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THE EFFECTS OF IN-STREAM MINING ON CHANNEL STABILITY

Task 3 Report:
Statewide River Classification
and
Recommended River Study Reaches

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March 16, 1987

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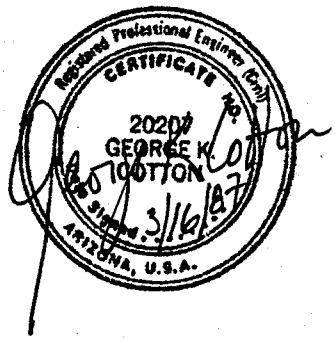

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I. INTRODUCTION

In accordance with Task 3 of the Scope-of-Work for Research Project No. HPR-PL-1(30) Item 250, Effects of In-Stream Mining on Channel Stability, Simons, Li & Associates, Inc., has established a statewide river classification system. This classification system was used in turn to select river reaches for more detailed study during subsequent tasks in this research project.

This report presents the classification system used to assess, at a statewide 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 is structured to identify river reaches that have both acceptable quality and quantity of sand and gravel reserves, and to identity incentives and constraints to the development of those reserves, including:

- Regional market potential
- In-stream structures
- Social/environmental setting

II. DATA SOURCES

To execute the classification task, data was compiled from a number of sources. A primary data requirement for Task 3 was identification of in-stream sand and gravel resources in Arizona. Resource information for this element of Task 3 was compiled from data obtained from the U.S. Bureau of Mines, Arizona Bureau of Geology and Mineral Technology, 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. 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 1960's, 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.

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.

A variety of structures are constructed in or near Arizona's rivers and washes. The transmission and transportation routes that interconnect Arizona

cities, and provide interstate routes, frequently have river-crossing structures. Highway bridges are probably the most numerous river-crossing structures, and it is assumed that the frequency of bridge crossings is a good indicator of the overall number of river-crossing structures in a river reach. Bridge crossings are constructed by federal, state, county, and local highway departments. Information on non-federal structures is maintained by ADOT in conjunction with their bridge inspection program. Data on the damage to bridge structures can be inferred from emergency repair (ER) projects, funded by the Federal Highway Administration, which ensue after natural disasters. Nearly all ER projects 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 through the work of ADOT's "scour team".

Data on social and environmental conditions in Arizona are limited. The primary environmental data of interest is the location of riparian and wetland habitat in Arizona. Sources of data on riparian habitat include the U.S. Fish and Wildlife Service and the Arizona Game and Fish Department. 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 USGS 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.

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 analysis, it is our assumption that the sand and gravel industry is currently achieving acceptable levels of air, noise, and water quality.

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.

III. RESOURCE IDENTIFICATION

The distribution of sand and gravel in Arizona is the result of natural disintegration and abrasion of rock, and its 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 1 gives a breakdown of sand and gravel quality by parent-rock type. Table 2 shows the relationship of sand and gravel quality to transport mechanisms. 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 upon the parent-rock source and the deposition process.

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. Based on these conditions, Arizona can be divided into three physiographic regions (Figure 1) that characterize these regional differences: the Basin and Range deserts of southern and western Arizona; the mountainous Central Highlands; and, in the north, the Colorado Plateau. The Gila River and the Colorado River, below Hoover Dam, are the primary drainages for the Basin and Range Region. The Central Highlands are drained by the upper tributaries of the Gila River: the Verde and the Salt Rivers. The Plateau region is drained by the Colorado and Little Colorado Rivers. The geology of these three regions is complex and varied.

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

TABLE 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 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

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 three-inches in diameter 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 coarse fractions of bed material were reported.

Using the published information in the Materials Inventory, supplemented 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 3 summarizes this overview of sand and gravel resources by physiographic region, and for the major river reaches located within each region. The quantity estimate assumes single-lift mining to a depth of 30 feet for the river width along the identified reach length.

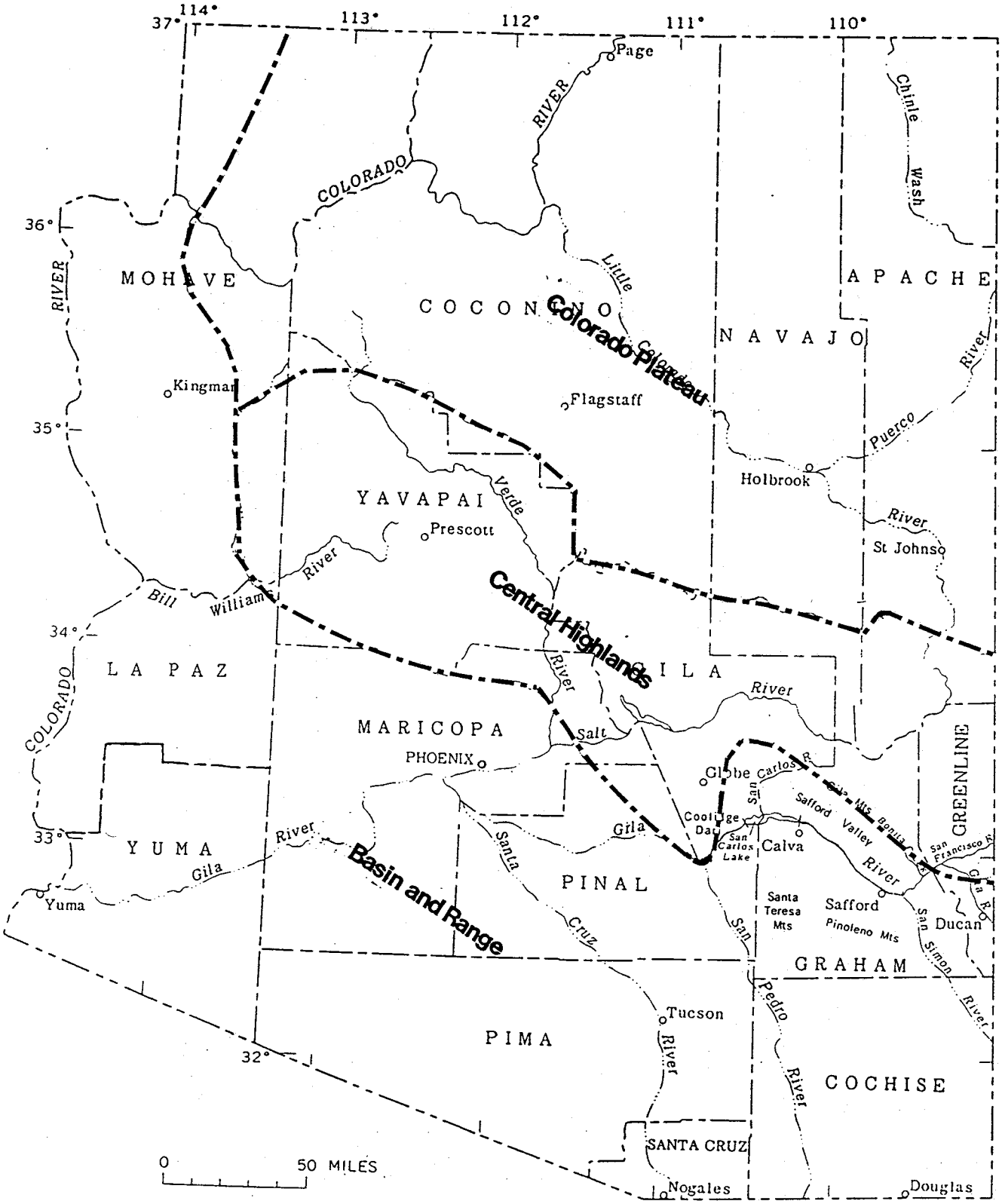


Figure 1. Physiographic Regions in Arizona
(Source: Keith, 1969)

TABLE 3

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

30' excavation

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			
	Salt	Confluence-Granite Reef	1100	96	6.7	Cobbles
		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
	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 in this reach
1 = exclude Alamo Lake
2 = exclude Martinez Lake
3 = exclude Lake Havasu
4 = within Grand Canyon
5 = contains unmeasured cobble sizes

D_{50} = median diameter, by weight of material

$$G = \frac{1}{2}\left(\frac{D_{50}}{D_{16}} + \frac{D_{84}}{D_{50}}\right)$$

* Single lift mining 30 foot excavation

IV. MARKET POTENTIAL

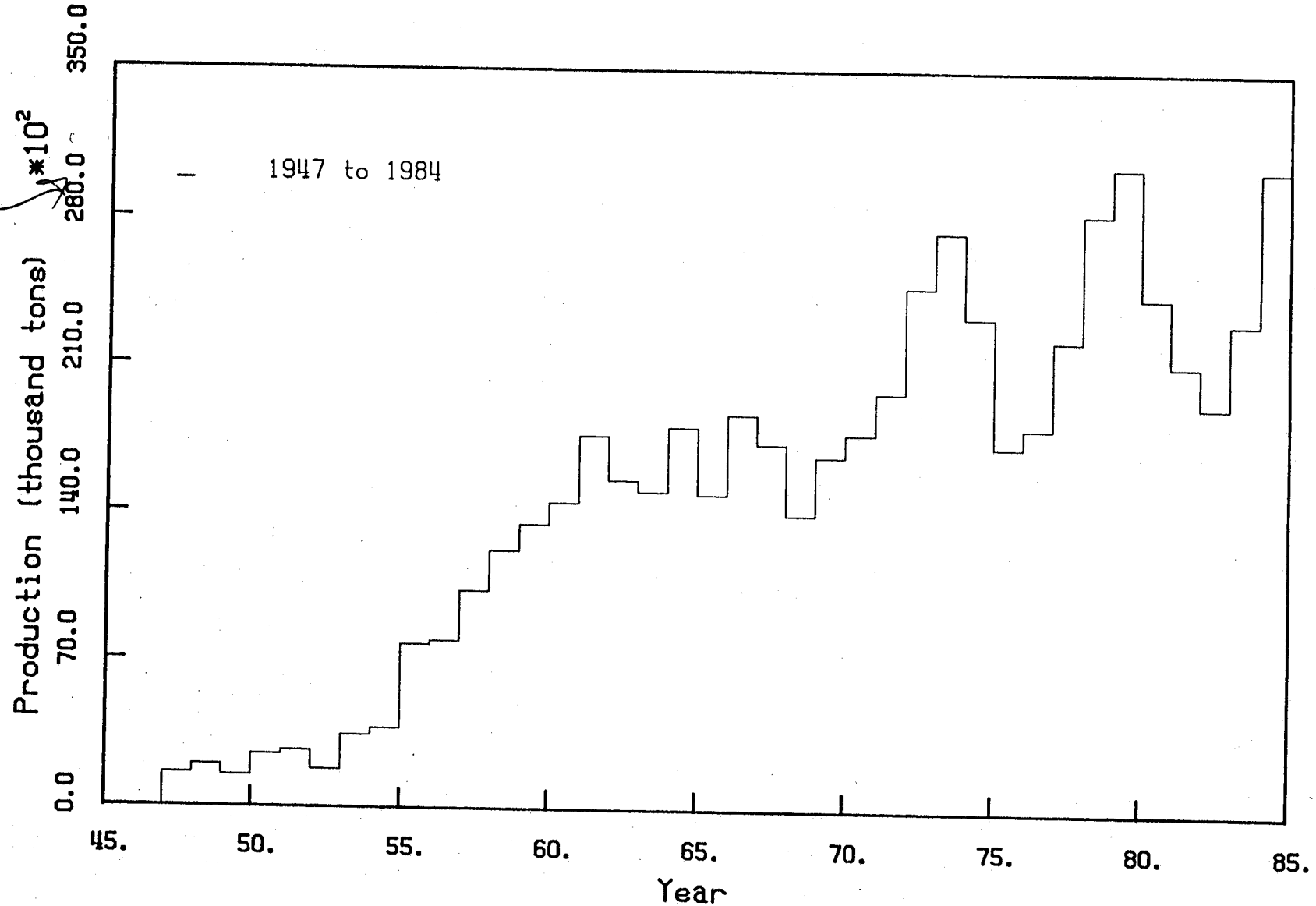
Products derived from sand and gravel mining are utilized in a wide variety of building materials, such as concrete, asphalt paving, aggregate base-coarse, concrete-wall blocks, and many others. These building materials are fundamental to the construction industry. The market potential for sand and gravel products is, therefore, tied closely to the economic activity of the construction industry, which includes construction of new homes, city streets, urban-arterial streets, freeways, private office and industrial buildings; and other, large, public-works projects such as dams and canals. 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-works projects must be estimated separately.

The demand for sand and gravel products can be constrained by a number of factors. These include restricted access to mining sites, a small alluvial deposit in the channel, or poor quality of the alluvial material. If production from in-stream resource areas is sufficiently constrained, it can become economically feasible to obtain sand and gravel products from other areas, such as floodplain terraces, alluvial-fan deposits, or rock quarries.

4.1 Regional Demand

To obtain a historical perspective of market potential, data on prior sand and gravel production was reviewed, along with associated data on construction activity, which included building permits and population growth. Figure 2 shows the historic increase of sand and gravel production for Arizona from 1947 to 1984. This 38-year record shows that 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 the introduction of the Federal Aid to Highway Program. The period from 1956 to 1961 saw steady, above-average growth in 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.



28 million

Figure 2. Sand and Gravel Production (1947-1984)
(Source: Minerals Yearbook, U.S. Department of the Interior)

Recent production rates have increased rapidly, preliminary estimates for 1985 production indicate a record production level.

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 intermittantly reported (1977, 1978, 1979, 1980 and 1982). Table 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 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 commulatively had less than eight percent of total state production in 1975.

Historic data since 1970 indicates that county production of sand and gravel can be grouped into the following catagories:

High Production - Maricopa County (60% of total state production)
Moderate to Low 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)

There appears to be a gradual increase in Maricopa County production relative to other counties in the state. 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.

Data on housing units authorized by building permits is published by the U.S. Department of Commerce, Bureau of Census. This data was input to the study database for the period from 1955 to 1985. Figure 3 shows the historic increase in the number of building permits issued during this period for the State of Arizona. There are interesting similarites and differences between sand and

TABLE 4

Sand and Gravel Production by County

County	(1960) Production ($X10^3$ tons)	Percent
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 ($X10^3$ tons)	Percent
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 ($X10^3$ tons)	Percent
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 ($X10^3$ tons)	Percent
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

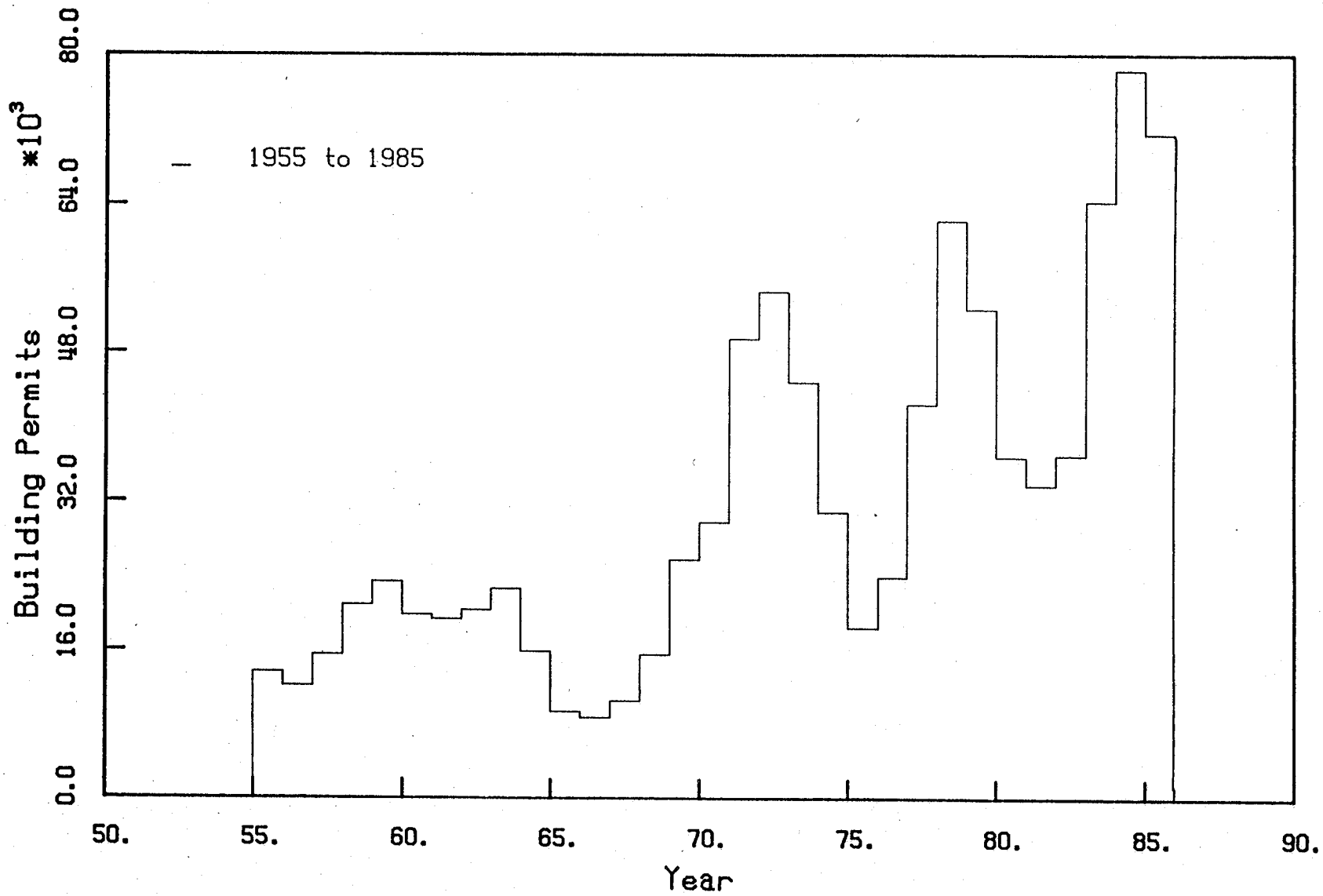


Figure 3. Authorized Building Permits in Arizona (1955-1985)
(Source: U.S. Department of Commerce, Bureau of the Census)

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, the strong demand for sand and gravel during this period was a consequence of the initiation of the Federal Aid to 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 middle and late 1960's. Economic activity accelerated in the early 1970's, and both the issuance of permits and sand and gravel production increased. In 1972, building permits peaked about one year before sand and gravel production, suggesting that about a one-year lag exists between the time that a permit is issued and actual construction begins. Building permits and sand and gravel production hit lows in 1975, followed by a period of increased construction activity, with 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 production in the sand and gravel industry reaching a low in 1982.

This review of construction history indicates that sand and gravel production in Arizona has two primary markets: one being road building; and the second being residential, commercial, and industrial building. Commercial construction includes the construction of apartments, office buildings, retail businesses, and motels/hotels. This sector of the construction industry has been a leading area of activity in recent years, particularly the building of apartments (1). Since the economic behavior of commercial and residential construction is similar, previous data on residential-home building permits should be indicative of the entire commercial/residential construction market. It has been estimated by others (2) that road building consumes approximately one-third of sand and gravel production. Since the rate of consumption for road building is probably more uniform, compared to residential, commercial, and industrial construction, the fluctuation in sand and gravel production is most likely associated with non-road-building construction.

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(1) Ronan, B, 1986, Arizona's Changing Economy, Trends and Prospects, Arizona Department of Commerce.

(2) Keith, K.B., 1969, Mineral and Water Resources of Arizona - Sand and Gravel, Arizona Bureau of Mines.

Population growth is another important component of sand and gravel demand. Obviously, the demand for new homes, apartments, office buildings, roads, and major infrastructure projects arises from population growth and the ensuing economic activity. Figure 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 1960's population grew 34 percent, adding 439,000 people; and in the decade of the 1970's 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 1970's.

Per-capita consumption of sand and gravel, relative to the increase of Arizona's population, was 370 tons/new person in the 1960's; and was 266 tons/new person in the 1970's. Consumption in the 1980's is running at 290 tons/new person. There was one building permit issued for every 2.6 additional persons during the 1960's, and one for every 2.1 additional persons during the 1970's. Permitting for residential construction in the 1980's is running at one unit for every 1.6 additional persons. These statistics indicate two opposing trends in the construction industry: the first being a reduction in the amount of sand and gravel used in construction; and the second being an increase in the number of housing units per capita. It is surmised that 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.

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 1970's per-capita consumption is considered to provide a reasonable guide to a lower limit of sand and gravel consumption. The 1980's per-capita consumption is used as the best estimate of average sand and gravel consumption. The mean between the 1960's and 1970's per-capita consumption is taken as an approximate upper limit of sand and gravel consumption. This gives the following bounds for per-capita consumption of sand and gravel in Arizona:

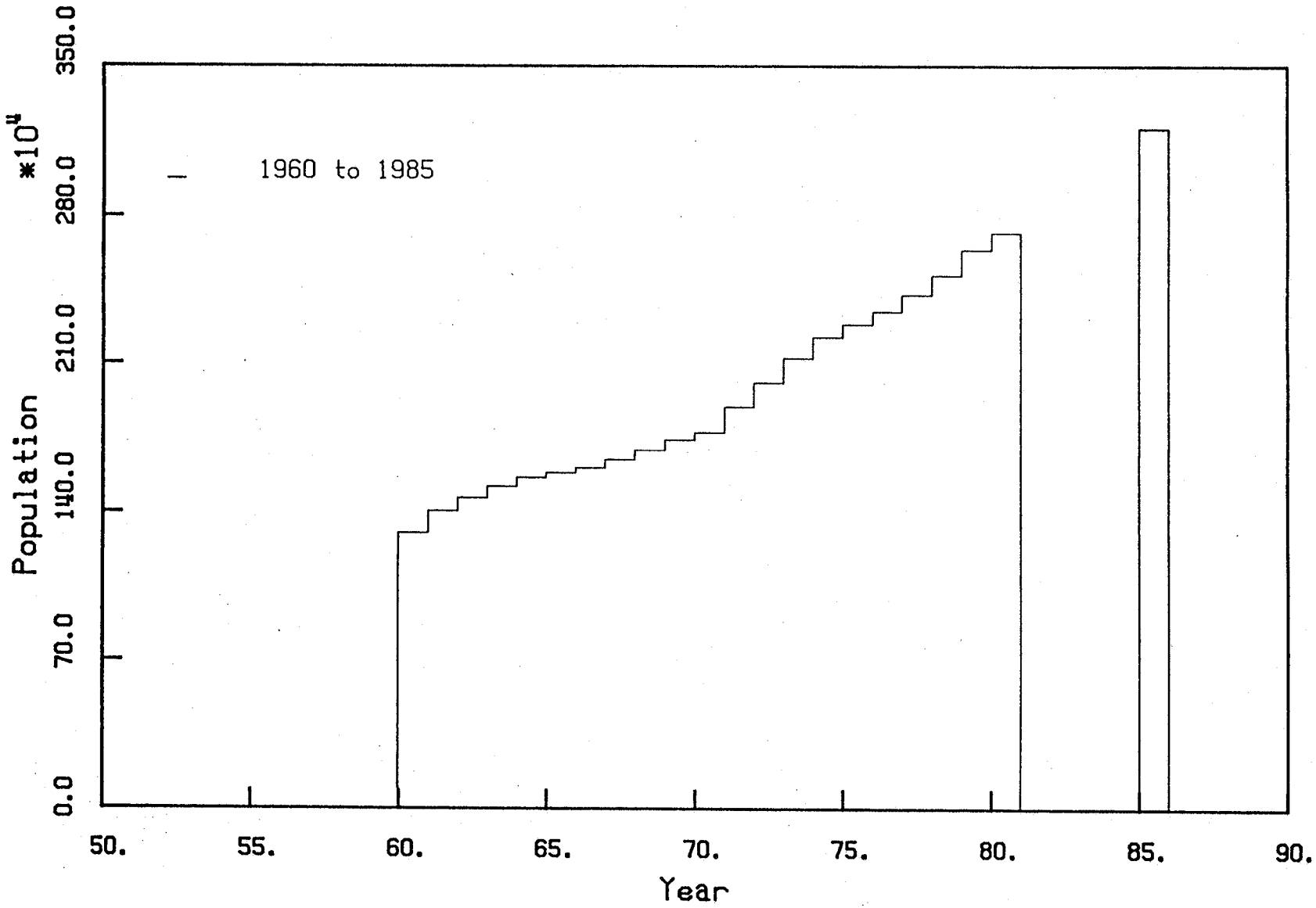

Figure 4. Arizona Population Growth (1960-1985)
(Source: Arizona Statistical Review)

Lower bound : 270 tons/person
Mean : 290 tons/person
Upper bound : 320 tons/person

4.2 Site Access and Haul Distance

Most major river reaches in Arizona are paralleled by transportation routes, but in some cases, reaches exist that are relatively inaccessible. Even 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 5 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 a reach considered within reasonable haul distance was determined by measuring a ten-mile radius around all cities located along the reach which issued more than 100 residential building permits in 1985.

4.3 Projected sand and gravel production

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 6 summarizes sand and gravel consumption, by county, at ten-year intervals. State production of sand and gravel, based on forecasted population growth, ranges from 370,000,000 tons/decade to 400,000,000 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 account for up to 68 percent of the total state sand and gravel production through 1995, and then average 62 percent through 2035. Pima County's production is expected to reach 16 percent by 1995; and increase to 20 percent in the following decade, remaining at that level through 2035. Together, Maricopa and Pima Counties are projected to account for 82 to 85 percent of total state production through 2035. Production rates in Cochise, Coconino, Mohave, Pinal, Yavapai, and Yuma Counties are expected to account for 11 percent of the total production by 1995, and increase to 14 percent by 2035. Yavapai County is expected to account for one percent of the increase, with Coconino, Mohave, and Pinal Counties accounting for most of the remaining increase. Figure 5 graphs the percentage of consumption of sand and gravel, by county, from 1985 to 2035.

TABLE 5

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
	Salt	Confluence-Granite Reef	Metro Phx	38	35	93	43
		Hassayampa	Wickenburg	86	18	21	0
		Agua Fria	Avondale	50	24	48	12
		New River	Peoria	47	16.5	35	11
	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 Phx	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

TABLE 6

Forecasted Sand and Gravel Production, 1986 to 2035
(based on population forcasts Arizona Department of Economic Security, 1986)

	Ten-Year Production Rates (thousand tons)				
County	1995	2005	2015	2025	2035
Apache	4785	4234	4901	4553	4553
Cochise	6177	6380	7627	6989	6989
Coconino	7656	8758	10991	9860	9889
Gila	870	1769	2030	1769	1769
Graham	406	464	725	609	609
Greenlee	0	0	116	58	58
La Paz	377	899	1653	2262	2900
Maricopa	255171	247515	239888	243716	243716
Mohave	5684	7221	8932	8091	8062
Navajo	4959	4901	5394	5162	5162
Pima	60900	73660	82389	78039	78010
Pinal	8439	9889	11194	10527	10527
Santa Cruz	2407	2349	2639	2494	2494
Yavapai	8381	12180	14848	13514	13514
Yuma	5539	6728	7830	7279	7250
Total	371751	386570	400258	393269	393240

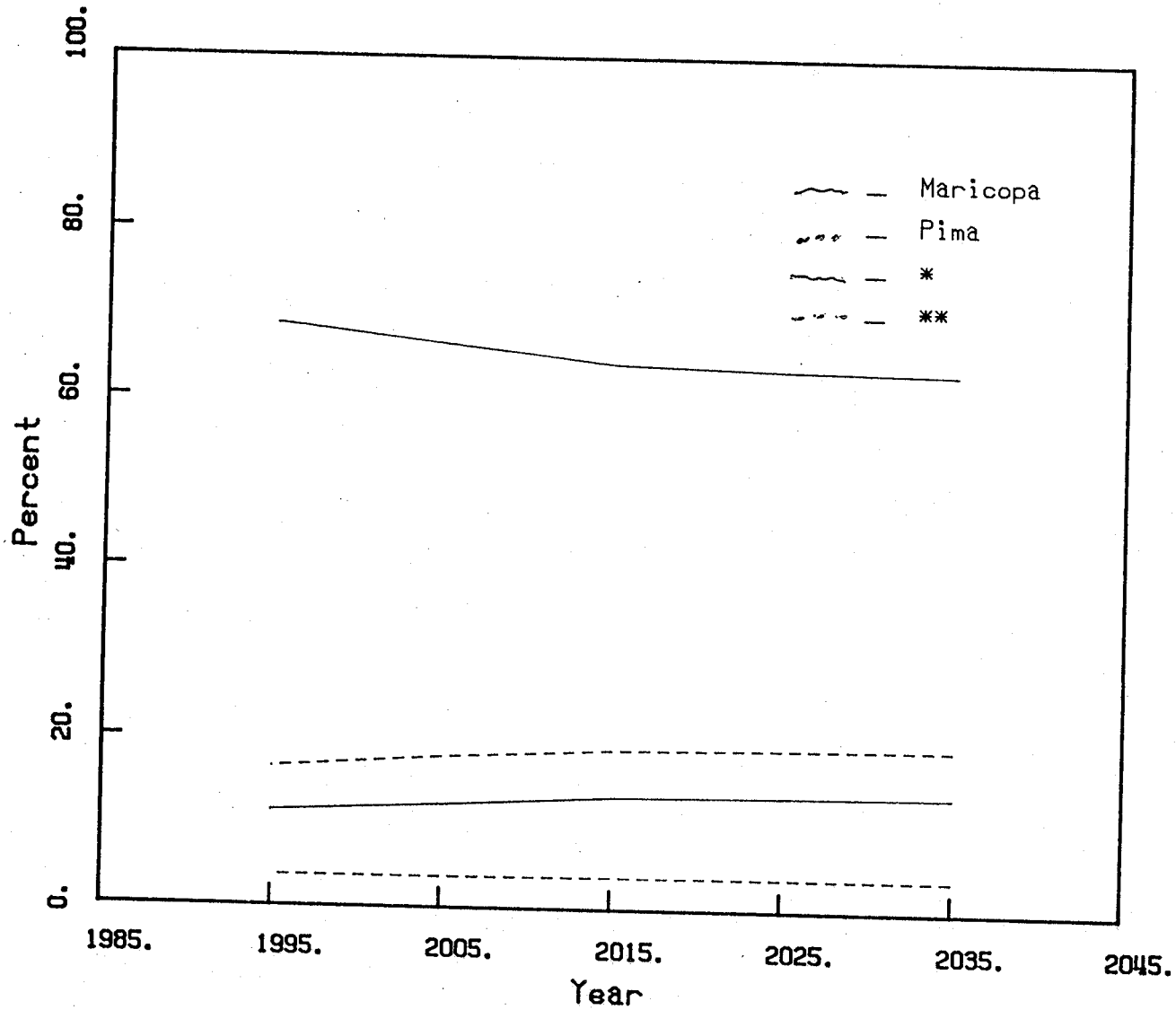

Figure 5. Percent Consumption by County (1995-2035)

* Cochise, Coconino, Mohave, Pinal, Yavapai, and Yuma
** Apache, Gila, Graham, Greenlee, La Paz, Navajo, Santa Cruz

V. POTENTIAL HAZARDS TO STRUCTURES

Arizona is criss-crossed by comprehensive networks of transportation and transmission routes. Transportation facilities include: rail, highway, and air routes. 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 man-made waterways are a frequent occurrence, and are at significant risk of loss due to 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 the 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 type of river-crossing structures, and can be assumed to characterize many of the problems of other river-crossing structures in a river reach. Highway bridges 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 County, have ADOT conduct this inspection. ADOT has a computer database with information on the majority of bridges in the state (excluding bridges on private land, military bases, forest service roads, and national parks).

Data on damage to highway bridges was compiled from Flood Damage Reports and Federal/State Damage Survey Reports in the previous report for Tasks 1 and 2 of this study. Additional data on specific projects that ADOT has conducted on an emergency basis have been downloaded for use with this study. Emergency repair (ER) project funds are made available to ADOT after disasters, and nearly all ER projects in Arizona are associated with flood damage to bridge structures. ADOT also maintains documentation on repair costs 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".

5.1 Existing bridge structures crossing waterways

ADOT's inventory of Arizona bridges lists 1,514 structures over waterways. ADOT also inspects 895 county bridges and 606 city bridges that are over waterways. Table 7 gives a breakdown, by county and city, of bridge structures over waterways. 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.

5.2 Flood damage to existing bridge structures

Table 8 summarizes the frequency and cost of emergency-repair projects in Arizona. Table 9 summarizes flood damages to transportation systems as reported from Corps of Engineers (COE) flood-damage reports. Records by the ADOT Structure Section show that $7,000,000 was committed to construction of scour countermeasures from 1979 to 1985 at 70 bridge sites. Most of these projects are on smaller tributaries of the river reaches presented in this report.

5.3 Transportation Planning

Arizona's highway system has been expanding to keep pace with population growth. In the future, a similar trend or sustained population growth is expected in all areas of the state. The state's highway network will also expand, adding road mileage. Much of the increase in the size of the transportation system will occur in metropolitan areas. Three out of four new people moving to Arizona between now and the year 2000 will 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 mid-sized 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 10 identifies the capital investment planned to be made by the various Arizona counties through fiscal year 1991.

TABLE 7

Bridge Structures 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			2
Peoria			2
Phoenix			138
Scottsdale			90
Tempe			19

Table 8 left out

TABLE 9

SUMMARY OF FLOOD DAMAGES TO TRANSPORTATION SYSTEMS

RIVER	1/ Dec 1965 Jan 1966	2/ Oct 1972	3/ Oct 1977	4/ Feb-March 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 @ Clifton		184,000					
Nogales Wash Santa Cruz County			69,000				
Santa Cruz River, Santa Cruz County			682,000		8/		8/
Santa Cruz River, Pima County			784,000		8/		8/
Santa Cruz River, Pinal County			54,000		8/		8/
Salt River from Granite Reef Dam To 115th Ave.				11,809,000			
Gila River, Maricopa County				340,000			8/
Salt River, Metropolitan Phoenix					17,985,000	16,399,000	
Gila River, Metropolitan Phoenix					1,526,000	1,360,000	
Aqua Fria River, Metropolitan Phoenix					1,999,000	4,242,000	
All rivers within Pima County	8/				8/		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 9

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

8/ Damages undoubtedly occurred during this flood, but they are not reported on Federal Disaster Survey Reports.

TABLE 10

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

VI. SOCIAL AND ENVIRONMENTAL FACTORS

6.1 Land-use conflicts

It is assumed that sand and gravel mining from river reaches within city boundaries have a strong potential of encountering some conflicts with adjacent land uses. Table 5 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.

6.2 Proximity to wildlife habitat

River reaches with perennial and intermittant flows, either natural, regulated, or man-induced from wastewater discharges, are taken as an indicator of riparian habitat. 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. Wetland habitat has been mapped by the U.S. Fish and Wildlife Service, but these maps were not available for use in this study during the time frame of the Task 3 work involved.[1]

It is recognized that habitat resources in the desert environment of Arizona are complex. Ephemeral reaches may provide dynamic habitat that florishes briefly between dry periods. Likewise, man-created habitat may also play a role in providing riparian habitat. Table 11 summarizes the relative percentages of perenial and ephemeral segments of the selected river reaches.

6.3 Noise, dust, and visual pollution

Research for this report has not lead to a conclusion that 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.

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1 The riparian maps are reference documents maintained by the Arizona Department of Fish and Game. The department is currently in the process of moving its location.

TABLE 11

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	
	Salt	Confluence-Granite Reef	0	100	
		Hassayampa	20	-	80
		Agua Fria	24	-	76
	?	New River	11	-	89
	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

VII. STATEWIDE CLASSIFICATION OF RIVER REACHES

7.1 Rating criteria

River reaches in Arizona were qualitatively rated on factors related to market potential, structure hazard, and social/environmental conditions. The rating was judgemental, and was based on the information collected and summarized in this report.

7.2 Statewide Classification

Table 12 is the classification matrix developed for Arizona. This matrix was used to rank and then select the river reaches to be used in the more-detailed study effort to follow within subsequent tasks of this study.

TABLE 12

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
SALT:								
Confluence-Granite Reef	3	2	3	3	3	3	3	2
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
SANTA CRUZ:								
Confluence-Tucson	3	2	2	3	2	3	1	2
Rillito/Pantano	3	1	2	3	3	3	3	3
Tucson-Nogales	3	1	3	3	3	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	none	none	none	none	1	3
Hoover-Glen Canyon	NA	NA	none	none	none	none	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

1 = Low
2 = Medium
3 = High
NA = Not Available

VIII. CONCLUSIONS AND RECOMMENDATIONS

The completion of Task 3 of this study effort has resulted in the development of a statewide classification of major river reaches which incorporates important characteristics of their sand and gravel resources, the economic aspects of that resource development, and various development constraints. The data gathering and analysis conducted as a part of the classification effort provides a necessary overview of the management task that is at hand. Arizona's steady growth in population creates a significant demand for construction materials in the major metropolitan and urban areas of the state. The river reaches outlined in this report provide the highest quality and most cost efficient source of sand and gravel for a wide range of construction products. Development of this resource will change these river environments, and planning for this change will be essential in reducing the risk to river-crossing structures, while at the same time maintaining environmental quality.

It is recommended that the classification system be reviewed on an annual basis, and refined to include some of the economically important smaller tributaries. The classification system can be considered as an indicator of sand and gravel resource development, which should be monitored and reported on a routine basis. The data sources for the classification system needs improvement in order to more accurately assess the utilization of the resource. The following improvements in the data sources are recommended:

1. County sand and gravel production rates should be published annually in the Minerals Yearbook. (Maintained by 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. (Maintained by Arizona Bureau of Mines)
3. Material Inventories should be updated for all counties in the state whose inventories were published prior to 1975. (Arizona Department of Transportation)
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 in diameter. (Arizona Department of Transportation)
5. The number of miles of federal, state, county and local roadway constructed in Arizona should be compiled and published on an annual

basis. (Arizona Department of Transportation)

Task 4 will focus on 30 river miles which will be selected based on the general classification procedure described in this report. An enhanced database will be developed for these specific reaches that will provide the basis for developing technical guidelines and procedures.

One basic physical property that is considered fundamental to the type and magnitude of river response is the gradation of the bed material. Another consideration in recommending river reaches is the availability of data. River reaches with previous sediment-transport studies provide additional data over and above published sources. Table 13 lists the recommended river reaches for Task 4. These reaches occur on rivers with large reserves of sand and gravel, and with a strong market for this raw material. These reaches have a history of flood damages, which includes damages to bridge crossings; and, therefore, then provide invaluable case-history information with which to develop technical guidelines. Environmentally sensitive reaches are also included.

Overall, the selected river reaches should provide an adequate database for the technical work yet to be conducted in this study. The specific locations of the Task 4 study reaches will be decided upon in consultation with the Project Technical Review Committee and the Project Task Force, which are both actively involved in this study effort.

TABLE 13

RECOMMENDED RIVER REACHES
TO BE STUDIED IN TASK 4

River System Category	Recommended River	Recommended Reach	Proposed Sub-Reach Length (miles)	Primary Data Base
1. Sand-Bed	a. Agua Fria River		5	Hydraulic & Geomorphic Analysis of The Agua Fria River, SLA, Sept. 1983 Final Sediment Transport Study of The Agua Fria River, SLA, Nov. 1984
	b. New River		4	Final Sediment Transport Report For The New River And Skunk Creek, SLA, Jan. 1985
	c. Santa Cruz River	Tucson to Nogales	3	Santa Cruz River Management Plan Study, SLA, Apr. 1985
	d. Rillito/ Pantano River		3	River Management Plan For The Rillito River And Major Tributaries, SLA, Mar. 1984

TABLE 13 (continued)

RECOMMENDED RIVER REACHES
TO BE STUDIED IN TASK 4

River System Category	Recommended River	Recommended Reach	Proposed Sub-Reach Length (miles)	Primary Data Base
2. Cobble-Bed	a. Salt River	Confluence to Granite Reef Downstream of 35th Strong potential	10	Hydraulic & Sediment Transport Data Developed by SLA for the East Papago Freeway & Red Mountain Parkway 1986-1987 HEC-2 Profiles Developed by the Corps of Engineers for Flood Insurance Studies Impact of Gravel Mining On The Proposed Salt River Channelization Project, Anderson-Nichols & Colorado State University, Nov. 1980
	b. Verde River	Camp Verde to headwaters	5	Study of Gravel Mining Impacts, Verde River At Cottonwood, AZ, SLA, May 1985 Flood Insurance Study, Town of Cottonwood, AZ, Yavapai County, FEMA, March 1981 Flood Insurance Study, Yavapai County Arizona Unincorporated Areas, FEMA, Aug. 1985 (3 volumes)