GROUND MOVEMENT STUDY

LIVERMORE VALLEY, CALIFORNIA

Prepared for Zone 7 Water Agency

AGENDA

- Introductions
- Presentation
- Questions Regarding Study

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PRESENTATION OUTLINE

- Purpose of Study – Evaluate Livermore Valley Ground Movement Processes
  - Soil-related
  - Groundwater-related
  - Tectonic-related
- Soil/Geologic/Groundwater Setting for Livermore Valley
- Expansive Soil Movement
  - Active zone
  - Effects on structures
  - Associations
- Groundwater Fluctuations and Effects
  - Elastic ground movement
  - Inelastic ground movement
- Tectonic Movement
- Ongoing Monitoring – Findings
  - Ground surface elevation
  - Groundwater elevation
  - Tectonic
- Observed Distress – What we're seeing, not seeing
- Conclusions
- Questions On Study Findings

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PURPOSE

- Purpose:

 - Identify the primary movement mechanisms that have potential to result in significant ground movement in the Livermore Valley.

 - Develop an understanding of how those processes work, and how they are typically manifested at the ground surface.

 - Evaluate the kinds of impacts these various movement mechanisms may have in the Livermore Valley.

SCOPE

- Literature Review – Research, assemble and review information such as regional geologic mapping and reports; regional soils mapping; geohydrologic reports; tectonic modelling.
- Aerial Imagery Review
- Review Monitoring Data – Including ground surface elevation monitoring; groundwater level monitoring; GPS (tectonic) monitoring.
- Reconnaissance
- Summary Report – Describing conclusions regarding ground movement mechanisms, how they are expressed, and likely impacts in the Livermore Valley.

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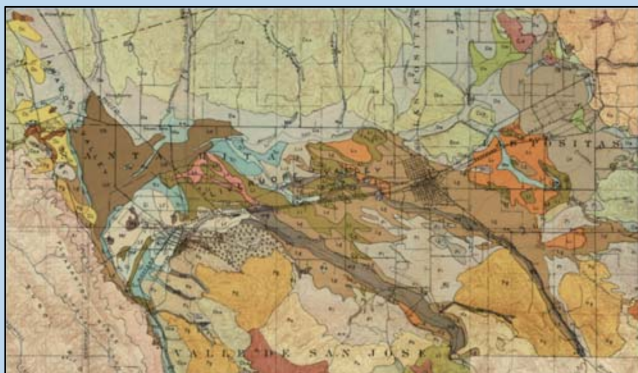
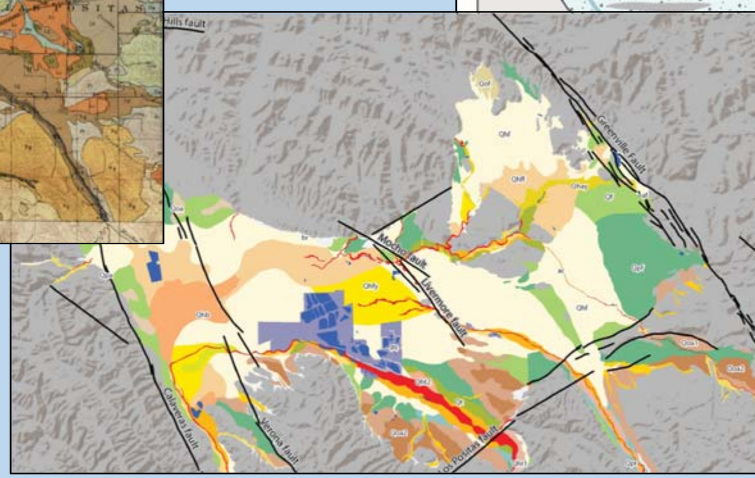
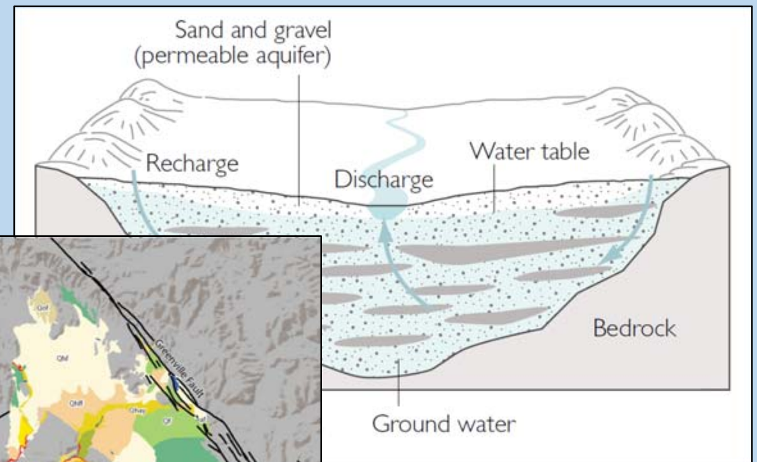
SOIL/GEOLOGY/WATER BACKGROUND







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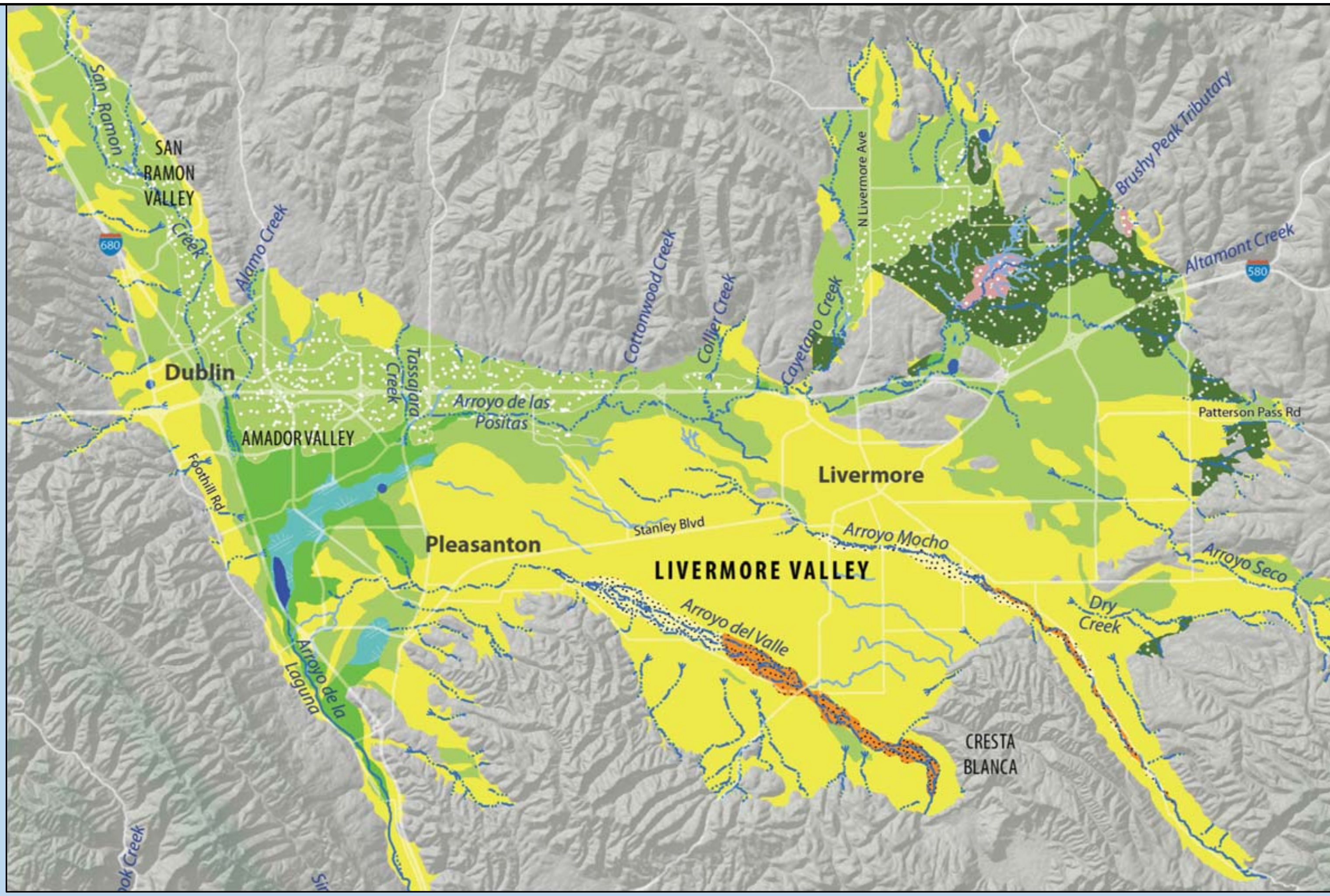

(Adapapted from SFEI, 2013)

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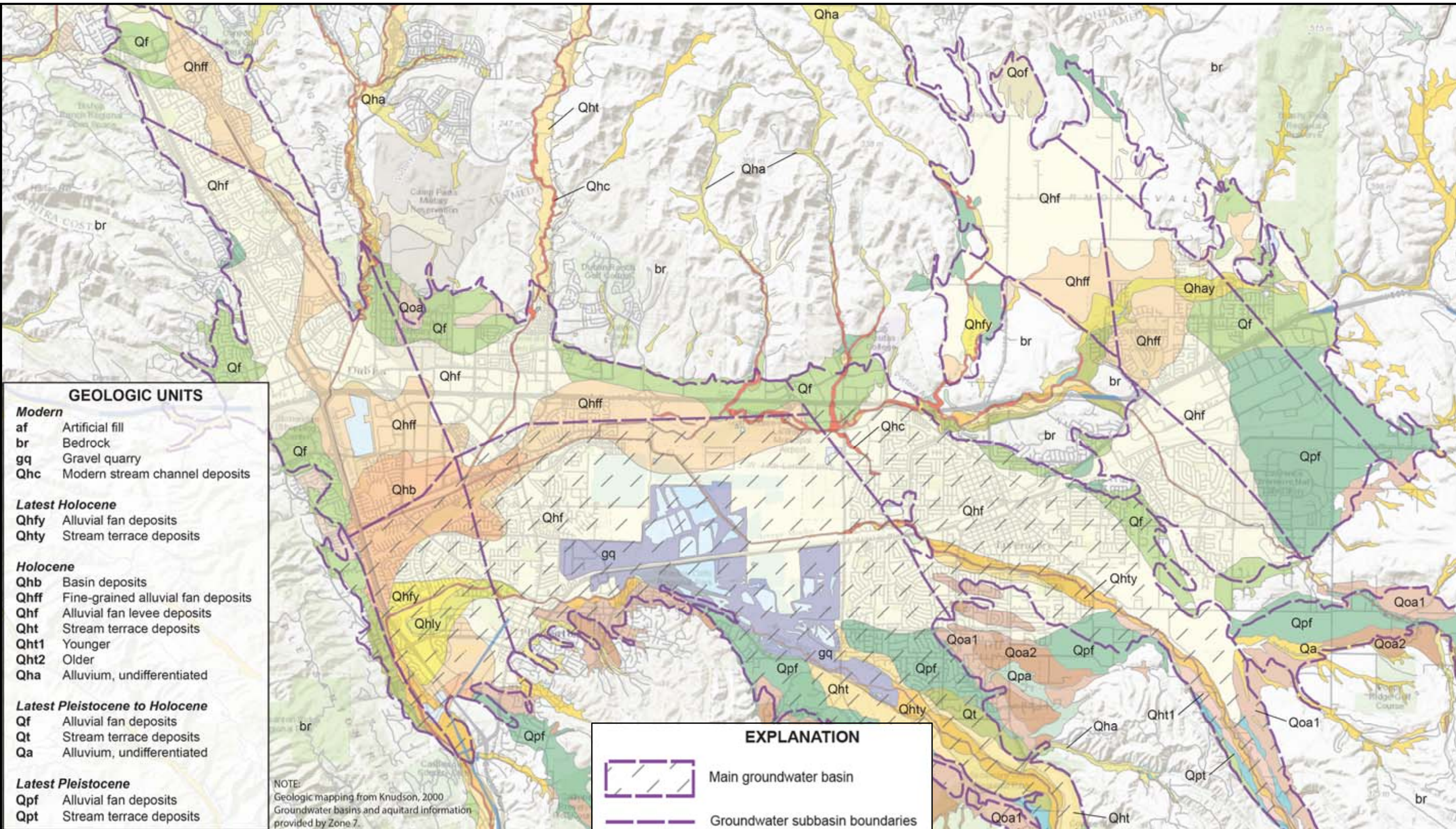
HISTORIC MARSH TERRAIN



(Geology from Knudsen and others, 2000)

RECENT GEOLOGIC DEPOSITS, MAIN GROUNDWATER BASIN
(street base screened back)

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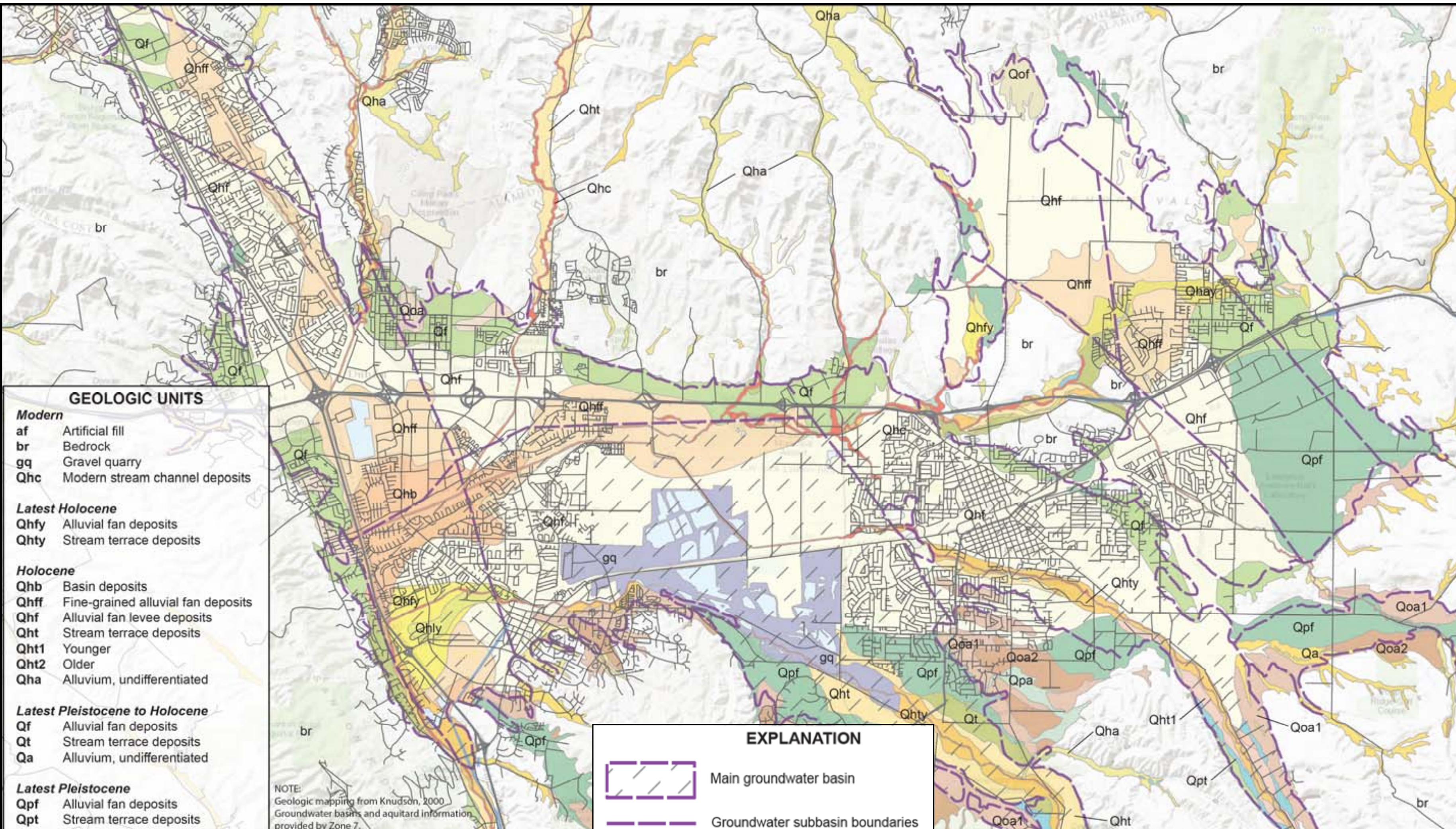

(Geology from Knudsen and others, 2000)

RECENT GEOLOGIC DEPOSITS, MAIN GROUNDWATER BASIN
(street base [~2004] added)

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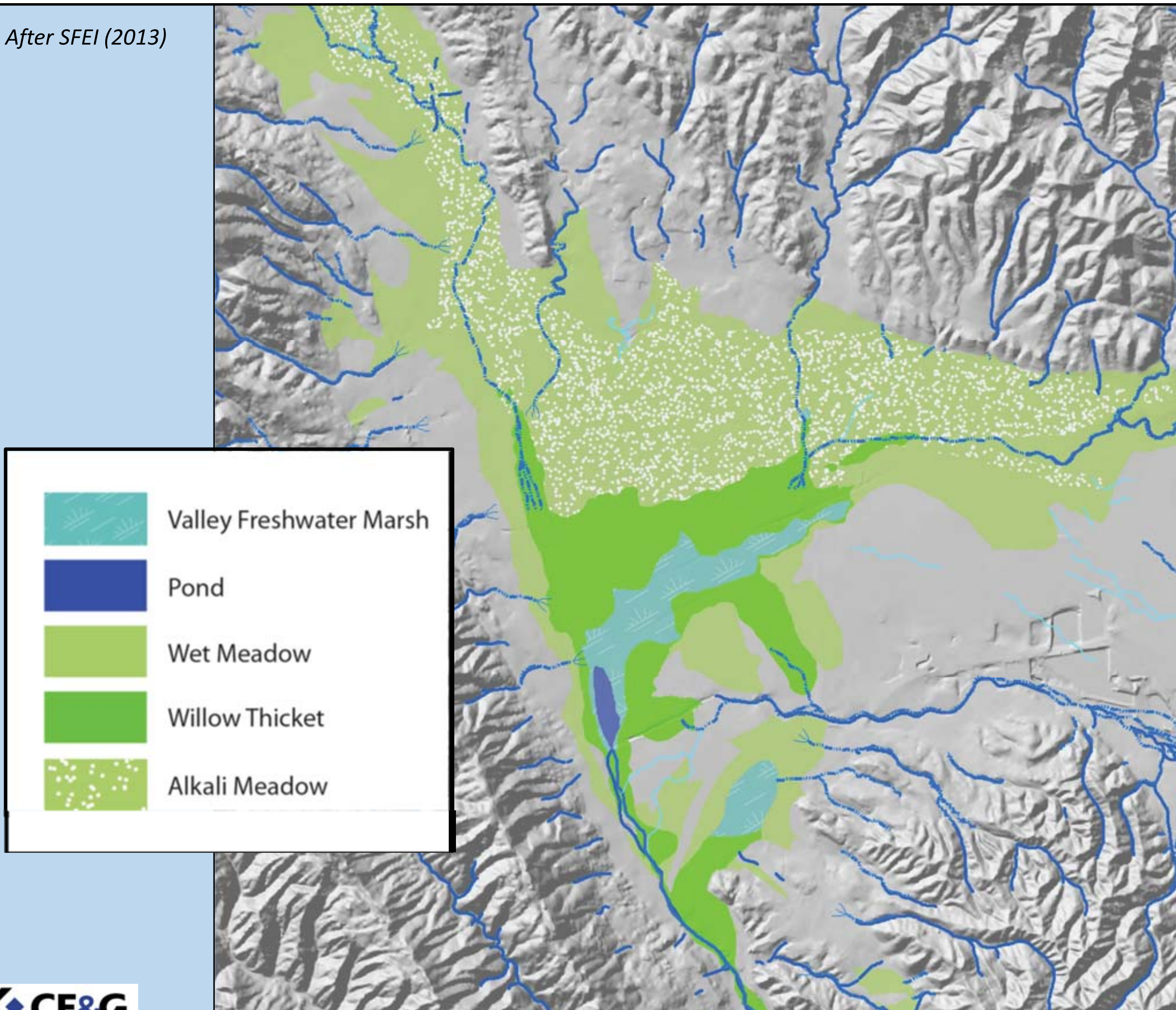
After SFEI (2013)



ARROYO MOCHO AND
ARROYO LAS POSITAS – Historic Setting

- Confluence in broad marsh area
- No single continuous creek link to Arroyo de la Laguna

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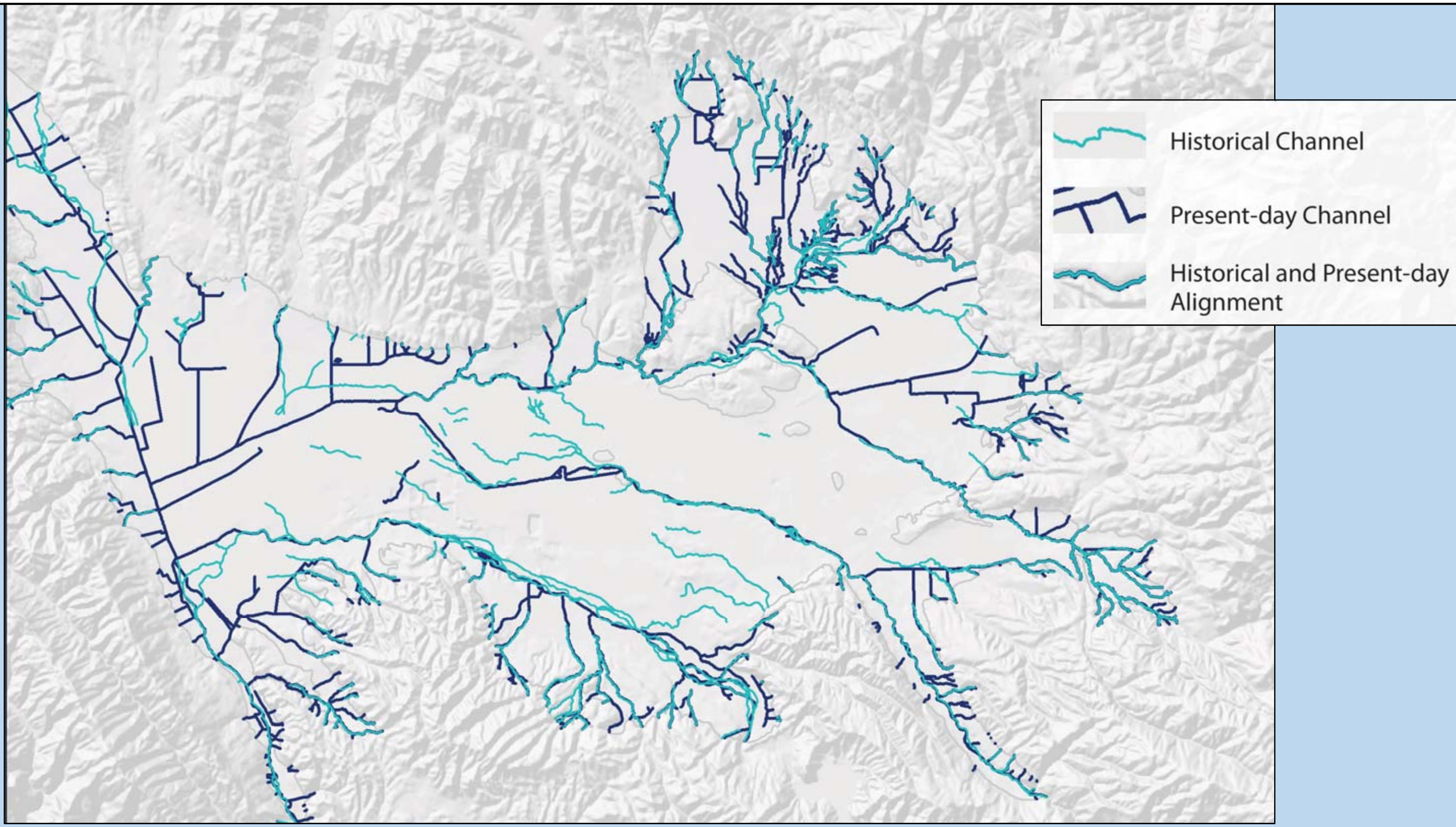
From SFEI (2013)



COMPARISON OF MODERN AND HISTORICAL CREEK CHANNELS
- Historical Channels Often Not Continuous

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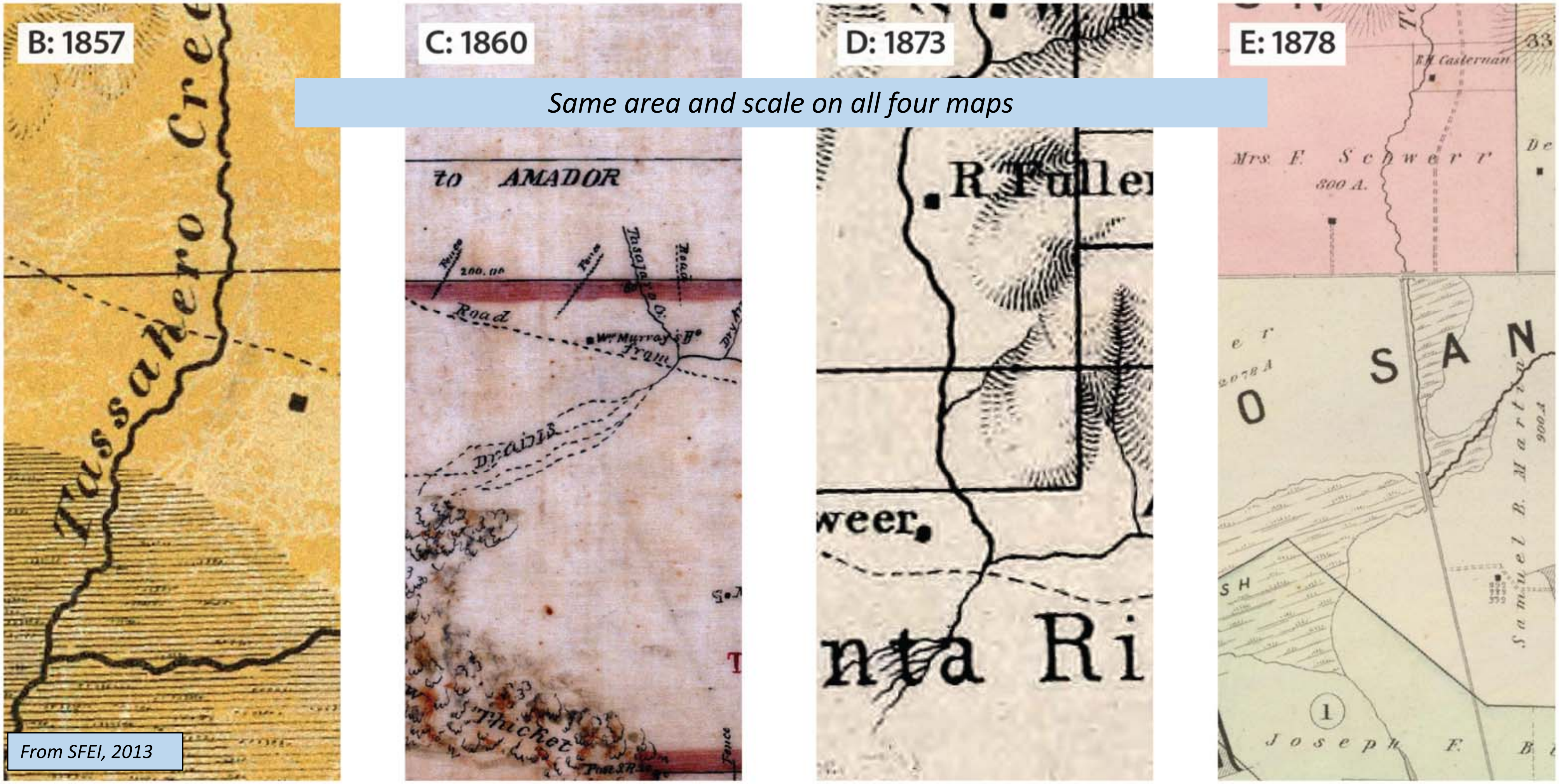
Same area and scale on all four maps



From SFEI, 2013

CONFLUENCE OF TASSAJARA CREEK AND ARROYO LAS POSITAS
- Poorly defined flow paths and creek channels

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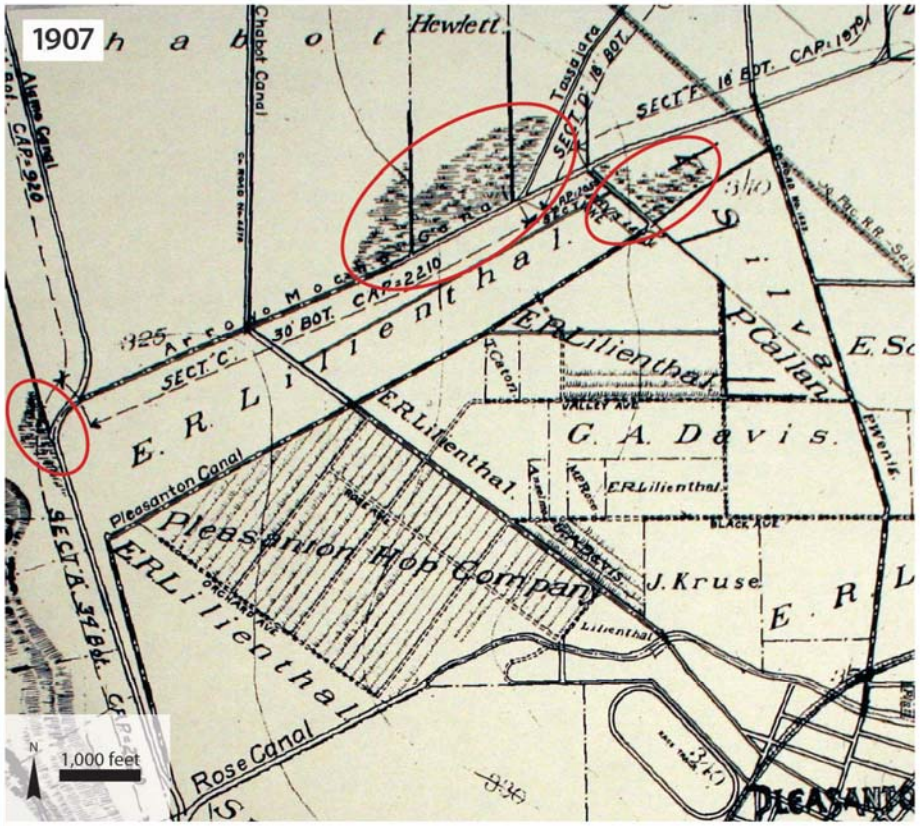

Figure 4.28. "Proposed location of the Pleasanton Canal Systems." This 1907 map shows proposed ditches that cut across the marsh complex. A few patches of remnant willow thicket remained at the time, circled in red here. (Tibbetts 1907b, courtesy Earth Sciences and Map Library, UC Berkeley)

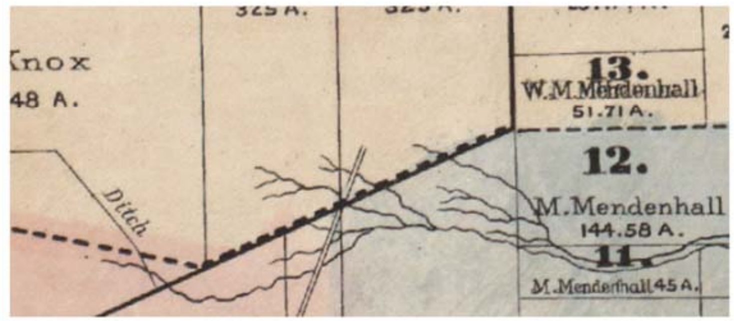

Figure 4.47. Mocho distributaries.
Early maps consistently show Mocho's distributaries with many small branching channels, although the exact location varies.

From SFEI (2013)

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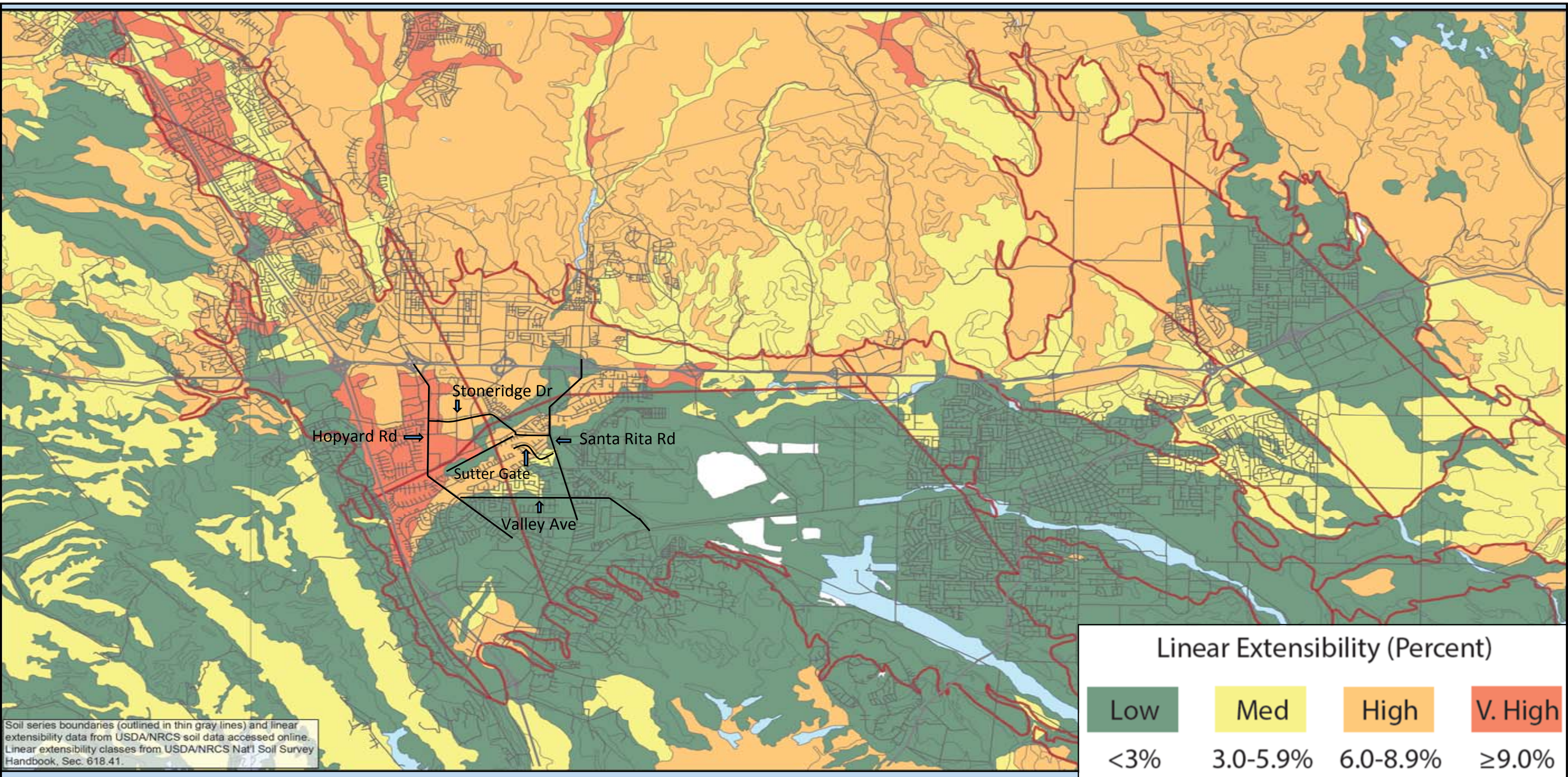
CONFLUENCE OF ARROYO MOCHO AND ARROYO LAS POSITAS
- Poorly defined flow paths and creek channels



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SOIL EXPANSIVITY –
Percent Soil Volume Change with Change in Soil Moisture

EXPANSIVE SOIL MOVEMENT
- Processes and Associations

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Expansive Soil
Desiccation Cracks

EXPANSIVE SOIL/BEDROCK
- annual US losses $16B per year (AGI, 2009)
- one of, or *the*, most expensive natural hazard in the US

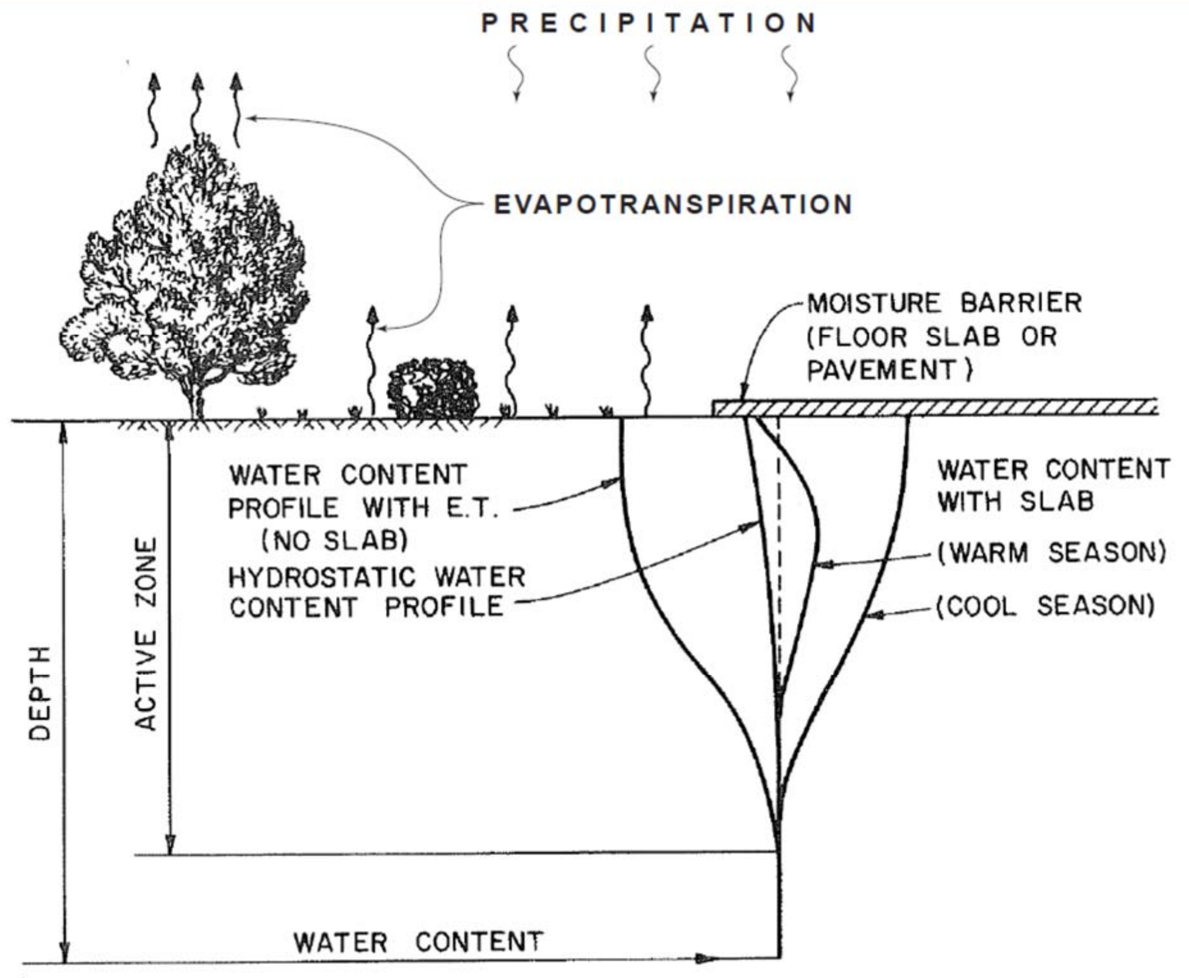
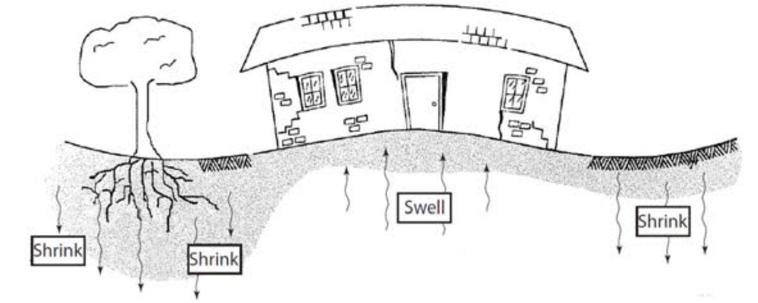
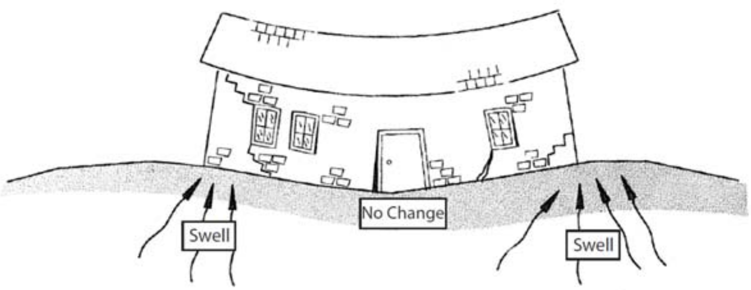


Figure adapted from Figure 2.2 in Nelson and Miller (1992)

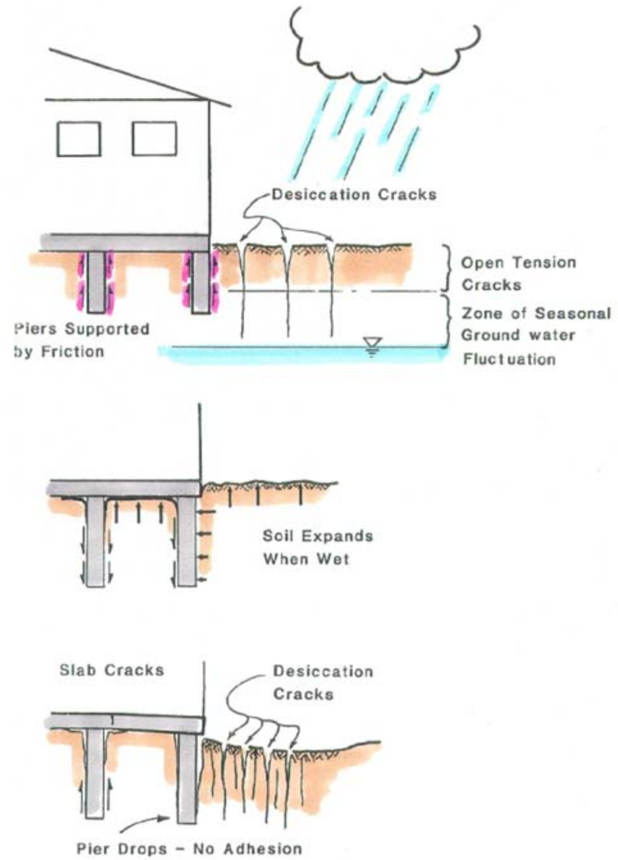
SOIL ACTIVE ZONE



Schematic illustration of how a structure can be distorted by shrinkage of soils around its perimeter, swelling of soils beneath the interior, or both. Note that trees can extract moisture from soils.

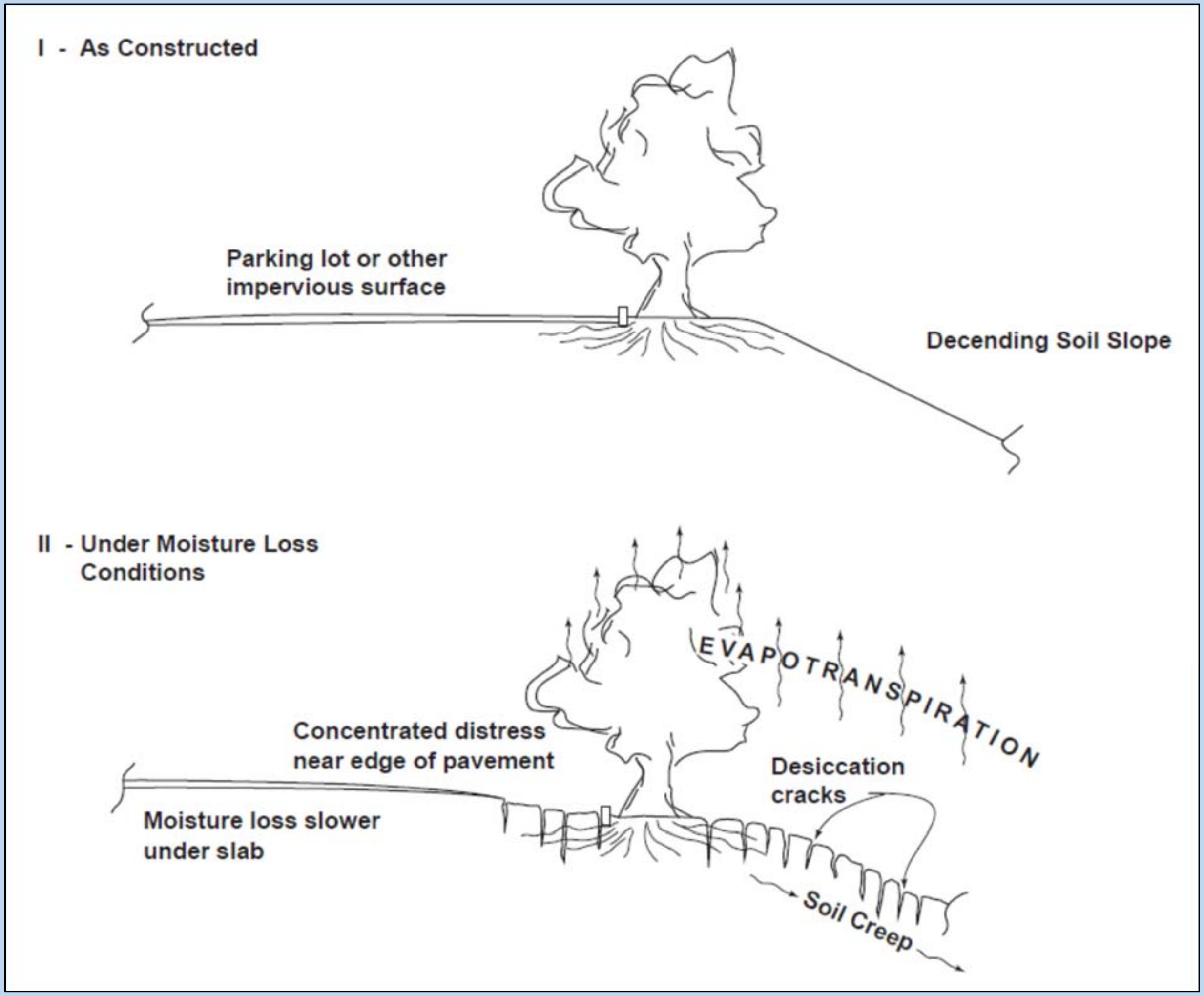


Schematic illustration of how a structure can be distorted by swelling of soils around its perimeter.



Example of how soil moisture changes can affect a structure on shallow piers.

EFFECT ON STRUCTURES



SLOPES AND UNEVEN MOISTURE LOSS

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EXPANSIVE SOIL – TAKEAWAY POINTS

- Distribution of expansive soil is controlled by area geology and natural setting
- Areas experiencing distress are strongly associated with occurrence of expansive soil
- Nature of distress is a localized phenomenon, strongly influenced by local conditions (cover, drying, irrigation, vegetation, grading, aspect, etc.)
- The more extreme the swings in moisture content, the more the effect is observed

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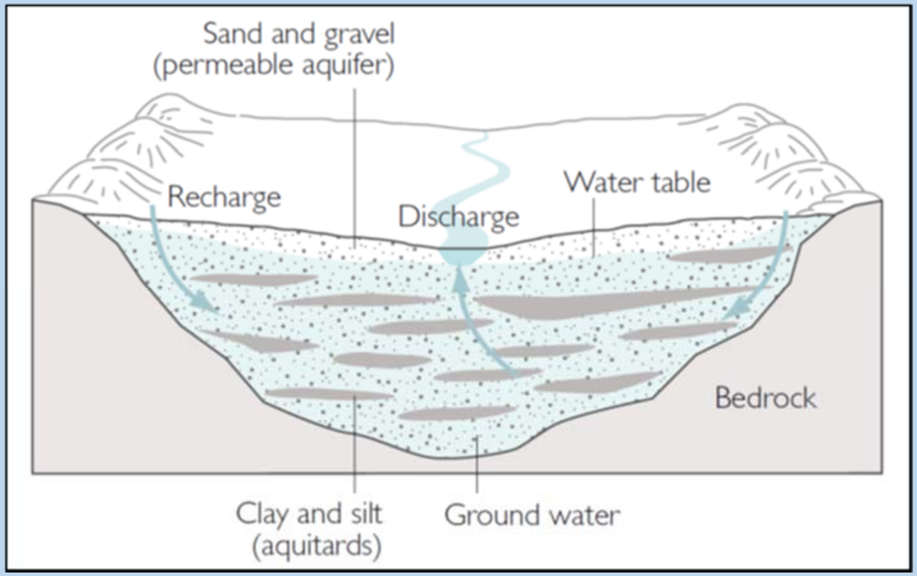

GROUNDWATER FLUCTUATIONS AND EFFECTS

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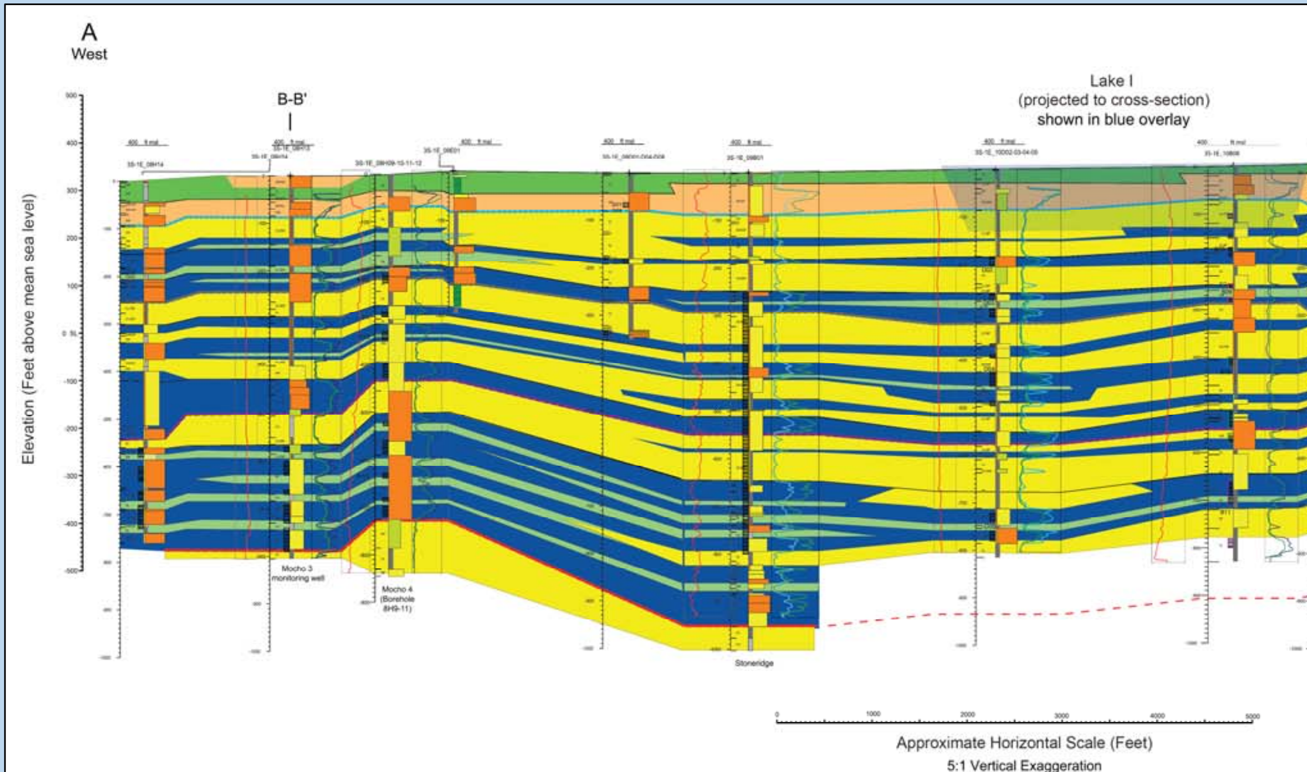
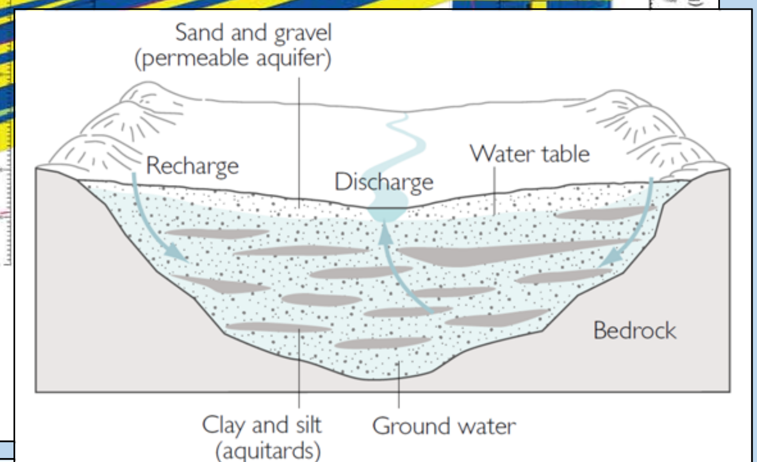


(from Norfleet Consultants, 2004)



Major Alluvium Types

- (Aquitard) - Overbank and lakebed clay and silt
- (Aquifer) - Fluvial gravel
- (Aquifer) - Fluvial overbank and floodplain clay and silt. May include lakebed deposits
- (Aquifer) - Fluvial and deltaic(?) sand and gravel
- (Aquitard) - Lakebed clay and silt (discontinuous). May include floodplain and overbank deposits.

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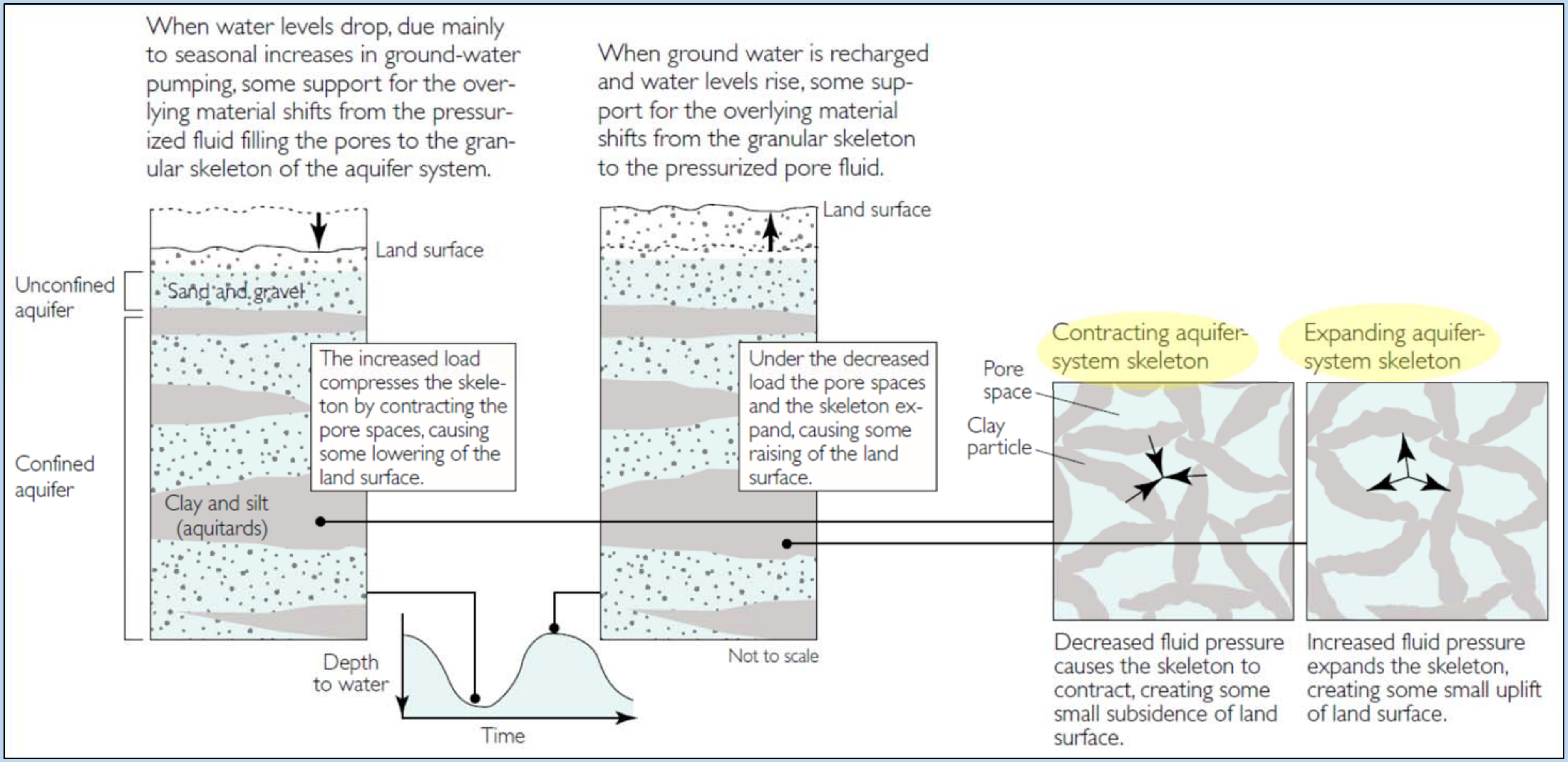
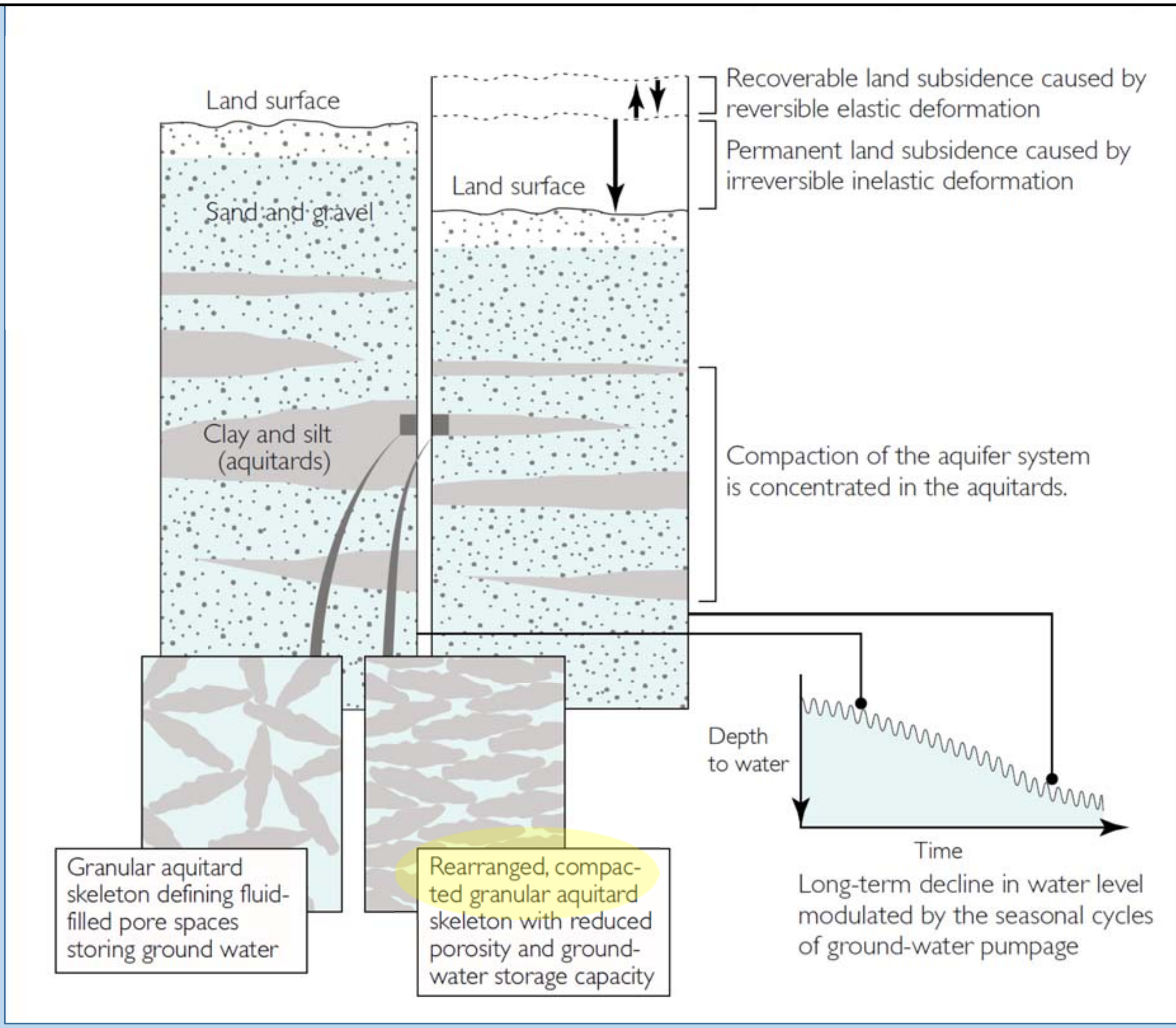
SCHEMATIC GEOLOGIC CROSS-SECTION of LIVERMORE VALLEY MAIN BASIN



(from Galloway and others, 1999)

ELASTIC (REVERSIBLE) SUBSIDENCE/UPLIFT



(from Galloway and others, 1999)

INELASTIC (NON-REVERSIBLE) SUBSIDENCE

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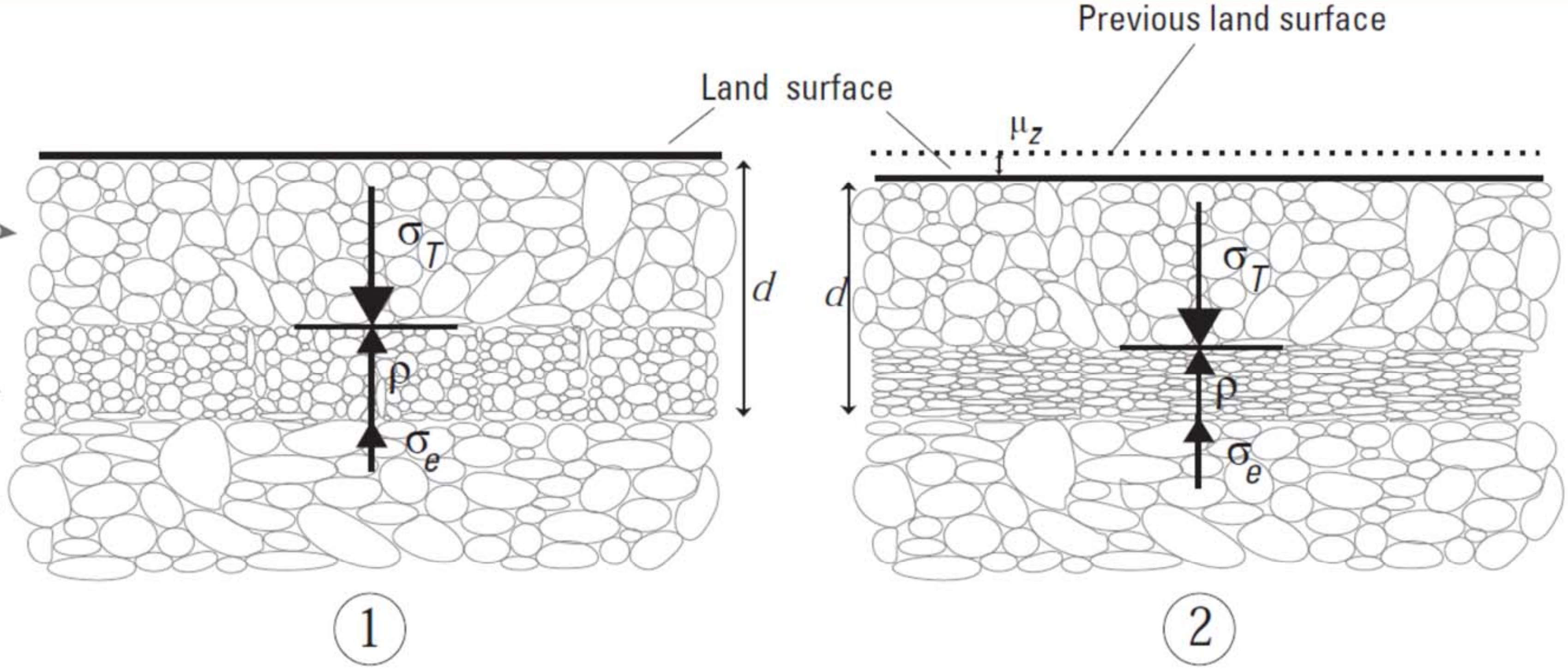
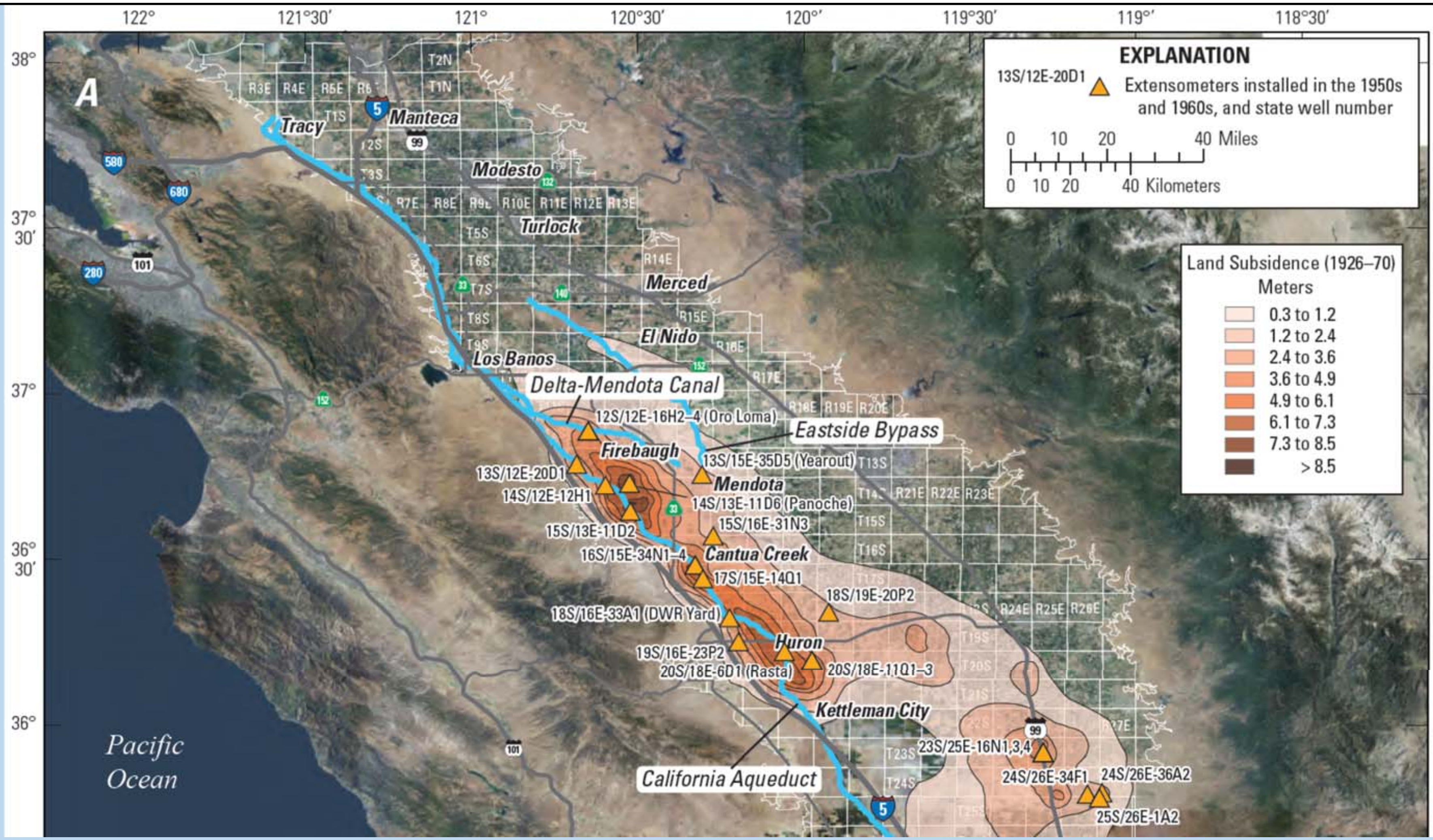


$$\sigma_e = \sigma_T - \rho$$

(from Sneed and others, 2013)

INELASTIC (NON-REVERSIBLE) SUBSIDENCE



(from Sneed and others, 2013)

INELASTIC (NON-REVERSIBLE) SUBSIDENCE
– Scale of Observation: over long distances

GROUNDWATER FLUCTUATIONS – TAKEAWAY POINTS

- Inelastic ground subsidence from pumping is a "long wavelength" phenomenon, typically detected over distances of miles, with very low angular distortion
- Distress typically seen as flexing (large radius of curvature), rather than cracking/breakage of surface improvements (e.g. curbs, foundations)
- Groundwater levels have to drop below historic lows for there to be potential for inelastic subsidence (not all sediments susceptible)
- Elastic response is also "long wavelength", is characteristic of recharge/withdrawal cycles, is typically minor (e.g. on order of <0.1 ft/yr) and cyclic

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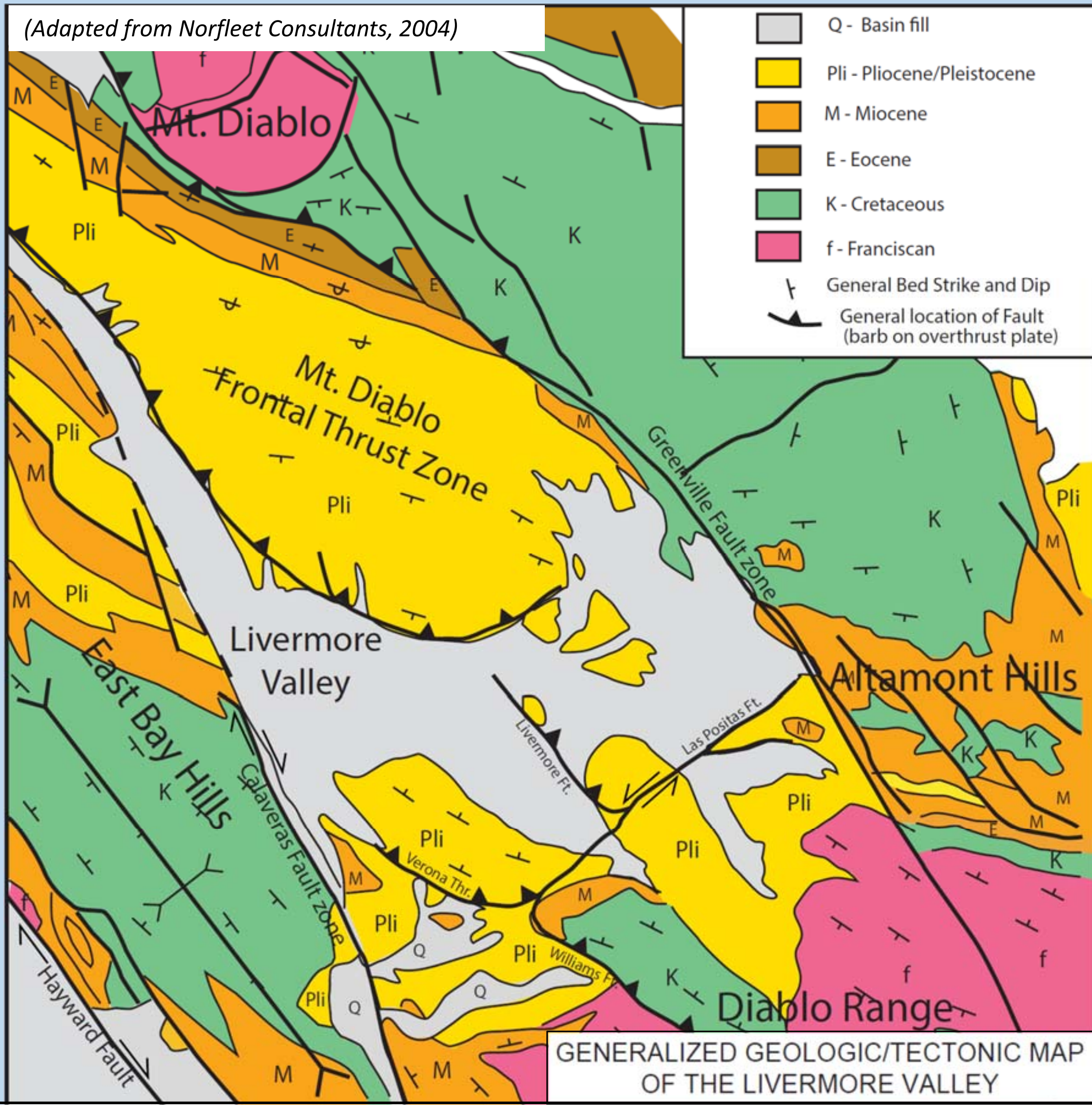

TECTONIC CONTRIBUTIONS

TECTONIC CREEP
- Observed along some faults

UPLIFT/SUBSIDENCE
- Observed at scale of ranges and basins

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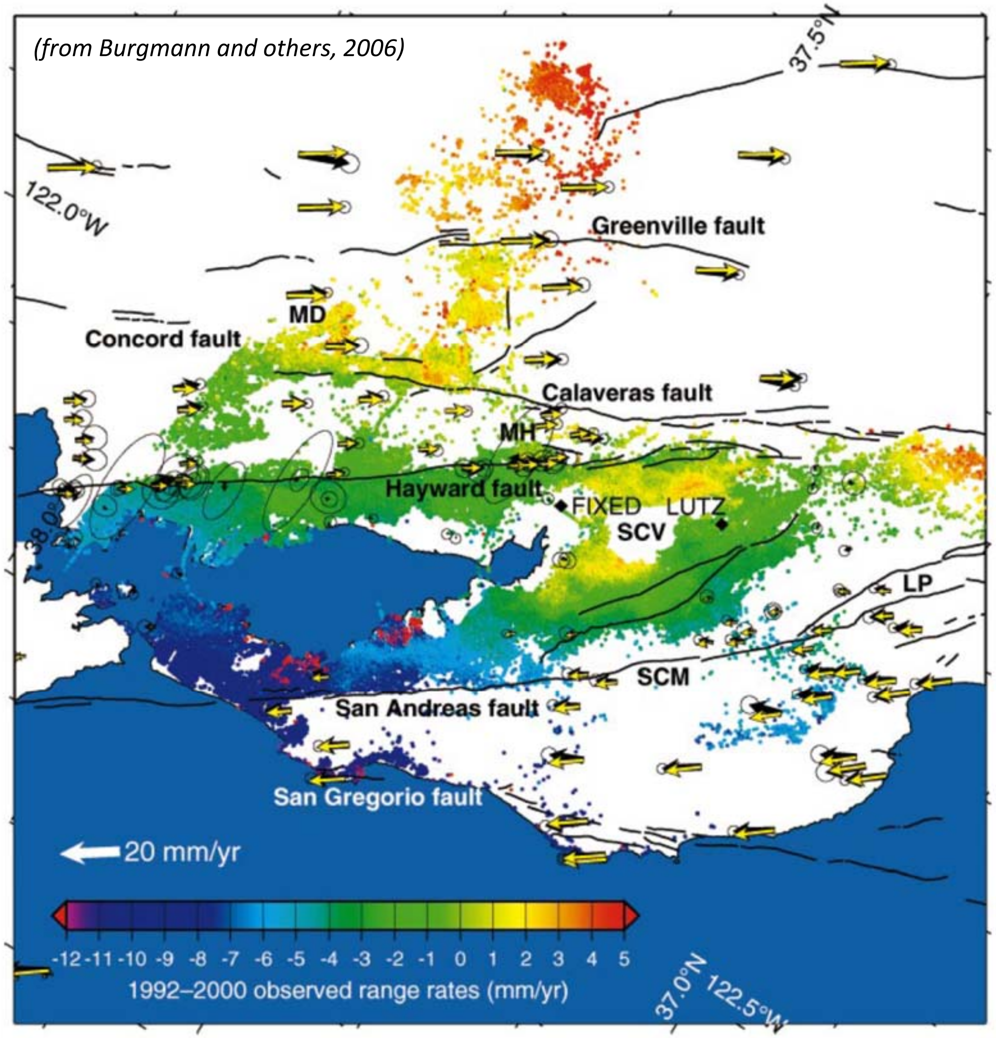

Horizontal plate motions (black arrow = vector) in mm/yr

Vertical motion (uplift = red; subsidence = blue) in mm/yr

TECTONIC PLATE MOTIONS

TECTONIC MOVEMENTS – TAKEAWAY POINTS

- Very long wavelength phenomena, typically detected over distances of tens to thousands of miles unless right at a fault
- Rates tend to be fairly stable
- Rates very low (on order of a few mm/yr)

ONGOING MONITORING
Findings in Livermore Valley Area

- Ground surface elevation monitoring – Biannual, by Zone 7. (Ref. Zone 7 GWMP Annual Report for WY2014). Expanded 2002 by Zone 7; considered prudent groundwater management practice.
- Groundwater elevation monitoring – Various schedules (biannual/monthly/datalogger), by Zone 7. (Ref. Zone 7 GWMP Annual Report for WY2014). Monitoring by Zone 7 since at least 1957; considered required for sustainable groundwater management.
- GPS/InSAR ground surface monitoring – ongoing by USGS, UC Berkeley, others; ref. Burgmann et al.(2006), Argus and Gordon (2001)
- Precipitation, Water Consumption– ongoing by Zone 7, others.

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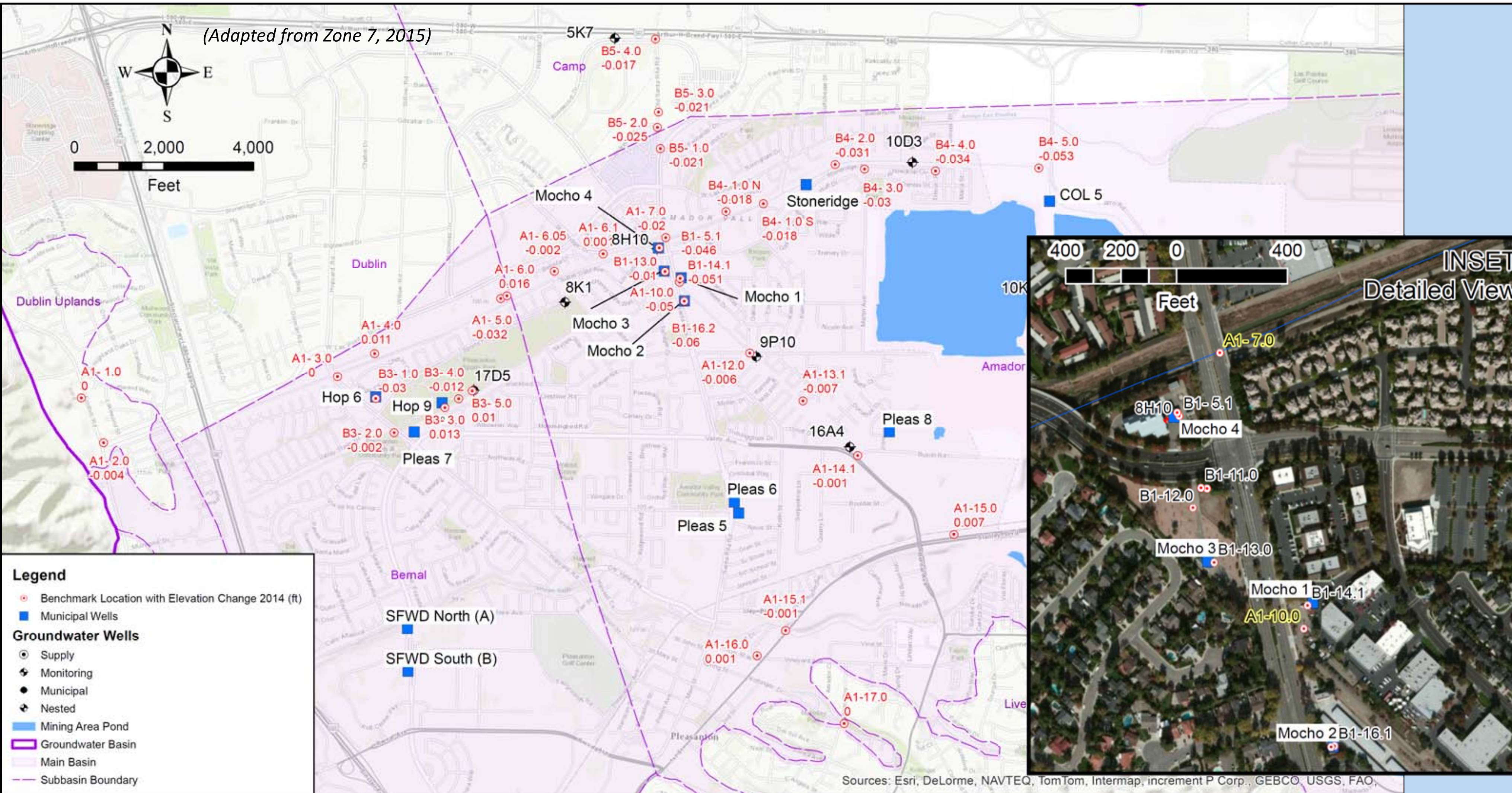

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GROUND SURFACE ELEVATION MONITORING RESULTS WY2014

Ground Surface Elevation Observations

- Trends show annual cyclicity on order of up to about 0.05 ft
- Relatively minor long-term change in elevation even through current drought (e.g. maximum net change in elevation since 2002 is 0.1 ft)
- Seeing localized small variations; not seeing basin-wide drops in elevation
- Benchmarks differ in types of foundations used; those on shallower foundations appear to reflect expansive soil movement

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Precipitation/Irrigation Trends

- Broadly, precipitation about 63% of average in WY2013, about 40% of average in WY2014, and about 85% of average in WY2015.
- Conservation has resulted in about 70% to 80% reduction in urban irrigation in 2014 and 2015 (for Zone 7 service area).
- Result is less water input to surficial soils from both these sources

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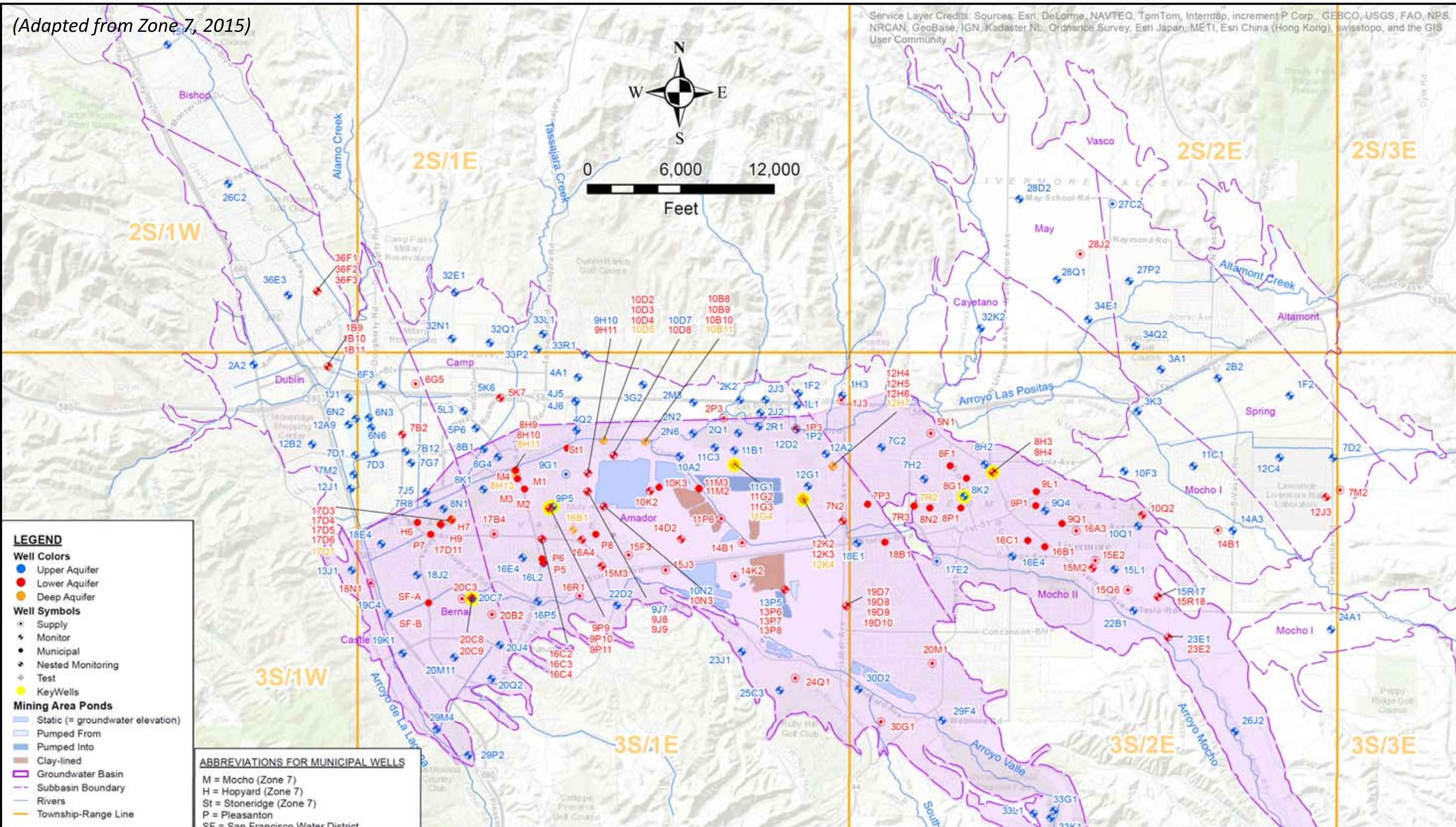
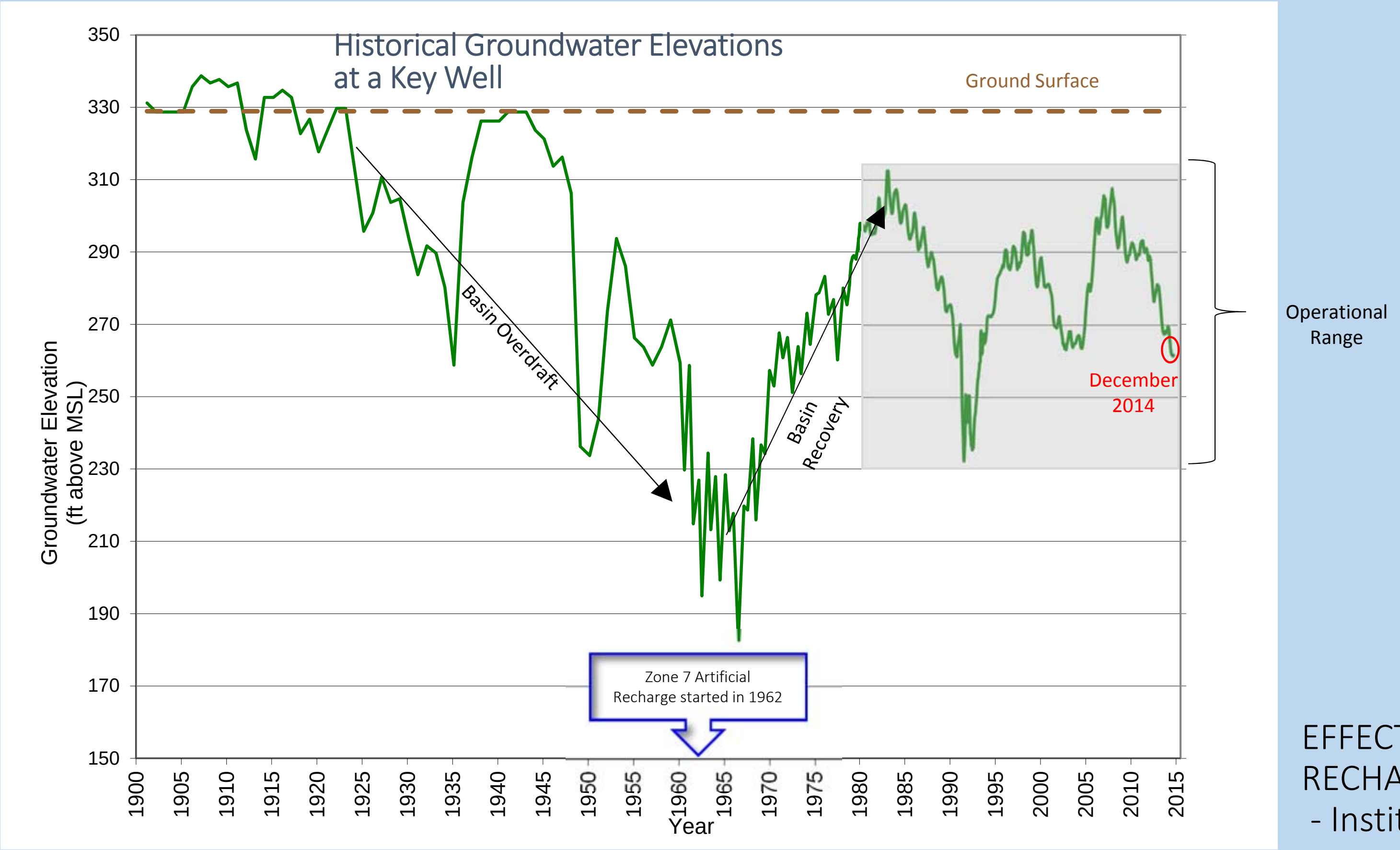
(Adapted from Zone 7, 2015)



GROUNDWATER ELEVATION MONITORING POINTS WY2014
- Zone 7, Water Retailers, Other Private Wells

(Provided by Zone 7, 2015)



EFFECT OF ZONE 7 GROUNDWATER RECHARGE PROGRAM
- Instituted 1962

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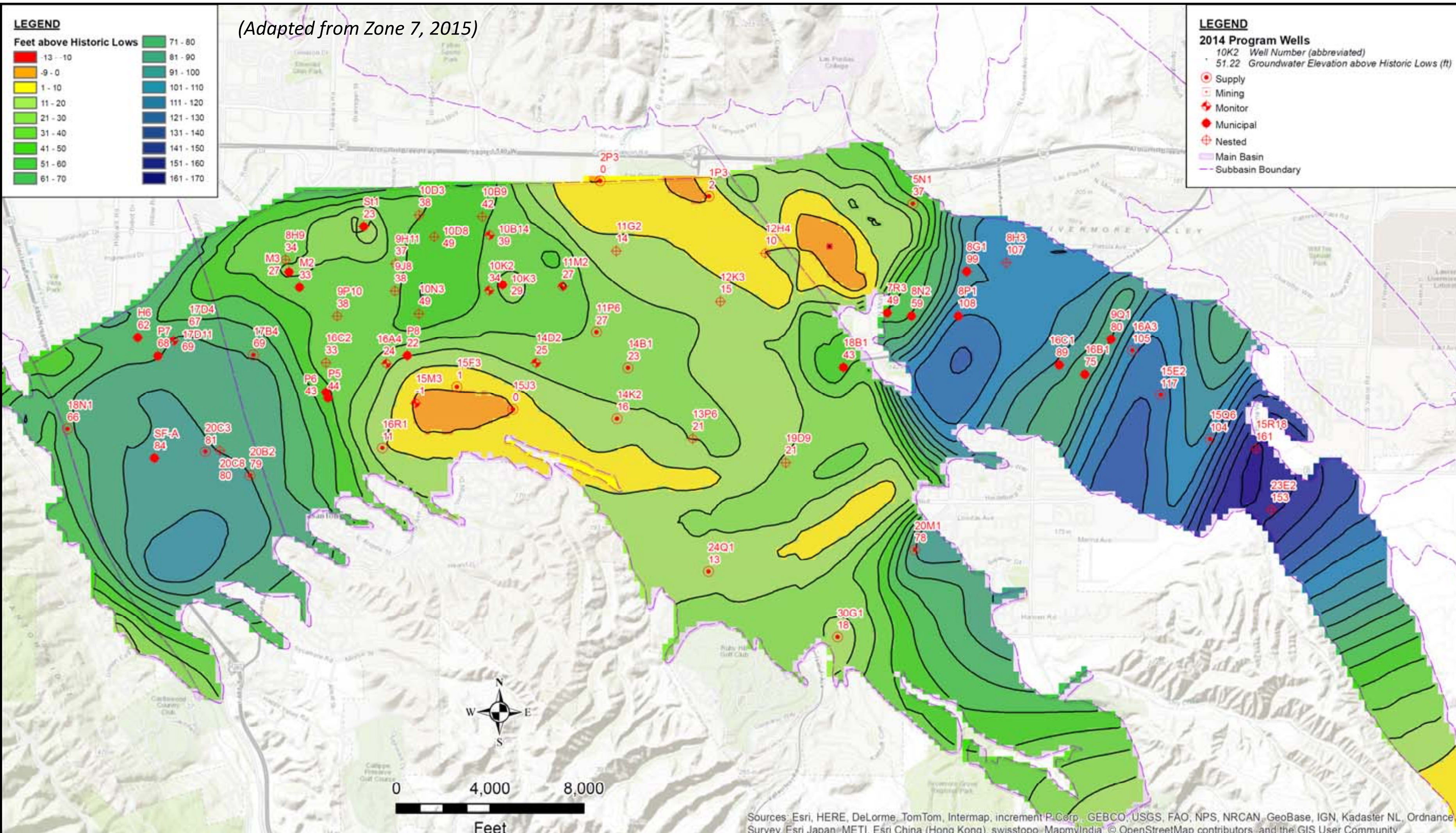

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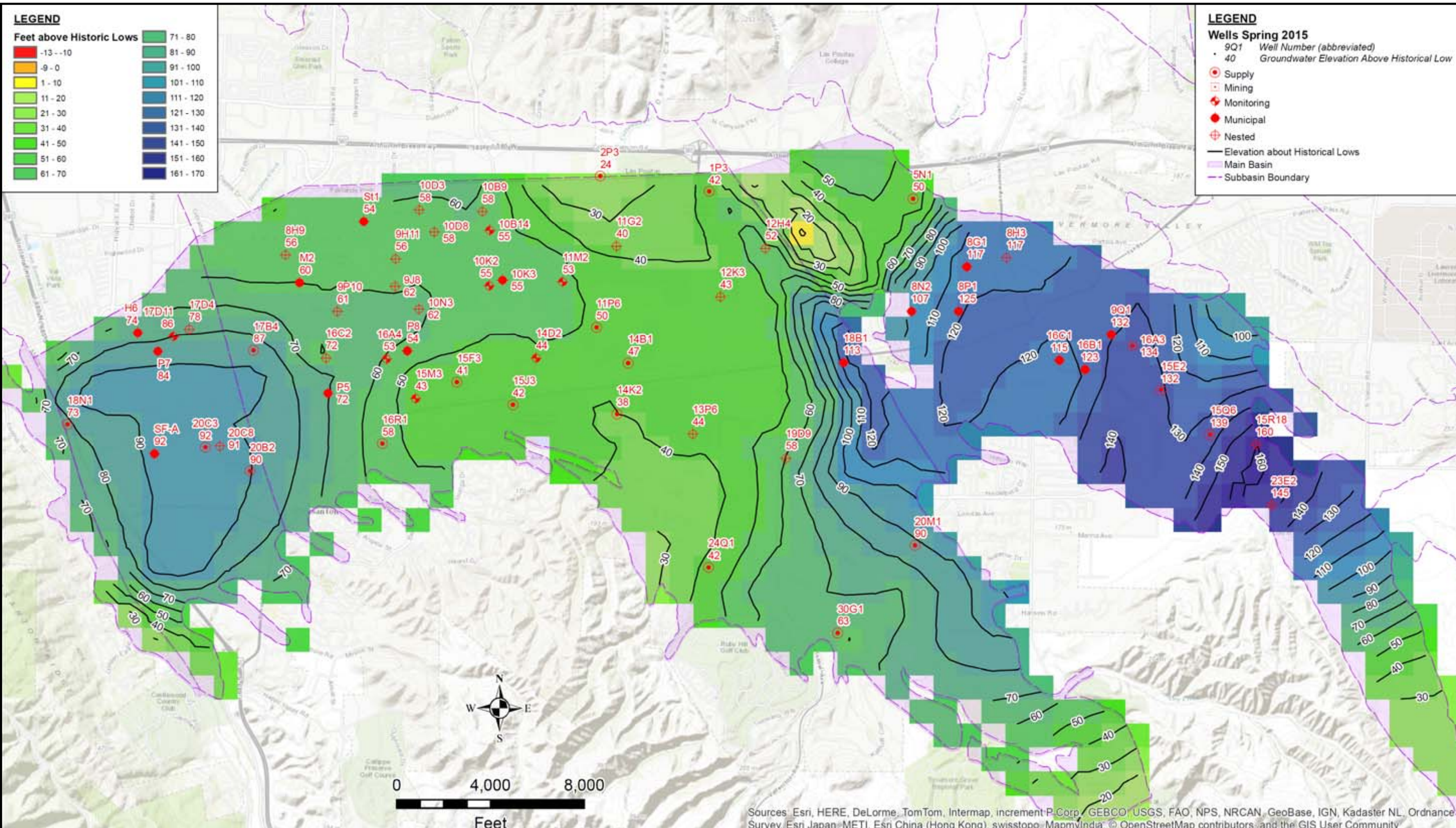
GROUNDWATER LEVELS - FALL WY2014
- Feet Above Historic Lows



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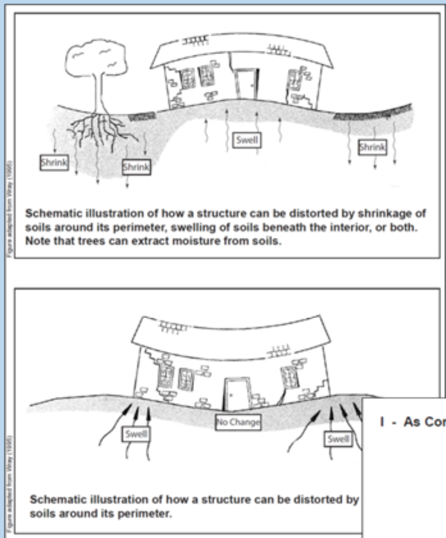
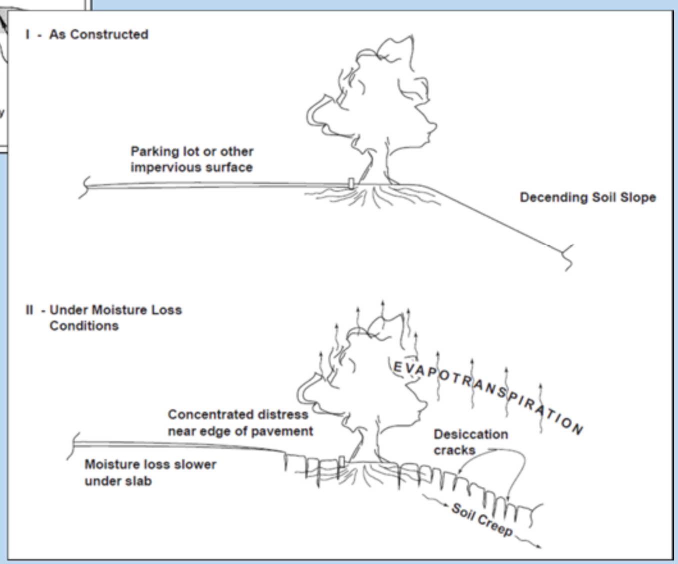
GROUNDWATER LEVELS – SPRING WY2015
- Feet Above Historic Lows





OBSERVED DISTRESS – EXAMPLES AND ASSOCIATIONS

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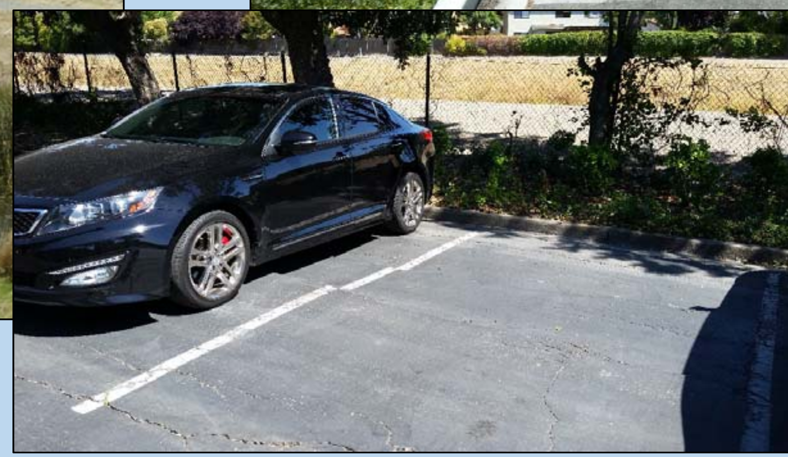

CRACKING AND DIFFERENTIAL VERTICAL OFFSET - Concentrations Near Large Exposed Unpaved Areas, Slopes (e.g. Canal Banks) In Areas With Expansive Soils, +/- Rows of Trees

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CRACKING AND DIFFERENTIAL VERTICAL OFFSET -
Concentrations Near Large Exposed Unpaved Areas, Slopes
(e.g. Canal Banks) In Areas With Expansive Soils, +/- Tree Rows

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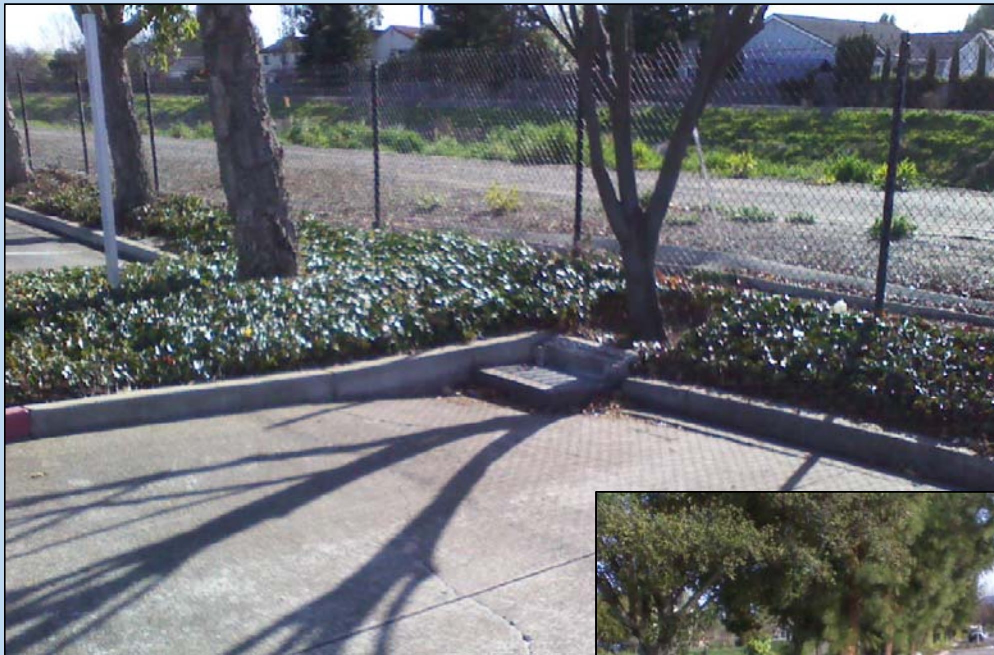

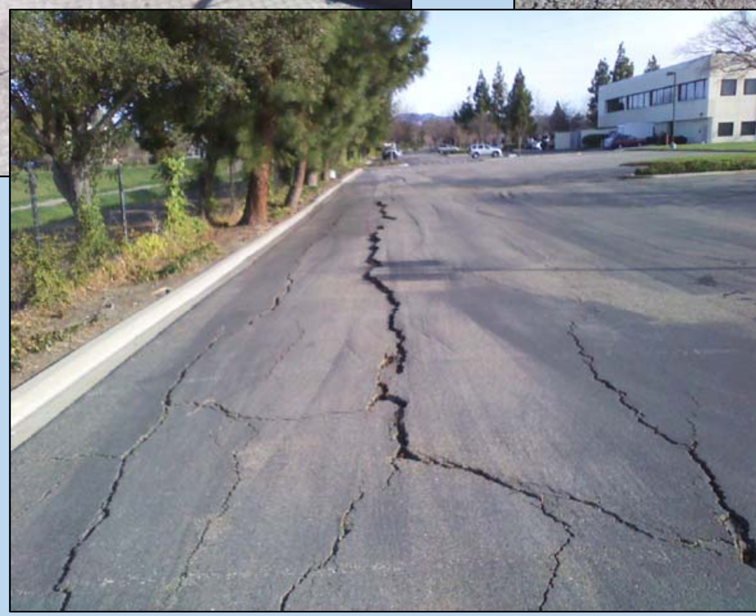

DISTRESS EXAMPLES –
Concentrations Near Large Exposed Unpaved Areas, Slopes (e.g. Canal Banks) In Areas With Expansive Soils, +/- Tree Rows

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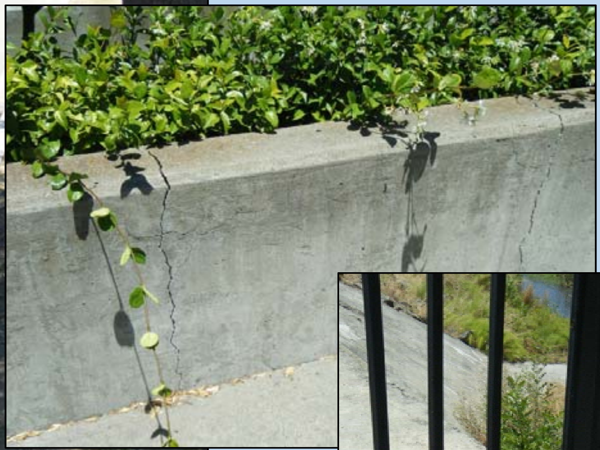

CULVERTS AND APPROACH RAMPS – (*Example*)
Culvert has deeper foundations, bottoming in likely saturated/wet soil
Approach founded in channel bank soils, fill tapering to zero at ground surface; fill and underlying soils have experienced drying

PAVEMENT DISTRESS

- Typically localized distress; commonly associated with poor subgrade drainage; transitions between graded areas or periods/techniques of construction; and with utilities where compaction uniformity is difficult to achieve.
- May be expansive soil component, but not necessarily due to it.

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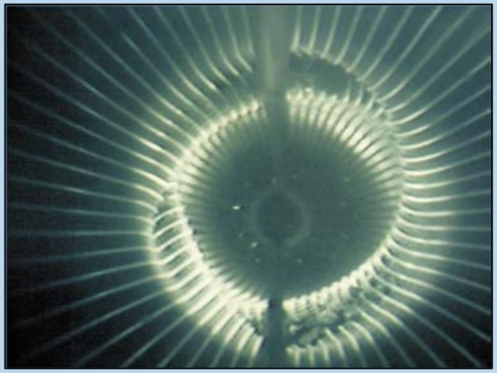
Not Seeing:

- Damaged well casings (which would suggest changes in thickness of aquifers)
- Differential vertical offset between wellheads and adjacent ground surface (which would suggest changes in thickness of aquifers)
- Basin-scale changes in benchmark elevations, or changes in gradient/flow capacity along canals/flood control channels (which would suggest long-wavelength subsidence
- Significant distress away from areas of historical marshland/channels and expansive soil



Galloway and others (2012)

Kretsinger and Borchers (2014)

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CONCLUSIONS

- Of the three potentially contributing processes to surface ground movements, expansive soil movement by far the greatest in magnitude.
- Geology, soils, and groundwater data, together with unprecedented drought, yield consistent picture with respect to observed movements.
- Types and localities of observed distress are strongly associated with areas of expansive soils, and historical creek/marsh settings.
- Impact of drought conditions (reduced precipitation) is compounded by reduced irrigation.
- Valley soils are drying more severely, and to greater depths, than ever before experienced since the area was settled.
- Groundwater system has been managed and monitored to stay above historic lows (observed in the 1960's, 1977, or 1987-1992 droughts). No patterns of observations suggest inelastic subsidence.
- Elastic movement is basin-wide in scale, quite small.

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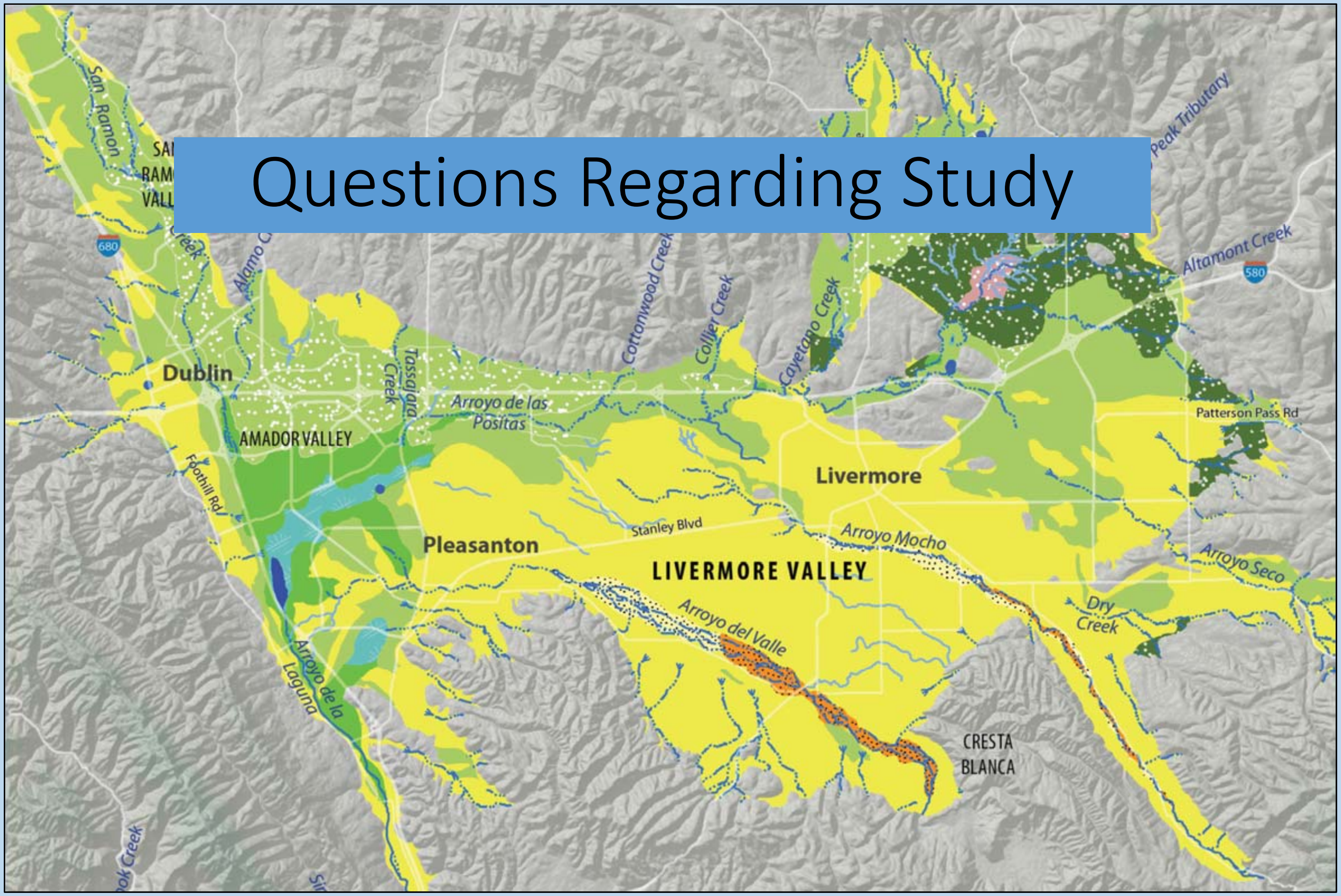
Questions Regarding Study



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