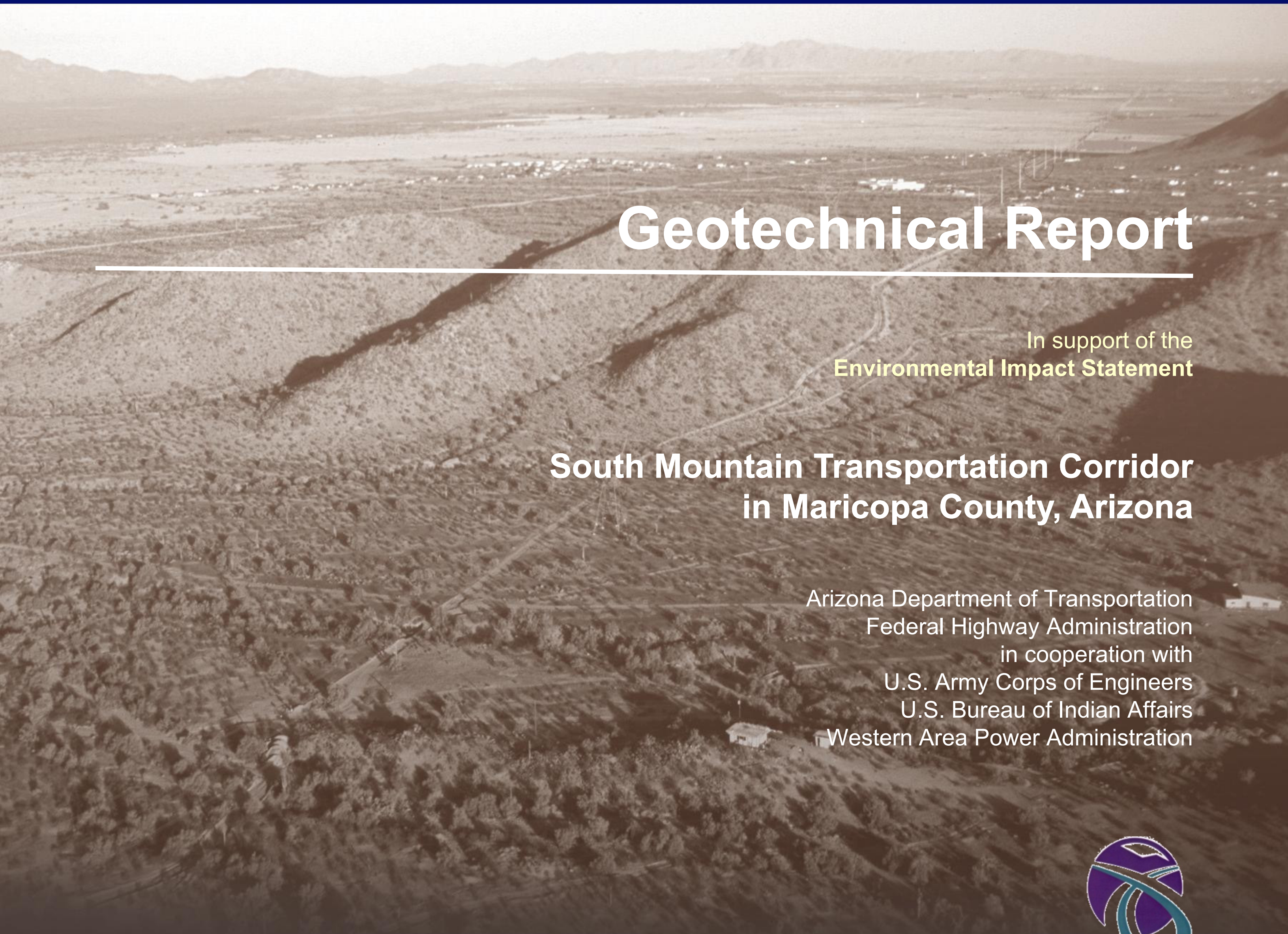
South Mountain corridor team



Geotechnical Report

In support of the
Environmental Impact Statement

South Mountain Transportation Corridor in Maricopa County, Arizona

Arizona Department of Transportation
Federal Highway Administration
in cooperation with
U.S. Army Corps of Engineers
U.S. Bureau of Indian Affairs
Western Area Power Administration

ADOT

November 2012

Federal-aid Project Number: NH-202-D(ADY)
ADOT Project Number: 202L MA 054 H5764 01L

Geotechnical Report

In support of the
Environmental Impact Statement

South Mountain Transportation Corridor in Maricopa County, Arizona

Arizona Department of Transportation
Federal Highway Administration
in cooperation with
U.S. Army Corps of Engineers
U.S. Bureau of Indian Affairs
Western Area Power Administration

November 2012
Federal-aid Project Number: NH-202-D(ADY)
ADOT Project Number: 202L MA 054 H5764 01L

Abstract: This document assesses and describes the effects on the geologic setting that would occur as a result of the construction and operation of the proposed South Mountain Freeway as adopted in the 2003 *Regional Transportation Plan*. Contents of this document will be presented in Chapter 4 of the South Mountain Transportation Corridor Environmental Impact Statement.

Table of Contents

List of Tables

List of Figures

List of Acronyms and Abbreviations

ADOT	Arizona Department of Transportation
ADWR	Arizona Department of Water Resources
AzMILS	Arizona Mineral Industry Location System
C	Central
C.F.R.	Code of Federal Regulations
E	Eastern
E1	E1 Alternative
EIS	environmental impact statement
FHWA	Federal Highway Administration
FR	Full Reconstruction
g	gravity
I-10	Interstate 10
InSAR	Interferometric Synthetic Aperture Radar
MAG	Maricopa Association of Governments
N	north
PR	Partial Reconstruction
p€e	Estrella Gneiss
p€k	Komatke Granite
Qm	Undifferentiated Qm1 and Qm2
Qm1	Older Alluvium
Qm2	Alluvium
Qy	Alluvial Fans and Terrace Deposits
Qyc	Active Channel Deposits
SMTC	South Mountain Transportation Corridor
SR	State Route

Td	Dobbins Alaskite
TI	traffic interchange
Ttp	Telegraph Pass Granite
USGS	U.S. Geological Survey
W	Western or west
W101CFR	W101 Alternative, Central Option, Full Reconstruction
W101CPR	W101 Alternative, Central Option, Partial Reconstruction
W101EFR	W101 Alternative, Eastern Option, Full Reconstruction
W101EPR	W101 Alternative, Eastern Option, Partial Reconstruction
W101WFR	W101 Alternative, Western Option, Full Reconstruction
W101WPR	W101 Alternative, Western Option, Partial Reconstruction
W59	W59 Alternative
W71	W71 Alternative

Glossary

active channel deposits	An unconsolidated geologic unit found in the Study Area.
adit	A passage or tunnel excavated in the ground for the purpose of mining.
affected environment	Those elements of the Study Area that may be changed by the proposed alternatives. These changes might be positive or negative in nature.
Alaskite	An igneous rock consisting of quartz and feldspar with little or no mafic constituents.
alluvial	Pertaining to or composed of unconsolidated sediments deposited by a stream or running water.
alluvial fan	An outspreading, gently sloping mass of alluvium deposited by a stream, especially in an arid or semiarid region where a stream issues from a narrow canyon onto a plain or valley floor.
alluvium	A general term for deposits made by streams on riverbeds, floodplains, and alluvial fans.
amphibole	A mafic mineral group.
amphibolite	A rock consisting of mainly amphibole and plagioclase with little or no quartz.
andesite	A dark-colored, fine-grained volcanic rock.
aquifer	A body of rock or alluvium that is sufficiently permeable to conduct groundwater and yield significant quantities of water to wells and/or springs.
Arizona Department of Transportation (ADOT)	The State agency responsible for state roads and highways.
bedrock	The solid rock that underlies gravel, soil, or other surficial material, or that is exposed in mountain highlands.
biotite	A common rock-forming mineral of the mica group.
biotitic	Pertaining to or composed of biotite.
calcium carbonate	A solid occurring in nature chiefly as the minerals calcite and aragonite, and a common binding agent in the soil cementation process.
capacity	The maximum number of vehicles that a given section of road or traffic lane can accommodate.
cementation	The process by which sediments become chemically and physically bonded.
Cenozoic	A geologic era lasting from about 65 millions years ago to the present.
colluvium	A general term applied to loose soil and broken rock deposits, usually at the foot of a mountain front or cliff and brought there chiefly by gravity.

cumulative impact	The impact on the environment that results from the incremental impact of the action when added to the other past, present, and reasonably foreseeable future actions regardless of what agency (federal or nonfederal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time. (40 Code of Federal Regulations § 1508.7)
dacite	A fine-grained extrusive rock with the same general composition as andesite. It is often considered the extrusive equivalent of granodiorite.
differential compaction	Reduction in bulk volume of sediments produced by uneven settling or differing degrees of compressibility.
dike	A tabular body of igneous rock that cuts across the structure of the intruded rock mass.
diorite	A group of intrusive, igneous rocks intermediate in composition; the intrusive equivalent of andesite.
dissected	Cut by erosion, especially streams.
distal	A sedimentary deposit of alluvial material formed far from the source area.
earth fissure	A fracture in unconsolidated deposits, usually associated with ground subsidence attributable to groundwater depletion.
Eastern Section	The portion of the Study Area located east of 59th Avenue.
environmental impact statement (EIS)	The project documentation prepared in accordance with the National Environmental Policy Act when the project is anticipated to have a significant impact on the environment.
ephemeral	Lasting a short time.
epoch	An interval of geologic time.
era	A geologic time unit.
extrusive	Descriptive of igneous rock that has been erupted onto the surface of the earth.
facies	The aspect, appearance, and characteristics of a rock unit, usually reflecting the conditions of its origin, especially as differentiating it from adjacent or associated units.
fault	A fracture or fracture zone along which there has been movement of the sides relative to one another.
Federal Highway Administration (FHWA)	A branch of the U.S. Department of Transportation responsible for administering the Federal-Aid Program. The program provides financial resources and technical assistance for constructing, preserving, and improving the National Highway System along with other urban and rural roads.
feldspar	A group of abundant rock-forming minerals.
felsic	An adjective applied to an igneous rock having abundant light-colored minerals, including quartz and feldspars.
felsite	A general term for any light-colored, fine-grained igneous rock composed chiefly of quartz and feldspar.

floodplain	The portion of a stream valley, adjacent to the channel, which is built of sediments deposited during the present regime of the stream and is covered with water when the stream overflows its banks at flood stage.
fracture	A crack, joint, or other break in rock.
geotechnical	Referring to the use of scientific methods and engineering principles to acquire, interpret, and apply knowledge of earth materials for solving engineering problems.
gneiss	A metamorphic rock in which there are alternate bands of minerals.
gneissic	Pertaining to the texture or structural type of gneisses.
granite	An intrusive igneous rock that is predominantly composed of quartz and feldspar.
granitic	Pertaining to or composed of granite.
granodiorite	A group of coarse-grained, intrusive igneous rocks; the intrusive equivalent of rhyodacite.
groundwater	The part of the subsurface water that is in the zone of saturation.
high-grade	Ore rock with a relatively high ore-mineral content.
Holocene	An epoch of the Quaternary period from the end of the Pleistocene, approximately 10,000 years ago, to present time.
igneous	A rock or mineral that solidified from molten or partly molten material.
intermediate	Igneous rock that is transitional between basic (mafic) and silicic (felsic).
intrusion	The process of emplacement of molten rock into a preexisting rock mass.
lithology	The description of rocks, or the physical character of a rock.
mafic	An igneous rock composed chiefly of dark minerals.
medial	Sedimentary deposit of alluvial material found a medium distance from the source area.
metamorphic	Pertaining to the process of metamorphism or to its results.
metamorphic rock	Any rock derived from preexisting rocks by mineralogical, chemical, and/or structural change in response to marked changes in temperature, pressure, shearing stress, and chemical environment.
mica	A group of minerals that are prominent rock-forming constituents of igneous and metamorphic rocks.
microdiorite	A fine-grained diorite.
migmatite	A rock composed of igneous or igneous-appearing and/or metamorphic materials.

mitigation	An action taken to reduce or eliminate an adverse impact stemming from construction, operation, or maintenance of a proposed action alternative. Mitigation could reduce the magnitude and extent of an impact from a level of significance to a level of insignificance. Mitigation includes *avoiding* the impact altogether by not taking a certain action or parts of an action; *minimizing* impacts by limiting the degree of magnitude of the action and its implementation; *rectifying* the impact by repairing, rehabilitating, or restoring the affected environment; *reducing or eliminating* the impact over time by preservation and maintenance operations during the life of the action; and *compensating* for the impact by replacing or providing substitute resources or environments. (40 Code of Federal Regulations § 1508.20)
mylonite	A compact rock with a streaky or banded structure, produced by extreme shearing of the rock mass.
mylonitic	Pertaining to or composed of mylonite.
perched groundwater	Unconfined groundwater separated from the underlying main body of groundwater by unsaturated rock or alluvium.
physiographic province	A region of which all parts are similar in geologic structure and climate, and which has had a unified geomorphic history; its relief features differ significantly from those of adjacent regions.
piedmont	Lying or formed at the base of a mountain or mountain range.
plagioclase	A mineral in the feldspar group.
Pleistocene	An epoch of the Quaternary period. It began 2 or 3 million years ago and lasted until the start of the Holocene, about 10,000 years ago.
porphyritic	A texture term referring to a bimodal grain size distribution in igneous rocks.
potassium feldspar	A mineral in the feldspar group.
Precambrian	All geologic time, and its corresponding rocks, before the beginning of the Paleozoic (~570 million years ago).
quartz	An important rock-forming mineral.
quartzite	A metamorphic rock consisting mainly of quartz.
quartzo-feldspathic	Pertaining to or composed of quartz and feldspar.
Quaternary	The second period of the Cenozoic era, following the Tertiary period. It began 2 or 3 million years ago and extends to the present.
recharge	The process involved in the addition of water to the zone of saturation; also, the amount of water added.
rhyodacite	A group of fine-grained, extrusive rocks; the extrusive equivalent of a granodiorite.
schist	A metamorphic rock.
sediment	A solid, fragmental material transported by wind, water, or ice; chemically precipitated from solution; or secreted by organisms and that forms in layers in loose, unconsolidated form.

seismicity	The measure of the frequency of earthquakes; the phenomenon of earth movement.
sill	A tabular igneous intrusion that parallels the planar structure of the surrounding rock.
stream terrace	One of a series of near-level surfaces in a stream valley, flanking and more or less parallel to the stream channel. It is above the level of the stream and represents the dissected remnants of an abandoned floodplain, streambed, or valley floor produced during a former stage of erosion or deposition.
Study Area	The geographic area within which build alternative solutions to the problem are developed.
subsidence	Sinking or downward settling of the earth's surface, not restricted in rate, magnitude, or area involved. Subsidence may be caused by natural geologic processes, such as solution, compaction, or withdrawal of fluid lava from beneath a sold crust, or by human activity such as subsurface mining or the pumping of oil or groundwater.
terrace	See *stream terrace*.
Tertiary	The first period of the Cenozoic era lasting from about 2 million to 65 million years before present.
undifferentiated alluvium	An unconsolidated geologic unit found within the Study Area.
unit gravity (g)	Unit of measure for the force of gravity.
Western Section	The portion of the Study Area located west of 59th Avenue.

1. Project Description and Purpose and Need

Project Description

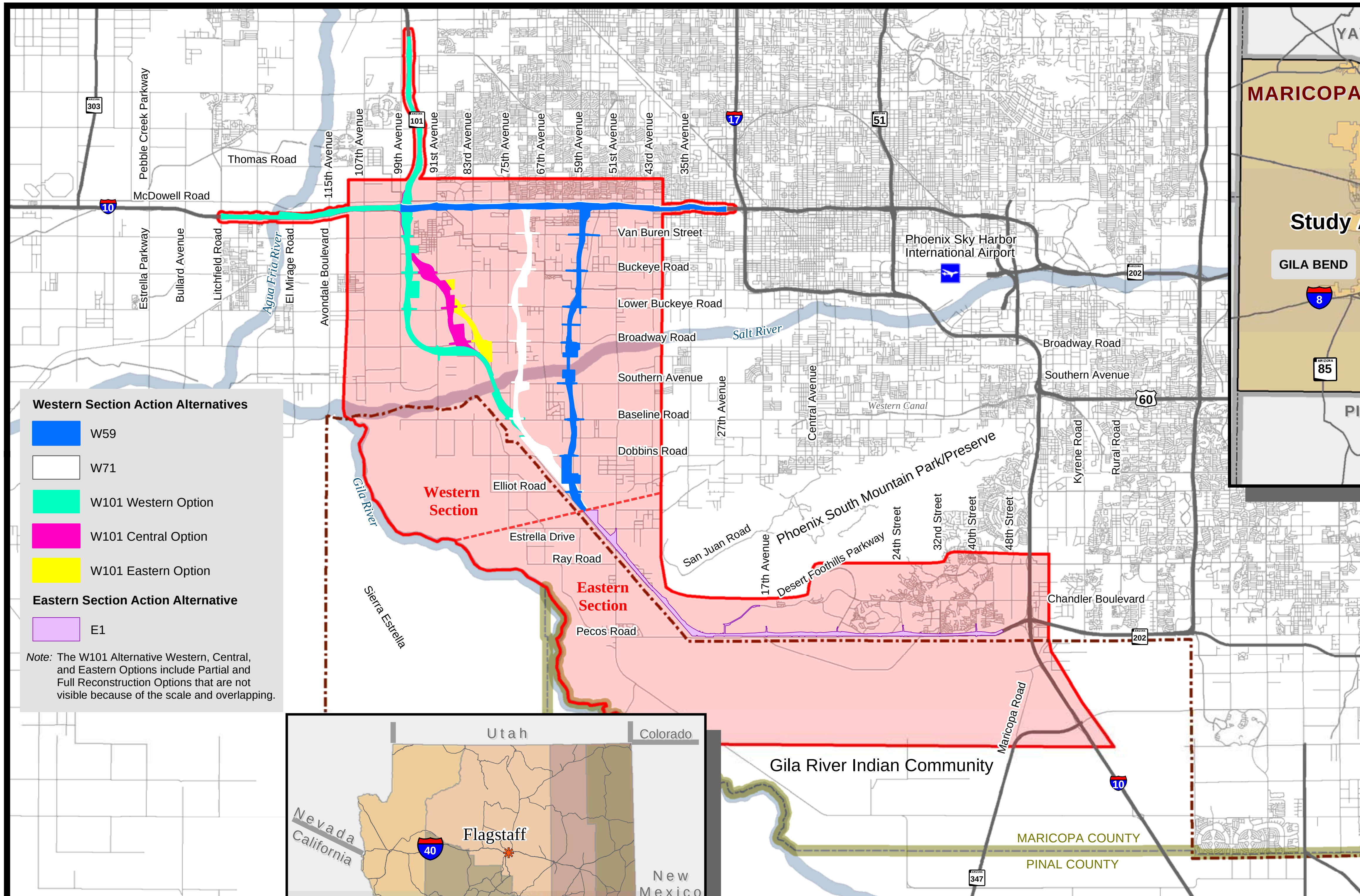
The Arizona Department of Transportation (ADOT) is studying the South Mountain Transportation Corridor (SMTC) in southern Phoenix, Maricopa County, Arizona. The South Mountain Freeway corridor was adopted into the Maricopa Association of Governments (MAG) regional freeway system in 1985 as part of the *MAG Freeway/Expressway Plan* (MAG 1985), at which time it was placed on the state highway system by the State Transportation Board. In 1988, ADOT prepared a design concept report and a state-level environmental assessment for the project, identified at that time as the South Mountain Parkway (ADOT 1988a, 1988b). As presented then, the project would connect Interstate 10 (I-10) (Maricopa Freeway) south of Phoenix with I-10 (Papago Freeway) west of the city, following an east-to-west alignment along Pecos Road through the western tip of the Phoenix South Mountain Park/Preserve, then north to I-10 between 59th and 99th avenues. Because of the time elapsed since those documents were approved and to secure eligibility for federal funding for a proposed project within this corridor, ADOT and the Federal Highway Administration (FHWA) are now preparing an environmental impact statement (EIS) in accordance with the National Environmental Policy Act. In November 2004, the MAG *Regional Transportation Plan* (2003) was placed before Maricopa County voters, who approved the sales tax funding the plan. The South Mountain Freeway was included in this plan.

Alternatives considered for the SMTC included past freeway proposals as well as transportation system management, transportation demand management, transit improvements, arterial street network improvements, and land use controls. A freeway facility was determined to best address the project purpose and need. Therefore, this report discusses the potential impacts of a proposed freeway in the SMTC.

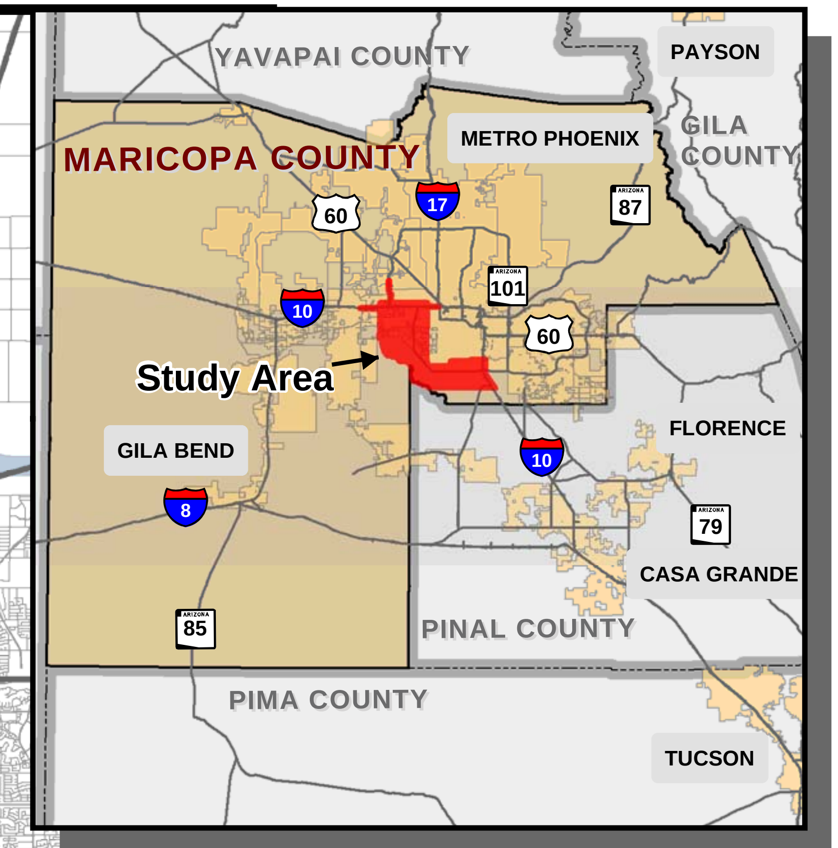
The Study Area for the EIS encompasses more than 156 square miles and is divided into a Western Section and an Eastern Section at a location common to all action alternatives (Figure 1). The division between sections occurs just east of 59th Avenue and south of Elliot Road.

Within the Western Section, three action alternatives are being considered for detailed study. These are the W59, W71, and W101 Alternatives. The W59 Alternative would connect to I-10 at 59th Avenue, while the W71 Alternative would connect at 71st Avenue. The W101 Alternative would connect to I-10 at the existing State Route (SR) 101L (Agua Fria Freeway)/I-10 system traffic interchange (TI) and has six associated options. The W101 Alternative options vary geographically among the Western (W), Central (C), and Eastern (E) Options and would vary geometrically based on a Partial Reconstruction (PR) or a Full Reconstruction (FR) of the system TI.

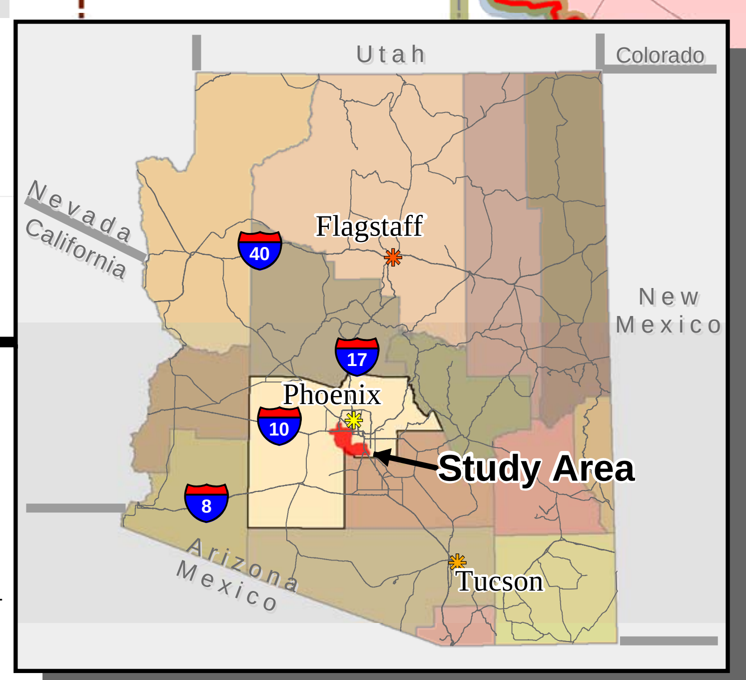
Improvements to I-10 (Papago Freeway) would occur for each Western Section action alternative (W59, W71, and W101). Improvements to SR 101L would occur for each option associated with the W101 Alternative.



Study Area and action alternatives



Location in county



Location in state

N

South Mountain Transportation Corridor
Federal-aid Project Number: NH-202-D(ADY)
ADOT Project Number: 202L MA 054 H5764 01L

E:\Projects\AZ\ADOT\SouthMtn\GRIC_Alignment\map_docs \mxd\NoE2_120220\Geo_Reg_Final

Figure 1

Study Area and Action Alternatives

Geotechnical Report

Within the Eastern Section of the Study Area, one action alternative is being considered. The E1 Alternative would begin near Elliot Road and 59th Avenue and proceed to the southeast to Pecos Road, which it would follow to the east until connecting to I-10 (Maricopa Freeway) at the Pecos Road/I-10/SR 202L (Santan Freeway) system TI.

The action alternatives and options are summarized in Table 1.

Table 1. Action Alternatives and Options

Section	Interstate 10 Connection	Action Alternative	Option – Broadway Road to Buckeye Road	Option – State Route 101L/ Interstate 10 Connection Reconstruction	Option Name
Western	59th Avenue	W59	—[a]	—	—
	71st Avenue	W71	—	—	—
	State Route 101L	W101	Western	Partial Reconstruction	W101WPR
				Full Reconstruction	W101WFR
			Central	Partial Reconstruction	W101CPR
				Full Reconstruction	W101CFR
			Eastern	Partial Reconstruction	W101EPR
				Full Reconstruction	W101EFR
Eastern	Pecos Road	E1	—	—	—

[a] not applicable

The No-Action Alternative is being considered for the entire Study Area.

Purpose and Need

An analysis of population trends, land use plans, and travel demand shows that a considerable traffic problem in the Phoenix metropolitan area is projected for the future, resulting in the need for a new freeway in the SMTC. This traffic problem is likely to worsen if plans are not made to accommodate the regional travel anticipated. The purpose of a freeway within the SMTC is to support a solution to traffic congestion. Between the early 1950s and the mid-1990s, the metropolitan area grew by over 500 percent, compared with approximately 70 percent for the United States as a whole (MAG 2001). From 1980 to 2005, the Maricopa County population more than doubled, from 1.5 million to 3.7 million. The MAG region has been one of the fastest-growing metropolitan areas in the United States; Phoenix is now the fifth-largest city in the country, and the region ranks as the 12th-largest metropolitan area in the country.

Travel demand and vehicle miles driven in the metropolitan area are expected to increase at a faster rate than the population. MAG projections (conducted in collaboration with the Arizona Department of Economic Security) indicate Maricopa County's population will increase from 3.7 million in 2005 to 6.5 million in 2035 (MAG 2009). It is projected that in the next 25 years, daily vehicle miles traveled will increase from 101 million to 185 million.

Even with anticipated improvements in light rail service, bus service, trip reduction programs, and existing roads and freeways, vehicle traffic volumes are expected to exceed the capacity of Phoenix metropolitan area streets and highways by as much as 11 percent in 2035. A freeway within the SMTC would accommodate approximately 6 percentage points of the 11 percent of the unmet travel demand and would be part of an overall traffic solution.

2. Affected Environment

Background

This report provides an overview of the Study Area geologic setting and preliminary information concerning potential geotechnical and geologic effects on the Study Area. This information will be used to support an analysis of SMTC alternatives and options. The evaluation presented in this report is based on available information on the regional and local geology, mining activity, regional seismicity, and regional land subsidence and earth fissuring.

Numerous geotechnical studies have been conducted in the Study Area. Two previous studies, the *Preliminary Geotechnical Investigation Report, Southwest Loop Highway – SR 218, I-10 & 59th Avenue to I-10 & Pecos Road* (Sergent, Hauskins & Beckwith 1987a), and the *Geotechnical Investigation Report, Southwest Loop Highway – SR 218, I-10 & 59th Avenue to I-10 & Pecos Road* (Sergent, Hauskins & Beckwith 1987b), were performed for ADOT. Reynolds (1985) performed a detailed study of geology at the South Mountains, and Demsey (1989), Reynolds and Skotnicki (1993), and Waters and Ravesloot (2000) published studies regarding the Quaternary geology in the Study Area. Studies regarding soils in the Study Area were performed by Adams (1974), Hartman (1977), and Johnson et al. (1986). Groundwater and well data are available from the Arizona Well Registry Distribution Database (Arizona Department of Water Resources [ADWR] 2002) and from the Groundwater Sites Inventory (ADWR 2008). Regional land subsidence and earth fissuring maps were created by Laney et al. (1978), Schumann (1974, 1992), Shipman (2007), the Arizona Geological Survey (2011), and the ADWR Hydrology Division (ADWR 2011). Regional seismicity was detailed by Euge et al. (1992), and local seismicity data were available through the U.S. Geological Survey (USGS) National Seismic Hazard Mapping Project, Earthquake Hazards Program (USGS 2006).

Overview of Geologic Conditions

The Study Area lies within the desert region of the Basin and Range Physiographic Province. The dominant physiographic feature in the Study Area is the South Mountains, which are isolated, northeast-trending ridges surrounded by a broad expanse of alluvial deposits. The northern side of the South Mountains is drained by the Salt River, and the southern and southwestern sides of the South Mountains are drained by the Gila River. The primary drainage intersecting the Western Section of the Study Area and all Western Section action alternatives is the Salt River. Many small-to-large ephemeral drainages emanating from the South Mountains traverse the Eastern Section of the Study Area and drain to the Gila River.

Study Area topography is dominated by the Salt and Gila rivers and the South Mountains. Elevation generally ranges from 2,400 feet above mean sea level at the crest of the South Mountains to 950 feet above mean sea level at the confluence of the Salt and Gila rivers, which is at the western edge of the Study Area boundary in the Western Section. In the Western Section of the Study Area, topography north of the Salt River is relatively flat, gently sloping to the southwest. Topography south of the Salt River also is relatively flat, gently sloping either to the northwest toward the Salt River or to the southwest toward the Gila River. Topography in the Eastern Section of the Study Area ranges from relatively flat to gently sloping, to undulating to steep and varies considerably in elevation, traversing the low foothills and several ridges of the South Mountains and adjacent floodplain and terrace deposits of the Gila River.

A geologic map of the Study Area is shown in Figure 2. The map was prepared by using an aerial photographic base and modifying previous work from Reynolds (1985), Reynolds and Skotnicki (1993), Demsey (1988, 1989), and Waters and Ravesloot (2000). The dominant geologic features are the bedrock of the southern and western flanks and foothills of the South Mountains, adjacent alluvial fans and piedmonts, and the basin sediments of the Salt and Gila rivers, including their associated floodplains and terraces.

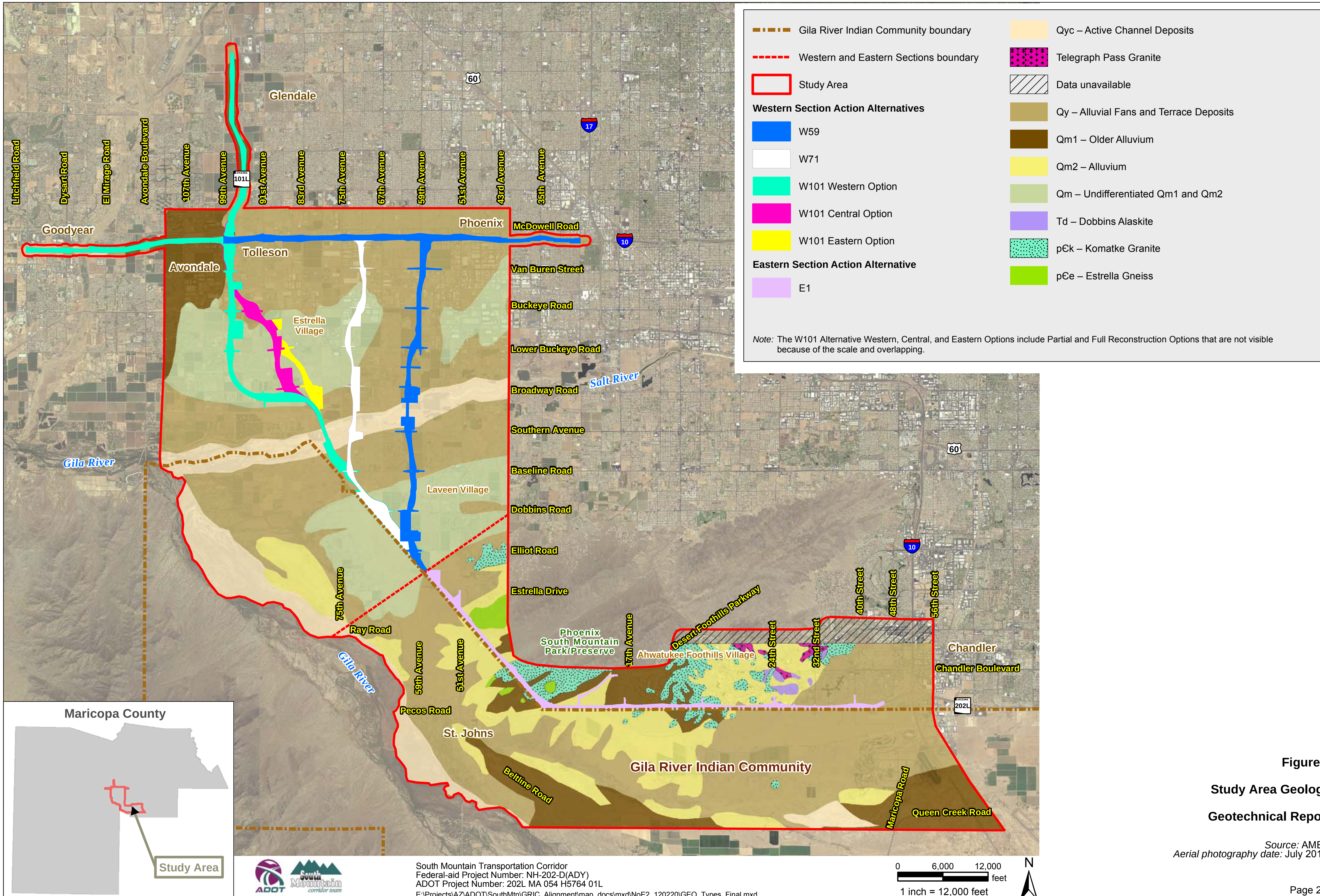
The bedrock geology of that portion of the South Mountains and their associated foothills within the Study Area consists of granitic and related rock (geologic map units p€k [Komatke Granite], Ttp, and Td) and metamorphic gneissic rock (geologic map unit p€e [Estrella Gneiss]). The alluvial fan deposits and piedmonts of the South Mountains are predominantly granular deposits that can include abundant cobble- and boulder-sized material (geologic map units Qm1, Qm2, and Qy that abut the South Mountains). These deposits vary in thickness and often exist as only a thin veneer of colluvium or alluvium overlying bedrock.

The geology of the Salt and Gila rivers and their associated floodplains and terrace deposits generally consists of highly stratified, predominantly fine-grained alluvial deposits and active channel deposits consisting of varying mixtures of clay, silt, sand, gravel, and cobbles (geologic map units Qm1, Qm2, Qm, Qy, and Qyc). Typically, the Gila River channel deposits contain more sand and less gravel and cobbles than do the Salt River deposits.

Bedrock Geology

Four mapped bedrock units outcrop within the Study Area, all of which are exposed within the Eastern Section of the Study Area. These units are the Estrella Gneiss, Komatke Granite, Telegraph Pass Granite, and Dobbins Alaskite (Reynolds 1985).

Between 32nd Street and 17th Avenue along the E1 Alternative in the Eastern Section of the Study Area, both the Estrella Gneiss and Dobbins Alaskite are exposed and may occur at shallow depths below unconsolidated deposits near the mountain front. While not exposed in this area, the Telegraph Pass Granite may also occur at shallow depths below unconsolidated deposits near the mountain front. West of 17th Avenue along the E1 Alternative, both the Estrella Gneiss and Komatke Granite are exposed and may also occur at shallow depths below unconsolidated deposits near the mountain front. The locations of mapped outcrops of these bedrock units are illustrated on Figure 2. These units are briefly described below.



South Mountain Transportation Corridor
Federal-aid Project Number: NH-202-D(ADY)
ADOT Project Number: 202L MA 054 H5764 01L
E:\Projects\AZ\ADOT\SouthMtn\GRIC_Alignment\map_docs\mxd\NoE2_120220\GEO_Types_Final.mxd

Figure 2

Study Area Geology

Geotechnical Report

Source: AMEC
Aerial photography date: July 2010

The Estrella Gneiss generally forms serrated ridges composed of dark-colored blocky outcrops. The Estrella Gneiss is a Precambrian-age, high-grade gneiss that consists of quartzo-feldspathic gneiss, amphibolite, biotitic gneiss, granitic gneiss, migmatite, mica schist, and uncommon quartzite (Reynolds 1985).

The Komatke Granite is generally exposed on low ridges that are similar in appearance to ridges of Estrella Gneiss. The granite is gray with a pinkish tint and is typically coarse-grained and porphyritic. The Precambrian-age Komatke Granite is predominantly quartz, plagioclase, and potassium feldspar with lesser amounts of biotite and occasional amphibole. Alaskitic and aplitic phases are common, especially near contacts with the Estrella Gneiss (Reynolds 1985).

The Telegraph Pass Granite is exposed primarily at the central portion of the South Mountains, and to a lesser extent along the southern foothills. Where unweathered or fresh, this granite is light gray; where weathered, it is tan to light brown. The Telegraph Pass Granite is medium grained and composed of nearly equal amounts of quartz, plagioclaise, and potassium feldspar with minor amounts of biotite (Reynolds 1985).

The Dobbins Alaskite consists of an assembly of alaskitic rocks that are interpreted to be a border phase of the Telegraph Pass Granite. Within the Study Area, the Dobbins Alaskite occurs as dikes, sills, and irregularly shaped intrusions within the Estrella Gneiss, and is locally mylonitic (Reynolds 1985).

In addition to the mapped bedrock units described above, intermediate-to-felsic dikes and sills are common in the foothills of South Mountains. The lithology of the dikes and sills varies, but they generally consist of rhyodacite, dacite, fine-grained granodiorite, andesite, felsite, mafic granodiorite, or microdiorite (Reynolds 1985).

Unconsolidated Units

Five mapped unconsolidated geologic units were identified in the Study Area, and all are present within the proposed action alternatives and options. These mapped unconsolidated geologic units are active channel deposits, alluvial fan and terrace deposits, younger middle alluvium, older middle alluvium, and undifferentiated alluvium (Reynolds and Skotnicki 1993). The locations of these mapped units are illustrated on Figure 2. These units, including their relative distribution and locations relative to the proposed action alternatives, are briefly discussed below.

Active channel deposits of the major axial drainages are interpreted to be less than 1,000 years old and, within the Study Area, are associated with the Salt and Gila rivers. These deposits typically consist of varying mixtures of clay, silt, sand, gravel, and cobbles (Demsey 1989). All three proposed action alternatives in the Western Section of the Study Area would encounter this unit near the Salt River. This unit is not present along the proposed E1 Alternative in the Eastern Section of the Study Area. Previous geotechnical investigations (Sergent, Hauskins & Beckwith 1987a, 1987b) suggest the active channel deposits are dominated by sand and gravel, with lesser amounts of cobbles (sizes range from 3 to 12 inches).

Alluvial fan and terrace deposits are interpreted to be Holocene and latest Pleistocene in age and consist of channel deposits and low terraces of small drainages, young alluvial fans, and broad terraces of the major drainages. This unit is widespread throughout the Study Area and would be encountered by all proposed action alternatives in both sections of the Study Area. Surfaces are very slightly dissected (less than 2 feet) by active gullies and washes. These deposits typically consist of silt and well-sorted sand with local occurrences of fine gravel; locally these deposits can be coarser. The alluvial fan and terrace deposits are often weakly-to-moderately cemented (see Machette, 1985, for a description of development of cementation) with calcium carbonate (Demsey 1989).

The younger middle alluvium unit is interpreted to be middle to late Pleistocene in age and generally consists of silt and well-sorted sand, gravel, and cobbles. This unit exists in both sections of the Study Area, but would be encountered along only the E1 Alternative in the Eastern Section. The alluvium unit exists as piedmont deposits associated with the southern and western flanks of the South Mountains and as terrace deposits along the Gila River and its tributary drainages. Surfaces are slightly-to-moderately dissected (3 to 12 feet) above active channels. These deposits are often weakly-to-moderately cemented with calcium carbonate (Demsey 1989).

The older middle alluvium unit is interpreted to be early-middle to middle Pleistocene in age, and deposits include silt, sand, gravel, and cobbles. This unit would be encountered by the W101 Alternative in the extreme northwestern portion of the Western Section of the Study Area, and by the E1 Alternative along central portions of its alignment in the Eastern Section of the Study Area. The older alluvium unit exists within the Study Area as piedmont deposits associated with the southern and western flanks of the South Mountains and as terrace deposits associated with the Gila and Salt rivers. In general, deposits are coarser and moderately sorted on the piedmonts, and finer grained (silt and sand) and well-sorted in the basins. The surfaces are typically moderately dissected (about 9 to 20 feet) above active channels. These deposits are often moderately to strongly cemented with calcium carbonate (Demsey 1989).

Undifferentiated alluvium represents undifferentiated Qm1 and Qm2 deposits, where the two units are mixed to a degree that precludes their differentiation at the scale of existing mapping (illustrated in Figure 2), or where there is uncertainty in assigning the deposits either a late or middle Pleistocene age category (Demsey 1989). This unit is fairly widespread across the Western Section of the Study Area and would be encountered by all three proposed action alternatives in that section. In the Eastern Section of the Study Area, this unit is limited to the extreme western end, where it would be encountered by the E1 Alternative.

At locations along the proposed action alternatives near bedrock outcrops near the South Mountains, the unconsolidated deposits discussed above typically exist as only thin veneers overlying bedrock. In addition, much of the Study Area (especially in the northern portion of the Western Section) has been under agricultural production and cultivated for many years and subjected to flood irrigation. In these agricultural areas, much of the cementation reported for alluvial deposits that exist in the Study Area, within roughly the upper 40 feet, has likely been affected by percolating irrigation water and driven deeper within the profile.

Groundwater

The Study Area lies in the West Salt River Valley Subbasin of the Phoenix Active Management Area. Groundwater distribution in the Study Area is highly variable. In the alluvial environments dominated by the Salt and Gila rivers, groundwater is abundant and may be found near the ground surface. In the bedrock, piedmont, and alluvial fan environments associated with the South Mountains, little-to-no groundwater is likely to be found. Groundwater use differs substantially in the Study Area. North of Estrella Drive, generally in the Western Section of the Study Area, groundwater is used extensively for agricultural and municipal purposes. South of Estrella Drive, generally in the Eastern Section of the Study Area, there is relatively little groundwater use.

Depth to groundwater varies throughout the Study Area. Along the Eastern Section of the Study Area, depth to groundwater is greater than 50 feet. ADWR groundwater level data were obtained in Ahwatukee Foothills Village for several different wells, and the depth to groundwater ranged between 97 and 117 feet below ground surface. Also in the Eastern Section, ADWR Groundwater Site Inventory data from 2007 to 2008 indicate depths to groundwater of about 65 to 75 feet below ground surface in Laveen Village just west of the western flanks of the South Mountains (based on data from two wells) and about 120 feet below ground surface in Ahwatukee Foothills Village near Chandler Boulevard and I-10 (based on data from one well). ADWR data for multiple wells in the Western Section of the Study Area (including Laveen Village and the Salt River areas) indicate that depths to groundwater range from 9 to 134 feet below ground surface. Areas south of Lower Buckeye Road may have depths to groundwater of less than 50 feet (ADWR 2002). Also in the Western Section, ADWR Groundwater Site Inventory data from 2007 to 2008 indicate depths to groundwater of about 40 to 120 feet below ground surface north of the Salt River (based on data from seven wells) and about 30 to 40 feet below ground surface south of the Salt River (based on data from four wells).

Shallow, perched groundwater could be present in the southern portion of the Eastern Section and the northern portion of the Western Section in areas under irrigation or previously under cultivation. In most instances, this groundwater would be the result of seepage from tailwater ditches or unlined irrigation laterals. In both the Eastern and Western Sections, progressing toward the South Mountains and their foothills, the unconsolidated deposits thin and groundwater may be absent or isolated in perched zones.

Land Subsidence and Earth Fissuring

Land subsidence related to groundwater withdrawal in alluvial basins in the Basin and Range Physiographic Province is a process of compression and subsequent consolidation of the alluvial sediments. Through geologic time, groundwater levels in the alluvial basin materials were at or near the ground surface, or at elevations controlled by the rivers and drainage systems traversing the basins.

Human activities have affected and are continuing to affect groundwater levels in many of these basins. Groundwater pumping, primarily for agricultural, industrial, and municipal use, has depleted stored groundwater in many areas. In addition, damming of rivers in mountainous portions of the surrounding watersheds has reduced the available recharge potential.

Based on regional mapping (Laney et al. 1978; Schumann 1974, 1992) and available National Geodetic Survey data, land subsidence in the Study Area has been limited to less than 1 foot. Historic groundwater declines have been between 50 and 100 feet in areas located away from the South Mountains and their associated foothills (Laney et al. 1978; Laney and Hahn 1986; ADWR 2002). Declines of this magnitude have resulted in only minor land subsidence within the Study Area. Scientists began to use Synthetic Aperture Radar and interferometric processing (Interferometric Synthetic Aperture Radar, or InSAR) to detect land surface elevation changes in the early 1990s. Use of InSAR has developed into a highly reliable land subsidence monitoring tool used by ADWR since 2002 to identify and map subsidence features in Arizona. The most current ADWR subsidence maps were reviewed at the ADWR Web site (ADWR 2011). Based on the ADWR mapping, no land subsidence zones exist within or immediately adjacent to the Study Area. The nearest subsidence zones are located approximately 6 to 7 miles to the north-northwest (the West Valley Subsidence Feature, which includes portions of Sun City, Surprise, Peoria, Glendale, and Avondale) and approximately 16 miles to the south (the Maricopa-Stanfield Subsidence Feature in the Maricopa area).

Earth fissuring poses an erosional hazard because normal surface drainage captured by fissures can result in the formation of substantial fissure gullies that can lead to catastrophic erosion at constructed improvements. Earth fissures in areas of large groundwater decline within alluvial aquifers are likely associated with a process termed “generalized differential compaction.” Because of this process, fissures commonly develop along the perimeter of subsiding basins, often in apparent association with buried or protruding bedrock highs, suspected mountain-front faults, or distinct facies changes in the alluvial section. The Arizona Geological Survey conducts comprehensive mapping of earth fissures and delivers earth fissure map data to the Arizona State Land Department. Earth fissure planning maps covering Arizona (Arizona Geological Survey 2011) and Maricopa County (Shipman 2007) were reviewed to identify known or reported earth fissures within or near the Study Area. Based on these maps, no earth fissures are known to exist within or immediately adjacent to the Study Area. The nearest earth fissures are located approximately 6 to 7 miles to the north-northwest and approximately 16 miles to the south; they are associated with the subsidence features described previously.

Regional and Local Seismicity

Minimal historical seismic activity has been recorded in Maricopa County and the Study Area. No recognized active faults are located within the proposed alignments of any of the action alternatives (USGS 2006). Euge et al. (1992) prepared a report for ADOT that included evaluation of seismic criteria for the State of Arizona. This report presents maps of expected horizontal acceleration in bedrock, with a 10 percent probability of exceedance in both 50 and 250 years. For the Study Area region, the approximate values of acceleration are 0.03 of unit gravity (g) for an exposure time of 50 years and 0.07g for 250 years.

While the Euge et al. (1992) report included a regional evaluation of seismic criteria, USGS data were used to evaluate a specific site within the Study Area. Probabilistic earthquake ground motion values were obtained from the USGS National Seismic Hazard Mapping Project, Earthquake Hazards Program (USGS 2002) for the intersection of 51st Avenue and Pecos Road (specifically, for 36.28 degrees N latitude, -112.16 degrees W longitude). Interpolated, probabilistic ground motion values of peak ground acceleration in rock for 2 and 10 percent probabilities of exceedance in 50 years were obtained for this location in the Study Area as follows:

- 10 percent probability of exceedance in 50 years, with a return period of 475 years: 0.037g
- 2 percent probability of exceedance in 50 years, with a return period of 2,475 years: 0.072g

These peak ground acceleration values are for firm rock (rock with shear-wave velocity of 2,500 to 5,000 feet per second in the upper 100 feet of profile), categorized as Site Class B in accordance with the International Building Code (Table 1613.5.2 in International Code Council, Inc. 2006). These values would need to be evaluated and adjusted as appropriate based on the subsurface profile encountered during final geotechnical investigations. Seismic ground motion values for design would need to be adjusted using appropriate attenuation factors for actual in-place materials as presented in Chapter 16 of the International Building Code (2006).

Mineral Resources

Mineral resources in the Study Area include sand and gravel and precious metals. Sand and gravel are the most important mineral resources in the Study Area and are primarily found adjacent to or within the active channels of the Salt and Gila rivers. The South Mountains and their associated foothills contain potential precious metal resources. Historic mining of precious metals has been limited in scope, however, and it is unlikely that mining in the Study Area would occur in the foreseeable future.

A number of sand and gravel mining operations exist in the Study Area. Of these sand and gravel pits, five located in the Western Section along and within the Salt River are likely to be affected by the action alternatives. A search of the Arizona Mineral Industry Location System (AzMILS) database (2001) indicated that one gold mining claim and six unknown mining claims are included in the database but are not located within the proposed alignments of the action alternatives. From topographic maps, several mine tunnels, adits, or prospects are shown to be located south of the South Mountains, but none of these are located within the proposed alignment of the E1 Alternative.

3. Environmental Consequences

Construction Impacts

The geologic environment would be affected by the construction of the facilities within the Eastern and Western Sections of the Study Area. Excavation likely would be needed in some locations, and placement of fill would be needed in some areas. Within the Eastern Section, rock excavation could be needed.

Based on this preliminary analysis, substantive variations in the geotechnical conditions do not appear to exist among the proposed action alternatives and options except with regard to bedrock in the Eastern Section. The E1 Alternative would encounter a number of bedrock outcrops (ranging from small hills or knobs to large ridges of the South Mountains) and would include steep grades and rock cuts.

Where these action alternatives and options would diverge, they would occur in terrain underlain by the unconsolidated alluvial sediments of the Salt River, near (3.5 to 5.7 miles east of) its confluence with the Gila River (at the western edge of the Western Section boundary). All of the Western Section action alternatives and options would cross the Salt River, with no notable distinction between the various locations when considering the anticipated surface/subsurface conditions that would be encountered. In like fashion, the alluvial deposits both north and south of the Salt River channel would be similar throughout the Study Area to a degree that no distinction should be made at the limited resolution of this analysis. Common to all proposed action alternatives and options would be several geotechnical constraints, as discussed below.

Within the Eastern Section of the Study Area, these constraints would include the likely excavation of competent bedrock and issues regarding the stability of cut slopes completed in this rock, especially in the case of the E1 Alternative. Possible oversized, excavated rock borrow would be a constraint within the Eastern Section. Shallow groundwater occurs in the Western Section of the Study Area. Coarse-grained alluvial deposits, some cemented soils, and the potential for encountering both expansive and compressible/collapsible soils in the shallow profile would be constraints within the Western Section.

As depicted on Figure 2, the E1 Alternative, in the Eastern Section, would traverse the foothills of the South Mountains along their southern and western flanks where competent bedrock, generally consisting of granite and gneiss, is exposed and likely underlies a thin veneer of colluvial and alluvial deposits. Construction of the freeway along the E1 Alternative would encounter these bedrock units, resulting in difficult excavation conditions in cut sections, possibly needing blasting to facilitate removal. The rock rubble resulting from the excavation of bedrock would be highly variable in particle size, with the likely production of some materials not directly suitable for use as roadway subgrade and embankment fill because of the occurrence of oversized particles. If produced, oversized materials would need to be rejected or subjected to additional processing prior to use as roadway subgrade or embankment fill.

Impacts from blasting during construction may include flyrock, airblast, and ground motion. Flyrock is rock that is propelled through the air from a blast. Flyrock is controlled by blasting methods that reduce the likelihood of flyrock's occurrence. Access is controlled at blast sites to reduce the potential for bodily injury. Airblast is the airborne shock wave that results from the blast. In some cases, the airblast is audible, but normally the predominant frequencies are below the range of human hearing; therefore, airblast is usually felt rather than heard. The primary cause of blast damage is ground motion. Ground motion is measured in terms of peak particle velocity, usually expressed in inches per second. As vibrations from a blast arrive at a particular location, a particle of soil or rock will vibrate randomly in all directions for a short period of time.

Construction through several rock slopes would occur along portions of the E1 Alternative, in the Eastern Section of the Study Area along the mountain flanks defined above. Design of these slopes would require a detailed geomechanical characterization to define the orientation and condition of rock discontinuities prior to establishing slope angles and configurations that are stable and for which rockfall containment sufficient to protect roadway vehicular traffic could be designed. These rock slopes would probably be influenced by neither groundwater seepage nor by freeze-thaw, and from a hydraulic standpoint these rock slopes would be expected to provide a relatively stable environment for safe slopes over the long term. The major design issue would be evaluation and mitigation of the potential for detachment of portions of the constructed slope face along natural joints and fractures in the rock mass, and associated rockfall.

Channel deposits of the Salt River and upland portions of alluvial fan and piedmont deposits likely contain a relatively coarse fraction. Selection or treatment may be needed to use these materials as structural fill. Upland unconsolidated alluvial deposits may also be cemented to a degree that would create moderately difficult excavation conditions.

Although their lateral distribution is not defined in the available data reviewed for this report, the valley floor and mountain flank geologic setting of the Study Area is conducive to the deposition of soils that may possess potential for either expansion or compression/collapse. Expansive clay soils and compressible/collapsible silt soils both may occur in the overbank deposits of the master streams, low in the valley floor. Moisture-sensitive, low-density alluvial deposits susceptible to compression/collapse often occur along the distal and medial fringes of alluvial fans. Also, in areas currently or historically under agricultural production/cultivation, the upper 3 to 5 feet of soil is likely disturbed from tilling and may be loose and/or compressible/collapsible. These potential conditions would be defined during the geotechnical characterization of the preferred alternative. Based on available data, no geotechnical constraints are anticipated.

Another geotechnical condition of note would be the existence of shallow groundwater throughout the areas where the action alternatives cross the terraces, floodplain, and active channel of the Salt River. Shallow groundwater conditions may influence both the design and method of construction of roadway sections and bridge foundations, but such conditions are common, and construction technologies to overcome these conditions are readily available. Some soils in irrigated portions of the Study Area may exist at above optimum moisture content near tailwater ditches and canals. If present, these soils would require drying before use as roadway embankment fill or as subgrade with sufficient bearing capacity under roadways or other structures. Because of recent rises in the groundwater table elevation within portions of the Study Area, and a slowing in the rate of decline within other parts of the Study Area, future land subsidence is expected to have only a minimal, if any, effect on the design or performance of project elements. If future groundwater withdrawal results in considerable groundwater-level decline, however, subsidence of sufficient magnitude to affect performance of project elements would be possible. Where land subsidence were to occur within or adjacent to the Study Area, earth fissures could develop.

Sand and Gravel Mining Operations Impacts

A number of sand and gravel mining operations exist within the Study Area. Of these sand and gravel pits in the Western Section, five located along and within the Salt River are likely to be affected by the action alternatives. No such operations (past or present) have been identified within the E1 Alternative in the Eastern Section.

W59 Alternative

The W59 Alternative would affect three sand and gravel operations along the Salt River. Most of the impacts to these operations would involve partial acquisitions and would occur both in areas of active mining and areas that are not actively mined.

W71 Alternative

The W71 Alternative would affect two sand and gravel operations along the Salt River. One of these mining operations would be a total acquisition; however, this does not appear to be an active mining operation. The other would be a partial acquisition in an area that does not appear to be actively mined.

W101 Alternative

The W101 Alternative would affect two sand and gravel operations along the Salt River. One of these would be a partial acquisition in what appears to be an active mining area. The other would be a very minor acquisition in a corner of a property that does not appear to be actively mined.

Operational Impacts

Assuming appropriate design and in full consideration of the known geologic and geotechnical conditions, no operational effects are anticipated.

Secondary and Cumulative Impacts

Assuming appropriate design and in full consideration of the known geologic and geotechnical conditions, no secondary and cumulative effects are anticipated.

No-Action Alternative

If the No-Action Alternative were selected, there would be effects only from ongoing development and construction activities in the Study Area.

4. Mitigation

The following describes potential mitigation measures for ADOT to consider as future commitments that could be implemented as part of the project to avoid, reduce, or otherwise mitigate environmental effects associated with the project. Discussion of these measures in this report does not obligate ADOT to these specific measures. ADOT, along with FHWA, may choose to modify, delete, or add measures to mitigate effects.

Construction Mitigation

Appropriate design of the facilities would mitigate geotechnical-related construction effects. Appropriate design would include excavations and slopes within soil and rock with an accepted degree of safety, placement of fills with an accepted degree of safety, protection of excavation and fill slopes against erosion, and design of roadway and bridge subgrade and foundations in accordance with accepted practices.

According to the *ADOT Standard Specifications for Road and Bridge Construction* (2008), Section 107.10, the contractor is responsible for all damage resulting from the use of explosives. Preblast surveys assess the condition of the dwellings or structures and document any existing defects and other physical factors that could reasonably be affected by blasting. Preblast surveys document existing damage by photographing and recording the location, length, and width of any existing crack or other visible defect in a building's foundation, interior, or exterior.

Postblast surveys may be performed following a blasting episode, but normally occur only if a blast-related damage claim is made by a property owner to the contractor. If damages were documented in the postblast survey, the contractor would be responsible for the damages. If blasting and/or heavy ripping is anticipated, ADOT would include a requirement in the special provisions of the construction contractor to perform in-depth pre- and postconstruction surveys for all structures located within one-half mile of any blasting and/or heavy ripping activity.

Implementation of any of the Western Section action alternatives would require acquisition of sand and gravel operations within the Salt River riverbed. These properties would be included in the project's acquisition and relocation assistance program. The program is conducted in accordance with the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970 (49 Code of Federal Regulations [C.F.R.] § 24), which identifies the process, procedures, and time frame for right-of-way acquisition and relocation of affected businesses. Relocation resources would be available to all business relocatees, without discrimination. All acquisitions and relocations resulting from the proposed freeway would comply with Title VI of the Civil Rights Act of 1964 and with 49 C.F.R. § 24. Private property owners would be compensated at fair market value for land and may be eligible for additional benefits. In the final determination of potential relocation impacts during the acquisition process, ADOT would provide, where possible, alternative access to properties losing access to the local road network. In the event that alternative access could not be provided, ADOT would compensate affected property owners in accordance with the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970 (49 C.F.R. § 24).

Prior to the Record of Decision for the SMTC, ADOT would consider protective and hardship acquisition on a case-by-case basis in accordance with criteria outlined in the ADOT *Right-of-Way Procedures Manual* (2006). After the Record of Decision, ADOT would consider protective and hardship acquisition of properties in those freeway sections not planned for immediate construction. Protective acquisition would aid in reducing the number of required acquisitions closer to the time of construction.

Operational Mitigation

Because there are no identified operational effects, no mitigation is required.

Secondary and Cumulative Impacts Mitigation

Because there are no identified secondary and cumulative effects, no mitigation is required.

No-Action Alternative

Because there are no identified effects related to the No-Action Alternative, no mitigation is required.

5. Bibliography/References

Adams, E. D. 1974. *Soil Survey, Eastern Maricopa and Northern Pinal Counties Area, Arizona*. U.S. Department of Agriculture, Soil Conservation Service.

Arizona Department of Mines and Mineral Resources. 2001. Arizona Mineral Industry Location System (AzMILS) Database. January.

Arizona Department of Transportation (ADOT). 1988a. *Southwest Loop Highway (SR 218) Design Concept Report*. September. Phoenix.

———. 1988b. *Southwest Loop Highway (SR 218) Final Environmental Assessment*. January. Phoenix.

———. 2006. *Right-of-Way Procedures Manual*. Phoenix.

———. 2008. *Standard Specifications for Road and Bridge Construction*. Phoenix.

Arizona Department of Water Resources (ADWR). 2002. Arizona Well Registry Distribution Database.

———. 2008. ADWR Water Resource Data. Groundwater Site Inventory. <http://arcims.azwater.gov/gwsi/waterresourcedata.aspx> (accessed October 21, 2009).

———. 2011. Maps of Land Subsidence Areas in Arizona. <http://www.azwater.gov/azdwr/Hydrology/Geophysics/LandSubsidenceMaps.htm> (accessed January 21, 2011).

Arizona Geological Survey. 2011. Earth Fissure Viewer. <http://services.azgs.az.gov/OnlineMaps/fissures.html> (accessed January 21, 2011).

Demsey, K. A. 1988. *Geologic Map of Quaternary and Upper Tertiary Alluvium in the Phoenix North 20′ × 60′ Quadrangle, Arizona.* Arizona Geological Survey Open-File Report 88-17.

———. 1989. *Geologic Map of Quaternary and Upper Tertiary Alluvium in the Phoenix South 30′ × 60′ Quadrangle, Arizona*.

Euge, K. M., B. A. Schell, and I. P. Lam. 1992. *Development of Seismic Acceleration Contour Maps for Arizona, Final Report*. Report No. FHWA-AZ92-344. Prepared for the Arizona Department of Transportation. September. Phoenix.

Hartman, G. W. 1977. *Soil Survey of Maricopa County, Arizona, Central Part*. United States Department of Agriculture, Soil Conservation Service.

International Code Council, Inc. 2006. *International Building Code*. Country Club Hills, Ill.

Johnson, W. W. Jr., P. D. Camp, and J. D. Preston. 1986. *Soil Survey of Gila Indian Reservation, Arizona, Parts of Maricopa and Pinal Counties*. United States Department of Agriculture Natural Resources Conservation Service and United States Department of the Interior Bureau of Indian Affairs in cooperation with the Arizona Agricultural Experiment Station and the Gila River Tribe.

Laney, R. L., and M. E. Hahn. 1986. *Hydrogeology of the Eastern Part of the Salt River Valley Area: Maricopa and Pinal Counties, Arizona*. United States Geological Survey Water Resources Investigations Report 86-4147.

Laney, R. L., R. H. Raymond, and C. C. Winikka. 1978. *Maps Showing Water Declines, Land Subsidence, and Earth Fissures in South-Central Arizona*. United States Geological Survey Water Resources Investigations Open-file Report 78-83.

Machette, M. N. 1985. Calcic Soils of the Southwestern United States. Geological Society of America Special Paper 203.

Maricopa Association of Governments (MAG). 1985. *MAG Freeway/Expressway Plan.* Phoenix.

———. 2001. *Valley Vision 2025*. August. Phoenix.

———. 2003. *Regional Transportation Plan*. November. Phoenix.

———. 2009. *Extension of MAG 2007 Socioeconomic Projections to 2035 for Population, Housing and Employment by Municipal Planning Area and Regional Analysis Zone*. January. Phoenix.

Reynolds, S. J. 1985. *Geology of the South Mountains*, *Central Arizona*. Bulletin 195, Arizona Bureau of Geology and Mineral Technology, Geological Survey Branch.

Reynolds, S. J., and S. J. Skotnicki. 1993. *Geologic Map of the Phoenix South 30′ × 60′ Quadrangle, Central Arizona*. Bulletin 195, United States Geological Survey Open-File Report 93-18.

Schumann, H. H. 1974. *Land Subsidence and Earth Fissures in Alluvial Deposits in the Phoenix Area*. United States Geological Survey, Miscellaneous Investigations Series, Map I-845-H.

———. 1992. *Land Subsidence and Earth-Fissure Hazards near Luke Air Force Base, Arizona*. United States Geological Survey Open-File Report 94-532.

Sergent, Hauskins & Beckwith. 1987a. *Preliminary Geotechnical Investigation Report, Southwest Loop Highway – SR 218, I-10 & 59th Avenue to I-10 & Pecos Road*. SHB Job No. E86-5.

———. 1987b. *Geotechnical Investigation Report, Southwest Loop Highway – SR 218, I-10 & 59th Avenue to I-10 & Pecos Road*. SHB Job No. E87-18.

Shipman, T. C. 2007. *Maricopa County Earth Fissures Planning Map, Arizona*. Arizona Geological Survey Open File Report 07-01, v.7, Sheet 2, scale 1:250,000.

U.S. Geological Survey (USGS). 2002. National Seismic Hazard Mapping Project, Hazard Map Analysis Tool. <http://gldims.cr.usgs.gov/nshmp2008/viewer.htm> (updated May 13, 2008, accessed October 2008).

———. 2006. Quaternary Fault and Fold Database of the United States. <http://earthquakes.usgs.gov/regional/qfaults/> (accessed October 21, 2009).

Waters, M. R., and J. C. Ravesloot. 2000. Late Quaternary Geology of the Middle Gila River, Gila River Indian Reservation, Arizona. *Quaternary Research* 54 (1): 49–57.