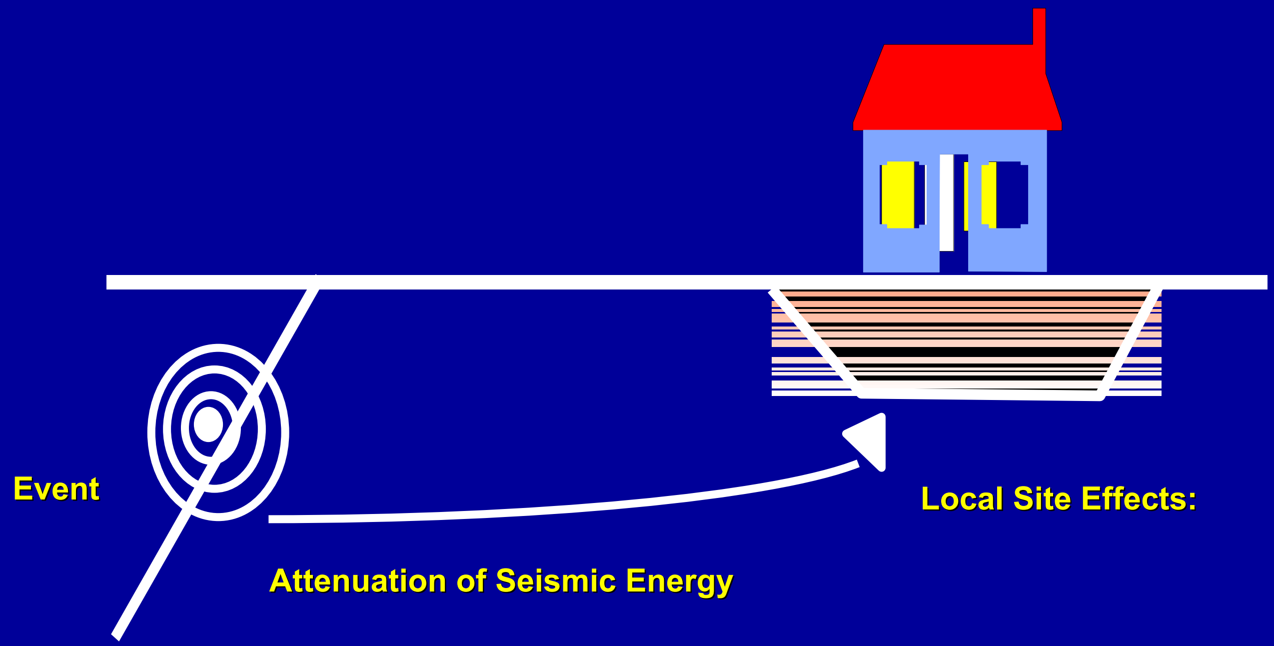
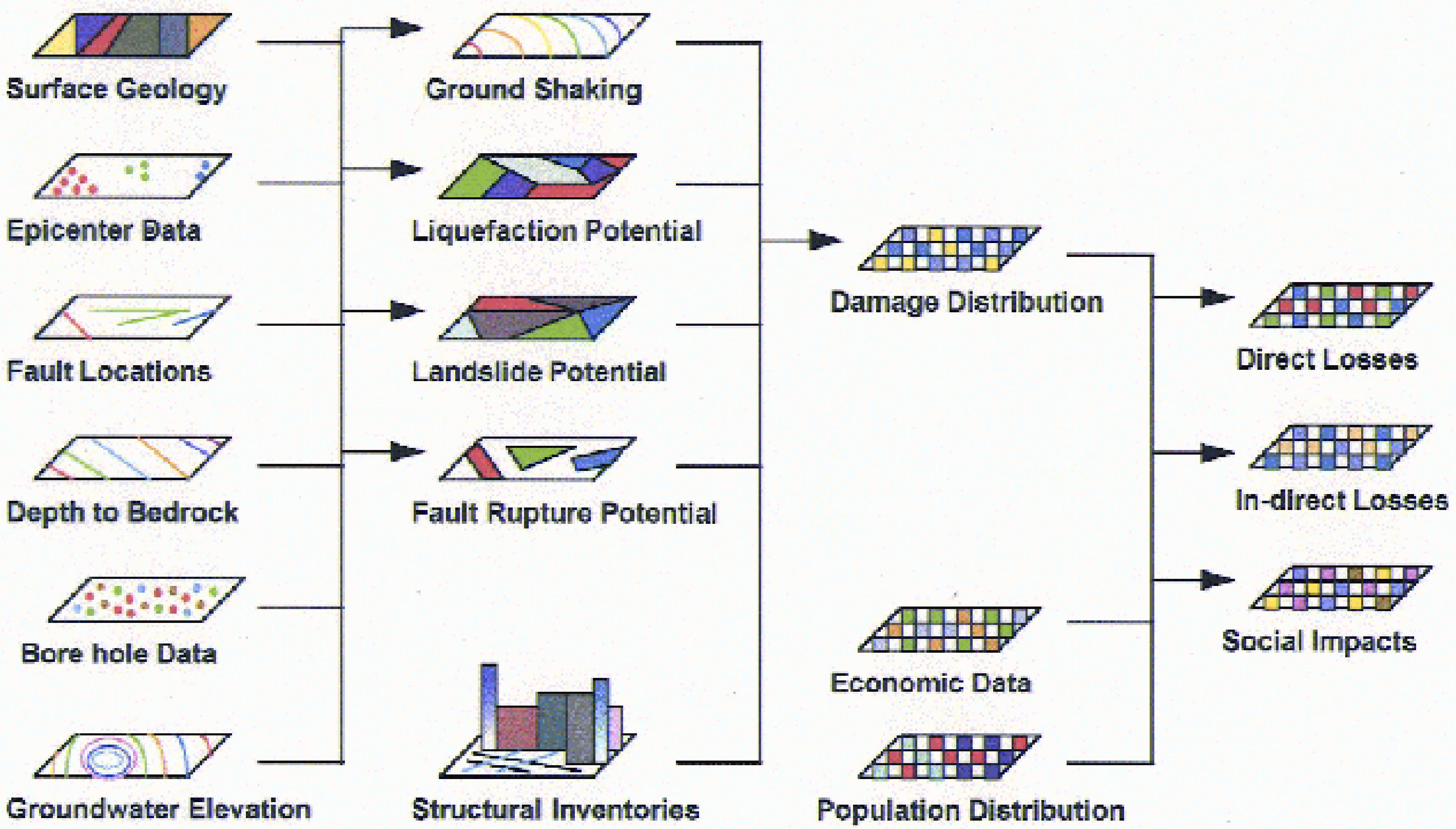
Seismic Hazard & Risk Assessment

- HAZARD ASSESSMENT
- INVENTORY OF ELEMENTS AT RISK
- VULNERABILITIES
- RISK ASSESSMENT METHODOLOGY AND SOFTWARE
- LOSS RESULTS



Regional Earthquake Loss Estimation

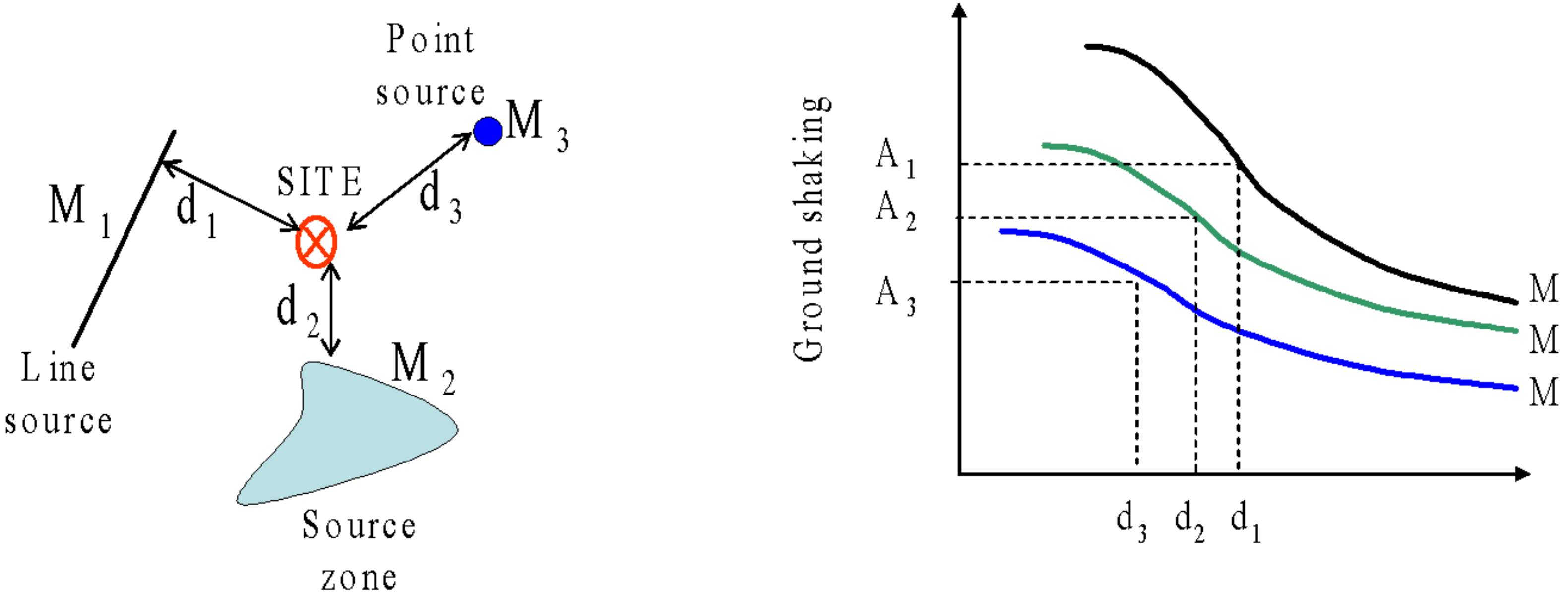


Deterministic vs Probabilistic

- Deterministic
  - Consider of small number of scenarios: Mag, dist, number of standard deviation of ground motion(ε)
  - Choose the largest ground motion from cases considered
- Probabilistic
  - Consider all possible scenarios: all mag, dist, and number of std dev
  - Compute the rate of each scenario
  - Combine the rates of scenarios with ground motion above a threshold to determine probability of "exceedance"

Deterministic Approach

- Select a specific magnitude and distance (location)
  - For dams, typically the "worst-case" earthquake
  - (Maximum Credible Earthquake)
- Design for ground motion, not earthquakes
  - Ground motion has large variability for a given magnitude, distance, and site condition
  - Key issue: What ground motion level do we select?



Deterministic hazard assessment: A=max(A1,A2,A3)

Worst-Case Ground Motion is Not Selected in Deterministic Approach

- Combing largest earthquake with the worst-case ground motion is too unlikely a case
  - The occurrence of the maximum earthquake is rare, so it is not "reasonable" to use a worst-case ground motion for this earthquake
  - Chose something smaller than the worst-case ground motion that is "reasonable".

What is “Reasonable” ?

- The same number of standard deviation of ground motion may not be “reasonable” for all sources
  - Median may be reasonable for low activity sources, but higher value may be needed for high activity sources
- Need to consider both the rate of the earthquake and the chance of the ground motion
  - Select ground motion below the worst-case

Considering Multiple Scenarios

- Once we back off from worst-case ground motion, can no longer ignore the smaller or more distant earthquakes
  - Can get the same ground motion from smaller magnitudes with larger number of std dev of ground motion
  - Flt1: M=6.5, R=10km, ε=0: PGA = 0.35g
    - Rate eqk = 1/5000, P(ε> 0)=0.5, combined=1/10,000
  - Flt1: M 5.5, R=10 km, ε=1.5, PGA=0.35g
    - Rate eqk = 1/500, P(ε> 0)=0.07, combined=1/7,000
  - Flt2: M 7.0, R=20 km, ε=1.2, PGA=0.35g
    - Rate eqk = 1/600, P(ε> 0)=0.12, combined=1/5,000
- What is "reasonable" needs to account for the multiple earthquakes that could cause the design ground motion to be exceeded

Basic Steps in Probabilistic Seismic Hazard Analysis

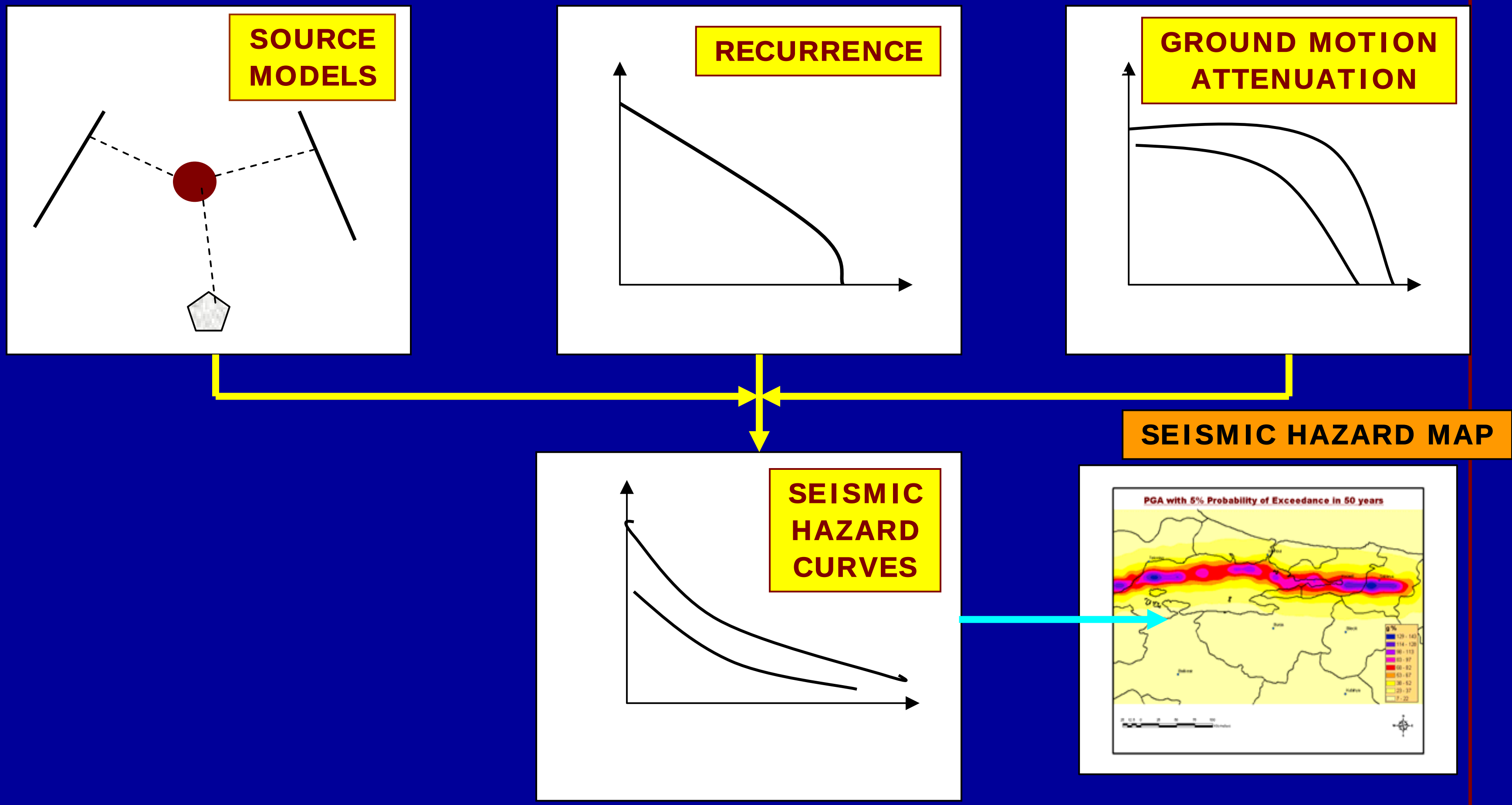
- Seismic source characterization
- Estimation of source seismicity parameters (recurrence) parameters and probabilistic model
- Selection of ground motion attenuation models
- Treatment of Epistemic Uncertainties with Logic Tree Models
- Quantification of the seismic hazard

Probabilistic Approach

- Consider all possible earthquakes and ground motion levels and compute rates of each scenario
- Hazard Calculation
  - Rank scenarios (M,R, ε) in order of decreasing severity of shaking (Typically use Sa)
  - Result: Table of ranked scenarios with ground motions and rates
  - Sum up rates of scenarios with ground motion above a specified level (hazard curve)
- Select a ground motion for the design hazard level
  - Back off from worst case ground motion until either:
    - The ground motion is does not lead to excessive costs, <u>or</u>
    - The hazard level is not too small (e.g. not too rare) to ignore (e.g. the design hazard level)

Basic steps in probabilistic seismic hazard analysis

- Seismic source characterization
- Estimation of seismicity (recurrence) parameters for each source
- Selection of ground motion attenuation models
- Quantification of the seismic hazard



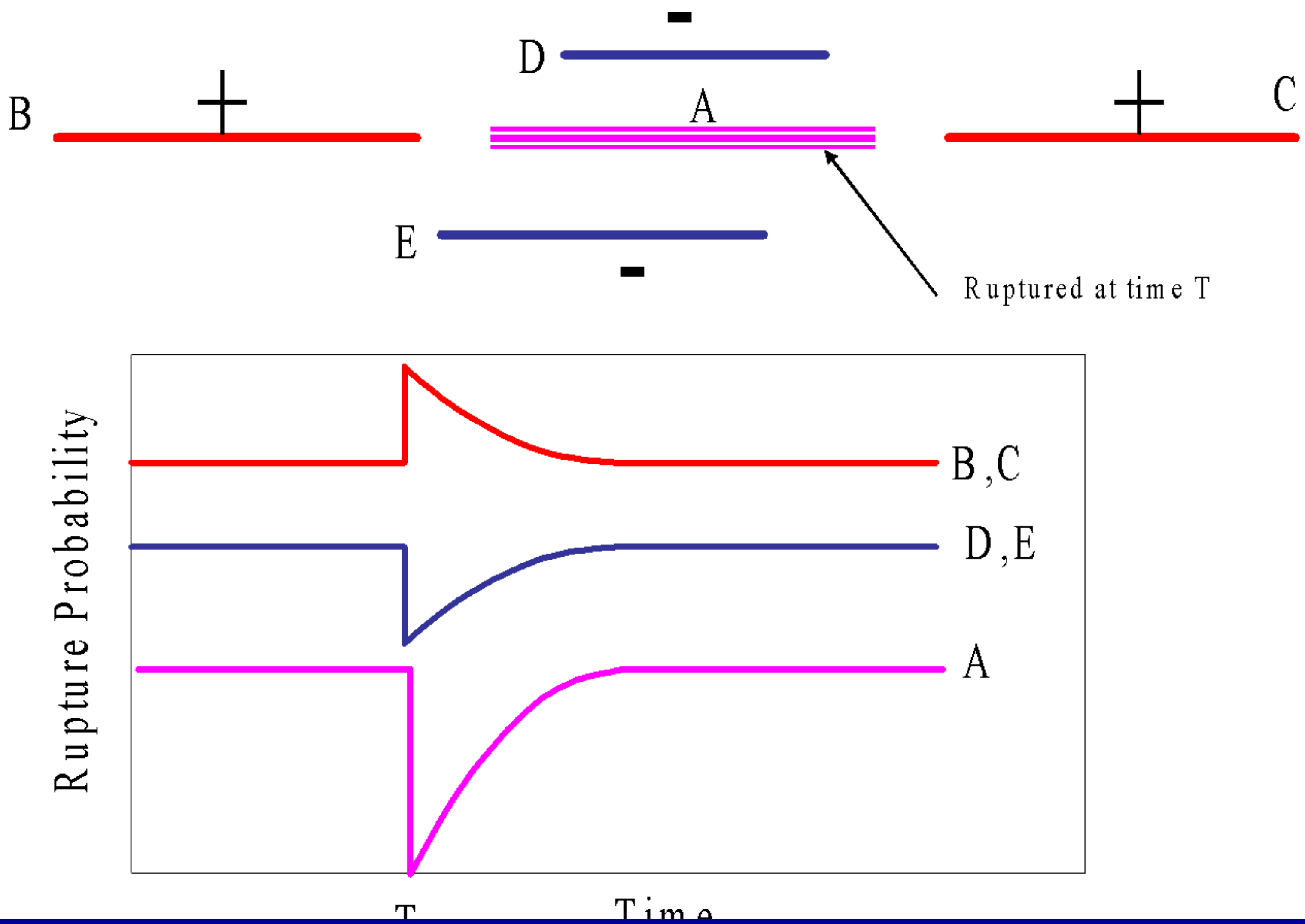
Earthquake Probability Estimation

Poissonian (“Time Independent”)
No memory -- probability is independent of past (recent) earthquake history

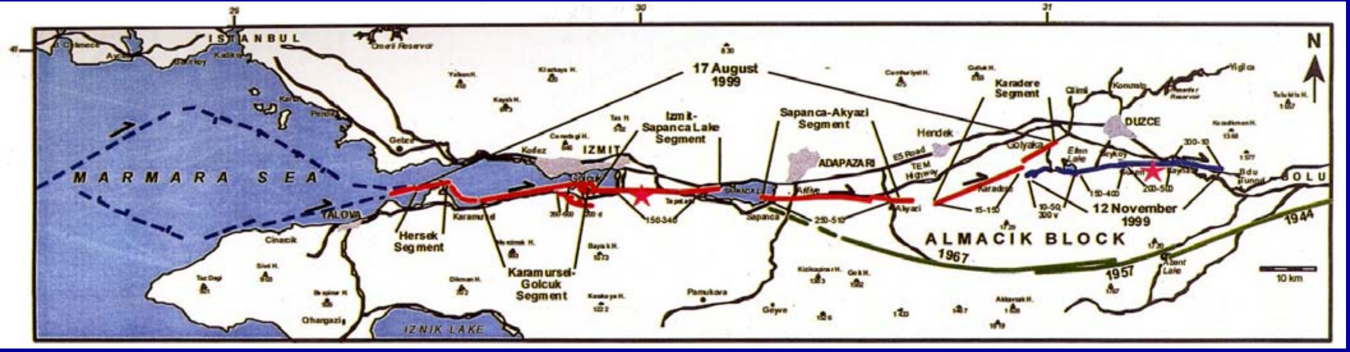
Time Dependent (“Predictable”)
Considers the time elapsed since the last event in estimating the probability of future events.

Stress Transfer (“Migration”)
Occurrence of earthquake on one fault has an impact on the probability of occurrence on another fault

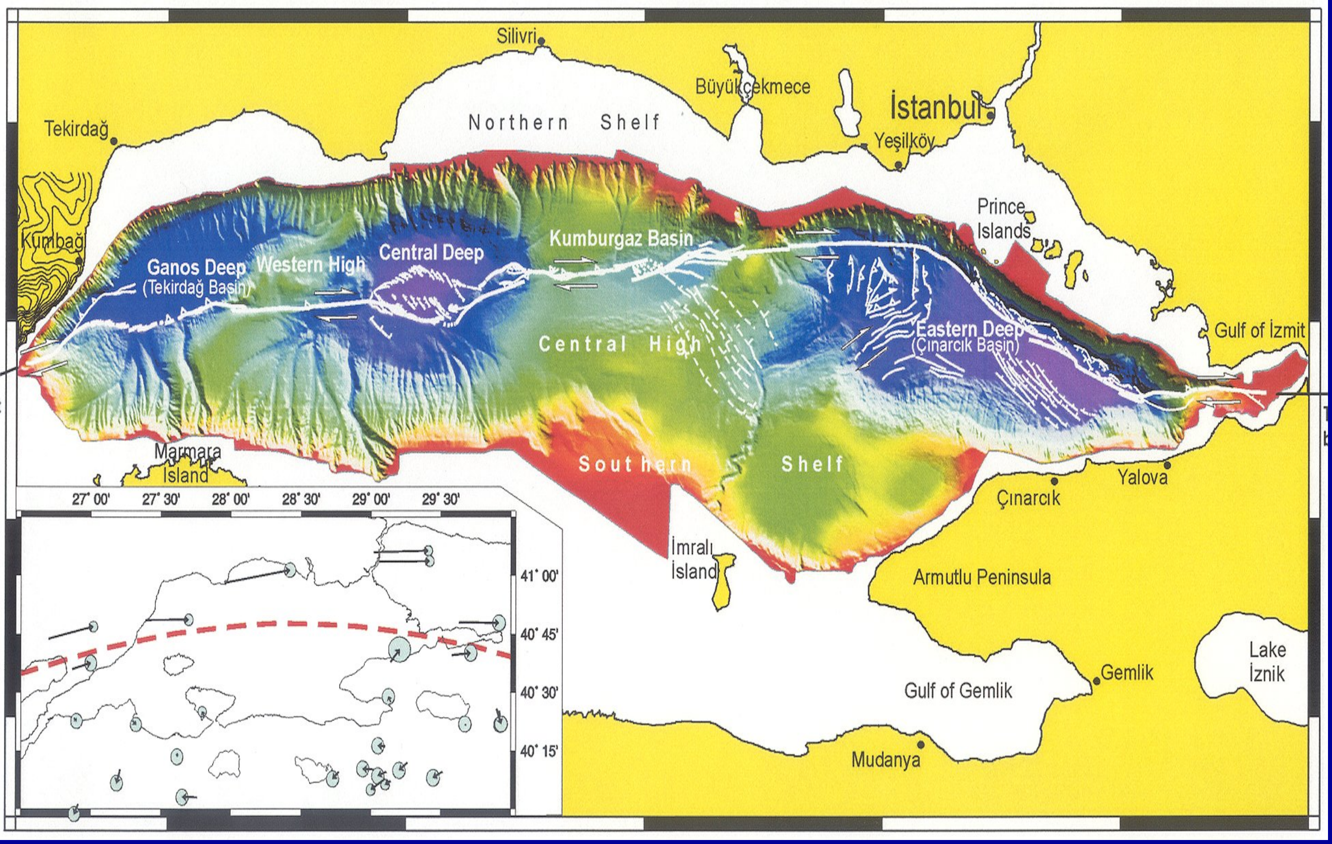
TIME DEPENDENCY AND INTERACTION OF FAULT RUPTURE



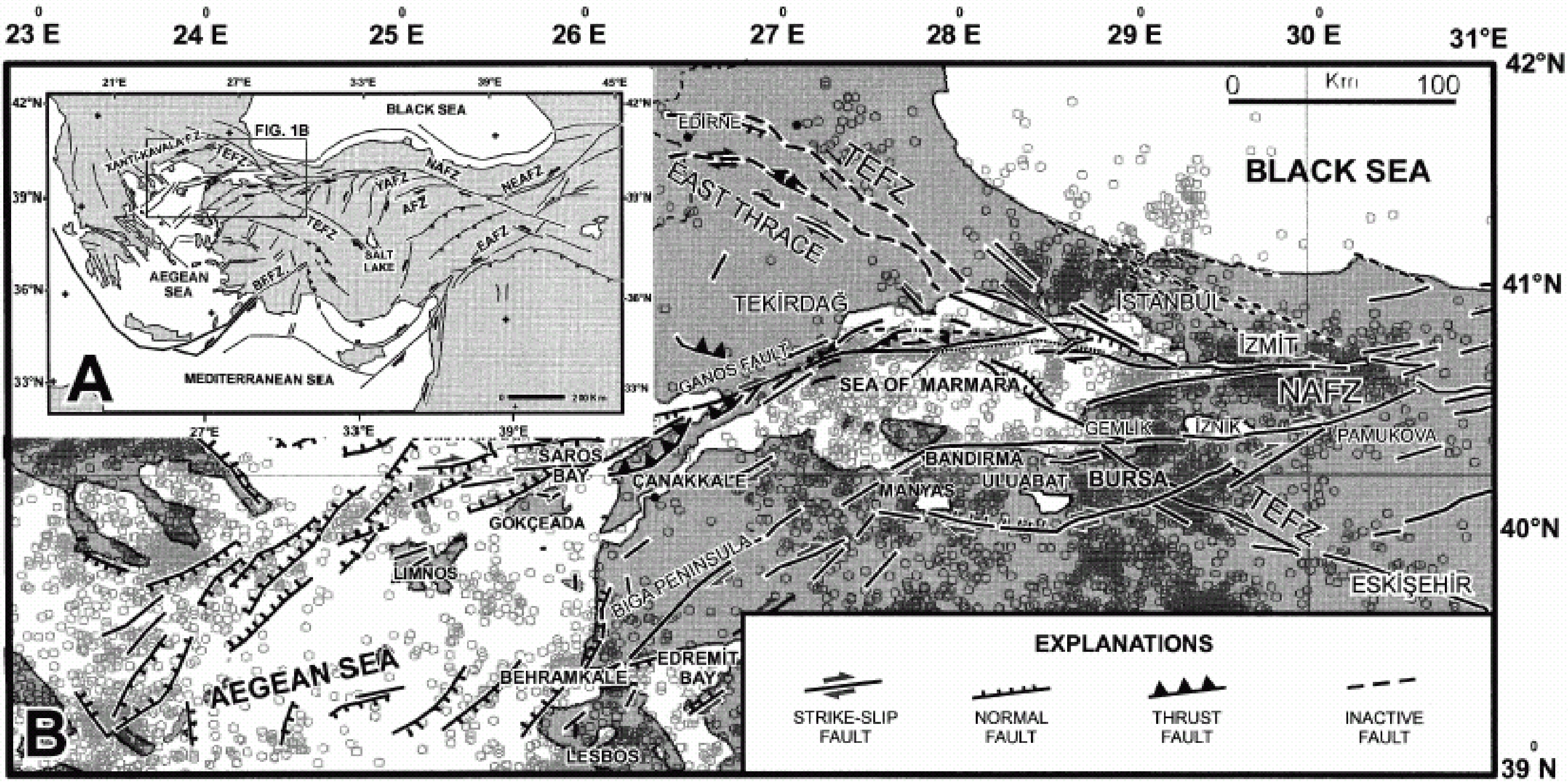
SOURCE CHARACTERIZATION



Active faults of eastern Marmara region during the last century (Akyuz et al., 2000)



The recent high-resolution bathymetric map obtained from the survey of the Ifremer RV Le Suroit vessel that indicates a single, thoroughgoing strike-slip fault system (LePichon et al., 2001)

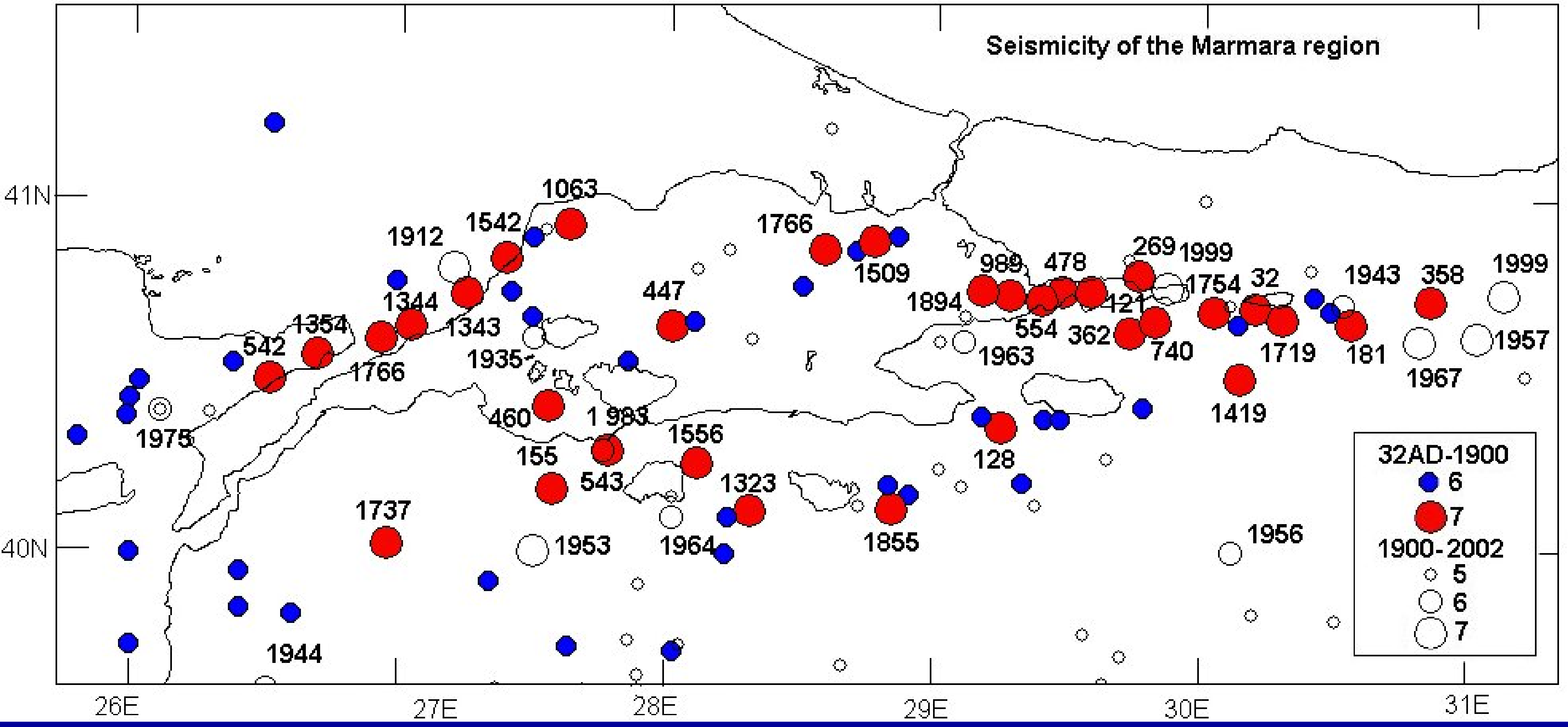


(A)Simplified tectonic map of eastern Mediterranean region,

(B) Seismotectonic map of the Marmara Sea Region (Yaltırak, 2002)

The Earthquake Catalog

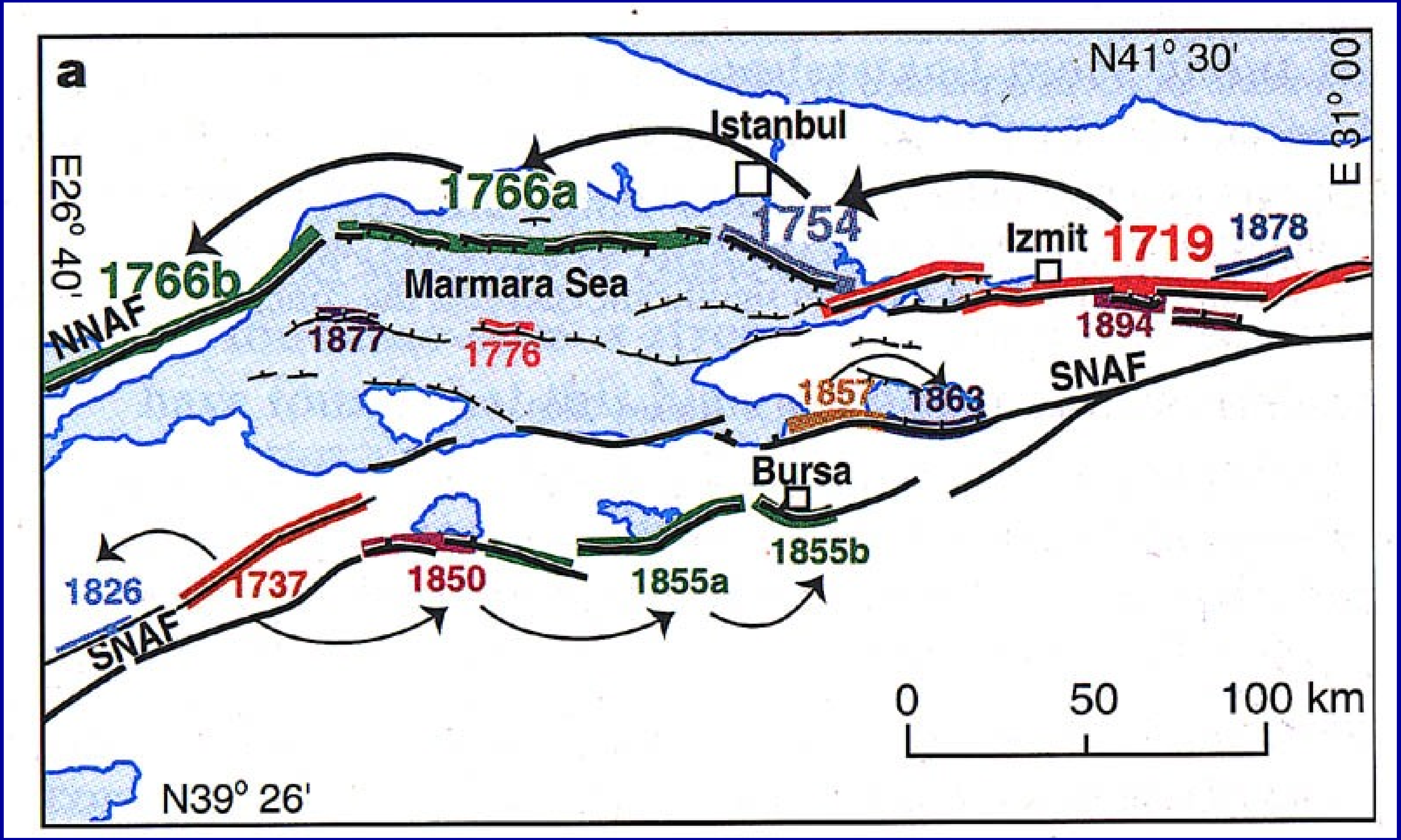
- Development of one catalog from several catalogs
- Declustering
- Use of the catalog
  - Calculation of the Gutenberg-Richter a and b values for the background
  - Assignment of major earthquakes to the segments in the fault segmentation model



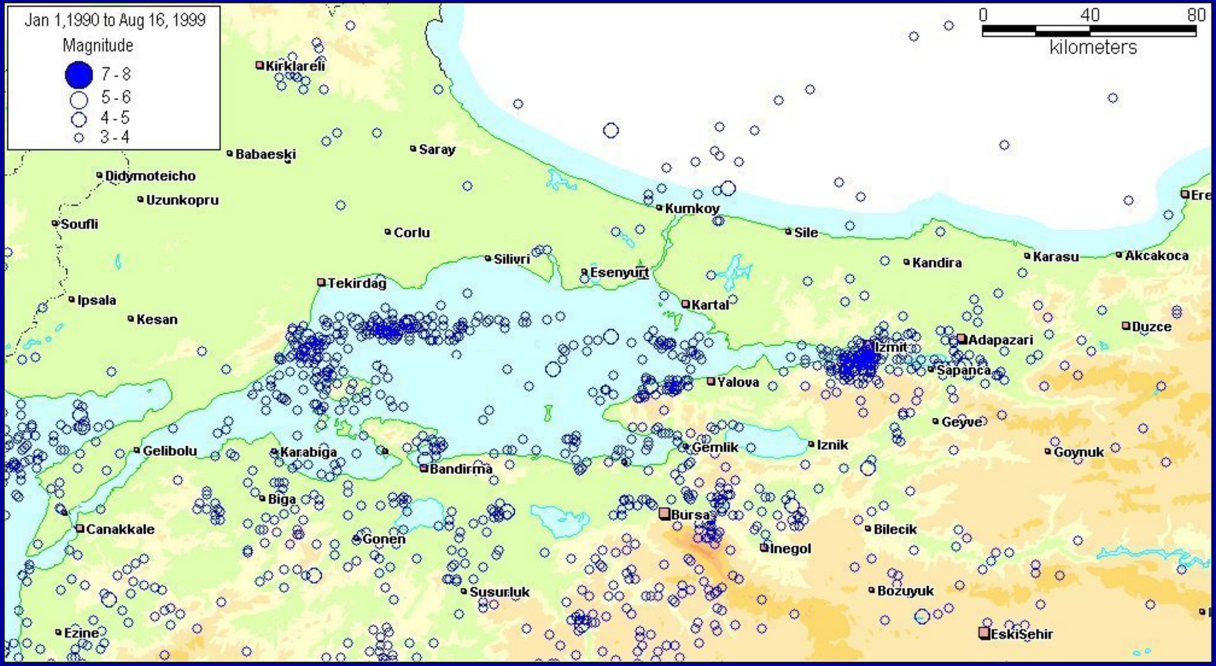
The long-term seismicity of the Marmara region
(Seismicity between 32 AD –1983 taken from Ambraseys and Finkel, 1991)

Association of major earthquakes between 1500-present with the segmentation proposed

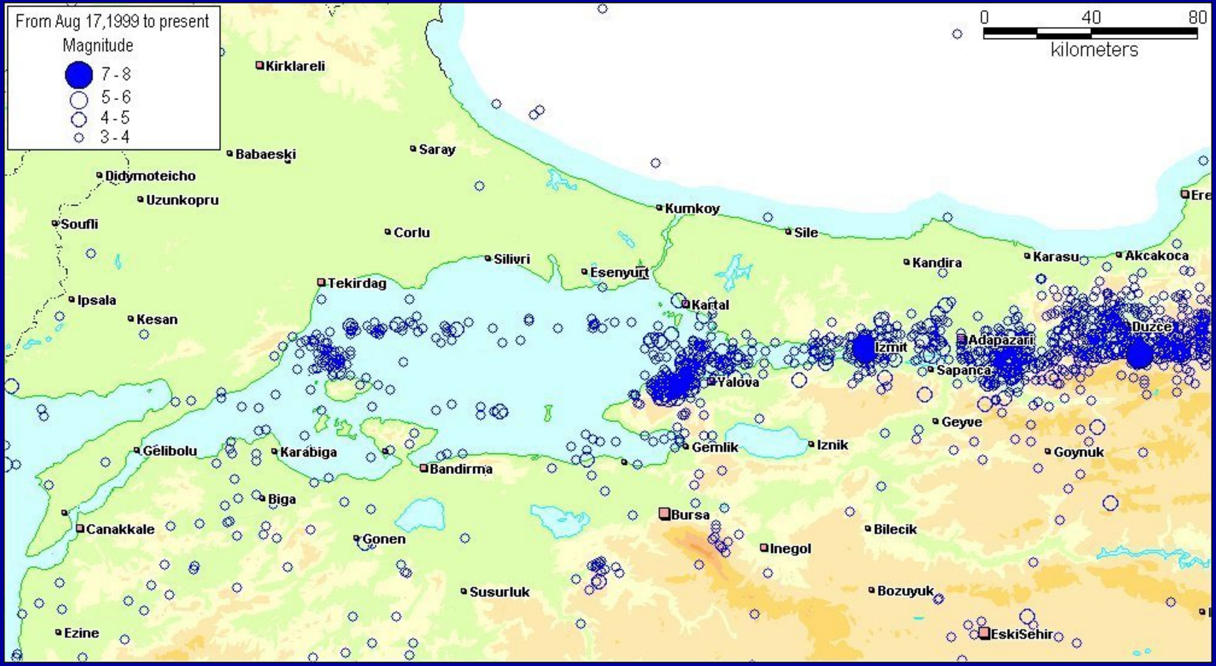
Earthquake	Fault Segment
10.9.1509 (Ms= 7.2)	7, 8
10.5.1556 (Ms=7.2)	9
25.5.1719 (Ms=7.4)	2, 3, 4, 5
2.9.1754 (Ms=6.8)	6
22.5.1766 (Ms=7.1)	7, 8
5.8.1766 (Ms=7.4)	11
10.7.1894 (Ms=7.3)	3, 4, 5
9.8.1912 (Ms= 7.3)	11
1.2.1944 (Ms=7.3)	19
26.5.1957 (Ms=7.0)	22
22.7.1967 (Ms=6.8)	12
17.8.1999 (Mw=7.4)	1, 2, 3, 4
12.11.1999 (Mw=7.2)	21



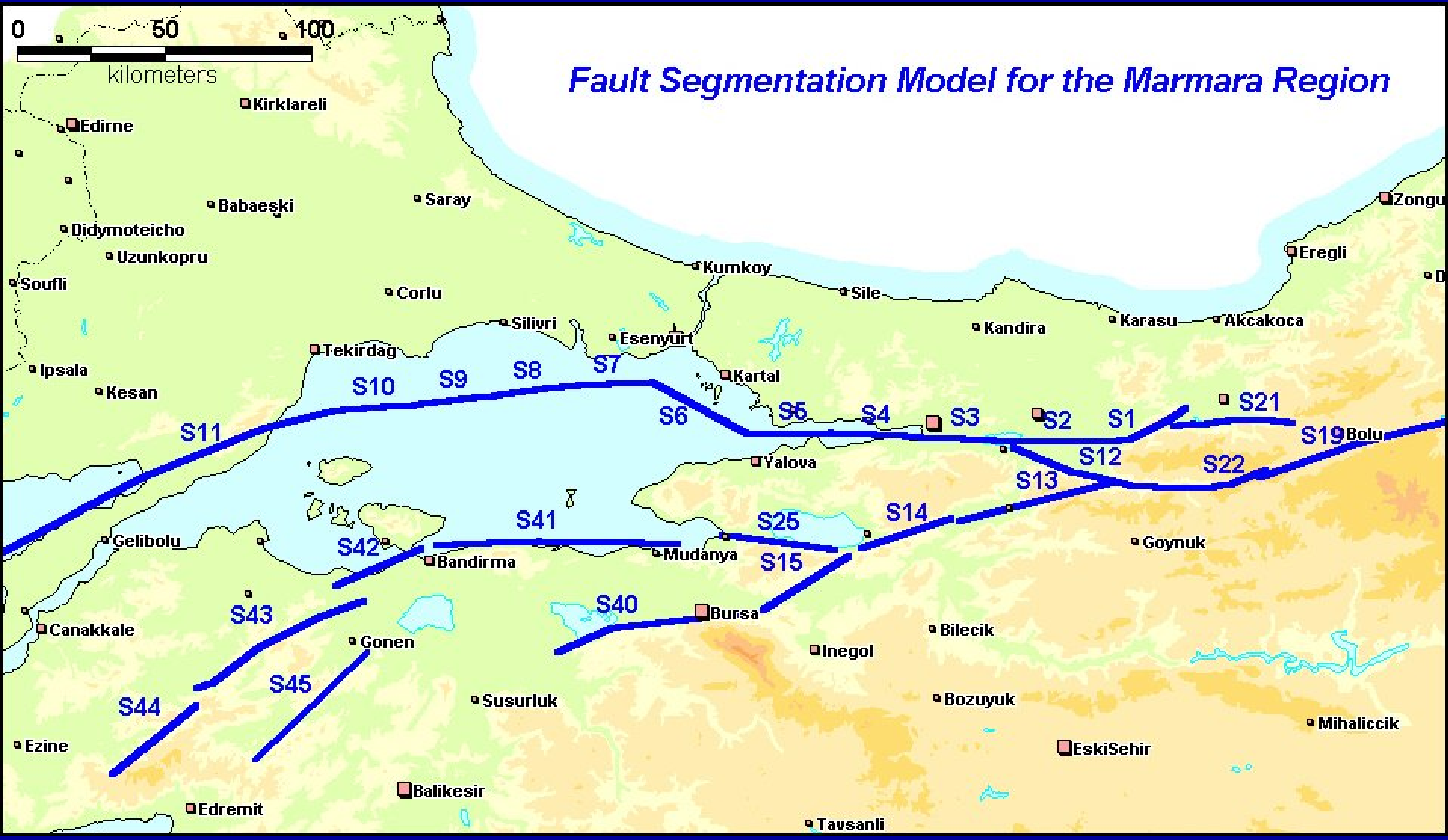
The sequence of earthquakes in the 18th century (after Hubert-Ferrari, 2000).



The seismic activity of the Marmara region with M>3 events from Jan 1, 1990 to August 16, 1999

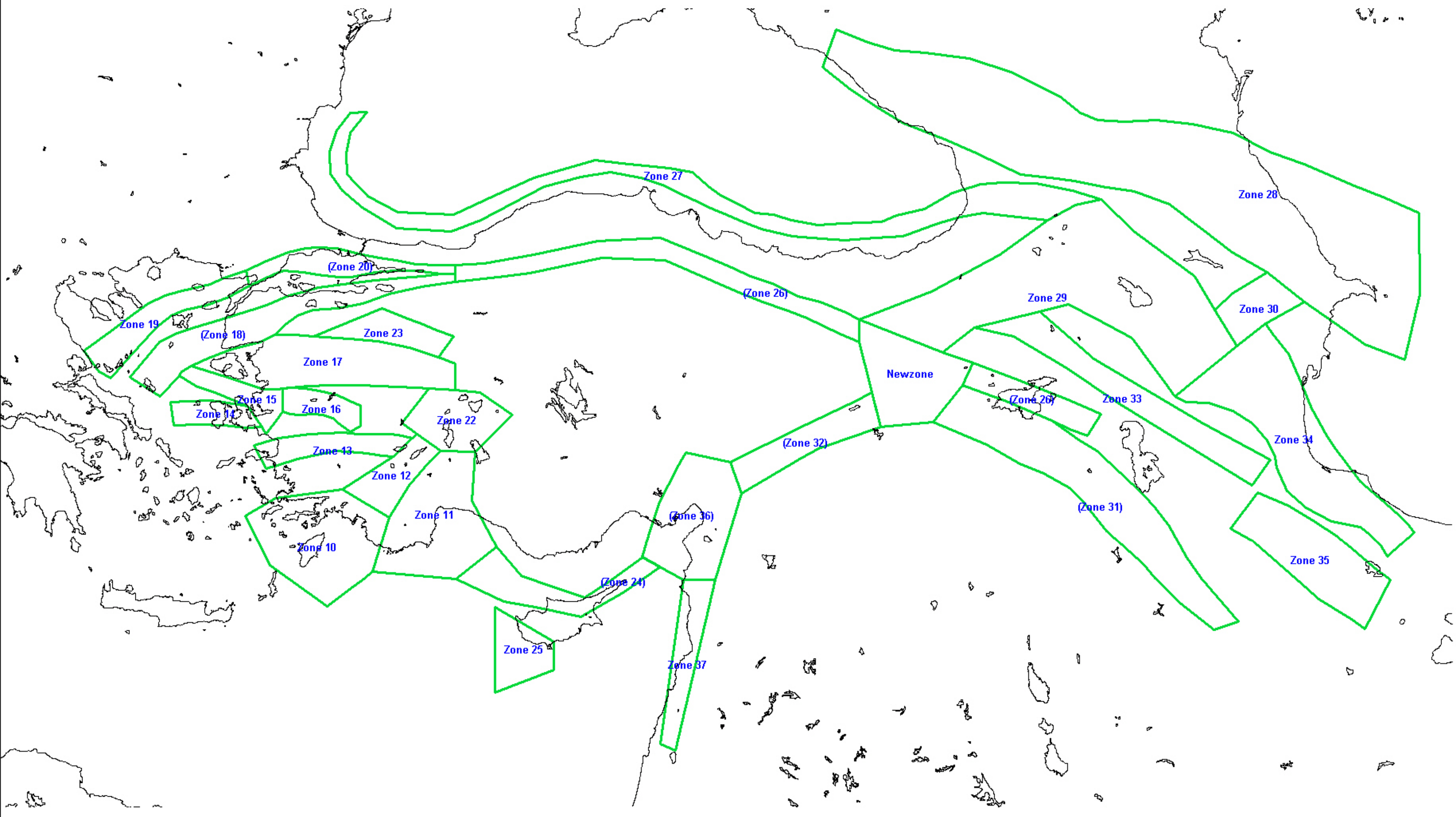


The seismic activity of the Marmara region with M>3 events from August 17, 1999 to present



Fault segmentation model developed for this study

Source Zonation Scheme



RECURRENCE RELATIONSHIPS

The earthquake recurrence models for the fault segments

- Poisson model
  - characteristic earthquake recurrence is assumed,
  - probability of occurrence of the characteristic event does not change in time
  - the annual rate is calculated as:

$$R = 1 / \text{mean recurrence interval}$$

- Time dependent (Renewal model)
  - the probability of occurrence of the characteristic event increases as a function of the time elapsed since the last characteristic event,
  - a lognormal distribution with a coefficient of variation of 0.5 is assumed to represent the earthquake probability density distribution.
  - the annual rate is calculated as:

$$R_{eff} = -\ln(1 - P_{cond}) / T$$

MAGNITUDE AND FREQUENCY DISTRIBUTION

1. Truncated Gutenberg-Richter distribution

logN(M)=a-bM **Richter (1958)**

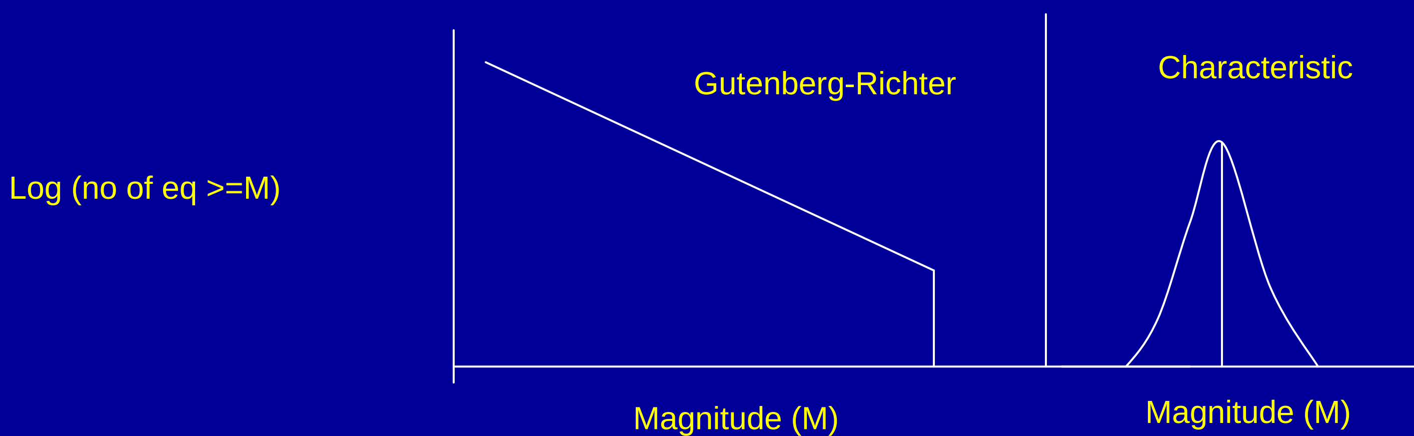
N: **The number of earthquakes per year with a magnitude equal to or greater than M . N is associated with a given area and time period.**

a ve b: **Constants for the seismic zone.**

2. Characteristic Distribution

a.Assess magnitude of potential earthquakes (segmentation, floating)

b. Calculate recurrence of earthquake (Wells ve Coppersmith, 1994) = moment of char earthquake/moment rate of fault
= rigidity*area*displacement/rigidity*area*slip rate
rigidity modulus (resistance to shearing motion we use in U.S. is 3.0 X 10exp11 gm/cm*s*s(dynes/cm*cm)



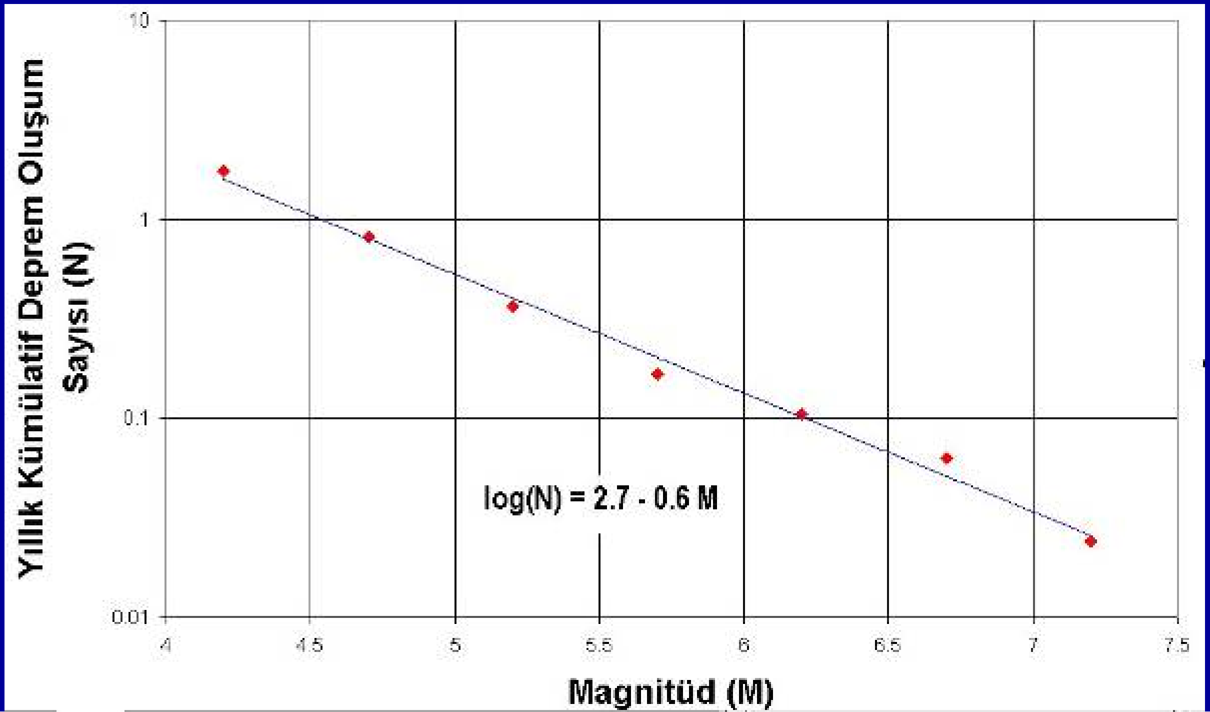
Gutenberg-Richter Distribution

Richter (1958) **$\log N = a - bM$**

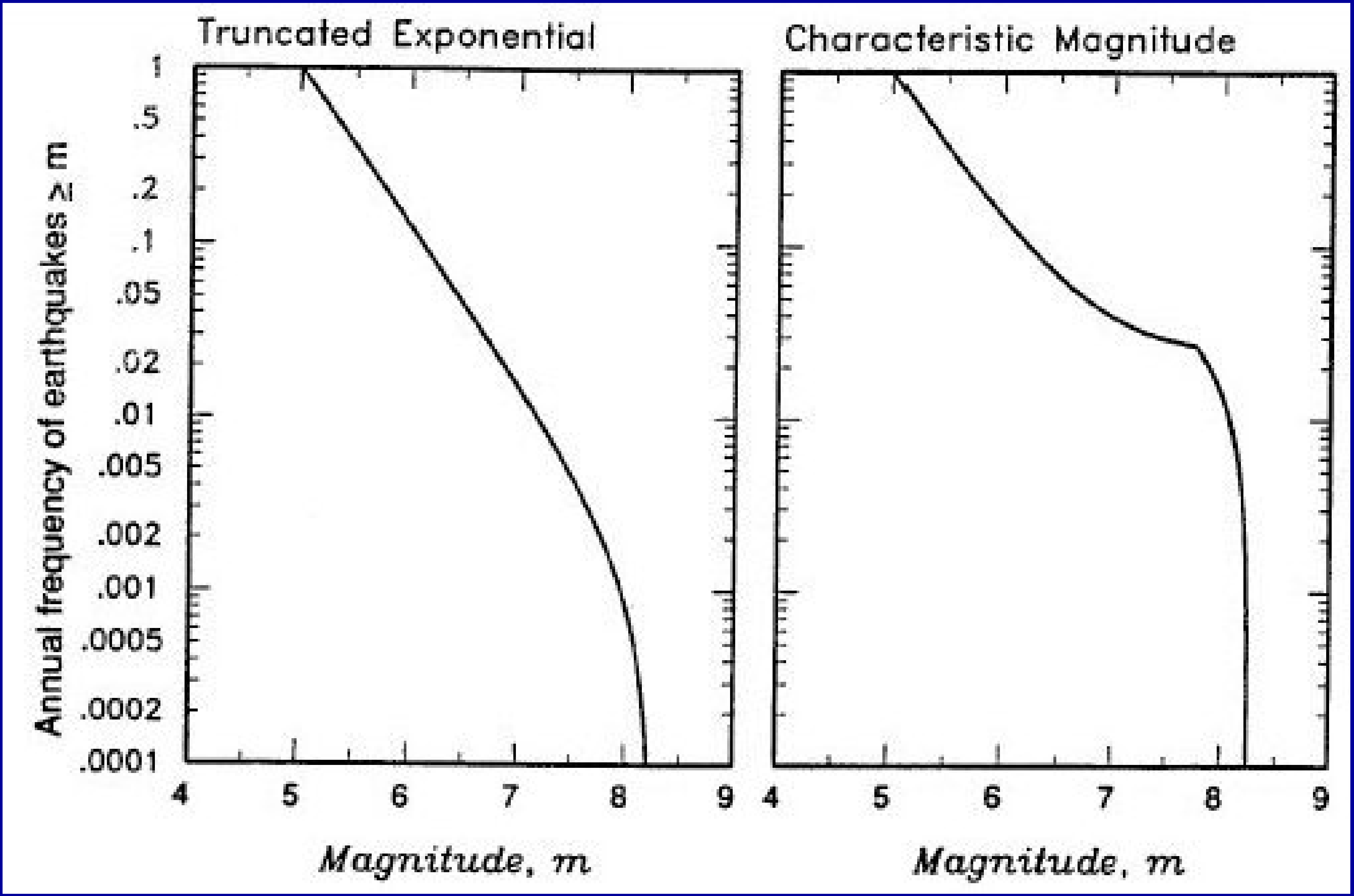
N: **The number of earthquakes per year with a magnitude equal to or greater than M . N is associated with a given area and time period.**
a ve b: **Constants for the seismic zone.**

The constant "a" is the logarithm of the number of earthquakes with magnitude equal to or greater than zero.

The constant "b" is the slope of the distribution and controls the relative proportion of large to small earthquakes.



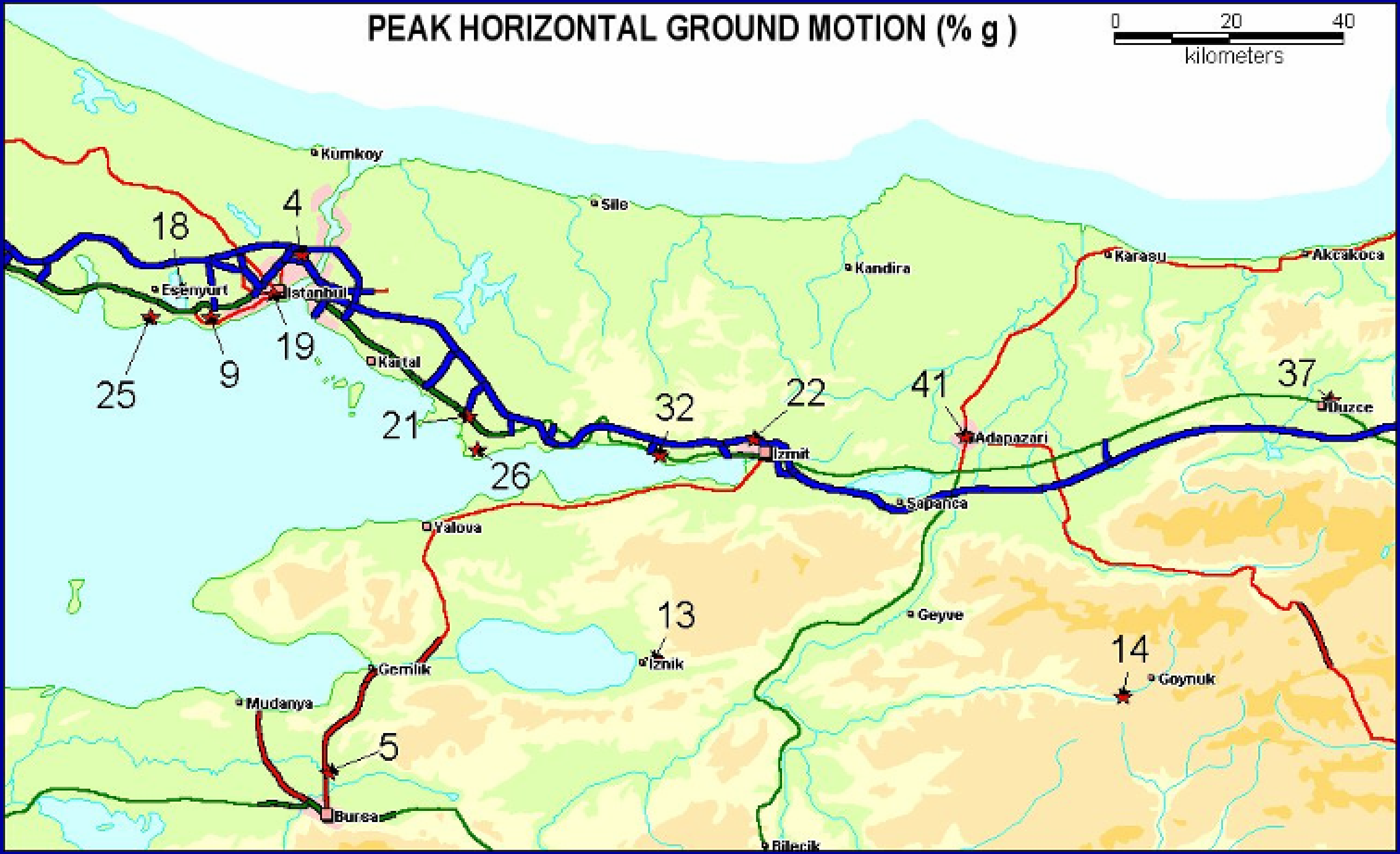
Recurrence Relationships



Cascading

- It is well known that, even though segments can be mapped separately at the surface, they could combine and be a single structure at depth, or a rupture on one segment could trigger ruptures on others in a cascade model. So two scenarios are envisioned:
  1. faults rupture independently, producing characteristic-size earthquakes, or
  2. fault segments rupture together as a cascade, producing earthquakes of $M>7$.
- The Cascade assumption increases the Maximum Magnitude but reduces the rate of occurrence of the more moderate events.
- Previous rupturing cycles around the Marmara Sea indicate that, on average, one out of three ruptures were multiple segments.
- The probabilistic results based on cascade models provided about the same earthquake hazard levels obtained from non-cascading models.

ATTENUATION MODELS



PGA =f (Magnitude, Distance, Fault type, Site condition)

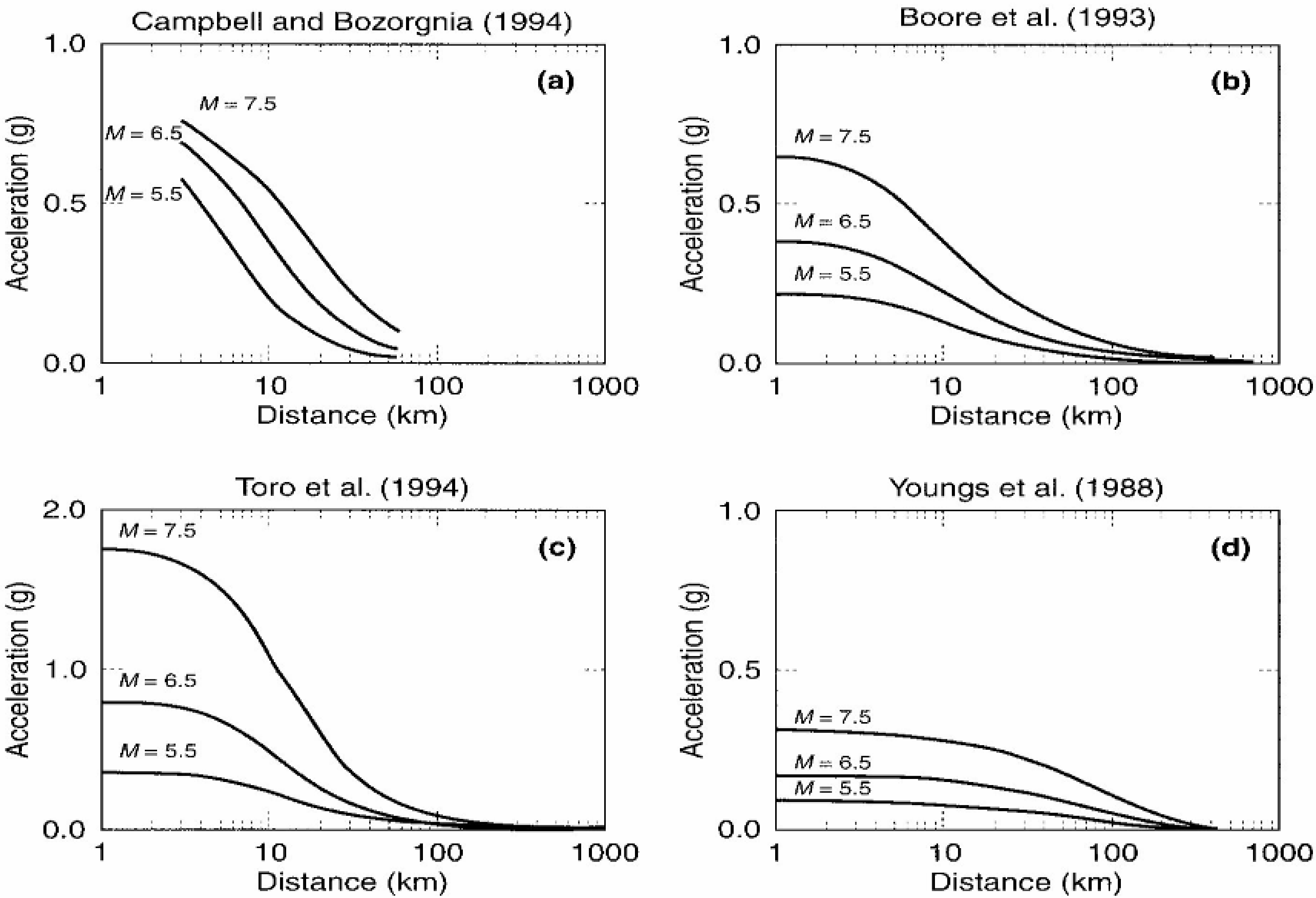
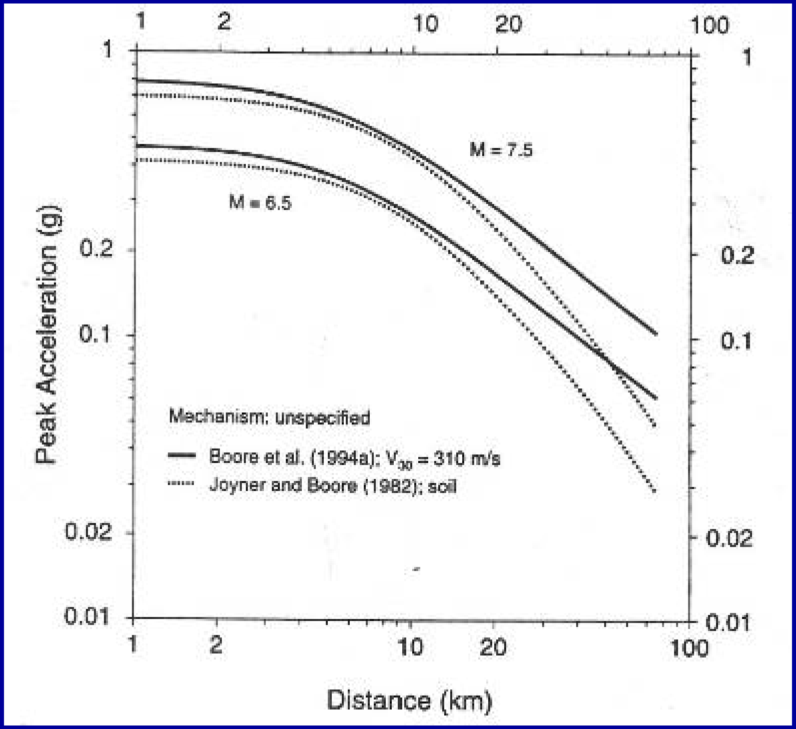
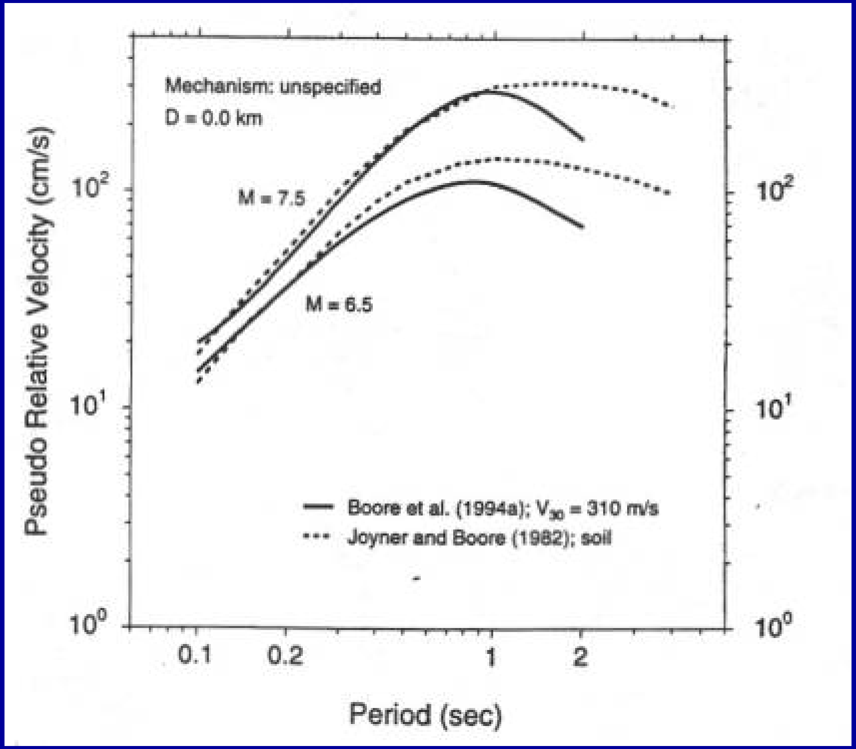


Figure 3.22 Variation of peak horizontal acceleration with distance for $M = 5.5$, $M = 6.5$, and $M = 7.5$ earthquakes according to various attenuation relationships: (a) Campbell and Bozorgnia (1994), soft rock sites and strike-slip faulting; (b) Boore et al. (1993), site class B; (c) Toro et al. (1994); and (d) Youngs et al. (1988), intraslab event.

Boore, Joyner, Fumal (1997)

- Based on Western North America data
- Distance measure is closest distance to surface projection of rupture
- Strike-slip and reverse faults
- Site conditions based on shear-wave velocity in upper 30 m of soil
- PSA from 0 to 2.0 seconds

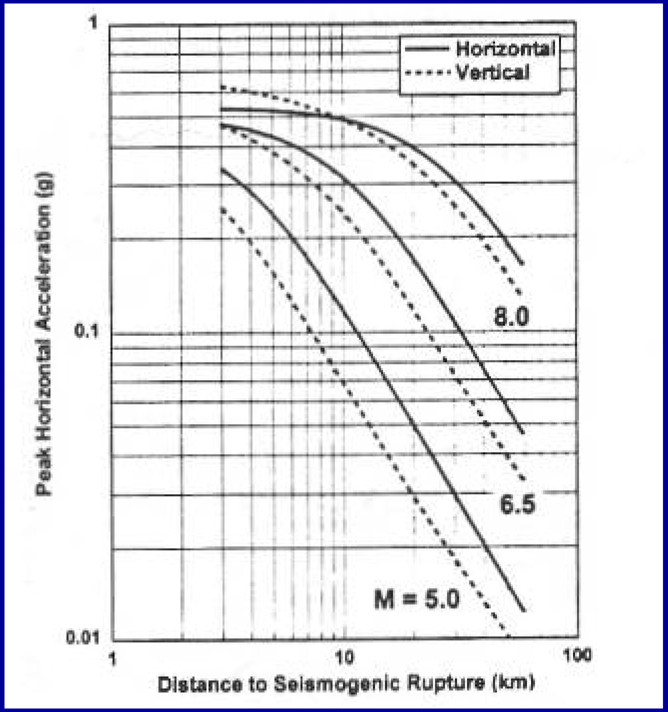




$$\ln(Y) = b_1 + b_2 (M\text{-}6) + b_3 (M\text{-}6)^2 + b_5 \ln r + b_V \ln (V_S / V_A)$$

Campbell 1997

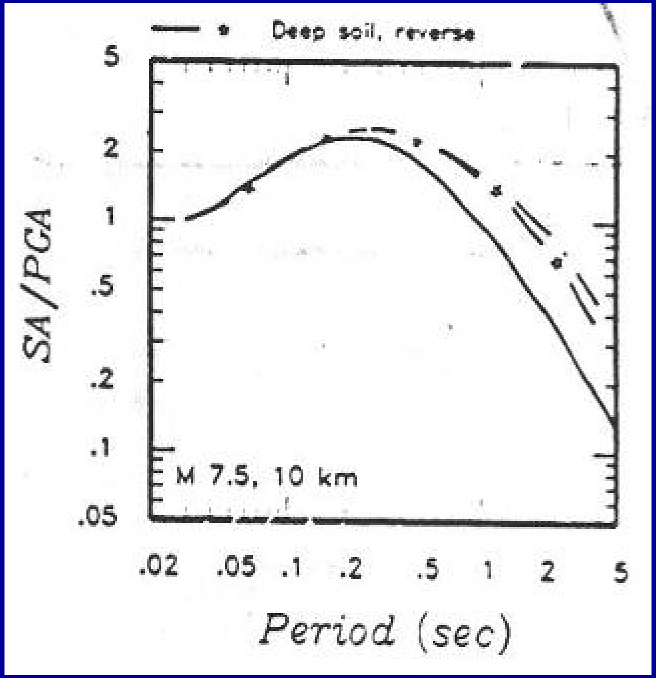
- Based on worldwide data
- Horizontal and vertical components
- Distance measure is shortest distance to seismogenic rupture
- Strike-slip and reverse faults
- Hard rock, soft rock (620 m/sec), and firm soil site conditions
- PSA from 0.05 to 4 sec

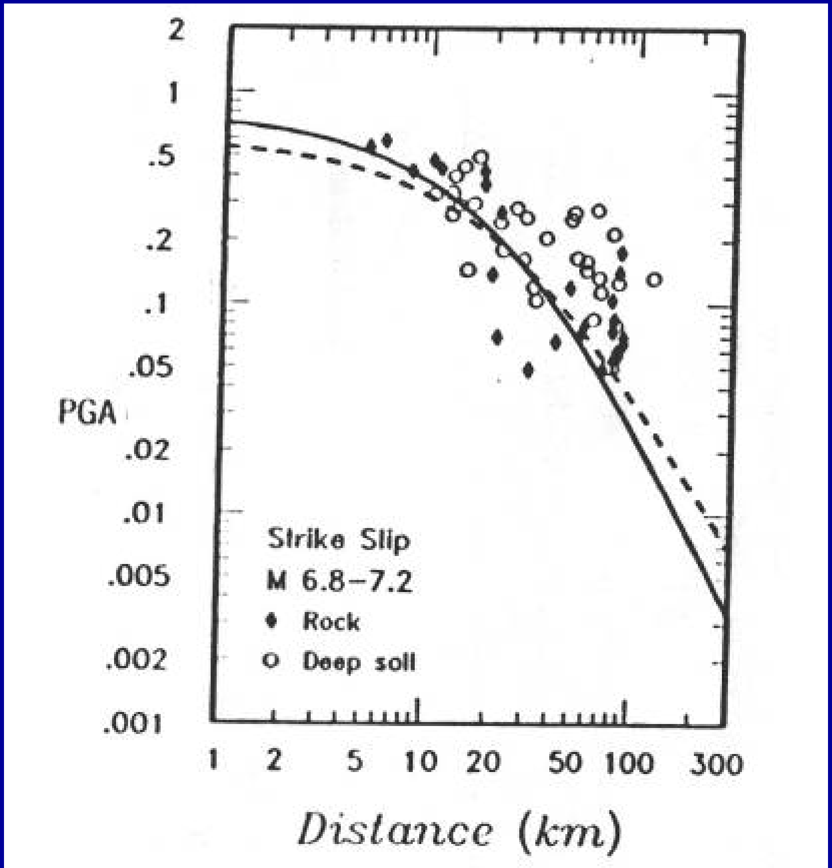


$$\ln(A_H) = -3.512 + 0.904M - 1.328\ \ln[R_{SEIS}{}^2 + (0\ 149e^{0.67M})^2]^{1/2}$$
$$+ [1.125 - 0.112\ln(R_{SEIS}) - 0.0957M]F$$
$$+ [0.440 - 0.171\ \ln(R_{SEIS})]\ S_{SR} + [0.405 - 0.222\ \ln(R_{SEIS})]\ S_{HR} + \varepsilon$$

Sadigh, 1997

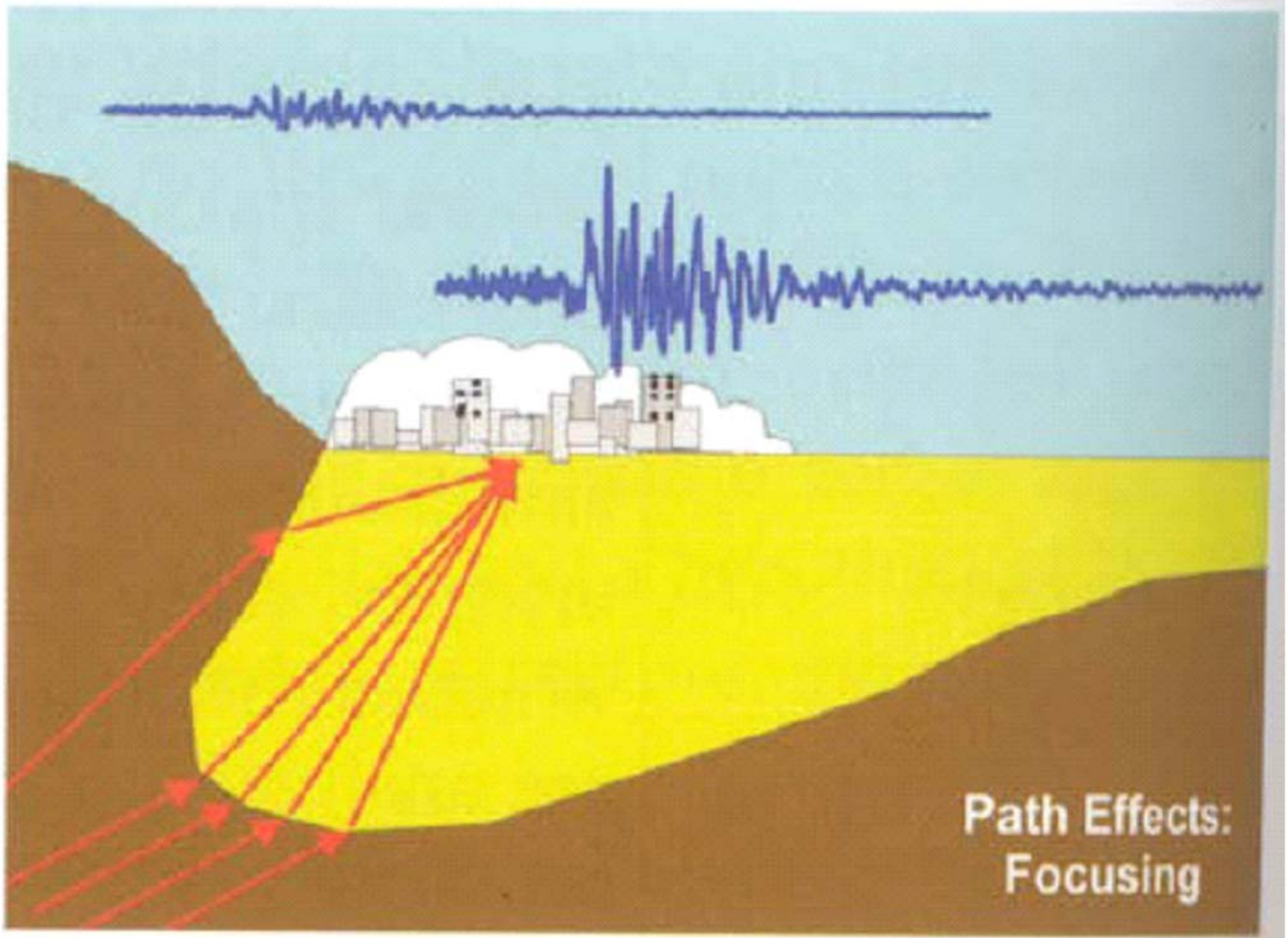
- Based on California data
- Horizontal and vertical components
- Distance measure is closest to rupture
- Strike-slip and reverse faults
- Rock and deep soil site conditions
- PSA 0.075 to 4.0 seconds



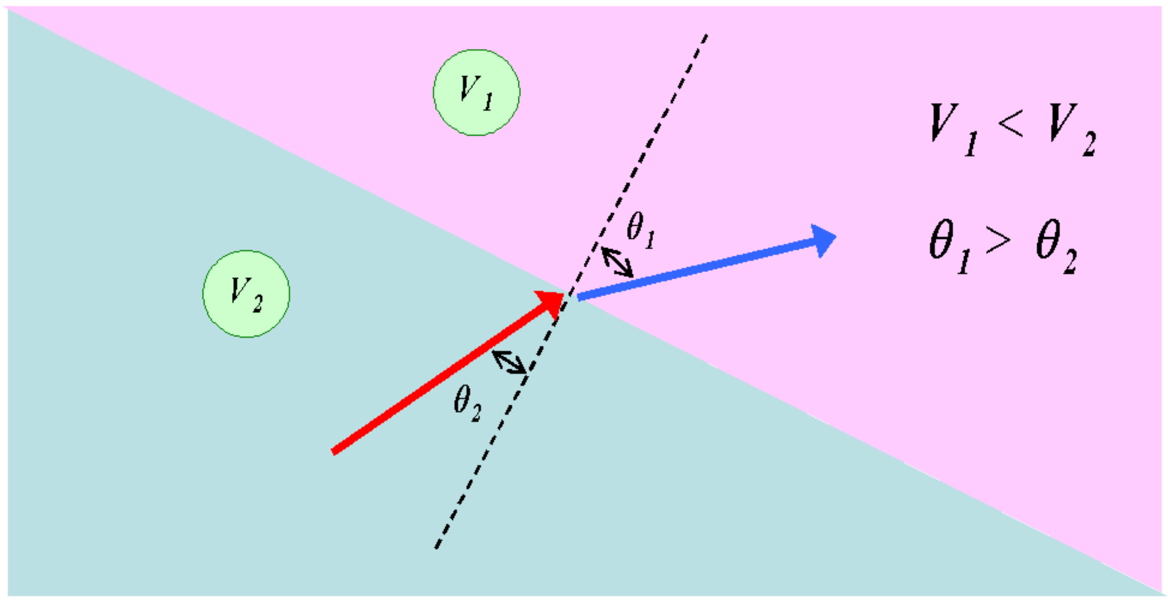


$$\ln(y) = C_1 + C_2M + C_3(8{,}5-M)^{2.5} + C_4\ln[r_{rup} + \exp(C_5+C_6M)] + C7\ln(r_{rup}+2)$$

NEHRP 1994	ABRAHAMSON & SILVA SADIGH et al. YOUNGS et al.	BOORE et al. 1993	BOORE et al. 1997	CAMPBELL 1997	IDRISS 1991	SPUDICH et al. 1997
A $V_s > 1500$ m/s	Rock	A	Rock 620[3] m/s	Hard Rock	Rock	Rock
B $760 < V_s <$ 1500 m/s	Rock	A 750 m/s < V_s	NEHRP B 1070[3] m/s	Hard Rock	Rock	Rock
C $360 < V_s <$ 760 m/s	Rock/Shallow Soil	B $360 < V_s$ < 760 m/s	NEHRP C 520[3] m/s	Soft Rock	Rock/Stiff Soil	Rock
D $180 < V_s <$ 360 m/s	Soil	C $180 < V_s$ < 360 m/s	NEHRP D 250[3] m/s	Firm Soil	Deep Soil	Soil
E $V_s < 180$ m/s	Soil	D $V_s < 180$ m/s	Soil 310[3] m/s	Soft Soil	Soft Soil	Soil
				Shallow Soil		

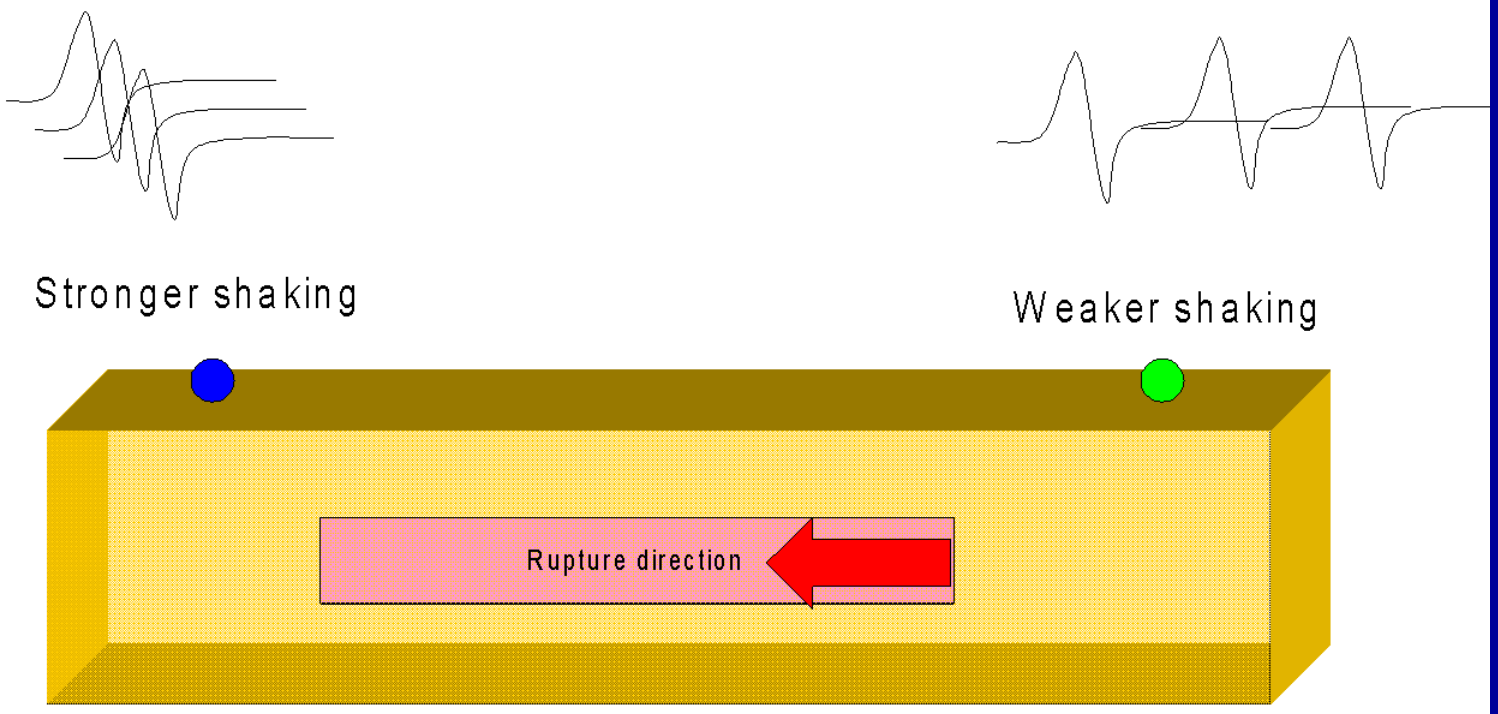

Path Effects:
Focusing

SNELL'S LAW

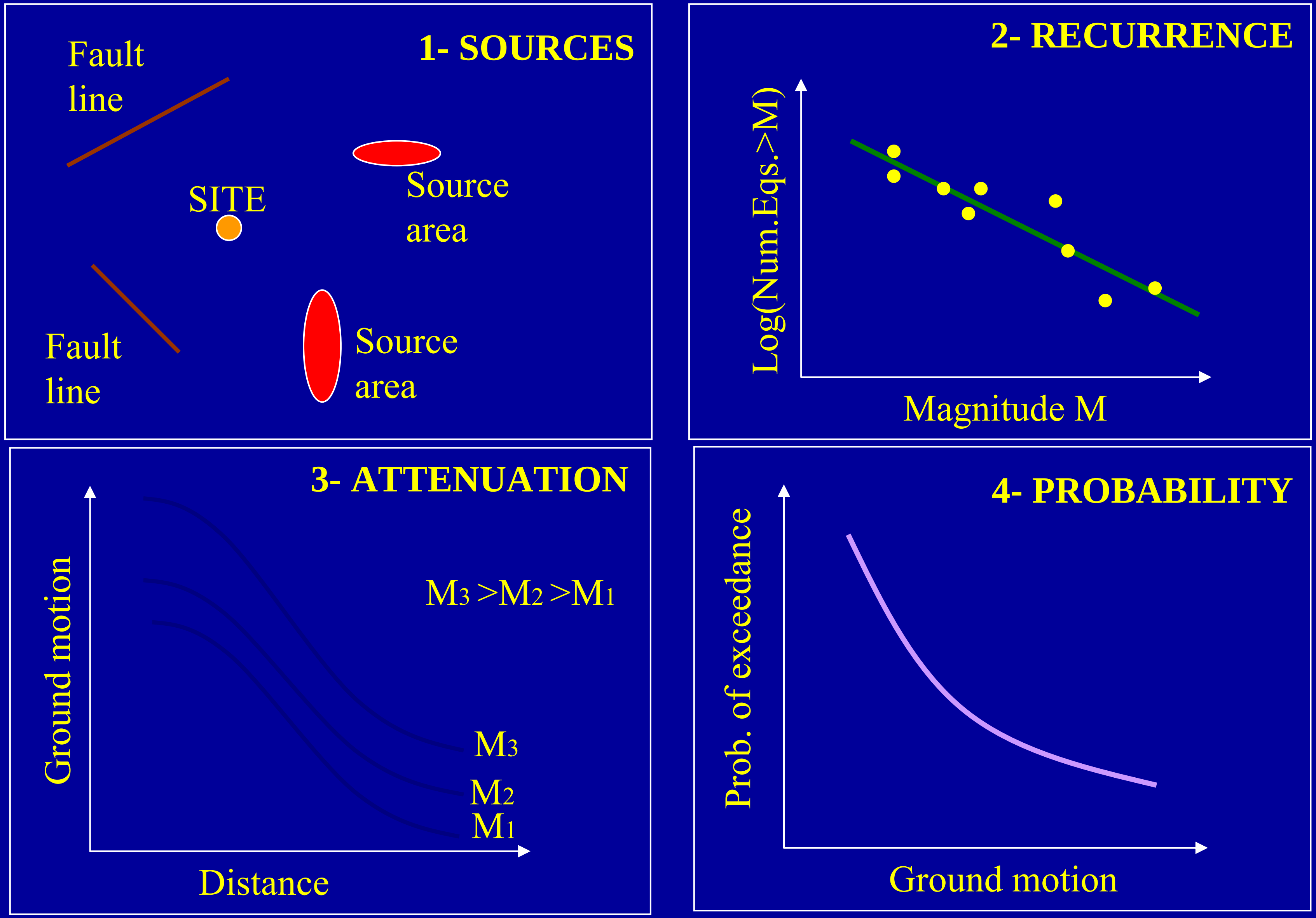


$$V_1 \cdot \sin\theta_1 = V_2 \cdot \sin\theta_2 \quad \rightarrow \quad \sin\theta_2 = \frac{V_1}{V_2} \cdot \sin\theta_1$$

DIRECTIVITY



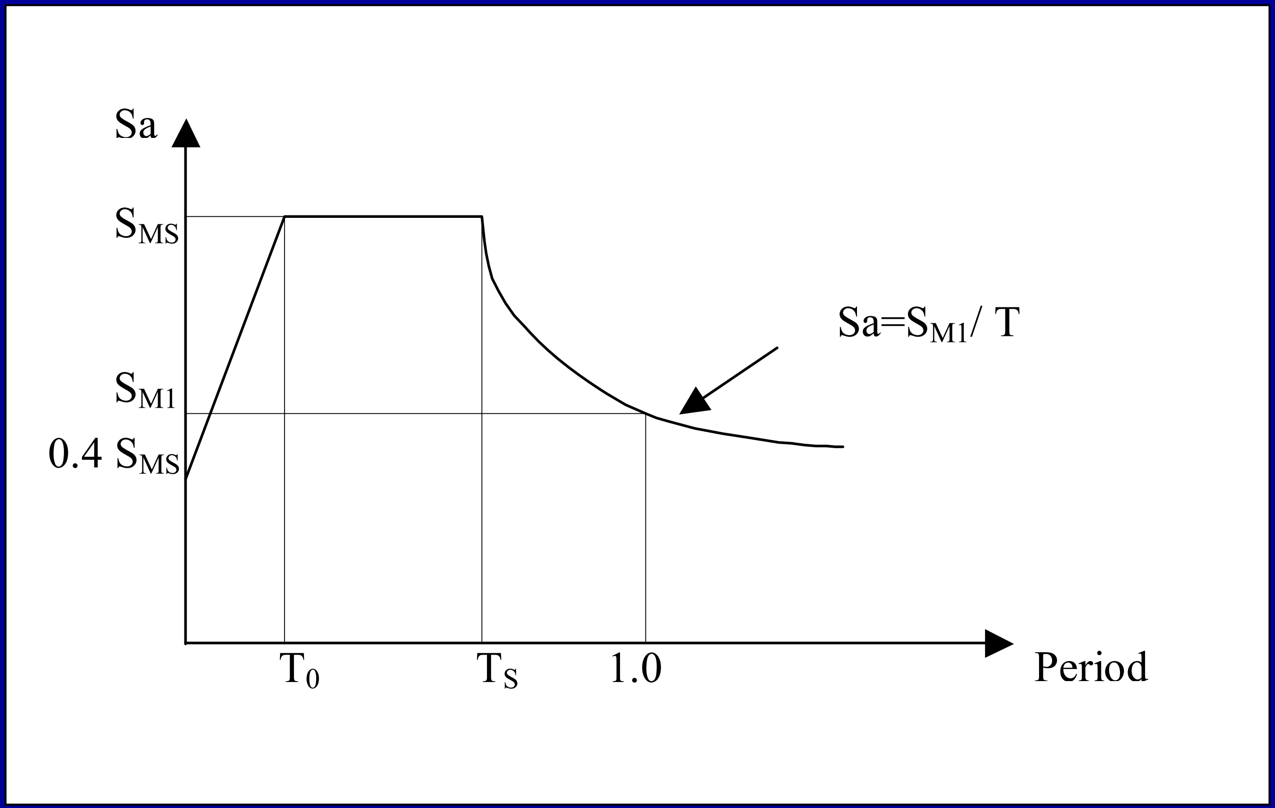
QUANTIFICATION OF THE EARTHQUAKE HAZARD



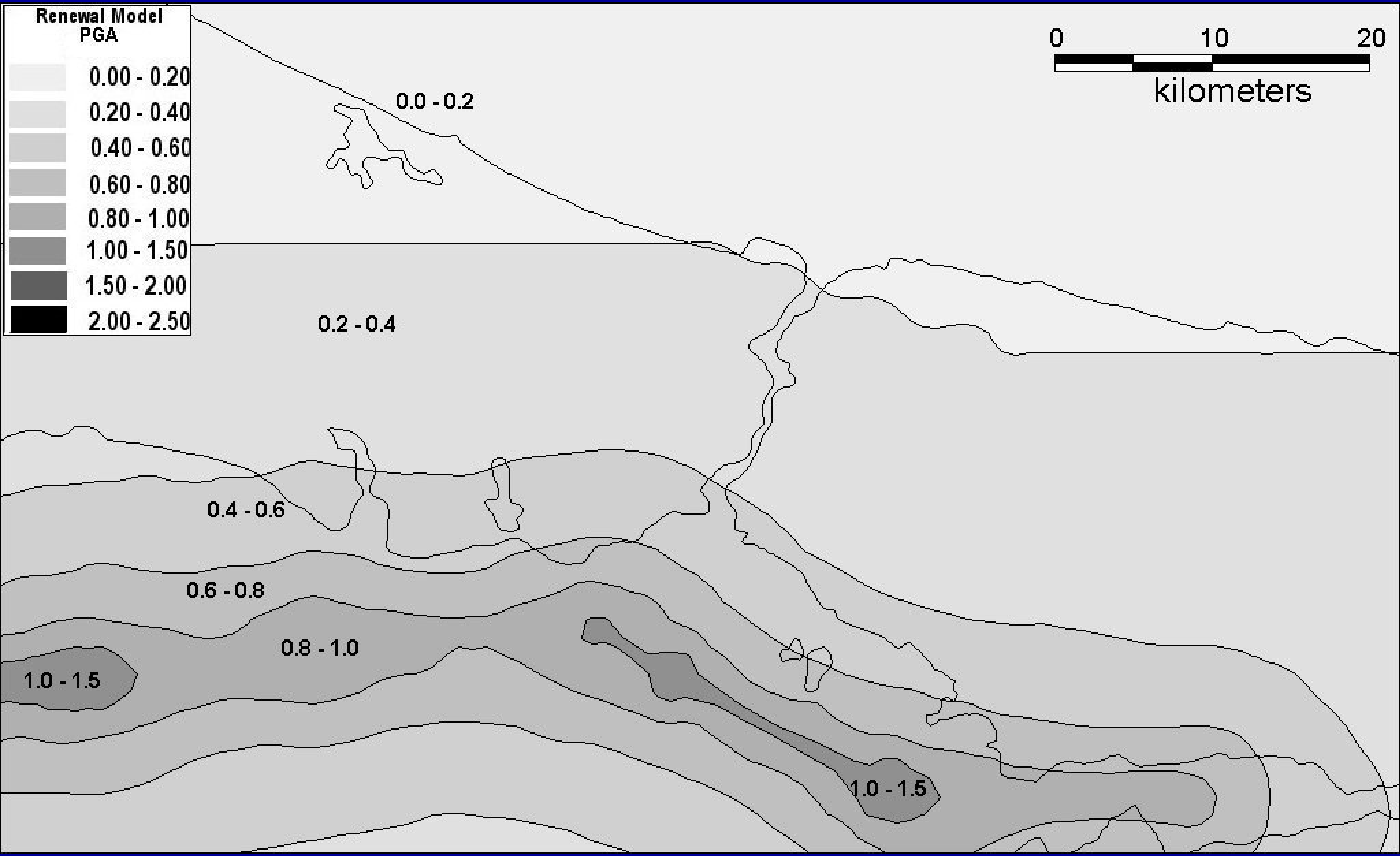
Steps of probabilistic seismic hazard analysis (1) definition of earthquake sources, (2) earthquake recurrence characteristics for each source, (3) attenuation of ground motions with magnitude and distance, and (4) ground motions for specified probability of exceedance levels (calculated by summing probabilities over all the sources, magnitudes, and distances).

The Earthquake Hazard

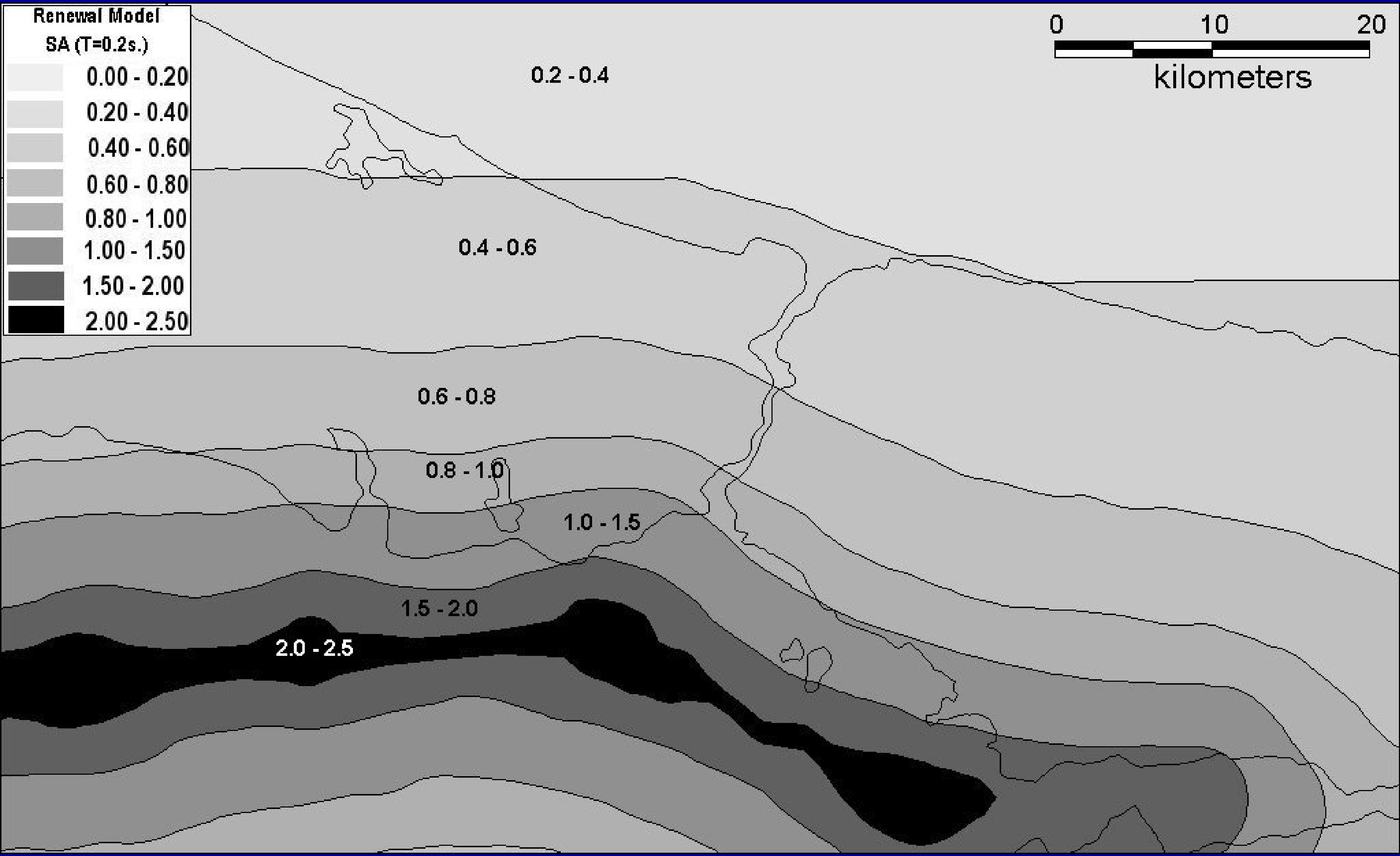
- The ground motion parameters used in the quantification of the earthquake hazard are the peak ground acceleration (PGA) and the spectral accelerations (SA) for natural periods of 0.2 and 1.0 seconds.
- The ground motions are determined for soft rock (NEHRP B/C boundary) conditions (Vs = 760m/s) .
- The results are presented as iso-intensity contour maps for 10% probability of exceedence in 50 years.



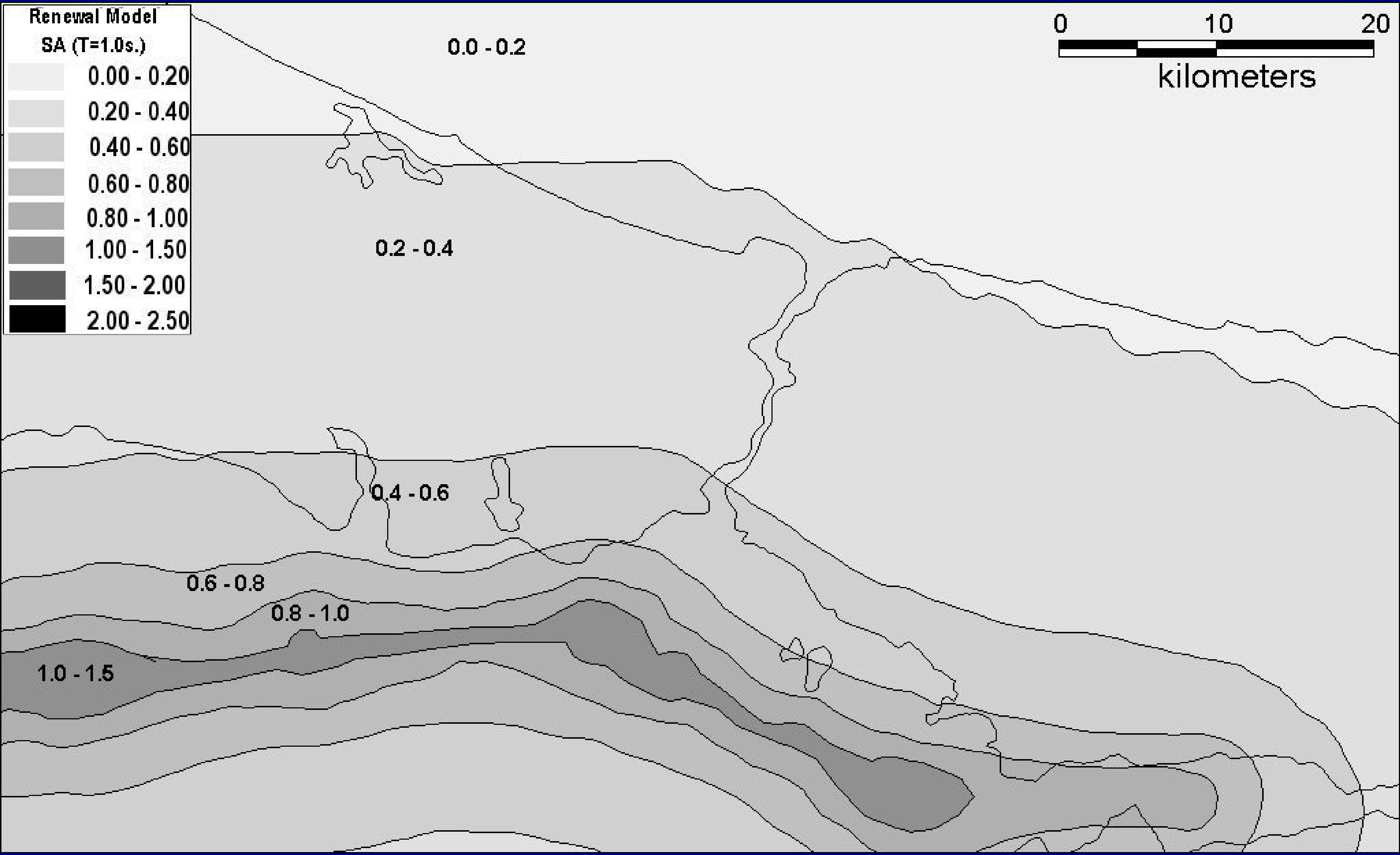
Standard Shape of the Response Spectrum (NEHRP 1997)



Time Dependent, Characteristic, PGA, %10 - 50



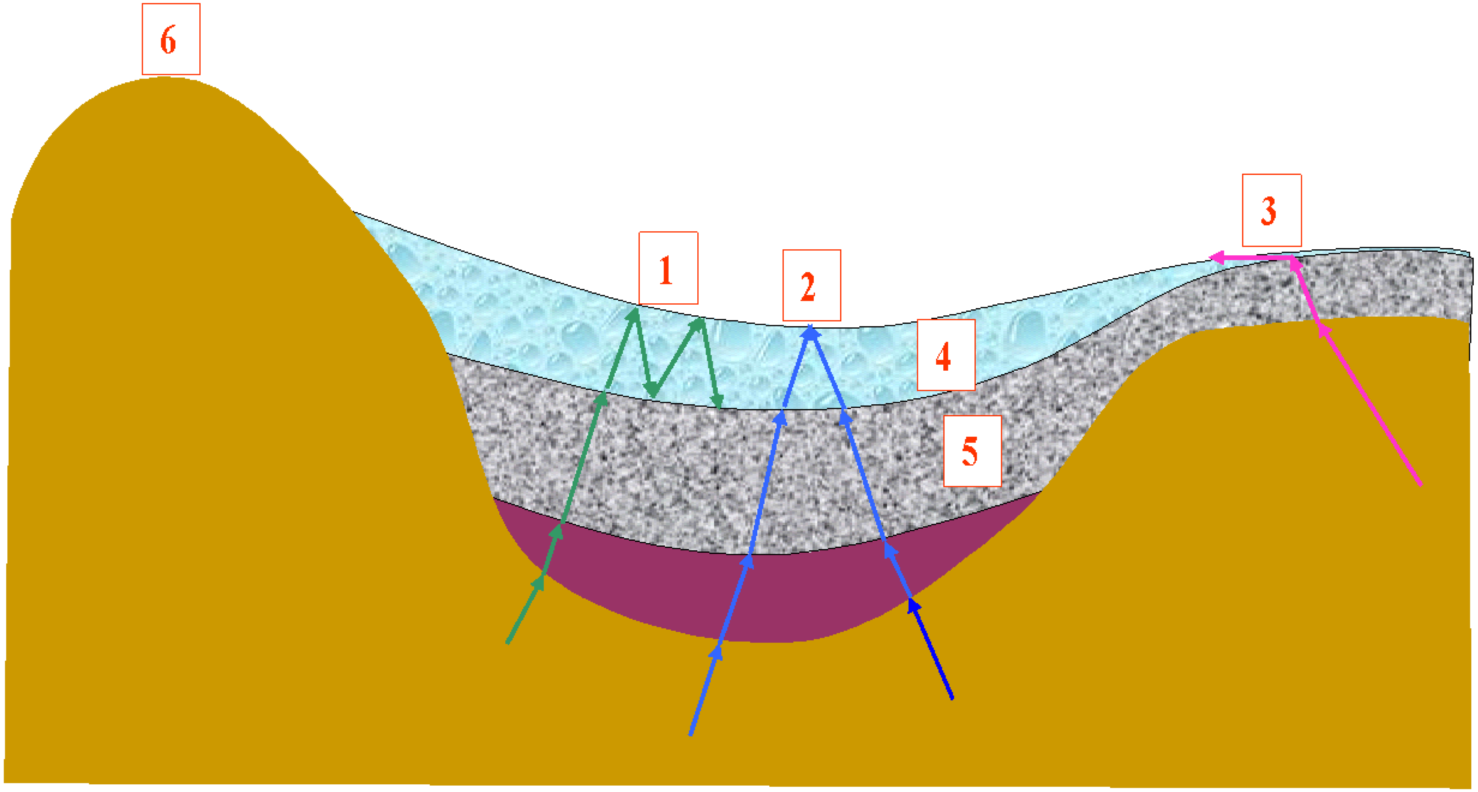
Time Dependent, Characteristic, SA (0.2), %10 - 50



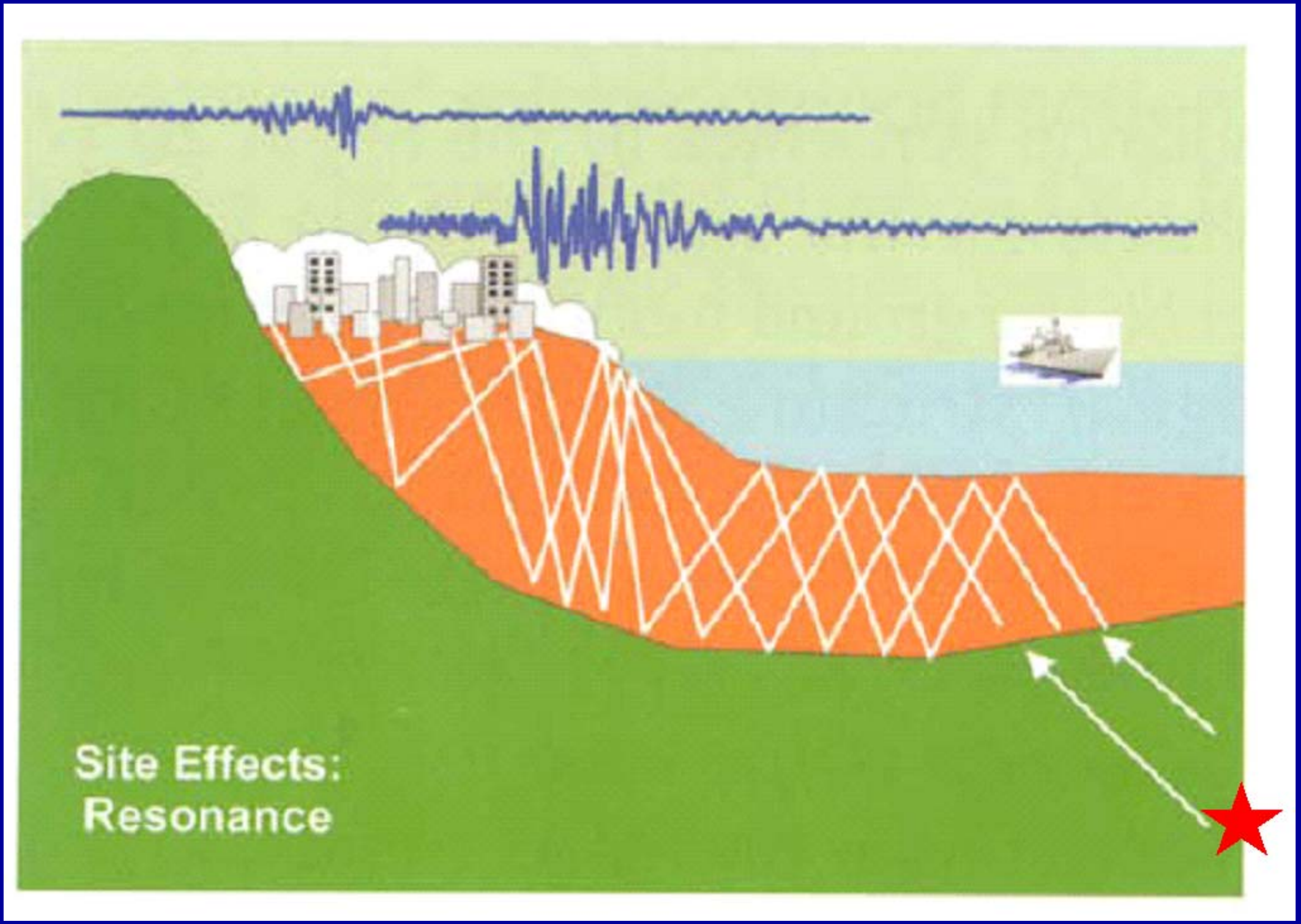
Time Dependent, Characteristic, SA (1.0), %10 - 50

SITE-DEPENDENT HAZARD

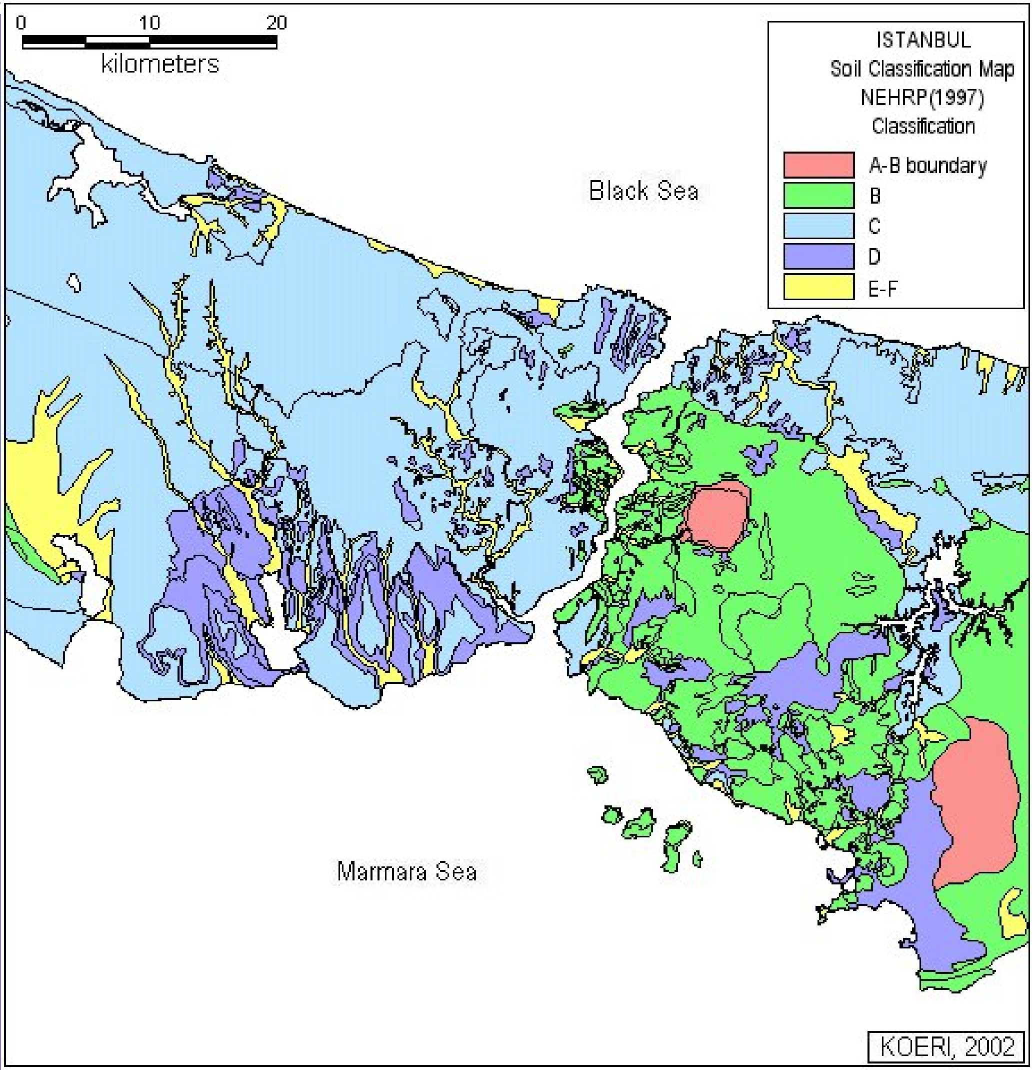
FACTORS AFFECTING SITE AMPLIFICATION



1- Resonances due to impedance contrasts
2- Focusing due to subsurface topography
3- Body waves converted to surface waves
4- Water content
5- Randomness of the medium
6- Surface topography


Site Effects:
Resonance

Name of classes	Explanations
A	Hard rock with measured shear wave velocity Vs > 1500 m/s.
B	Rock with (760 m/s< Vs< 1500 m/s)
C	Very dense soil and rock with (260 m/s < Vs < 760 m/s) or with either Standard Penetration Resistance N> 50 or Average Undrainded shear Strength at top 30m Su>= 100 kPa
D	Stiff soil with (180 m/s <Vs<<360 m/s) or with either 15<N<50 or (50 kPa< Suz100kPa)
E	A soil profile with Vs<180m/s or with PI>20 and Su<25 kPa
F	Soils requiring site-specific evaluations.



The NEHRP-based Soil Classification Map of Istanbul

The earthquake hazard results are converted to site-dependent values to reflect the local site effects in Istanbul. For this reason, spectral response acceleration values obtained for NEHRP site class B/C boundary (Vs= 760 m/sec) are adjusted using Fa factors for short period and Fv factors for long period site-correction defined in the 1997 NEHRP Provisions (NEHRP 1997).

$$S_{MS} = F_a S_s \qquad S_{M1} = F_v S_1$$

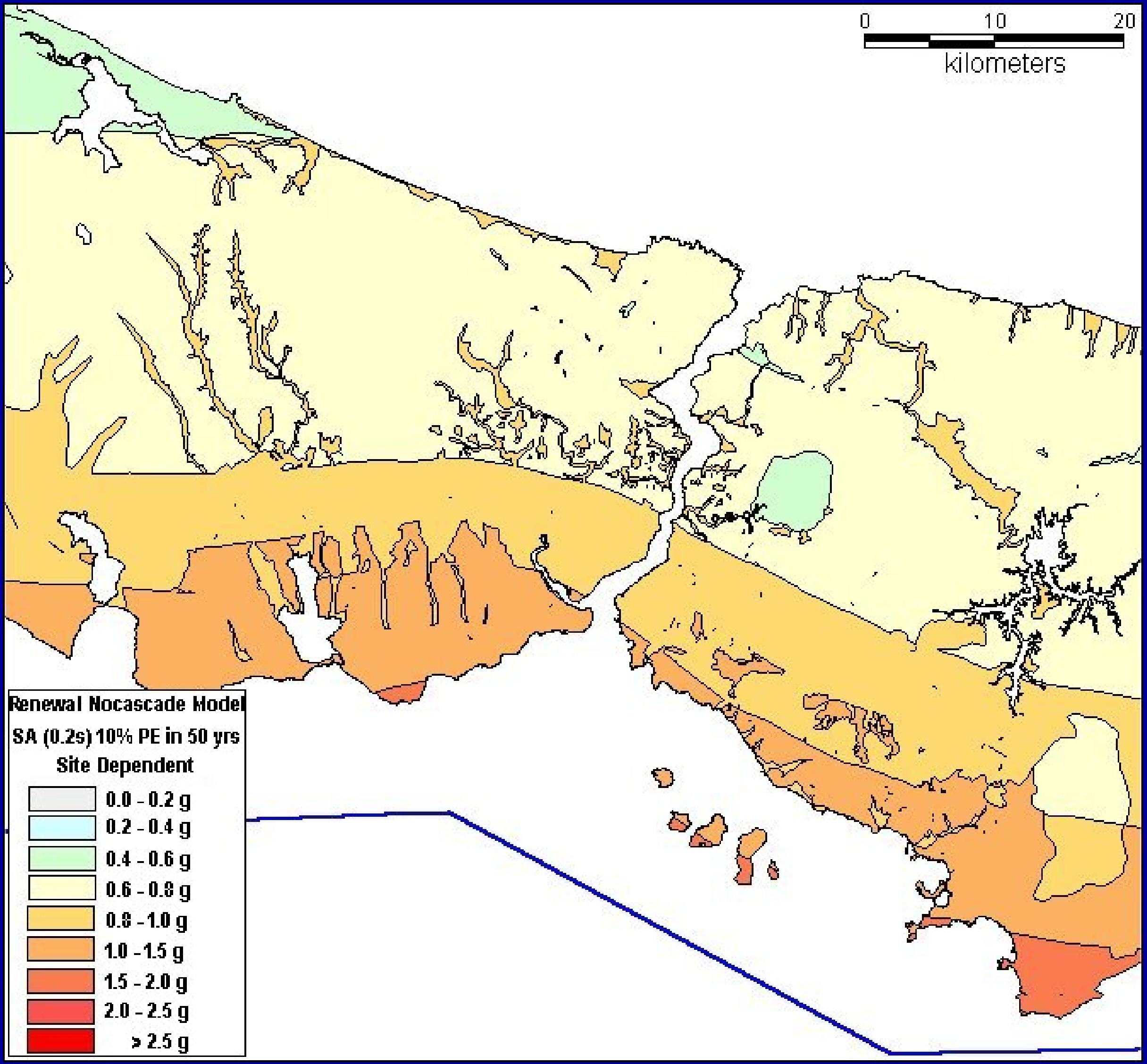
Fa, the short period site-correction defined in the 1997 NEHRP Provisions (NEHRP 1997)

Site Class	Ss≤ 0.25	Ss= 0.50	Ss =0.75	Ss=1.00	Ss ≥1.25
A	0.8	0.8	0.8	0.8	0.8
B	1	1	1	1	1
C	1.2	1.2	1.1	1	1
D	1.6	1.4	1.2	1.1	1
E	2.5	1.7	1.2	0.9	*
F	*	*	*	*	*

Fv, the long period site correction defined in the 1994 and 1997 NEHRP Provisions (NEHRP 1997)

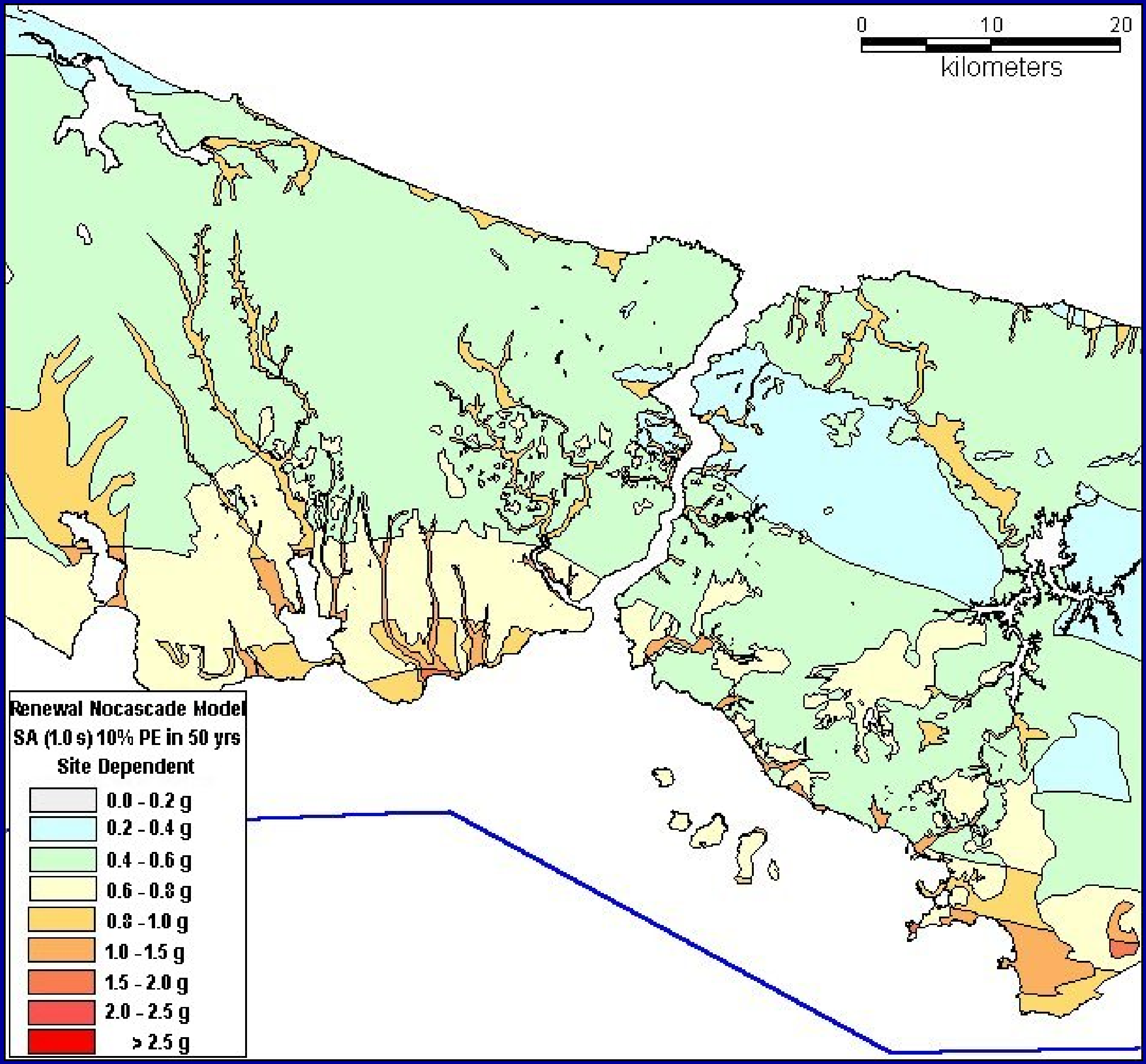
Site Class	Ss≤ 0.1	Ss= 0.20	Ss =0.30	Ss=0.40	Ss ≥0.5
A	0.8	0.8	0.8	0.8	0.8
B	1	1	1	1	1
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	*
F	*	*	*	*	*

Site dependent seismic hazard assessment



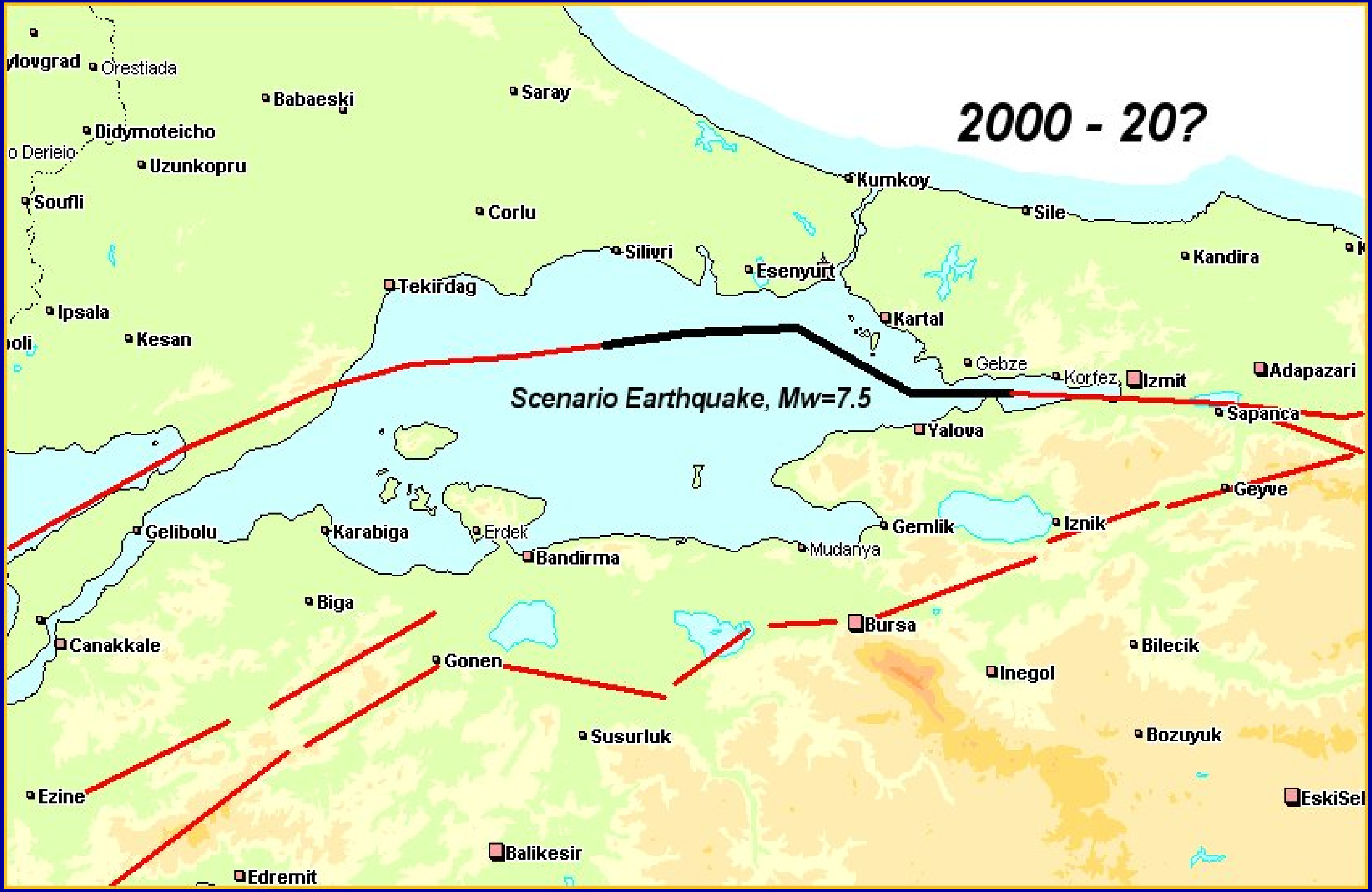
Site dependent SA (T=0.2 s) map at NEHRP B/C boundary site class for 10% probability of exceedence in 50 years

Site dependent seismic hazard assessment

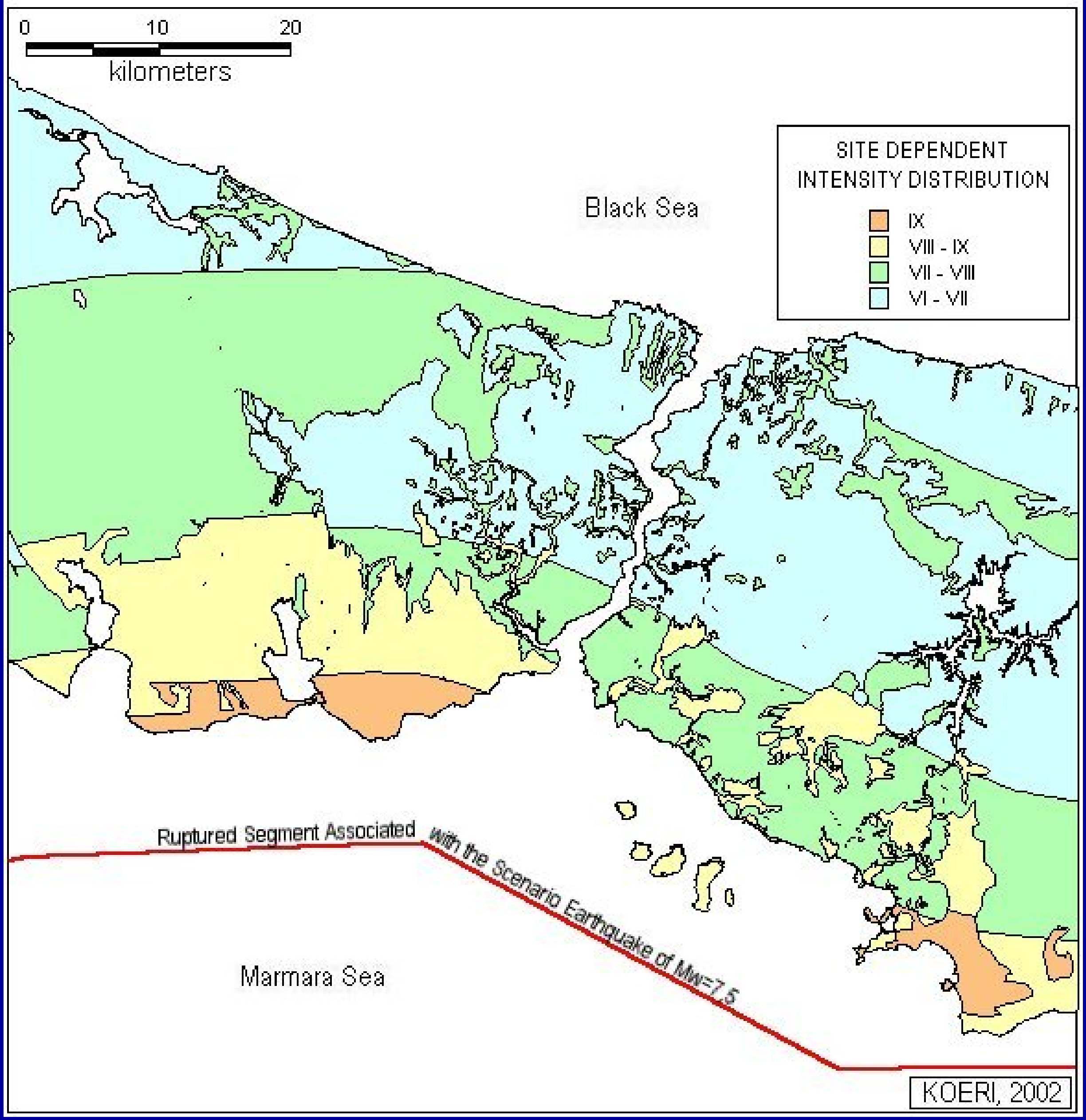


Site dependent SA (T=1.0 s) map at NEHRP B/C boundary site class for 10% probability of exceedence in 50 years

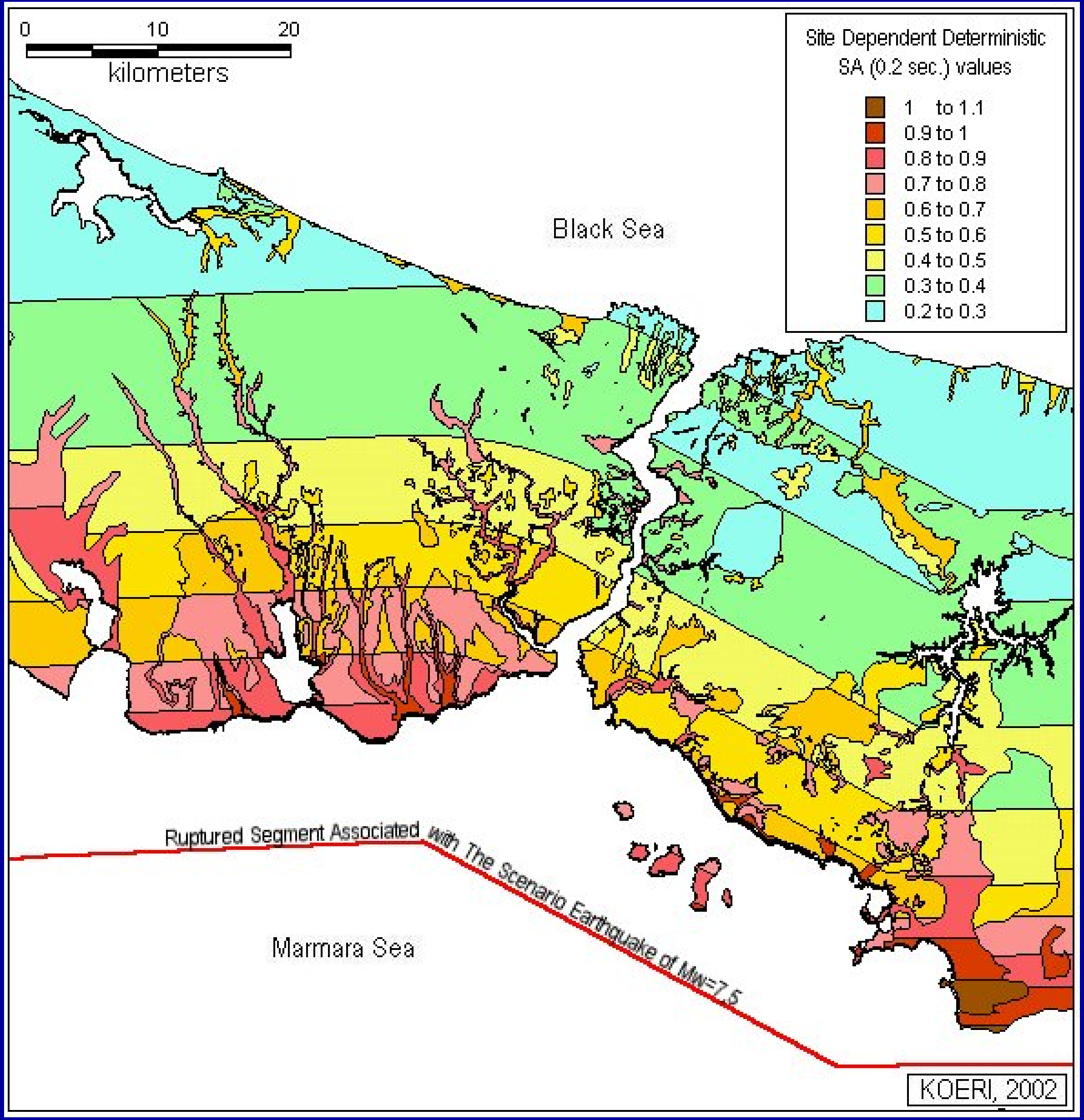
Deterministic Seismic Hazard



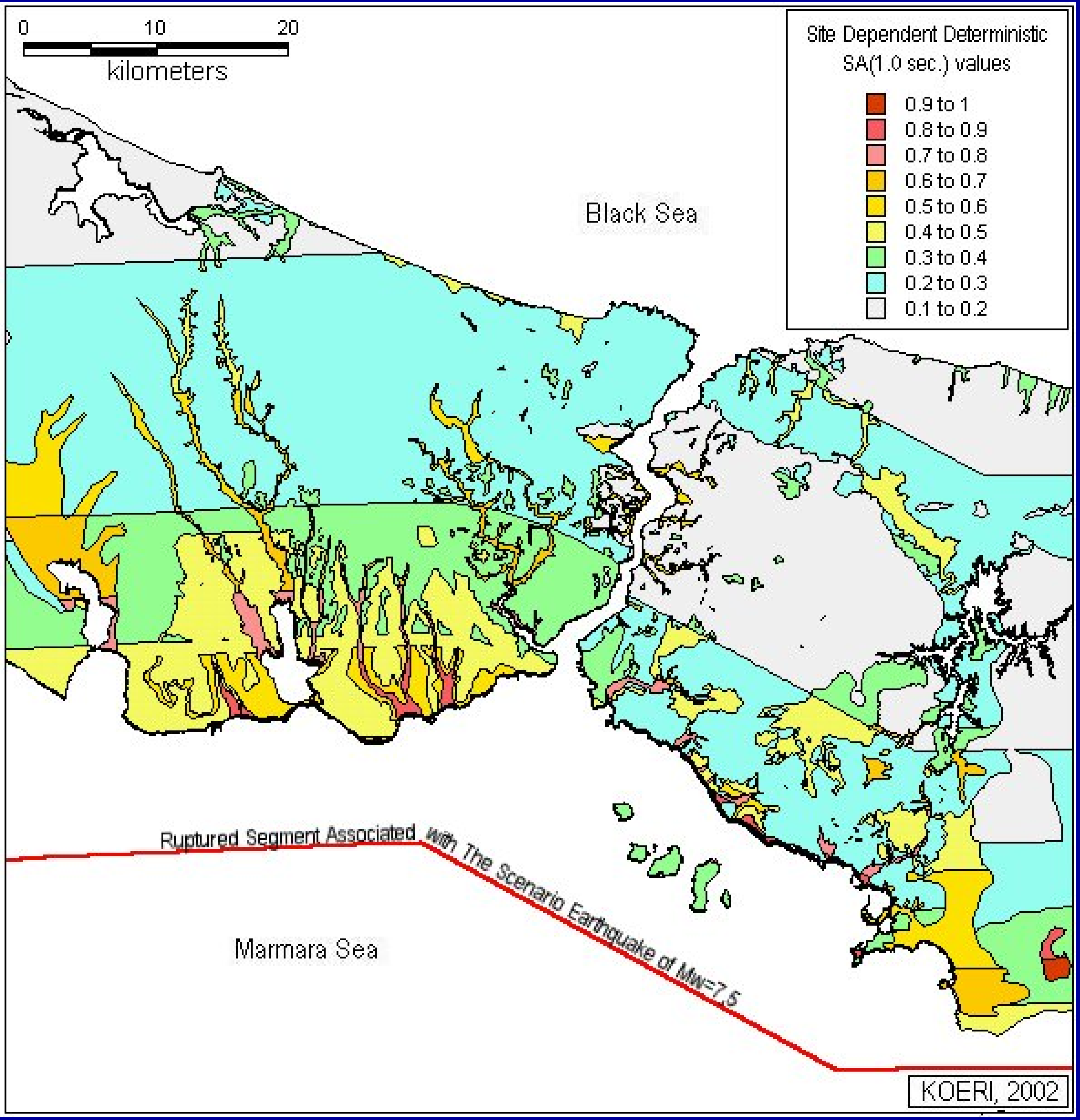
Mw=7.5 scenario earthquake for Istanbul and vicinity



Site dependent deterministic intensity distribution



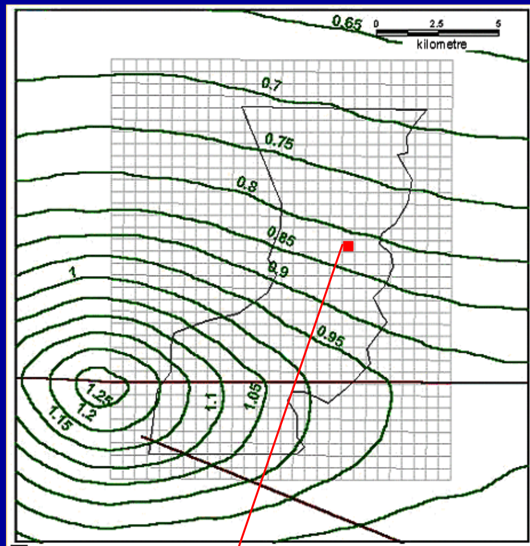
Site-dependent deterministic SA(T=0.2 sec) values in units of g



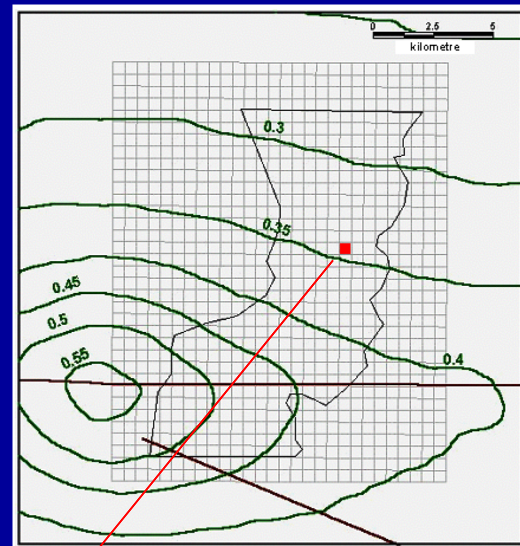
Site-dependent deterministic SA(T=1.0 sec) values in units of g

Earthquake Hazard Analysis

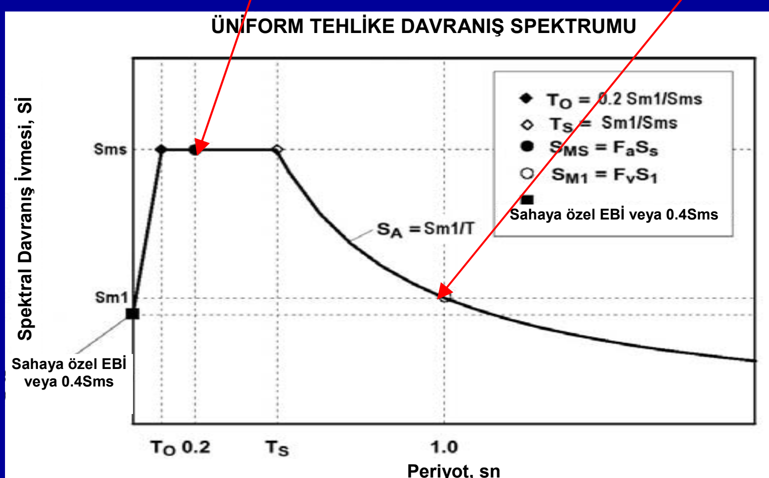
ADAPAZARI



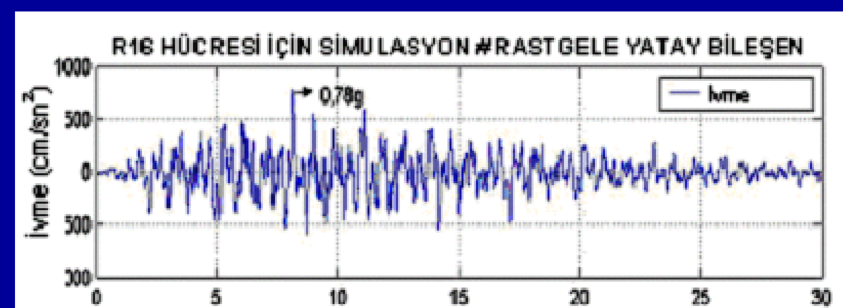
T=0.2sn'deki spektral ivmeler (%40/50)



T=1.0sn'deki spektral ivmeler (%40/50)



Her bir hücre için elde edilen eş tehlike spektrumu



. R16 Hücresi için Davranış Spektrumu Uyumlu Yatay Yer Hareketi (NEHRP B/C Yerel Zemin Koşulları için)

Site Response Analysis

Deterministic Seismic Hazard Estimation of Peak Ground Velocity (PGV) and Intensity

Peak Ground Velocity

Based on HAZUS99 recommendations PGV has been calculated from SA at T=1.0 using the following formula.

$$PGV = \left(\frac{386.4}{2\lambda} \cdot S_{A1} \right) / 1.65$$

where PGV is the peak ground velocity in inches per second and S_{A1} is the spectral acceleration in units of g, at T=1.0sec.

Intensity Based Deterministic Earthquake Hazard

The relationships between PGA, PGV and Modified Mercalli Intensity of Walid et al. (1999)

$$I_{mm} = 3.66 * \log PGA - 1.66, \text{ for } V \leq I_{mm} \leq VIII$$

$$I_{mm} = 3.47 * \log PGV + 2.35, \text{ for } V \leq I_{mm} \leq IX$$

Risk Assessment

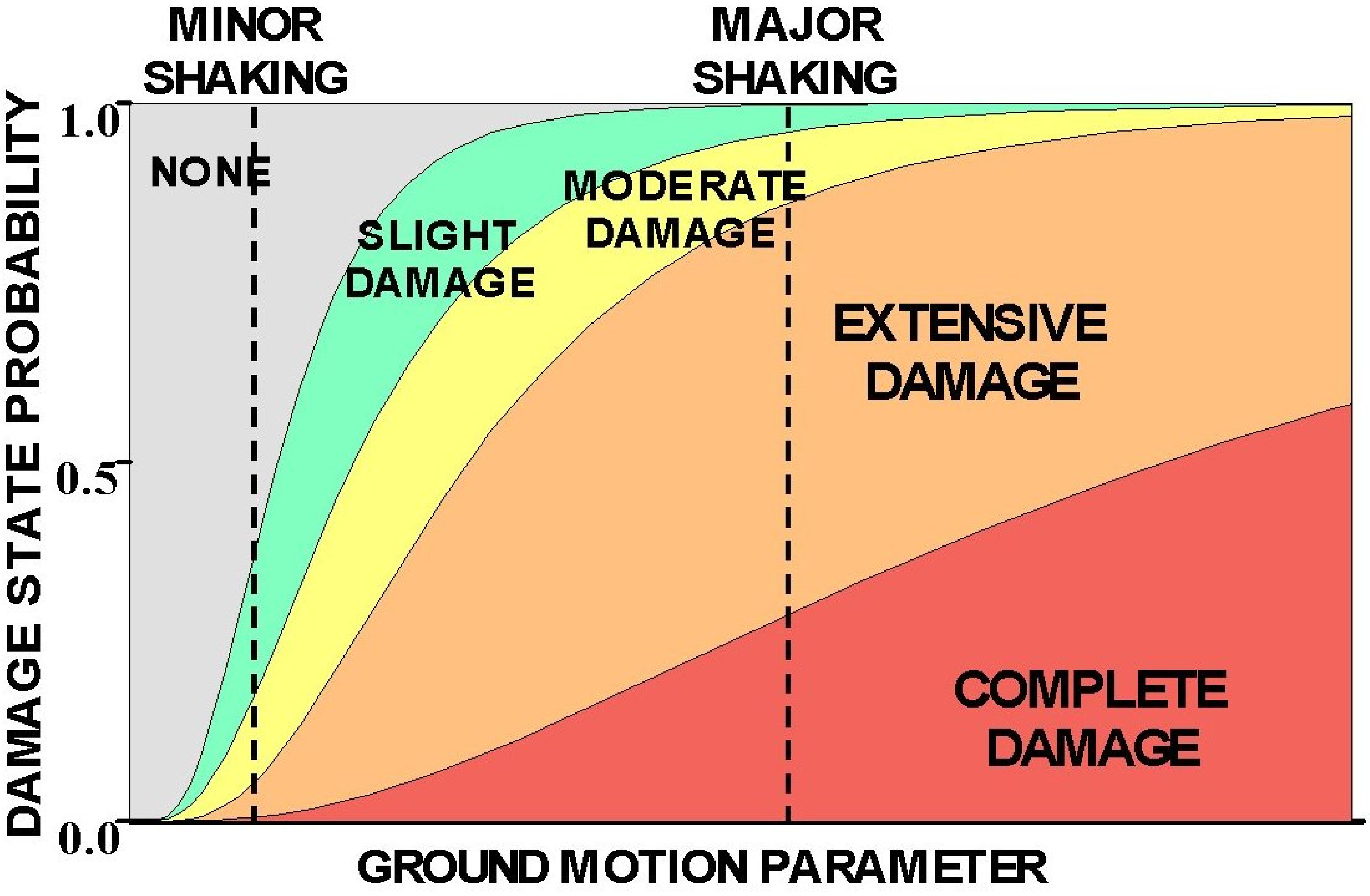
ELEMENTS AT RISK

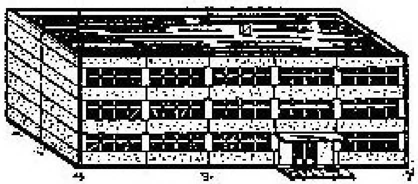
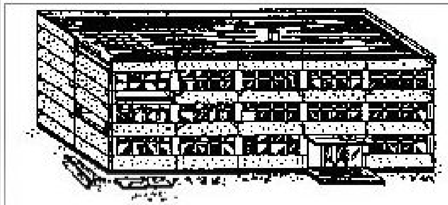
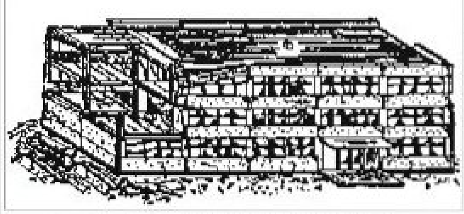
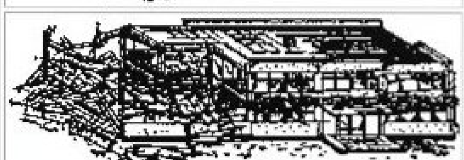
- Buildings
- Lifeline Systems → Built Environment
- Population
- Socio-Economic Activities

Vulnerability estimation methodology

Two alternative approaches:

- Observed Vulnerability (OV) – based on past damage and intensity
- Calculated Vulnerability (CV) – based on calculated performance of building types


MINOR SHAKING
MAJOR SHAKING
DAMAGE STATE PROBABILITY
1.0
0.5
0.0
NONE
SLIGHT DAMAGE
MODERATE DAMAGE
EXTENSIVE DAMAGE
COMPLETE DAMAGE
GROUND MOTION PARAMETER

Classification of damage to buildings of reinforced concrete	
	**Grade 1: Negligible to slight damage** **(no structural damage,** **slight non-structural damage)** Fine cracks in plaster over frame members or in walls at the base. Fine cracks in partitions and infills.
	**Grade 2: Moderate damage** **(slight structural damage,** **moderate non-structural damage)** Cracks in columns and beams of frames and in structural walls. Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of wall panels.
	**Grade 3: Substantial to heavy damage** **(moderate structural damage,** **heavy non-structural damage)** Cracks in columns and beam column joints of frames at the base and at joints of coupled walls. Spalling of conrete cover, buckling of reinforced rods. Large cracks in partition and infill walls, failure of individual infill panels.
	**Grade 4: Very heavy damage** **(heavy structural damage,** **very heavy non-structural damage)** Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforced bars; tilting of columns. Collapse of a few columns or of a single upper floor.
	**Grade 5: Destruction** **(very heavy structural damage)** Collapse of ground floor or parts (e. g. wings) of buildings.

Observed vulnerability (OV)

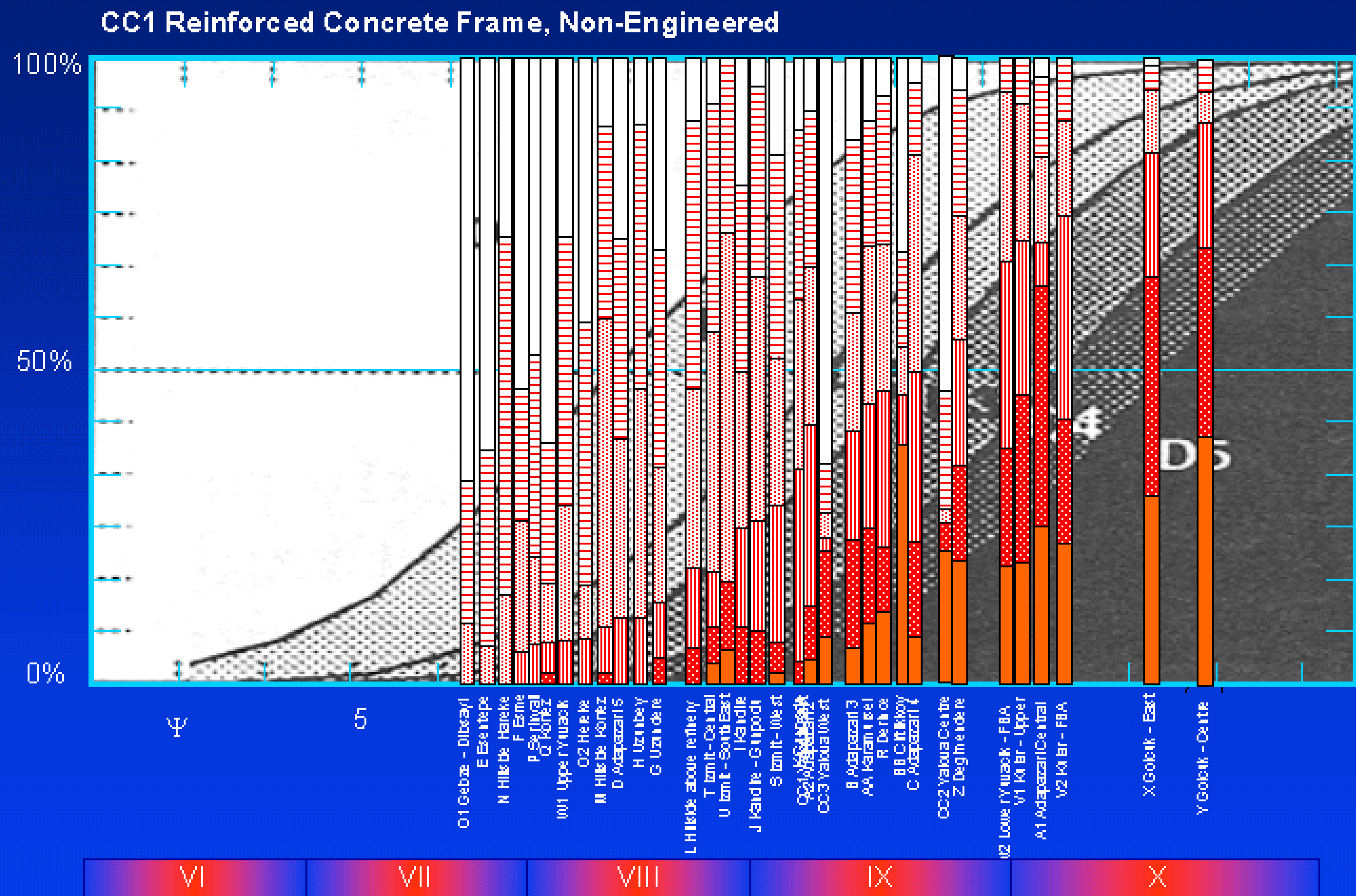
Advantages:

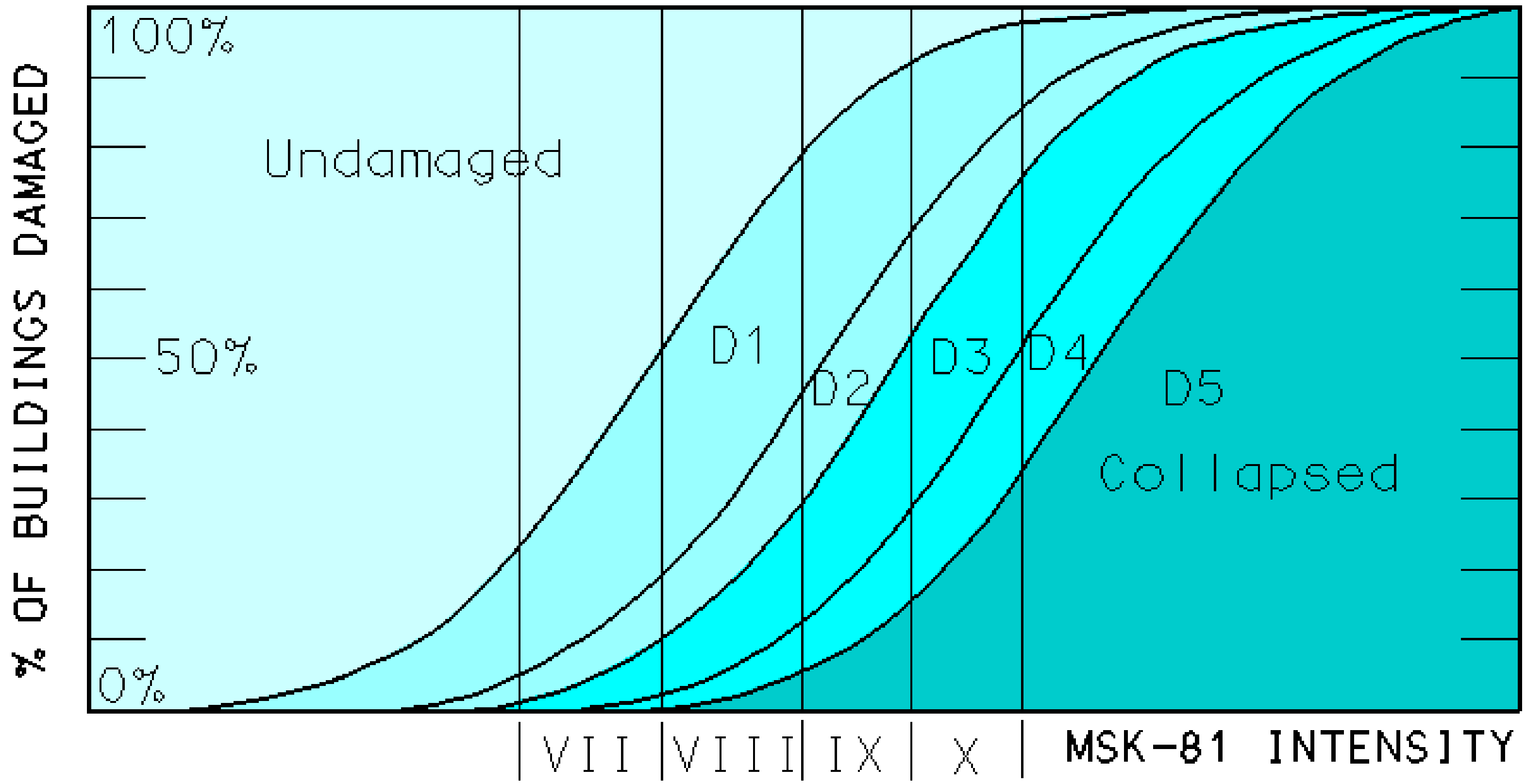
- Based on observed damage to actual building stock in area
- Takes account of real variety of failure modes
- Simple in concept and application to loss estimation – few assumptions

Limitations:

- Intensity measurement difficult when building stock is dynamic
- Does not fit with today's engineering parameters of ground motion
- No real modelling of interaction between ground motion, soil and structure response
- Difficult to apply to new or modified building types

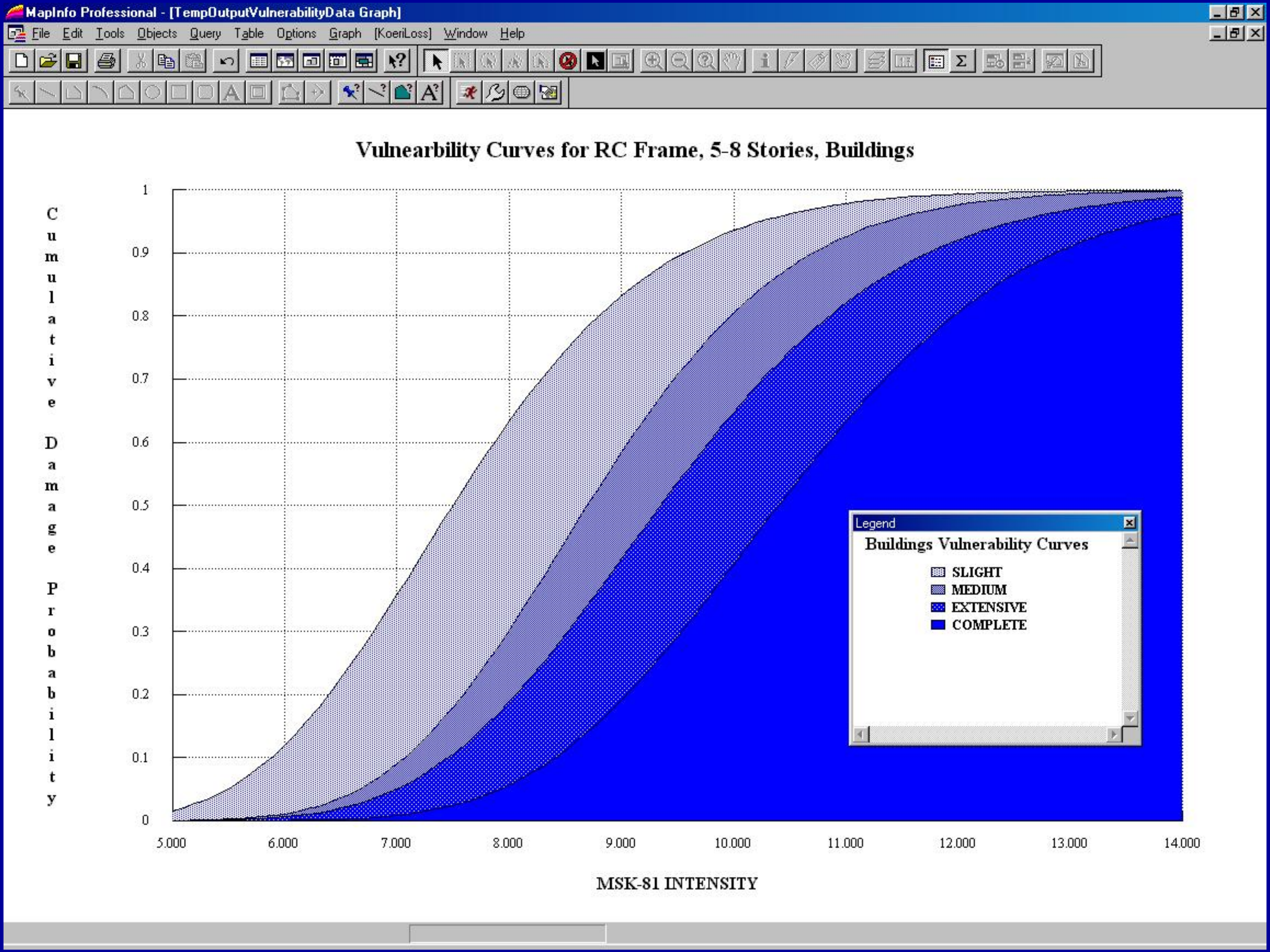
Surveys and their Intensity





MSK-81 DAMAGE GRADES

Damage Grade	R/C Framed Building
DI-Slight	Infill panels damaged
D2-Moderate	Structural cracks < lcm
D3-Heavy	Damage to structural members
D4-Destruction	Failure of structure or major deflection
D5-Collapse	Collapse of structural members and floor



Area plot for vulnerability curves

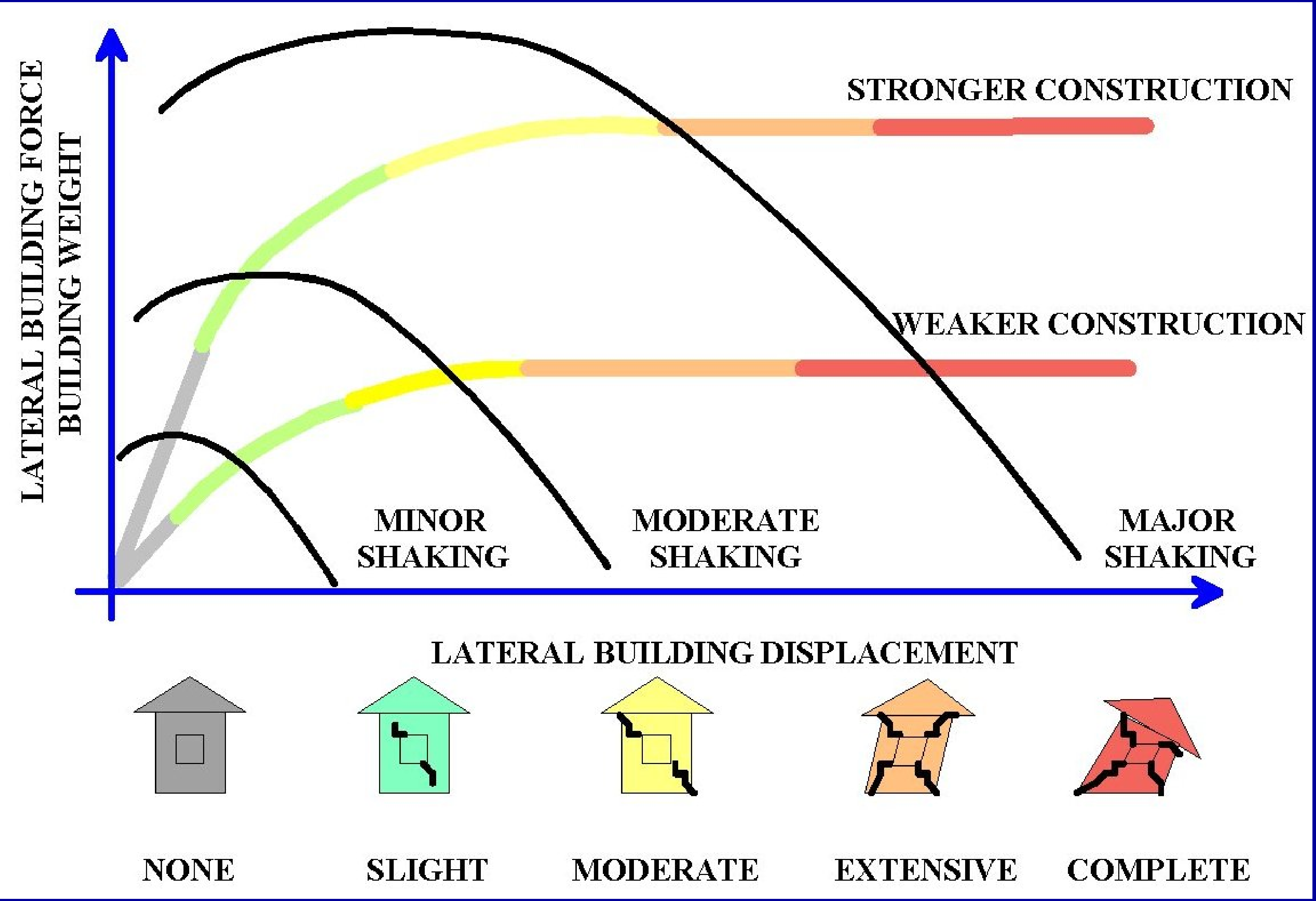
Calculated vulnerability (CV)

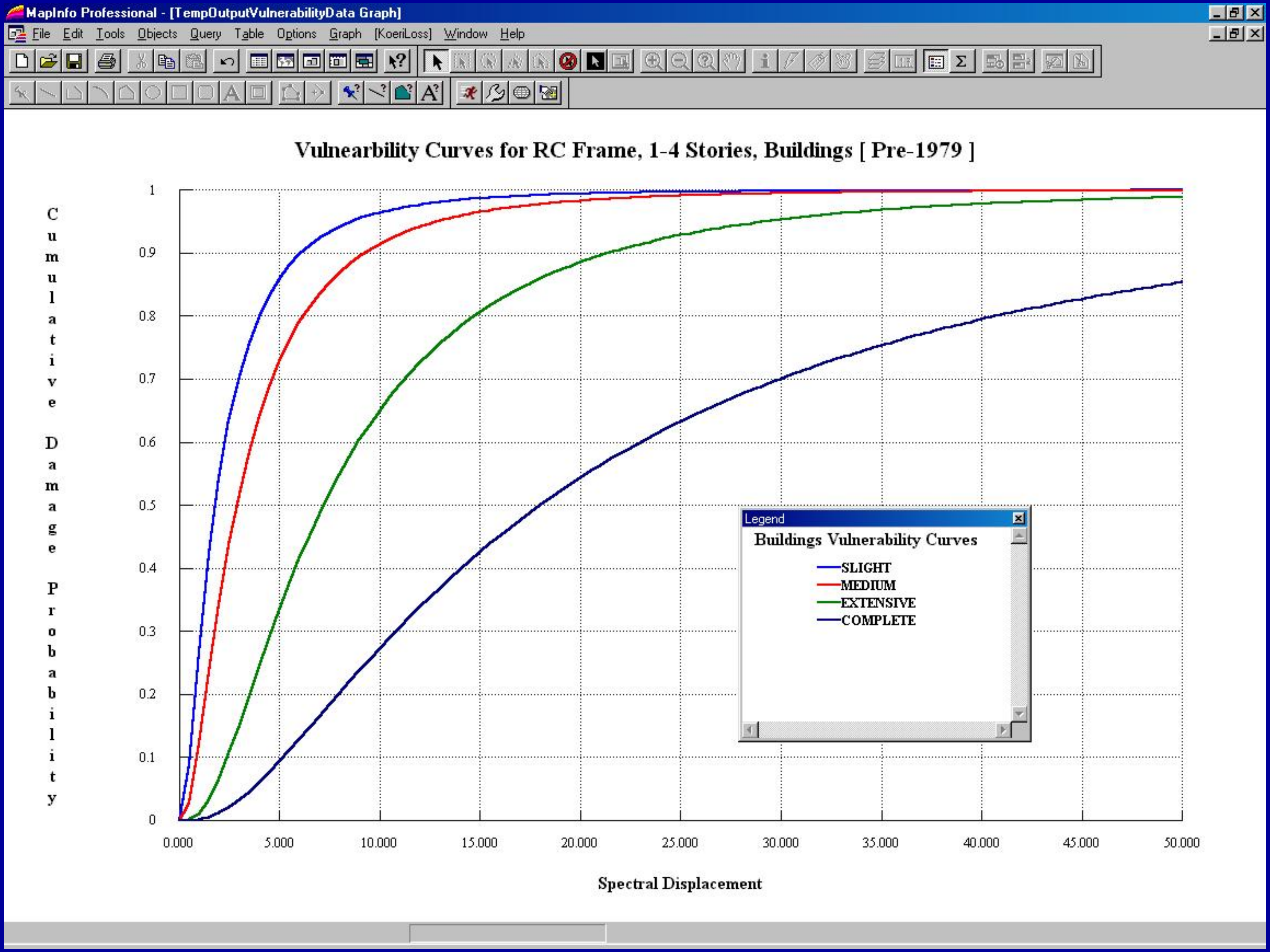
Advantages:

- Relates to engineering ground motion
- Can be applied to building types not previously damaged
- Models interaction between ground motion, soil and structure response
- Avoids the use of intensity

Limitations

- Not based on damage data
- Not valid for buildings which fail in non-structural ways
- Complex structure – many assumptions

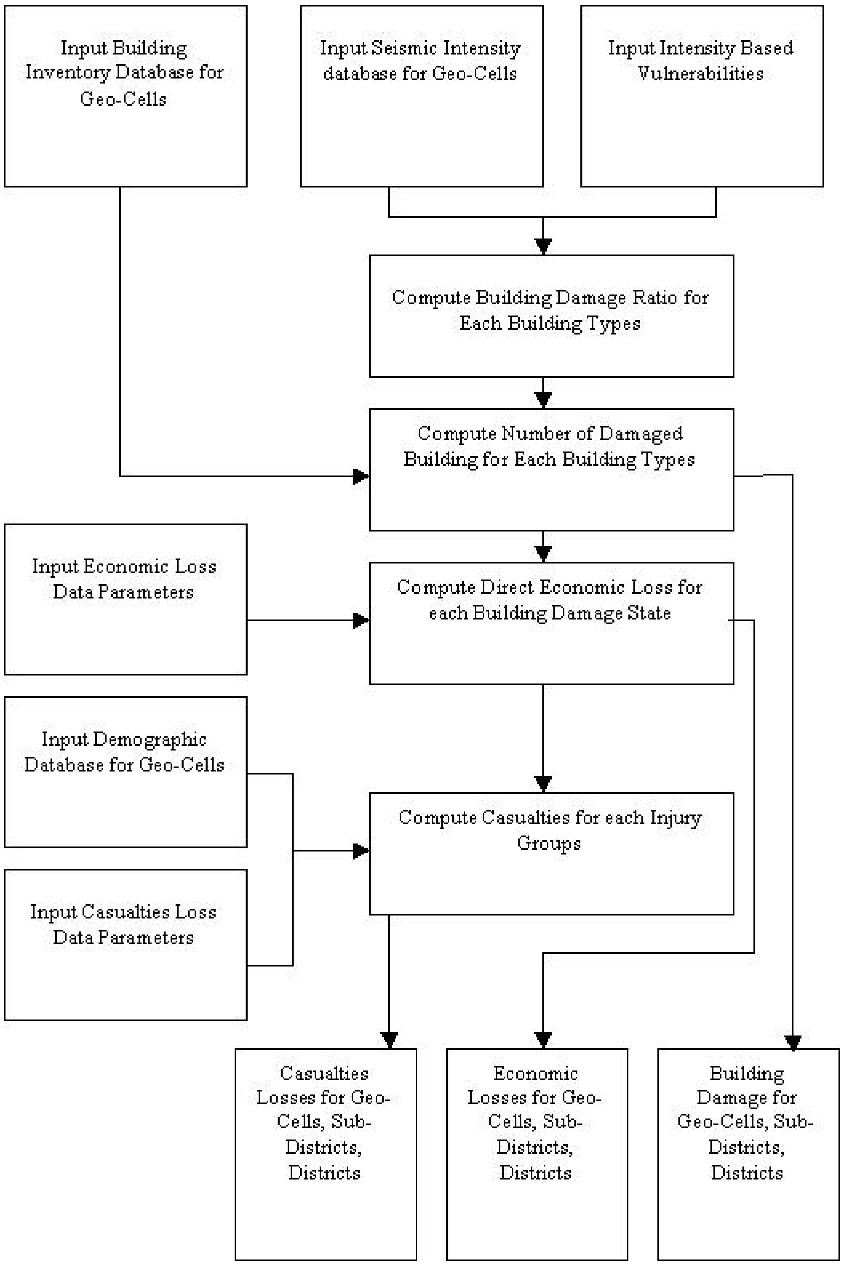

LATERAL BUILDING FORCE
BUILDING WEIGHT
STRONGER CONSTRUCTION
WEAKER CONSTRUCTION
MINOR SHAKING
MODERATE SHAKING
MAJOR SHAKING
LATERAL BUILDING DISPLACEMENT
NONE
SLIGHT
MODERATE
EXTENSIVE
COMPLETE



Line plot for vulnerability curves

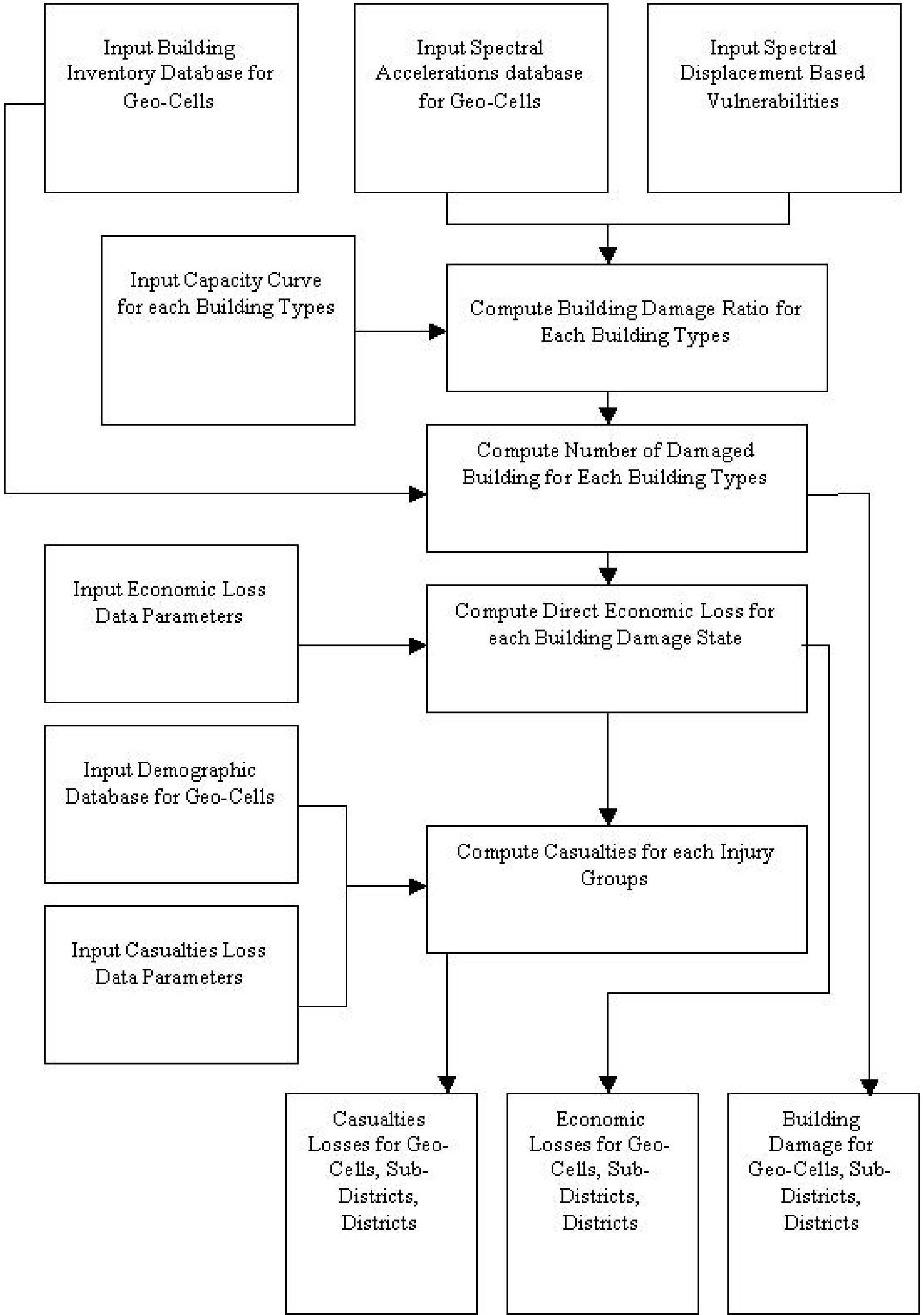
KOERILoss

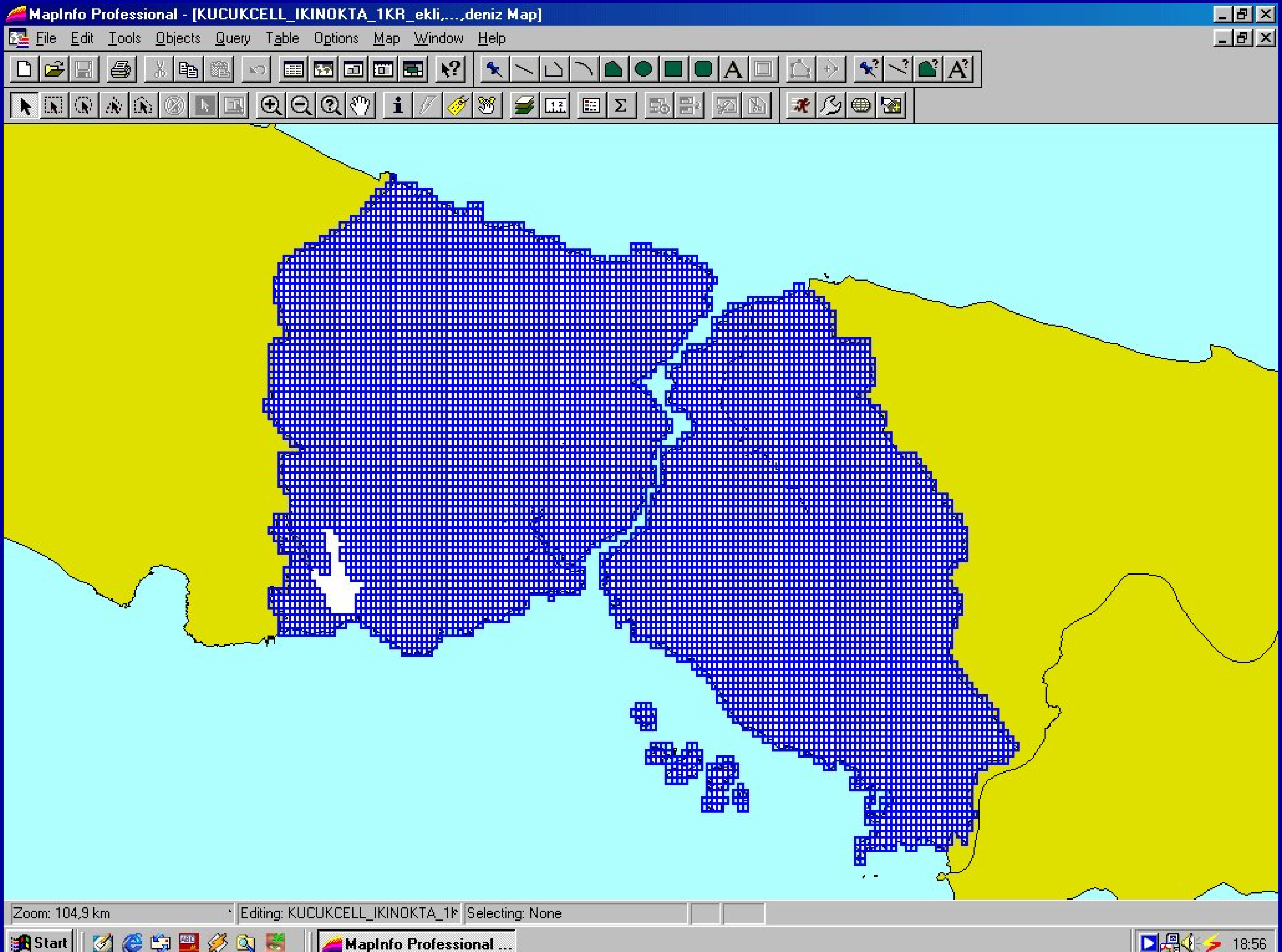
Intensity Based Loss Estimation Algorithm



KOERILoss

Spectral displacement Based Loss Estimation Algorithm




MapInfo Professional - [KUCUKCELL_IKINOKTA_1KR_ekli,...,deniz Map]
File Edit Tools Objects Query Table Options Map Window Help
Zoom: 104,9 km
Editing: KUCUKCELL_IKINOKTA_1K
Selecting: None
Start
MapInfo Professional ...
18:56

Classification of Building Data

- ✓ ***Structural systems category***
  - ➢ **I = 1** : RC frame building
  - ➢ **I = 2** : Masonry building
  - ➢ **I = 3** : Shear wall building (Tunnel formwork system)
  - ➢ **I = 4** : Pre-fabricated building
- ✓ ***Number of building stories category***
  - ➢ **J = 1** : 1 – 4 stories (including basement)
  - ➢ **J = 2** : 5 – 8 stories (including basement)
  - ➢ **J = 3** : > 8 stories (including basement)
- ✓ ***- Construction Year category***
  - ➢ **K = 1** : Construction year: pre-1979 (included)
  - ➢ **K = 2** : Construction year: post-1980

Classification of Structural Damage

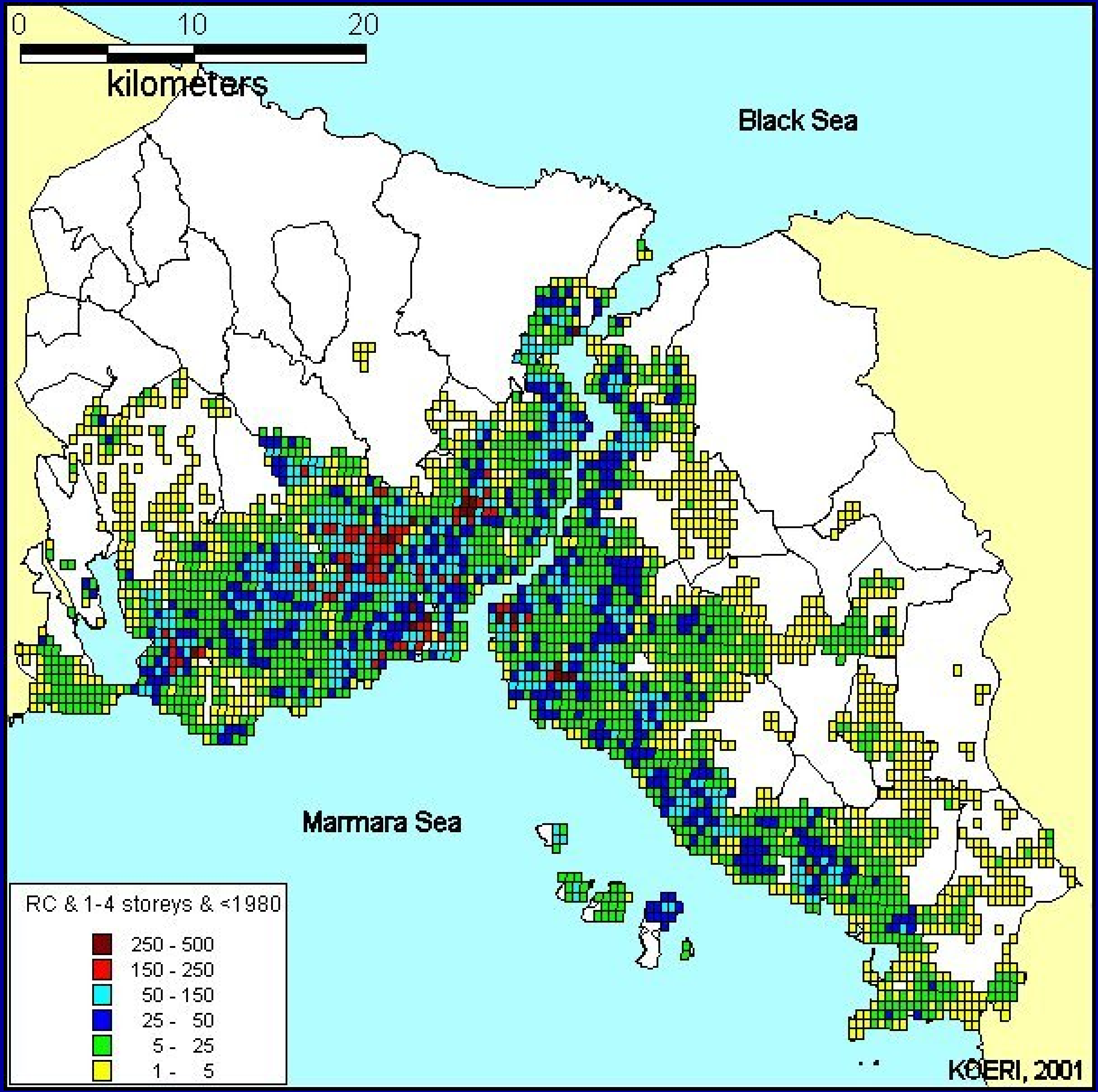
- S: Slight damage
- M: Moderate damage
- E: Extensive damage
- C: Complete damage

Classification of Casualties

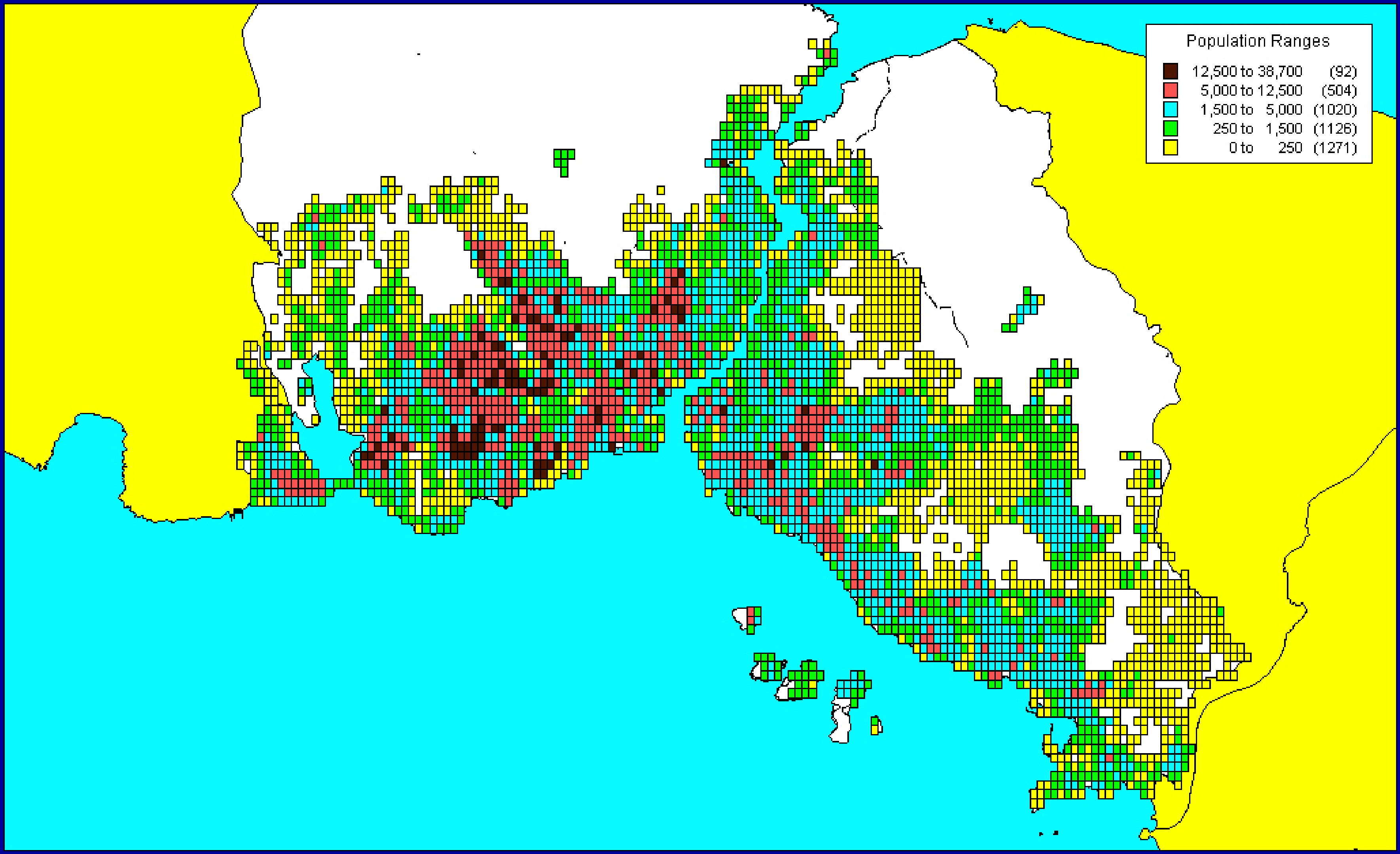
- Severity 1
- Severity 2
- Severity 3
- Severity 4

BUILDING INVENTORIES

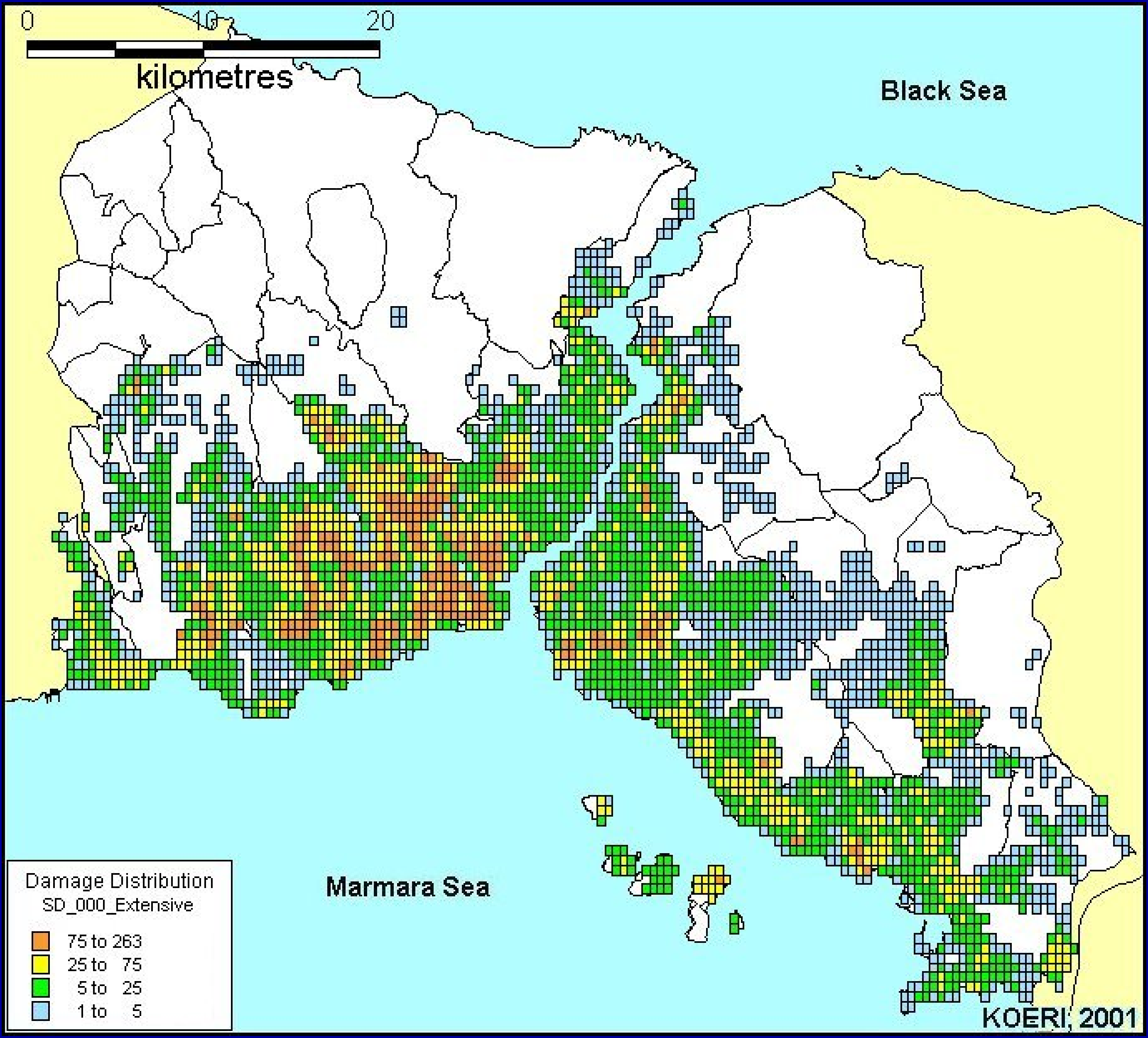
- Building Inventory based on aerial photos prepared by İki Nokta
- Data prepared by State Statistics Institute (SSI)


0
10
20
kilometers
Black Sea
Marmara Sea
RC & 1-4 storeys & <1980
250 - 500
150 - 250
50 - 150
25 - 50
5 - 25
1 - 5
KOERI, 2001

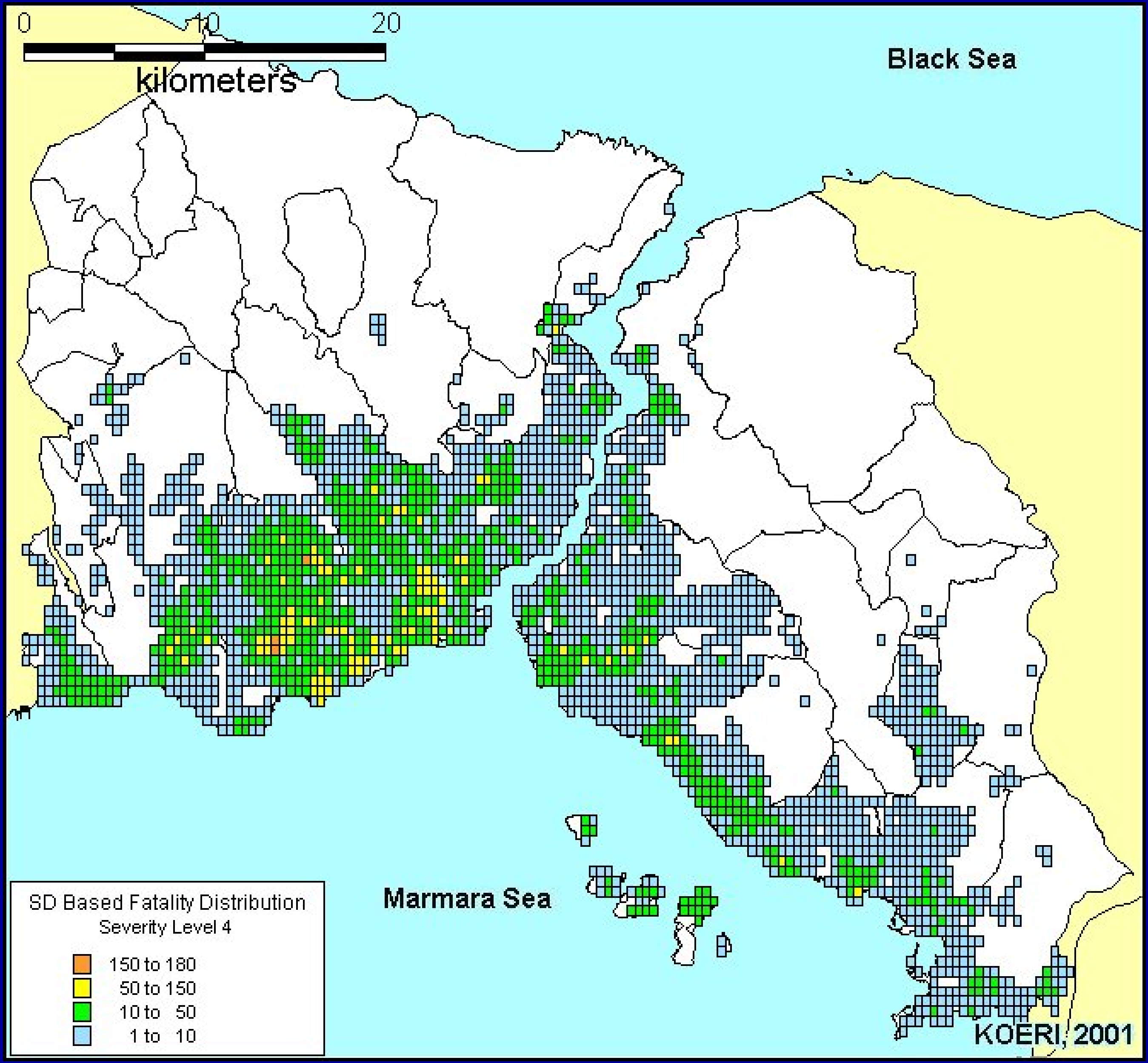
DEMOGRAPHIC DATA



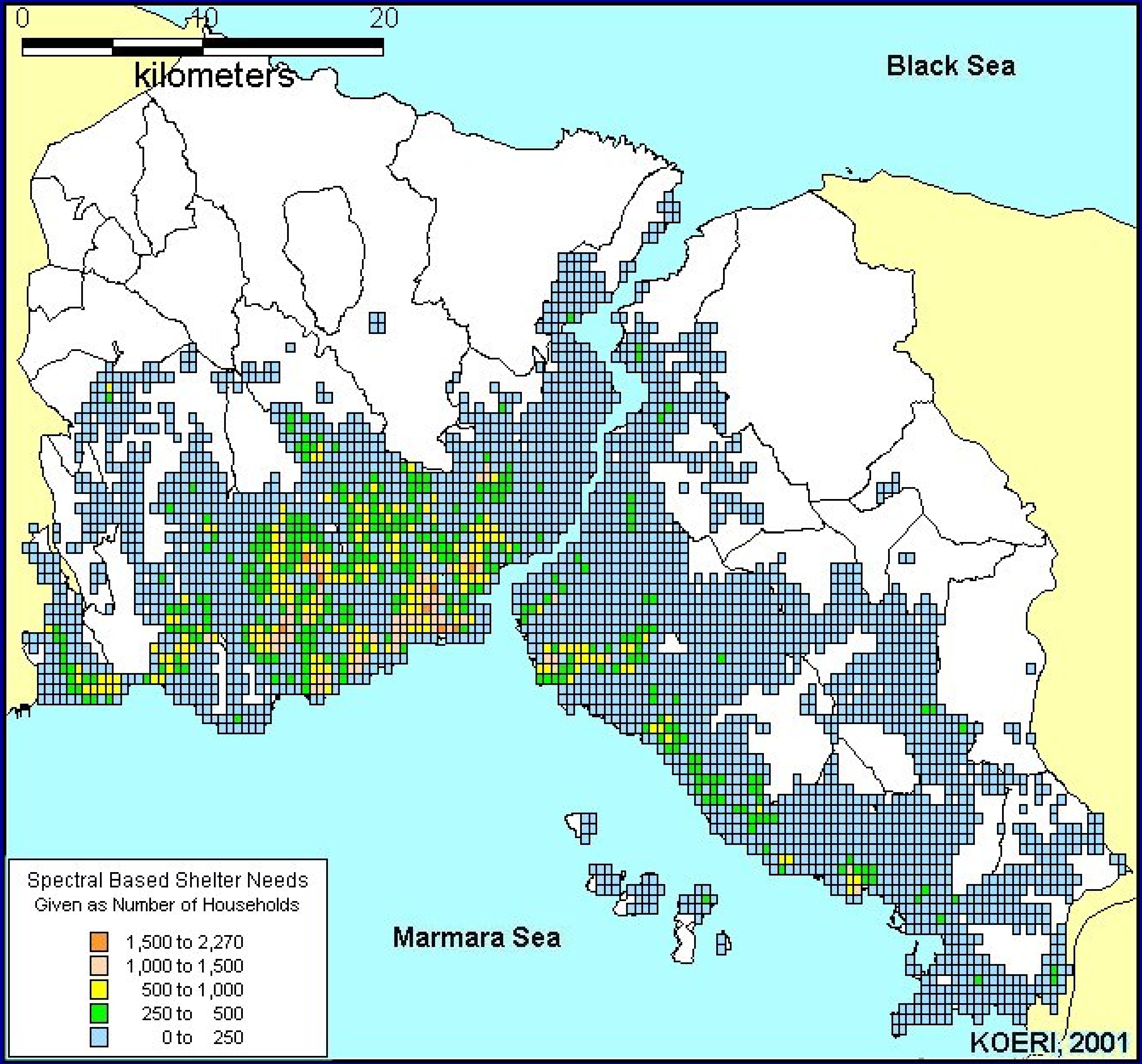
Total Extensive Damage Distribution

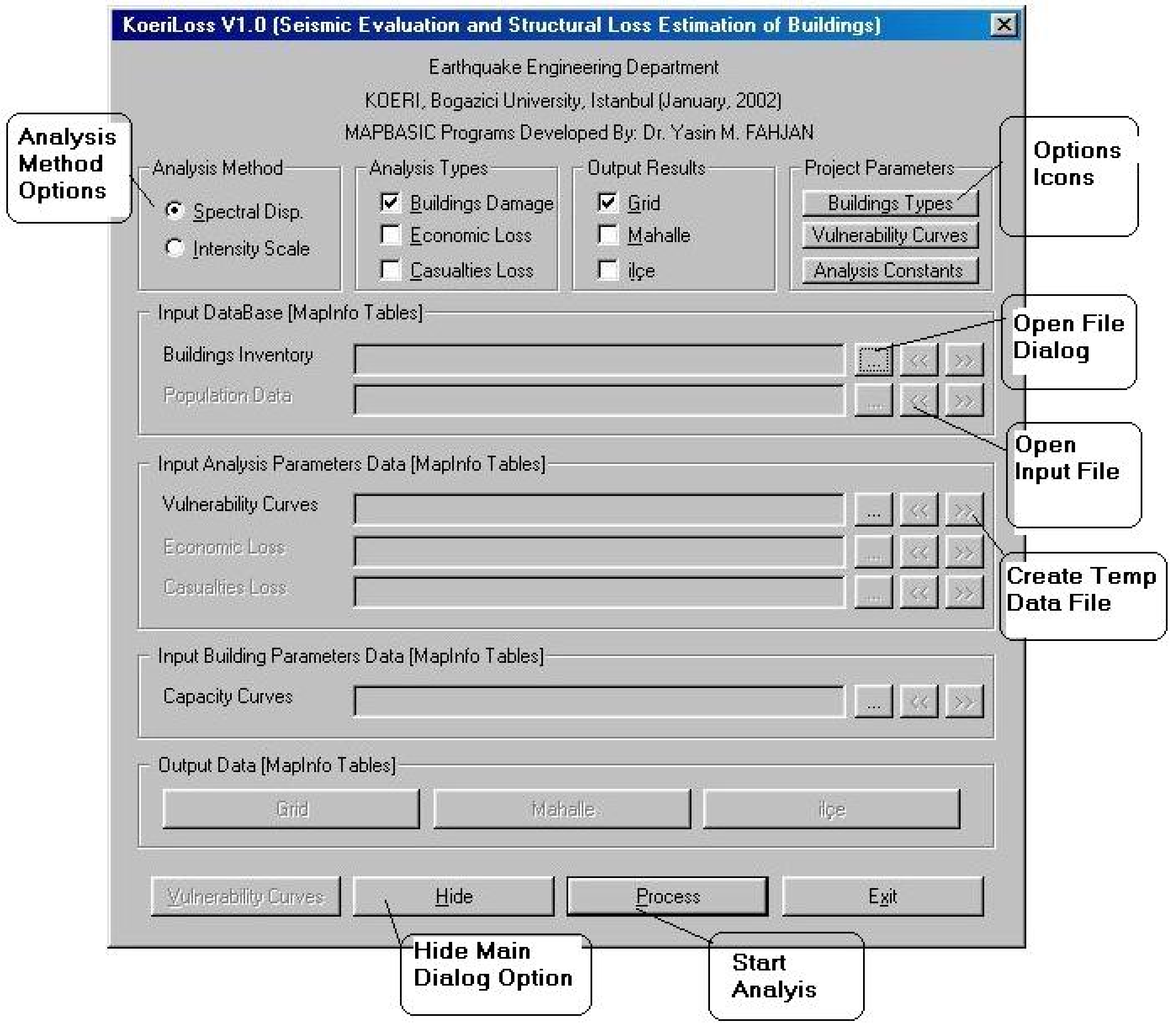


Casualty Distribution for Severity Level 4

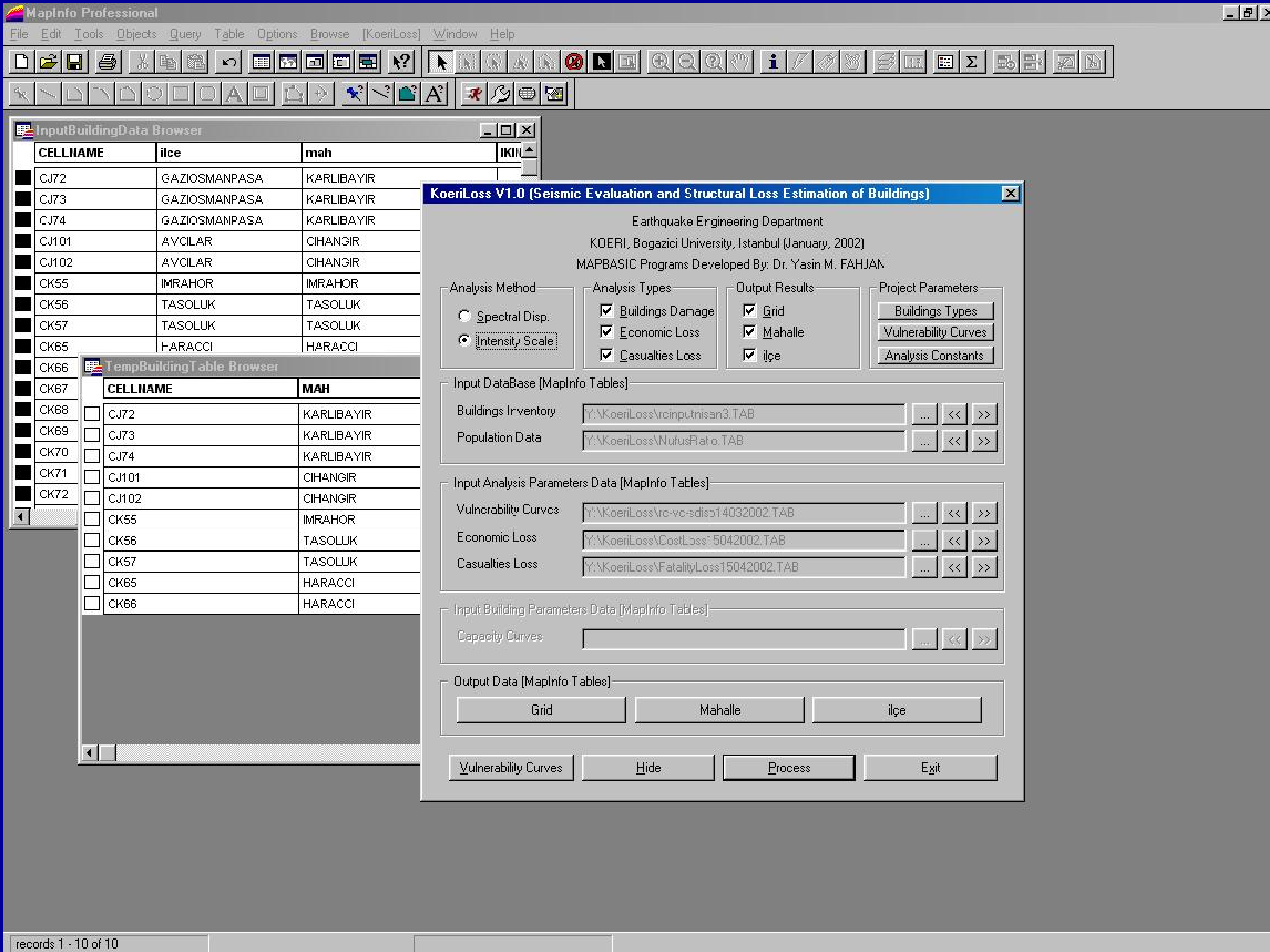


Shelter Need Distribution

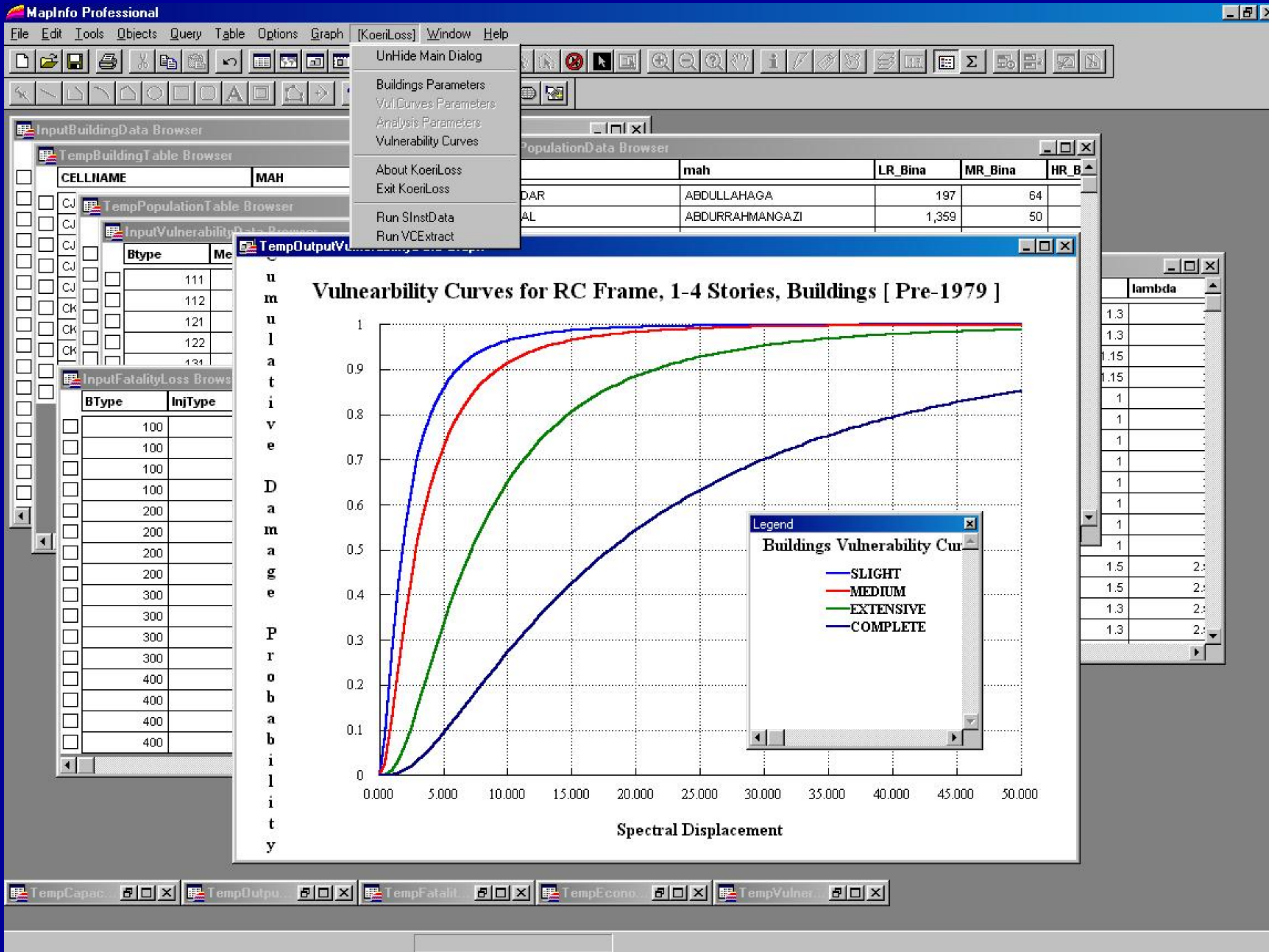




The main dialog of the KOERILoss



Integration of KOERILoss and MapInfo features



Integration of KOERILoss and MapInfo Graphics

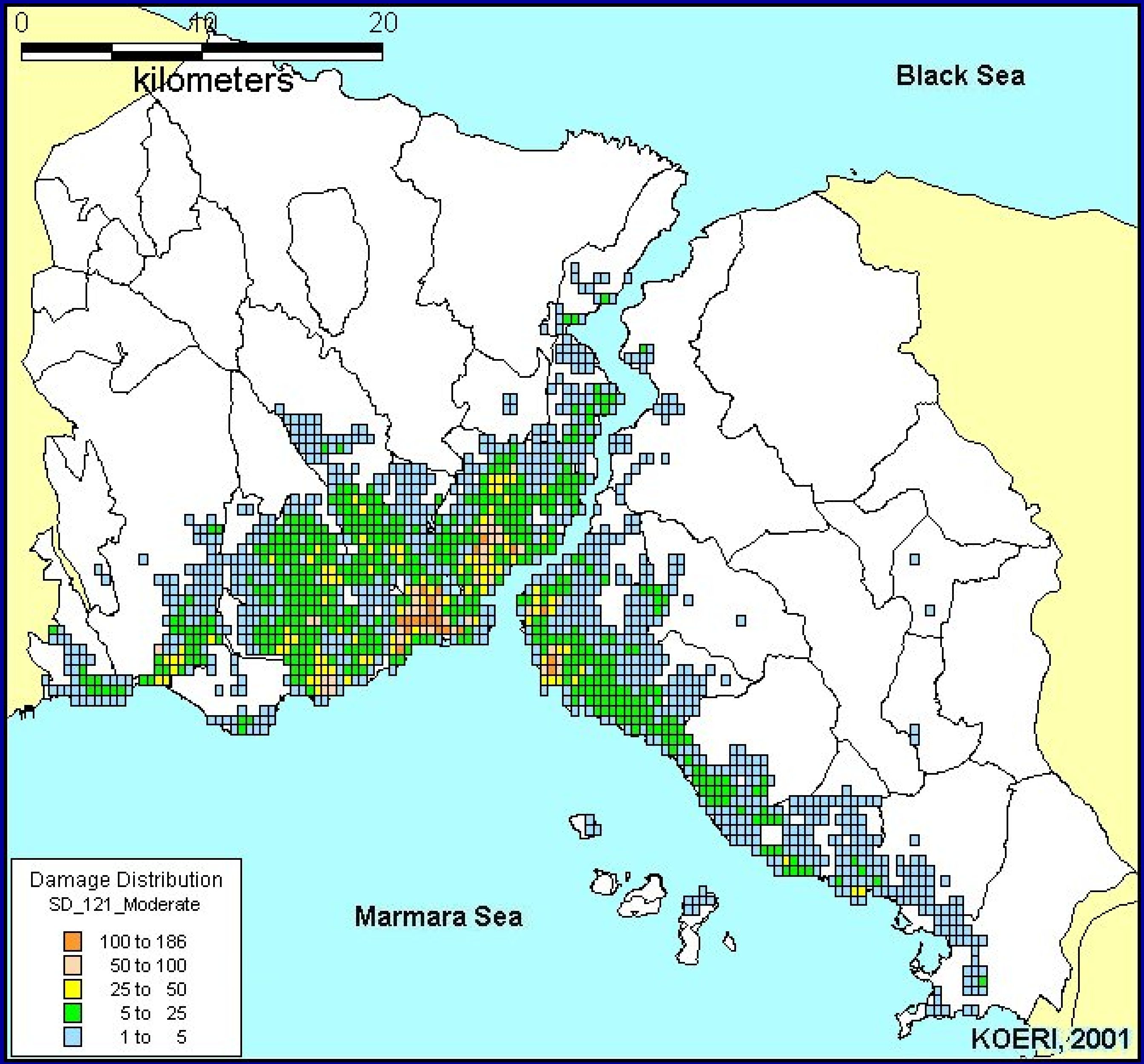
Output of the Analysis

- ✓ Buildings Damage Loss
- ✓ Direct Economic Loss
- ✓ Number of Casualties

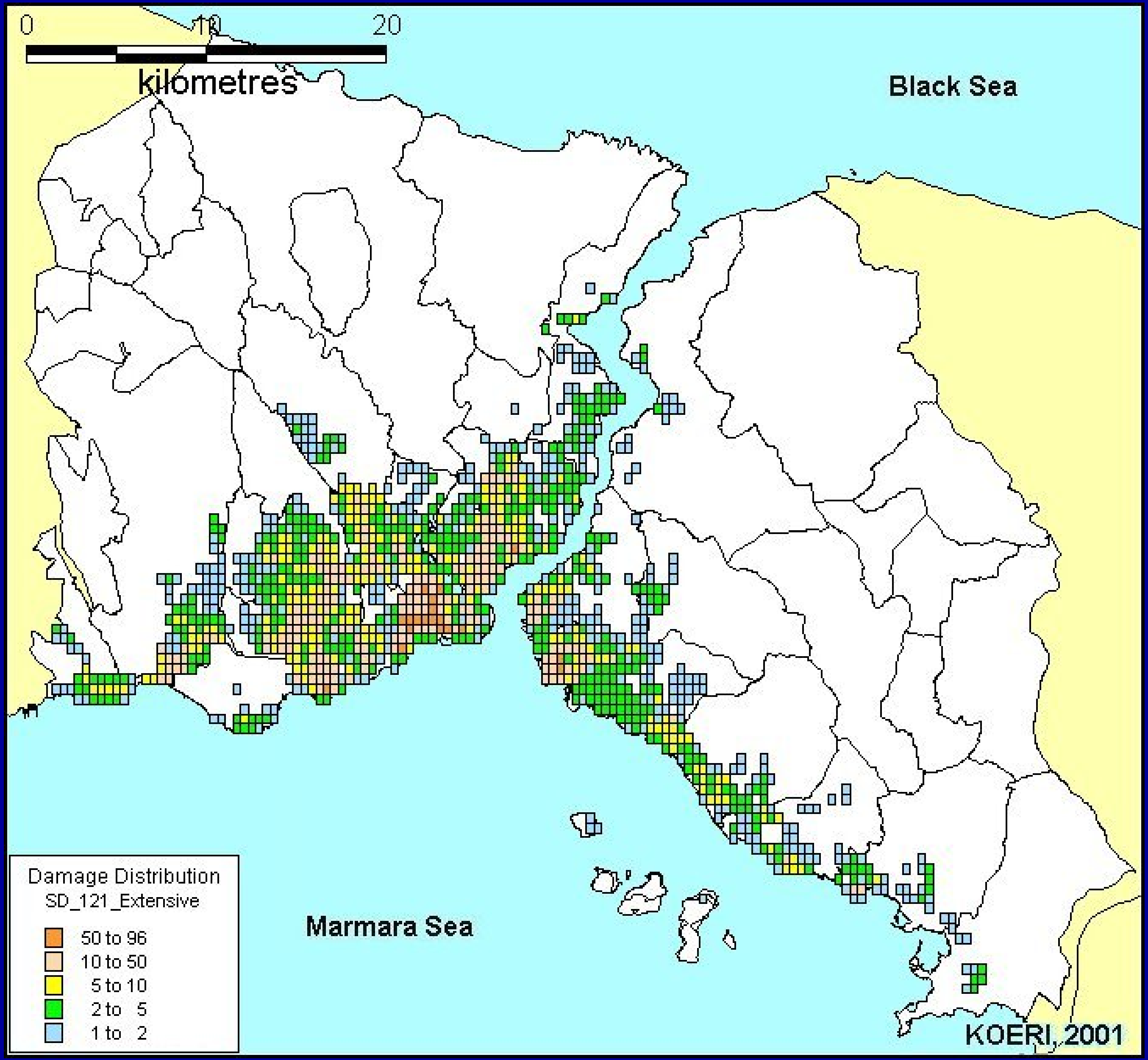
In terms of

- ❑ Geo-cells (Grids)
- ❑ Subdistricts (Mahalle)
- ❑ Districts (İlçe)

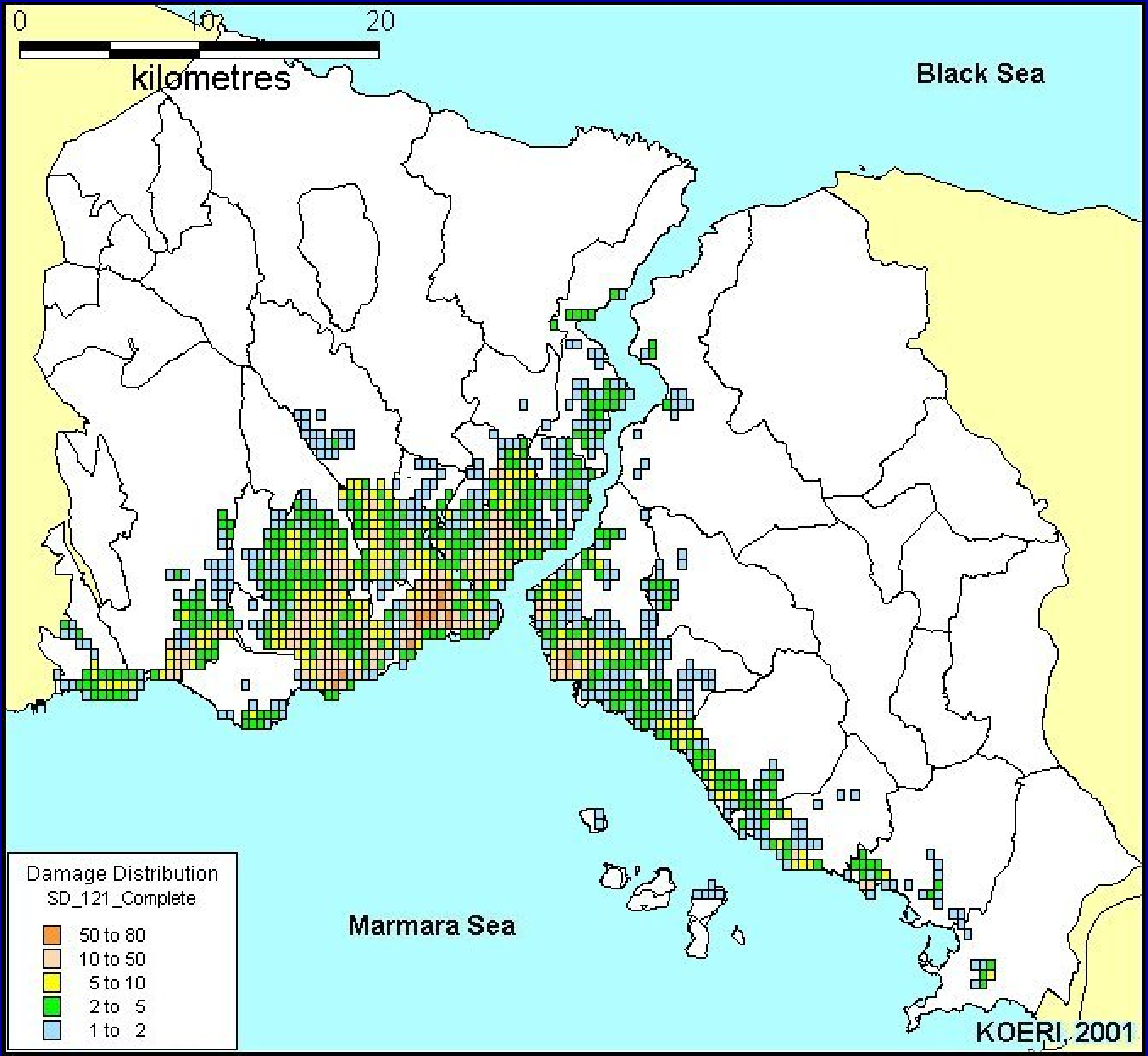
Moderate Damage Distribution of Mid-Rise Pre-1980 R/C Buildings



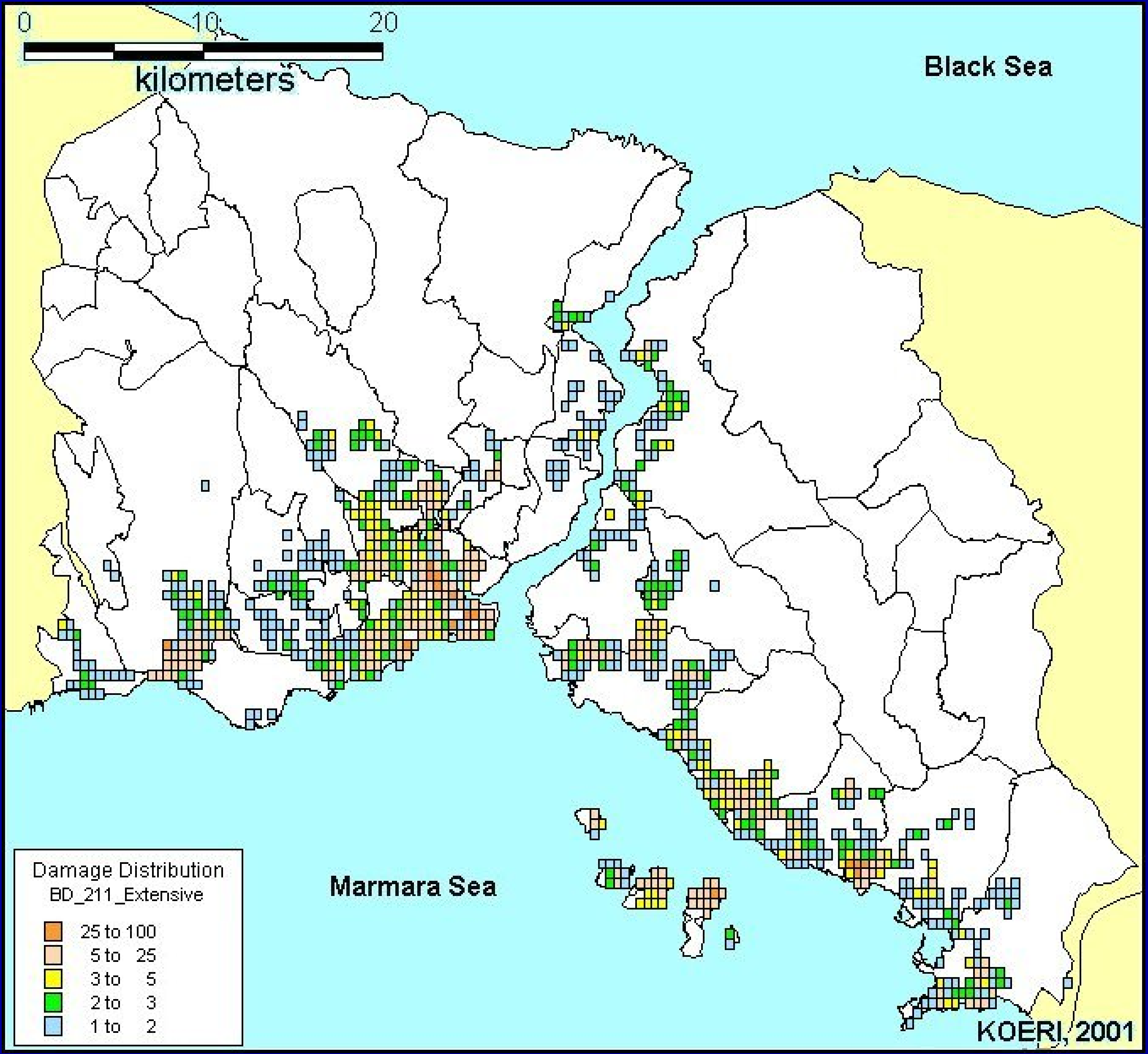
Extensive Damage Distribution of Mid-Rise Pre-1980 R/C Buildings



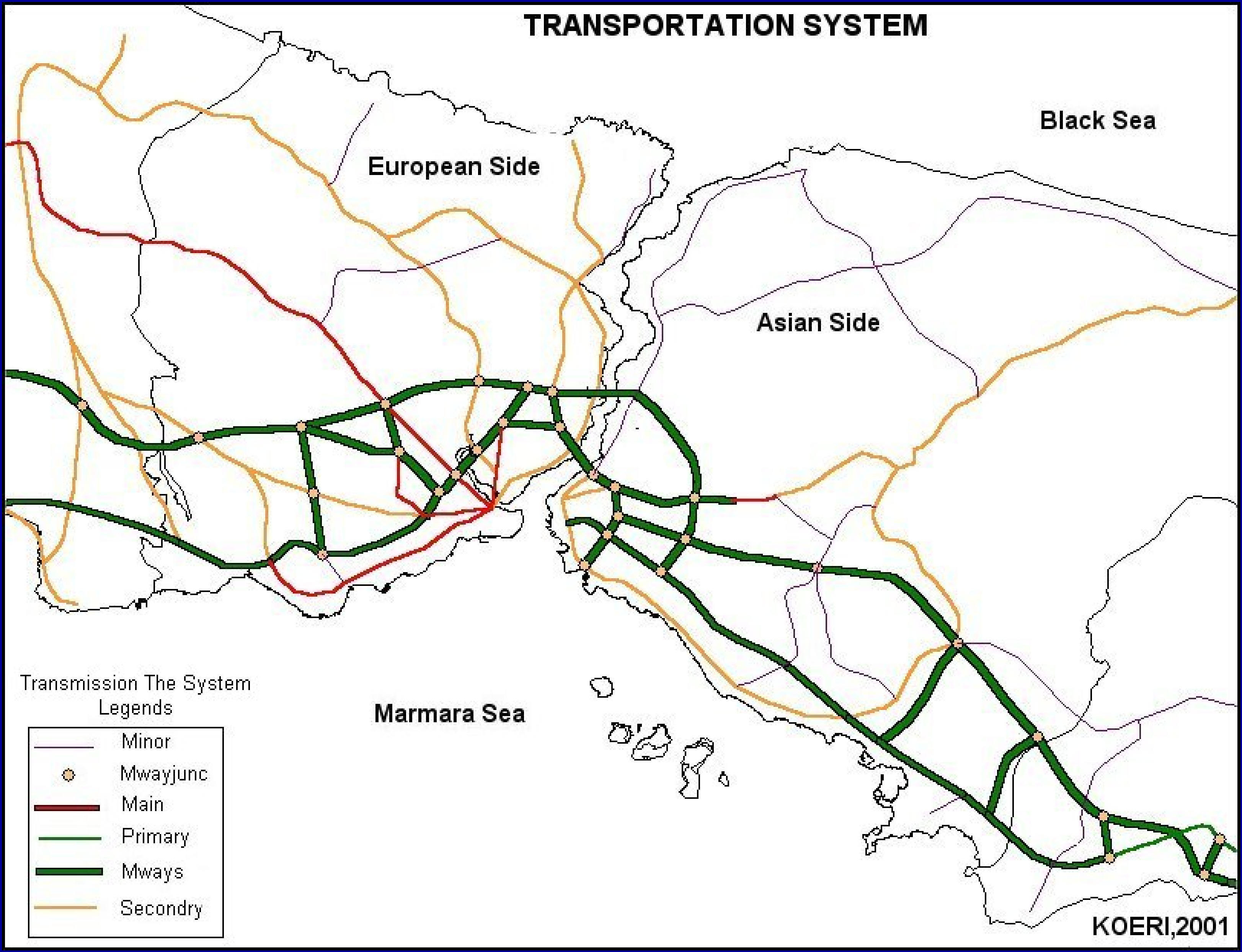
Complete Damage Distribution of Mid-Rise Pre-1980 R/C Buildings

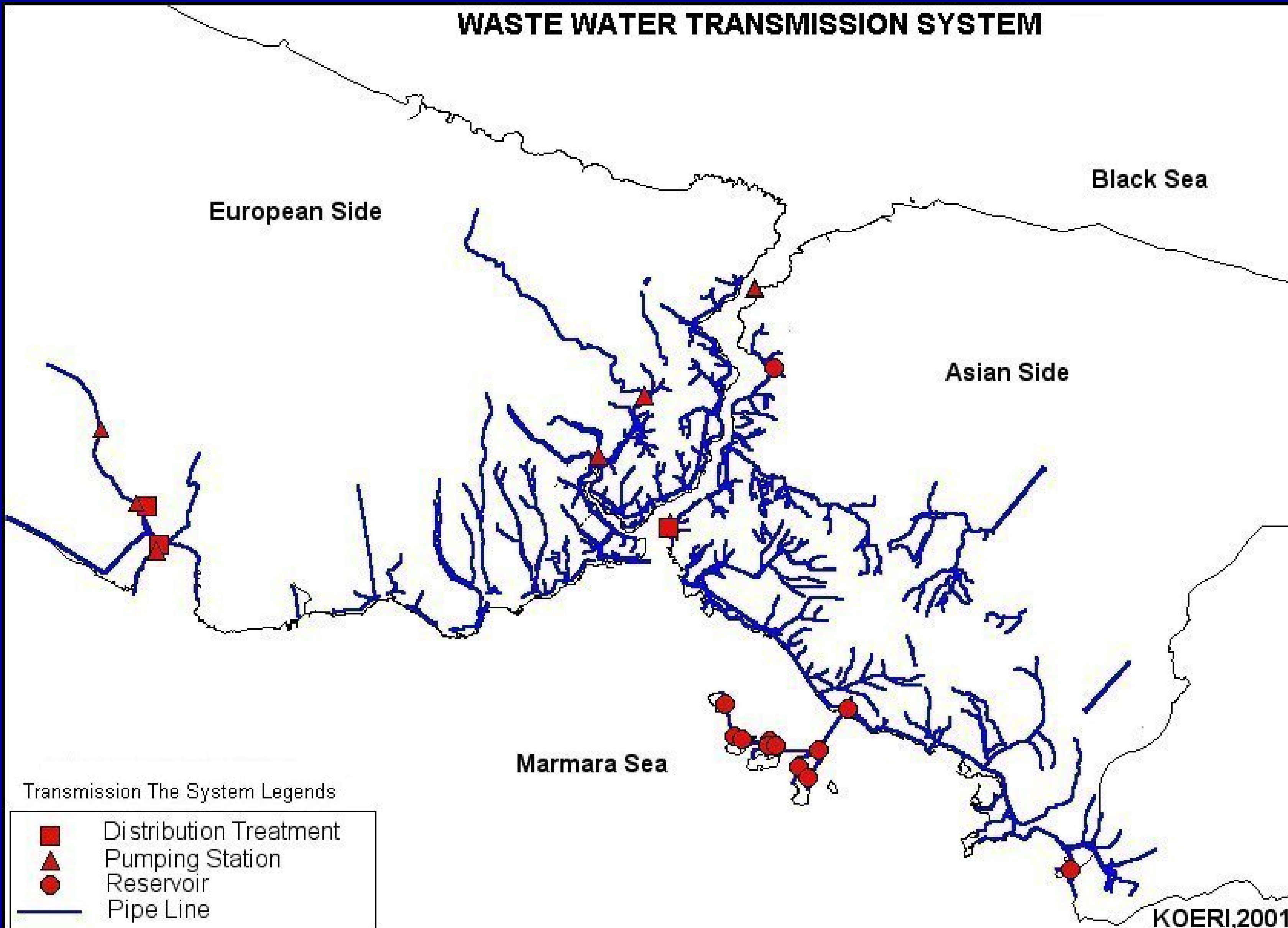


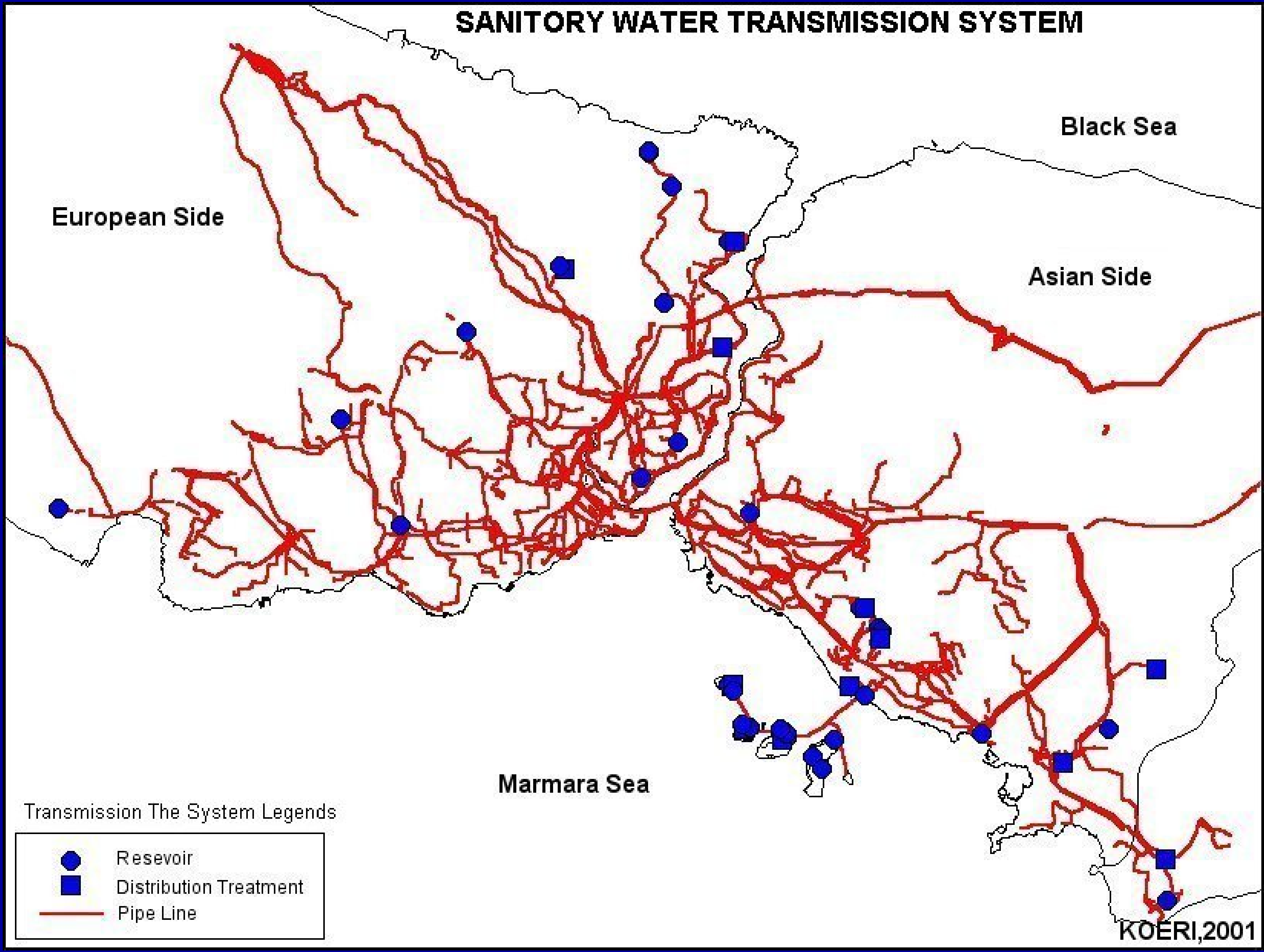
Extensive Damage Distribution of Low-Rise Pre-1980 Masonry Buildings

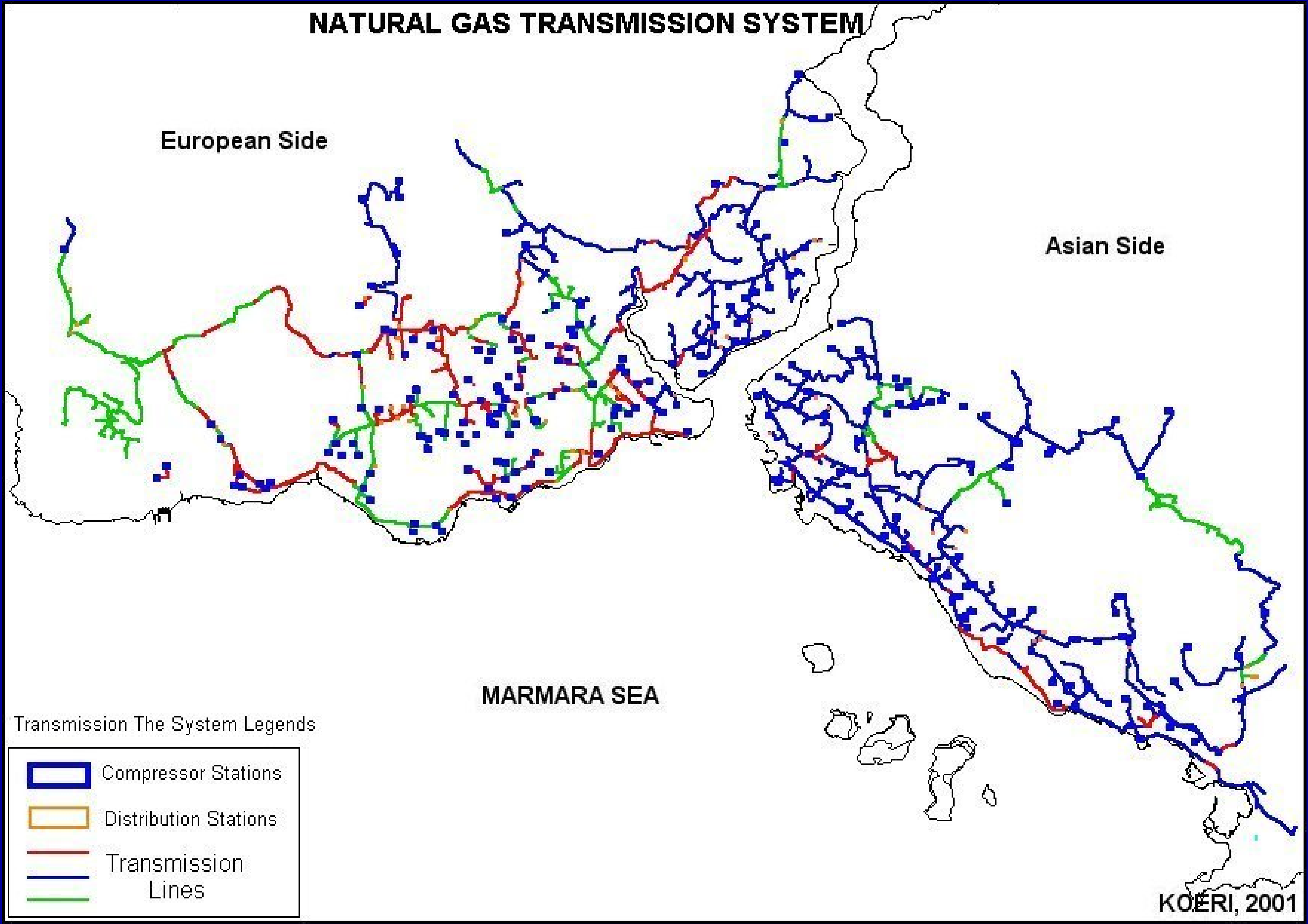


Lifeline Systems


TRANSPORTATION SYSTEM
Black Sea
European Side
Asian Side
Marmara Sea
Transmission The System
Legends
Minor
Mwayjunc
Main
Primary
Mways
Secondry
KOERI,2001


WASTE WATER TRANSMISSION SYSTEM
Black Sea
European Side
Asian Side
Marmara Sea
Transmission The System Legends
Distribution Treatment
Pumping Station
Reservoir
Pipe Line
KOERI,2001


SANITORY WATER TRANSMISSION SYSTEM
Black Sea
European Side
Asian Side
Marmara Sea
Transmission The System Legends
Resevoir
Distribution Treatment
Pipe Line
KOERI,2001



NATURAL GAS TRANSMISSION SYSTEM
European Side
Asian Side
MARMARA SEA
Transmission The System Legends
Compressor Stations
Distribution Stations
Transmission Lines
KOERI, 2001

Intensity Based Life Line Damage Assessment

Transportation system: Earthquake Vulnerability and Damage

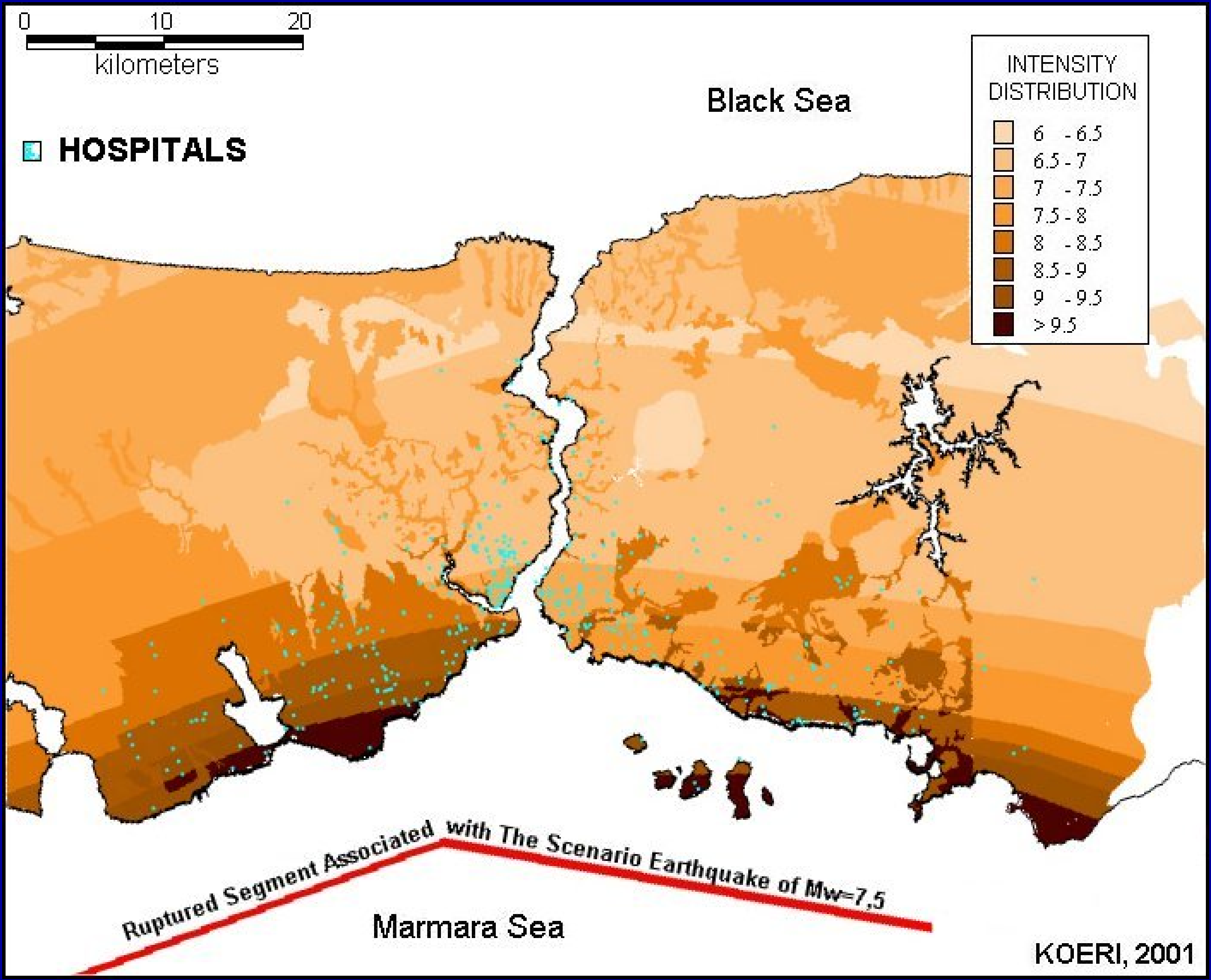
Road damages consist of the surface damages and collapse of the neighboring slopes or retaining walls.

Also collapsed underpasses or buildings can block the traffic even if the motorway is not damaged. According to ATC 25, the ratio of damage of local roads during an earthquake are given as %2 for MMI V, %4 for MMI VI, %11 for MMI VII, and %32 for MMI VIII

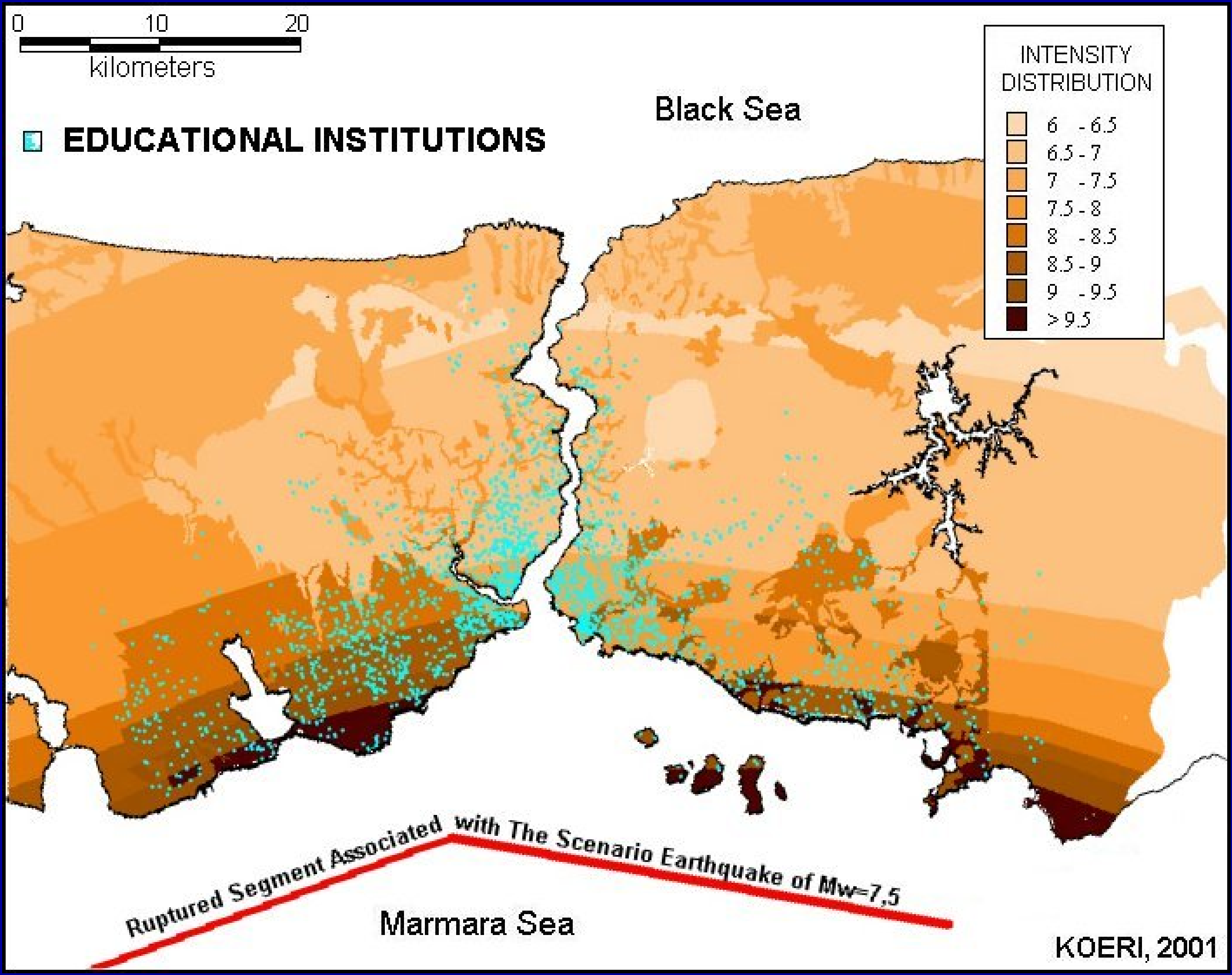
Water and Wastewater Transmission Systems

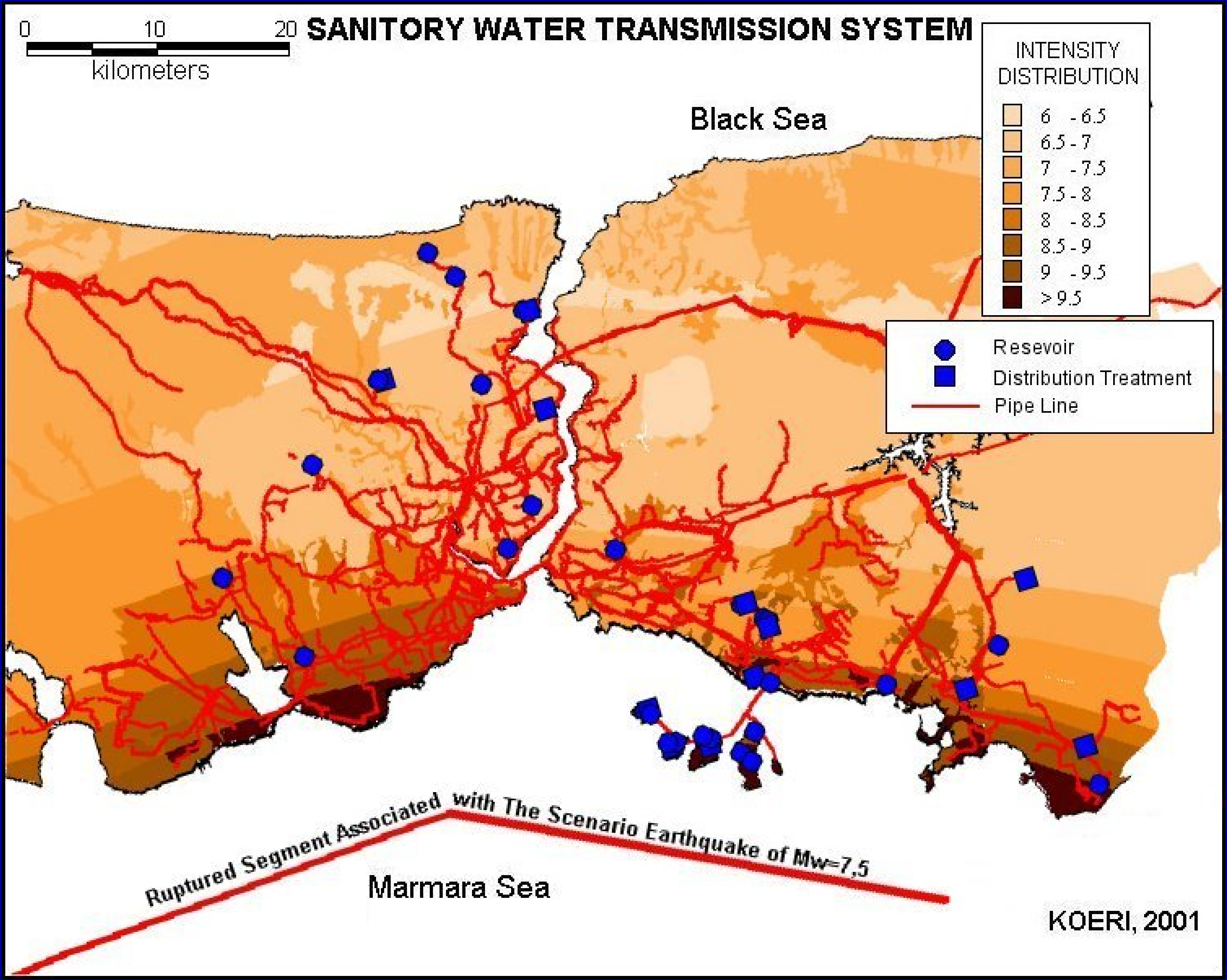
According to ATC 25, the ratio of damage of water transmission lines during an earthquake are given as %0 for MMI V, 1% for MMI VI, 4% for MMI VII, and 12% for MMI VIII.

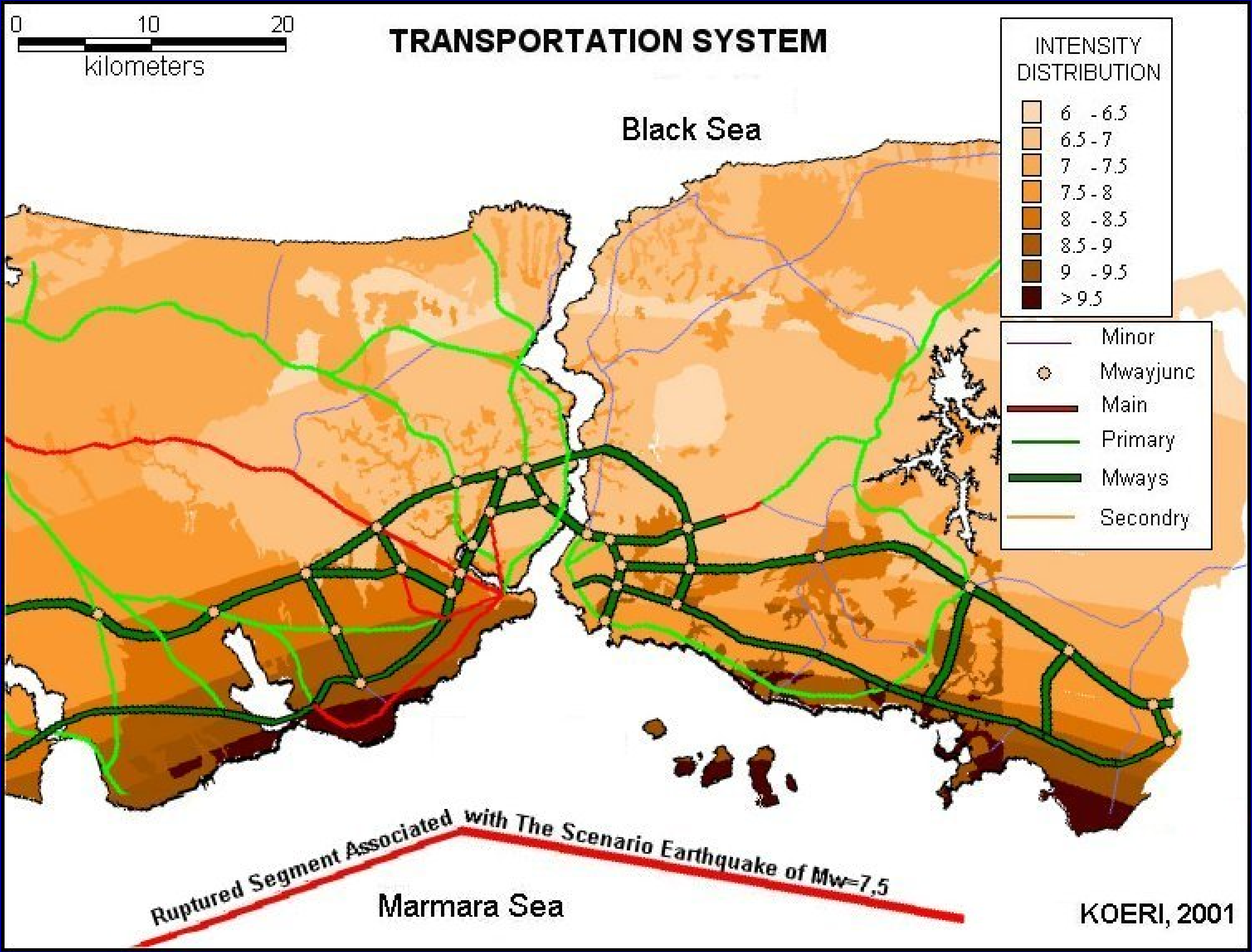
According to ATC 25, the ratio of damage of wastewater transmission lines during an earthquake are given as 0% for MMI V, 2% for MMI VI, 40% for MMI VII, and 100% for MMI VIII



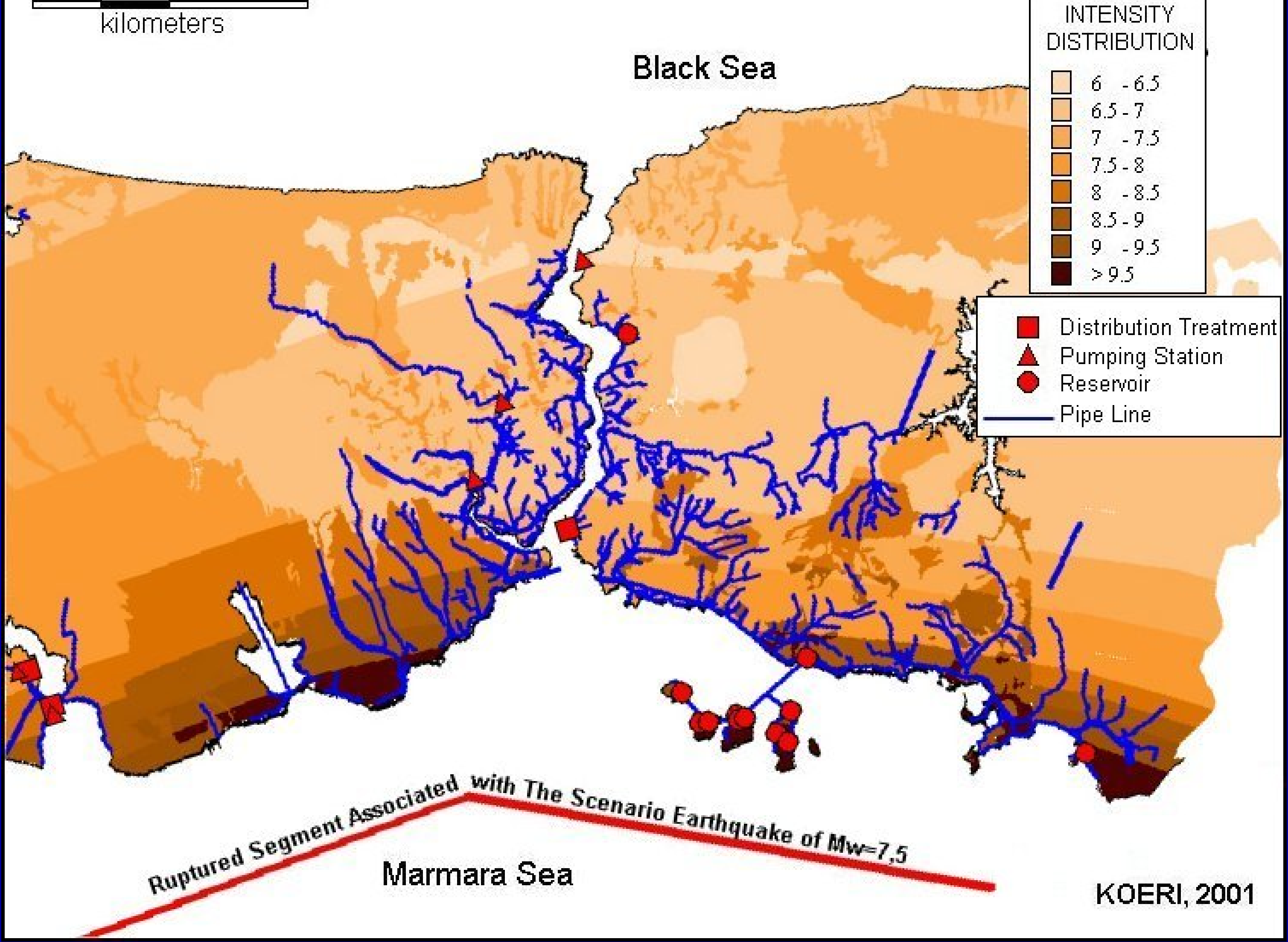
0 10 20
kilometers
HOSPITALS
Black Sea
INTENSITY DISTRIBUTION
6 - 6.5
6.5 - 7
7 - 7.5
7.5 - 8
8 - 8.5
8.5 - 9
9 - 9.5
> 9.5
Ruptured Segment Associated with The Scenario Earthquake of Mw=7.5
Marmara Sea
KOERI, 2001

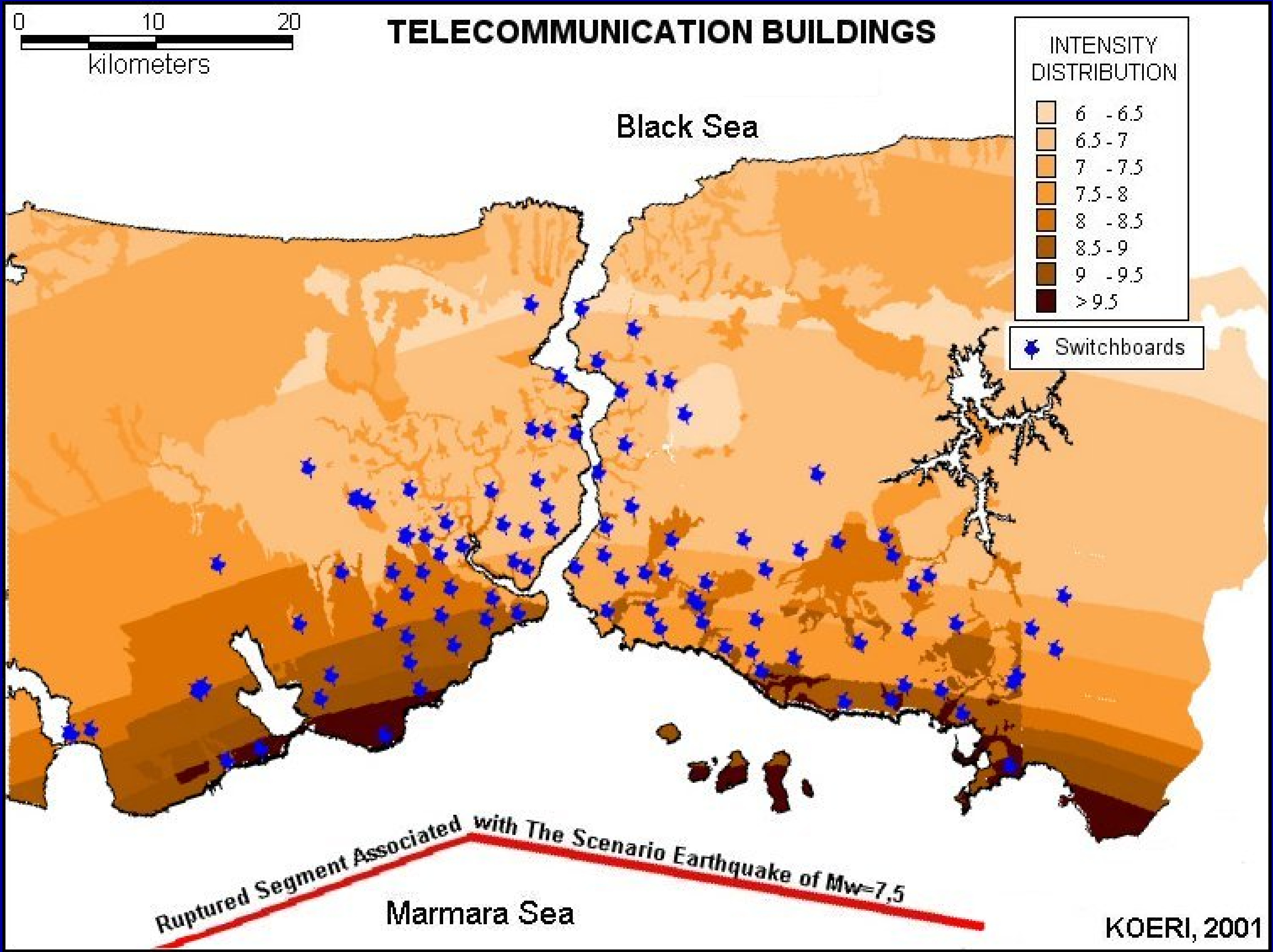

0
10
20
kilometers
EDUCATIONAL INSTITUTIONS
Black Sea
INTENSITY DISTRIBUTION
6 - 6.5
6.5 - 7
7 - 7.5
7.5 - 8
8 - 8.5
8.5 - 9
9 - 9.5
> 9.5
Ruptured Segment Associated with The Scenario Earthquake of Mw=7,5
Marmara Sea
KOERI, 2001

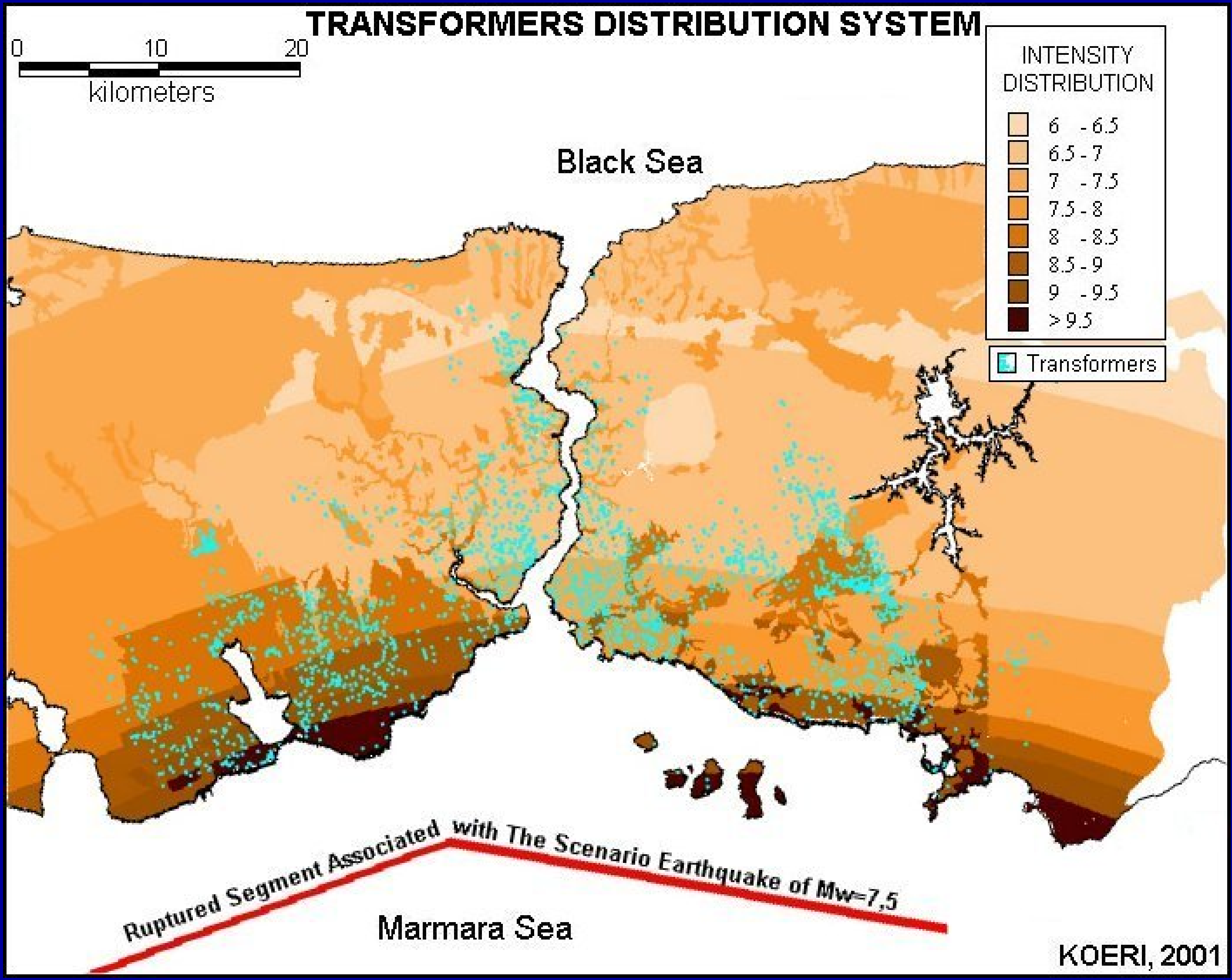

SANITORY WATER TRANSMISSION SYSTEM
0
10
20
kilometers
INTENSITY DISTRIBUTION
6 - 6.5
6.5 - 7
7 - 7.5
7.5 - 8
8 - 8.5
8.5 - 9
9 - 9.5
> 9.5
Resevoir
Distribution Treatment
Pipe Line
Black Sea
Marmara Sea
Ruptured Segment Associated with The Scenario Earthquake of Mw=7.5
KOERI, 2001

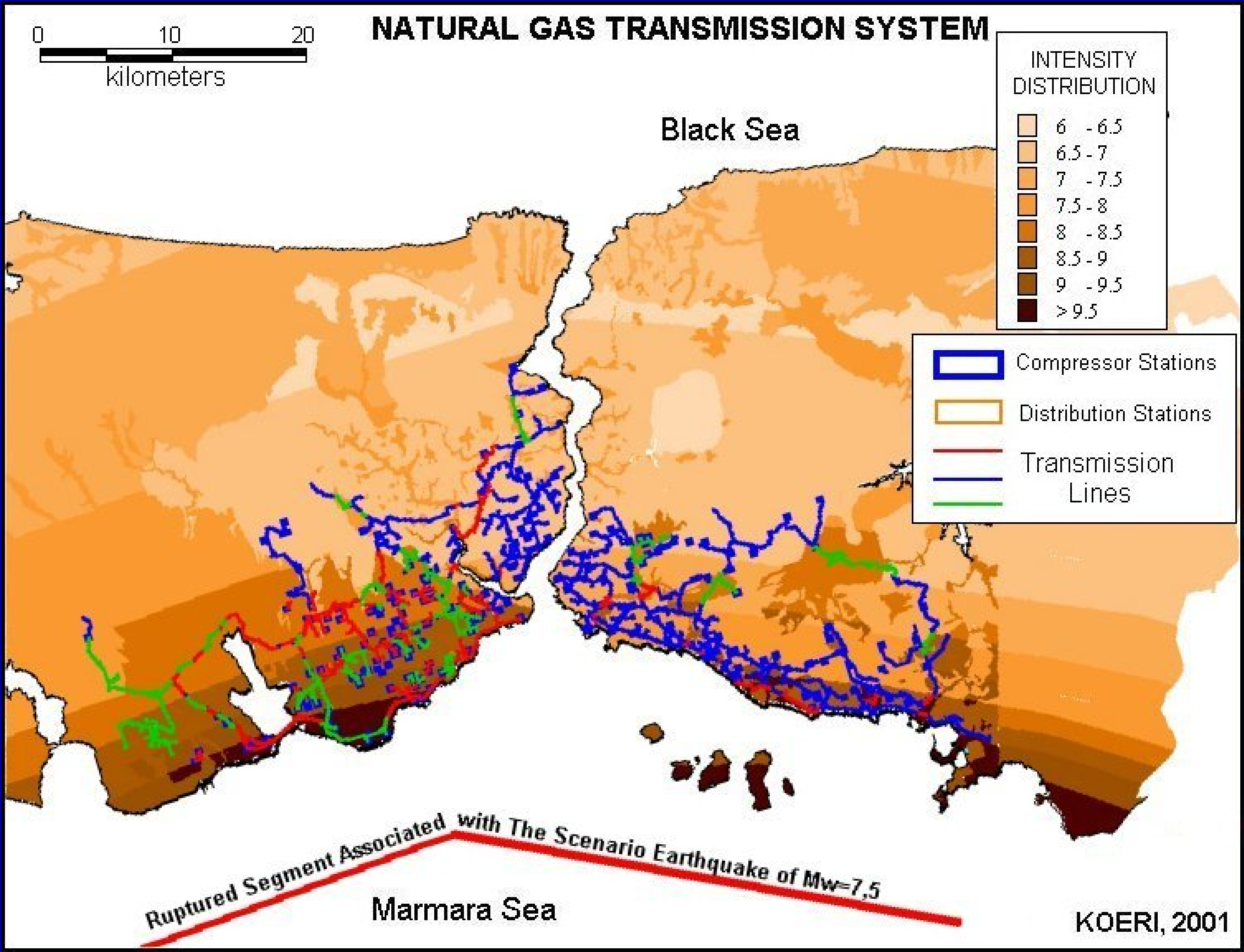

0 10 20
kilometers
TRANSPORTATION SYSTEM
INTENSITY DISTRIBUTION
6 - 6.5
6.5 - 7
7 - 7.5
7.5 - 8
8 - 8.5
8.5 - 9
9 - 9.5
> 9.5
Minor
Mwayjunc
Main
Primary
Mways
Secondry
Black Sea
Ruptured Segment Associated with The Scenario Earthquake of Mw=7.5
Marmara Sea
KOERI, 2001

WASTE WATER TRANSMISSION SYSTEM




0
10
20
kilometers
TELECOMMUNICATION BUILDINGS
INTENSITY DISTRIBUTION
6 - 6.5
6.5 - 7
7 - 7.5
7.5 - 8
8 - 8.5
8.5 - 9
9 - 9.5
> 9.5
Switchboards
Black Sea
Ruptured Segment Associated with The Scenario Earthquake of Mw=7,5
Marmara Sea
KOERI, 2001


TRANSFORMERS DISTRIBUTION SYSTEM
0
10
20
kilometers
INTENSITY DISTRIBUTION
6 - 6.5
6.5 - 7
7 - 7.5
7.5 - 8
8 - 8.5
8.5 - 9
9 - 9.5
> 9.5
Transformers
Black Sea
Ruptured Segment Associated with The Scenario Earthquake of Mw=7,5
Marmara Sea
KOERI, 2001



NATURAL GAS TRANSMISSION SYSTEM
0
10
20
kilometers
Black Sea
INTENSITY DISTRIBUTION
6 - 6.5
6.5 - 7
7 - 7.5
7.5 - 8
8 - 8.5
8.5 - 9
9 - 9.5
> 9.5
Compressor Stations
Distribution Stations
Transmission Lines
Ruptured Segment Associated with The Scenario Earthquake of Mw=7.5
Marmara Sea
KOERI, 2001