Revisiting earth fissures near Luke Air Force Base, central Maricopa County, Arizona

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Arizona Geological Survey

Strongly cemented carbonate beds drape across an earth fissure near Luke Air Force Base.

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Introduction

In February 2013, the Arizona Geological Survey (AZGS) was approached by NCS Consultants, LLC to assist in characterizing the state and extent of a zone of earth fissures near Luke Air Force Base (Luke AFB) in central Maricopa County. Some of these earth fissures underlie West Northern Avenue, which is currently in the design and early construction phase of a multi-million dollar Northern Parkway project (NCS Consultants, LLC, personal communication, February 2013). This zone of earth fissures appears on the AZGS Luke earth fissure study area map (AZGS, 2009). Geotechnical engineers tasked with designing the parkway want to account for the potential effects of continued land subsidence, erosion, and collapse along earth fissures near and beneath the roadway in order to minimize possible damage and repair to the parkway in the future. As part of this project they characterized the current state, appearance, and distribution of earth fissures in the vicinity of planned parkway construction. Previously mapped earth fissures on both sides of West Northern Avenue, between North Dysart and North El Mirage Road, were examined to compare current fissure conditions and extent with those depicted on the AZGS earth fissure map of the Luke study area (AZGS DM-EF-8) published in 2009.

The Luke earth fissure study area covers approximately 70 square miles located in central Maricopa County, Arizona east of the White Tank Mountains in the western Phoenix Valley (Fig. 1). This map combines previous earth fissure mapping with high-precision, GPS-controlled mapping conducted by the AZGS in 2008-2009. It is one of seven AZGS earth fissure maps in Maricopa County and 24 throughout southern Arizona. Earth fissures result from differential land subsidence driven by fluid withdrawal (groundwater in Arizona)

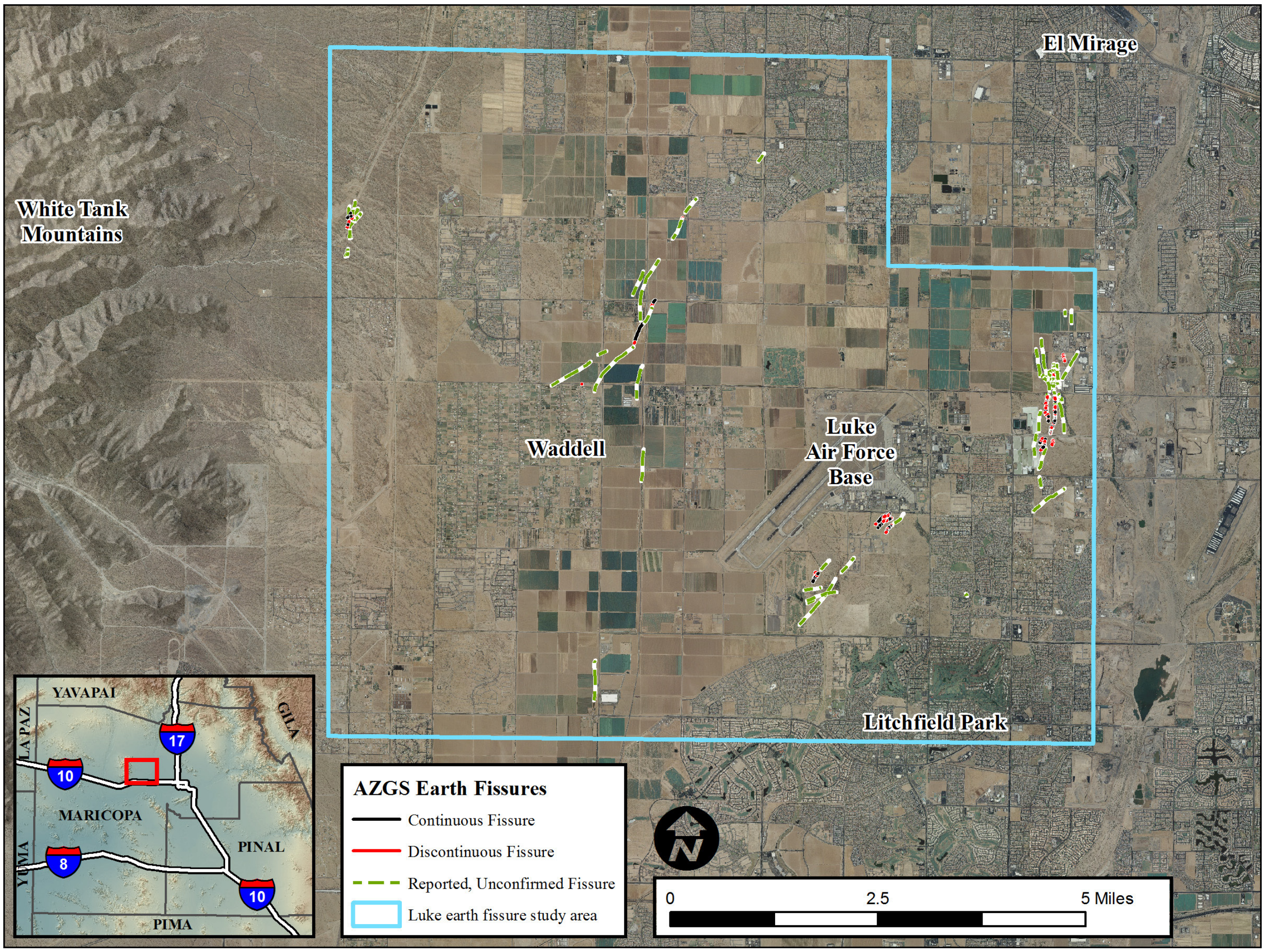

Figure 1. Location of AZGS Luke earth fissure study area and mapped earth fissures in central Maricopa County, Arizona. Aerial imagery from 2010 National Agricultural Imagery Program (NAIP) shows the extensive modern agricultural footprint in the west Phoenix Valley.

and occur in many deep sedimentary basins throughout southern Arizona and the southwest United States including California, Nevada, and Utah. The continuing appearance of new earth fissures and their impact on the landscape has prompted new considerations for infrastructure planning, design, development, and repair in areas affected by land subsidence and fissures. Planning and design for recent highway widening and overpass construction in the Luke study area incorporates strategies for managing continued land subsidence and the effects of earth fissures. The additional upfront cost of designing structures capable of mitigating the effects of earth fissures and land subsidence projections may save money in the long run when considering the cost of potential future repairs and maintenance related to damages from continued erosion along earth fissures and alteration of regional topography due to land subsidence.

Geologic setting

The Luke earth fissure study area is located in the Luke basin in the western Salt River Valley of the Basin and Range physiographic province of southern and central Arizona. Luke is one of many deep, broad alluvial basins bound by comparatively narrow fault block mountain ranges. Mountain ranges surrounding Luke basin include the White Tank Mountains to the west, Sierra Estrella Mountains to the south, and Heiroglyphic Mountains and numerous inselburgs to the north and northeast, respectively. Depth to bedrock in the Luke earth fissure study area ranges from less than 400 feet near the base of the White Tank Mountains on the western edge of the study area to greater than 11,200 feet near the eastern edge (Richard et al., 2007). The Luke basin contains a great volume of evaporite deposits indicating the basin was initially closed as it filled, allowing the accumulation of salts from a saline lake over time. The greatest depth to bedrock in the study area corresponds with the thickest region of the Luke Salt Body and shallowest depth to salt, 500 feet or less (Fig. 2, Rauzi, 2002a). The Luke Salt Body is a large salt dome or in situ evaporite prism approximately 9 miles (15 km) long, 6 miles (10 km) wide, and possily up to 10,000 feet thick (Eaton et al., 1972; Gootee, 2013; Rauzi, 2002b). Salt deposits of this size are not typically associated with non-marine origin but geochemical analysis has shown the salt likely precipitated from a saline lake in a closed basin prior to integration of the Salt-Gila River system (Eaton et al., 1972, Peirce, 1974). Younger (latest Pliocene to Holocene) valley fill alluvium including distal fan deposits derived from surrounding mountain ranges and piedmonts as well as alluvium deposited by the Agua Fria and New River from the north and Salt and Gila River to the southeast overlies more consolidated basin fill deposits throughout Luke basin (Field and Pearthree, 1991). Unconsolidated sediments filling the upper levels of Luke basin have been a source of groundwater in the area since the early 1900s.

History of land subsidence and earth fissures near Luke Air Force Base

In the late 1930s to early 1940s large-scale agricultural pumping had begun in the west Phoenix Valley near Luke AFB. By 1961, groundwater levels had dropped 150 feet; by 1977, groundwater had dropped 300 feet (Schumann and O'Day, 1995). Earth fissures were first documented in the fall of 1959 near an agricultural well field east of Luke AFB that had been pumping between 4,000 and 8,000 acre-feet annually since 1936 (Robinson and Peterson, 1962; Stulik and Twenter, 1964).

Large-scale groundwater withdrawal in excess of recharge can result in land subsidence, which can lead to formation of earth fissures. Robinson and Peterson (1962) demonstrated that earth fissures result from differential subsidence over buried bedrock topography driven by groundwater withdrawal. Schumann and Poland (1969) built upon this idea by associating earth fissure locations with steep Bouguer gravity gradients, suggesting many earth fissures occur above buried fault scarps. Subsequent studies have utilized gravity and seismic refraction surveys to confirm earth fissures form in areas of differential land subsidence above buried bedrock topography, usually within 1,000 ft of the surface (Raymond, 1985; Pankratz et al., 1978). Earth fissures also form near the margins of sedimentary basins where alluvial thickness tapers near the mountain front, above abrupt lateral facies change in basin filling sediments, and above other shallow relatively incompressible subsurface irregularities such as clay and salt bodies (Fig.2).

The AZGS earth fissure map of the Luke study area includes 2.8 miles of continuous and discontinuous earth fissures and 12.3 miles of previously mapped but unconfirmed earth fissures (Figure 1, AZGS, 2009). On AZGS earth fissure maps, continuous earth fissures represent uninterrupted, open earth fissures and fissure gullies, while discontinuous fissures include linear trends of intermittent elongated depressions, potholes, abbreviated open cracks, and other collapse features. Discontinuous earth fissures represent incipient surface expression of a collapsing earth fissure. Unconfirmed earth fissures were previously mapped and documented by Professional Geologists yet could not be confirmed during ground truthing by AZGS geologists. Some previously mapped earth fissures have since been covered by residential and commercial development, agricultural tilling, or are

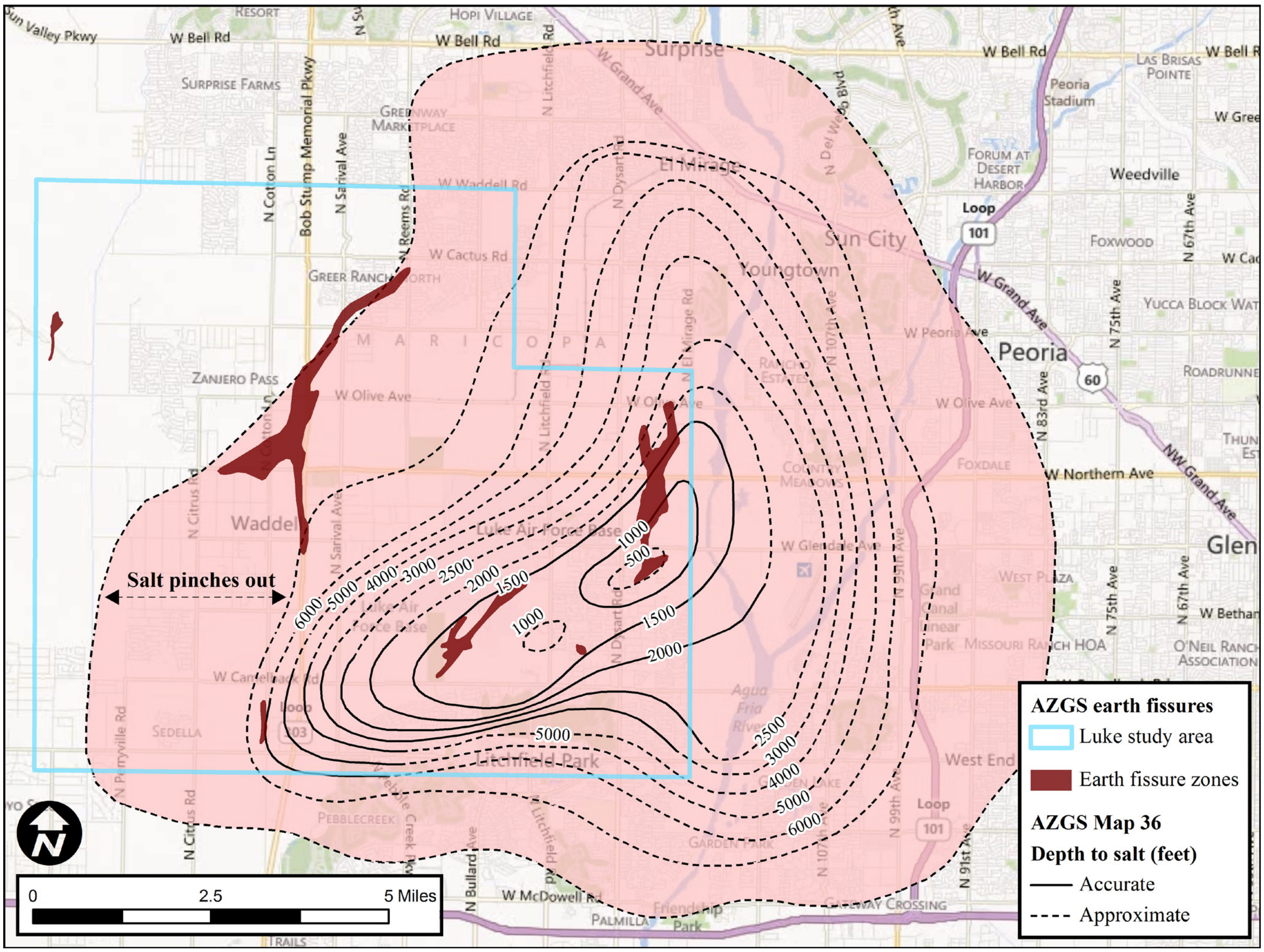

Figure 2. Location of earth fissure zones relative to near-surface salt deposits in the Luke earth fissure study area. Dramatic subsidence of over 18 feet centered several miles northwest of the salt dome crest has driven the formation of earth fissure zones above the ridge of the underlying salt dome. Fissure zones nearer the west edge of the study area may be related to subsidence over buried bedrock ridges, clay bodies, or other subsurface irregularities. Depth to salt contours digitized from Rauzi's (2002a) Luke salt deposit map.

otherwise obscured through subsequent erosion or alteration of the landscape. In instances such as these, the previously mapped earth fissures are included in the AZGS map as "unconfirmed" earth fissures.

Economic impact of land subsidence and earth fissures in Luke Basin

Land subsidence and earth fissures in the Luke study area have caused tens of millions of dollars in damages including drainage reversal of the Dysart Drain system, flooding of large portions of Luke Air Force Base (AFB), redesign and construction of new drainage networks, and repeated road repair (Schumann and O'Day, 1995). The Dysart Drain is a large flood control structure located along the northern boundary of Luke AFB. By the early 1990s up to 13.6 feet of local land subsidence caused reduction in slope of a portion of the drainage system, greatly reducing the capacity of the system. On September 20, 1992, heavy rains exceeded the capacity of the Dysart Drain system leading to extensive flooding across Luke AFB. Base closure and cost to clean up flooded areas exceeded $3 million. The cost to redesign the Dysart Drain system to accommodate land subsidence was estimated to exceed $16 million (Schumann and O'Day, 1995). Ongoing vertical offset along earth fissures underlying West Northern Avenue between North Dysart Road and North El Mirage Road has resulted in recurring damage to the road surface, requiring monitoring and repair. Periodic collapse of surface sediment into subsurface voids associated with earth fissures impacts local businesses and renders some portions of property unstable.

Land subsidence and earth fissure monitoring

The Arizona Department of Water Resources (ADWR) has been monitoring land subsidence using Interfermometric Synthetic Aperture Radar (InSAR) throughout central and south-central Arizona since 2002 (ADWR, 2013a) and has access to InSAR data in Arizona from the early 1990s forward. This method utilizes satellite-based instruments to collect data for the same area throughout the year. One dataset is compared to another to discern deformation of the land surface for that period of time with centimeter-scale resolution. InSAR data allows detailed measurement of land subsidence across large areas rather than single point measurements obtained through traditional surveying methods and portrays changing subsidence patterns through time. ADWR collected InSAR data in Luke basin at frequencies ranging from monthly to several times a year since 1992. A data gap exists from 2000 to late 2002 because no InSAR satellites were available to collect data in southern Arizona for that period of time. InSAR data indicates mild to moderate land subsidence is ongoing in areas with the most dramatic land subsidence prior to the 1991 survey. Two additional subsidence areas are evident in the InSAR data; one northwest of the US60/Arizona Loop 101 near El Mirage, and another to the southwest in Peoria (Fig. 3). The changing position of land subsidence over time reflects changing groundwater withrawal patterns, land use change, and the effects of decades of compaction of basin sediments in response to lowering of groundwater levels in certain parts of the Luke basin. Areas that experienced the most dramatic subsidence in the past may not be prone to comparable subsidence in the future due to the level of compaction already realized.

Irrigated agricultural operations remain widespread throughout Luke basin (Figure 1) although groundwater levels have been recovering throughout much of the basin since the early 2000s (ADWR, 2013b). Continued land subsidence despite rising groundwater levels indicates basin sediment compaction due to groundwater withdrawal may continue for years to decades following long term lowering of groundwater levels, even while recharge occurs. Recent land subsidence in Luke Basin is low relative to other areas in the west Salt River Valley (Fig. 3). Because groundwater withdrawal has been ongoing in this area since the 1930s it is possible most land subsidence resulting from lowering of groundwater levels has already occurred. However, because significant land subsidence due to groundwater withdrawal continues nearby in the vicinity of El Mirage and Peoria (areas A and B in figure 3), and to a lesser degree along the crest of the underlying Luke Salt Body which is located within 1,000 feet of the surface, favorable conditions for earth fissure formation remain in place in the west Salt River Valley. Extension along existing earth fissure trends, and formation of new earth fissures are all possible with continued land subsidence.

Reconnaissance of earth fissures in Glendale and El Mirage, Arizona, February 21, 2013

Earth fissures underlying West Northern Avenue between North Dysart and North El Mirage Road were first observed in the fall of 1959 (Robinson and Peterson, 1962). These same fissures were later interpreted (Stulik and Twenter, 1964; Eaton, 1972; Laney et al., 1978; and Schumann and O'Day, 1995) as tensional surface cracks above and adjacent to the underlying crest of the Luke salt deposit, resulting from land subsidence driven by long term groundwater withdrawal in excess of recharge in the area surrounding Luke Air Force Base. These earth fissures were previously mapped at various scales by multiple authors (Stulik and Twenter, 1964; Eaton, 1972; Sergeant, Hauskins, and Beckwith, 1982; Harris, R.C., 2000; and Larkin, 2001). In 2008, AZGS geologists mapped these earth fissures using handheld GPS receivers capable of sub-meter accuracy (AZGS, 2009). Some previously mapped earth fissure lineaments were not evident at the surface when AZGS mapping was conducted. These lineaments are depicted as "unconfirmed" earth fissures on the AZGS Luke earth fissure map (AZGS DM-EF-8). No evidence of earth fissure activity was observed along reported/

unconfirmed fissure traces during the site visit on February 21, 2013. Earth fissures mapped as continuous or discontinuous fissures in 2008 were still clearly evident in the landscape during the same inspection (Figure 5). Existing mapped fissure traces showed no evidence for extension and no new fissures were encountered. AZGS DM-EF-8 released in February 2009 still accurately depicts earth fissure location and extent at this location.

North-south trending fissure zones shown on the AZGS Luke earth fissure map south of Northern Avenue and immediately east of the Morton Salt evaporation ponds are still evident in the landscape (Fig. 4). The earth fissure zones consist of numerous parallel to sub-parallel rounded fissure gullies, steep-sided open cracks, potholes up to 8 feet deep, slumped depressions, and vegetated traces. The fissures cross a relatively undisturbed lot which is largely unvegetated along broadly incised drainages and earth fissure lineaments. In these areas, surface flow is captured, infiltrates the soil, and contributes to greater available moisture content than the surrounding soil. Consequently, shrubs, desert broom, and isolated salt cedar preferentially inhabit these zones and persist along trends between open earth fissures, indicating connecting voids or cracks in the subsurface likely exist. Incision and headcutting along otherwise minor, unincised drainages upslope of intersections with earth fissures indicates the fissures are still active and have

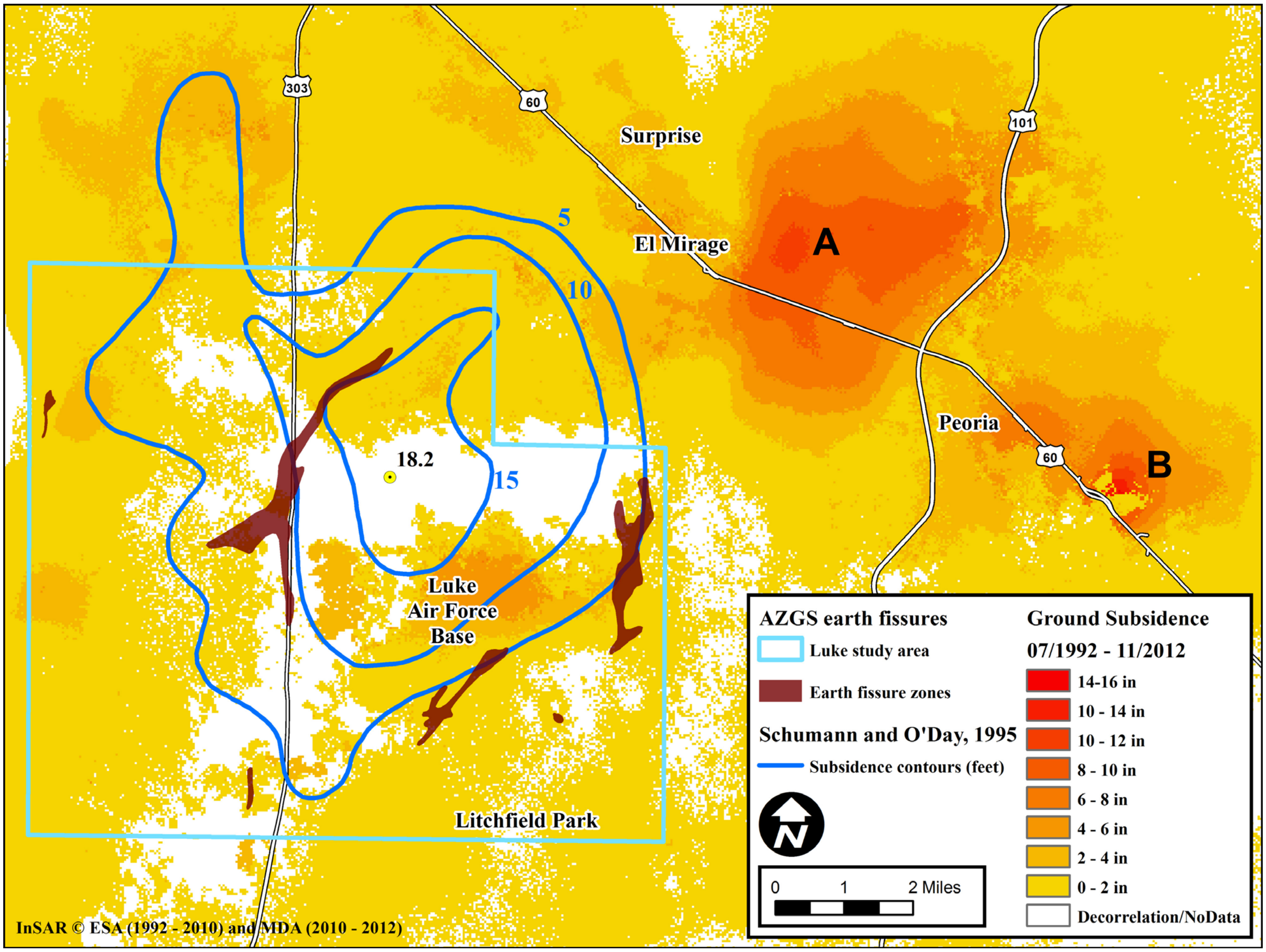

Figure 3. Land subsidence map of Luke Air Force Base and surrounding areas. Blue land subsidence contours are modified from Schumann and O'Day (1995). Note point of maximum subsidence (18.2 feet) measured in 1991. Subsequent land subsidence has been measured by InSAR and is represented by the color ramp. Because multiple land subsidence plots were used to create this figure, each individual plot varies in extent and area of decorrelation, and a data gap exists from 2000-2002, the land subsidence values shown here represent a minimum from 1992-2012. More dramatic land subsidence in the vicinity of El Mirage (A) and Peoria (B) is ongoing outside the Luke study area.

the capacity to intercept surface flow and associated eroded sediment without aggrading.

Active earth fissures in this location are sharp-edged, narrow, vertical-walled cracks with open cracks at the bottom. Less active to dormant fissures and fissure vertical offset corresponds with an abrupt rise of 2-3 feet and multiple generations of road repair evident in West Northern Avenue to the north.

North of West Northern Avenue the fissure zones are largely obscured by plowed fields and developed areas.

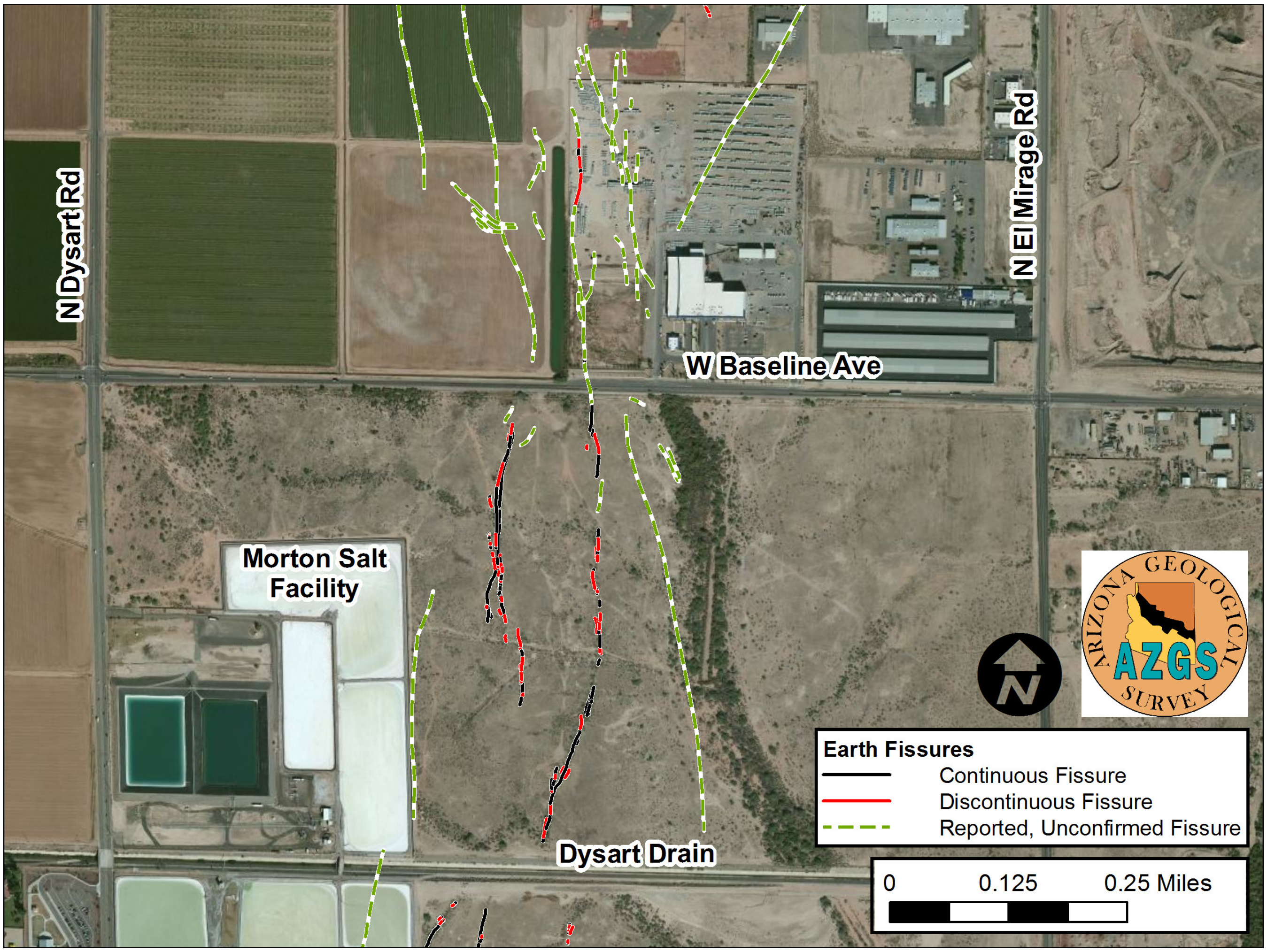

Figure 4. Location map of mapped earth fissures in the vicinity of West Northern Avenue between North Dysart and North El Mirage Road, Maricopa County, Arizona. Earth fissures shown here are the same as those depicted in the AZGS Earth Fissure Map of the Luke Study Area (AZGS DM-EF-8) overlain on 30 centimeter pixel 2010 Bing aerial imagery.

gullies are typically wider, well-rounded, and include arroyo-like sections with flat, sandy bottoms. Some earth fissure trends are composed of disconnected potholes and collapse features. Some potholes are shallow (less than 1 foot deep) while others exceed 7-8 feet in depth and exhibit an open crack that tapers deeper underground and disappears into the subsurface. Strongly cemented calcium carbonate beds broken by earth fissures were exposed along some earth fissure traces and up to 3 feet of vertical offset (down to the west) was observed in several locations (Figure 5). The trend of the fissure zone exhibiting

A short (less than 25 foot) earth fissure is mapped near the southwest corner of a drainage impoundment immediately north of a gravel-covered slope on the Hanson Pipe and Precast property (Figure 4). This crack does not show evidence of major collapse and consists only of shallow (less than 1 foot deep) cracks, depressions, potholes, and vegetation trends. The southern terminus of this mapped crack corresponds with a small offset in a cinder block wall at the top of the gravel-covered slope. The drainage impoundment area to the north is covered by thick stands of desert broom but some possibly anomalous depression trends were observed along reported/unconfirmed fissure traces. Because this area is heavily disturbed and inundated periodically following rains it is difficult to state with certainty whether or not these depression trends are the result of earth fissure collapse.

An earth fissure reported to exhibit repeated collapse is located approximately 1,000 ft north of West Northern Avenue near the western edge of the Hanson Pipe and Precast property. According to accounts by employees interviewed during the site visit, several hundred feet along an earth fissure zone has repeatedly opened and collapsed since 2008. The depression formed by each collapse created a hazard on the property which was temporarily mitigated by filling in the collapsed fissure with sand and gravel. During one instance, the ground adjacent to the open fissure gave way beneath a front end loader being used to fill in the cavity, requiring a second vehicle to remove the first. A series of discontinuous potholes and depressions several feet wide by 1-2 feet deep interspersed with vegetated zones was observed along the infilled zone of repeated collapse during the site visit. An elongate stretch of persistently ponded water lies within 30 feet of the fissure trace adjacent to the western Hanson property wall alongside extensive agricultural fields. This source of constant standing water likely saturates the nearby fissure zone in the subsurface, thereby contributing to continued subsurface erosion, piping, and subsequent collapse of overlying material into the earth fissure on the Hanson property. Although the ponded agricultural water likely contributes to repeated surface ruptures, these failures indicate fissure zones north of West Northern Avenue, although depicted on AZGS maps as reported/unconfirmed, are potentially active and the potential for sudden collapse exists.

Earth fissures in the vicinity of West Northern Avenue between North Dysart Road and North El Mirage Road exhibit characteristics indicative of active fissures such as open voids extending laterally along fissure trends, drainage capture, open cracks tapering into the subsurface, vertical offset, and lack of aggradation within the open portions of the fissure. Although lacking in surface expression at the time of AZGS mapping, an extension of these fissures located to the north has repeatedly opened and collapsed abruptly. This collapse is likely due, at least in part, to the close proximity of ponded agricultural water that enables subsurface erosion and piping along the fissure trend.

Conclusion

Mitigation efforts that minimize the impact of earth fissures on new or existing infrastructure in the Luke basin may help avoid costly redesign and/or repairs in the future. Because subsurface voids and channels may exist along earth fissure zones, any development or alteration of the land surface adjacent to or across these areas should avoid redirecting, concentrating, or impounding precipitation runoff in the proximity of known fissures in order to avoid inducing erosion or collapse of overlying material. In general, diverting surface water and runoff away from fissures is recommended to avoid enhancing erosion leading to collapse along the fissure. Land subsidence and earth fissures in the Luke study area and throughout south-central Arizona can potentially impact homes, property values, land use, flood control structures, and transportation infrastructure. Groundwater withdrawal and associated land subsidence is ongoing in the Luke basin and many other basins throughout Arizona (ADWR, 2013a). With continued land subsidence comes the possibility for growth and extension of existing earth fissures and formation of new fissures. Wise land management and use, coupled with mitigation strategies, such as diverting water away from earth fissures, may result in reduced damage to infrastructure, property loss, and repair cost in the future.

References Cited

Arizona Department of Water Resources, 2013(a), Arizona InSAR and land subsidence data, accessed at: http://www.azwater.gov/AzDWR/Hydrology/Geophysics/LandSubsidenceInArizona.htm

Arizona Department of Water Resources, 2013(b), Groundwater Site Inventory (GWSI) database, accessed at: https://gisweb.azwater.gov/waterresourcedata/gwsi.aspx

Arizona Geological Survey, 2009, Earth Fissure Map of the Luke Study Area: Maricopa County, Arizona. Arizona Geological Survey Digital Map Series – Earth Fissure Map 8 (DM-EF-8), 1 sheet, 1:24,000 scale.

Eaton, G.P., 1972, Deformation of Quaternary Deposits in Two Intermontane Basins of Southern Arizona, U.S.A., Report of the Session International Geological Congress. 24; 3, p. 607-616.

Eaton, G.P., Peterson, D.L., Schumann, H.H., 1972, Geophysical, Geohydrological, and Geochemical

Figure 5. View to north along western earth fissure zone approximately 900 feet south of West Northern Avenue. Here, strongly cemented carbonate beds are broken and draped across several feet of vertical offset (down to the west). Fissure depth in the vicinity of carbonate bed offset often exceeds 6 feet with a narrow open crack tapering deeper into the subsurface.

Reconnaissance of the Luke Salt Body, Central Arizona

Gootee, B.F., 2013, An Evaluation of Carbon Dioxide Sequestration Potential in the Luke Basin, south-central Arizona: Arizona Geological Survey Open-File Report 13-05, 10 p., 2 sheets, 1:300,000 scale.

Harris, R.C., 2000, Land Subsidence and Earth Fissures in Luke Basin, Maricopa County, Arizona, Arizona Geological Survey Open-File Report 00-03, 15 p.

Laney, R.L., Raymond, R.H., and Winikka, C.C., 1978, Maps showing water-level declines, land subsidence, and earth fissures in south-central Arizona: U.S. Geological Survey Water-Resources Investigations Open-File Report WRI 78-0083, 2 sheets, scale 1:125,000.

Larkin, H.D., 2001, Environmental Management of Groundwater Contamination in Land Subsidence and Fissure Areas: Tempe, Arizona State University, M.S. Thesis, 199 p.

Pankratz, L.W., Hassemer, J.H., and Ackermann, H.D., 1978, Geophysical studies relating to earth fissures in central Arizona [abs.]: Geophysics, v. 44, p. 367.

Peirce, 1974, Thick evaporites in the Basin and Range Province – Arizona, in Coogan, A.H., ed., Fourth Symposium on Salt: Cleveland, Northern Ohio Geological Society, v.1, p. 47-55.

Rauzi, S.L., 2002(a), Luke Salt Deposit, Arizona Geological Survey Map 36, 1 sheet.

Rauzi, S.L., 2002(b), Arizona Has Salt!, Arizona Geological Survey Circular 30, 36 p.

Raymond, R.H., 1985, Earth fissure investigations for reaches 2A, Salt-Gila aqueduct, Central Arizona Project, Arizona: U.S. Bureau of Reclamation, unpublished report, 23 p., 7 sheets.

Richard, S.M., Shipman, T.C., Greene, Lizbeth, Harris, R.C., 2007, Estimated Depth to Bedrock in Arizona:

Tucson, Arizona Geological Survey Digital Geologic Map 52 (DGM-52), version 1.0, 1 Adobe Acrobat (PDF) file (8 p., 1 sheet), design scale 1:1,000,000. Robinson, G.M., and Peterson, D.E., 1962, Notes on Earth Fissures in southern Arizona, U.S. Geological Survey Circular 466, 7p.

Robinson, G.M., and Peterson, D.E., 1962, Notes on earth fissures in southern Arizona: U.S. Geological Survey Circular 466, 7 p.

Schumann, H.H. and O'Day, C.M., 1995, Investigation of Hydrology, Land Subsidence, and Earth Fissures, Luke Air Force Base, Arizona, U.S. Geological Survey Administrative Report, 62p.

Schumann, H.H., and Poland, J.F., 1969, Land subsidence, earth fissures and groundwater withdrawal in south-central Arizona, U.S.A, in Land subsidence: Proceedings of the Tokyo Symposium, September 1969, Volume 1: International Association of Scientific Hydrology (lASH), and UNESCO, Studies and Reports in Hydrology, Publication No.8, p. 295-302.

Sergent, Hauskins and Beckwith, 1982, McMicken Dam Restoration Study, Maricopa County, Arizona, Report prepared for the Flood Control District of Maricopa County, SHB Job No. E81-138 Phase II, March 9, 4 sheets, 1:25,344 scale.

Stulik, R.S., and Twenter, F.R., 1964, Geology and Ground Water of the Luke Area Maricopa County, Arizona, U.S. Geological Survey Water Supply Paper 1779-P, 30 p.