KNOWLEDGE NOTE 5-1

CLUSTER 5: Hazard and Risk Information and Decision Making

Risk Assessment and Hazard Mapping

GFDRR
Global Facility for Disaster Reduction and Recovery

THE WORLD BANK

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Risk Assessment and Hazard Mapping

Hazard and risk assessments are the crucial first step in disaster risk management (DRM) and the basis for formulating DRM policies. They must take into account worst-case scenarios in the event of the largest possible hazard, while recognizing that hazard assessments of earthquakes and tsunamis will always have their limitations and associated uncertainties. In Japan so-called hazard maps, that combine hazard information with evacuation routes and locations of evacuation centers, are effective tools for promoting evacuation procedures and risk awareness among the public. However, in the case of the Great East Japan Earthquake (GEJE), these hazard maps, created before the event, may have given people a false sense of security by underestimating the disaster's potential impact. Hazard maps should be designed to guide and facilitate prompt evacuation. They should be easy to understand and readily available.

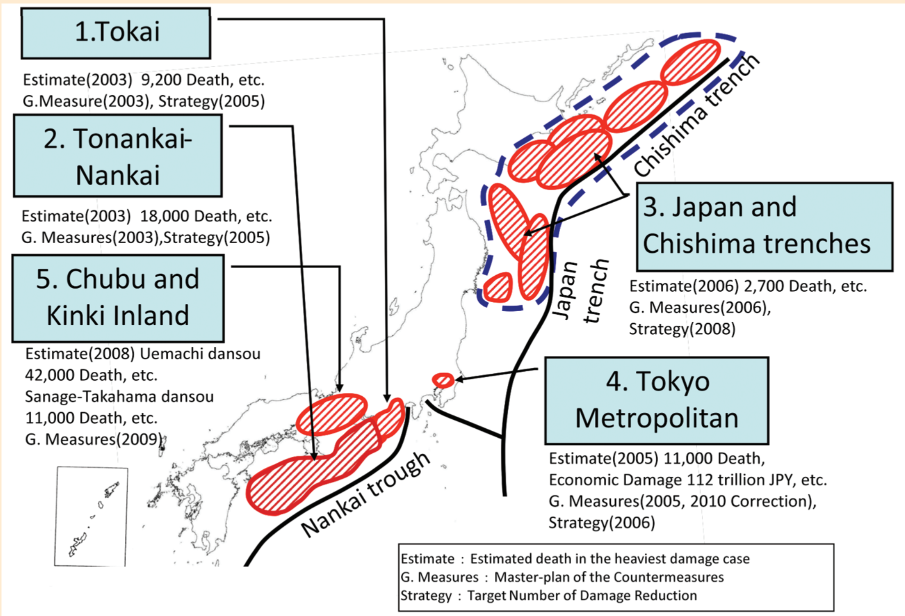
Risk assessment involves estimating the hazard levels of possible earthquakes and tsunamis to be considered when formulating disaster management policies. It is the first step in developing disaster risk management (DRM) plans and countermeasures. In Japan, the responsibility for risk assessment rests with government agencies at multiple levels. Implementing agencies at the national, prefectural, and municipal levels normally conduct risk assessment to inform their planning and the design of preventive measures. The national government is responsible for providing information and technical assistance to help prefectural and municipal entities assess risks properly and to reflect these risks in DRM measures.

FINDINGS

MEGADISASTER HAZARDS CONSIDERED IN RISK ASSESSMENT

In Japan, countermeasures against earthquakes and tsunamis have been based on the risks associated with five large earthquakes that have occurred over the past several hundred years (figure 1 and box 1). The Central Disaster Management Council has set up a committee to investigate and assess the potential hazard levels and expected damages

FIGURE 1: **Five megaearthquakes used as basis for risk assessment**



Source: Cabinet Office (CAO).

from each of these scenarios. The committee also developed DRM strategies and a master plan for preventive actions as well as postdisaster response and recovery measures. DRM measures implemented at the national, prefectural, and municipal levels have traditionally been based on these strategies and plans.

The March 11 disaster occurred in the vicinity of the Japan and Chishima trenches—the region where the Central Disaster Management Council's committee had investigated trench-type earthquakes. From the list of past earthquakes in the region (figure 2), eight were selected for consideration, based mainly on their intensity, frequency, and the possibility of recurrence in the same area. The selected historic earthquake scenarios included the Meiji-Sanriku Earthquake Tsunami of 1896, which generated a giant 20-meter-high tsunami, and Miyagi-ken-oki (Miyagi Prefecture) earthquakes that have been occurring at 40-year intervals. On the other hand, earthquakes such as those off the coast of Fukushima Prefecture were not selected because their probability of occurrence was estimated to be low, at 7 percent (figure 3). Furthermore, the Jogan Earthquake of 869, believed to have caused massive tsunamis in the east Japan region, was excluded because the available modeling techniques were unable to replicate its seismic intensity and tsunami height, and the probability of recurrence in the same area was considered to be very low.

BOX 1: **Principles for selecting large-scale earthquake scenarios and the actual earthquakes selected**

- Repeated occurrence
- High probability of future occurrence
- Possibility of occurring within the next 100 years
- Not considered if an active fault earthquake has occurred in the last 500 years
- A significant number of occurrences can be identified in historical records
- Magnitude is between M7 to M8
- Consider the economic and social activities and central administrative functions to be protected

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Earthquakes meeting the above criteria:

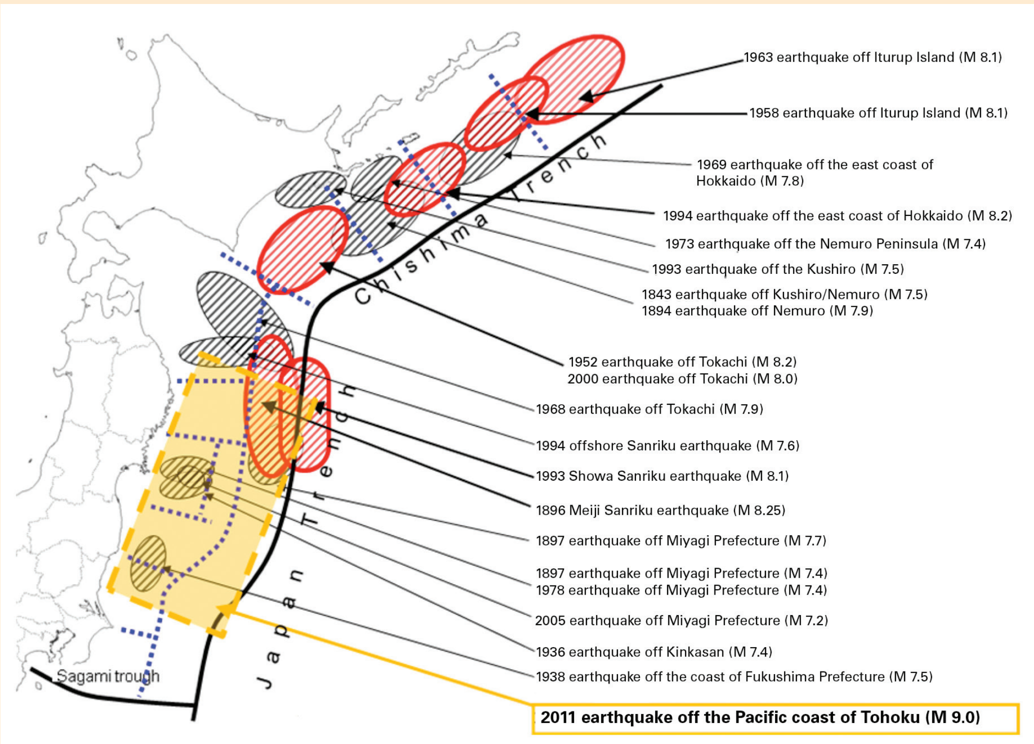
- Tokai earthquake (M8.0)
- Tonankai/Nankai earthquake (M8.6)
- Japan and Chishima trenches earthquake (M7.6-8.6)
- Tokyo Metropolitan inland earthquake (M6.9-7.5)
- Chubu and Kinki inland earthquake (M6.9-8.0)

THE MAGNITUDE OF EARTHQUAKE AND TSUNAMI HAZARDS EXCEEDED PREDISASTER ESTIMATES

As illustrated in figure 2, the March 11 earthquake had a very large epicentral and tsunami source area, larger than any earthquake recorded in Japan's history. Furthermore, its magnitude of Mw9.0 exceeded the hazard level of any earthquake in the country ever considered for purposes of disaster management. Thus, the extent of the high seismic intensity area of the actual earthquake was much larger than expected, and the area that experienced Japanese seismic intensity of 5+ or larger was about 10 times the estimate (figure 4). Furthermore, the actual tsunami height was twice the height used in the predisaster tsunami hazard predictions (figure 5).

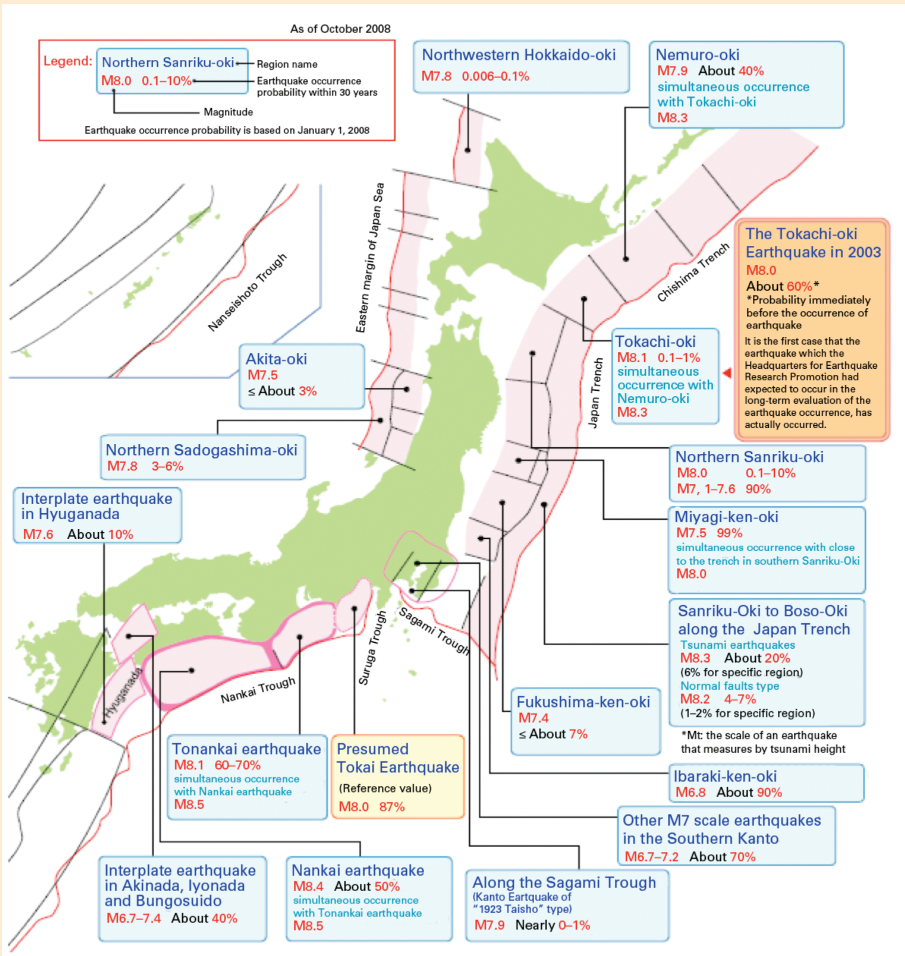
Because the magnitude of the GEJE and tsunami far exceeded the predisaster estimates, the Japanese government has been revising its methods of assessing earthquakes and

FIGURE 2: **Historical occurrence of trench-type earthquakes in the vicinity of Japan and the Chishima trenches**



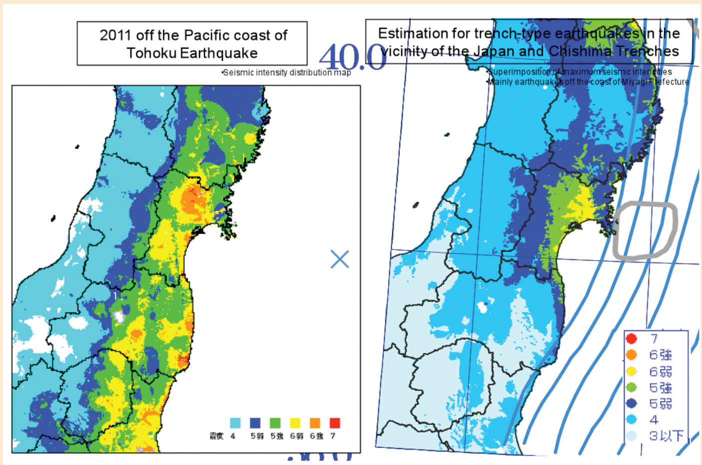
Source: CAO.

FIGURE 3: **The probability of occurrence, magnitude, and location of potential earthquakes in Japan**



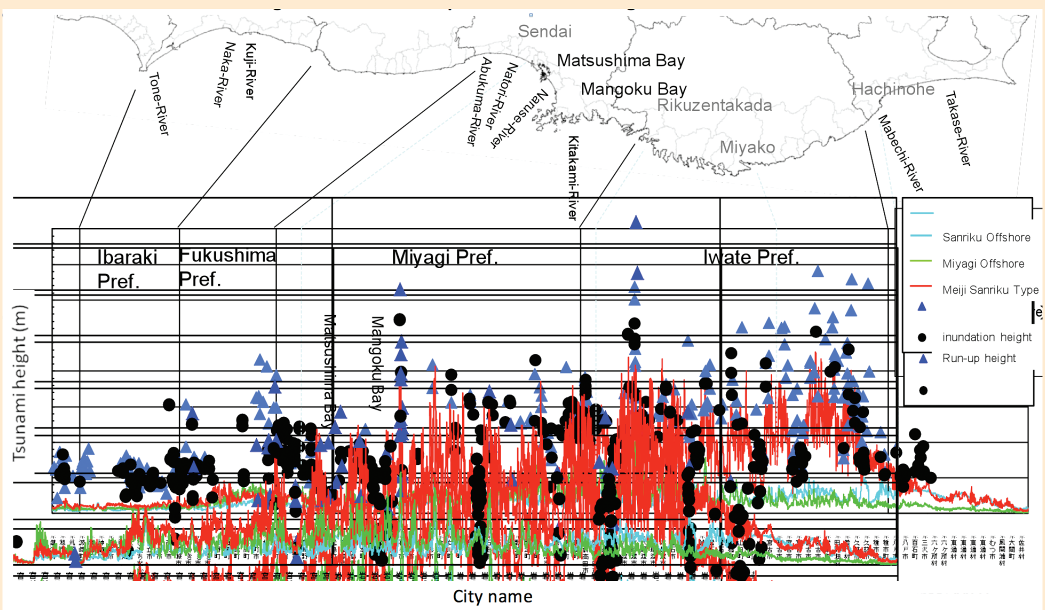
Source: Headquarters of Earthquake Research Promotion.

FIGURE 4: **Actual versus predicted seismic intensity**



Source: CAO.

FIGURE 5: **Actual versus predicted tsunami height**



Source: MLIT.

tsunami hazards. The Basic Disaster Management Plan, revised after the GEJE, provides the following guidelines for estimating earthquakes and tsunamis.

- Earthquake and tsunami countermeasures should be based on scenarios that take into account the largest-possible earthquakes and tsunamis, which should be considered from every possible angle using all scientific means.
- Earthquake and tsunami scenarios should be based on the most accurate earthquake records available, going as far back in history as possible, and in combination with an analysis of historical literature, topographical and geological studies, as well as other scientific findings.

ESTIMATING DAMAGE

Because of the underestimation of the earthquake and tsunami hazards, the damage caused by the GEJE far exceeded the predisaster damage estimates. The number of completely destroyed buildings was about six times the estimated amount, and the number of human lives lost was more than seven times the estimation (table 1). The conventional methodology for estimating damages can be characterized as follows.

- Quantitative estimation including direct physical damage, human loss, damages to lifeline and transportation infrastructure, economic losses (direct and indirect).
- Qualitative estimation including fires induced by tsunami; critical lifeline infrastructure facilities such as power plants, gas production plants, water and wastewater treatment plants, and so forth.
- Three scenarios reflecting different seasons and times of day (winter 5 am, summer 12 pm, winter 6 pm), which are likely to affect fire scale and incidence.

TABLE 1: **Comparison of estimated and actual damage**

	Estimation	*GEJE*	*Ratio*
Area with seismic intensity of 5+ or larger (km^2)	3,540	34,843	9.8
Inundation area (km^2)	270	561	2.1
Buildings completely destroyed	21,000	128,530	6.1
Disaster waste (tons)	1,400,000	24,900,000	17.8
Deaths (includes missing)	2,700[a]	19,185[b]	7.1

Note: The figures for estimation reflect the larger of the damage estimates for the Miyagi-ken-oki and Meiji-Sanriku earthquakes.
a. Estimation of deaths uses the case of the Meiji-Sanriku earthquake case with a low disaster awareness level.
b. Deaths from the GEJE as of January 31, 2012.

- A facility is considered to have received no damage if it is equipped with enough mitigation measures against ground motion and fire.

A quantitative estimation of the impact was carried out using the relationship between the magnitude of the hazard (seismic intensity, maximum ground velocity, tsunami inundation depth, and so on) and the actual damage (number of destroyed houses, human loss, and so on), which was established based on historical earthquakes. For example, tsunami damage to buildings was estimated using the assumption that a building is completely destroyed if the inundation depth is 2.0 meters or more based on empirical evidence. Human losses caused by tsunamis were estimated based on the tsunami-affected population and historical records of death by tsunami inundation depth and estimated evacuation rates (percentage of people who can obtain warning information and the time it takes for people to evacuate). These were calculated for 50-meter-by-50-meter grid cells, and overlaid on exposure data, such as spatial socio-demographic data, available nationwide from the Geospatial Information Authority of Japan (GSI). Furthermore, infrastructure damage was estimated on the basis of the estimated number of destroyed buildings, lifeline failure rates and the number of days required for restoration, for which empirical relationships have been established based on previous disasters.

The underestimation of damage in the case of the GEJE was largely due to an underestimation of the magnitude of the hazards involved. Also, it has been pointed out that some factors—such as evacuation rates—used for damage estimation purposes were higher than actual rates, which could have further contributed to an underestimate of human losses. At the time of this writing, the damage estimation methodology is being revised.

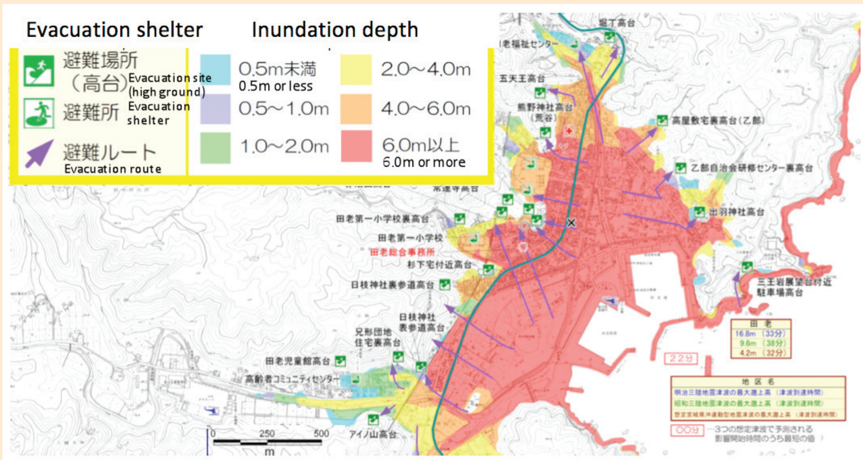
EARTHQUAKE AND TSUNAMI SIMULATION AND HAZARD MAPPING

Hazard maps provide important information to help people understand the risks of natural hazards and to help mitigate disasters. Hazard maps indicate the extent of expected risk areas, and can be combined with disaster management information such as evacuation sites, evacuation routes, and so forth. In Japan, hazard maps are prepared and made available for various hazards such as earthquakes, tsunamis, floods, landslides, liquefaction, and volcanic eruption (KN 5-2 and 5-3).

Japan's prefectural governments conduct hazard mapping, and the hazard data they prepare, for example, expected inundation depth and extent, is in turn used by the municipalities to prepare disaster management maps called hazard maps, that indicate not only the expected hazard but also information such as evacuation routes and evacuation sites (figure 6). The Act on Special Measures for Earthquake Disaster Countermeasures, passed in 1995, mandates the prefectural governments and local municipalities to prepare these maps to promote awareness of earthquake and tsunami risks in their respective jurisdictions. As of 2010, more than 80 percent of the prefectures had prepared tsunami inundation maps and 50 percent of coastal municipalities were equipped with tsunami hazard maps.

The national government provides technical assistance and guidelines to promote hazard mapping by local governments. In 2004, the central government prepared *Tsunami and Storm Surge Hazard Map Guidelines* to help the municipalities in creating hazard maps and to promote the use of hazard maps throughout the country. The guidelines provide infor-

FIGURE 6: **An example of a tsunami hazard map, Miyako City, Iwate Prefecture**

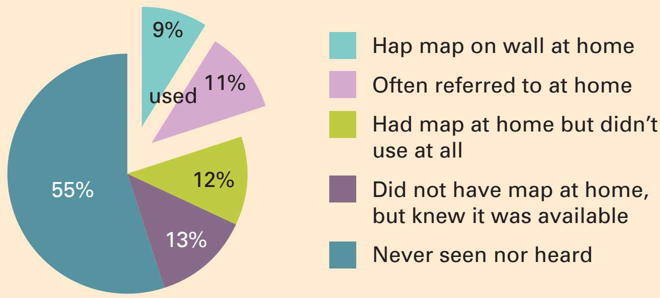


Source: Miyako City.

TABLE 2: **Methods for defining inundation risk areas**

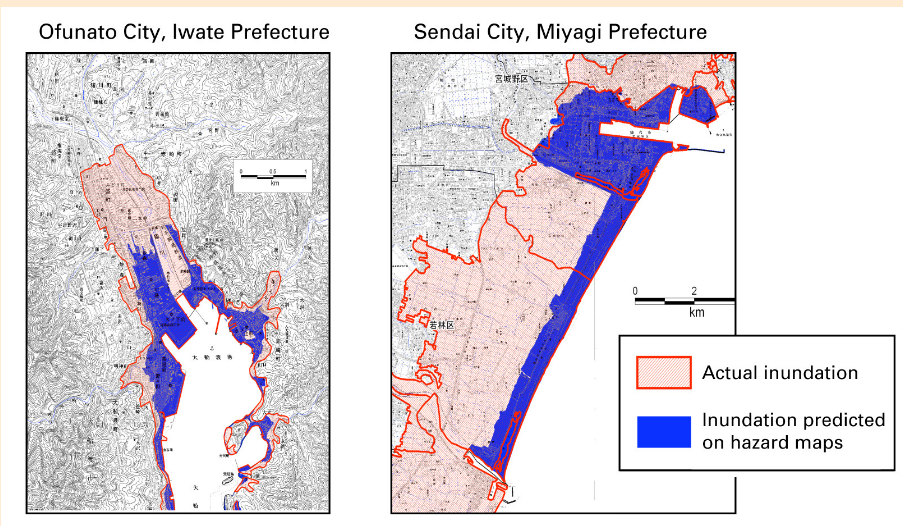
Method	*Procedure*	*Advantages/disadvantages*
Numerical simulation in time series	Use numerical models to estimate inundation area as well as inundation depth and flow velocity, inundation time.	Precise assessment is possible and can take into account the effects of the disaster mitigation structures. Resource intensive.
Level-filling method	Calculate the inundation based on the height and width of the tsunami and estimate the extent of inundation based on the topographical data.	Not so resource intensive. Ignores the effects of structures and buildings and the momentum of water flow (tsunami run-up).
Prediction based on past inundation	Define the risk area based on the inundation area of historical tsunami events.	Simple and low cost. Cannot be used for areas with no historical records. Cannot reflect changes such as construction of disaster reduction facilities.
Estimation based on ground elevation	Define high-risk areas as those areas lying lower than the expected tsunami height.	Simple and low cost. Cannot take into account the effects of structures and buildings and the momentum of water flow (tsunami run-up).

FIGURE 7: **Hazard map usage patterns**



Source: CAO..

FIGURE 8: **Inundation area: hazard map versus actual**



Source: CAO..

mation on the basic concepts of tsunami and storm surge hazard maps, and the standard methodology for preparing them. The guidelines explain in depth the numerical simulation methodology for identifying inundation risk areas, which is the principal means of tsunami hazard mapping. Alternative methodologies, as shown in table 2, are also explained so that the best method can be selected according to the resources and data available. Numerical simulation of tsunamis generally requires the following steps.

- Development of a fault model
- Topographic data
- Setting of initial water level conditions (typically uses the vertical displacement calculated by the fault model)
- Calibration and verification of the model
- Predictive simulation

Hazard maps in Japan have been used by the municipalities to design evacuation procedures. But they have not been utilized for land use or development planning. The lessons learned from the GEJE have prompted the Japanese government to implement a new act to create tsunami-resilient cities. The new legislative framework calls for the prefectural governments to prepare an inundation risk map, which is to be used for regulating land use and mitigating the effects of a tsunami (KN 2-7).

HAZARD MAPS IN THE DISASTER-AFFECTED AREAS

All municipalities hit by tsunamis during the GEJE had prepared hazard maps before the earthquake and tsunami. But surveys show that only 20 percent of the people knew about these hazard maps (figure 7); and the extent of flooding indicated on the hazard maps was in many cases underestimated compared to the actual inundation area (figure 8). It is likely that these maps provided residents with a false sense of safety, and prevented people from evacuating, resulting in greater human losses.

LESSONS

- Hazard assessment is critical since it serves as the basis for DRM policies. Earthquake and tsunami hazard assessment is conducted extensively in Japan to raise public awareness and to prepare for disasters.
- Predisaster damage estimation was low due to the underestimation of hazard levels. Past assessments did not adequately consider certain kinds of damage, including from long-period seismic waves, tsunami-induced fires, and nuclear accidents.
- Recognizing the uncertainties associated with hazard assessment, the largest-possible hazard scenario should have been used, drawing on all available information including not only seismological but also geological, archaeological, and historical studies looking at tsunami deposits, ancient documentation, and so on.
- Hazard maps were developed by all municipalities in the disaster-hit areas, and served as important tools for designing evacuation procedures.
- Hazard maps should facilitate and guide people's evacuation efforts and should not contribute to a false sense of safety. Providing information on inundation risk zones

for multiple levels of hazards including low-frequency events, or information directly linked with tsunami warnings would be effective. The meaning of the information provided on the maps needs to be clear and adequately explained to the users.

- Risk information must be communicated to the public effectively. In the GEJE, only 20 percent of the people made use of hazard maps.

RECOMMENDATIONS FOR DEVELOPING COUNTRIES

- Understanding hazard and risk is a vital component of DRM. Quantitative estimation of potential damage is important as it informs the appropriate strategies and measures to be taken. Risk exposure data should be collected, mapped, and shared as they are vital components of risk assessment.

- While bearing in mind that the hazard assessment of earthquakes and tsunamis has limitations and uncertainties, the largest possible hazard should be investigated and considered in formulating DRM policies. Hazard assessment should not rely solely on statistical analysis based on historically recorded earthquakes and tsunamis, because historical records may not account for the maximum-possible hazard levels that may occur in the future. Also, disasters have occurred for which there are no records available. The level of hazard to be used in designing structural measures should be selected based on local conditions. Hazard and risk assessment should be revised and updated periodically with the latest findings and in light of more recently experienced disasters.

- Hazard maps are effective tools for promoting risk awareness, for designing evacuation procedures, and for deciding the locations of evacuation facilities and shelters. Hazard maps should be easy to understand and easy to use for purposes of prompt evacuation, and users should be aware of the limitations and uncertainties of the information they contain. Considering budget and technical constrains, risk estimation methods can be selected as explained in table 2.

- Sharing hazard and risk data and information is crucial. Data can be shared through central depositories that are open to the public, among other means (see KN 5-2).

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