Plate 9
Utah Geological Survey Special Study 148
State Route 9 Corridor Geologic-Hazard Study Area

UTAH GEOLOGICAL SURVEY
*a division of*
Utah Department of Natural Resources

## EXPLANATION

H **High Susceptibility** - Geologic units that consist of well-sorted sands, silty sands, and gravels where Natural Resources Conservation Service (NRCS) and/or geotechnical data indicate depth to groundwater is ≤50 feet.

$L_1$ **Liquefaction-Susceptibility Zone$_1$** - Geologic units with textural characteristics of the high-susceptibility category, but geotechnical data on groundwater conditions are lacking. However, these units are mapped by the NRCS as poorly drained soils (low–moderate permeability) that may develop shallow groundwater locally when rates of water application exceed the soil's drainage capacity. Because these soils naturally drain slowly, they may remain wet for most of the year, even though water is applied only during the growing season. Permanent shallow groundwater is possible following urbanization.

$L_2$ **Liquefaction-Susceptibility Zone$_2$** - Geologic units with textural characteristics of the high-susceptibility category, but geotechnical and NRCS groundwater information is lacking.

## INTRODUCTION

Liquefaction and liquefaction-induced ground failure are major causes of earthquake damage (Keller and Blodgett, 2006). During liquefaction, a soil loses its strength and ability to support the weight of overlying structures or sediment. Soil liquefaction is caused by strong earthquake ground shaking where saturated, cohesionless, granular soil is transformed from a solid to a nearly liquid state. Soil liquefaction generally occurs in sand, silty sand, and sandy silt soils (Youd and Idriss, 1997). All of the following conditions are required for liquefaction to occur:

- The soils must be below the water table.
- The soils must be loose to moderately dense.
- The ground shaking must be intense.
- The duration of ground shaking must be sufficient for the soils to lose their shearing resistance.

Plastic or clay-rich soils having either a clay content greater than 15 percent, a liquid limit greater than 35 percent, or a moisture content less than 90 percent of the liquid limit are generally immune to liquefaction (Seed and Idriss, 1982; Youd and Gilstrap, 1999).

Four types of ground failure commonly result from liquefaction: (1) loss of bearing capacity, (2) ground oscillation and subsidence, (3) lateral spreading, and (4) flow failure (Youd, 1978, 1984; Tinsley and others, 1985; figure 1). The expected mode of ground failure at a given site largely depends upon the ground-surface slope. Where slope inclination is less than 0.5 percent, liquefaction may cause damage in one of two ways. The first is the loss of bearing capacity and resulting deformation of soil beneath a structure, which causes the structure to settle or tilt. Differential settlement is commonly accompanied by cracking of foundations and damage to structures. Buoyant buried structures, such as underground storage or septic tanks, may also float upward under these conditions. The second results from liquefaction at depths below soil layers that do not liquefy. Under these conditions, blocks of the surficial, non-liquefied soil detach and oscillate back and forth on the liquefied layer. Damage to structures is caused by subsidence of the blocks, opening and closing of fissures between and within the blocks, and formation of sand blows as liquefied sand is ejected through the fissures from the underlying pressurized liquefied layer.

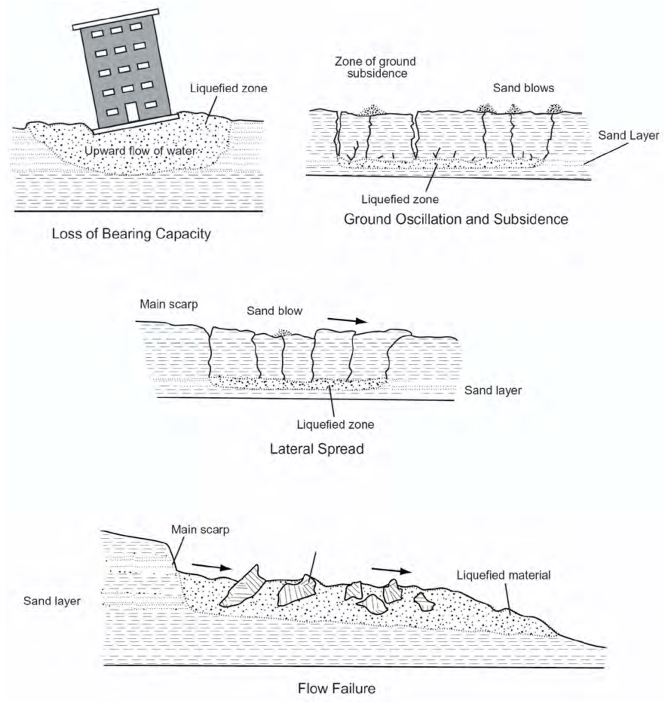



**Figure 1.** *Four principal types of liquefaction-induced ground failure; arrows indicate direction of movement (modified from Youd, 1984; Harty and Lowe, 2003).*

Lateral spreading may occur where the ground surface slopes from 0.5 to 5 percent, particularly near a "free face" such as a stream bank or cut slope. Lateral spreads are characterized by surficial soil blocks that are displaced laterally downslope as a result of liquefaction in a subsurface layer. Lateral spreading can cause significant damage to structures and may be particularly destructive to pipelines, utilities, bridges, roadways, and structures with shallow foundations.

Flow failures may occur where the ground surface slopes more than about 5 percent. Flow failures are composed chiefly of liquefied soil or blocks of intact material riding on a liquefied layer. Flow failures can cause soil masses to be displaced several miles and are the most catastrophic mode of liquefaction-induced ground failure.

## SOURCES OF INFORMATION

Sources of information used to evaluate liquefaction susceptibility in the State Route 9 Corridor Geologic-Hazard Study Area (SR-9 study area) include (1) the four Utah Geological Survey (UGS) 1:24,000-scale geologic quadrangle maps that cover the study area (Virgin [Hayden and Sable, 2008], Springdale West [Willis and others, 2002], Springdale East [Doelling and others, 2002], and Smithsonian Butte [Moore and Sable, 2001]), (2) 40 geotechnical reports on file with the National Park Service (NPS), the Utah Department of Transportation (UDOT), and the towns of Springdale and Virgin, (3) 16 water-well drillers logs on file with the Utah Division of Water Rights, (4) the occurrence of wet, or potentially wet soils mapped by the Natural Resources Conservation Service (NRCS) (formerly Soil Conservation Service) (Mortensen and others, 1977), (5) *Engineering Geologic Map Folio, Springdale, Washington County, Utah* (Solomon, 1996), (6) *Geologic Hazards and Adverse Construction Conditions, St. George–Hurricane Metropolitan Area, Washington County, Utah* (Lund and others, 2008b), and (7) *Geologic Hazards of the Zion National Park Geologic-Hazard Study Area, Washington and Kane Counties, Utah* (Lund and others, 2010). Geotechnical and groundwater data are limited in both amount and distribution, and are generally available only where development has already occurred. Consequently, depth to groundwater information is not available for much of the SR-9 study area, including many areas where development may occur in the future.

## HISTORICAL LIQUEFACTION IN SOUTHWESTERN UTAH

The September 2, 1992, M 5.8 St. George earthquake produced liquefaction in saturated sand deposits along the Virgin River (Black and others, 1995). The earthquake's epicenter was in Washington Fields east of St. George, and the earthquake possibly was the result of movement on the Hurricane fault (Pechmann and others, 1995). Liquefaction occurred along the river from approximately 1 mile south of Bloomington to approximately 4 miles west of Hurricane (Black and others, 1995). The affected geologic deposits consisted of well-sorted, modern channel sands covered by thin layers of silt and clay from overbank flooding. Observed liquefaction features included lateral spreads (figure 2), caved stream banks, and sand blows (figure 3). Lateral spreads were the most common feature (17 recorded); the largest was 200 feet long and 66 feet wide, and had total lateral movement of about 19 inches (Black and others, 1995). The greatest distance reported by Black and others (1995) between a recognizable liquefaction feature and the earthquake epicenter was 10.6 miles. No facility damage due to liquefaction was documented from the St. George earthquake.

**Figure 2.** *Lateral-spread cracking from liquefaction along the Virgin River resulting from the September 2, 1992, M 5.8 St. George earthquake. Folding shovel for scale (photo credit W.E. Mulvey).*

**Figure 3.** *Sand blows from liquefaction along the Virgin River resulting from the September 2, 1992, M 5.8 St. George earthquake. Scale card shows centimeters (left) and inches (right) (photo credit W.E. Mulvey).*

## SOURCES OF EARTHQUAKE GROUND SHAKING

Potential sources of strong earthquake ground shaking in the SR-9 study area include (1) the Hurricane fault less than 1 mile west of the study area (Lund and others, 2007), (2) the comparatively short normal-slip faults with very long recurrence intervals within or close to the study area (see Surface-Fault-Rupture Hazard map [plate 8]), (3) the Sevier fault about 15 miles east of the study area (Lund and others, 2008a), and (4) a random background earthquake with a magnitude below that required to produce surface rupture (~M 6.5) that occurs either within or near the study area on an unrecognized fault. While all of these sources could potentially produce ground shaking, the shorter normal faults and the Sevier fault have very long recurrence intervals for moderate to large earthquakes, and have a low likelihood to produce ground shaking strong enough to cause liquefaction in the study area. However, the Hurricane fault shows evidence for large, surface-faulting earthquakes during the Holocene (Lund and others, 2007), and an earthquake >M 6.5 on the Hurricane fault near the study area within the next several decades cannot be discounted. Similarly, a moderate-magnitude (M 5.0–6.5) background earthquake in or near the study area is also a possibility. Earthquake ground shaking from either a Hurricane fault earthquake or a background earthquake may liquefy loose, saturated unconsolidated deposits along perennial streams and in wet areas within the study area.

## LIQUEFACTION HAZARD CLASSIFICATION

As first determining factors, we considered the age, textural characteristics (grain size and sorting), and cementation of unconsolidated geologic units as characterized by UGS mappers and the limited geotechnical database to classify unconsolidated geologic units as potentially liquefiable. Table 1 summarizes potentially liquefiable geologic deposits in the study area. Age is an important consideration for liquefaction hazard because the older the unit, generally the more consolidated or cemented it is and the less susceptible it becomes to liquefaction. The limited geotechnical data available within and near the study area come chiefly from lower Zion Canyon in the Zion National Park administrative area and from the towns of Springdale and Virgin. Review of these data showed that unconsolidated deposits (chiefly alluvium and colluvium) in valley-bottom areas typically consist of silty sand, clayey sand, sandy silt, sandy clay, and silty clay with occasional lenses of cleaner sand, gravel, cobbles, and boulders. Laboratory consolidation test results show that some sand, silt, and clay deposits have low densities and are subject to collapse (see Collapsible-Soil Susceptibility map [plate 4]). Standard Penetration Test blow-count $(N_1)_{60}$ data confirm the low density of many deposits. $(N_1)_{60}$ values of <10 blows per foot were not uncommon. An $(N_1)_{60}$ value <15 in sandy soil is an indicator of liquefaction susceptibility, with well-sorted, cohesionless sands generally being more susceptible to liquefaction than silty sands and sandy silts.

We then compared units classified as potentially liquefiable with available groundwater information. Where depth to groundwater was ≤50 feet, we classified the liquefaction susceptibility of the corresponding geologic unit as high.

Due to a lack of groundwater information, we employ a numbered susceptibility ranking as opposed to a severity ranking for the remaining potentially liquefiable units in the study area. Where depth to groundwater was not known, we defined two "Liquefaction-Susceptibility Zones." These zones delineate areas where deposit texture and groundwater conditions may be suitable for liquefaction to occur, but determining whether liquefaction is in fact possible at any given location requires additional site-specific information about the texture and density of the deposits, groundwater conditions, and anticipated earthquake ground motions. Note that liquefaction susceptibility differs from liquefaction *potential*, which combines susceptibility with consideration of the probability of a sufficiently high ground acceleration occurring within some specified time interval.

The Liquefaction-Susceptibility Zones are described in the Explanation section.

Unclassified areas on this map include areas of exposed or shallow (≤5 feet) bedrock, unconsolidated geologic deposits with textural or cementation characteristics that generally preclude liquefaction, and areas where depth to groundwater is estimated to be >50 feet. Unclassified areas are considered to have no liquefaction susceptibility; however, areas of liquefaction susceptibility too small to show at the scale of the map prepared for this study may exist locally within unclassified areas, particularly near springs and seeps.

**Table 1.** *Unconsolidated geologic deposits[1] in the SR-9 study area that may be susceptible to liquefaction if saturated.*

| Stream and Terrace Alluvium | Fan Alluvium | Eolian Deposits | Colluvial Deposits | Lacustrine Deposits |
|---|---|---|---|---|
| $Qa_1$, $Qa_2$, $Qat_1$, Qath, Qatm, Qaes, $Qae_2$, $Qaf_1$, $Qaf_2$, Qay | Qae, Qac, Qaf, Qafc, Qao | Qes, Qea, Qer | Qc, Qmts | Qlg |

[1]Refer to UGS 1:24,000-scale geologic maps (see Sources of Information section) for a description of map units.

## USING THIS MAP

This map shows areas where liquefaction may be possible in the SR-9 study area. This map is based on limited information about the textural characteristics of unconsolidated geologic units and the distribution and depth of groundwater in the study area. This map does not integrate earthquake ground motions with material characteristics and depth to groundwater, which is required to determine relative liquefaction potential in susceptible deposits. Consequently, the map does not differentiate ground-failure types or amounts, which are needed to fully assess the hazard and evaluate possible mitigation techniques.

This map is intended for general planning and design purposes to indicate where liquefaction hazards may exist and to assist in liquefaction-hazard investigations. In Utah, soil-test requirements are specified in chapter 18 (Soils and Foundations) of the 2009 *International Building Code* (IBC) (International Code Council, 2009a) and chapter 4 (Foundations) of the 2009 *International Residential Code for One- and Two-Family Dwellings* (IRC) (International Code Council, 2009b), which are adopted statewide. IBC Section 1803.2 requires a geotechnical investigation be performed in accordance with IBC sections 1803.3 through 1803.5. Section 1803.3 requires an investigation to evaluate liquefaction, and Section 1803.5.11 requires a liquefaction evaluation for structures in Seismic Design Categories C, D, E, and F (see Earthquake-Ground-Shaking Hazard section of accompanying text document). In general, seismic design categories in the SR-9 study area for structures built on unconsolidated materials fall into Seismic Design Categories C and D, thus triggering the IBC requirement for a liquefaction investigation. Although the IRC does not specifically mention liquefaction, IRC Section R401.4 states that the local building official determines whether to require soil tests in areas likely to have expansive, compressive, shifting, or other unknown soil characteristics, such as liquefiable soils.

International Building Code seismic design categories are determined on a site-specific basis, and vary throughout the study area depending on IBC site class, maximum considered earthquake ground motions, and the IBC occupancy category of the proposed structure (see Earthquake-Ground-Shaking Hazard section of accompanying text document). Because the risk to human life and the requirement that certain essential structures remain functional during and after disasters varies by occupancy category, we recommend the following levels of liquefaction-hazard investigation for the different IBC occupancy categories (table 2) in areas identified on this map as high susceptibility or potentially liquefiable. Detailed (quantitative) subsurface investigations should be performed for Occupancy Category II, III, and IV structures, and reconnaissance (screening) investigations for Occupancy Category I structures. Additionally, a reconnaissance investigation should be performed for Occupancy Category II, III, and IV structures in areas mapped as not susceptible to liquefaction followed by a detailed investigation if a liquefaction hazard is determined to be present. Investigations are not recommended for Occupancy Category I structures in nonsusceptible areas. Martin and Lew (1999) provide guidelines for conducting both reconnaissance and detailed liquefaction investigations.

**Table 2.** *Recommended requirements for liquefaction-hazard investigations.*

| Liquefaction Hazard | Occupancy Category | | | |
|---|---|---|---|---|
| | I | II | III | IV |
| | Buildings and Other Structures That Represent a Low Hazard to Human Life in the Event of Failure (IBC) | All Other Buildings and Structures Except Those Listed in Categories I, III, and IV (includes One- and Two-Family Dwellings and Townhouses) (IRC) (IBC) | Buildings and Other Structures That Represent a Substantial Hazard to Human Life in the Event of Failure (IBC) | Buildings and Other Structures Designated as Essential Facilities (IBC) |
| High Susceptibility | Reconnaissance[2] | Detailed[1] | Detailed[1] | Detailed[1] |
| Susceptibility Zone$_1$ | Reconnaissance[2] | Detailed[1] | Detailed[1] | Detailed[1] |
| Susceptibility Zone$_2$ | Reconnaissance[2] | Detailed[1] | Detailed[1] | Detailed[1] |
| Not Susceptible | None | Reconnaissance[2] | Reconnaissance[2] | Reconnaissance[2] |

[1]Detailed evaluation necessary; a detailed liquefaction investigation should be interdisciplinary in nature and performed by qualified experienced geotechnical engineers and engineering geologists working as a team.
[2]A reconnaissance investigation should be followed by a detailed investigation if a liquefaction hazard is determined to be present.

## HAZARD REDUCTION

Although potentially costly when not recognized and properly accommodated in project design, problems associated with liquefaction rarely are life threatening. As with most geologic hazards, early recognition and avoidance are the most effective ways to mitigate this hazard. However, avoidance may not always be a viable or cost-effective option and other techniques are available to reduce liquefaction hazards (National Research Council, 1985).

Liquefaction damage may be reduced either by using ground improvement methods to lower the liquefaction hazard (for example, compacting or replacing soil; installing drains or pumps to dissipate or lower the water table) or by designing structures to withstand liquefaction effects (using deep foundations or structural reinforcement). Existing structures threatened by liquefaction may be retrofitted to reduce the potential for damage. Because the cost of reducing liquefaction hazards for existing structures may be high relative to their value, and because liquefaction is generally not a life-threatening hazard, we consider it prudent, although not essential, to reduce liquefaction hazards for existing structures, unless significant ground deformation (lateral spreading) is anticipated and the structures fall into IBC Occupancy Categories III or IV, in which case retrofitting is recommended.

## MAP LIMITATIONS

This map is based on limited geological, geotechnical, and hydrological data; a site-specific investigation is required to produce more detailed information. This map also depends on the quality of those data, which varies throughout the study area. The mapped boundaries of the Liquefaction-Susceptibility Zones are approximate and subject to change as new information becomes available. Liquefaction susceptibility at any particular site may be different than shown because of geologic and hydrologic variations within a map unit, gradational and approximate map-unit boundaries, and the map scale. Small, localized areas of liquefaction susceptibility may exist anywhere within the study area, but their identification is precluded because of limitations of either data or map scale. Seasonal and long-term fluctuations in groundwater levels can affect liquefaction hazard at a site. This map is not intended for use at scales other than the published scale, and is intended for use in general planning and design to indicate the need for site-specific investigations.

## REFERENCES

Black, B.D., Mulvey, W.E., Lowe, M., and Solomon, B.J., 1995, Geologic effects, *in* Christenson, G.E., editor, The September 2, 1992 $M_L$ 5.8 St. George earthquake: Utah Geological Survey Circular 88, p. 2–11.

Doelling, H.H., Willis, G.C., Solomon, B.J., Sable, E.G., Hamilton, W.L., and Naylor, L.P., II, 2002, Interim geologic map of the Springdale East quadrangle, Washington County, Utah: Utah Geological Survey Open-File Report 393, 19 p., scale 1:24,000.

Harty, K.M., and Lowe, M., 2003, Geologic evaluation and hazard potential of liquefaction-induced landslides along the Wasatch Front, Utah: Utah Geological Survey Special Study 104, 40 p.

Hayden, J.M., and Sable, E.G., 2008, Geologic map of the Virgin quadrangle, Washington County, Utah: Utah Geological Survey Map 231, 2 plates, scale 1:24,000, CD.

International Code Council, 2009a, International building code: Country Club Hills, Illinois, 678 p.

International Code Council, 2009b, International residential code for one- and two-family dwellings: Country Club Hills, Illinois, 870 p.

Keller, E.A., and Blodgett, R.H., 2006, Natural hazards—Earth's processes as hazards, disasters, and catastrophes: Upper Saddle River, New Jersey, Pearson Prentice Hall, 395 p.

Lund, W.R., Hozik, M.J., and Hatfield, S.C., 2007, Paleoseismic investigation and long-term slip history of the Hurricane fault in southwestern Utah—Paleoseismology of Utah, Volume 14: Utah Geological Survey Special Study 119, 81 p., CD.

Lund, W.R., Knudsen, T.R., and Sharrow, D.L., 2010, Geologic hazards of the Zion National Park geologic-hazard study area, Washington and Kane Counties, Utah: Utah Geological Survey Special Study 133, 95 p., 9 plates, GIS data, DVD.

Lund, W.R., Knudsen, T.R., and Vice, G.S., 2008a, Paleoseismic reconnaissance of the Sevier fault, Kane and Garfield Counties, Utah—Paleoseismology of Utah, Volume 16: Utah Geological Survey Special Study 122, 37 p., CD.

Lund, W.R., Knudsen, T.R., Vice, G.S., and Shaw, L., 2008b, Geologic hazards and adverse construction conditions, St. George–Hurricane metropolitan area, Washington County, Utah: Utah Geological Survey Special Study 127, 105 p., DVD.

Martin, G.R., and Lew, M., editors, 1999, Recommended procedures for implementation of DMG Special Publication 117, Guidelines for analyzing and mitigating liquefaction hazards in California: University of Southern California, Southern California Earthquake Center, 63 p.

Moore, D.W., and Sable, E.G., 2001, Geologic map of the Smithsonian Butte quadrangle, Washington County, Utah: Utah Geological Survey Miscellaneous Publication 01-1, 30 p., scale 1:24,000.

Mortensen, V.L., Carley, J.A., Crandall, G.C., Donaldson, K.M., Jr., and Leishman, G.W., 1977, Soil survey of Washington County area, Utah: U.S. Department of Agriculture Soil Conservation Service and U.S. Department of the Interior Bureau of Land Management and National Park Service, 139 p., 95 plates, scale 1:24,000.

National Research Council, 1985, Liquefaction of soils during earthquakes: Washington, D.C., National Academy Press, 240 p.

Pechmann, J.C., Arabasz, W.J., and Nava, S.J., 1995, Seismology, *in* Christenson, G.E., editor, The September 2, 1992 $M_L$ 5.8 St. George earthquake: Utah Geological Survey Circular 88, p. 1.

Seed, H.B., and Idriss, I.M., 1982, Ground motion and soil liquefaction during earthquakes: Oakland, California, Earthquake Engineering Research Institute, 135 p.

Solomon, B.J., 1996, Engineering geologic map folio, Springdale, Washington County, Utah: Utah Geological Survey Open-File Report 340, 6 plates, scale 1:14,400.

Tinsley, J.C., Youd, T.L., Perkins, D.M., and Chen, A.T.F., 1985, Evaluating liquefaction potential, *in* Ziony, J.I., editor, Evaluating earthquake hazards in the Los Angeles region—an earth science perspective: U.S. Geological Survey Professional Paper 1360, p. 263–315.

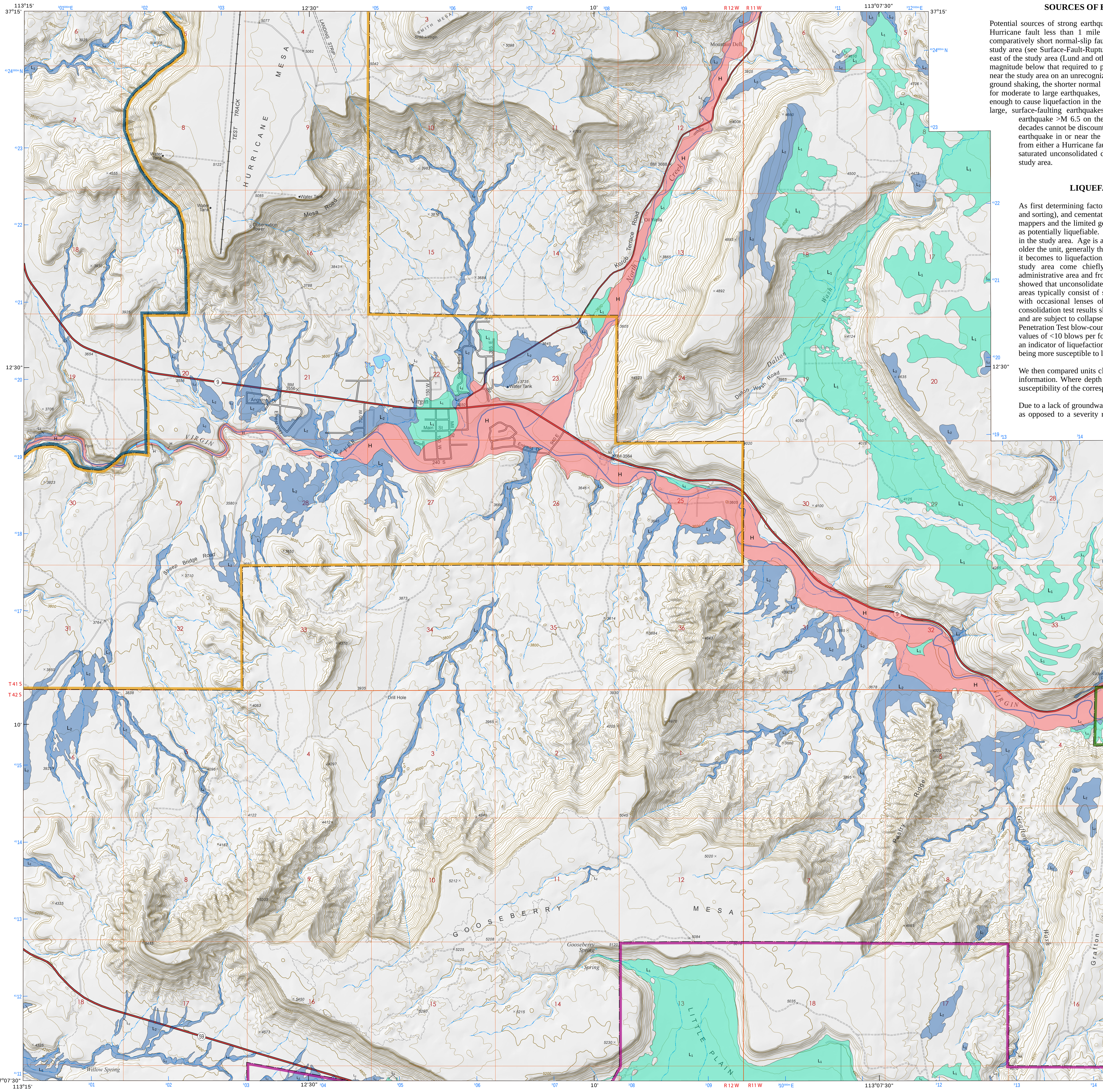
Willis, G.C., Doelling, H.H., Solomon, B.J., and Sable, E.G., 2002, Interim geologic map of the Springdale West quadrangle, Washington County, Utah: Utah Geological Survey Open-File Report 394, 20 p., scale 1:24,000.

Youd, T.L., 1978, Major cause of earthquake damage is ground failure: Civil Engineering, v. 48, p. 47–51.

Youd, T.L., 1984, Geologic effects—liquefaction and associated ground failure: U.S. Geological Survey Open-File Report 84-760, p. 210–232.

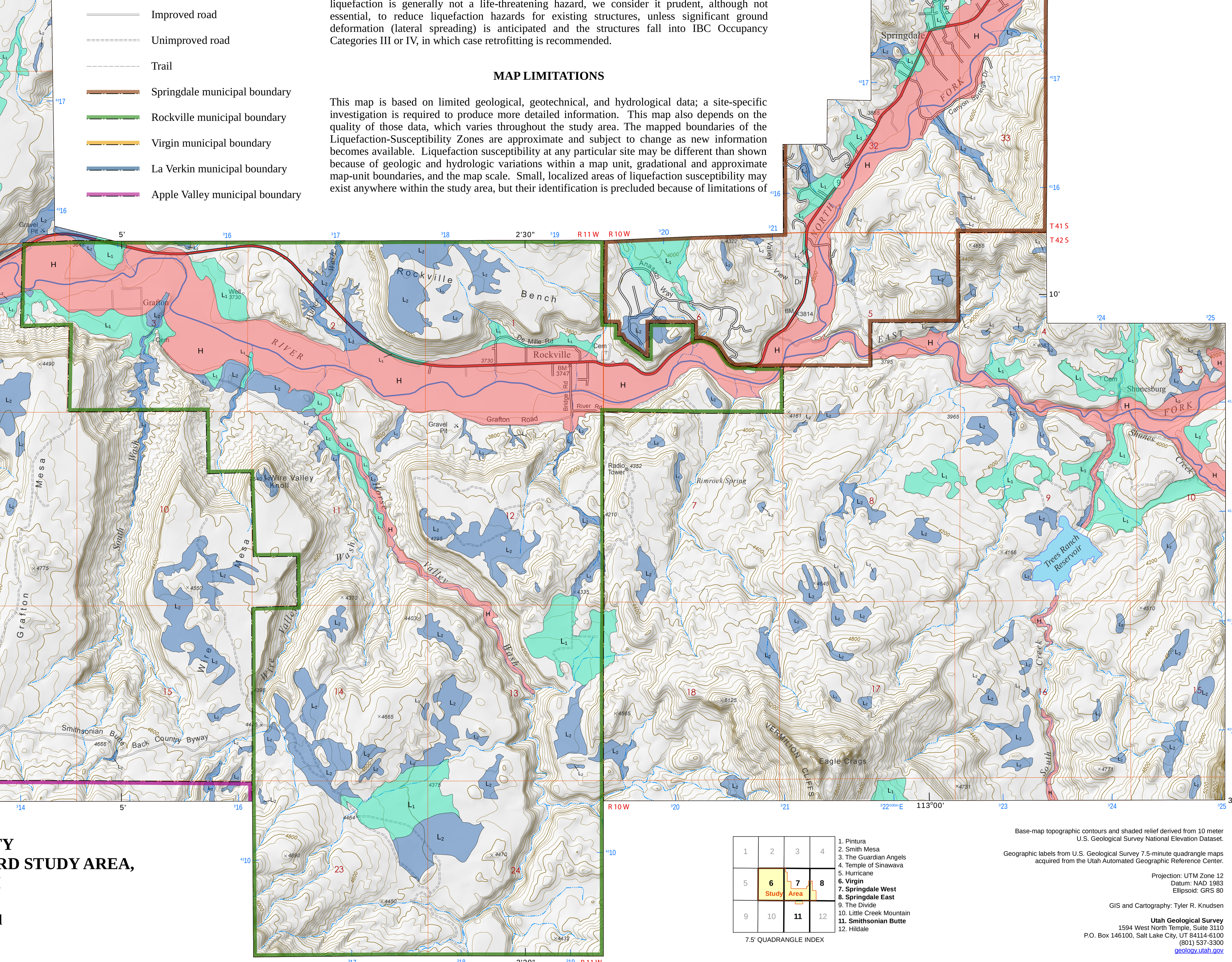
Youd, T.L., and Gilstrap, S.D., 1999, Liquefaction and deformation of silty and fine-grained soils, *in* Seco e Pinto, editor, Proceedings of the Second International Conference on Earthquake Geotechnical Engineering: Lisbon, Portugal, 21-25 June 1999, p. 1013-1020.

Youd, T.L., and Idriss, I.M., 1997, Summary report, *in* Proceedings of the NCEER workshop on evaluation of liquefaction resistance of soils, December 31, 1997: National Center for Earthquake Engineering Research Technical Report NCEER-07-0022, p. 40.




## MAP SYMBOLS

State highway
Primary paved road
Secondary paved road
Improved road
Unimproved road
Trail
Springdale municipal boundary
Rockville municipal boundary
Virgin municipal boundary
La Verkin municipal boundary
Apple Valley municipal boundary






11°42'
APPROXIMATE MEAN DECLINATION, 2013

SCALE 1:24,000
1 0.5 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 0.5 0 1 KILOMETER
CONTOUR INTERVAL 40 FEET

UTAH
MAP LOCATION

# LIQUEFACTION SUSCEPTIBILITY
# STATE ROUTE 9 CORRIDOR GEOLOGIC-HAZARD STUDY AREA, WASHINGTON COUNTY, UTAH

by
Tyler R. Knudsen and William R. Lund

2013

7.5' QUADRANGLE INDEX

1. Pintura
2. Smith Mesa
3. The Guardian Angels
4. Temple of Sinawava
5. Hurricane
6. **Virgin**
7. **Springdale West**
8. **Springdale East**
9. The Divide
10. Little Creek Mountain
11. **Smithsonian Butte**
12. Hildale

Study Area

Base-map topographic contours and shaded relief derived from 10-meter U.S. Geological Survey National Elevation Dataset.

Geographic labels from U.S. Geological Survey 7.5-minute quadrangle maps acquired from the Utah Automated Geographic Reference Center.

Projection: UTM Zone 12
Datum: NAD 1983
Ellipsoid: GRS 80

GIS and Cartography: Tyler R. Knudsen

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