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Earthquake Scenario Pilot Project: Assessment of Damage and Losses

Prepared by Metro and the Oregon Department of Geology and Mineral Industries

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EXECUTIVE SUMMARY

The pilot earthquake scenario was undertaken by the Metro and Oregon Department of Geology and Mineral Industries (DOGAMI) to develop and provide an information system to support earthquake preparedness planning in the Portland metropolitan region.

The project is a first step toward developing an accurate, uniform data set that will provide emergency management and service planners, land use planners, structural engineers, architects, businesses, policy makers and citizens in the region with a common framework for earthquake hazard mitigation.

The process of developing the pilot damage and loss database and model involved the collection of land improvements data and relating same to geologic hazards. The pilot assess building damage and casualties in the 60-block study area (see Figure 1) as a result of a hypothetical moderate earthquake. The damage and casualty values result from GIS analysis of data layers describing the geologic variations of earthquake hazard, the characteristics of buildings and infrastructures, and statistical relations between earthquake intensity and damage for variety of building types. Some of the products of the model include:

1. Estimates of total dollars worth of damage sustained by buildings within the study area based on the scenario magnitude 6.5 earthquake.

2. Estimates of percentage of building value available for use within the study area immediately following the scenario earthquake.

3. Estimates of the number of people sustaining injuries within study area based on the scenario earthquake.

4. Estimates of the number of deaths within the study area based on the scenario earthquake.

The techniques used for damage and loss assessment do not allow the information to be generated for individual buildings but rather give overall numbers for classes of building construction. For this pilot study formal assessments of damage and losses to utilities and lifelines in the study area were not done, but will be part of future refinements of the technique. Summaries of critical facilities and lifeline systems found in the study area are in Appendix C.
Some of the important findings of this study are:

1. For the scenario earthquake, the damage will equal approximately 12 percent of the overall building value.

2. While there will likely be both injuries and deaths, the vast majority of the occupants will be unhurt.

3. Only approximately 54 percent of the total building value will be available for use immediately following the scenario earthquake. This means that 46 percent of the housing and business space, in the short-term, will be removed from the economy or have to be replaced with temporary facilities.

I. PURPOSE

The primary focus of this pilot project is to: 1) identify an objective methodology and information requirements for assessment of damage and losses that would result from earthquakes; 2) develop damage and loss information important to planning effective emergency response needs; and 3) identify policy issues and directions for earthquake mitigation, preparedness, response and recovery.[1] The pilot also provided an opportunity for understanding the interdisciplinary elements necessary for conducting a vulnerability analysis using an earthquake scenario.

This study provides:

- an indication of the dollar amount of damage associated with a moderate earthquake;
- an approach for identifying potential liability issues;
- an indication of areas requiring greater emergency response priority following a moderate earthquake;
- an indication of the variations in expected loss by structural types of buildings and critical facilities;
- a data collection system that may assist development of regional earthquake hazards mitigation program;
- analytical tools that may be useful in identifying policy issues relating to earthquake planning that are regional in scope; and
- an indication of the nature and of recovery and reconstruction processes that may be needed after a moderate earthquake.

II. METHODOLOGY

There are many factors to consider in evaluating the vulnerability of a given structure or facility to an earthquake. For example, data on buildings and critical facilities (private or public) must be accurate and depict quality of design, construction and ductility. The hypothetical earthquake source must be related to local geology in such a way that the impact of ground motions resulting from the earthquake at any point in space away from the earthquake source is determined. The buildings and critical facilities data must be site specific in order to make the link to site specific geology. With all this in mind, there is a need for a study design that is simple and applicable

[1]Emergency management includes mitigation, preparedness, response and recovery.

region wide and user friendly. The conceptual framework below was developed to guide the pilot study. The modeling includes:

- design and structure of the model;
- justification or rationale for the type of earthquake chosen; and
- relating geology and seismic hazards of pilot area to:
  - ground shaking or acceleration; and
  - buildings and infrastructure.

CONCEPTUAL FRAMEWORK OF THE STUDY

Select Study Area

|
v

Collection of Data (Buildings and Critical Facilities)

|
v

Database Design and Integration of Databases

|
v

Choose Earthquake Damage and Loss Model

|
v

Run and Test the Earthquake Damage and Loss Model on a Scenario Earthquake

|
v

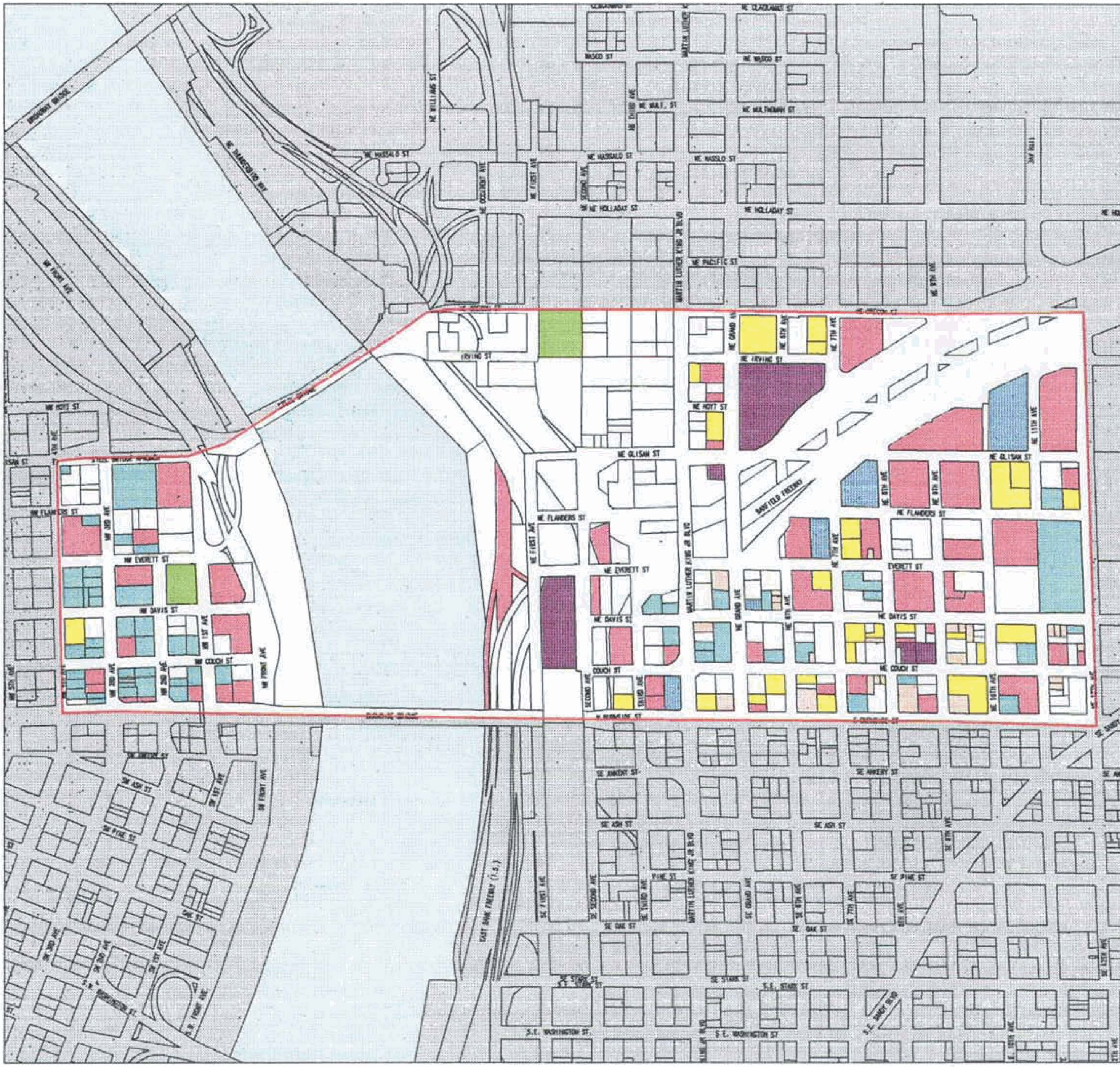
Assess the Extent of Earthquake Damage and Loss

III. STUDY AREA

A. General

The study area shown in Figure 1 is within the City of Portland and includes about 60 city blocks. The northern boundary is NW Glisan Street and NE Oregon Street, the west boundary is NW 4th Avenue, the east boundary is NE 12th Avenue and the south boundary is W and E Burnside.

The area is bisected by the Willamette River. In this report, the east and west sides of the Willamette River will be referred to as the east and west sides of the study area respectively. The study area includes 441 parcels of land with 185 buildings, railroad tracks and lifelines such as electrical power and communication lines, gas and water pipe systems, sanitary and storm sewers, and roadways and overpasses. The study area includes landmarks such as the Oregon Convention Center, Metro's new headquarters, the State Office Building, the I-5 and I-84 freeways, and the Steel and Burnside Bridges.



R L I S

Study Area Building Types

Earthquake Preparedness
Metro/DOGAMI Pilot Project

- C1 C3/M-INF C3/S5 RM RM*
- C2 C2*
- PC1 PC1-TU PC2 PC2*
- S1 S1* S2
- S3
- URM URM*
- W

Scale approximately 1 inch = 700 feet

Metropolitan Service District
2000 SW First Avenue
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92028 Plot date: January, 1993

FIGURE 2

Structure Types of Buildings in the Study Area

C1	Concrete moment resisting frames
C2	Concrete shear wall buildings
C3/S5	Concrete or steel frame buildings with unreinforced masonry infill walls
PC1(TU)	Tilt-up buildings
PC2	Precast concrete frames
RM	Reinforced masonry
S1	Steel moment resisting frames
S2	Braced steel frames
S3	Light metal frames
URM	Unreinforced masonry
W	Wood frame buildings

The population of the study area is estimated to be 37,000 during typical working hours (week day, daytime) and 17,000 at nighttime. These estimates were derived from the U.S. Census of Population conducted in 1990, total employment workplace estimated by Metro, patronage per square foot by type of establishment in the study area estimated by Metro, and maximum existing capacity of the Oregon Convention Center. Although these figures represent the best estimates of day and night population, there were substituted with occupancy ranges for each building in modeling the process.

B. Summary of Local Geology and Earthquake Hazards Assessment

The geologic model of the Portland Quadrangle Pilot project area is composed of five different types of material, layered in various thicknesses at different areas of the quadrangle.

The entire pilot area is underlain by Columbia River Basalt, which constitutes "bedrock," at a depth of 500 to 650 feet. This basalt is in turn overlain by claystone and siltstone of the Sandy River Mudstone which is about 230 feet thick on the west edge of the pilot study and thins to about 165 feet thick on the eastside. The Sandy River Mudstone is overlain by Troutdale Conglomerate which is about 165 feet thick on the westside of the study area and thickens to about 360 feet thick on the eastside.

These three layers of material are overlain by gravel, sand and silt deposits from great ice-age floods. The gravel deposits are only present at the extreme edges of the pilot study area, about 15 feet thick at the western edge and 40 feet thick on the eastern edge. The flood sand and silt overlies the flood gravel and the Troutdale Conglomerate on the eastern side of the area where it is about 25 to 50 feet thick.

The ancient Willamette River carved a deep canyon through the flood deposits. The modern river, following the same course, has filled the canyon with loose sand, silt and clay alluvium. The banks of the Willamette on the eastside of the pilot study area are largely composed of Troutdale Conglomerate or flood gravels. The only exception on the eastside is where mostly Sullivan Gulch comes into the river canyon from the east, directly under the I-5 and I-84 interchange. This part of the east bank is also filled with alluvium up to depths of 155 feet.

The west bank of the river is covered with the sand and silt alluvium in thicknesses starting between 25 and 50 feet and growing up to 100 feet in the few blocks just before the river.

There are some areas along the river front that contain artificial fill, however, it is too variable in its characteristics to be treated separately. It is assumed that the hazard in the fill areas will be dominated by the characteristics of the underlying alluvium.

A parallel study has been completed for the Portland, Oregon Quadrangle Map which incorporates detailed information about the geology into a Geographic Information System (GIS) database. This geologic data was also analyzed with respect to how the geologic materials would respond to earthquake shaking. This detailed analysis of the geologic response to earthquake shaking is a unique refinement to damage and loss assessment techniques.

IV. BUILDINGS AND CRITICAL FACILITIES DATA NEEDS AND COLLECTION

As described in the previous section, the characteristics of the buildings, critical facilities and lifeline systems need to be known to evaluate how they will be affected by a scenario earthquake. There are four types of data needed. They are: 1) inventory of buildings, critical facilities and lifeline systems; 2) descriptions of key attributes of each item in the inventory; 3) a valuation of the items in the inventory (either assessed value, market value or replacement cost); and 4) statistics on the number of people affected by each item in the inventory. Candidates for buildings and critical facilities to be included in an inventory are: 1) buildings; 2) storage tanks (i.e., water, fuel or hazardous material); 3) pipelines (water, sewer or gas); 4) electric and telephone lines; 5) roadways, overpasses and bridges; and 6) special treatment of emergency response facilities (hospitals, fire and police stations).

Detailed information on the buildings for the pilot study area came from information already in Metro's GIS and from a rapid visual screening survey[2] done of the area by the Bureau of Buildings, City of Portland. Details of information on critical facilities and lifeline systems that were collected, but not included in the modeling process are in Appendix C. It should be noted that the population information used in the injury and death estimates was based on occupancy ranges for each building, not the more exact total day and night population data presented earlier. Certainly future refinement of the model will include damage and loss estimates for critical facilities and lifeline systems and better population numbers.

V. CHOOSING THE EARTHQUAKE SCENARIO AND MODEL

A. Earthquake Scenario

The pilot area is vulnerable to earthquakes from three types of faulting: shallow crustal earthquakes; intraplate earthquakes; and subduction zone earthquakes. Shallow crustal earthquakes may occur on local faults throughout the Portland metropolitan area that may be as large as magnitude 6.0 to 6.5. The largest historical events in the area were in 1877 (estimated at magnitude 5.7) and 1962 (magnitude 5.2). Intraplate earthquakes occur in rocks that used to make up the Pacific Ocean floor, but have since been pushed (or subducted) beneath North

[2] Details of the rapid visual screening technique is published in FEMA (1988), Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook; Earthquake Hazards Reduction Series 41.

America. Faulting in these rocks has produced devastating earthquakes in the Puget Sound region in 1949 (magnitude 7.1) and 1965 (magnitude 6.5). Small magnitude earthquakes of this type have been recorded in the Portland area. It is believed that magnitude 6 to 7 earthquakes of this type occur in the Portland area as well, but much less often than in the Puget Sound Region. Evidence now indicates that the process of subduction which is actively taking place along the Oregon and Washington coasts produces subduction zone interface earthquakes. These prehistoric earthquakes were of magnitude 8 to 9, or 'Great' earthquakes. There is reason to believe that these subduction zone interface earthquakes will be repeated in the future. The last subduction zone interface earthquake occurred 300 years ago.

Exactly when the next of any of these types of earthquakes will strike Portland cannot be predicted. For the purposes of this study, a moderate crustal earthquake on one of the faults in the area most likely to be active was chosen. A small section of the Portland Hills fault zone was chosen and the length of the section would indicate that if it were to rupture the magnitude of the resulting earthquake would be 6.5. The study area is four miles from the section of the fault zone chosen. The bedrock ground shaking used in the model was 0.33g.

B. Model Specification

The model for damage assessment combines a hypothetical fault rupture with data about the geologic conditions, buildings, lifelines and population of the area. The pilot study was limited to considering only the data on geologic conditions and buildings. Earthquake damage and loss estimation techniques are available in a variety of published sources. The general approach for buildings outlined in the St. Louis City and County study by the Federal Emergency Management Agency (FEMA) in 1990[3] was used in this study. This choice was based on simplicity and the parallels which can be drawn between the history of seismicity and construction in the two cities. Future development of the methodology will involve drawing on all available sources to develop the best possible approach for the Portland metropolitan area.

For the pilot study a uniform strength of bedrock ground shaking was applied to the entire area. This strength was based on the distance to the source earthquake and the size of the earthquake. In a complete development of the technique, a hypothetical earthquake will be defined to the GIS as a line on a map (or perhaps a rectangle for very large or gently dipping earthquakes ruptures). This information will be used by the GIS to automatically compute a magnitude for the earthquake. Then the bedrock acceleration or velocity at any point away from the fault can be

[3] Federal Emergency Management Agency, 1990, Estimated Future Earthquake Losses for St. Louis City and County, Missouri, Earthquake Hazards Reduction Series 53.

calculated based on the distance from the fault. Attenuation relationships have the general form:

Ground Motion = Constant x Magnitude -Constant x Distance from the fault + Constant

A GIS system can easily calculate the distance between points, in this case the fault and a given item of infrastructure (i.e., a building). There are also equations similar to the attenuation relationships that give the duration of ground shaking as a function of magnitude and distance. Duration may also be used as a factor in more refined damage and loss estimation techniques.

The bedrock ground shaking at the location of, for example, a building can then be multiplied by the value for soil amplification contained in the GIS database for that location. This will give the value of the ground surface acceleration at the location. The magnitude of the ground surface acceleration (or velocity) is one of the parameters which most controls the damage which the earthquake causes. This was done in the pilot area for each building site. The strength of ground shaking will be combined with the liquefaction hazard database in the GIS in future complete implementations of this methodology. This will allow the damage which liquefaction can cause, especially to lifelines, to be included in the estimates.

For each item of infrastructure in the study area the characteristics of the item and the strength of the earthquake effects (ground shaking or liquefaction) can be used as the two values to enter a damage or loss estimation matrix. Table 1 is an example of the matrices used in the pilot study. Matrices such as this can be borrowed from other studies, or developed by combing information from different studies, for all structures and lifelines. For this study, the matrices for buildings from the St. Louis study were used (all the matrices used can be found in Appendix A).

Table 1

Sample of Damage and Loss Matrix

Structure Type	Damage %	acceleration (g)			
	Structure Class	0.07g	0.15g	0.30g	0.55g
URM	URM < 6 story	3.1%	15.2%	25.8%	40.8%
URM	URM >= 6 story	5.8%	18.9%	32.3%	48.8%
C2, S4	SW < 6 story	1.0%	3.5%	7.1 %	11.4%
C2, S4	SW >= 6 story	2.1%	8.3%	12.7 %	21.3%
C1, C3, RM	RCF >= 14 story	3.2%	9.9%	15.2 %	26.4%
TU, PC2	PC	3.3%	10.4%	15.5%	53.4 %
S1, S2, S5	SF < 14 story	1.6%	5.6%	9.45%	16.4%
S1, S2, S5	SF >= 14 story	0.4%	3.0 %	5.3%	7.9%
S3	LM	2.1%	6.5%	9.4%	17.7 %
W	W	0.9%	4.1%	8.4 %	15.3 5
C1	RCF < 6 story	1.0%	3.5%	7.1%	11.4%
C1	RCF 6 to 13 story	2.1%	8.3%	12.7 5	21.35

The result is that each structure or lifeline will be evaluated, approximately, as to its performance during the a scenario earthquake. The factors that are included in this technique are: 1) the scenario earthquake chosen; 2) an evaluation of the site conditions; and 3) all the characteristics available to describe the structure or lifeline. This evaluation may take the form of dollars worth of damage or the structural soundness of the building. Both are reported for the buildings in the study area. The effects on the occupants of buildings can also be estimated. It should always be remembered that these are only statistical estimates, not detailed analyses. Although each building is evaluated individually, this evaluation only has meaning when applied to numerous buildings. The performance of individual buildings is not the product of this type of analysis, only the composite behavior of a group of buildings.

VI. INTEGRATION OF DATABASES AND TESTING OF THE TECHNIQUE

A. Integrating Earthquake Hazard and Building Data into the GIS

The modeling process involves combining data for structures and lifelines with geologic conditions and the earthquake magnitude and location. Land improvement databases were designed so that information on structures, lifelines and population at a particular location can be easily integrated with the geologically based earthquake hazards information. The result is an estimate of potential damage or loss that would occur in the scenario earthquake.

The GIS used address and tax lot numbers to reference building information to map coordinates. The earthquake hazards information is represented in the GIS as a database of map coordinates on a 30-meter (100 feet) grid with corresponding numeric values that represent the severity of the effects. For example, the ground shaking amplification database consists of the grid coordinates paired with a value of amplification. This amplification value indicates the factor by which bedrock ground shaking should be multiplied. The GIS then determines the earthquake effects at a building's location by finding the nearest grid point in the hazard database.

B. Results of the Study

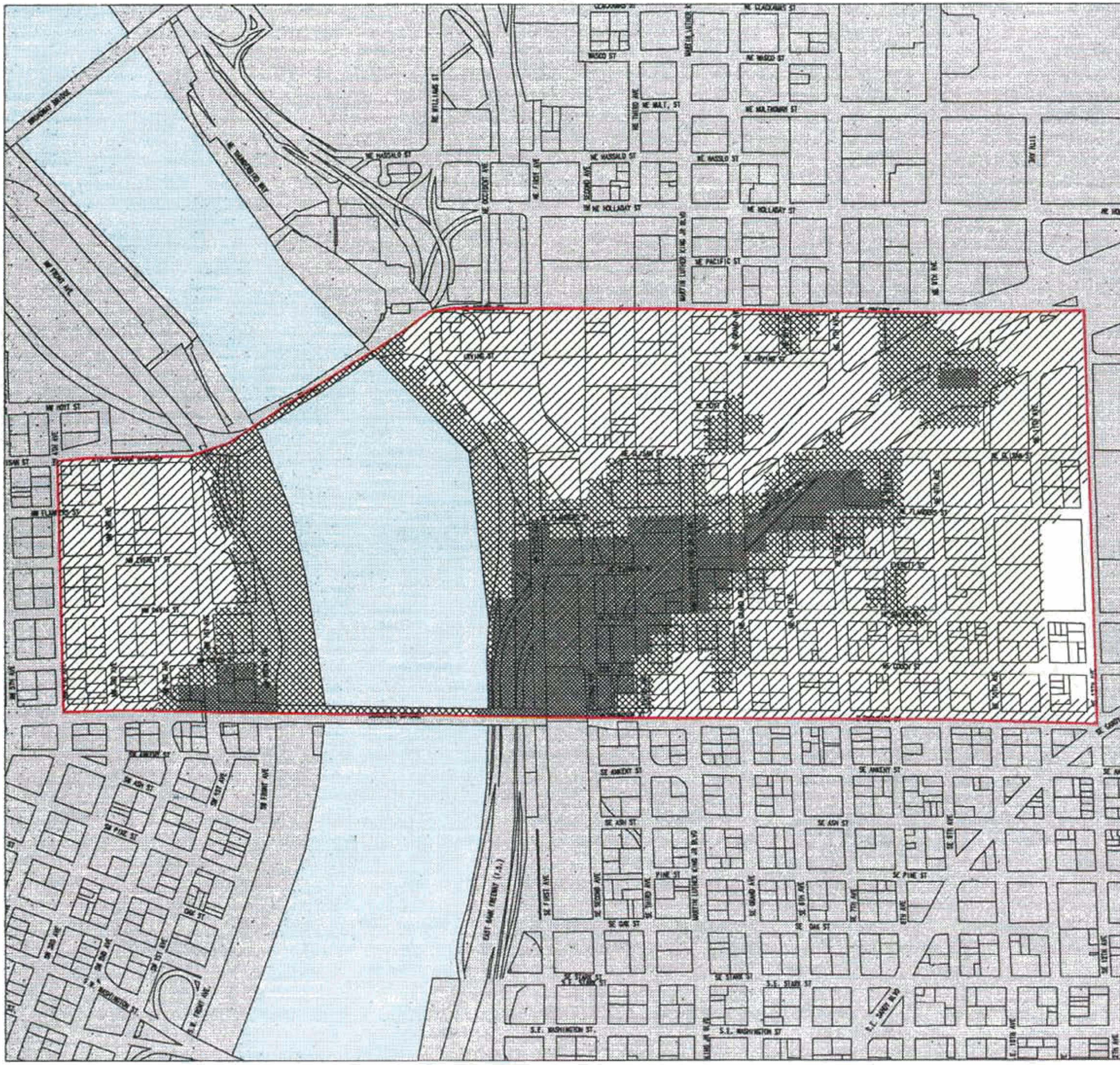
Products of the study include: 1) map of building location by type; 2) estimates of the total dollar damage and damage by construction type; 3) ratio of the dollar damage to the assessed value of the improvements, again both total and by construction type; and 4) estimates of the total injuries and deaths.

Figure 3 is a map of the relative earthquake hazard in the study area. Figure 4 is a map showing the building locations, color coded by construction type, overlaid on a relative earthquake hazard map. Table 2 is a listing of the structure types found in the study area and the numbers of each type. The most common building construction type (35 percent) in the study area is unreinforced masonry (URM). The second most common building type (26 percent) are concrete shear wall construction.

Table 2

Structural Types of Buildings in the Study Area

Structural Type	Identifier	Number of Buildings	Percentage of Buildings
Concrete moment resisting frames	C1	1	0.5%
Concrete shear wall buildings	C2	49	26.5%
Concrete or steel frame buildings with unreinforced masonry infill walls	C3/S5	2	1.1%
Tilt-up buildings	PC1(TU)	4	2.2%
Precast concrete frames	PC2	2	1.1%
Reinforced masonry	RM	25	13.5%
Steel moment resisting frames	S1	2	1.1%
Braced steel frames	S2	1	0.5%
Light metal frame	S3	6	3.2%
Unreinforced masonry	URM	65	35.1%
Wood frame buildings	W	28	15.1%



R L I S

Relative Earthquake Hazard Map

Earthquake Preparedness
Metro/DOGAMI Pilot Project

Zone IV ---- Greatest Hazard
Zone III
Zone II
Zone I ---- Least Hazard

Scale approximately 1 inch = 700 feet

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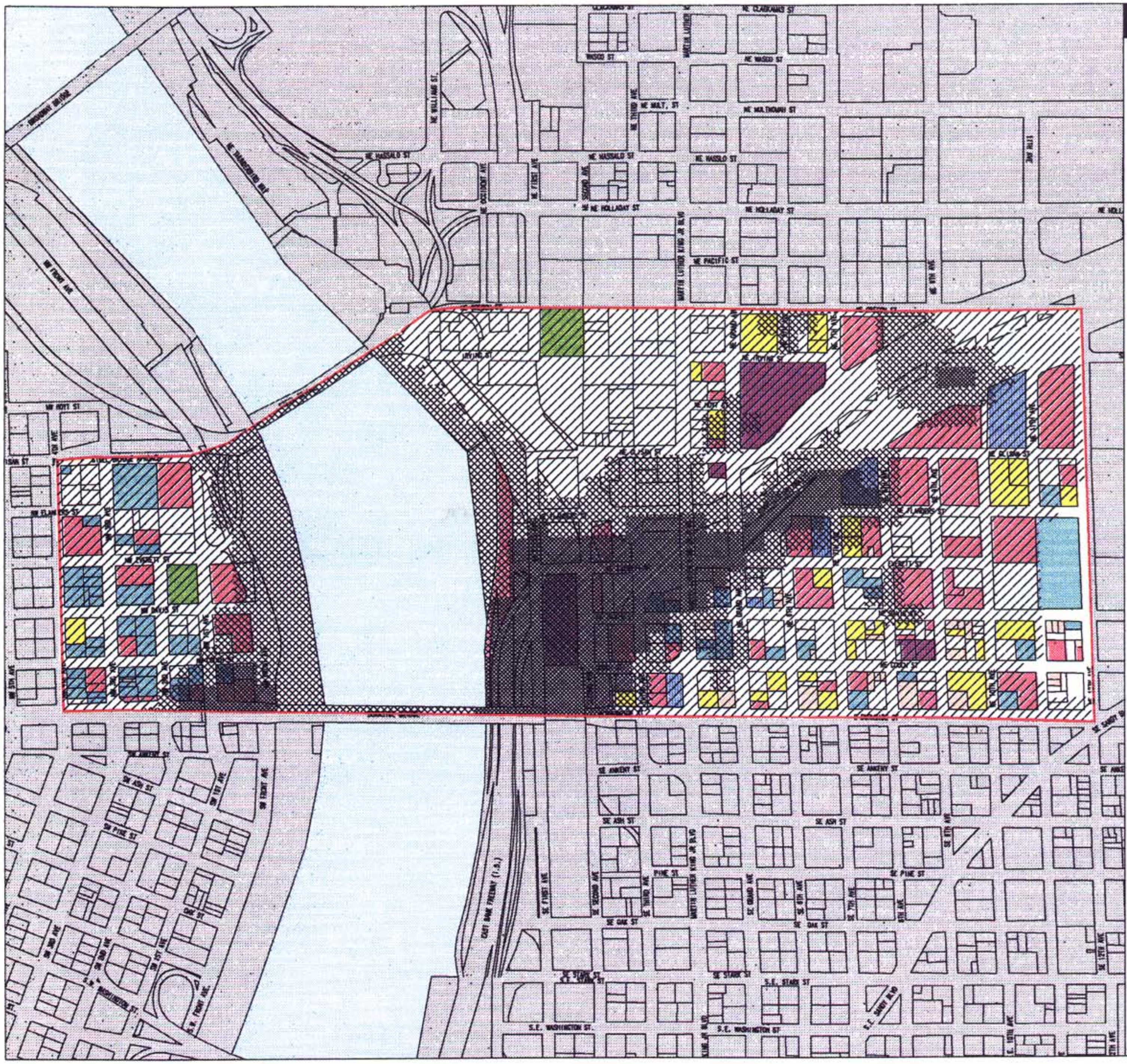
RLIS

Study Area Building Types and Hazards

Earthquake Preparedness
Metro/DOGAMI Pilot Project



- C1 C3/M-INF C3/S5 RM RM*
- C2 C2*
- PC1 PC1-TU PC2 PC2*
- S1 S1* S2
- S3
- URM URM*
- W

- Zone IV ---- Greatest Hazard
- Zone III
- Zone II
- Zone I ---- Least Hazard

Scale approximately 1 inch = 700 feet

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92028 Plot date: January, 1993

The total assessed value of improvements in the study area is about $177,937,250. Total damage to these buildings, in terms of dollars, for the scenario earthquake is estimated at $20,639,654 or 11.6 percent of the total value.

The damage and availability by structure class are summarized in Table 3. The percent damage to type of building, as shown in Table 3, represents only total damage sustained by a building type. Figure 5 is a graphical representation of the number of buildings and damage by structure class.

Table 3

Damage and Availability for the Study Area

Structural Type	Value in Dollars	Damage in Dollars	% Damage	Available in Dollars	% Available
Concrete moment resisting frames	162,600	22,764	14.0%	69,918	43.0%
Concrete shear-wall building	51,482,690	4,499,663	8.7%	25,826,640	50.2%
Concrete or steel frame building with unreinforced masonry infill walls	362,600	49,715	13.7%	89,031	24.6%
Tilt-up building	1,728,900	356,896	20.6%	367,780	21.3%
Precast concrete frame	491,200	85,468	17.4%	191,290	38.9%
Reinforced masonry	5,071,860	809,586	16.0%	2,070,443	40.8%
Steel moment resisting frame	18,707,300	1,686,337	9.0%	14,360,401	76.8%
Braced steel frame	78,828,400	7,882,840	10.0%	44,143,904	56.0%
Light metal frame	553,070	54,882	9.9%	318,652	57.6%
Unreinforced masonry building	19,261,530	5,074,506	26.3%	7,024,270	36.5%
Wood frame building	1,287,100	116,997	9.1%	812,551	63.1%
TOTAL	177,937,250	20,639,654	11.6%	95,274,880	53.5%

One of the least represented building type in the study area, braced steel frame (S2, 0.5 percent), makes up the greatest assessed value ($78,828,400 or 44.3 percent) and, therefore, also sustains the greatest dollar damage ($7,882,840 or 38.2 percent) of any structure type. However, it should be remembered that this is a statistical technique and that such a small sample size for this structure class means that the results are less meaningful.

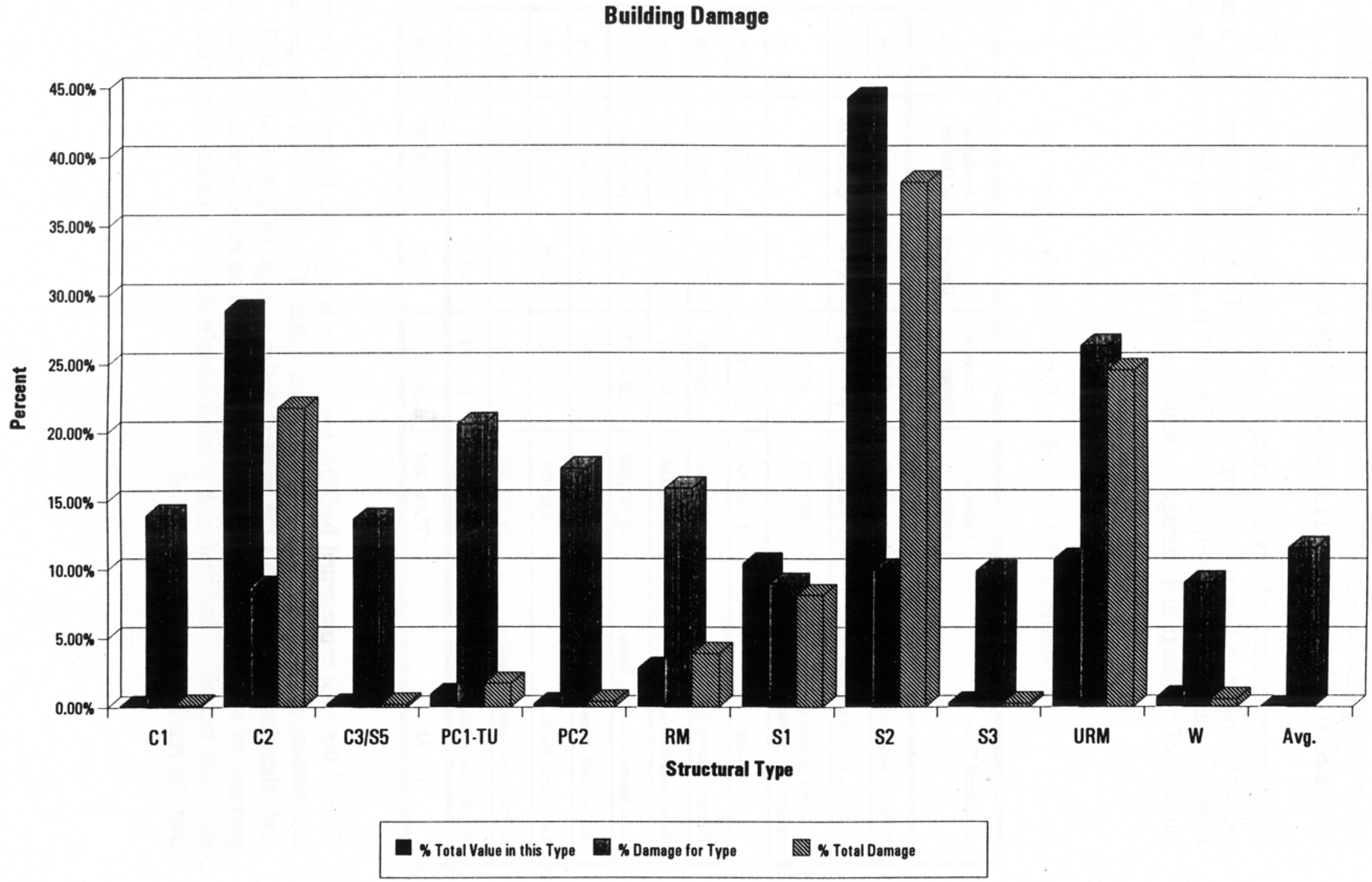


FIGURE 5
BUILDING DAMAGE

The most common structure type, URM (35.1 percent), ranks third in proportion of the total improvements value ($19,261,530 or 10.8 percent), but would sustain the second highest dollar damage ($5,074,506 or 24.6 percent). This reflects the traditionally poor performance that URM buildings exhibit in earthquakes. Concrete shear-wall buildings (C2) rank second in both number (26.5 percent) and total assessed value of the improvements ($51,482,690 or 28.9 percent), but would be the third highest dollar damage ($4,499,663 or 21.8 percent). Wood frame buildings ranked third in number (15.1 percent) and seventh in both total assessed value or improvements ($1,287,100 or 0.7 percent) and dollar damage sustained ($116,997 or 0.6 percent).

The results of the casualties analysis were based on very crude estimates of the building populations. The total population based on these crude techniques was 12,661 as compared to the more sophisticated analysis, not broken down by building, of 37,000. Using the crude techniques it was estimated that 39 people would be injured and 11 people would be killed. These represent injury and death rates of 3.08 per thousand and 0.87 per thousand, respectively. If these rates are applied to the larger population estimates then there would be 114 injuries and 32 deaths in the pilot area for moderate magnitude 6.5 earthquake.

VII. <u>CONCLUSIONS</u>

In conclusion, a reasonable methodology for damage and loss assessment has been developed for the building component of facilities at risk. The concise results are that a magnitude 6.5 earthquake in the study area will likely cause $20,000,000 worth of damage, injure 39 people, and perhaps kill 11 within the 60-city block area. If these numbers can be extrapolated to the entire City of Portland or the metropolitan region of Portland the social and economic effects of such an event would be enormous. Clearly an expanded version of this model will provide a powerful tool for planning and motivating measures to mitigate losses from future earthquakes.

APPENDIX A

DAMAGE AND LOSS MATRICES USED IN THE STUDY

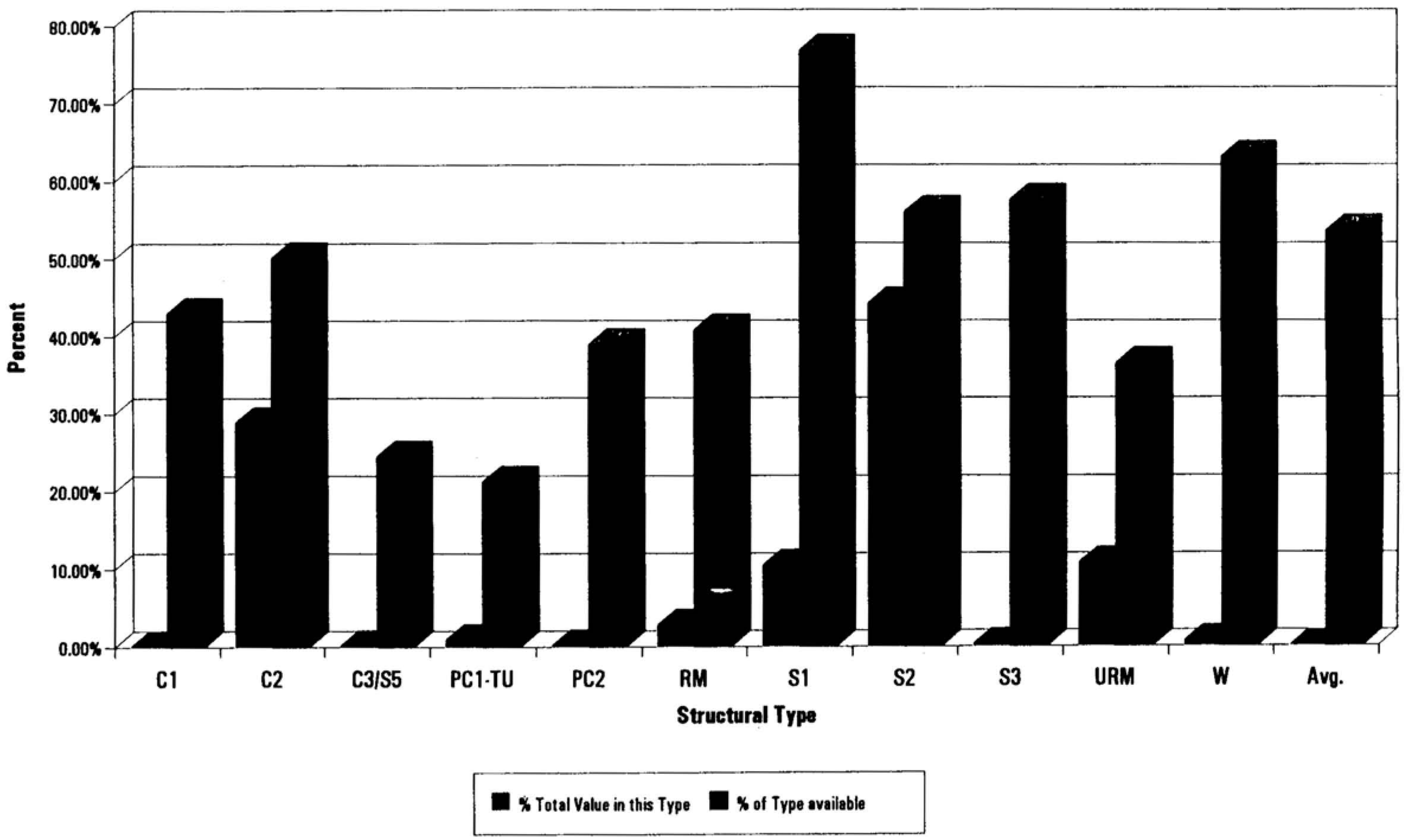
	% Damage	acceleration (g)			
	Structure Class	0.07	0.15	0.3	0.55
URM	URM < 6 story	3.1	15.2	25.8	40.8
URM	URM >= 6 story	5.8	18.9	32.3	48.8
C2,S4	SW < 6 story	1	3.5	7.1	11.4
C2,S4	SW >= 6 story	2.1	8.3	12.7	21.3
C1,C3,RM	RCF >=14 story	3.2	9.9	15.2	26.4
TU,PC2	PC	3.3	10.4	15.5	53.4
S1,S2,S5	SF < 14 story	1.6	5.6	9.4	16.4
S1,S2,S5	SF >= 14 story	0.4	3	5.3	7.9
S3	LM	2.1	6.5	9.4	17.7
W	W	0.9	4.1	8.4	15.3
C1	RCF < 6 story	1	3.5	7.1	11.4
C1	RCF 6 to 13 story	2.1	8.3	12.7	21.3

	% Availible	acceleration (g)			
	Structure Class	0.07	0.15	0.3	0.55
	URM < 6 story	91.1	63.2	39	17.4
URM	URM >= 6 story	85.1	55	34	11.2
URM	SW < 6 story	97.6	91	77.3	62.2
C2,S4	SW >= 6 story	93.9	73	57.5	38.3
C2,S4	RCF >=14 story	90.9	69.2	50.5	27.6
C1,C3,RM	PC	90.8	67	48	5.2
TU,PC2	SF < 14 story	95.9	83.2	69.6	50.8
S1,S2,S5	SF >= 14 story	100	97.9	89	74.7
S1,S2,S5	LM	94.4	80.2	70.8	50.5
S3	W	100	94	76.9	56.1
W	RCF < 6 story	97.6	91	77.3	62.2
C1	RCF 6 to 13 story	93.9	73	57.5	38.3

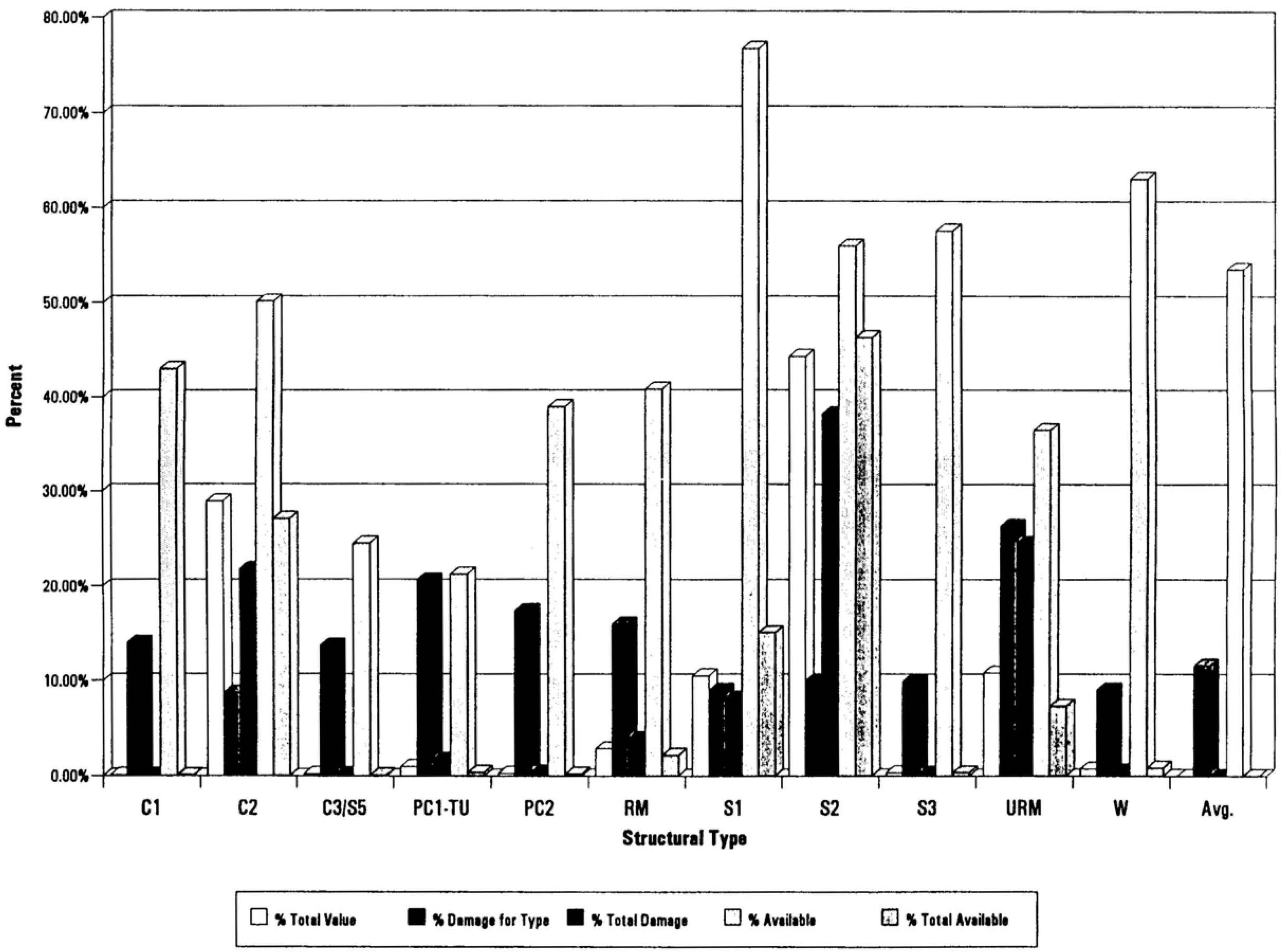
	Deaths/Occupant	acceleration (g)			
	Structure Class	0.07	0.15	0.3	0.55
	URM < 6 story	0.000012	0.000661	0.001378	0.008685
URM	URM > = 6 story	0.000047	0.000913	0.002274	0.01443
URM	SW < 6 story	0.000003	0.00002	0.000049	0.000122
C2,S4	SW > = 6 story	0.000008	0.000059	0.000137	0.000672
C2,S4	RCF > = 14 story	0.000011	0.000096	0.000203	0.003227
C1,C3,RM	PC	0.000012	0.000098	0.000244	0.020166
TU,PC2	SF < 14 story	0.000006	0.000039	0.000084	0.000405
S1,S2,S5	SF > = 14 story	0.000001	0.000007	0.000017	0.000049
S1,S2,S5	LM	0.000001	0.000006	0.00001	0.000062
S3	W	0	0.000002	0.000006	0.000043
W	RCF < 6 story	0.000003	0.00002	0.000049	0.000122
C1	RCF 6 to 13 story	0.000008	0.000059	0.000137	0.000672

	Injuries/Occupant	acceleration (g)			
	Structure Class	0.07	0.15	0.3	0.55
	URM < 6 story	0.000046	0.002646	0.005513	0.022339
URM	URM > = 6 story	0.000187	0.003654	0.009096	0.035319
URM	SW < 6 story	0.000014	0.00008	0.000196	0.000488
C2,S4	SW > = 6 story	0.000032	0.000236	0.000547	0.002689
C2,S4	RCF > = 14 story	0.000045	0.000383	0.000812	0.008108
C1,C3,RM	PC	0.000048	0.000394	0.000977	0.047062
TU,PC2	SF < 14 story	0.000023	0.000156	0.000335	0.001619
S1,S2,S5	SF > = 14 story	0.000003	0.000029	0.000069	0.000195
S1,S2,S5	LM	0.000003	0.000024	0.000038	0.000249
S3	W	0.000001	0.000007	0.000022	0.000172
W	RCF < 6 story	0.000014	0.00008	0.000196	0.000488
C1	RCF 6 to 13 story	0.000032	0.000236	0.000547	0.002689

Building Availablity



Building Damage and Availablity



APPENDIX C

DESCRIPTION OF BUILDINGS AND LIFELINE SYSTEMS IN THE STUDY AREA

A. BUILDINGS

For the entire pilot study area, there is a total of 185 buildings and nearly 70 percent of them are one- or two-story structures. The average age of all the buildings is 59 years, but range from 2 to 116 years. Unreinforced masonry is a predominant structure type, consisting of almost 35 percent of the buildings in the study area as shown in Table C-1.

TABLE C-1

NUMBER/AGE/HEIGHT OF BUILDINGS BY STRUCTURAL CLASSIFICATION FOR PILOT STUDY AREA

Classification	Percent of Total Number	Average Age	Average Height (# of floors)
C1	0.5%	87	6
C2	26.5%	54	2
C3/S5	1.1%	20	1
PC1/TU	2.2%	16	1 - 2
PC2	1.1%	42	2 - 3
RM	13.5%	31	1 - 2
S1	1.1%	17	7
S2	0.5%	2	2
S3	3.2%	23	1
URM	35.1%	82	2 - 3
W	15.1%	71	2

On the westside of the Willamette river there are 62 buildings. These buildings consist of a sizeable portion of the old downtown area, and are, for the most part, commercial in use. The heights of the buildings range from 1 to 13 floors. The age of the buildings average 77 years and range from 4 to 116 years. Nearly 75 percent of all the buildings in this half of the study area are constructed of un-reinforced masonry (URM). The URM class alone ranges from 13 to 116 years in age with the average being 84 years; they range in height from one to six stories but most are two or three stories tall. This region of the study area is historical and most of the buildings are marked by beautiful classical architecture.

Many years ago, the eastside was mixed residential and commercial, but today it is predominantly commercial. There are 123 buildings on the eastside of the pilot study area and they account for over 65 percent of the total number for this study. The buildings range from 1 to 11 stories in height with the most common being only two floors. The average age of the buildings on the eastside is 51 years (26 years younger than the westside) but range from 2 to 103 years. The type of building construction varies tremendously, but there are four different types of construction which account for nearly 85 percent of all the buildings. These main types include, in roughly the same proportion: concrete shear wall (C2), reinforced masonry (RM), unreinforced masonry (URM) and wood frame (W). Overall, the architecture on the eastside is not as impressive as the west, but there are some new landmark structures which stand-out, mainly the new Convention Center and the State Building.

B. CRITICAL FACILITIES AND SYSTEMS

The critical facilities in the pilot area include those in the following categories:

- transportation system; and
- utility system

The description of facilities that follows is based on information collected from government officials in the City of Portland, Multnomah County, State of Oregon and utility companies.

1. Transportation System

The City of Portland owns and maintains a variety of transportation related structures within the study area, they include bridges, overcrossings, retaining walls and a harbor wall. Other facilities are owned by the state, county and private parties and include bridges, railway, station platforms, overcrossings, surface streets and freeways (also see Table C-2).

a. SURFACE STREETS AND FREEWAYS: Within the study area there is a total of 9.9 miles of roadway. In terms of total land area, the road surface (excluding bridges) is 50 acres and the remaining 27 acres is composed of sidewalks, curbs, gutters and medians. The various transportation facilities are owned and maintained by either the state, city or county governments, or private interests.

The length of freeways, which are owned and maintained by the state is estimated at 10,000 feet (1.9 miles). Nearly 70 percent of this figure is comprised of the Interstate 5 and Banfield Freeway (I-84) interchange includes several elevated structures. These structures, most of which were built in and around 1963, account for 6,800 linear feet (1.3 miles) of roadway. The construction type of this interchange is mixed in the sense that girder types vary from span to span. The spans, for the most part, consist of a concrete deck on steel or concrete girders with non-ductile concrete columns on timber pilings. Presently, the State of Oregon is evaluating the seismic resistance of these structures and complete information is not yet available. The seismic vulnerability of the roadway is considered low and what damage is sustained is easily repaired. However, the total replacement cost for the freeway and interchanges in the study area is estimated at about $50 million.

b. BRIDGES: Multnomah County built and maintains the Burnside Bridge which is double leaf bascule type bridge. The bridge was built in 1928 and its total replacement cost is estimated at approximately $133 million which includes not only the main structure with its lift span, but also the approach ramps as well. The replacement estimate also accounts for plans of adding additional deck width to accommodate bicycle traffic. The nature of its earthquake resistance is not known at this time.

   Along the northern boundary of the study area, crossing the Willamette River, is the historical and unique Steel Bridge. This structure is owned and managed by the Union Pacific Railroad who leases its use to various parties including the City of Portland and Tri-Met. The bridge is a steel, double vertical lift type with a main span of about 800'x75'and a lift span of 210'x75'. The Steel Bridge is one of the only, if not the only, double lift span bridges in the world where the two lift decks can be operated separately (the lower deck can be raised without disrupting the traffic on the upper deck). The upper deck accommodates both automobile and light rail traffic while the lower is only for standard railroad. The bridge was opened in 1914 and is considered to be in good condition. The replacement cost for the Steel Bridge is estimated at $225 million.

   On NW Everett at 1st & Front Avenues by the west end approach of the Steel Bridge there is another bridge constructed in several parts. The first part (east of NW 1st) consists of pre-stressed concrete slab (P/S) and steel pile bents with cast-in-place (CIP) reinforced concrete caps. The part of the structure west of NW 1st is made of precast concrete panels on steel bents with CIP sidewalks. The ramps NE of the Light Rail structure consist of CIP deck slap on steel bents. The bridge was built in 1986 and is considered to be in good condition. The replacement cost is estimated at $2.8 million. It's design lateral force is not known.

c. OVERCROSSING: The bridge on NE 12th Avenue that crosses over the Banfield Freeway consists of a concrete deck and sidewalks on steel girders and towers with reinforced concrete abutments. The bridge was built in 1910 and its general condition is considered satisfactory. The replacement cost is estimated at $2.6 million. The design lateral force of the bridge is not known.

   There are two State-owned freeway overcrossings on NE Grand Avenue and Martin Luther King, Jr. Boulevard which are similar in construction and use to the 12th Avenue overcrossing. The exact age of the bridges is not available, but they are of the same vintage as the 12th Avenue overcrossing. They are both in good condition and their combined replacement cost is about $5.5 million.

d. HARBOR WALL: The harbor wall runs along the west bank of the Willamette River throughout the study area. It is a concrete gravity type wall on timber cribbing and was built in 1928. The entire wall runs between the Broadway Bridge and Riverplace, however, the replacement cost of $19 million is only for the span contained within the study area. Its general condition is considered good.

e. RETAINING WALLS: The City also built and maintains four separate retaining walls and a pedestrian stairway as part of their inventory of transportation structures. All are considered to be in good to satisfactory condition. The following descriptions are listed by location, type, year built and replacement cost:

- NW Glisan & Front, concrete wall, year unknown, $12,500
- SW 1st & Burnside, concrete wall, year unknown, $3,650
- NW Front & Glisan, re-con cantilever type wall, 1986, $29,000
- NW Front & Glisan, re-con gravity type wall, 1986, $9,300
- NE Oregon & Occidental, re-con stairs on grade, unknown, $1,500

f. RAILWAY: Within the study area Tri-Met maintains about 1.25 miles of its electrified light rail transportation system (MAX). Within the study area, except for the crossing over the Steel Bridge, the light rail way is, for the most part, embedded in the surface streets. There are two station platforms, track electrification equipment, a network of train signals and other related items contained within the system. The system is in good repair and the total replacement cost is estimated at $12.5 million.

Union Pacific Railway owns and operates about 6,600 feet (1.25 miles) of freight and passenger railway within the study area. Approximately 1,000 feet of this railroad is part of the Willamette River overcrossing where the tracks cross the river on the lower deck of the Steel Bridge. There are two track switches within the area. The replacement cost of the railway facilities is not available.

TABLE C-2

TRANSPORTATION RELATED STRUCTURES						
Transporation System	Location (Area)	Structure Type	Size	Structure Construction	Age (Years)	Condition
(Lightrail)	Skidmore	Station Platform with Ticket Machine		Concrete, Steel Pole, Glass	7	Good
	Old Town	Station Platform with Ticket Machine		Concrete, Steel Pole, Glass	7	Good
	Whole System	Railroad Track in Roadway	3,200' (0.6 miles)	Iron Rail, Concrete, Masonry	7	Good
	Whole System	Track Electrification	3,200' (0.6 miles)	Steel Pole, O/H Cable	7	Good
	Whole System	Signals and Central Boxes		Steel Pole	7	Good
(Railraod)	Eastside	Passenger and Freight Railroad	6,660'	Iron Rail Wood and Concrete Ties		
(Public Roadway)	Burnside Bridge	Double Leaf Bascule Bridge with Ramps	82 x 604 ft (w/o Ramps) 82x 1,453 (with Ramps)		7	
	N.E. 12th and Banfield Freeway	Bridge Freeway Over Crossing		Steel Girders/ ReCon Abatements	82	Satisfactory
	N.E. Everett at 1st and Front	Bridge		P/S Slabs Steel Bents	7	Good
	N.W. Front and Glisan	Retaining Wall		Concrete R-Wall (TYPE UNKNOWN)		Satisfactory
	S.W. 1st and Burnside	Retaining Wall		Concrete R-Wall (TYPE UNKNOWN)		Good
	N.W. Front by Glisan	Retaining Wall		Re-Con. Cantilever Type	7	Good
	N.W. Front by Glisan	Retaining Wall		Re-Con. Gravity Type		
	N.E. Oregon and Occidental	Stairway		Re-Con. Stairs on Grade		Satisfactory
	Steel Bridge	Double Verticle Lift Bridge	800' x 75' Main Span	Steel Girder	78	Good
	I-5, I-84 Interchange	Freeway Bridges	6,800' (1.3 miles)	Concrete Deck on Steel or Concrete Girders on Croncrete Columns	30	Good
River	Waterfront	Harbor Wall		Concrete Gravity Type on Timber Cribbing	64	Good

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2. Water Supply System

Within the study area there are approximately 45,700 feet (8.65 miles) of water mains and feeders with a total of 225 services on both sides of the river. The pipes vary from 1.5 to 20 feet (as shown in Table C-3) in diameter with the average size of medium and large mains being 6 to 8-inches and 14 to 18 inches, respectively. The system operates at around 95 psi on the westside and 130 psi on the east. The pipes are either constructed of cast iron with oakum caulked joints or ductile iron with slip joints. There is roughly one gate or butterfly valve per 150-200 feet of line. Pipes are buried at a depth of 40 inches and the age of segments in the system vary from 4 to 90 years. The study area is served by a total of about 87 fire hydrants and four drinking fountains.

TABLE C-3

WATER LINES					
Location (Area)	Structure Type	Structure Size	Total Linear Footage	Age (Years)	Operating Pressure/ Voltage
	Underground Water Mains and Feeders	1 ½-20" Ductile or Cast Iron Pipe	45,700	4-90	95-130 psi

3. Storm and Sanitary Drainage System

The pilot study area contains about 46,800 feet (8.8 miles) of both storm and sanitary sewers (see Table C-4) . The pipes in the system vary in size from 8 to 102 inches (8½ feet) in diameter with the average being about 22 inches. The system is constructed with a variety of materials including concrete sewer pipe, poured-in-place concrete, ductile iron pipe and vitrified (clay) sewer pipe which are buried at an average depth of 12½ feet. Concrete and vitrified sewer pipes account for a little over 80 percent of all pipe in the area. The age of the segments vary from 3 to 107 years with the average being 57 years. Underneath the I-5 and I-84 interchange there is the Sullivan Pumping Station which pumps the waste water and sewage that collects on the low end of Sullivan's Gulch up to another main line that goes to the treatment plant on the Columbia River. The system is in good shape and its total replacement cost is estimated at about $7.34 million.

TABLE C-4

STORM AND SEWER					
Location (Area)	Structure Type	Structure Size	Total Linear Footage	Age (Years)	Average Operating Slop (% Grade)
Eastside	CIP	I	60'	39	.4
	CON	III	3,091'	3-37	?
	CSP	I II III	6,196' 3,411' 4,145'	3-89	.13
	VSP	I II	13,928' 2,256'	12-100	.03
	VAR	I	498'	52-93	.02
Westside	CON	II	190'	Unknown	?
	CSP	I II III	577' 4,506' 289'	20-75	.01
	DIP	I II	490' 482'	8-12	.007
	SP/VAR	I	2,668' 216'	?-107	.09
	VSP	I II	3,331' 508'	71-107	.02

<u>Table Legend</u>

Type:
- CIP - Cast Iron Pipe
- CON - Poured-In-Place Concrete
- CSP - Concrete Sewer Pipe
- DIP - Ductile Iron Pipe
- SP - Sewer Pipe (type unidentified, most likely CON or VSP)
- VAR - Variable Material (see SP)
- VSP - Vitrified Sewer Pipe (clay tile pipe)

Size:
- I - 8-20" pipe
- II - 24-48" pipe
- III - 50-102" pipe

4. Gas System

Within the pilot study area Northwest Natural Gas Company (NNG) operates a piping system with a total of 19,434 feet (3.68 miles) of gas line. The system consists of an extensive piping grid on both sides of the Willamette River and has 143 services. Pipe does not cross the river within the study area.

All gas lines contained in the study area, with the exception of two pipes that cross the I-84 (Banfield Freeway) on the Grand Avenue Bridge, are constructed of buried welded carbon steel (CS) piping. Outside the study area, NNG also has polyethylene and cast iron pipe. The cast iron pipe predates 1916 and what is left in service is currently being replaced.

The gas lines within the study area vary from 20-inch high pressure gas mains (which operate at up to 400 psi) to 1-inch low pressure feeder lines. All gas lines within the study area are in excellent repair at this time.

NNG estimated the replacement cost of the system to be $1,042,000.

TABLE C-5

NATURAL GAS LINE					
Location (Area)	Structure Type	Structure Size	Total Linear Footage	Age (Years)	Operating Pressure (psi)
Westside	Welded CS Pipe Class D System	20"	1,705	13-20	up to 400
	Welded CS Pipe Class B System	16"	70	34	25-45
	Welded CS Pipe Class B System	12"	525	13-33	25-45
	Welded CS Pipe Class B System	6"	300	7	25-45
	Welded CS Pipe Class B System	4"	3,214	7-28	25-45
	Welded CS Pipe Class B System	2"	1,045	9-20	25-45
	Welded CS Pipe Class B System Crossing	1"	435	8-20	25-45
Eastside	Welded CS Pipe Class C System	12"	740	4	up to 175
	Welded CS Pipe Class B System	12"	1,525	79	25-45
	Welded CS Pipe Class B System	8"	400	36	25-45
	Welded CS Pipe Class B System	6"	1,570	4-79	25-45
	Welded CS Pipe Class B System	4"	1,443	23-71	25-45
	Welded CS Pipe Class B System	2"	6,462	1-32	25-45

5. Electric Power System

The electrical power distribution and transmission systems in the pilot study area are owned and operated by two separate power utility companies, and the totals for these systems have been combined for this study. Within the study area there are both overhead and underground power distribution systems. Underground facilities exist on the westside whereas overhead facilities exist on the eastside.

Both the aerial transmission and distribution facilities are comprised of overhead power cable on wooden utility poles which operate at 115,000 and 12,500 respectively. There is a total of 5,200 feet (0.99-mile) of transmission line and 24,500 feet (4.64 miles) of distribution line within the study area. The overhead facilities vary in age from 1-67 years and all are considered to be in good condition.

The subterranean distribution systems on the westside are comprised of cable buried in 4- to 6-inch PVC, fibre or tile duct at a depth of 40 inches and are accessible by a series of concrete vaults with manholes. They operate at 11,000v and 12,500v. There is a total of 20,000 feet (3.8 miles) of underground distribution line and all is considered to be in good condition at this time. The age of the facilities on the westside vary from six months to 62 years.

Most of the customers in the entire study area are commercial with the only "lifeline" customer being the City of Portland's Sullivan Pumping Station at NE 2nd and Everett. The pumping station happens to have two alternate electrical services aside from its normal service. The total replacement cost for all power systems with in the study area is estimated at $5.4 million.

TABLE C-6

POWER LINES-DISTRIBUTION AND TRANSMISSION

Location (Area)	Facility Type	Applicable Structure Size and Type	Total Linear Footage	Age (Years)	Operating Voltage (kv)
Westside	Underground Distribution System	4" and 6" Fibre and Tile Duct	13,020' (2.5 miles)	1-62	11 kv and 12.5 kv
	Underground Distribution System	4" and 6" PVC Duct	7,000' (1.3 miles)	1-25	12.5 kv
Eastside	Overhead Distribution System	Overhead Cable on Wood Poles	24,440' (4.6 miles)	1-67	12.5 kv
	Overhead Transmission System	Overhead Cable on Wood Poles	5,000' (0.95 miles)	1-25	115 kv

6. Other Critical Faculties in the Study Area

Data for the communication facilities and system in the study area was not available to be included in this report.