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EFFECTS OF IN-STREAM MINING ON CHANNEL STABILITY

Volume I I

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16. Abstract

This report consists of the Executive Summary of Volume II, Final Report addressing the impacts of in-stream sand and gravel mining upon the stability of river systems in Arizona. The Executive Summary is a condensed version of the Final Report and includes discussion relative to all major categories such 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 recommendations for further monitoring and data collection.

Final Report, Volume II
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EFFECTS OF IN-STREAM MINING ON CHANNEL STABILITY

EXECUTIVE SUMMARY

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.

* 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 data set 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.

HISTORICAL PROBLEMS

Arizona is crisscrossed by comprehensive networks of transportation and transmission routes. These routes 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 problems of other river-crossing structures in a river reach.

Data on damage to highway bridge structures was compiled from Flood Damage Reports and Federal/State Damage Survey Reports. 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 million dollars and $11.5 million dollars, respectively. This time period encompassed the years during which major hydrologic events caused substantial flooding to occur in the river systems in Arizona.

Case histories of existing gravel pits and bridge sites within the study river reaches were compiled. 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. In other cases, the natural response of the river during a flood created hydraulic conditions adverse to the hydraulic performance of the bridge. Two conditions adversely impacting bridge crossings in mined channels were identified. 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. 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. 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.

ECONOMIC VALUE

To obtain a historical perspective of market potential, data on prior sand and gravel production was reviewed along with associated data on construction activity including building permits and population growth. Figure 1 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 increased significantly but at a rate that reflected fluctuating economic cycles in the construction industry.

The historic increase in the number of building permits issued during this period for the State of Arizona is shown in Figure 2. There are interesting similarities and differences between sand and gravel production and the issuance of building permits. This review of construction history indicated 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. It has been estimated by others that road building consumes approximately one-third of sand and gravel production. Information on the rate of consumption for road building limited, but assumed to be more uniform. This implied that the fluctuations in sand and gravel production were 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 3 shows the growth in Arizona population from 1960 to 1985. Two countervailing trends were identified 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 reflected 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

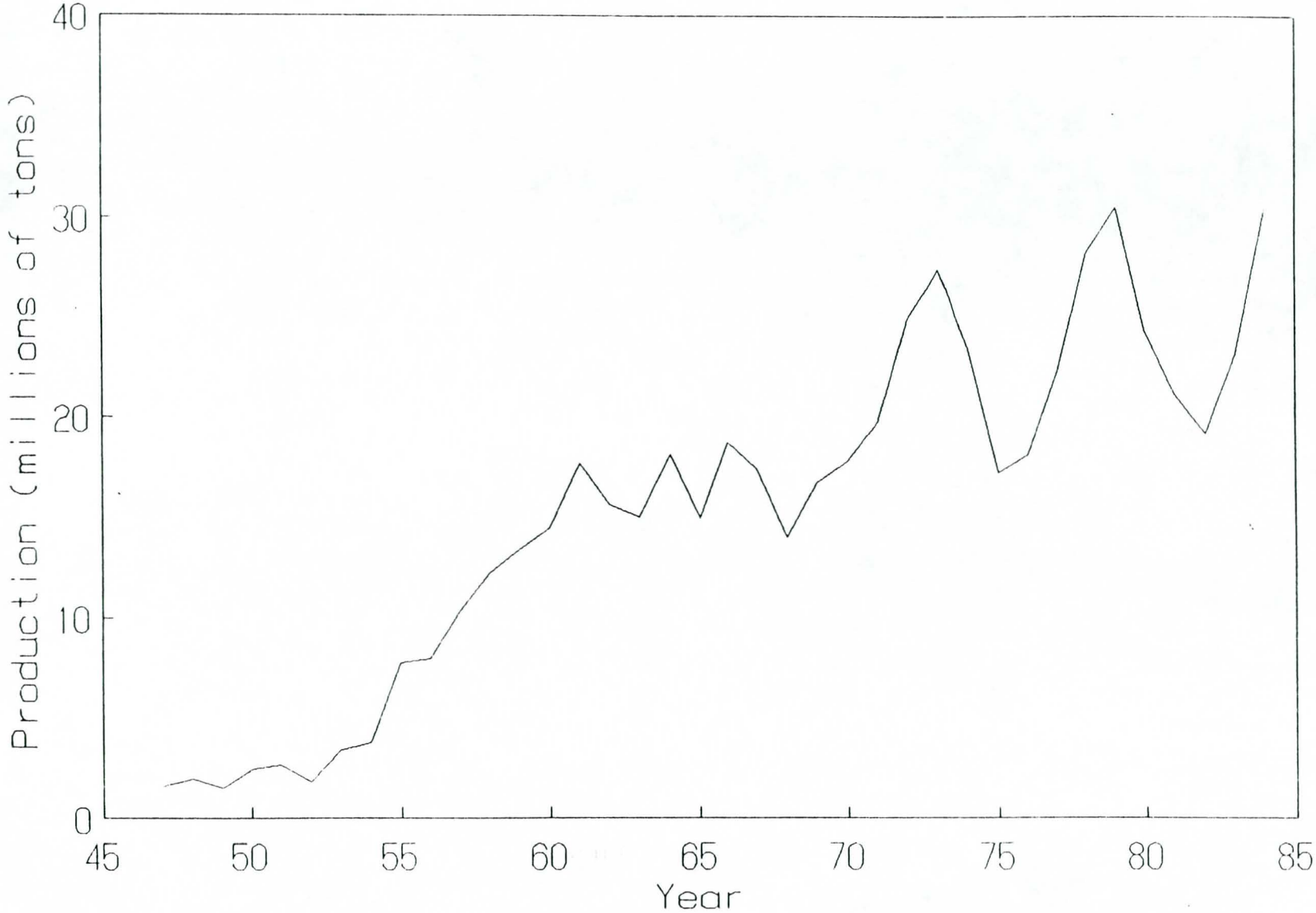


Figure 1. Sand and Gravel Production (1947-1984)

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

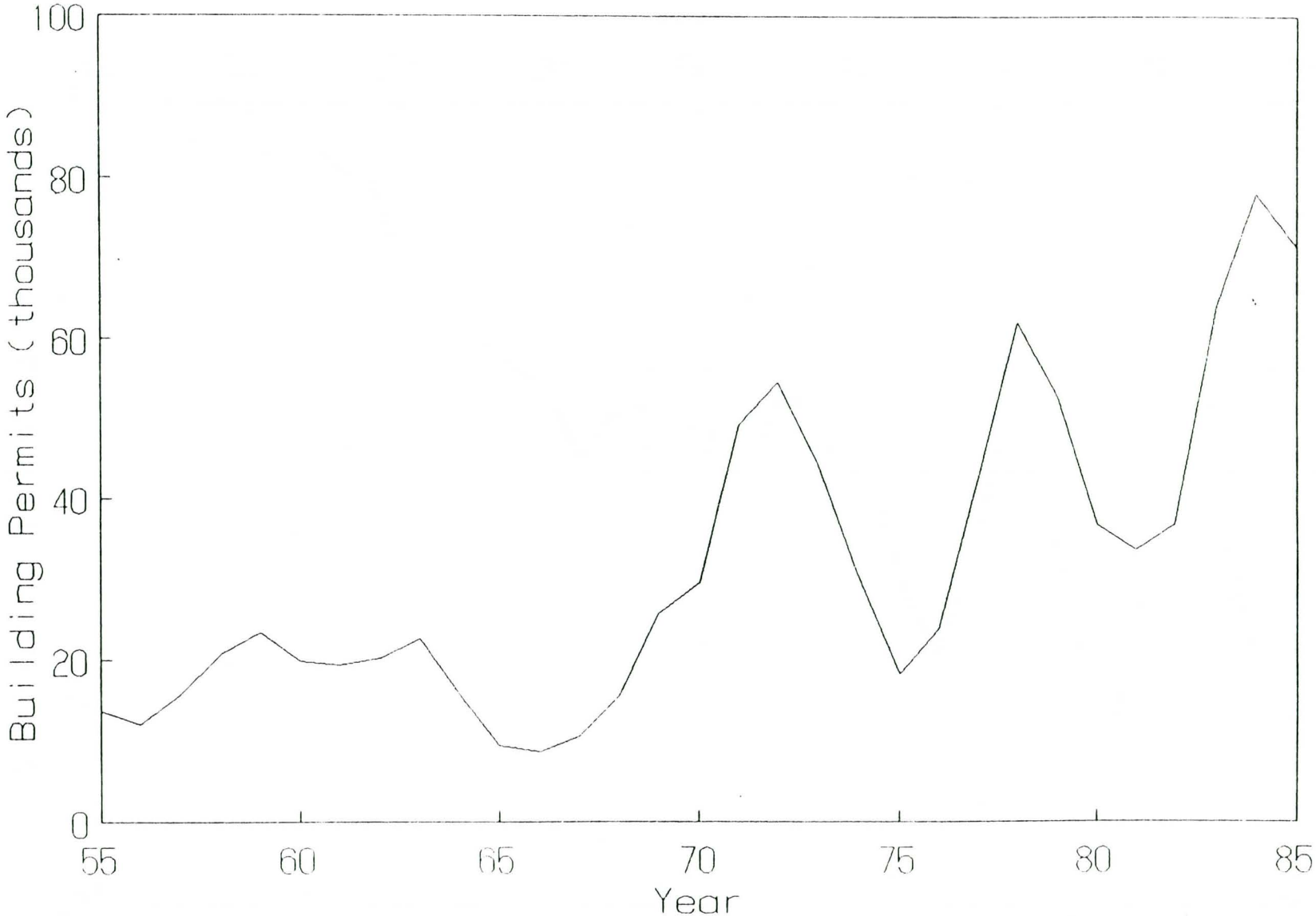


Figure 2. Building Permits in Arizona (1955-1985)

Source: U.S. Department of Commerce, Bureau of the Census

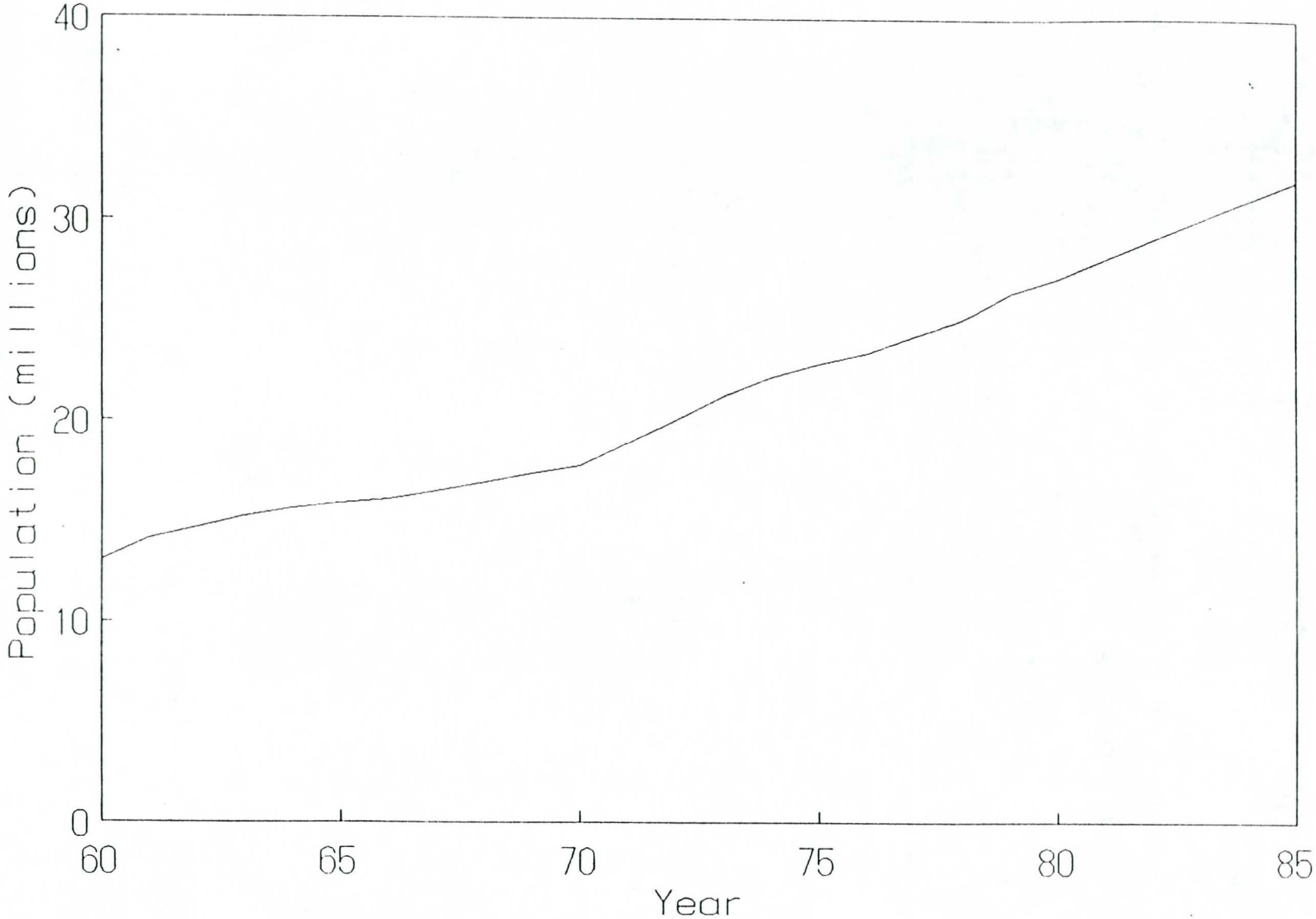


Figure 3. Arizona Population Growth (1960-1985)

Source: Arizona Statistical Review

reduced the demand for aggregate. The increase in housing units per capita indicated a trend toward smaller households. 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.

Using forecasted population growth for the next 50 years for Arizona counties, an estimate of ten-year sand and gravel consumption rates was made. Table 1 summarizes sand and gravel consumption by county at ten-year intervals. State production of 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. Figure 4 graphs the percentage of consumption of sand and gravel by county from 1985 to 2035.

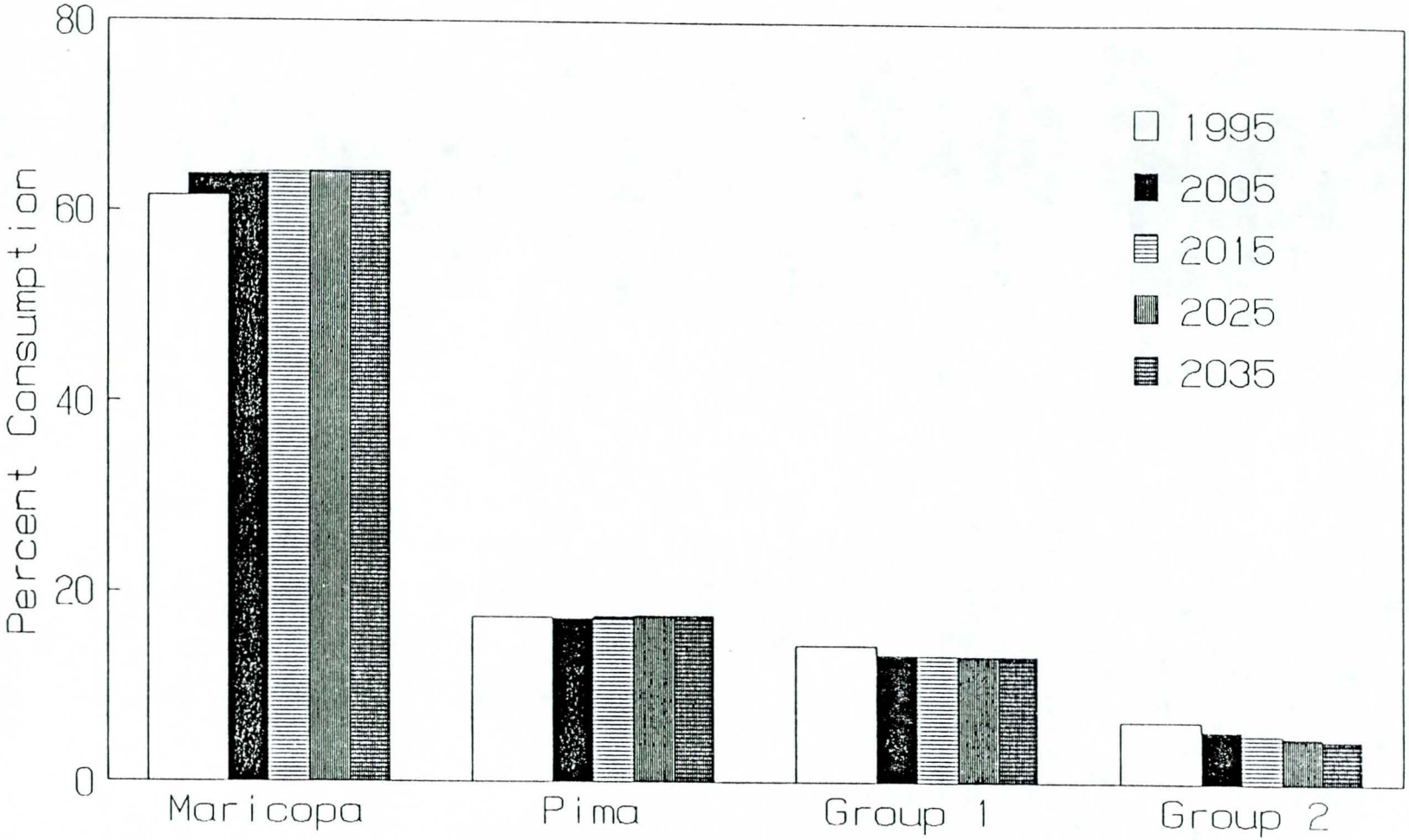
TABLE 1

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

STATEWIDE CLASSIFICATION OF RIVER REACHES

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



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

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

Figure 4. Percent Consumption by County (1995-2035)

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.

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.

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. The reaches on the Verde River were included to provide more information on gravel-bed conditions.

ENGINEERING PARAMETERS AND TECHNICAL PROCEDURES

Engineering parameters were formulated to facilitate the development of technical procedures for assessing the effects of in-stream sand and gravel mining on channel stability. The development of engineering parameters required the compilation of four data sets for each of the eight study reaches. The result-

ing database contains data sets on river channel topography, bed material gradation, hydrologic conditions, and mining activity. The database provides a quantitative description of river characteristics over time, and the factual basis underlying the technical procedures.

Technical procedures were formulated to assess both short- and long-term river channel response for reaches with mining. The short-term procedure is based on a mathematical model that simulates the channel response to an in-stream excavation during a single flood event. The mathematical model was calibrated and verified to a field site, and then applied to a series of conditions characteristic of Arizona channels. This provided a large synthetic data set, which in turn became the basis for the short-term envelope curves. The long-term procedure is based entirely of measurements of topographic changes and mining activity over a period of time ranging from one to several decades.

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.

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 was addressed. The present problems related to the practice of in-stream mining were evaluated 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.

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.

Based upon the evaluation of the present problems and future impacts related to the practice of in-stream mining, it was concluded that sufficient justification exists to support the need for regulation. The key findings of this study relative to regulatory justification are summarized below:

* 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.

IMPLEMENTATION PLAN

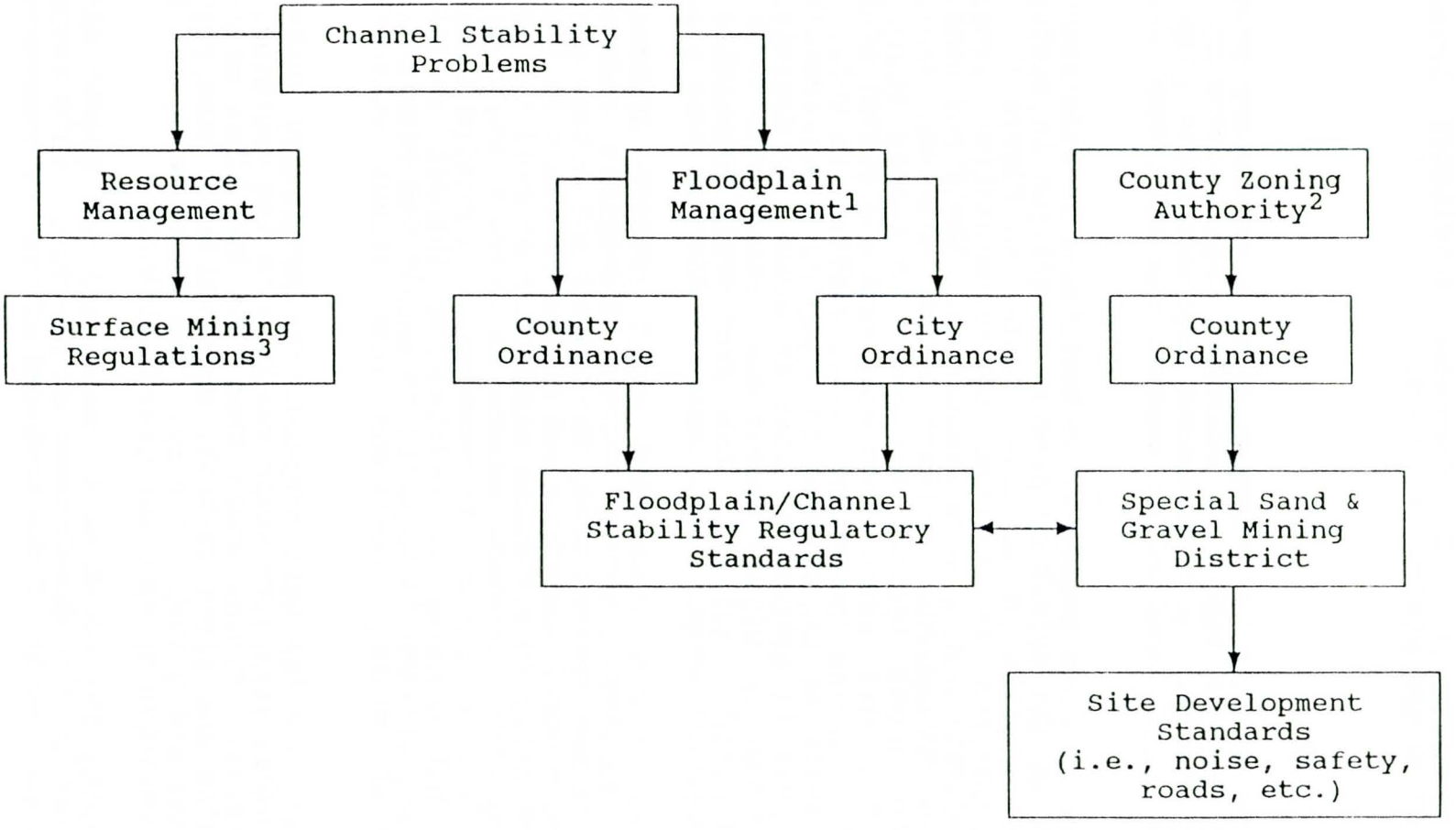
Alternative avenues to bringing about a regulatory program were explored on the basis of existing legal authority and regulatory efficiency. A recommended implementation plan was identified and steps required to conduct the work were formulated.

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 5. Two regulatory approaches to address channel-stability problems related to in-stream mining were identified. The first consists of a resource management approach which balances resource requirements and costs against the costs to assure other in-stream uses. This would address not only sand and gravel mining, but other surface mining operations (i.e., mineral) as well. 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. No specific language exists in current enabling law which extends the authority of counties or municipalities to regulate for the purpose of maintaining channel stability. Consequently, legislation is required to enable the regulation of sand and gravel mining operations that affect watercourse stability.

If such legislation were adopted, the regulatory authority relative to channel stability 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. This proposed legislation is the result of the combined efforts of representa-



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

Figure 5. Legislative Option Decision Tree

tives of the Maricopa County Planning and Zoning Commission and the Arizona Rock Products Association. The bill provides for the regulation of sand and gravel operations in counties which have adopted specific sand and gravel operations overlay zoning districts. 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 stability 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-stability impacts. Such standards could include "red-line" limits, set-backs, pit slope/depth criteria, mitigation requirements, etc. However, the key step which must be taken prior to adopting and implementing this type of regulatory program is to enable, through legislation, the city or county floodplain managers the authority to regulate channel stability. 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.

The first step in the legislative approach is to extend the authority of flood control districts to regulate watercourse stability and sediment transport. A proposed bill drafted by the project attorney 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.

A "red-line" 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 methodology for the system-wide, river resources management study 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 anticipated 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. The river resources management study consists of three major parts: 1) aggregate resource identification; 2) river system analysis; and, 3) economic evaluation.

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.

Mitigation Measures

* 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 data sets 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 data set, 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.

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 approach is to extend the authority of flood-control districts to regulate watercourse stability and sediment transport.

* A system-wide analysis of watercourse stability to find the allowable longitudinal and lateral limits for mining operations should be conducted. 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 include pertinent operational standards.

* A system-wide, river resources management study should be initiated which 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 to aggregate resources and operational requirements. The study should be an open process, soliciting the input of the industry and other affected interests. Details for conducting such a study are included in Volume II of this report.

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 or 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:

* The existing database must be improved to provide an accurate assessment of the utilization of aggregate resources and concurrent changes within river systems.

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

* Legislation should be enacted. 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.