A PRELIMINARY ASSESSMENT OF TSUNAMI HAZARD AND RISK IN THE INDONESIAN REGION

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ABSTRACT

The natural hazard of tsunami has, for too long, been underrated as a potential cause of major disasters. However, several devastating tsunamis in and around the Pacific Ocean Basin over the last decade - all claiming significant loss of life, major property and environmental damage and severe socio-economic losses - have heightened the awareness of this natural hazard. As a consequence, significant mitigation strategies and measures in tsunami-prone regions of the world (such as the Pacific Basin, Mediterranean Region, Atlantic Ocean) have been undertaken in recent years. However, for the high tsunami risk Indonesian Region, a more considered approach needs to be addressed.

Indonesia is a region with a considerable record of tsunami occurrence dating back hundreds of years. In a large number of these instances, devastating effects have been repotted. However, reliable and complete data bases, scientific analyses and integration of relevant information into disaster planning have been lacking. This paper reviews the status of available tsunami information (with particular reference to Indonesian and Japanese studies and the recently published Historical Tsunami Data Base for the US Pacific Coast UTDBIUS). presents a comprehensive data base (the central element to any tsunami hazard assessment) for the period 2000BC through 2001AD in the approximate region 9ON to IO’S, 104”E to 140”E and reviews available quantitative hazard and risk assessments. Comments are made on the integration of such assessments to the reduction of community vulnerability and to the prevention of potential damage (risk management) to major commercial development projects for the Indonesian region.

INTRODUCTION

The Indonesian region is a very complex and violent tectonic zone on the Earth's surface in relation to the geological evolutionary processes (known as plate tectonics). Several tectonic plates converge herein, as evidenced by subduction zones, major faults, volcanoes and other geological processes. This tectonic situation is manifested in the natural hazards of earthquake, volcanic eruptions and collateral hazards of landslide and tsunami. The historical record, at least for the past 2000 years, documents the frequent and continuing suffering of and devastation upon all sectors of the Indonesian peoples, in all aspects of their human, built and natural environments as inflicted by these natural hazards of earthquake, volcano and tsunami.

In the period 2000BC - 2001AD, 179 destructive tsunamis are documented to have occurred in the region. The return period for such tsunamis is difficult to explicitly determine however, a deterministic view would suggest one tsunami occurrence every 10 to 25 years. The tsunamigenic sources are either earthquakes or volcanoes or landslides (resulting from earthquakes or volcanoes). While the majority of these relate to near-field sources (within the Indonesian region), far-field sources (within the Pacific Ocean and Indian Ocean Basins) must also be considered. Because of this wide-spread nature of the tsunamigenic sources, the tsunami parameters, relative to a specific site under consideration, cover a very wide range. For near-field sources, tsunami travel times range from minutes to several hours, with wave heights and runup heights varying from less than one metre to many tens of metres. This makes tsunami warnings a very difficult matter. For far-field sources, travel times range from a few hours up to 20 hours, with wave heights and runup heights usually very small.

The central element of a tsunami hazard assessment (and thus a risk assessment) is a comprehensive tsunami data base. Such has been developed as the provisional CERA Indonesia Tsunami Data Base (CITDB), compiled from all published information available through 2001. Based on this CITDB, a preliminary analysis determined several tsunami functional relationships.

It is clear that the awareness of this natural hazard of tsunami for the Indonesian region must be understood. Tsunami mitigation strategies and measures should be taken into consideration in risk management, emergency planning procedures and engineering design of potential commercial development projects. This study was part of a project in planning for a major engineering project.

TECTONIC SETTING FOR INDONESIA

Over the last 40 years, detailed studies have provided great insight into the complex situation of the Indonesian region (for example: Hamilton, 1979; Addicott and Richards, 1986; Hall, 1996, Hamzah et al, 2000). Tectonic studies of particular areas within the Indonesian region have also been undertaken, most of which are published in the Indonesian and Japanese earth science literature.

To briefly summarise. the region has a very complicated system of plate convergences consisting of subduction, collision, back-arc thrusting and back-arc basins. This relates to the major Eurasian, Indo-Australia. Pacific, Caroline and Philippine Sea plates, and several minor plates including the Molucca Sea plate. These plates are moving relative to each other in a combination of many directions. The tectonics are identified in terms of:

(a) Three major trenches : Java, Timor, Philippines

(b) Five active island arcs:

- Sunda -convergence of Indo-Australia and Eurasian plates/ underthrusting at Java Trench
  -western islands of Andaman, Sumatra and Java
  -eastern islands of Bali, Lombok and Sumba

- Banda -convergence (collision) of Indo-Australian and Eurasian plates/underthrusting at Timor Trench
  - islands of Bali, Lombok, Flares and Tanimbar
  islands of Ceram and Bum
- Sangihe
- Halmahera
- North Sulawesi

vv Major fault : Sarong Fault in western Irian Jaya I northern Banda Sea.

This complex and active tectonic situation is manifested in the very high seismic activity and significant numbers of active volcanoes.

In the global perspective of plate tectonics, the very high level of earthquake occurrence in the Indonesian region is well known (for example: Bolt, 1993; Hamzah et al, 2000). These earthquakes occur over the entire range of focal depths - shallow, intermediate, deep. In their own right, many of these earthquakes have inflicted great devastation in many areas.

Volcanoes are the other manifestation of global plate tectonics (Simkim and Siebert. 1994). They occur in those areas “behind” the trenches (or subduction zones) as a consequence of heated mantle rocks relative to the down-going slate being forced through the Earth’s crust to the surface. Indonesia leads the world in both the number and the global proportion of eruptions in each of the four eruptive characteristics - fatalities, destruction of land and property, mudflows and tsunamis. The levels of these effects are closely followed by the volcanic eruptions in the Philippines. The distribution of volcanoes in this region is given in the CD ROM of Gusiakov and Hagemeyer (2000).

Although the incidence of tsunami is a well documented, common and frequently devastating natural disaster in the Indonesian region, their nature, mechanism and regional characteristics are not well known. Tsunamis are a consequence of both earthquake and volcano, and are also known to have been generated by collateral landslide occurrences.

TSUNAMIGENIC SOURCES RELATIVE TO INDONESIA

All tsunamis catalogued in this CITDB were caused by NEAR-FIELD sources, that is, within the Indonesian region. This also includes sources related to the highly seismic areas of the Philippine Trench - Southern Mindanao (Philippines). The vast majority, namely 153, were caused by earthquakes. Of the remainder, volcanic eruptions accounts for 26 tsunamis, landslides associated with earthquakes four (4) and landslides associated with volcanic eruptions one (1). Maps of such sources can be found in the CD ROM of Gusiakov and Hagemeyer (2000).

FAR-FIELD tsunamis are those generated primarily by earthquakes in the Pacific Ocean and Indian Ocean Basins. A preliminary search of the Worldwide and Pacific Ocean Basin data bases I catalogues (Gusiakov and Hagemeyer, 2000 - HTDB CDROM; NOAA-NGDC; USGS-NEIC) indicates that while several large tsunamis may(?) have been observed on tide-gauge recordings in the Indonesian Region, the wave heights (or equivalent run-ups) may be presumed to have been less than 20cm. It is noted that some of these large tsunamis were recorded on tide-gauges in the US Possessions in the Western Pacific (Caroline Is, Yap Is. Paula; Lander and Lockridge. 1969) and in eastern Australia (Rynn and Davidson, 1999). On the average, the recorded wave heights were lo-20cm, with the rare occasion of the order of Im (for example: 1960 Chile recorded in Sydney, Australia). However, a systematic search of the Indonesian records would be required to definitely determine such far-field tsunami wave heights and runups.

TSUNAMI DATA BASE FOR INDONESIA - CITDB (PROVISIONAL)

A provisional tsunami data base was compiled for the Indonesian region - CERA Indonesian Tsunami Data Base (CITDB) for the period ZOOOBC - 2001AD to include the region 9’N - 10% and 104% - 139’E.

The CITDB was compiled from all available relevant published data bases / catalogues, as listed in Table 1. The most recent data bases, the HTDB of Gusiakov and Hagemeyer (2000) and that of Hamzah et al (2000) (the latter regarded by Indonesian authorities as the most up-to-date study on the subject) were used as the “master” lists.

This CITDB, prepared as Table 2, contains the relevant information on the tsunamigenic source parameters, tsunami parameters and resulting socio-economic effects of the impacts (explanation of parameters given in Table 3). 179 tsunamis are listed.

The limitations and uncertainties in all tsunami data bases (catalogues), including this CITDB, need to be clarified. It is considered that information on and understanding of tsunami in the Indonesian region is the least known of all such areas around the globe (pers.comm., Pacific Tsunami Warning Centre. Hawaii, 2000). It is only very recently that a more intensive scientific interest is being taken, clearly because of the several devastating tsunamis that have occurred over the last decade. This relates primarily to the completeness and availability of Indonesian records and data. In the historic data record, there is always the possibility that a “tsunami” may have been caused by local flooding resulting from meteorological phenomena, particularly storm surges.

In the development of CITDB. many inconsistencies between the various data bases / catalogues for the parameters for several specific tsunamis were noted. Hence **CAUTION** must be exercised in undertaking statistical analyses of the data bases (such as the functional relationships) in the assessment of the tsunami hazard (return period, probability statements, etc).

In terms of the distress and disruption to normal life (the “socio-economic effect”). the combined forces of earthquake, volcano and landslide have taken more than 250,000 lives (and this figure relates only to those deaths reported - with the very diverse population, the true number is considered to be much greater) and have been responsible for the destruction of countless villages and towns along with their local economies. While no official estimate is available for such losses due to tsunami alone, it is clearly evident from the CITDB that a significant proportion of losses has resulted from tsunami.

TABLE 1

AVAILABLE TSUNAMI DATA BASES FOR INDONESIAN REGION

(DATA : ZOOOBC _ ZOOIAD)

Published information on tsunamis in the Indonesian Region defined within Q.OO'N to 10.00'S; 104.00'E to 140.00'E (including Indonesia (except Sumatra) and Southern Philippines).

	PUBLICATION		TSUNAMI DATA	
IATA	TYPE	REFERENCE	TIME PERIOD	REGION
002	LISTING	ITIC Tsunami Newsletter Vol XXXIV No. 1	2001 DEC	Pacific Ocean Basin
001	LISTING	ITIC Tsunami Newsletter Vol XXXIII Nos. I-5	2001 JAN - NOV 2000 DEC	Pacific Ocean Basin
1000	LISTING	ITIC Tsunami Newsletters Vol XXXII Nos.I-2	2000 JAN - NOV	Pacific Ocean Basin
:000	CATALOGUE (CDROM)	Gusiakov and Hagemeyer (2000)	2000BC 2000AD	Pacific Ocean Basin and Caribbean
1000	CATALOGUE	Hamzah et al (2000)	1600 1999	Indonesia
999	CATALOGUE	Davidson and Rynn (1998) Rynn and Davidson (1999) CERAfBoM unpublished files	1788-1995	Pacific Ocean and Indian Ocean Basins
993	CATALOGUE	Lander et al (1993)	1806-1992	Pacific Ocean Basin
992	CATALOGUE	Dunbar et al (1992)	215080 - 199IAD	Worldwide
992	CATALOGUE	Soloviev et al (1992)	1969 1982	Pacific Ocean Basin
989	CATALOGUE	Lander and Lockridge (1989) Caribbean	1690 1988	Pacific Ocean Basin
1986	CATALOGUE	Hedervari (1986)	1900-1959	Worldwide
1984	CATALOGUE	Hedervari (1984)	1500BC - 1899AD	Worldwide
1984	MAP	Lockridge and Smith (1989)	1900 - 1983	Pacific Ocean Basin
1984	CATALOGUE	Soloviev and Go (1984)	173.1968	Western Shore of Pacific OCC?I"
1977	CATALOGUE	Everingham (1977)	1768-1972	New Guinea, Solomon Is
I970	CATALOGUE	Cox (1970)	416 1969	Indonesia. Philippines China, Taiwan
1969	CATALOGUE	Pararas-Carayannis (1969)	1813.1968	Pacific Ocean Basin
1969	CATALOGUE	Berninghausen (1969)	416.1965	Indonesia. Philippines China, Taiwan
1966	CATALOGUE	Berninghausen (1966)	1750.1945	Indian Ocean and Indonesia
1947	CATALOGUE	Heck (1947)	479BC 1946AD	Worldwide

TABLE 2
CITDB : TSUNAMI DATA BASE FOR INDONESIAN REGION 2000BC - 2000AD
NEAR-FIELD TSUNAMIGENIC SOURCES
(PROVISIONAL)

DATE	TSUNAMIGENIC SOURCE									TSUNAMI PARAMETERS						SOCIO ECONOMIC EFFECTS	
	TYPE	LATITUDE	LONGITUDE	LOCATION	EARTHQUAKE				VOLCANO	Tm	I(T)	WAVE HEIGHT		RUN-UP		DEATHS	DAMAGE
					FOCAL DEPTH (KM)	MAGNITUDE ML	MS	MW				MAX M	LOCALITY	MAX M	LOCALITY		
416 SEP 10	V	10.00°S	105.45°E	Sunda St						3.0	3.5	obs	Sunda St	(>15)	Sunda St	many	extreme
1608 JUL 1	V								Tidore				Makian Is		Makian St		limited
1629 AUG 1	E	4.30°S	129.60°E	Banda Sea			*7.0*			4.0	3.0	*15.0*	*Palau*	*16*	*Bandaneira*		*severe*
1659 NOV 11	V	6.90°S	129.20°E	Banda Sea					Teun			1.5	Ambon				limited
1659 DEC	*E*			*Ceram*											*Buru*		
1673 MAY 20	V	1.37°N	127.52°E	Halmahera					Gamkonora			mod	Ternate	mod	Ternate	many	
1673 AUG 12	*E*	*0.80°N*	*127.30°E*	*Halmahera*								*mod*	*Ternate*		Ternate		extreme
	V	0.80°N	127.32°E	Halmahera	(assoc. with earthquake?)				Ternate	1.0	1.0	mod	Ternate		Ternate		
1674 FEB 17	E	3.50°S	128.20°E	Ceram			8.0			6.0	4.0			100.0	Ceyt	2970	extreme
1674 MAY 06	E	3.40°S	128.00°E	Ceram			6.0			1.0		weak	Ambon				
1708 NOV 28	E	3.00°S	128.00°E	Ceram						2.0	2.0	mod	Ambon				severe
1710 MAR 06	E	4.30°S	129.60°E	Banda Sea						1.0	1.5				Bandaneira		moderate
1711 SEP 05	E	4.00°S	129.00°E	Banda Sea						1.0	1.5	1.2	Ambon		Ambon		moderate
1749 AUG 11	V	14.00°N	121.00°E	Philippines					Taal								
1754 MAY 13	V	14.00°N	121.00°E	Philippines					Taal								
1754 AUG 18	E	3.50°S	128.50°E	Banda Sea			6.5					mod	Haruku		Haruku		severe
1754 SEP 07	E	3.50°S	128.50°E	Banda Sea						1.0		mod	Haruku		Haruku		
1754 NOV 28	V	14.00°N	121.00°E	Philippines					Taal								limited
1757 AUG 24	E	6.00°S	107.00°E	Sunda St								0.5	Jakarta				
1763 SEP 01	V	0.80°N	127.32°E	Halmahera					Ternate	(0.0)		9.0	Ternate	obs	Ternate		

TABLE 2 (Continued)																				
DATE			TSUNAMIGENIC SOURCE									TSUNAMI PARAMETERS							SOCIO ECONOMIC EFFECTS	
			TYPE	LATITUDE	LONGITUDE	LOCATION	EARTHQUAKE				VOLCANO	Tm	I(T)	WAVE HEIGHT		RUN-UP			DEATHS	DAMAGE
							FOCAL DEPTH	MAGNITUDE ML	MS	MW				MAX M	LOCALITY	MAX M	LOCALITY			
1763	SEP	12	E	4.30°S	129.60°E	Banda Sea							2.5	9.0	Bandaneira	>10.0	Bandaneira		7	extreme
1770	(?)		E	5.00°S	102.00°E	Sumatra			7.0				0.5				Bengkulu			
1775	*APR*	*19*	*E*	*4.00°S*	*128.00°E*	*Ceram*						*.0)*		*weak*	*Ambon*					
1802	AUG		E	4.00°S	128.00°E	Ceram						.0)			Ambon	large	Ambon			severe
1814	(?)		E	11.00°S	124.00°E	Timor						.0)					Kupang			
1815	APR	11	V	8.20°S	118.00°E	Sumbawa					Tambora	.0	1.5	3.5	Tambora	6.0	Tambora		92,000	extreme
1815	NOV	22	E-L	8.00°S	115.20°E	Bali	122		7.0			.0	1.5	large	Bali	large	Bali		10,253	extreme
1818	MAR	18	E	4.00°S	101.50°E	Sumatra			7.0				1.5			large	Bengkulu			moderate
1818	NOV	08	E	7.00°S	117.00°E	Bali	600		8.5				2.0	large	Bali St	3.5	Bali St			moderate
1820	DEC	29	E	7.00°S	119.00°E	Sumbawa	80		8.5			.0	3.5	25.0	Bulukumba	400	Nipanipa		500	extreme
1823	SEP	09	E	6.50°S	108.50°E	Java	150		8.5				-1.5			0.3	Ceribon			
1833	NOV	24	E	3.50°S	102.20°E	Sumatra	75		8.2				2.5	large			Bengkulu			moderate
1836	MAR	05	E	8.00°S	119.00°E	Sumbawa										obs	Bima			
1836	NOV	28	E	8.00°S	119.00°E	Sumbawa										obs	Bima			
1843	FEB	07	E	7.20°S	114.00°E	Java			6.0					obs	Genteng					
1845	FEB	08	E	1.30°S	124.50°E	Sulawesi			7.0					obs		large	Kema			severe
1846	*JAN*	*25*	*E*	*2.00°N*	*126.50°E*	*Halmahera*			*7.2*				*0.5*	*mod*	*Ternate*	*1.2*	*Ternate*			*moderate*
1851	MAY	04	E	5.00°S	105.00°E	Sumatra							1.5			1.5	Telukbetung			
1852	JAN	09	E	5.00°S	105.00°E	Sumatra										obs	Telukbetung			
1852	NOV	06	E	5.00°S	130.00°E	Banda Sea								obs	Ambon					
1852	NOV	26	E	4.30°S	129.50°E	Banda Sea	100		8.2			.0	2.5	8.0	Ambon	8.0	Bandaneira		60	extreme
1852	DEC	25	E	5.00°S	130.50°E	Banda Sea			7.0				2.0			obs	Bandaneira		few	severe
1854	JAN	04	E	3.50°S	128.60°E	Ceram			6.0							obs	Haruku			
1854	SEP	27	E	1.00°N	127.33°E	Halmahera								obs	Ternate					none
1856	MAR	02	V	3.67°N	125.50°E	Sangihe					Awu	.0	1.0	obs	Sangihe	obs	Tahuna		2806	extreme
1856	JUL	25	E	8.50°S	116.00°E	Lombok								obs	Ampenam					
1857	MAY	13	E	8.00°S	125.50°E	Timor	50		7.0			.5	2.0	3.0	Dili	(<6.0)	Likisia		40	severe
1857	NOV	17	E	1.00°N	125.00°E	Sulawesi							1.5	obs	Ternate	large	Ternate			moderate
1857	NOV	18	E	1.00°N	125.00°E	Sulawesi								obs	Kema					
1858	DEC	13	E	1.00°N	126.00°E	Sulawesi			7.4			.0	1.5	obs	Ternate	obs	Ternate			severe

TABLE 2 (Continued)

DATE	TSUNAMIGENIC SOURCE									TSUNAMI PARAMETERS						SOCIO ECONOMIC EFFECTS	
	TYPE	LATITUDE	LONGITUDE	LOCATION	EARTHQUAKE				VOLCANO	Tm	I(T)	WAVE HEIGHT		RUN-UP		DEATHS	DAMAGE
					FOCAL DEPTH	MAGNITUDE ML	MS	MW				MAX M	LOCALITY	MAX M	LOCALITY		
1859 JUN 28	E	1.00°N	126.50°E	Halmahera			7.0			3.0	3.0	obs	Ternate	10.0	Sidangoli		limited
1859 JUL 20	E	5.00°S	130.00°E	Banda Sea								obs	Lonthor				
1859 JUL 29	E	0.00°N	125.50°E	Sulawesi			7.2			1.0	1.5	mod	Kema	obs	Bangai		moderate
1859 SEP 25	E	5.50°S	130.50°E	Banda Sea			6.7			1.0	0.5	obs	Bandaneira	obs	Bandaneira		
1859 OCT 20	E	9.00°S	111.00°E	Java							1.0	obs	Patjatan	mod	Patjatan		limited
1859 DEC 17	E	2.00°N	125.00°E	Sulawesi										obs	Belang		
1859 DEC 26	E	2.00°N	125.00°E	Sulawesi						1.0				obs	Kema		limited
1860 OCT 06	E	1.40°S	128.50°E	Halmahera								obs					
1861 JUN 05	E	6.30°S	107.30°E	Java						1.0					Karawang		
1864 MAY 23	E	1.00°S	135.00°E	Irian Jaya			7.8			1.5	1.5	3.0	Geelvink	12.0	Geelvink	250	
1871 MAR 02	V	2.27°N	125.42°E	Sangihe					Ruang	4.0	3.5	large	Tahulandang	25.0	Buhias	460	extreme
1875 MAR 28	E	8.30°S	110.70°E	Java										obs	Sth Java		
1865 MAY 28	E	3.00°S	127.20°E	Ceram			6.8					obs	Buru	0.3	Kayali		limited
1882 OCT 10	E	5.00°S	130.00°E	Banda Sea								obs	Bandaneira				
1883 AUG 26	V	6.10°S	105.40°E	Java					Krakatau								
1883 AUG 27	V	6.10°S	105.40°E	Java					Krakatau		4.5	large	Sunda St	35	Merak	00,000	catastrophic
1884 JAN	V	6.10°S	105.40°E	Java					Krakatau			obs					
1885 APR 30	E	2.50°S	128.50°E	Ceram			7.2				0.5	obs	Kayeli	1.2	Djikomurasa		severe
1889 SEP 06	E	1.00°N	125.60°E	Sulawesi	70		8.0			1.0	2.5	9.0	Bentenan	4	Kema		severe
1889 SEP 09	V	3.14°N	125.49°E	Sangihe					Banau Wuhu			1.5	Tareona				
1889 NOV 23	E	7.00°S	113.50°E	Java			6.0				1.0	obs	Madura				
1891 OCT 05	E	9.00°S	124.00°E	Sunda St	80		7.0				0.5	obs	Ende	obs	Ende		
1892 JUN 07	V-L	3.67°N	125.50°E	Sangihe					Awu	1.0	1.0	1.5	Ambon			1,532	severe
1892 NOV 18	E	3.00°S	127.80°E	Ceram	70		7.0				-1.0	obs	Kayeli				
1896 APR 18	E	8.00°S	125.00°E	Timor										obs	Alor	250	
1896 OCT 10	E	3.50°S	102.50°E	Sumatra	130		6.8					obs	Singkel				
1897 JAN 03	E	6.00°N	122.70°E	Philippines			8.2							obs	Sulu	100	
1897 MAR 15	E	6.80°S	120.80°E	Flores	15		5.5				1.0	obs	Kajuadi				
1897 SEP 21	E	6.80°N	122.00°E	Philippines			8.6				1.0	obs	Jolo				
1897 SEP 21	E		122.10°E	Philippines						1.0	2.5	6.0	Jolo	7.0	Isabela	100	severe

TABLE 2 (Continue

DATE	TSUNAMIGENIC SOURCE									TSUNAMI PARAMETERS						SOCIO ECONOMIC EFFECTS	
	TYPE	LATITUDE	LONGITUDE	LOCATION	EARTHQUAKE				VOLCANO	n	I(T)	WAVE HEIGHT		RUN-UP		DEATHS	DAMAGE
					FOCAL DEPTH	MAGNITUDE ML	MS	MW				MAX M	LOCALITY	MAX M	LOCALITY		
1899 SEP 29	E-L	3.50°S	128.50°E	Banda Sea	60		7.8			0	3.0	9.0	Ceram	12.0	Tehorw	3,864	extreme
1900 JAN 10	E			Halmahera								obs	Galela				
1900 OCT 08	E	3.50°S	136.00°E	Irian Jaya	33		7.8				1.5	obs		(<6.0)	Napan	5	limited
1902 AUG 21	E	6.30°N	123.60°E	Philippines			7.2							obs	Illana	many	severe
1903 MAR 30	E	3.00°S	127.50°E	Ceram			6.5					1.0	Tifu	(<2.0)			
1907 MAR 30	E	3.00°N	122.00°E	Celebes Sea	500		7.3				1.5	obs	Talaud	4.0	Karakelong	400	extreme
1908 MAR 24	E	8.70°S	124.70°E	Timor			6.6			0				25.0	Atupupu		
1910 DEC 18	E	4.00°N	127.00°E	Talaud	33		6.7				-1.0	obs	Lirung	(<2.0)			
1913 MAR 14	E	4.80°N	126.60°E	Sangihe	25		8.3							obs			
1914 MAY 26	E	2.00°S	137.00°E	Irian Jaya	60		7.9	7.9		0	2.0			<6.0	Pom	many	moderate
1915 NOV 06	E	1.00°S	136.00°E	Irian Jaya			6.0							obs	Korim		
1917 JAN 21	E	8.00°S	115.40°E	Bali	33		6.5							obs	Bali	15,000	severe
1917 JAN 31	E	5.60°N	124.80°E	Philippines	33		6.4					1.5	Glan	<2.0		7	limited
1918 JUL 18	V	3.14°N	125.49°E	Sangihe					Banua Wuhu								
1918 AUG 15	E	5.77°N	123.64°E	Philippines	57		8.3	8.2		5	2.5	obs	Halmahera	7.0	Glan	102	severe
1919 JAN 01	E	7.28°N	126.88°E	Philipines	9		7.4	7.0		.0							
1920 JAN 29	*E*	*0.00°N*	*124.00°E*	*Sulawesi*								obs	Gorontalo	*2.0*	*Donggala*		
1921 MAY 14	E	0.70°N	117.90°E	Kalimantan	20		6.2				0.5			1.0	Sekurau		moderate
1921 SEP 11	E	11.00°S	111.00°E	Java			7.5					0.1	Tjilatjap				
1921 SEP 29	E	8.00°N	127.00°E	Philippines	10		7.5				0.5			1.9			
1921 NOV 11	*E*	*8.00°N*	*127.00°E*	*Philippines*	*60*		*7.5*	*7.3*			*1.0*	*obs*	*Sangihe*	*(<2.0)*	*Manay*	*600*	*moderate*
1922 SEP 01	E	9.00°N	123.30°E	Philippines	33		6.0				0.5	obs	Negros	0.1	Zamboanga		limited
1923 FEB 23	E	6.75°N	123.56°E	Philippines							0.5	obs	Cotabato				
1923 MAR 02	E	7.63°N	124.85°E	Philippines	94		7.2	7				obs	Cotabato	(<2.0)			
1923 JUL 18	*E*	*9.50°N*	*125.00°E*	*Philippines*	*33*		*5.5*				*1.0*	*large*	*Mambajao*	*(<2.0)*	*Mambajao*		*limited*
1924 APR 14	E	6.79°N	126.08°E	Philippines	14		8.3	8.1			0.5	large	Caraga	(<2.0)	Binuangan		moderate
1924 AUG 30	E	9.04°N	126.18°E	Philippines	115		7.2	7.1			0.5	obs	Bislig	(<2.0)			moderate
1925 JAN 08	E	8.00°S	116.00°E	Bali								obs	Butung	(<2.0)			
1925 MAY 05	*E*	*9.72°N*	*123.02°E*	*Philippines*	*16*		*6.8*				*0.5*			*(<2.0)*	*Negros*	*17*	*moderate*
1927 AUG 07	V	8.32°S	121.71°E	Flores					Paluweh	0	3.0	10.0	Palu	10.0	Palu	226	severe

TABLE 2 (Continued)

DATE			TSUNAMIGENIC SOURCE									TSUNAMI PARAMETERS						SOCIO ECONOMIC EFFECTS	
			TYPE	LATITUDE	LONGITUDE	LOCATION	EARTHQUAKE FOCAL DEPTH	EARTHQUAKE MAGNITUDE ML	MS	MW	VOLCANO	Tm	I(T)	WAVE HEIGHT MAX M	LOCALITY	RUN-UP MAX M	LOCALITY	)EATHS	DAMAGE
1927	DEC	01	E	0.50°S	119.50°E	Sulawesi	33		6.0			.0	3.0	obs	Palu	15.0	Palu	14	severe
1928	MAR	26	V	6.10°S	105.40°E	Java					Krakatau			obs					
1928	*DEC*	*19*	*E*	*6.87°N*	*124.84°E*	*Philippines*	*12*		*7.3*	*7.3*				obs	*Illana*	*(<2.0)*	*Cotabato*	*4*	moderate
1929	JUN	13	E	7.95°N	126.76°E	Philippines	51		7.2	7.0				obs	Hinatuan	(<2.0)			moderate
1930	MAR	17	V	6.10°S	105.40°E	Java					Krakatau			500	Krakatau				
1930	JUN	19	E	5.60°S	105.30°E	Java	33		6.0					obs	Telukbetung	(<2.0)			
1930	JUL	19	E	9.30°S	114.30°E	Bali	33		6.5					0.1	Besuki	(<2.0)			
1930	*SEP*	*11*	*E*	*2.00°N*	*124.00°E*	*Sulawesi*										*(<2.0)*	*Amurang*		
1931	SEP	25	E	5.41°S	102.34°E	Sumatra	87		7.5	7.3						1.0	Enggano		limited
1932	SEP	09	E	3.60°S	128.30°E	Ceram	33		6.2					obs	Piru	(<2.0)			moderate
1934	JUL	19	E	0.73°S	133.36°E	Irian Jaya	15		7.0					obs					
1936	APR	01	E	4.18°N	126.55°E	Talaud	54		7.7	7.6			1.5	obs	Sangir	3.0	Salebabu		severe
1937	NOV	06	E	3.00°S	132.00°E	Irian Jaya			6.0							(<2.0)			
1938	FEB	02	E	5.10°S	131.53°E	Banda Sea	30		8.2	8.2		.5		1.0	Tual	(<6.0)	Tajandu		severe
1938	FEB	13	E	3.00°S	132.00°E	Irian Jaya								0.5	Fakfak	(<2.0)			
1938	*MAY*	*19*	*E*	*1.00°S*	*120.00°E*	*Sulawesi*	*60*		*7.9*			.5		*3.0*	*Tomini*	*3.0*	*Toribulu*	*16*	severe
1938	OCT	10	E	2.41°N	126.67°E	Halmahera	70		7.3	7.1			-2.0			0.1			
1939	DEC	21	E	0.01°N	122.68°E	Sulawesi	150		8.6					obs	Tomini	(<2.0)	Langoan		extreme
1950	OCT	08	E	3.80°S	128.30°E	Banda Sea	60		7.6	7.4			1.5			(<6.0)			
1952	MAR	19	E	9.50°N	127.20°E	Philippines	25		7.9	7.6			-2.0	0.7	Palau				
1957	JUN	22	E	1.94°S	136.62°E	Irian Jaya	35		7.3	7.3		.0				1.8			
1957	SEP	26	E	8.20°S	107.30°E	Java	33		5.5							(<2.0)			
1957	OCT	26	E	2.00°S	116.00°E	Kalimantan	33		6.0							(<2.0)			
1958	APR	21	E	4.58°S	104.09°E	Sumatra	179		6.5					obs		(<2.0)			
1963	DEC	16	E	6.50°S	105.38°E	Java	53		6.5					obs	Labuhan	(<2.0)			
1965	JAN	24	E	2.46°S	125.96°E	Ceram	30		7.6	8.0		.0	1.5	obs	Sanana	(<6.0)	Sanana	71	severe
1967	APR	11	E	3.47°S	119.07°E	Sulawesi	19		5.8				1.5	obs	Tinambung	(<6.0)	Tinambung	58	severe
1968	AUG	10	E	1.42°N	126.26°E	Sulawesi	19		7.6	7.5		.0	-2.0	obs		0.14			
1968	*AUG*	*14*	*E*	*0.06°N*	*119.70°E*	*Sulawesi*	*17*		*7.7*	*7.3*		*.0*	*3.0*	*10.0*	*Donggala*	*10.0*	*Donggala*	*392*	severe
1969	FEB	23	E	3.18°S	118.80°E	Sulawesi	60		6.9			.0	1.5	4.0	Paletoang	(<6.0)	Madjene	600	severe

TABLE 2 (Continued)

DATE	TSUNAMIGENIC SOURCE									TSUNAMI PARAMETERS						SOCIO ECONOMIC EFFECTS	
	TYPE	LATITUDE	LONGITUDE	LOCATION	EARTHQUAKE				VOLCANO	Tm	I(T)	WAVE HEIGHT		RUN-UP		DEATHS	DAMAGE
					FOCAL DEPTH (KM)	MAGNITUDE						MAX M	LOCALITY	MAX M	LOCALITY		
						ML	MS	MW									
1970 JAN 10	E	6.79°N	126.68°E	Philippines	60		7.3				-3.0	0.1	Davao				
1972 DEC 02	E	6.47°N	126.65°E	Philippines	80		7.8	8.0		-1.0	-1.0	0.5		<2.0			moderate
1975 JAN 15	E	5.00°S	130.00°E	Banda Sea			5.9					obs	Bandaneira				limited
1975 MAR 05	E	2.40°S	126.10°E	Sulawesi			6.5			1.0				1.2	Sanana		limited
1976 AUG 16	E	6.28°N	124.08°E	Philippines	58		8.0	8.1		-1.0	2.5	4.8	Moro	5.0	Alicia	8000	extreme
1977 AUG 19	E	11.13°S	118.38°E	Sumba	21		8.0	8.3		3.0	3.5	30.0	Sumba	15.0	Sumba	189	severe
1978 JUN 14	E	8.28°N	122.40°E	Philippines	36		6.9			0.0		obs		<2.0			
1979 APR 15	E	3.11°N	128.15°E	Halmahera	125		5.0			0.0							
1979 JUL 18	E-L	8.50°S	123.50°E	Flores						3.0	3.0	9.0	Lomblen	10.0	Lomblen	539	severe
1979 SEP 12	E	1.69°S	135.97°E	Irian Jaya	21		8.1	7.5			0.0	obs	Biak	2.0	Yapan	100	severe
1982 DEC 25	E-L	8.40°S	123.00°E	Flores	33		5.9			(1.0)				obs	Larantuka	13	moderate
1983 MAR 12	E	4.09°S	127.85°E	Banda Sea	30		6.0	6.1			1.5			3.0	Ambon		
1984 JAN 08	E	2.90°S	118.70°E	Sulawesi	43		6.6					obs	Mamoju				
1985 APR 13	E	9.21°S	114.20°E	Bali	88		6.2	5.9									
1987 NOV 26	E	8.40°S	124.30°E	Flores	33		6.2			1.0				obs	Pantar		
1989 JUL 14	E	8.10°S	125.10°E	Flores	52		6.2			0.0				obs	Alor	7	limited
1989 JUL 31	E	8.10°S	121.40°E	Flores			6.3			0.0				obs	Maumere	3	limited
1990 APR 18	E	1.20°N	122.82°E	Sulawesi	36		7.4	7.6									
1992 MAY 17	E	7.23°N	126.75°E	Philippines	63		7.5	7.2									
1992 JUN 20	E	1.96°N	122.80°E	Sulawesi			6.2			0.0				obs	Kuandang		
1992 JUL 04	E	8.10°S	124.70°E	Flores			6.2					obs	Alor	obs	Kalabahi	23	moderate
1992 DEC 12	E	8.50°S	121.84°E	Flores	29		7.5	7.7			2.7	25.0	Maumere	26.18	Maumere	2200	extreme
1994 JAN 21	E	1.04°N	127.77°E	Halmaherea	19		7.3	6.9			1.5			2.0	Maluku		
1994 FEB 15	E	5.01°N	104.26°E	Sumatra	23		7.0	6.8									
1994 JUN 02	E	10.42°S	112.91°E	East Java	34		7.2	7.8			2.5			13.9	Sumba	250	severe
1994 OCT 08	E	1.21°S	127.98°E	Halmahera	17		6.8	6.8			1.5			3.90	Obi	1	moderate
1995 JAN 27	E	4.46°S	134.45°E	Irian Jaya	26		6.8	6.8									
1995 FEB 13	E	1.33°S	127.48°E	Halmahera	19		6.8	6.7			1.5			3.0	Obi	1	moderate
1995 MAR 19	E	4.14°S	135.11°E	Irian Jaya	28		7.1	6.8									
1995 MAY 14	E	8.47°S	125.04°E	Timor	20		7.0	6.9			1.5			4.0	E. Timor	8	limited

TABLE 2 (Continued)

DATE	TSUNAMIGENIC SOURCE									TSUNAMI PARAMETERS						SOCIO ECONOMIC EFFECTS	
	TYPE	LATITUDE	LONGITUDE	LOCATION	EARTHQUAKE				VOLCANO	Tm	I(T)	WAVE HEIGHT		RUN-UP		DEATHS	DAMAGE
					FOCAL DEPTH (KM)	MAGNITUDE											
						ML	MS	MW				MAX M	LOCALITY	MAX M	LOCALITY		
1996 JAN 01	E	0.70°N	119.90°E	Sulawesi	25		7.7	7.9			1.8			3.43	Palu	24	Severe
1996 FEB 17	E	0.92°S	136.98°E	Irian Jaya	35		8.1	8.2			1.8			7.68	Biak	108	Severe
1998 NOV 29	E	1.97°S	124.88°E	Sulawesi	22		7.6	7.7			1.5			2.75	Taliabu	34	moderate
2000 MAY 04	*E*	*1.11°S*	*123.57°E*	*Sulawesi*	*26*		*7.5*	*7.6*			*1.0*			5.00			
2000 JUN 04	E	4.72°S	102.09°E	Sumatra	33		8.0	7.9									

TABLE 3

CITDB : TSUNAMI DATA BASE FOR INDONESIAN REGION 2000BC - 2001AD (PROVISIONAL)

EXPLANATION OF PARAMETERS

DATE: All dates are in Universal Coordination Time UT

TSUNAMIGENIC SOURCE

TYPE:	
E	Earthquake
V	Volcano
E-L	Landslide caused by earthquake
V-L	Landslide caused by volcano

EARTHQUAKE PARAMETERS : Where applicable, these parameters referred To the USGS-NEIC earthquake catalogues and US-NOAA tsunami catalogues.

TSUNAMI PARAMETERS

Tm	Tsunami magnitude (Section 3.22; lida et al, 1967)	
	(. .) denotes estimated (not calculated) value	
I(T)	Tsunami intensity (Section 3.2.2; Goloviev and Go, 1974)	
WAVE HEIGHT:	Maximum value and its locality as reported	
	obs	tsunami waves observed, no value reported
	weak	small tsunami waves observed, no value reported
	mod	significant tsunami waves observed, no value reported
	large	large tsunami wave observed, no value reported
RUN-UP :	Maximum value and its locality reported	
	(.. .)	denotes estimated (not calculated) value
	obs	runup observed, no value reported
	mod	significant runup observed, no value reported
	large	large runup observed, no value reported

SOCIO-ECONOMIC EFFECTS

DEATHS : Number of fatalities as reported noting this value is the total Number including the original source (earthquake, volcano) and the

few	small number (probably less than IO), no value reported
many	large number (probably more than 50), no value reported

DAMAGE : As defined by US-NOAA including the built, natural and human Environments

limited	slight, minor, light
moderate	significant
severe	major, heavy
extreme	devastating
catastrophic	total destruction

(More detailed information can be sourced from the data bases/ catalogues referenced in TABLE 1).

TSUNAMI HAZARD ASSESSMENT (PRELIMINARY)

The information contained in the tsunami data base CITDB of TABLE 2, that is, historical tsunami data, provides an empirical method for the preliminary tsunami hazard assessment of the Indonesian region. The following elements were considered in this assessment:

1. TSUNAMI DATA BASE CITDB (TABLE 2)

The tsunami data base CITDB for the time period 2000BC 2001AD clearly shows that a significant number, 179, have impacted upon the region. Of these, 43 tsunamis have been characterised as severe/extreme, with run-up values grater than about 5m and damaging effects recorded. This historical records shows that wave heights of up to IO-20m and runup heights of up to 25m have been recorded. Such events have occurred throughout the Indonesian region, including the Indonesian Arc islands, around the Molucca Sea the near islands of Halmahera, Ceram, Talaud and Sulawesi, and in the Southern Philippines area. Note should be taken of the extreme events such as the 1883 Krakatau volcanic eruption and the 1874 Ceram and 1820 Sumbawa earthquakes where reports suggest runup heights of hundreds of metres.

2. TSUNAMI PARAMETERS

The complete set of tsunami parameters should include those parameters relating to both the “source” of the tsunami generation and the “effects” at the point of maximum tsunami impact.

(a) Tsunamigenic source parameters:

earthquake	origin time, epicentre, focal depth, moment magnitude MW, focal mechanism
volcano	name, location coordinates, type of disruption volcano eruption index (per Acharyn, 1989)
landslide -	cause, origin time, location, type/description

(b) Tsunami effects parameters (at impact site):

wave height -	actual height of tsunami waves in open water; instrumentally recorded on tide-gauges with wave parameters taken from marigrams; anecdotal information (observer location, description of waves, estimated wave heights)
runup	maximum vertical height on land that tsunami waves have reached, above a reference sea level

CAUTION: Questions have been raised as to the validity of some runup values published in tsunami data bases/catalogues. It is has been shown that in some cases such “runup” values were actually wave heights. This issue must be taken into consideration when using published “runup” values for the derivation of other tsunami parameters.

Tide state	In considering the potential effects of tsunami impacts on Coastlines in terms of runup values, the state of the tide when the tsunami reaches the shore may be critical. The maximum runup for a given tsunamic wave height will be greater at the time of high tide than at low tide. This will be accentuated in those regions which have very large ocean tide fluctuations. There is also the case where a small tsunami occurring at high tide may reach a higher elevation on shore than that for a larger tsunami occurring at low tide.

(c) derived parameters

derived parameters	Tm tsunami magnitude Tm = log,H. H = runup (m) (lida et al, 1967) I(T) tsunami intensity I(T) = log2 (2”’ H) (Soloviev and Go, 1974)

3. FUNCTIONAL RELATIONSHIPS

These analyses are based on the statistical processing of historical tsunami runup observations (per tsunami data bases/catalogues) at particular sites. They usually refer to an area or region, rather than being site-specific. **EXTREME CAUTION** must be exercised in attempting to interpret the results for practical applications. This particularly relates to the limitations and uncertainties of the tsunami data base, specifically in terms of the quantity (usually small numbers of observations) and quality of the runup values. As this is a developing scientific tool, such results should be considered only as a guide.

For some areas, because of the sparsity of the tsunami data (that is, irregular and infrequent occurrences), consideration should be given to a deterministic approach and not just the probabilistic (statistical) methods (for example: for Australia; Rynn and Davidson, 1999).

A preliminary estimate of three functional relationships using the tsunami data base and statistical relations of Gusiakov and Hagemeyer (2000) - HTDB CDROM were made for the Indonesian region in toto (taken as lOaN 10%. IIOOE - 140'E) and for a particular localised area around Halmahera Island (taken as 6'N 5% 123OE - 136OE) for a 400 year period (1600 - 2000; default status) for each case. Again, **CAUTION** must be exercised in assigning some reliability to the results.

Indonesian Region (lOoN - IO'S, IIO'E - 140°E)

Tsunami Runup Heights versus Time : A simple geographical description of the nature of tsunami occurrences in a related area. It was clearly evident that there is a probable bias in the available data from about 1800 to 1930 (times of historical exploration) and 1995 to 2000 (instrumental records available). Only 39 events were used in the analysis. A simple view may consider that since 1800, the return period for a significant tsunami event was about 10 years.

Tsunami Runup Frequency Function (F-function) : When statistical analysis that provides an empirical frequency of recurrence (that is, the reverse value to the return period) for potential runup heights.

For example: For Runup H = 20m, Return Period - 100 years
For Runup H = lOm, Return Period - 25 years.

Tsunami Hazard Function (H-function) : A statistical analysis that provides tsunami hazard curves (probability functions) showing the probability of exceedence of any selected runup height for a given period of time (the Return Period).

For example: For Runup H = 60m, Return Period T = 10 years Probability 0.01
Return Period T = 50 years Probability 0.05
Return Period T = 100 years Probability 0.10
Return Period T = 1000 years Probability 0.65.

Halmahera Island Area (6'N 5'S, 123OE - 136'E)

Tsunami Runup Heights versus Time : The same qualifications as for the Indonesian region apply. Only 17 events were used in the analysis. The return period for a significant tsunami event is even less definitive.

F function : This relationship shows, for example, that for
runup H = 20m, Return Period - 300 years
runup H = lOm, Return Period - 80 years.

H -function : While calculations were performed, no reliability can be assigned to this graph.

An example of these estimates of tsunami parameters for the localised area of Halmahera Island is given in the Table 4, where the NEAR-FIELD : LOCAL is defined as the area within 500km of Halmahera Island and NEAR FIELD : REGIONAL as the remainder of the Indonesian Region.

TABLE 4

ESTIMATES OF TSUNAMI PARAMETERS IN RELATION TO POTENTIAL TSUNAMIGENIC SOURCES FOR THE HALMAHERA ISLAND AREA

TSUNAMIGENIC SOURCE			TSUNAMI PARAMETERS		
			RETURN PERIOD (YEARS)	WAVE HEIGHT (MAX M)	RUNUP HEIGHT (MAX M)
EARTHQUAKE	NEAR-FIELD	LOCAL	10	>10.0	50.0
		REGIONAL	1-5	10.0	20.0
	FAR-FIELD	Philippines	10	10.0	25.0
		Pacific Ocean	10	0.5	0.5
		Indian Ocean	100	(small)	(small)
VOLCANO	NEAR-FIELD	LOCAL	25	25.0	25.0
		REGIONAL	100	10.0	10.0
	FAR-FIELD	Philippines	?	(10.0?)	(10.0?)
		Pacific Ocean	(100?)	(small)	(small)
LANDSLIDE	NEAR-FIELD	LOCAL			
		Earthquake	?	(10.0?)	(10.0?)
		Volcano	?	(10.0?)	(10.0?)
		REGIONAL			
		Earthquake	(100?)	10.0	10.0
		Volcano	(100?)	10.0	10.0
	FAR-FIELD	(E-L/V-L)	?	(small)	(small)
DIAPIRS			(no information available)		
ASTEROID IMPACT			(no information available)		
NUCLEAR EXPLOSION			(no information available)		

4. POTENTIAL TSUNAMIGENIC SOURCES

The potential tsunamigenic sources considered in this hazard assessment, for both the near-field and far-field, included:

- earthquake
  - Indonesian Region (Gusiakov and Hagemeyer, 2000; Hamzah et al, 2000)
  - Pacific Ocean and Indian Ocean Basins (Rynn and Davidson, 1999)
- volcano
  - Indonesian Region (Latter, 1981; Gusiakov and Hagemeyer, 2000)
- submarine landslide
  - turbidity currents (Tappin et al..1999; Prasad et al, 2000)
  - gravity slides (Campbell and Nottingham, 1999)
  - meteorological phenomena (large storms)
- asteroid impacts (Solem, 1999)
- diapiric eruptions (DeLange and Hull, 1994)
- nuclear explosions (at sea).

Those identified in all available seismological analyses are listed in Table 5.

TABLE 5

POTENTIAL TSUNAMIGENIC SOURCES IN THE INDONESIAN REGION

EARTHQUAKE ZONES

Southwest Sumatra, Java, Sumbawa, Sumba. Flares, Banda Sea, Sulawesi. lrian Jaya, Ceram, Sula, Sangihe, Talaud, Molucca, Halmahera. Southern Philippines

VOLCANO

Krakatau	Sunda Strait	6.1 O'N	105.42"E
Tambora	Sumbawa	8.25'N	118.80°E
Rokatenda	Flores	8.60°N	121.70"E
Paluweh	Flares	8.32ON	121.71'E
Yersey	Banda Sea	7.53'N	123.95"E
Emperor of China	Banda Sea	6.62ON	124.22"E
Nieuwerkerk	Banda Sea	6.60"N	124.68"E
Teen	Banda Sea	6.92"N	129.13"E
Banda Api	Banda Sea	4.52'N	129.87'E
Ternate (Gamalama)	Halmahera	0.80°N	127.33OE
Gamkonora	Halmahera	1.38ON	127.52OE
Ruang	Sangihe	2.28ON	125.43OE
Banau Wuhu	Sangihe	3.67ON	125.50"E
Jolo (Bau Dajo)	Phjlippines	5.95'N	121.07'E
Taal	Philippines	14.00°N	120.99"E

LANDSLIDE

Volcano induced	Sangihe. Ceram
Earthquake induced	Flares, Bali

5. SEICHE

Seiches are wave activity related to tsunamis, both being gravity waves. Whereas a tsunami is a travelling wave, a seiche is a standing wave. Seiches occur in fully or partially enclosed bodies of water such as lakes or embayments/harbours, respectively. When the period of the tsunami source wave is close to that of the normal mode of the body of water, seiches can resonate and amplitudes then increase. The potential for seiche occurrence would be in site-specific locations.

6. TSUNAMI TRAVEL TIME CHARTS

Tsunami travel times are dependent on the distance and path from source to point of impact. Account must be taken of geography of the region (shape of coastline, islands etc) for reflections and refractions of the tsunami waves. This element is vital in notification of WARNINGS and emergency procedures. At present, these are published for the Pacific Ocean Basin by the US/NOAA Pacific Tsunami Warning Centre (PTWC) in Hawaii, and for the Indian Ocean basin in the publication of Otto and Murty (1996).

7. COMPUTER MODELLING

In recent years, with the availability of more accurate bathymetric data, numerical modelling by computer has advanced to provide greatly improved theoretical estimates of tsunami wave travel times, wave heights and runup heights. Currently, extensive research is being undertaken to better delineate source characteristics, particularly gravity induced (slope) and submarine landslides.

TSUNAMI HAZARD ZONING

This preliminary tsunami hazard assessment was quantified in terms of “Tsunami Hazard Zones”, a given in Table 6.

TABLE 6

TSUNAMI HAZARD ZONES (PROVISIONAL)
FOR INDONESIAN REGION

CHARACTERISTIC	TSUNAMI HAZARD ZONES		
	HI	MED	LO
RUN-UP HEIGHT	>4	24m	c2m
TSUNAMI MAGNITUDE	>2	1	<o
TSUNAMI WAVE HEIGHT	>Im	O.I-lm	<O.lm
DAMAGE OBSERVED FROM HISTORIC TSUNAMIS	SIGNIFICANT	MINOR	NONE
COASTLINE ADJACENT TO NEAR-FIELD TSUNAMIGENIC SOURCES	YES	YES	NO
POTENTIAL TSUNAMI INUNDATION IN THE FUTURE	PROBABLE	POSSIBLE	UNLIKELY

TSUNAMI VULNERABILITY ASSESSMENT

The potential damage from a tsunami impact at a site is relative to the runup height at that site. Such damage refers to the built, natural and human environments (at the coastline), and so includes coastal towns and villages, development and major industrial projects. A vulnerability assessment at a specific location can be characterised by integrating the vulnerability inventory (catalogue of attributes with comparison maps and GIS surveys) with damage assessments (if available, based on historic records of damage). This would involve both the terrestrial and marine environments, to include:

- human toll
  - deaths
  - injuries
  - socio-economic effects
- built environment
  - property
  - infrastructure
  - agriculture
- natural environment
  - topography
  - bathymetry

TSUNAMI RISK ASSESSMENT

A comprehensive risk assessment involves the integration of the hazard and vulnerability assessments, both quantitatively and qualitatively (for example: Rynn and Davidson, 1999, for Australia and its Island Territories; Prasad et al, 2000, for the City of Suva, Fiji).

TSUNAMI WARNINGS

The concept of tsunami warnings relate to emergency procedures to be taken to reduce potential losses from an impending tsunami. At this time, there appears to be no warning system in relation by Indonesia. However, normal operations of the Pacific Tsunami Warning Center in Hawaii do include Indonesia in their warnings for tsunamis generated in the Pacific Ocean Basin. There are no warnings issued for Indian Ocean Basin tsunamis.

In the event of the tsunami warning being issued, the most reliable information available is by reference to the tsunami travel time charts. However, in localised in areas of near-field tsunamis, where travel times would be less than 1-2 hours, such warnings would be far too short to enact emergency procedures (as was the case, for example, in the July 1998 Aitape, Papua New Guinea tsunami wherein travel times were about 10 minutes; Tappin et al, 1999). A provisional tsunami warning approach is given in Table 7.

TABLE 7

TSUNAMI WARNINGS (PROVISIONAL)
FOR INDONESIAN REGION

TSUNAMI CLASSIFICATION	DISTANCE (KM)	TSUNAMI TRAVEL TIME (HOURS)	TSUNAMI WARNING
NEAR-FIELD	0 - 50	< 0.5	NONE
	50 500	< 0.2	NONE
	500 - 1500	2 - 3	LIMITED
	1500-2500	3 - 6	PROBABLE
FAR-FIELD	>2500	6 - 16	AMPLE

SUMMARY

Tsunamis, in addition to earthquakes and volcanic eruptions, are a major natural hazard for Indonesia. Their effects have been, and have future potential to be, devastating on the coastal areas of many, if not all, of the Indonesian islands. In the historical record, the human toll, damage to the built (major centres of population, villages, buildings, infrastructure, etc) and natural environments, and disruption to the socio-economic fabric of the nation and its peoples, are well documented. The tsunamigenic sources have all been in the near-field (within the Indonesian region) as a consequence of earthquakes, volcanoes and collateral landslides.

Based on the tsunami data base CITDB, and in view of the continuous tectonic activity in the region, there is unquestionably a real and significant probability that impacts of near-field tsunamis, with consequential potential damage, will be a realistic situation in the future. Serious consideration should be given to mitigation strategies and measures for this natural hazard of tsunami in terms of both expanded hazard assessments (more detailed deterministic and probabilistic analyses of the available data and computer modelling) and vulnerability assessments. Practical applications of the consequent tsunami risk assessments would then provide a proactive approach to:

- reduction of community vulnerability
- establishment of a local tsunami warning system
- development of disaster plans
- development of evacuation plans
- risk management procedures
- implementation into engineering design of major developmental projects, both on land and in the adjacent sea areas.

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