# SPECIAL STUDY 150: INVESTIGATION OF LAND SUBSIDENCE AND EARTH FISSURES IN CEDAR VALLEY, IRON COUNTY, UTAH

2014

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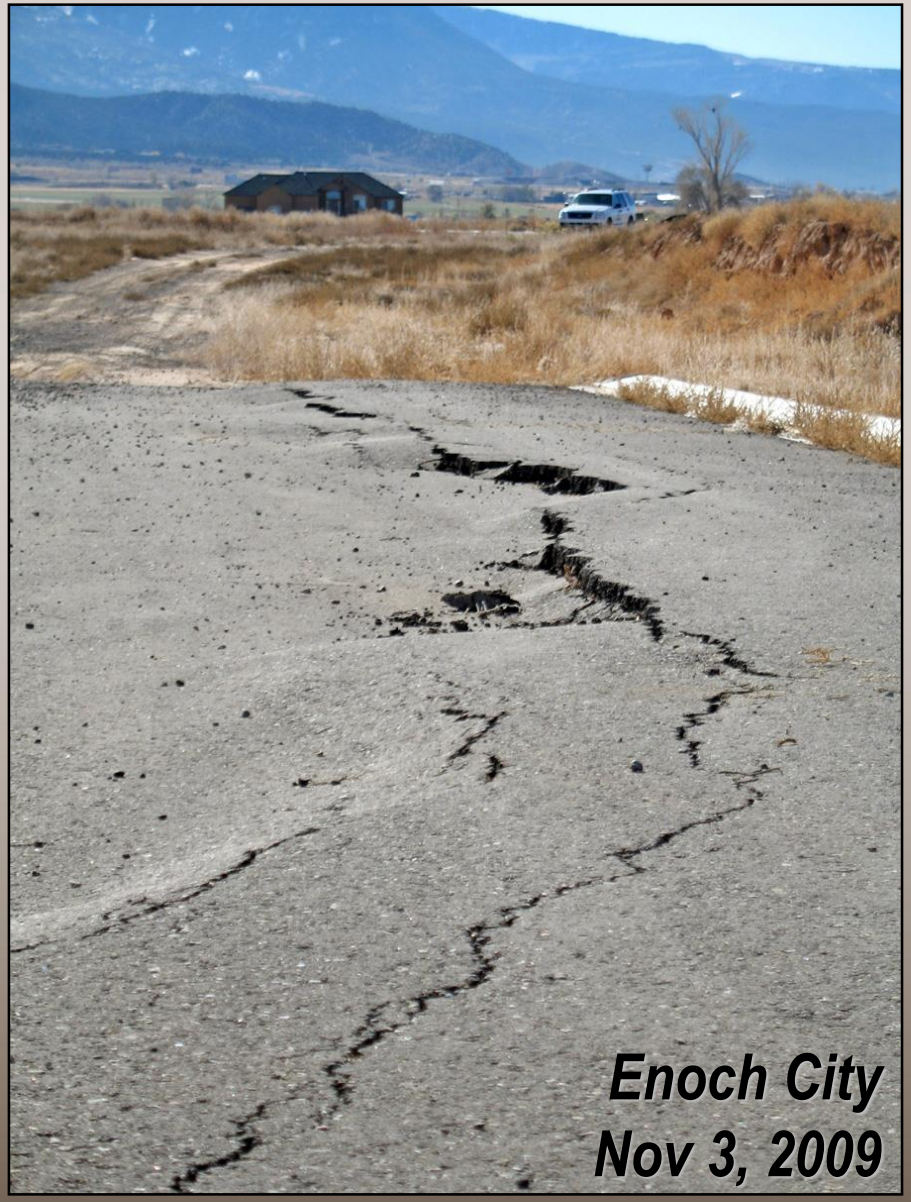
Bill Lund (geology, hazards)
Paul Inkenbrandt (groundwater)
Mike Lowe (groundwater)
Steve Bowman (remote sensing)

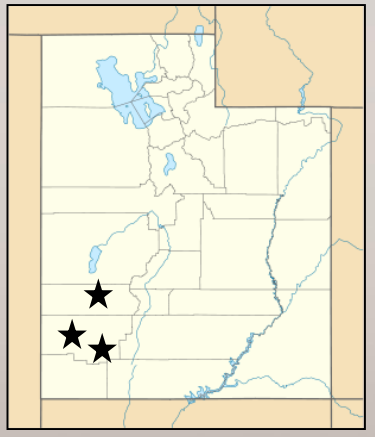


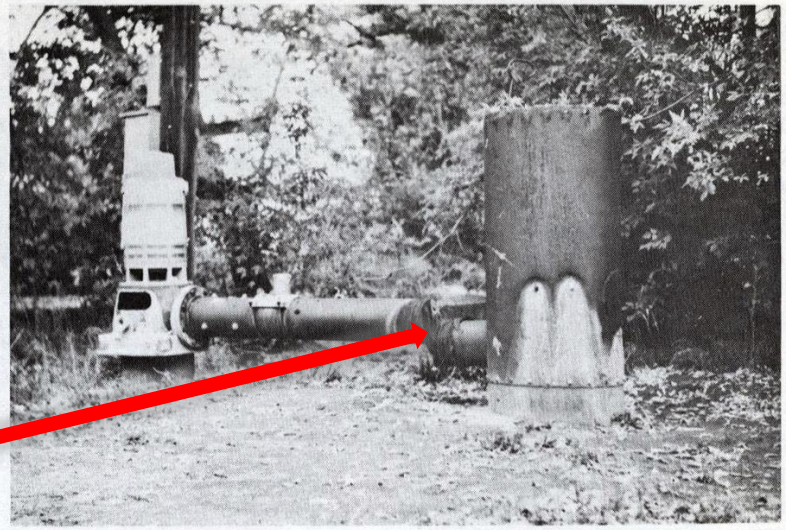
# Utah Geological Survey

- **Mission:** To provide timely scientific information about Utah's geologic environment, resources, and hazards.
- **UGS role includes:** Identify, inventory, assess, and mitigate Utah's geologic and subsurface environmental hazards to promote safe and responsible land use.
- **State Code 63-73-6:** Determine and investigate areas of geologic and topographic hazards that could affect the safety of, or cause economic loss to, the citizens of the state.

# Subsidence and Earth Fissures in Utah

- 1974 – Milford Valley–USGS/DNR Technical Pub. 43
- 2005 – Beryl-Enterprise Area UGS Special Study 115
- **2009 – Cedar Valley** (first place in Utah to significantly impact infrastructure)





4 inch offset

Figure 10.—Photograph showing a result of land subsidence at well (C-29-10)6baa-2 in the Milford area. The offset between the well discharge pipe and pipeline is due to subsidence. Diameter of discharge pipe is 8 inches (20.3 cm). Photograph taken October 5, 1972.

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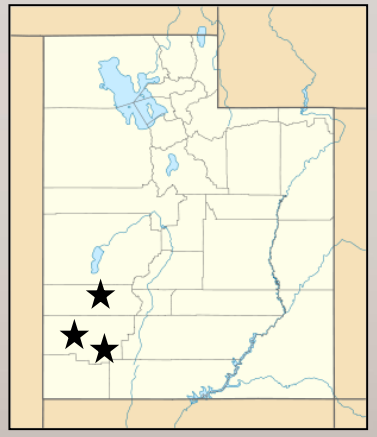
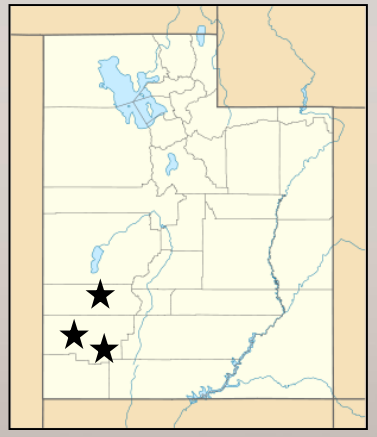


Near Beryl Junction

# Subsidence and Earth Fissures in Utah



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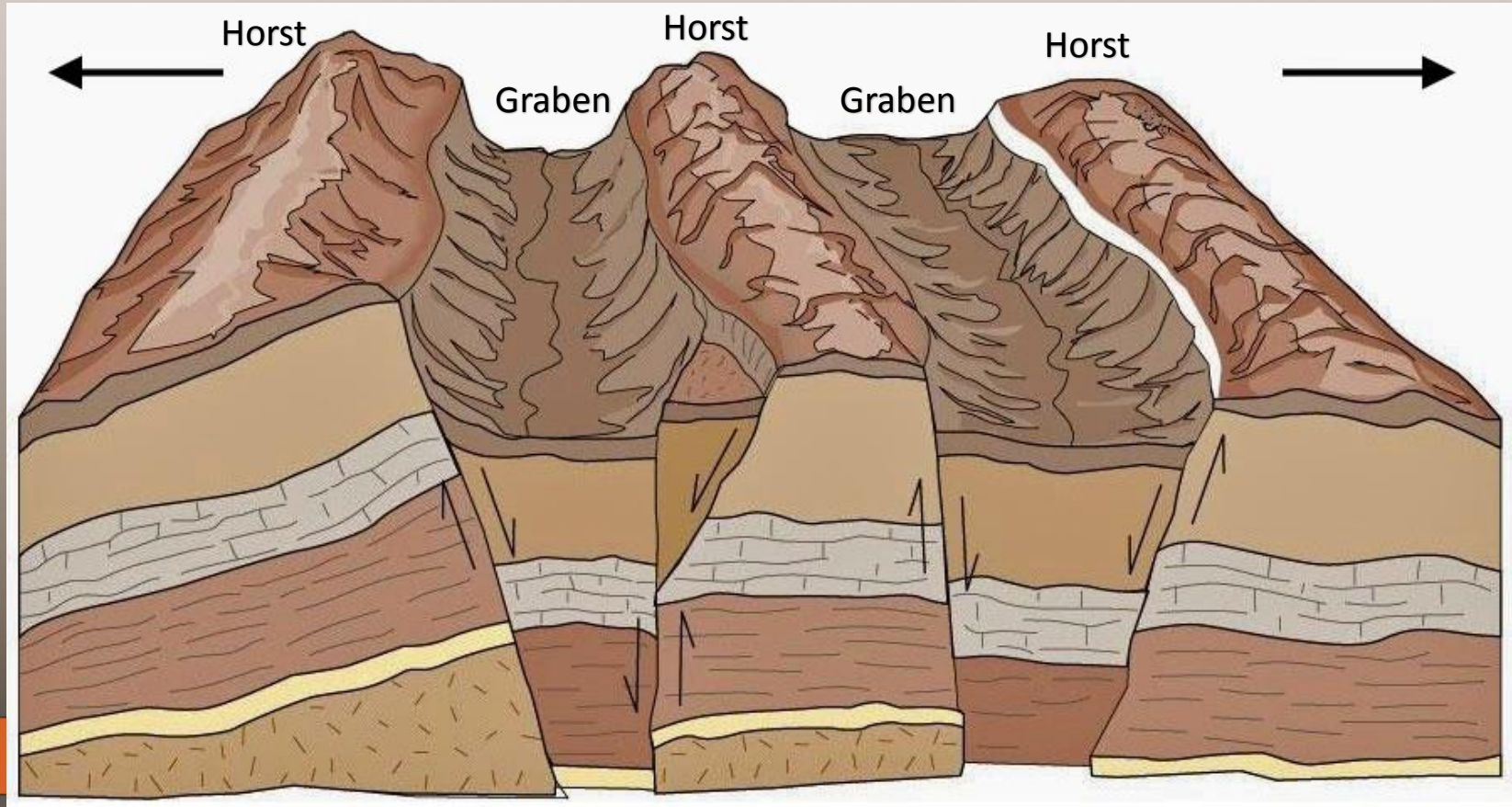
- While relatively new to Utah, nearby states affected by subsidence (Arizona, Nevada, California) have been dealing with subsidence and earth-fissure issues for many years.

- Lessons learned in those states can be applied in Utah.

# Geologic Setting for Cedar Valley

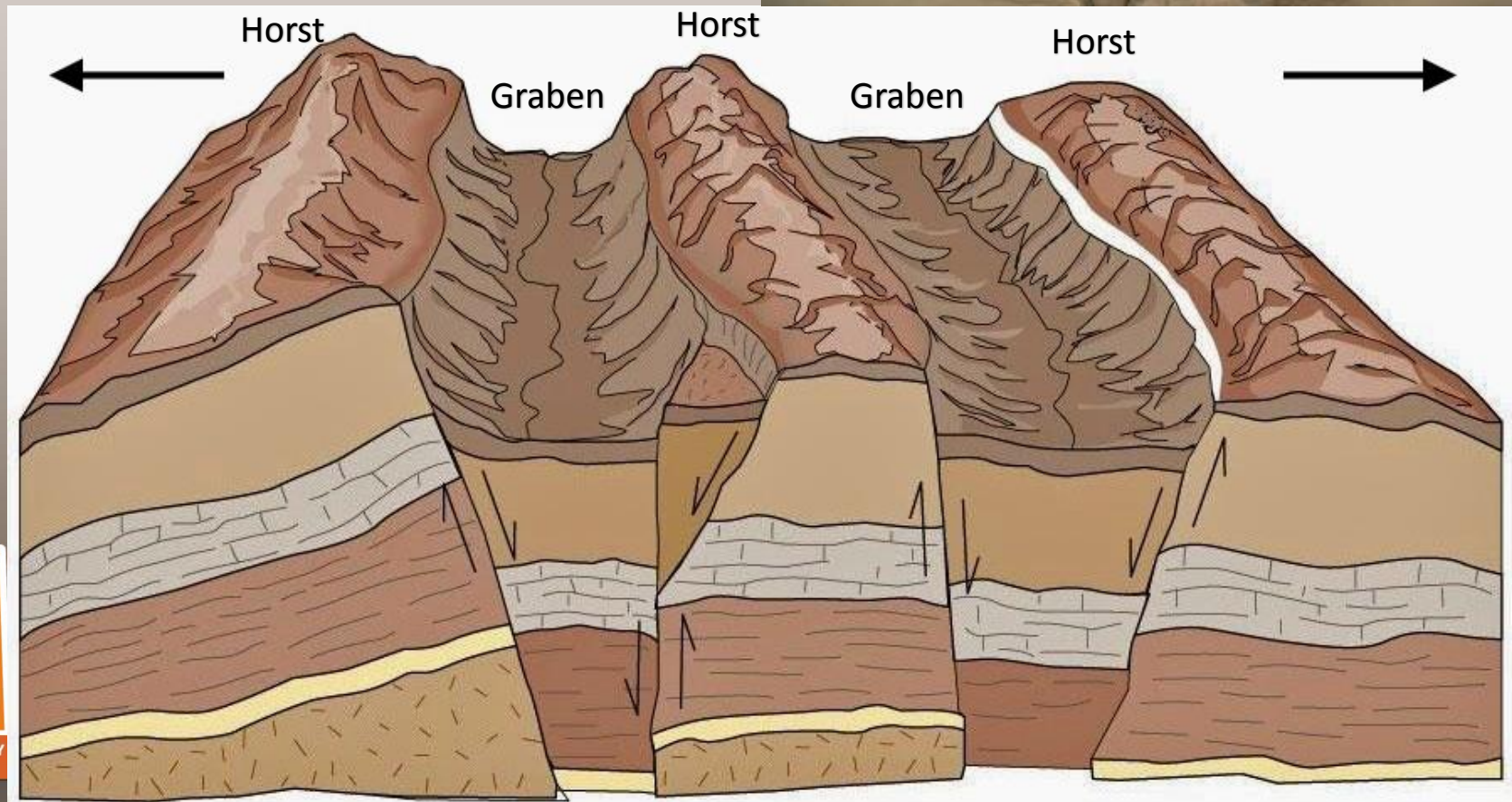
- Western US (Basin & Range) has been highly extended over past 20 million years
- Block faulting that continues to this day




UTAH DNR GEOLOGICAL SURVEY

# Geologic Setting for Cedar Valley

- **Alluvial fans** – primary mechanism for infilling of grabens (valleys) with sediment

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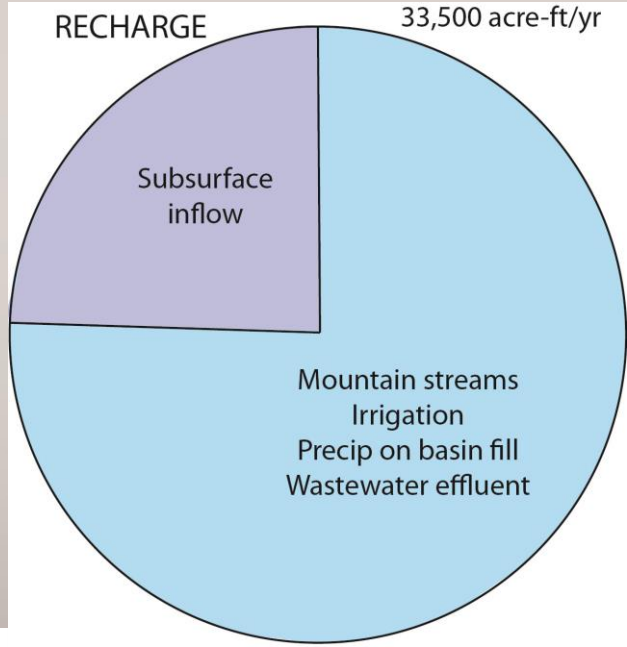
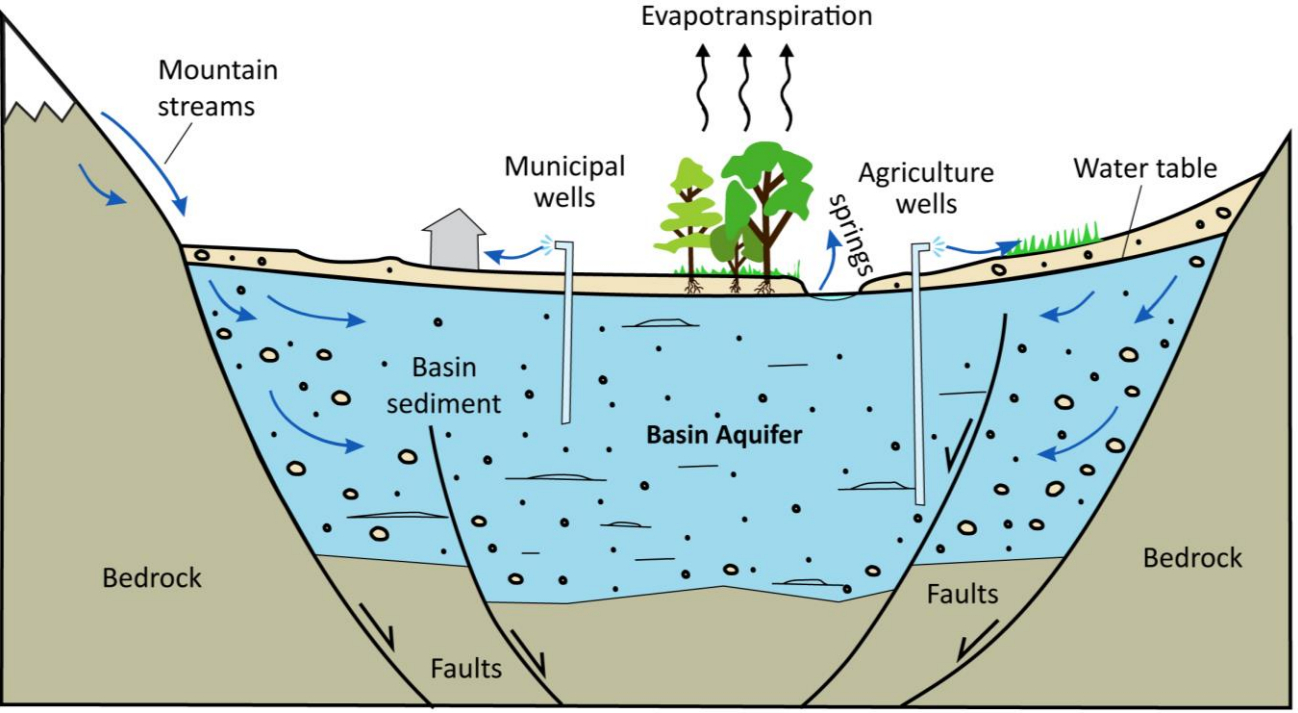
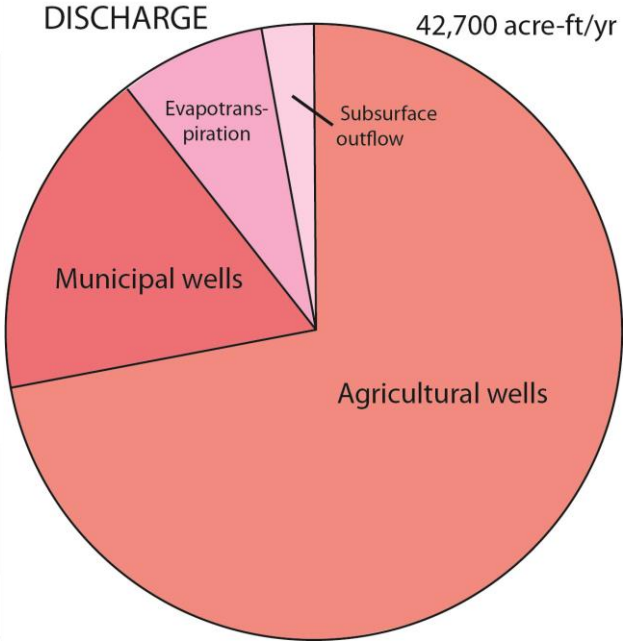
# Cedar Valley

- Typical Basin and Range fault-bounded basin
- Water occupies sediment pore spaces
- Groundwater budget = recharge - discharge
  (safe yield) (depletion)
- USGS estimated deficit = 9,000 acre/ft
- State Engineer estimated deficit = 7,000 acre/ft



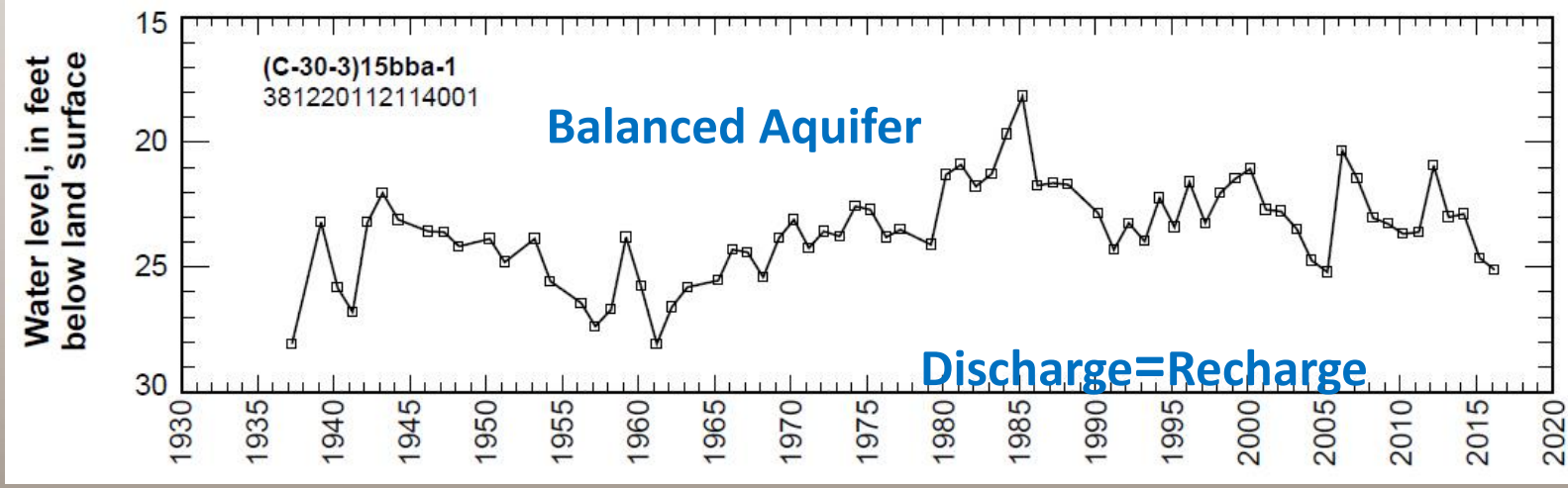



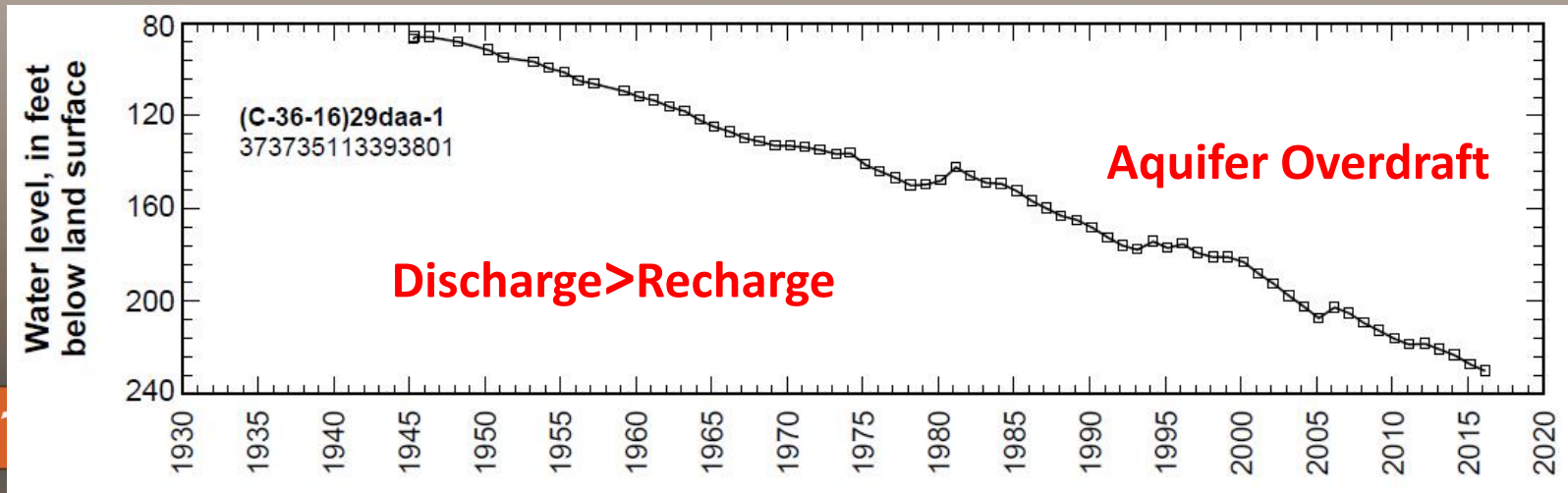



# Groundwater Decline

- Hydrographs – show changing water levels through time
- Healthy, balanced aquifers maintain consistent water levels
- Aquifers in overdraft have consistently declining water levels

USGS

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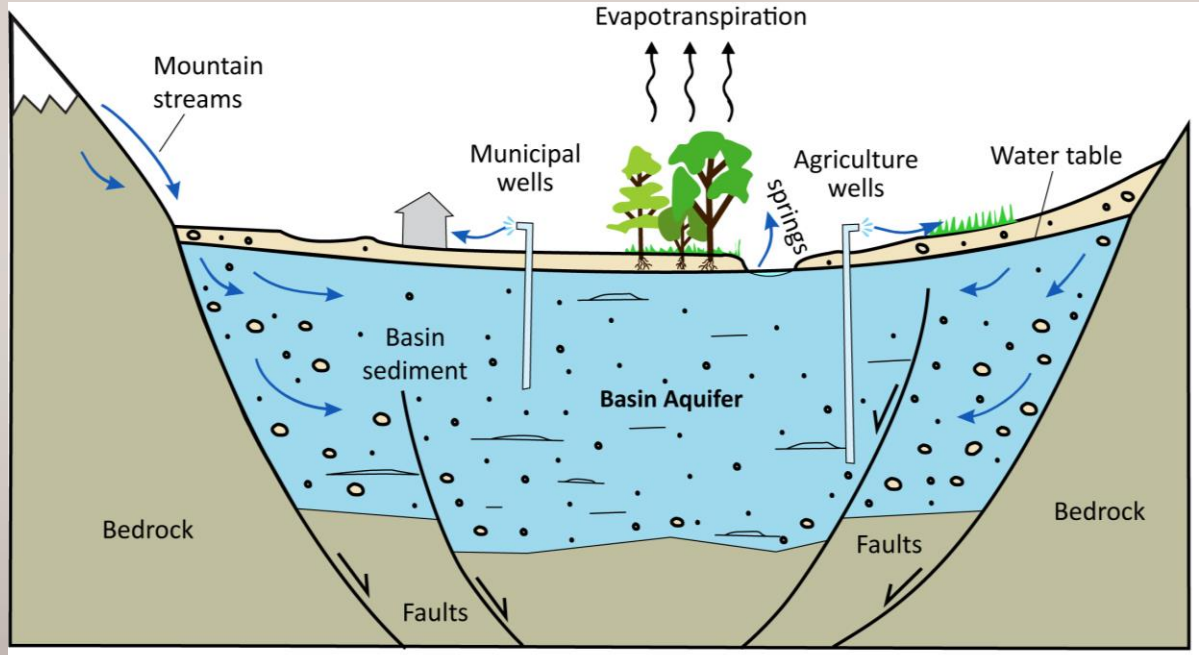
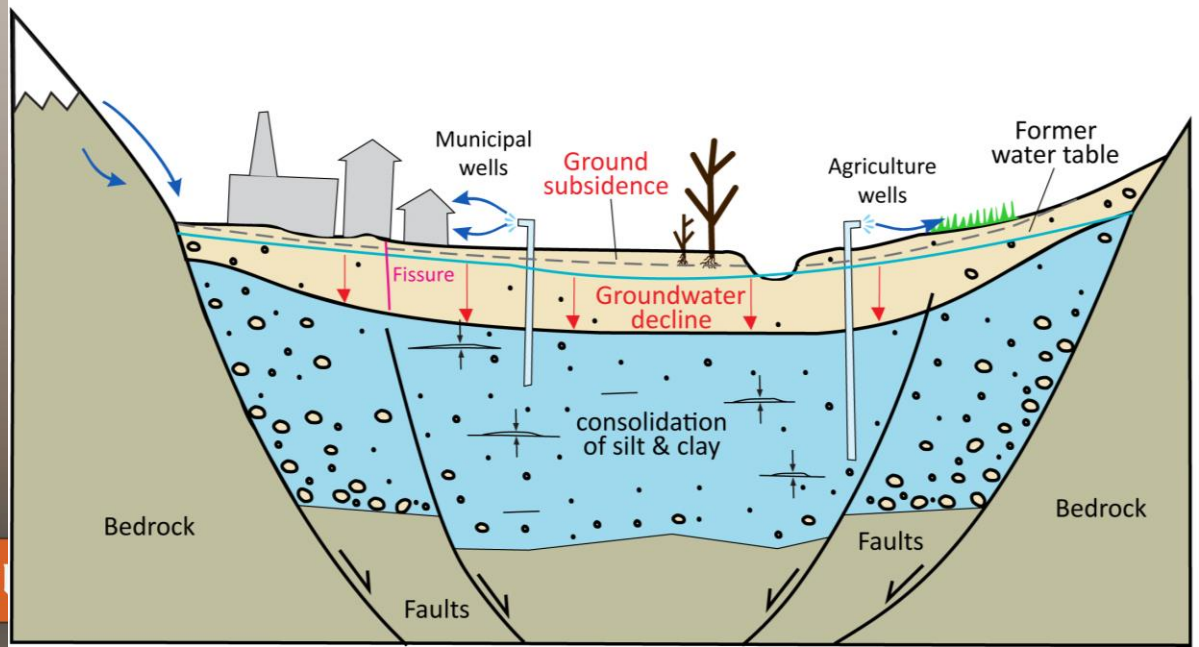
# Subsidence & Earth Fissures

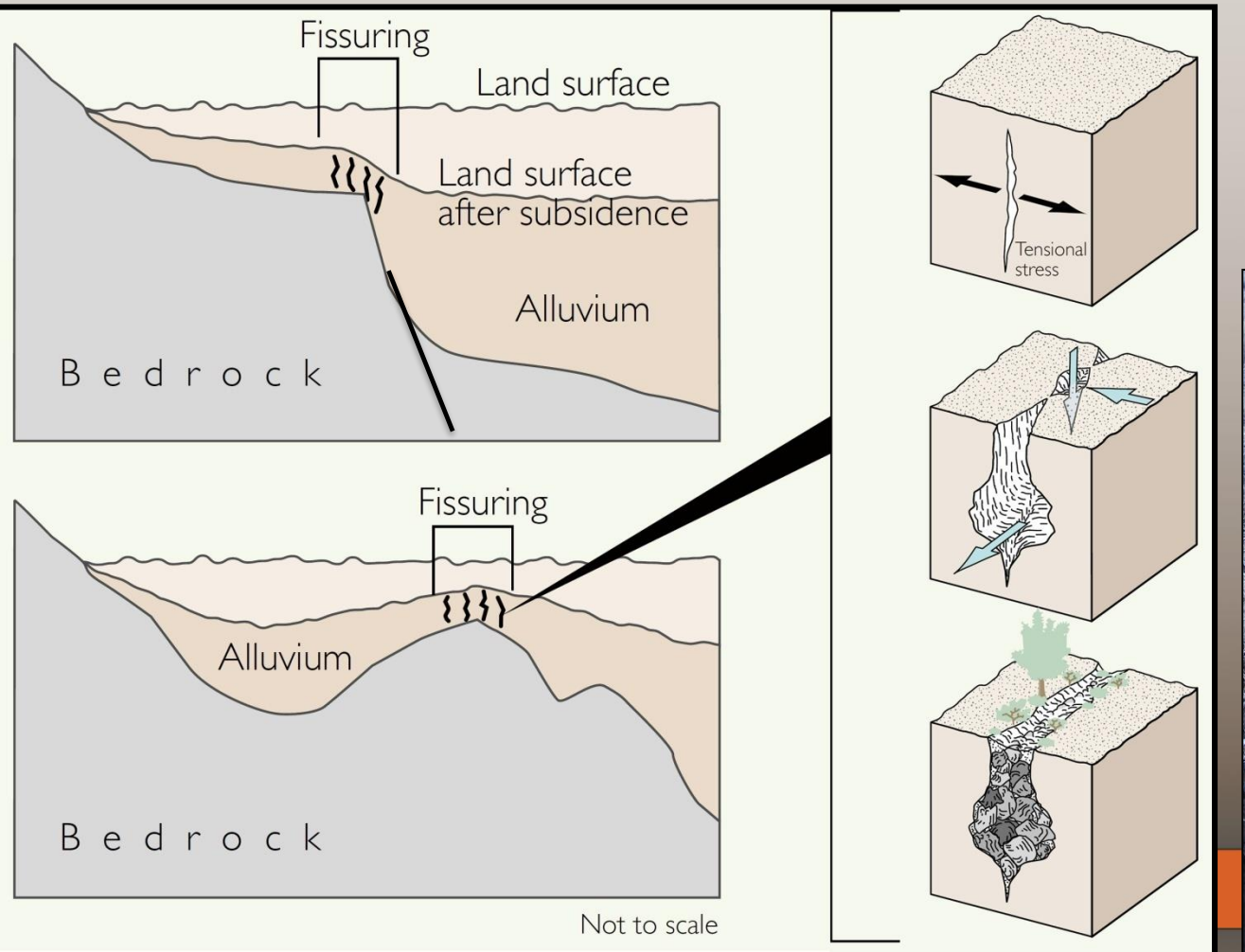
- Increased population/agriculture/ drought cause discharge to exceed recharge
- Water table drops
- Reduction of pore-water pressure causes compression in fine-grained sediment
- Development of tension cracks (fissures) due to differential compaction of the aquifer material



# Earth Fissures

- Typically form as hairline cracks extending to water table
- Enlarged by surface-water erosion




# Cedar Valley – Iron County

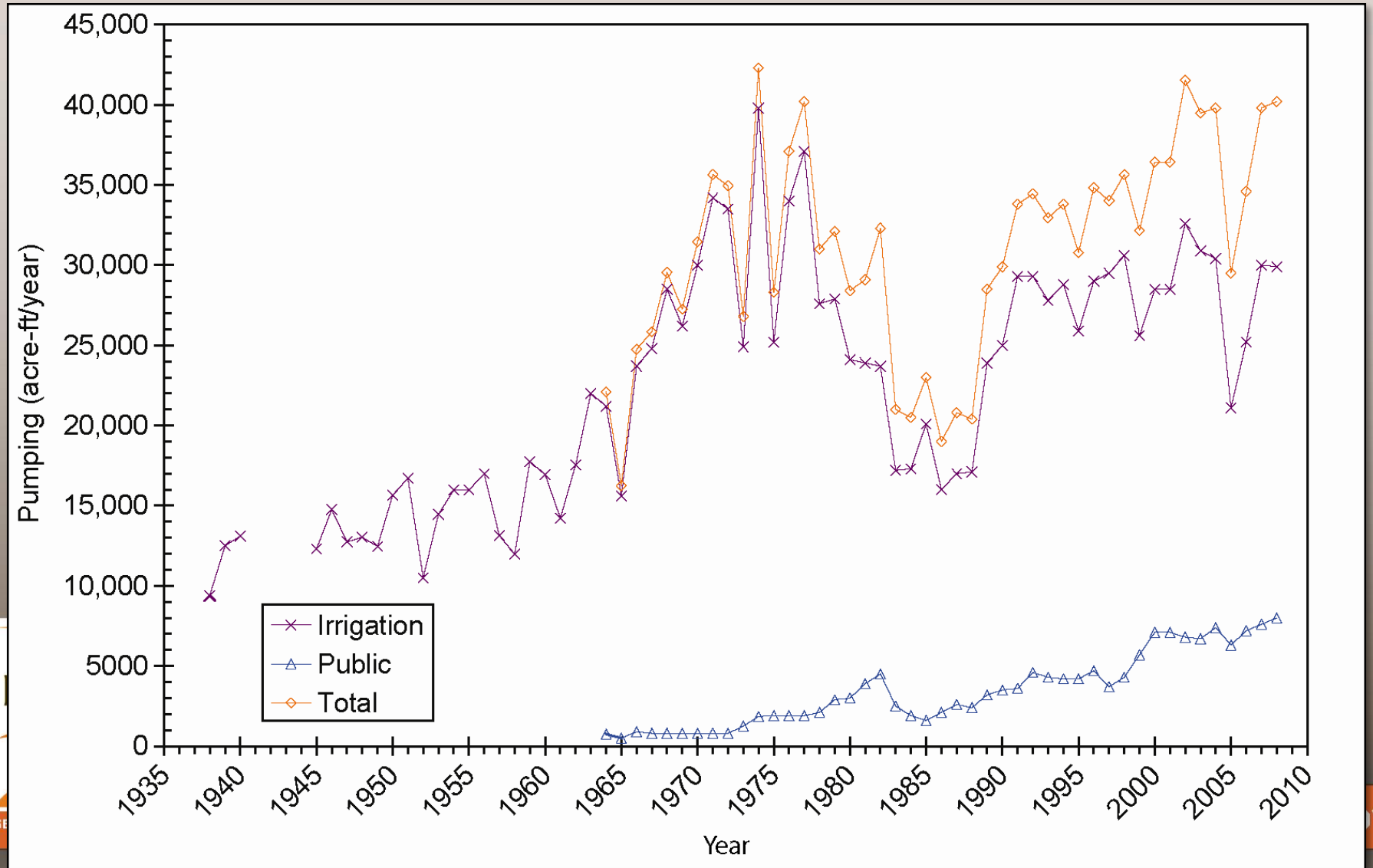
- May, 2009: Enoch City contacted the UGS to report a “fault” bisecting the new ~300-lot Parkview subdivision
- Cracked and displaced pavement/curbs, sewer line
- Nearly 2 ½ miles long fissure
- First subsidence/fissure to cause substantial damage to Utah’s built environment
  - Contracted with CICWCD to perform detailed study

# Study Goals

- Assess the amount of groundwater-level decline in Cedar Valley
- Map extent and nature of fine-grained compressible sediments
- Map the extent of earth fissures in Cedar Valley
- Quantify changes in land surface elevation
- Prepare final report and maps detailing findings + recommendations for future land and water use in the region

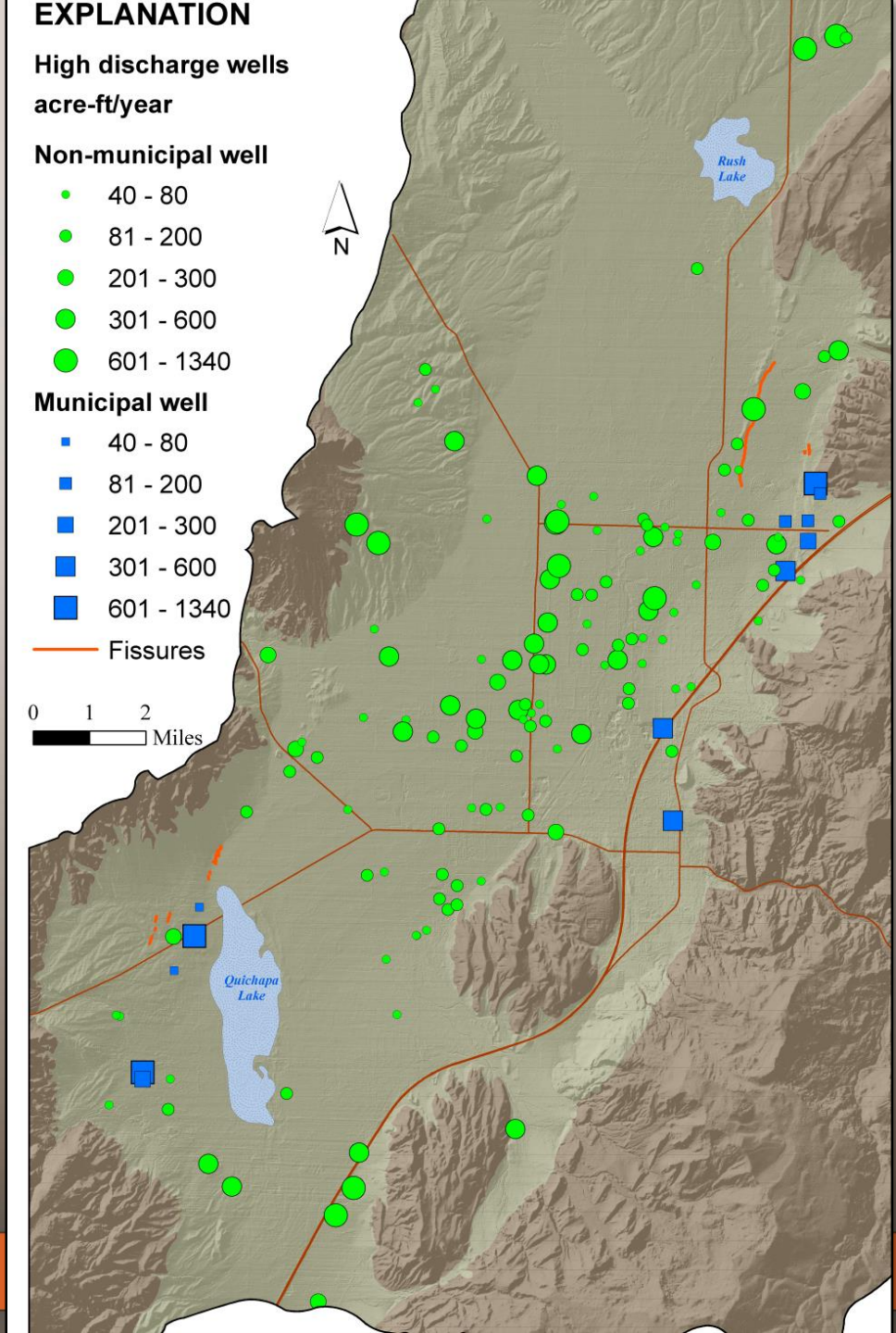
# Cedar Valley Groundwater Conditions (2009)

- Usage (groundwater pumped from wells)



# Cedar Valley Groundwater Conditions (2009)

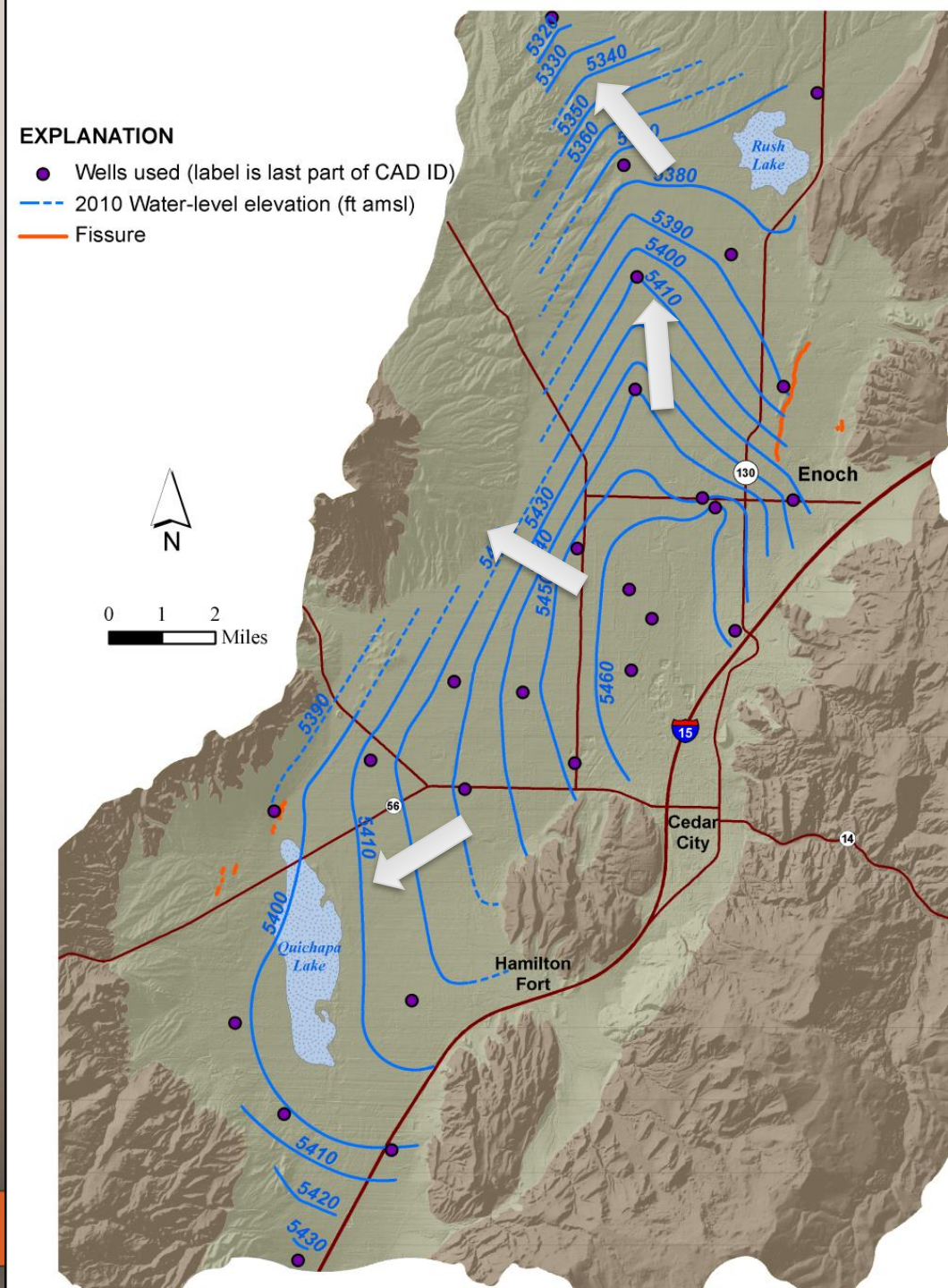
- Well distribution: Agriculture vs. Municipal
- Ag wells are generally well-distributed
- Municipal wells are concentrated in high-producing fields (Enoch and Quichapa)




UTAH GEOLOGICAL SURVEY

# Cedar Valley Groundwater Conditions (2010)

- 33 wells measured
- Water table elevation
- Generally mimics the ground surface
- Groundwater flows from higher elevations to lower elevations

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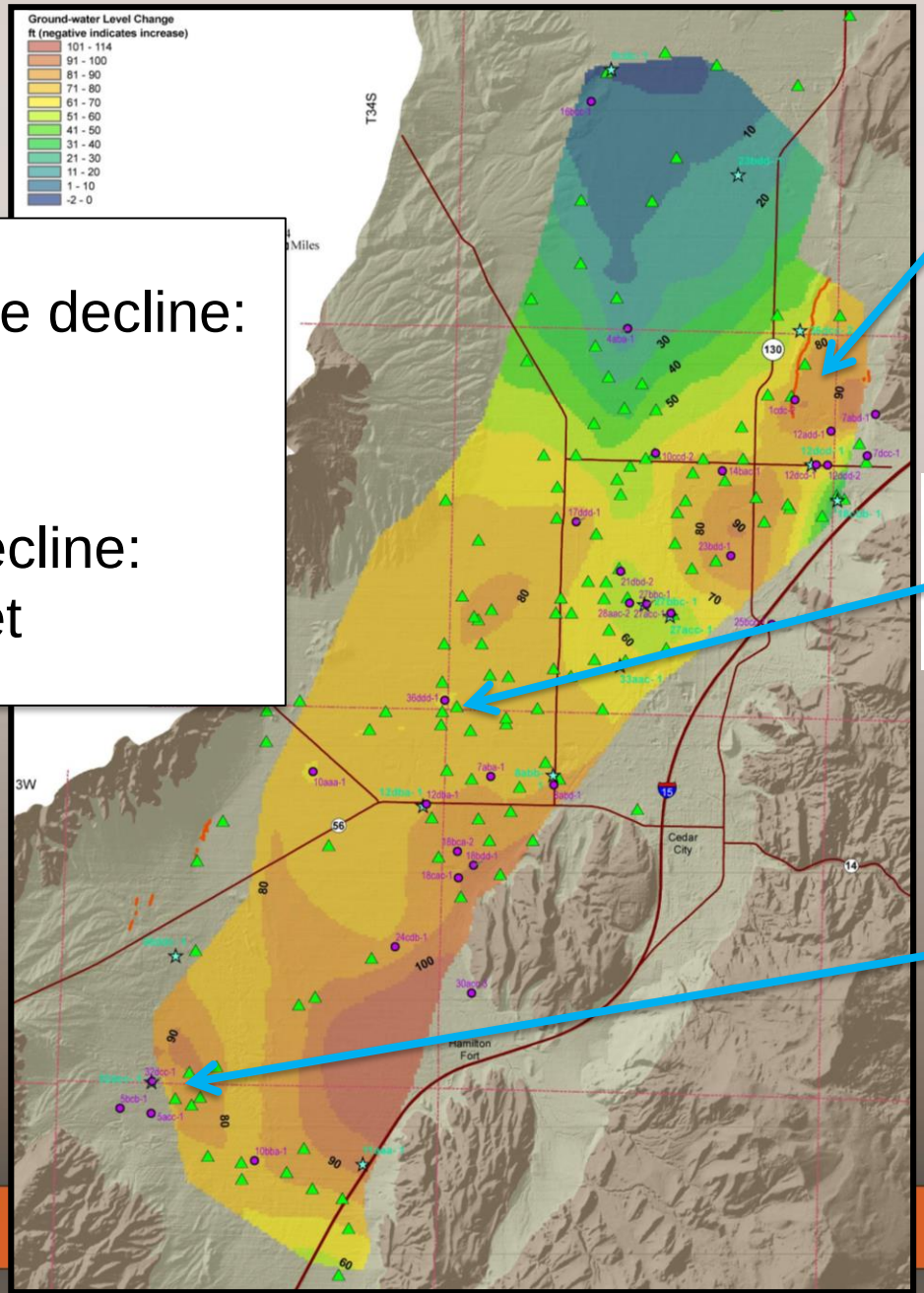
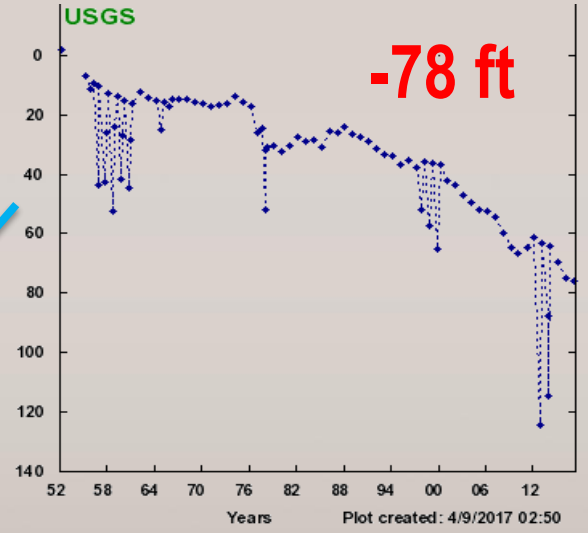
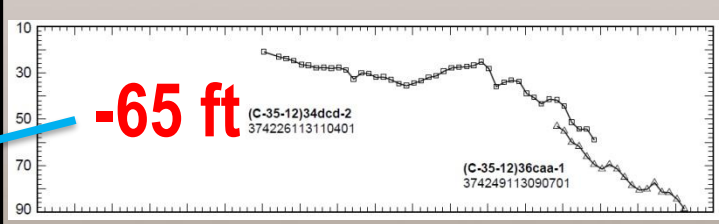
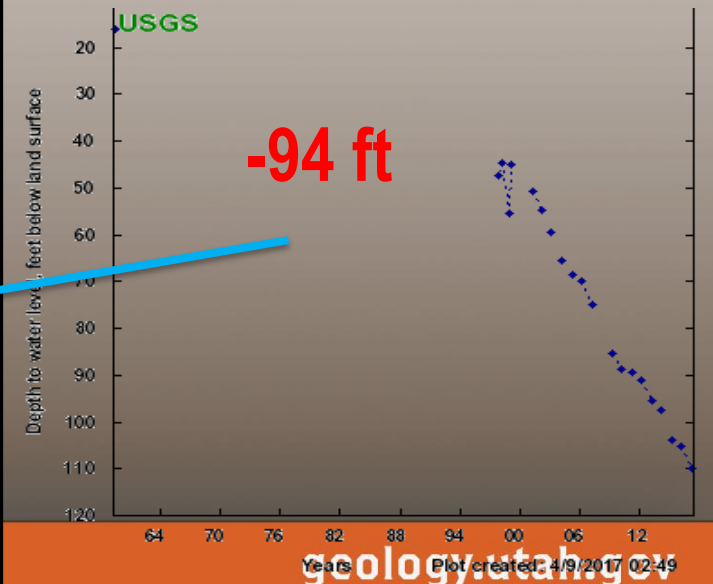
# Ground-Water Level Decline 1939-2009

- Average decline: 62 feet
- Max decline: 114 feet



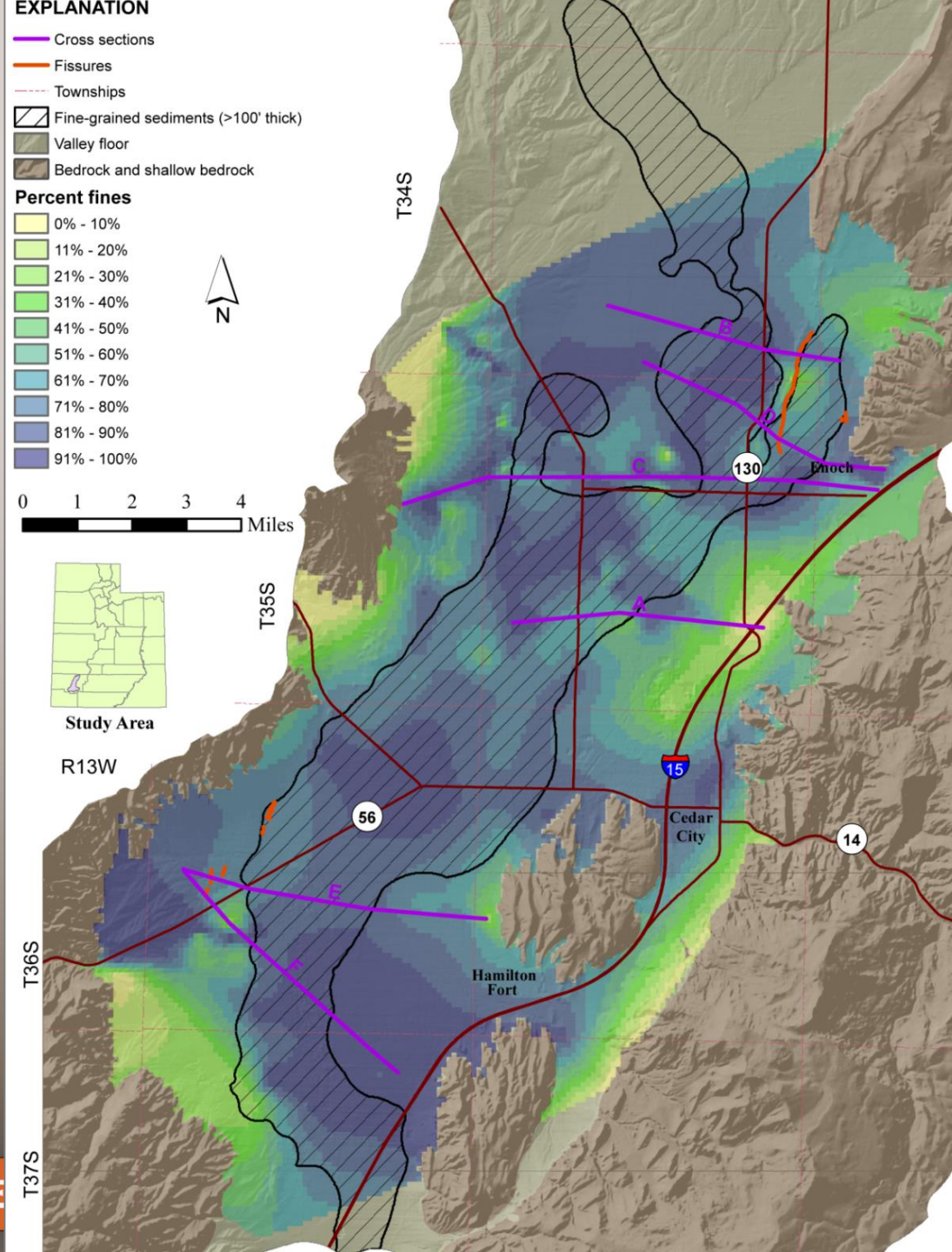




UTAH DNR GEOLOGICAL SURVEY

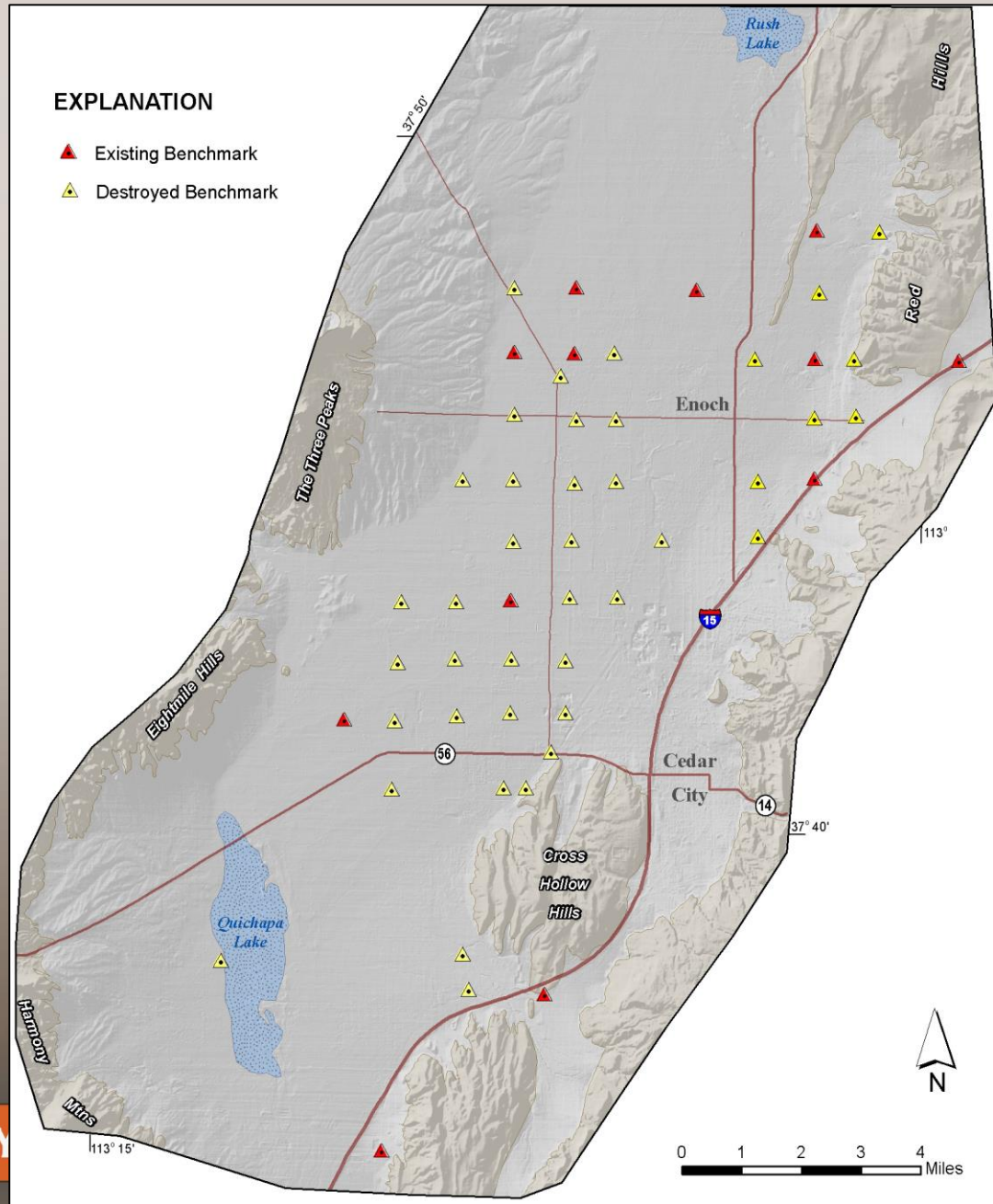
# Fine-Grained Sediments

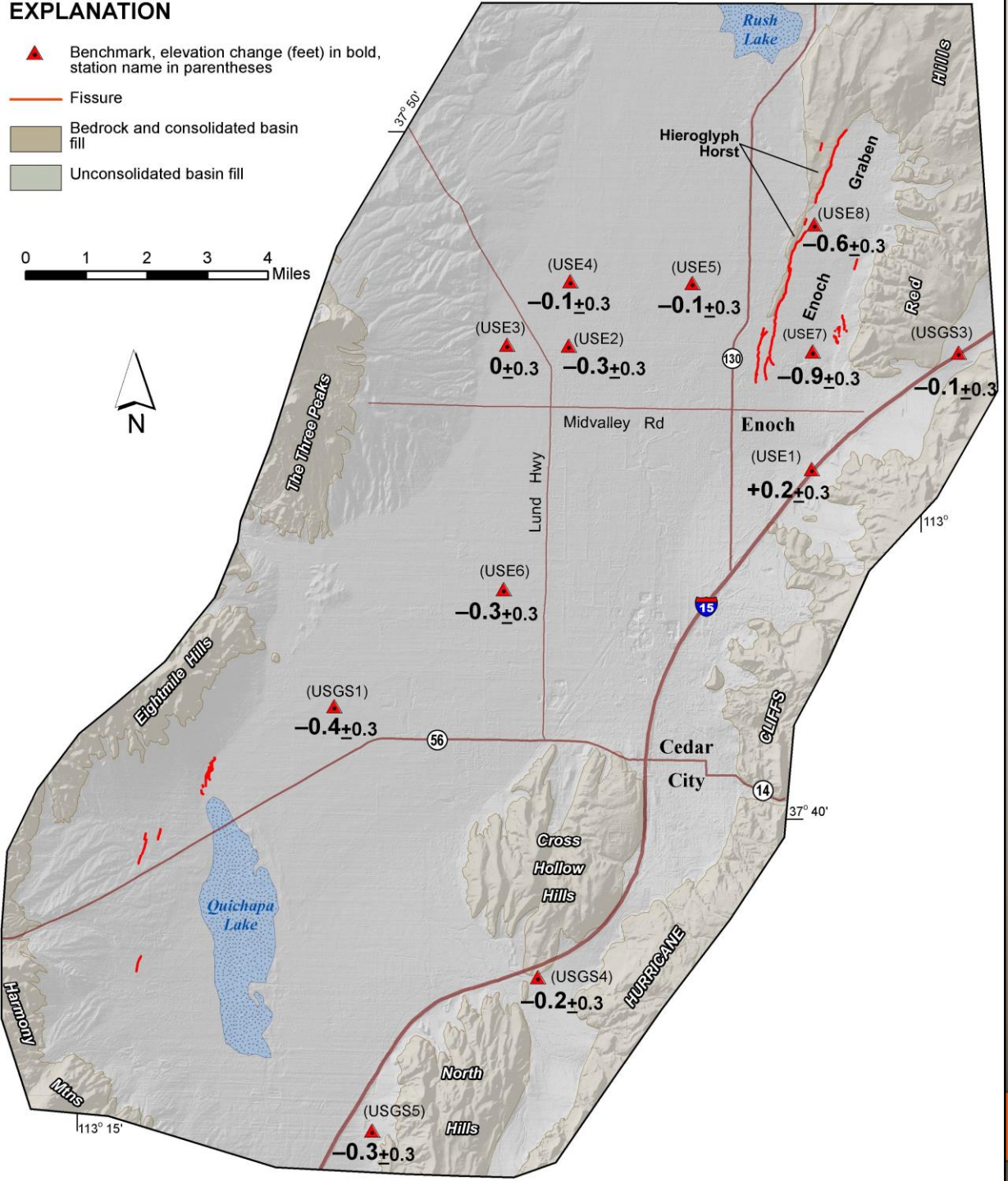
- 300 drillers' logs
- Our data + several other studies used to determine thick (>100 feet), predominantly fine-grained sediments (hachured area)



# Long-Term Subsidence

- Re-survey historical benchmarks with GPS
- 53 BMs installed before 1950 in Cedar Valley
- Recovered only 12 benchmarks with historical elevation data prior to 1949 – accuracy varies
- Remaining BMs are not in optimum locations

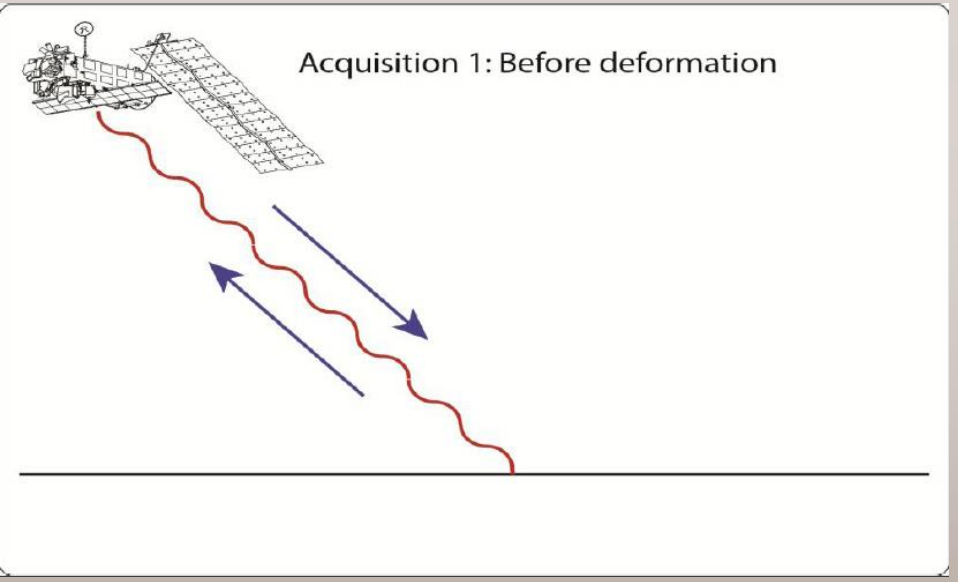



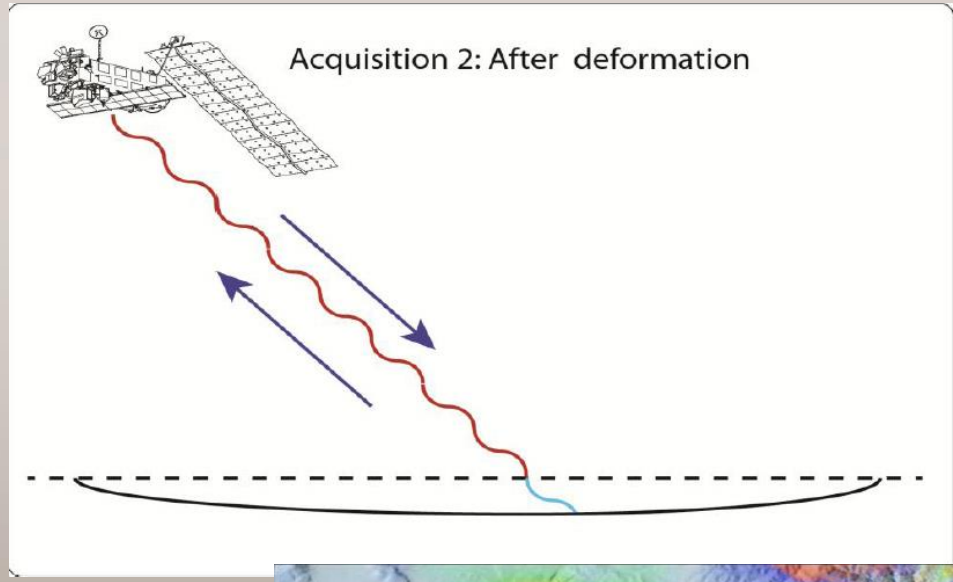


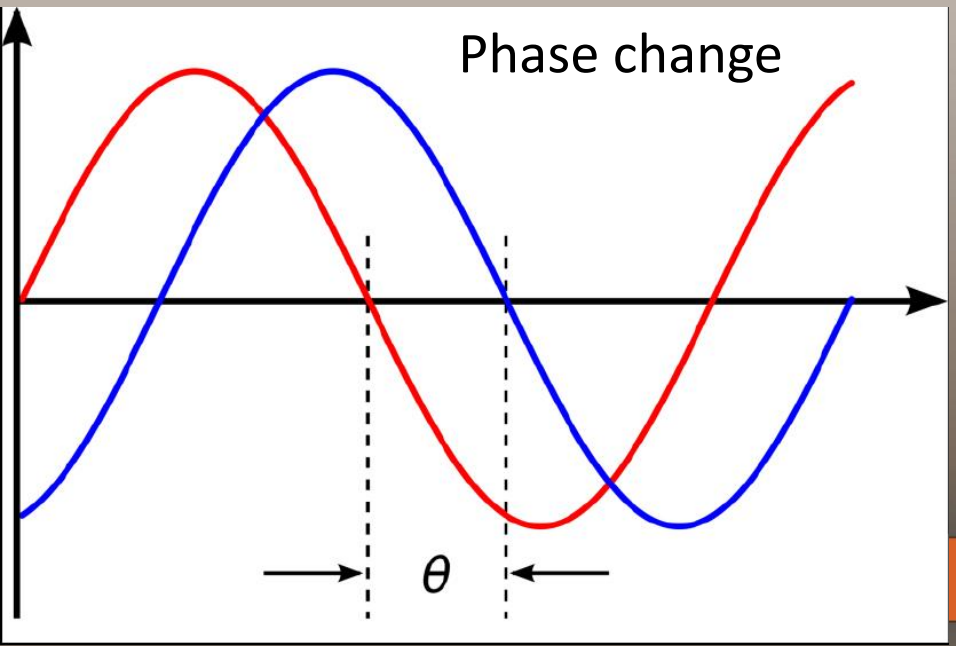

# Pre-1949 to 2011 Subsidence

- Results show nearly 1 foot of subsidence in the Enoch graben area.
- Most remaining subsidence amounts are within +/- 0.3 foot error.
- Absolute subsidence remains unknown over much of Cedar Valley due to the absence of historical benchmarks.
- Needed: Repeat static GPS/GNSS surveys of more dense network; InSAR.

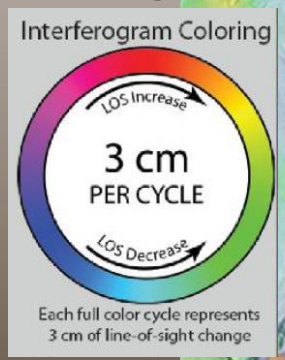
# InSAR (Interferometric synthetic aperture radar)

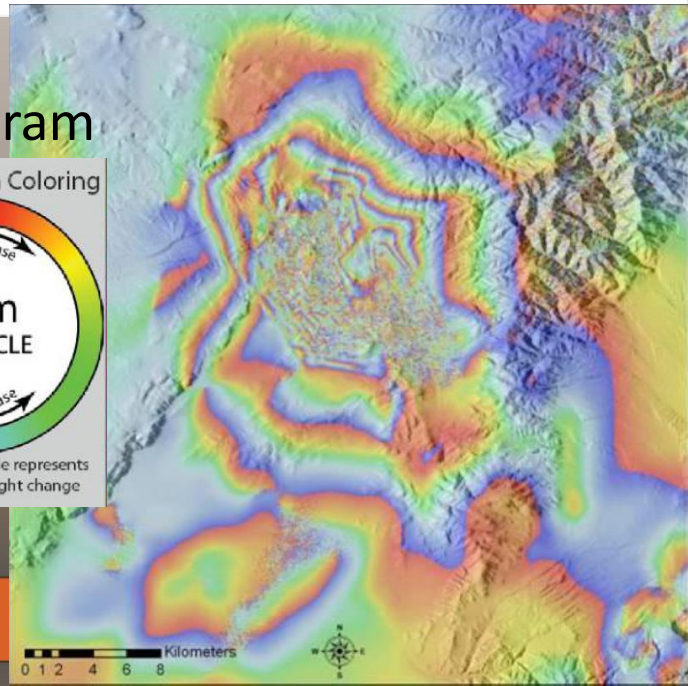


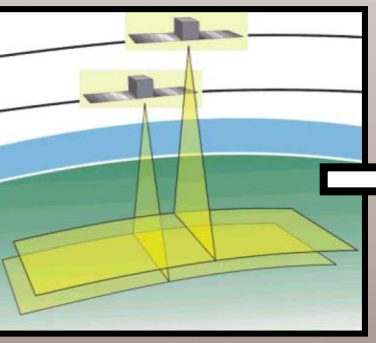

Interferogram



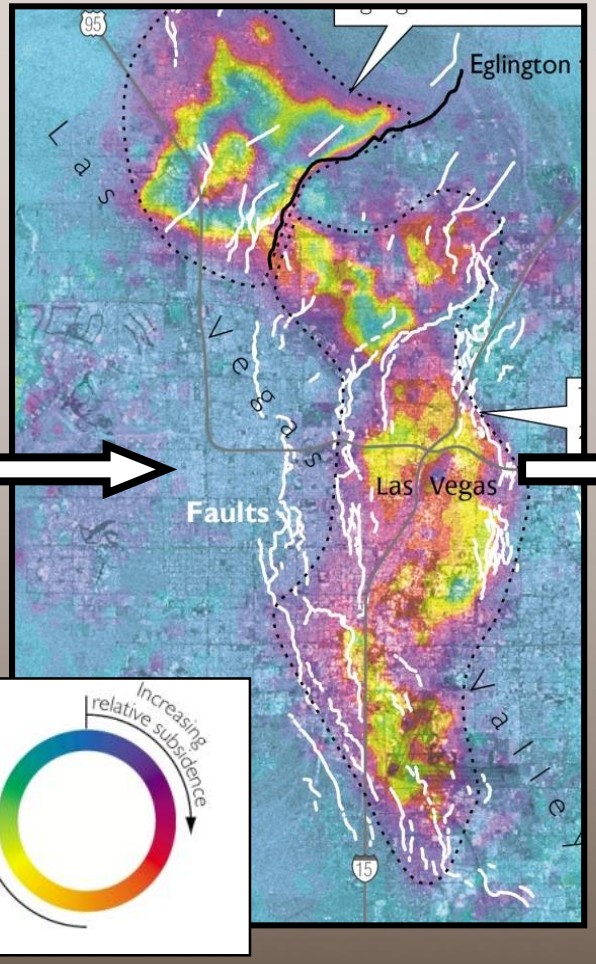



# InSAR

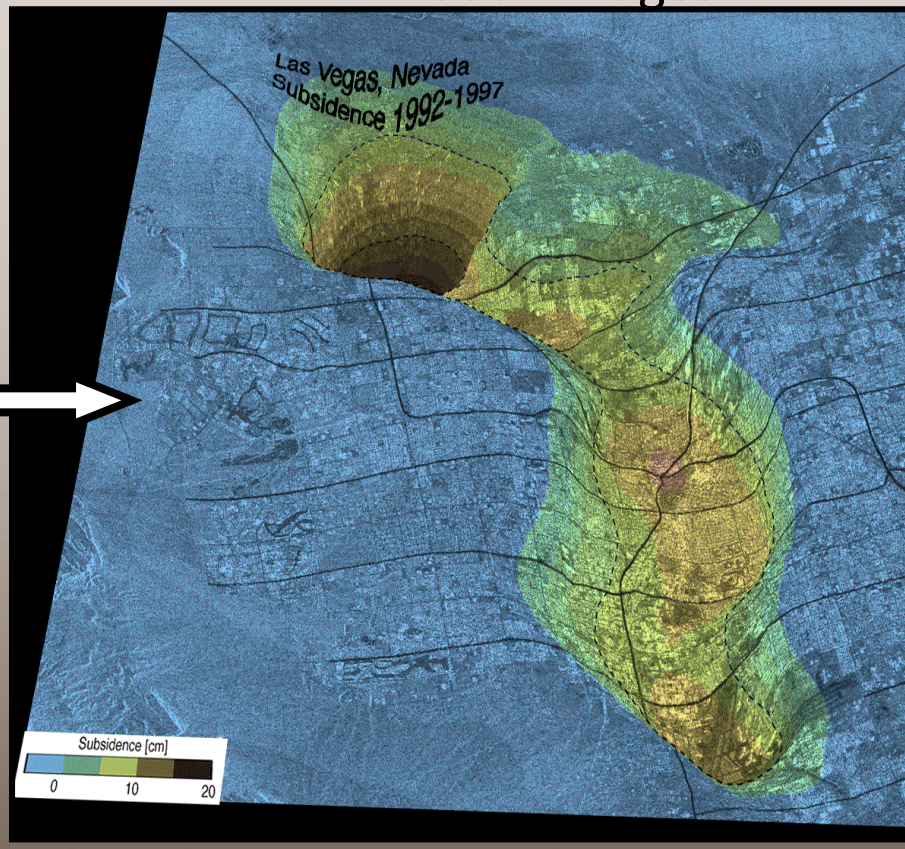
2 radar images



Phase change
(Interferogram)




Subsidence for period between radar images



# InSAR (Interferometric synthetic aperture radar)

## Pros

- <cm vertical accuracy
- Covers large area at high density
- Relatively inexpensive

## Cons

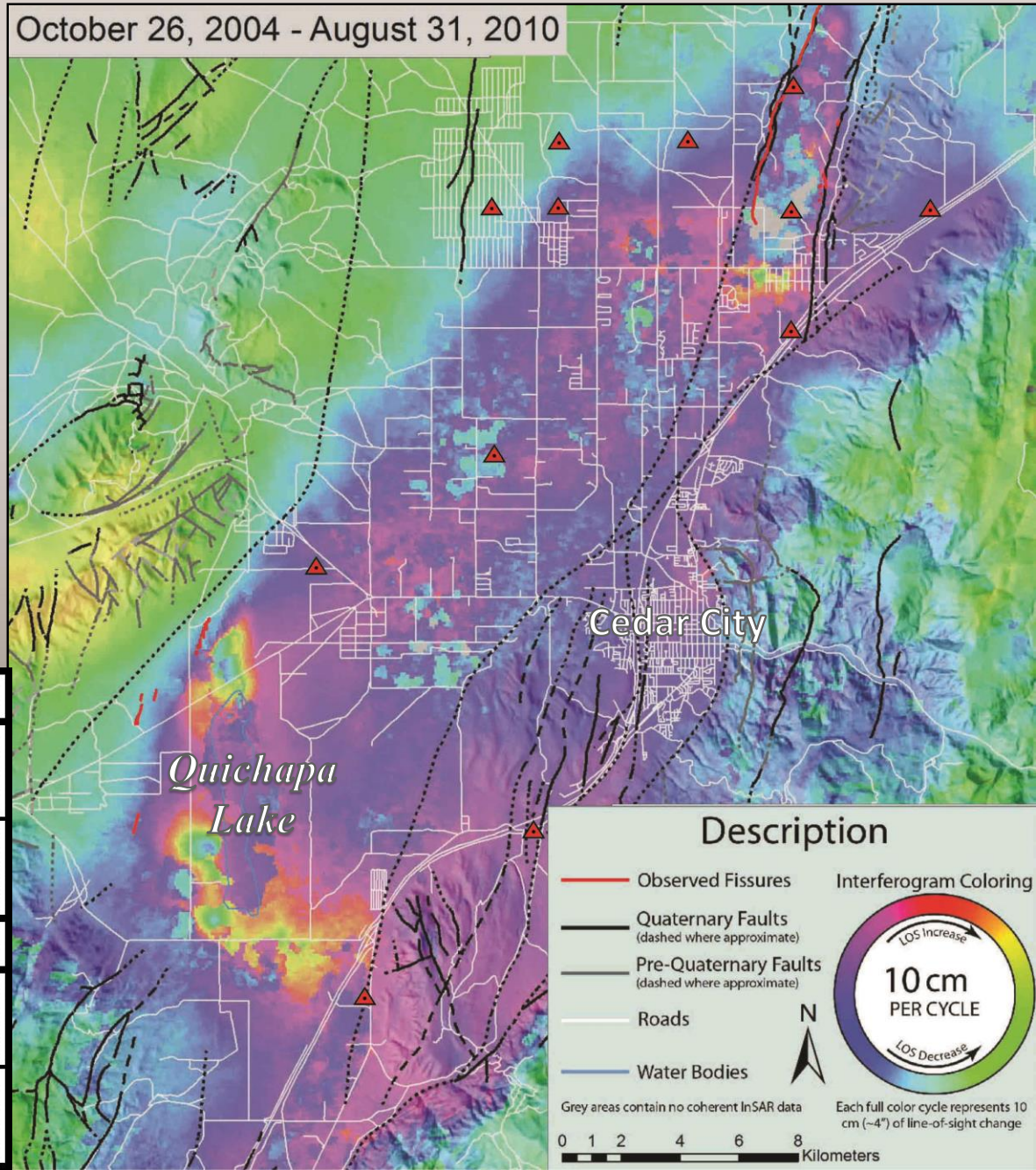
- Limited data availability (post 1990s only, data gaps)
- Decorrelation in farmed areas, snow

# InSAR Results

- 24 Interferograms developed for the periods 1992-2000 and 2004-2010: all show measurable amounts of subsidence.
- Decorrelation prevented accurate estimates of subsidence in the Enoch graben.

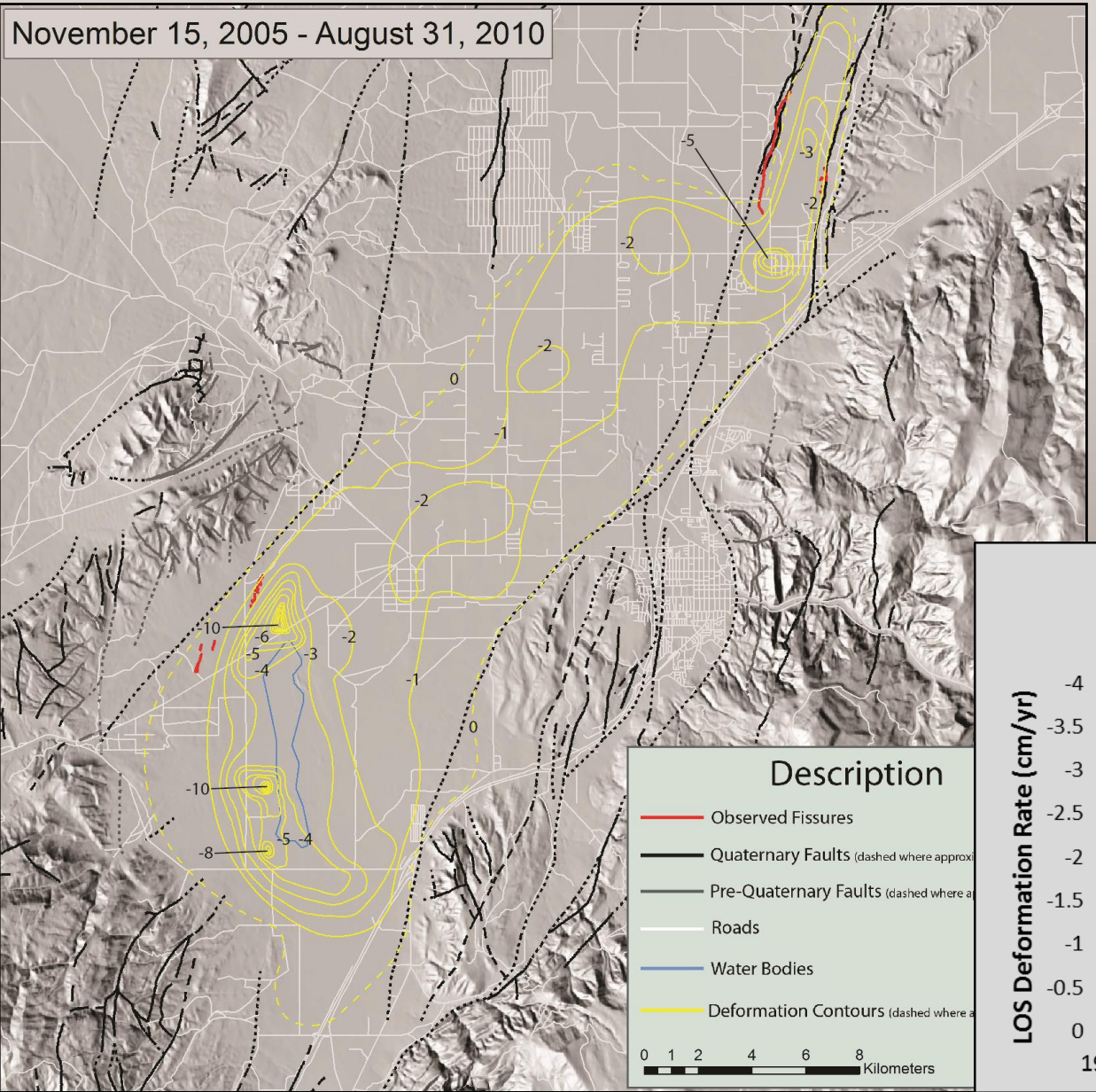
| Central Cedar Valley | | |
|---|---|---|
| Period | Measured (inches) | Maximum Rate (in/yr) |
| 1992-2000 | > -1.5 | -0.7 |
| 2004-2010 | > -2.4 | -1.2 |
| **Quichapa** | | |
| Period | Measured (inches) | Maximum Rate (in/yr) |
| 1992-2000 | > -2 | -0.8 |
| 2004-2010 | > -4.7 | -1.5 |

Stacked Interferogram (Katzenstein, 2013)



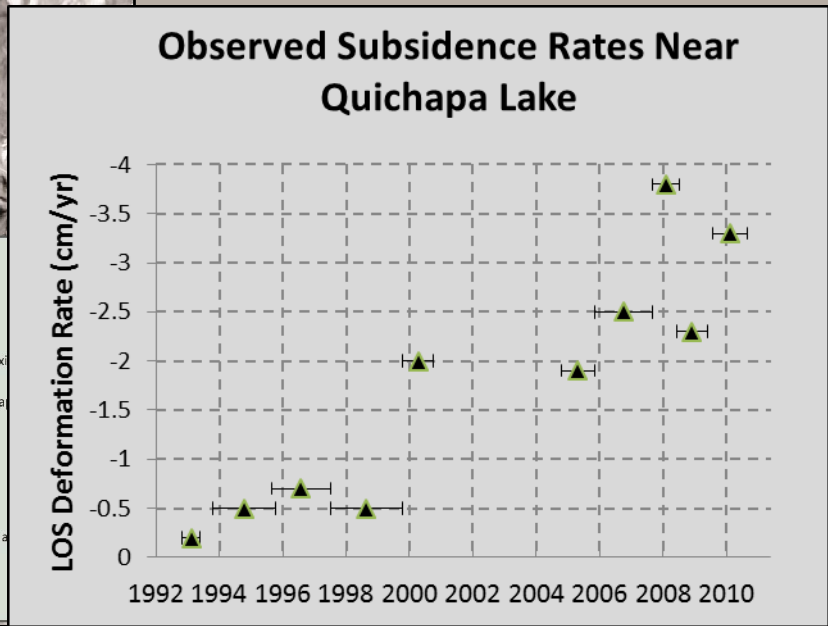
# InSAR Results

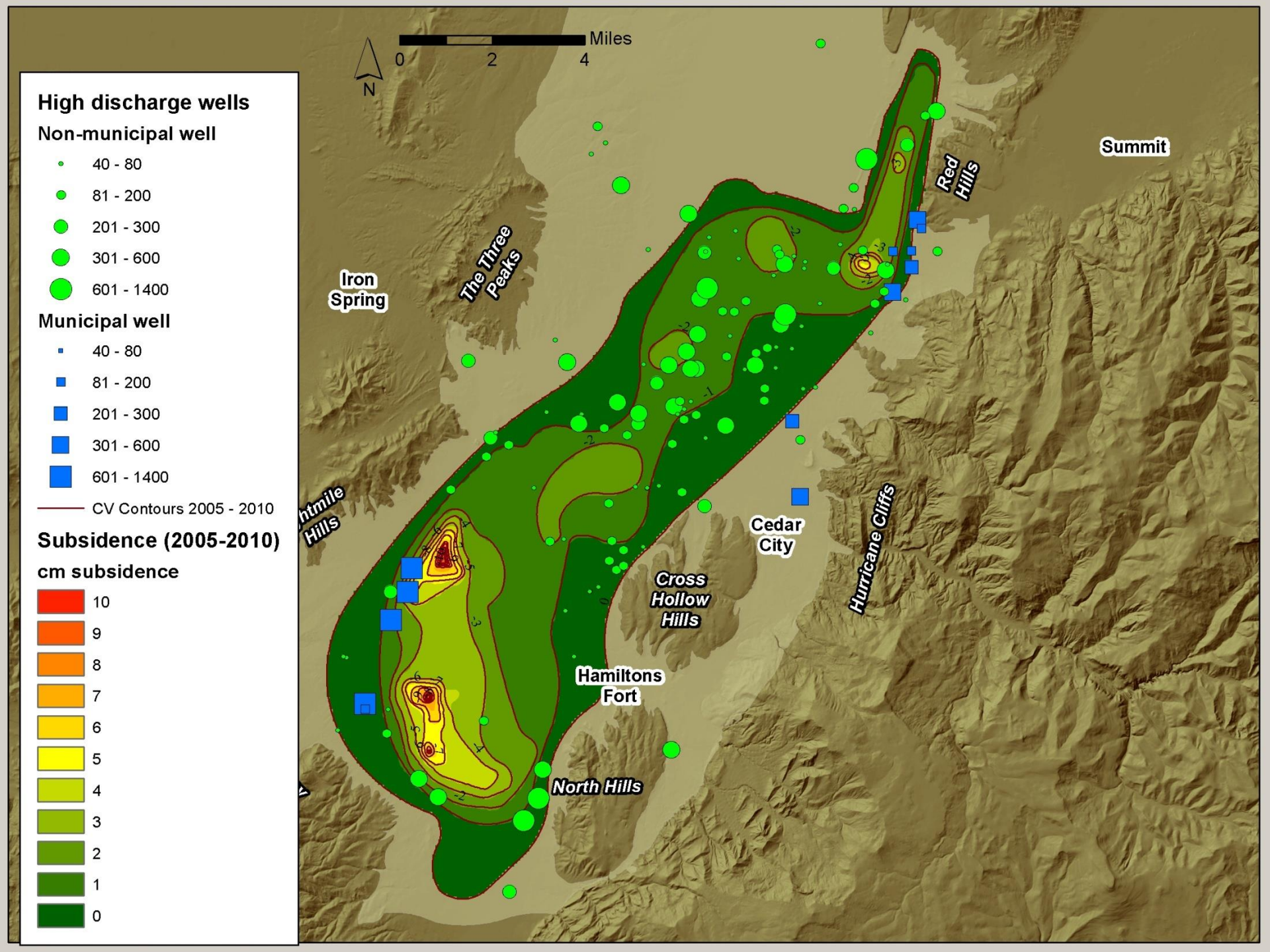
Satellite Line of Sight Displacement Change (cm) (Katzenstein, 2013)




Contour map of satellite line of sight change (ground deformation) based on the stacked interferograms.

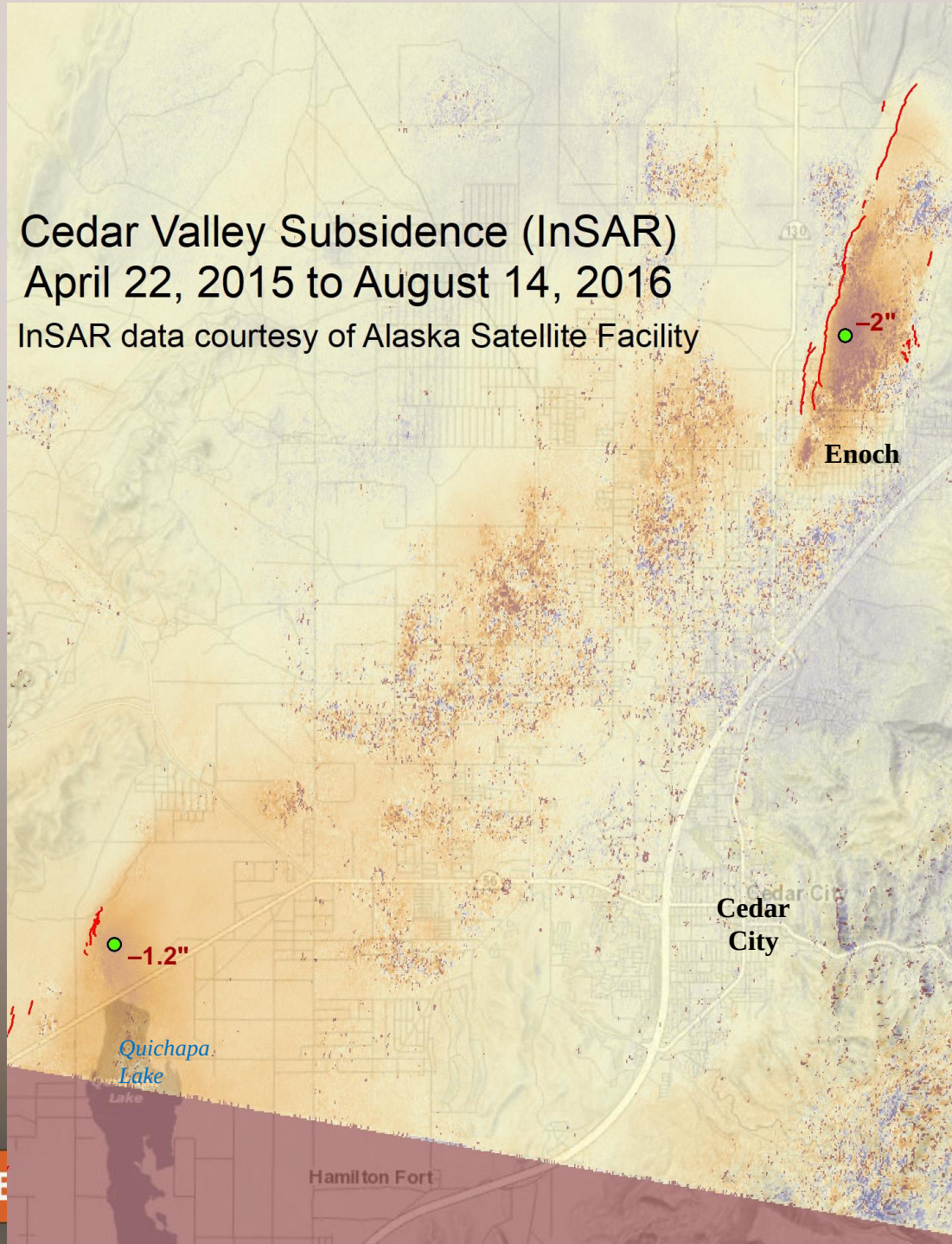
InSAR shows increasing subsidence rates over time near Quichapa Lake.



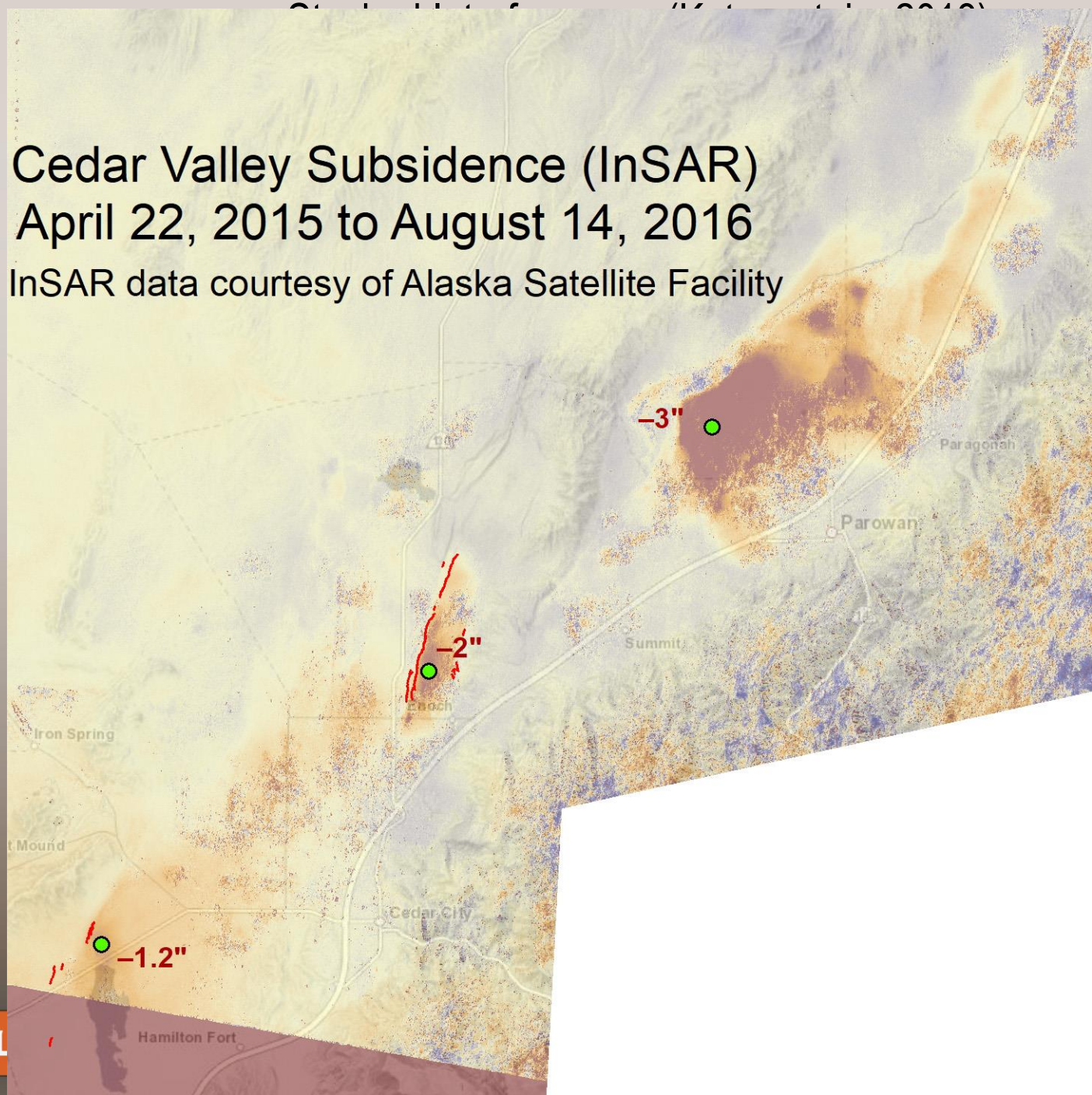

Miles
0
2
4
N
High discharge wells
Non-municipal well
40 - 80
81 - 200
201 - 300
301 - 600
601 - 1400
Municipal well
40 - 80
81 - 200
201 - 300
301 - 600
601 - 1400
CV Contours 2005 - 2010
Subsidence (2005-2010)
cm subsidence
10
9
8
7
6
5
4
3
2
1
0
Summit
Red Hills
The Three Peaks
Iron Spring
htmile Hills
Cedar City
Hurricane Cliffs
Cross Hollow Hills
Hamiltons Fort
North Hills

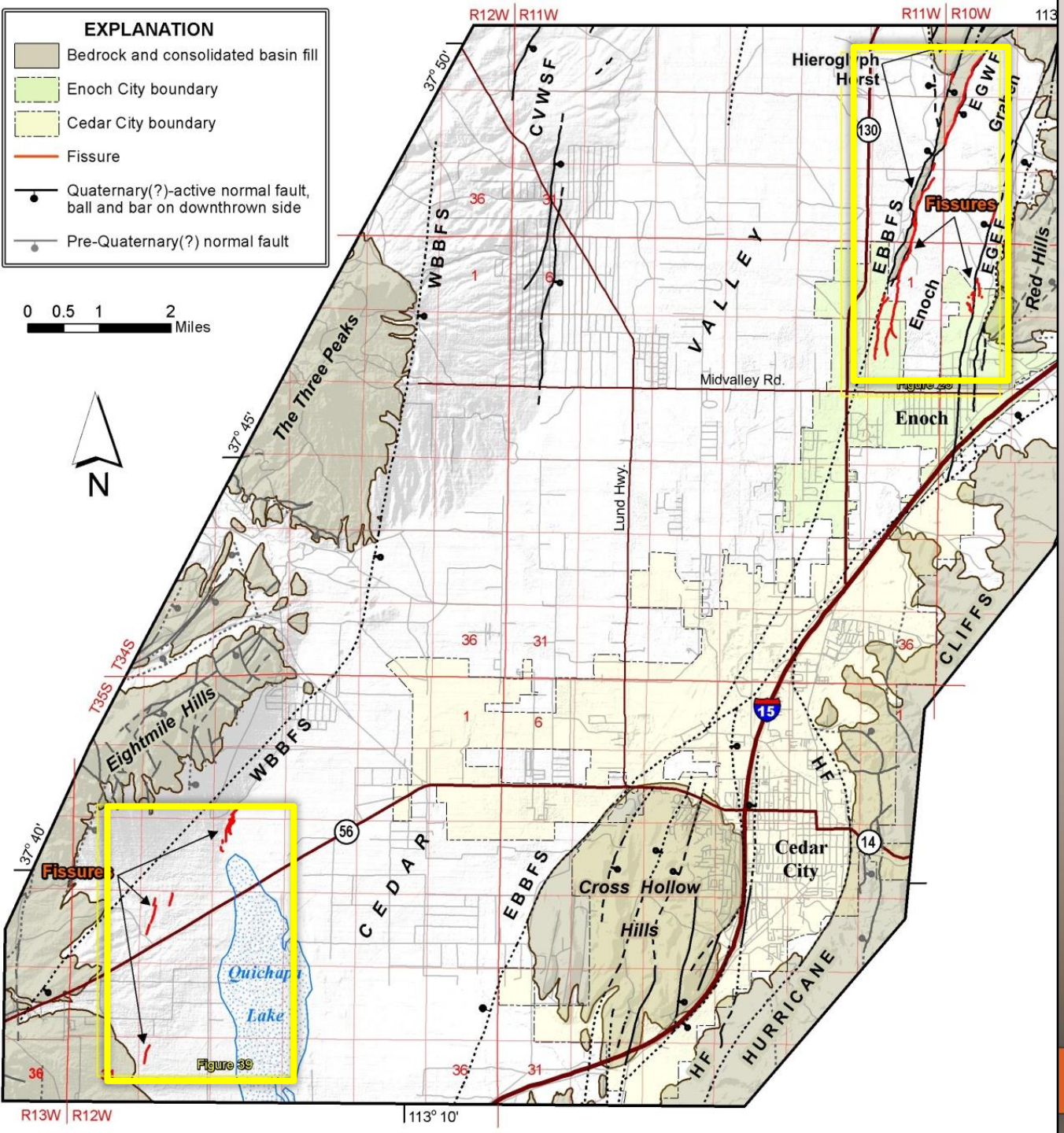
# InSAR

- Most recent data available from Alaska Satellite Facility, Fairbanks



# InSAR


Cedar Valley Subsidence (InSAR)
April 22, 2015 to August 14, 2016
InSAR data courtesy of Alaska Satellite Facility
–3"
–2"
–1.2"
Paragonah
Parowan
Summit
Iron Springs
Cedar City
Hamilton Fort

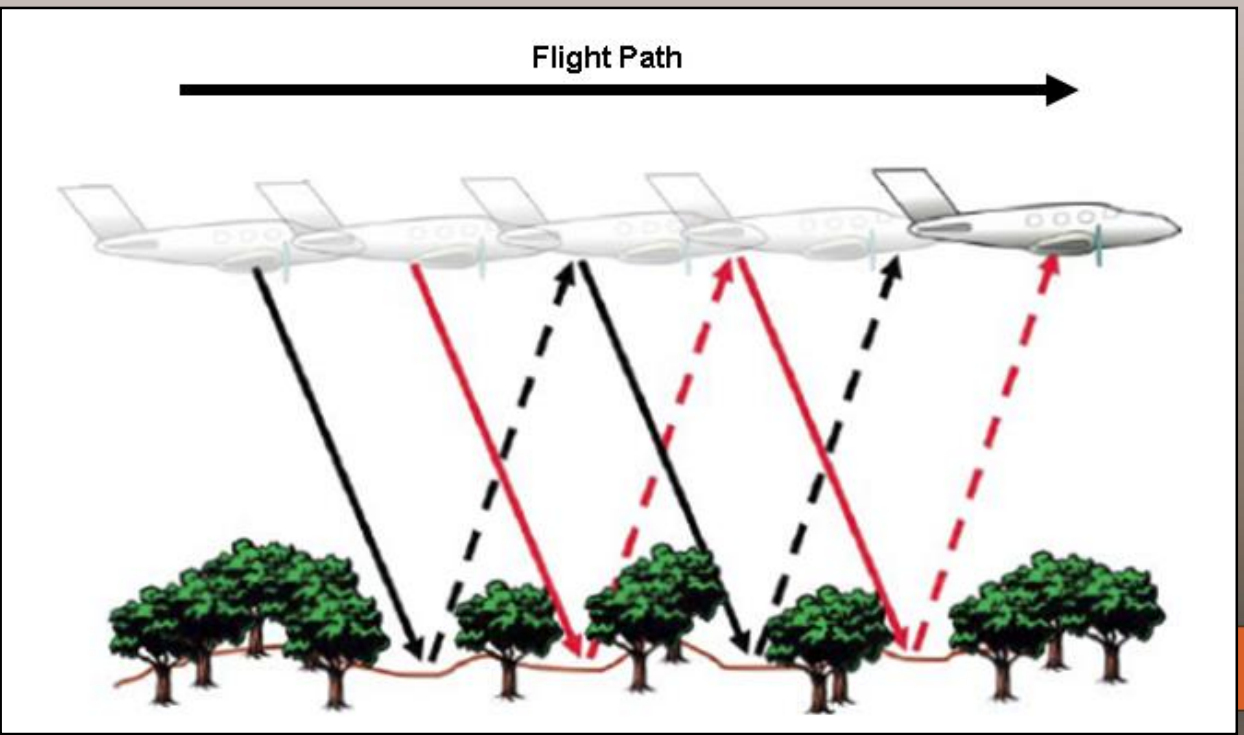



# Fissure Inventory

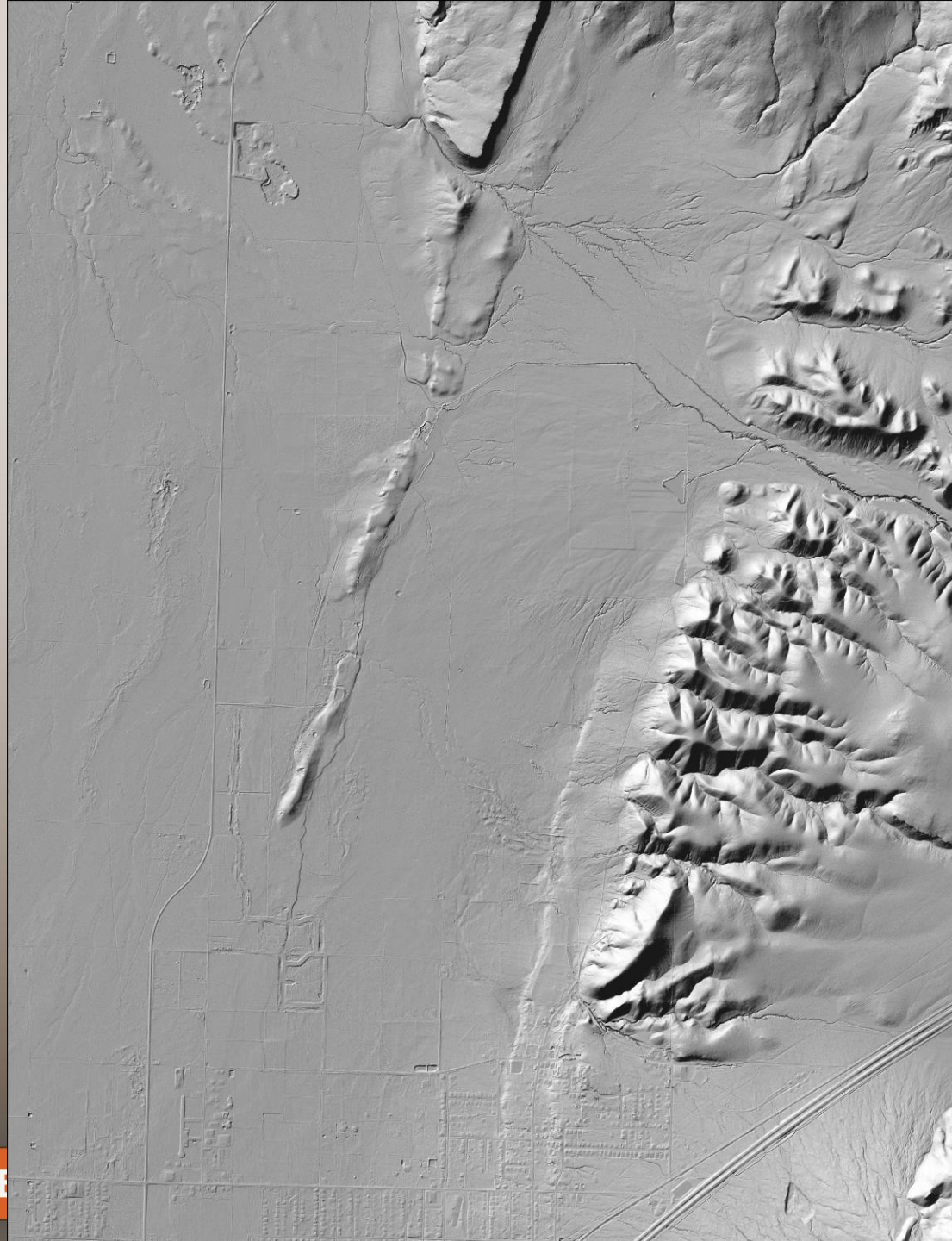
- Initial inventory relied on aerial photography analysis and identified 3.9 miles of fissures in the Enoch graben and near Quichapa Lake
- Second inventory incorporated new LiDAR imagery acquired in Fall, 2011, and identified 8.3 miles of fissures in Cedar Valley

# Airborne LiDAR Data Acquisition

- LiDAR - Light detection and ranging uses reflected laser pulses to create highly accurate, bare-earth digital elevation models (DEMs).

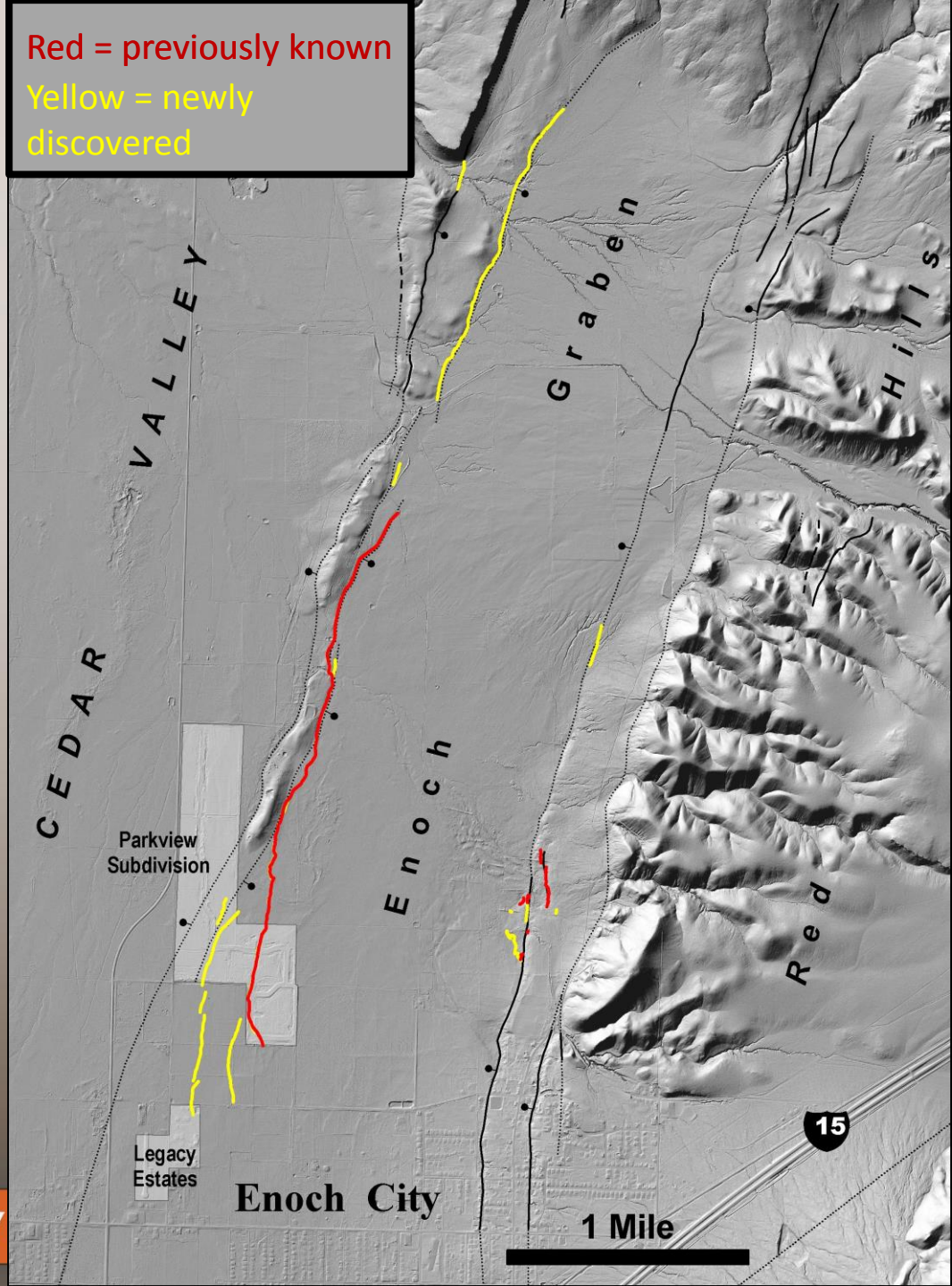



# Lidar bare-earth DEM



# Enoch Graben Fissures

- Air Photo = 2.7 mi.
  LiDAR = 5.9 mi.
- Many Enoch fissures exhibit ongoing vertical surface offset
- Closely aligned with existing Quaternary faults




2011 1-m LiDAR

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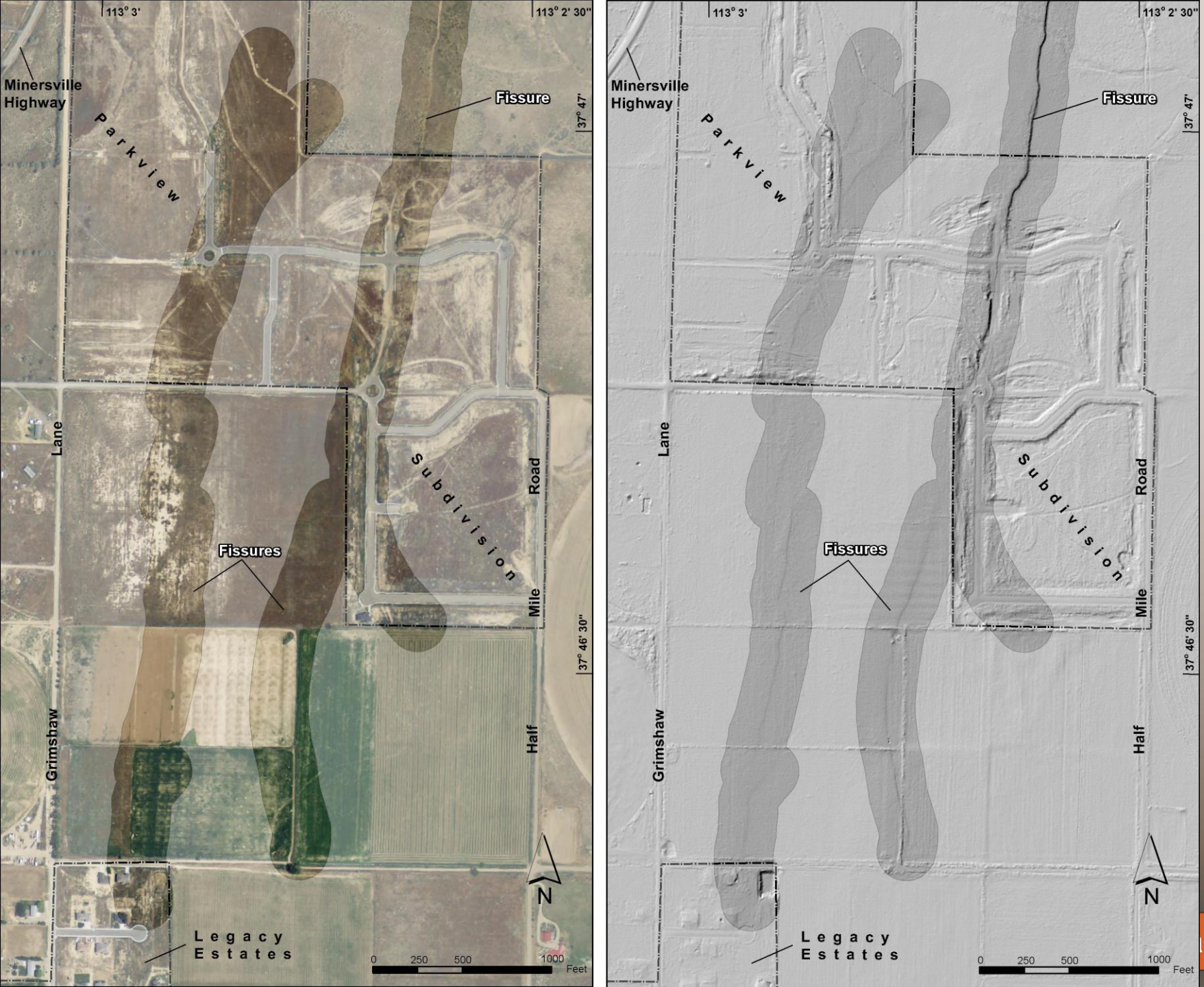
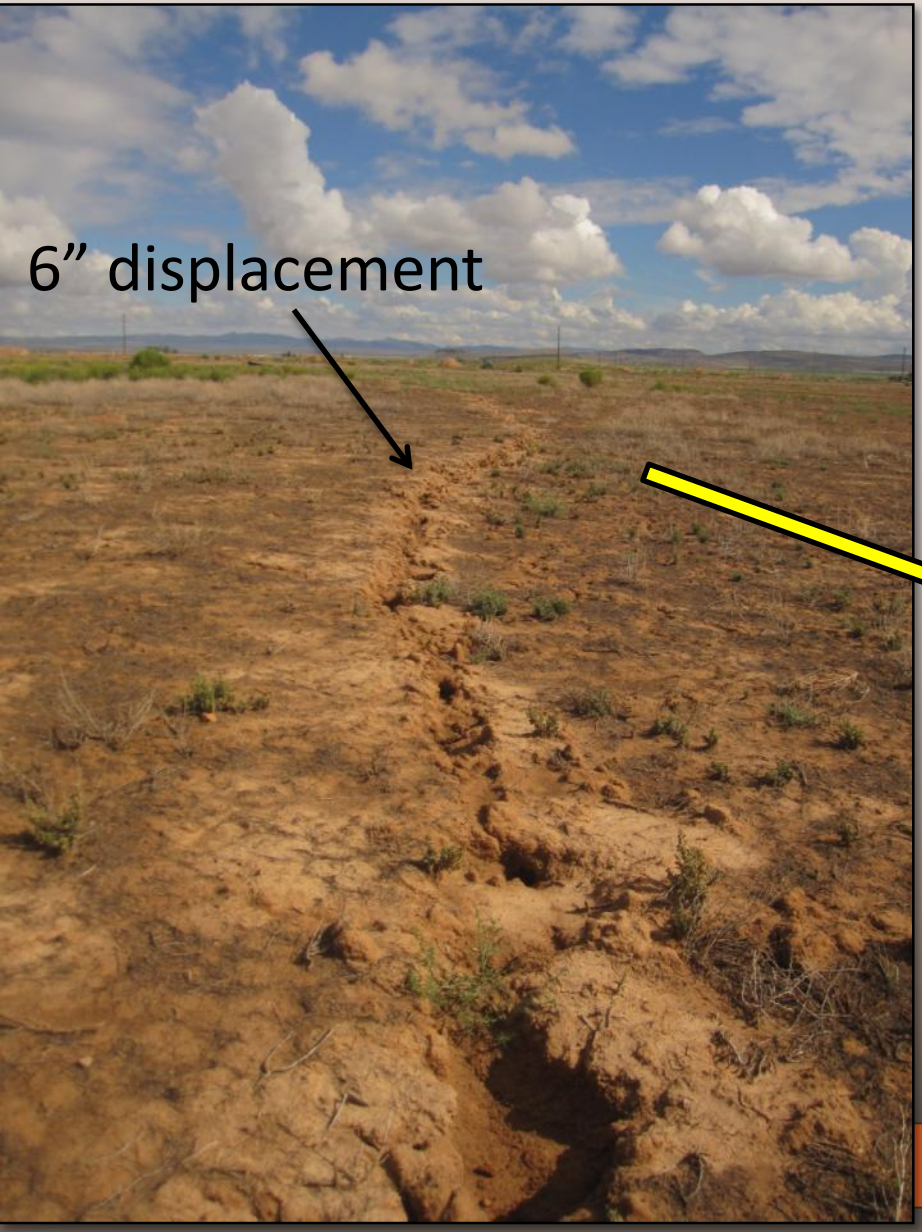
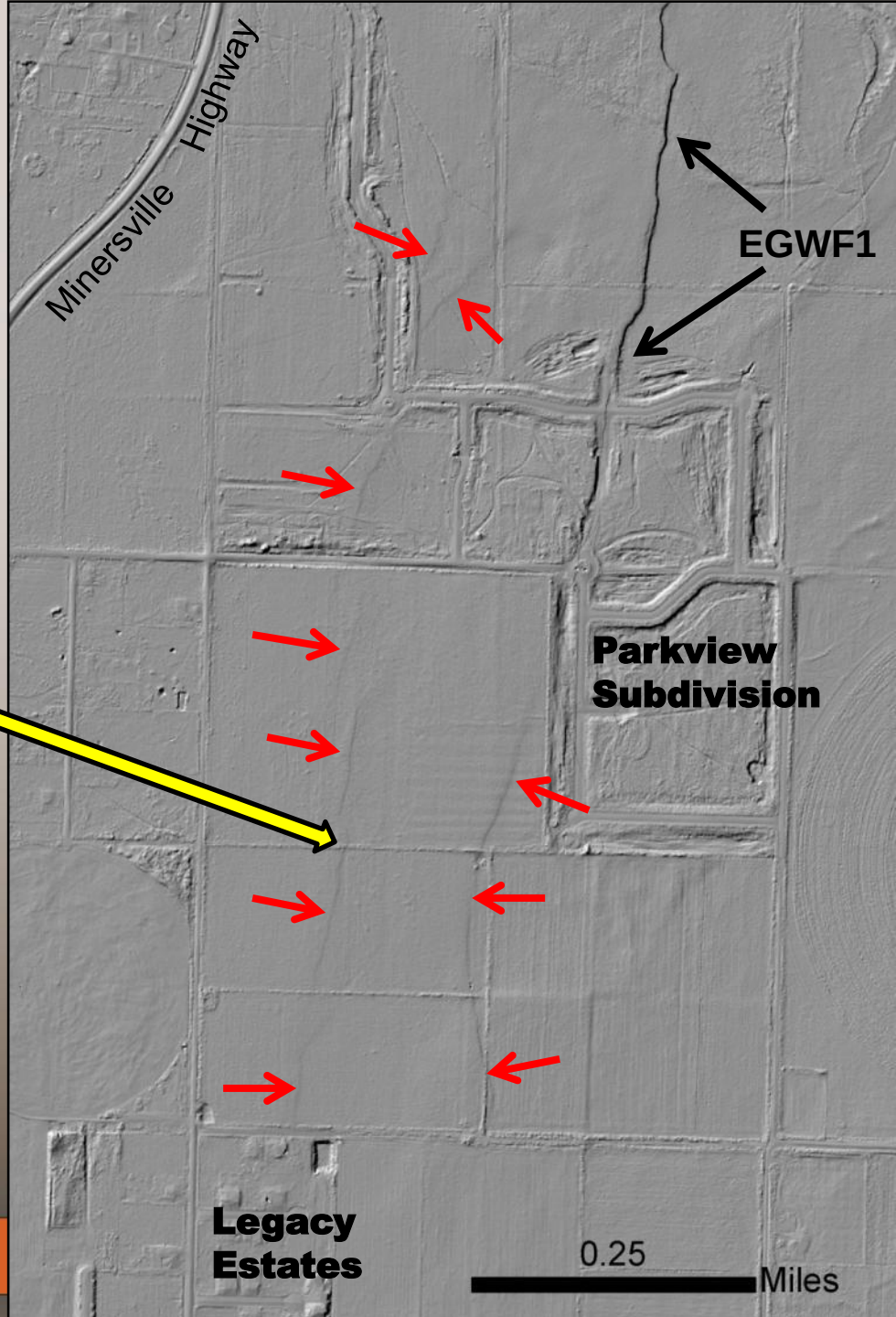
UTAH GEOLOGICAL SURVEY


113° 3'
113° 2' 30"
37° 47'
37° 46' 30"
Minersville Highway
Parkview
Fissure
Lane
Subdivision
Road
Fissures
Mile
Grimshaw
Half
Legacy Estates
N
0 250 500 1000 Feet

# August 23, 2012, After Heavy Rain Storm



# Alternative Explanation for Enoch Graben-West Fissure?

- Air photo analysis at Parkview, 1960 to 2009

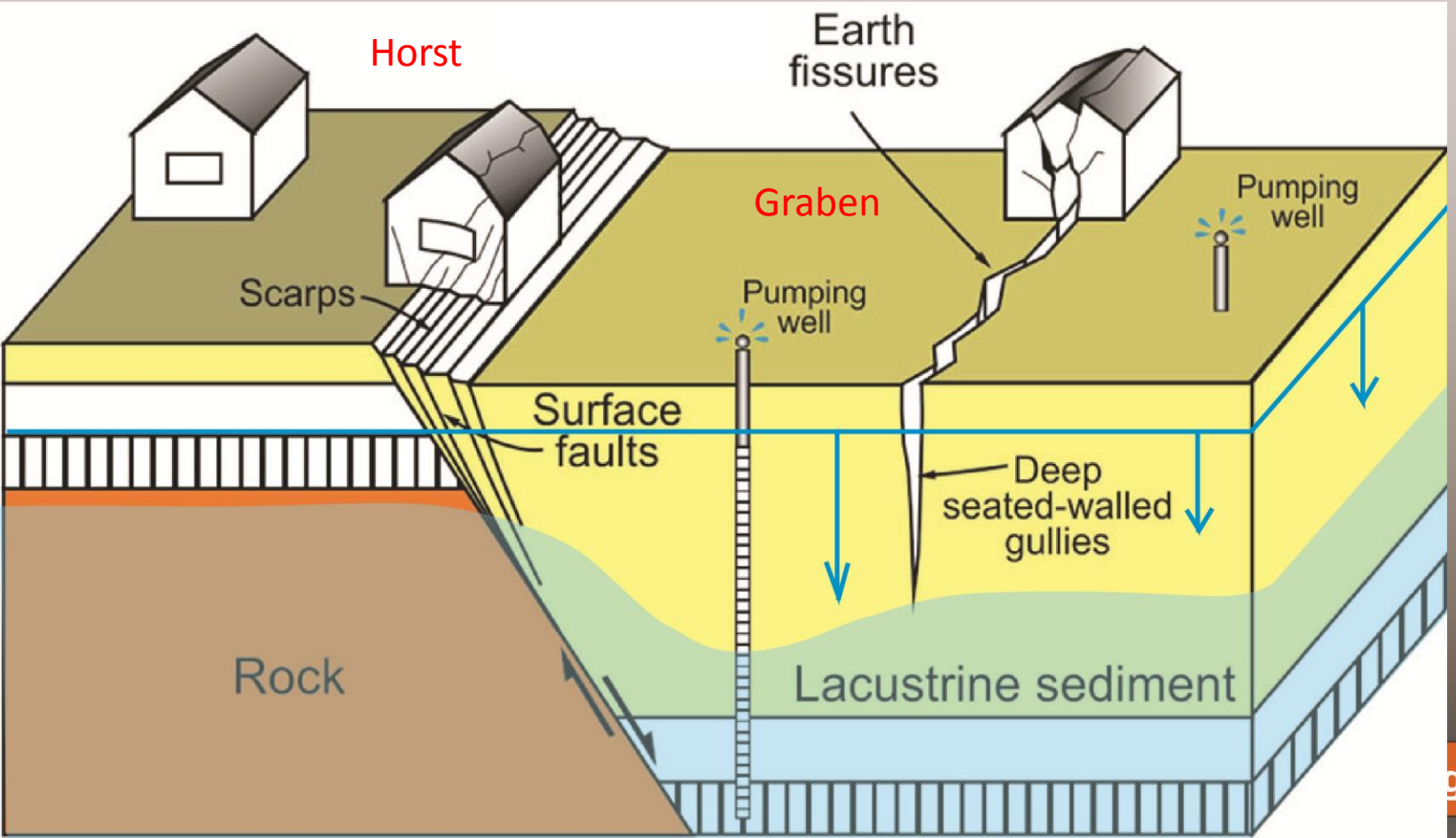
# Alternative Explanation for Enoch Graben-West Fissure?

- Geologically young fault scarp existed prior to fissure development

1934 M6.6 Hansel Valley, UT

# Pre-existing Faults are Planes of Weakness

- Groundwater declines & subsidence "re-activates" faults although the movement is non-tectonic, doesn't result from earthquakes, and occurs only at shallow depths (less than a few hundred feet)




Enoch City

# Enoch
# Fissure Continues to Grow

- Vertical displacement rate of the Enoch-graben-west fissure has been about 1.7 inches/year

Apr ‘11



# E
# Fissure Cor

- Vertical displace
  graben-west fiss
  inches/year

July 2015

Apr '11

# Quichapa Lake Area

¼ mi

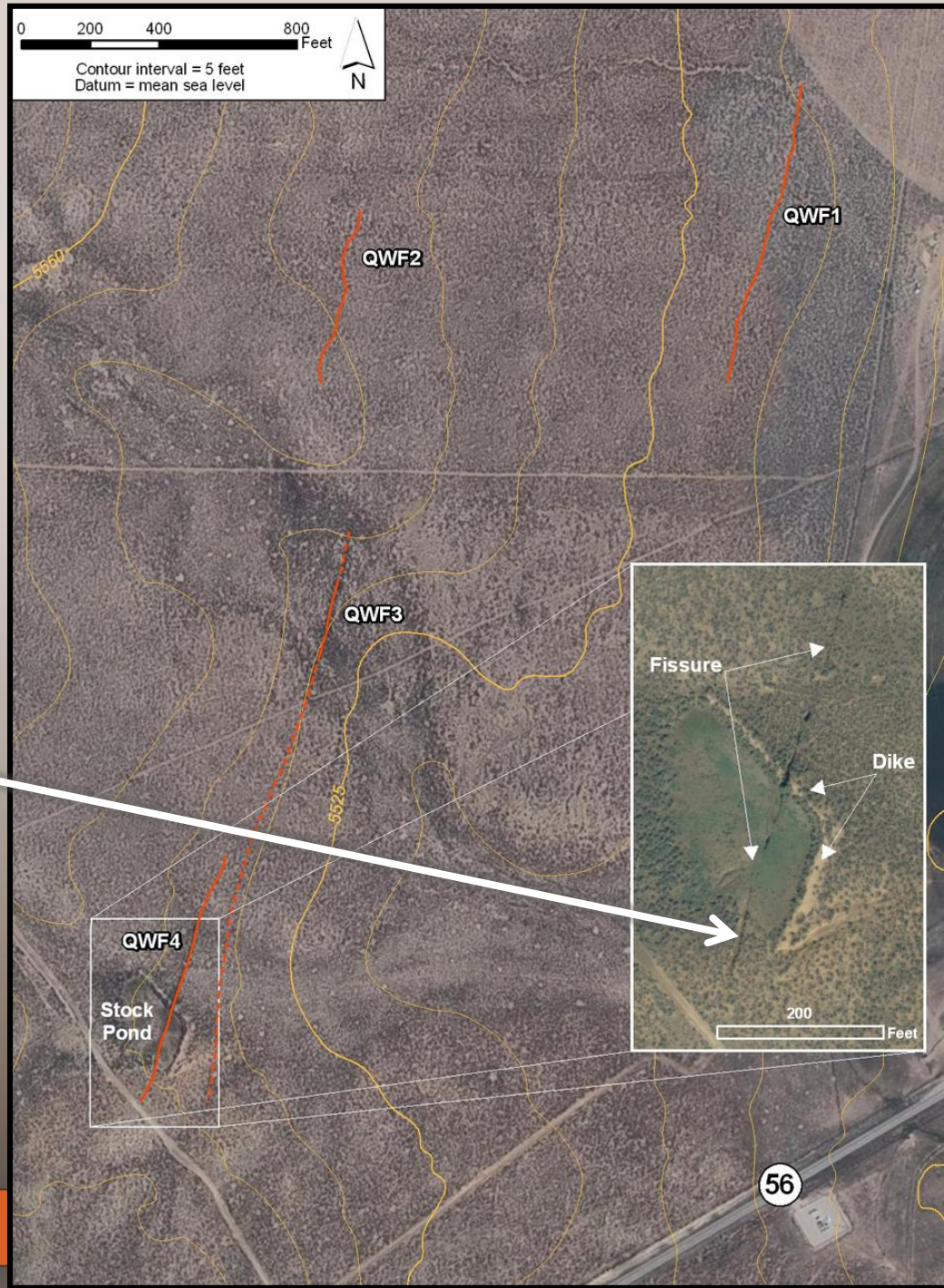
2011 LiDAR

Fissure
Normal fault, dotted where concealed, bar and ball on downthrown side
Contact
Photolineament
Shoreline, may coincide with geologic contact
0 0.125 0.25 0.5 Mile
Contour interval = 20 feet
Datum = mean sea level
N

Quichapa-North Fissures
Area of Figure 40
Quichapa-West Fissures
Area of Figure 42
Quichapa-Southwest Fissure
2005 Sinkhole
WBBFS
Quichapa Lake
1700 S
1800 S
2000 S
2200 S
2800 S
8900 W
8100 W
7700 W
56
Taf
Qafy
Qaly
Qap
Qafc
Qes
Qea
Qal
Qp
Qp/Qafc
5600
8
9
16
17
18
19
20
21
28
29
30
31
32
33

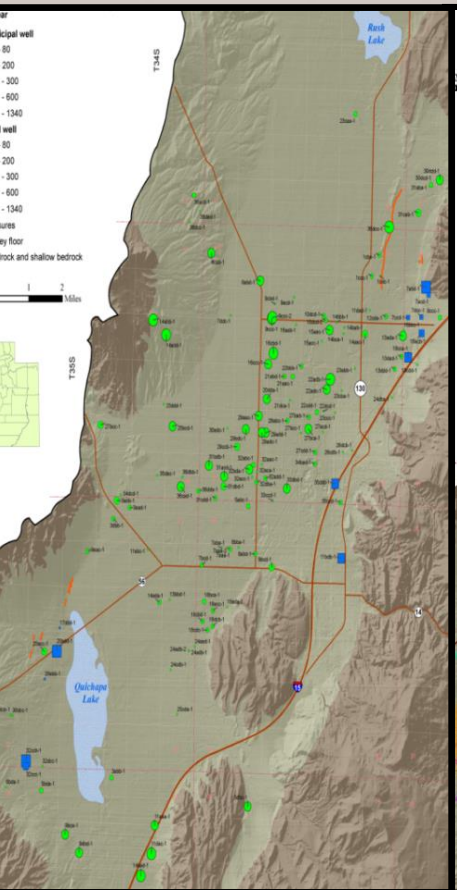
# Quichapa Lake Area

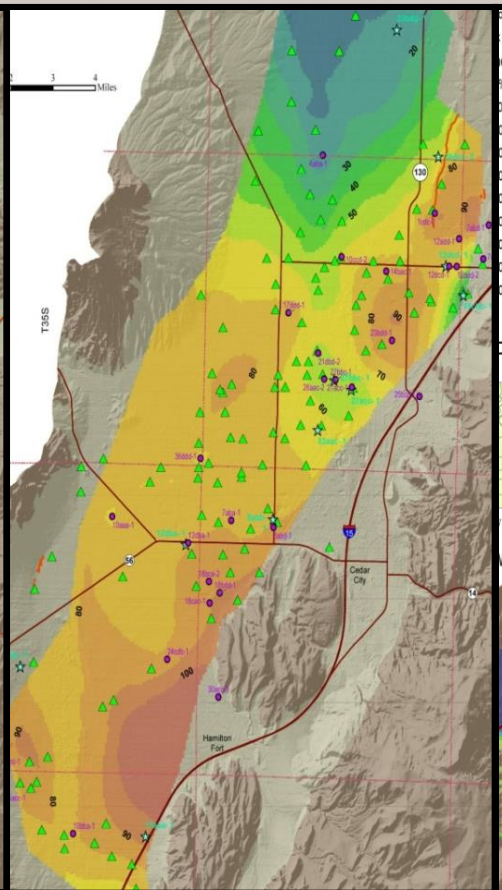


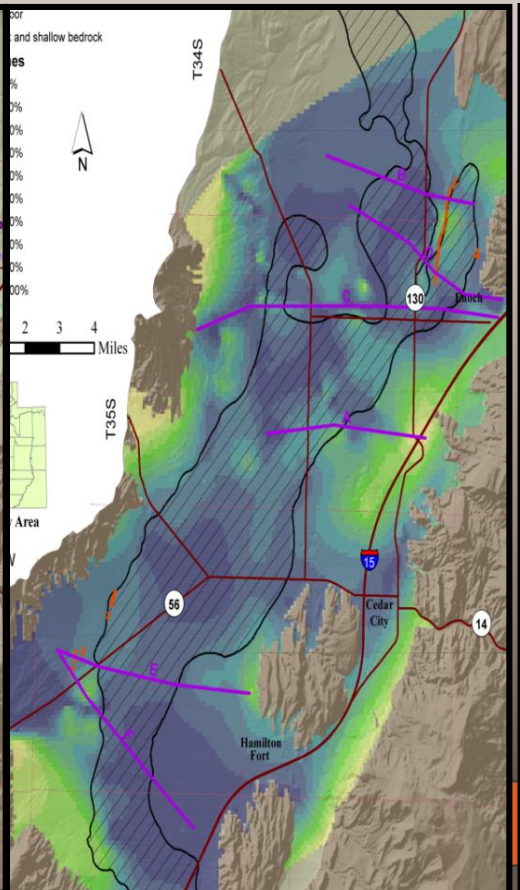


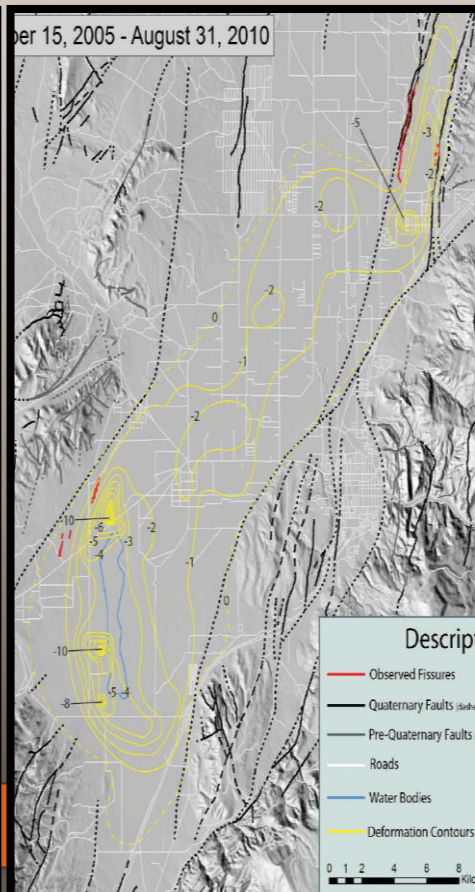
# Conclusions

Distribution of High Discharge Wells **+** Ground Water Decline **+** Fine Grained Sediments >100’ thick **=** **Subsidence & Earth Fissures**

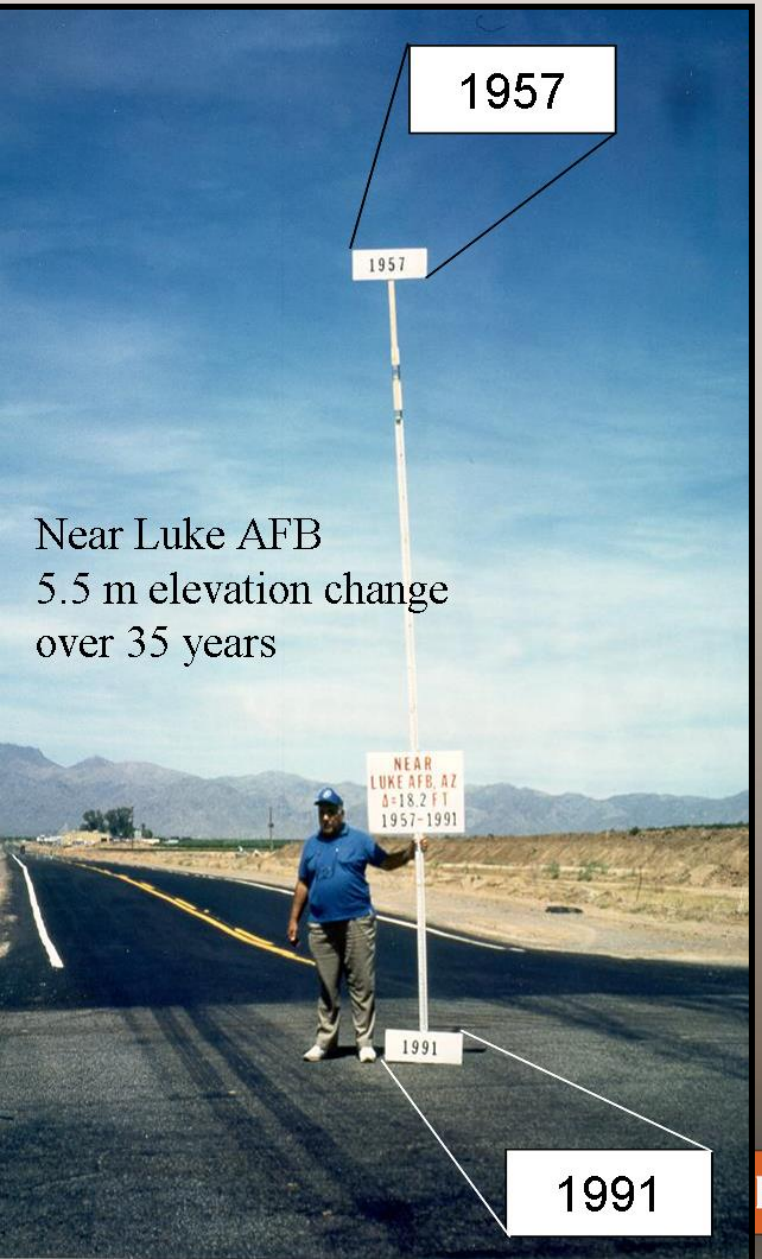


# Subsidence Hazards – Conveyance Structures




- Canals, storm drains, water/sewer lines adversely affected
- 1992 – Flow reversed in Dysart Drain at Luke AFB, Arizona
  - 100 homes/runways flooded
  - $3 million: base closure/cleanup
  - $16 million: redesigned flood control to accommodate subsidence

RVEY

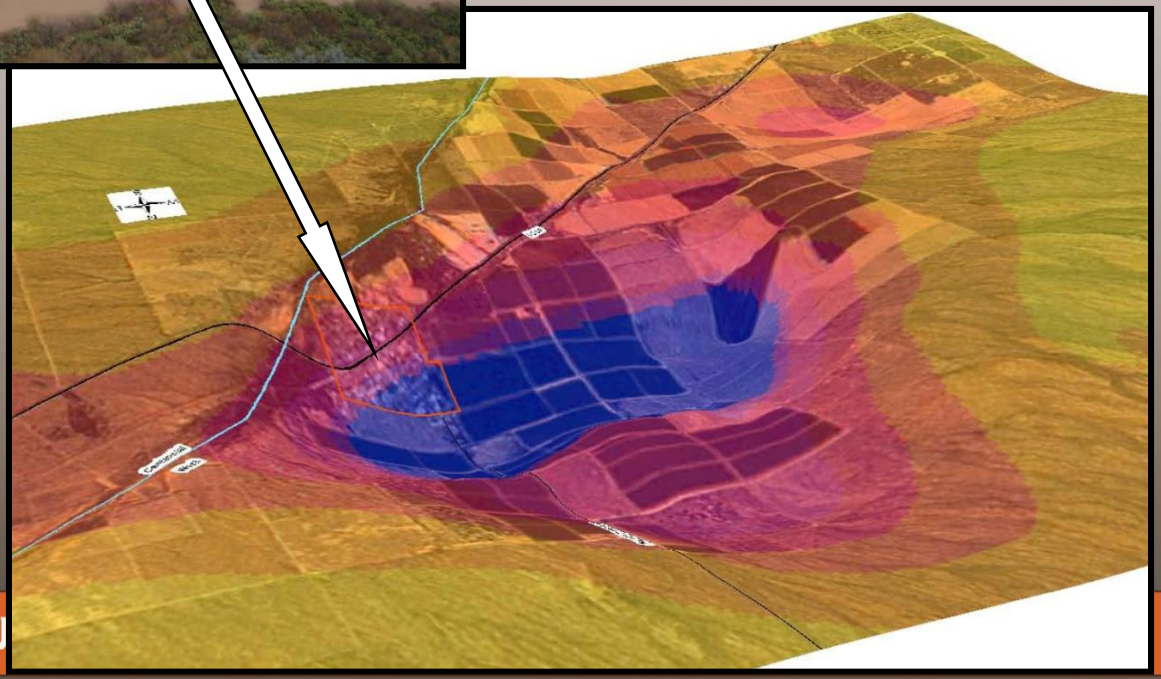

# Subsidence Hazards

- Change natural flood patterns
- January, 2010 flood in Wenden, SW Arizona
- InSAR reveals subsidence bowl near agricultural wells

**Arizona Department of Water Resources**

InSAR = ~2 in / year

GPS = 2.7 ft since 1991



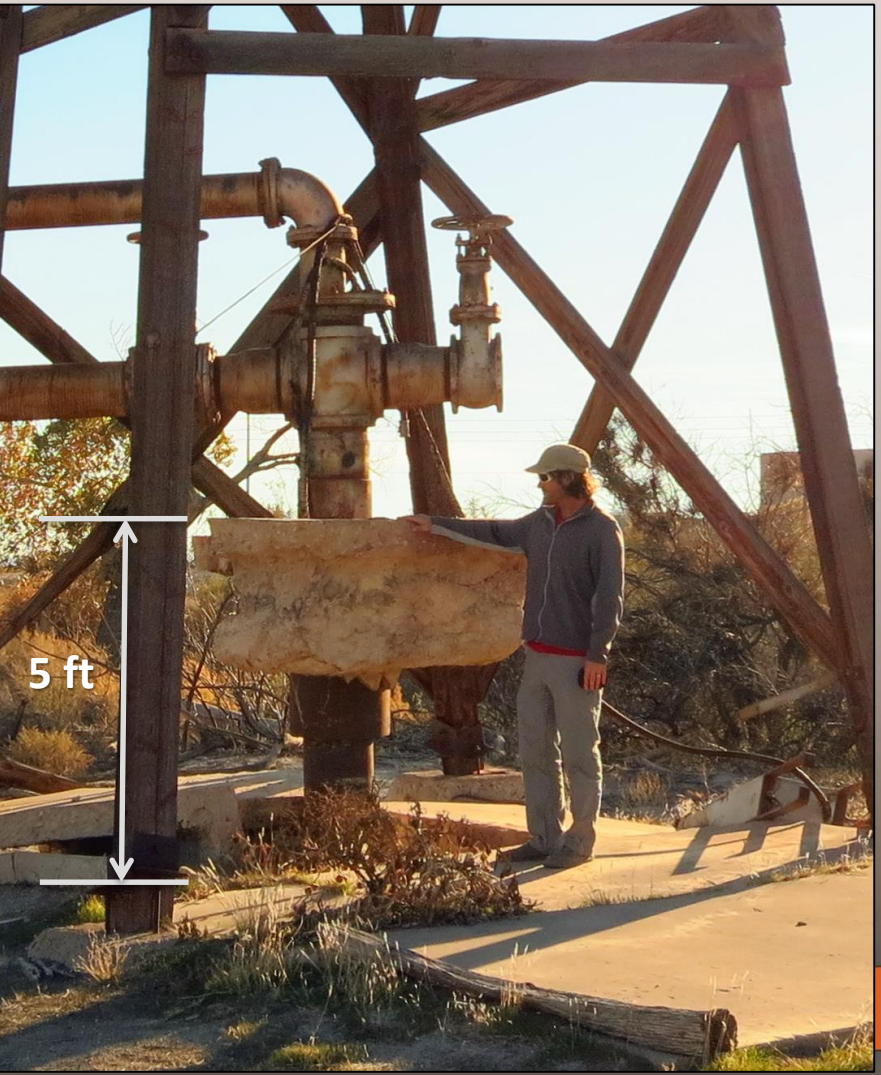
UTAH DNR GEOLOGICAL SURVEY

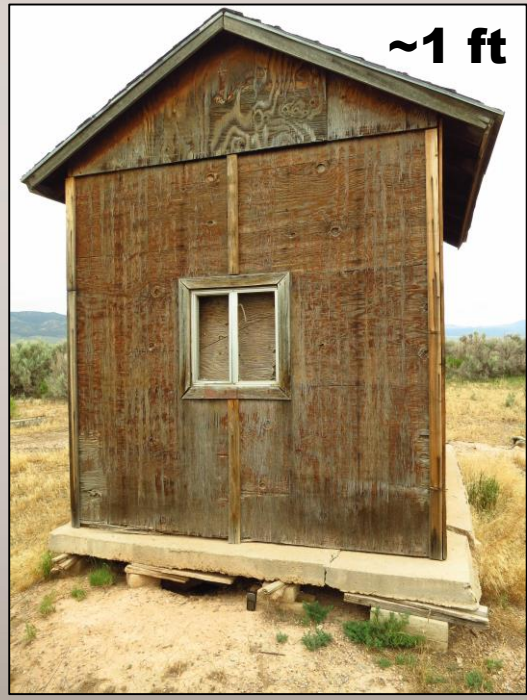
UTAH GEOLOGICAL SU

# Subsidence Hazards – Stressed Well Casings

## Protruding wells

Las Vegas Springs Preserve-2015

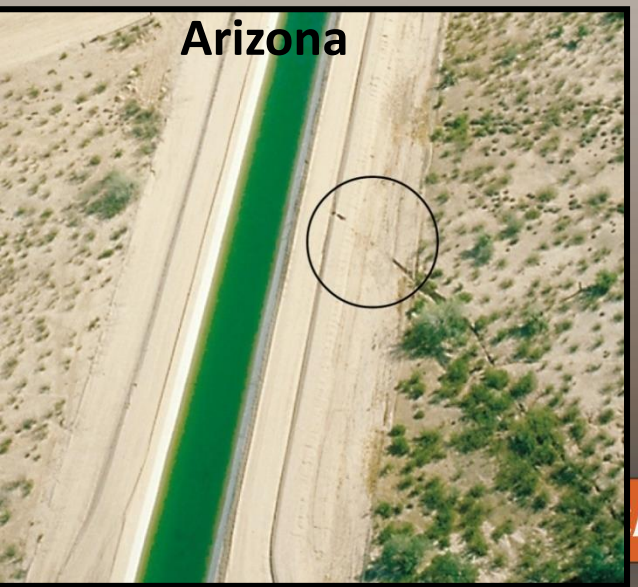



Parowan Valley

# Fissure Hazards

- Undercut and damage infrastructure
- Can widen/deepen dramatically within hours
- **AZ:** hundreds of millions of dollars in damage to buildings, roadways, railroads, utilities, aqueducts, etc



AL SURVEY

# Fissure Hazards

- **Nevada:** 135 homes abandoned and removed in Windsor Park subdivision in North Las Vegas in early 1990s (cost=~$20 million)


John Bell

NBMG

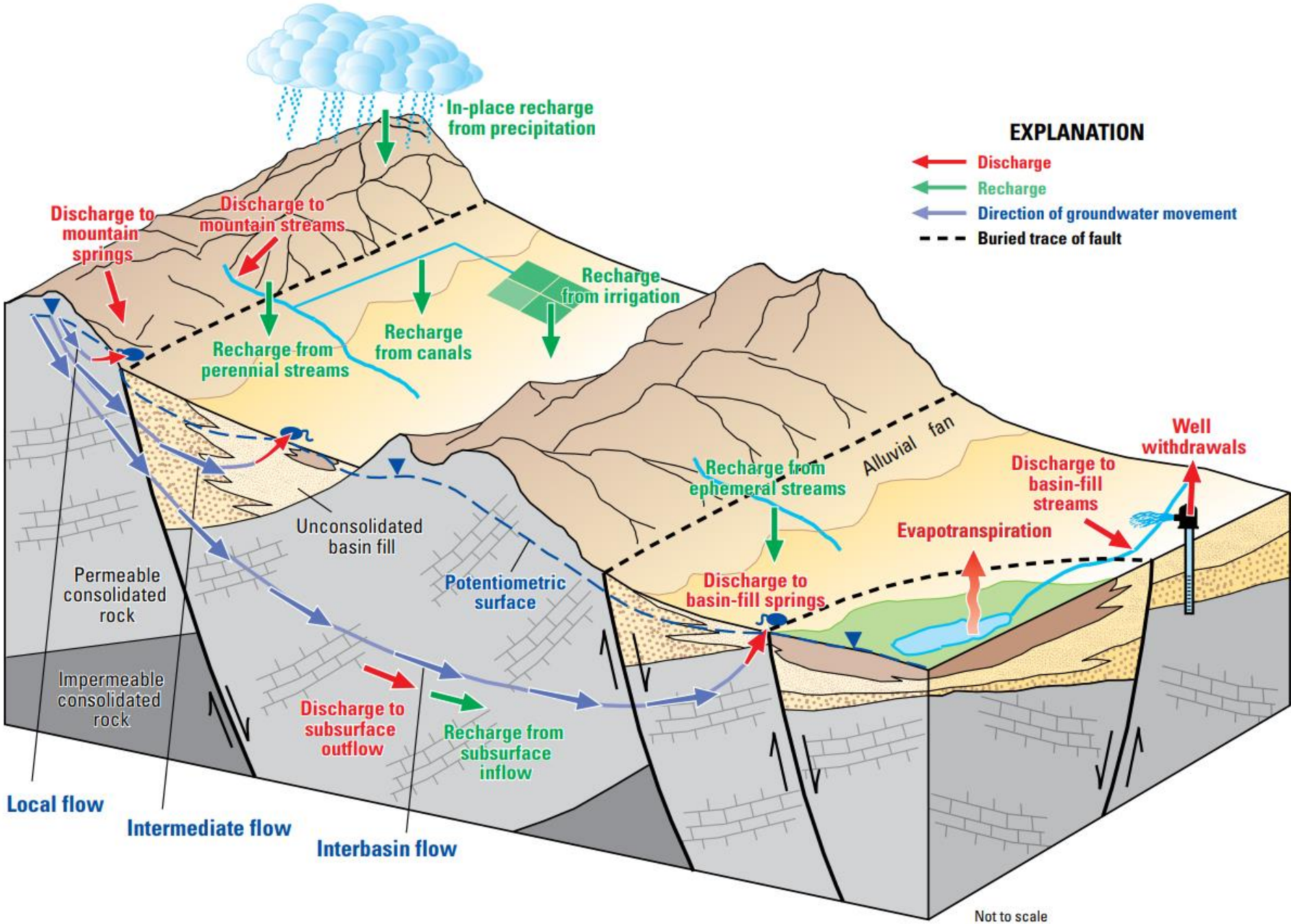
# Earth-Fissure Hazards

- Can provide direct conduits for contaminated surface water to reach aquifers
- AGS: refrigerators, pharmaceuticals, tires, manure, garbage, dead animals, 55-galon barrels of ?


AZ

# Best Aquifer Management Practices Tool Kit

- Increase overall water resources
  - Import water from other basins (water rights needed)
- Increase recharge to the basin-fill aquifer in Cedar Valley
  - Aquifer storage and recovery projects (ASR) - artificial recharge
  - ASR most beneficial in areas of ongoing subsidence
- Disperse high-discharge wells
  - Areas with significant groundwater declines near Enoch and west of Quichapa Lake correlate with areas of high-discharge wells (including many public-supply wells)
  - Decrease reliance on these wells by drilling new wells in other areas
- Reduce groundwater withdrawals
  - Use 'safe yield' or 'optimal yield' water resource management practices
  - Acquire and retire existing water rights
  - Regulate groundwater pumping and/or groundwater price (local districts)
  - Implement water conservation measures (incentive pricing, outdoor watering guidelines, landscape guidelines, water audits, water meters, leak detection)


In-place recharge from precipitation
Discharge to mountain springs
Discharge to mountain streams
Recharge from perennial streams
Recharge from canals
Recharge from irrigation
Recharge from ephemeral streams
Alluvial fan
Well withdrawals
Discharge to basin-fill streams
Evapotranspiration
Discharge to basin-fill springs
Unconsolidated basin fill
Potentiometric surface
Permeable consolidated rock
Impermeable consolidated rock
Discharge to subsurface outflow
Recharge from subsurface inflow
Local flow
Intermediate flow
Interbasin flow
EXPLANATION
Discharge
Recharge
Direction of groundwater movement
Buried trace of fault
Not to scale