LAND SUBSIDENCE
& EARTH FISSURE INVESTIGATION - TASK 1

MARICOPA WATER DISTRICT PROPERTIES
NOS. 1, 2, AND 3 - 2,508 ACRES

MARICOPA COUNTY, ARIZONA

GEOLOGICAL CONSULTANTS INC.

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& EARTH FISSURE INVESTIGATION - TASK 1

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MARICOPA COUNTY, ARIZONA

MWD Project No. 99-03

Prepared For:

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Project No. 2002-136

August 5, 2002

NOTICE

The geologic and soils observations, findings, conclusions and recommendations presented in this report are based on (1) data from published and unpublished sources available at the time of this study, (2) photo-geological interpretation and (3) geological field reconnaissance of the properties. The services provided by Geological Consultants to the Maricopa Water District were performed according to generally accepted principals and standard practices used by members of the geological profession in this locale at the time of this study.

It must be recognized that subsurface geologic and soil conditions may vary from place to place and from those interpreted at locations where evaluations are made by the investigator. No warranty or representation, either expressed or implied, is or should be construed regarding geological or soil conditions at locations other than those observed by the investigators.

This report was prepared in accordance with the scope of work outlined in Geological Consultants proposal for geological services dated May 6, 2002 and as authorized by James Sweeney for the Maricopa Water District on May 21, 2002, for Maricopa Water District Project No. 99-03.

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REGISTERED GEOLOGIST
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LAND SUBSIDENCE
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1.0 INTRODUCTION

This report presents the results of a preliminary assessment of land subsidence and earth fissures (ground cracks) in the vicinity of Maricopa Water District (MWD) properties in the West Salt River Valley. The proposed development encompasses approximately 2,508-acres which is generally located between Perryville Road and the Beardsley Canal, stretching from Camelback Road to Bell Road in Maricopa County, Arizona (Figure 1). A detached portion of the property which occupies less than ½-square miles is located northeast of the corner of Citrus Road and Olive Avenue (Figure 1).

Information contained herein completes the Task 1 research phase as outlined in Geological Consultants Inc. proposal dated May 6, 2002. The objectives of this study are to compile information concerning land subsidence and earth fissuring at the proposed development to:

1) Assess land subsidence within and adjacent to the study area.
2) Identify suspect and known earth fissures within and adjacent to the study area.
3) Make appropriate recommendations in regards to the subsidence and earth fissure phenomenon that could potentially impact proposed development of the MWD properties.

1.1 Scope of Work

The scope of work for the land subsidence and earth fissure evaluation included the following activities designed to satisfy the objectives of the study:

- Review and summarize available data concerning site geology, groundwater withdrawal, land subsidence, and earth fissuring near the MWD property.

- Use available aerial photography for geological photo interpretation to identify suspect earth fissures that may present within and adjacent to the study area.

- Complete a geological reconnaissance of the parcel to verify, refine, and update earth fissure and land subsidence data compiled during Task 1.

- Compilation and analysis of the data gathered to prepare a preliminary earth fissure/subsidence map of the project area and target areas for the Task 2 earth fissure exploration program (if necessary).

- Preparation of this report documenting the Task 1 study findings and conclusions.

Geological Consultants Inc. used available research reports and maps from various sources including the Arizona Geological Survey, the U.S. Geological Survey, and unpublished consultant reports as part of its geological research database for this Task 1 study. The field reconnaissance of the site was conduced by Jason Williams, G.I.T. and Jesse Laurie, G.I.T under the supervision of Kenneth M. Euge, R.G.

2.0 CONCLUSIONS AND RECOMMENDATIONS

2.1 The study area is within an area of active land subsidence and earth fissuring. Research data indicates that land subsidence and related earth fissuring have been active for more than 50 years. Based on previous reports (Schumann, 1995 and SHB, 1981), measured land subsidence due to groundwater withdrawal within the study area ranges from about 2- to 6-feet. Subsidence rates during these periods range from about 0.182 feet per year to 0.035 feet per year.

2.2 West of and parallel to the project area, a recent unpublished consultants report (AMEC, 2002) reported leveling data along the crest of McMicken Dam for the years 1985-2001 and interferogram data for the years of 1996-2000. Both sets of data suggest subsidence was ongoing in the northern half of the study area throughout the year 2000.

The natural slope of the land surface throughout the parcel is to the east and southeast. Based upon the work by Schumann (1995), it would appear that greater subsidence has occurred on the east side of the property rather than on the west. When designing storm drains, sewers, or any other gravity dependant utility, the fact that future subsidence could increase the gradient to the east should be factored into the design of these structures.

2.3 Based on the results of previous investigations by other researchers and by Geological Consultants for this project, there are known earth fissures located east and west of the subject site (Figure 2). None of theses fissures project toward the subject development property.

2.4 Since the early 1900's, groundwater levels east of the study area have dropped from 300 feet to 500 feet (Schumann, 1986). Analysis of water level data (ADWR, 2002) from selected wells in the area indicates water levels have indeed dropped from 150 to 250 feet from the 1940's through the mid 1980's (Figure 3). Since the mid 1980's, water levels have stabilized somewhat and in some cases have increased from 50 to 150 feet (Figure 3). The water levels for the project area have not recovered to pre-pumping levels.

2.5 Analysis of historic elevation data suggest that residual land subsidence is continuing in the project area. However, the annual rate of subsidence appears to be diminishing with time as the basin and aquifer system reaches an equilibrium condition. If groundwater levels continue to rise or remain static, land subsidence rates could diminish to negligible levels over the next twenty to forty years.

Based on an analysis of the available data, supplemented with our field reconnaissance data, we consider the future earth fissure development potential to be low provided groundwater levels in the area remain static or start to rise. If groundwater levels in the future start to decline again, the potential for earth fissure development in the area could be rated moderate to severe depending upon the location of the pumping centers relative to the property.

Considering the locations of known earth fissures relative to the property and the present groundwater level conditions, no special preventive mitigative measures are recommended in relation to earth fissures.

2.6 Based on the results of our research, aerial photograph analysis, and field reconnaissance, in our opinion, the implementation of Task 2 described in Geological Consultants proposal is not required. No earth fissures were identified on the property, nor were any earth fissures identified that trend toward the property.

3.0 GEOGRAPHIC SETTING

3.1 Location

The proposed development lies within northern Maricopa County, approximately three-miles east of the White Tank Mountains. The land parcel is, for the most part, a ½-mile wide strip of land stretching from Camelback Road to Bell Road (Figure 1). Most of the land is undeveloped, native desert. The land between Bell Road and Greenway Road, while mostly undeveloped, has been graded and stripped of most of the natural vegetation. A University of Arizona agricultural facility is located between Greenway Road and Waddell Road. The property is surrounded by undeveloped land, as well as residential properties and agricultural areas.

3.2 Physical Features

Regionally, the project area is situated within an area referred to as the West Salt River Valley Basin. The basin is bounded on the north by the Hieroglyphic Mountains and Hedgpeth Hills, the east by the Union Hills, Phoenix Mountains and Papago Buttes, the south by South Mountain and the Estrella Mountains, and on the West by the White Tank Mountains, which are approximately 3-miles west of the project area. The White Tank Mountains rise to an elevation of 4,018 feet.

Maximum relief within the Project area is approximately 200 feet measured from the highest point located at a benchmark along Bell Road (elevation 1,335) the lowest point at Camelback Road and Perryville Road (elevation 1,135).

3.3 Climate and Vegetation

The climate of the area is arid to semiarid. Average annual temperature ranges from about 67° to 74° Fahrenheit (F) with summer maximums reaching more than 100° F and winter minimums below freezing (32° F). The precipitation is confined to essentially two seasons during the year, one in the summer and the other in the winter. Average annual rainfall is about 6 to 8 inches. Natural desert vegetation is dominantly creosotebush, mesquite, and paloverde (Hartman, 1977).

4.0 GEOLOGICAL EVALUATION

4.1 Site Setting

The site is located within the Sonoran Desert region in the north-central portion of the Basin and Range Physiographic Province near its boundary with the Transition Zone. The Basin and Range Province is characterized by northwest, north, and northeast trending mountains that rise abruptly from broad, elongated, deep sediment-filled valleys produced by block faulting and folding. The mountains and hills southeast of the proposed development area, the White Tank Mountains, are composed predominately of old, Pre-Cambrian age (570 million years ago (mya)) metamorphic and granitic crystalline bedrock, intruded by younger dikes. The bedrock is locally overlain by Tertiary age (66 mya to 1.6 mya) volcanic rock and Quaternary are (younger than 1.6 mya) alluvium. The basin fill within the valley commonly makes up the principle groundwater aquifer of the region.

Structurally, the region has been uplifted to its present position by episodes of mountain/basin bounding fault movements (Cooley, 1977). The tectonic episodes and deformation, evident in the orientation of foliation planes and joint dip set discontinuities exposed in the bedrock terrain, have provided the mechanics necessary for deep intermontane basins that were subsequently filled with sediment.

4.1.1 Basin Stratigraphy

The study area is situated near the west-central portion of a broad alluvium-filled valley, referred to as the West Salt River Valley Basin, that is bounded on the west by the White Tank Mountains. The alluvial deposits range in depth from a few feet near the mountains to more than 1,200 feet in the majority of the basin (Cooley, 1973). The maximum depth is unknown, but in the deeper part of Township 2 North, Range 1 West these deposits are estimated to be 10,000 to 15,000 feet thick (USDI, Bureau of Reclamation, 1977). The estimated thickness of the alluvial deposits at the MWD property ranges from greater than 800 feet to about 2,000 feet thick, based on an analysis of depth to bedrock data (Oppenheimer, 1980). The alluvium thickness/depth to bedrock increases to the east across the property.

The basin stratigraphy under the study area is typical of the stratigraphy found in the west Salt River Valley area. The study area is underlain by three distinct alluvial units: the lower middle, and upper alluvial units. Bedrock underlies the lower alluvial unit. The exact depth to basement rock under the study area is unknown, but is probably in the 800-feet to 2,000-feet depth range (Oppenheimer, 1981). The exact thickness of these units under the study area is unknown. These units are grossly subdivided into three zones:

Upper Alluvial Unit:	Gravel, and sand with lesser amounts of silt and clay. Mostly unconsolidated with locally strong cementation near mountain fronts and major stream courses (SGC, 2000).
Middle Alluvial Unit:	Silt, and clay with thin interbeds of silty sand and gravel. Mostly weakly consolidated, but moderately to well-cemented. Grades to fine-grained mudstone and evaporite deposits in the central part of the basin near Luke Air Force Base (Schumann, 1995).
Lower Alluvial Unit:	Silt, gravel, and conglomerate. The lower and older part of this unit is moderately to well-consolidated. Toward the center of the basin, east of the study area, the sediment grades to a finer-grained sand, silt and clay with intercalated massive evaporite deposits near Luke Air Force Base.

Due to the proximity of the MWD property to the White Tank Mountains, the middle alluvial unit may not underlie this area.

5.0 LAND SUBSIDENCE

5.1 Overview

Land subsidence is known to occur in alluvium filled valleys of Arizona where agricultural activities and urban development have caused substantial over-drafting or removal of groundwater from thick basin aquifers. The magnitude of subsidence is directly related to the subsurface geology, the thickness, and compressibility of the alluvial sediments deposited in the valleys, and the net groundwater decline This effect is clearly illustrated by comparing water level decline to measured subsidence along Northern Avenue (Figure 5). According to Bouwer (1977), land subsidence rate range from about one- hundredth to one-half feet per 10-foot drop in groundwater level, depending on the thickness and compressibility of the basin fill sediments.

5.2 Groundwater

The major human-induced factor contributing to subsidence is the large scale pumping and removal of groundwater. Nearly all of the populated southern Arizona basins from Phoenix to Tucson have experienced at least a 100+ foot drop in groundwater level, and an area surrounding the town of Stanfield, Arizona has dropped more than 500 feet (Schumann, 1986). The groundwater level east of the study area have dropped from 300 feet to 500 feet (Schumann, 1986).

5.2.1 Groundwater Use in the West Salt River Valley Sub-Basin

The 2,508-acre parcel is within the West Salt River Valley Sub-Basin, one of the seven groundwater sub-basins within the Phoenix Active Management Area (AMA) as defined by the Arizona Department of Water Resources (ADWR, 1994). Prior to 1923, the groundwater system in the West Salt River Valley was in equilibrium, recharge and outflow were balanced. Groundwater underflow was to the south toward the Gila and Salt Rivers. Agricultural activity increased dramatically in the 1930's by utilizing the large-scale pumping of groundwater. By 1923, 2.3 million acre-feet per year were needed to meet agricultural demands. As a result, groundwater flow directions were impacted due to the lowering of the water table. The water table decline appeared to reached its maximum in the mid 1980's. A significant groundwater sink, or lowering of the water table occurred northeast of the Luke AFB area causing groundwater flow direction to concentrate in that area (Schumann, 1995).

For approximately the last 20 years (since the mid 1980's) groundwater levels have either stabilized or increased as much as 125 feet in the project vicinity. This trend has also been noticed in areas east of the project location (Figure 6) This is likely in response to flood recharge, increased use of Central Arizona Project (CAP) water in lieu of groundwater, and possibly changes of land use from agricultural to urban. This slight increase had a negligible effect on the overall 300 feet decline in the groundwater table that occurred before 1978 (Schumann, 1995).

Analysis of water level data (ADWR, 2002) from selected wells in the area indicates water levels have indeed dropped from 150 to 250 feet from the 1940's through the mid 1980's (Figure 3). Since the mid 1980's, water levels have at least leveled out, and in some cases have increased from 50 to 150 feet (Figure 3). The water levels for the area have not recovered to pre-pumping levels.

5.3 Regional Subsidence

Prior to the utilization of groundwater resources within the Phoenix area, the water table was higher and hydrogeologic conditions were in equilibrium. Water levels within the aquifer were lowered when pumping was initiated and the basin fill sediments were dewatered. In the arid southwest, the water in the aquifer may be removed by pumping faster than it can be naturally replenished causing a net water table decline. As a result, the weight of the soil column is gradually increased as the buoyant effects and aquifer pressures induced by the water acting on the soil column are decreased. This condition causes increased loading stresses to consolidate portions of the thick compressible sediments that result in the lowering (subsidence) of the land surface over a large area.

Land subsidence was first documented in Arizona in 1934 following the releveling of first-order survey lines by the Coast and Geodetic Survey (now the National Geodetic Survey (NGS)). Subsequent leveling by the NGS, the U.S. Geological Survey, the Bureau of Reclamation, and the ADOT has documented substantial land surface subsidence in south central Arizona including the Salt River Valley, the Queen Creek Apache Junction area, and the Eloy Casa Grande Stanfield area as overdrafting of the aquifer continues.

Subsidence and earth fissures in urban areas can cause a variety of problems. Structures built across fissures may be damaged, street cracks, flow in gravity water and sewer lines can be reversed, and differential subsidence (although rare) can rupture buried utilities (Arizona Geological Survey, 1987). However, design measures can be implemented to mitigate the effects of land subsidence. Some of these measures can include additional structural reinforcement, over-sized pipes, surface drainage controls, bridging the subsidence feature, and avoidance.

5.3.1 Study Area Subsidence

Land subsidence is well documented within the project area. An NGS level line using benchmarks located along the Beardsley canal was used to record subsidence from 1948 to 1981 (Table 1). Figure 7 shows an overall view of subsidence within the West Salt River Valley between 1957 and 1991 as compiled by Schumann (1995). And continued releveling along the crest of McMicken Dam recovered relatively significant changes in elevation along the crest of the dam between 1985 and 1991 (Table 2). Interpretation of Interferogram data indicated that changes in elevations occurred between 1996 and 2000 for portions of the northern portions of the study area (Figure 8).

Table 1
Subsidence Along Beardsley Canal[1]

Location along Beardsley Canal	1948-1967		1967-1981		Total Subsidence 1948-1981 (feet)
	Subsidence (feet)	Subsidence Rate (ft/yr)	Subsidence (feet)	Subsidence Rate (ft/yr)	
Union Hills Road	-1.2	0.062	-1.2	0.088	-2.4
Bell Road	-1.9	0.099	-2.2	0.156	-4.1
Cactus Road	-1.7	0.090	-1.6	0.114	-3.3
Peoria Avenue	-1.6	0.083	-2.5	0.179	-4.1
Olive Avenue	-1.25	0.064	-1.05	0.077	-2.3

[1]SHB, 1981

Table 2
Subsidence Along Perryville Road[1]

Location along Perryville Road	1957-1991	
	Subsidence (feet)	Subsidence Rate (ft/yr)
Waddell Road	-0.1	Negligible
Peoria Avenue	-6.2	0.182
Olive Avenue	-2.4	0.071
Northern Avenue	-1.2	0.035
Glendale Avenue	-3.3	0.097
Bethany Home Road	-2.9	0.085
Camelback Road	-2.6	0.076

[1]Schumann, 1995

The available land subsidence data indicate that this has been an area of recorded active subsidence for nearly 55 years. Land subsidence in this area has probably been ongoing as long as farmers have been tapping into the regional aquifer to water crops. Recent data (last 20 years) seem to indicate that subsidence is ongoing even though the trend over the last 10 to 15 years has been one where the water table decline has either leveled out, or reversed and started to rise. Should water levels in the area remain static, or continue to rise, subsidence in this area will eventually cease.

The Beardsley Canal is ½-mile west of Perryville Road. The land subsidence data shown in Tables 1 and 2 show comparable subsidence rates where the north south trending level lines cross common east west trending streets (Olive and Peoria Avenues). Along Perryville Road, the calculated subsidence rate was 0.071ft/yr at Olive Avenue and 0.182 ft/year at Peoria Avenue (between 1957 and 1991). Along the Beardsley Canal, the subsidence rate was 0.077 at Olive Avenue and 0.179 at Peoria Avenue (between 1967 and 1981).

A Flood Control District of Maricopa County (FCDMC) report (Staedicki, 1995), reported that subsidence measurements taken at White Tanks FRS #3 (Figure 8)showed an overall increase in ground elevation at the toe of the dam. No explanation was given for this finding.

Data collected by Schumann (1995) reported subsidence amounts of 0.1 to 0.2 feet from 1957 to 1991 in this general vicinity. While these two sets of data are not in complete agreement, they do suggest that negligible subsidence has occurred in the vicinity of the Beardsley Canal between Bethany Home Road and Northern Avenue.

5.4 Earth Fissures

Fissures occur in unconsolidated sediments, typically near the margins of alluvial valleys or near the bedrock pediment edge where land water levels have dropped from about 200 feet to 500 feet below land surface (Schumann, 1986).

Fissures are initiated deep underground when tensile stresses exceed the strength of the soils. Tensile stresses induced by the subsidence continue to increase until the ground breaks to form earth fissures. The fissures then propagate upwards to intersect the ground surface. Examples of typical earth fissure characteristics are provided in Figure 9. Early signs of earth fissuring are small en echelon hairline cracks and irregular spaced depressions at the surface. As fissures develop, the cracks grow in length to create fissures 1 foot to more than 10 feet deep when subject to erosion caused by surface runoff. The fissures often have vegetation growing in them because the ground is commonly moister along the earth fissure. Other physical features associated with fissures are slump-related escarpments from one inch to a few inches in height, as well as a drainage pattern associated with the fissure that does not conform to the areas local drainage pattern.

Field evidence indicates fissures propagate upward and are exposed after overlying sediments are eroded by surface water runoff from rainfall or irrigation (Pewe, 1982). The surface expressions of the fissures are exaggerated because the initial hairline crack is attacked by water to create wide (10 to 20 feet) and deep (more than 15 feet) erosional gullies that often have vegetation growing in them. The fissures are commonly perpendicular to natural drainage channels. The length of the fissure at the ground surface varies, usually less than one mile but one fissure near Picacho is more than 9 miles long. These features are easily recognizable on aerial photographs and in the field except where the ground surface is modified by agricultural activities or urban development.

Other indirect investigation techniques, such as gravity surveys, can be used to interpret subsurface conditions that can influence earth fissure development. Gravity studies can be an important tool in predicting the location of potential earth fissure zones. One common use of gravity studies is to indirectly determine the depth to bedrock for an area. This is useful since isolated buried bedrock highs as well as sudden bedrock drop-offs (faults) make for favorable conditions for earth fissure development when combined with land subsidence.

Two separate gravity surveys have been conducted in the study area vicinity. One was at a regional scale (Oppenheimer, 1980), and one was site specific for the McMicken Dam structure analysis (AMEC, 2002). The Oppenheimer map estimated the depth to bedrock under the study area to be from 800 feet to about 2,000 feet below ground surface, with the depth to bedrock increasing to the east. No unusual buried bedrock highs were interpreted within the project area from this data. An unpublished report (AMEC, 2002) shows the results of a gravity study in the McMicken Dam portion of the project area. The gravity results in the AMEC report showed a prominent bedrock drop-off to the east along the Beardsley Canal. Earth fissures commonly form at these drop-off locations in response to (lowering of water table, and consolidation of basin fill sediments). To date, however, the only documented earth fissures are at the south end of McMicken Dam, about ½-mile west of the property. These fissures do not trend towards the property. The results of these studies show that the western border of the property is a likely candidate area that could experience future earth fissure activity. However, if the water table in the area continues to rise, there should be a low probability for earth fissures to develop in the future.

5.4.1 Known Earth Fissures in the Project Vicinity

Known earth fissures are fissures that have been documented by others or were verified during the field reconnaissance. Earth fissures have been documented in the vicinity of the MWD property (Figure 8). The fissures mapped adjacent to the east and west property boundary trend in a north/south direction. Projecting the potential future growth of these fissures, it does not appear that they will directly affect the MWD property. The earth fissures west of the property near McMicken dam are likely related to shallow bedrock (Fenne Knoll) in the area providing a hinge point for earth fissure formation. The earth fissures documented east of the property have likely developed around the margins of the Luke Salt Body (Figure 7).

5.4.2 Known Earth Fissure Within the MWD Property

Based on our review of available literature, no known earth fissures have been previously documented within the MWD property. According to a Maricopa County Flood Control District report (Staedicke, 1995) the area in the vicinity of White Tank FRS#3 was searched for earth fissures by a consultants study in 1981. As a result, no earth fissures were found. This reconnaissance would have included our project area from Bethany Home road to Northern Avenue. An analysis of available aerial photography (ADOT, 1989) revealed some suspect features (potential earth fissures) within the property. However, these features were either abandoned irrigation canals or lines of desert vegetation not related to fissuring. The result of a ground truth (on-foot) reconnaissance of the entire 2,508-acre property found no surface evidence of earth fissuring on the subject property. Only a small portion of the property cannot be characterized as undeveloped desert. Almost the entire area between Bell Road and Greenway Road is graded. A University of Arizona agricultural center occupies a large chunk of land between Greenway Road and Waddell Road. Earth fissures that may have developed in these areas would have had their surface expression obscured by surface grading activities.

5.4.3 Future Potential Earth Fissure Development

The potential for future earth fissure development on the subject property should be considered low for the following reasons.

- Subsidence has been documented throughout the property since 1948. And even though most of the property has remained in an undisturbed natural state, no earth fissures, or evidence of earth fissuring, have developed on the property.

- Groundwater decline in the project vicinity has either ceased or reversed based upon well data obtained from the Arizona Department of Water Resources. If this trend continues, subsidence, and related earth fissuring, will decrease in the area and eventually cease.

- The future development of earth fissures in response to excessive groundwater withdrawal will likely occur along pre-existing zones of weakness where earth fissure presently exist. Existing earth fissures provided a foci along which additional tensional stresses can be relieved. Although the existing earth fissure lengths could be extended, new fissure development would likely be confined to a relatively discrete zone(s) defined by existing earth fissures.

Should water levels in this area, at some point in the future, reverse the current trend and start to decline, the earth fissure potential for this area should be revised to moderate. This would be due to continued subsidence and the presence of the interpreted "hinge" point located approximately under the Beardsley Canal (Figure 8).

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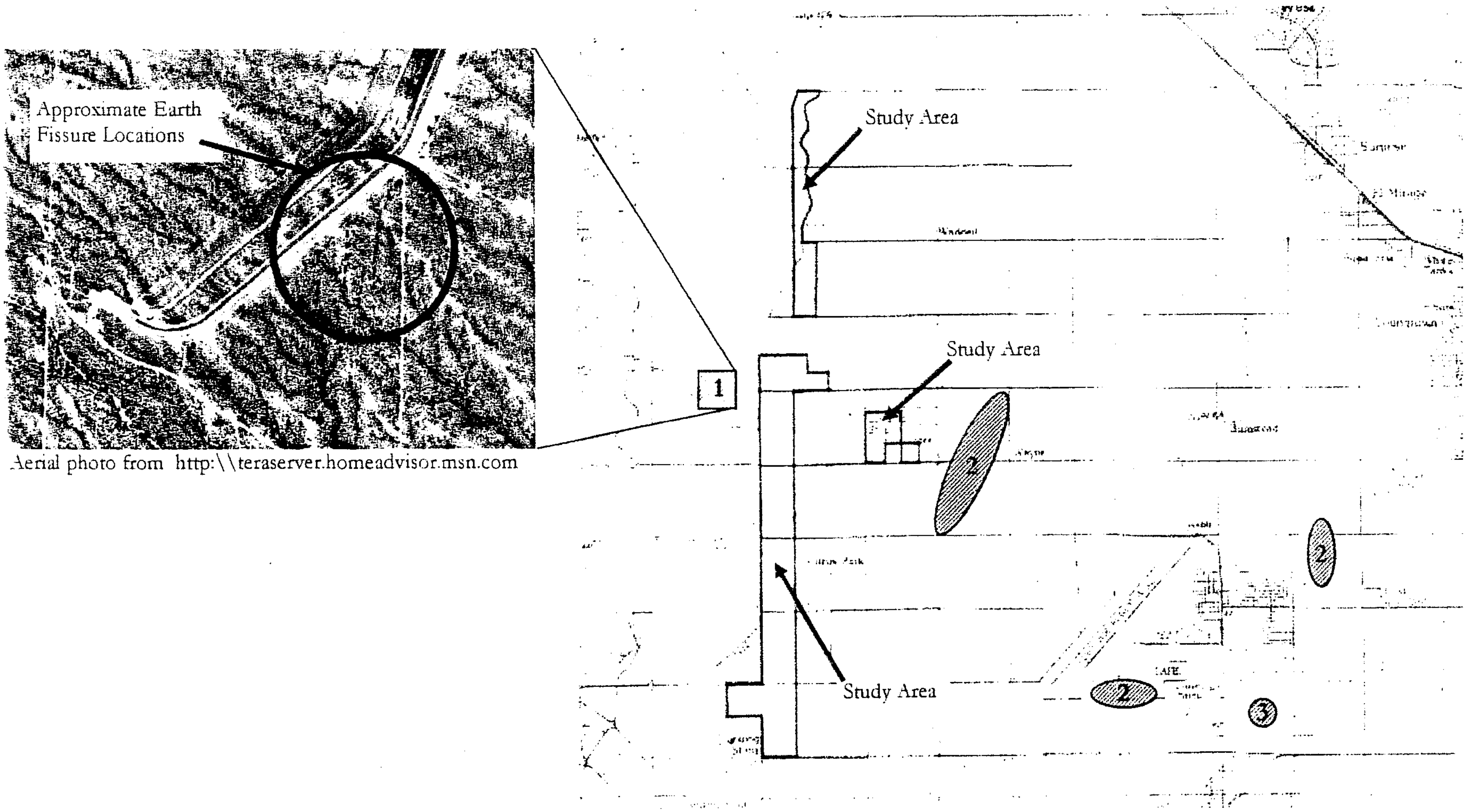
Figures



Aerial photo from http:\\teraserver.homeadvisor.msn.com

Base Map: USGS Phoenix North 15' Quadrangle.

EXPLANATION:

(2) Generalized locations of previously mapped earth fissures. Number indicates appropriate reference. (1) - AMEC, 2002; (2) Schumann, 1995; and (3) Geological Consultants, 1998.

- - - - Approximate trend of earth fissures.

N

Not to Scale

Maricopa Water District Properties
Land Subsidence and Earth Fissure Investigation

Figure 2
Earth Fissure Location Map

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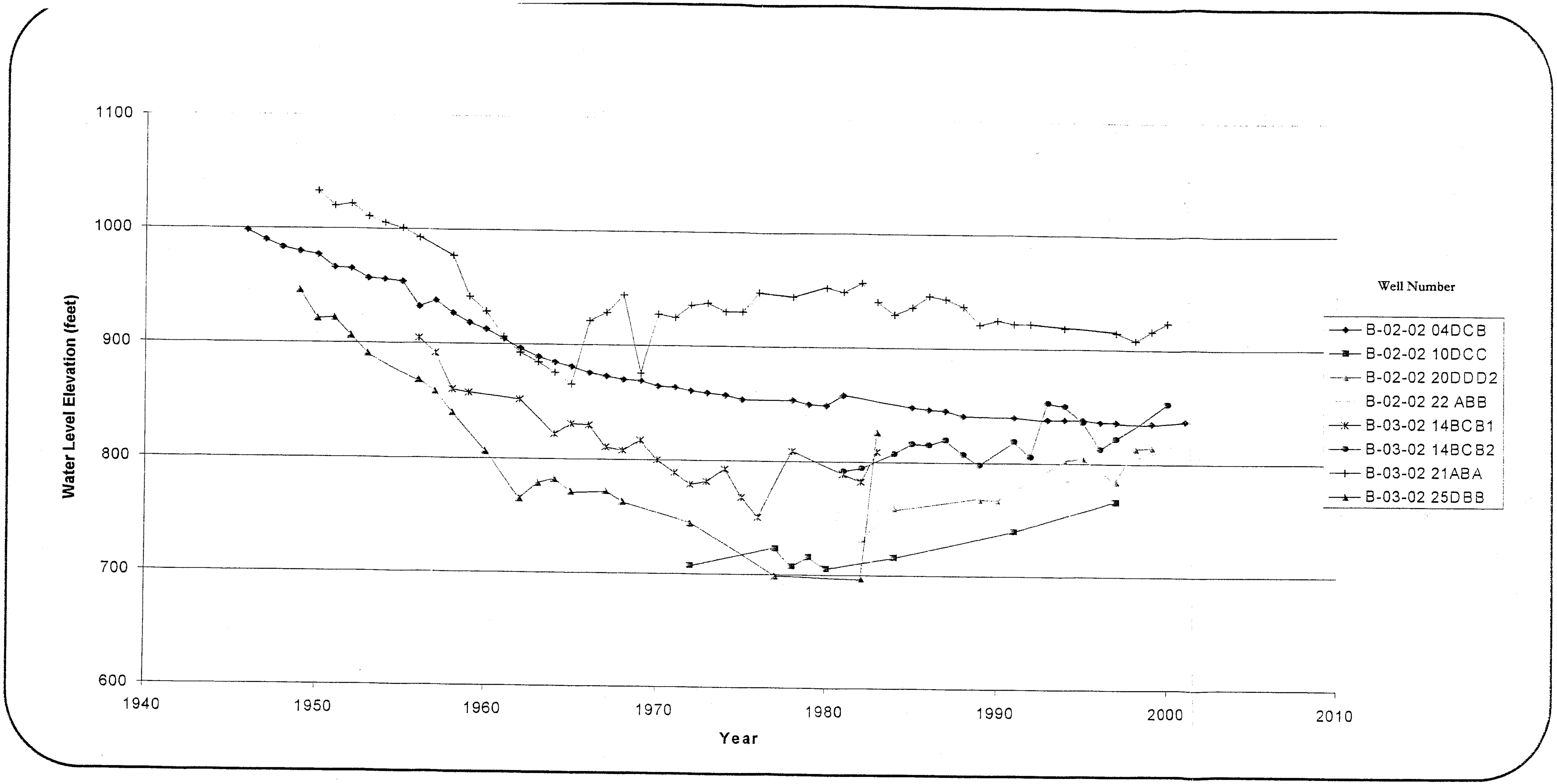
2333 West Northern Ave. Ste 1A
Phoenix, Arizona 85021



Note: Refer to Figures 4a and 4b for well locations.

Water level data source: ADWR, 2002

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Figure 3
Water Level Hydrograph

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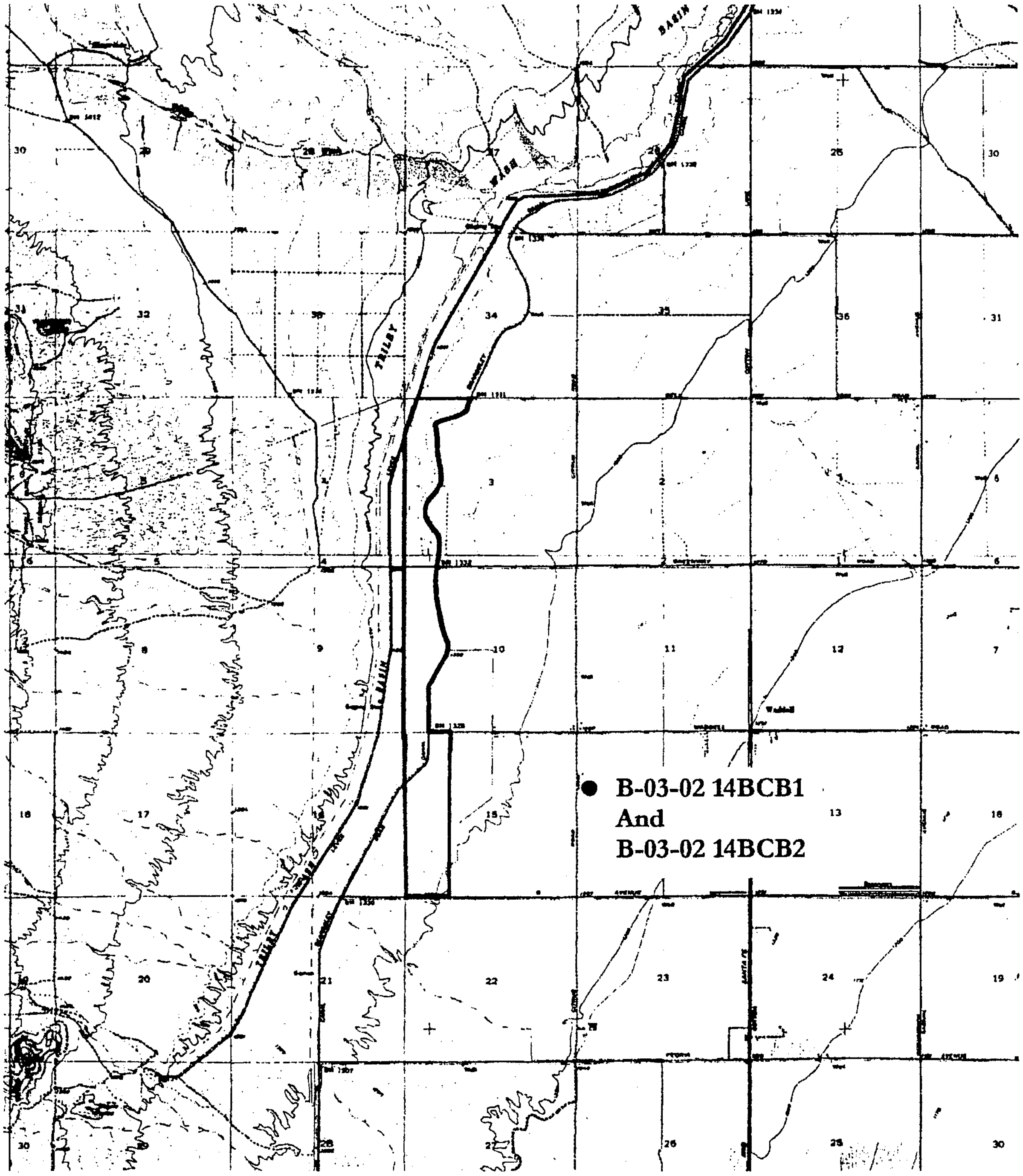

Well location source: ADWR, 2002

N

Not to Scale

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Figure 4a
Well Location Map—North Study Area

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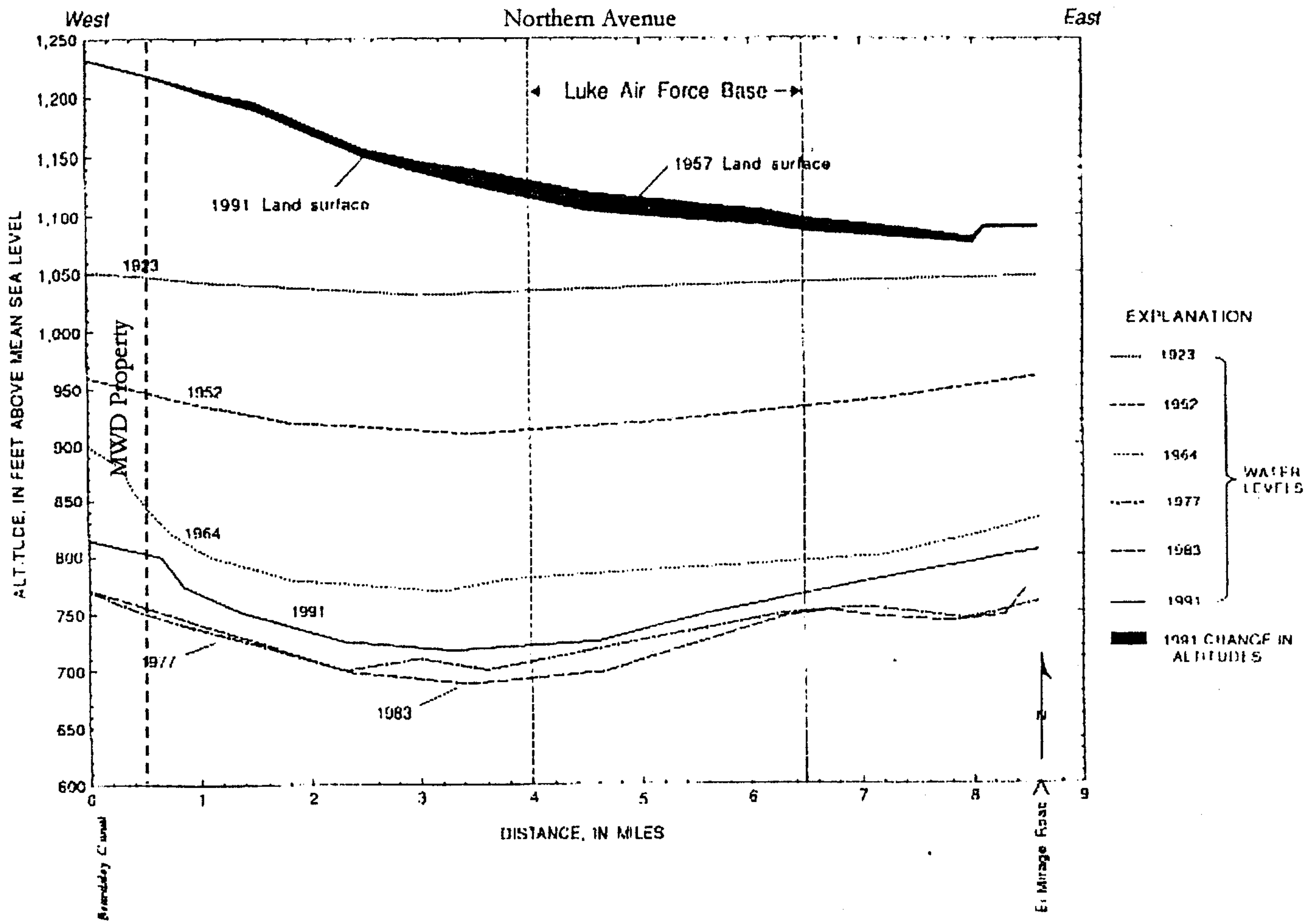

Figure modified from Schumann, 1995

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Figure 6

Incremental Subsidence and Water Level Decline / Northern Ave

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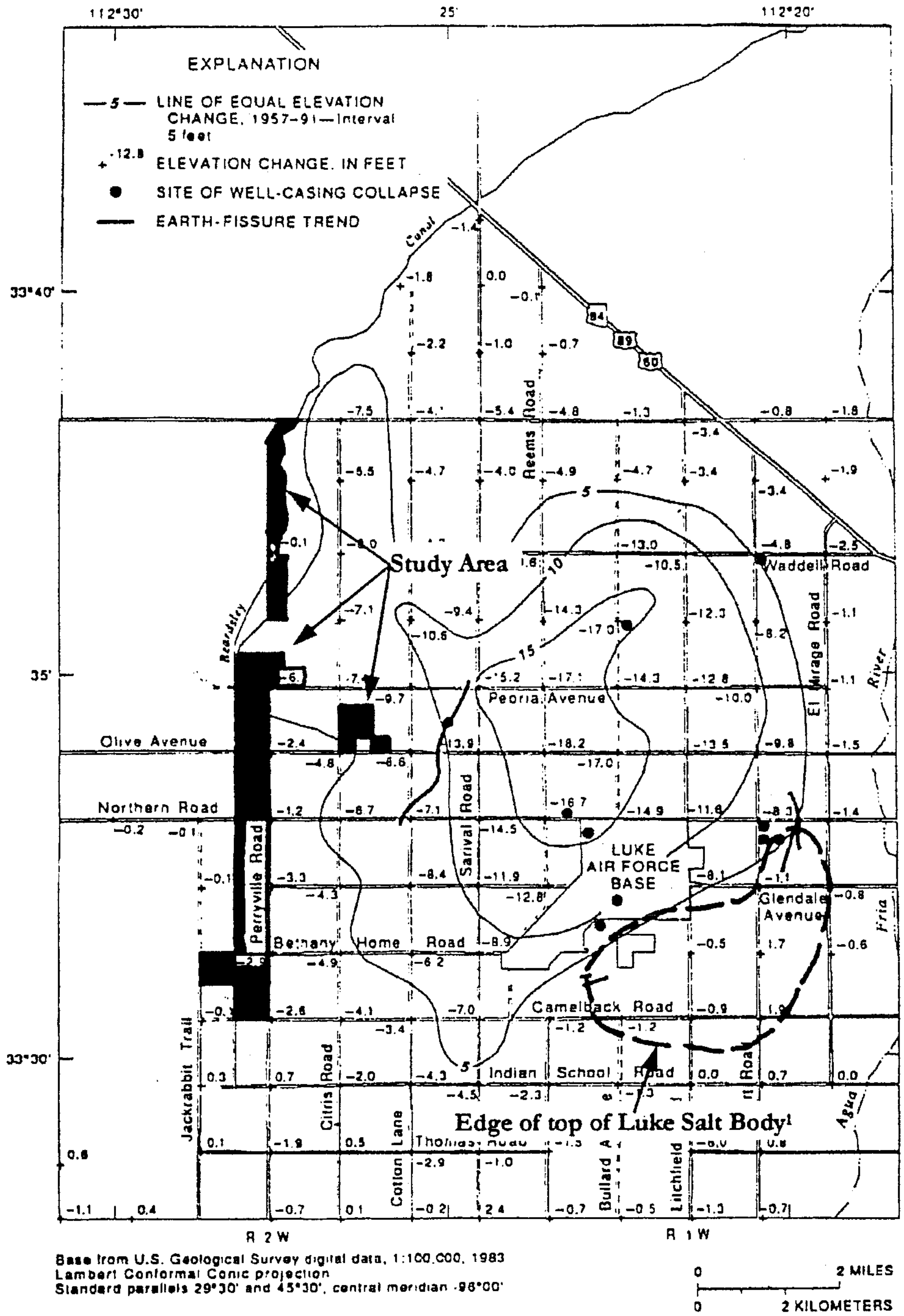

Figure modified from Schumann, 1995

[1]Eaton, 1972

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Figure 7
West Valley Subsidence Map 1957-1991

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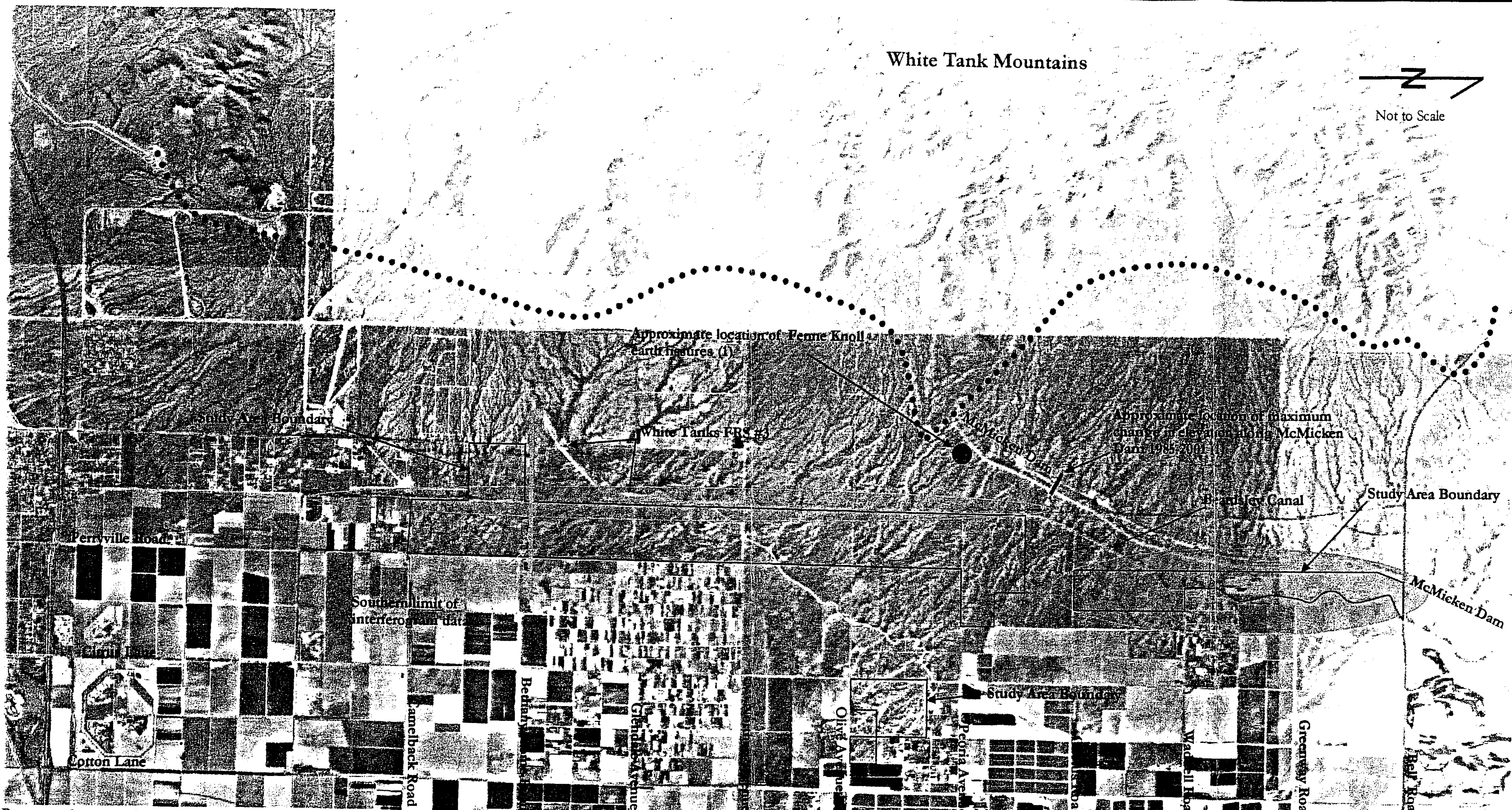

Base map from: http:\\teraserver.homeadvisor.msn.com

Explanation:

Interpretation of gravity data indicates a possible hinge point for fissure development exists in this area. (1)

Areas within or adjacent to property where interferogram data (1) indicates ongoing subsidence 1986 to 2000. (1)

• • • • • • Approximate location of basinward pediment boundary. (2)

Reference:

(1) AMEC, 2002
(2) Field, 1991

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Figure 8
Compilation of Subsidence Related Ground Conditions

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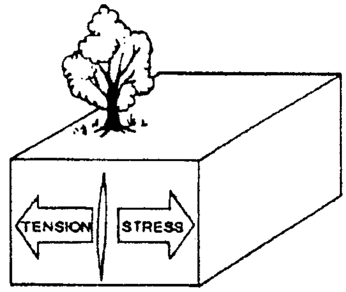
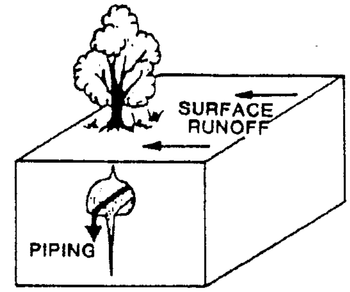
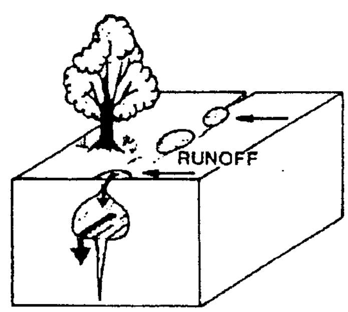


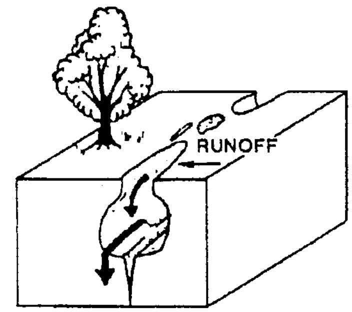
1. Lateral stresses induce tension cracking



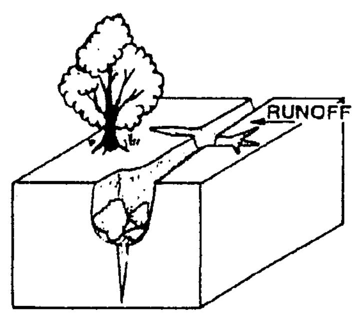
2. Surface runoff and infiltration enlarge crack through subsurface piping



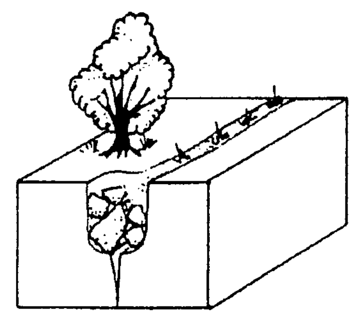
3. As piping continues, fissure begins to appear at surface as series of potholes and small cracks



4. As infiltration and erosion continue, fissure enlarges and completely opens to surface as tunnel roof collapses



5. The entire fissure is opened to the surface and enlargement continues as fissure walls are widened, extensive slumping and side-stream gullying occur



6. Fissure becomes filled with slump and runoff debris and is marked by vegetation lineament and slight surface depression, it may become reactivated upon renewal of tensile stress

Figure from Pewe, 1982.

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Figure 9
Generalized States of Earth Fissure Development

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