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Arizona Geological Survey

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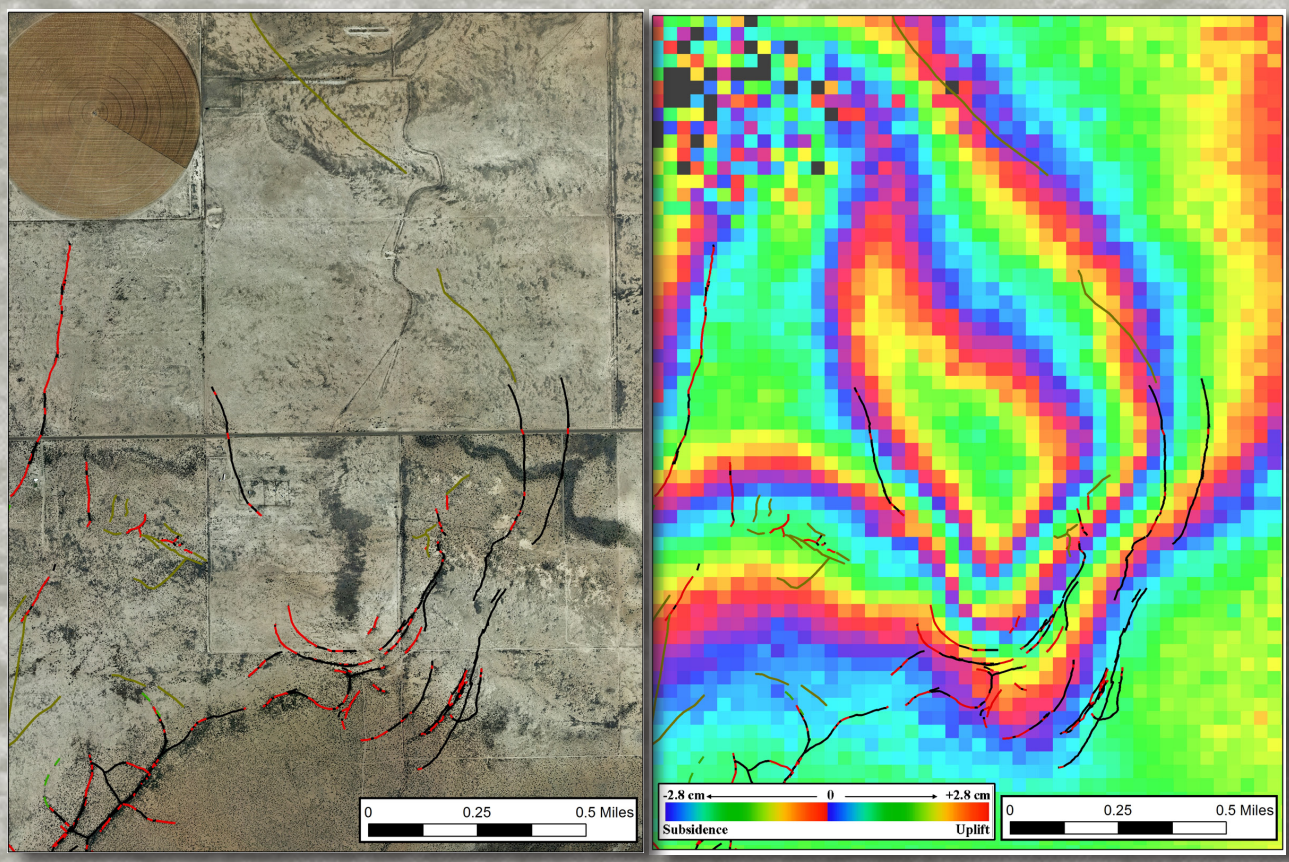

Aerial photograph and InSAR interferogram of Three Sisters Buttes area, Cochise County, Arizona showing mapped continuous (black) and discontinuous (red) earth fissures.

Suggested guidelines for Investigating Land-Subsidence and Earth Fissure Hazards in Arizona

August 2011

Arizona Land Subsidence Interest Group

ARIZONA GEOLOGICAL SURVEY

SUGGESTED GUIDELINES FOR INVESTIGATING LAND-SUBSIDENCE AND EARTH-FISSURE HAZARDS IN ARIZONA (August 2011)

These guidelines provide professionals evaluating site-specific conditions in areas known or suspected to be subsiding with a standardized minimum level of investigation for land-subsidence and earth-fissure hazards. The guidelines do not include systematic descriptions of all available investigative techniques or topics, nor is it suggested that all techniques or topics are appropriate for every project. Variations in site conditions, project scope, economics, and level of acceptable risk may require that some topics be addressed in greater detail than is outlined in these guidelines. However, all elements of these guidelines should be considered in comprehensive land-subsidence and earth-fissure hazard investigations, and may be applied to any project site, large or small. These guidelines are largely modified from draft recommendations prepared by Lund and others (2010). That draft, in turn, was developed using existing guidelines for preparing engineering geologic reports in Utah (Utah Section of the Association of Engineering Geologist, 1986), guidelines for evaluating surface-fault-rupture and land-subsidence hazards in Nevada (NESC, 1998), and guidelines for evaluating surface-fault rupture in California and Utah (California Geological Survey, 2002; Christenson and others, 2003), with additions and comments from various professionals involved in land-subsidence and earth-fissure investigations.

I. DISCLAIMER

Unlike most geologic hazards which can be mapped and then avoided or mitigated, land-subsidence and earth fissures are typically a response to human-induced ground-water mining (extraction of groundwater from aquifers by human activity, typically pumping at levels leading to overdraft conditions); as such, they will continue to occur and may expand as long as overdraft ground-water mining is permitted to continue. The fact that land subsidence is not currently occurring in an area experiencing ground-water mining is no guarantee that subsidence will not arise in the future. Likewise, the absence of detectable earth fissures at the ground surface in a subsiding area provides no assurance that fissures are not present in the shallow subsurface or will not form in the future. In addition, other surficial geologic phenomena such as desiccation, can result in earth cracks with different implications for development and infrastructure, but may be difficult to distinguish from earth fissures by visual observation alone. As long as overdraft ground-water mining continues, land subsidence and earth fissures present long-term hazards to infrastructure that a hazard investigation, no matter how detailed, can only partially mitigate.

II. WHEN TO PERFORM A HAZARD INVESTIGATION

An investigation of potential land-subsidence and earth-fissure hazards should be made for all proposed development in areas of known or suspected land subsidence. Existing infrastructure and other facilities in areas of known or suspected land subsidence may need investigations as well. A land-subsidence and earth-fissure hazard evaluation may be conducted separately or as part of a comprehensive geologic-hazard/geotechnical site investigation.

III. DESCRIPTION OF INVESTIGATION

A. Qualifications of Investigators

Land subsidence and related hazard evaluations, and the development of appropriate mitigation alternatives, often require the expertise of professionals from multiple disciplines. These disciplines include civil and geotechnical engineering, geophysics, geology, hydrogeology, land surveying and surface water hydrology. In the State of Arizona, the practices of engineering, land surveying and geology are regulated by the Arizona State Board of Technical Registration (SBTR), with the requirement that these professionals are registered. Hydrogeology is considered by the SBTR to be an activity within the discipline of geology, and surface water hydrology and geotechnical engineering are considered as part of the practice of civil engineering. Geophysical studies are completed in the State by both geologists and geotechnical engineers.

The SBTR, like many other state boards, have a provision for what is termed, “incidental practice.” This provision allows for licensed professionals to perform functions normally undertaken by professionals in another licensed profession if the one performing such incidental work is experienced and competent in the work being performed. Such incidental work must be supportive in scope and directly related to completion of work within the licensed professional’s own discipline.

For Arizona land subsidence problems, studies commence with critical evaluations of available geological, geotechnical, geodetic, hydrogeological, and remote sensing data. Analyses often ensue, with the interpretations of remote sensing data, such as aerial photography. This is an example of an activity that requires considerable geological knowledge and experience to ensure that the interpretations are useful in reducing risks associated with land subsidence critical to the protection of the Public Health, Safety, and Welfare. As an evaluation progresses from characterization to development of a solution, which may include a significant change in the land use for these areas The effort may require the expertise of several engineering sub-disciplines including geotechnical and/or hydrological specialists and, if appropriate, structural engineers. The challenge to completing a quality land subsidence evaluation is to form a team that includes registered engineers, geologists and land surveyors, applying core skills while providing incidental contributions for which they have demonstrated competence.

B. Literature Review

a. Review published and unpublished literature, maps, and records relevant to the site and site region's geology and hydrology, and past history of land subsidence and earth fissure formation. Maps of known, confirmed earth fissures in Arizona are maintained by the Arizona Geological Survey; information can be obtained at www.azgs.az.gov.

b. Review survey data which may indicate past land subsidence. As-built plans of linear infrastructure such as roads, canals, dams and levees should be evaluated for usable historic elevation data or design grades that can be compared to current elevations.

c. Review available maintenance records of nearby wells for signs of subsidence related damage.

d. Review available historic water-level data, and subsurface units from well driller's logs for nearby water wells. Collect and review borehole geophysical data, if available, from deep wells in the area to assess stratigraphy.

e. Review available projections or predictive scenarios for anticipated future groundwater decline. An example is the 100-year Predictive Scenarios Used for the Determination of Physical Availability in the Phoenix Active Management Area, Modeling Report No. 22 (Hipke, 2010).

C. Analysis of Remote Sensing Data

Analysis should include interpretation of aerial photographs and, if available, InSAR (Interferometry by Synthetic Aperture Radar), LiDAR (Light Detection and Ranging), and other remotely sensed images for evidence of land subsidence and fissure-related lineaments, including vegetative lineaments, gullies, and vegetation/soil contrasts. Where possible, the analysis should include both stereoscopic low-sun-angle and vertical aerial photography. Examination of repeat aerial photographs and/or LiDAR imagery from multiple years may show fissure growth. The area interpreted usually should extend beyond the site boundaries.

The importance of satellite-based InSAR results cannot be over-emphasized when the best possible understanding and characterization of subsidence is critical to the success of a subsidence investigation. Where ground surface conditions are compatible with the technology, InSAR technology maps recent historic subsidence patterns and magnitudes over large areas and (if archived data is available) has the potential to map historic subsidence back to as early as 1992. InSARs' potential is demonstrated at www.azwater.gov/AzDWR/Hydrology/Geophysics/InSAR.htm (ADWR, 2010) where InSAR data is processed, and subsidence results are made available for many basins in Arizona. Some InSAR is available for other areas; an example of subsidence from 1993

to 1998 documented through InSAR in southwest Utah can be found at http://geology.utah.gov/online/mp/mp06-05.pdf (Forster, 2006).

D. Surface Investigation

Surface investigation should include mapping of geologic and soil units, fissures, faults or other geologic structures, geomorphic features and surfaces, vegetative lineaments and animal burrowing patterns, and deformation of engineered structures due to land subsidence or earth fissures both on and beyond the site as appropriate. Special attention should be paid to linear infrastructure such as roadways, pavements, canal liners, dams and levees, etc. Level surveys of linear infrastructure and comparison with design elevations may be appropriate to detect the presence or absence of measurable subsidence, and in the case of dams and levees, should be a mandatory part of the investigation. Remote sensing methods provide preliminary means to identify potential subsidence features, but physical ground truthing is required to help validate suspicious conditions.

Post-storm event surface investigation (surface investigation immediately following significant rain events that would be expected to cause surface flows) should also be performed if and when possible. Rain events likely to cause surface flows include short-duration, high-intensity localized thunder storms typical of Arizona's summer monsoon season and long-duration, low- to high-intensity frontal system storms typical of Arizona winter rainy season. Post-storm event investigation can provide information on the stage of fissure development and may be the only time fissures are expressed at the surface in areas under agricultural production or regular surface grading. In consideration of personal health and safety, fissures should not be approached during surface flows. Highly active fissures can rapidly open, widen, and extend in response to surface flows posing a serious threat of inundation/engulfment and possible death.

E. Subsurface Investigation

Earth fissures tend to be vertical to near-vertical features in the shallow subsurface to depths typical for geotechnical investigations. In an uneroded state, the aperture of an earth fissure may commonly be on the order of only 4 to 25 mm (0.25 to 1 inch) or less, and may be open or filled. Situations may arise where there is no current surficial expression of earth fissures, but the presence or absence of shallow subsurface earth fissuring that could lead to future surface expression needs to be assessed or confirmed. Primarily lateral subsurface investigation methods, such as trenching or shallow surface geophysics (see Section F), tend to be most effective in these situations. Vertically focused methods such as drilling or push technologies tend to be useful for general subsurface characterization in a potential fissure zone; an uneroded fissure in the subsurface is a very small target for borehole sampling. Subsurface characterization may be especially important when assessing whether subsurface conditions are consistent with a surface feature being an earth fissure or a giant desiccation crack.

a. Trenching or other excavation with appropriate logging and documentation to permit detailed and direct observation of continuously exposed geologic units, soils, fissures, and other geologic features. This includes trenching across (perpendicular to the axis) known earth fissures or suspicious zones to determine the location and width of fissures and fissure zones, general fissure geometry and depth, and displacement, if any, across fissures. Trenching to appropriate investigation depths may necessitate the use of stepped excavations and / or shoring to provide safe access for cleaning (by hand tools, compressed air, vacuum, etc) and preparing trench walls for detailed investigation and mapping.

b. Borings, test pits and possibly continuous soundings (such as cone penetrometer testing) to permit collection of data on geologic units and ground water, and to verify fissure plane geometry. Data points should be sufficient in number and adequately spaced to permit correlations and interpretations.

F. Geophysical Investigations

Geophysical methods should seldom be employed alone without knowledge of the site geology; yet, where there is no other geologic information available, geophysics may be the only economically viable means to perform deep geologic reconnaissance. These are indirect methods that require knowledge of specific geologic conditions for reliable interpretations. Although geophysical methods can be used to infer the presence and location of shallow earth fissuring, such methods alone never prove the absence of a fissure or fault at depth. It may be useful to apply geophysical surveys to known earth fissures in the vicinity of the project in similar geologic conditions to develop characteristic fissure signals or signatures. Geophysical methods can provide critical information concerning subsidence potential, especially compressible basin fill and bedrock geometry that may not otherwise be available. Geophysical techniques used may include, but are not limited to, high resolution seismic reflection, ground penetrating radar, seismic refraction, magnetic profiling, electrical resistivity, and gravity. A recent subsidence and earth fissure case study demonstrating the integrated application of InSAR, gravity, electrical resistivity and refraction microtremor seismic methods for characterization (Rucker and Fergason, 2009) can be found at www.eegs.org/portals/2/fasttimefiles/ft1401_mar2009_low.pdf. A recent case study (LASI, 2009) with side-by-side testing of the capabilities of shallow seismic refraction, ground penetrating radar, electromagnetic (EM) resistivity/conductivity, and magnetometer for characterization at both an earth fissure and a desiccation crack in an alluvial basin setting can be found at www.lasi.arizona.edu/GEN%20416%202009%20Final%20Report.doc.

G. Other Methods

Other methods should be incorporated when special conditions permit or requirements for critical structures or facilities require more intensive investigation, and especially monitoring over long time periods. Possible methods may include, but are not limited to:

a. Aerial reconnaissance over-flights

b. Installation and monitoring of piezometers

c. High precision surveying or geodetic measurements, including comparison surveys with infrastructure design grades and monitoring program of repeat surveys

d. Strain (displacement) measurement both at the surface and in borings as part of a long-term monitoring program

e. Age-dating, including but not limited to radiometric analysis (^{14}C, K-Ar), optical stimulated luminescence or other thermoluminesence techniques, soil-profile development, tephrochronology, and dendrochronology.

IV. SUGGESTED OUTLINE FOR A LAND-SUBSIDENCE AND EARTH-FISSURE HAZARD INVESTIGATION REPORT

A. Text

a. Purpose and scope of investigation; description of proposed project.

b. Geologic and hydrologic setting

c. Site description and conditions, including dates of site visits and observations. Include information on geologic and soil units, hydrology, topography, graded and filled areas, vegetation, existing structures, presence of fissures on or near the site, evidence of land subsidence, and other factors that may affect the choice of investigative methods and interpretation of data.

d. Methods of investigation

1. Detailed description of the investigation method(s), including explanations of how method(s) function and are valid to the investigation process

2. Lead personnel and firms providing field and laboratory investigation/testing work.

e. Conclusions

1. Location and existence (or absence) of land subsidence and earth fissures on or adjacent to the site and existing/proposed infrastructure.

2. Statement of relative risk that addresses the probability or relative potential for future earth fissure formation or growth of existing fissures and the rate

and amount of anticipated land subsidence. This may be stated in semi-quantitative terms such as low, moderate, or high, or quantified in terms of fissure growth rates or land subsidence rates.

3. Degree of confidence in, and limitations of, the data and conclusions.

4. If fissures are identified, provide a description of the probable cause of occurrence and a theoretical basis for the presents of fissures.

f. Recommendations

1. Setback distance from fissures or areas of anticipated fissure growth. Review state or local regulations concerning regulatory or statutory setbacks. Examples: http://www.maricopa.gov/EnvSvc/WaterWaste/OWS/pdf/site.pdf, [MCESD, 2010, page 16]), and Arizona Administrative Code Title 18, Chapter 9, Article 3. Aquifer Protection Permits – General Permits, Part A. General Provisions, R18-9-A312 Facility Design for Type 4 Onsite Wastewater Treatment Facilities, C. Setbacks. Item 15. Earth Fissures, Setback For An On-Site Wastewater Treatment Facility, Including Reserve Area, 100 feet (ADEQ, 2011), see http://www.azsos.gov/public_services/Title_18/18-09.pdf.

2. Mitigation measures to control fissure growth, prevent surface-water from flowing into fissures, strengthen structures that must bridge fissures, flexible utility connections in subsidence areas or where utilities cross fissures displaying differential displacement.

3. Limitations on the investigation, need for additional studies, or inspection during construction, and long-term monitoring.

B. References

a. Literature and records cited or reviewed; citations should be complete.

b. Remote sensing images interpreted – list type, date, scale, source, and index numbers.

c. Other sources of information, including well records, personal communication, and other data sources.

C. Illustrations

a. Location map – identify site location and significant physiographic and cultural features.

b. Site development map – show site boundaries, existing and proposed structures, graded and filled areas, streets, exploratory test pits, trenches, borings, and geophysical traverses

c. Geologic map(s) – site map showing distribution of bedrock and unconsolidated geologic units, faults or other geologic structures, geomorphic features, earth fissures, areas of subsidence, and, if available, InSAR results. For large projects (dams, canals, pipelines, etc.) a regional geologic map and InSAR presentations also may be required to adequately depict all important geologic features and recent subsidence trends.

d. Geologic cross sections, if needed, to provide three-dimensional site representation.

e. Logs of exploratory trenches and borings – show details of observed features and conditions; should not be generalized or diagrammatic. Trench logs should show topography and geologic features at the same horizontal and vertical scale to be visually consistent with documenting photographs and avoid geometric distortions in presentation.

f. Geophysical data and interpretations.

g. Photographs that enhance understanding of site/trench conditions.

D. Appendices

Supporting data not included in the body of the report (e.g., water-well data, survey, data, etc.). Include calculations, if appropriate.

E. Authentication

Report signed and authenticated in accordance with applicable statutory requirements.

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