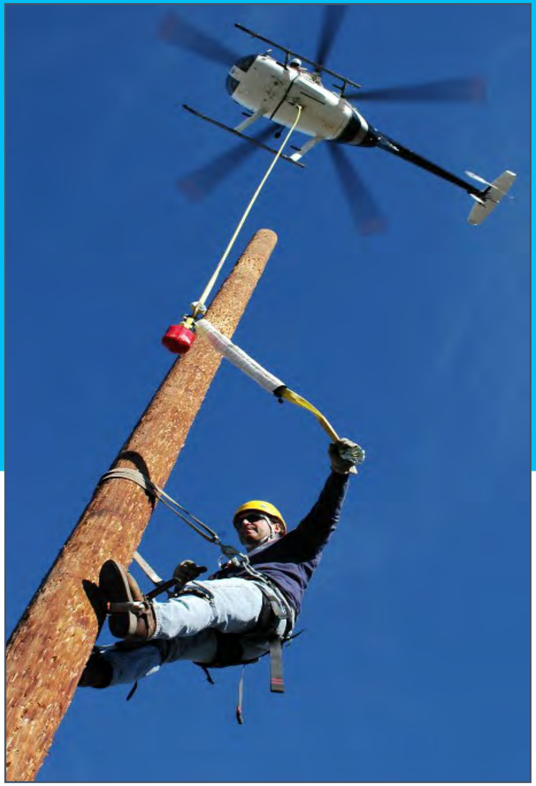
Implementation of Remote Sensing Data: Pacific Gas & Electric Company

Evaluation, Mitigation, and Monitoring of Gas & Electric Infrastructure in Central and Northern California

Jeff Bachhuber, Chris Madugo – Geosciences
Eric Woodyard – Electric Vegetation Management
Teddy Atkinson – Gas Transmission TIMP



Together, Building a Better California

Drive to Integrate Technology – Consistent with PG&E's Mission, Vision, Culture

Remote Sensing

Benefits:

- Cost & Time Efficiency
- Higher Quality
- Access (e.g. tower equipment)
- Safety
- Documentation
- Multi-use (e.g. VM, equipment condition, geotechnical)

Challenges:

- New
- Takes Time to Develop Confidence
- Incomplete Data Sets
- Over-Expectations
- Traditional Job Change/Perceived Threat

Mission Vision Culture

Our Mission

To safely and reliably deliver affordable and clean energy to our customers and communities every single day, while building the energy network of tomorrow.

Our Vision

With a sustainable energy future as our North Star, we will meet the challenge of climate change while providing affordable energy for all customers.

Our Culture

We put safety first.

We are accountable. We act with integrity, transparency and humility.

We are here to serve our customers.

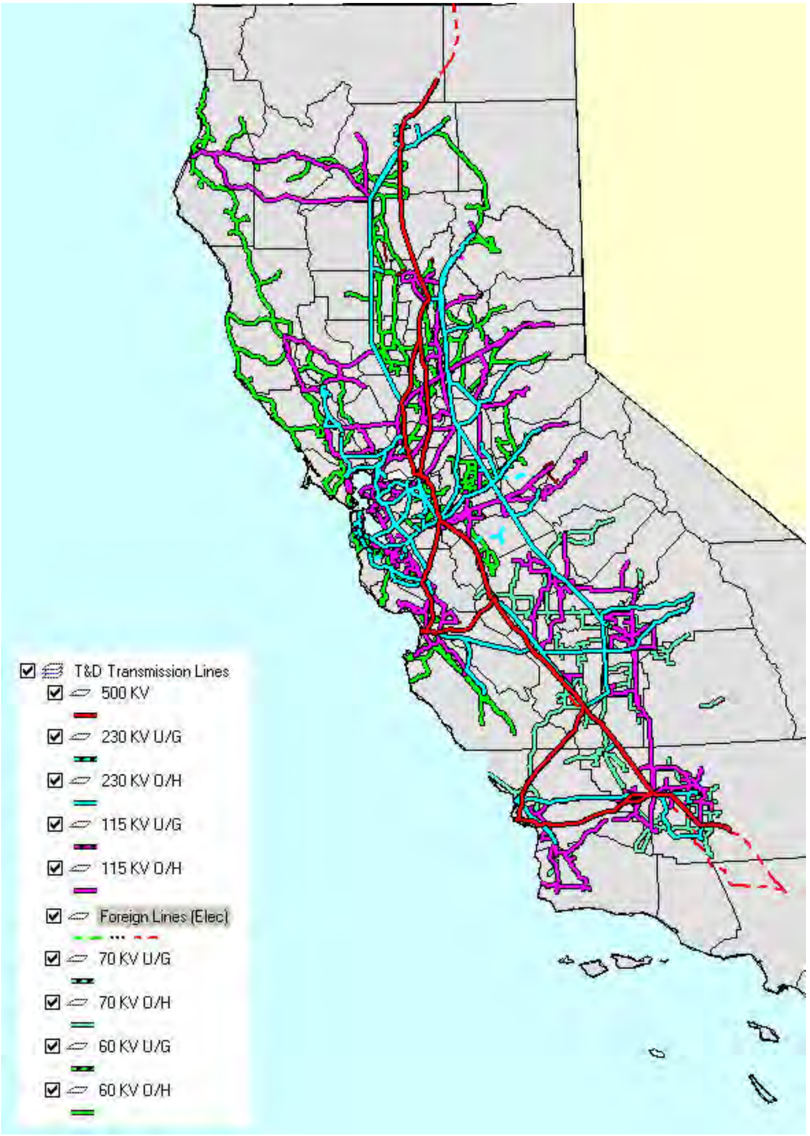
We embrace change, innovation and continuous improvement.

We value diversity and inclusion. We speak up, listen up and follow up.

We succeed through collaboration and partnership. We are one team.

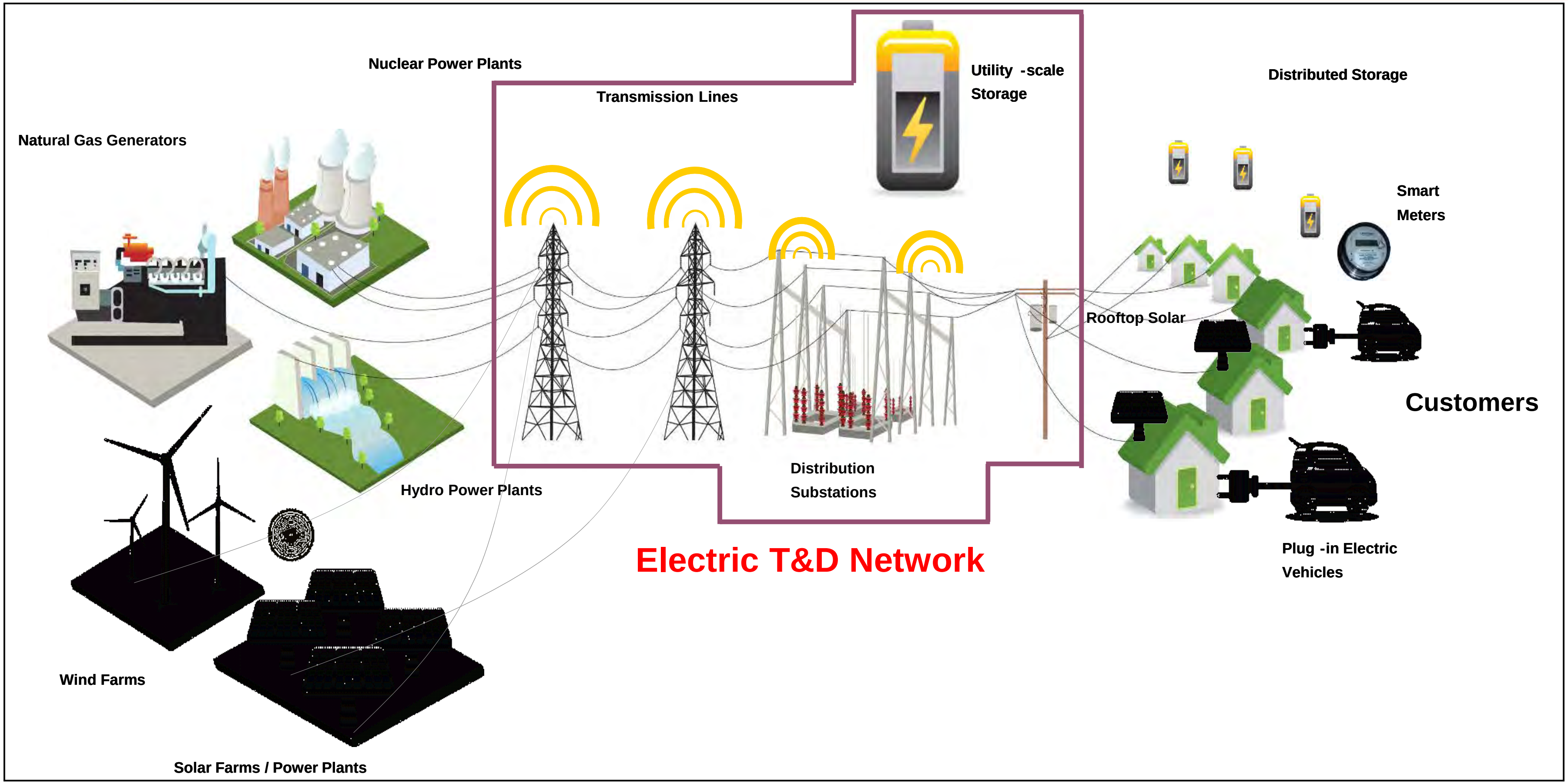
Maps of PG&E's Electric & Gas System

Electric: +18k mi. ET, +123k mi. ED



Gas: 48k mi. GTD

Diverse Electric Generation, T&D Network & Customer Base



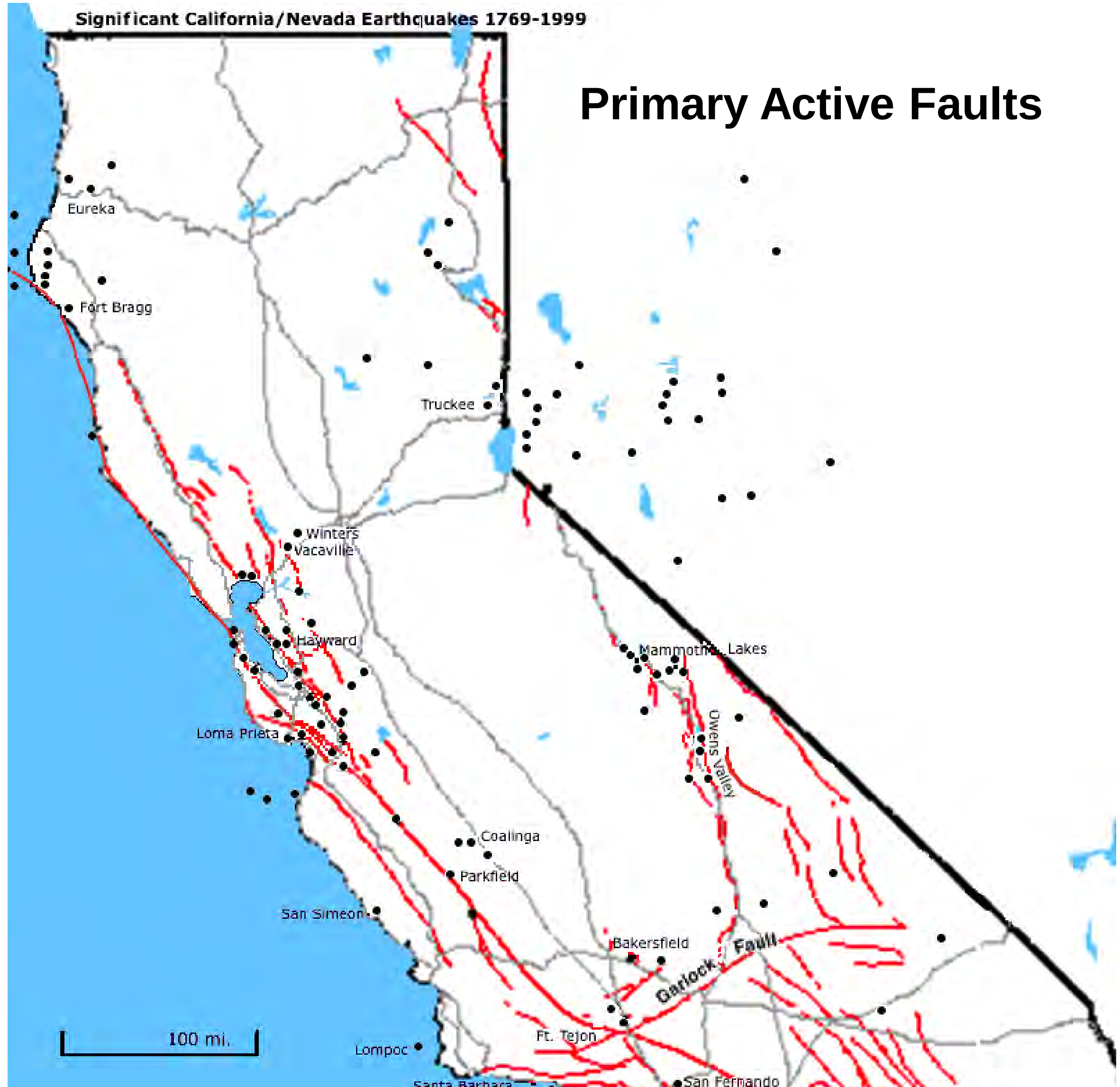
Electric System Includes:

- Transmission lines, substations & the distribution system
- Greater than 1,000,000 transformers and 850 substations
- 66 hydroelectric powerhouses/169 dams generation, gas plants, increasing rooftop solar
- 5.3 million electric customers serving 15 million people [1 in 20 Americans]

Overview of Natural Hazards in Northern/Central CA

- **Earthquakes and Fault Displacement (active plate boundary)**
- **Erosion/Scour**
- **Geotechnical-Foundation Issues**
- **Storm-Induced Landslides & Flooding (atmospheric rivers)**
- **Subsidence & Sea Level Rise (accelerated by climate change)**
- **Wildfire & Debris Flows**

Significantly Affected by Climate Change



Electric Transmission & Distribution System:

- LiDAR Database
- Vegetation Management

PG&E Electric Vegetation Management By The Numbers…

1 – annual patrol

100,000 – Line Miles Patrolled Annually

1,400,000 – Trees Pruned Annually

123,000,000 – Trees Adjacent to Lines*

****Drought & Bark Beetle Tree Kills Have Increased Hazard***

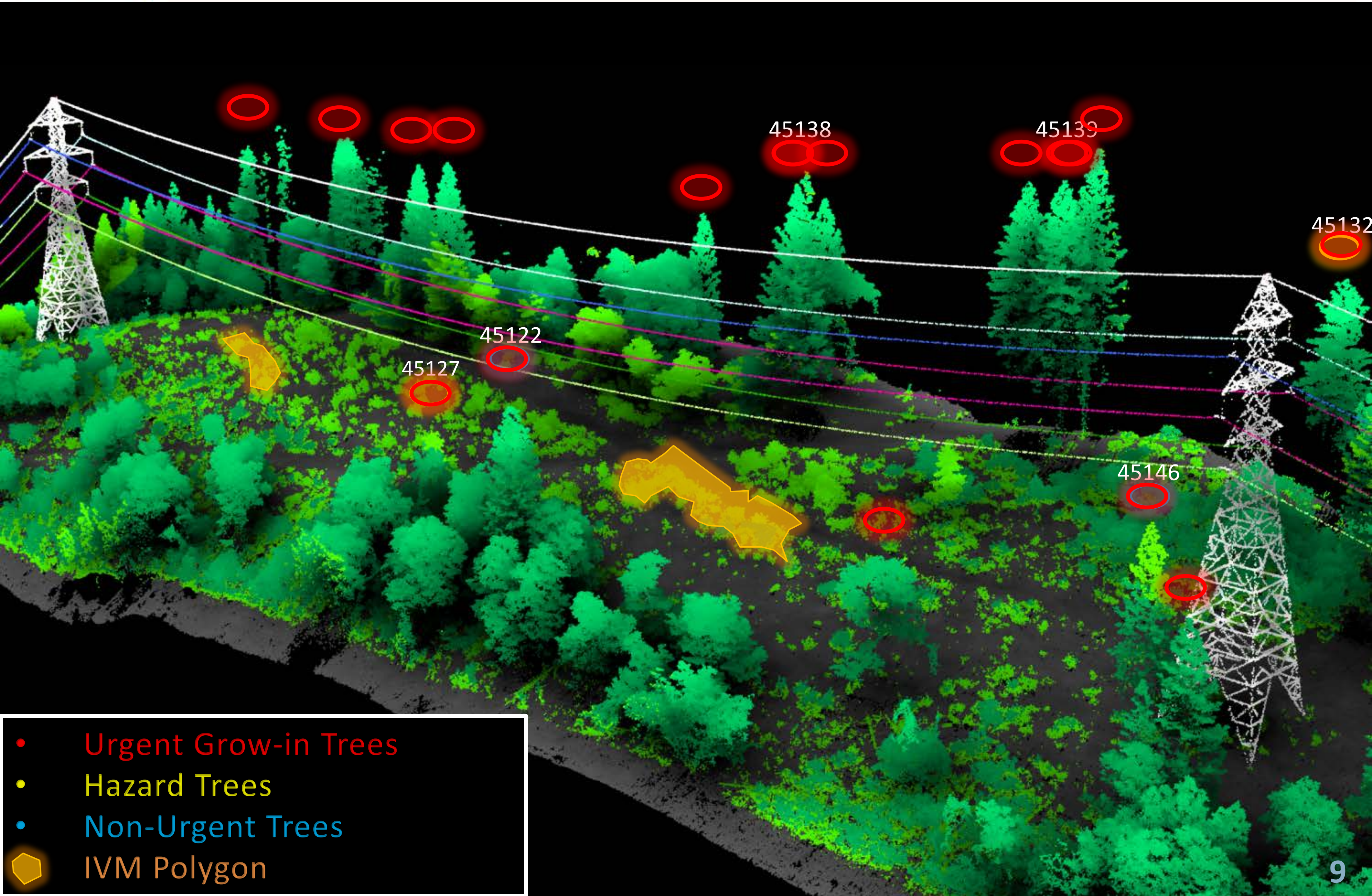
****Climate Change to Drier Conditions Increases Fuel Risk***

LiDAR Program

- Typical acquisition using 20-30 points/meter
- Outsourced, but evaluating using internal LiDAR resources
- Annual budget ~$15M/year

- Compiled in a database with increasing use of change detection
- Field reconnaissance and vegetation removal reporting for calibration & detail
- Multiple users identified (e.g., electrical engineers component assessment, Geosciences ground stability)
- Pilot Program - Evaluated hyperspectral data collection for vegetation “typing” (but would double annual acquisition costs)

Using Analytics to Optimize Decision-making; Identifying Problem Trees



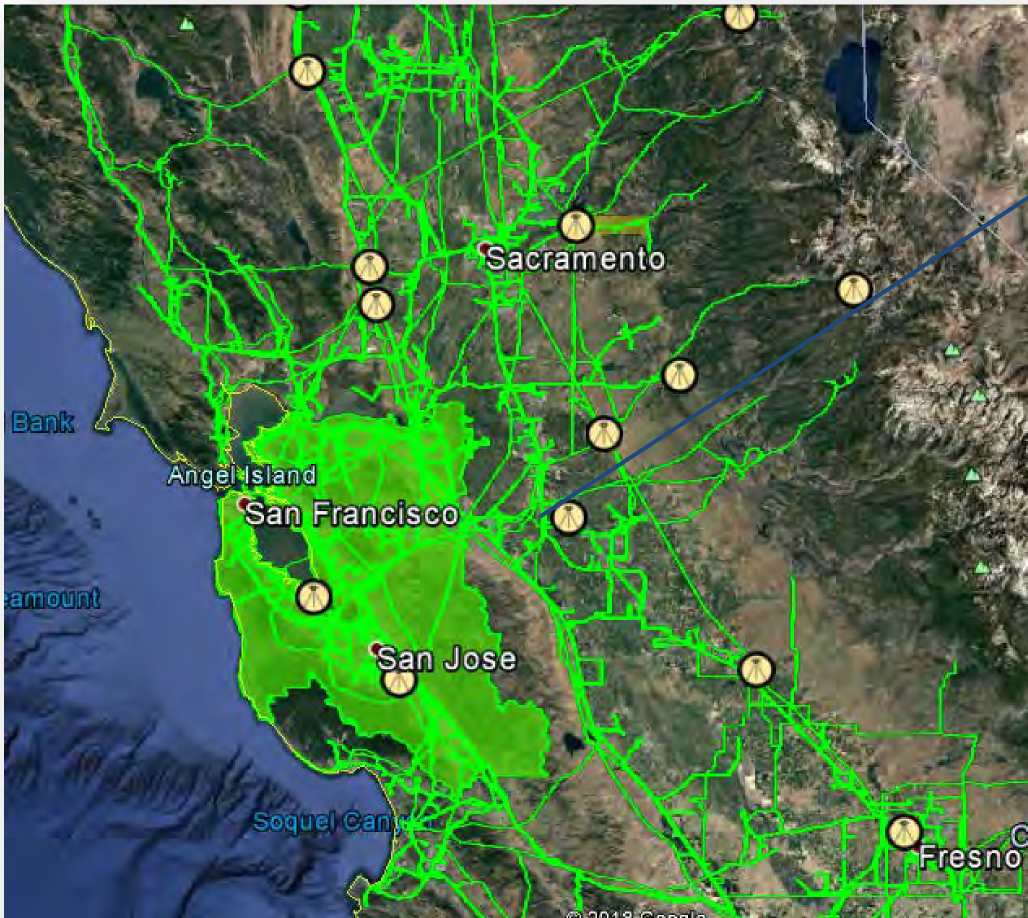
Using Data in the Field for Work Efficiencies – Hand-Held Devices and Apps

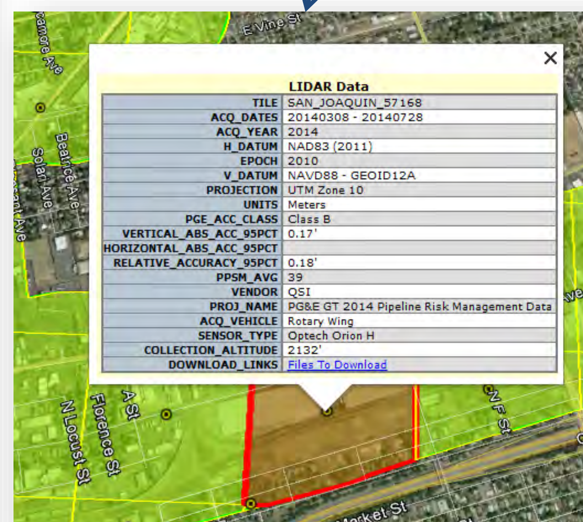
Red Dots: Overhanging Trees

Green Dots: Encroachment Trees

Field Crews Use Tree Inventory & Rating Database for Target Tree Identification, Vegetation Removal Planning, and Work Documentation. Apps Developed In-House with End User Feedback

Remote Sensing Geospatial Data Catalog





LIDAR Data

TILE	SAN_JOAQUIN_57168
ACQ_DATES	20140308 - 20140728
ACQ_YEAR	2014
H_DATUM	NAD83 (2011)
EPOCH	2010
V_DATUM	NAVD88 - GEOID12A
PROJECTION	UTM Zone 10
UNITS	Meters
PGE_ACC_CLASS	Class B
VERTICAL_ABS_ACC_95PCT	0.17'
HORIZONTAL_ABS_ACC_95PCT	
RELATIVE_ACCURACY_95PCT	0.18'
PPSM_AVG	39
VENDOR	QSI
PROJ_NAME	PG&E GT 2014 Pipeline Risk Management Data
ACQ_VEHICLE	Rotary Wing
SENSOR_TYPE	Optech Orion H
COLLECTION_ALTITUDE	2132'
DOWNLOAD_LINKS	Files To Download

Metadata – Vintage, Project, Acquisition Parameters
Multi-LOB Uses

How to Move Forward with an Imperfect Data Set

LiDAR Strengths and Limitations	
Strengths	**Limitations**
Compliance assessments	Vegetation Health
Risk assessments	Cracks in tree trunks; uprooting trees
Historical Comparisons	Secondary wires and service drops
Forecasting; data scaling	Tree counting
Asset and Vegetation Mapping	Pole loading

- ***Continued validation with field observations over time and building out LiDAR dataset help address this***

Subsidence in Central Valley Impacts to Gas System

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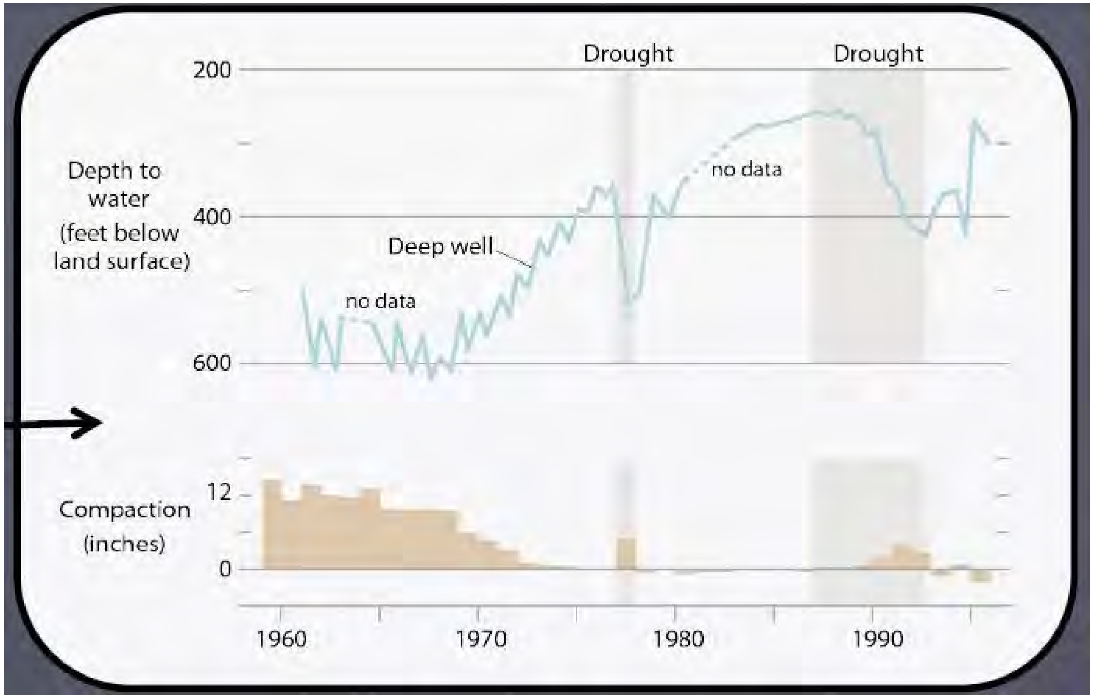
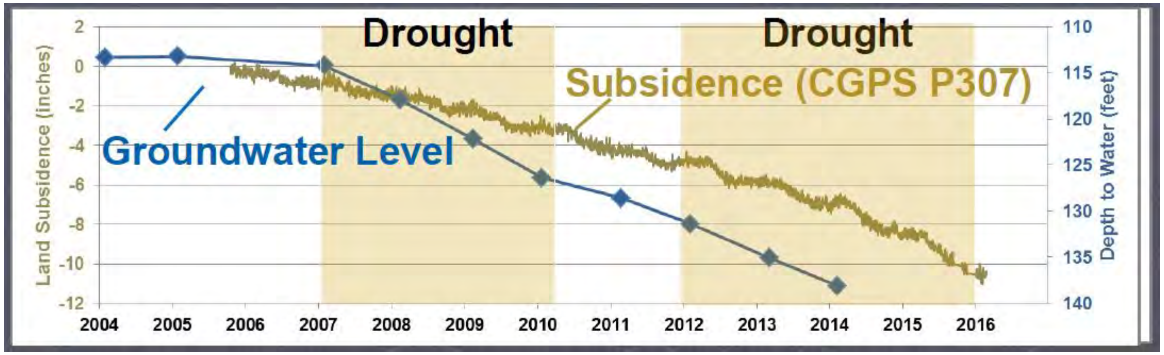
Long History of Subsidence in Central Valley Strongly Correlated with Groundwater Pumping & Drought Periods

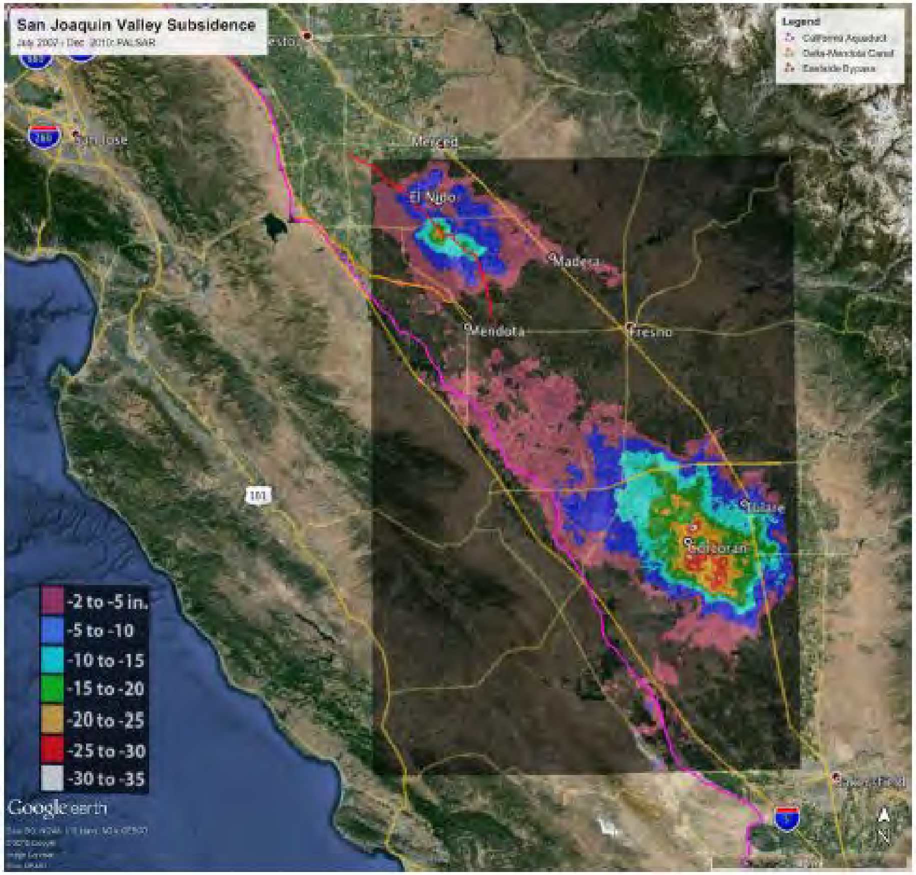




Source: Michelle Sneed, USGS, 2016

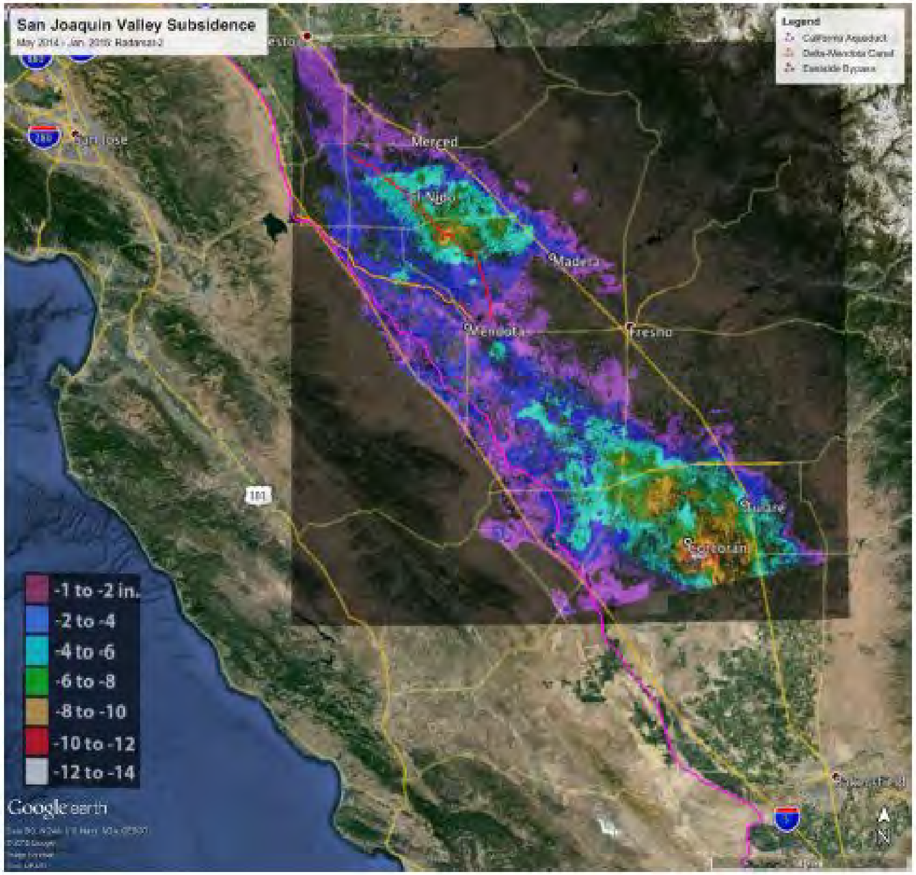
InSAR data effectively identifies vertical subsidence distribution and rates since the 1990's

June 2007 – December 2010



(42 mo. = 20 to 30 in.)

May 2014 – January 2015



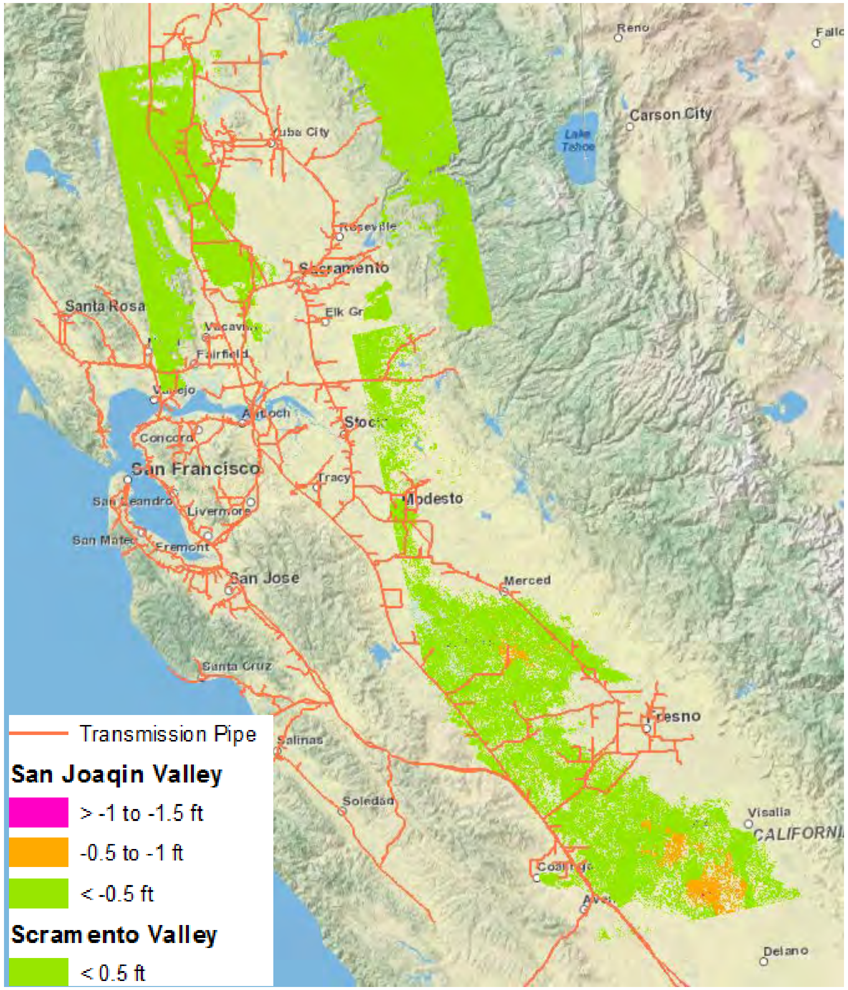
(9 mo. = 8 to 12 in.)

Rates of Subsidence Significantly Increased During 2000's Drought

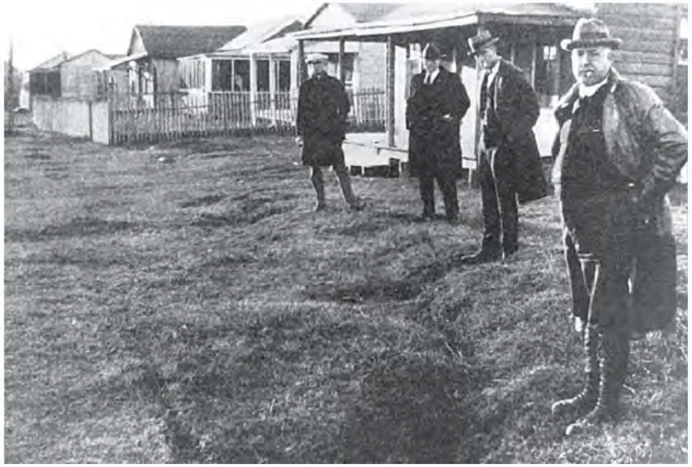
Impacts on PG&E's Gas Infrastructure

- **Approximately 972 miles of 6,650 mile System Affected by 0.5-ft. or Greater Subsidence**
- **Evaluate pipeline response to subsidence in most rapidly subsiding area**
- **Use results to develop guidelines for addressing subsidence in other areas**
- **InSAR Provides Broad and Accurate Definition of Subsidence Cost-Time Effectively**

NASA JPL data 5/2014 – 1/2015



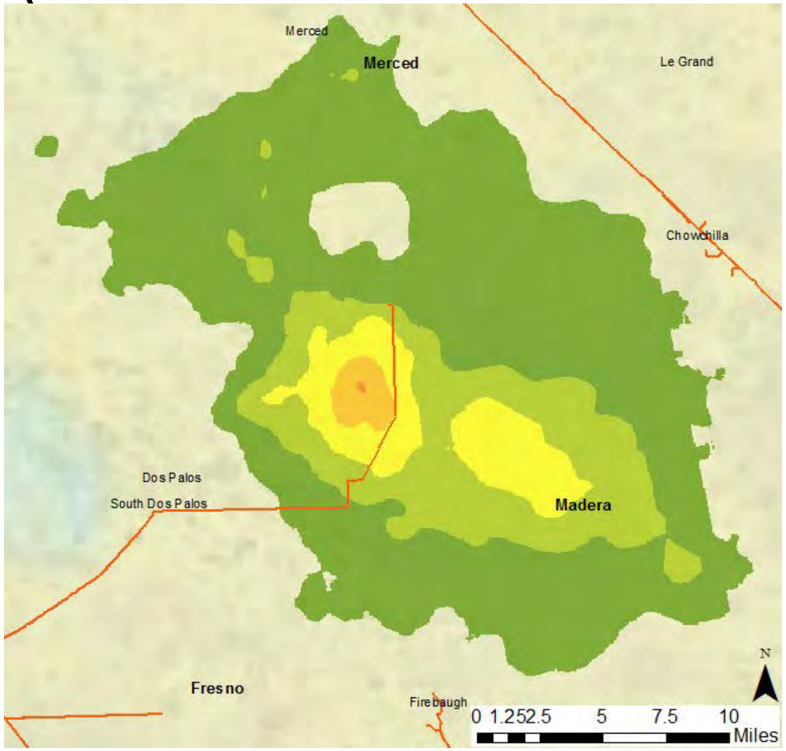
Line 186 Study Area in "El Nido" Subsidence Bullseye



Extension & Fissuring (Shoulders of bullseye…)

Compressional Buckling (Transition in Bottom of Bowl)

NASA JPL data 6/2007 – 1/2011 (Plane-Borne Terrestar



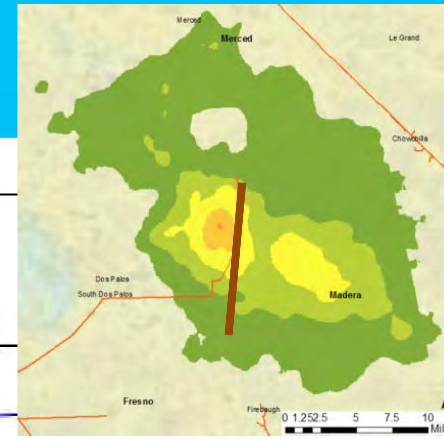
Transmission Pipe

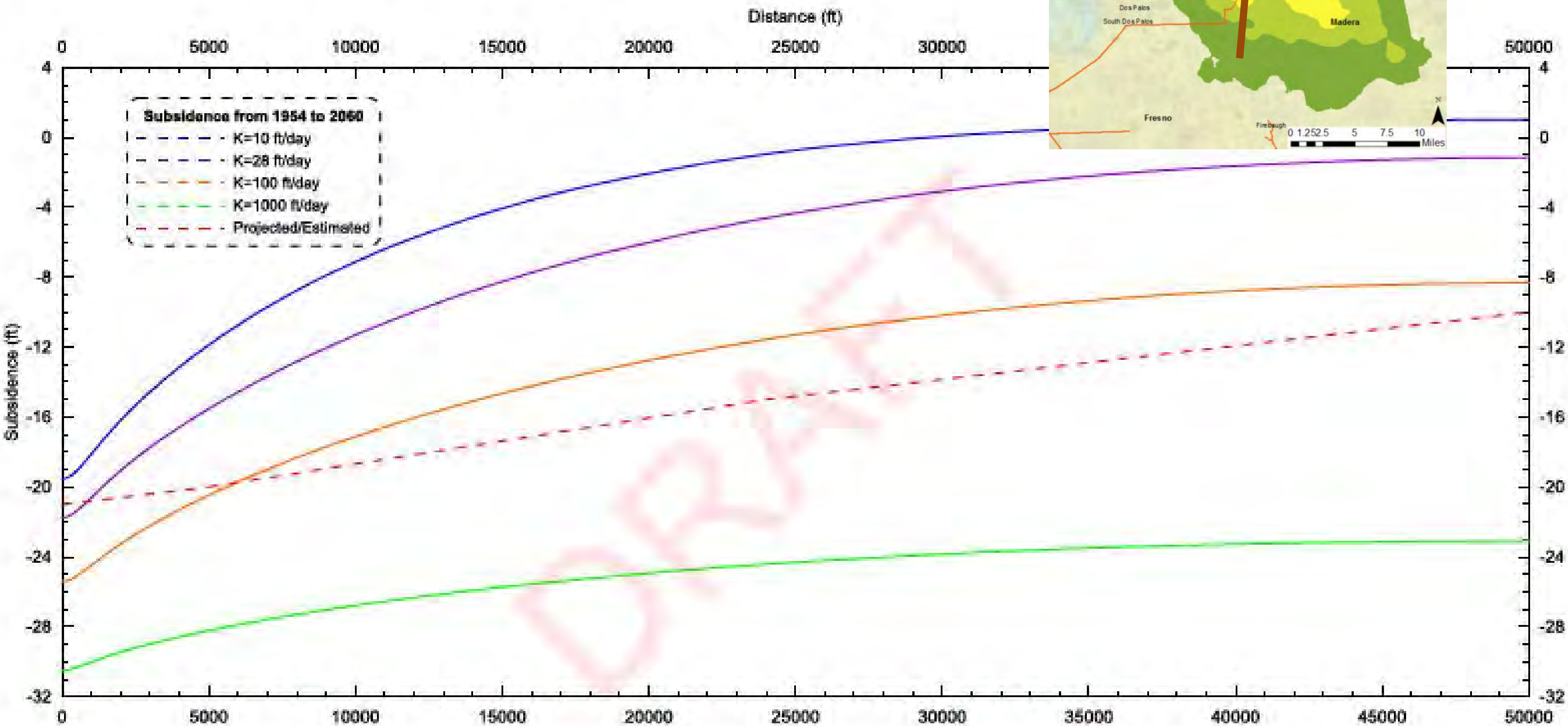
San Joaquin Valley

- -0.5 to -1.0 ft
- > -1.0 to -1.5 ft
- > -1.5 to -2.0 ft
- > -2.0 to -2.5 ft
- > -2.5 to -3.0 ft
- > -3.0 ft

~ 3 ft. Subsidence in 4.5 yrs.

Predicted Vertical Deformation 2000 - 2060

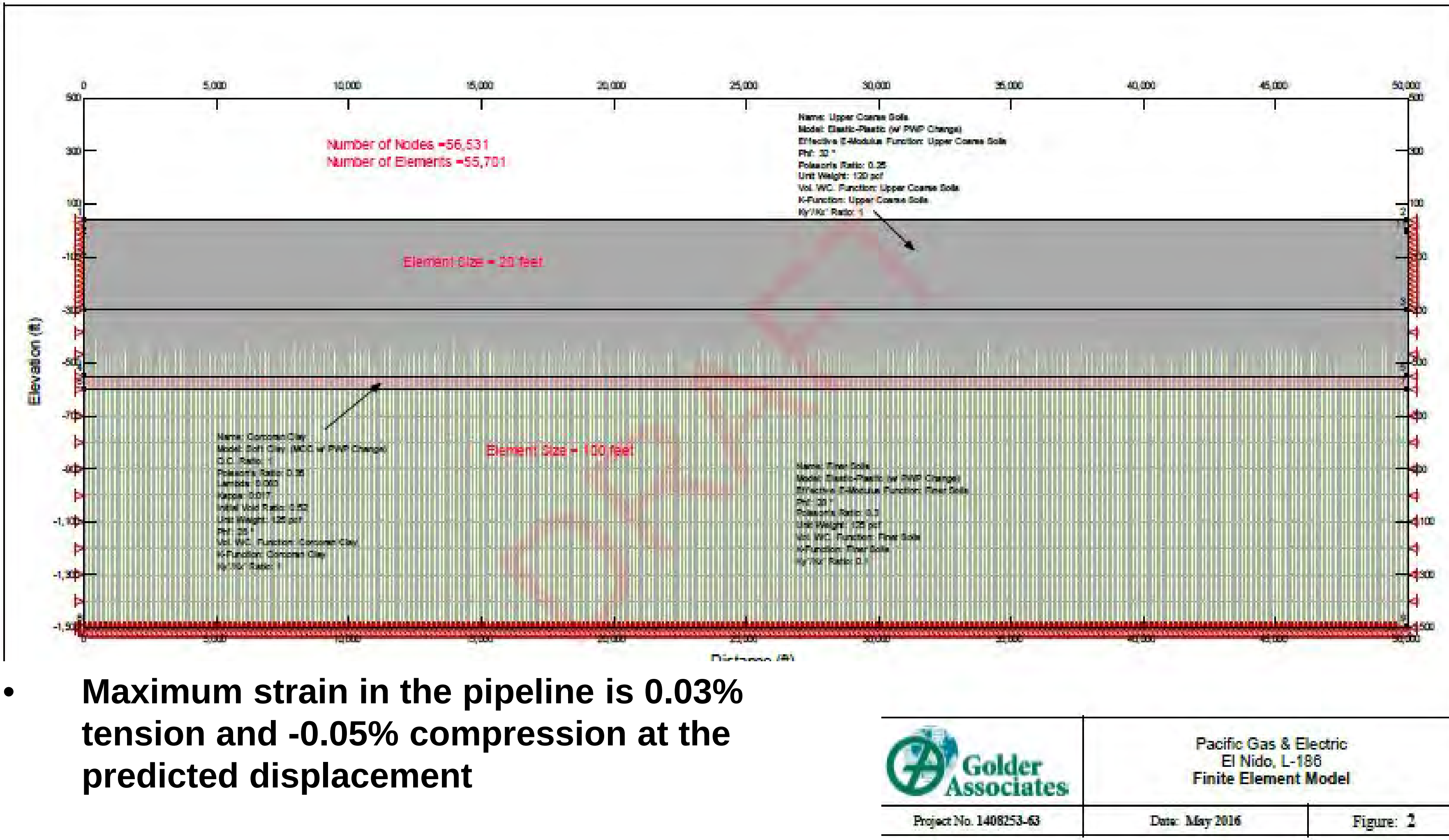




Note:
The projected/estimated subsidence profile shown in dashed line is approximated based on a combination of the subsidence contours shown in the San Joaquin River Basins Comprehensive Study conducted jointly by the Reclamation Board of the State of California and the U.S. Army Corps of Engineers (2002 for the time period between 2000 and 2060, and the estimated subsidence between 1954 and 2000 shown in Figure 3.

Golder Associates	Pacific Gas & Electric El Nido, L-186 **Simulations of Subsidence 1954 – 2060** **Variation of Subsidence Profile with Hydraulic Conductivity**	
Project No. 1408253-63	Date: May 2016	Figure: 5

Finite Element Model of Pipe Response & Strain



- Maximum strain in the pipeline is 0.03% tension and -0.05% compression at the predicted displacement
- 0.05% tension and -0.09% compression at 1.5 times the predicted displacement
- Pipeline responding elastically

Future Studies

- **Additional InSAR and LiDAR Acquisition for Change Detection/Monitoring**
- **Correlations of Subsidence with Groundwater & Land Use (Help Forecast Where and Why – Possible Broad Mitigation)**
- **Instrumented Boreholes to Evaluate Depth Profile of Subsidence**
- **California Energy Commission Funded Studies Correlated to Climate Change and Gas System Reliability**

Gas Transmission System:
- Fault Crossings
- Landslide & Erosion

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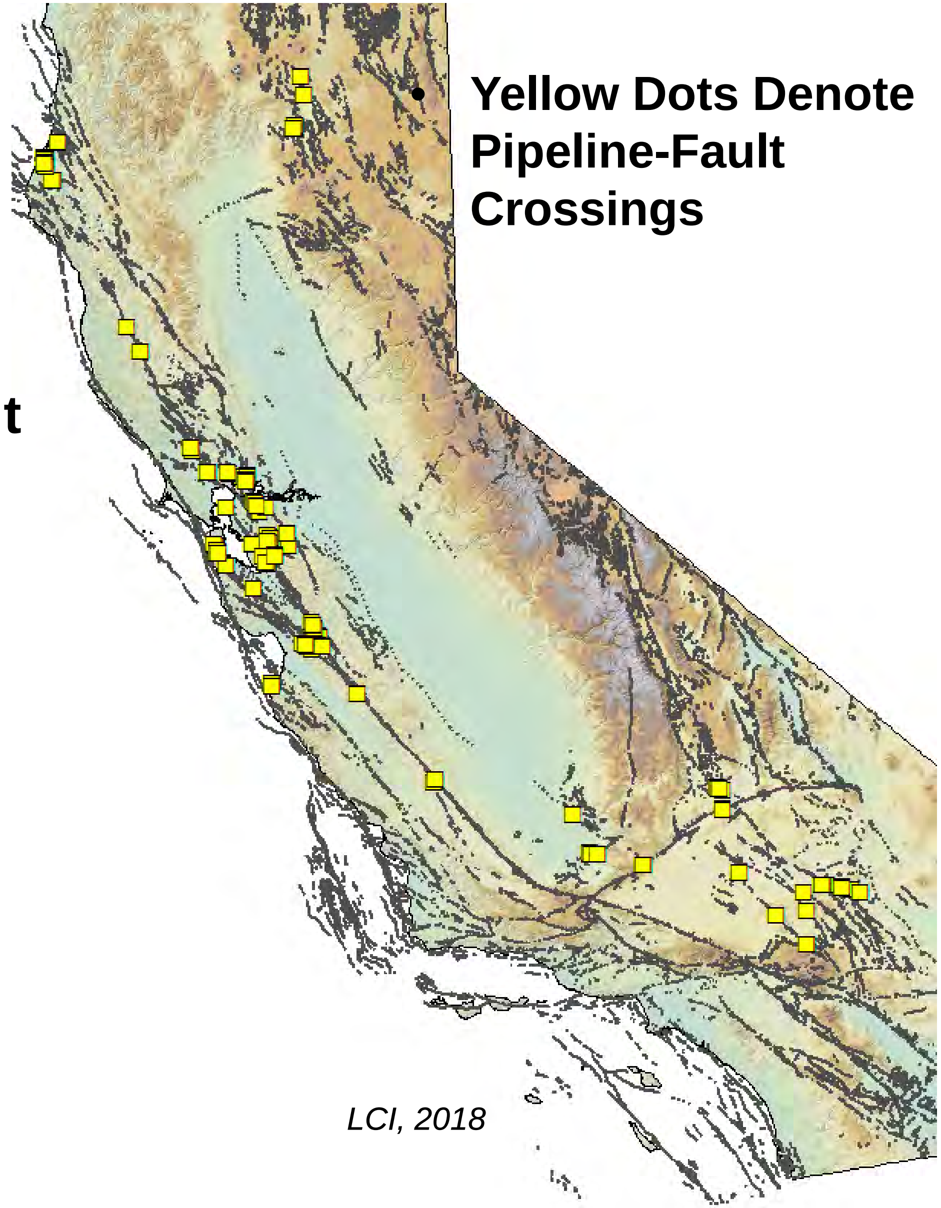
Gas Transmission Fault Crossing Evaluation Program



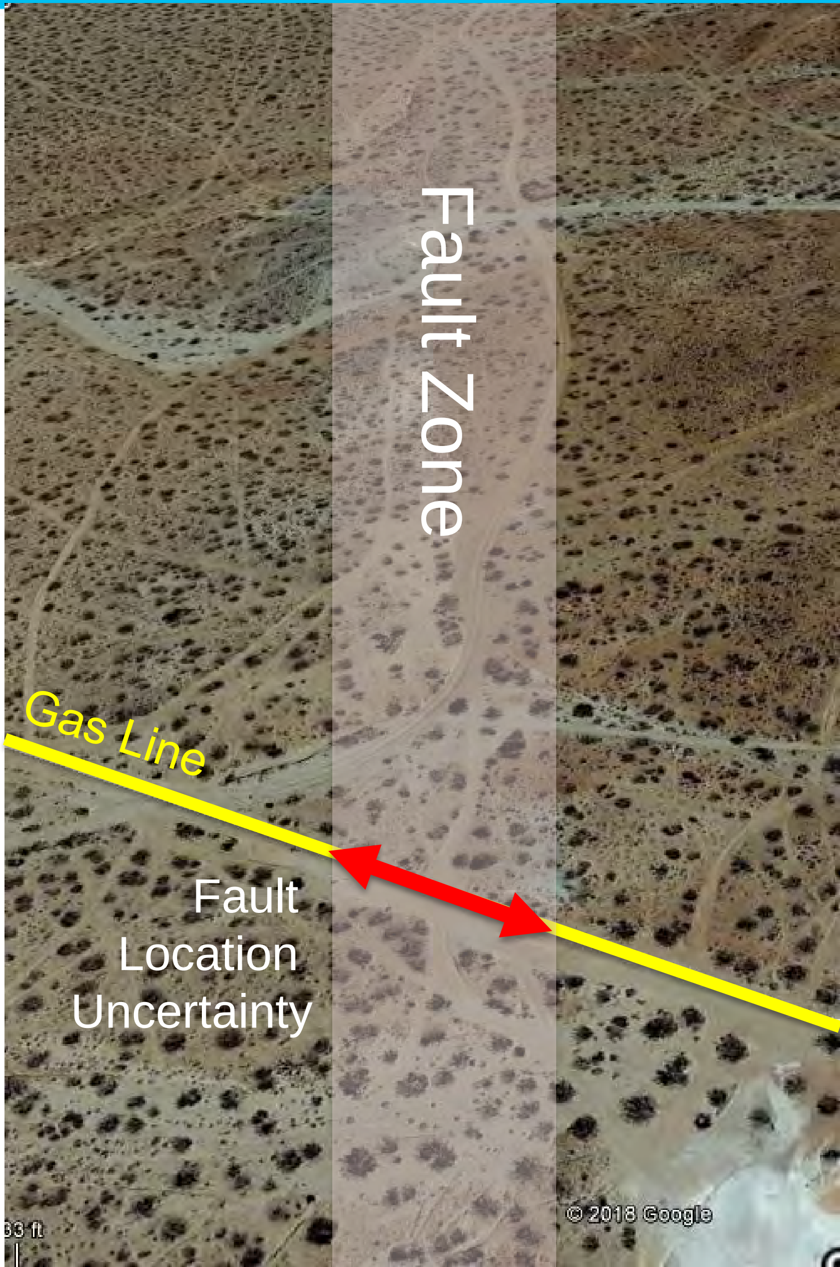
- Yellow Dots Denote Pipeline-Fault Crossings

- **Over 250 gas transmission-fault crossings**
- **~90% of fault crossings have been studied: Proceeding from Most Active Faults to Least Active**
- **Ranking/Prioritization for Mitigation**

Fault Zone Parameters Are Important For Pipeline Risk Evaluation

- Width (Length) of Mitigation
- Strain Capacity of Pipeline
- Primary and/or Secondary Displacement Fields
- Fault Crossing Geometry (Pipe Put in Compression or Extension)

Garlock Fault Crossing – Google Earth

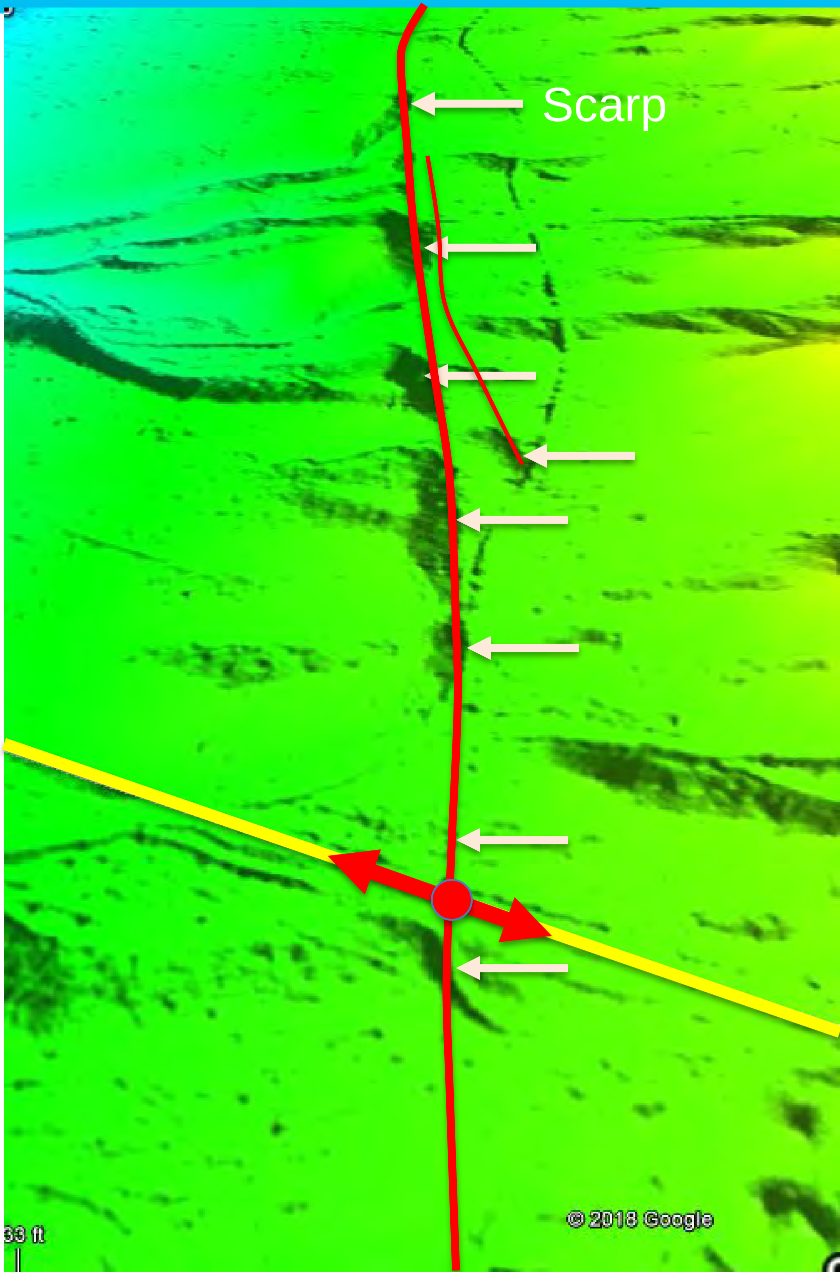


Gas Transmission Fault Crossing Evaluation Program

PG&E Fault Studies Use High Resolution LiDAR-derived Digital Elevation Models to Map Pipeline Fault Crossing Locations

Note How Fault Trace "Pops-Out" With LiDAR

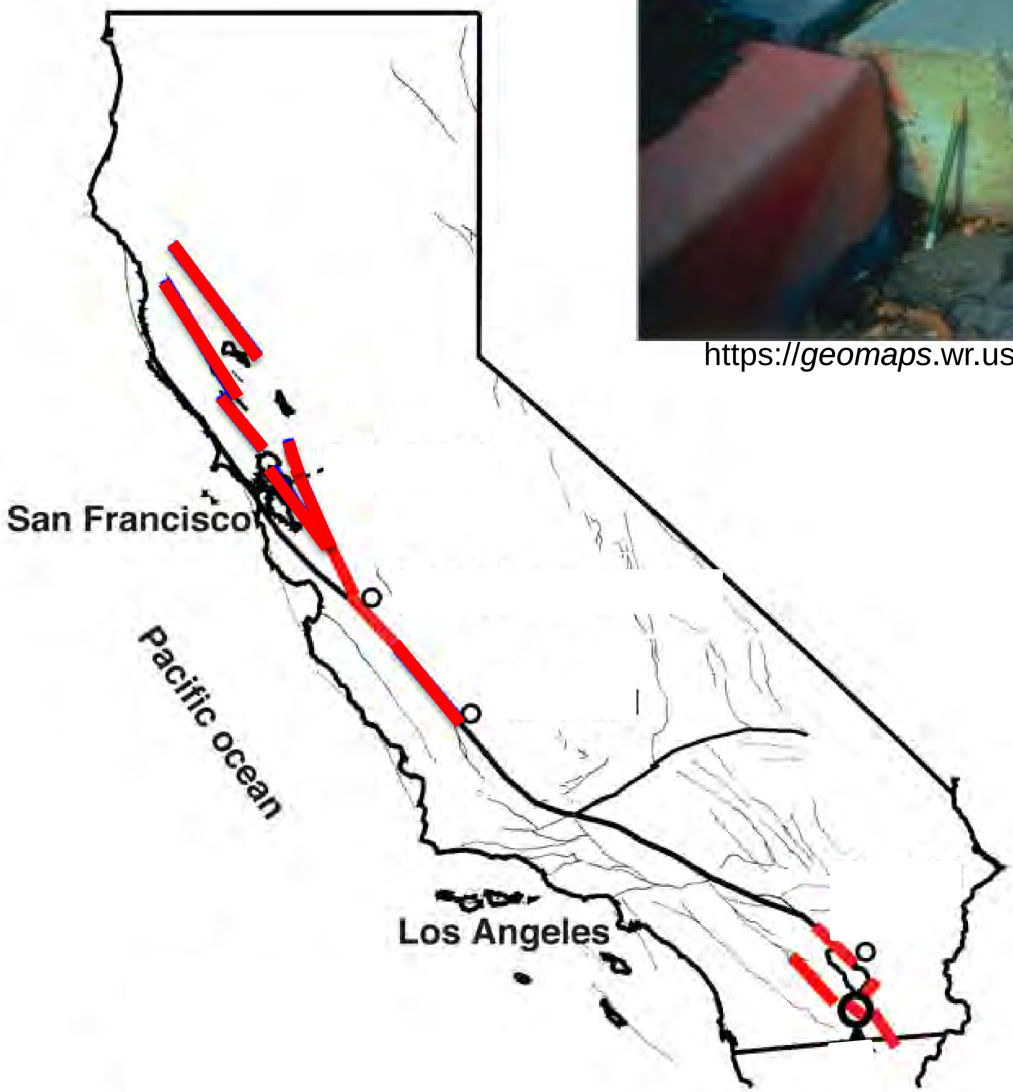
Lidar Can Help Significantly Reduce Fault Location Uncertainties, and Provide Estimates of Width of Crossing



Garlock Fault Crossing – LiDAR DEM

Gas Transmission Fault Creep Monitoring Program

Becky Oskin, 2013



Example Hayward Fault

https://*geomaps*.wr.usgs.gov/sfgeo/quaternary/stories/hayward_creep.html

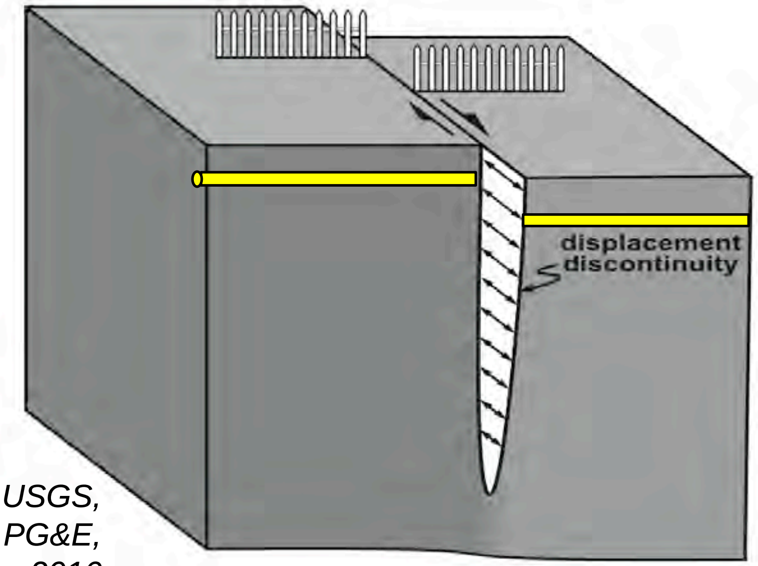
- **Many Faults in California Move Aseismically (fault creep)**
- **PG&E Gas Transmission Lines Cross Several Creeping Faults**

Gas Transmission Fault Creep Monitoring Program

- **Pipeline Fragility Can Be Sensitive to Width of Deformation Zone**

- **Fault Tips for Some Creeping Faults Reach the Surface, Causing Knife-Edge Dislocations at Pipeline Depth**

Example Hayward Fault

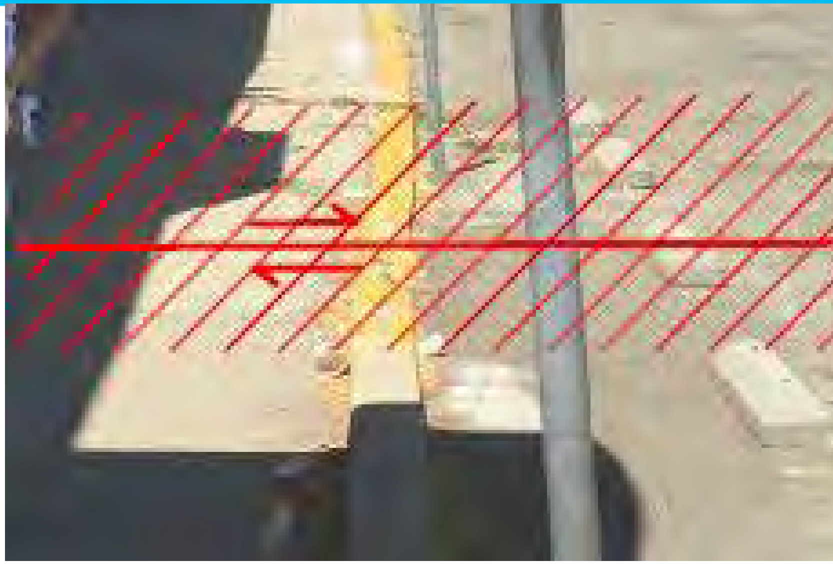


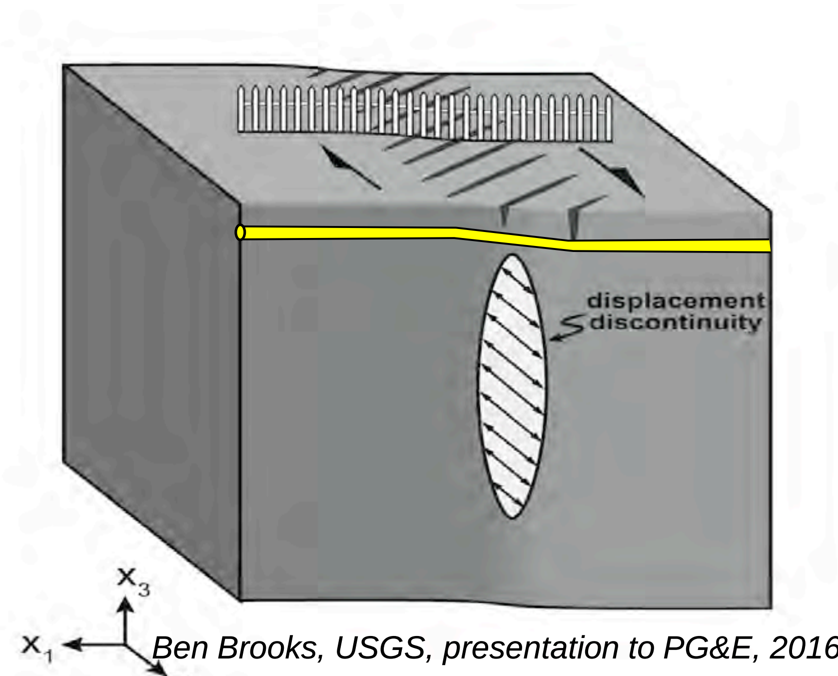
Ben Brooks, USGS, presentation to PG&E, 2016

Gas Transmission Fault Creep Monitoring Program

- **Some Fault Tips Stop Before Reaching the Surface, Causing Broad Warping at Pipeline Depth (Less Damaging)**

- **Width of Warping is Dependent on Depth of the Fault Tip**

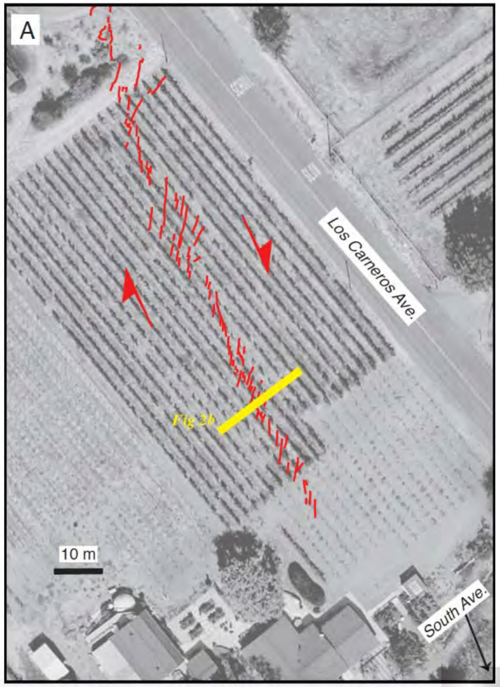




Ben Brooks, USGS, presentation to PG&E, 2016

Gas Transmission Fault Creep Monitoring Program

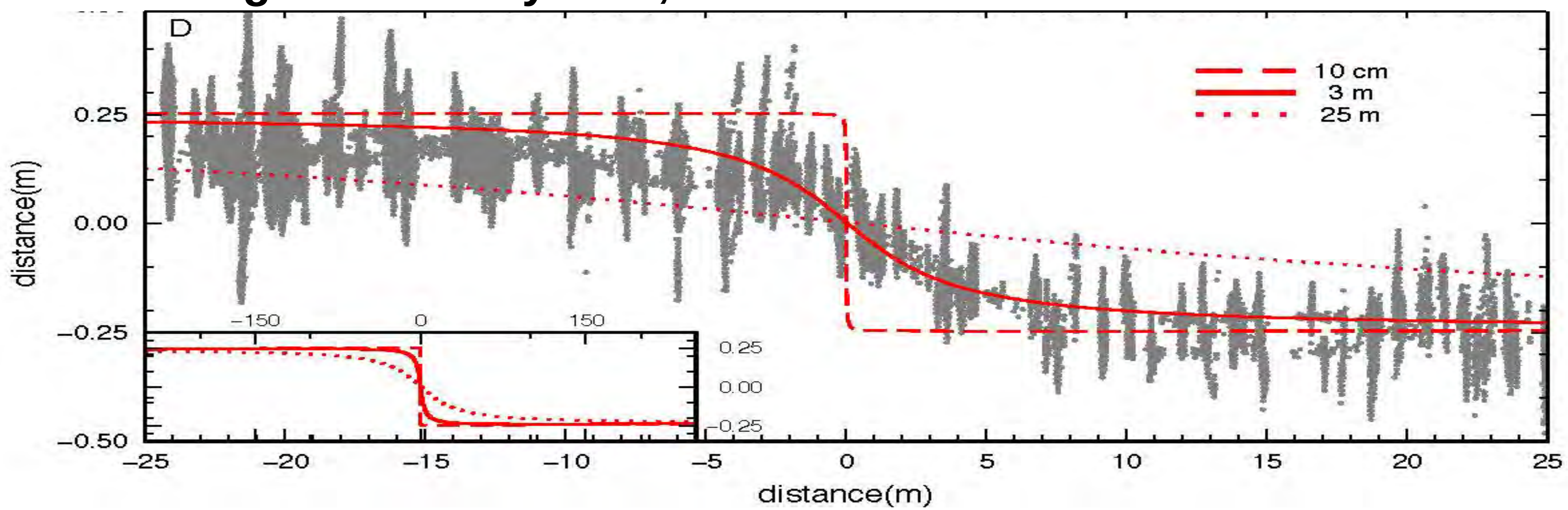
- **Following the 2014 Napa Earthquake, USGS Used Ground Based LiDAR to Characterize Surface Deformation Field Using Offset Vine Rows.**



Ben Brooks, USGS, presentation to PG&E, 2016

Gas Transmission Fault Creep Monitoring Program

- **USGS Napa lidar data showed a broad deformation pattern, indicating that fault died below the surface**
- **PG&E gas lines did not rupture as deformation was broadly distributed**
- **PG&E has funded the USGS to characterize creep at pipeline fault crossings on the Hayward, Calaveras and Maacamma faults**



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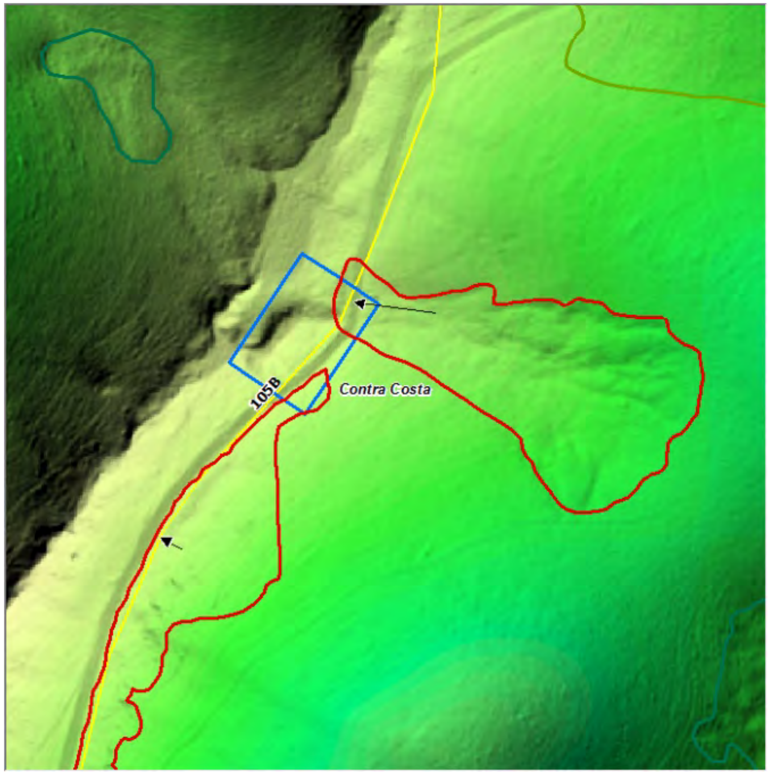
TIMP Geohazards Program

Implements a standardized methodology for identifying, characterizing, monitoring, and mitigating geohazards along 6800 miles of gas transmission line located in 40 counties in California

- **Landslides/Debris Flows**
- **Slope Creep**
- **Erosion Gullying**
- **Stream Scour**



LiDAR and Orthophotography – Cornerstone of Program

- **Baseline to Catalog and Rate Geohazards over Entire Gas Transmission System (2014; Over 4 Month Period)**

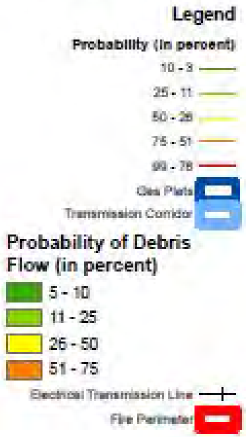
  - 11,384 Landslides

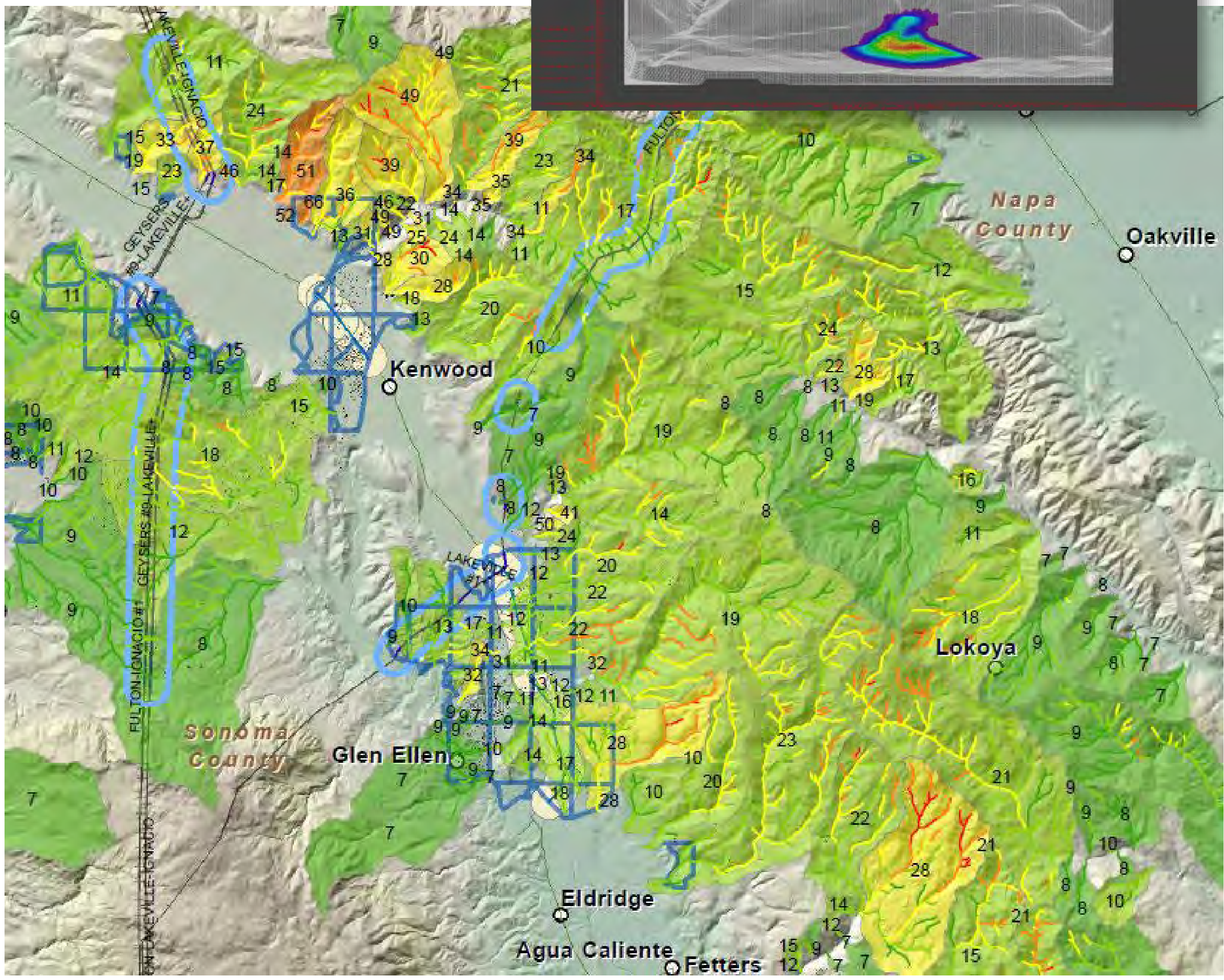
  - 3,350 Erosion Features (includes sinkholes)

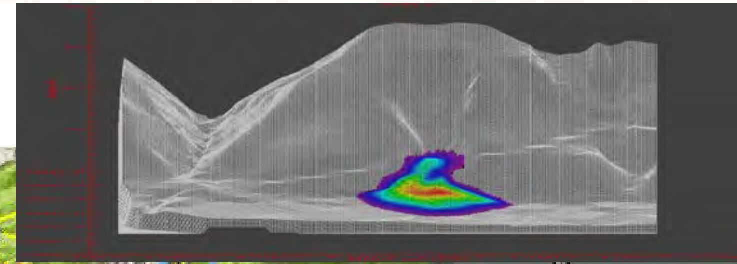
- **Field Verification Campaigns**
- **With Repeat LiDAR Program is Progressing Towards Change Detection Monitoring and New Feature Identification**
- **Permits smaller team for TIMP program by Targeting Field Assessments & Prioritizing Areas of Highest Hazard**

Fire Burn Debris-Flow Model (USGS Model) Example

Source:
USGS Debris Flow Models, PG&E facility datasets.



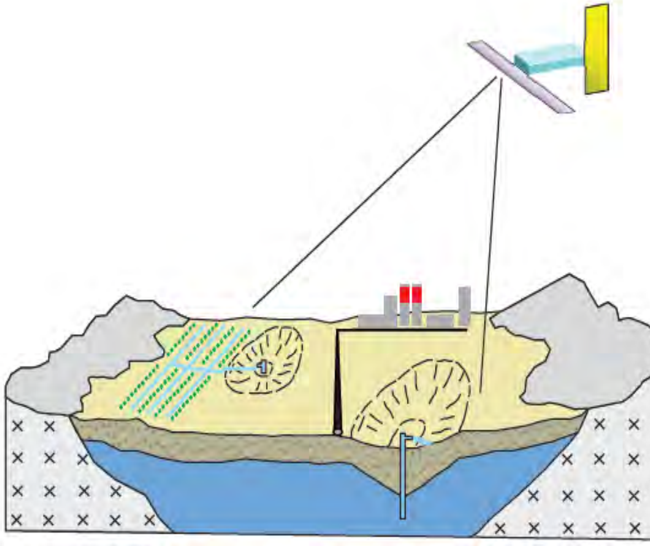




- **Yellow-Red Zones & Tracks Denote High Debris Flow Potential**
- **PGE Gas T&D Facilities in Blue**
- **Post-Fire & Post Rainfall Season Repeat LiDAR Used to Calibrate Model**

Key Take-Aways

- Remote Sensing Fits with Company Mission, Vision, Culture
  - Long Term Commitment/Investment
- Helps Evaluate & Plan for Climate Change
- New Technology - Benefits vs. Challenges
  - Need to Temper Expectations/Reinforce Value of Incomplete Datasets
- Multiple Approaches Provide Best Results
- Importance of Field Calibration (Validation)
- Integrated System-Wide Hazard Framework
  - Multi-LOB Uses
- Proactive, Beyond Compliance
- Driving Innovation By Research
- Important Monitoring Tool



Questions – Contact Information

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