Napa Earthquake of 8.24.2014
Performance of Lifelines

Water, Power, Gas, Fires

What does it mean for the Peninsula?
Is Pipe Replacement in Our Future?

City and County Engineers Association of San Mateo County

Iron Gate Restaurant, Belmont, CA, March 17 2016

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G&E Engineering Systems Inc.
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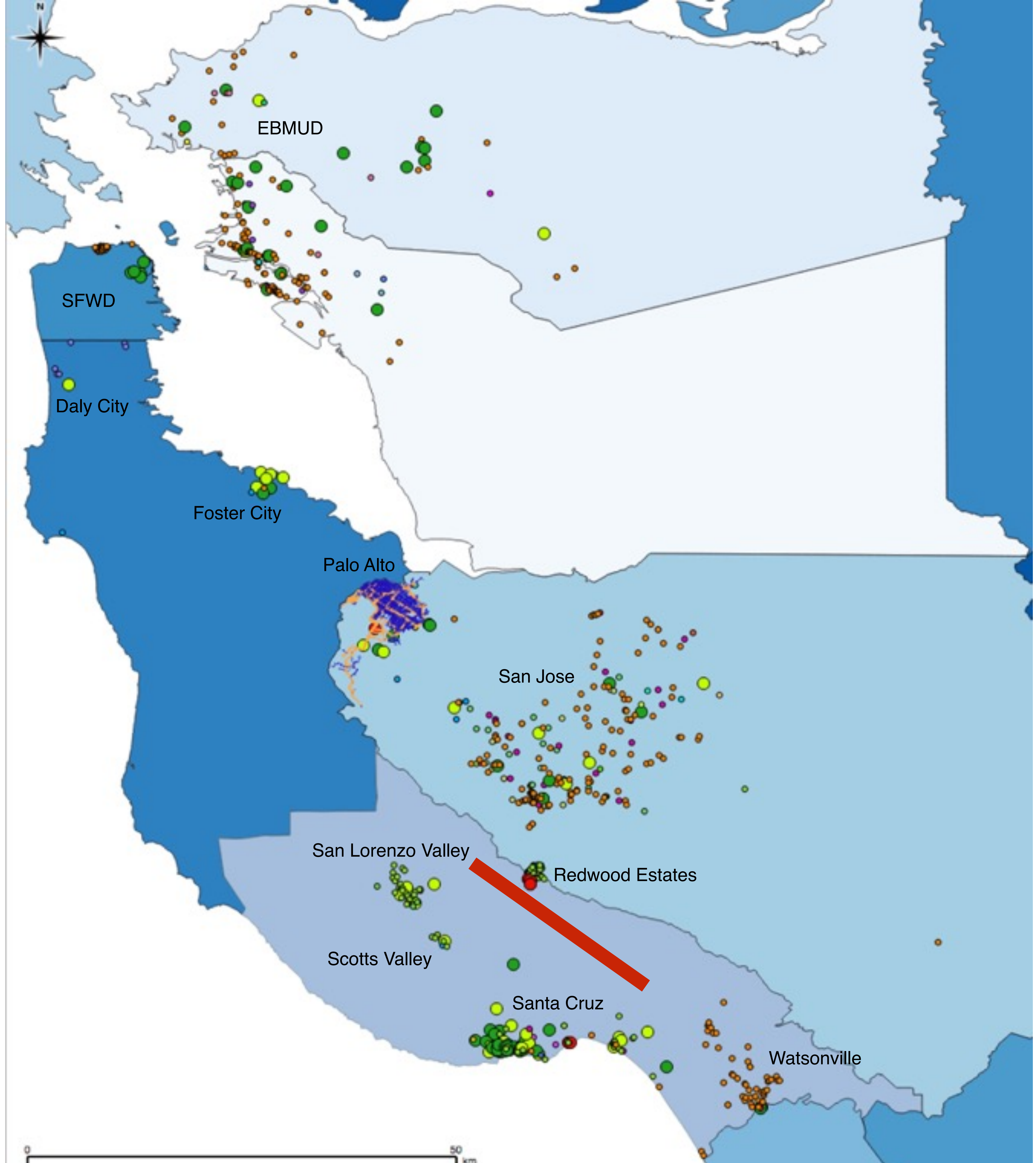
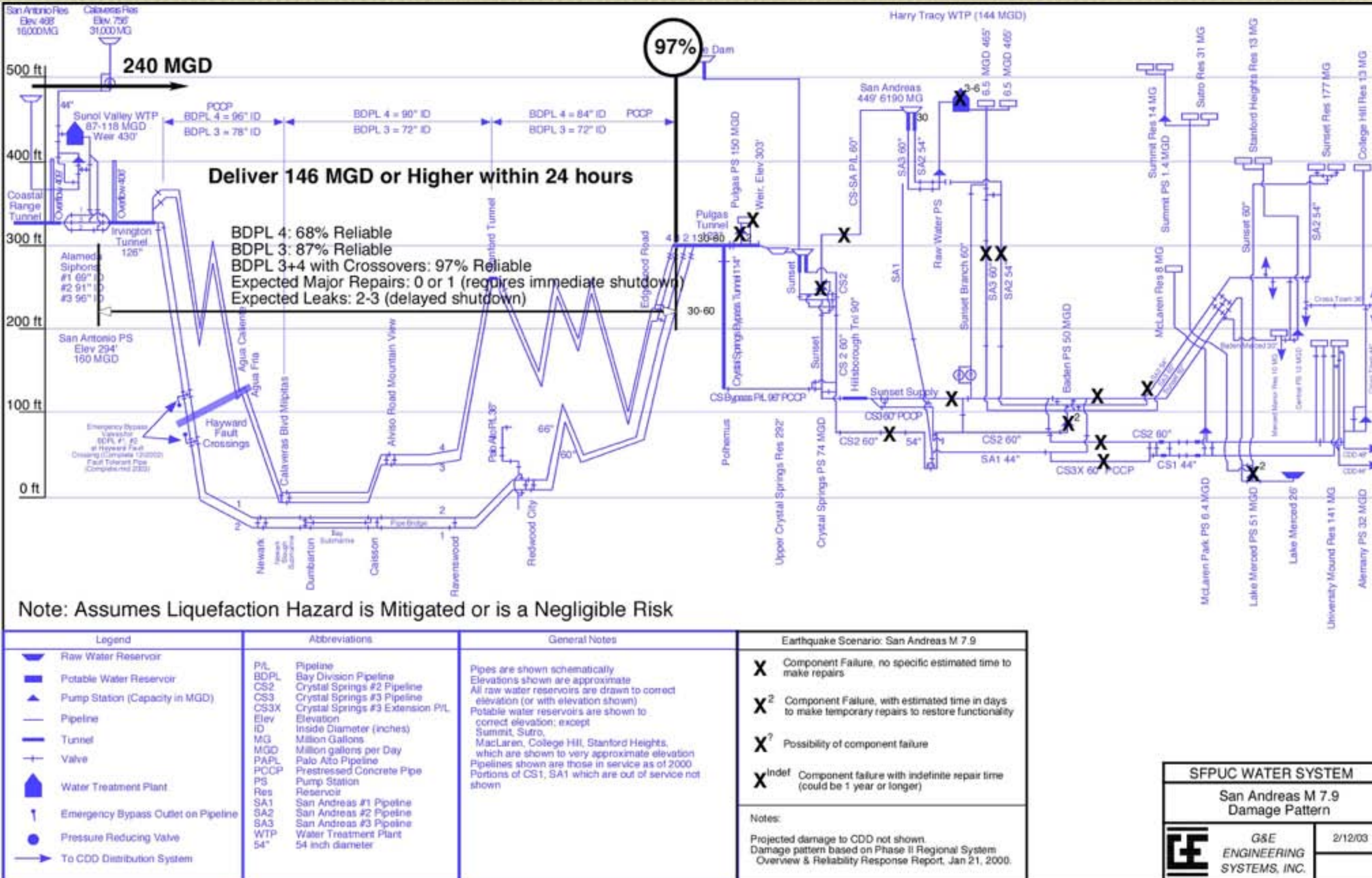
Damaged Pipes in the Loma Prieta 1989 Earthquake for Selected Water Systems



- Damaged Cast Iron Pipe
- Damaged AC Pipe
- Damaged ABS Pipe
- Damaged PVC Pipe
- Other damaged pipe

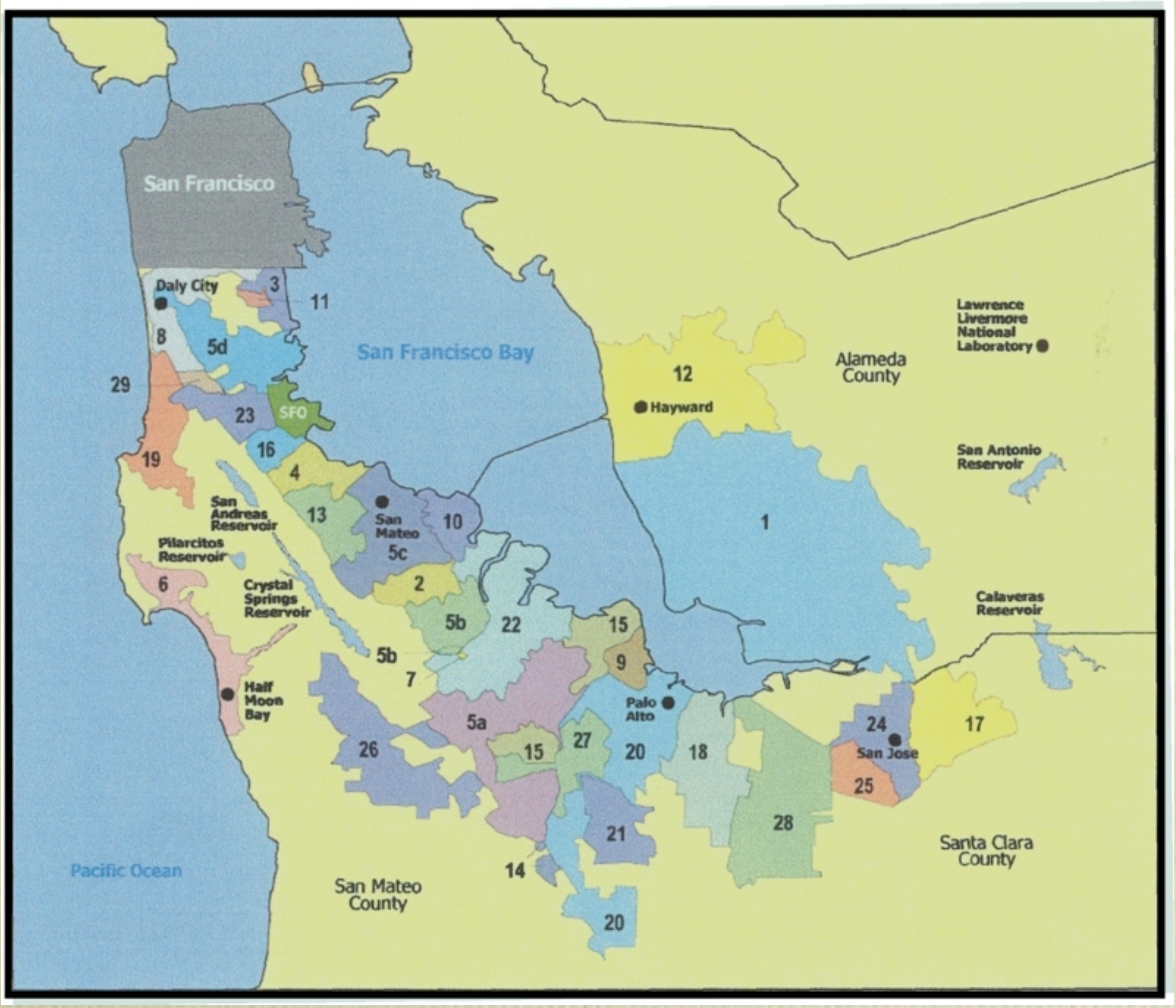
Note: not all pipe repairs shown.
City of Santa Clara pipe repairs not shown.



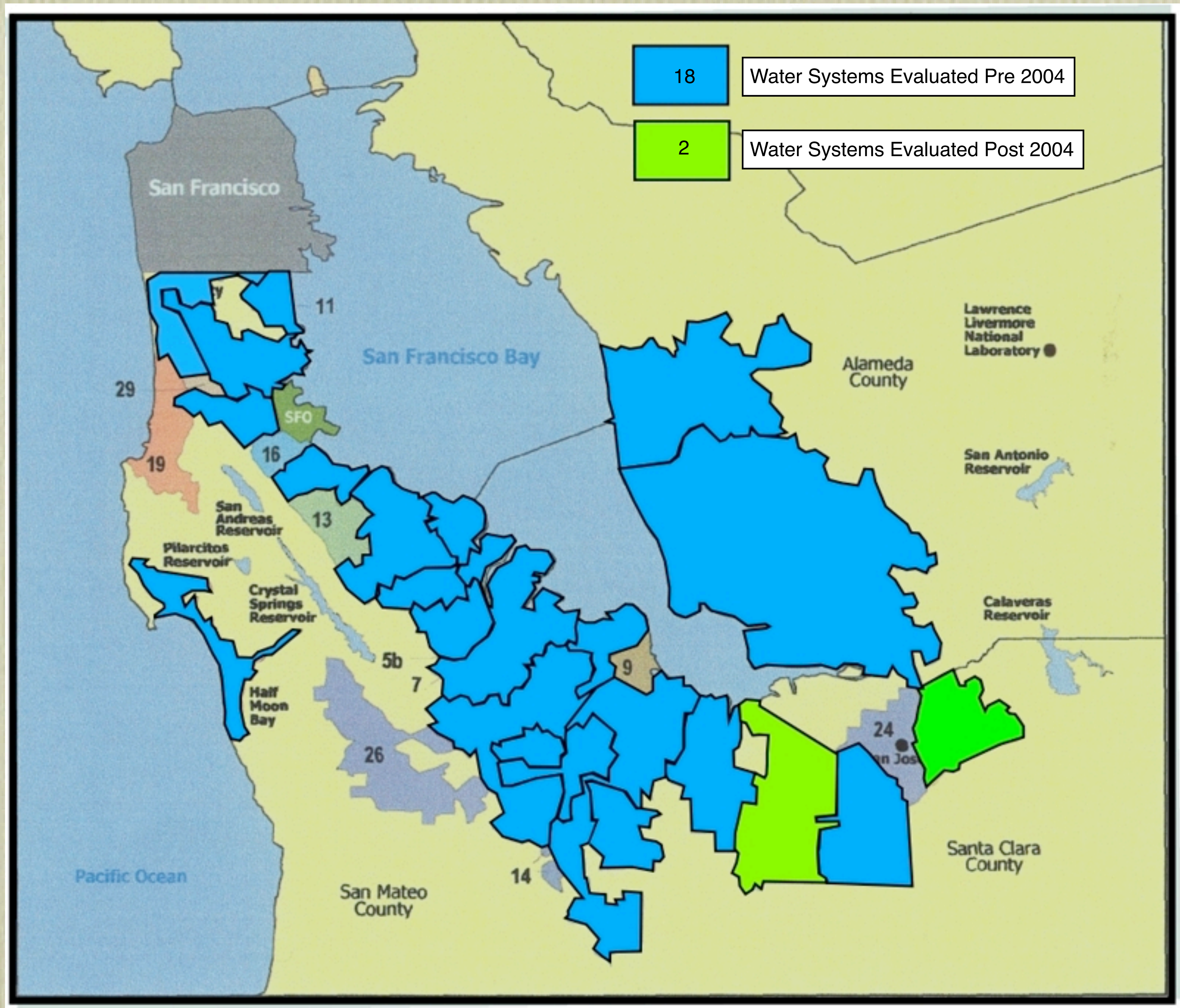
San Andreas M 7.9

Good news: The 97% figure assumed good quality construction. Something has been done to address the “X” points
Bad news: BDPL 1, 2, 5 may have weld problems. Portions of BDPL 1, 2 have been retired. Water rates are high.
Distribution weaknesses are not addressed by the SFPUC. Unknown hazards likely exist.
AS of 2016, the 97% figure is probably lower.

Water Systems in San Mateo County and Nearby (BAWSCA)



Water Systems with Earthquake Risk Assessment by G&E in San Mateo County and Nearby (BAWSCA)



Also: EBMUD, SCVWD, SFPUC, Zone 7. About 100 water systems from Canada to Mexico

Item	EBMUD	SFPUC + 20 Suburban Customers
Miles of Transmission Pipes	200	220
Miles of Distribution Pipes	3,900	3,700
Tunnels	16	20
Treatment Plants	6	8
Storage Tanks	175	202
Pump Stations	125	157
Small Pipes crossing active faults (<18")	178	66
Large pipes crossing active faults (≥20")	27	11
Tunnels crossing active faults	2	0
Pipe repairs, Loma Prieta 1989 EQ	~135	~400
Pipe Repairs, San Andreas M 7.9	< 1,000	1,190 to 3,030
Pipe Repairs, Hayward M 7.1	3,300 to 5,000	920 to 2,580

Item	EBMUD	SFPUC + 20 Suburban Customers
Seismic Upgrade, Transmission System	$140 million	$2,000 million
Seismic Upgrade, Distribution System	$100 million	$75-$100 million
Seismic Improvements, Total (plus dams)	$240 million	$2075 to $2100 million
Ratio, Distribution Costs to Total Costs	42%	4% to 5%
Population Served	1,300,000	2,500,000
Cost per person	$185	$840

EBMUD: includes Mokelumne Aqueduct Upgrades
SFPUC: a portion of $4.7 Billion Reliability Upgrades

Water Distribution Pipes

- EBMUD: excludes money for pipe replacement
- SFPUC: excludes money for pipe replacement
- Pipe replacement: This is the ELEPHANT in the room

Replacing Seismically-Weak and Aging Water Pipes

The ELEPHANT in the room

ASCE's Viewpoint

- Aging Infrastructure
- Score Card: D- to C-
- Is this Rational, Silly, or what?

Why Replace Pipes?

- Cause 1. Pipes leak! Aging, Corrosion, Earthquake, etc.
- Cause 2. Relocations (new highway, etc.)
- Cause 3. Growth. Flow rate of an older 4" pipe no longer meets modern flow requirements
- Cause 4. After earthquakes, either patch the leaks (sporadic) or replace (severe damage)

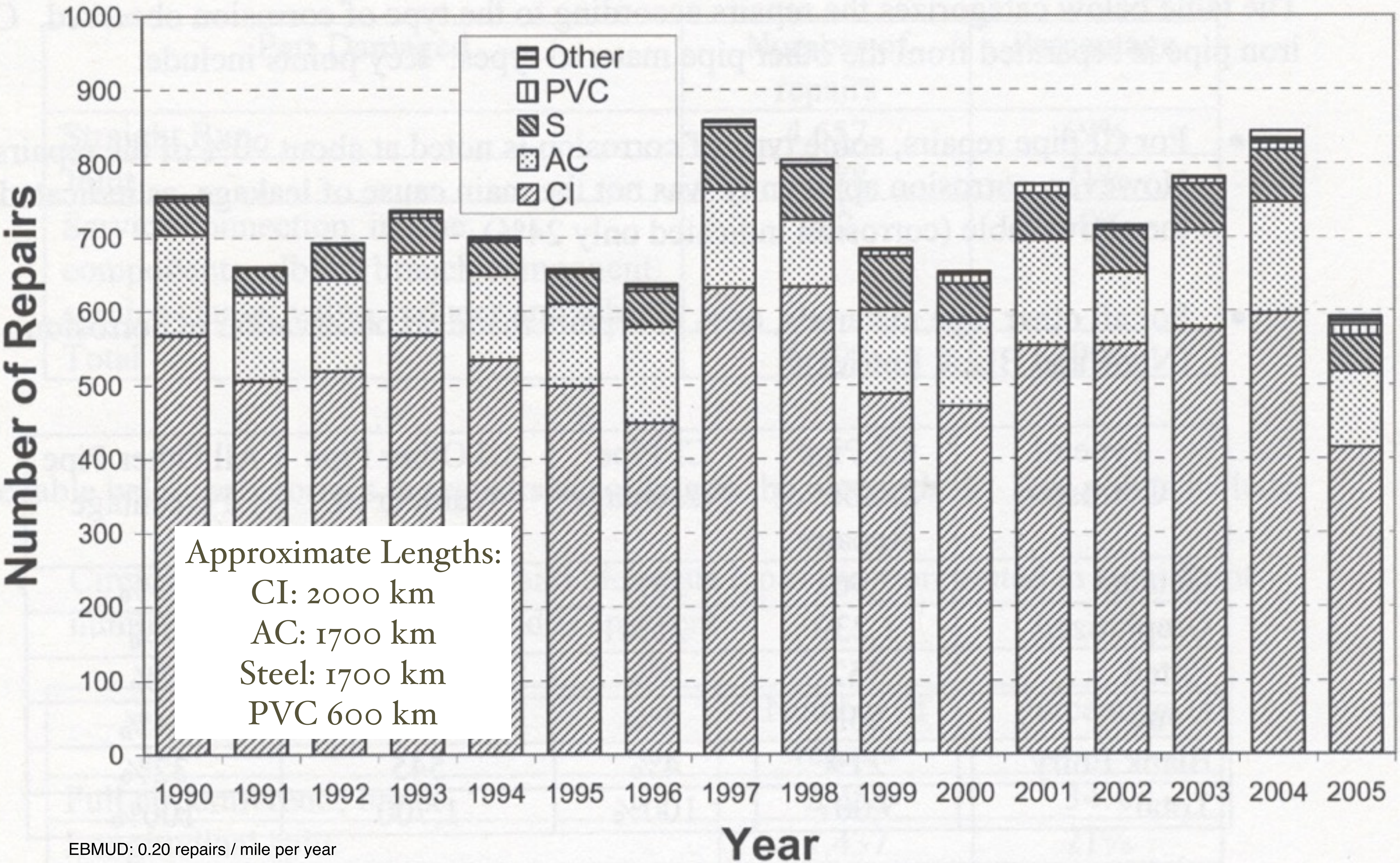
Japan and USA Practices

- Japan: All (most) water pipes are replaced after about 65 years. JWWA / DI manufacturers seem to set the rules. Customers pay.
    - Everyone is happy.
- USA. No water pipes are replaced until they are leaking like sieves. If asked, Customers say no. If asked, FEMA (often) says no.
    - Everyone is unhappy.

The Big Question

- My pipes (Cast Iron) are 50 to 90 years old.
- My pipes (Asbestos Cement) are 35 to 60 years old.
- Many of them are at the end of their lives (or so one might think).
- I need a rate increase of 30% in order to replace them on a 100 year cycle.
- How do I convince the Board / City Council / customers to accept this rate increase?

Pipe Repairs - EBMUD (11,500 Repair Database)



Approximate Lengths:
CI: 2000 km
AC: 1700 km
Steel: 1700 km
PVC 600 km

EBMUD: 0.20 repairs / mile per year

Burbank: Home of Movies!

105,000 people

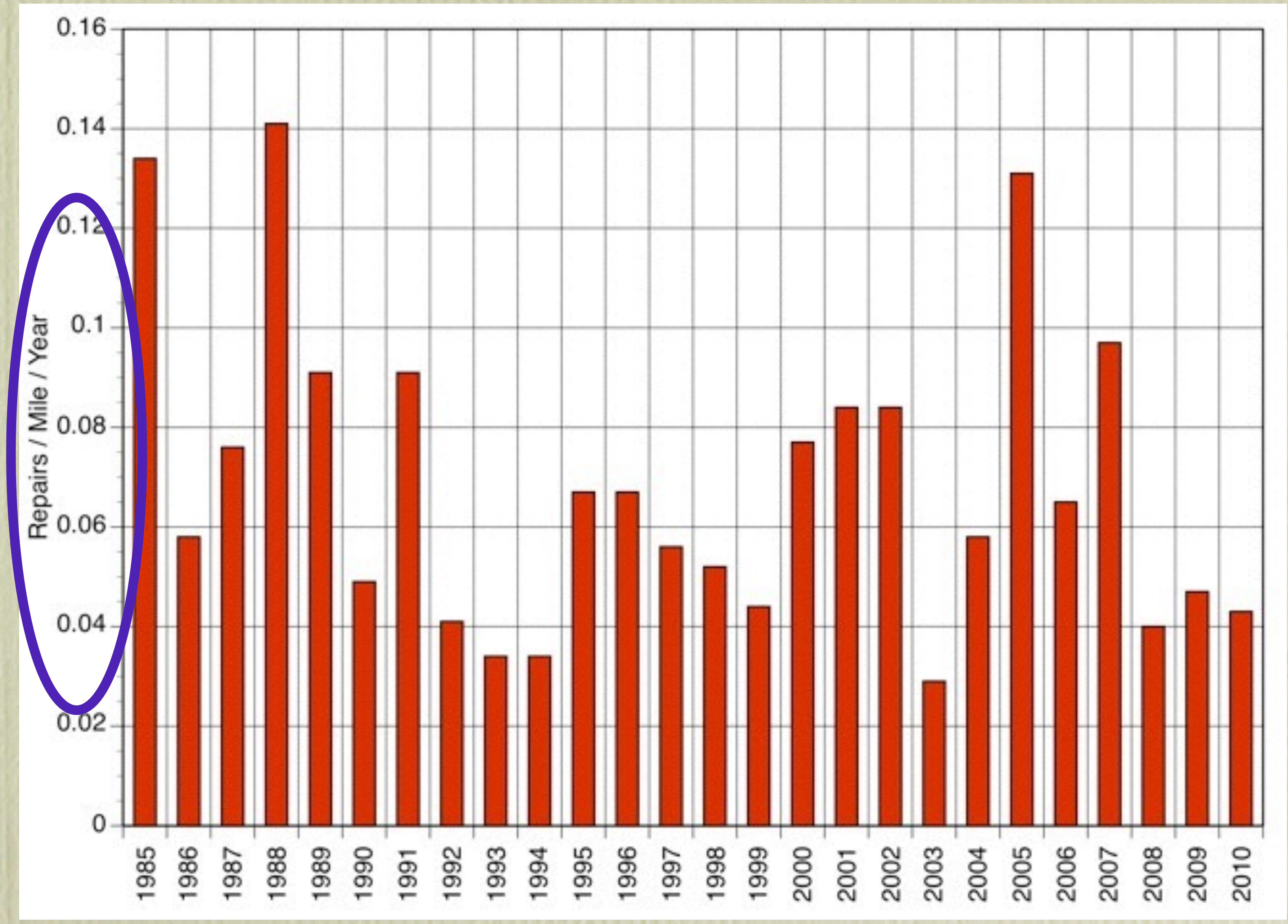
500 km of water pipes

85% are "old" Cast Iron Pipes (1910-1930)

City of Burbank Leak History
All Leaks

Burbank Leak History

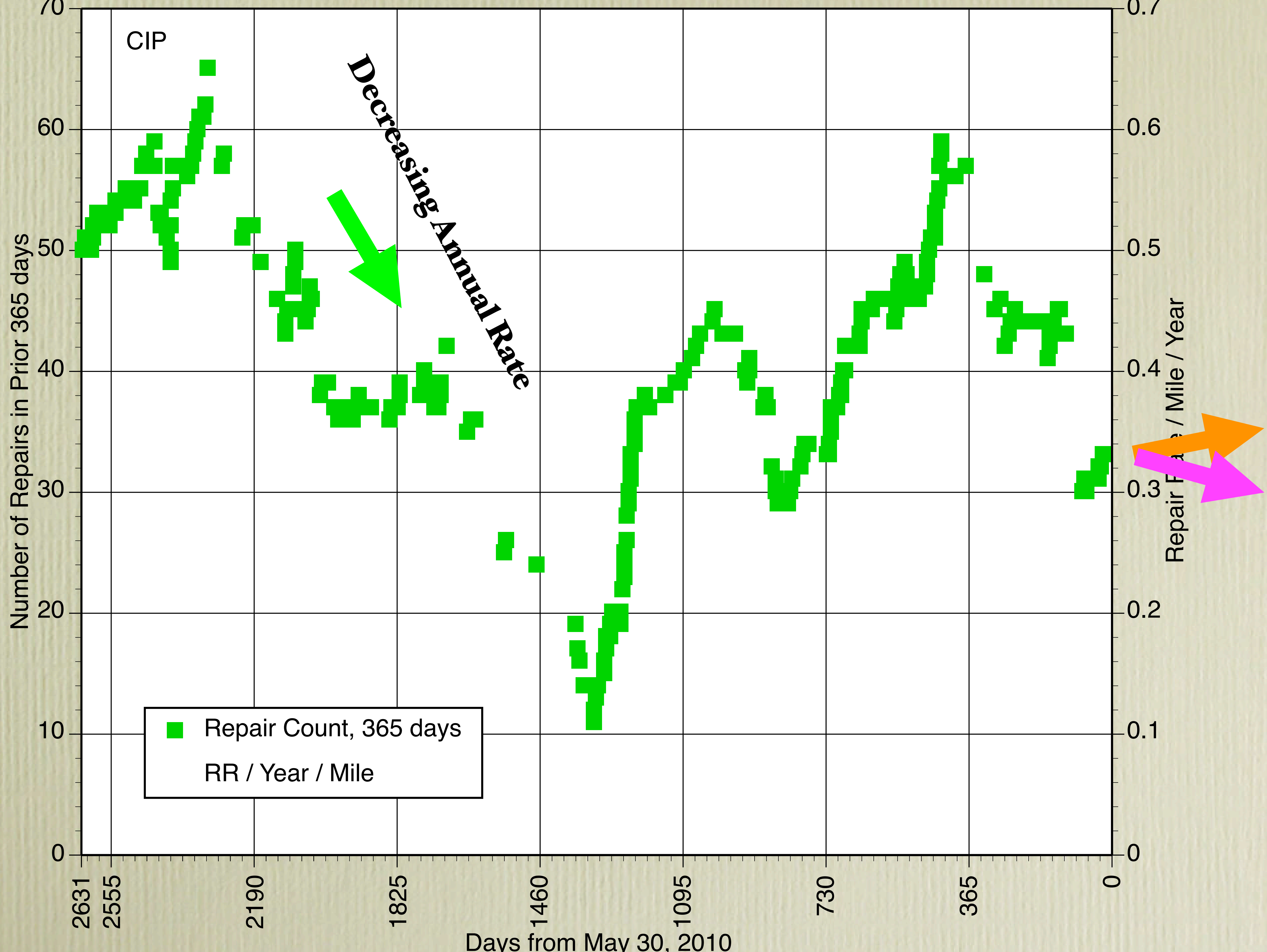
Industry Average: 0.24 to 0.27

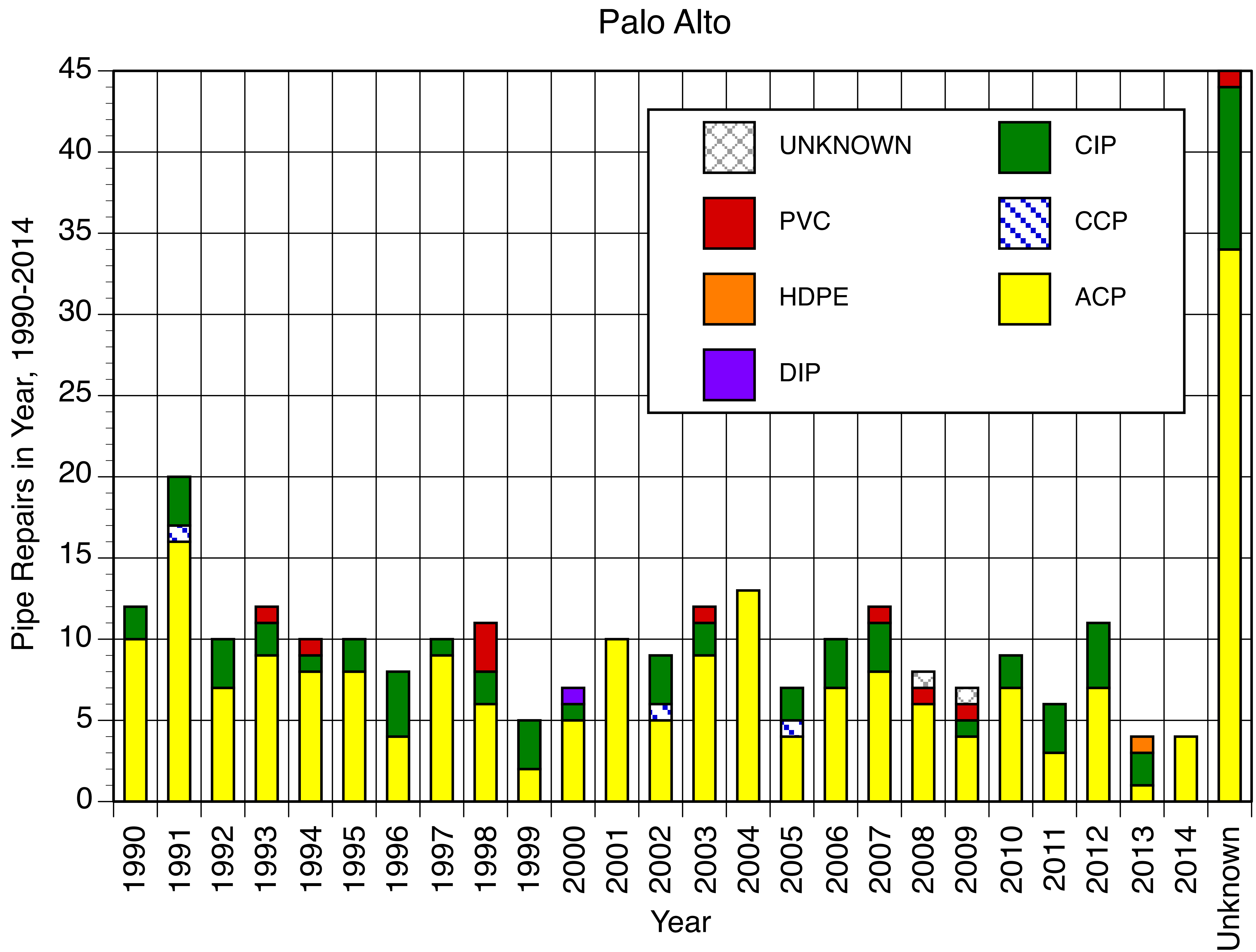


No trend for increasing leak rate in past 24.5 years

excludes leaks on service laterals

Redwood City Cast Iron Pipe





Palo Alto
Pipe Repairs in Year, 1990-2014
0
5
10
15
20
25
30
35
40
45
UNKNOWN
CIP
PVC
CCP
HDPE
ACP
DIP
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
Unknown
Year

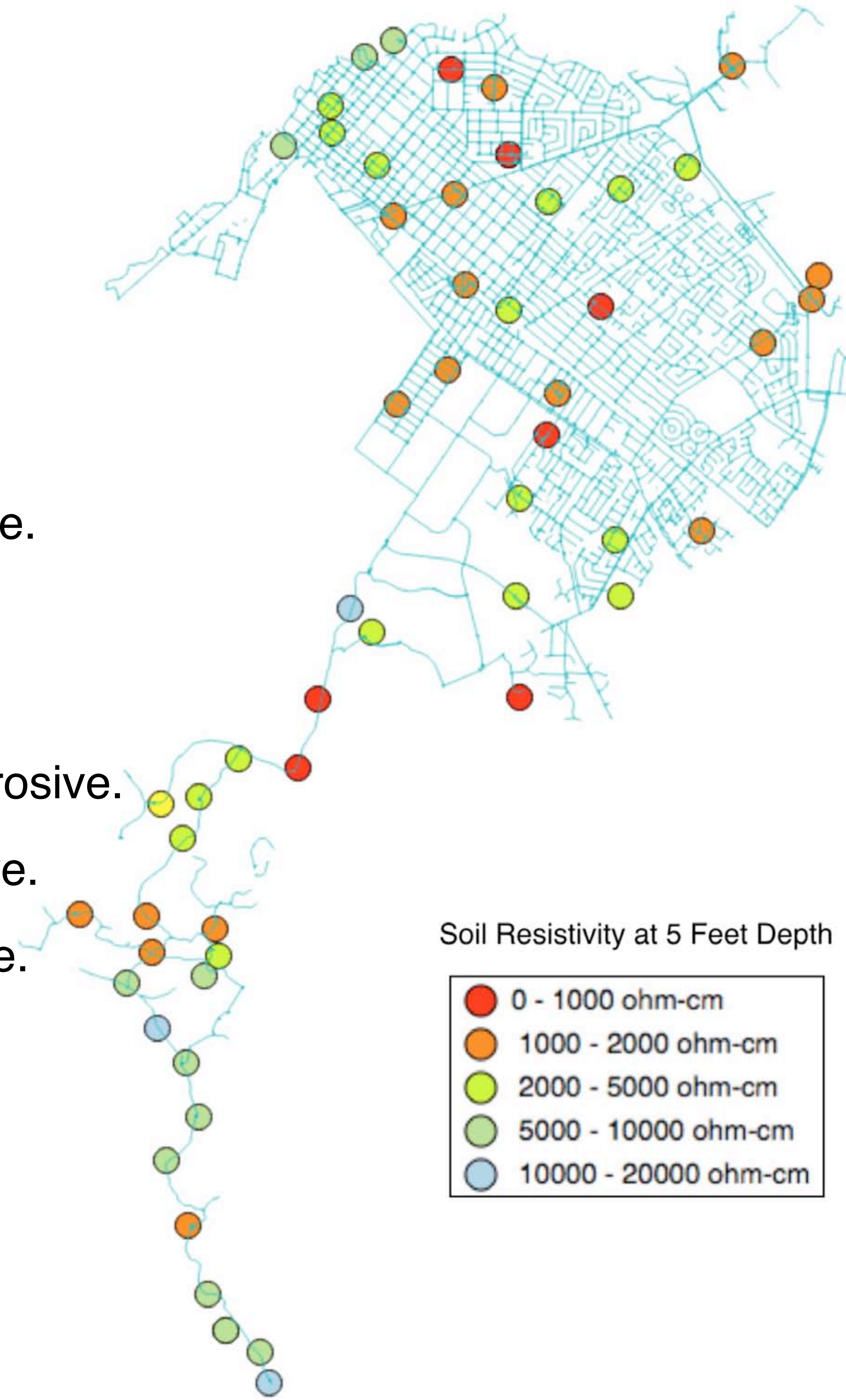
Corrosion

- Does soil resistance (Rho, ohm-cm) have influence over leak rates for metal pipes?
- Measure Rho
- Correlate Rho versus historical leak rate

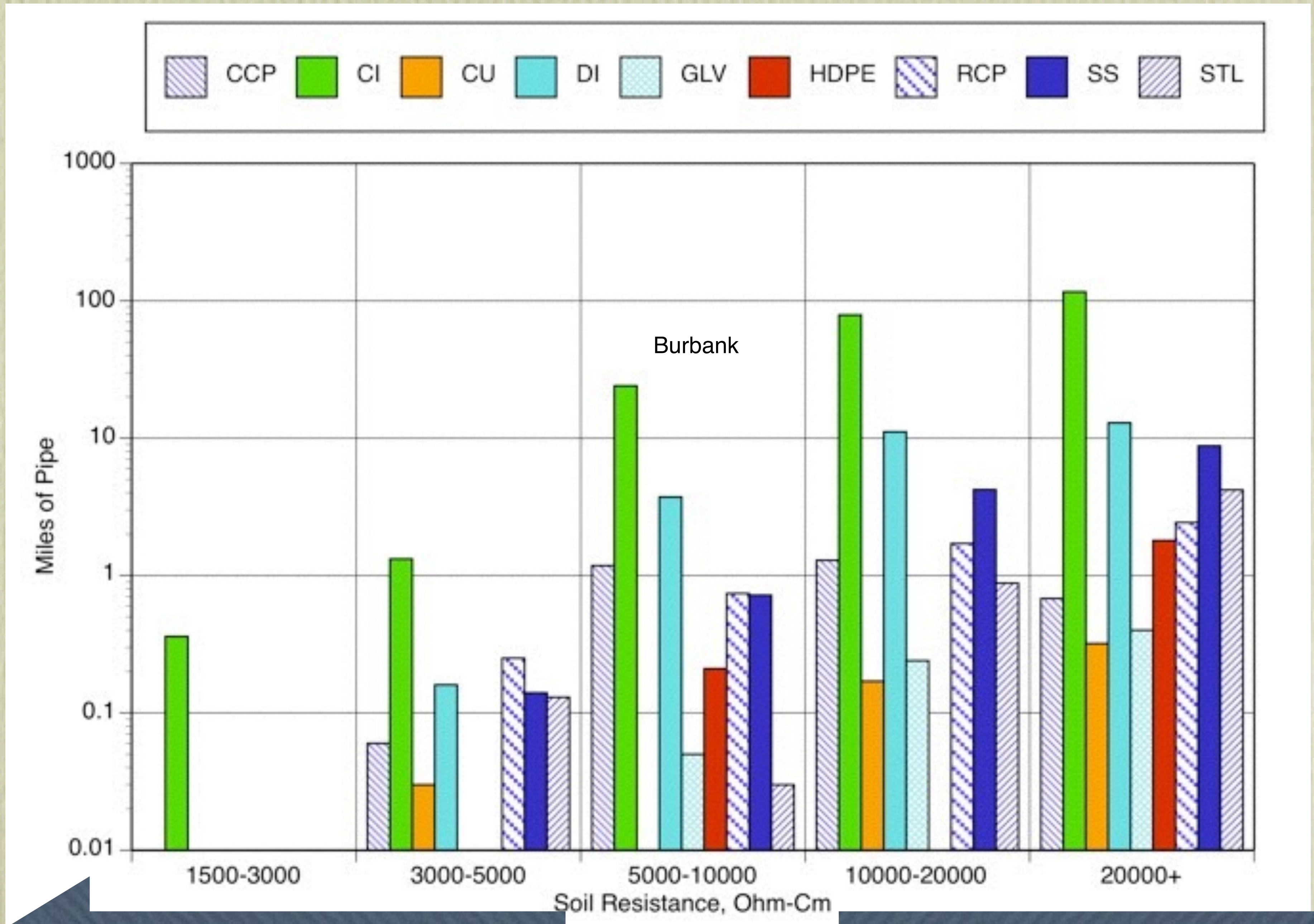
Performed soil resistivity testing at various locations in Palo Alto

Rho value interpretation:

- R = 500 to 1,500 ohm-cm. Extremely corrosive.
- R = 1,500 to 3,000 ohm-cm. Highly corrosive.
- R = 3,000 to 5,000 ohm-cm. Corrosive.
- R = 5,000 to 10,000 ohm-cm. Moderately corrosive.
- R = 10,000 to 20,000 ohm-cm. Mildly corrosive.
- R > 20,000 ohm-cm. Essentially non-corrosive.



Miles of Pipe vs Soil R



Corrosive Mild Low

Leak Model. RR = k1 * k2 * k3

k1 Matl, Diam

Type / Diameter	CCP, RCP	HDPE	CI	CU	DI	GLV	SS, STL (≤12")	STL (>12")	UNK
Any	0.015	0.010	0.030	0.150	0.015	0.600	0.500	0.015	0.070
1" to 2"		0.010	0.400	0.150	0.015	0.600	0.500		0.400
4"		0.010	0.150		0.015	0.600	0.500		0.150
6"		0.010	0.030		0.015		0.500		0.070
8" – 12"	0.015	0.010	0.020		0.015		0.500		0.050
16" – 30"	0.015	0.010	0.020		0.015			0.015	0.015

k2 Age

Type / Age (Years)	CCP, RCP	HDPE	CI	CU	DI	GLV	SS, STL (≤12")	STL (>12")	UNK
Any	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0 to 20	0.90	0.95	0.90	0.75	0.80	0.80	0.80	0.90	0.90
20 to 40	1.00	1.00	0.95	1.00	1.00	1.00	0.90	0.95	1.00
40 to 60	1.10	1.05	1.00	1.25	1.10	1.00	0.95	1.00	1.00
60 to 80	1.15	1.10	1.25	1.50	1.15	1.20	1.00	1.00	1.10
80 to 100	1.20	1.15	1.50	2.00	1.25	2.00	2.00	1.10	1.15
100 +	1.50	2.00	2.00	2.50	2.00	2.50	2.50	1.30	

k3 R

Applicability: Granular Soils

Type / Resistance (Ohm-cm)	CCP, RCP	HDPE	CI	CU	DI	GLV	SS, STL (≤12")	STL (>12")	UNK
Any	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1500-3000	1.50	1.00	1.50	2.00	1.25	2.00	2.00	1.25	1.25
3000-5000	1.10	1.00	1.10	1.25	1.10	1.25	1.25	1.10	1.10
5000-10000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10000-20000	0.90	1.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90
20000+	0.90	1.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90

Different for Clay Soils

k1 Factors (Material + Diameter)

k1 = Base rate * Factor
Example for 4" CIP: k1 = 0.112 * 1.4 = 0.157
(repairs / mile / year)

Base Rate	ACP	CCP	CIP	DIP	PVC
Pipe Size	0.064	0.008	0.112	0.006	0.006
<=4"	2	1	1.4	1.2	1.1
6"	1.1	1	1.2	1.2	1.1
8"	0.9	1	1	1.1	1
10"	0.8	1	0.9	1	0.9
12"	0.7	1	0.8	1	0.8
14"	0.6	1	0.7	0.9	0.8
16"	0.5	1	0.6	0.9	0.8
18"	0.5	1	0.5	0.8	0.8
20"	0.5	1	0.5	0.7	0.8
24"	0.5	1	0.5	0.6	0.8
27"	0.5	1	0.5	0.6	0.8
30"	0.5	1	0.5	0.6	0.8

Palo Alto Soils (Clay-like)

k1 Factors (Material + Diameter), cont'd

Base Rate	CU	HDPE	Steel	Unknown (same as CIP)
Pipe Size	**0.02**	**0.01**	**0.15**	**0.112**
<=4"	1	1	2	1.4
6"	1	1	1	1.2
8"	1	1	0.8	1
10"	1	1	0.7	0.9
12"	1	1	0.6	0.8
14"	1	1	0.6	0.7
16"	1	1	0.5	0.6
18"	1	1	0.5	0.5
20"	1	1	0.5	0.5
24"	1	1	0.5	0.5
27"	1	1	0.5	0.5
30"	1	1	0.5	0.5

Palo Alto Soils (Clay-like)

k2 Factors

Pipe Age, yr	ACP	CCP	CIP	DIP	PVC
Unknown	**1**	**1**	**1**	**1**	**1**
1-10	0.4	0.8	0.3	0.8	0.9
11-20	0.6	0.8	0.3	0.9	0.9
21-30	0.8	0.8	0.3	1	1.0
31-40	1	0.8	0.5	1	1.0
41-50	1.2	0.8	0.7	1.1	1.0
51-60	1.2	0.9	1	1.1	1.1
61-70	1.2	1	1.2	1.15	1.1
71-80	1.2	1.1	1.4	1.2	1.1
81-90	1.4	1.2	1.6	1.3	1.2
91-100	1.6	1.2	1.8	1.4	1.2
101-110	1.8	1.3	2	1.5	1.2
111-120	2	1.4	2	1.7	1.2
>120	2	1.5	2	2	1.2

Palo Alto Soils (Clay-like)

k2 Factors, cont'd

Pipe Age, yr	CU	HDPE	Steel	Unknown
Unknown	**1**	**1**	**1**	**1**
1-10	0.75	0.95	0.8	0.5
11-20	0.75	0.95	0.8	0.6
21-30	1	1	0.9	0.7
31-40	1	1	0.9	0.8
41-50	1.25	1.05	0.95	0.9
51-60	1.25	1.05	0.95	1
61-70	1.5	1.1	1	1.2
71-80	1.5	1.1	1.2	1.4
81-90	2	1.15	1.4	1.5
91-100	2	1.15	1.6	1.6
101-110	2.5	1.2	1.8	1.7
111-120	2.5	1.2	2.0	1.8
>120	2.5	1.2	2.5	2

Palo Alto Soils (Clay-like)

k3 Factors

Rho	CIP, CU, Unknown	DIP	CCP	Steel	All non-metallic
1000	1.2	1.1	1.1	1.15	1.0
2000	1.1	1.0	1.0	1.1	1.0
3000	0.8	1.0	1.0	1.0	1.0
4000	0.7	1.0	1.0	1.0	1.0
5000	0.6	0.9	0.9	0.9	1.0
6000+	0.5	0.9	0.9	0.9	1.0

Rho adopted is at 5 feet bgs

Palo Alto Soils (Clay-like)

How to combine Pipe Aging with Earthquakes?

- Benefit Cost Ratio (BCR)
- BCR > 1, Replace the pipe
- BCR < 1, Let the customer be cheap

EXAMPLES

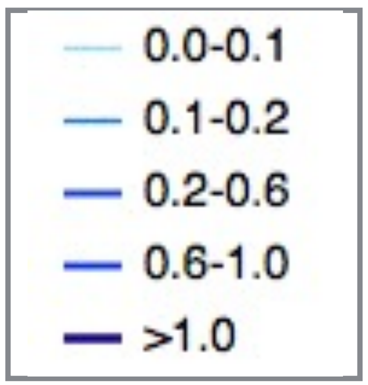
Parameter	MainID 7	MainID 4326	Units
MainID	7	4326	
Length	928.72	185.17	Feet
Year installed	1991	1971	
Age	20	40	Years
Material	CI	CI	
Diameter	6	4	Inches
Soil resistance	17402	28421	Ohm-cm
Liquefaction susceptibility	L	H	
Fault susceptibility	VL	VL	
Background repair rate	0.0243	0.1283	Repairs / mile / year
Number of Leaks	1	0	In past 24.5 years
Number of recent leaks	1	0	Since 1/1/2003
De-facto repair rate	0.1290	0.0045	Repairs / pipe / year
Outage time	6.79	6.05	Hours
Outage Length	750	500	Feet
Replacement Cost	$83,585	$11,110	
Repair cost per year	$516	$18	
Claim cost per year	$52	$2	
GDP loss per year	$312	$3	
Sales loss per year	$1	$0	
Repair costs per year (E)	$882	$23	Existing Pipe
Material Replacement Pipe	DI	HDPE	
Repair costs per year (N)	$22	$2	Replaced Pipe
NPV, Reduced repair costs	$19,455	$475	
BCR, Replacement (Repair)	0.233	0.043	
Losses per year, Seismic (E)	$72	$977	Existing Pipe
Losses per year, Seismic (N)	$7	$98	Replaced Pipe
NPV, Reduced seismic costs	$1,465	$19,893	
BCR, Replacement (Seismic)	0.018	1.791	
BCR, Total	0.250	1.833	

r=4%, 60 Years

Example Results - Redwood City

Existing Pipe	Replaced Pipe	Seismic Hazards	Recent Breaks	Corrosivity	BCR Aging	BCR Seismic	BCR Total
6" CIP, 90 yrs	6" HDPE	PGV, PGD	1	High	0.46	2.14	2.6
6" CIP, 90 yrs	6" PVC	PGV	1	High	0.46	0.1	0.56
2" GIP, 90 yrs	6" PVC	PGV	1	High	1.05	0.13	1.18
12" DIP, 30 yrs	12" PVC	PGV	0	High	0	0.05	0.05
8" CIP, 50 yrs	8" PVC	PGV	3	Mod	1.29	0.08	1.37
20" CCP, 40 yrs	20" WSP	PGV, PGD	0	High	0.002	0.643	0.644

Aging Benefit-Cost Ratio Results

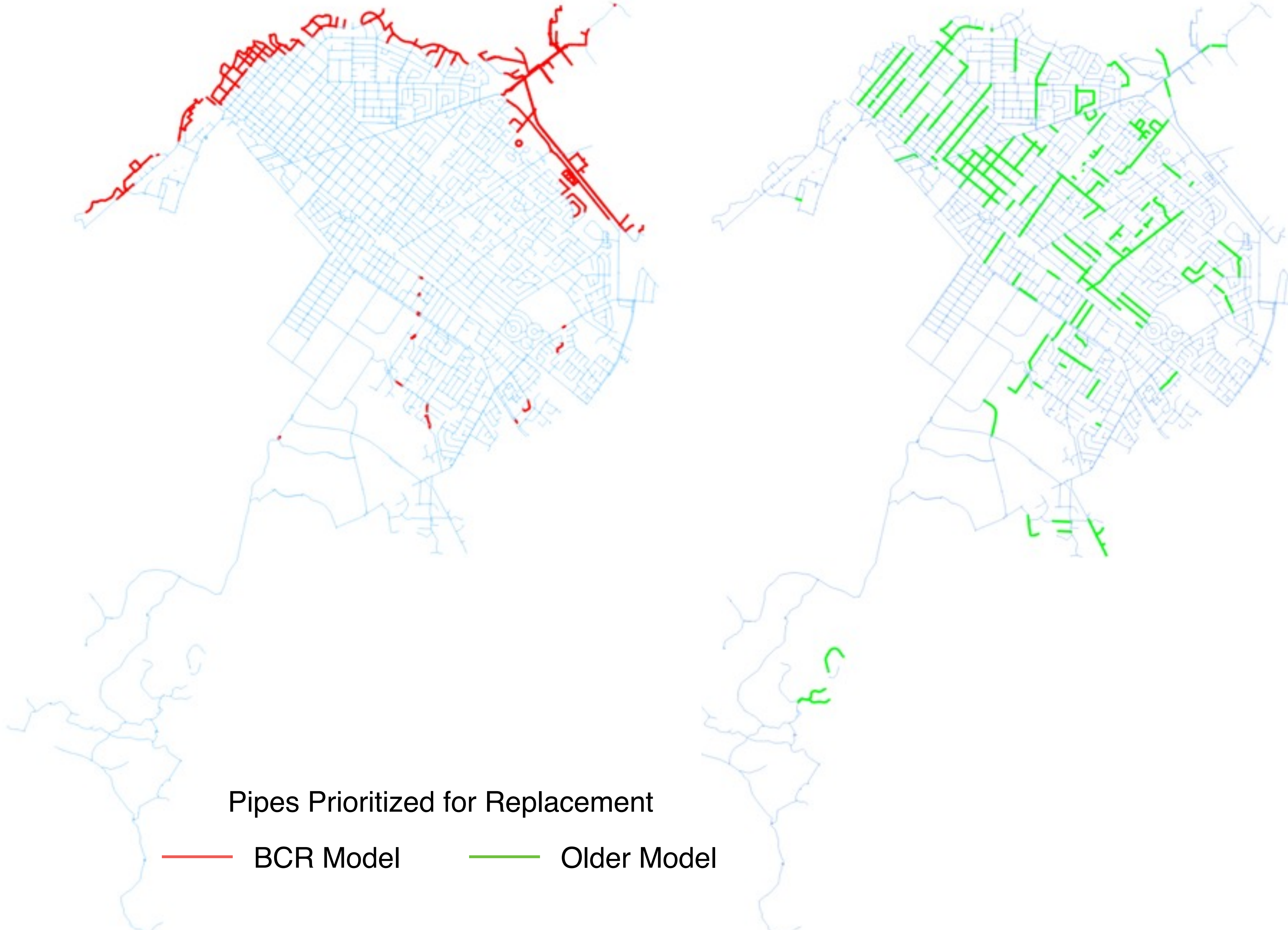


Palo Alto

Seismic + Aging Benefit-Cost Ratio Results

—	0.0-0.1
—	0.1-0.2
—	0.2-0.6
—	0.6-1.0
—	>1.0

Palo Alto



Comparison of BCR Model (Left) to Older Model (Right)

Conclusions

- Beyond the initial "break in" period, there is no observable trend that says older pipes leak “much” more often
- Seismic only: upgrade only the worst pipes in zones with PGDs and very high economic activity
- Aging Only: replace if 2 or more breaks in past 8+ years; otherwise, live with repairs
- Seismic + Aging. Rank Replacement Priority using BCR Model

Age Based Model

- After the "break in" period, there is no empirical evidence to say that ferrous pipes leak at a higher rate as they age
- "If it ain't broke, don't fix it"

South Napa M 6.0 Earthquake of August 24, 2014

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Revision 1
March 17, 2015

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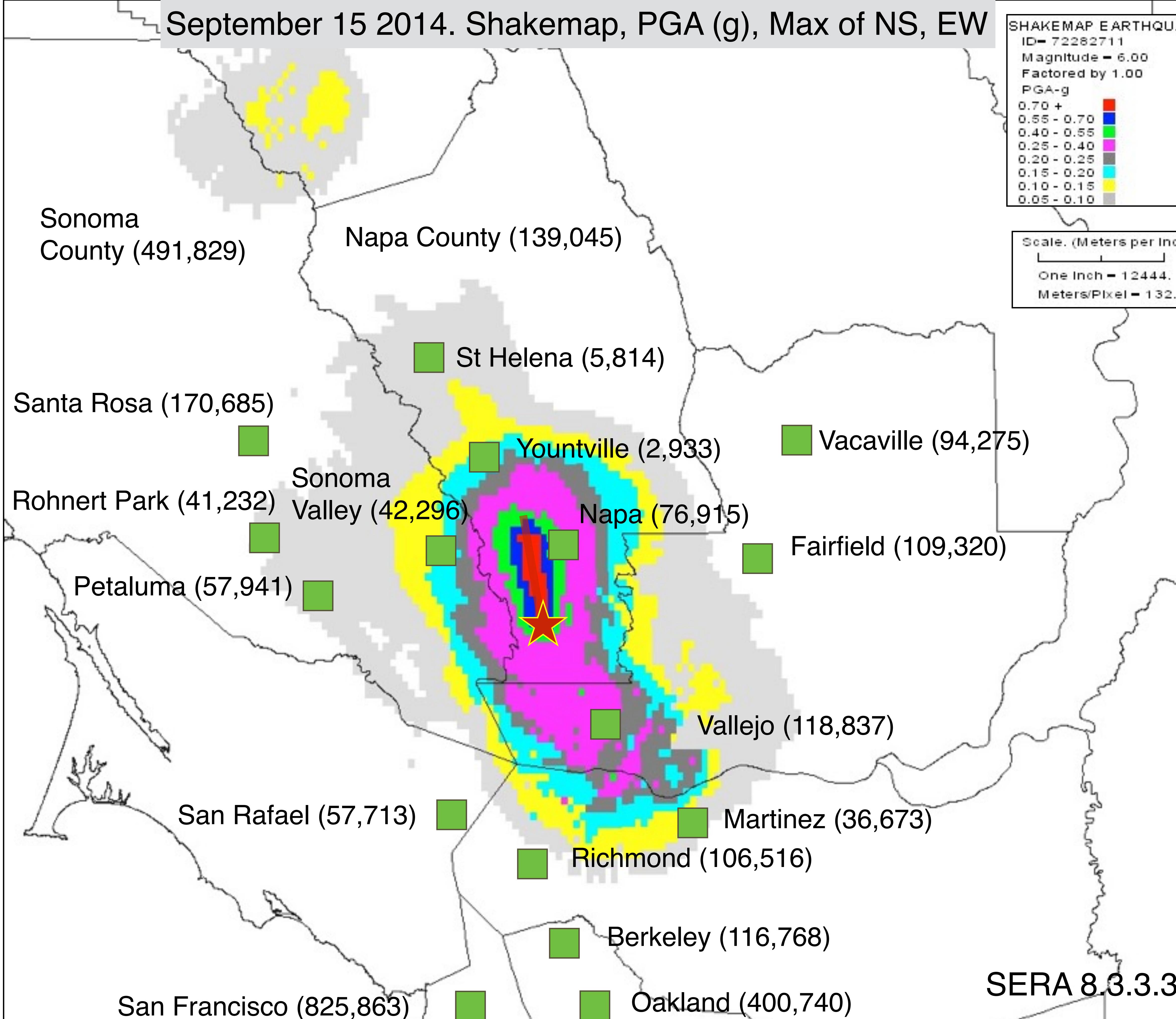
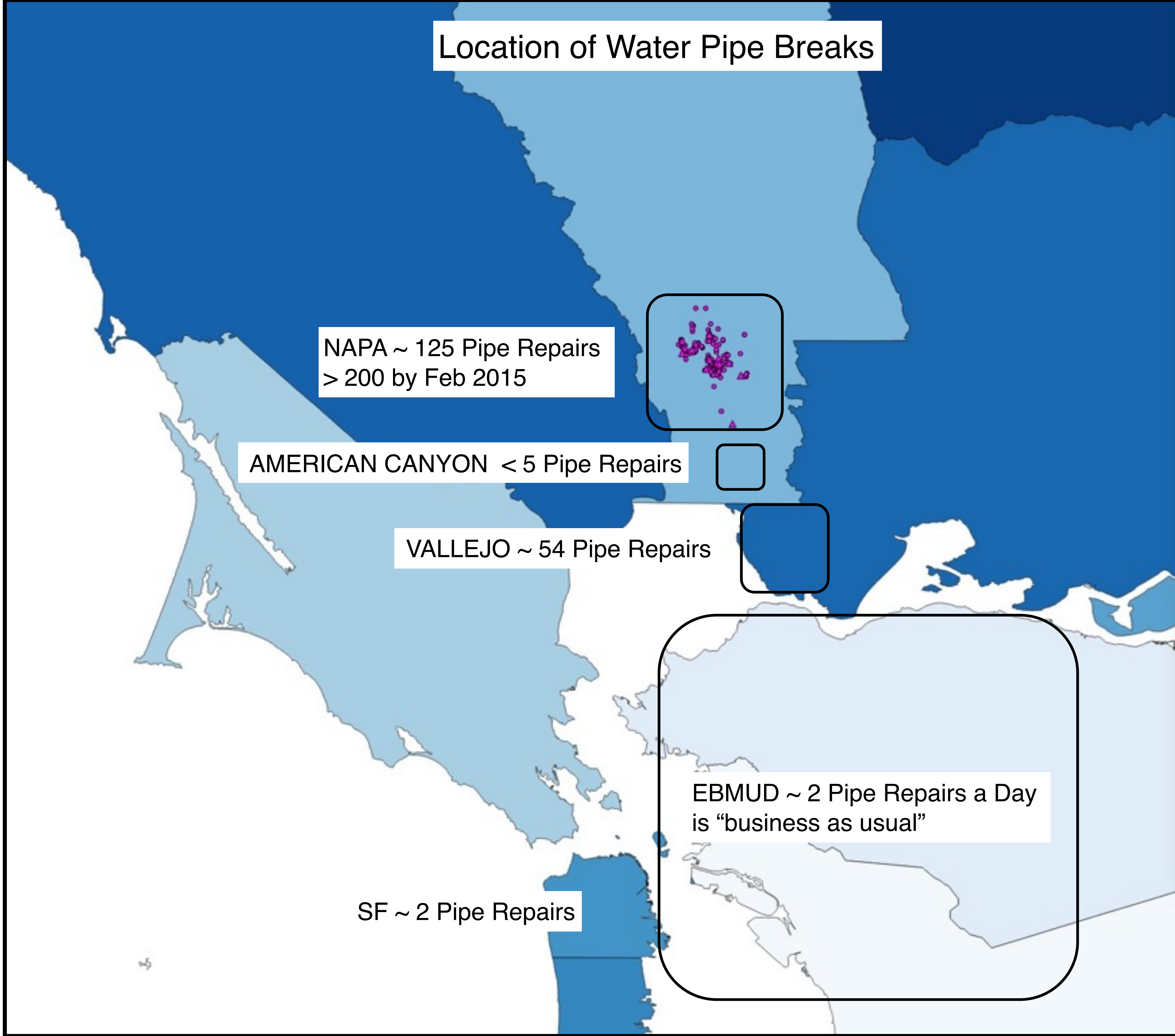
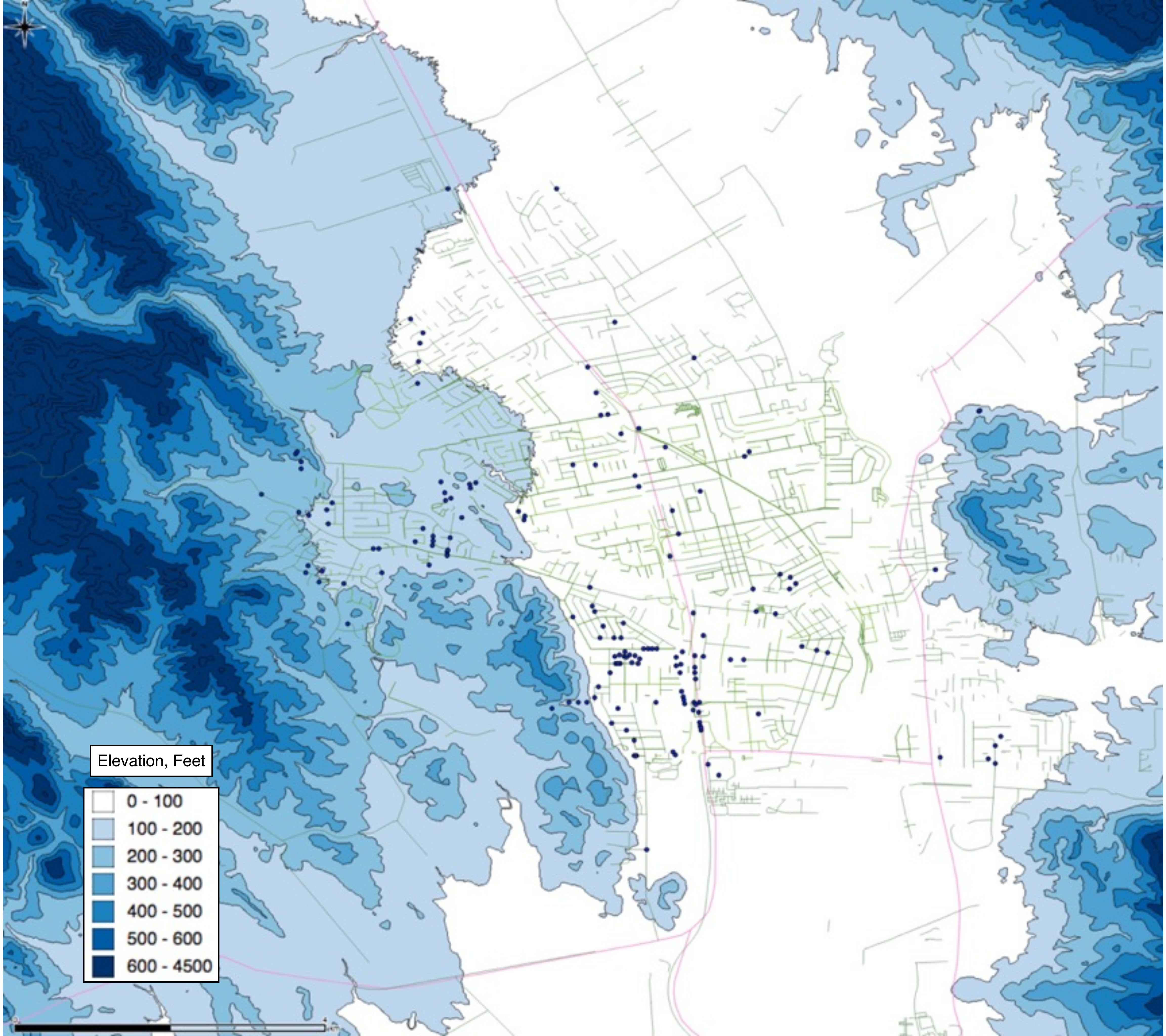

September 15 2014. Shakemap, PGA (g), Max of NS, EW
SHAKEMAP EARTHQUAKE
ID= 72282711
Magnitude = 6.00
Factored by 1.00
PGA-g
0.70 +
0.55 - 0.70
0.40 - 0.55
0.25 - 0.40
0.20 - 0.25
0.15 - 0.20
0.10 - 0.15
0.05 - 0.10
Scale. (Meters per Inch)
One Inch = 12444.
Meters/Pixel = 132.
Sonoma County (491,829)
Napa County (139,045)
St Helena (5,814)
Santa Rosa (170,685)
Yountville (2,933)
Vacaville (94,275)
Sonoma Valley (42,296)
Rohnert Park (41,232)
Napa (76,915)
Fairfield (109,320)
Petaluma (57,941)
Vallejo (118,837)
San Rafael (57,713)
Martinez (36,673)
Richmond (106,516)
Berkeley (116,768)
San Francisco (825,863)
Oakland (400,740)
SERA 8.3.3.3


Location of Water Pipe Breaks
NAPA ~ 125 Pipe Repairs
> 200 by Feb 2015
AMERICAN CANYON < 5 Pipe Repairs
VALLEJO ~ 54 Pipe Repairs
EBMUD ~ 2 Pipe Repairs a Day
is “business as usual”
SF ~ 2 Pipe Repairs


Elevation, Feet
0 - 100
100 - 200
200 - 300
300 - 400
400 - 500
500 - 600
600 - 4500


CITY OF NAPA
STREETS

Tank “B”

SALT LAKE CITY, UTAH PUBLIC UTILITIES

CITY of NAPA

Tank "B"

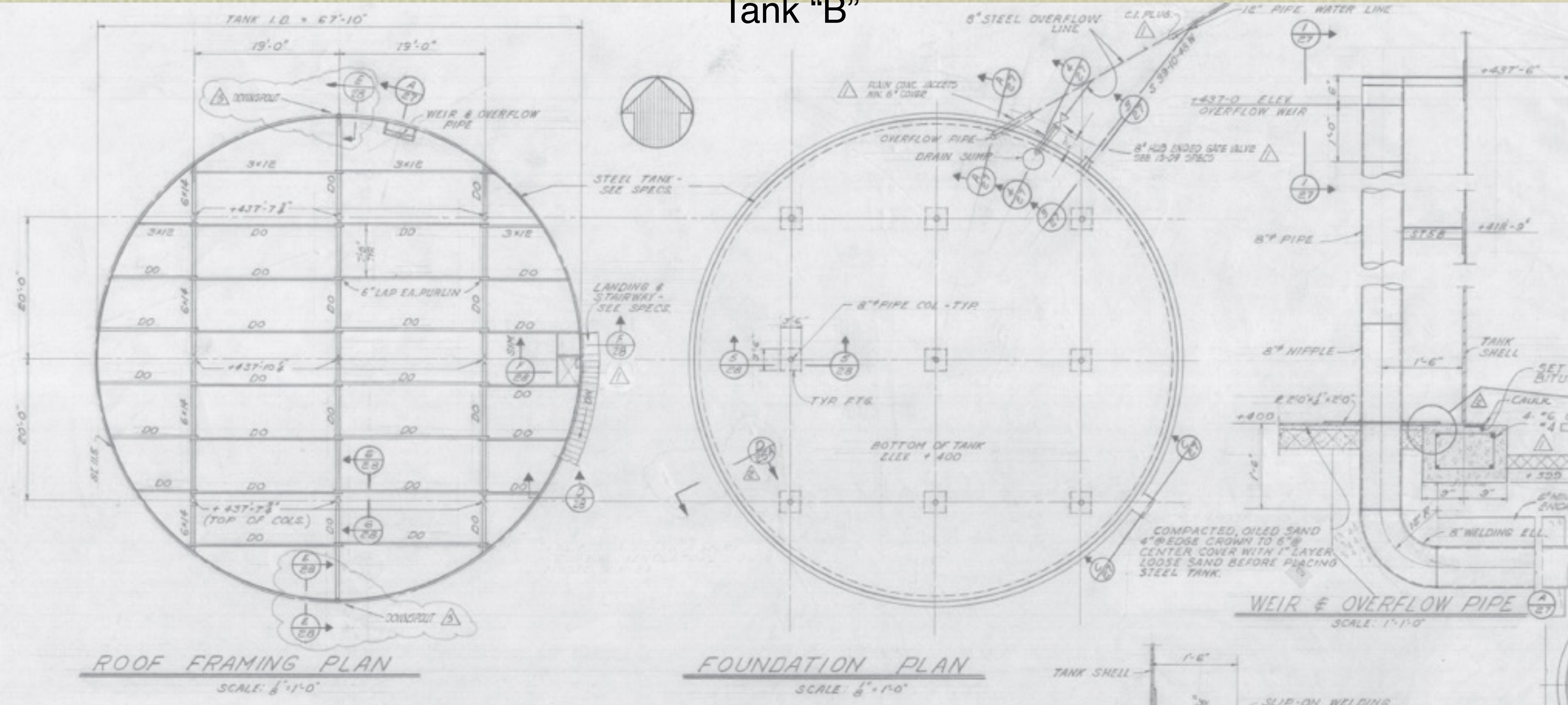
CITY of NAPA

Tank “B”

CITY of NAPA

Tank “B” After Roof is Replaced

Tank “B”



Unanchored Steel Tank

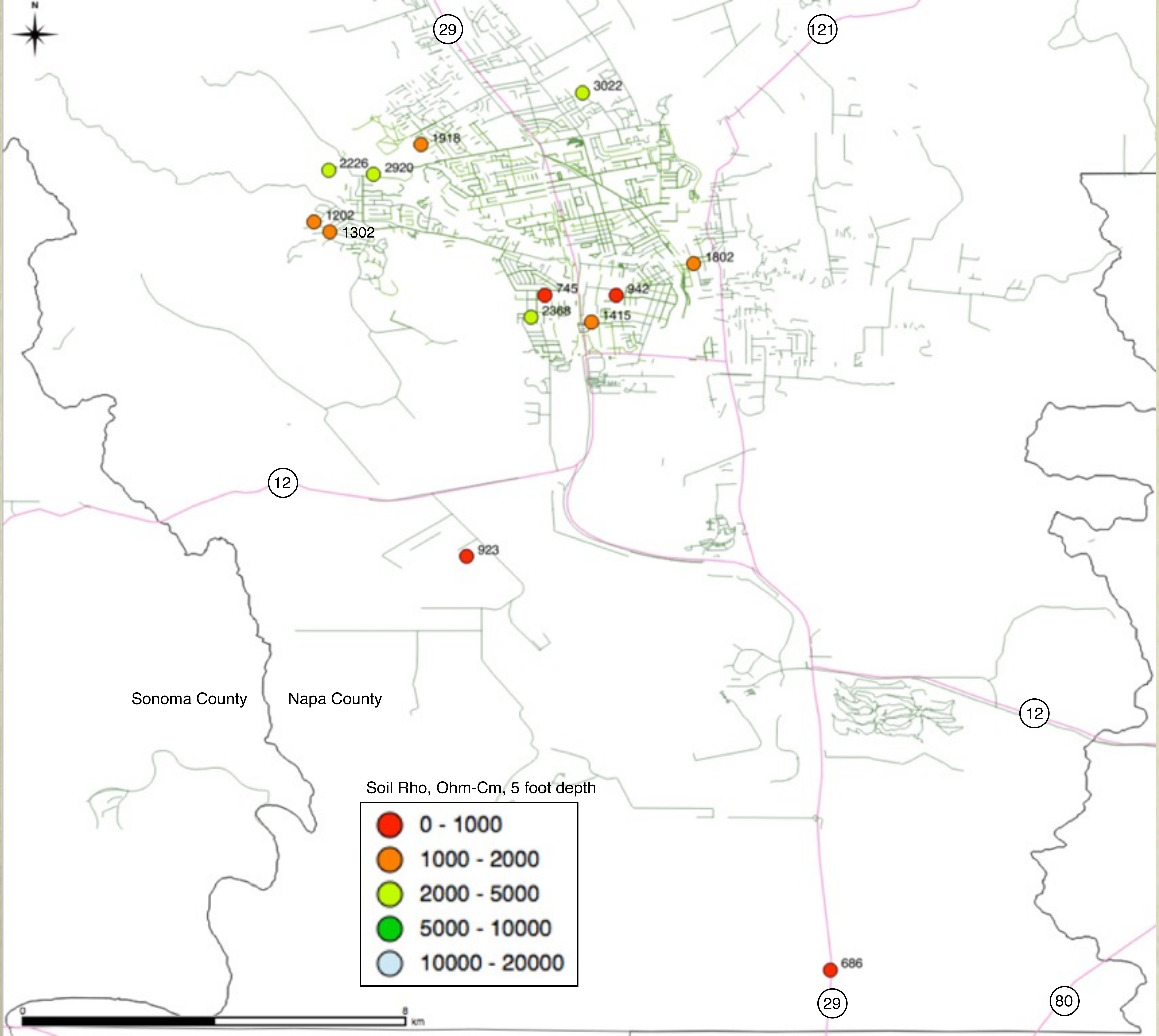
Design by Pat Creegan, 1960 of Creegan and D’Angelo. C&D SF Office closed in 2015, RIP.

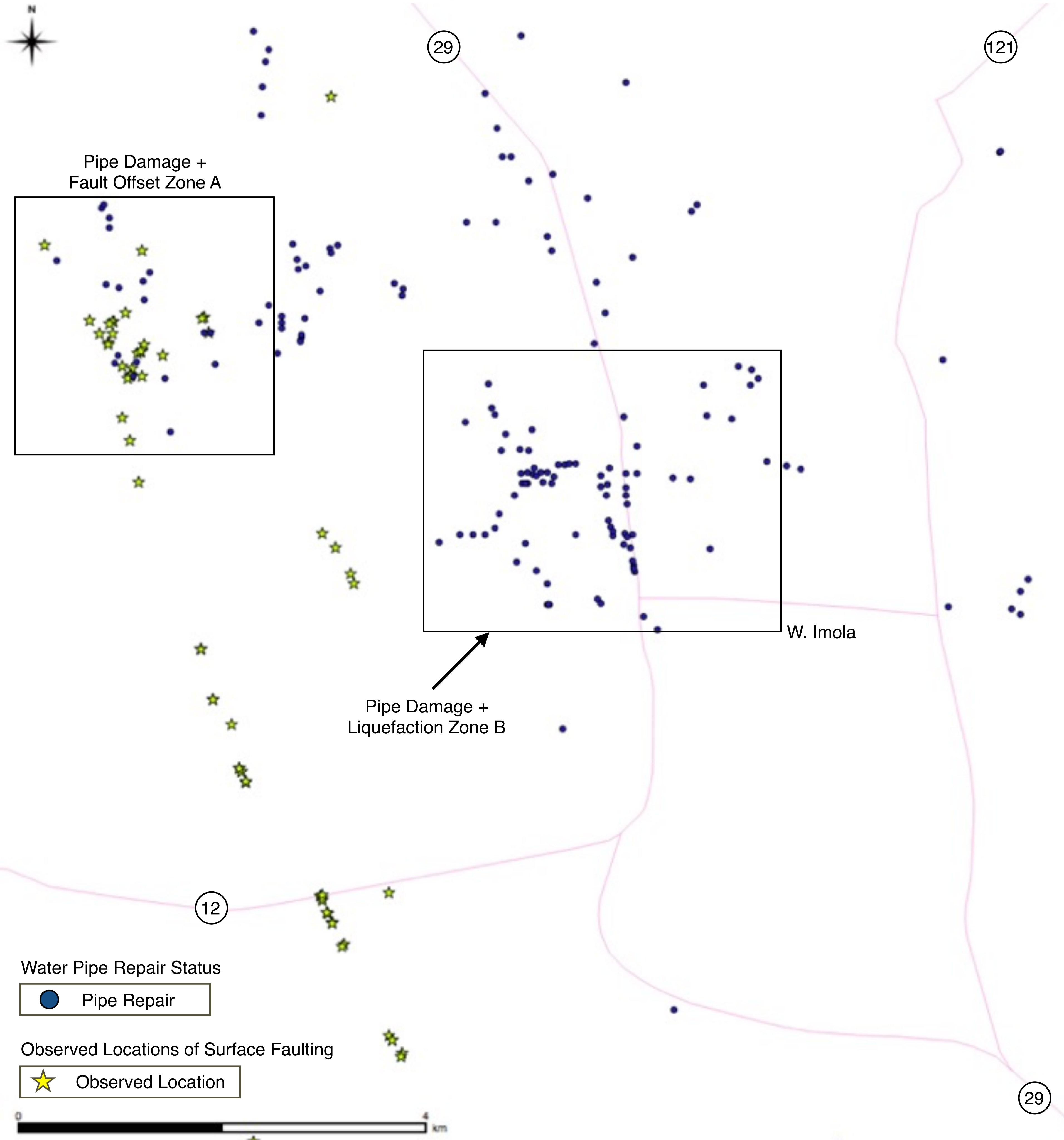
(Pat thought “R” is real… but it is not. See Paper on Magic R for steel tanks)

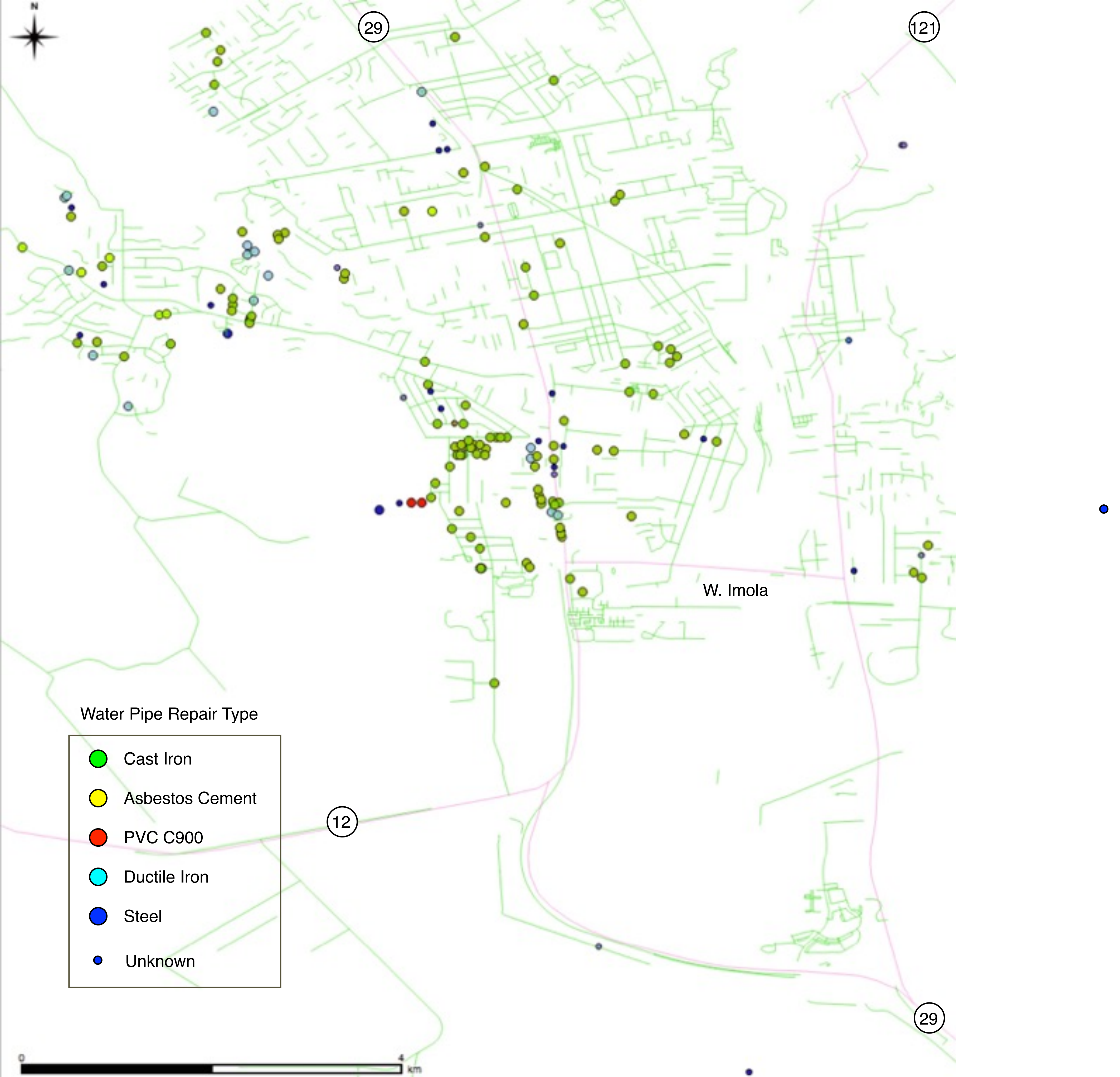
No Seismic Design Concepts

EBAA Flextend had been previously installed for Inlet-outlet pipe (good thing, BUT…)

- The outlet pipe broke in the street, so the tank drained anyways (missed the big picture)
- The Roof was damaged due to water sloshing and tank wall uplift (who cares, FEMA pays)
- Napa replaced the roof
- Then, Napa wanted to “raise” the roof top repvent future roof damage (IMHO, a waste of $$)

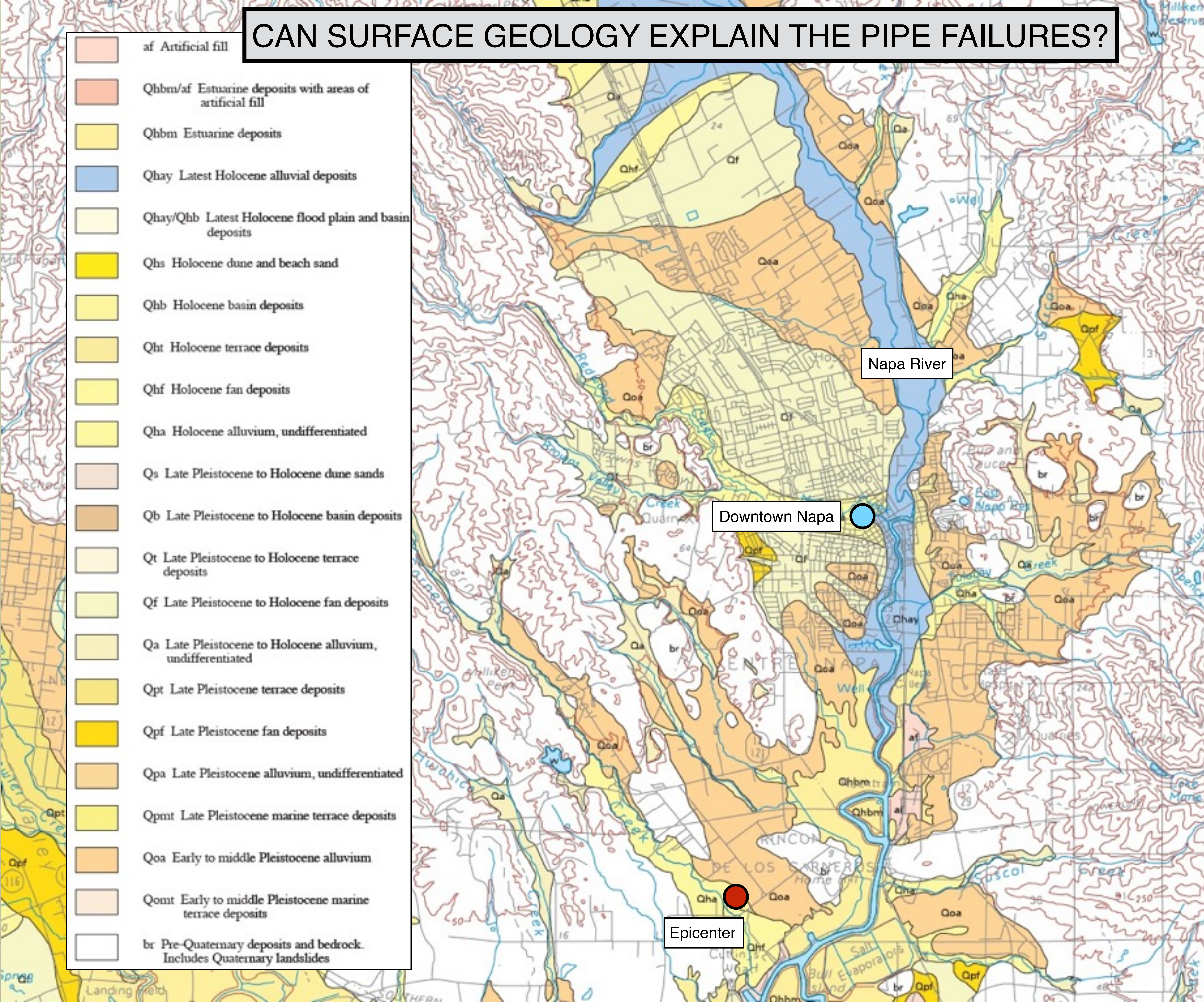

N
29
121
3022
1918
2226
2920
1202
1302
1802
745
942
2368
1415
12
923
Sonoma County
Napa County
12
Soil Rho, Ohm-Cm, 5 foot depth
0 - 1000
1000 - 2000
2000 - 5000
5000 - 10000
10000 - 20000
686
29
80
0
8
km


N
29
121
Pipe Damage +
Fault Offset Zone A
W. Imola
Pipe Damage +
Liquefaction Zone B
12
29
Water Pipe Repair Status
Pipe Repair
Observed Locations of Surface Faulting
Observed Location
0
4
km



N
29
121
W. Imola
12
29
Water Pipe Repair Type
Cast Iron
Asbestos Cement
PVC C900
Ductile Iron
Steel
Unknown
0
4
km

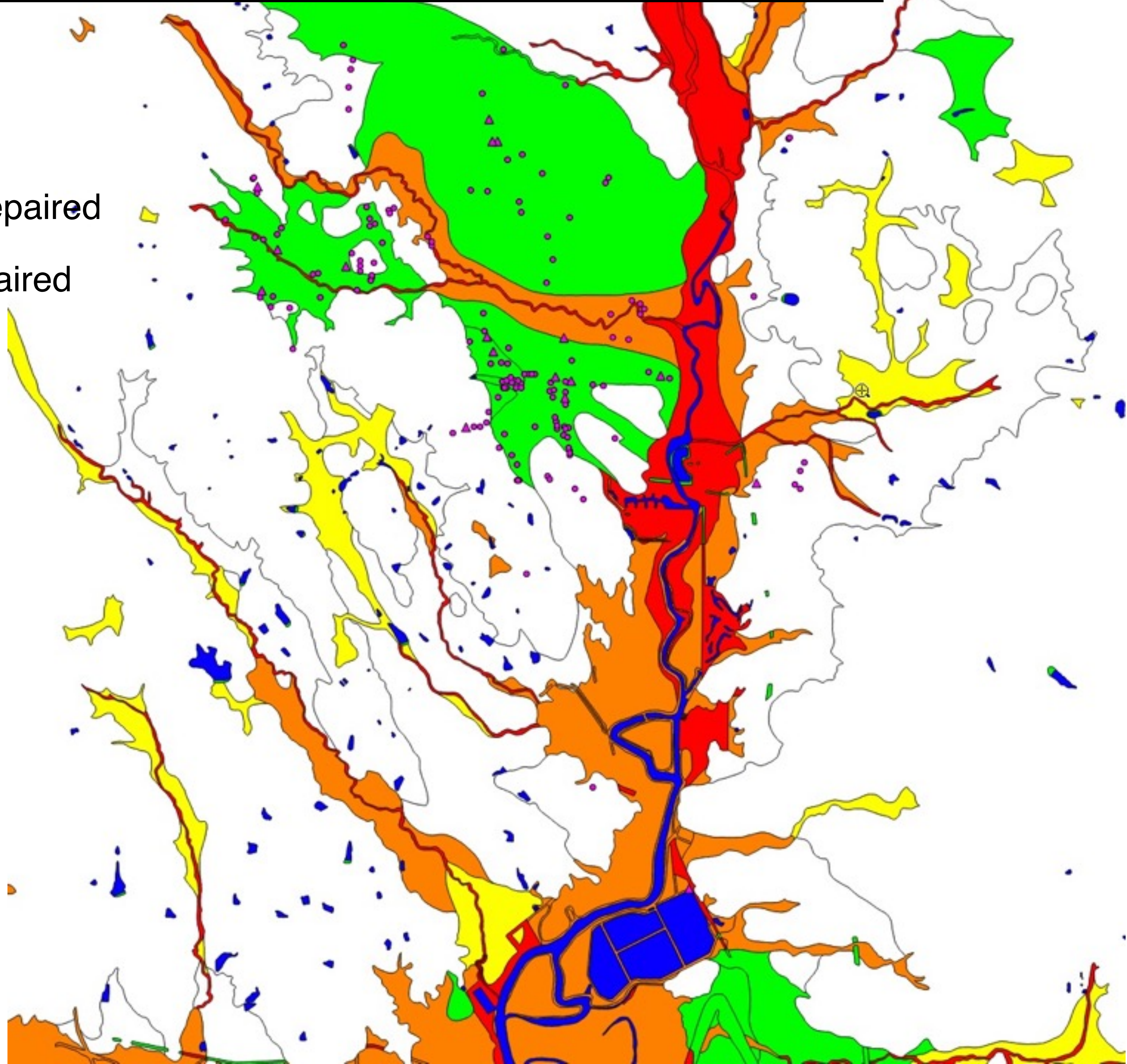
CAN SURFACE GEOLOGY EXPLAIN THE PIPE FAILURES?



CAN LIQUEFACTION EXPLAIN THE PIPE FAILURES?

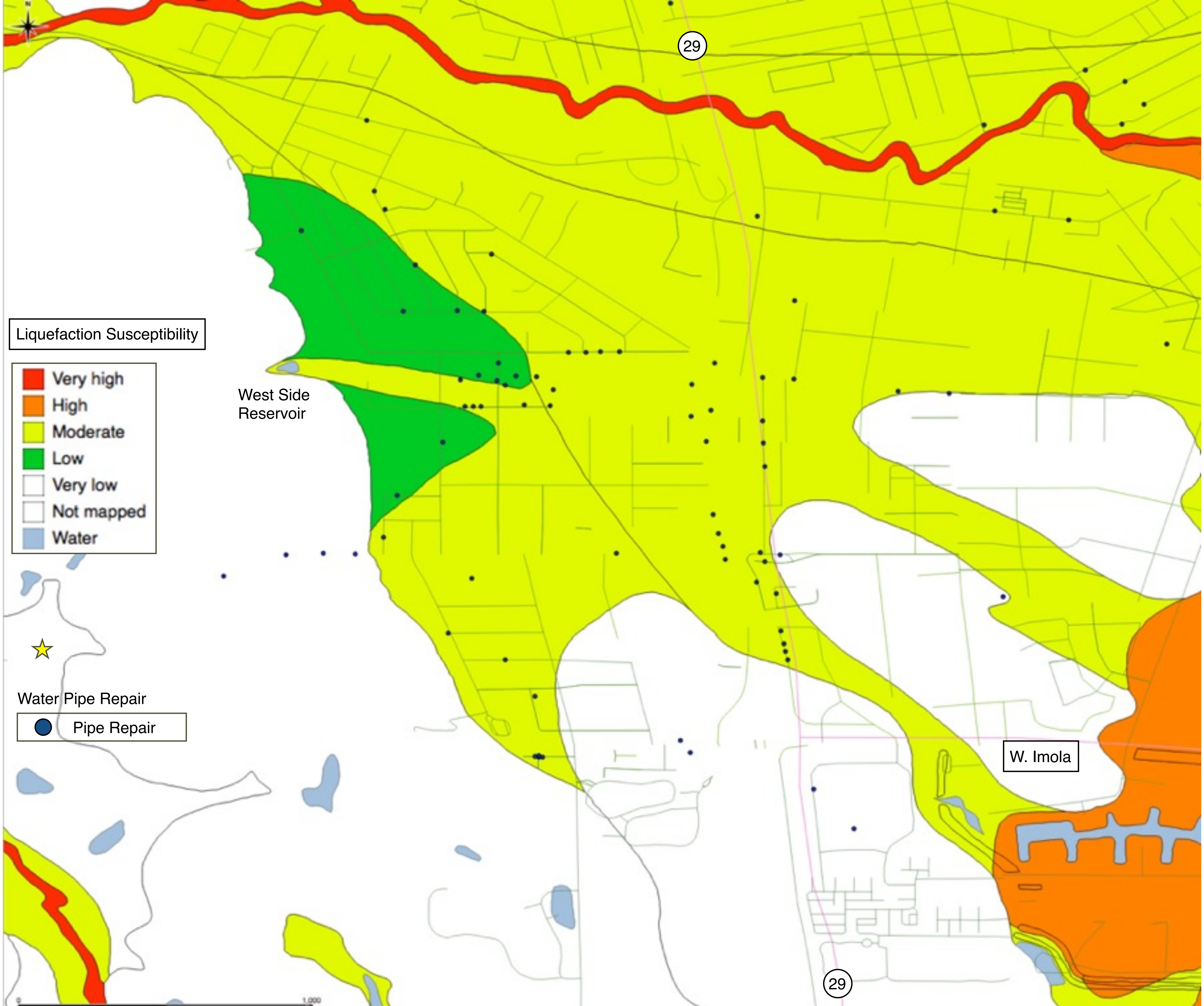
● Pipes Already Repaired

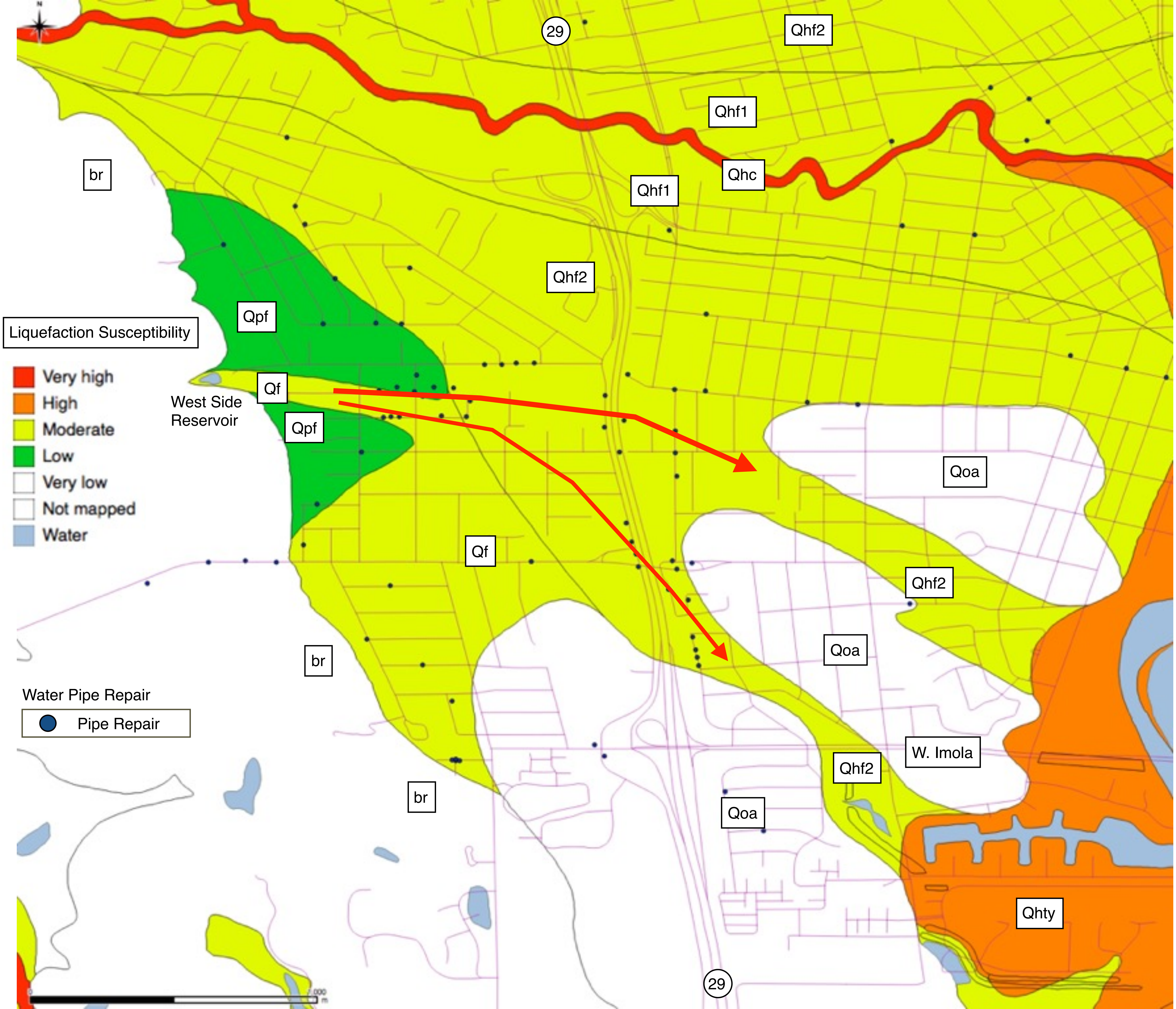
▲ Pipes To Be Repaired



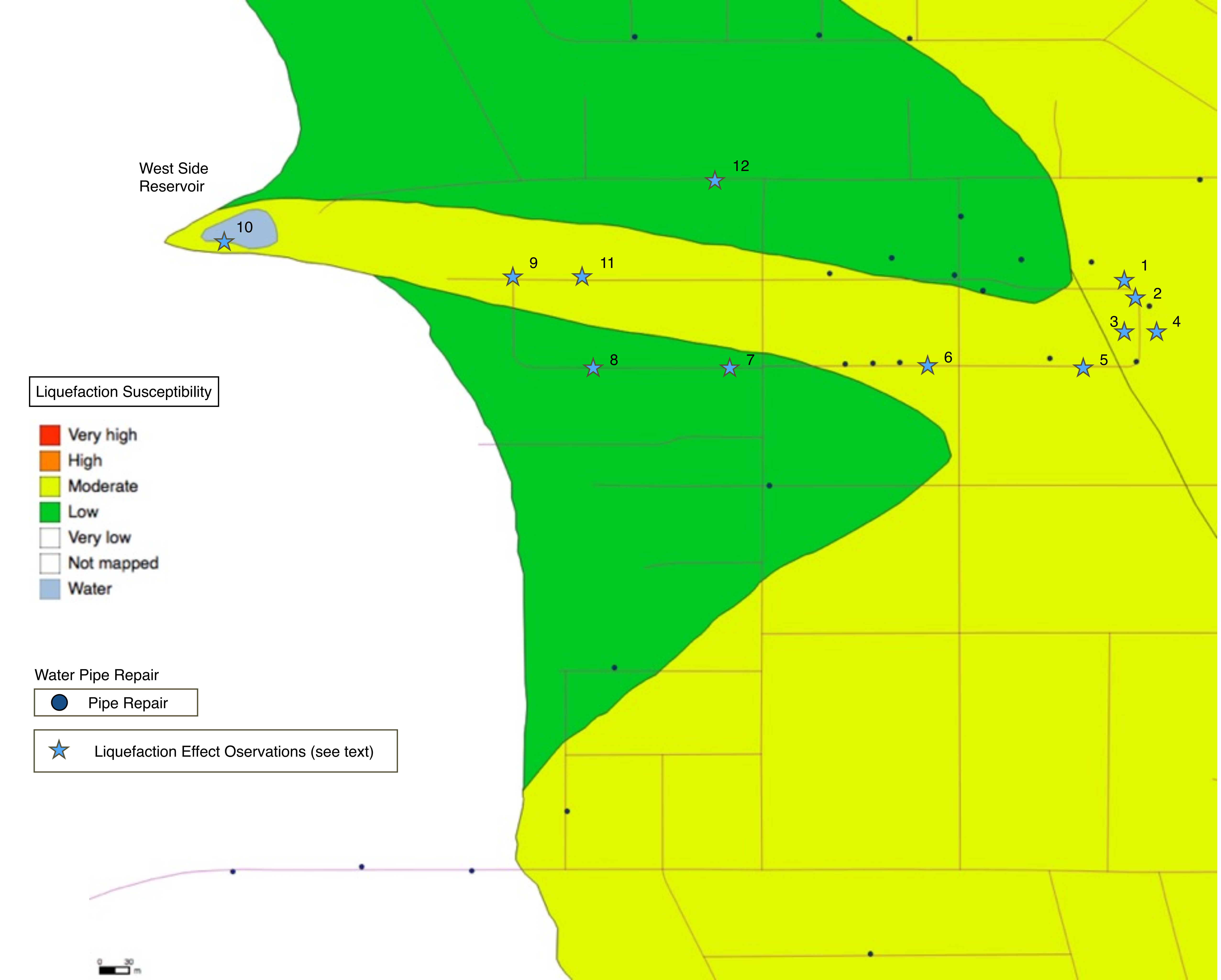
Liquefaction Susceptibility

- VH
- H
- M
- L
- VL
- W


29
Liquefaction Susceptibility
Very high
High
Moderate
Low
Very low
Not mapped
Water
West Side
Reservoir
Water Pipe Repair
Pipe Repair
W. Imola
29



Liquefaction Susceptibility
Very high
High
Moderate
Low
Very low
Not mapped
Water
Water Pipe Repair
Pipe Repair
West Side
Reservoir
29
Qhf2
Qhf1
Qhc
br
Qpf
Qf
Qoa
W. Imola
Qhty


West Side Reservoir
1
2
3
4
5
6
7
8
9
10
11
12
Liquefaction Susceptibility
Very high
High
Moderate
Low
Very low
Not mapped
Water
Water Pipe Repair
Pipe Repair
Liquefaction Effect Oservations (see text)


Location 1. Hilltop Drive
Residential Construction
1950s Vintage
Road Entirely Resurfaced After September 2014
Pipe Repair Post October 2014

Location 2. Mannering Street
Residential Construction
1950s Vintage
Road Entirely Resurfaced After September 2014
Pipe Repairs Post October 2014


Location 3. Mannering Street
Unreinforced concrete patio
Cracks due to differential settlements

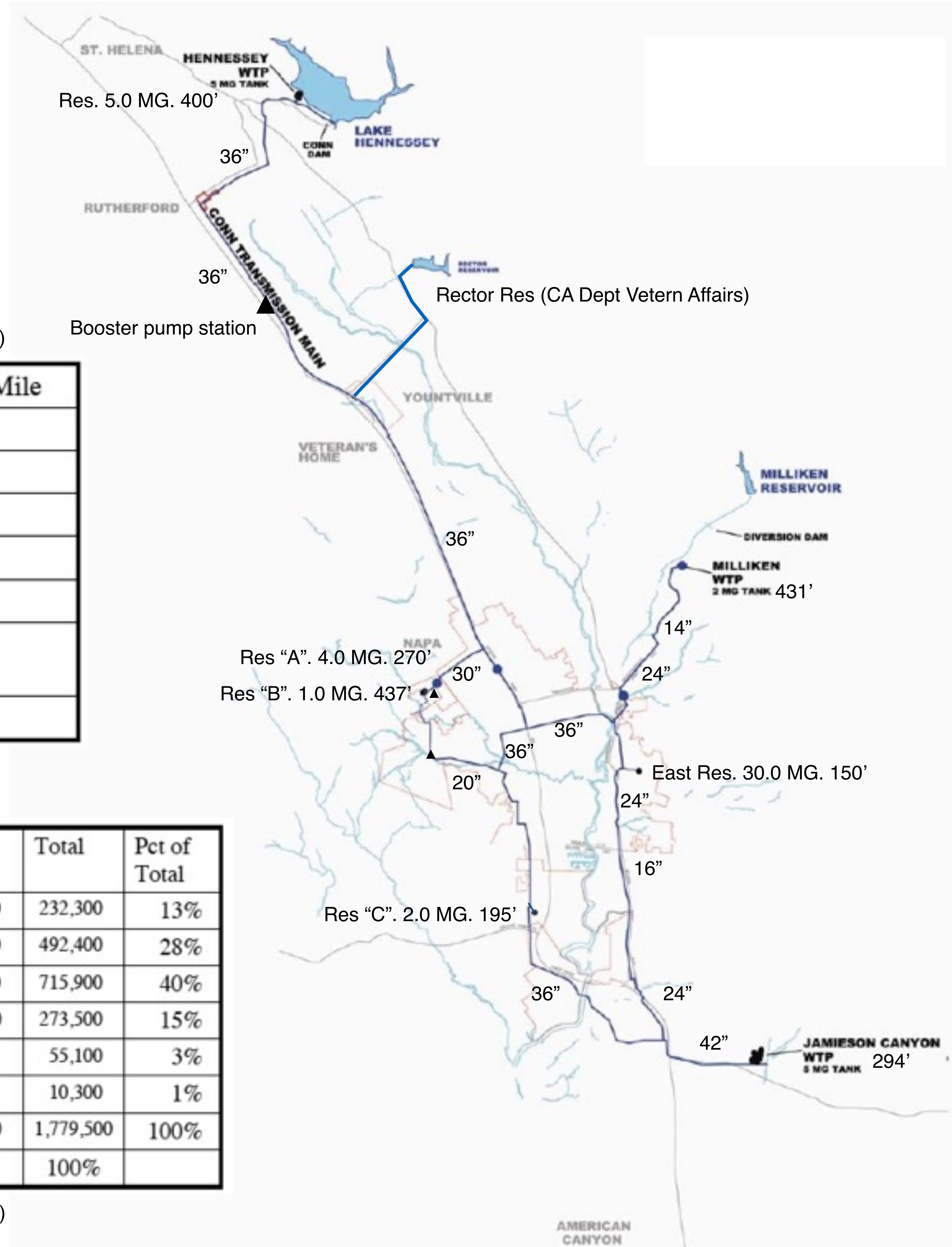
Total Pipe Repairs, By Sept 15 2015 (add 50% Sept-Jan 2015)

Material	Repairs	% Repairs	% Pipe	Repair per Mile
AC	8	5%	10%	0.23
PVC	2	1%	2%	0.34
CI	123	75%	44%	0.82
DI	18	11%	34%	0.16
Steel	3	2%	9%	0.10
Other / unk	7	4%		
Total	163	100%		

Total Pipe Length, 337 Miles

Age (years)	PVC	DI	CI	AC	RCCP	STL	Total	Pct of Total
< 20	6,600	225,600				100	232,300	13%
20-40	24300	370,500	83,400	14,100		100	492,400	28%
40-60		12,300	466,700	167,200	9,900	59,800	715,900	40%
60-80			173,100			100,400	273,500	15%
80-100			55,100				55,100	3%
> 100			10,300				10,300	1%
Total	30,900	608,400	788,500	181,300	9,900	160,400	1,779,500	100%
	2%	34%	44%	10%	1%	9%	100%	

Length of Pipe in Napa Water System (2012, feet)



Breakdown of actual pipe damage in Napa Earthquake

Pipe Type	Length, System-wide (miles)	Repairs due to Shaking (PGV)	Repairs due to Liquefaction (PGD)	Repairs due to Surface Faulting (PGD)	Total Repairs, August 24 to Sept 15 2014
AC	34.34	2	0	5	7
CI	149.34	86	19	5	110
DI	115.23	8	4	5	17
PVC	5.85	2	0	0	2
STL	30.38	2	0	0	2
RCCP	1.88	0	0	0	0
UNK		22	0	3	25
Total	337.01	122	23	18	163

Breakdown of pipe damage in Napa Earthquake due to Shaking (no liquefaction, no surface faulting)

Pipe Type	Length, System-wide (miles)	Actual Repairs due to Shaking	Forecast Repairs due to Shaking
AC	34.34	2	2.4
CI	149.34	86	88.5
DI	115.23	8	12.3
PVC	5.85	2	0.4
STL	30.38	2	5.0
RCCP	1.88	0	0.1
UNK		22	
Total	337.01	122	108.8

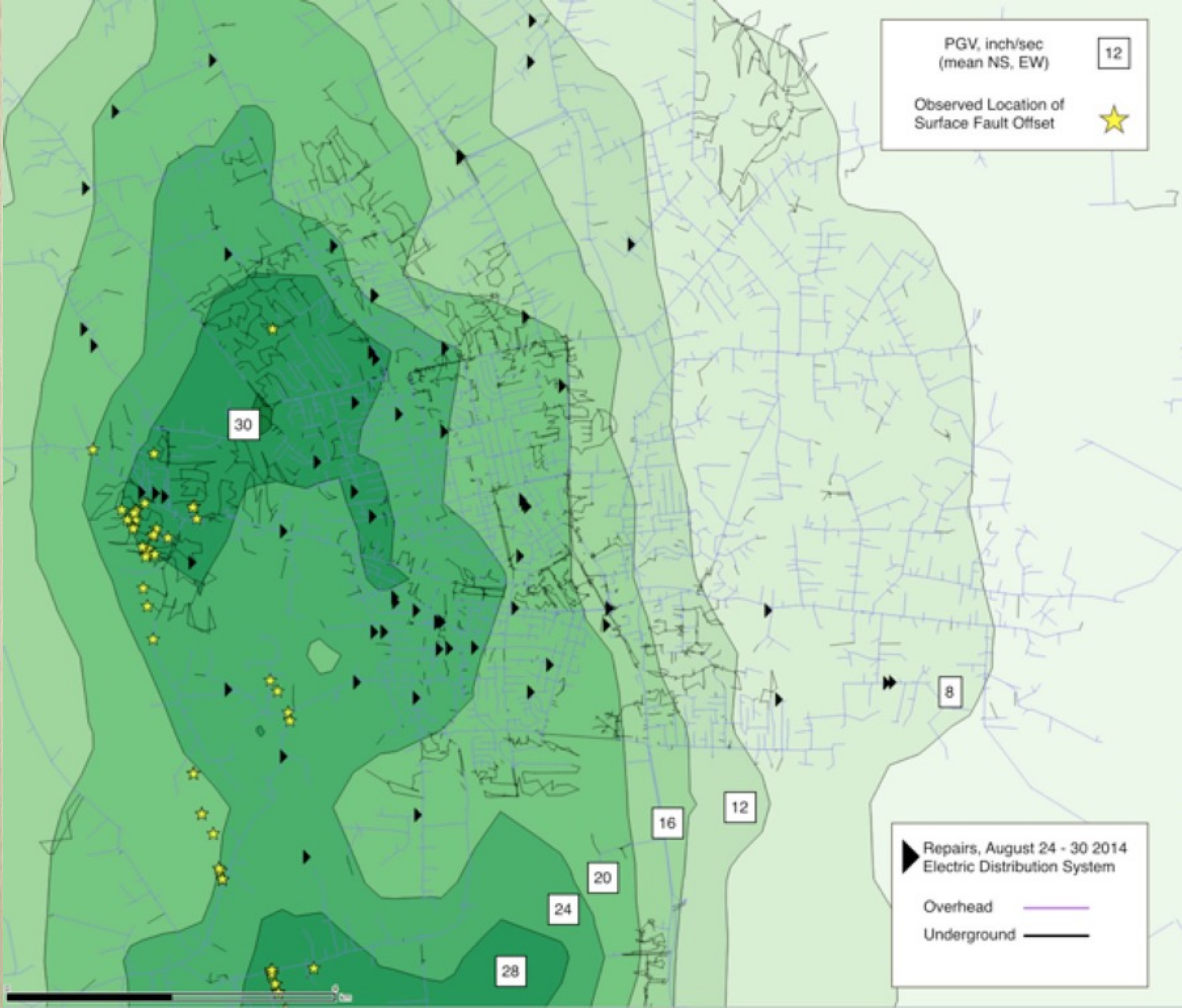
With 2015-vintage Seismic Models
including effects of Rho, corrosion

Breakdown of pipe damage in Napa Earthquake due to Liquefaction

Pipe Type	Length, System-wide (miles)	Actual Repairs due to Liquefaction	Forecast Repairs due to Liquefaction
AC	34.34		
CI	149.34	19	21.2
DI	115.23	4	4.3
PVC	5.85		
STL	30.38		
RCCP	1.88		
UNK		0	
Total	337.01	23	25.5

With 2015-vintage Seismic Models
including effects of Rho, corrosion

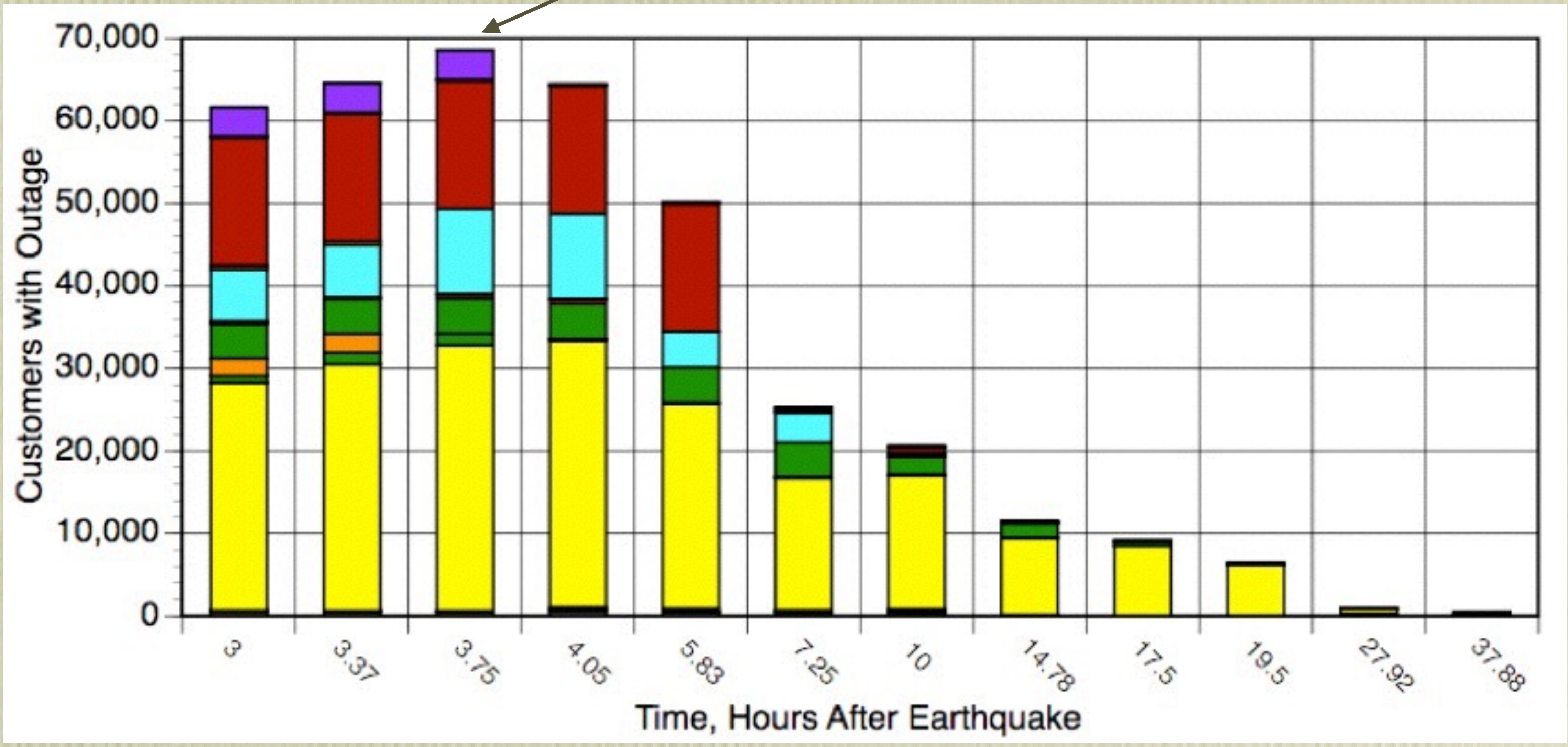
PG&E Power Outages



PGV, inch/sec
(mean NS, EW)
12
Observed Location of
Surface Fault Offset
30
8
12
16
20
24
28
Repairs, August 24 - 30 2014
Electric Distribution System
Overhead
Underground

PG&E Customers without Power

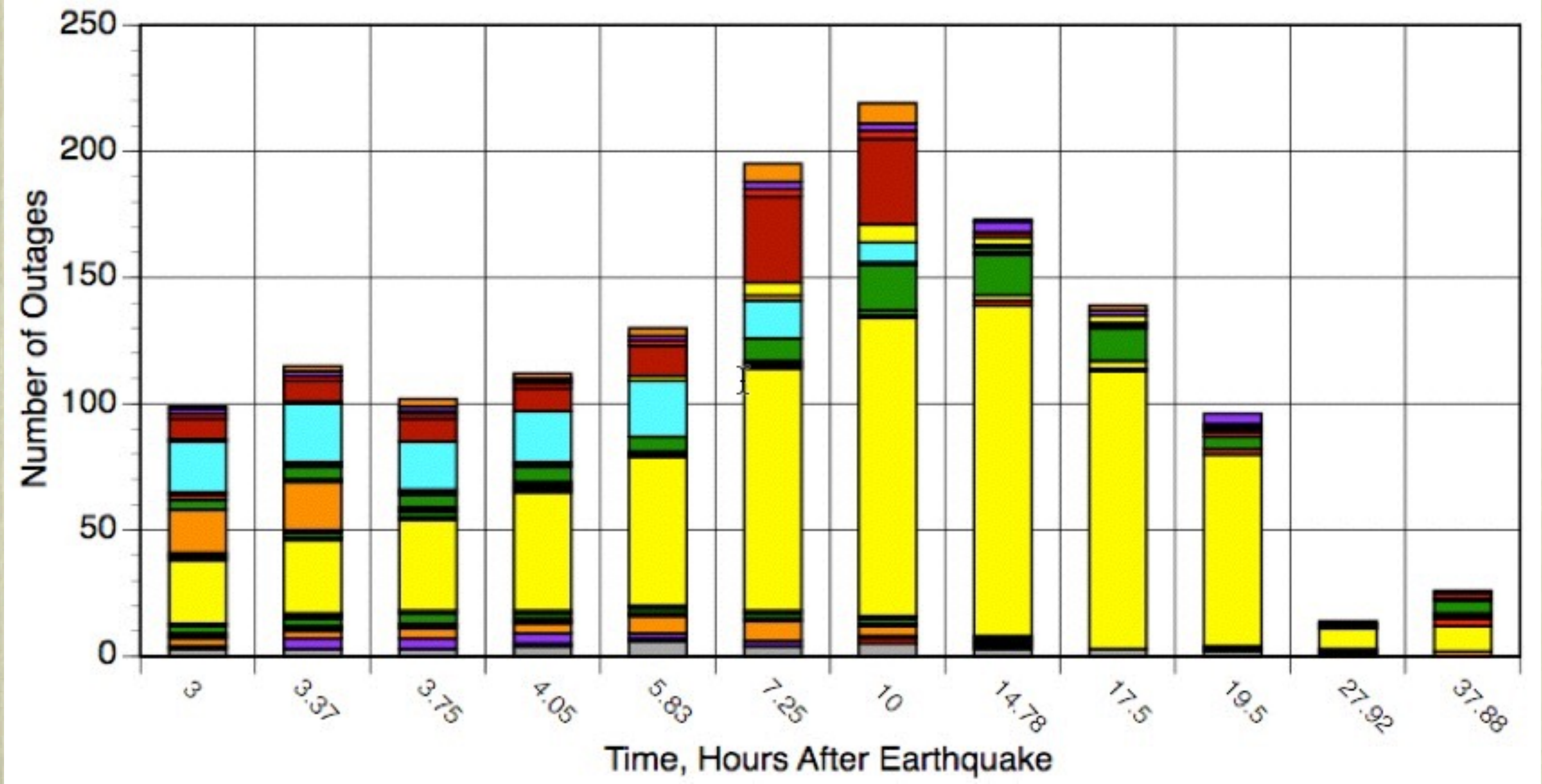
1.4% of PG&E's 5,100,000 Customers



Yellow: Napa
Orange: Rohnert Park
Green: Saint Helena
Cyan: Santa Rosa

Red: Sonoma Valley
Grey: American Canyon
Blue: Vallejo

Number of Power Outages
(number of faulted feeders, or part thereof)



Yellow: Napa
Orange: Rohnert Park
Green: Saint Helena
Cyan: Santa Rosa

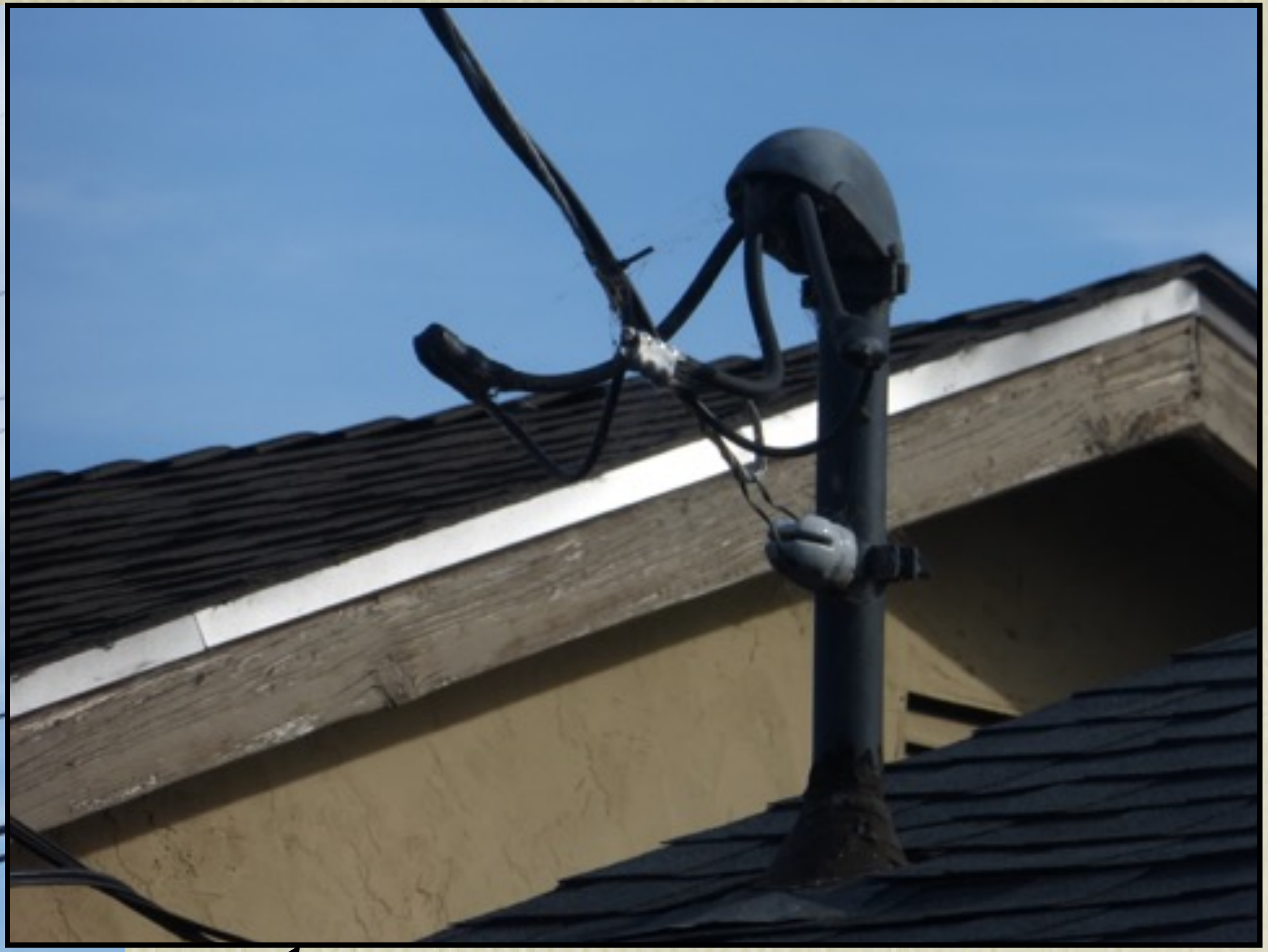
Red: Sonoma Valley
Grey: American Canyon
Blue: Vallejo

PG&E Power Outages

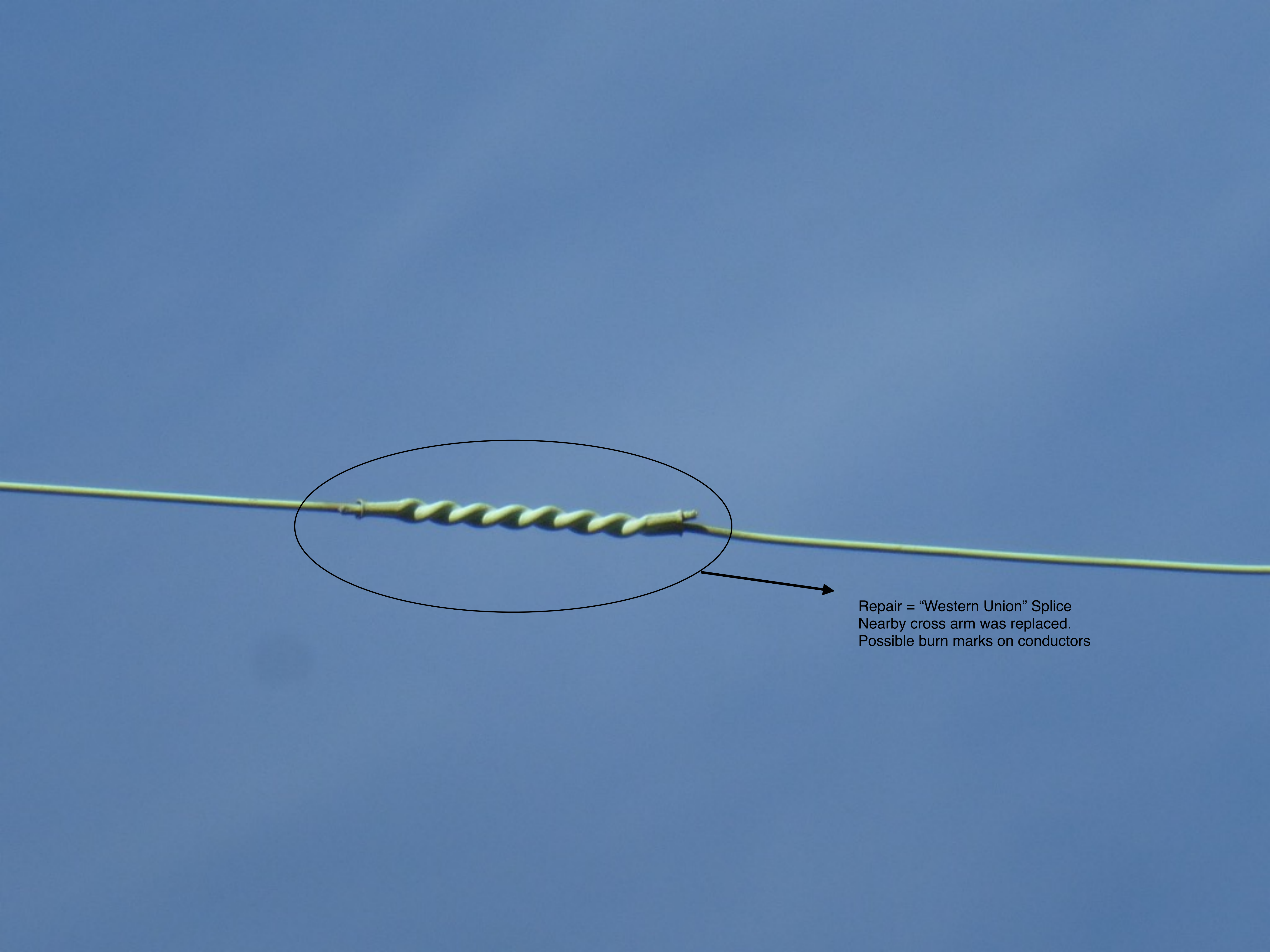
- High Voltage Transmission. Most had been seismic upgraded between 2000 and 2012, many $millions. **No material damage. No outages**.
- Low Voltage Distribution. Pretty good performance (**127 repairs, 37 hour restoration**). Why? Lessons learned in 1952 led PG&E to modify the way transformers are attached to wood poles: all through bolted, none on cross arms, none resting on platforms. Big repair crew (nothing else happening).

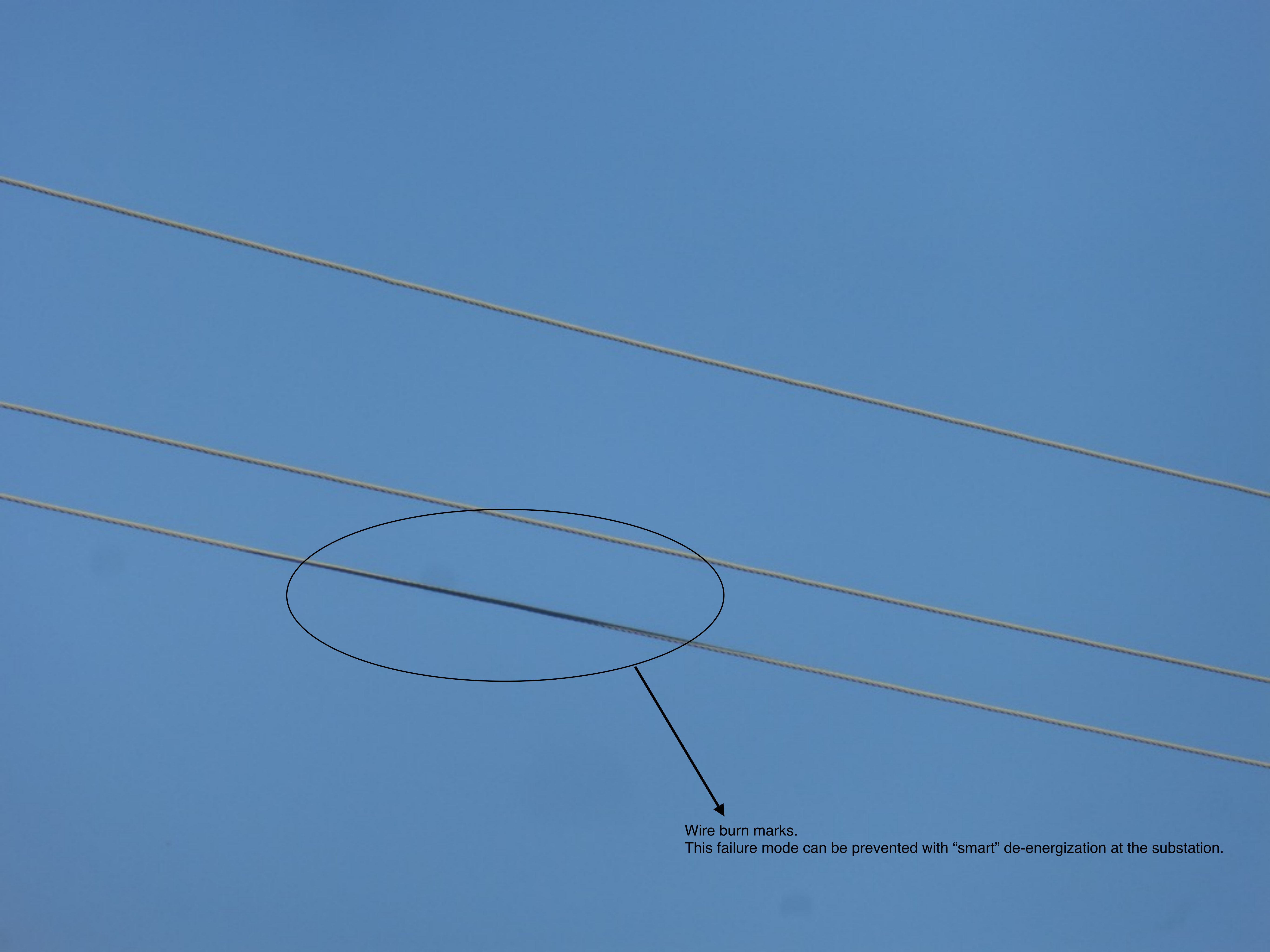
PG&E Distribution Damage

Repair Item	Total Manhours	Number of Repair Items	Average Manhours per Repair Item
Conductor	1147	68	17
Connector	42	4	11
Cross Arm	247	12	21
Cutout	41	3	14
Enclosure, Lid, Frame	24	1	24
Guy	45	6	8
Hardware / Framing	34	3	11
Insulator	42	3	14
Jumper	81.5	8	10
Switch / J-Box	21	1	21
Tie Wire	25	2	12
Transformer, Regulator Booster (OH)	630	8	79
Transformer Pad mount (UG)	28	2	14
Transformer Subsurface (UG)	71	2	36
Logistics	2000	4	500
Grand Total	4478.5	127	35



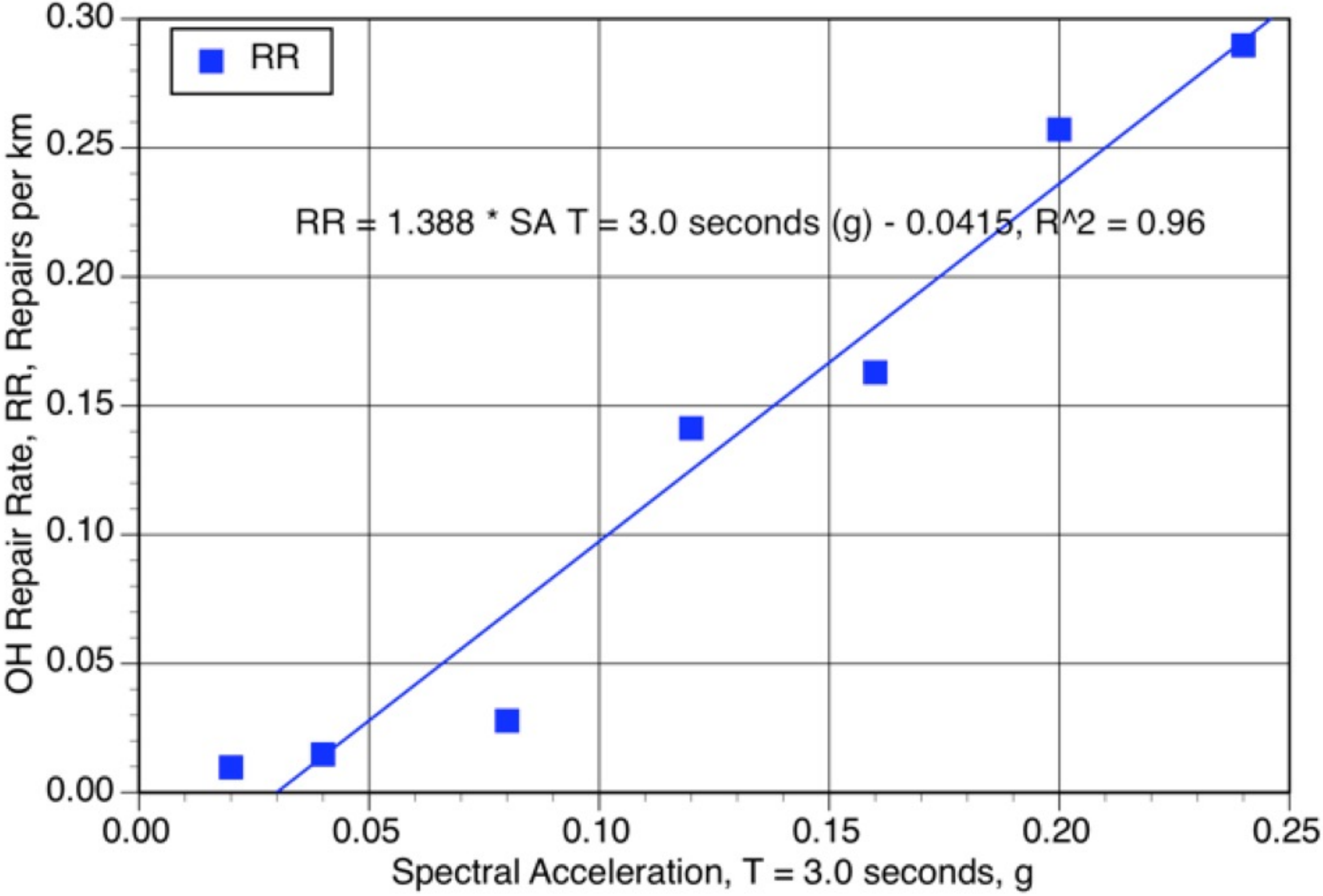
Swaying of pole and inadequate slack on secondary line drop to house led to failure of the insulator connection on the house.

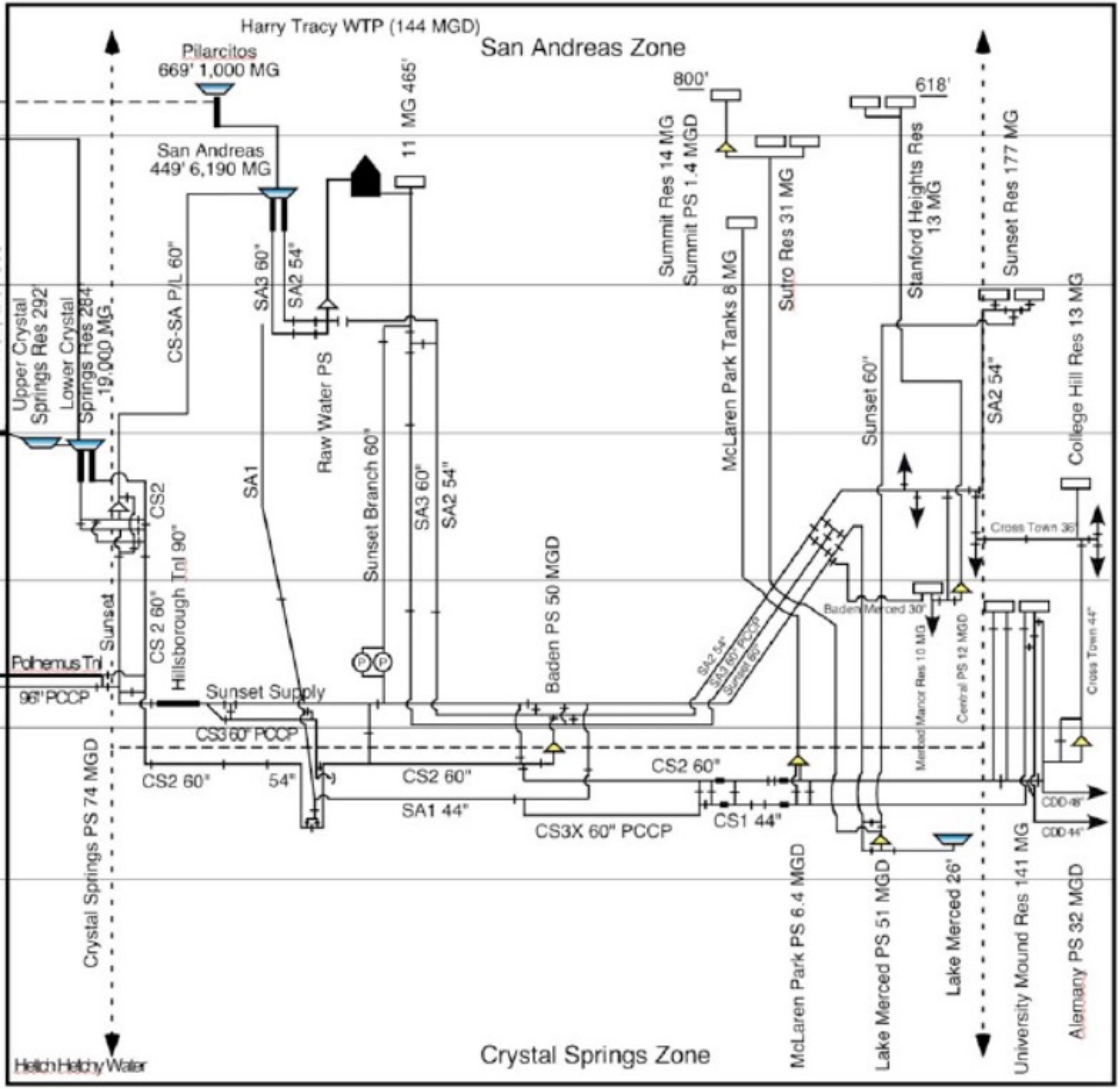

Repair = “Western Union” Splice
Nearby cross arm was replaced.
Possible burn marks on conductors


Wire burn marks.
This failure mode can be prevented with “smart” de-energization at the substation.

cross arm damged due to unbalanced “snap” loads

Overhead Distribution Repair Rate





Harry Tracy WTP (144 MGD)
San Andreas Zone
Pilarcitos
669' 1,000 MG
San Andreas
449' 6,190 MG
11 MG 465'
800'
618'
Summit Res 14 MG
Summit PS 1.4 MGD
Sutro Res 31 MG
Stanford Heights Res
13 MG
Sunset Res 177 MG
Upper Crystal Springs Res 292'
Lower Crystal Springs Res 284' 19,000 MG
CS-SA P/L 60"
SA3 60"
SA2 54"
Raw Water PS
McLaren Park Tanks 8 MG
Sunset 60"
SA2 54"
College Hill Res 13 MG
CS2
SA1
Sunset Branch 60"
SA3 60"
SA2 54"
Cross Town 36"
Hillsborough Tnl 90"
Baden PS 50 MGD
Baden Merced 30"
Sunset
CS 2 60"
Polhemus Tnl
96" PCCP
Sunset Supply
SA2 54"
SA3 60" PCCP
Sunset 60"
Merced Manor Res 10 MG
Central PS 12 MGD
Cross Town 44"
CS3 60" PCCP
CS2 60"
54"
CS2 60"
CS2 60"
SA1 44"
CS3X 60" PCCP
CS1 44"
CDD 48"
CDD 44"
Crystal Springs PS 74 MGD
McLaren Park PS 6.4 MGD
Lake Merced PS 51 MGD
Lake Merced 26'
University Mound Res 141 MG
Alemany PS 32 MGD
Crystal Springs Zone
Hetch Hetchy Water

Transmission Damage

Sorry! Really nothing major to report! PG&E did “a good enough” mitigation effort

Modern Control Building…. “many times stronger than code”

Old Control Building (Behind). Why replace it if it still plenty strong?
and Battery Enclosure (Front). Why build a Tesla when a Prius will do?

Everything OK at PGA = 0.30g.

Modern Transformer 230 kV - 60 kV (built 2010).
Anchorage capacity was sufficient so that PGA = 0.30g was small enough to not overcome sliding / rocking.
Modern composite bushings.
Lots of cable slack.
No damage.

Modern Circuit Breaker 230 kV (built 2010).
Shake Table Tested to PGA = 0.5g.
Steel supports are elastic to PGA >> 1.0g. (No “R” values allowed like for regular buildings)
Lots of cable slack.
No damage.

230 kV Horizontal Break switch atop heavily braced frame.

Lots of cable slack.

No damage.

230 kV. Wave trap supported buy two post-insulators, on same stand with Trench CCVT (composite)

Prof. Anshel Schiff.

Prof Schiff is the “father” of seismic design of high voltage equipment.

Left: a modern circuit switcher (1999) (no damage).

Right: a “vintage” power transformer (with minor oil leaks).

A second transformer at this substation (not seen in this photo) is new and seismically qualified. So, even had the old transformer failed, customers would have had power within an hour

115 kV - 12 kV Bank 1

Oil leaks appears to be from top pipe connections (as expected / common)

Station Service Transformers. Heavy braced. No damage.

Vintage transformers. No damage at PGA ~0.30g. Well anchored.
A new parallel transformer bank was installed so these are somewhat “Redundant”

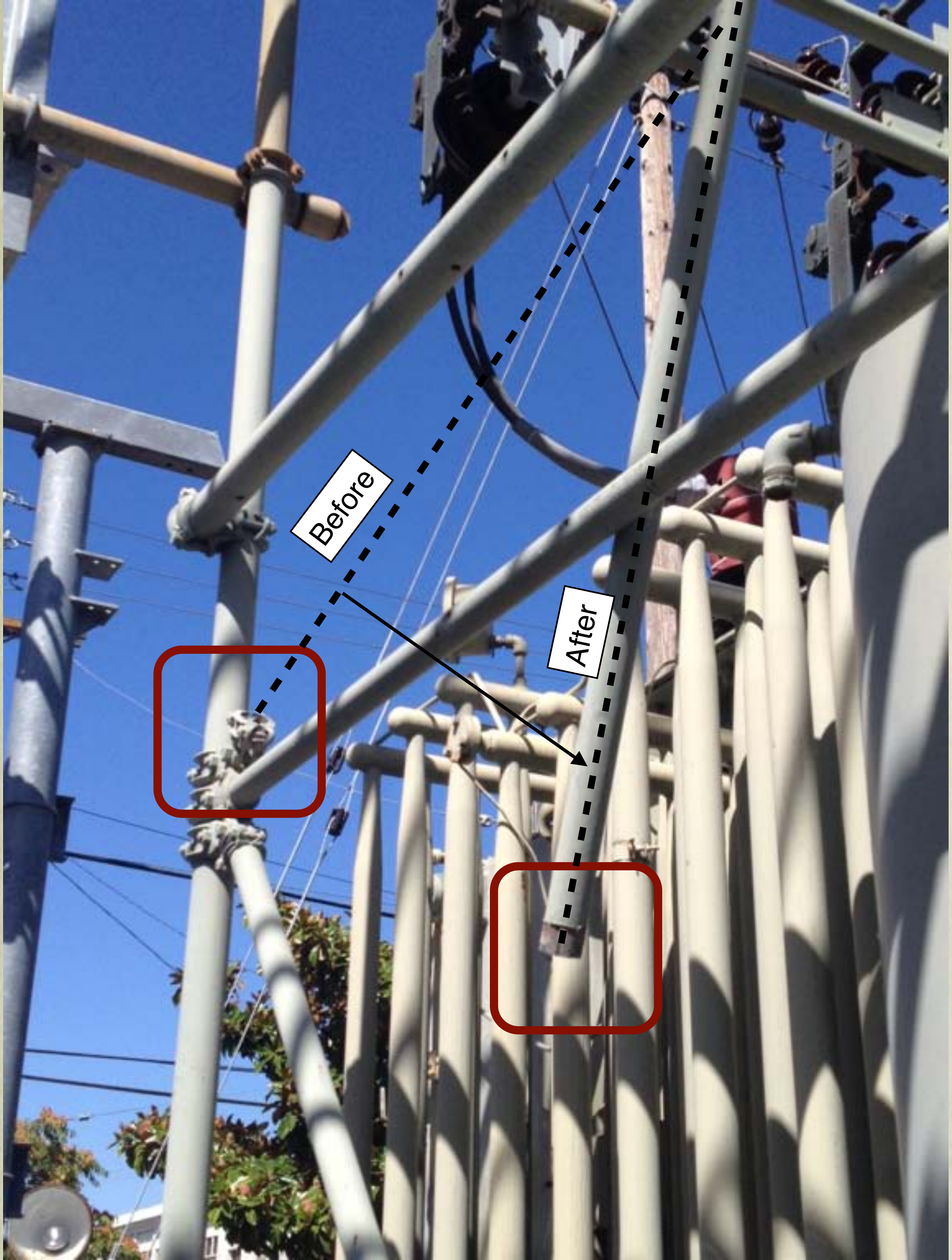
Upgrades of heavily loaded scaffolding might be a good thing.

Diagonal in scaffolding that was damaged in earthquake.

This is on “low voltage” side of yard.

If this rack had collapsed, (PGA = 0.6g?) there would have been long power outages to downtown Napa.

Now, re-assessing all such racks at key substations; some new racks already installed.



12 kV Circuit Breaker and switches
some settlement

12 kV Circuit Breaker and switches some settlement

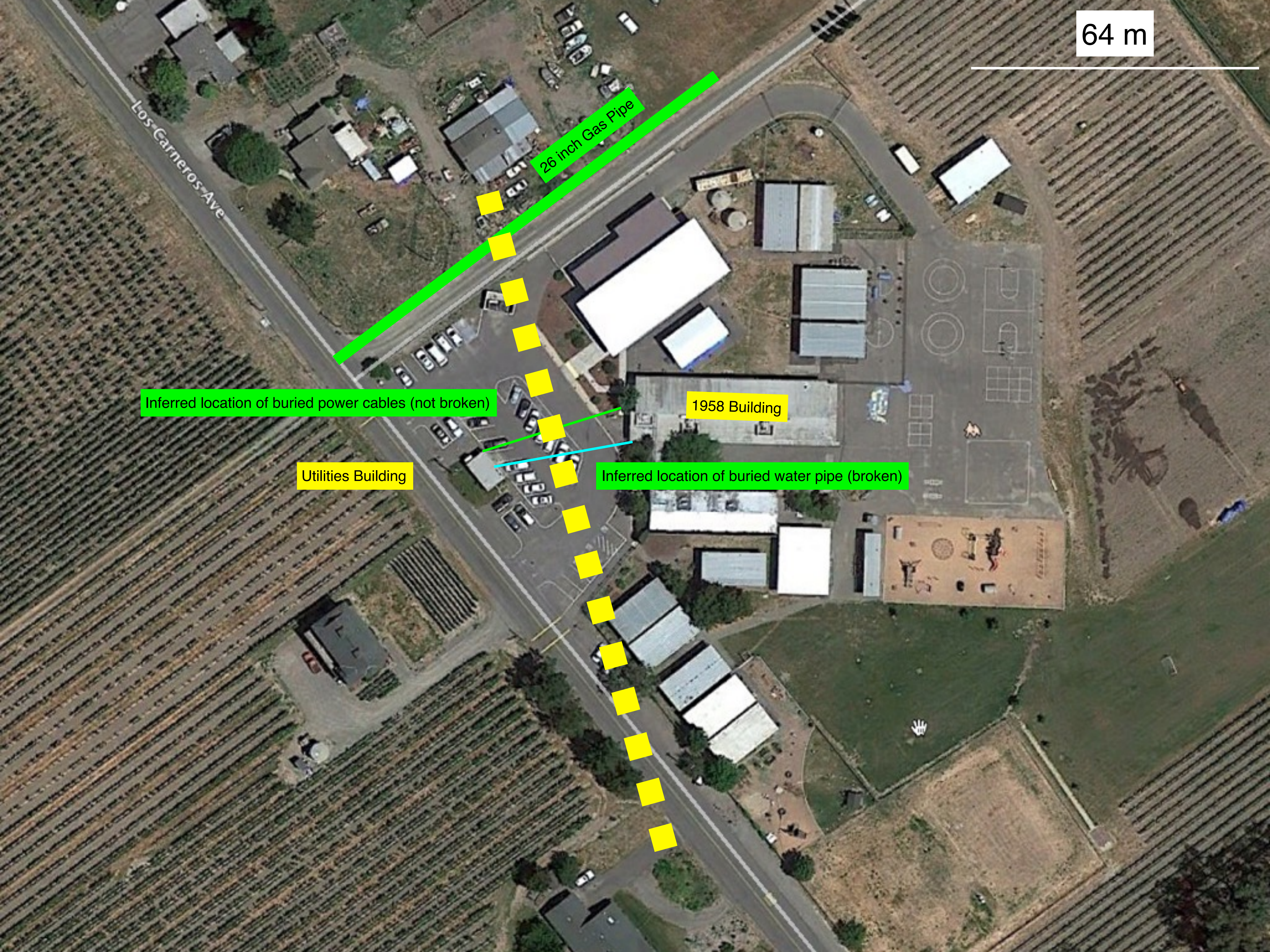
Unanchored Cabinets rocked to these positions (formerly cabinets were tight against each other). Mitigating this “housekeeping” weakness is an ongoing process.

Summary - Power

- Why did PG&E do so well? IEEE 693 and Bellcore and lessons learned from past earthquakes. Thanks to Anshel Schiff, Alex Tang (Nortel), Dennis Ostrom (SCE), Ed Matsuda (PG&E), Eric Fujisaki (PG&E), Leon Kempner (BPA), Lana Gilpin Jackson (BC Hydro), Ron Tognazini (LADWP), Craig Riker (SDG&E) and many others.
- These standards cost $millions, and take decades to implement.

PG&E Gas Issues

- 160 loss of service due to damage to customer facilities
- PG&E responded to >8,000 service "tags" (report of gas odor, leak, safety check, ...)
- Total relights, appliance checks > 2,500 (926 in Napa, 110 in Vallejo)
- PG&E **replaced** 200 feet of 26-inch diameter Steel pipe that underwent some fault offset. No damage in old pipe. New pipe is ~2 times tougher.
- PG&E **replaced** 7,000 feet of 12-inch diameter PE pipe located in the fault zone (the pipe had no leak or apparent damage, but might be prone to pre-mature cracking)


64 m
Los Carneros Ave
26 inch Gas Pipe
Inferred location of buried power cables (not broken)
1958 Building
Utilities Building
Inferred location of buried water pipe (broken)

Line 021A.

AT&T - Communications

Wall Panel Fell. Was held by 4 tabs, for future expansion. Building racking damaged the tabs.
Panel fell onto HVAC equipment, damaging cooling system.
PG&E power equipment was also damaged by the falling wall.
Emergency generator failed to start.
Back up batteries worked well. But, batteries need to be recharged…. a priority to get a generator to recharge the batteries.
No real loss of service, as AT&T was able to respond.

Sewer

WWTP did well. Why? found on clay (no liquefaction)

Sewer Pipes Broke Repaired at fault crossings

Residual pipe damage remains to be found

Zone with Concentrated Sewer Pipe Breaks

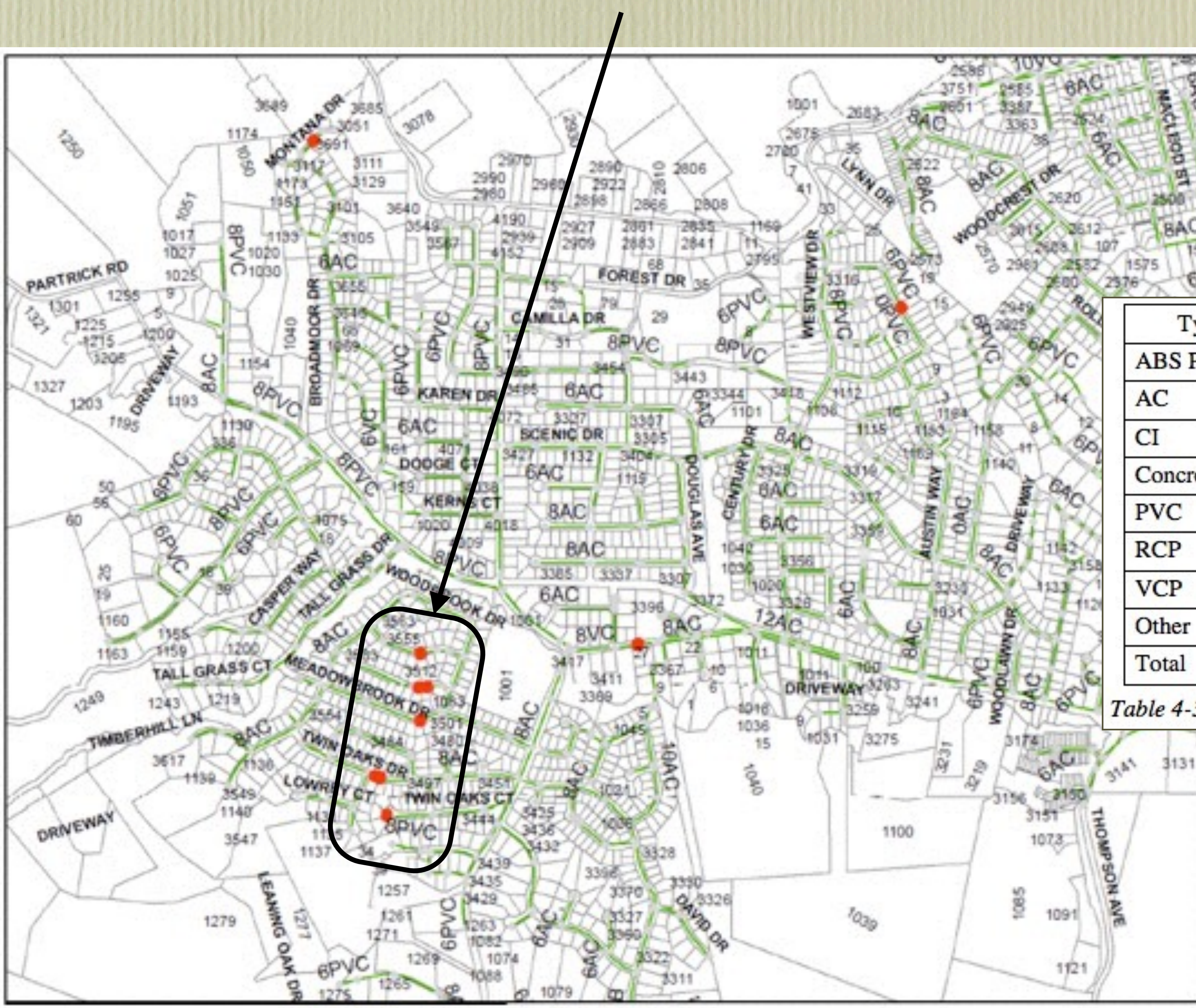


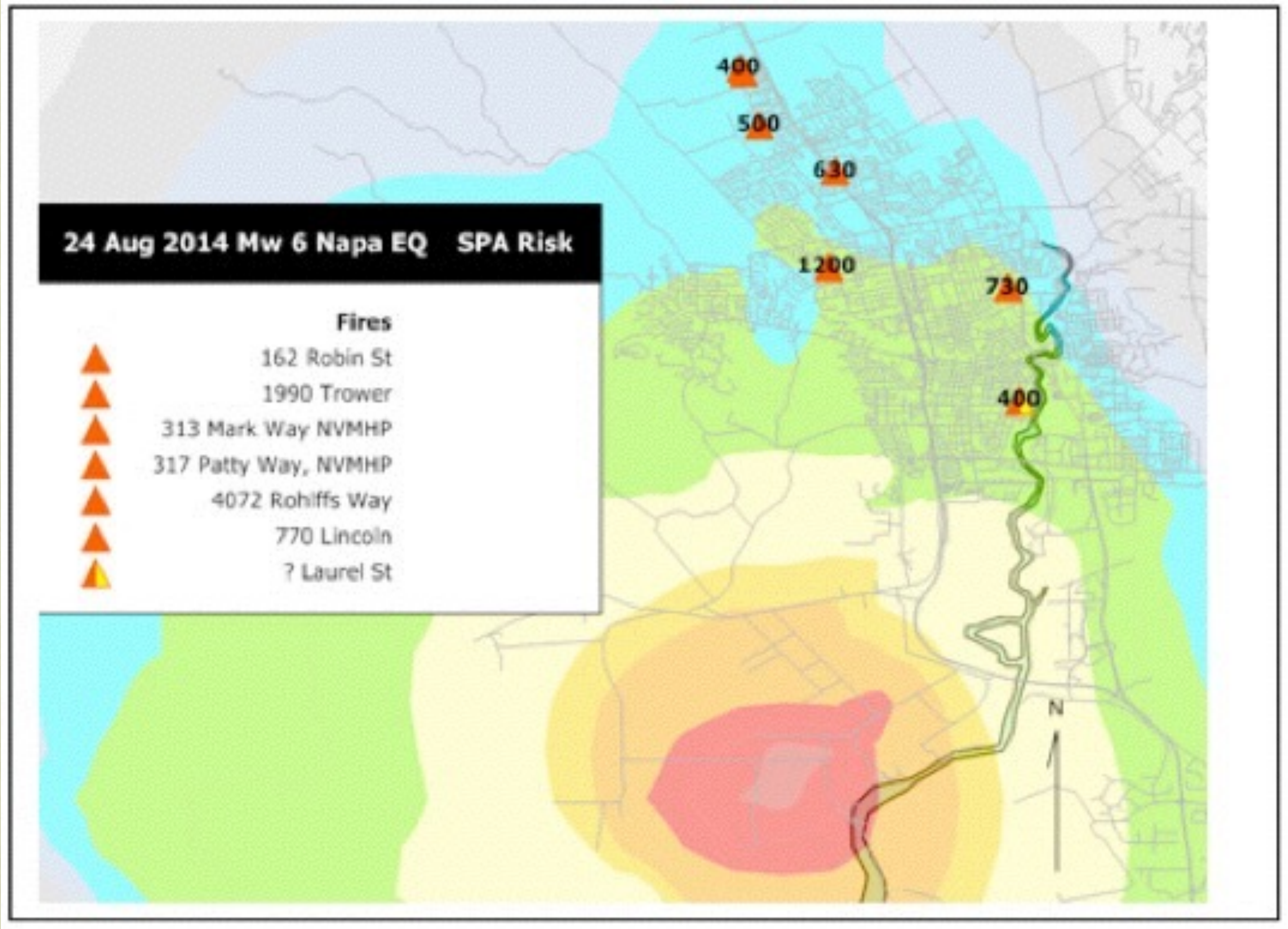
Figure 4-16. Location of Sewer Breaks

Type	Miles	Pct of Total
ABS Plastic	2	0.7%
AC	124	45.9
CI	1	0.4
Concrete	3	1.1
PVC	61	22.6
RCP	7	2.6
VCP	70	25.9
Other	2	0.7
Total	270	100%

Table 4-3. Length of Sewer Pipes – Napa (Miles)

Possible Rocking of Center Tower in Clarifier

Fire Following Earthquake

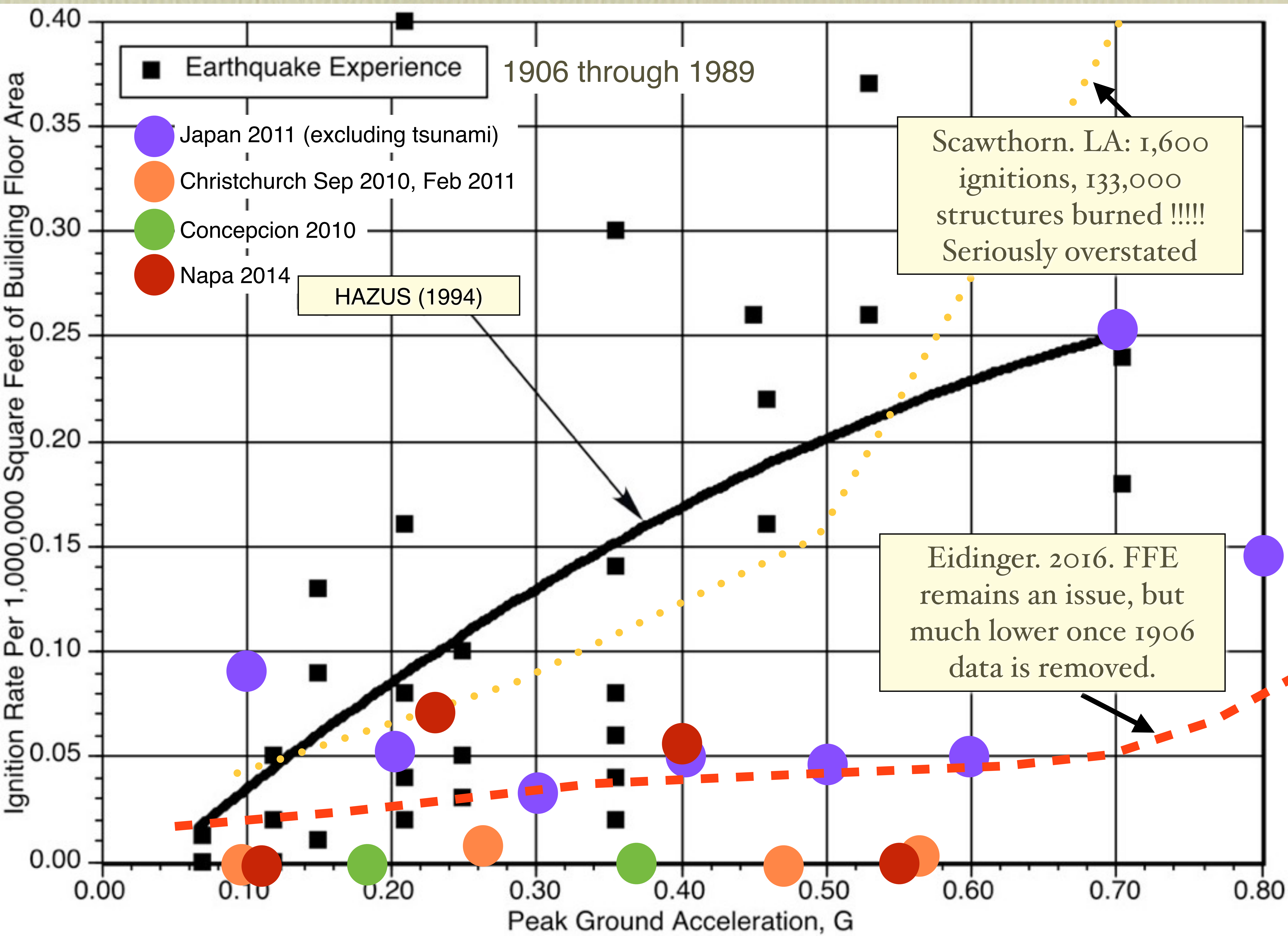


Fire Ignitions Attributed to the August 24 2014 Main Shock

No.	Time of Report (approx.)	Location	Description (see below)
1	0330	Orchard Ave	Napa Valley Mobile Home Park (NVMHP) – actually two ignitions – see narrative
2	0400	Laurel St. (no street number)	2 story, 2 unit residence, roof collapse, started fire
3	0500	162 Robin at Solano	Dbl wide home
4	0630	1990 Trower	Smoke inside structure
5	0730	770 Lincoln x Soscol	Electrical fire in substructure of a mobile home
6	1200	4072 Rohlffs Way x Fair	Kitchen fire in single story multi-unit senior housing complex

FFE

- There were several fire ignitions
- There was NO wind at the time of the earthquake
- If it had been windy (say 20 mph), with the loss of water pressure due to damage in the water system, then a LOT of Napa would have burned to the ground



Earthquake Experience
1906 through 1989
Japan 2011 (excluding tsunami)
Christchurch Sep 2010, Feb 2011
Concepcion 2010
Napa 2014
HAZUS (1994)
Scawthorn. LA: 1,600 ignitions, 133,000 structures burned !!!!! Seriously overstated
Eidinger. 2016. FFE remains an issue, but much lower once 1906 data is removed.
Ignition Rate Per 1,000,000 Square Feet of Building Floor Area
Peak Ground Acceleration, G
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80

Summary - Underground Pipes

- Damage to buried water (and sewer) pipes is the ELEPHANT in the room.
- PG&E's buried pipes are MUCH more "resilient" than Napa's buried water pipes
- If we do not install seismic-resistant pipes in a pro-active manner, some pipes are doomed in future earthquakes... Long outages.... Economic Consequences.... Loss of Water for Fire Fighting.... Raw sewage dumped into our waterways....
- ALA 2005 is a Guideline to design buried water pipes. It might be time to make it a mandatory Standard.
- At $2 million per mile, this is not going to be cheap, and this is not going to happen overnight. Use BCR Models to help decide. Use real data, not "make believe". If we do not start, we will never finish.

Do Utilities Do or Not Do?

- Do-ers: Knowledge of weaknesses, followed by careful assessment, followed by capital improvements.
- Non-Do-ers: Unaware of the risks. Or, aware of the risks, but unwillingness to fund.