Appendix H. Geotechnical Information

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MEMORANDUM (DRAFT)

To: David Perkins, PE – Kimley Horn and Associates, Inc.

From: Naresh Samtani, PE, PhD

Date: June 01, 2011

Re: Geotechnical Assessment
North–South Corridor Study – US 60 to I-10, Pinal County, Arizona
Federal Aid No. STP-999-A (BBM), ADOT Project No. 999 PN 000 H7454 01L

1.0 Introduction

The purpose of this memorandum is to summarize geotechnical information that has been obtained in support of the North-South Corridor, Alternatives Selection Report. This memorandum identifies the geotechnical features within the general project limits that will impact the development and screening of North-South Corridor alignment alternatives.

The North-South Corridor Study is currently in the Alternatives Selection Report phase. As such, the scope of work for this task is to document major geotechnical impacts to assist in determining alignment options for the proposed corridor. No formal or detailed geotechnical studies such as field investigations and the development of design recommendations are required at this time; such studies will be done in later stages of the project once definite alignments have been identified.

2.0 Project Location and Description

Project No. 999 PN 000 H7454 01L consists of a new transportation facility that is generally described as the “North-South Corridor”. The North-South Corridor begins at US 60 in Apache Junction, Pinal County, and extends south for approximately 40 miles to connect with Interstate 10 (I-10) in the vicinity of Picacho and Eloy, Pinal County.

The initial study area for the North-South Corridor encompassed more than 900 square miles. Opportunities and constraints within the initial study area were assessed, and avoidance areas identified that led to a reduction in the initial study area to approximately 300 square miles. The reduced study area is referred to as the Corridor Opportunity Area (COA). Avoidance areas are those areas within the initial study area through which a corridor should be avoided if possible. Figure 1 shows the COA, which is sub-divided into various corridors identified by alpha-numeric designations such as 1W and 1E. Corridors are defined areas through which multiple alignment alternatives may pass. The identification of corridors facilitates the systematic description and analysis of alignment alternatives. The study team is collecting and reviewing technical information for each corridor, including existing and future developments, drainage features, geotechnical features, utilities, travel demand and the projected economic development of each community within the corridor. Figure 1 also shows the major streets and physical features such as the Central Arizona Project (CAP) canal that help put the various corridors in a geographical context.

3.0 Geotechnical Assessment

From a geotechnical perspective, the evaluation was performed based on "deep-seated" and "near-surface" considerations. "Deep-seated" assessment is related to features such as ground subsidence and earth fissures. "Near-surface" assessment is related to features such as bedrock outcrops and mechanical and physical characteristics of soils at shallow depth below existing grades, e.g., volume change (shrink/swell/collapse), plasticity index (PI), etc.

3.1 Deep-Seated Geotechnical Assessment

The most relevant deep-seated geotechnical considerations within the study area relate to ground subsidence and earth fissuring. Both of these considerations are related to the decline of the groundwater table elevations within the study area. The decline in groundwater table is because of groundwater withdrawal by pumping that has been ongoing for decades. As the groundwater table elevation decreases, the effective stress in the sediments overlying bedrock increases because of a loss of buoyancy. The increase in effective stress causes a reduction in the volume of the sediments through consolidation-type mechanisms. Consolidation in the geotechnical engineering literature refers to a time-dependent process that occurs in saturated sediments in which excess pore water pressures induced by the loss of buoyancy dissipate with time. The resulting reduction in volume is commonly termed "compaction" in the geological literature. Therefore, consolidation settlement, which is reflected as subsidence at the ground surface, can continue to take place long after groundwater withdrawal has ceased. Since this memorandum deals with the geotechnical issues related to the proposed North-South Corridor alignment, the word "consolidation" will be used to refer to the phenomenon described above.

Figure 2 shows the mechanics of earth fissure formation. The consolidation process and associated ground subsidence create differential stress fields in the ground. The differential stresses result because of the variation of the thickness of the sediments being impacted by groundwater withdrawal. In the case of the consolidation of natural sediments due to groundwater withdrawal, differential settlement is commonly a reflection of a rapidly changing underlying bedrock profile as seen at the boundaries of alluvium-filled basins. Changes in the lithology with no abrupt changes in bedrock can also lead to differential settlements of the ground surface. Earth fissures occur when the tensile stresses developed in the soil by differential settlements resulting from ground subsidence exceed the tensile strength of the soil, which is generally small in natural soils. The zone of maximum tension is usually oriented perpendicular to the longitudinal axis of the fissure and in the direction of greater subsidence. Greater magnitudes of subsidence generally occur in areas of thicker layers of unconsolidated sediments, which typically exist towards the center of the basin (Jachens and Holzer, 1979). For this project, the phenomena of earth fissuring noted above was systematically documented by researching records from the United States Geological Survey (USGS), the Arizona Geological Survey (AzGS), the Arizona Department of Water Resources (ADWR), the Arizona

Department of Transportation (ADOT) and by using other information developed by the project team. Figure 3 shows a composite map of the corridors in Figure 1 overlain with documented earth fissures, depth to bedrock contours and areas of ground surface subsidence.

The cumulative effect of decades of groundwater pumping is reflected in the areas of subsidence shown on Figure 3. Subsidence in excess of 15 feet has been documented by USGS in Eloy, which is located just northwest of the intersection of SR 87 with I-10 as shown in Figures 3. The magnitude of subsidence is influenced not only by the groundwater decline but also by the thickness of the sediments that will experience consolidation. The thickness of the sediments can be expressed in terms of depth to bedrock. In Figure 3, the contour labels indicate the depth to bedrock based on Richard et al. (2007). As noted by Richard et al. (2007), the depth to bedrock contours "should be considered qualitative" because "horizontal accuracy of these contours cannot be rigorously quantified, but is estimated to be in the range of ± 1–3 km". Richard et al. (2007) further state that the "depth estimates are poorly constrained and should be considered highly uncertain, in the range of ± 20–30 percent, except in the vicinity of well penetrating bedrock". Thus, it is important to correlate the depth to bedrock with other local physiographic features such as mountains and local outcrops. Mountain ranges are shown in Figure 1. By comparing Figures 1 and 3, it can be noted that depth to bedrock increases rapidly around the Picacho Mountains in the southeast portion of the study area. Similar observation can be made with respect to the Santan Mountains to the west of the study area. The larger the value on the contour line of depth to bedrock at a given location, the deeper the bedrock and the thicker the sediment at that location. As can be seen in Figure 3, there appears to be a direct correlation between the areas of subsidence and the areas where the depth to bedrock (i.e., thickness of sediment) below existing grades is significant. Thus, for example, the large subsidence documented by USGS in the Eloy area is due to the deeper bedrock at that location.

Based on the subsidence pattern and depth to bedrock shown in Figure 3, and the mechanisms shown in Figure 2, earth fissures can be expected to occur closer to the Picacho Mountains than in areas to the west of the central third of the study area where the depth to bedrock is generally constant and relatively shallow. Indeed, as shown in Figure 3, the area immediately to the west of the Picacho Mountains is where the greatest concentration of earth fissures occurs within the study area. The numerous fissures noted in Figure 3 developed around the fissure that was first observed in 1927 and documented by Leonard (1929). The original fissure is commonly referred to as the Picacho fissure in the literature. Almost all of the fissures in the vicinity of the Picacho fissure are "sympathetic" fissures, i.e., their development was influenced by the original Picacho fissure. Based on the documentation of these fissures available from AzGS, the sympathetic fissures have developed steadily since 1929 with the most recent fissures documented as recently as the mid-1980s. As can be seen from Figure 3, some of the fissures intersect I-10. NCS (2007) presents a detailed report on the mapping of the Picacho fissure and its characteristics at the I-10 location.

In Figure 3 some concentration of fissures is also observed towards the north end of the study area where the CAP canal intersects US 60 as well as where Loop 202 intersects US60. The mechanism of formation of fissures in these areas is similar to that near the Picacho Mountains in the sense that it is related to the subsidence that is shown in Figure 3 towards the north end of the study corridor. Although not shown in Figure 3, a fissure crosses the Loop 202 alignment at

Apache Trail, just north of Pueblo Avenue shown at the top of Figure 3. Engineered mitigation measures were implemented by ADOT to protect Loop 202 and the Apache Trail Bridge against the adverse effects of this so-called Apache Trail Fissure (NCS, 2005). Additional information on earth fissures in the northern corridors 1W and 2W can be found in KHA (2010) where an earth fissure crossing the Powerline Flood Retarding Structure (FRS) was noted. The presence of this earth fissure led the ADWR to classify the Powerline FRS as being in an "unsafe, non-emergency, *elevated risk*" condition. As such, the Powerline FRS is one of ADWR's highest priority unsafe dams in the state.

3.2 Near-Surface Geotechnical Assessment

As noted earlier, "near-surface" assessment is related to features such as bedrock outcrops and mechanical and physical characteristics of soils at shallow depths below existing grades, e.g., volume change (shrink/swell/collapse), plasticity index (PI), etc.

With respect to bedrock outcrops, major obstacles that will influence the location of potential corridors in the study area include mountains and areas of relatively high and steeply sloping outcrops of bedrock. These features should be avoided because hard-rock tunneling, which is costly and could be time-consuming, would likely be required to cross them. These features can be seen clearly in Figure 3 as areas where the bedrock contours are so close to each other that they form distinct features such as the Picacho Mountains in the southern portion of the study area. Similar features are evident on the eastern and western boundaries near the center of the study area.

The Natural Resources Conservation Service (NRCS) of the United States Department of Agriculture (USDA) is an excellent source of information on soil properties within 5 feet below existing grades. The NRCS data can be accessed at http://websoilsurvey.nrcs.usda.gov/app/. Table 1, which was developed from data on the NRCS (2011) website, identifies the figures that were prepared by superimposing NRCS data within the study area. The reader is referred to http://soils.usda.gov/technical/handbook/contents/part618.html#38 for definitions of various parameters, e.g., linear extensibility, gypsum, etc., noted in Table 1 and Figures 4 to 9.

The following points should be noted when interpreting the data in Figures 4 to 9.

- The NRCS database demarcates geographical areas into "soil series" and soils within a given series have similar properties. Each soil series is given a name that is based on a nearby town or a geographical feature where that particular soil was first observed and mapped. Within the project study area, hundreds of soil series were noted in the NRCS database. To make the data usable in the context of the present study, the various soil series were superimposed on the corridor and truncated at the corridor limits.
- Once the NRCS data regarding soil series were processed as noted above, the soil properties of interest were identified. The NRCS database provides a minimum and maximum value for each property. The maximum values for a given property were extracted from the NRCS database and were plotted in Figures 4 to 9. The purpose for selecting only the maximum values was to study the relative variation of the maximum value between various corridors.

Table 1
Summary of Figures Showing NRCS Data within Corridor Limits

Figure: Title	Feature Depiction and Implication
4: Soils Linear Extensibility	Shows the volume change characteristics expressed in terms of linear extensibility percent (LEP). An evaluation of this parameter helps to identify areas where at- or near-grade facilities may require overexcavation and replacement of soils and/or chemical treatment to mitigate the volume change potential.
5: Soils Gypsum	Shows areas where gypsum may be encountered. Gypsum is a hydrated form of calcium sulfate. Sulfates are detrimental to concrete structures.
6: Soils Passing #200 Sieve	Shows percentage of soil particle sizes smaller than the No. 200 sieve or 0.074 mm, which is also referred to as "percent fines". The particle sizes smaller than the No. 200 sieve include silts and clays.
7: Soils PI	Shows the plasticity index (PI) of soils. Taken in context with percent fines shown Figure 6, the information regarding PI is useful in identifying areas of low R-values, which impact pavement design.
8: Soils pH	Shows pH of soils, which is one of the key parameters in assessing the electro-chemical properties of soils.
9: Soils Corrosion Potential for Concrete	Shows the corrosion potential of soils with respect to degradation of concrete. Along with pH, this property that evaluates the sodium and magnesium sulfate content is another electro-chemical property of soils that can be useful in selection of the appropriate type of cement for concrete structures.

The following general conclusions can be drawn based on the data presented in Figures 4 to 9:

1. Figure 4: Soils in Corridor 9E and 4W have the greatest areas of large volume change potential as evidenced by the LEMax value of 8.9 in these corridors. The Picacho Reservoir has some documented problems due to large volume change soils in this area. Minor areas within Corridors 2E, 5E, 5W and 6E also have soils with an LEMax value of 8.9.

2. Figure 5: Corridor 5E has the greatest area of large concentration of gypsum (10). This is consistent with the gypsum deposits that are known to occur in this area.

3. Figure 6: All the corridors appear to have a large percentage of fines (> 50%), i.e., silt and clay size particles. Corridors 9E and 6W have the greatest areas of the relatively highest percent fines (> 90%). Minor areas within Corridors 1W, 4W and 7 also have soils with > 90% fines.

4. Figure 7: Soils in Corridor 9E and 4W have the greatest areas of soils having a maximum PI value of greater than 45. Minor areas within Corridors 2E, 2W and 6E also have soils with a maximum PI value of greater than 45. As noted in Table 1, soils having a combination of a large percentage of fines and a large PI value generally have small R-values indicating that the soils will be unsuitable for pavement

subgrade and will require overexcavation and replacement and/or chemical (e.g., lime) treatment.

5. Figure 8: Most of the southern half of the study area including Corridors 7, 8W, 8E and 9E contain the greatest areas of soils that are highly alkaline as evidenced by a pH value greater than 9. Based on the NRCS database, the minimum pH value within the study area was 7.4 which indicates that acidic soils are not anticipated.

6. Figure 9: Most of the southern half of the study area including Corridors 7, 8W, 8E and 9E contain the greatest areas of soils that have a high potential to cause concrete degradation. This finding is consistent with pH values greater than 9 in the same areas as shown in Figure 8. In these areas, an appropriate type of cement should be used for all concrete structures to mitigate the detrimental effects of potential degradation of concrete.

Table 2 provides a geotechnical assessment for each corridor shown in Figure 1 based on these observations and conclusions.

4.0 Geotechnical Features to Absolutely Avoid

In general, there are no geotechnical features which should be absolutely avoided because all of them can be addressed by an engineered solution. In most cases, however, such engineered solutions will not be practical because they are generally not cost-effective. Therefore, the following section identifies the geotechnical features that should be avoided whenever possible.

5.0 Geotechnical Features to Try to Avoid

While it is true that all of the geotechnical features within the study area can be addressed by engineered solutions, the cost of mitigating the adverse effects of earth fissures, the major obstacle related to geotechnical features, may be very significant. Similarly, the cost of navigating around natural features such as water bodies and mountains may be costly. In this regard, the following guidance is provided:

1. Avoid crossing an earth fissure with a minimum setback distance of approximately ¼-mile from any documented fissure.

2. If fissures cannot be avoided, then constructing facilities parallel to the fissure(s) should be avoided. It may be easier to cross a fissure by using bridging techniques in the form of at-grade flexible reinforced soil platforms. The soil reinforcement may be geosynthetics or welded wire mesh depending on the facility and the specific fissure(s) under consideration. Such measures were designed by NCS (2005) and implemented by ADOT at the location of the Apache Trail Fissure crosses the Loop 202 alignment at Apache Trail, just north of Pueblo Avenue near the northern boundary of the corridor study area (see Figure 3). It is important to note that each fissure is unique and mitigation measures are site-specific. Some knowledge of fissure characteristics including a history of movements is required before mitigation measures for a specific fissure can be designed.

Table 2
Summary of Geotechnical Assessment

Corridor	Advantages	Disadvantages
1W		• Earth fissures, subsidence.
1E	No earth fissures, limited subsidence.	• Subsidence.
2W		• Subsidence.
2E	Areas on the east end have no reported subsidence.	• Subsidence in other areas.
3	Little to no subsidence issues.	•
4W	Distant from the local rock outcrops in Corridor 5E.	• Soils with large volume change potential in southern portion. • Soils with high plasticity and percent fines suggesting potentially low R-values for pavement subgrade design.
4E	No geotechnical issues	
5W	Distant from the local rock outcrops in Corridor 5E.	
5E	Could cost a little more but it may be less hazardous in terms of fissures if roadway is on rock surface above the groundwater table.	• Rock outcrops requiring potential rock cuts. • Potential future fissures. • Large gypsum deposits that would degrade concrete structures if proper sulfate resistance concrete is not used.
6W		• Subsidence. • Potential future fissures in the eastern half. • Soils with large percentage of fines and high plasticity suggesting potentially low R-values for pavement subgrade design.
6E		• Subsidence. • Potential future fissures.
7	Western half does not have fissures.	• Subsidence. • Potential future fissures in the eastern half.
8W	Presence of SR 87 corridor. Fewer fissures than in Corridor 8E. Avoids Picacho Reservoir area.	• Few existing fissures. • Soils with high potential for corrosion of concrete.
8E		• Existing and potential future fissures. • Soils with high potential for corrosion of concrete.
9W		• Existing and potential future fissures based on major fissures just south of the corridor. • Subsidence.
9E		• Major fissures near the east end. • Subsidence. • Potential future fissures based on major fissures just south of the corridor. • Soils with large volume change potential. • Soils with large percentage of fines and high plasticity suggesting potentially low R-values for pavement subgrade design.

3. Areas where the magnitude of subsidence and the rate of change of ground elevation is the largest should be avoided. Part of this assessment must consider future land use that may make current, relatively benign conditions significantly worse. Therefore, this is not exclusively a geotechnical consideration since it has socio-economic as well as political implications.

4. Avoid areas where soils have a large volume change potential because constructed facilities on such soils will experience distress because of differential movements.

5. From the perspective of pavement subgrades, avoid areas with soils that have a large percentage fines and a large plasticity index because significant overexcavation and replacement and/or chemical (e.g., lime) treatment will be required in those areas.

6.0 Recommendations Based on Geotechnical Assessment

Based on the geotechnical assessments described in the previous sections, Table 3 provides recommendations for a preferred alignment starting from I-10 and proceeding north to US 60.

Table 3
Recommendations for Preferred Alignment Based on Geotechnical Assessment Only

Corridor	Comment
9W	Stay parallel and adjacent to SR 87 to avoid most fissures.
8W	Stay parallel and adjacent SR 87 to avoid most fissures.
7	Stay close to the western boundary to avoid fissures.
6W	Stay close to the western boundary to avoid fissures. Turn east on SR 287 and progress to the east side of corridor 5E.
5E	Stay east of the local outcrops east of Clemans-Felix Road and south of Arizona Farms Road. Note that this corridor will encounter the gypsum deposits but it is easier to deal with such deposits by using an appropriate type of sulfate resistance cement rather than deal with the differential distress encountered in the large volume change soils that would be encountered in Corridor 4W.
4E	From a geotechnical perspective, this corridor has no issues as noted in Table 2. Therefore, any alignment within this corridor is acceptable. An alignment to the eastern boundary might be preferable to enable smooth transition from corridors 5E and 3.
3	Stay close to eastern boundary to continue the roadway from corridor 4E.
2E	Stay close to eastern boundary to avoid the subsidence zone. Localized zones of large volume change soils will be encountered.
1E	Stay close to eastern boundary.

7.0 Summary and Closure

The major potential geotechnical impacts for determining alignment options for the proposed "North-South Corridor" have been identified and assessed in terms of avoidance. Preliminary general guidance is provided for preferred alignment through various corridors based on our assessments of existing data. The results of our assessments and the preferred preliminary alignment option based on those assessments must be evaluated with respect to the results of analyses performed by other members of the project team. A detailed assessment of preferred alignment is not within the scope of this study. Any conclusions drawn from this preliminary assessment are subject to further analyses and may be premature at this stage.

During further analyses in future design stages of the project it is recommended that the designers contact the AzGS for any refined earth fissure maps and information on deep (> 1,000 feet) borings that they may have based on past investigations done by salt mining operations within the study area, the ADWR for refined subsidence data, and agencies such as Central Arizona Project (CAP) and Salt River Project (SRP) for any relevant and useful geotechnical investigations and facility performance data for the major linear features such as the CAP canal and the 500 kV line within the project corridors as shown in Figure 1. Similarly, reports such as those developed by KHA (2010) and Flood Control District of Maricopa County as well as by the railroads should be researched and evaluated for updated information. Finally, performance records of major transportation corridors such as SR 87, SR 287 and SR 79 should be evaluated during final designs if the new alignments will be close to these existing roadways.

8.0 References

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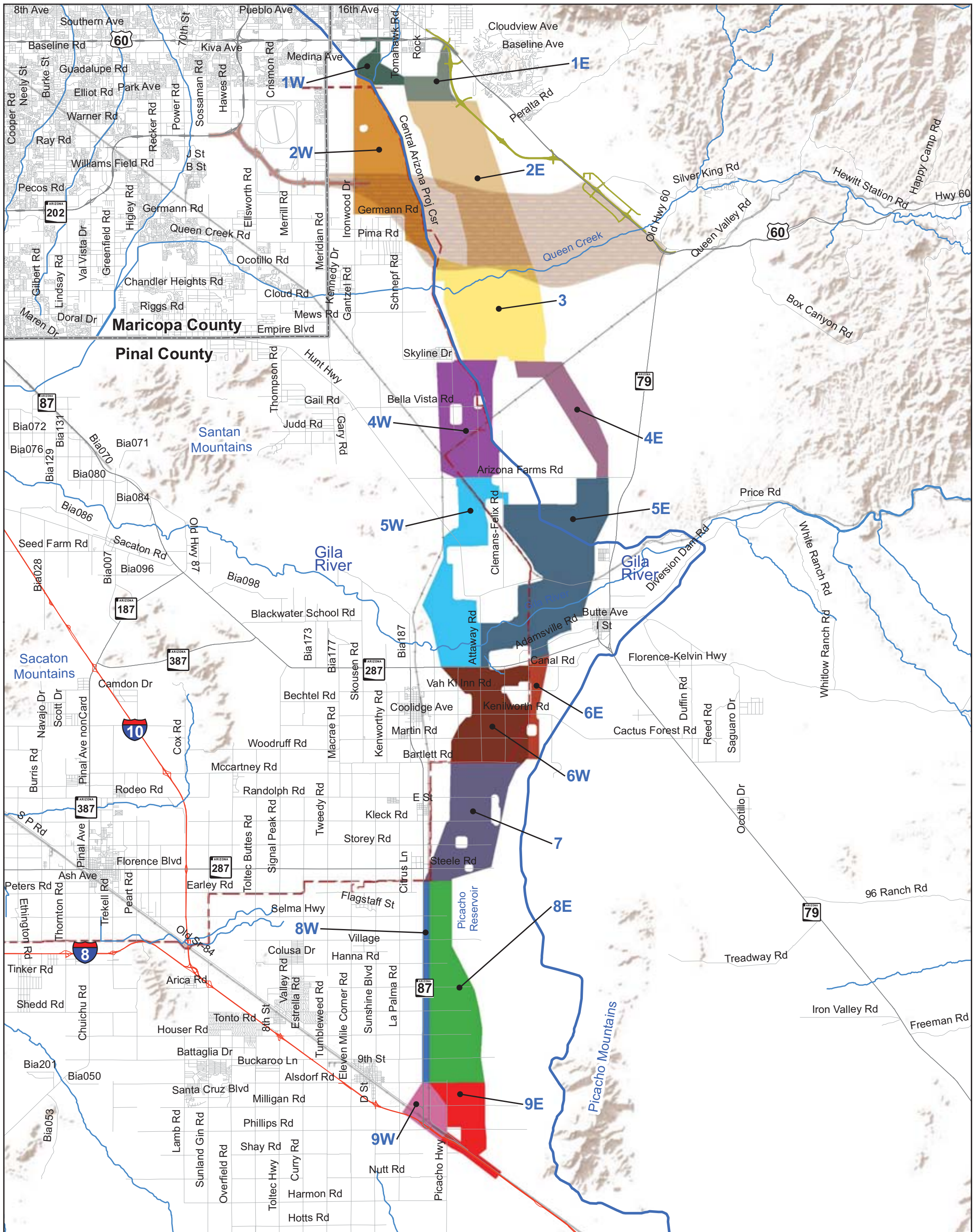

Legend

- CAP Canal
- Stream
- Interstate Highway
- U.S. / State Highways and Freeways
- Local Roadway
- Proposed US 60 Alignment
- SR 24 Preferred Alignment
- SR 24 Study Area
- Railroad
- SRP 500 kV Line Easements
- <00> Corridor Number

NORTH–SOUTH CORRIDOR STUDY

Corridors

Figure 1

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Federal Aid No. STP-999-A(BBM)

NORTH

0 0.5 1 2 3 4 5 6 7 8 9 10 Miles

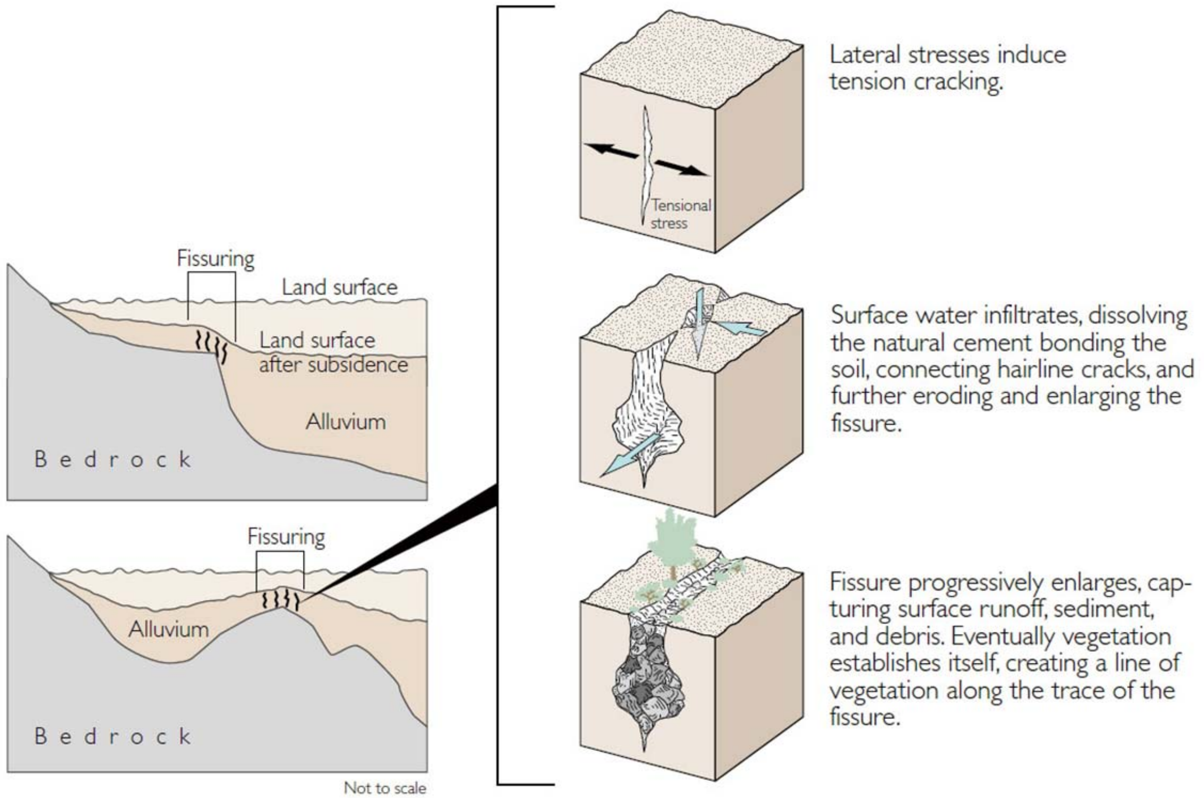
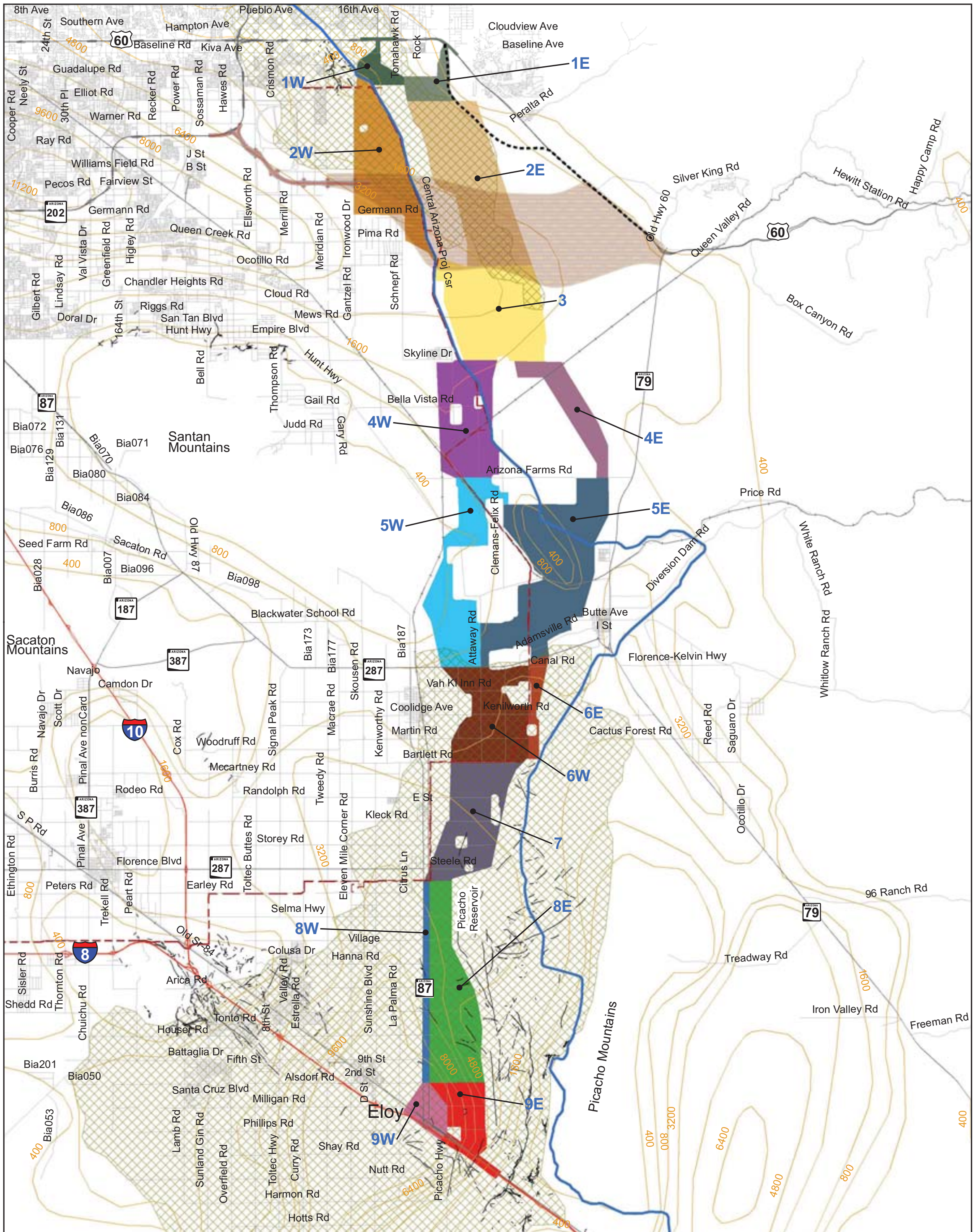


Figure 2
Earth Fissure Formation
(Carpenter, 1999)



Legend

- CAP Canal
- SRP 500 kV Line Easements
- Railroad
- Interstate Highway
- U.S. / State Highways and Freeways
- Local Roadway
- Proposed US 60 Alignment
- SR 24 Preferred Alignment
- SR 24 Study Area
- <00> Corridor Number
- Earth Fissures
- Depth to Bedrock Contours
- Subsidence Areas
- <00> Contour Depth (ft)

NORTH–SOUTH CORRIDOR STUDY

Earth Fissures, Depth to Bedrock and Subsidence

Figure 3

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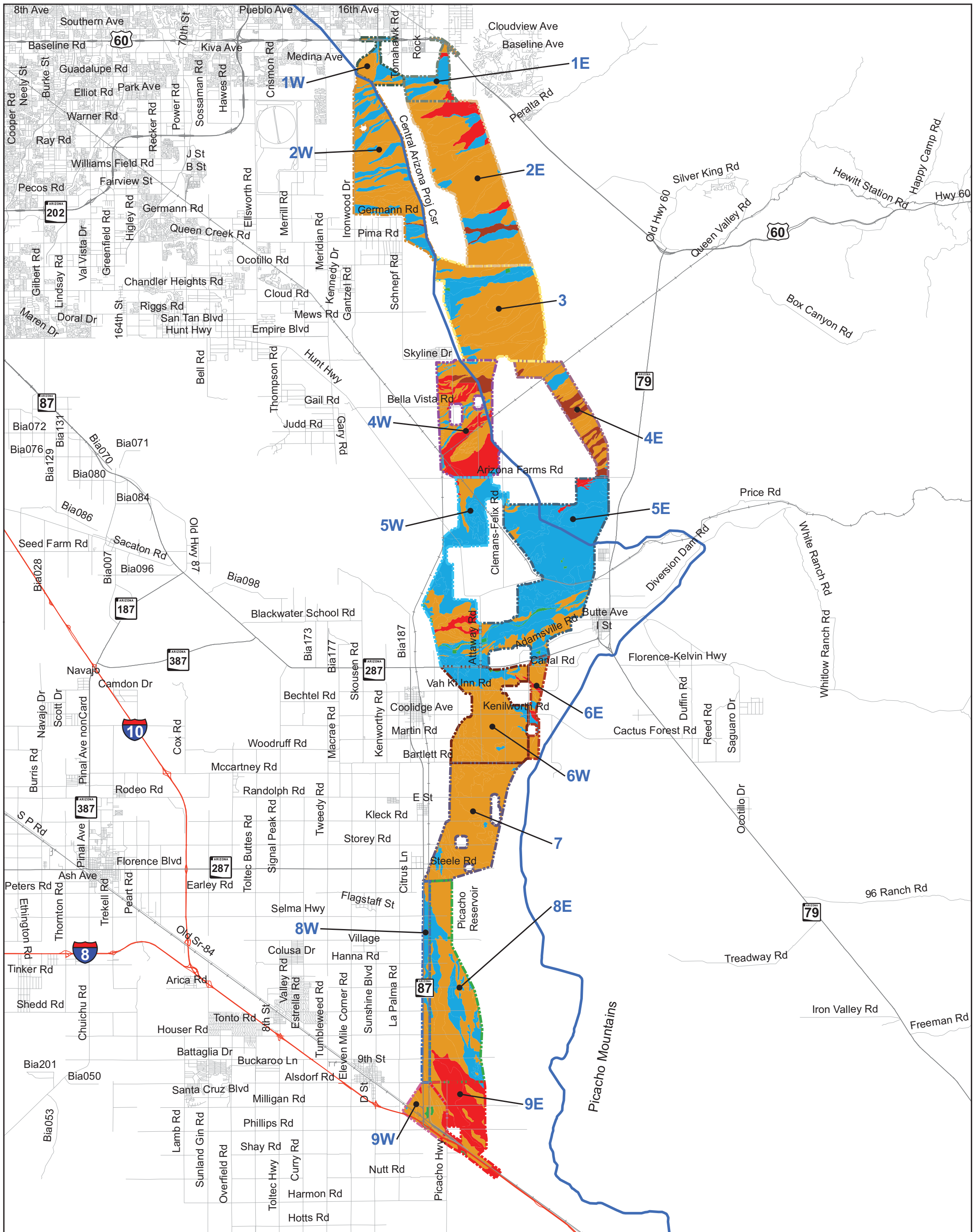
NORTH

0 0.5 1 2 3 4 5 6 7 8 9 10 Miles



NORTH–SOUTH CORRIDOR STUDY

Soils Linear Extensibility

Figure 4

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Legend

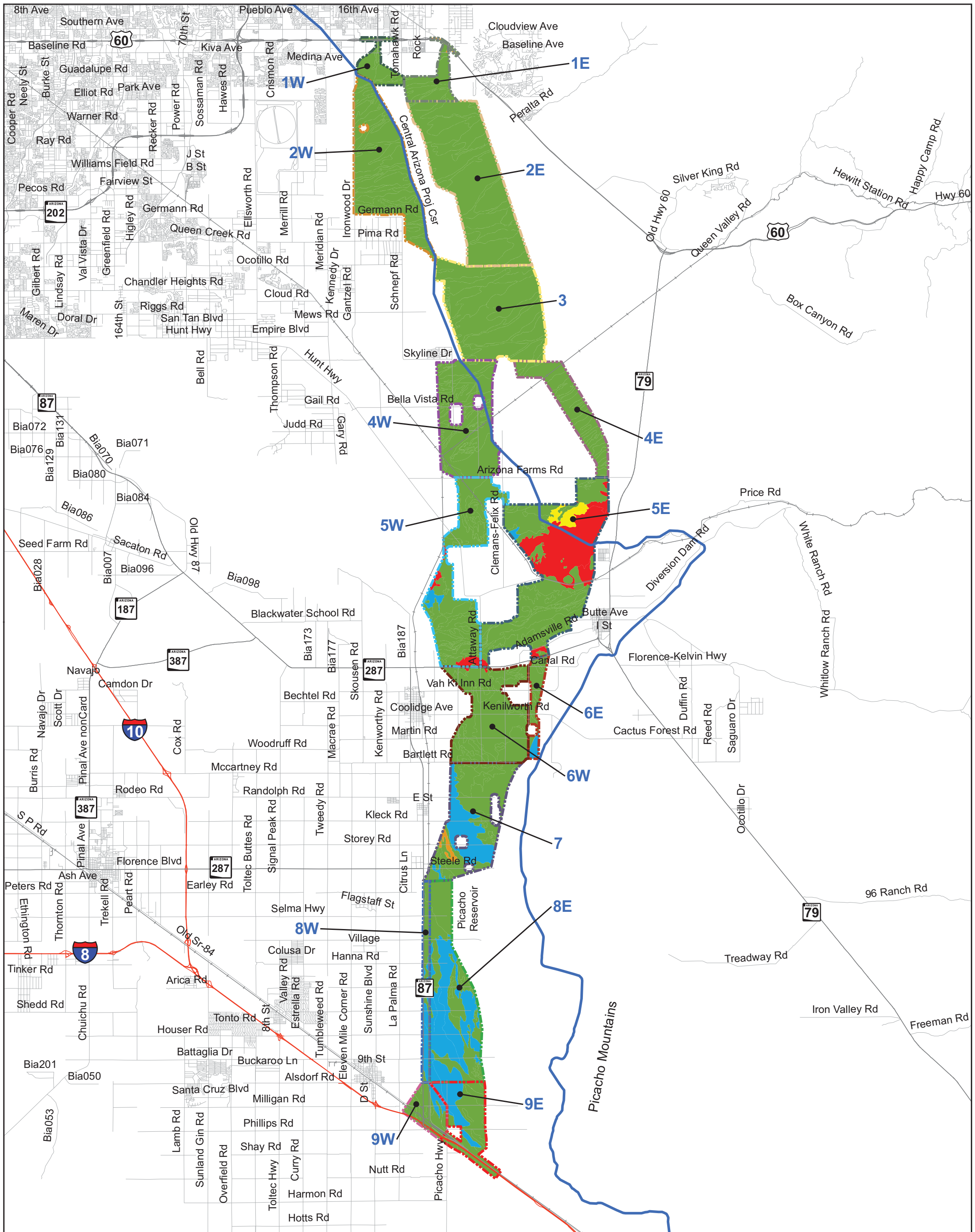
- CAP Canal
- Interstate Highway
- U.S. / State Highways and Freeways
- Local Roadway
- Railroad
- <00> Corridor Number

LEMax

- 0
- 2.9
- 5.9
- 7.5
- 8.9

NORTH

0 1 2 4 6 8 10 Miles



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Soils Gypsum

Figure 5

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Legend

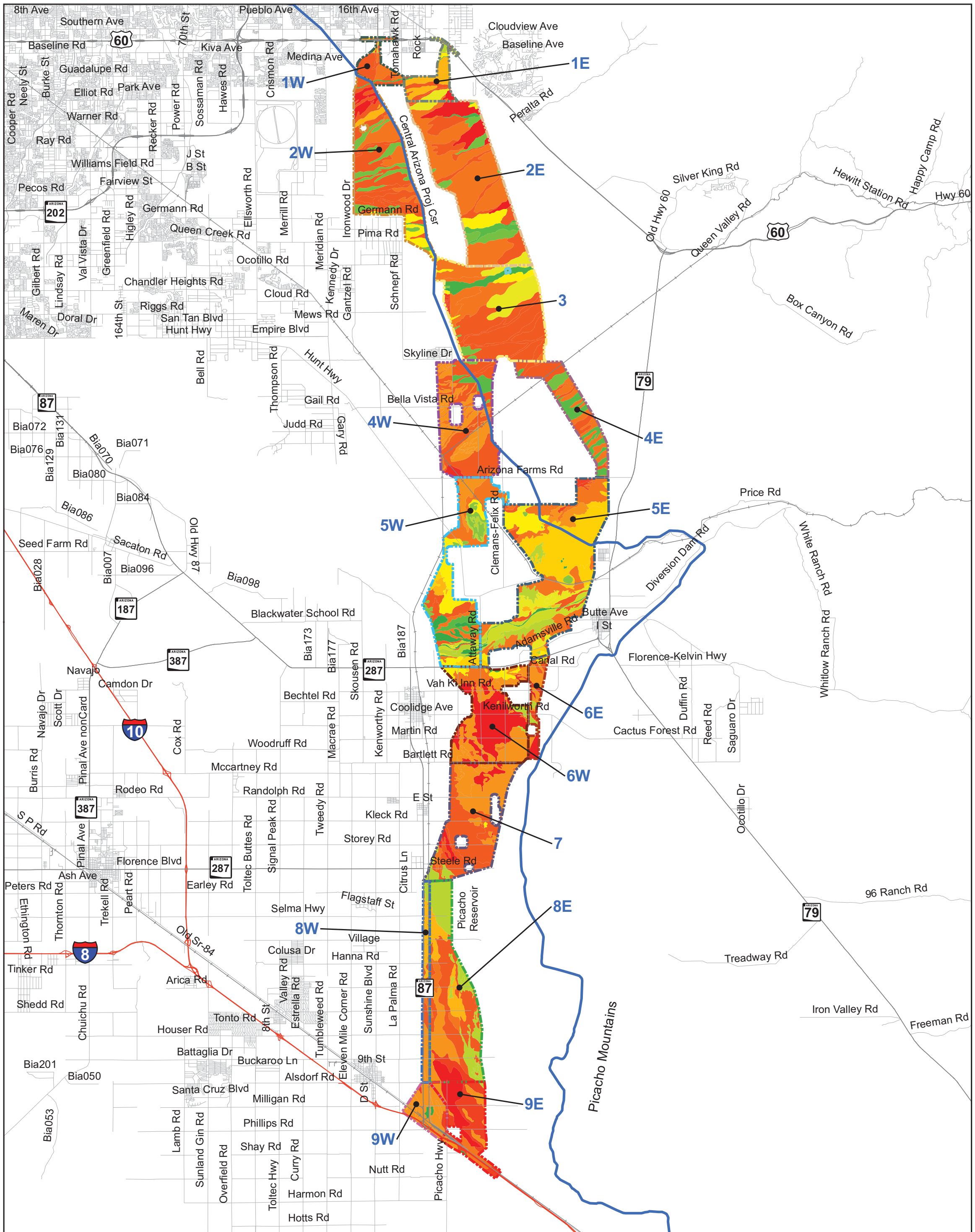
- CAP Canal
- Interstate Highway
- U.S. / State Highways and Freeways
- Local Roadway
- Railroad
- <00> Corridor Number

Gypsum

- 0
- 3
- 4
- 5
- 10

NORTH

0 1 2 4 6 8 10 Miles



NORTH–SOUTH CORRIDOR STUDY

Soils Passing #200 Sieve

Figure 6

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NORTH

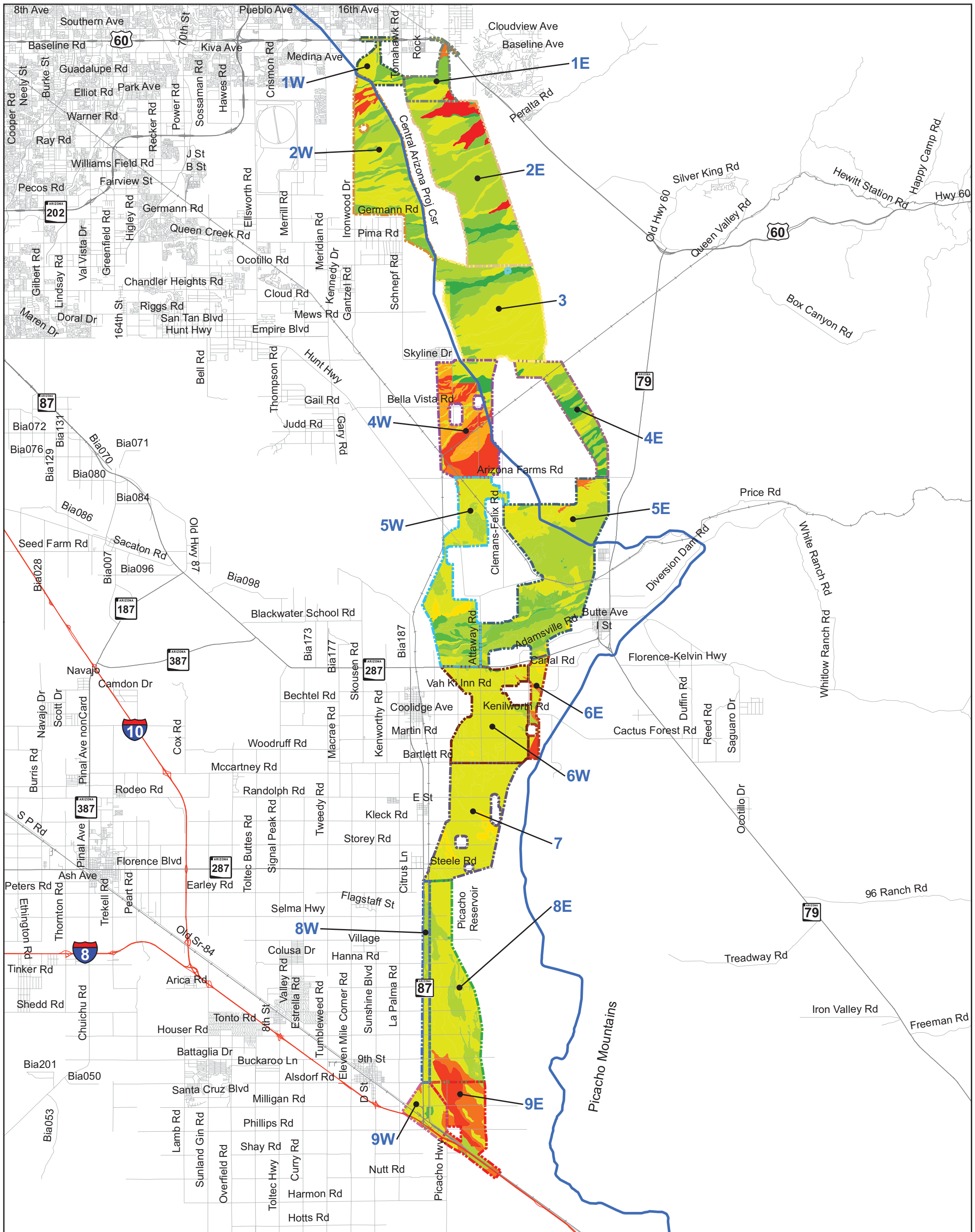
0 1 2 4 6 8 10 Miles

Legend

- CAP Canal
- Interstate Highway
- U.S. / State Highways and Freeways
- Local Roadway
- Railroad
- <00> Corridor Number

Max

0	25	50	80
7	30	55	85
15	35	65	90
20	40	70	95
	45	75	



NORTH–SOUTH CORRIDOR STUDY

Soils PI

Figure 7

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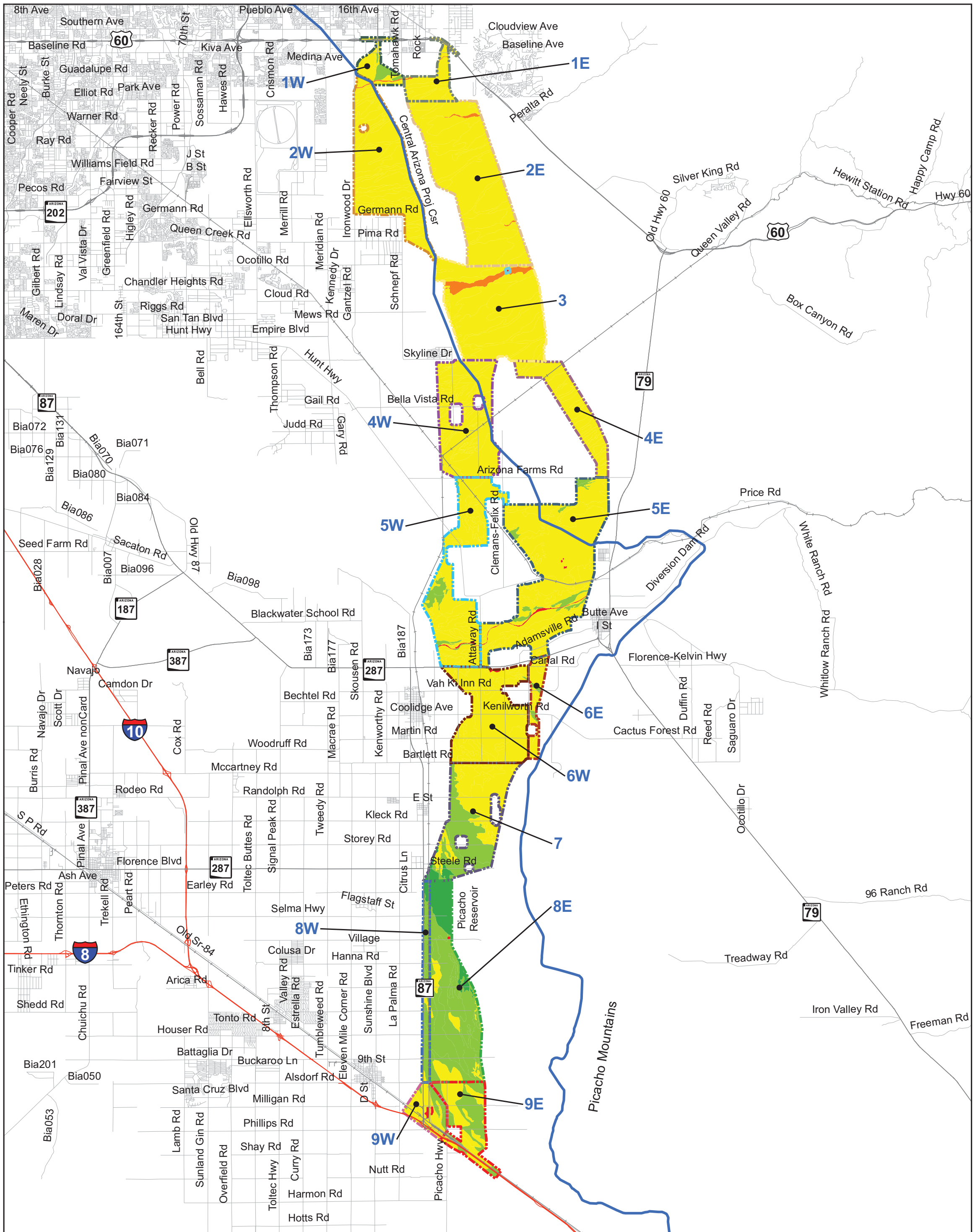
NORTH

0 1 2 4 6 8 10 Miles

Legend

- CAP Canal
- Interstate Highway
- U.S. / State Highways and Freeways
- Local Roadway
- Railroad
- <00> Corridor Number

PI_Max			
NP		20	
0		25	
5		30	
10		35	
15		45	



NORTH–SOUTH CORRIDOR STUDY

Soils pH

Figure 8

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NORTH

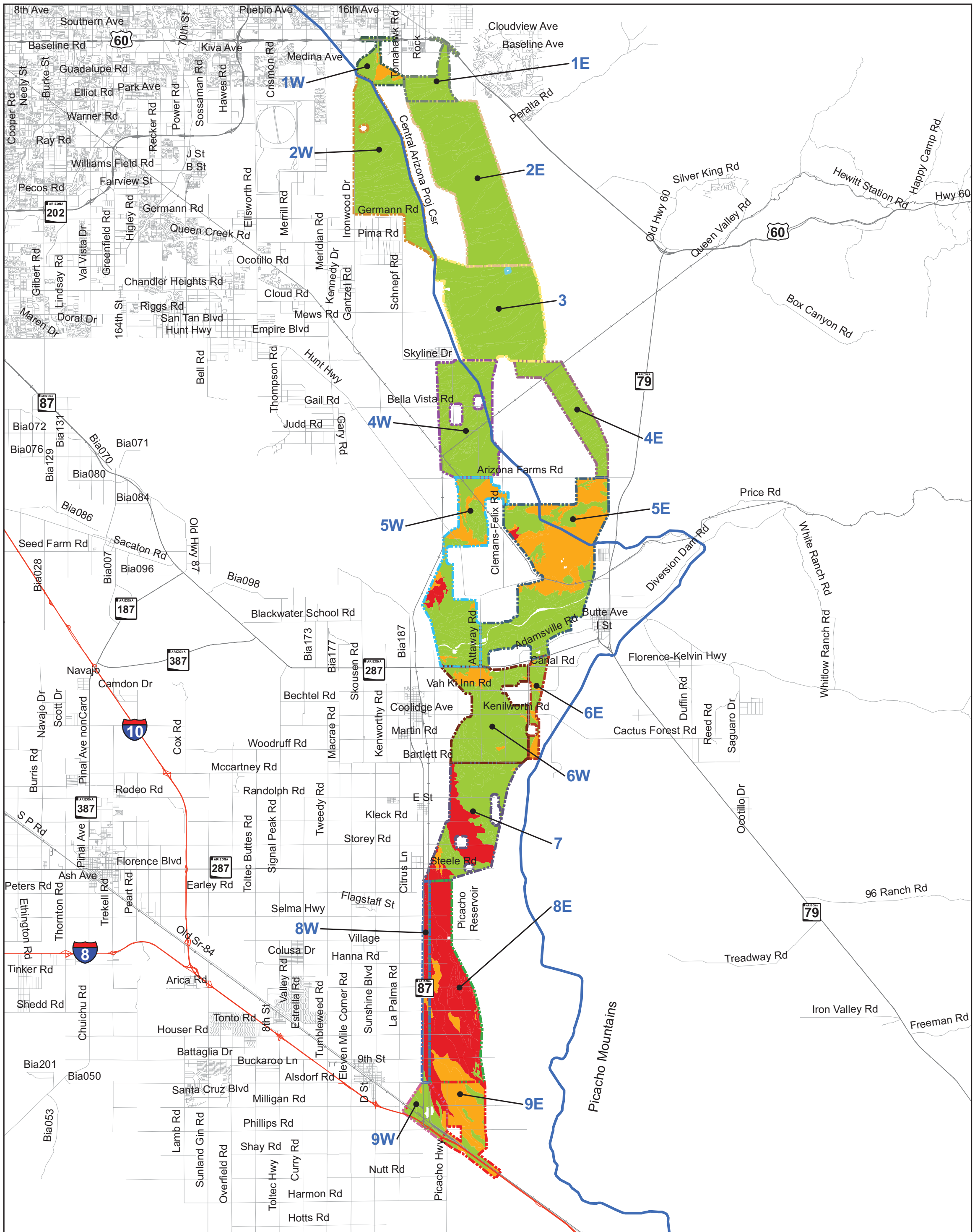
0 1 2 4 6 8 10 Miles

Legend

- CAP Canal
- Interstate Highway
- U.S. / State Highways and Freeways
- Local Roadway
- Railroad
- <00> Corridor Number

pH_Max

- 0
- 7.8
- 8.4
- 9
- 11



NORTH–SOUTH CORRIDOR STUDY

Soils Corrosion Potential for Concrete

Figure 9

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DRAFT 3-8-2011
Concepts are preliminary and subject to change/modification
Federal Aid No. STP-999-A(BBM)

Legend

- CAP Canal
- Interstate Highway
- U.S. / State Highways and Freeways
- Local Roadway
- Railroad
- <00> Corridor Number

Corrosion Potential

- High
- Moderate
- Low

NORTH

0 1 2 4 6 8 10 Miles

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