Working Group 2 B
Infrastructure: Lifelines, Roads

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Water and Sewage Systems

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Bridges

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Water and Sewage Systems

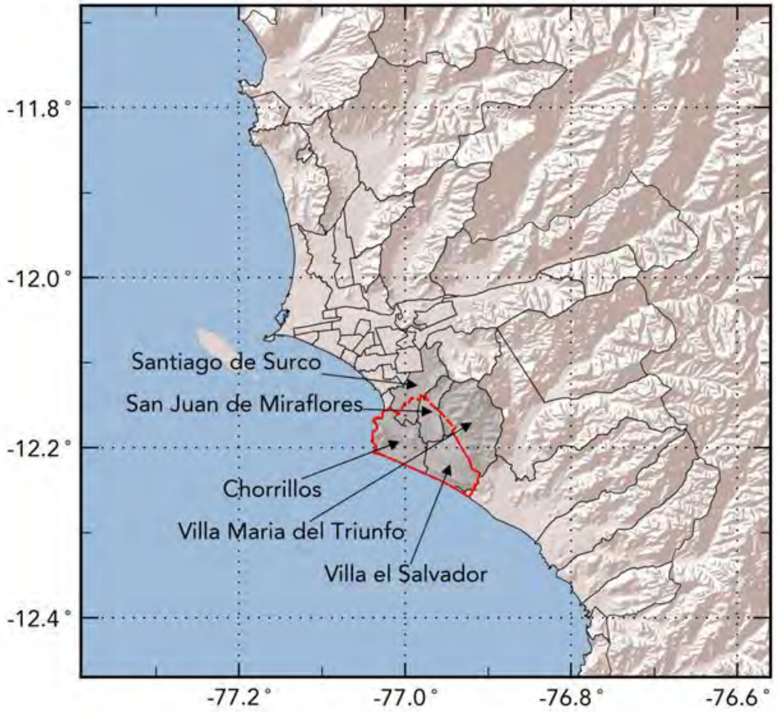
2B-1: Survey of lifeline systems (water and sewage), road network and their environment, such as soil condition, supply área, and their Seismic vulnerability in study área.

2B-1: Estudio de los sistemas vitales (agua y alcantarillado), la red de carreteras y su entorno, como el estado del terreno, el área de suministro y su vulnerabilidad sísmica en la zona de estudio.

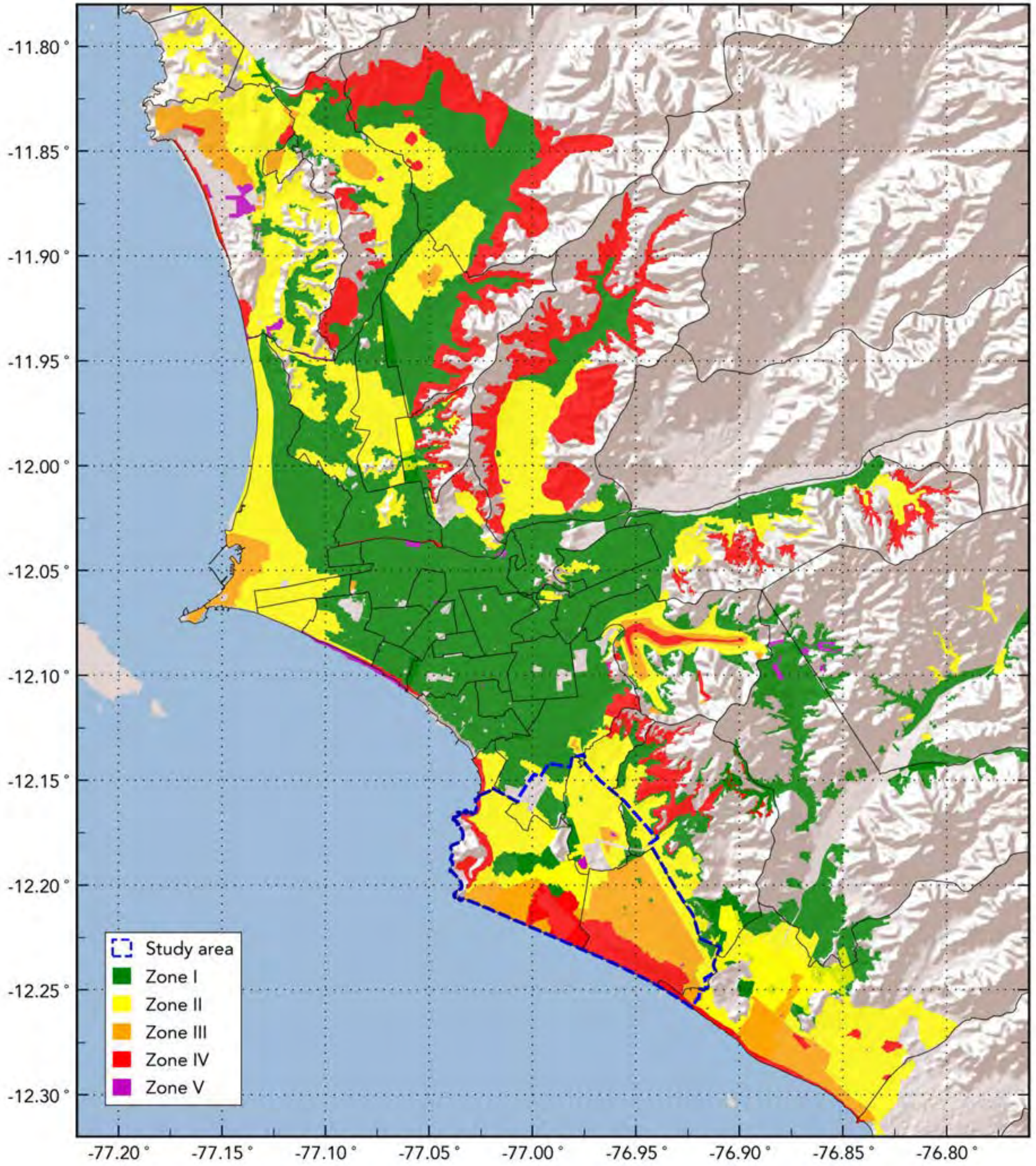
Study Area

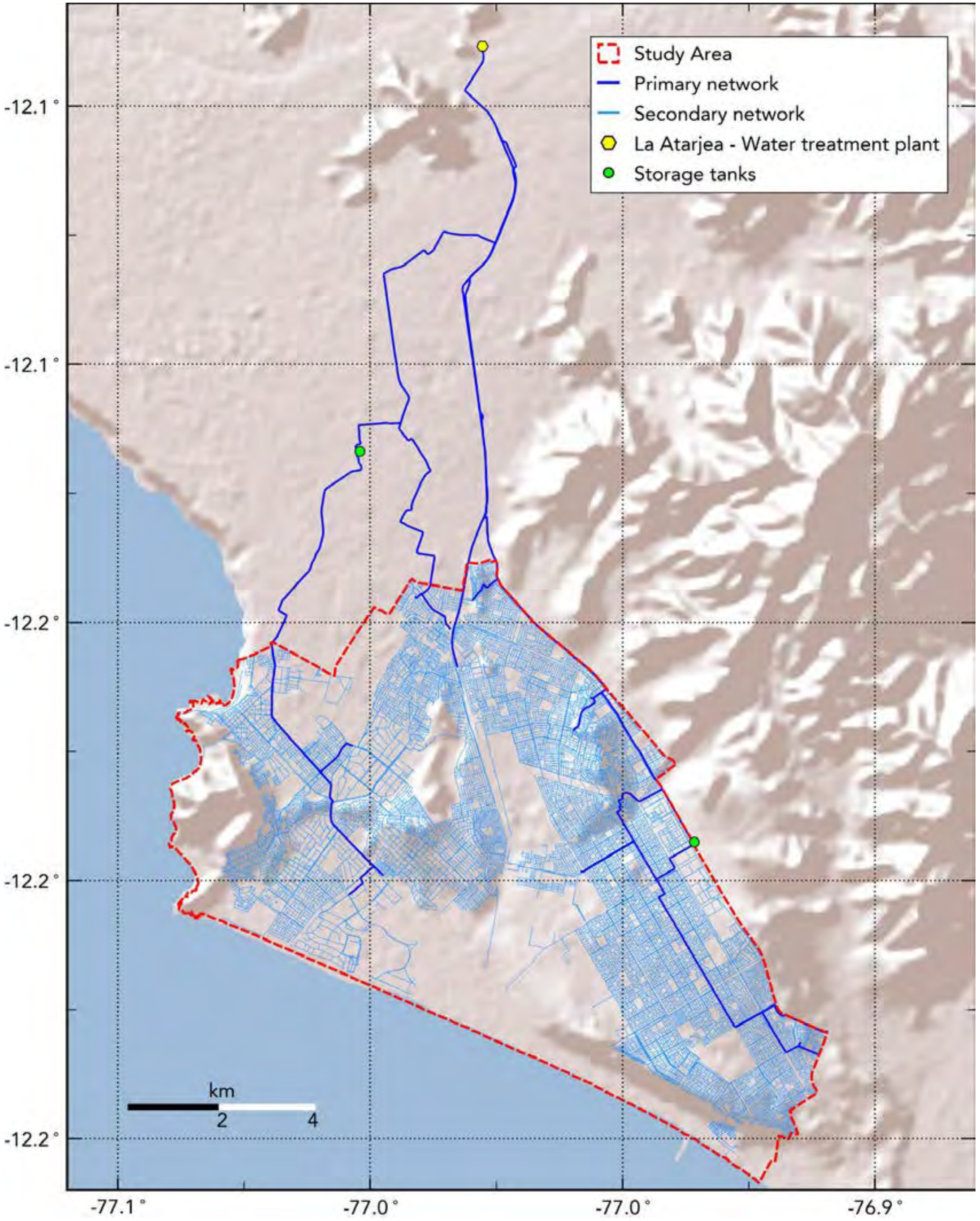
- Study area covers five districts of Lima City, completely Chorrillos and Villa el Salvador districts; and part of Santiago de Surco, San Juan de Miraflores and Villa Maria del Triunfo.
- Five different seismic microzoning zones are included in this study area.

Lima City



Seismic Microzoning Map

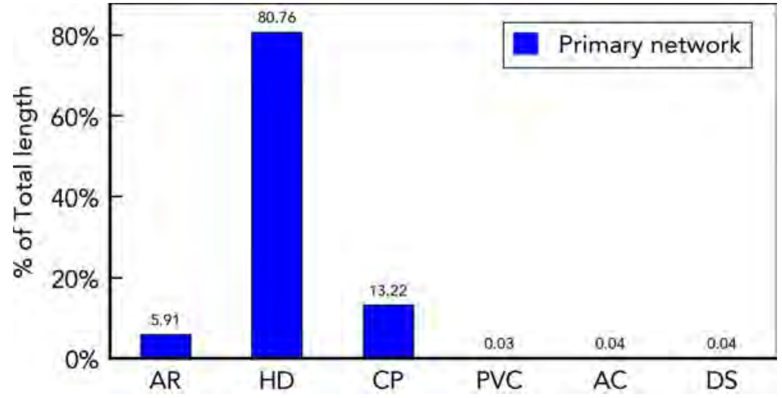


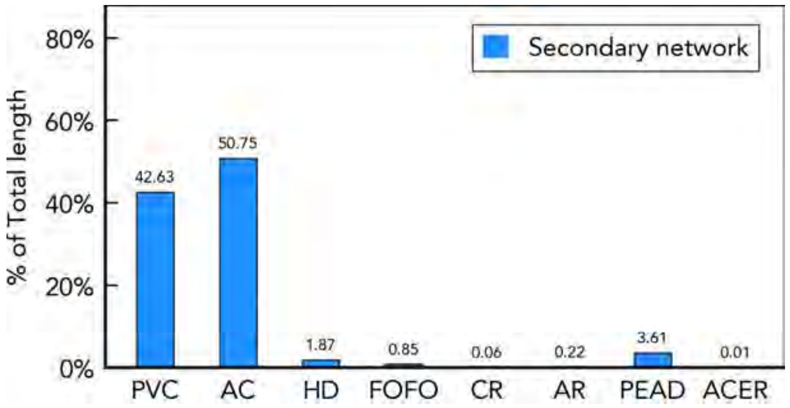


Water Distribution Networks

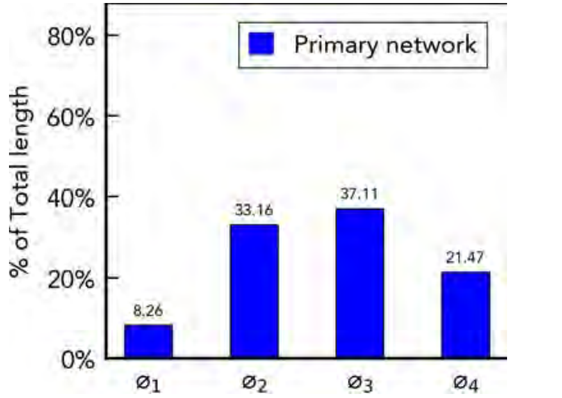
- **Primary** distribution networks
- **Secondary** distribution networks

Pipeline material

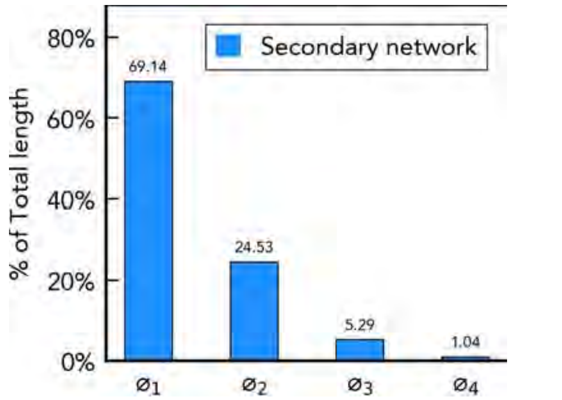




Pipeline diameter

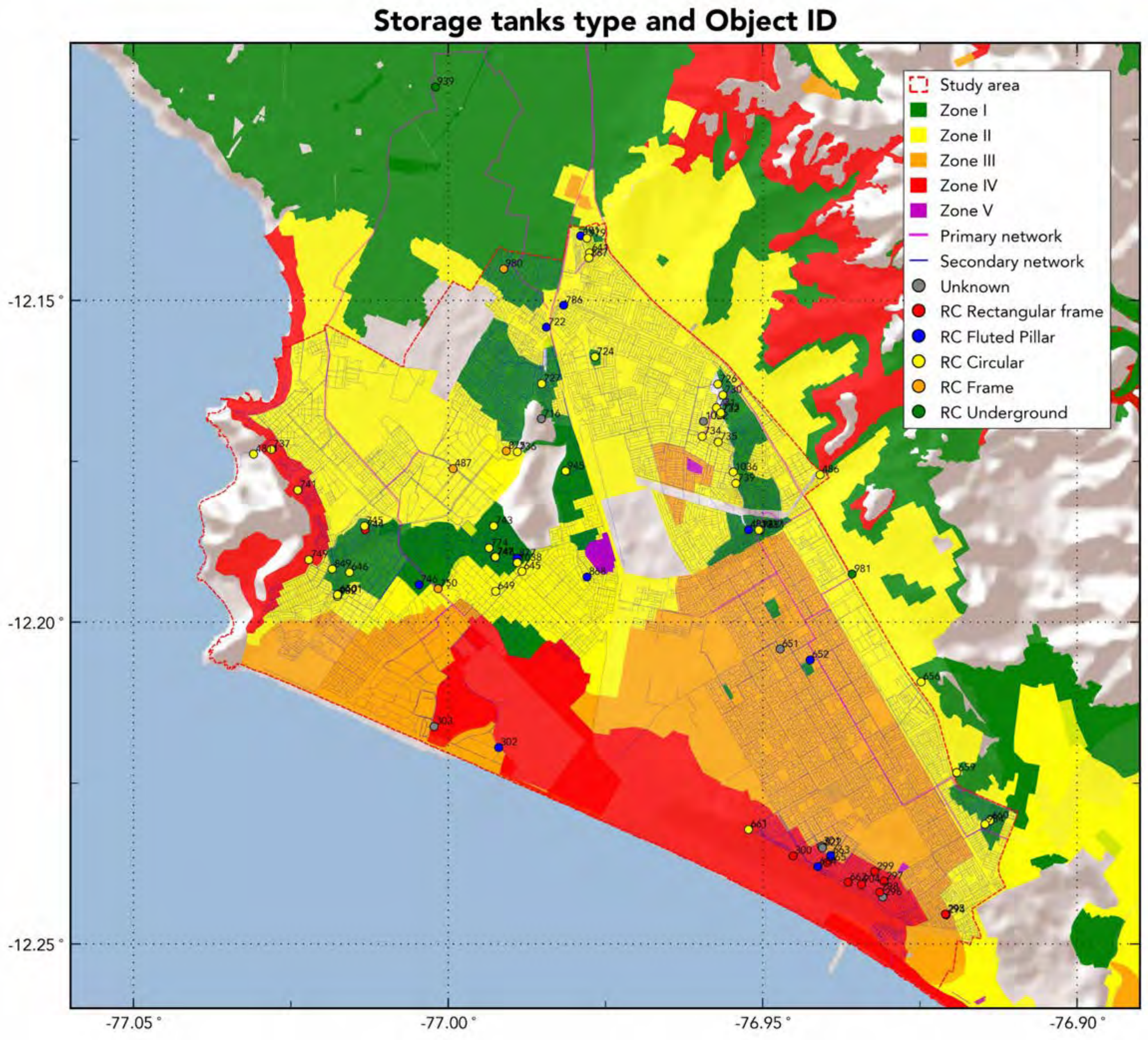


Note: Diameter ranges in mm : $\varnothing_1$ <500, 500 ≤ $\varnothing_2$ <1000, 1000 ≤ $\varnothing_3$ < 1500 and 1500 ≤ $\varnothing_4$ ≤1800



Note: Diameter ranges in mm : $\varnothing_1$ < 150, 150 ≤ $\varnothing_2$ <300, 300 ≤ $\varnothing_3$ < 450 and 450 ≤ $\varnothing_4$ ≤ 600

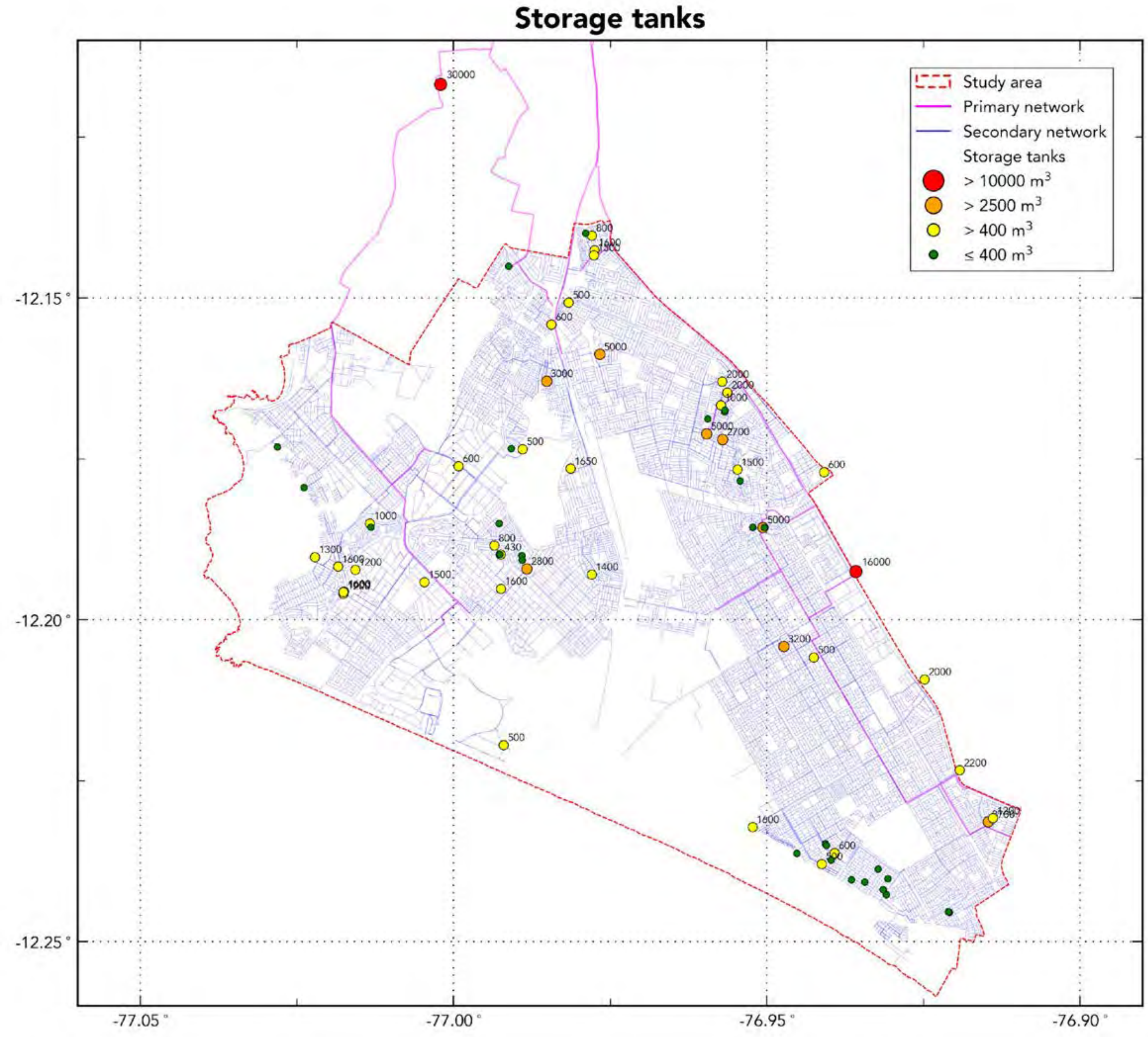
Water Treatment Plant "La Atarjea"

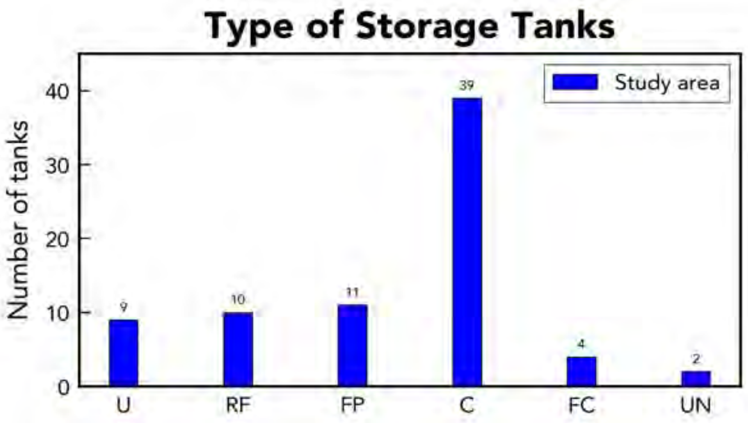


Storage Tanks

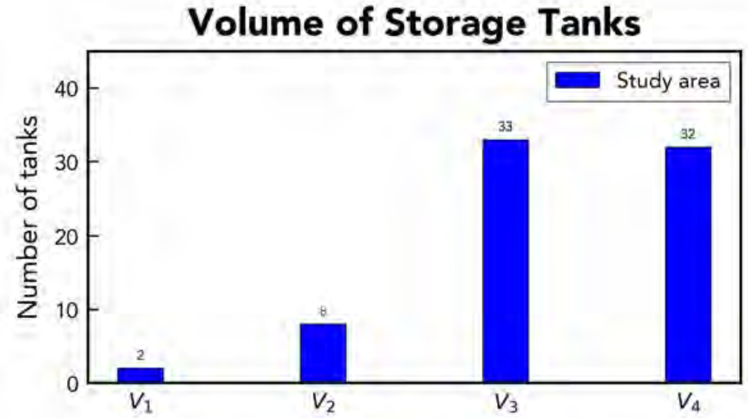
Dataset

Types storage tanks	
Elevated	
RC Frame	RC Fluted Pillar
	
RC Underground	RC Circular
	

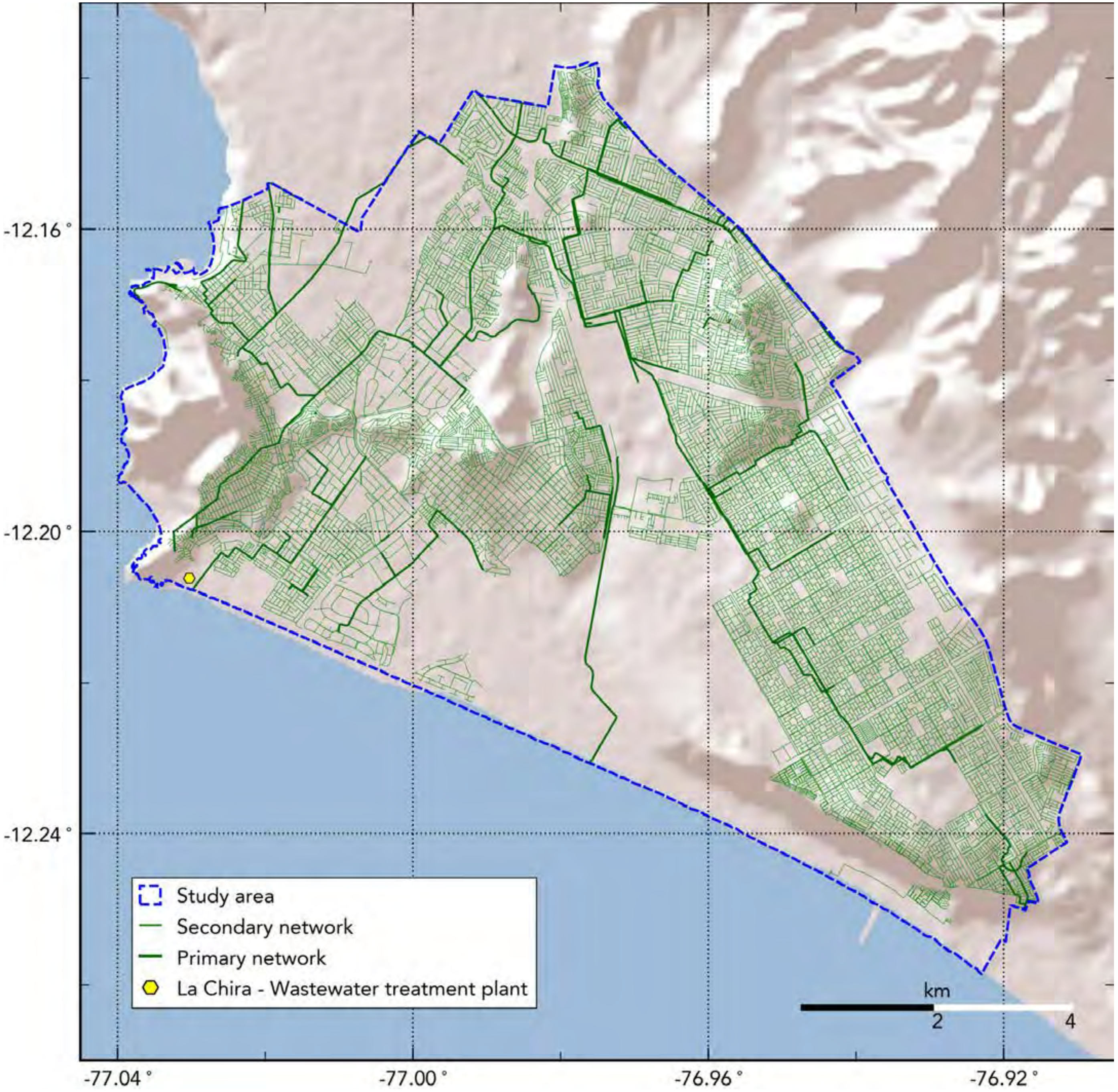




Note: U (unknown), RF (RC rectangular frame), FP (RC Fluted Pillar), C (RC on-ground Circular), FC (RC Frame) and UN (RC underground)



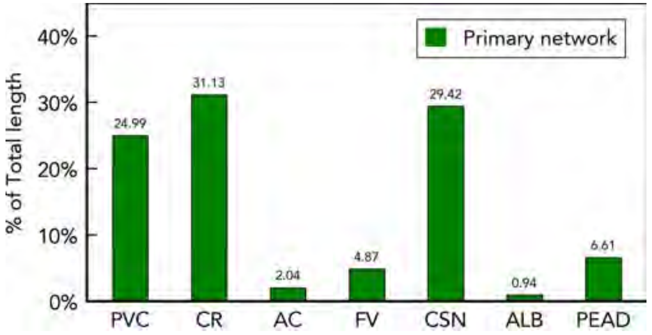
Note: Volume ranges in m^3 : $V_1 > 10000$, $10000 \geq V_2 > 2500$, $2500 \geq V_3 > 400$, $400 \leq V_4$

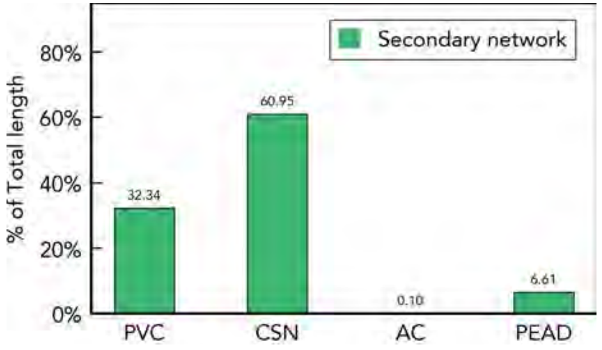


Sewage Collection Networks

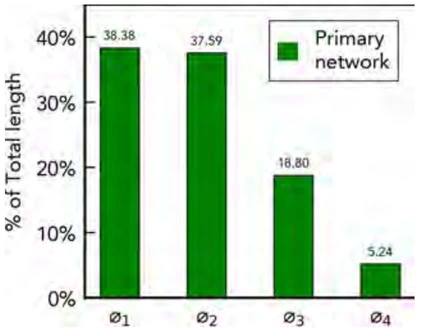
- **Primary** Collection networks
- **Secondary** Collection networks

Pipeline material

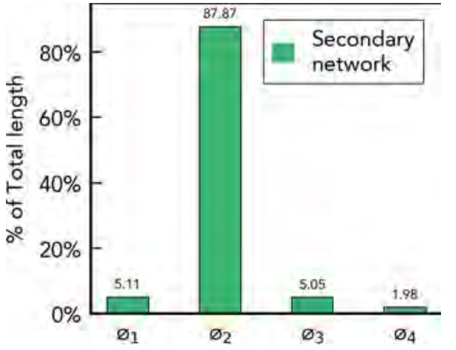




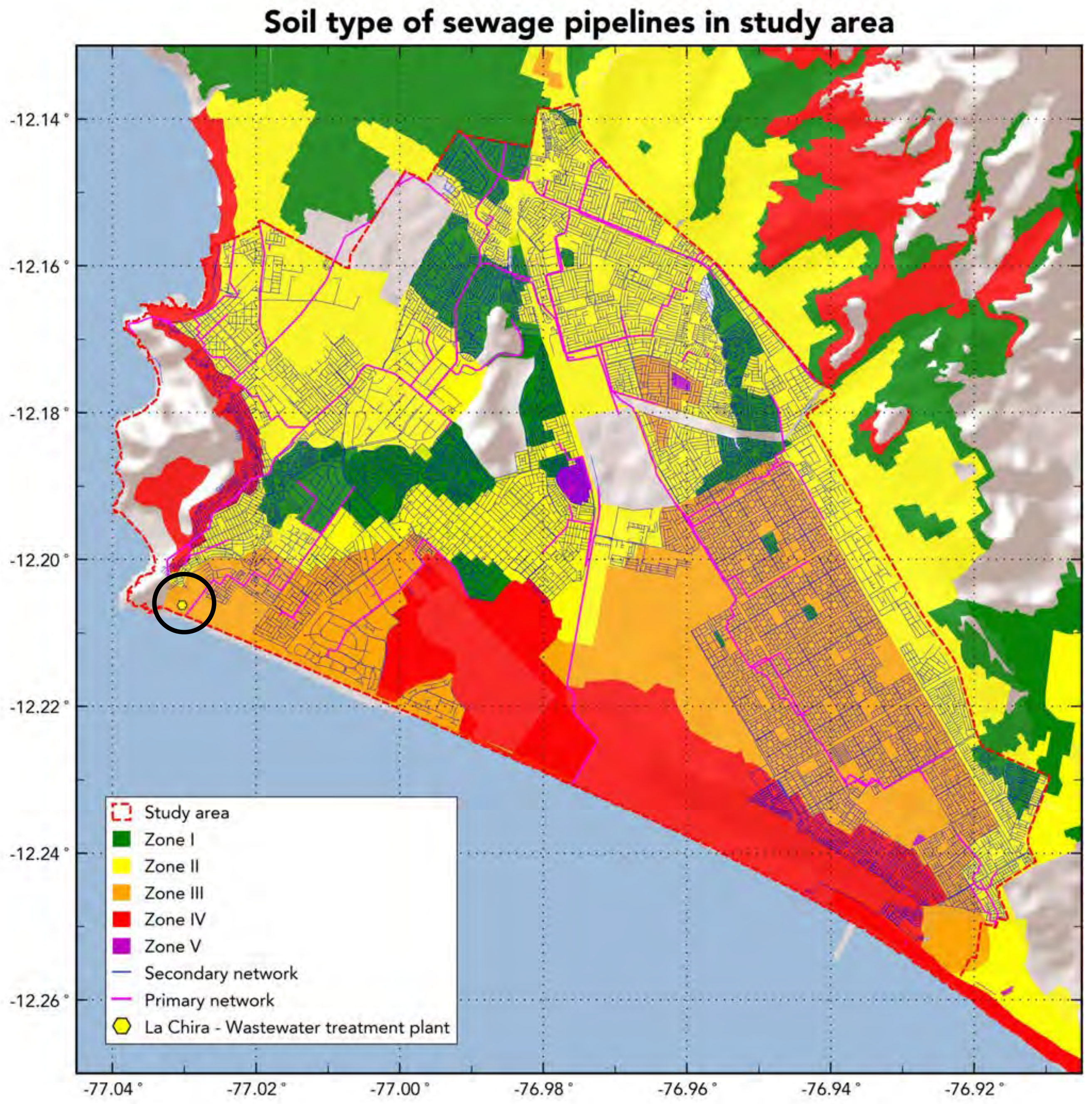
Pipeline diameter



Note: Diameter ranges in mm : $\varnothing_1$ <500, 500 ≤ $\varnothing_2$ <1000, 1000 ≤ $\varnothing_3$ < 1500 and 1500 ≤ $\varnothing_4$ ≤1800



Note: Diameter ranges in mm : $\varnothing_1$ < 200, $\varnothing_2$ = 200, 200 < $\varnothing_3$ < 300 and 300 ≤ $\varnothing_4$ ≤ 350



Wastewater Treatment Plant

La Chira

2B-2: Development of real-time damage assessment system for infrastructures.

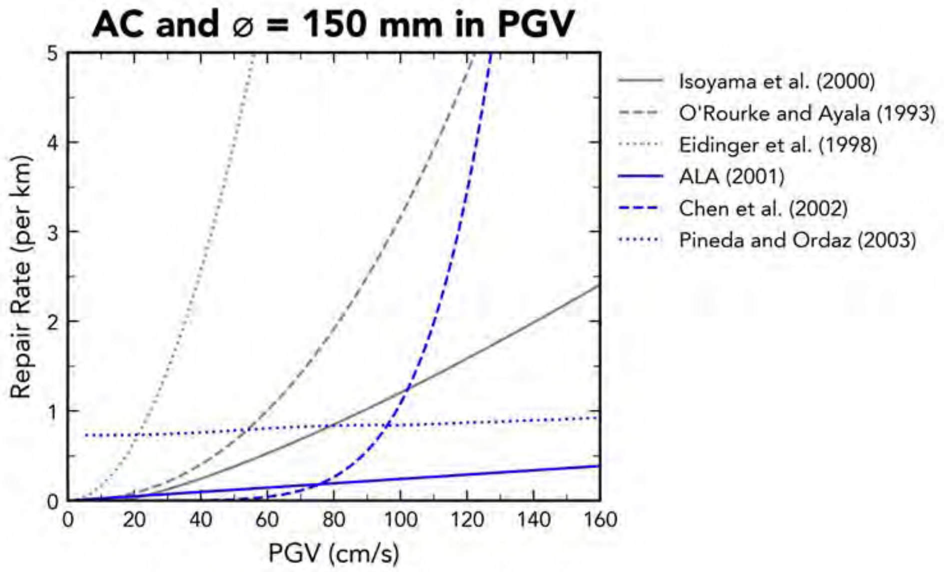
2B-2: Desarrollo de un sistema de Evaluación de daños en tiempo real para infraestructuras y líneas de vida.

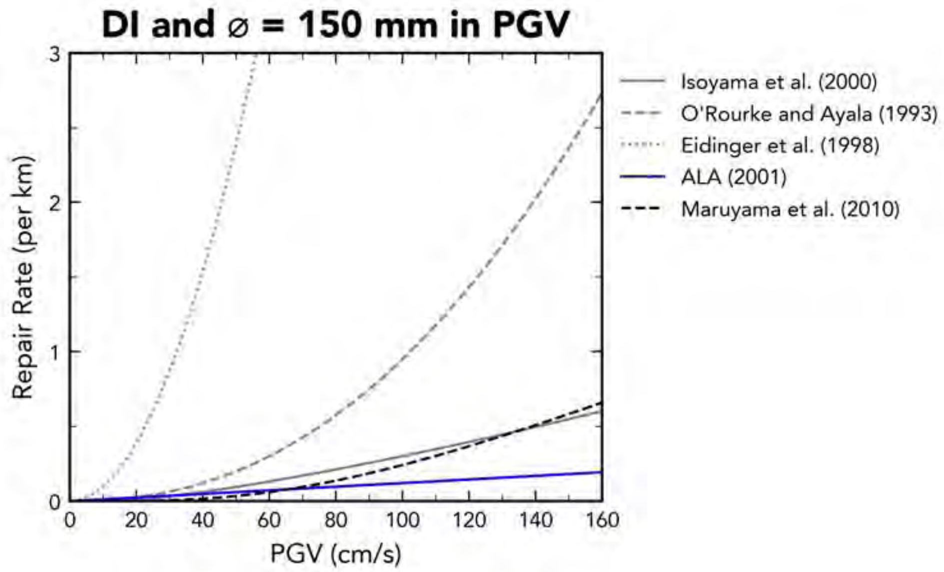
Pipeline Fragility Functions

Damage Parameter (DP) to pipelines is commonly repair rate (RR), i.e. number of repairs per unit of length (usually in km).

Fragility Function	DP	IM	Typology	Information	Formulation
O'Rourke and Ayala (1993) NIBS (2004) FEMA (2020)	RR	PGV	Brittle or flexible pipes, for ductile pipelines (Steel, Ductile iron, and PVC) the value is multiplied by 0.3	Empirical (6 earthquakes) Used in HAZUS methodology	$RR \approx 0.0001 \cdot PGV^{2.25}$
ALA (2001)	RR	PGV	Material type (Unknown, Cast iron, Welded steel, Asbestos cement, Concrete, PVC, Ductile iron) Joint type Soil type Diameter (mm; small 100-300, large 300)	Empirical (12 earthquakes) Database: cast iron (38 data points) followed by steel (13), asbestos cement (10), ductile iron (9), and concrete (2).	$RR = K_1 \cdot 0.002416 \cdot PGV$

Comparative of Pipeline Fragility Functions





Damage Assessment of Buried Pipelines

Preliminary estimation of IM's (PGA and PGV)

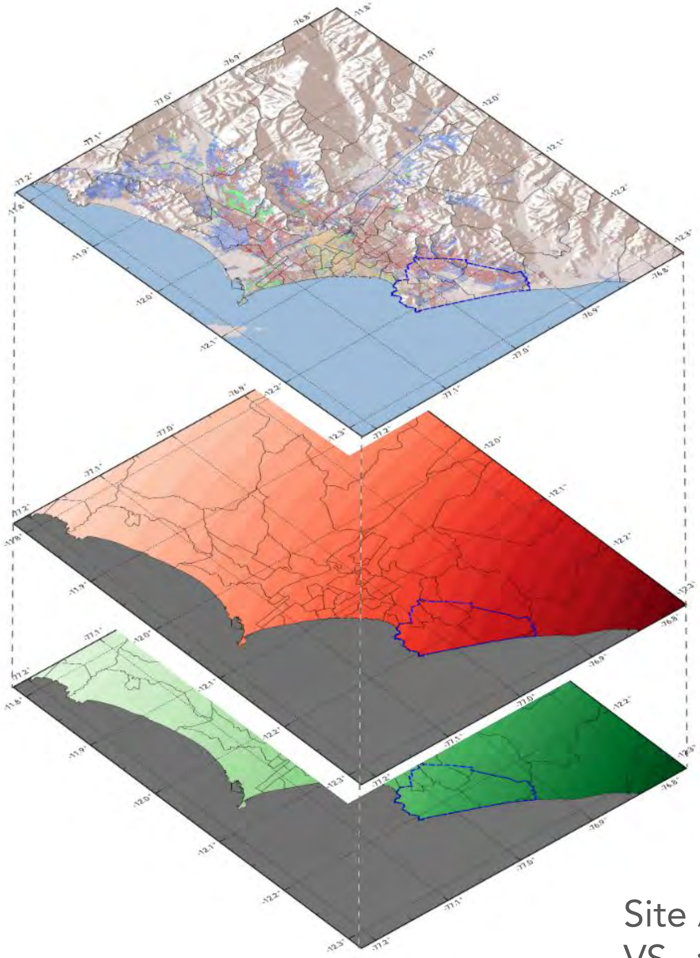
Dataset (SEDAPAL)

Source Models
Aguilar et al. (2017)

Ground Motion Prediction Equation (GMPE)
Youngs et al. (1997)
Boore et al. (2014)
Zhao et al. (2016)
Montalva et al. (2017)
Abrahamson et al. (2020)
Parker et al. (2020)
...

Magnitude Scaling Relationship
Strasser et al. (2010)
Thingbaijam et al. 2017

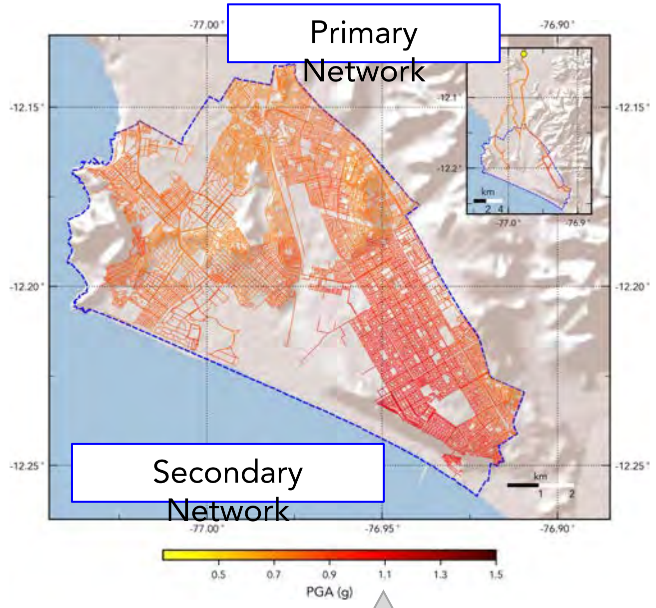
Deterministic and Probabilistic Analysis



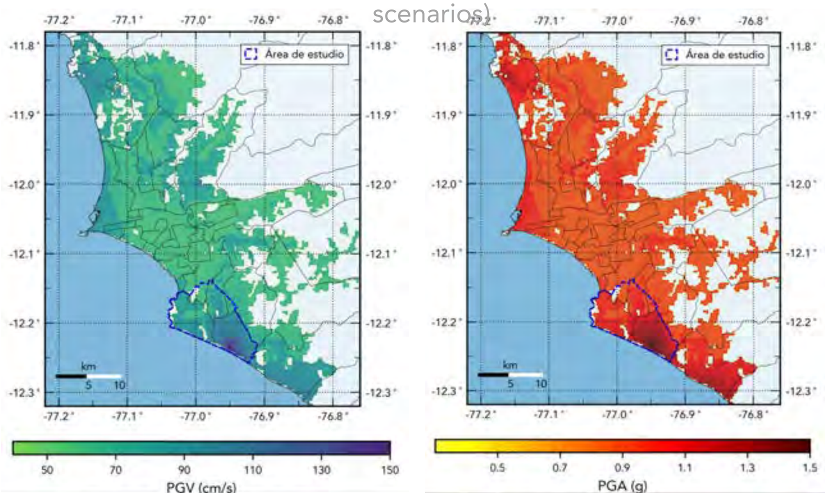
PGA (g)

PGV (cm/s^2)

Site Amplification
VS_{30}: Sekiguchi et al. (2012)
PGA : Calderon et al. (2014)
PGV : Miura et al. (2020)



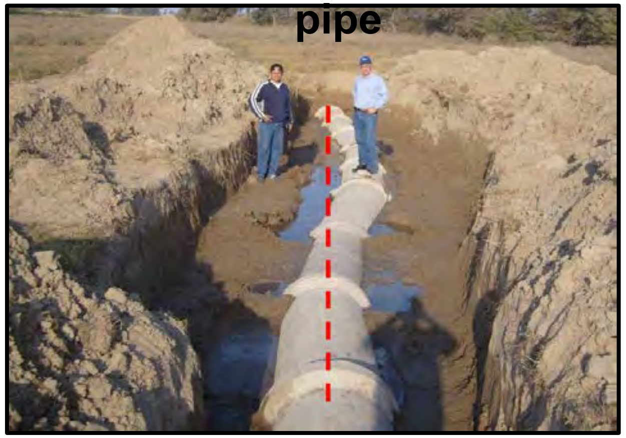
T_r = 2475 years
(Similar for 475, 975 and deterministic scenarios)



Pisco, Peru, Earthquake of August 15, 2007 Damage Review

Storage Tank Damage

Lateral displacement CR pipe



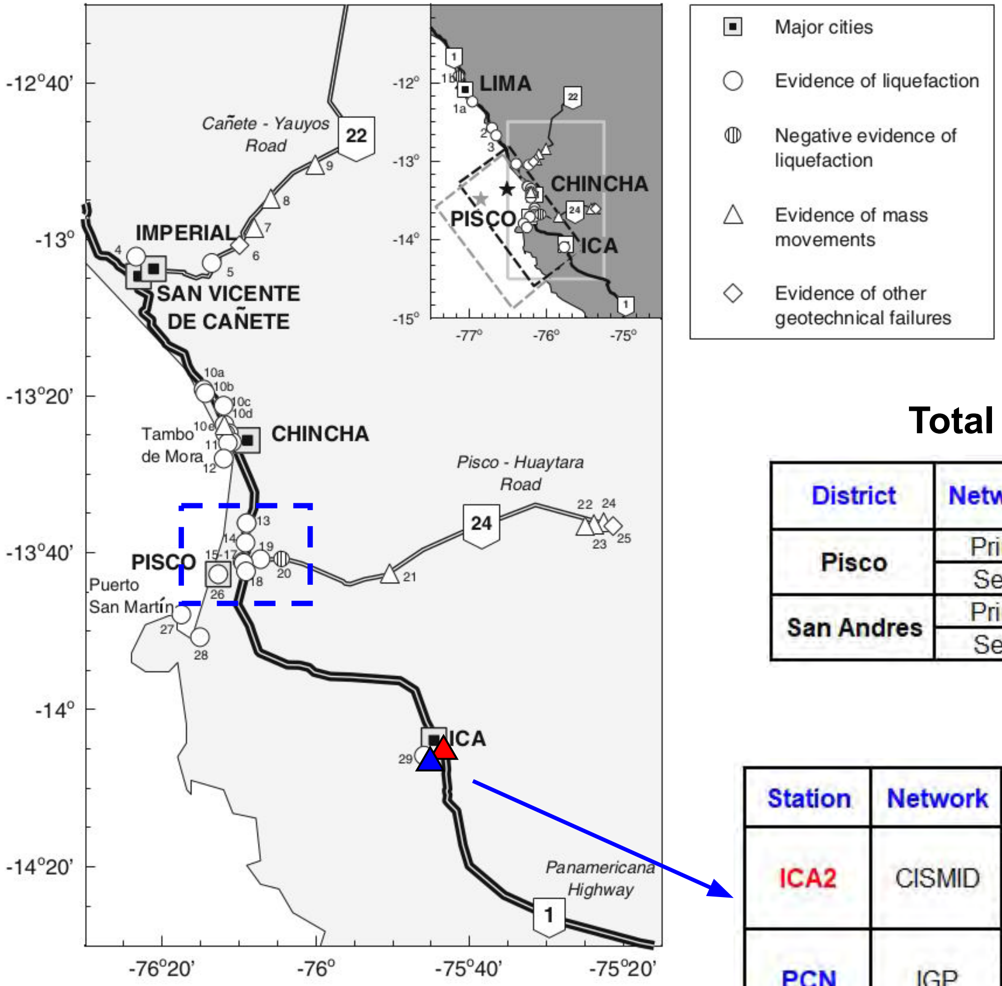
Replacement of AC pipe for PVC pipe

Leak AC pipe

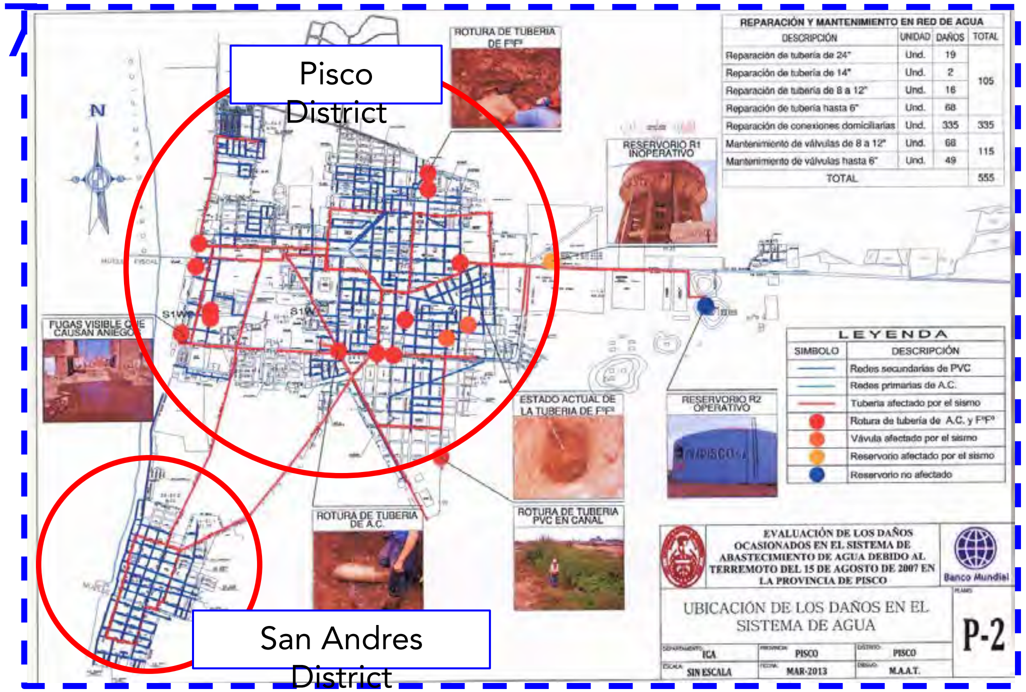
Break FOFO pipe

Pisco, Peru, Earthquake of August 15, 2007

Damage Review
(Update)



Tavera et. Al (2009)



Alcantara (2013)

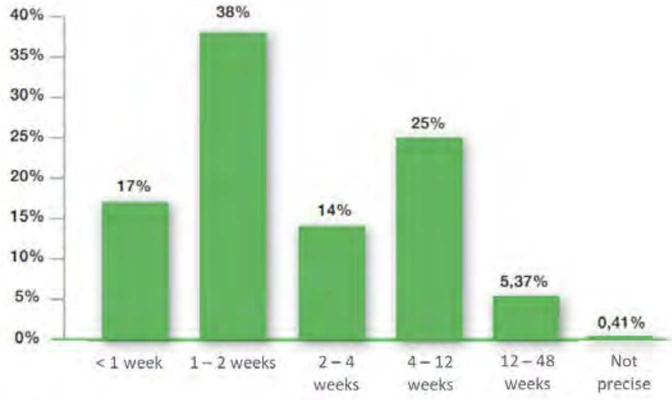
Total pipe lengths (km)

District	Network	Material		
		PVC	AC	Cast Iron
Pisco	Prim.	39.83	26.33	8.29
	Sec.	21.37	9.64	1.2
San Andres	Prim.	8.92	11.46	
	Sec.		2.47	

Station	Network	Channel	PGA (cm/s^2)	PGV (cm/2)
ICA2	CISMID	EW	271.6	39.06
		NS	334.1	**62.27**
		UD	192.9	15.05
PCN	IGP	EW	**488.4**	23.58
		NS	457.5	28.03
		UD	300.2	15.37

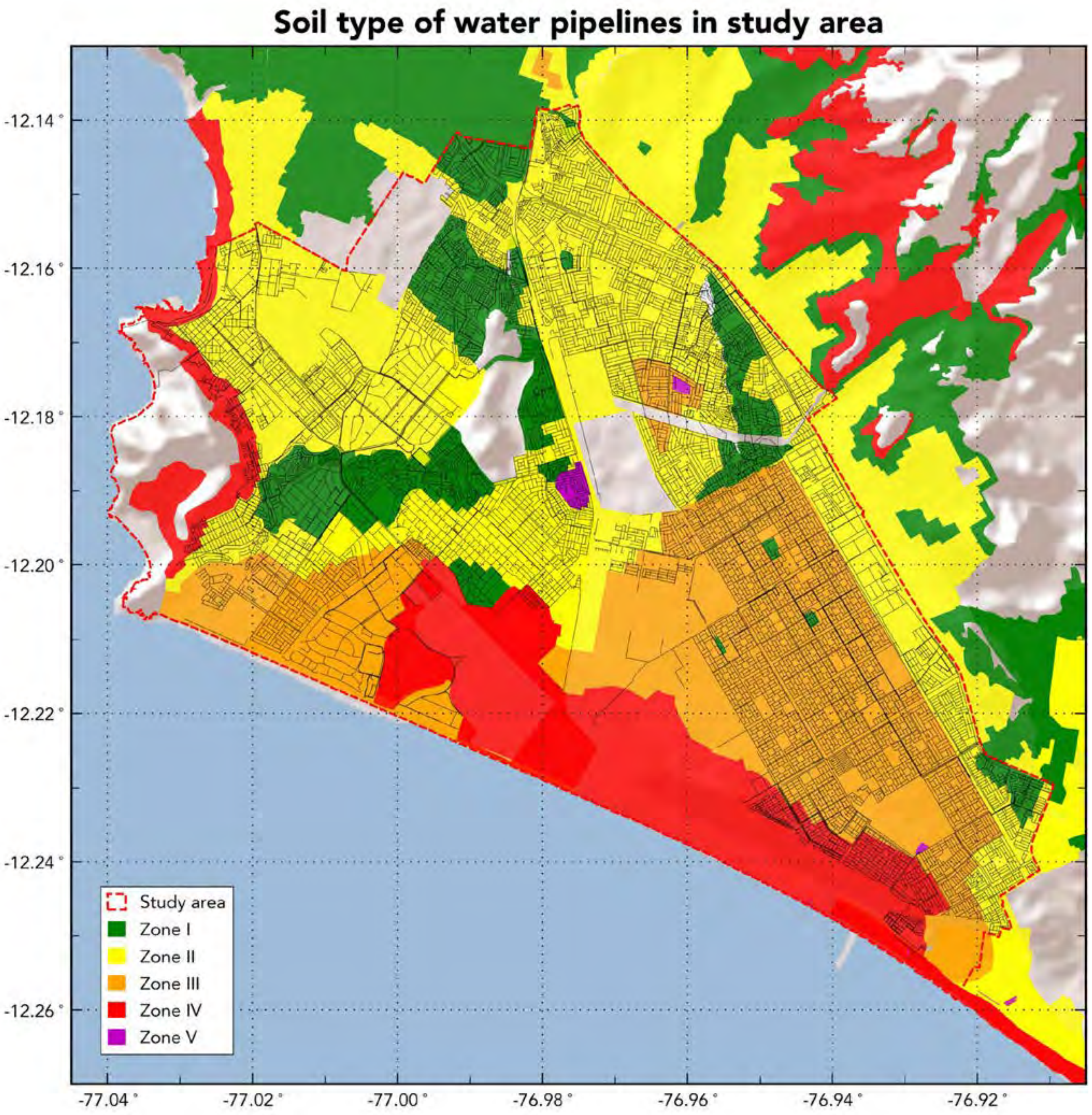
Water service restoration time

Information from surveys (Pisco, Chincha, Ica and Cañete)



World Bank (2011)

ZONES	DESCRIPTION
Zone I	Rock outcrop zones with different degrees of fracturing, gravel and sand deposits of dense to very dense compactness, silt and clay deposits of stiff to very stiff consistency. Environmental vibration periods less than 0.30 s.
	Zonas de afloramiento de roca con diferentes grados de fracturación, depósitos de grava y arena de compacidad densa a muy densa, depósitos de limos y arcillas de consistencia rígida a muy rígida. Periodos de vibración ambiental menores a 0.30 s.
Zone II	Deposits of medium to dense sand or medium consistency clays and silts. Environmental vibration periods less than 0.40 s.
	Depósitos de arena de compacidad media a densa o arcillas y limos de consistencia media. Periodos de vibración ambiental menores a 0.40 s.
Zone III	Sandy deposits of loose to medium compactness, silt and clay deposits of soft to medium consistency. Periods of environmental vibration greater than 0.40 s.
	Depósitos de arena de compacidad suelta a media, depósitos de limos y arcillas de consistencia blanda a media. Periodos de vibración ambiental mayores a 0.40 s.
Zone IV	Unstable slopes with steep gradients, informal quarries, swampy soil deposits, potentially liquefiable loose eolian sand deposits. Areas with high seismic amplification.
	Taludes inestables con fuerte pendiente, canteras informales, depósitos de suelos pantanosos, depósitos de arenas eólicas de compacidad suelta potencialmente licuables. Zonas con alta amplificación sísmica.
Zone V	Deposits of rubble and/or waste, anthropic fills inside old mining excavations.
	Depósitos de escombros y/o desechos, rellenos antrópicos en el interior de antiguas excavaciones mineras.

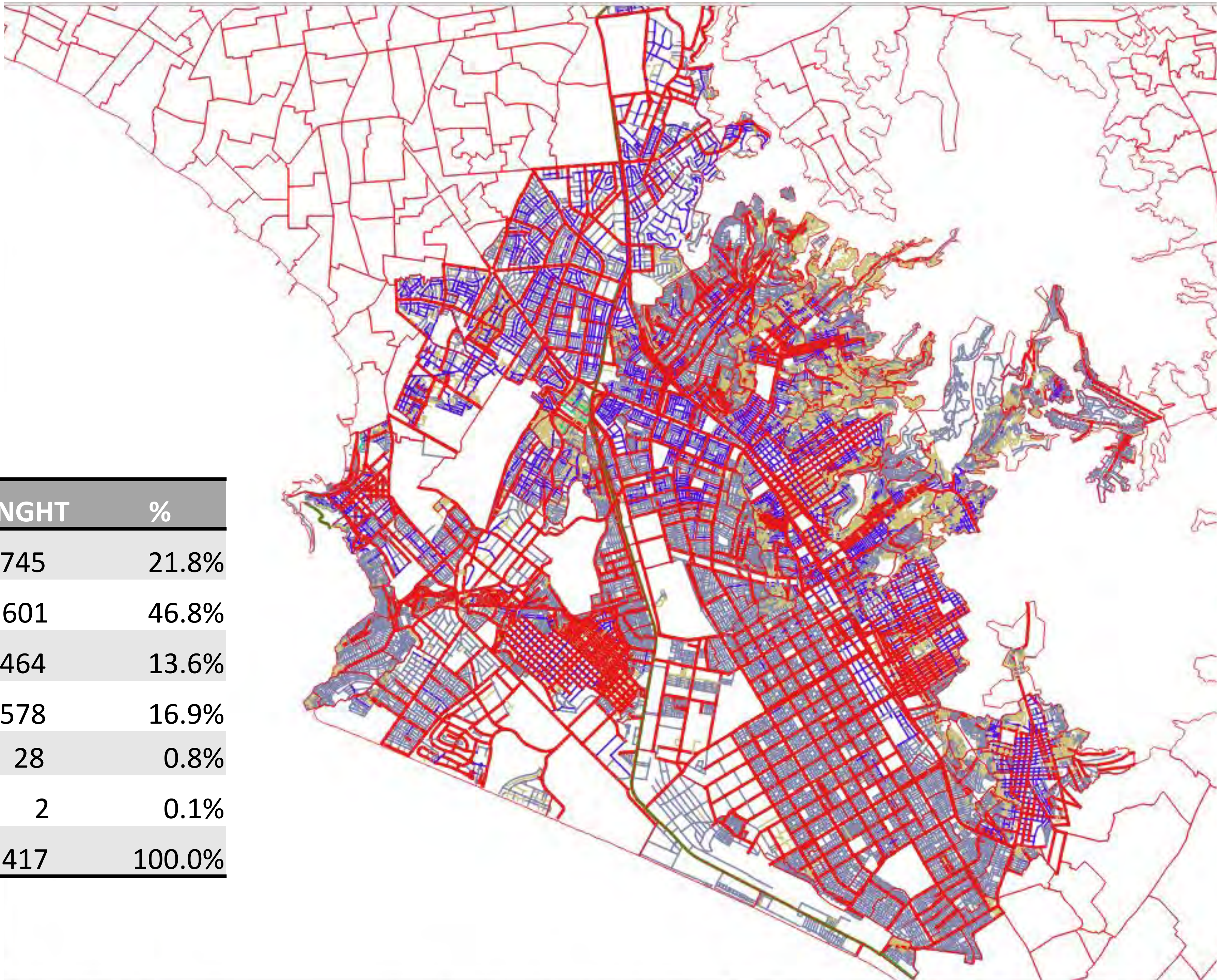


Roadways

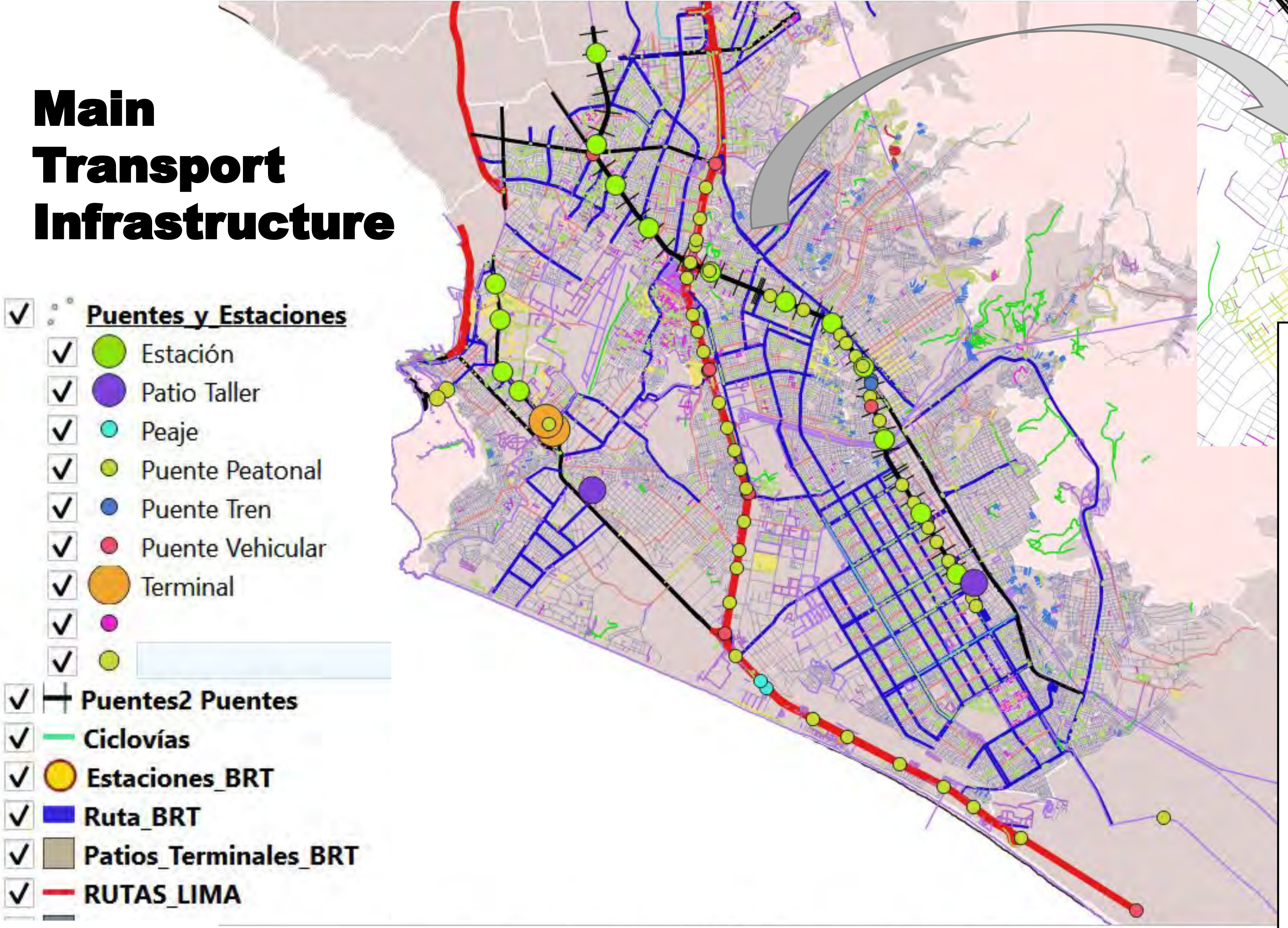
2B-3: Evaluation of Seismic vulnerability of road network, and Development of a system to estimate evacuation routes considering the locations of the main hospital and shelters.

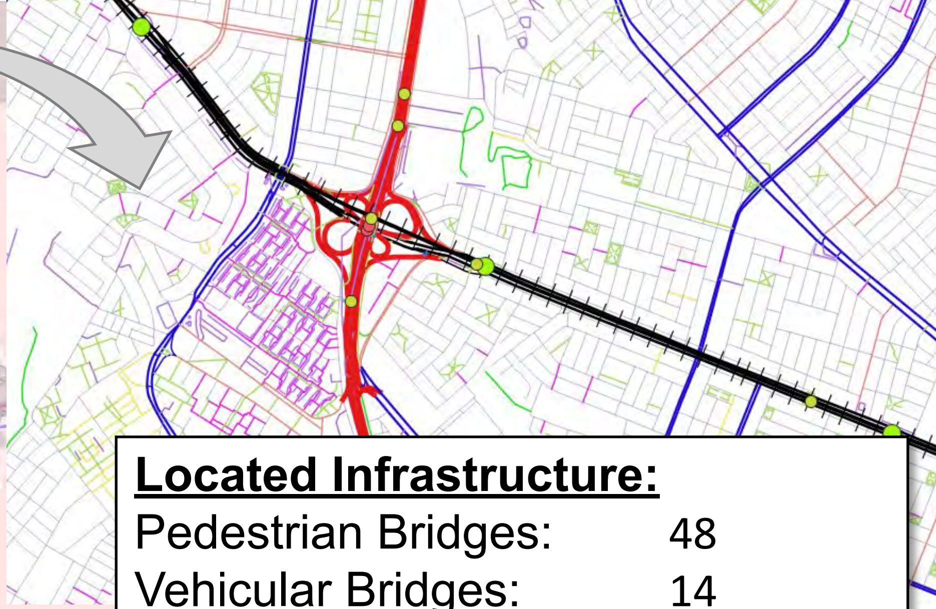
ROAD NETWORK

CATEGORY	ELEMENTS	LENGHT	%
AVENUES	7,950	745	21.8%
STREETS	23,821	1,601	46.8%
SHREDS	4,814	464	13.6%
PASSAGES	9,471	578	16.9%
HIGHWAYS	75	28	0.8%
OTHER	68	2	0.1%
TOTAL	46,199	3,417	100.0%



Main Transport Infrastructure





Located Infrastructure:

Pedestrian Bridges:	48
Vehicular Bridges:	14
Train Bridge:	04
Tunnel:	01
Stations (busses and metro):	15
Depot (busses and metro):	02
Peaje:	01
Terminal:	01

Metro Line 1:

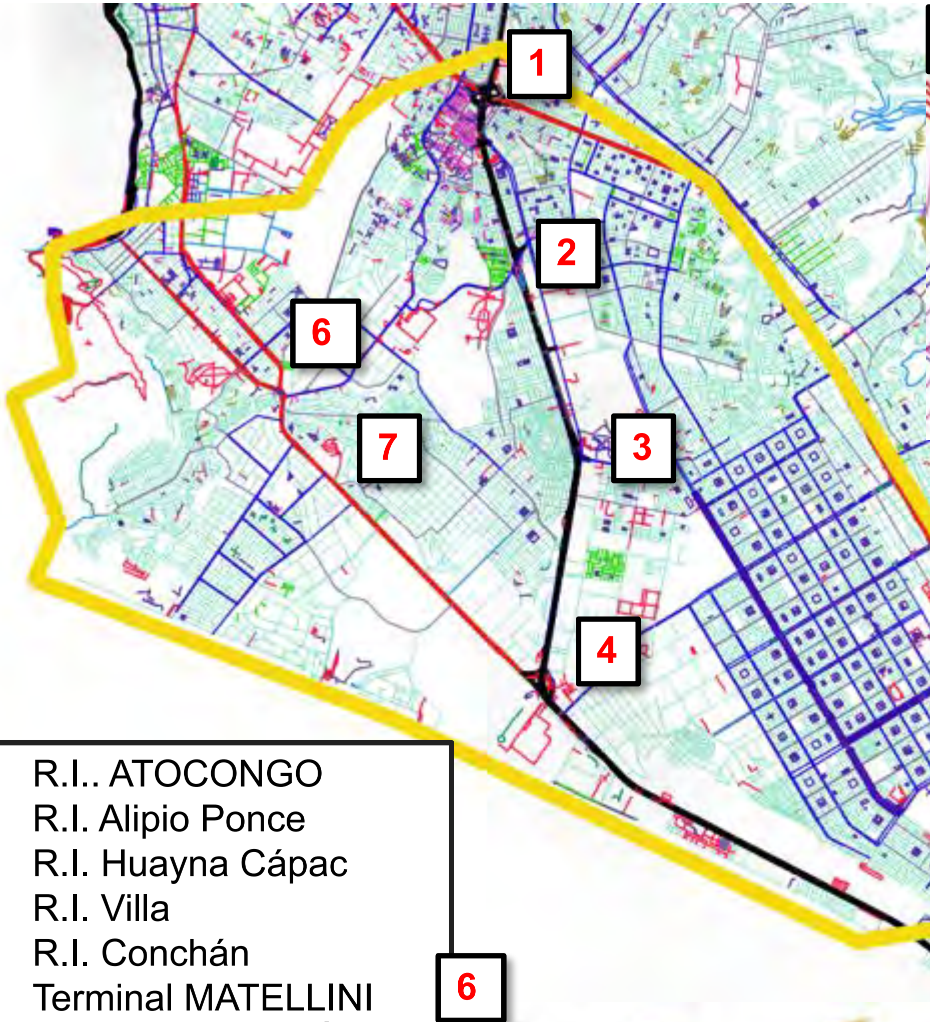
At Level:	5.69 Km
Ramp – Viaduct:	1.66 Km
Viaduct:	7.61 Km

Metropolitano (BRT) 5.77 Km

Bike paths: 27.85 Km

Routes System (166, 5,507.2 Km)

Road Interchange And Main Mass Transit Facilities



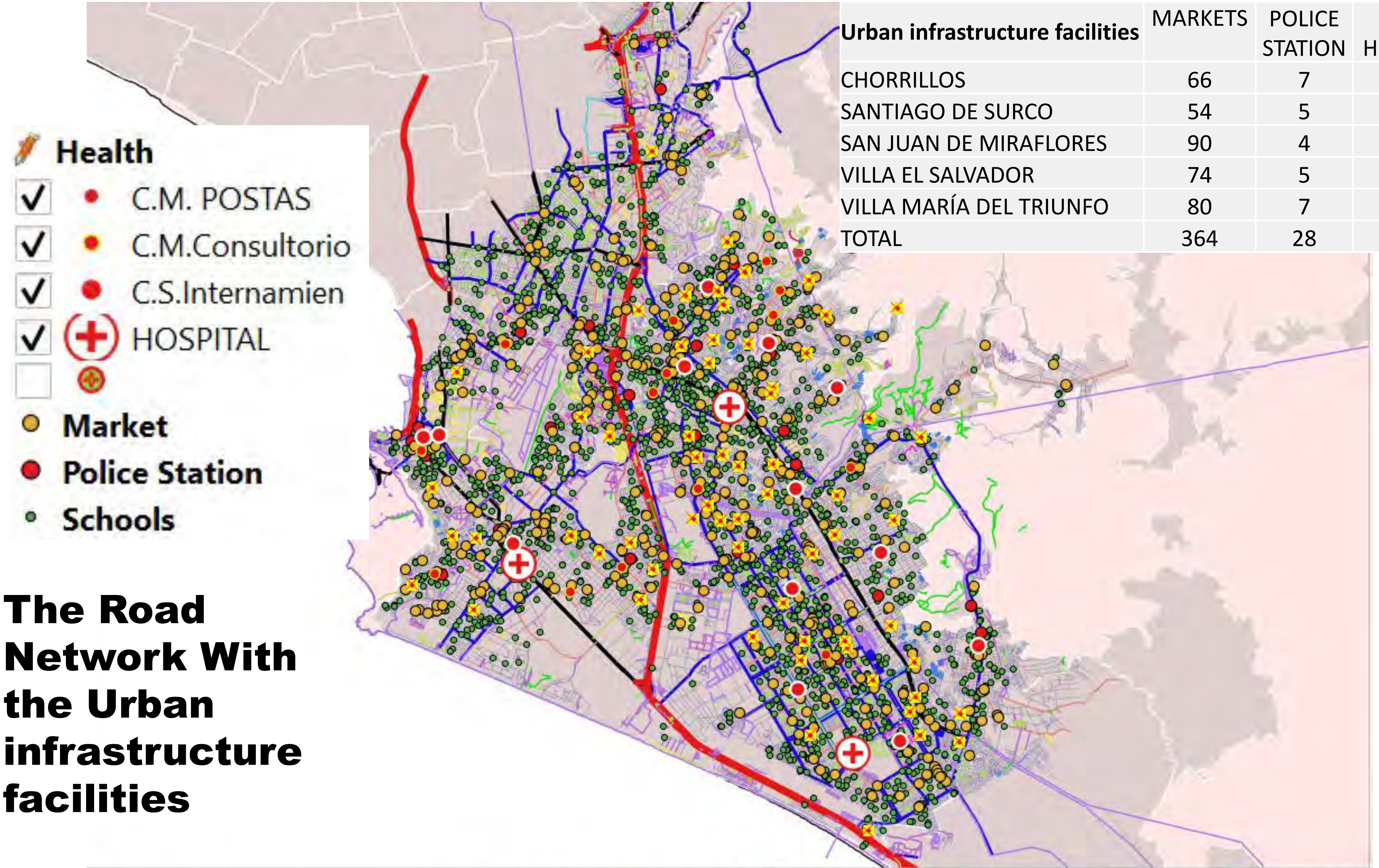
1. R.I.. ATOCONGO
2. R.I. Alipio Ponce
3. R.I. Huayna Cápac
4. R.I. Villa
5. R.I. Conchán
6. Terminal MATELLINI
7. Depot TARAPACÁ
8. Depot LINEA 1 METRO

6

7

8

The Road Network With the Urban infrastructure facilities



Urban infrastructure facilities	MARKETS	POLICE STATION	Health	Schools
CHORRILLOS	66	7	19	353
SANTIAGO DE SURCO	54	5	6	335
SAN JUAN DE MIRAFLORES	90	4	27	85
VILLA EL SALVADOR	74	5	18	524
VILLA MARÍA DEL TRIUNFO	80	7	26	462
TOTAL	364	28	96	1759

Restoration Simulation of Water Pipeline System in Lima, Peru

Yoshihisa Maruyama

Chiba University

Damage to Water Supply System after Earthquakes

The water supply system is an extremely important lifeline facility in modern society. Recent earthquakes in Japan occasionally caused severe damage to water distribution pipelines, and water supply was disrupted for weeks in the heavily affected area.

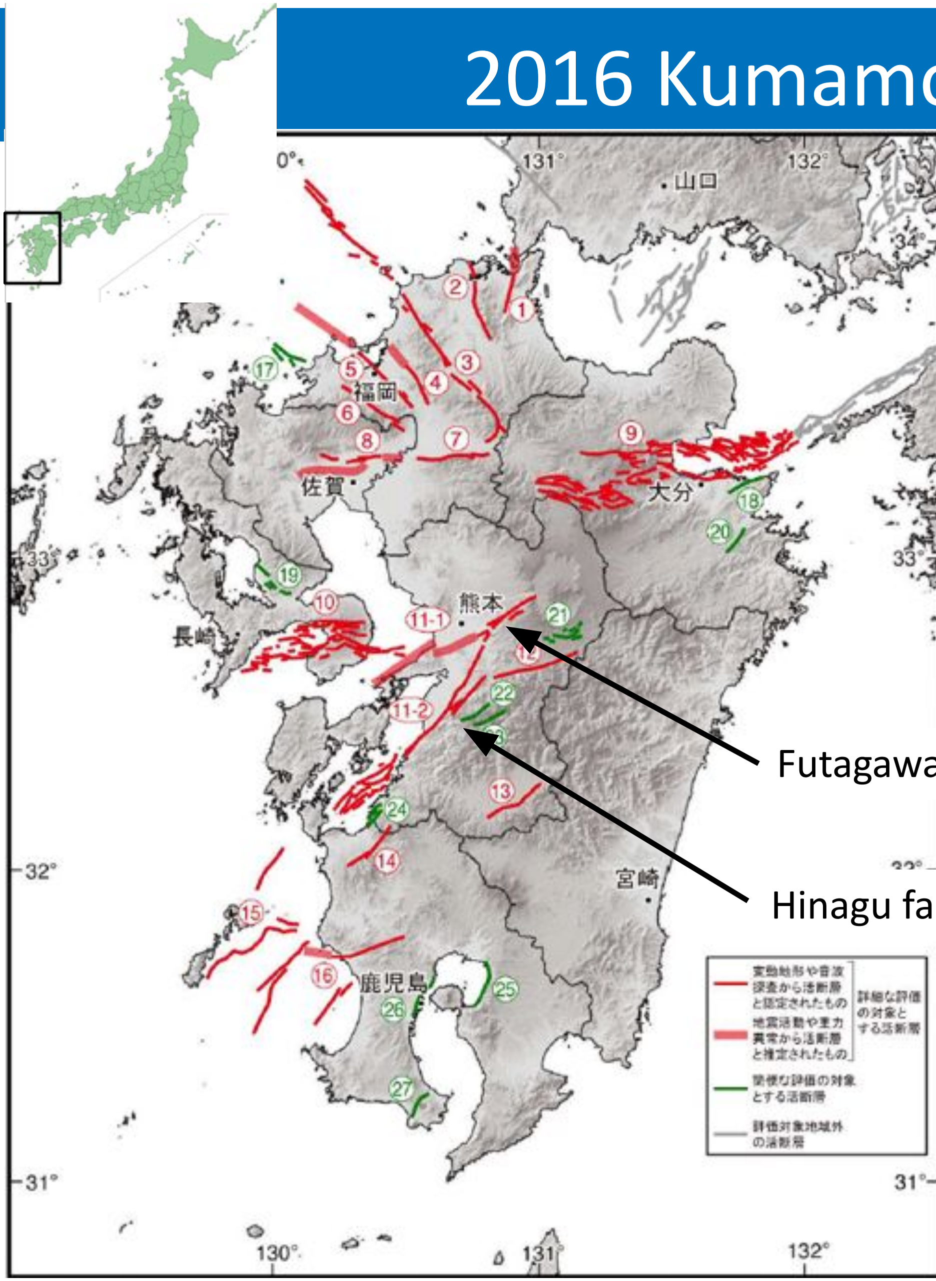
2016 Kumamoto EQ.
DIP φ 200 mm

2011 Tohoku EQ.
SP φ 2400 mm

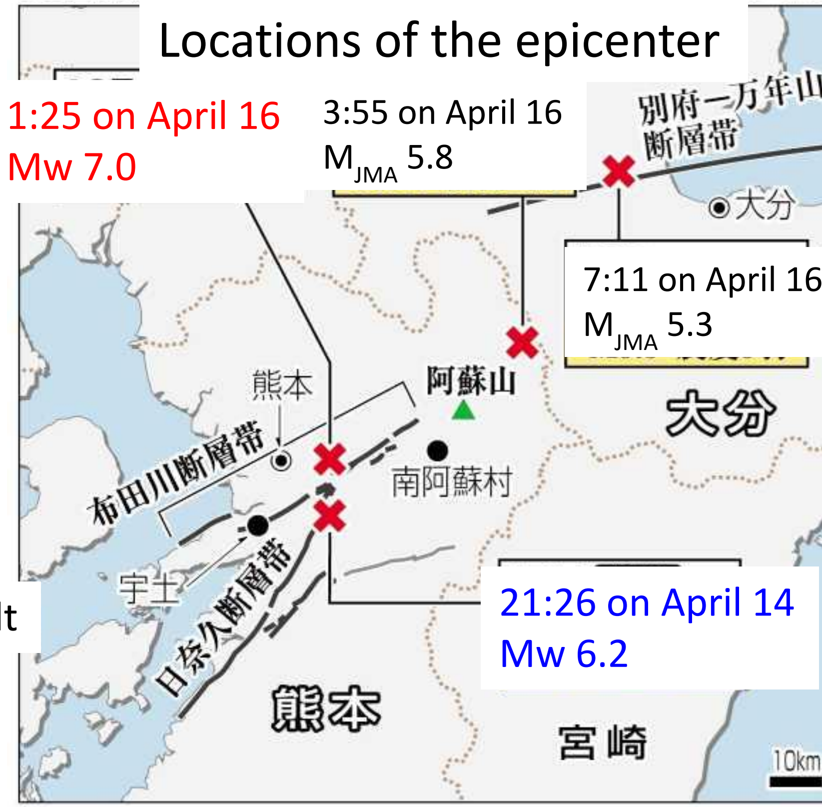
2011 Tohoku EQ.
SP φ 125 mm

Based on the lessons after the Kobe earthquake, the important facilities for water supply systems were retrofitted against a large earthquake. However, the water supply was occasionally disrupted for several days or weeks because of recent large earthquakes.

2016 Kumamoto Earthquake



http://www.jishin.go.jp/main/choukihyoka/kyushu.htm



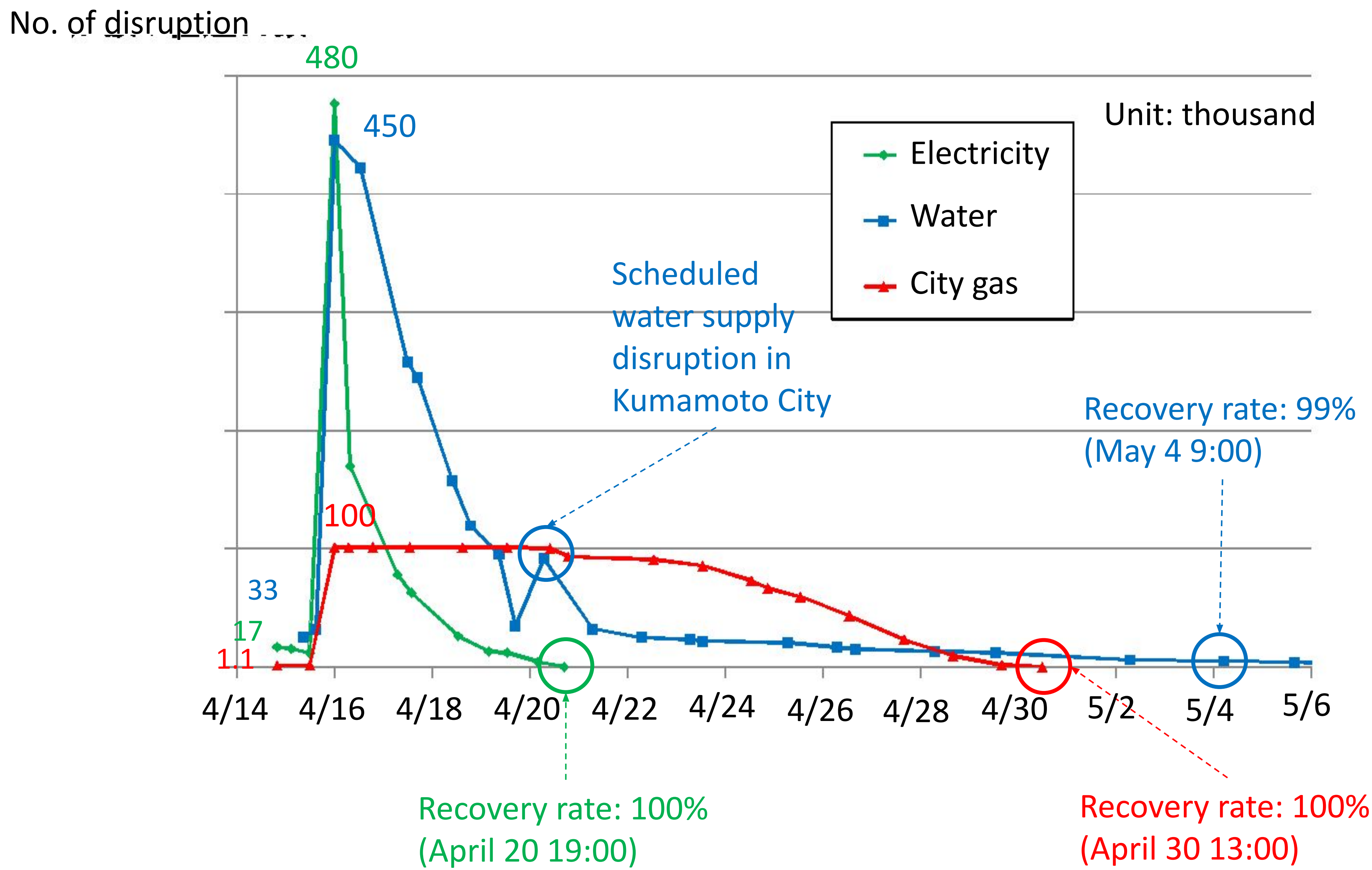

Mashiki Town (April 16, 2016)


Mashiki Town Hall (April 16, 2016)

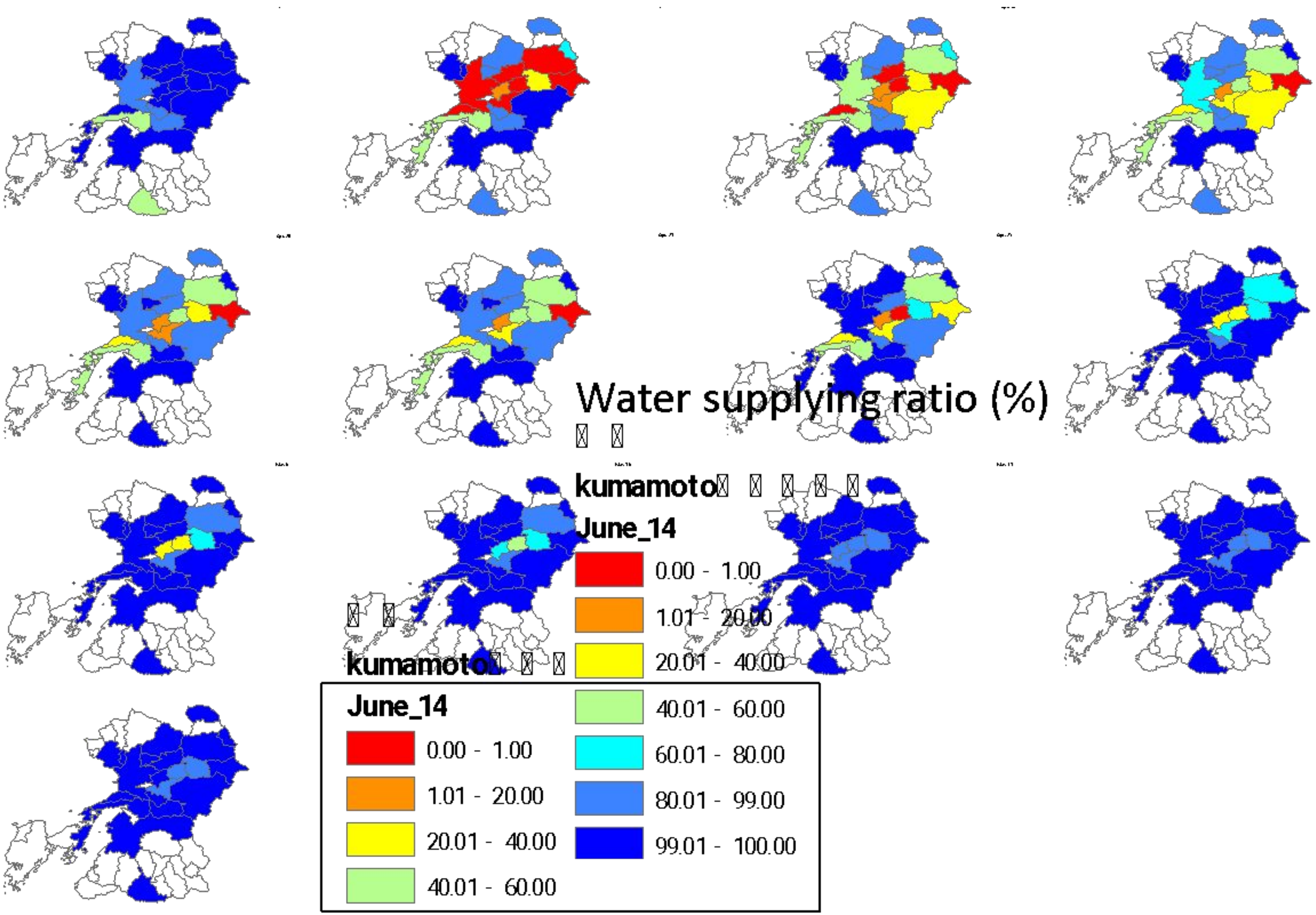

Kumamoto Castle (April 16, 2016)


Mashiki Town (April 17, 2016)

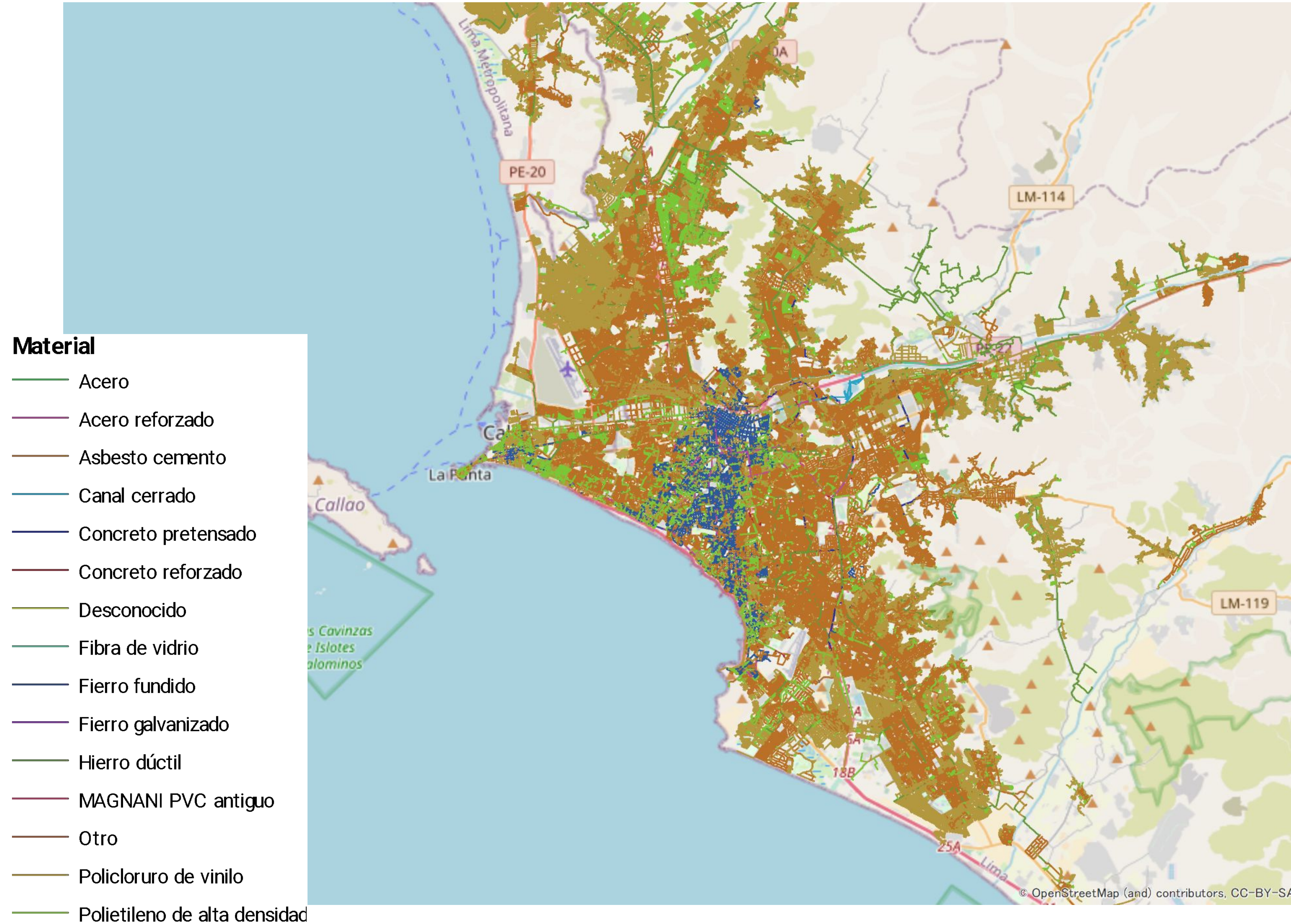
Recovery Process of Utility Lifelines



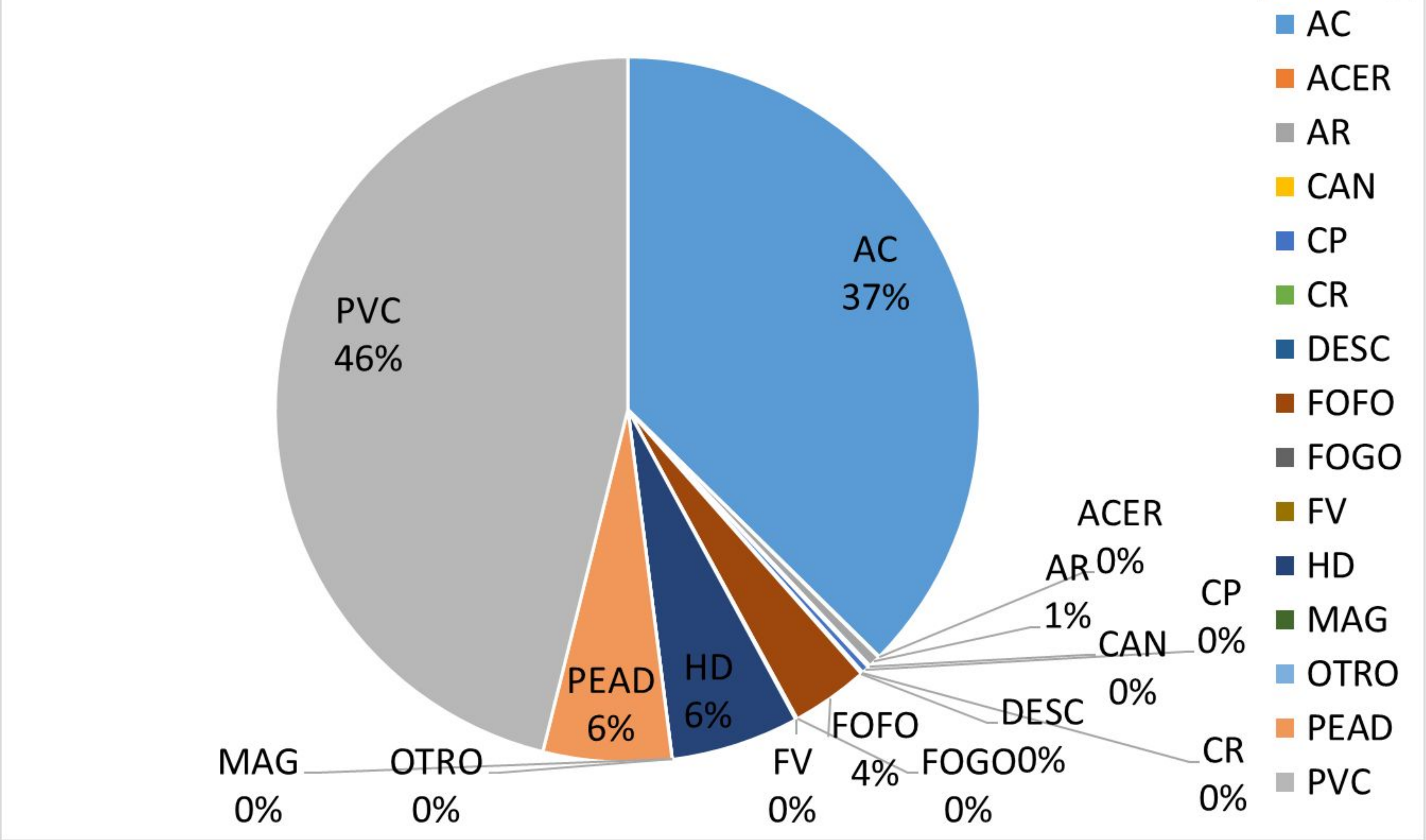
Restoration Process of Water Supply after the 2016 Kumamoto Earthquake, Japan



Water Pipeline in Lima



Percentage of Pipe Material



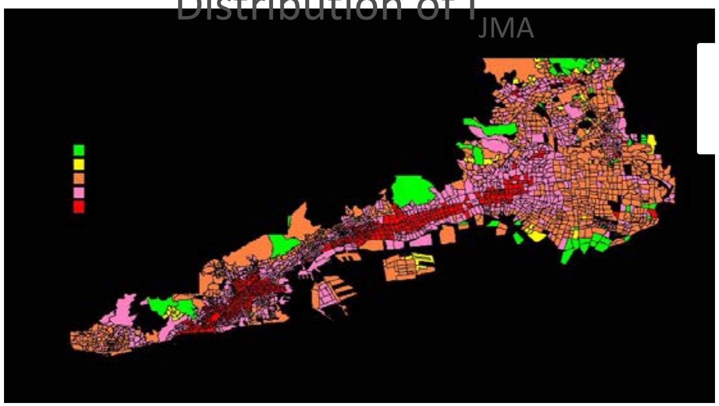
Asbestos cement pipes (AC) and Polyvinyl chloride pipes (PVC) are mainly used. Ductile iron pipes (HD), High-density polyethylene pipes (PEAD), and Cast iron pipes (FOFO) are rarely used in Lima.

Simulation of Restoration Period

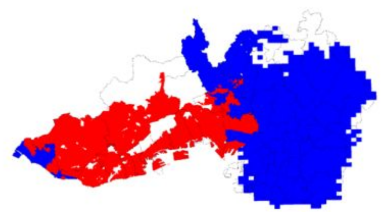
Nojima and Sugito (2003)

1995 Kobe Earthquake

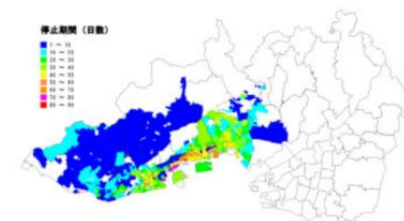
Distribution of I_{JMA}



Water supply outage

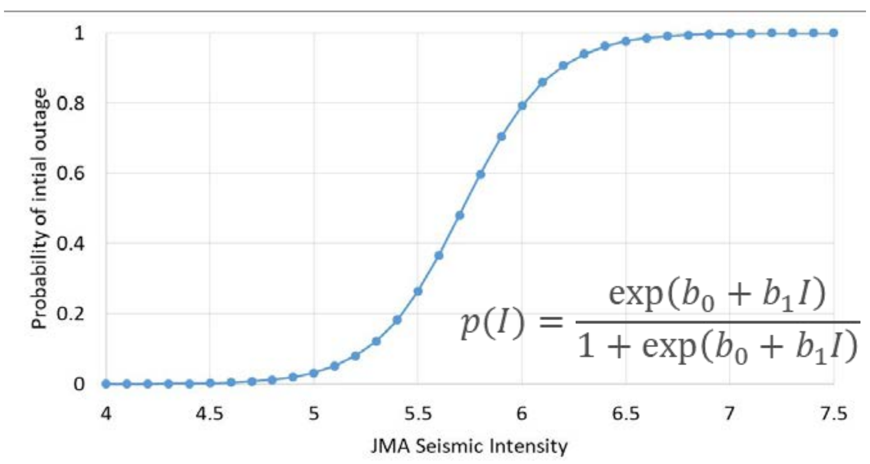


Restoration period

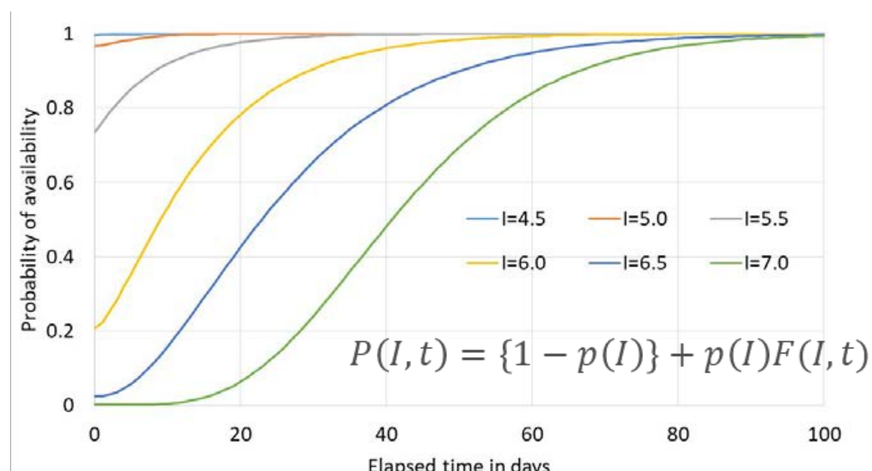


I: JMA seismic intensity

Functional fragility function



Post-earthquake serviceability curve

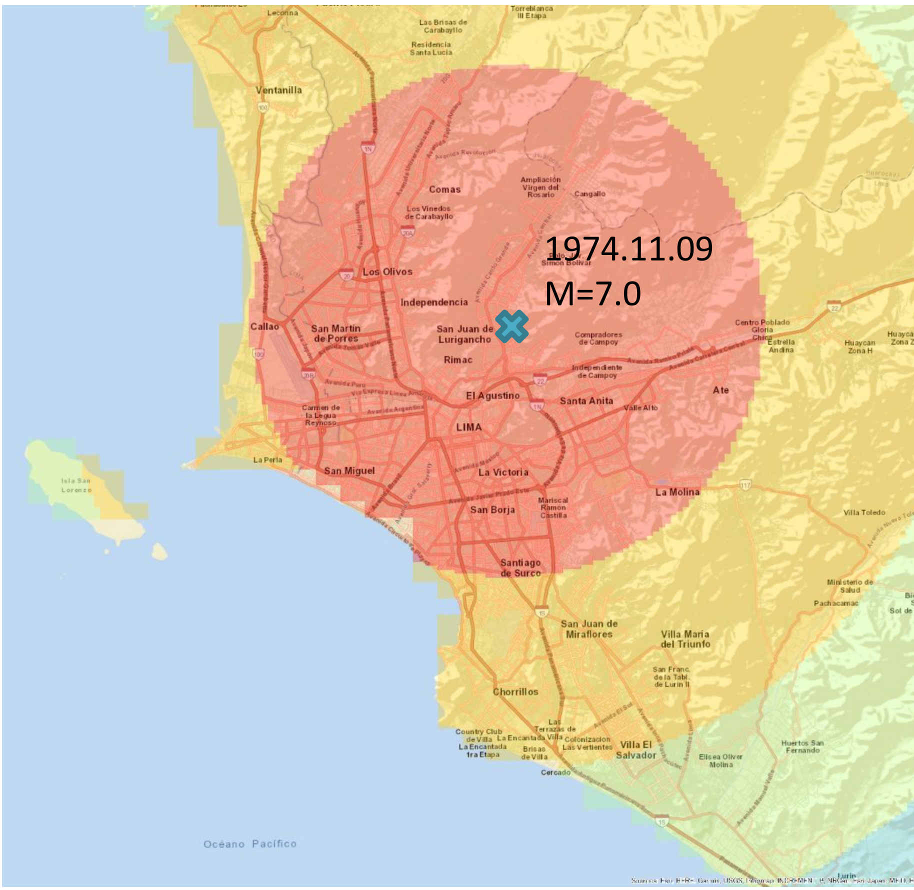


Simulation of Restoration Period

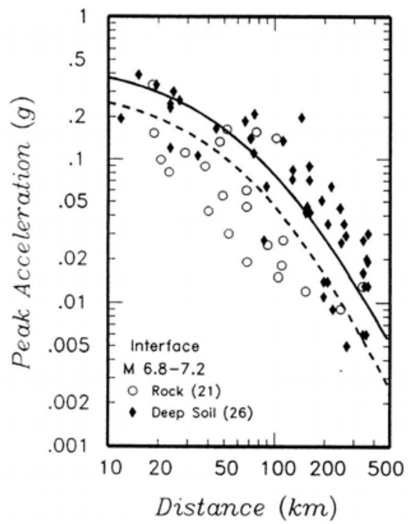
Youngs et al. (1997)

Scenario Earthquake

Distribution of the peak ground acceleration (PGA)



Attenuation relationship



$$\ln(PGA) = -0.6687 + 1.438M - 2.329\ln(R + 1.097\exp(0.617M)) + 0.00648H$$

PGA_SOIL (cm/s^2)

	110.25 - 150.00
	150.01 - 175.00
	175.01 - 200.00
	200.01 - 225.00
	225.01 - 250.00

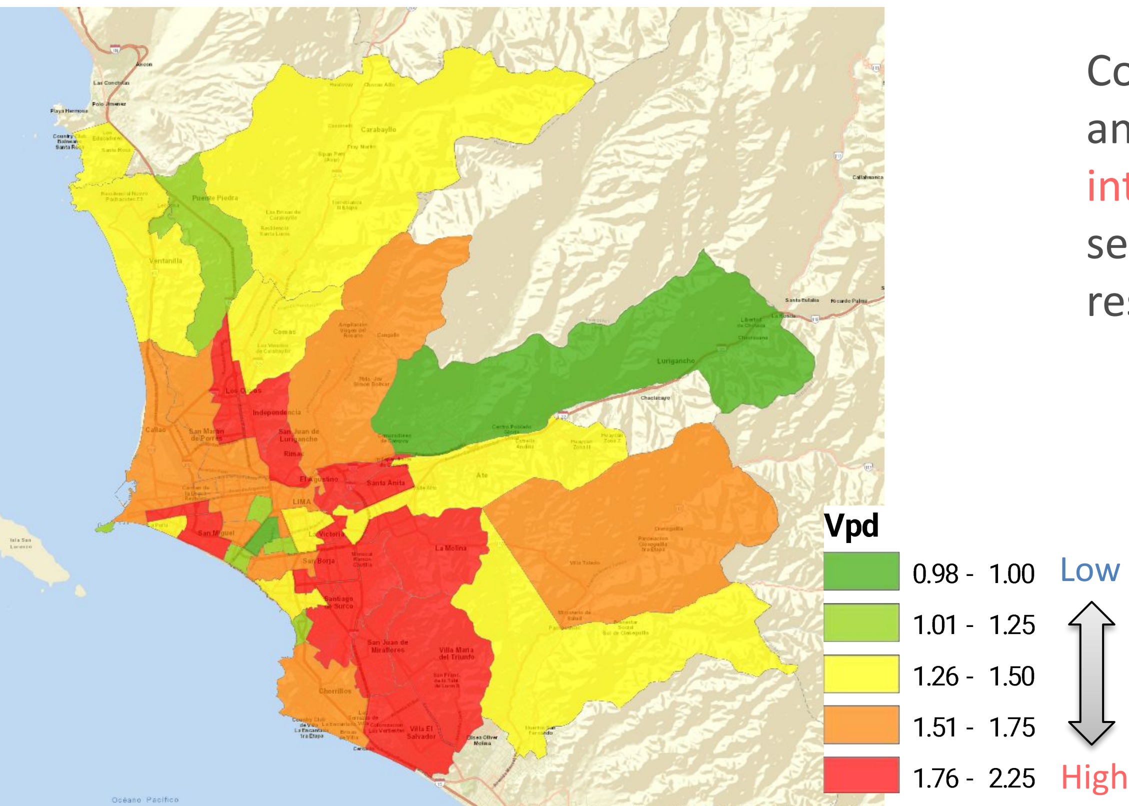
Vulnerability Index of Water Pipeline

Diameter (mm)	Cd
~ 75	1.6
100 ~ 250	1.0
300 ~ 450	0.7
500 ~ 900	0.5
1000 ~	0.2

Pipe material	Cp
DIP	0.3
CIP	1.0
VP	1.0
PE	0.3
ACP	2.5

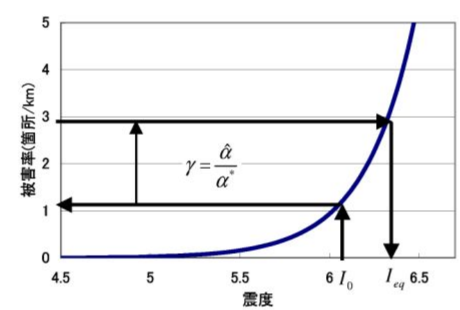
Vulnerability index

$$V_{pd} = \frac{\sum_i \sum_j C_{d_i} C_{p_j} L_{ij}}{\sum_i \sum_j L_{ij}}$$

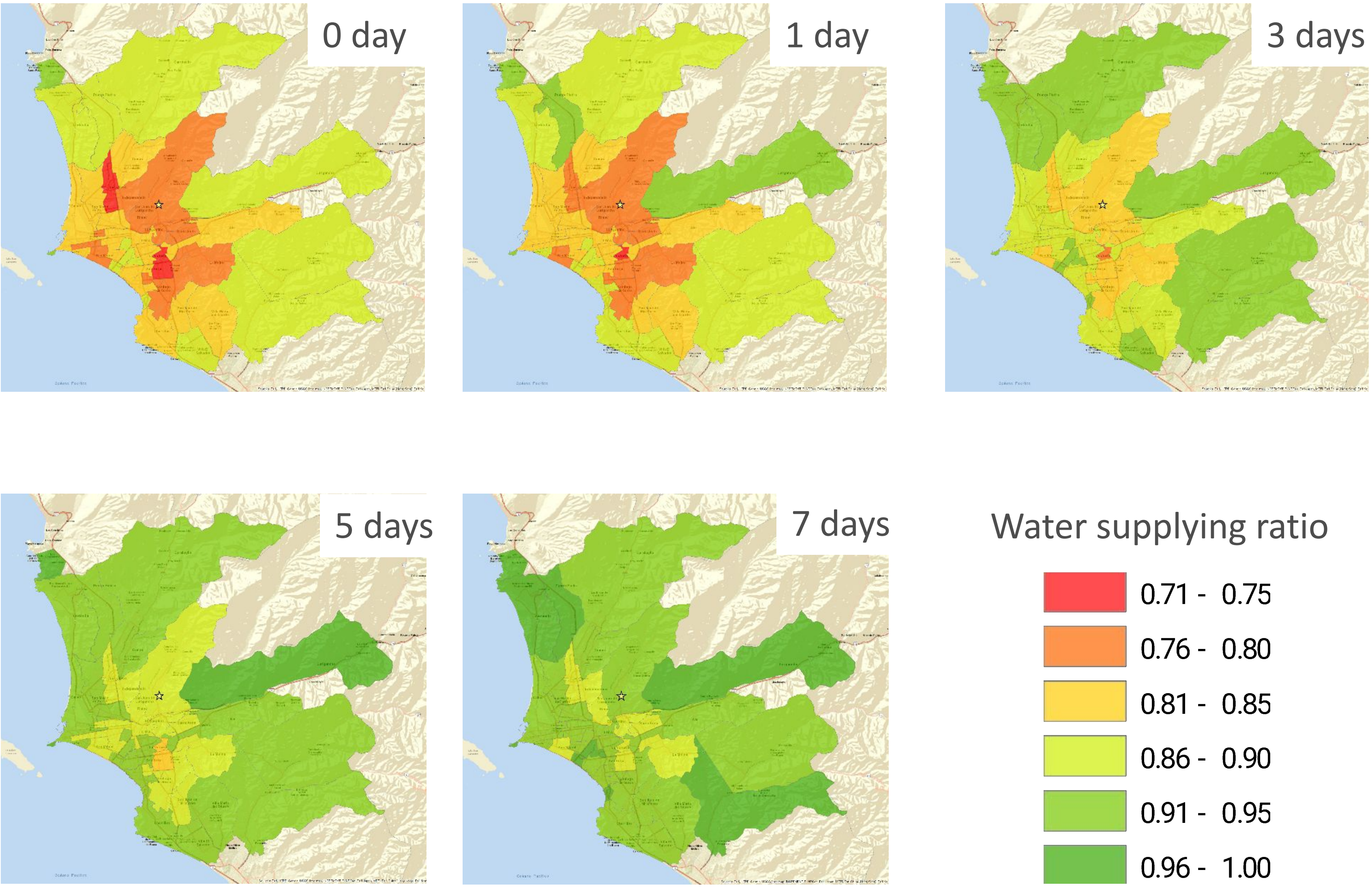


Considering the difference of V_{pd} of Lima and that of Kobe (0.446), the seismic intensity is adjusted through the JMA seismic intensity to estimate the restoration period.

$$I_{eq} = I_0 + 0.647 \log_{10} \frac{V_{pd}}{0.446}$$



Simulated Water Supplying Ratios



Conclusions

The restoration period of water supply pipeline in Lima was estimated based on the equations developed after the 1995 Kobe earthquake.

- ✔ The water supplying ratio of smaller than 80% is estimated in some areas even under the moderate earthquake.
- ✔ It takes longer than one week for fully restoration in some districts.

The coefficients to calculate the vulnerability index will be revised considering the pipe characteristics in Lima.

Thank you very much.