A digital liquefaction susceptibility map for the HAZUS earthquake loss estimation of the San Juan metropolitan area, Puerto Rico

By Marilyn Santiago and Jesús Rodríguez-Martínez

I. Introduction

Puerto Rico is part of a seismically active region. Earthquakes of low to moderate intensity regularly affect Puerto Rico and the surrounding region (McCann, 1985). Historical records document that earthquakes caused extensive damage in Puerto Rico in 1670, 1787, and 1918. The intensities of these three earthquakes may have been capable of inducing land-deformation processes, such as liquefaction. Liquefaction occurs when a saturated soil loses its cohesive properties owing to excess pore-water pressure generated by and accumulated during strong earthquake ground shaking. Areas vulnerable to liquefaction are particularly vulnerable to extensive property damage during earthquakes. The earthquakes of 1670 and 1918 possibly caused liquefaction in the coastal zone of western Puerto Rico (Moya and McCann, 1994).

Several studies have described the nature and occurrence of earthquake-induced deformation processes, including liquefaction (Youd and Perkins, 1978; Fairless and Berril ,1984; Hamada and others, 1986). Studies describing potential liquefaction in Puerto Rico include those by Molinelli-Freytes (1985), McCann (1985), McCann and Associates (1994), and Bachhuber and Hengesh (1999).

The National Institute of Building Science (NIBS) in cooperation with the Federal Emergency Management Agency (FEMA) developed the “Hazards in the United States” software (HAZUS), a standardized methodology based on a Geographic Information System (GIS), to estimate losses from land-deformation processes, such as liquefaction caused by earthquakes. HAZUS uses mathematical formulas and information about building stock, local geology and the location and size of potential earthquakes, economic data, and other information to generate earthquake loss estimates. Loss estimates can provide the basis for developing mitigation policy, for developing and testing emergency preparedness and response plans, and for planning for post-disaster relief and recovery. HAZUS can produce three levels of accuracy on estimated losses based on the detail of the data available. Level one (Default Data Analysis), uses default data (general information from national databases) included in the HAZUS software to produce a rough estimate of losses. Levels two (User-Supplied Data Analysis) and three (Advanced Data and Models Analysis) require more extensive inventory information to produce more accurate levels on estimated losses.

The U.S. Geological Survey, in cooperation with the Puerto Rico Planning Board (PRPB), developed a digital map of the San Juan metropolitan area classifying areas according to susceptibility to liquefaction. A liquefaction susceptibility map is one of the data layers needed to implement the HAZUS software in Puerto Rico at accuracy levels two and three. The San Juan metropolitan area (fig. 1) includes the municipalities of San Juan, Carolina, Bayamón, Guaynabo, Cataño, Toa Baja, and Trujillo Alto.

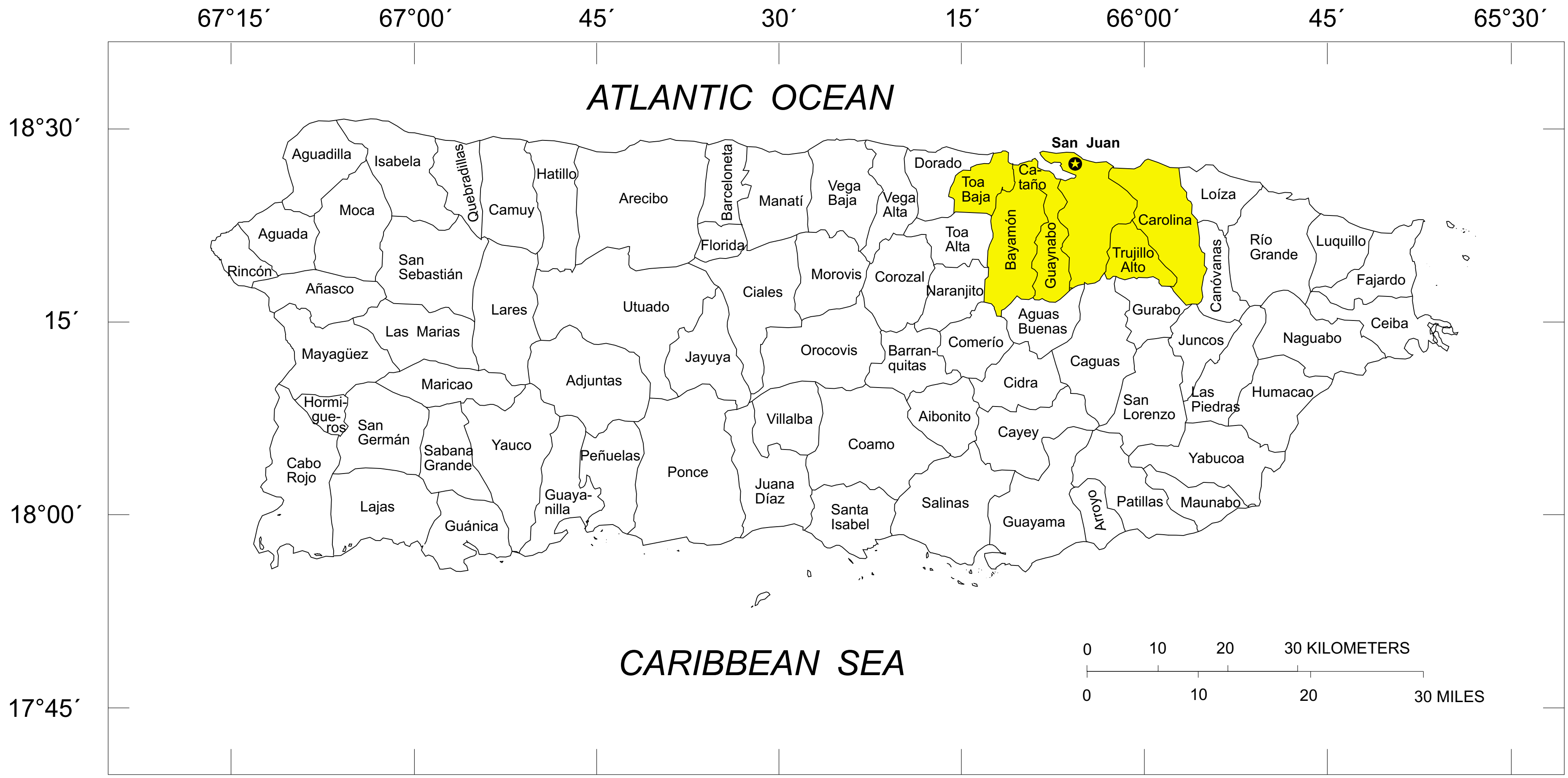

Figure 1. San Juan metropolitan area, Puerto Rico.

This CD contains a digital map of liquefaction susceptibility for the San Juan metropolitan area to be used in a GIS software.

II. Methods

Two different methodologies were followed in developing the digital map of liquefaction susceptibility for the San Juan metropolitan area. For the municipalities of Carolina, Bayamón, Guaynabo, Cataño, Toa Baja, and Trujillo Alto, maps of liquefaction susceptibility were developed following the standardized methodology specified in "Earthquake loss estimation methodology HAZUS technical manual" Volume I (Section 4.2) by NIBS (1997). Liquefaction susceptibility in the municipality of San Juan was obtained from a study by Bachhuber and Hengesh (1999).

The HAZUS methodology rates geologic units as to their liquefaction susceptibility (very low to very high) following a classification system (Youd and Perkins, 1978) presented in the "Earthquake loss estimation methodology HAZUS technical manual." This classification system uses age, depositional environment, and material type of the geologic units (table 1). The method used by Bachhuber and Hengesh (1999) in the municipality of San Juan closely follows that of Youd and Perkins (1978), but includes subsurface data such as depth to ground water, lithologic variations with depth, and geotechnical properties of the geologic units. Areas of equal susceptibility to liquefaction were delineated using the 1:20,000 scale USGS geologic maps that compose the San Juan metropolitan area (references are listed in section VI). Table 2 shows the relations between liquefaction probability and peak horizontal acceleration (PGA) for the five susceptibility categories (very low to very high) as presented in the HAZUS technical manual (NIBS, 1997). Arc/Info (by Environmental Systems Research Institute), a vector GIS software, was used to develop the digital liquefaction-susceptibility map (coverage).

III. Results

Table 3 lists the frequency distribution of liquefaction susceptibility of the geologic units in the San Juan metropolitan area. Susceptibility classifications with the superscript "1" were obtained from the Bachhuber and Hengesh (1999) study in the municipality of San Juan (see, for example, cases 55 through 59 in table 3). Minor inconsistencies in the identification of geologic units across adjacent USGS geologic quadrangles, particularly among surficial deposits can cause distinct differences in the liquefaction susceptibility across geologic quadrangles. These differences across geologic quadrangle boundaries could on occasion, be minimized or completely eliminated, as in case 64 in table 3, where a surficial deposit was mapped as Quaternary Alluvium Terrace (Qat) and Quaternary Alluvium (Qal) on contiguous sides of the Gurabo and Aguas Buenas 1:20,000 scale USGS geologic quadrangles, respectively. In this case, the differences in liquefaction susceptibility between the two units is minimal and both are classified as having very low liquefaction susceptibility (VL) according to the classification system by Youd and Perkins (1978).

Table 1. Liquefaction susceptibility of sedimentary deposits (from Youd and Perkins, 1978)
[--, not applicable]

Type of deposit	***General distribution of cohesionless sediments in deposits***	***Likelihood that cohesionless sediments when saturated would be susceptible to liquefaction (by age of deposit)***			
		< 500 yr Modern	***Holocene < 11 ka***	***Pleistocene 11 ka - 2 Ma***	***Pre-Pleistocene >2Ma***
(a) Continental Deposits					
River channel	Locally variable	Very High	High	Low	Very Low
Flood plain	Locally variable	High	Moderate	Low	Very Low
Alluvial fan and plain	Widespread	Moderate	Low	Low	Very Low
Marine terraces and plains	Widespread	--	Low	Very Low	Very Low
Delta and fan-delta	Widespread	High	Moderate	Low	Very Low
Lacustrine and playa	Variable	High	Moderate	Low	Very Low
Colluvium	Variable	High	Moderate	Low	Very Low
Talus	Widespread	Low	Low	Very Low	Very Low
Dunes	Widespread	High	Moderate	Low	Very Low
Loess	Variable	High	High	High	Unknown
Glacial till	Variable	Low	Low	Very Low	Very Low
Tuff	Rare	Low	Low	Very Low	Very Low
Tephra	Widespread	High	High	--	--
Residual soils	Rare	Low	Low	Very Low	Very Low
Sebkha	Locally variable	High	Moderate	Low	Very Low
(b) Coastal Zone					
Delta	Widespread	Very High	High	Low	Very Low
Estuarine	Locally variable	High	Moderate	Low	Very Low
Beach					
High Wave Energy	Widespread	Moderate	Low	Very Low	Very Low
Low Wave Energy	Widespread	High	Moderate	Low	Very Low
Lagoonal	Locally variable	High	Moderate	Low	Very Low
Fore shore	Locally variable	High	Moderate	Low	Very Low
(c) Artificial					
Uncompacted Fill	Variable	Very High	--	--	--
Compacted Fill	Variable	Low	--	--	--

Table 2. Conditional probability relations for liquefaction susceptibility categories (from HAZUS technical manual, NBIS, 1997).

Susceptibility Category	P[Liquefaction | PGA = a]
Very high- VH	0 <= 9.09a – 0.82 <= 1.0
High - H	0 <= 7.67a – 0.92 <= 1.0
Moderate - M	0 <= 6.67a – 1.0 <= 1.0
Low - L	0 <= 5.57a – 1.18 <= 1.0
Very Low - VL	0 <= 4.16a – 1.08 <= 1.0
None	0.0

PGA- Peak Horizontal Ground Acceleration

Table 3. Frequency distribution of liquefaction susceptibility of geologic units in the San Juan metropolitan area

Case number	Frequency (number of Polygons)	Geologic Unit	Liquefaction susceptibility	Geologic map quadrangle
1	115	(Water Body)		
2	4	Kb	VL	Gurabo
3	44	Kc	VL	Aguas Buenas, Naranjito
4	5	Kcb	VL	Gurabo
5	5	Kcbv	VL	Gurabo
6	26	Kcf	VL	Aguas Buenas, Naranjito
7	11	Kcg	VL	Naranjito
8	1	Kcgt	VL	Naranjito
9	1	Kcl	VL	Gurabo
10	22	Kcm	VL	Aguas Buenas
11	9	Kcn	VL	Naranjito
12	8	Kco	VL	Gurabo
13	10	Ke	VL	Naranjito
14	1	Keb	VL	Naranjito
15	11	Kep	VL	Naranjito
16	5	Kes	VL	Naranjito
17	9	Kf	VL	Carolina,Gurabo
18	1	Kfc	VL	Aguas Buenas
19	2	Kff	VL	Gurabo
20	6	Kfl	VL	Carolina, Gurabo
21	15	Kg	VL	Aguas Buenas, San Juan
22	2	Kgb	VL	Aguas Buenas
23	3	Kgf	VL	Aguas Buenas
24	13	Kgl	VL	Agus Buenas, San Juan
25	1	Kgll	VL	Aguas Buenas
26	8	Kgm	VL	Aguas Buenas, San Juan
27	21	Khp	VL	Gurabo
28	5	Khpb	VL	Gurabo

29	3	Khpl	VL	Gurabo
30	7	Kil	VL	Gurabo
31	4	Kim	VL	Gurabo
32	5	Kiv	VL	Gurabo
33	20	Kl	VL	Aguas Buenas, Gurabo
34	12	Klc	VL	Aguas Buenas
35	37	Kll	VL	Aguas Buenas, Gurabo
36	14	Km	VL	AguasBuenas,Carolina, San Juan
37	7	Kmg	VL	Carolina, Gurabo
38	3	Kml	VL	San Juan
39	4	Kmt	VL	Aguas Buenas, San Juan
40	1	Kn	VL	Naranjito
41	3	Kpa	VL	Naranjito
42	8	Kr	VL	Naranjito
43	1	Krc	VL	Naranjito
44	4	Krf	VL	Naranjito
45	64	Ks	VL	Aguas Buenas, Naranjito
46	6	Ksb	VL	Naranjito
47	8	Ksp	VL	Naranjito
48	1	Kss	VL	Aguas Buenas
49	20	Kt	VL	Aguas Buenas
50	3	Ktl	VL	Aguas Buenas
51	3	Kts	VL	Aguas Buenas
52	4	Kz	VL	Aguas Buenas
53	2	Kzs	VL	Aguas Buenas
54	15	QTb	L	Bayamón
55	1	QTt	L [1]	San Juan
56	9	QTt	VL [1]	Carolina, San Juan
57	7	Qa	H [1]	Carolina,Naranjito,San Juan
58	49	Qa	L [1]	Bayamón,Carolina,Gurabo,Naranjito, SanJuan,Vega Alta
59	6	Qa	M [1]	Naranjito,San Juan
60	18	Qa	VH [2]	Bayamón, Gurabo
61	15	Qa	VL [1]	Carolina, Gurabo
62	29	Qal	VH	Aguas Buenas
63	32	Qat	L [3]	Aguas Buenas, Gurabo, Naranjito
64	11	Qat	VL [3]	Gurabo
65	10	Qb	H	Bayamón, San Juan
66	2	Qbq	H	Carolina
67	23	Qe	L	Bayamón, Carolina, San Juan
68	7	Qf	L [1]	San Juan
69	1	Qf	VL [1]	San Juan
70	30	Ql	L	Aguas Buenas, Bayamón, Vega Alta
71	2	Qr	L	Bayamón
72	2	Qrt	L	Vega Alta
73	34	Qs	VH	Bayamón, Carolina, San Juan
74	6	Qss	H [1]	Carolina, San Juan
75	9	Qss	L [1]	Bayamón, Carolina, San Juan
76	1	Qss	VH [1]	San Juan
77	101	Qt	L	Aguas Buenas, Bayamón, Naranjito

				San Juan
78	13	Qts	L	Naranjito
79	5	TKa	VL	Naranjito
80	250	TKd	VL	Aguas Buenas, Bayamón, Naranjito
81	14	TKh	VL	Aguas Buenas, Naranjito
82	4	TKk	VL	Naranjito
83	2	TKm	VL	Gurabo
84	1	TKmb	VL	Gurabo
85	79	TKmi	VL	Gurabo
86	1	TKmt	VL	Gurabo
87	5	TKp	VL	Aguas Buenas
88	98	Ta	VL	Bayamón, Carolina, San Juan, Vega Alta
89	1	Tab	VL	Bayamón
90	118	Tay	VL	Bayamón, Carolina, San Juan, Gurabo Gurabo Vega Alta
91	16	Tc	VL	Aguas Buenas, Bayamón, Carolina, San Juan, Vega Alta
92	5	Tcq	VL	Bayamón
93	1	Tcr	VL	Bayamón
94	22	Tcu	VL	Baymón
95	125	Td	VL	Aguas Buenas, Naranjito, San Juan
96	17	Tg	VL	Aguas Buenas, Carolina, Naranjito, San Juan
97	1	Tgb	VL	Gurabo
98	15	Tgl	VL	Aguas Buenas, Carolina, Gurabo
99	1	Tgm	VL	Gurabo
100	1	Tgv	VL	Aguas Buenas
101	9	Tm	VL	Bayamón, San Juan
102	1	Tn	VL	Naranjito
103	12	Tr	VL	Bayamón, Carolina, San Juan
104	6	Trc	VL	Aguas Buenas, Naranjito
105	1	Trl	VL	Aguas Buenas
106	7	Trs	VL	Aguas Buenas, Naranjito
107	7	Tru	VL	Aguas Buenas, Naranjito
108	18	Ts	VL	Bayamón, Naranjito, San Juan
109	1	Tscw	VL	Bayamón
110	15	af	H [4]	Bayamón, Carolina, San Juan
111	47	af	L [4]	Bayamón, Carolina, San Juan

VL – Very low, L - Low, M - Moderate, H - High, VH - Very High

1. Obtained from Bachhuber and Hengesh (1999).
2. Classification on the same type of geologic unit varies due to known differences in degree of cohesion.
3. Slightly modified to compensate for minor differences in the identification of geologic units across adjacent geologic quadrangles.
4.Classification varies on known degree of compaction.

For the San Juan metropolitan area, both Youd and Perkins (1978) and Bachhuber and Hengesh (1999) identify the geologic units having high susceptibility to liquefaction during the occurrence of an earthquake as: swamp deposits, minor alluvial units generally younger than 11,000 years old, landslide deposits less than 11,000 years old, and uncompacted deposits. When saturated, these sedimentary deposits are poorly consolidated and have poor cohesive properties. The swamp deposits generally are restricted to the coastal portion of the study area. The alluvial deposits classified as having high to very high liquefaction susceptibility are restricted to recent braided channels, narrow alluvial valleys, abandoned meanders, and recent channel gravel and sands. The landslide deposits classified as highly susceptible to liquefaction are minor in aerial extent and are restricted to the interior, close to the southernmost border of the San Juan metropolitan area. The classification of the liquefaction susceptibility of swamp deposits in the municipality of San Juan was obtained from Bachhuber and Hengesh (1999). Most of the artificial deposits are near the coast and result from the infilling of swamps. The artificial deposits range from low to very high susceptibility to liquefaction depending on the degree of compaction of the sediments. In municipalities other than San Juan, field reconnaissance combined with U.S. Geological Survey maps and documents available from state agencies and private consultants were used to estimate the degree of compaction of the artificial deposits. Artificial deposits with none or very poor compaction are considered to be highly to very highly susceptible to liquefaction. Well-compacted artificial deposits are assigned a low susceptibility to liquefaction. Those artificial deposits with a moderate degree of compaction are considered as being moderately susceptible to liquefaction.

IV. CD-ROM contents

1. GIS data:
a) liq-metro
Arc/Info (ver 7.2) coverage delimiting areas of equal susceptibility for the municipalities of Bayamón, Carolina, Cataño, Guaynabo, San Juan, Toa Baja, and Trujillo Alto. The file is georeferenced to the earth's surface using the State Plane coordinate system, NAD27 datum (units in meters).

Attributes on the Polygon Attribute Table (PAT):
LIQUE-CODE defined as 3 3 C (character)

Item LIQUE-CODE contains the liquefaction susceptibility:
VL - Very Low
L - Low
M - Moderate
H - High
VH - Very High
W - Lake (No susceptibility rating assigned)

TYPE defined as 1 1 N (numeric)

Item TYPE is a numeric code for each liquefaction susceptibility:

0 - No susceptibility rating assigned
1 - Very Low
2 - Low
3 - Moderate
4 - High
5 - Very High

b) liq-metro.e00

Arc/Info (version 7.2) export file of file described above (a)

c) liqmetro.shp

ArcView shapefile containing areas of equal susceptibility for the municipalities of Bayamón, Carolina, Cataño, Guaynabo, San Juan, Toa Baja, and Trujillo Alto. The file is georeferenced to the earth's surface using the State Plane coordinate system, NAD27 datum (units in meters).

2. Metadata:

a) liq-metro.txt

b) liqmetro.txt

Text files containing metadata for the liq-metro coverage and the liqmetro shapefile. These files comply with the Federal Geographic Data Committee (FGDC) standard FGDC-STD-001-1998 of the FGDC Content Standards for Digital Geospatial Metadata (CSDGM version 2).

3. Data viewer software

a) aeclient.exe

This setup program installs the 1.1 version of the Environmental Systems Research Institute, INC. ESRI ArcExplorer application.

V. Use and precautions

Loss estimates are not precise predictions, but rather estimates based on available scientific and engineering information. The areas defining liquefaction susceptibility are intended for HAZUS and were derived using the methodology established by the NIBS for defining areas of equal susceptibility to liquefaction. Therefore, use of this data set is limited to regional, applications where this methodology is appropriate, and must be used with considerable care and judgment. These data are not to be used at scales greater than 1:20,000.

VI. Selected References

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is organized with the following directory structure:

\ACROBAT-READER	<DIR>	Acrd4enu.exe - Setup program to install Acrobat Reader.
\AEXPLORER	<DIR>	Aeclient.exe - setup program to install the 1.1 version of the ArcExplorer application ARCEXPLORER.PDF - Adobe Acrobat file describing ArcExplorer.
\AI-EXPORT	<DIR>	LIQ-METRO.E00 - Arc/Info (7.2) export file LIQ-METRO - Arc/Info (7.2) coverage LIQ-METRO.TXT - Metadata file for liq-metro coverage
\SHAPEFILE	<DIR>	liqmetro.shp - ArcView (3.2) shapefile liqmetro.txt - Metadata file for liqmetro shapefile
Document.pdf		File listing contents of the CD-ROM as well as background information regarding the description of the data set

To get started:

PC-Windows users should open the file *"Readme.txt"* to obtain information about this CD-ROM.

Install *Acrobat Reader 4* on your hard drive if not already installed (*Acrobat Reader* is included on this disk).

Launch *Acrobat reader* and open the *Document.pdf* file to view the report.

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