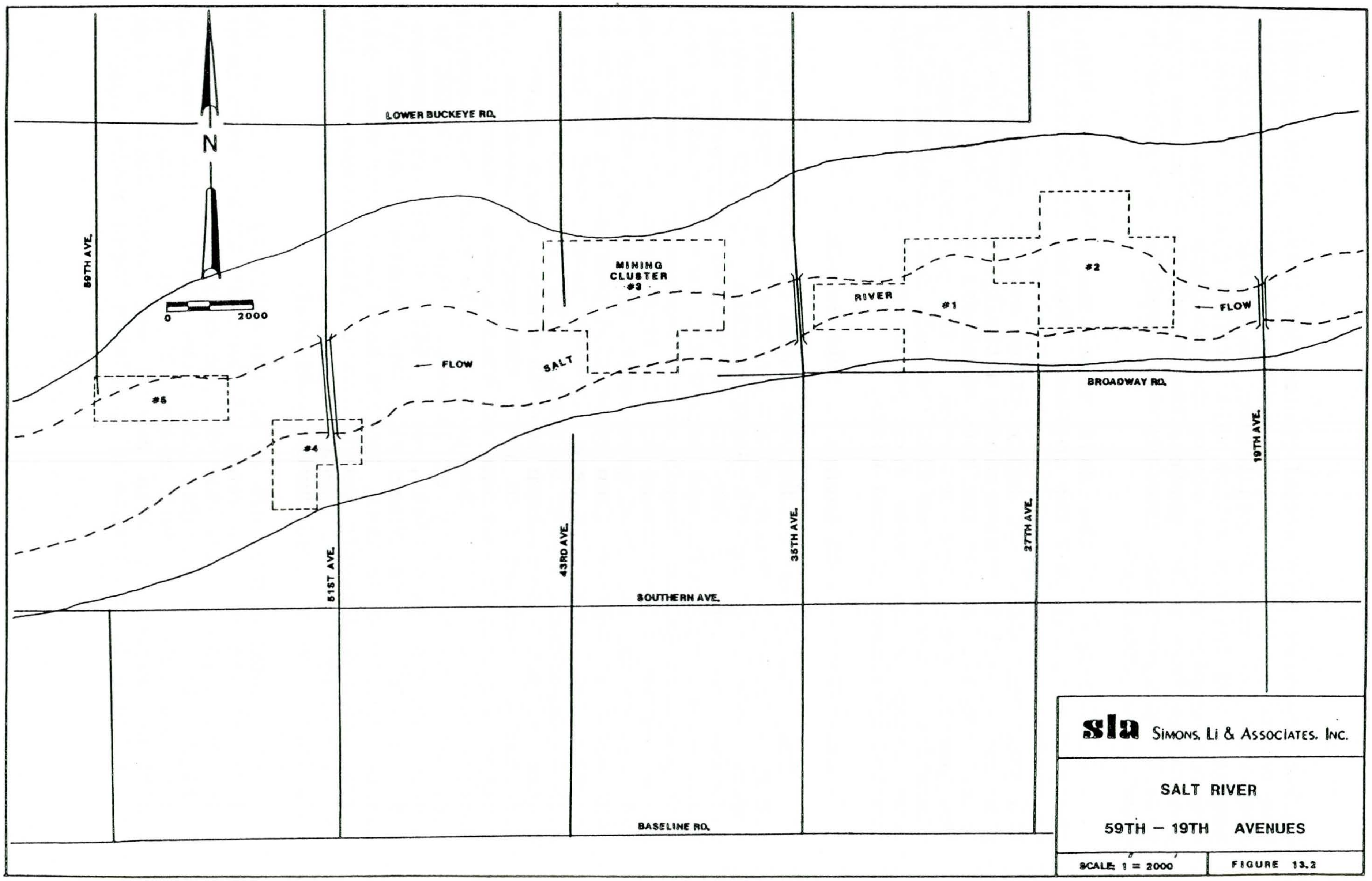
volume measured from aerial photos for 1969. This approximation was necessary because aerial photographs of this reach prior to 1969 were not readily available, and a total production estimate was required for the entire 1962 to 1986 period to coincide with the topographic mapping window for analysis purposes. To obtain the volume from aerial photos, the depth of mining was based on a visual interpretation from physical features and discussion with experienced operators.

This reach of the Salt River has undergone significant change during the past two decades. The aerial extent and volume of production has greatly increased since 1983. In response to the combined effect of major flood events, channelization improvements, and extensive mining activity, the reach has degraded an average of 7.2 feet for both mined and non-mined cells, during the period from 1962 to 1986. The maximum changes in bed elevation in the main low flow channel, for non-mined cells below Alma School Road, range from 14 to 16 feet where mining has created a narrower channel width.

Salt River - 59th Avenue to 19th Avenue

Sand and gravel mining was known to exist in this reach as early as 1958. A review of old Arizona Highway Department Field Reports and Material Pit Recapitulation reports indicate that material was removed for use as mineral aggregate, aggregate base, select material, and borrow for several roadway construction projects in the Phoenix area. Documentation exists for five mining areas in particular within this reach of land, owned by federal, state, and local government, that were excavated to augment material obtained from commercial sources for use in project construction. Two pits were mined on land owned by the Arizona Highway Department (later by ADOT). The first was located in the channel directly downstream of 35th Avenue, where 101,000 tons of material was excavated in 1973; the second excavation site was located directly downstream of 43rd Avenue, where 36,000 tons were removed in 1979. Two pits in this reach were operated on land owned by the City of Phoenix. One was located at 22nd Avenue and the Salt River, where 560,000 tons was removed from 1958 to 1965. The other site was located just west of 27th Avenue; from 1961 to 1962, 205,000 tons were excavated. Finally, a pit located directly downstream of 51st Avenue was mined on land owned by the U.S. Bureau of Reclamation, where 162,000 tons of material was removed during 1959-1960.

Six distinct clusters of mining activity, within the channel and floodplain of this reach of the Salt River, were identified from aerial photographs for the period from 1972 to 1983. Refer to Figure 13.2 for cluster locations. Table 13.2 summarizes the production data for each mining cluster. A large pit at the southeast corner of 35th Avenue and Lower Buckeye Road was located outside the limits of available topographic mapping and,



LOWER BUCKEYE RD.
N
0 2000
59TH AVE.
51ST AVE.
43RD AVE.
35TH AVE.
27TH AVE.
19TH AVE.
MINING CLUSTER #3
RIVER
#1
#2
FLOW
SALT
FLOW
#5
#4
BROADWAY RD.
SOUTHERN AVE.
BASELINE RD.
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SALT RIVER
59TH – 19TH AVENUES
SCALE: 1" = 2000'
FIGURE 13.2

Table 13.2. Summary of Sand & Gravel Mining Clusters SALT RIVER - 59TH AVENUE TO 19TH AVENUE			
Cluster Number	Estimated Excavated Volume	Mining Period	Comments
	(tons)		
#1	10,200,000	1962-1983	The mining activity appeared to be large in aerial extent in the channel, but shallow in depth of excavation. Production peaked in 1975-78 and greatly decreased after the large magnitude floods of 1978, 1979, and 1980. Following the 1980 flood, the main concentration of mining activity shifted from this in-stream excavation area to Cluster #2.
#2	7,400,000	1962-1983	The channel in its undisturbed state in this area is braided. Two drain outfalls located on the north bank outlet into a secondary channel. The pits in this cluster have been developed towards the south encroaching into the main channel while maintaining a relief channel for the drain outlets to the north. Excavation proceeded south thereby constricting the main channel to a width of about 1000 feet. In 1986, levees were constructed on both the north and south sides of the river for a distance of 1 mile downstream of 19th Avenue further constricting the main channel to an average width of approximately 500 feet. Some excavation was also performed to shape the channel within the levees. Recent topographic mapping for this area was unavailable to determine what impact these channel improvements have had on the adjacent upstream and downstream river reaches.
#3	4,500,000	1973-1983	Mining activity began in 1973 and continues to date. The pits in this cluster appear to contain lifts of different levels of excavation; some areas are being excavated much deeper than others. Dikes were constructed along differing alignments in 1981, 1985 and 1987 to protect portions of the mining activity from river flows. While a portion of the pit cluster was captured during the 1980 flood, this excavation area was not affected as severely as those previously described located upstream of 35th Avenue. Production continued during the floods of the late 1970s and has consistently increased from 1983 to the present.
#4	500,000	1980-1983	This operation began mining in 1980 and has remained active in recent years.
#5	500,000	1973-1983	Production began in 1973 and has continued intermittently to the present. This appears to be a shallow excavation of comparatively larger areal extent. A dike was constructed in 1987 to protect the upstream boundary from river flows.

therefore, was not included in the analysis.

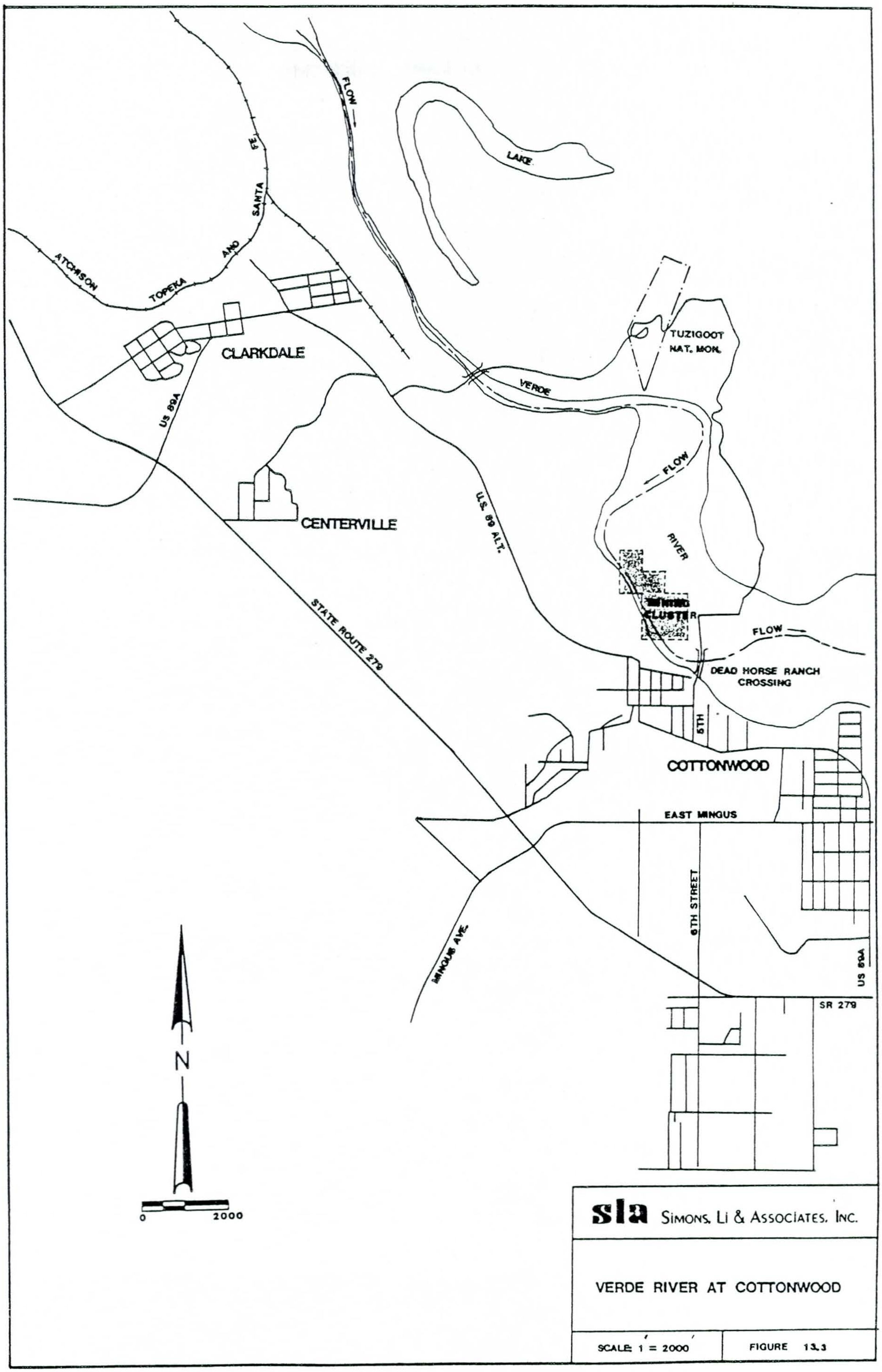
The total estimated production for the five mile reach from 59th Avenue to 19th Avenue was 23.1 million tons for the period from 1962 to 1983. This extraction estimate is the sum of the measured volume of material removed from 1972 to 1983, determined from aerial photographs for this time period, plus an approximation of the volume of material mined from 1962 to 1972. The approximation of production from 1962 to 1972 assumed that production increased linearly with time from zero in 1962 to the volume measured from aerial photos for 1972. This approximation was necessary because aerial photographs of this reach prior to 1972 were not readily available, and a total production estimate was required for the entire 1962 to 1983 period to coincide with the topographic mapping window for analysis purposes.

Several changes were observed in the river in combined response to major flood events and material extraction. The bed topography for both mined and non-mined cells in this reach has degraded an average of 1.9 feet, with a maximum change for non-mined cells of 6.9 feet occurring in the main channel upstream of the 51st Avenue bridge. The large mining operations near 19th and 27th Avenues were filled and re-worked after being captured by the major floods of the late 1970s. Interpretation of photos, taken following the 1978 flood, indicated that the channel became generally narrower with some evidence of bank steepening below 19th Avenue on the south side of the river. Also, some channel incisement in the vicinity of 27th Avenue was observed after the 1980 flood.

Verde River - Cottonwood

A 1971 Field Report of the Arizona Highway Department Materials Division shows a potential aggregate and borrow source of an estimated 88,000 cubic yards directly upstream of the old 5th Street river crossing in the northeast overbank. No documentation was found indicating that this potential source had been used. The U.S.G.S. 7.5 minute quadrangle map, published in 1973, depicts a sand and gravel operation in the Verde River floodplain, approximately one-half mile upstream of the present Dead Horse Ranch State Park crossing. Although aerial photos taken in the mid to late 1970s show decreased vegetative cover and increased gravel mining activity, a more intensive level of activity becomes apparent in photos taken from 1982 to 1985.

A cluster of three pits with a combined surface area of 9 acres were excavated in 1983-84 approximately one-quarter mile upstream of the park crossing. Refer to Figure 13.3 for pit locations. The increased mining activity in the east overbank caused some diversion of low flows along a new alignment through the pit area located northeast of the old low-flow channel that had existed through the area since 1977-1978. An earthen berm



FLOW
LAKE
ATCHISON TOPEKA AND SANTA FE
CLARKDALE
TUZIGOOT NAT. MON.
VERDE
US 89A
FLOW
CENTERVILLE
U.S. 89 ALT.
RIVER
CLUSTER
FLOW
STATE ROUTE 279
DEAD HORSE RANCH CROSSING
5TH
COTTONWOOD
EAST MINGUS
6TH STREET
MINGUS AVE.
US 89A
SR 279
N
0
2000
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VERDE RIVER AT COTTONWOOD
SCALE: 1' = 2000'
FIGURE 13.3

was constructed in an attempt to block the new low-flow channel; however, the berm failed in 1985 allowing water to flow through the pit area.

In addition, in 1984, fill was placed in a 1200 foot length of channel along the south bank of the river immediately upstream of the park crossing, effectively blocking the existing low flow channel and creating a new low flow alignment approximately 150 feet to the north. The re-alignment of flows through previously vegetated overbank areas has apparently contributed to bank erosion and adversely impacted the stability of large trees situated in this area.

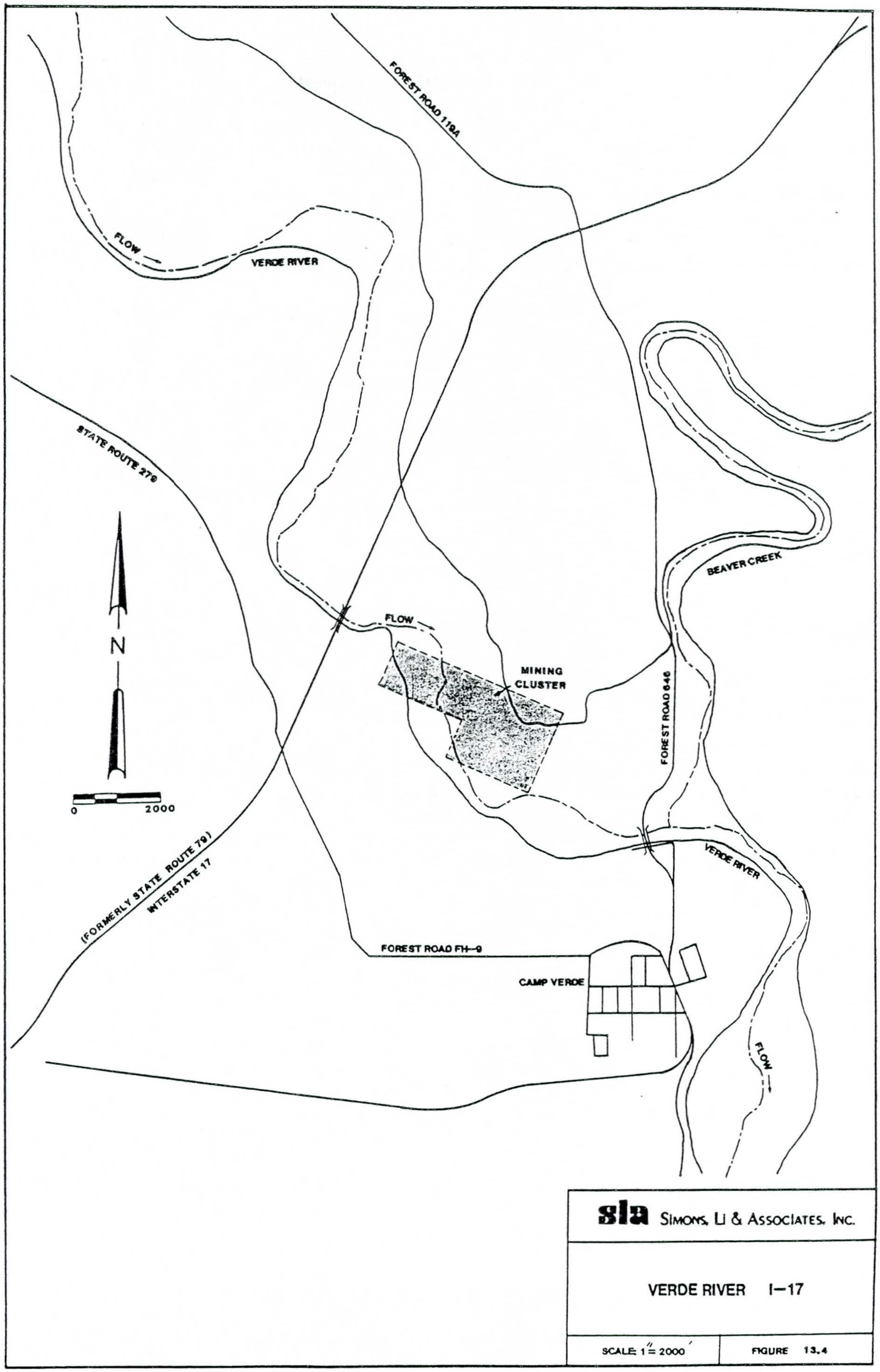
Sand and gravel extraction was estimated at 400,000 tons for the period from 1982 to the present. Only limited topographic mapping and aerial photography is available for this reach. Two years of mapping coverage are available for 1976 and 1982, but inconsistencies in this data render a direct comparison of bed topography unreliable. Likewise, the aerial photography readily available are only for 1982 and 1987, during the period of active mining. Since the topographic mapping data window and the mining activity data window do not overlap, no direct correlation may be determined between excavation volume and average changes in bed topography for the entire reach.

A previous study by SLA (1985) noted an approximate four-foot drop of the channel bed downstream of the Dead Horse Ranch State Park crossing following the 1980 flood. The drop in bed elevation immediately downstream of the crossing was prevented from migrating further upstream because the low water crossing functioned as a man-made grade control structure. A comparison of spot elevations directly upstream of the park crossing, indicated a degradational trend on the order of about one foot from 1982 to 1987.

Verde River - I-17

Only limited information is available for this reach, regarding changes in bed topography and sand and gravel extraction. Mapping and aerial photography were obtained solely for 1979. Based on photo interpretation, material extraction was estimated at 280,000 tons for 1979. Refer to Figure 13.4 for location of excavation areas.

A review of a 1957 Field Report of the Arizona Highway Department Materials Division indicated that 90,600 cubic yards of borrow was excavated from a pit, located about a quarter mile upstream of the SR79 bridge, in the overbank northeast (inside) of a bend in the low flow channel. The material was used for roadway construction. A 1966 Field Report shows the location of a potential borrow source of an estimated 60,000 cubic yards, about one-half mile upstream of the SR79 bridge in the overbank,


FOREST ROAD 119A
FLOW
VERDE RIVER
STATE ROUTE 279
N
0
2000
FLOW
MINING
CLUSTER
BEAVER CREEK
FOREST ROAD 646
VERDE RIVER
(FORMERLY STATE ROUTE 79)
INTERSTATE 17
FOREST ROAD FH–9
CAMP VERDE
FLOW
sla SIMONS, LI & ASSOCIATES, INC.
VERDE RIVER I–17
SCALE: 1" = 2000'
FIGURE 13.4

southwest (outside) the bend in the low-flow channel opposite the 1957 borrow pit. Another potential aggregate source in this reach, described in a 1967 Field Report, is located one-third of a mile downstream of the SR79 bridge. No documentation was found indicating whether or not these last two borrow sources were actually used. It was noted, however, that the channel thalweg had shifted about 500 feet southwest around the borrow site, identified in the 1967 Field Report to its present location. This shift in low-flow channel alignment may be related to the mining activity evident in the 1979 aerial photo.

Since mapping was only obtained for one year, no direct correlation is possible between excavation volume and changes in bed topography for this reach. However, a comparison of the channel invert at the I-17 bridges was made using data from As-Built plans, a field survey, and an inspection report. This comparison showed a 3.9 foot drop in the invert elevation from 1955 to 1978. The channel degraded an additional 9.1 feet from 1978 to 1987, for a total change in elevation of 13 feet in the past 32 years.

Agua Fria River - Buckeye Road to Camelback Road

The Agua Fria River in its natural condition through this reach is a generally wide, braided river with poorly defined and unstable banks. Sand and gravel mining operations, other urban and agricultural encroachments, and upstream flood control improvements have combined to alter the shape of the river and the bed topography.

Seven clusters of mining activity within the channel and overbank of this reach were identified from aerial photographs for the period from 1975 to 1981. Figure 13.5 shows the cluster locations. Table 13.3 summarizes the production data for each mining cluster. The total estimated production for the five mile reach, extending from Camelback Road to Buckeye Road, was 11.8 million tons for the period from 1972 to 1981. Observed changes in the bed topography during this period include an average degradation for the mined and non-mined cells within the entire reach on the order of 1.5 feet. The maximum change in bed elevation for non-mined cells in the main channel is 6.7 feet, just upstream of the Indian School Road bridge. The total production estimate is the sum of the measured volume of material removed from 1975 to 1981, determined from aerial photographs for this time period, plus an approximation of the volume of material mined from 1972 to 1975. The approximation of production from 1972 to 1975 assumed that production increased linearly with time from zero in 1972, to the volume measured from aerial photos for 1975. This approximation was necessary, because aerial photographs of this reach prior to 1975 were not readily available, and a total production estimate was required for the entire 1972

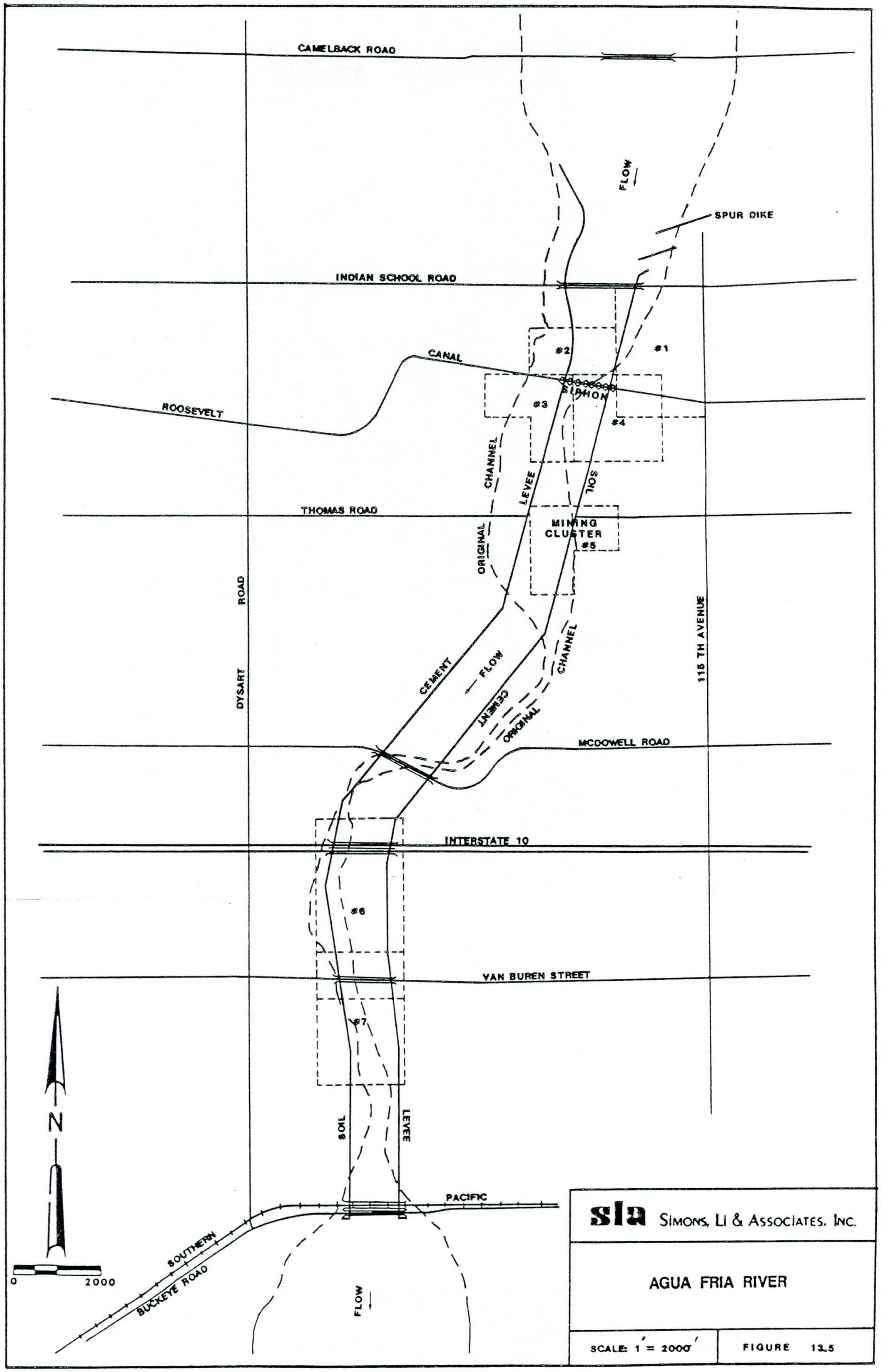

CAMELBACK ROAD
FLOW
SPUR DIKE
INDIAN SCHOOL ROAD
#2
#1
CANAL
SIPHON
ROOSEVELT
#3
#4
CHANNEL
LEVEE
SOIL
THOMAS ROAD
MINING CLUSTER
#5
ORIGINAL
DYSART ROAD
115 TH AVENUE
CEMENT
FLOW
CEMENT
ORIGINAL
CHANNEL
ORIGINAL
MCDOWELL ROAD
INTERSTATE 10
#6
VAN BUREN STREET
#7
N
SOIL
LEVEE
PACIFIC
SOUTHERN
BUCKEYE ROAD
0
2000
FLOW
sla SIMONS, LI & ASSOCIATES, INC.
AGUA FRIA RIVER
SCALE: 1" = 2000'
FIGURE 13.5

Table 13.3. Summary of Sand & Gravel Mining Clusters
AGUA FRIA RIVER - BUCKEYE ROAD TO CAMELBACK ROAD

Cluster Number	Estimated Excavated Volume (tons)	Mining Period	Comments
#1-4	9,500,000	1972-1981	This cluster is the major production site in this reach. The pits in this area are excavated to comparatively large depths. During the channelization of the river in 1985-86, that portion of the pits in this cluster lying within the channel levees were re-filled and compacted to form a uniform section.
#5	360,000	1972-1980	Excavation at this site was underway in 1975 and continued until the 1978 flood which re-filled the pits and removed the old plant. Mining activity resumed as shallow exploratory test holes were dug. The entire operation was gone following the 1980 flood.
#6	1,400,000	1972-1981	A plant was located in this area and shallow excavation was underway in the main channel in 1975. Production increased consistently until 1978 when a major flood re-filled the pits. Renewed pit development is evident from aerial photos after the 1980 flood, however, at a much reduced scale. In 1986, a grade control structure was constructed directly downstream of the I-10 bridge at the northern end of this excavation area. The channelization project for this reach of the river is currently under construction. The pits located in the channel have been re-filled and compacted as part of the levee construction project.
#7	630,000	1978-1981	It appears from aerial photo interpretation that Cluster #3 expanded in a downstream direction beginning in 1978 forming Cluster #4 directly downstream of Van Buren Street. The 1978-1980 floods curtailed production. After 1981-1982, excavation increased steadily through 1986. The channelization project for this reach of the river is currently under construction. The pits located in the channel have been re-filled and compacted as part of the levee construction project.

to 1981 period to coincide with the topographic mapping window for analysis purposes.

Mining activity within this reach is concentrated near the Indian School Road bridge and the Roosevelt Irrigation District (RID) siphon. In-stream sand and gravel mining near Indian School Road began in the late 1950s. During the early 1960s, mining was concentrated in the west branch of the low-flow channel, above Indian School Road and the old RID flume. Prior to 1964, the east branch of the low-flow channel was more defined than the west branch. By 1964, the west low-flow channel had deepened and widened due to the extraction of sand and gravel. The west low-flow branch became the dominant low-flow channel prior to the construction of Indian School Road Bridge in 1970. However, the river started migrating gradually eastward, after construction of the bridge. Examination of the 1980 aerial photograph reveals the channel upstream of the bridge shifted 700 feet east of the east abutment. The migration of the channel to the east, upstream of the bridge, resulted in the flow attacking the bridge piers at a severe angle during the 1980 flood.

Downstream of the bridge, mining was underway on both over-banks. Dikes were constructed to protect the gravel pits in the west overbank from the flow. Still, some pits were damaged by the flood. Photo interpretation indicated that the channel appeared more entrenched with steeper banks in this area, following the 1980 flood. In addition, the Indian School Road bridge failed during the flood event.

In 1982, a dike was built on the east side of the channel from Indian School Road to a quarter mile south of the RID flume. This narrowed the river channel to just 400 feet upstream of the RID flume. Expansion of the pits in both overbanks progressed south of the RID flume toward Thomas Road during the early 1980s.

Repairs to the Indian School Road bridge were completed in 1984. A large flood control project, constructed in 1986, consisted of the channelization of the river with soil cement protected levees and grade control structures. The levees extended from just upstream of Indian School Road, proceeding through the pit area, ending at Thomas Road on the east side of the channel and continuing to the I-10 bridge on the west side. In 1987, the bank protection on the east side of the channel was completed, connecting to the previously constructed levee terminus at Thomas Road on the north, and extending to McDowell Road on the south. The channelization project currently under construction extends from the I-10 bridges to a point directly downstream of Buckeye Road.

The channelization project greatly impacted the mining activity in the west overbank, between Indian School Road and the RID flume, reducing the size of the plant and taking a large portion of the pits out of production. In 1987, new pits were excavated to the west of the plant. The flood control project also realigned the river toward the west, between Thomas Road and McDowell Road, by straightening out a bend in the natural horizontal alignment of the river.

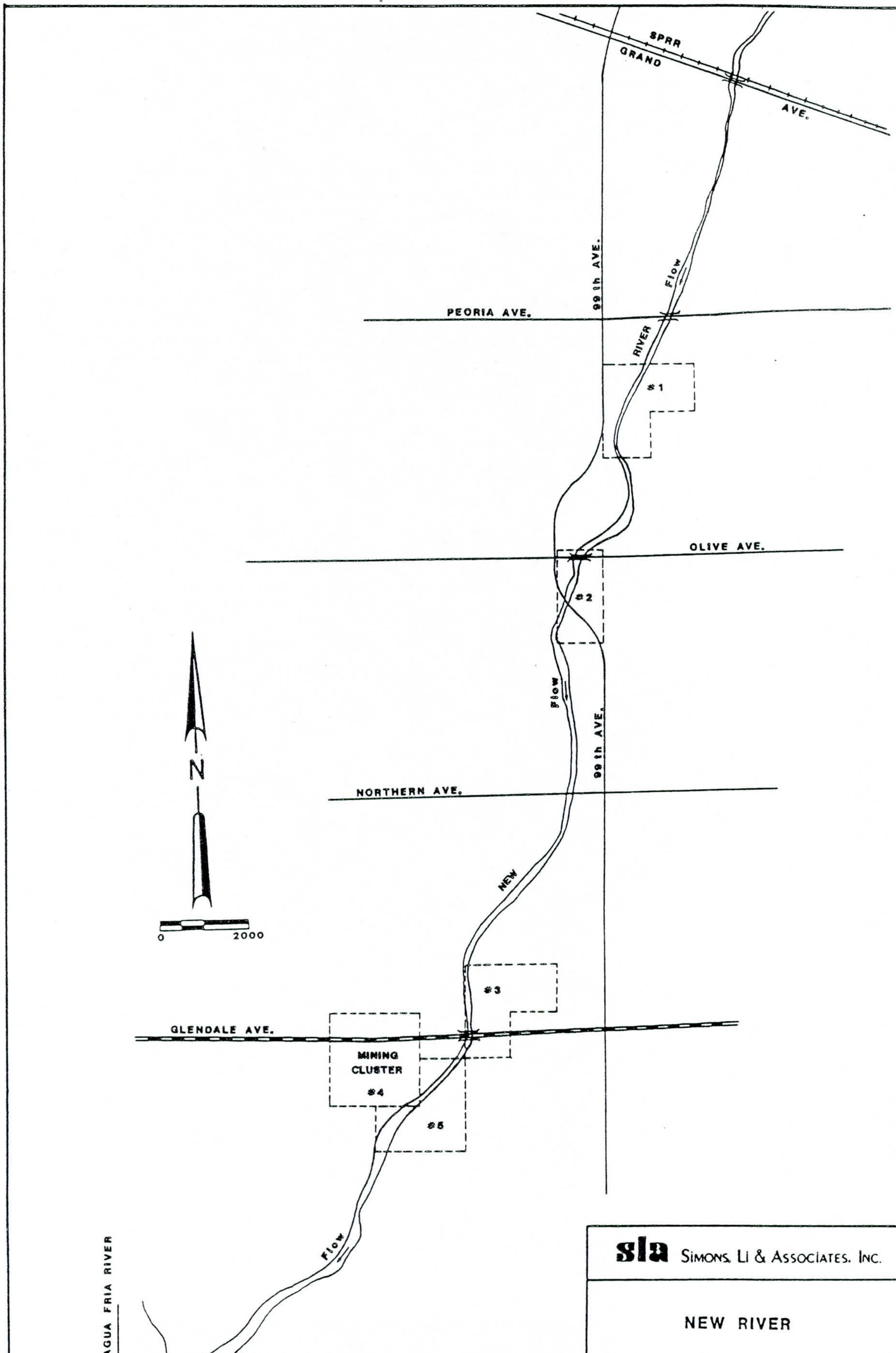
New River - Agua Fria River Confluence to Peoria Avenue

Five mining clusters within this reach were identified from aerial photographs for the period from 1976 to 1987. Refer to Figure 13.6 for cluster locations. Table 13.4 summarizes the pro-duction data for each mining cluster. A mining operation located just upstream of Peoria Avenue was outside the study limits and, therefore, not included in the analysis.

A recently developed pit cluster is located about 1200 feet downstream of Northern Avenue in the channel and west overbank. Mining activity began in 1981, remaining relatively small scale until expanding significantly in 1986. Since this pit development occurred after the date of the latest available topographic mapping, it was not included in the analysis.

The total estimated production for the entire four mile reach, from Peoria Avenue to the Agua Fria River confluence, was 1.8 million tons for the period from 1976 to 1981. This extraction estimate was measured from aerial photos for this time period. Comparison of bed topography mapped in 1976 and 1981 indicated an average degradation for mined and non-mined cells in the reach of 0.6 feet. The maximum elevation change within non-mined cells of 6.4 feet occurred immediately up-stream of the Glendale Avenue bridge, and was probably directly influenced by the mining activity concentrated in this area.

Analysis of the correlation between changes in bed topography and the rate of production indicated that extraction of material from this reach was underestimated. Material harvesting methods for this reach included some channel clearing/shaping, undertaken at the request of the City of Peoria to increase channel capacity, improve channel efficiency, and reduce the floodplain width for insurance purposes. This type of excavation is difficult to detect through photo interpretation, as compared to standard pit development. Some evidence of channel clearing was noted in 1982, 1986 and 1987 directly upstream of Olive Avenue, but no attempt was made to quantify the volume of material removed. In addition, extensive channel clearing and shaping was undertaken in 1986 for a distance of about one mile upstream of the confluence with the Agua Fria River. The channel improvement work was completed in conjunction with the construction of the new Glendale Airport to the west of the channel.



sla Simons, Li & Associates, Inc.

NEW RIVER

SCALE: 1" = 2000'

FIGURE 13.6

Table 13.4. Summary of Sand & Gravel Mining Clusters NEW RIVER - AGUA FRIA RIVER CONFLUENCE TO PEORIA AVENUE			
Cluster Number	Estimated Excavated Volume	Mining Period	Comments
	(tons)		
#1	110,000	1976-1981	This relatively small operation was underway in 1976 and expanded until the 1978-1980 floods re-worked the channel bed. A renewed excavation effort in 1980 was washed out. No activity was evident again until 1986 when an area previously mined before the floods was redeveloped.
#2	120,000	1976-1981	A review of Arizona Highway Department Materials Division Field Reports and Material Pit Recapitulation sheets indicates that this area was excavated from 1960-1967 yielding approximately 86,000 tons of various aggregate products for roadway construction in this vicinity. Based on photo interpretation, it appears the pits sustained damage and were re-filled during the 1978 flood. No operation is evident after 1979 until some small pits were developed in the main channel adjacent to the old site in 1986-1987. In addition, it was noted that the channel narrowed downstream of this area following the major flood events of 1978-1980.
#3	400,000	1976-1981	Mining activity in this reach is concentrated in the vicinity of Glendale Avenue. ADOT records show that an excavation site in the channel and east overbank directly upstream of Glendale Avenue was used as a source of approximately 100,000 tons of mineral aggregate, aggregate base, select material and borrow for nearby roadway construction from 1961 to 1967. More recent aerial photos show that while production in the channel was impacted by the flooding of the late 1970s, mining in the east overbank proceeded steadily through this period. Renewed activity in the channel occurred in 1987.
#4	370,000	1977-1980	
#5	800,000	1976-1981	This pit operation steadily grew in surface area from 1976 to 1987 with a temporary interruption during the 1978 and 1979 floods. Interpretation of photos taken following the 1980 flood shows evidence of the formation of a headcut at the upstream end of the pit area.

Santa Cruz River - Valencia Road to I-19

The Santa Cruz River is geomorphically active through the reach between Valencia Road and I-19. A well-established meander pattern is apparent from Valencia Road to Martinez Hill. In the vicinity of Valencia Road, the channel changes from a 500-1000 foot-wide, shallow arroyo upstream, to a relatively stable 150 foot-wide, entrenched channel downstream of the bridge.

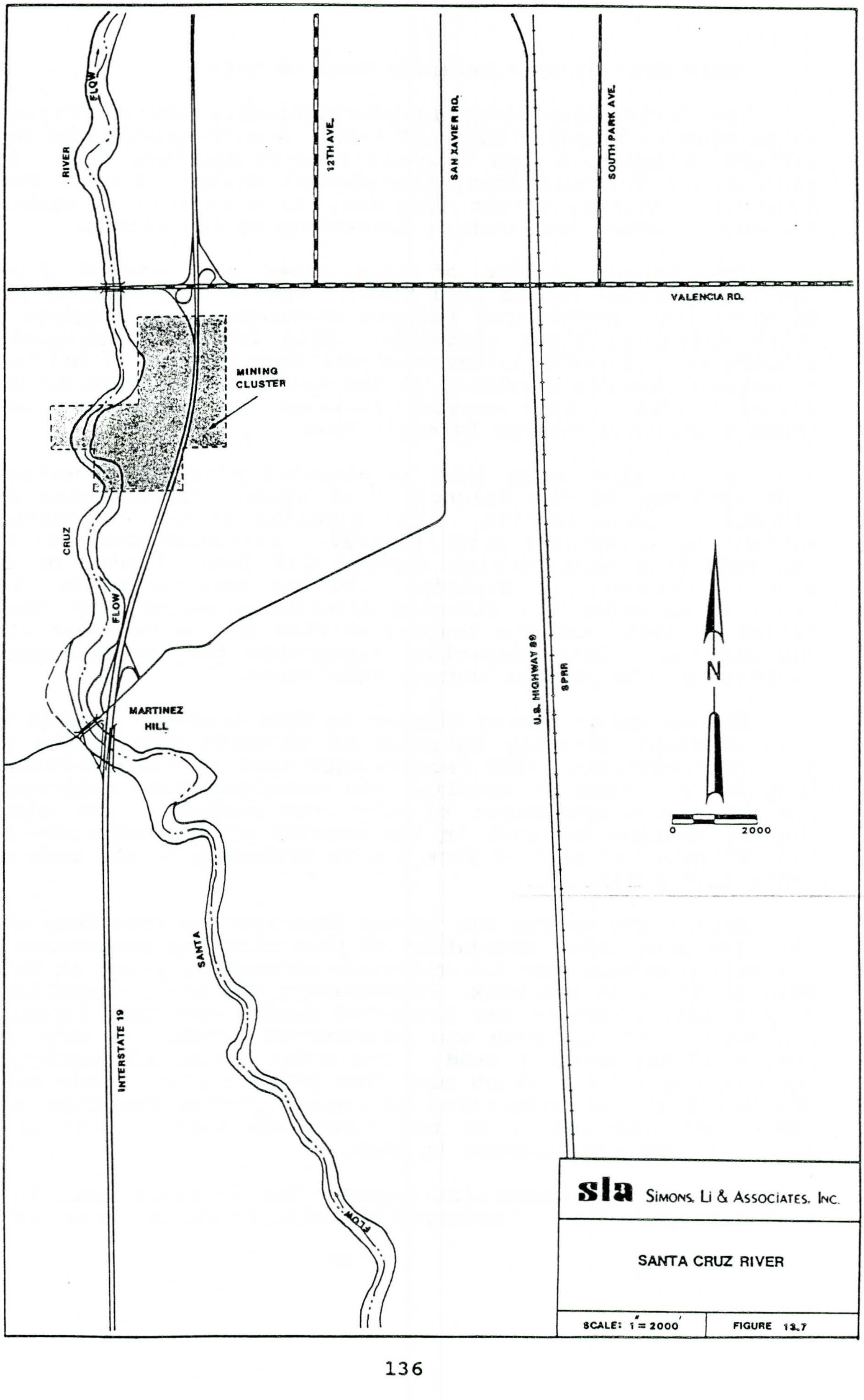
The dynamic nature of this river was evident from the channel response to the 1983 flood. The natural meander pattern of the river encountered bedrock obstruction at Martinez Hill, which deflected flows westward. This induced pronounced bank erosion at the north abutment of the northbound I-19 bridge, and a westward meander migration at the southwest abutment of the San Xavier bridge. Bank erosion followed the pattern of meander bends downstream towards Valencia Road.

It was also noted that an elevated pipeline crossing 6000 feet upstream of the Valencia Road bridge was impacted by the pattern of bank erosion. The pipeline initially spanned the channel as it existed prior to 1980. Following the 1983 flood, the resultant bank erosion exposed 200 feet of pipe on either side of channel. A training dike was constructed in 1984 to route flows under the elevated pipeline crossing, but the dike failed in 1985, and the thalweg shifted to the far east side of the channel. This situation illustrates the local morphologic activity of the channel through this reach.

The one major mining cluster in this reach is located in the east overbank directly upstream of Valencia Road. See Figure 13.7 for location. ADOT records show that in the mid-1960s more than 500,000 tons of material was excavated from this area for use in the construction of the I-19 roadway. In addition, channel shaping resulted in the removal of approximately 50,000 tons of material in 1962 from a side tributary to the east of the Santa Cruz River.

Aerial photos for the period from 1974 to 1985 were reviewed. The area under excavation at this site has progressed about one mile upstream from the materials processing plant at Valencia Road in the east overbank. Presumably, the main excavation site in the east overbank was inundated during the 1983 flood. The following year, a levee was constructed around the site on the inside of the meander bend. The total estimated production at this site was 2.6 million tons from 1974 to 1985. This estimate was based on interpretation of aerial photos for this period. Additional excavation, in the floodplain west of the channel, began in 1984 and expanded in 1985.

ADOT Bridge Inspection Reports for Valencia Road indicate that six feet of scour occurred at this location from 1977 to


RIVER
FLOW
12TH AVE.
SAN XAVIER RD.
SOUTH PARK AVE.
VALENCIA RD.
MINING CLUSTER
CRUZ
FLOW
MARTINEZ HILL
U.S. HIGHWAY 89
SPRR
N
0
2000
SANTA
INTERSTATE 19
FLOW
sla Simons, Li & Associates, Inc.
SANTA CRUZ RIVER
SCALE: 1" = 2000'
FIGURE 13.7

1984. It appears that the response of the narrow entrenched river through this area was mainly by channel scour. This contrasts with the observed changes upstream at the I-19 and San Xavier bridges, where the wider, more shallow channel flow attacked the banks causing severe erosion. Due to a lack of topographic data for this river reach, an overall average change in bed topography was not computed.

Rillito Creek - I-10 to La Cholla Boulevard

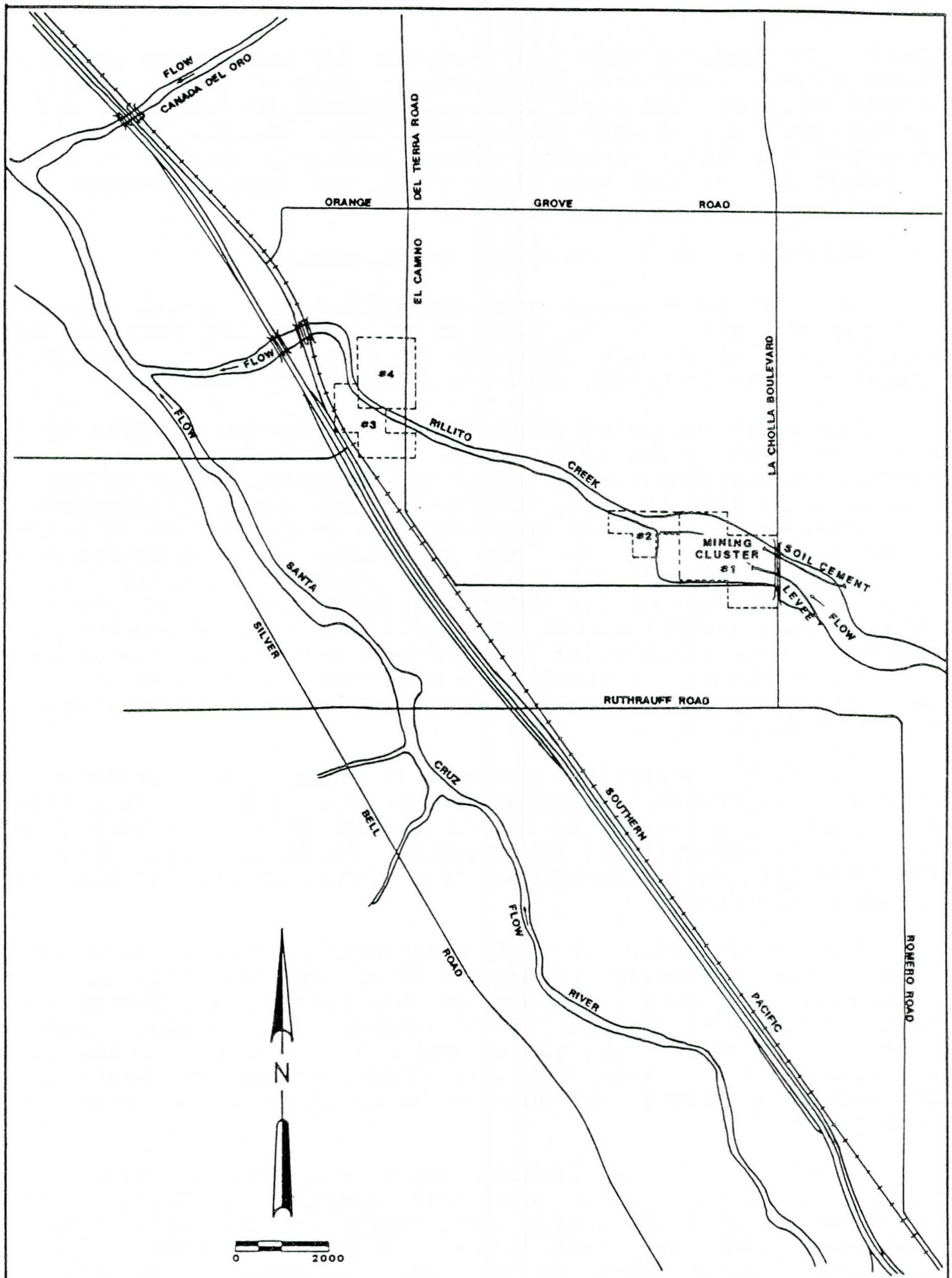
Four mining clusters were identified from aerial photos for the period from 1974 to 1985 in this reach of Rillito Creek. Figure 13.8 shows the location of the clusters. Table 13.5 summarizes the pertinent data for each mining cluster.

The total estimated production, for the period from 1967 to 1984 for this three-mile reach, is 2.7 million tons. This extraction estimate is the sum of the measured volume of material removed from 1974 to 1984, determined from aerial photographs for this time period, plus an approximation of the volume of material mined from 1967 to 1974. The approximation of production from 1967 to 1974 assumed that production increased linearly with time from zero in 1967 to the volume measured from aerial photos for 1974. This approximation was necessary because aerial photographs of this reach prior to 1974 were not readily available and a total production estimate was required for the entire 1967 to 1984 period to coincide with the topographic mapping window for analysis purposes.

Material harvesting methods in this reach include some shallow, longitudinal scraping in the main channel. This type of excavation is difficult to detect through photo interpretation as compared to standard pit development. It is possible, therefore, that the production determined from aerial photos for this reach is underestimated.

The reach below La Cholla Boulevard contains some of the widest and narrowest channel widths in the Rillito Creek. Topwidths vary from a maximum of 600 feet to a minimum of 200 feet. Flooding in the 1970s eroded river banks, partially captured old excavation sites, and caused local widening of the river channel. During the 1983 flood, pronounced bank erosion followed the pattern of meander bends as allowed by piecemeal bank protection.

A mining site is located about 1000 feet upstream of La Cholla Boulevard within the main channel of Rillito Creek. Development of this mining site began in the late 1950s and continued until the late 1970s. During the late 1950s, the mining operation began on the south channel overbank of the river. During the 1960s and early 1970s, mining at the site included extensive extraction of materials from the channel bed.



sla SIMONS, LI & ASSOCIATES, INC.

RILLITO CREEK

SCALE: 1' = 2000'

FIGURE 13.8

Table 13.5. Summary of Sand & Gravel Mining Clusters
RILLITO CREEK - I-10 TO LA CHOLLA BOULEVARD

Cluster Number	Estimated Excavated Volume	Mining Period	Comments
	(tons)		
#1	1,200,000	1967-1984	Arizona Highway Department Materials Division records indicate that 97,000 tons of select material, aggregate base, and mineral aggregate were mined from 1958 to 1960 for use in roadway construction. Initially this site was the location of the materials processing plant. At that time, the principle extraction hole was located approximately 1000 feet south of the channel bank and immediately west on La Cholla Boulevard. Excavation of this area ceased at some time during the late 1960s. In addition, considerable in-channel mining took place immediately west of La Cholla during the late 1960s and early 1970s. The principle mining site then moved to a location immediately adjacent to the channel bank. Prior to the 1983 flood, soil cement bank protection was constructed for a distance of approximately 1800 feet on both banks of the river through the La Cholla Boulevard bridge area. The bank adjacent to the mining cluster has remained stable.
#2	175,000	1967-1984	This mining cluster is a relatively shallow excavation in the main channel and south overbank. Production began in 1984 and expanded in 1985.
#3	210,000	1978-1984	This mining site began development in 1978 and has expanded through 1985.
#4	1,200,000	1978-1984	This mining operation began development in 1978. The Rillito River flooding of December 1978 inundated this gravel pit and caused a shut-down in the operation for a brief period of time. The flooding caused local headcutting along the periphery of the pit. No substantial damages resulted from the 1978 flood, however, some channel widening and bank erosion occurred directly upstream of the SPRR bridge. The main channel flowed along the railroad embankment south of the bridge necessitating some channel shaping and the construction of wing dikes to deflect flow away. The pit was again filled during the October 1983 flood.

Floods during the past two decades captured the gravel pit and shifted the channel southward for a distance of about 800 feet. Floods during the 1970s have in-filled the channel and previous overbank pits, obscuring most evidence of its prior existence. The most notable remnant of the mining operation is a substantial widening of the channel through this reach.

A former mining site is located in an old meander loop of the river just downstream of the Shannon Road alignment, along the north channel bank. The Rillito Creek flood of December 1978 eroded the bank between the channel and pit. After eroding the channel bank between the pit and river, floodwaters overtopped the northern bank of the excavation area and flooded the Pegler diversion channel. The lateral flooding into the diversion channel initiated a headcut which in a short time connected with the material borrow pit. From that point on, a portion of the river's floodwaters flowed through the connection channel, into the Pegler Wash, and finally back to Rillito Creek at a downstream confluence point. The overall impact was a local widening of the channel immediately adjacent to the pit.

The potential for lateral migration of the river channel occurs in the narrow section downstream of La Cholla Boulevard, because of severe overloading of the narrow channel section with sediment. The wide sections upstream of this reach can contain the flow and sustain high sediment transport rates. The narrow section downstream has the tendency to aggrade, forcing water into the floodplain where erosion then occurs in less resistant materials allowing the channel to migrate laterally.

A previous report by SLA (1982b) found that the reach below La Cholla Boulevard had aggraded slightly between 1967 and 1979. Possible causes cited were a widened channel and a reduction in mining activity during this period. Since 1979, the combined effect of increasing urbanization in the basin and increased sand and gravel mining has lead to a degradational trend. The average change in bed elevation for mined and non-mined cells measured from topographic mapping from 1967 to 1984 is 1.6 feet. A maximum change for non-mined cells of 8.1 feet occurs in the main channel approximately 1.2 miles below La Cholla Boulevard.

13.1.2 Analysis of Trends

Various trends were observed in reviewing the mining activity case histories. Generally speaking, the impact of the individual pits on local river morphology appeared minimal; however, the collective effect of several pit clusters on the entire reach contributed to the general degradation of the river bed and some overall stability problems.

* The flood damage sustained by the mining operations mainly consisted of loss of protective dikes, re-filling of open

pit areas, damage to materials processing plants and loss of production time. In some cases, excavation of material at the same location was renewed following the flood and mining operations re-established and/or expanded. Likewise, other damaged sites were abandoned. A trend noted following the major floods in the study reaches was the gradual movement of mining operations out of the main channel and into floodplain areas to minimize risk.

* Localized entrenchment of the main channel was noted in both gravel and sand-bed river systems. In the Salt River at 19th Avenue, encroachment of the mining cluster into the main channel narrowed the available cross-section considerably, and lead to entrenchment of the river through the mining area and for a distance downstream. Evidence of channel incisement and bank steepening were noted from aerial photography.

* Analysis of the long-term changes in bed topography for all reaches indicated a general degradational trend. Several factors including, but not limited to, sand and gravel mining, other urban and agricultural encroachments, and local flood control improvements have combined to force the river to adjust to changes in the sediment supply and sediment transport characteristics of the system.

* A comparison of the long-term changes in the two study reaches of the Salt River shows that the reach from Hayden Road to Country Club Drive is undergoing more intense mining activity. Mining in this area has been most intensive from 1983 to the present; a relatively recent period of no major flooding events. The full potential impacts of the mining on the channel remain to be seen for this reach. In contrast, the reach from 59th Avenue to 19th Avenue has been mined for a comparatively longer time. The reach has experienced major flows during periods of peak production of in-stream excavations. In response, the reach is narrower in width and shows fewer channel instabilities than the other Salt River reach from Hayden Road to Country Club Drive.

* Cases of bank erosion and bank failure were noted from aerial photography. In some areas (the Tucson study reaches in particular) pronounced bank erosion occurred during the major flood events. Bank failure in the Verde River reach at Cottonwood occurred just upstream of the Dead Horse Ranch Crossing, resulting in loss of vegetation in this vicinity. Channel alignment changes related to the gravel mining upstream may be directly related to the bank stability problems in this reach. Generally speaking, however, the resolution of the topographic mapping and aerial photography was not detailed enough to pick up bank stability/failure

problems, other than the extreme cases cited above.

13.2 Bridge Scour

This sections presents case histories on bridge structures in the study reaches. Twenty bridges are located in the study reaches, providing examples of the wide range of hydraulic conditions that can occur at bridge sites in river reaches with sand and gravel mining activity. The case studies are reviewed on a reach-by-reach basis. First, an overview of river conditions, structure type, and mining activity is given. This is followed by an analysis of bridge failures and channel stability problems found to exist in each reach.

13.2.1 Overview of Past History and Trends

Salt River - Hayden to Country Club

This reach of the Salt River has three bridge crossings: at Hayden Road, Alma School Road and County Club Road. Bridges in the reach are of recent construction, dating from 1980 (Alma School Road). No significant flooding has occurred since the construction of these structures; however, a significant increase in sand and gravel mining activity has taken place.

The Country Club Road bridge has a length of 1348 feet with 10 spans. The foundation is drilled caissons set to an elevation of 1111.0 or 60 feet below the present depth of mining in the reach. The Hayden Road bridge has a length of 1184 with 8 spans. The bridge is designed with the northern approach below the low chord of the bridge to convey the full discharge during the 100-year flood. The foundation is drilled caissons set to an elevation of 1046.0 or 84 feet below the present depth of mining. The structure at Alma School Road is a set of two bridges, which was designed prior to an expansion of gravel mining operations downstream of the site, although mining operations were present at the time of design and construction. A pile foundation was constructed for the two bridges with pier caps set at elevation 1175.5, approximately ten feet below the channel bed. In conjunction with the construction of the Alma School bridges, an unlined channel was constructed for approximately 1500 feet upstream and downstream of the bridges. Subsequent mining downstream of this channelization has left the downstream channel invert approximately 20 feet below the pre-mining channel invert at the bridges, or 10 feet below the pile cap elevation.

All three bridges are aligned with the prevailing direction of flow in the channel, and span the floodplain without any significant encroachment. The use of a dual bridge crossing at Alma School Road makes for a more complex split flow condition at this site. The relative size and location of the two bridges mimics the former braided channel form in this reach. However, mining activity both upstream and downstream of the bridge site is rapidly changing the braided form of the river to a narrower, entrenched channel form. Because of the altered channel gradients in the vicinity of the bridges, it is anticipated that the hydraulic performance of the bridges will be significantly different compared to the original design.

Sand and gravel extraction in this study reach was estimated at 58.5 millions tons (see Section 13.1.1) for the period from 1962 to 1986. Aerial interpretation of mining activity indicates that the aerial extent and volume of production has increased greatly since 1983. The change in bed topography in the reach averaged 7.2 feet in this period. Changes in the local bed profile at the bridge sites since the construction of the bridges has been relatively small. However, a fairly steady degradation of the channel occurred prior to bridge construction.

The undisturbed bank-full width of the Salt River channel varies along this reach, averaging 3500 feet in width. The channel narrowed to 2500 feet in the reach from Country Club Roads to Alma School Road, expanded to 4500 feet in width in a braided reach of river below Alma School, and narrowed to 2500 feet above Hayden Road. Mining in the reach has created a narrower channel width, which averages 1500 feet, which is the approximate length of the three bridges in the reach.

Since 1962, the channel invert at Hayden Road has degraded 14 feet, and immediately upstream of the bridge, the channel invert in existing mining excavations is 35 feet below the 1962 invert elevation. The reach of the Salt River below Hayden Road sustained a series of flood flows (1978, 1979, 1980 and 1983) and has not been rechannelized or disturbed by mining since. The channel profile at this location shows a distinct reduction in gradient from the prevailing 0.002 ft/ft to less than 0.001 ft/ft. The channel resumes the steeper gradient, one mile below the Hayden bridge. The reduction of the channel gradient in this reach is indicative of clear water scour caused by a reduction in sediment supply. Trapping of sediments in upstream sand and gravel excavations is the cause of the reduced sediment supply.

At Alma School Road the channel has degraded 6 to 7 feet since 1962, and 30 to 40 feet below the 1962 invert elevation in mining excavations located 1500 feet downstream of the bridge site. At Country Club Road, the channel invert is 15 feet below the 1962 elevation at the bridge site, and 30 to 35 feet below the 1962 invert elevation in the mining excavations located immediately below the bridge.

Salt River - 59th Avenue to 19th Avenue

This reach of the Salt River has three bridge crossings: at 51st Avenue, 35th Avenue and 19th Avenue. Bridges crossings in the reach date from 1966, with the construction of a four span, 120 foot-long bridge constructed at 19th Avenue. Also in 1966, a five-cell, box culvert was constructed at 35th Avenue. In 1975, a culvert and bridge combination was constructed as a crossing at 51st Avenue. The culvert was a double 12-foot by 8-foot concrete box culvert, and the bridge was a 160 foot-long, 4 span concrete structure. All of these crossings were severely damaged by the series of floods that occurred in January 1978, December 1979, and February 1980, and were replaced by larger structures beginning in 1981 with the bridge at 51st Avenue.

The existing structure at 19th Avenue was completed in 1982, it is a 1006 feet long, 8 span prestressed, concrete structure. The foundation is drilled caisson (three, 6-foot diameter caissons per bent), the tip elevation averages elevation 915.0, 117 feet below the existing channel invert. Dumped riprap bank protection was installed at both bridge abutments.

The existing structure at 35th Avenue was completed in 1983. It is a 505-foot long, 5 span prestressed, concrete-reinforced structure. The bridge foundation is drilled caissons (two 5-foot diameter caissons per bent) with the tip elevations at 930.0, which is 80 feet below the existing channel bed. The bridge is designed to convey 105,000 cfs through the bridge waterway, and the total design discharge of 200,000 cfs by breaching the south approach fill. Dumped riprap bank protection was installed at both bridge abutments.

The existing bridge at 51st Avenue was completed in 1981. It is a 1602-foot long, 16 span, prestress concrete girder bridge. The foundation is piles, with an average pile tip elevation of 925.0, the bottom of the pile cap is at elevation 975.0, which are 70 feet and 20 feet below the existing channel bed, respectively. The abutment banks are protected with grouted riprap, toed-down to the pile cap elevation. The piers are protected near the pile cap with a pad of six-inch riprap, nine feet around the circumference of the pier at a depth of five feet.

Sand and gravel extraction in this study reach was estimated at 23.1 millions tons (see Section 13.1.1) for the period from 1962 to 1986. Aerial interpretation indicates that mining activity is concentrated near 19th Avenue, and has proceeded at a fairly uniform rate, with disruptions from floods and periodic economic slowdowns. The change in bed topography in the reach averaged 1.9 feet in this period. The maximum change in the local bed profile at the bridge sites since the construction of the bridges have ranged from 3 to 10 feet.

The undisturbed bank-full width of the Salt River channel is fairly uniform along this reach, averaging 3500 feet. Since 1962, the channel invert at 51st Avenue has degraded 3 feet. At

35th Avenue, the channel has degraded approximately 8 feet since 1962, and approximately 10 feet below the 1962 invert elevation in mining excavations located 500 feet downstream of the bridge site. At 19th Avenue, the channel invert is 8 to 9 feet below the 1962 elevation. No mining excavations are located in the main channel below the bridge site at this time; general degradation below the bridge is also 8 to 9 feet.

All three existing bridges are aligned with the prevailing direction of flow in the channel. The reach is relatively straight but braided. Sand and gravel mining has removed many of the features of the braided channel, such as bars and the multiple low flow channels. This has resulted in a single channel with a more definite alignment. Where mining activity has been greatest, the channel has reached its narrowest width, and likewise the bridge lengths are shorter. The 51st Avenue bridge is the longest bridge and is located in the least mined portion of the reach. One the other hand, the 35th Avenue and 19th Avenue bridges are significantly shorter, and are located in the portion of the reach with the most intensive mining.

Verde River - Cottonwood

No bridge crossing exists in this reach of the Verde River. An at grade crossing of the river exists at Dead Horse Ranch crossing. With the opening of Dead Horse Ranch State Park in 1977, a raised-river crossing was built to access the park along an extension of 5th Street from the town of Cottonwood. This crossing consisted of a concrete road surface placed over a battery of fourteen, 36-inch diameter corrugated metal pipes. The crossing was severely damaged by floods occurring in March and December of 1978. A new "at-grade" low-water crossing constructed without culverts was completed at the same location in November of 1979, and was subsequently damaged by a flood which occurred in February 1980. Repair of the crossing was completed in November of 1981, by installing a gabion mattress along the downstream side of the crossing embankment. This crossing is still in service.

The undisturbed bank-full width of the Verde River channel in this reach is 150 to 200 feet, with a valley width of 1500 feet. The sinuosity of the channel is 1.6, which can be classified as a meandering channel pattern. The floodplain of the river is well vegetated with large trees and associated riparian plants. Recent migration of the channel has caused damage to adjacent vegetation including loss of large trees.

Only limited information exists in this reach on the history of sand and gravel extraction, and the change in bed topography. Mapping and aerial photography is only available for two years, 1976 and 1982. However, comparison of topographic maps indicated large discrepancies at locations where substantial change is unlikely. Therefore, only the most recent mapping has been used. A field investigation of the site was made by SLA (1985) in conjunction with a study of sand and gravel mining impacts on the Dead Horse Ranch crossing. This study provides data on river conditions and mining activity since 1982, however, no additional topographic mapping was produced during this study.

Verde River - I-17

This reach of the Verde River has two bridge crossings, the Interstate 17 north and south bound structures. The I-17 south-bound structure was completed in 1957, when the highway was State Route 79. This structure is a seven span, continuous steel girder bridge, with an H-pile foundation set on or near bedrock. The north-bound structure was completed in 1979 and is similar in design to the south-bound structure.

The I-17 south-bound bridge is 525 feet long. The piers and abutments are H-piles that extend to an elevation of approximately 3054, which is 30 feet below the existing channel invert. Originally, the abutment construction included sheet piling and wire-tied riprap for bank protection, which extended a short distance upstream. The piers are of wall-type design with a 20 degree skew relative to the bridge centerline. The bridge waterway was sized to convey a 60,000 cfs flood flow.

The I-17 north-bound bridge is 524 feet long and is located downstream of the south-bound bridge. The structure is basically identical in all respects to the south-bound bridge, except that it carries a wider roadway section. The abutments are protected by rock and rail bank protection that extends between both structures.

Only limited information exists in this reach on the history of sand and gravel extraction, and the change in bed topography. Mapping and aerial photography is only available for one year, 1979. The undisturbed bank-full width of the Verde River main channel in this reach is 400 to 500 feet with a floodplain width of 1500 to 1800 feet. The sinuosity of the channel is 1.3, which can be classified as a meandering channel form. Evidence of channel response was found in bridge inspection records at the site, which are summarized in the following paragraphs.

The first inspection of the south-bound bridge in January of 1967 discovered extensive bank protection damage. The roadway embankment was damaged, and a scour hole 16 feet deep had developed in front of the sheet piling. Up to ten feet of embankment had eroded along with the railbank protection for several hundred feet upstream of the sheet piling on the N.W. bank. The 1971 inspection reported 2 to 3 feet of scour at pier 1. In 1973, the inspection report found "enormous pits being excavated" accompanied by "a drastic loss of channel under the bridge." This mining operation was located 600 to 800 feet downstream of the south-bound structure. In 1975, it was reported that 6 feet of scour had occurred at the sheet piling. The 1978 storm damage inspection noted minor scour damage at the northwest corner of the abutment. In July of 1979, as a result of the spring floods, the channel invert was reported to have moved from span 7 to span 2. The bed elevation at pier 2 was now one foot below the pier wall, exposing the H-piles at the upstream end.

In a 1984 letter to the ADOT District Engineer, it was stated that the piles rested on bedrock according to as-built geotechnical data and that scour should not be cause for concern at that time. However, the letter cautioned that the structure should be monitored closely. By June of 1987, the bottom of pier wall 3 was exposed. All of pier wall 4 was exposed along with the top of the H-piles. A substantial length of H-piles remained exposed on pier 5.

The first inspection of the north-bound bridge, in July of 1979, noted minor scour around the piers with the railbank in good condition. The February 1980 flood inspection reported high water marks above the top of the railbank, yet the bank protection exhibited no apparent damage. The August 1981 inspection recorded that the low flow channel had shifted north under spans 5 and 6. The inspection in February 1984 reported that, "normal high flows exposed the piling supporting the piers." The October 1984 inspection reports 3 to 4 feet of local scour at piers 5 and 6. In September of 1987, the inspection reported a total of 8 feet of degradation at span 4.

Agua Fria River - Buckeye Road to Indian School Road

This reach of the Agua Fria River has eight bridge crossings: Buckeye Road (State Route 85), Southern Pacific Railroad (SPRR), Van Buren Street, Interstate 10 eastbound and westbound structures, McDowell Road, Indian School Road, and Camelback Road.

Highway bridges in this reach date from about 1915 with the construction of the original Buckeye Road structure, upstream of the SPRR trestle existing at that time. The original Buckeye Road structure was replaced in 1930 by five steel trusses, with eight concrete girder approach spans on each end. Bridge construction did not occur again in this reach until the mid-1970s when a third replacement Buckeye Road bridge was constructed. Additional bridge construction and channel improvements proceeded through the 1970s and 1980s; most recently with the 1987 construction of the Van Buren Street bridge.

The existing structure at Buckeye Road (SR 85) was constructed during the mid-1970s. The bridge is a 1202.5 foot long, 15 span concrete structure. The foundation is H-piles that extend to a minimum tip elevation of 924, which is approximately 29 feet below the existing channel invert. The Agua Fria River Improvement Project (FCD85-37) was constructed in 1987 by the Flood Control District of Maricopa County. The project, extending from Buckeye Road to I-10, included the placement of soil cement protection at the Buckeye Road bridge abutments. In addition, a 100' x 1100' x 5' continuous riprap blanket was placed at the channel invert directly below the structure to protect the piers.

The SPRR bridge is located directly upstream of the Buckeye Road bridge. The bridge is 1300-feet long, consisting of seven steel trusses with 220-foot long, timber-approach spans on each side. The SPRR trestle was modified at the east and west banks during the construction of the channelization project in 1987. Foundation modifications included replacing the old timber bents with H-piles and concrete caps. The old timber approach spans at both soil cement protected banks were replaced with prestressed concrete spans during the channelization construction.

The existing Van Buren Street bridge, under construction in 1987, is 1160-feet long. The bridge was constructed in conjunction with the river channelization project. Soil cement bank protection was installed at the abutments. The sand and gravel pits formerly located within the channel right-of-way, both upstream and downstream of the structure, have been re-filled and compacted.

The existing I-10 eastbound and westbound structures were completed in 1979. They are 1502-foot long, 20 span, prestressed, concrete girder bridges. The foundation is spread footings at an average elevation of 945, which is 25 feet below the existing channel invert. A grade control structure is located approximately 500 feet downstream of these structures. A channel improvement project (FCD85-16) completed in 1986 included soil cement bank protection at the abutments. Interpretation of aerial photos in this area show that significant bank erosion on the outside of the natural river bend upstream of I-10 occurred during the 1980 flood. Additionally, aerial photos from 1982 show some evidence of flow around the east abutments of these structures prior to channelization of the river in this area.

The existing bridge at McDowell Road was completed in 1986 in conjunction with the construction of channel improvements in the river. The structure is a 1247 foot-long, 10 span prestressed, concrete girder bridge. The foundation is 7-foot diameter drilled caissons with tip elevations at 906.5, which is 69 feet below the existing channel bed. The abutment banks are protected with riprap, toed-down below the channel invert. The caissons are also protected for a distance below the channel bed with riprap.

The old Roosevelt Irrigation District (RID) Flume, built in the 1920s, formerly spanned the river approximately 2,200 feet downstream of Indian School Road. In 1985-86, the RID constructed a siphon to replace the elevated structure. This work was completed in conjunction with the channelization project in the river.

The existing Indian School Road bridge, originally built in 1970 and subsequently widened in 1978, is a 1652-foot long, 18-span prestressed, concrete girder bridge. The foundation is spread footings at elevation 983 and piles at the abutments at elevation 980, which are 16 feet and 19 feet, respectively, below the channel invert. The abutments are soil cement protected. The Indian School Road bridge failed during the 1980 flood, and was repaired in 1983-84 under an emergency repair program. The river was channelized in this vicinity in 1985-86; the sand and gravel pits formerly located within the channel right-of-way downstream of the bridge were re-filled and compacted. ADOT inspection reports of 1987 indicate this structure has a high repair priority.

The existing structure at Camelback Road was built in 1984. The bridge is a 15 span, 1725-foot long prestressed, concrete girder bridge. The structure is founded on drilled caissons (three, 4-foot diameter caissons per bent) with tip elevations at 946, which is approximately 71 feet below the channel invert. Each pier bent is protected by a 20' x 66' x 4' riprap blanket, 5-feet below the channel bed. Riprap installations also protect both bridge abutments.

Sand and gravel extraction in this study reach was estimated at 11.8 million tons (see Section 13.1.1) from 1972 to 1981. Aerial interpretation indicates mining activity is concentrated near the Indian School Road bridge. Mining has proceeded uniformly, with disruptions due to floods and impacts from the extensive channelization of river during the mid-1980s. The change in bed topography in the reach averaged 1.5 feet during this period. Observed changes in the local bed profile at the bridge sites since construction have been on the order of 4-5 feet. Aggradation of about 3 feet at the Buckeye Road bridge site was noted following the 1980 flood.

The Agua Fria River, in its undisturbed condition upstream of Indian School Road, is about 2700 feet wide and braided with poorly defined and unstable banks. From Indian School Road downstream to Buckeye Road, the river has been channelized to a width of 1200 feet. The existing bridges are aligned with the prevailing direction of flow in the channel, with the exception of McDowell Road, which is at a 20 degree skew. Bridge lengths are fairly uniform, averaging about 1400 feet. The river has also been vertically stabilized in this reach by the construction of grade control structures at certain intervals in the channel bed. All sand and gravel pits have been re-filled and compacted within the channel right-of-way. The channel stabilization work has masked the general degradation observed over the long-term, below the bridges in this reach.

New River - Confluence to Peoria Avenue

This reach of the New River has three bridge crossings: at Glendale Avenue, Olive Avenue, and Peoria Avenue. Bridge construction in the reach began in 1960 when the Glendale Avenue structure was completed and ended with the construction of the Olive Avenue crossing in 1978. The existing bridges were in place prior to a period of major flooding from 1978 to 1980. Sand and gravel mining activity has steadily progressed in the reach with a temporary interruption during major flood events.

The existing structure at Glendale Avenue was built in 1960. It is a 358-foot long, 7 span steel girder bridge founded on spread footings. Dumped rock riprap was placed at both abutments. ADOT inspection reports dating from 1972 indicate concerns regarding the stability of this structure. In 1973, channel degradation estimated at 7-9 feet exposed the top of the pier footings. Remedial protection from scour at the piers was suggested in 1977 and again in 1980. Following considerable erosion in 1982, grouted rock, concrete, and concrete rubble were placed at several piers and at the abutments. In 1986, cost estimates were developed for extensive remedial repair to the structure and for scour protection.

The existing Olive Avenue Bridge, built in 1978, is a 300-foot long, prestressed concrete girder bridge. The foundation is spread footings at elevation 1063.5 which is 15-feet below the channel invert elevation in 1981. Dumped rock riprap was installed at both abutments and spur dikes.

The existing structure at Peoria Avenue was built in 1972. It is a 304-foot long, 4 span precast concrete girder bridge. The foundation is spread footings at elevation 1091, which is about 1-foot below the channel invert elevation in 1981. The abutments are protected by dumped rock riprap.

Sand and gravel extraction in the study reach was estimated at 1.8 million tons (see Section 13.1.1) for the period from 1976 to 1981. Mining activity in this reach is concentrated near Glendale Avenue. In addition, channel clearing/shaping was undertaken in this study reach by the City of Peoria. The change in bed topography in the reach averaged 0.6 feet during this period. Changes in the local bed profile at the bridge sites, since the construction of the bridges, have been locally larger ranging from 5.5 to 9 feet.

The undisturbed bank-full width of the New River channel is relatively uniform, averaging 500 feet in this reach. Between 1960 and 1981, the channel invert at Glendale Avenue has degraded 5.5 feet. A large mining operation is located directly downstream of the bridge site, and has been actively mined since 1961. Extensive channel shaping and clearing was done in 1986, downstream of the mining operation in conjunction with the construction of Glendale Airport. There is also mining in the channel upstream of Glendale Avenue. At Olive Avenue, the channel has degraded 7.5 feet from 1977 to 1981. A mining operation downstream of the bridge terminated in 1979, while channel clearing has taken place upstream in recent years. In 1981, the channel invert at Peoria Avenue was 9 feet below the 1972 elevation. A small mining operation downstream of the bridge disappeared following the 1978-1980 floods.

The structures at Olive Avenue and Peoria Avenue are oriented at a slight skew to the flow direction, while Glendale Avenue is normal to the channel. The New River channel has a much more defined cross-section than the Agua Fria River with banks approximately eight feet high. The pronounced localized scour at the bridge sites is a situation which requires close monitoring. Otherwise, the channel has remained fairly stable during the past decade.

Santa Cruz River - Valencia Road to I-19

This reach of the Santa Cruz River has four bridge crossings: at Valencia Road, San Xavier Mission Road, and the Interstate 19 southbound and northbound structures. The original bridges date from the late 1950s and 1960s, but have undergone extensive modifications after the major flood events of October 1977 and October 1983. The emergency bridge repairs were required following dramatic changes in the channel configuration and severe bank erosion resulting from the floods.

The Valencia Road bridge was originally built in 1957. It is a 180 foot long, 3-span prestressed concrete T-girder structure. The foundation is piles driven to point bearing in hard material at about elevation 2398, which is approximately 42.5 feet below the 1984 channel invert. The pile caps were exposed following the October 1977 flood; therefore, the piles were encased in concrete seven feet below the existing pile cap for protection from additional scour. The original bank protection at the abutments consisted of a vertical sheet pile wall built with steel sheet pile of alternate lengths of 15 and 25 feet. Riprap was placed at a 1.5:1 slope above the top of the sheet pile wall. In subsequent years, additional bank protection, consisting of mortared stone, rubble, and dumped concrete, was added to the fill above the sheet pile wall. Emergency repairs after the 1977 flood called for the removal of the old fill and bank protection. This was replaced with fully compacted granular material, and pneumatically placed mortar reinforced with welded wire fabric. In conjunction with the 1985 channelization project of the Santa Cruz River in this area, soil cement and reinforced concrete bank protection replaced the old bank stabilization system.

The original San Xavier Mission Road bridge was completed in 1956. It was a 253-foot long, 5-span, continuous steel, girder structure founded on piles at an average tip elevation of 2462, which is about 24-feet below the channel invert as of 1984. The original bank protection at the abutments consisted of a vertical sheet pile wall driven to an undetermined depth. A 2-foot thick layer of riprap protection was placed above the sheet pile wall. The October 1983 flood caused severe erosion, washing out 150 to 200 feet of the southwest approach leaving the west abutment standing in the middle of the channel. Extensive emergency repairs and modifications were undertaken in 1985. The bridge was extended towards the west 193 feet (446-foot total bridge length) with a 4-span, continuous steel, girder structure. Foundation modifications included the addition of scour plating to the existing bridge piers which consisted of two layers of 1-foot thick gabion mattresses at a 2:1 slope for a distance of 13.4 feet away from the piers. The foundation for the new spans is H-piles at an estimated tip elevation of 2445, approximately 41 feet below the 1984 channel invert. Following the substantial erosion of the west bank, a comprehensive bank protection plan was implemented. Soil cement bank stabilization was installed along the west bank from the I-19 bridges south abutments through the west abutment of the San Xavier Mission Road bridge and keyed into the natural bank at a point 120 feet downstream of the abutment.

The I-19 southbound and northbound structures were originally constructed in 1967. Both bridges were 410 foot long, 4-span, continuous steel girder structures. The pier foundation was spread footings at an undetermined depth while the abutments are founded on piles at varying tip elevations ranging from 2467 to 2473 for both structures. The abutments were originally protected by vertical sheet pile walls with wired riprap placed on the embankment above the top of the walls. During the flood of October 1983, the upstream approach angle of the river at the north abutment of the northbound structure caused pronounced erosion at this location. The northernmost span of the northbound structure lost support at the abutment and collapsed into the river. Emergency repair of the northbound structure was undertaken in 1986. The bridge was lengthened to a total bridge length of 516 feet, as the north abutment was relocated further north to take advantage of the natural protection of Martinez Hill. The entire bridge was widened and repaired with a new single span steel girder extension. The new Pier #4, located near the old abutment site, is founded on a spread footing at elevation 2469.75 about 20 feet below the 1983 channel invert.

In addition, soil cement bank stabilization was installed to protect both abutments. The soil cement toedown is located at the bottom of the spread footing of the nearest pier and keyed one foot into bedrock. Soil cement protected spur dikes are located upstream of the abutments.

Sand and gravel extraction in this study reach was estimated at 2.6 million tons for the period from 1974 to 1985. Interpretation of aerial photographs indicates mining activity is concentrated near Valencia Road and has expanded uniformly despite the impacts of flooding upon the operations.

The undisturbed bank-full width of the Santa Cruz River varies through this reach from a shallow 500-1000 feet wide arroyo upstream of the Valencia Road crossing to an entrenched 150 foot wide channel downstream of the bridge. ADOT inspection reports for the Valencia Road bridge indicate six feet of scour between 1977 and 1984. The change in the channel invert for one year from 1983 to 1984 was observed to be 2.6 feet at this location. A large mining operation is located directly upstream of this bridge in the east overbank. At the San Xavier Mission Road bridge, approximately 2 feet of degradation was observed between 1983 and 1984. An excavation site was formerly located 1200 feet downstream of this bridge, but was presumably inundated during the 1977 flood and work did not resume after this time. At the I-19 bridges, ADOT inspection reports note 5 feet of degradation following the 1977 flood.

The Valencia Road and San Xavier Mission Road bridges are generally aligned with the prevailing direction of flow. The I-19 structures are aligned at about a 45-degree skew to the channel. This study reach is dynamic in nature and exhibits a well-established meander pattern. The main concentration of mining activity lies in the east overbank, and is protected by levees aligned along the general meander bends.

Rillito Creek - I-10 to La Cholla Boulevard

This reach of Rillito Creek has five bridge crossings: the Interstate 10 eastbound and westbound structures, the East Frontage Road, the Southern Pacific Railroad (SPRR), and La Cholla Boulevard. Very limited information was available for the SPRR and Frontage Road structures, but it is known that these bridges were in place prior to 1951.

The existing I-10 Eastbound bridge was built in the early 1950s. It is a 342.5 foot long, 11-span, reinforced concrete continuous slab bridge. The foundation is piles of an estimated length of 25 feet at the piers and 35 feet at the abutments. Rock and rail type bank protection was installed at both abutments. In addition, 565 linear feet of rock and rail bank protection was installed along the north bank between the I-10

Eastbound and the existing East Frontage Road bridges. ADOT Inspection Reports indicate that in 1981 one concrete pile cap was exposed at the upstream end. An inspection following the 1983 flood indicated 3 to 4 feet of scour under the first 7 spans.

The existing I-10 Westbound structure was built in 1965 directly upstream of the Eastbound bridge. The structure is a 342.5 foot long, 11-span, reinforced concrete continuous slab founded on piles. The minimum penetration elevation specified for the piles is 2184 at the piers and 2188 at the abutments, which is about 19 feet and 15 feet, respectively, below the 1984 channel invert. Rock and rail bank protection was installed at both abutments. The north abutment bank protection was keyed into the existing rock and rail stabilization along the north bank extending upstream to the East Frontage Road bridge north abutment. Following the flood of December 1978, the entire length of the rock and rail stabilization between these two bridges was eroded out. The 1983 flood caused channel degradation of about 3 to 4 feet exposing pier pile caps. Additional degradation has been noted recently.

The railbank protection at the north abutment of the East Frontage Road bridge has a problematic history. Damage has occurred periodically during high flows. The channel directly upstream of the SPRR bridge has migrated westward, such that the prevailing flow attacks the south approach embankment. Rock and rail wing dikes constructed in the late 1970s, to guide flow away from the embankment, were damaged during the 1983 flood.

The existing La Cholla Boulevard bridge was constructed in 1983. Soil cement bank protection was also placed, at this time, for a distance of approximately 1700 feet along both banks, thereby protecting the bridge abutments.

Sand and gravel extraction in this study reach was estimated at 2.7 million tons for the period between 1967 and 1984. Mining activity is concentrated near the La Cholla Boulevard crossing and the SPRR bridge. The change in bed topography for the entire reach averaged 1.6 feet during this period. Locally larger changes in bed profile were noted at the bridge sites.

Since 1968, the channel invert at the I-10 Eastbound and Westbound structures has degraded 2 to 3 feet. The channel degradation since 1968 at the East Frontage Road and SPRR bridges has ranged from 1 to 2 feet. Significant bank erosion and widening of the channel has occurred upstream of the SPRR crossing. Large gravel mining operations are located directly upstream of the SPRR bridge and downstream of the I-10 Eastbound structure. At the La Cholla Boulevard bridge site, the channel invert has dropped about 4 feet since 1967. Mining activity in this vicinity has been underway since the late 1950s, with extensive in-stream excavation occurring during the 1960s and early 1970s.

13.2.2 Review of Bridge Failures and Channel Stability Problems

The bridge data collected for development of the preceding case studies provided information regarding the failure of certain bridges and other channel stability problems within the study reaches. This section addresses these situations by identifying the external forces and factors, which significantly influenced the dynamic behavior of these reaches.

The Indian School Road bridge crossing of the Agua Fria River was severely damaged during the 1980 flood. Six spans at the east end of the 1652-foot long, 18-span structure were lost or damaged. The river had migrated eastward, 700 feet east of the east abutment. The migration of the channel to the east upstream of the bridge resulted in flow attacking the bridge piers at a severe angle during the 1980 flood. The piers are founded on spread footings. At the time of the bridge failure, large sand and gravel mining operations were located in the east and west overbanks. Dikes had been constructed to protect the gravel pits from flows which constricted the channel just 300 feet downstream of the bridge, to a width of about 800 feet or one-half the length of the bridge opening located directly upstream. The dike alignment further constricted the channel to a 400 foot width, 1600 feet downstream of the bridge. The failure occurred on the same side of the bridge as the constricted section was located in the river channel.

The I-19 Northbound bridge at the Santa Cruz River has sustained damage from flooding since construction in 1967. Problems with the stability of bank protection at both abutments occurred periodically during the 1970s and early 1980s. Following the 1977 flood, significant changes were noted in the horizontal configuration and vertical profile of the channel. In 1978, additional changes in the channel altered the upstream approach angle of flow, such that the force of the flow attacked the north abutment and caused failure of the sheet piling and rock bank protection. Again in February 1983, a major flood caused erosion of the northeast corner of the bank protection at the north abutment despite extensive riprap revetments at this site. The October 1983 flood completely eroded the encroaching north abutment approach embankment resulting in the failure of the northernmost bridge span. The foundation is spread footings. The bridge was repaired and lengthened so that the new north abutment was relocated further north, taking advantage of the natural protection of Martinez Hill. Soil cement bank protection was installed at the abutments of both the northbound and southbound structures. Spur dikes were constructed upstream from the abutments. There are no sand and gravel mining operations located in the immediate vicinity of the I-19 crossing.

The San Xavier Mission Road bridge has experienced erosion problems at the west abutment during major flows. The original protection at the abutments consisted of a sheet pile wall and riprap. The 1977 and 1983 floods caused channel changes upstream so that the meander pattern of the Santa Cruz River was deflected westward by the natural obstruction of Martinez Hill, inducing bank erosion at the San Xavier Road bridge site. In 1977, the west abutment fill was washed out exposing the piles. The bridge was repaired under emergency contract. During the 1983 flood, flow deflected at Martinez Hill caused severe bank erosion of the meander bend at the San Xavier Road bridge west abutment. Approximately 200 feet of the southwest approach was eroded away, leaving the west abutment free-standing in the channel. The bridge was lengthened to span the newly eroded area. Soil cement bank protection was installed to protect the abutments and the bank on the outside of the meander. A mining operation, located 1200 feet downstream of the bridge, was active in the early 1970s, but ceased in 1974.

Two other bridges experienced a similar failure mechanism. Both the original 19th Avenue bridge and the original Hayden Road bridge at the Salt River, sustained damage from the major floods of the late 1970s. The bridges were sized to pass low magnitude river flows. The approach embankments on both sides of these bridges encroached into the main channel of the Salt River. The large magnitude floods eroded the approach embankments leaving the bridges completely free-standing. These bridges were replaced in the early 1980s with larger structures sized to pass the 100-year discharge. The new 19th Avenue bridge is a 1006 foot long structure, however, directly downstream of the bridge, the channel narrows to a width of 500 feet or one-half the bridge opening due to encroachment of fill placed on the north bank. A dike along the south bank further constrains the channel downstream; pits are under excavation behind the south dike. The bridge foundation is drilled caisson, 117 feet below the channel invert.

The Valencia Road bridge at the Santa Cruz River is founded on piles driven to a depth of approximately 42 feet below the channel invert. Scour occurred during the October 1977 flood, which undermined the west pier and bank protection, exposing the piling. An emergency repair project encased the piles in concrete an additional seven feet below the bottom of the existing pile cap. Six feet of degradation has been observed at this location from 1977 to 1984. Mining activity has been prevalent directly upstream of the bridge in the channel and east overbank. An analogous situation exists at the Glendale Avenue bridge at New River, where channel degradation on the order of 7-9 feet has exposed the top of the spread footings. Mining operations have been active upstream and/or downstream of the bridge since its construction in 1960. Similarly, the Alma School Road bridge at the Salt River is founded on piles and was designed prior to the expansion of gravel mining activity in the river reach. Subsequent mining downstream of the bridge has lowered the channel invert approximately 20 feet below the pre-mined invert at the bridges, which is only 10 feet below the pile cap elevation.

In summary, bridge failure and channel stability problems were identified in all study reaches. However, the condition of in-stream mining in these reaches is not always the dominant cause of bridge failure and channel stability problems. Several bridges failed simply because the flood magnitude greatly exceeded the design of the bridge (19th Avenue and 35th Avenue crossings). In other cases, the natural response of the river during a flood created hydraulic conditions adverse to the hydraulic performance of the bridge (I-19, Santa Cruz, San Xavier Road, and I-10 Rillito). The remaining bridges show varying degrees of two conditions that adversely impact bridge crossings in mined channels. First, the flow alignment can be altered by the presence of an excavation either above or below the bridge. This can result in a local increase in either pier or abutment scour. The failure of the Indian School Road bridge illustrated this process. Encroachment by mining operations is a related factor, where diversion dikes or equipment pads are placed near a bridge in such a manner that the waterway area is reduced or flow is diverted adverse to the bridge alignment. Mining facilities near 19th Avenue on the Salt River are a good example of such an encroachment.

The second condition is channel degradation which eventually exposes the bridge foundation. This appears to develop over a long period of time in most cases. Examples of bridges with notable degradation include: Valencia Road on the Santa Cruz River, I-10 on the Rillito River, I-17 on the Verde River, all crossings on the New River, and Alma School Road on the Salt River. The Alma School Road site has a history of channel degradation and is currently experiencing headcut scour. This is a particularly good site to monitor since both types of scour are present.

XIV. JUSTIFICATION FOR REGULATION OF IN-STREAM MINING

The response of a river study reach to the influences of in-stream sand and gravel mining over both the short-term and long-term has been studied and documented. From this base, the existing justification for regulation of in-stream mining from both a technical and non-technical perspective is addressed. The present problems related to the practice of in-stream mining are discussed in terms of the impacts upon the public and private infrastructure, channel stability, and the operating environment (both economic and social) under the current regulatory climate. Forecasts are made of the future impacts to be expected, if regulatory procedures are not prudently structured and enacted.

14.1 Technical Issues

Work completed as part of this study included the evaluation of case histories of in-stream sand and gravel mining operations and bridge structures within specified study reaches. The resulting observations indicated that the predominant technical issues related to in-stream mining include impacts to the public infrastructure (i.e., bridge, road, and utility crossings) and channel stability problems.

Road and bridge crossings are at a significant risk of damage from flooding. Several routes in the study reaches have been interrupted by periods of flooding, due either to bridge damage or failure. (See Section 13.2.2) The extent of in-stream mining is not always the dominant cause of bridge failure and channel stability problems. Other causes of bridge failure observed in the case studies include the flood magnitude greatly exceeding the design of the bridge, and the creation of hydraulic conditions adverse to the hydraulic performance of the bridge by the natural response of the river during a flood.

The case histories also included situations where bridge failures were directly related to in-stream sand and gravel mining. The flow alignment can be altered by the presence of an excavation site either above or below the bridge, resulting in a local increase in either pier or abutment scour. A contributing factor is the encroachment by mining operations where diversion dikes or processing plants are placed near a bridge in such a manner that the cross-sectional area of the channel is reduced or flow is diverted adverse to the bridge alignment. Another failure mechanism related to in-stream mining is the long-term general degradation of the channel bed, which eventually exposes the bridge foundation.

The short-term impacts of in-stream sand and gravel mining upon channel stability involve scour processes in the vicinity of the excavation. These impacts will be of concern where structures are located in a river reach where active mining exists, or immediately upstream or downstream of such a reach. The most pronounced short-term scour occurs at the upstream and downstream brink of the excavated pit. The upstream scour is caused by the acceleration of the flow into the excavated area. The increased velocity near the excavation brink locally increases the transport of sediment, and results in headcut scour of the channel bed. The process of downstream scour occurs due to a reduction in the sediment supply for the channel reach below the excavation caused by the trapping effect of the pit. As the flow leaves the excavation, it regains velocity, and the sediment transport rate increases. The bed material is scoured to make up the difference between upstream supply and downstream transport capacity.

From a long-term perspective, the collective effect of several pit clusters on the entire actively-mined reach contributes to a general degradational trend. This trend was observed in all the study reaches, indicating that sediment was being removed from the system at a rate faster than it was being re-supplied. Channel entrenchment through an actively-mined reach is accompanied by bank steepening to the limiting threshold of bank stability. Once this threshold is exceeded, bank erosion and bank failure occurs, resulting in significant lateral instability of the channel.

14.2 Non-Technical Issues

In addition to technical engineering issues, the in-stream sand and gravel mining industry impacts the economic, social, and physical environments in which it operates. Likewise, these environments affect the industry in various ways. The following discussion highlights the key interdependencies between the industry and its operating environment.

Two major variables drive sand and gravel production requirements: population growth and the activity of the construction industry. Population growth leads to increased demand for housing, services, and associated infrastructure, which in turn increases the demand for sand and gravel production. The market potential for aggregate products is tied closely to the economic activity of the construction industry; which includes road building as well as residential, commercial, and industrial building. Production of aggregate materials has increased significantly; but at a rate that reflects fluctuating economic cycles in the construction industry.

This symbiotic situation is fueled by public and private economic investments. Large public investments, such as transportation systems, trigger private investment in the sand and gravel industry in the form of capital equipment and materials-processing plants. The presence of in-stream mining operations near major bridge crossings within urban centers is often a consequence of a product cost-reduction strategy by minimizing haul distance. This location strategy results in both advantageous and disadvantageous consequences. Because of this close proximity, in-stream mining contributes to the frequency and cost of emergency repair projects associated with flood damage to bridge structures, as well as repair costs associated with scour damage for non-disaster related conditions. In addition to damage costs, the periodic interruption of the transportation service these bridges provide is often more costly in economic terms and to the public safety and welfare. Flood damage sustained by the mining operations themselves consist of loss of protective dikes, damage to materials processing plants, and loss of production time. A trend noted following the major floods in the study reaches was the gradual movement of mining operations out of the main channel and into floodplain areas to minimize risk.

On the other hand, mining sand and gravel from the channel bed provides the benefit of increasing the channel capacity, thus reducing the potential for overbank flooding in some areas. The recovery of an economic resource in the form of aggregate materials for construction, and consequent reduction in the floodplain width, can serve to offset the costs incurred in the related damages to in-stream structures during flood events. The availability of an economical, convenient source of quality construction material is fundamentally important to the development of the public and private infrastructure. Consideration should be given to the impact to the overall economy resulting from the cost of restricting the recovery of limited aggregate reserves and/or of implementing disjointed, uncoordinated regulation.

Pertinent social issues related to in-stream sand and gravel mining involve the problems that arise from land-use conflicts with adjacent non-industrial land uses. This situation is especially relevant in urban areas, where residential and commercial land uses are progressively encroaching into previously undeveloped land adjacent to mining operations. As a consequence, problems arise affecting public health and safety. Of concern are air, noise, and water pollution. Data regarding the extent of these impacts is not generally available; but apparent nuisance issues include dust in the air, unsightly visual settings, noise and vibration from on-site equipment, increased traffic congestion, and increased road repairs caused by haul trucks. It is not known if noise or dust levels at sand and gravel mining operations violate current pollution standards.

Development of aggregate resources will change these river environments, and planning for these changes will be essential in reducing the risk to river crossings and mitigating channel stability problems, as well as minimizing economic, social and environmental impacts, while at the same time economically providing needed aggregate products.

14.3 Regulatory Issues

Existing regulatory requirements at the federal, state, and local level relative to management of in-stream sand and gravel mining operations were reviewed. Findings are briefly recapitulated below. Refer to Chapter II of this report for a more in-depth discussion of current regulation.

There is no federal regulation of in-stream sand and gravel mining. Some federal laws could be interpreted as having an indirect effect on sand and gravel mining activities. These include the Rivers and Harbors Act of 1899 (Section-10), the Federal Water Pollution Control Act (FWPCA) Amendments of 1972 (Section 404), the National Environmental Policy Act, the Federal Land Policy and Management Act, and the National Flood Insurance Policy Act. Because federal law does not directly control in-stream mining operations, most of the responsibility is at the state and local government level.

The Federal Water Pollution Control Act, Section-404, is administered by the Corps of Engineers. Section-404 governs the discharge of dredged or fill materials in the waters of the United States. The extent of the Corps' jurisdiction under Section-404 covers virtually all waters in Arizona. Any person, firm or agency (including federal, state, and local government agencies) planning to work in the waters of the United States must first comply with the permitting requirement of the Corps regulatory branch, as applicable. The necessary permits are required even when land next to or under the water is privately owned.

A Section-404 permit is required for the discharge of fill or dredged material into intermittent and perennial fresh water streams, lakes, and adjacent wetlands. Fill material is material used to change the bottom topography of a water of the U.S. or replace an aquatic area with dry land. It includes riprap, rock, gravel, soil, cement, etc. Dredged material is material excavated from a water of the U.S.

Section-404 permits are necessary for such activities as bank protection (gabions, riprap, soil cement etc.), realignment of existing stream channels, backfill, grading within stream channels, temporary stockpiling of material, landfills for future developments, road crossings, and bridge protection. Typical activities not regulated under Section-404 include excavation or dredging, clearing of vegetation (if no soil is moved), structures, and waste disposal.

The primary tool for implementing the Section-404 regulatory program is the permit. Forms of authorization include the individual permit, nationwide permit, and general permit. The

Corps has implemented the concept of a nationwide permit that permits, by regulation, many routine activities not specifically exempted by definition. If an activity is covered by a nationwide or general permit, it is not necessary to apply for an individual permit. Many of the issued permits are modified to mitigate for negative impacts to the environment. The mitigation may involve modifying the project to reduce impacts at the site, or replacing "in-kind" the disturbed resource at another location. Increased coordination and consultation with the U.S. Fish & Wildlife Service and/or the Arizona Game & Fish Department will be necessary if Section-404 actions are triggered by mining operations in the river.

Projects impacting ten acres or greater of a water of the United States will require a formal Section-404 Permit Application, with Public Notice. The application must describe and graphically represent the nature and extent of flood-control/-floodplain-modification measures proposed. The lateral limits of Corps jurisdiction in waters of the United States is to the Ordinary-High-Water-Mark on each bank. The regulatory limit of the Ordinary-High-Water-Mark is normally determined by a defined bank line and/or changes in vegetation which indicate the normal limits of flow. In Arizona, streambeds are often braided and defined bank lines nonexistent. In these situations, current interpretation of the Corps' Ordinary-High-Water-Mark jurisdictional limits is defined as the 25-year floodplain limit. This indicates that, in the case of a braided channel with ill-defined normal flow limits, a sand and gravel mining operation located outside the 25-year floodplain would not need to apply for an individual permit.

At the State level, the regulation of sand and gravel operations in association with floodplain management is based on ARS 48-3613, which addresses the authorization required for construction in watercourses. The law provides that sand and gravel operations which will divert, retard, or obstruct the flow of waters in a watercourse must comply with adopted regulations governing floodplains and floodplain management, and that operators shall secure written authorization from the board of the district in which the watercourse is located. A substantial amount of in-stream mining is not subject to floodplain regulations, because state law exempts floodplain users prior to enactment. However, additions or changes are subject to regulation.

ARS 11-251 allows the board of supervisors of a county to adopt and enforce standards for excavation, landfill, and grading to prevent unnecessary loss from erosion, flooding and landslides subject to the prohibitions, restrictions, and limitations as set forth in ARS 11-830. ARS 11-830 addresses restrictions on regulation through zoning ordinances. The law provides that nothing contained in any zoning ordinance shall prevent, restrict, or otherwise regulate the use or occupation of land or improvements for "mining purposes", if the tract concerned is five or more contiguous commercial acres.

The Arizona Department of Transportation (ADOT) does not directly regulate sand and gravel mining operations throughout the State. However, ADOT does control the use of materials on highway construction projects through their construction specifications. Section 106.03 of the 1985 ADOT Supplemental Specifications limits the use of material sources situated within the 100-year floodplain of a watercourse, and located within one mile upstream and two miles downstream of a highway structure or roadway crossing. Within these boundaries, existing commercial sources may not be utilized as a source of borrow; nor will any new source or existing non-commercial source be approved for any materials. ADOT policy relative to the suitability of a material source for use in ADOT construction projects stipulates that the following criteria be met prior to the use of that material source:

> "The location of any new material source or existing non-commercial material source proposed for use on this project shall be reviewed by the appropriate agency having floodplain management jurisdiction for the area in which the proposed source is located. The contractor shall obtain a letter from the agency addressed to the Engineer certifying that the location of the proposed source conforms to the requirements of the Specifications."

In monitoring Department-owned sources in the floodplain, ADOT requires the Materials Section to evaluate potential risk to public or private improvements located one mile up and downstream of the materials operation. A mining plan and an environmental assessment, which includes a hydraulic study, is required under certain conditions. Based on the case histories compiled as part of this study, it was observed that the ADOT policy influences only a small portion of the total mining activity in the river reaches. In essence, the ADOT policy was considered ineffective in limiting mining activity in the majority of cases observed.

At the present time, the primary vehicle for regulation of in-stream sand and gravel operations is through local zoning and floodplain ordinances applied on a site specific basis. Requirements for issuance of a Floodplain Use Permit are tailored to the specific operation under consideration; and can vary significantly depending on the operation plan, site conditions and the county jurisdiction within which it is located. The focus of this regulation is primarily on operation development and reclamation plans, not on planned resource development or environmental management. Enforcement is carried out first through contact with the operator; and then, if necessary, through litigation in civil court.

Work completed as part of this study also included a review of the regulation of in-stream mining operations in eight other western states. (See Sections 2.3 and 2.4) The objective of this review was to compare the status of in-stream mining regulation in Arizona to that in other states. As noted above, floodplain-management regulations are the predominant method of regulating sand and gravel operations in Arizona at the present time. Regulations implemented in the State of California for management of sand and gravel resources addresses issues and conditions most similar to those in Arizona, compared to the other state regulations reviewed. The California regulations take a resource-management approach toward sand and gravel regulation, which balances resource requirements and costs against costs to assure other in-stream uses.

The State of California has passed a fairly comprehensive piece of legislation that regulates surface mining. The Surface Mining and Regulatory Act of 1975 (SMARA) is administered by the Department of Conservation, Division of Mines, and the Geology Reclamation Board. The actual implementation of the act is a function of individual city or county governments in which the mining operations are located. The Reclamation Board reviews local actions, and can intervene if they feel the act is not being enforced. The act sets standards for mining practice and reclamation. The act also seeks to classify mineral lands, and provides guidelines for mineral-resource management.

The Reclamation Board has a special policy for sand and gravel operations in floodways. The Board found that sand and gravel extraction near a levee can be detrimental to the integrity of the levee and/or can result in channel changes. The need to clear riparian vegetation during mining was found to be detrimental to flood management and wildlife habitat. Permit approval by the Reclamation Board is required before mining is allowed in a designated floodway. Several general and specific requirements, addressing minimum standards pertaining to the operation and reclamation of in-stream mining sites, must be met in order to obtain a permit.

The current regulatory climate in Arizona has fostered administration and enforcement problems for governmental agencies as well as compliance problems for the sand and gravel mining operators. Enforcement of existing regulations is hindered by multi-jurisdictional responsibilities. There is fragmented jurisdictional authority, with involvement on the part of separate governments representing the Indian Reservations, the counties, and municipalities. Federal laws are not applicable to Indian reservations; but are followed on federal lands, or when federal grant monies to Indian Tribes are involved. The counties administer all unincorporated areas, and the municipalities administer within their corporate boundaries. Streambed lands are under both public and private ownership, further complicating the situation.

Sand and gravel operators face compliance problems presented by land use, zoning, permitting, and environmental regulations. Over-restrictive, multilayer regulatory procedures back mining operators into a corner, curtailing the needed volume of production and eliminating such benefits provided by mining activity as floodplain reduction through increased channel capacity. The major issues identified from a producer survey by Pit & Quarry (Michard, 1987) follows:

* New zoning ordinances regulating aggregate resource development cover an increasing spectrum of items including: licensing, site fencing, mandatory engineering studies, archaeological surveys, limitations on operating hours, reclamation requirements, and long-term impact reports detailing future land use.

* More stringent zoning and permitting requirements have significantly increased the time and expense spent by the operators on the permitting process, in some cases discouraging the development of available resources.

* The permitting process is complicated by the many layers of bureaucracy involved. Each governmental agency has its own regulatory requirements and procedures. The operators maintain that the permit process is hindered by a lack of practical experience or knowledge of industry processes on the part of the officials involved.

* Land-use conflicts with adjacent residential neighbors are an increasing problem. Noise and dust emissions are a primary source of conflict.

In Arizona, proposed legislation has been introduced which addresses these issues. HB 2315 amends ARS 11-830 by prescribing planning and zoning requirements for county regulation of certain sand and gravel operations. The bill provides for the regulation of sand and gravel operations in counties which have adopted a specific sand and gravel operations zoning district. The zoning district shall include all properties approved jointly by county officials and representatives of a majority of the property owners engaged in sand and gravel operations. The counties must adopt, as internal administrative regulations, district standards limited to permitted uses, procedures for approval of property development plans, and site development standards. The site development standards include dust control, height regulations, setbacks, days and hours of operation, off-street parking, screening, noise, vibration and air-pollution control, signs, roadway-access lanes, arterial highway protection, and property reclamation. The counties must also adopt procedures to modify the sand and gravel operations zoning-district boundaries and standards only after approval by a majority of the property owners engaged in sand and gravel operations in the district.

This proposed legislation is the result of the combined efforts of representatives of the Maricopa County Planning and Zoning Commission and the Arizona Rock Products Association. HB 2315 has not yet been acted upon by the state legislature. The changes proposed in the bill will work to alleviate land-use conflicts by providing special districts set aside for sand and gravel mining, and by establishing operating standards which would reduce nuisance issues with residential neighbors. If enacted, the bill would also serve to clarify and standardize the procedures for county approval of mining-property development plans. HB 2315 also provides a channel of input for the mining operators in the process of establishing or modifying the sand and gravel operations zoning-district boundaries and standards. The bill does not specifically address floodplain or channel-stability issues.

14.4 Future Impacts

A forecast of future impacts that will occur if regulatory procedures addressing in-stream sand and gravel mining are not enacted includes technical, non-technical, and regulatory issues. Arizona's projected population growth will require a concurrent increase in public and private infrastructure needs. This, in turn, will increase the demand for aggregate products for construction. In order to economically meet the projected increase in future aggregate-product needs, sand and gravel mining operations must remain in the major river systems close to urban centers with easy access to transportation facilities. Without regulation or operating standards, mining will continue in the same manner as in the past--contributing to channel instability problems, and thereby potentially endangering in-stream structures.

Without prudent regulatory structure and procedures, problems in administration and enforcement by governmental agencies will increase as mining activity escalates and expands to meet future needs. Without a coordinated, resource management approach to regulation of in-stream mining activities, the necessary volume of economical aggregate materials required for future growth in Arizona may not be produced. Mining operators will face increasing complexity in complying with zoning and permitting processes, under the current regulatory climate. Without minimum operational standards, land-use conflicts and public health and safety issues between encroaching residential neighbors and expanding mining operations will increase in number and intensity.

14.5 Justification

* The technical issues need to be addressed through regulatory procedures which provide guidelines for assessing the engineering impacts of mining activity on channel-system stability and in-stream structures.

* The economic justification for regulation lies in the balance between the value of the sand and gravel resource to the economy and the estimated damages to the public and private infrastructure due to mining-related channel stability problems. These systems must operate interdependently to achieve the common goal of productive growth in Arizona. The regulatory procedures should incorporate effective management practices that would allow in-stream mining to operate economically, but in a manner that would not jeopardize river-system stability.

* Projected population growth will result in continued encroachment of residential and other non-industrial land-uses adjacent to mining-operation sites. Site-development standards and proper zoning are needed to circumvent, or mitigate, land-use conflicts.

* The justification for regulations, procedures, and operating standards is evident in the need to clarify governmental responsibilities towards administration and enforcement by streamlining review procedures and addressing jurisdictional issues. A coordinated, resource-management approach to regulation of in-stream mining activities will enable the production of the necessary volume of economic aggregate resources required for future growth in Arizona. A reduction in the complexity and obstacles of the zoning and permitting process will decrease compliance problems experienced by the mining operators.

Based upon the evaluation of the present problems and future impacts related to the practice of in-stream mining, it is concluded that sufficient justification exists to support the need for regulation.

XV. IMPLEMENTATION PLAN

The justification for the need for regulation has been established, based on the evaluation of the present problems and future impacts related to the practice of in-stream mining as outlined in Chapter XIV of this report. From this finding, alternative avenues to bringing about a regulatory program were explored on the basis of existing legal authority and regulatory efficiency. A recommended implementation plan was identified and steps required to conduct the work were formulated.

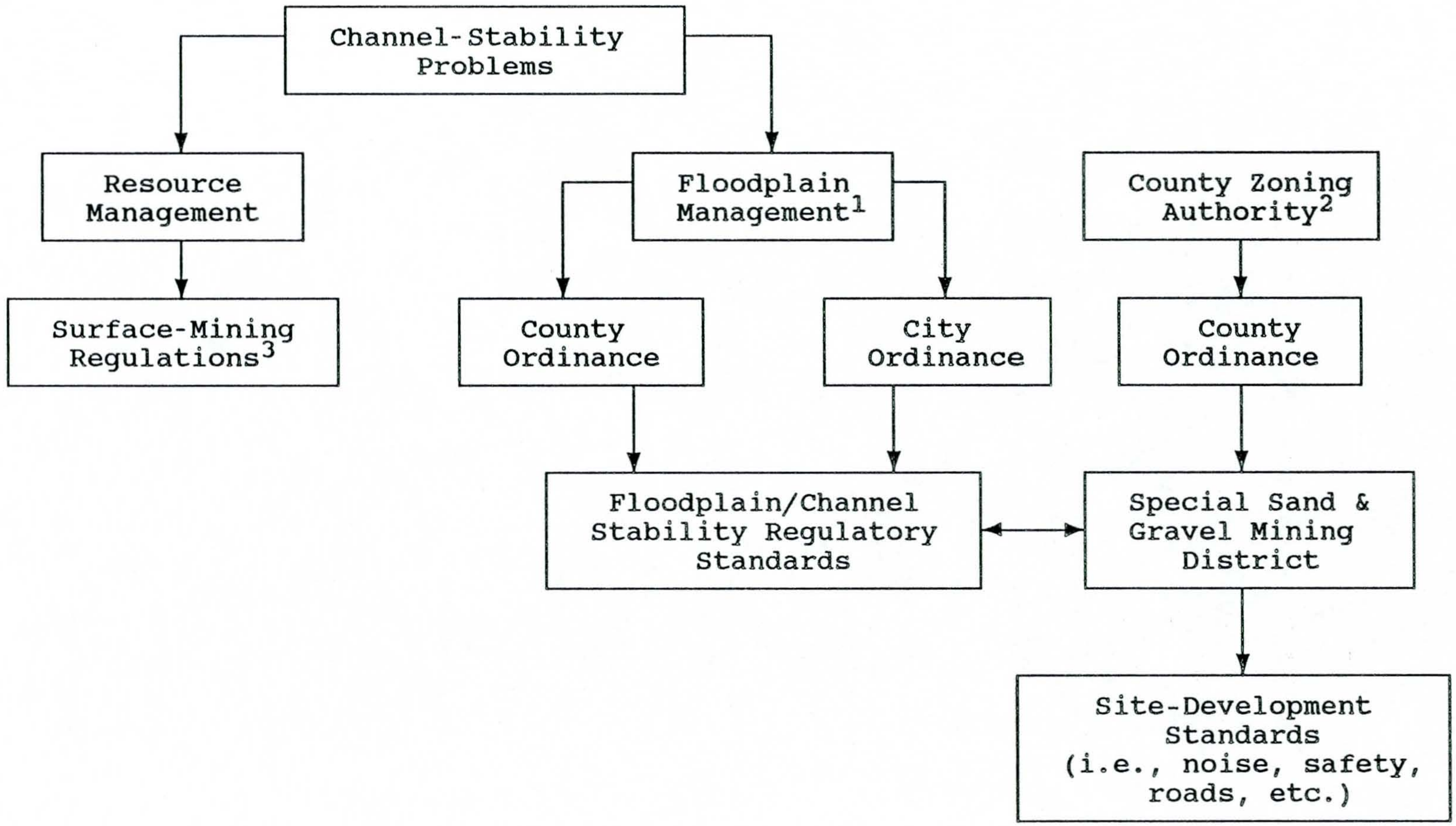
15.1 Model Legislation

15.1.1 Legislative Options

The impacts of in-stream sand and gravel mining may be assessed in terms of channel-dynamics problems, land-use problems, and economic factors. The focus of this entire study has centered on channel-dynamics issues; therefore, the legislative approach to regulation resulting from this research effort correspondingly addressed channel-dynamics problems.

A decision tree was developed to facilitate an understanding of the evaluation and selection process undertaken in exploring the alternative legislative options (refer to Figure 15.1). Two regulatory approaches to address channel-dynamics problems related in in-stream mining were identified. A resource-management approach balances resource requirements and costs against the costs to assure other in-stream uses. This type of approach was found to be the basis of several other western-state regulatory programs; most notably the State of California Surface Mining and Reclamation Act (SMARA). This law addresses not only sand and gravel mining, but other surface-mining operations (i.e., mineral) as well. No such law currently exists in Arizona. The problem which would be encountered in applying a surface-mining regulatory program in Arizona is that it would, by definition, involve many types of mining operations, other than sand and gravel, not currently regulated. This fact would jeopardize any chance for successful adoption and implementation of such a law.

The second avenue identified would involve approaching regulation of in-stream mining through floodplain-management legislation. At the present time, the powers and duties granted to county flood-control districts and cities or towns is limited in terms of authority to establish regulation of sand and gravel mining. The legal opinion on this subject provided by the project attorney describes the current situation in detail (see Exhibit 15.1.). No specific language exists in current enabling law which extends the authority of counties or municipalities to regulate for the purpose of maintaining channel morphology. Consequently, legislation is required to enable the regulation of



[1] Amendment to ARS 48-3609
[2] Amendment to ARS 11-830
[3] Not available in Arizona

Figure 15.1. Legislative-Option Decision Tree

sand and gravel mining operations that affect watercourse stability.

If such legislation were adopted, the regulatory authority relative to channel dynamics would reside with the counties and the municipalities. Cities would then have two lines of legal authority, zoning and flood control, upon which to base regulation of the sand and gravel industry. The counties do not have zoning powers relative to sand and gravel mining.

The authority for counties to zone sand and gravel mining has been pursued in the development of HB 2315 (see Section 14.3.). The bill provides for the regulation of sand and gravel operations in counties which have adopted specific overlay zoning districts for sand and gravel operations. In addition, the counties must adopt district standards addressing permitted uses, approval procedures of property-development plans, and site-development standards. These standards only specifically address noise, dust, safety, roads, etc.; and do not include items related to floodplain or channel-dynamics issues.

The focus of the recommended approach to regulation of in-stream mining operations within special overlay districts is then centered on the development of standards and procedures, through city and county ordinances, which specifically address channel-dynamics impacts. Such standards could include "red-line" limits, set-backs, pit slope/depth criteria, mitigation requirements, and reclamation. However, the key step which must be taken <u>prior to</u> adopting and implementing this type of regulatory program is to enable, through legislation, the city or county floodplain managers to have the authority to regulate channel-dynamics. Only after this line of authority is clearly established, may ordinances be adopted by the city or county to regulate in-stream mining operations through a zoning ordinance. In order to accomplish a system-wide analysis in multi-jurisdictional rivers, it will be necessary for city and county agencies to conduct the analysis via an intergovernmental agreement that designates one agency as the lead agency.

15.1.2 <u>Recommended Legislative Approach</u>

ARS Section 48-3609 authorizes the issuance of regulations for uses in floodplains that may divert, retard, or obstruct floodwater, and threaten public health or safety or the general welfare. The legal opinion (Exhibit 15.1) provided by the project attorney states:

> "For county flood control districts, the ability to regulate sand and gravel operations that 'divert, retard or obstruct the flow of waters in a watercourse' is clear. The extent of that regulation is not clear. The article describing the program focuses on the use of regulatory authority to protect structures. It does

not focus on maintaining watercourse 'stability'. Even though the grant of authority in Section 48-3609 is broad enough to include general welfare regulatory powers as well as threats to public health or safety, and thus overcome one of the restrictions of the Cardi case, the basic thrust of the authority is still to protect structures and to regulate the diversion, retardation or obstruction of floodwaters."

The first step in the legislative approach is to extend the authority of flood-control districts to regulate watercourse stability and sediment transport. The draft bill given in Exhibit 15.2 provides the flood-control districts with the general authority to conduct this regulation. The current legislative effort by the Arizona Rock Products and the Maricopa County Planning and Zoning Commission in preparation of HB-2315 would provide a zoning authority for counties in specially designated sand and gravel mining overlay districts. This would give both cities and counties in the State of Arizona zoning authority. Passage of these two bills would create a clear line of authority necessary to establish a regulatory program for sand and gravel mining via a county ordinance.

Given this authority, it is recommended that the local jurisdiction conduct a system-wide analysis of watercourse stability to find the allowable longitudinal and lateral limits for mining operations. Based on this analysis, an ordinance would be developed establishing these limits as the "red-line" boundary, outside of which mining would not be permitted. The ordinance would also include pertinent operational standards. For a multi-jurisdictional watercourse, it is recommended that the system-wide analysis be conducted by a lead flood-control agency, which would in most cases be the county flood-control district. Ordinances would then be adopted by the respective jurisdictions, consistent with the system-wide analysis.

The following section discusses how a "red-line" study would be conducted. This study involves technical issues regarding the analysis of watercourse stability; and the impacts of sand and gravel mining; and non-technical issues regarding the economic value of aggregate resources and operational requirements. The study is intended to be an open process, soliciting the input of the industry and other affected interests. The resulting "red-line" ordinance should represent a concensus of opinion as to watercourse stability and the economic value of the aggregate resource. An example model "red-line" ordinance is presented in Exhibit 15.3.

15.2 River Resources Management Study

The objective of a River Resources Management Study is to identify the proper management scheme for a river system that maximizes the utilization of aggregate resources, while minimizing potential watercourse-dynamics impacts. The development of a useable management plan requires a thorough understanding of the entire river and watershed system, and the relavent physical processes that affect that system. Natural processes of erosion and sedimentation are determined by the supply of sediments from the watershed and sediment-transport capacity of the river. The river environment is the most dynamic portion of this fluvial system, continually adjusting to variations in the sediment budget by adjusting channel geometry and bed profile. Man's development activity within this complex system can alter the sediment budget and impact the behavior of the natural fluvial system. To fully utilize the resources available in the system without adversely impacting the stability of the river, a comprehensive analysis of the potential system response must be conducted.

This section outlines the methodology to be used in conducting a River Resources Management Study. The methodology is intended to provide a comprehensive technical analysis of the river system, and also to provide the sand and gravel mining industry a means of identifying their in-stream production areas and the anticiapted demand. The resulting "red-line" boundaries are intended to represent a balance between demand for aggregates, and constraints present in the river system. Since it is society-at-large which assumes the cost of production of aggregate resources and damages caused by river instabilities, an economic component is included in the methodology where, to the extent possible, the incremental costs between aggregate production and stabilization measures are assessed.

A River Resources Management Study consists of three major parts: 1) aggregate-resource identification; 2) river-system analysis; and 3) economic evaluation.

15.2.1 <u>Aggregate-Resource Identification</u>

The first phase of a River Resources Management Study consists of the identification of lands within the local jurisdiction containing significant aggregate resources. The statewide classification matrix (Chapter VI) provides an appropriate framework for this identification process. The criteria within the matrix addressing resource quality/quantity and market demand/access aid in identifying specific jurisdictional areas of significant aggregate-resource potential. The objective of the identification process is to insure, through appropriate lead-agency policies and procedures, that mineral deposits of statewide or regional significance are available when needed.

As part of this identification process, criteria are applied in classifying lands that are threatened by uses which are incompatible with or preclude the mining of the aggregate resources contained therein. Appropriate criteria to be applied in making this determination consists of the historic/future structure-hazard and social/environmental components of the statewide classification matrix.

After consultation with lead agencies and other interested parties, those areas containing mineral deposits of regional or statewide significance are so designated; and thus could be protected from land uses incompatible with the extraction of aggregate resources through the establishment of sand and gravel mining overlay districts.

15.2.2 River-System Analysis

15.2.2.1 Specific-Analysis Methodology

A complete three-level analysis procedure is used to study the river system. The entire river system is first analyzed qualitatively (Level I), based on field investigations and the study of aerial photographs. This qualitative analysis is crucial to the understanding of the physical system, proper interpretation of the available data, and the results of quantitative analysis.

The two levels of quantitative analysis are then completed. These two levels are: 1) engineering analysis (Level II), and 2) mathematical model simulation (Level III). In the engineering analysis, a rigid boundary (no change to the river bed or banks) is assumed for the backwater computations and hydraulic analyses. Sediment-discharge relations are developed for the study reach using the measured sediment data, the results of the rigid-boundary hydraulic analyses, and applicable sediment-transport theories. These relations are applied to estimate the sediment flow and transport capacities. The characteristics of channel degradation/aggradation along the study reach under various flow and channel conditions are then estimated based on the sediment-continuity principle. This level of analysis is an efficient approach to obtaining an initial assessment of the complicated geomorphic problems associated with gravel mining, and to evaluating the short-term and long-term channel responses to natural flooding and man's activities. It also provides a basis for checking the results of more complex mathematical modeling-analysis techniques in Level III.

Mathematical model simulation of channel response is one of the major elements of a river-system study. Two models are developed: one for simulating the headcutting and filling process around a gravel pit during a major flood; and another for estimating the general aggradation/degradation along the channel. Model simulation provides detailed information on river-bed changes under various flow conditions, and in response to selected channel-development alternatives.

15.2.2.2 <u>Study Objectives</u>

To analyze the river system and its responses to natural and man-induced changes, a comprehensive hydraulic, erosion, and sedimentation study is required. The study must address past, present, and future conditions, with results that support selection of the best-management alternative.

The major objectives of a study are as follows:

1. Analyze river response in the past, particularly during major floods.

2. Analyze river response for various alternatives, including sand and gravel mining, in-stream structures, and other management plans. This analysis includes:

    a. As-is conditions.

    b. Conditions with mining plans for maximum extraction proposed by all operators, and presently approved by the County.

    c. Development of "red-line" boundaries considering maximum impact of mining on general degradation, as well as the constraint of critical scour associated with in-stream structures.

    The "red-line" boundaries will be established in joint coordination with the lead agency, mining companies, and other interested parties. The procedure to be used in establishing the "red-line" will be based primarily on the three-level analysis approach.

3. Evaluate and interpret the results of "red-line" conditions in a resource-management context.

4. Provide the final "red-line" profile and boundary maps.

5. Provide the lead agency with the necessary supporting documentation for their future administration of the "red-line" boundaries.

15.2.2.3 <u>Scope of Work</u>

The following tasks represent the specific scope of work required to accomplish project objectives.

Task A - Site Reconnaissance, Data Assembly, and Public-Meeting Support

1. Site inspection - familiarize all key project personnel with the study area.

2. Data search and review - assemble all available data for the following data sets:
   - River-channel topography
   - Hydrologic conditions
   - Mining activity
   - Bed-material gradation

3. Data gathering - gather additional data, where possible, to fill gaps in available data.

4. Be available to support the Lead Agency in public hearings, as required.

Task B - Level-I Analysis, Qualitative Geomorphic Analysis

1. Analyze aerial photographs for historical patterns of river response, floodplain land-use, and in-stream mining activity.

2. Identify lateral-migration trends and locations of channel bank instability.

3. Apply qualitative geomorphic relations to classify the river form and characterize the natural response of the river system.

Task C - Level-II Analysis, Quantitative Geomorphic and Basic Engineering Analysis

1. Determine quantitatively the hydraulic, sediment-transport and erosion/sedimentation characteristics for the baseline (pre-mining) conditions.

2. Define the critical-structure locations, and critical features adjacent to the channel boundary. Identify natural or man-made control structures in the river reach.

3. Determine quantitatively the hydraulic, sediment-transport and erosion/sedimentation characteristics for the post-mined condition. Use long-term and short-term scour-analysis procedures.

4. Conduct a stability analysis of resulting channel banks in the vicinity of actively mined areas and critical structures.

5. Compare estimated scour elevation to the elevation of critical structures, and the lateral location of adjacent critical features.

Task D - Level-III Analysis, Quantitative Analysis with Mathematical Modeling

1. Perform movable-bed analysis for the proposed mining condition based on excavation to a preliminary "red-line" boundary.

2. Identify the impact of the proposed mining condition within the actively mined area, and upstream and downstream of that area, for a single design event.

Task E - Preparation and Presentation of Report

1. Based on the results of the previous steps, recommend the "red-line" boundary, which is defined as a set of channel slopes, river-control elevations, and lateral limits for sand and gravel extraction.

2. Prepare a detailed report presenting study methods, results, and conclusions.

Task F - Provide Supporting Documentation to Lead Agency

1. Provide all data sets, computer models, and associated input and output.

2. Provide user's manual, including a discussion of data requirements, assumptions, and limitations of the results; and an explanation of the multiple-level-analysis approach.

15.2.3 Economic Evaluation

The final phase of a River Resources Management Study evaluates additional alternatives that may require the construction of mitigation structures. These alternatives may result in increased production of aggregates in the actively mined areas of the river system. An economic analysis investigates the cost of these structures relative to the increase in aggregate production. This analysis must also identify methods of financing the cost of design and construction for these mitigation structures.

The additional alternatives are evaluated in accordance with the requirements of the river-systems-analysis phase of the project (Section 15.2.2). Significant analysis effort is required to fully evaluate an additional alternative. If several alternatives are proposed, methods for screening the effect of a set of alternatives should be developed in order to reduce the overall level of effort. Optimization techniques may reduce the level of effort, if the set of alternatives is sufficiently large.

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of Counsel
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March 17, 1987

Mr. Robert L. Ward, P.E., Manager
Simons, Li & Associates, Inc.
1225 E. Broadway Road, Suite 200
Tempe, Arizona 85282

Re: Research Project No. HPR PL 1(29) Item 250 for ADOT

Dear Mr. Ward:

You have asked me to address two issues that have arisen in the interim during your study on the effects of In-Stream Mining on Channel Stability.

The first question was whether the three-tier approach described in your interim report can be implemented under existing statutes. It is my opinion that under current law the regulatory aspects of the three-tier approach could be implemented with some restrictions within municipalities that had chosen to undertake floodplain regulation and to a much more limited extent within areas under the jurisdiction of county flood control districts. The regulatory program in its entirety as you describe in your interim report could not be implemented in Arizona under existing law.

As you correctly describe in your interim study, both zoning and floodplain management powers are the purview of county and municipal governments and special districts.

Counties may, "Subject to the prohibitions, restrictions and limitations as set forth in Section 11-830, adopt and enforce standards for excavation, landfill and grading to prevent unnecessary loss from erosion, flooding and landslides". ARS Section 11-251.

Section 11-830 of the Arizona Revised Statutes provides two limitations on county authority. It prohibits any county zoning ordinance from preventing, restricting or otherwise regulating the use or occupation of land or improvements for mining purposes, among other purposes, if the tract in question is five

EXHIBIT 15.1

or more contiguous commercial acres. Prior to 1972, the test was not less than two contiguous commercial acres. The 1972 law that amended the statute further provided that any existing uses between two and five contiguous acres that existed at that time were still shielded from any ordinance for the stated purposes, including mining, as long as the tract in question is continuously used for such purpose. Thus, mining uses of two to five acres in existence prior to the effective date of the 1972 act continue to be exempt from county zoning powers as long as used and tracts of five commercial acres or more continue to be exempt both as to existing and new uses. Operation of a sand and gravel pit constitutes mining within the purview of this statute. Hazard v. Superior Court in and for Pima County, 82 Ariz. 211, 310 P.2d 830 (1957).

I note that this restriction is to this very day generally accepted. Indeed, H.B. 2122 in the current legislative session proposed to remove sand and gravel extraction from the restriction on regulation of mining in Section 11-830. Last Thursday morning, the bill was used as a "striker" on another subject and the issue appears dead for this session. The testimony on the bill uniformly was that counties lacked zoning authority over sand and gravel operations. I gather that such blanket statements are a recognition of the fact that no new sand and gravel pit has recently been established that covers less than five acres and that there is no such thing as a commercial sand and gravel operation operating on less than two acres.

ARS Section 11-830 contains a second limitation. It prohibits any county zoning ordinance from affecting existing uses of property or the right to continued use thereof or reasonable repair or alteration thereof for the purpose for which used at the time the ordinance affecting the property took effect. I would take this to be existing law from a constitutional perspective even if it were not stated in the statute. What this means is that, were the above-cited provision concerning mining to be limited to other than sand and gravel operations, existing operations would still be covered by the prohibition against affecting existing uses. Such limitation would affect the ability to use the so-called red-line approach to limiting excavation through the zoning power. County governments are therefore not appropriate regulatory authorities under existing law.

Cities are not so limited. ARS Section 9-461, et. seq., provides the basic zoning power for municipalities in Arizona. Those powers are not limited as to the types of uses that can be regulated. Thus, the city zoning power does apply to sand and gravel operations within city limits. This power is nevertheless restricted under Arizona case law to prospective application in virtually the same way the provision in Section 11-830 announces that restriction as to counties. See: Kubby v. Hammond, 68 Ariz. 17, 198 P.2d 134 (1948). Moreover, ARS Section 9-462.01 provides zoning authority to establish floodplain zoning districts to protect life and property from the hazards of periodic inundation. The same statute also provides related authorities but does not specifically grant authority to regulate sand and gravel businesses for all purposes. The zoning authority is ambiguous as to the kind of regulatory authority contemplated in the three-tier approach of the interim report. Under such circumstance, a challenge to use of the red-line technique might be successful from the standpoint of vagueness. See: State v. Owens, 114 Ariz. 565, 562 P.2d 738 (1977). Thus, cities would be limited in using their zoning powers to prospective application of red-line limits, and may be limited as to the extent of that use for purposes of watercourse stability.

The powers and duties granted to county flood control districts is the third source of statutory authority in this analysis. ARS Section 48-3603 contains the general powers and duties of a county flood control district. ARS Section 48-3609 requires the district to delineate or require developers to delineate floodplains consistent with floodplain criteria developed by the Department of Water Resources. The statute also protects existing legal uses and reasonable repair or alteration of property. However, actions taken which would increase flood damage potential by 50% or more are regulated. ARS Section 48-3613 contains the authorization for regulating construction in a watercourse. This statute clarifies that sand and gravel operations which will divert, retard or obstruct the flow of waters in a watercourse may be regulated.

The basic limitation in this program is contained in ARS Section 48-3609, which authorizes the issuance of regulations for uses in floodplains that may divert, retard or obstruct floodwater and threaten public health or safety or the general welfare. The law was first passed in 1973 and substantially revised in 1984. Its permitting authority, except possibly for substantial changes that would increase flood damage potential by 50% or more, are prospective in nature and cannot be required of operations already in existence. Pima County v. Cardi, 123 Ariz. App 424, 600 P.2d 37 (1979).

Under ARS Section 48-3610, a city or town can assume the powers and duties prescribed by Section 48-3609. The powers and duties of the rest of this article are not included in that assumption of responsibility.

For a city or town that has assumed flood control duties under ARS Section 48-3610, sand and gravel operations would be included both here and by virtue of zoning authority. The sand and gravel regulatory authority under ARS Section 48-3613 might impliedly also be carried over but zoning authority exists in any event.

Thus, cities may have two lines of authority, zoning and flood control, upon which to base regulation of the sand and gravel industry. Both powers are limited as to pre-existing uses. The zoning power may be limited also as to the risks avoided, i.e., not available merely to "stabilize" a watercourse. The cities' assumption of flood control authority may also carry with it limitations. For county flood control districts, the ability to regulate sand and gravel operations that "divert, retard or obstruct the flow of waters in a watercourse" is clear. The extent of that regulation is not clear. The article describing the program focuses on the use of regulatory authority to protect structures. It does not focus on maintaining watercourse "stability". Even though the grant of authority in Section 48-3609 is broad enough to include general welfare regulatory powers as well as threats to public health or safety, and thus overcome one of the restrictions of the <u>Cardi</u> case, the basic thrust of the authority is still to protect structures and to regulate the diversion, retardation or obstruction of floodwaters. Floodwaters are temporary rises in water level constituting overflow of water onto lands not normally covered by water. Since the red-line approach is aimed primarily at stabilizing any watercourse to regulate sediment deposit and not to regulate floodwaters, there is some question whether the regulatory aspect of this program could be put in place under existing authorities for county flood control districts. Assumption of those authorities by a city or town would not change this distinction. The municipality could attempt to rely on its power to establish zoning districts, but here again that authority is expressed in terms of protecting life and property from the hazards of periodic inundation. Moreover, the zoning power is specifically limited as to existing uses. Limiting the location and amount of excavation from materials in an existing sand and gravel pit, especially for purposes of maintaining watercourse "stability", may be outside the purview of the zoning authority as well.

In summary, there is no clear-cut line of authority to establish a regulatory program as contemplated by the interim report. There seems to be a larger bundle of authorities for a municipality in Arizona to use the red-line approach, especially as to new sand and gravel facilities, but establishment of such an approach by a county flood control district carries with it more problems. It would essentially be impossible if attempted by a county.

The answer to your second question is much easier. The general authorities of ARS Section 48-3603 are broad enough to include accepting funds at the county level for red-line studies. The assumable authorities that a city might acquire under Section 48-3609 do not include accepting funds and conducting studies, but the general authorities under the statutes granting cities zoning powers are clearly broad enough to encompass such activities as long as they are not used for regulatory purposes. Thus, the second level of analysis, that is the development of these red-line boundaries, could be undertaken by the State, the counties or the cities. It is only when they would be used for regulatory activities that our statutes appear to be deficient.

I hope this analysis is adequate for your purposes. Please do not hesitate to get in touch with me if you have any questions.

Sincerely,

Robert S. Lynch

RSL:psr

STATE OF ARIZONA
39th LEGISLATURE
FIRST REGULAR SESSION

Reference Title: Floodplain regulation; sediment deposition

______ BILL _____
Introduced

____

Introduced by

AN ACT

RELATING TO COUNTY FLOOD CONTROL DISTRICTS; REQUIRING REGULATION OF WATER COURSE STABILITY AND SEDIMENT DEPOSITION, AND AMENDING SECTION 48-3609, ARIZONA REVISED STATUTES.

Be it enacted by the Legislature of the State of Arizona:

Section 1. Section 48-3609, Arizona Revised Statutes, is amended to read:

48-3609. Floodplain delineation; regulation of use

A. Except as provided in Section 48-3610, the board within its area of jurisdiction shall delineate or may by rule require developers of land to delineate for areas where development is ongoing or imminent, and thereafter as development becomes imminent, floodplains consistent with the criteria developed by the director of water resources.

B. Except as provided in Section 48-3610, the board shall adopt and enforce regulations governing floodplains and floodplain management in its area of jurisdiction which shall include the following:

1. Regulations for all development of land, construction of residential, commercial or industrial structures or uses of any kind which may divert, retard or obstruct floodwater, AFFECT WATER COURSE STABILITY OR CONTROL OF SEDIMENT DEPOSITION, and threaten public health or safety or the general welfare.

etc.

EXHIBIT 15.2

JOINT RESOLUTION OF THE COUNTY OF __________
AND THE ____________ COUNTY FLOOD CONTROL DISTRICT
ESTABLISHING A "RED-LINE" PROFILE AND
WIDTH POLICY FOR MINING AND EXCAVATION

WHEREAS, sediment-transport studies of the ____________ River have identified sand and gravel mining as a major cause of riverbed degradation which has resulted in damage to in-river structures and bank erosion during past major floods; and

WHEREAS, ____________ a River Resources Management Study by the ____________ County Flood Control District has developed "red-line" profile and width-of-excavation standards based on the considerations of structural safety, sand and gravel replenishment, and downstream channel impact; and

WHEREAS, ____________ County Flood Control District recommends the "red-line" profile and width standards for regulating river excavation to control further degradation near structures, while allowing mining where more balanced sediment-flow conditions can be achieved; and

WHEREAS, establishment of a "red-line" profile and width policy for mining and excavation in the ____________ River is needed to provide guidance and direction for management of the total river system, including planning and regulating the construction of in-river facilities and use of river resources.

NOW, THEREFORE, be it resolved that the Board of Supervisors of the County of ____________ and the ___________ County Flood Control District adopt the following policy:

1. In-river mining will be considered on the basis of a river-management strategy as delineated in the __________ River Resources Management Study.

2. Excavation will be limited to the "red-line" profile and width standards as determined by the Flood Control District and ____________ River Resources Management Study, and defined by the attached table of horizontal- and vertical-control data and excavation widths which have been plotted on drawings on file with the ____________ County Flood Control District.

3. Exempted from this policy are excavations required for emergency measures to protect life and property, and flood-control approved channelization projects.

Example tables of horizontal and vertical control data:

TABLE 1
HORIZONTAL CONTROL POINTS

Station (100 ft.)	North (ft.)	East (ft.)
	COORDINATES	
0+00	269,775	1,620,070
100+00	269,855	1,624,275
200+00	269,720	1,632,650
300+00	270,030	1,637,550
400+00	270,340	1,638,500

TABLE 2
VERTICAL CONTROL POINTS

Station (100 ft.)	Elevation (ft.)
0+00	1005.5
100+00	1032.3
200+00	1058.0
300+00	1080.0
400+00	1100.0

TABLE 3
MAXIMUM ALLOWABLE EXCAVATION WIDTHS

Station (100 ft.)	Width (ft.)
0+00	
	1000
100+00	
	1000
200+00	
	(No excavation permitted)
300+00	
	600
400+00	
	800

XVI. CONCLUSIONS

The completion of work on this research project has provided significant insight into the influences of in-stream sand and gravel mining upon the stability of river systems. Additionally, the issues surrounding the relationship of the aggregate mining industry to the economic, social/environmental, and regulatory climate have been evaluated. The major findings of this research project are summarized below.

Regulatory Practices

* The Federal Flood Insurance Program has significant influence on in-stream and floodplain sand and gravel operations. Federal water quality regulations on dredged and fill material (Section 404) must be complied with by sand and gravel operators, but do not restrict such operations.

* Regulations implemented in the State of California for management of sand and gravel resources address issues and conditions similar to those in Arizona. A resource management approach toward sand and gravel regulation balances resource requirements and costs, against costs to assure other in-stream uses.

* Floodplain management regulations are the predominant method of regulating sand and gravel operations in Arizona at the present time.

Structure Hazard

* The reported flood damages to roads/bridges and to the sand and gravel industry in Arizona for the period from 1965 to 1983 was estimated at $97,297,586 and $11,531,000, respectively, (Flood Damage Reports).

Economic Value

* Sand and gravel products are a fundamental resource for the construction industry.

* The sand and gravel mining industry in Arizona is a very competitive, productive industry that is an efficient supplier of sand and gravel products.

* The primary benefit of in-stream sand and gravel operations is an economical, convenient source of quality construction materials. Other benefits include: (a) increased channel capacity; (b) reduced potential for overbank flooding; (c) partial runoff storage; (d) minor, local groundwater recharge; and (e) job creation and increased tax base.

* The cost of sand and gravel products to the consumer is a function of both production costs and transportation costs. Production costs are a function of the quality of the sand and gravel resource available to the operator, and demand for sand and gravel products. Transportation costs are a function of the distance from the mining operation to the consumer.

* The value of sand and gravel production for the ten-year period from 1975 to 1984 was $646,951,000 (Mineral Yearbook). The value of sand and gravel production for 1985 was $122,900,000 (Arizona Rock Products Association).

Social and Environmental Factors

* Sand and gravel mining is an industrial land use and, as such, may conflict with adjacent non-industrial land uses. As with other industrial land uses, sand and gravel mining has operational activities that are considered a nuisance to commercial or residential land uses.

* Nuisance issues include visual setting, dust in the air, noise of machinery and equipment on site, as well as the effects of truck traffic on flow of local traffic and the frequency of street repairs.

* A study of the impact of the sand and gravel mining industry on air, noise, and water quality has not been conducted in Arizona. In lieu of such an analysis, it is not known if noise or dust levels at sand and gravel mining operations violate pollution standards.

Statewide Classification

* A classification matrix was developed to facilitate the selection of river reaches for further detailed analysis. The river reaches were qualitatively rated according to the following criteria: resource quality/quantity, market demand/access, structure hazard, and social/environmental conditions. The rating was judgmental, based on the information presented in this report.

Review of Methodologies

* There is no standard methodology presently being used in Arizona to analyze the impacts of in-stream sand and gravel mining.

* Methods of analysis include field measurements, physical models, and analytical techniques.

* Field measurements are best suited to monitoring existing sand and gravel mining operations.

* Physical models provide a relative assessment of river conditions, but have limited application because of their cost and accuracy.

* A wide range of analytical methods are available, including at least eight models for simulating general river response, and two models for simulating in-stream mining.

* A multi-level approach for evaluating response of river systems is available, and is preferable as a technique for integrating both qualitative geomorphic, engineering, and modeling information.

* Procedures are available for assessing the large scale effect of sand and gravel mining in a river basin, and for evaluating local effects. The "red-line" procedure sets mining limits for entire river reaches. The Corps of Engineers sand and gravel mining guidelines pertain to specific sand and gravel mining sites.

<u>Mitigation Measures</u>

* Two structural measures for mitigating in-stream mining impacts have been identified as being both functional and effective. These include grade-control structures and lateral flow-control structures.

* Non-structural measures considered effective include: 1) buffer zones which provide for a conservative setback between gravel pit operations and in-stream structures; and 2) operation standards which establish minimum acceptable practices related to the manner in which sand and gravel is to be mined.

* The protection of endangered structures, utilizing mitigation measures, must consider the impacts of existing and impending mining operations upon these structures.

* The proper approach to the implementation of mitigation measures for a specific river reach involves the development of a comprehensive plan for aggregate mining in that system from a resource-management perspective. It would include the selection of a cost-effective combination of measures, both structural and non-structural, which efficiently mitigates impacts to in-stream structures while allowing for the continued use of the aggregate resources in the river system.

Engineering Parameters

* The development of engineering parameters required the compilation of four datasets for each study reach, including: river channel topography; bed material gradations; hydrologic conditions; and, mining activity. The resulting engineering database provides a quantitative description of river characteristics over time, and the factual basis underlying the technical procedures.

Long-Term Procedure

* For gravel-bed channels, the supply of sediment is relatively small. In the case of reaches analyzed on the Salt River, sand and gravel production far exceeds the supply. As a result, the volume of material lost from the river channel can be closely approximated by the volume of sand and gravel production.

* For sand-bed channels, the sediment supply is more significant than for gravel bed channels. In the case of reaches on the Rillito, Agua Fria, and New Rivers, it was found that the supply of sediment to mined reaches partially replenishes the sediments removed from channel bed. However, the condition in these reaches still shows a distinct degradational trend.

* Procedures were developed that provide a prudent estimate of the long-term response of a river channel to mining activity. The approach is based on the basic physical principle of sediment continuity. It is strongly advised that an ongoing data gathering effort be adopted for the purpose of refining and broadening the applicability of this approach.

* An estimate of the downstream impact of in-stream mining was formulated for gravel-bed channels from measured data. The procedure predicts the downstream extent of scour and the scour depths. On the basis of limited data, comparison of predicted scour depth and length showed good agreement with measured values. Because of the limited dataset, it is recommended that continued data collection be conducted for gravel-bed channels.

* The downstream effects of in-stream mining on sand-bed channels is more variable and, as a result, a procedure for estimating the long-term impacts was not developed. In general, it is expected that sand-bed channels will recover more quickly from mining activity because of the larger sediment-transport rates for the bed material. It is proposed that the short-term procedure be used in lieu of a long-term procedure. It is recommended that continued data

collection be conducted for sand-bed channels.

* The lateral stability of channels was found to be associated primarily with bank stability. Estimates of allowable bank height and side-slope were made, based on observed bank stability and engineering judgement. This approach recognizes the number of parameters that contribute to bank stability, their spacial variability in a river reach, and the limited amount of data available.

Short-Term Procedure

* Short-term scour is most pronounced at two locations: near the upstream and downstream brink of an excavation. This will affect structures located in a river reach with active mining immediately upstream or downstream of such a reach.

* The short-term behavior of in-stream excavation is hydrodynamically complex, and depends on the following factors:

  - Bed-material gradation
  - Variation in discharge
  - Excavation configurations, i.e. the width, depth, and length
  - The prevailing channel slope

* A computational model, Channel Response due to In-Stream Mining (CRISM), was developed for this study for the purpose of simulating several channel-response conditions characteristic of a river reach with in-stream mining. The model was developed for the purpose of synthesizing additional data for the development of envelope-type relationships for an initial regulatory evaluation of the effects of in-stream mining operations.

* Procedures were developed which estimate the depth, width and length of short-term scour near the upstream and downstream limit of a sand and gravel mining excavation.

River Response Simulation Procedure

* A sediment routing model, Model HEC-2SR, was modified for simulation of general degradation or aggradation after the sand and gravel pit boundaries have been smoothed out through initial headcut, backfill and downstream erosion processes. The simulation reach is not limited to the excavated area, but normally includes the entire study reach where the effects of mining on other structures are to be investigated.

Case Histories

* Case histories of the existing gravel pits and bridge sites within the study reaches were compiled to obtain a better understanding of the interaction of mining operations, bridge structures and channel behavior.

* Flood damage sustained by mining operations mainly consist of the loss of protective dikes, damage to materials processing plants and loss of production time.

* Flood damage sustained by bridges within the study areas shows that while in-stream mining activity occurs in all reaches, it is not always a dominant cause of bridge failure. However, the trend in production rates and mining activity warrants careful attention to bridges that have experienced problems. Two factors dominate bridge-scour problems associated with in-stream mining: 1) the redirection of the channel flow pattern to an angle at the bridge that increases scour at a pier or abutment; and 2) degradation (typically long-term) that might potentially undermine the bridge foundation.

Justification for Regulation

* Based upon the evaluation of the present problems and future impacts related to the practice of in-stream mining, it is concluded that sufficient justification exists to support the need for regulation.

* The technical issues need to be addressed through regulatory procedures which provide guidelines for assessing the engineering impacts of mining activity on channel-system stability and in-stream structures.

* The economic justification for regulation lies in the balance between the value of the sand and gravel resource to the economy and the estimated damages to the public and private infrastructure due to mining-related channel stability problems. These systems must operate interdependently to achieve the common goal of productive growth in Arizona. The regulatory procedures should incorporate effective management practices that would allow in-stream mining to operate economically, but in a manner that would not jeopardize river-system stability.

* Projected population growth will result in continued encroachment of residential and other non-industrial land-uses adjacent to mining-operation sites. Site-development standards and proper zoning are needed to circumvent, or mitigate, land-use conflicts.

* The justification for regulations, procedures, and operating standards is evident in the need to clarify governmental responsibilities towards administration and enforcement by streamlining review procedures and addressing jurisdictional issues. A coordinated, resource-management approach to regulation of in-stream mining activities will enable the economic production of the necessary volume of aggregate resources required for future growth in Arizona. A reduction in the complexity and obstacles of the zoning and permitting process will decrease compliance problems experienced by the mining operators.

Implementation Plan

* Alternative avenues to bringing about a regulatory program were explored on the basis of existing legal authority and regulatory efficiency. A recommended implementation plan was identified and steps required to conduct the work were formulated.

* The recommended approach to regulation of in-stream mining is through floodplain management legislation. The first step in the legislative process is to extend the authority of flood control districts to regulate watercourse stability and sediment transport. The current legislative effort by the Arizona Rock Products and the Maricopa County Planning and Zoning Commission in preparation of HB-2315 would provide a zoning authority for counties in specially designated sand and gravel mining overlay districts. This would give both cities and counties in the State of Arizona zoning authority. Passage of these two bills would create a clear line of authority necessary to establish a regulatory program for sand and gravel mining via a county ordinance.

* Given this authority, it is recommended that the local jurisdiction conduct a system-wide analysis of watercourse stability to find the allowable longitudinal and lateral limits for mining operations. Based on this analysis, an ordinance would be developed establishing these limits as the "red-line" boundary, outside of which mining would not be permitted. The ordinance would also include pertinent operational standards.

* A system-wide, river-resources management study involves technical issues regarding the analysis of watercourse stability, and the impacts of sand and gravel mining; and non-technical issues regarding the economic value of aggregate resources and operational requirements. The study is intended to be an open process, soliciting the input of the industry and other affected interests. The resulting "red-line" ordinance should represent a consensus of opinion

as to watercourse stability and the economic value of the aggregate resource.

* The river resources management study consists of three major parts: 1) aggregate resource identification; 2) river system analysis; and, 3) economic evaluation.

XVII. RECOMMENDATIONS

The work conducted for this research project addressed an extensive array of technical and non-technical issues related to the impact of in-stream sand and gravel mining on river stability. This resulted in a better understanding of river channel behavior in actively mined reaches. It also provided significant insight into the relationship of the sand and gravel mining industry to the economic and regulatory environment. Based upon the enhanced perspective gained through this research effort, the following recommendations are made:

* Development of in-stream aggregate resources will change the river environments in Arizona. Planning for these changes will be essential to reducing risk to river crossing structures and to maintaining channel stability. To facilitate planning, the existing database must be improved to provide an accurate assessment of the utilization of aggregate resources and concurrent changes in the river channels. The following improvements to the database are recommended:

    1. County sand and gravel production rates should be published annually in the Mineral Yearbook maintained by the Arizona Bureau of Mines.
    2. An accounting of sand and gravel production for major river reaches should be conducted on an annual basis in addition to Mineral Yearbook statistics.
    3. Material Inventories maintained by the Arizona Department of Transportation should be updated for all counties in the state whose inventories were published prior to 1975.
    4. The Material Inventory sand and gravel gradation data for major river reaches should be revised to include bed material with sediment sizes larger than three inches.
    5. The number of miles of federal, state, county, and local roadway constructed should be compiled and published annually in Arizona.
    6. An on-going data collection program should be adopted to monitor channel stability in actively mined reaches.

* The modeling tools and design procedures developed as part of this study were based on sound physical principle supported by extensive data gathering. Because data gaps were a pervasive problem in developing these analysis procedures, verification of each approach was performed where possible. It is strongly recommended that monitoring

programs be initiated for the purpose of gathering additional data and that continued funding be provided to further verify and enhance the analysis procedures.

* The regulatory program should take into account the resource requirements for various sections of the state to assure that an adequate supply of sand and gravel is available at a reasonable cost to consumers. To the extent possible, the incremental cost of any regulation to the sand and gravel industry should be compared to the benefits derived.

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