

# Potential effects of sea-level rise on energy infrastructure in the Sacramento-San Joaquin Delta

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William Fourt<sup>1</sup>, Wei-Chen Hsu<sup>1</sup>, Uriel Garcia<sup>4</sup> and Ben Wheeler<sup>3</sup>



University of California, Berkeley



# Assessment of Bay Area Gas Pipeline Vulnerability to Climate Change

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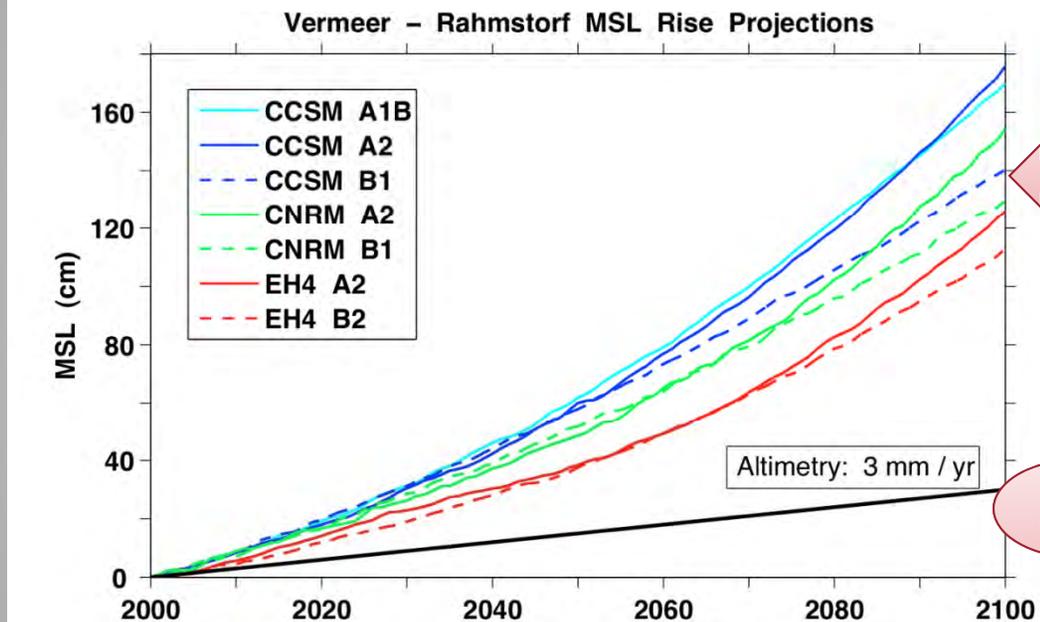
# The Pipelines we are looking at:

## Transmission Pipelines in the National Pipeline Mapping System (NPMS)

- Natural Gas Pipelines
  - Mainly methane
  - Most of the intra-state pipelines in CA that are regulated by CPUC
- Hazardous Liquid Pipelines
  - Crude oil, petroleum products, anhydrous ammonia etc.
  - In CA (intra-state and inter-state) safety is regulated by Office of the State Fire Marshall.
- Pipelines can be “gathering”, “transmission” or “distribution”
  - Sizes vary
  - Pressure under which product is transported also varies

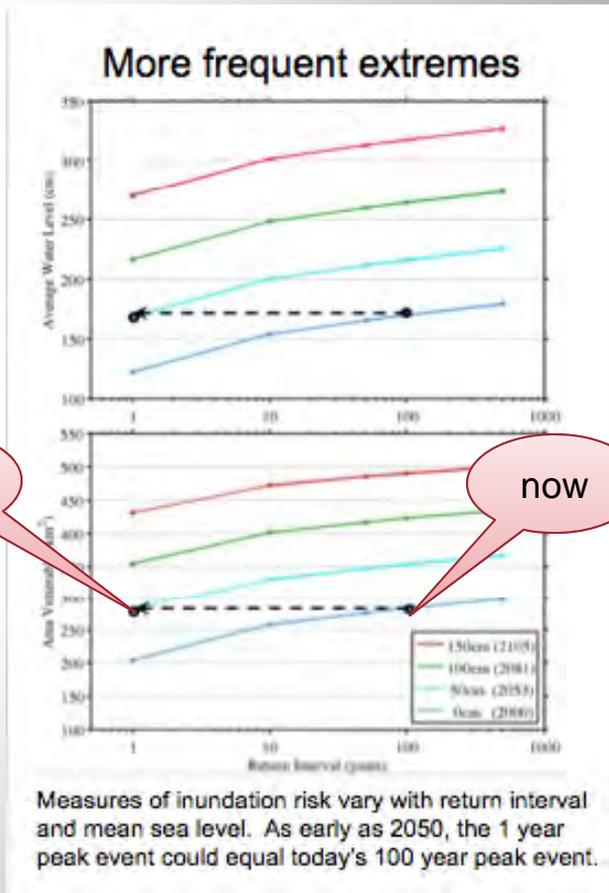
# Global circulation models: The Crisis

... global change.



1.4

2100



(Source) Bromirski, P. D., D. R. Cayan, N. Graham, R. E. Flick and M. Tyree (Scripps Institution of Oceanography). 2012. Coastal Flooding Potential-Projections 2000-2100. California Energy Commission. CEC-500-2012-011

# Data: Surface Model

Lidar → DEM & DSM

LiDAR data

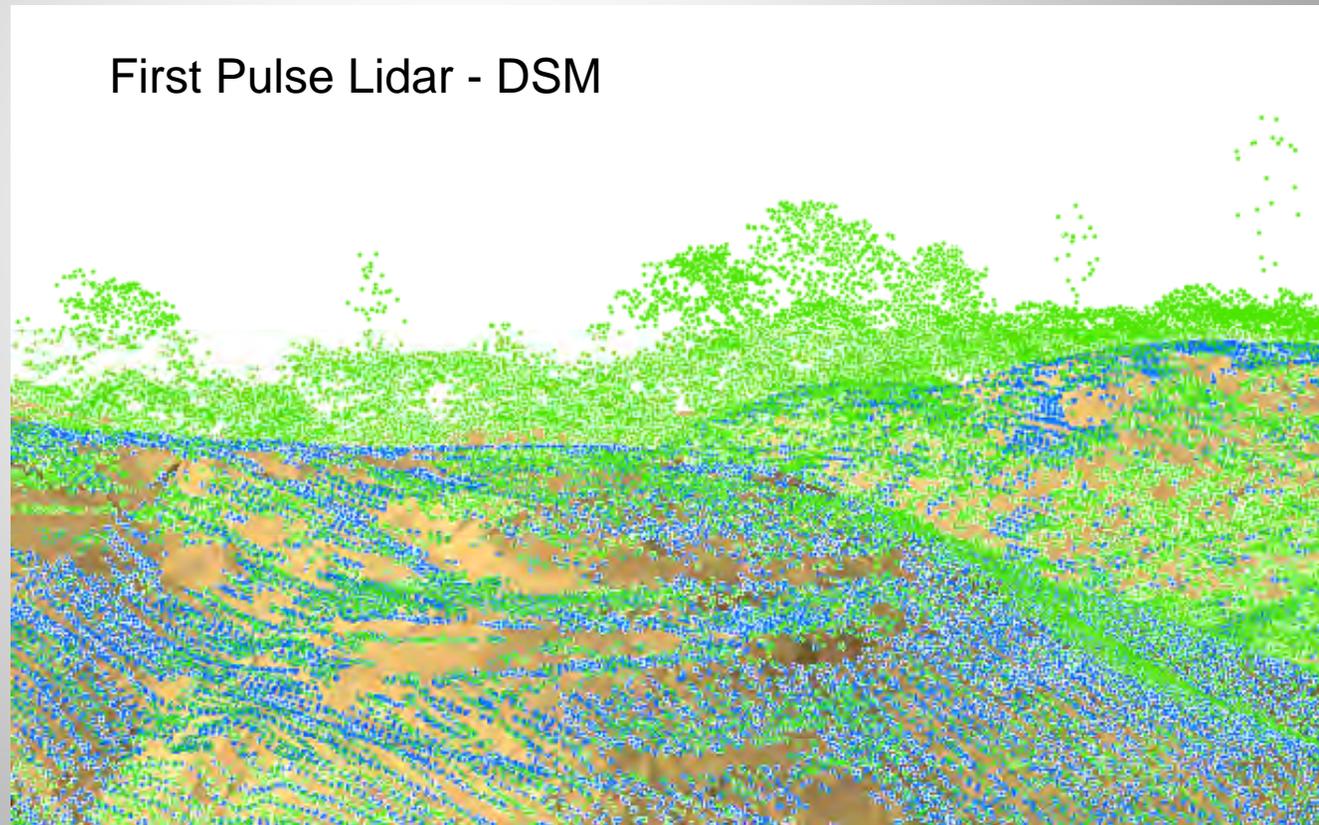


DEM

DSM



First Pulse Lidar - DSM

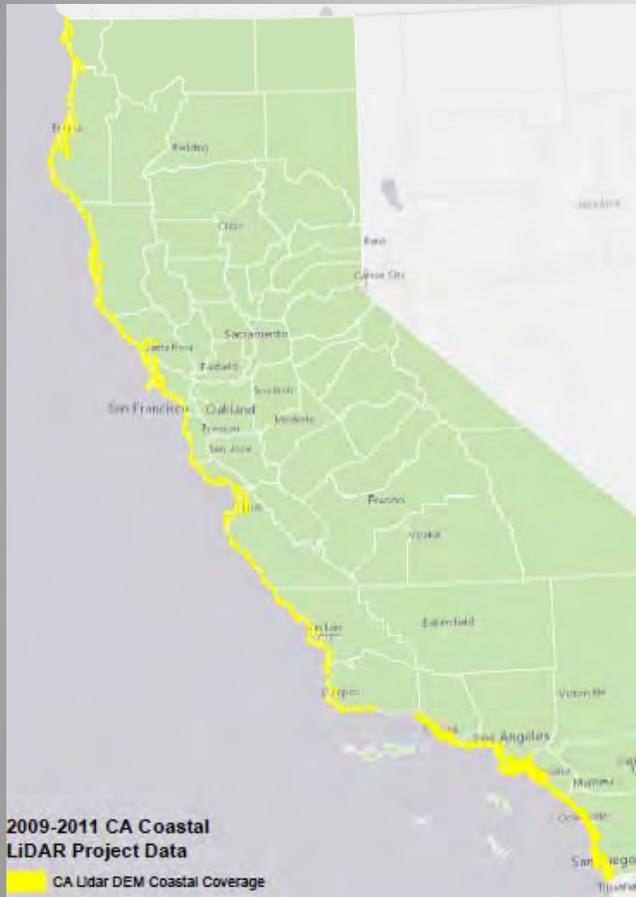


# Lidar Coverage:

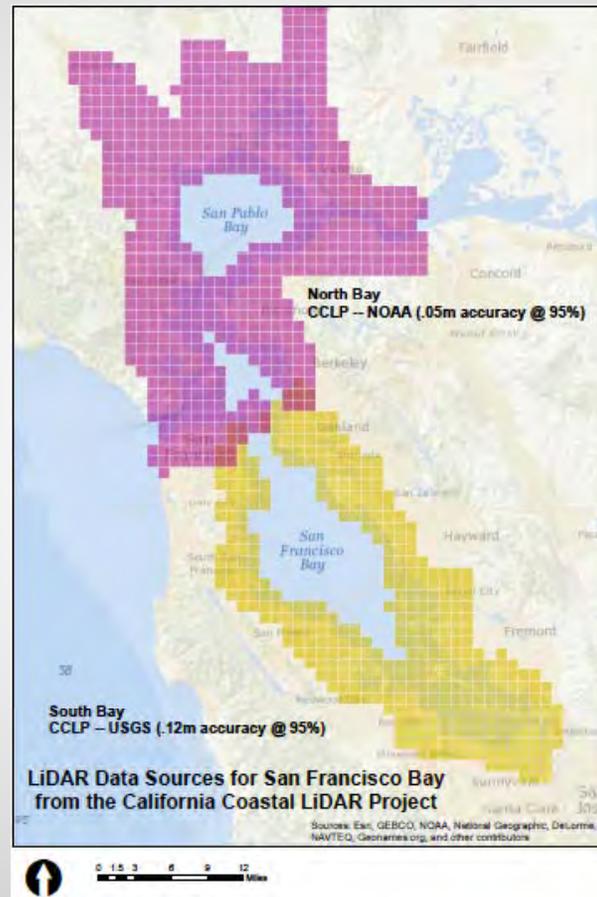
– California Coast

– SF Bay

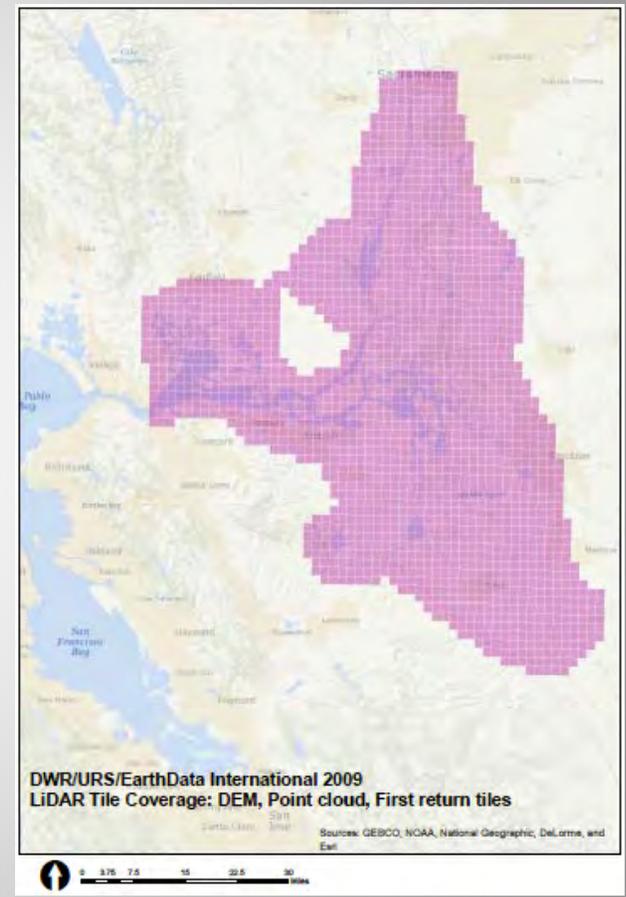
– Sacramento-San Joaquin Delta



NOAA California Coastal LiDAR project

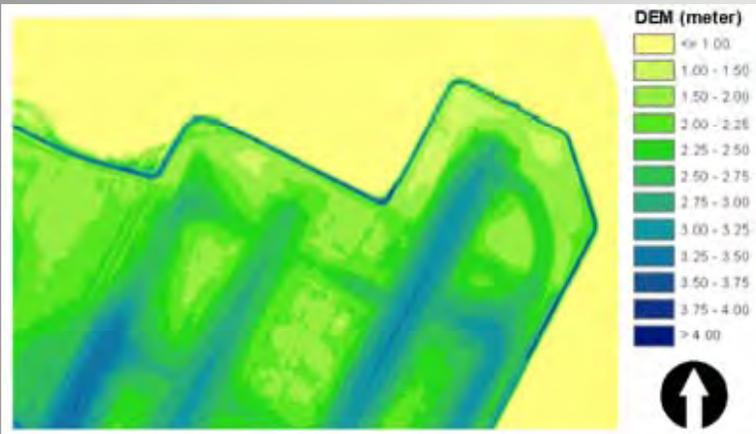


USGS California Coastal LiDAR Project



DWR Delta LiDAR Project

# Lidar → DEM - an illustration of the resolution of our study



a. Source: CEC-500-2012-040

An Example of the DEM: San Francisco International Airport. (a) Detailed view of the DEM for SFO, (b) the overview of the area (Google Earth), and (c) an oblique view (Google Earth) of a retaining structure at SFO pointed to in (b). The elevation data set is referenced to NAVD88 vertical datum.



b. Source: Google Earth



c. Source: Google Earth

# Data: Pipelines

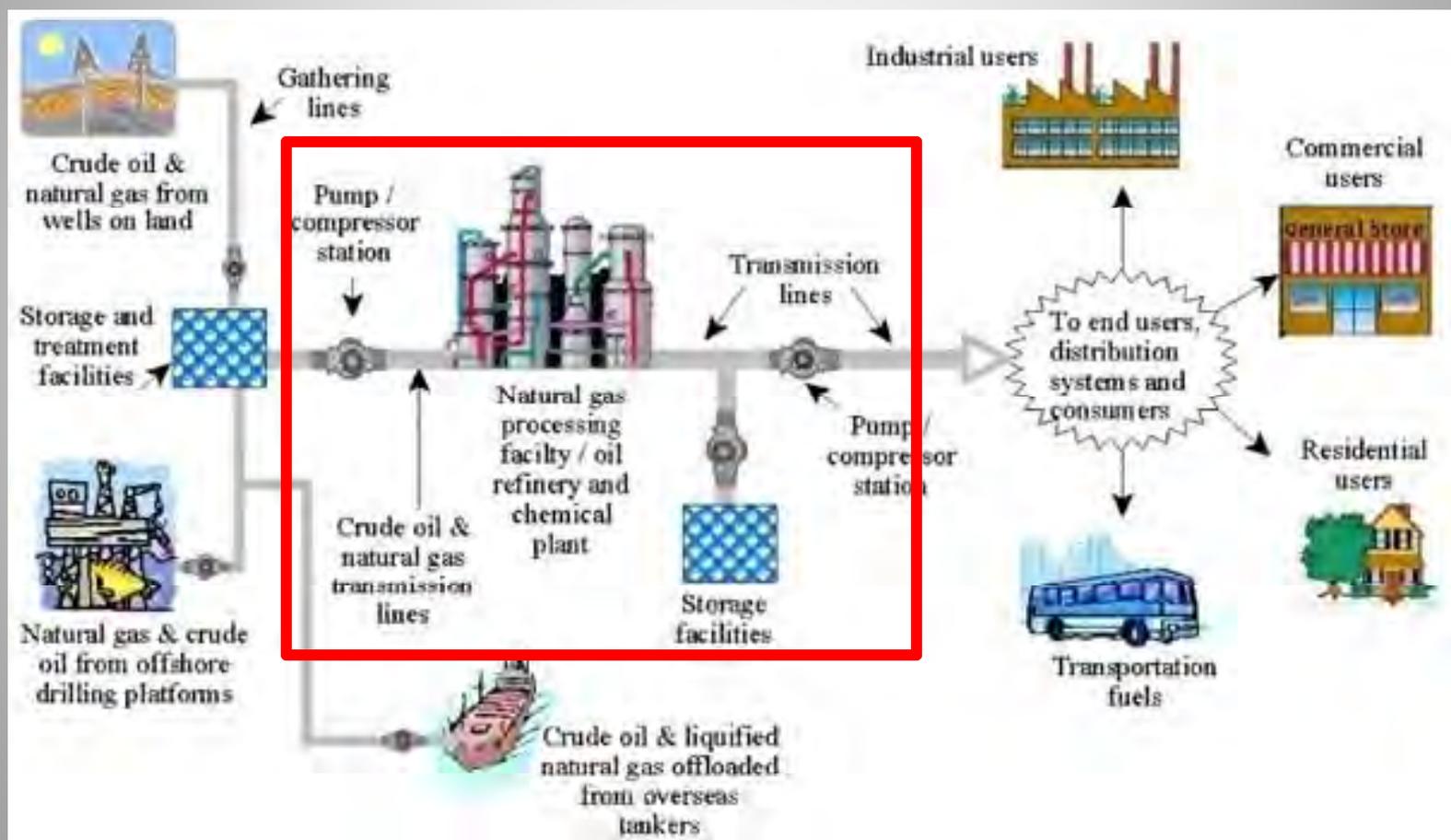


## NPMS: National Pipeline Mapping System

- Pipeline and Hazardous Materials Safety Administration (PHMSA)
- Pipeline operators required annually to review NPMS data (Dec 31)
- Data:
  - Updated in March (by repository staff – Michael Baker Jr. Corp.)
  - Gives data of natural gas and hazardous liquid trunk lines (transmission), does not contain distribution or gathering pipeline information.
  - Part of data is relevant for mapping purposes, part gives detailed information about a specific pipeline.

# In the World of Pipeline Infrastructure ...

The NPMS data base contains only part of the following diagram ...



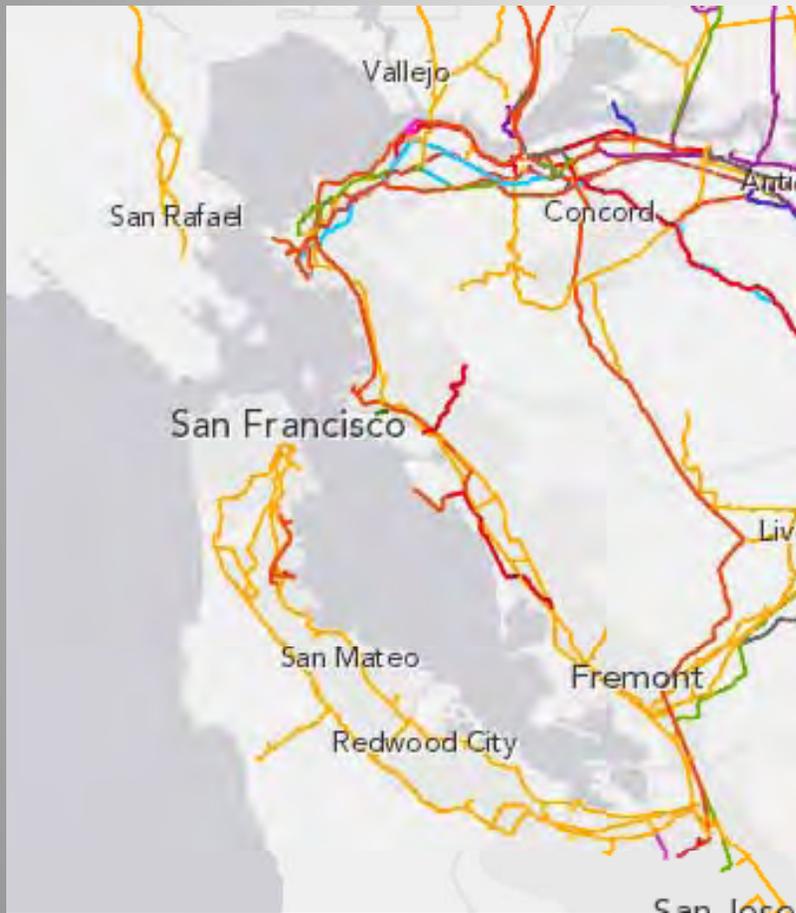
# California pipelines from NPMS data base



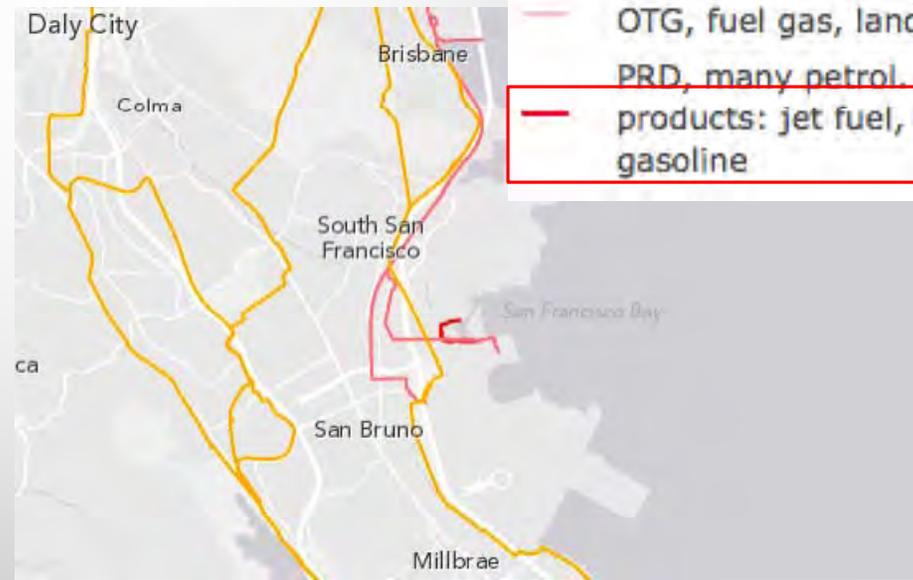
— PACIFIC GAS & ELECTRIC CO

— SOUTHERN CALIFORNIA GAS CO

# Pipeline Infrastructure: SF Bay Region



SF Bay Area



SFO Airport, for example

NPMS transmission pipelines	
—	CRD, e.g., crude oil
—	EPG, empty gas
—	EPL, misc. empty liquid
—	ETH, ethanol
—	HG, hydrogen
—	HVL, butane, propane
—	LPG, liquid petroleum gas
—	NG, natural gas
—	NGL, produced liquids
—	OHV, propane
—	OTG, fuel gas, landfill gas
—	PRD, many petrol
—	products: jet fuel, diesel, gasoline

# Pipeline Infrastructure in Sacramento-San Joaquin Delta

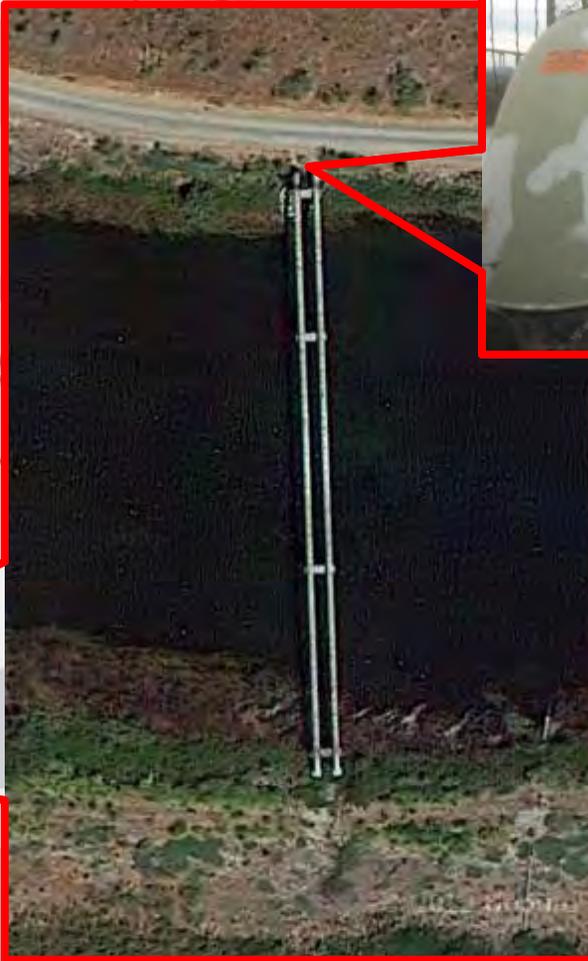


NPMS transmission pipelines	
	CRD, e.g., crude oil
	EPG, empty gas
	EPL, misc. empty liquid
	ETH, ethanol
	HG, hydrogen
	HVL, butane, propane
	LPG, liquid petroleum gas
	NG, natural gas
	NGL, produced liquids
	OHV, propane
	OTG, fuel gas, landfill gas
	PRD, many petrol. products: jet fuel, diesel, gasoline

# Pipeline Infrastructure in Sacramento-San Joaquin Delta

— NG, natural gas

Sherman Island



McDonald Island

# Pipelines: a typical record in the NPMS database

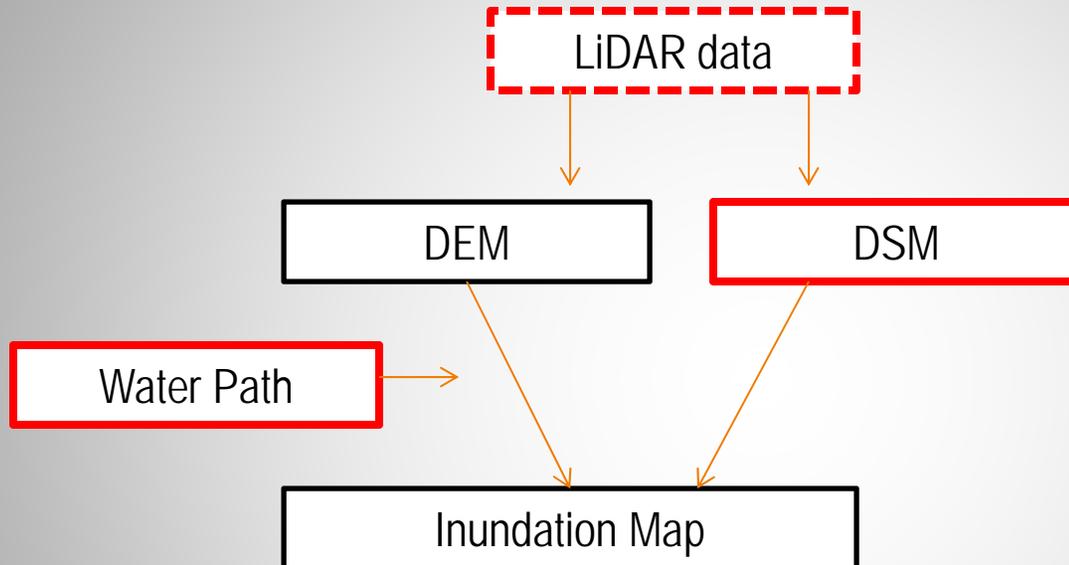
## Identify

FID: 223  
objectid: 4038  
opid: 18092  
oper\_nm: SFPP, LP  
sys\_nm: SFPP\_NORTH  
subsys\_nm: LS-8; RICHMOND -  
**CONCORD 8"**  
pline\_id: 485008RMCC  
diameter: 8.63  
miles: 22.40301  
commodity: PRD  
cmdty\_dtl1:  
cmdty\_dtl2:  
cmdty\_dtl3:  
cmdty\_desc: MULTI-PRODUCTS  
interstate: Y  
low\_stress: N  
status\_cd: I  
quality\_cd: V  
revis\_cd: B  
sub\_date: 6/14/2012  
revis\_date: 6/14/2012  
submit\_id: 18092-0017  
cnty\_fips: 06013  
cnty\_mixed: Contra Costa  
st\_fips: 06  
st\_mixed: California  
os\_yn: NO  
st\_length\_: 46708.191433

## NPMS Attributes:

- Required by operators to submit:
  - Operator ID
  - System Name (syst\_nm)
  - Pipeline ID (pline\_id)
  - Commodity (PRD here = petroleum product)
  - Interstate designation
  - Status of segment
  - Quality of positional accuracy (quality\_cd)
- Also includes meta data information, examples:
  - Metadata file name
  - Date on which NPMS received data
  - Date on which NPMS received notice of update or change in data

# Inundation Pathway



# Comparison of 2 methods for estimating inundation with a DEM and DSM

Overestimation of inundation with a 2.0 m (water Level) using a bathtub model

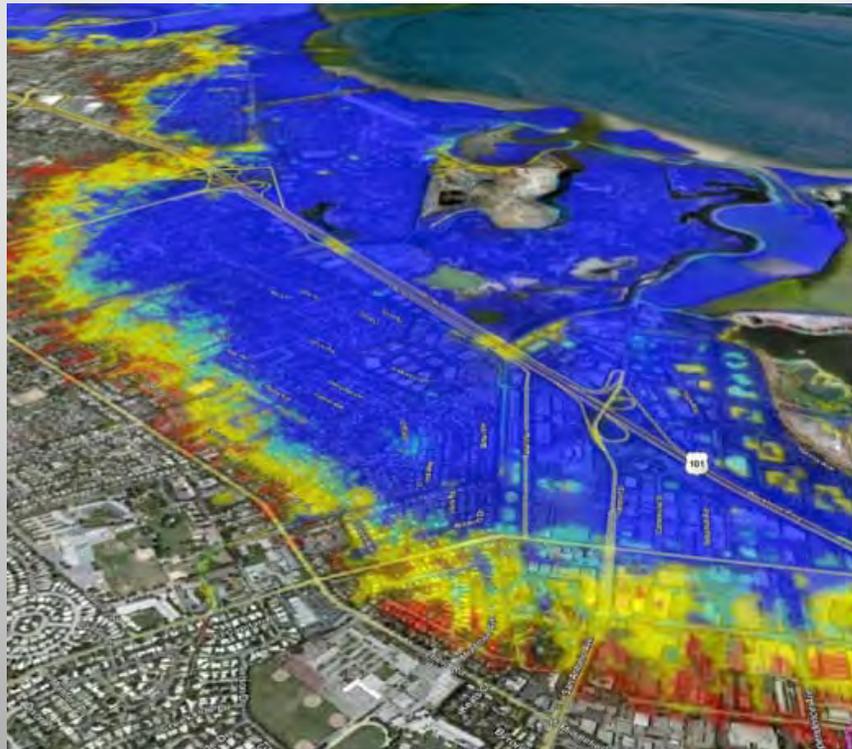


Improvement of inundation estimation with a 2.0 m (water level) with water pathway model

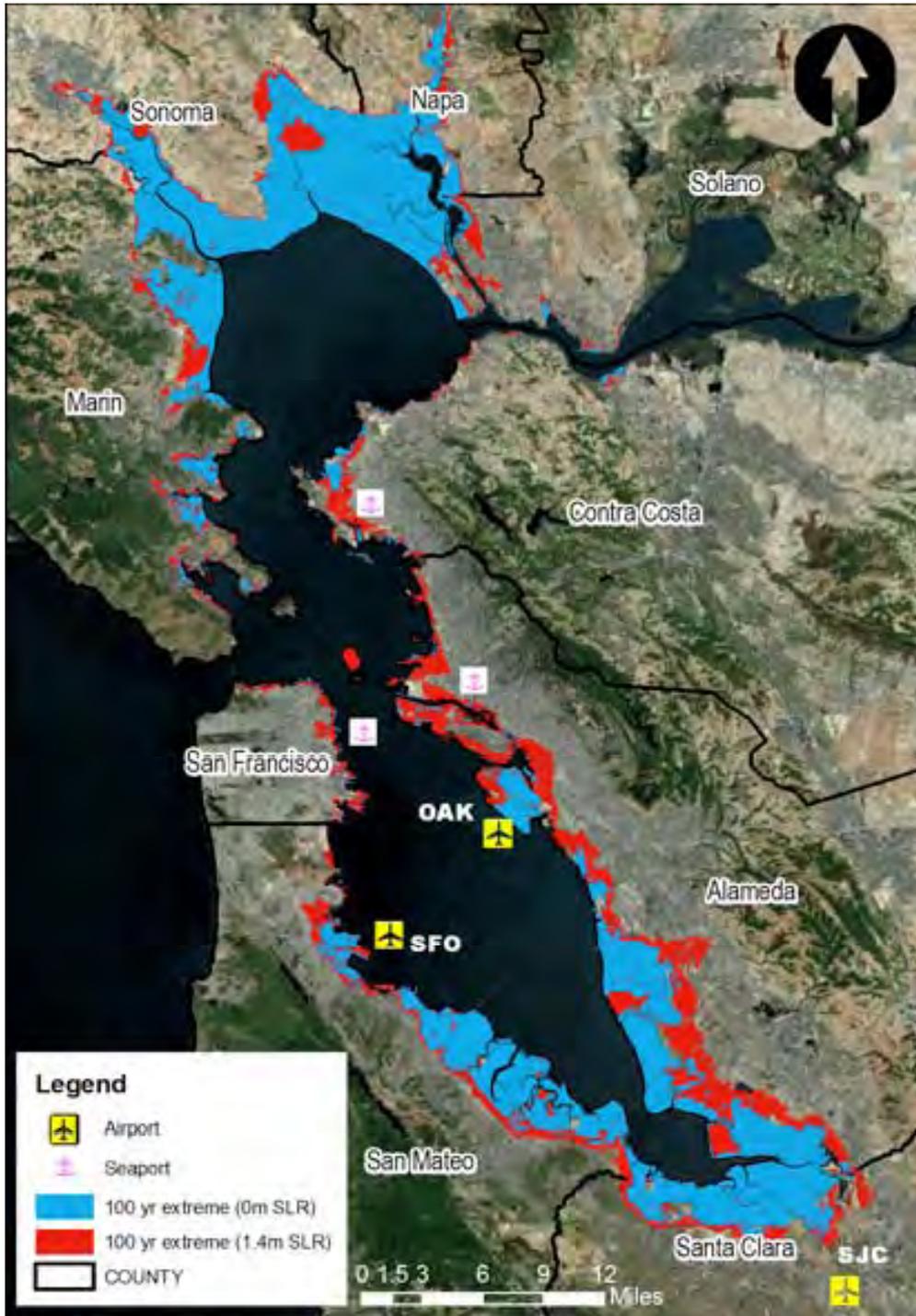


$$PWL_x = SLR_x + ESE_{100}$$

- We model four sea-level rise ( $SLR_x$ ) increments { $x$ : 0 m, 0.5 m, 1.0 m or 1.4 m}
- to which we add the 100-year extreme storm event ( $ESE_{100}$ )
- without sea-level rise and then with sea-level rise



# SF Bay Area Inundation Results



  $SLR_0 + ESE_{100}$

  $SLR_{1.4} + ESE_{100}$

# The Delta Inundation Process → the Dynamics are Different

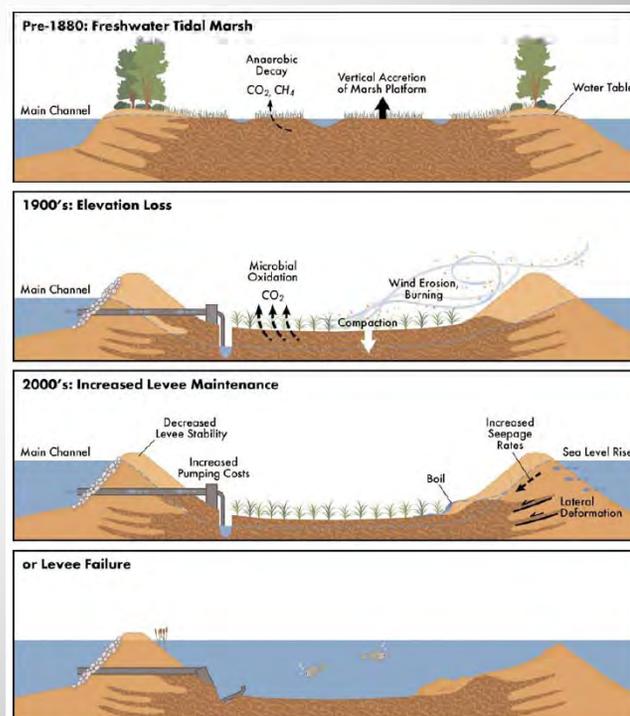
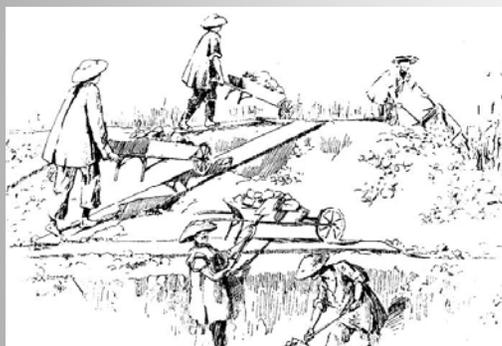
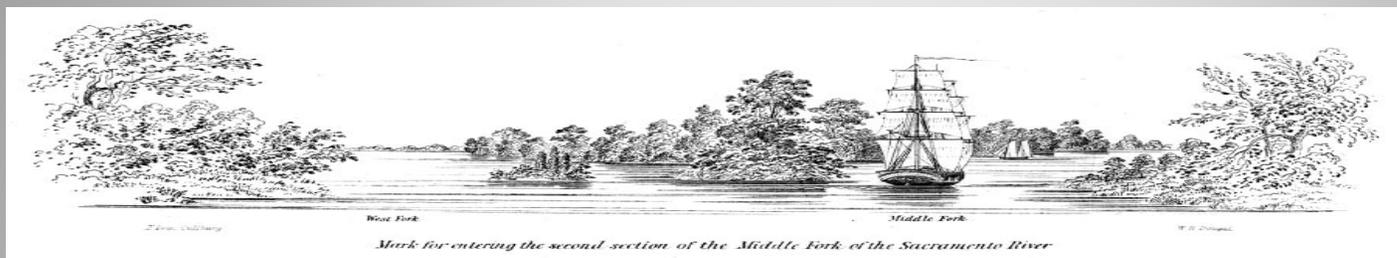
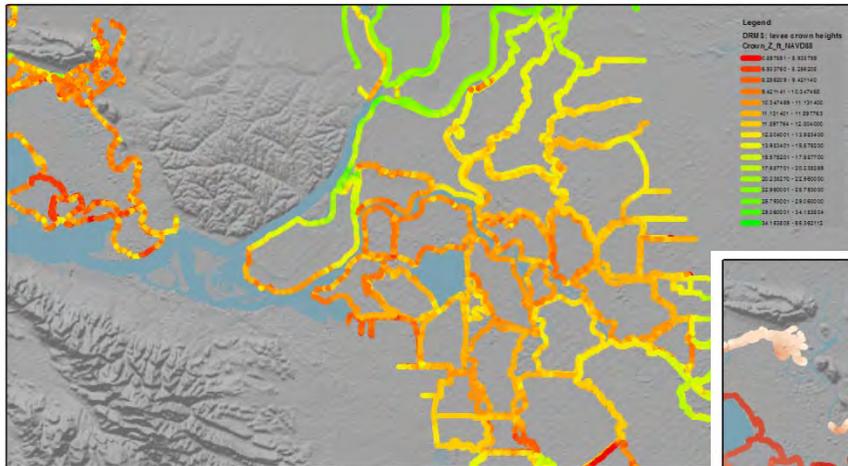


Figure 2. Conceptual diagram illustrating evolution of Delta islands due to levee construction and island subsidence. Modified from Ingebritsen et al. (2000).

(Source) Mount, J.F. and R. Twiss (2005), "Subsidence, sea level rise, seismicity in the Sacramento-San Joaquin Delta," San Francisco Estuary and Watershed Science, v. 3, article 5, 2005.

# Levee issues

1100 miles of levees

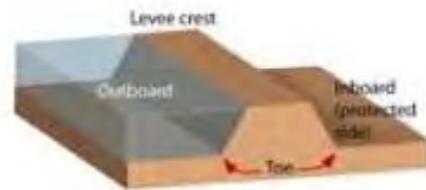


# Island Levee: incremental construction, seepage, subsidence

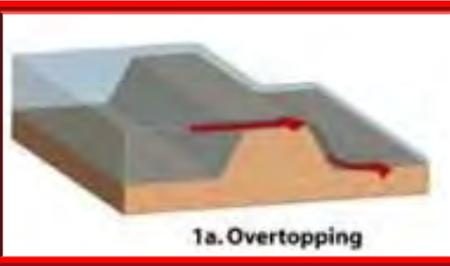


(Source) RESIN Research Group, UC Berkeley

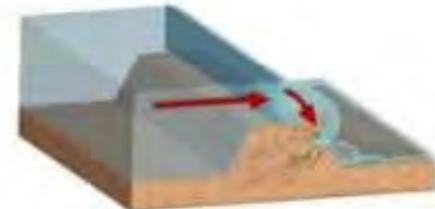
# Levee Failure Modes



Anatomy of a levee



1a. Overtopping



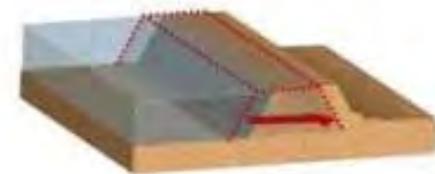
1b. Overtopping/Jetting



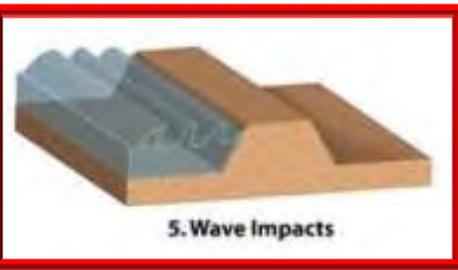
2. Internal Erosion/Piping



3. Surface Erosion



4. Sliding



5. Wave Impacts



6. Structural Impacts



7. Liquefaction



8. Piping of substratum



9. Tree damage



10. Slope failure

# Problem Amplification



Source: <http://web.mst.edu/~rogersda/levees/california.htm>



Source: <http://news.stanford.edu/news/2006/may17/delta-051706.html>



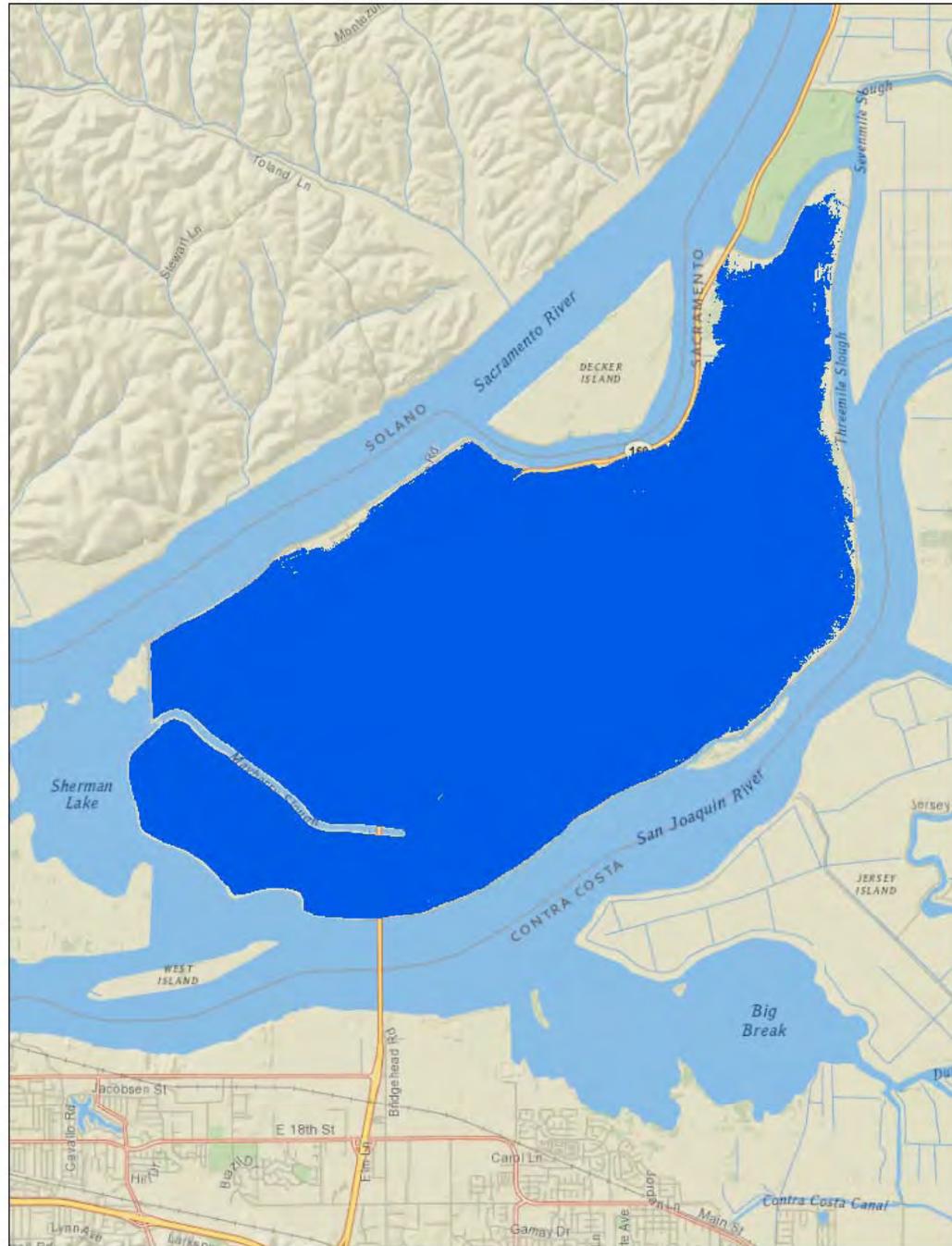
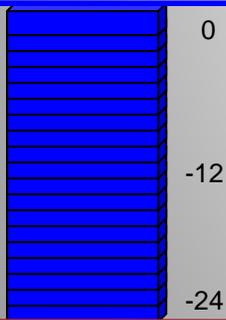
Source: California Department of Water Resources



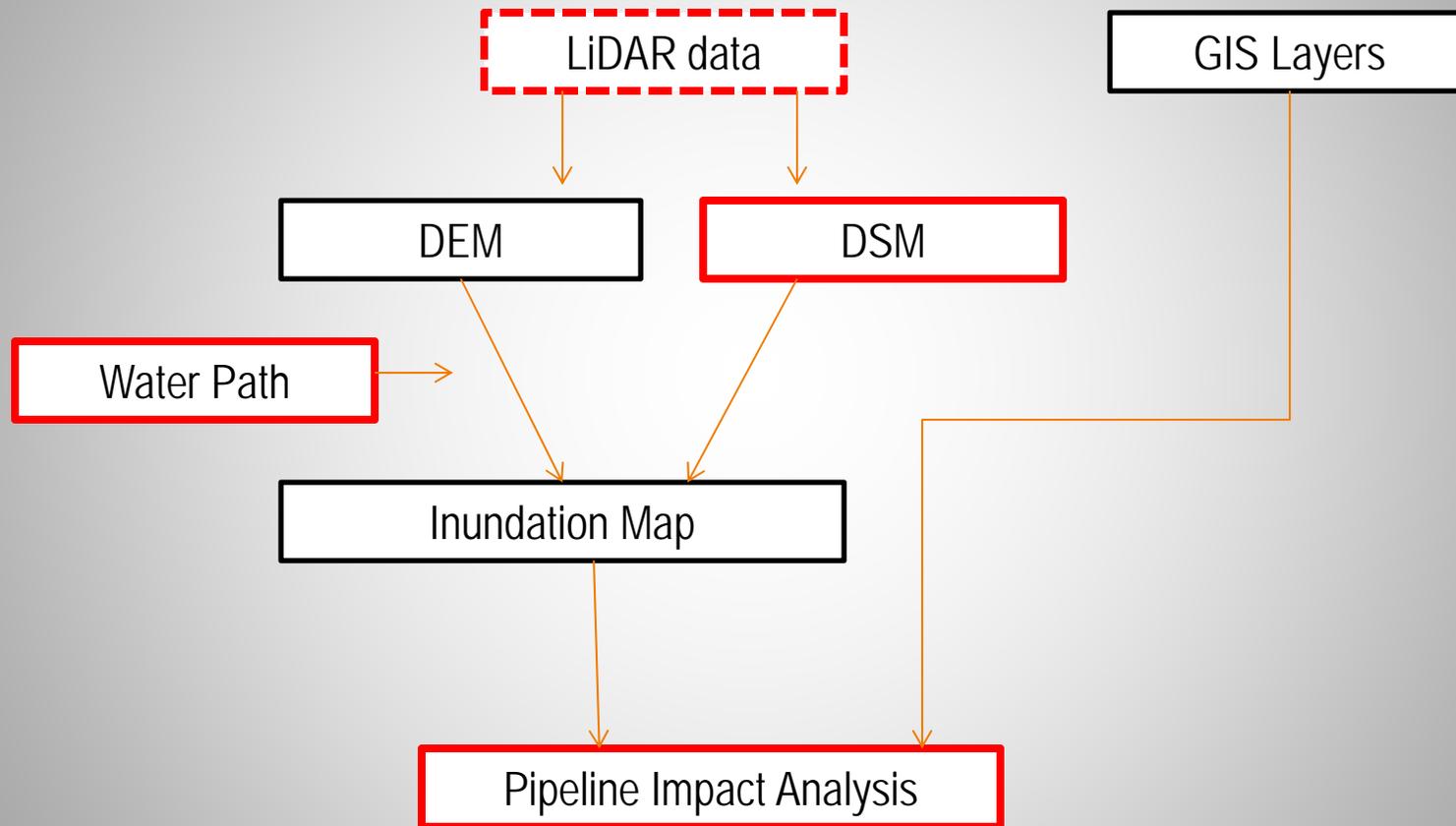
Source: California Department of Water Resources

# Inundation Delta Islands

Flooding scenario  
Sherman Island

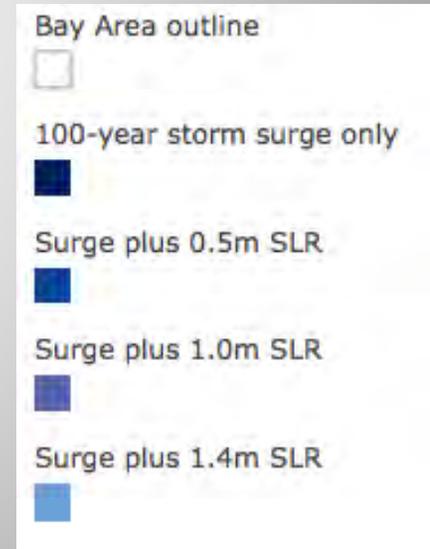
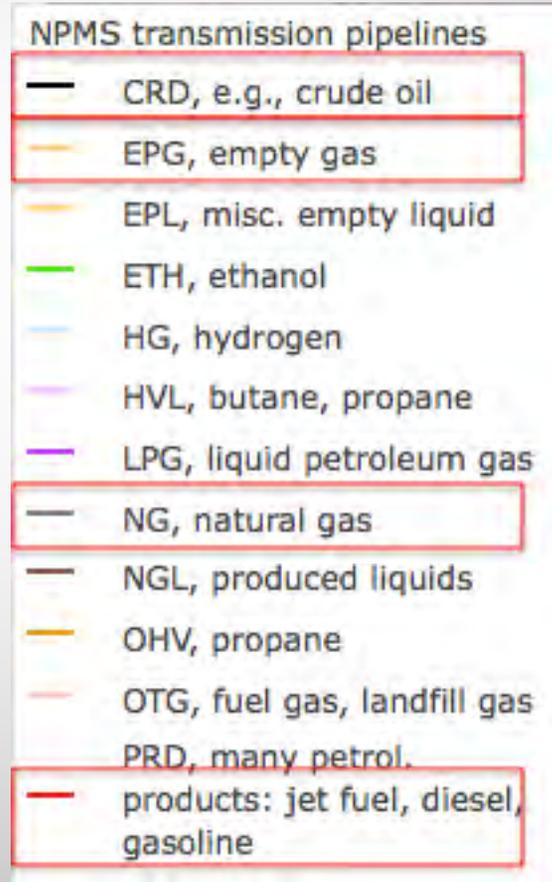
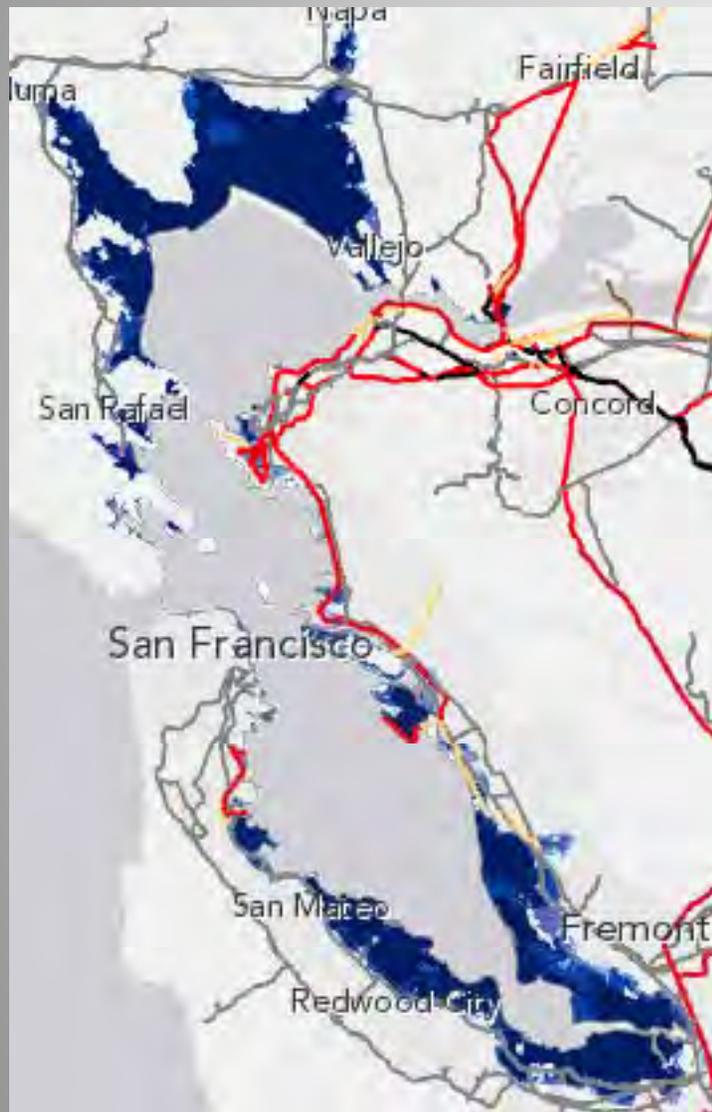


# Analysis pathway



# Results to date:

## Impacted Pipeline in SF Bay Region



# Impacted Pipeline in SF Airport Region

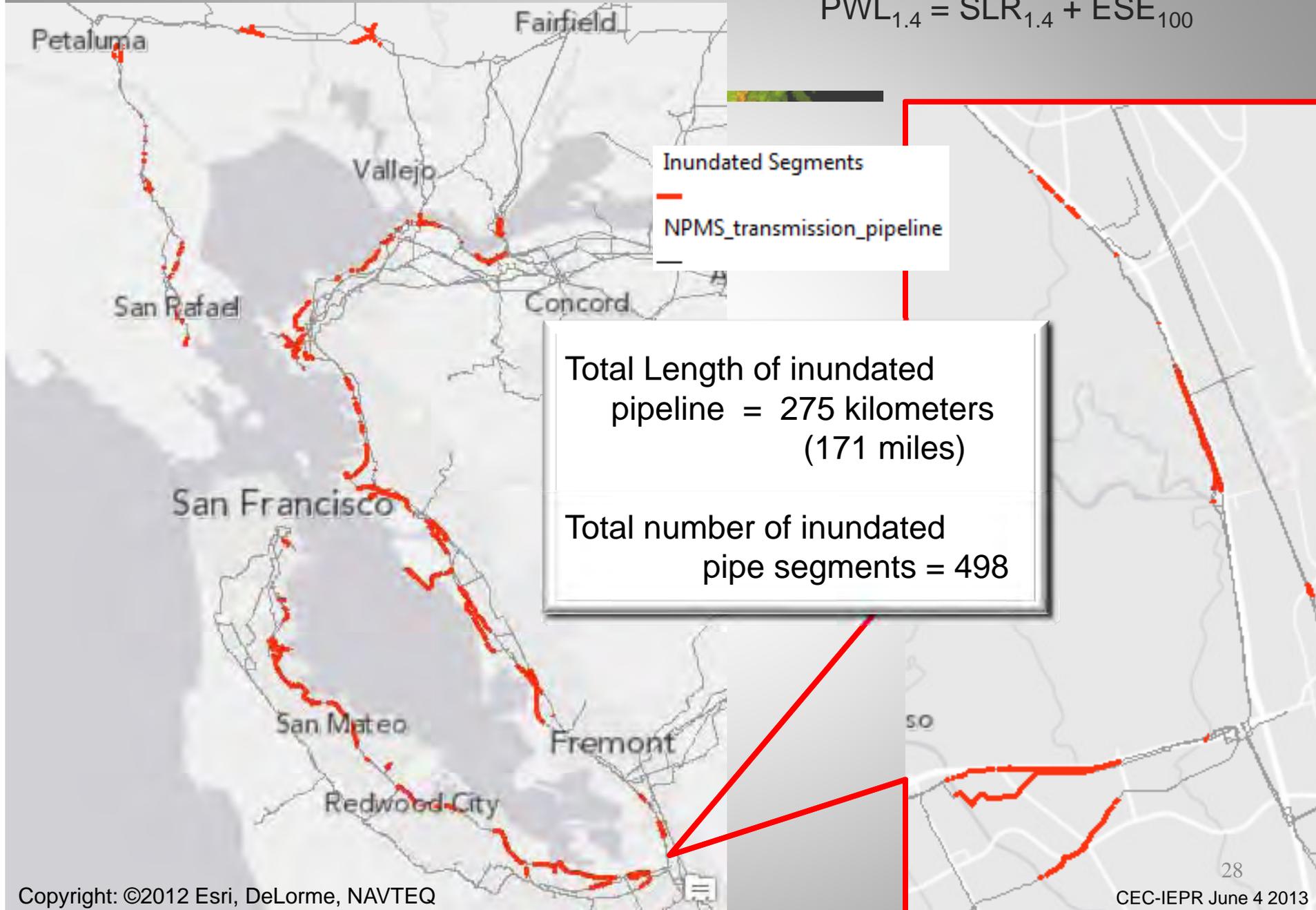


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  - EPL, misc. empty liquid
  - ETH, ethanol
  - HG, hydrogen
  - HVL, butane, propane
  - LPG, liquid petroleum gas
  - NG, natural gas
  - NGL, produced liquids
  - OHV, propane
  - OTG, fuel gas, landfill gas
  - PRD, many petrol. products: jet fuel, diesel, gasoline

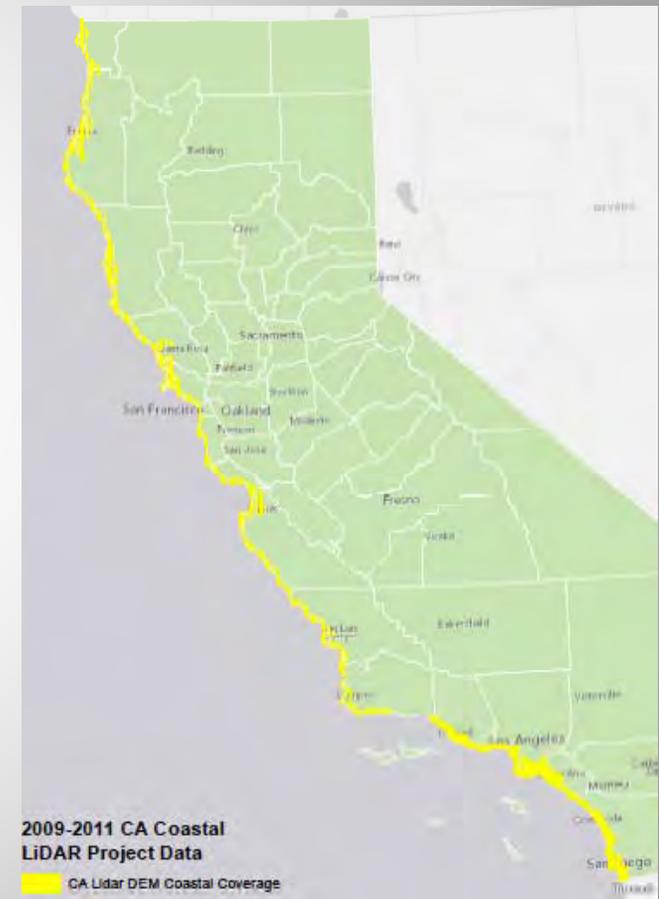
- Bay Area outline
- 100-year storm surge only
  - Surge plus 0.5m SLR
  - Surge plus 1.0m SLR
  - Surge plus 1.4m SLR

# Inundated Pipeline in SF Bay Region

$$PWL_{1.4} = SLR_{1.4} + ESE_{100}$$

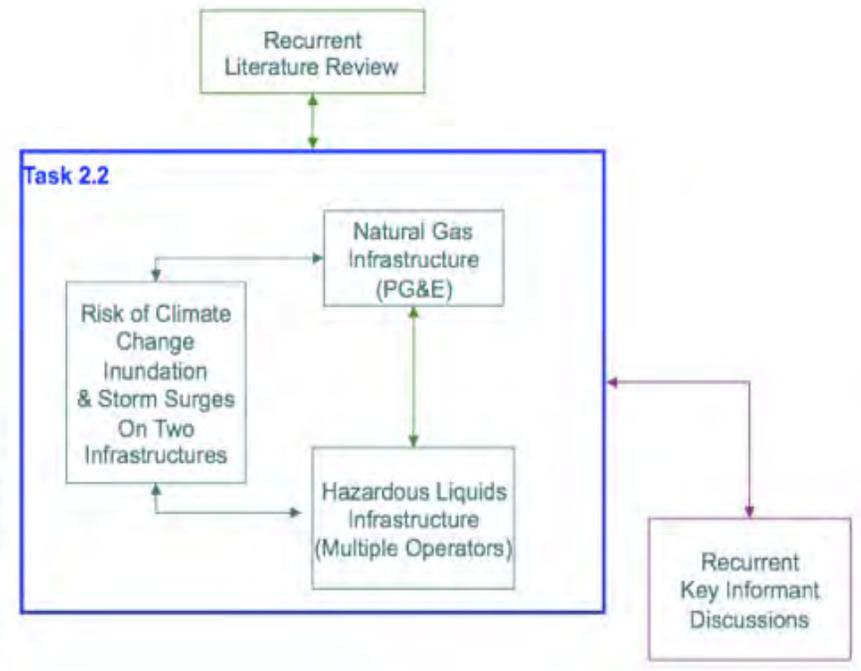
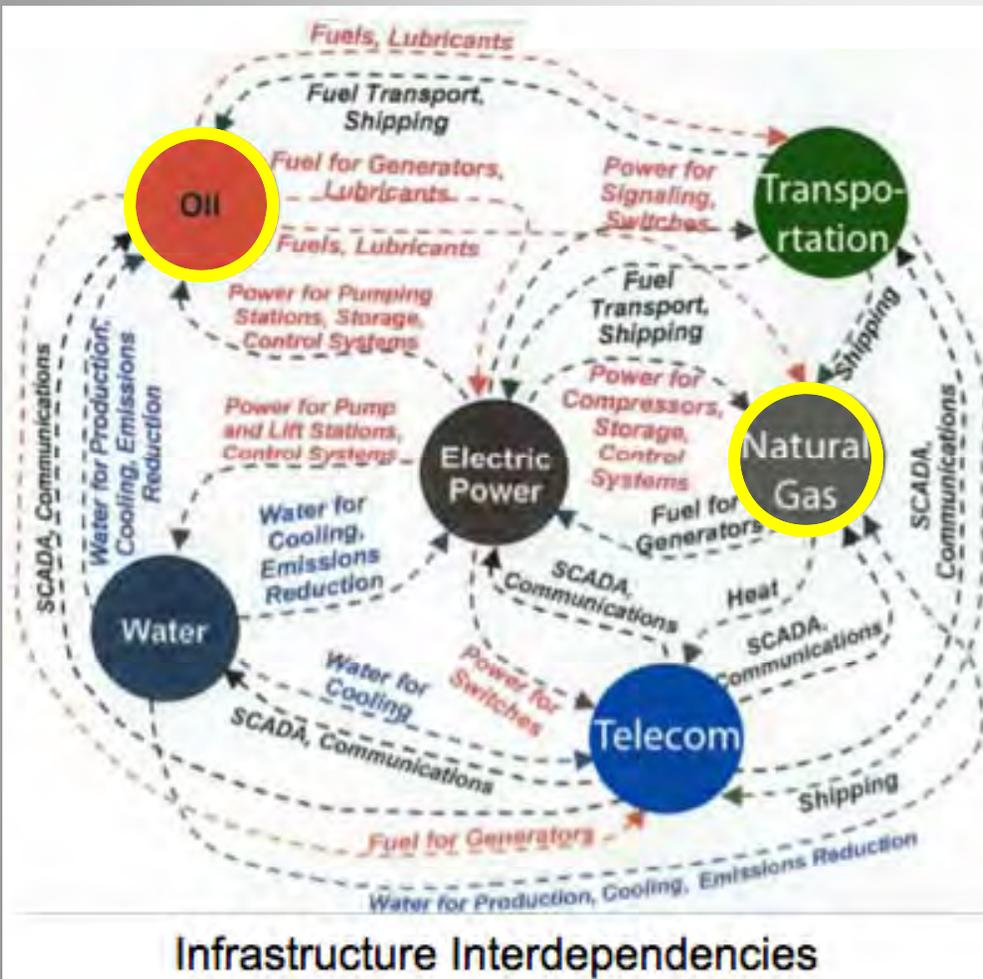


# To Do: Impacted Pipeline in Delta Region & California Coast



# To Do: Assess vulnerability of pipeline network

Employing this process:



Determine where interconnected critical pipeline infrastructures are impacted.