JRC Scientific and Technical Reports

Handbook of Tsunami Evacuation Planning

SCHEMA (Scenarios for Hazard-induced Emergencies Management),
Project n° 030963, Specific Targeted Research Project, Space Priority

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Executive summary

This handbook is dedicated to provide thorough and hands-on information and a fully-comprehensive methodology of tsunami evacuation plan generation. Hence community-employed decision makers or similar stakeholders are supplied with a detailed guideline to implement a fully-fledged evacuation plan within three stages: set-up of valid first instance of evacuation plan, mid-term revision, and long-term revision and integration.

Local tsunami risk assessment and all subsequent implications on evacuation planning are based on (1) knowing the to-be-expected tsunami wave height, and (2) the to-be-expected arrival time of the first devastating tsunami wave. The first parameter helps to calculate the area at risk; the second parameter gives an indication of how fast the evacuation has to take place. . Evacuation has to take place on a given network of suitable roads or paths. In this context, if necessary, the methodology foresees also the inclusion of additionally to be built escape routes and/or safe places in order to produce a fully working evacuation plan that fulfils the basic requirements. Safe areas (shelters) are higher located places, either on natural ground, or on artificially built-up constructions including buildings higher than three storeys

The methodology also explains how to implement a valid instance of evacuation plan by marking the identified escape routes and shelters in reality, and how to disseminate all information to the affected population. Within a mid-term review the evacuation plan has to be maintained constantly and appropriate authority-own measures have to be guaranteed.

The long-term review, finally, keeps track of all other information needed to run the evacuation plan properly: integration with early-warning systems, integration with other emergency plans, checking of legal obligations. Ideally, the whole evacuation plan should be reviewed together with the affected population to obtain maximum acceptance. In this context, and if necessary, adaptations should be made in order to guarantee the well-functioning of the whole plan within its best performance.

The handbook also presents the results gathered during interviews with potentially affected persons (Setubal case study) and concludes mentioning the difficulties and limitations that may arise during the generation of evacuation plans.

This work has been realized in the framework of the FP6 European co-funded SCHEMA project (SCenarios for Hazard-induced Emergencies MAnagement, www.schemaproject.org). A description of the purposes and achievements of the project together with the list of the partners can be found in the Annex.

1 Strategy for tsunami hazard risk reduction

1.1 Scientific basis of the decision process for tsunami warning

1.1.1 Assess the exposure level of population: use of scenarios

The risk of tsunami striking a coastline is determined by either the probability of having disastrous tsunami waves or the maximum expected wave height coupled to the degree of vulnerability of exposed stakes (buildings, life, lifelines, and environment)

The quintessence of SCHEMA project is the use of realistic scenarios of potential tsunami wave generation. These scenarios can be selected on the basis of historical events (e.g. the 1755 Lisbon earthquake and tsunami or the 1979 Nice submarine landslide) or scientific insights (e.g. knowledge of existing active faults or submarine instabilities).

As several possible scenarios may exist in each location, it has been commonly agreed within SCHEMA project [Tinti et al., 2010] to take the worst-case scenario for which the following information can be obtained by means of numerical modelling: the maximum expected wave height, the run-up, the land area that will be flooded by the tsunami waves, the velocity of the incoming waves and the maximum retreat of the sea. Among other usages, this information allows checking the stability of exposed buildings and to create a selection of non-collapsing houses.

1.1.2 Influence of source distance and early warning efficiency

The available time to evacuate depends on the distance from the source (earthquake, landslide, volcanic eruption) and on the existence or efficiency of the tsunami early warning system.

Around the Mediterranean basin many locations are exposed to near-field tsunamis (distance to source up to 400km). In the worst-case situations, warning time delays are minimal (up to 5 minutes). In other basins, a tsunami warning may precede various hours before the arrival of the striking waves. Message Content 1 – 3, for example, show a Pacific-wide tsunami warning issued after the February 2010 earthquake off the Chilean coast. Tsunami early warnings are issued after appropriate measures have been undertaken that detect anomalous wave heights (often after an earthquake has happened).

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TSUNAMI BULLETIN NUMBER 017
PACIFIC TSUNAMI WARNING CENTER/NOAA/NWS
ISSUED AT 2241Z 27 FEB 2010

THIS BULLETIN APPLIES TO AREAS WITHIN AND BORDERING THE PACIFIC
OCEAN AND ADJACENT SEAS...EXCEPT ALASKA...BRITISH COLUMBIA...
WASHINGTON...OREGON AND CALIFORNIA.

... A WIDESPREAD TSUNAMI WARNING IS IN EFFECT ...

A TSUNAMI WARNING IS IN EFFECT FOR

 CHILE / PERU / ECUADOR / COLOMBIA / ANTARCTICA / PANAMA /
 COSTA RICA / NICARAGUA / PITCAIRN / HONDURAS / EL SALVADOR /
 GUATEMALA / FR. POLYNESIA / MEXICO / COOK ISLANDS / KIRIBATI /
 KERMADEC IS / NIUE / NEW ZEALAND / TONGA / AMERICAN SAMOA /
 SAMOA / JARVIS IS. / WALLIS-FUTUNA / TOKELAU / FIJI /
 AUSTRALIA / HAWAII / PALMYRA IS. / TUVALU / VANUATU /
 HOWLAND-BAKER / NEW CALEDONIA / JOHNSTON IS. / SOLOMON IS. /
 NAURU / MARSHALL IS. / MIDWAY IS. / KOSRAE / PAPUA NEW GUINEA /
 POHNPEI / WAKE IS. / CHUUK / RUSSIA / MARCUS IS. / INDONESIA /
 N. MARIANAS / GUAM / YAP / BELAU / JAPAN / PHILIPPINES /
 CHINESE TAIPEI

THIS BULLETIN IS ISSUED AS ADVICE TO GOVERNMENT AGENCIES.  ONLY
NATIONAL AND LOCAL GOVERNMENT AGENCIES HAVE THE AUTHORITY TO MAKE
DECISIONS REGARDING THE OFFICIAL STATE OF ALERT IN THEIR AREA AND
ANY ACTIONS TO BE TAKEN IN RESPONSE.

AN EARTHQUAKE HAS OCCURRED WITH THESE PRELIMINARY PARAMETERS

 ORIGIN TIME -  0634Z 27 FEB 2010
 COORDINATES -  36.1 SOUTH   72.6 WEST
 DEPTH      -  55 KM
 LOCATION   -  NEAR COAST OF CENTRAL CHILE
 MAGNITUDE  -  8.8
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Message Content 1: Tsunami warning issued at the occasion of the Chile earthquake (February 2010)

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MEASUREMENTS OR REPORTS OF TSUNAMI WAVE ACTIVITY

 GAUGE LOCATION       LAT  LON   TIME      AMPL      PER
 ------------------- ----- ------ ----- --------------- -----
 NUKUALOFA TO        21.1S 175.2W 2024Z  0.10M /  0.3FT  62MIN
 KAWAIHAE HAWAII     20.0N 155.8W 2211Z  0.52M /  1.7FT  24MIN
 BARBERS PT HI       21.3N 158.1W 2140Z  0.19M /  0.6FT  76MIN
 KAUMALAPAU HAWAII   20.8N 156.9W 2136Z  0.18M /  0.6FT  56MIN
 KAHULUI MAUI        20.9N 156.5W 2147Z  0.98M /  3.2FT  22MIN
 NAWILIWILI KAUAI    22.0N 159.4W 2151Z  0.28M /  0.9FT  44MIN
 PAGO PAGO AS        14.3S 170.7W 2132Z  0.66M /  2.2FT  12MIN
 MONTEREY HARBOR CA  36.6N 121.9W 2031Z  0.32M /  1.1FT  56MIN
 SANTA MONICA CA     34.0N 118.5W 2035Z  0.41M /  1.4FT  32MIN
 SANTA BARBARA CA    34.4N 119.7W 2029Z  0.22M /  0.7FT  48MIN
 SAN DIEGO CA        32.7N 117.2W 2036Z  0.13M /  0.4FT  20MIN
 APIA UPOLU WS       13.8S 171.8W 2018Z  0.16M /  0.5FT  16MIN
 RAROTONGA CK        21.2S 159.8W 1907Z  0.15M /  0.5FT  24MIN
 ACAPULCO MX         16.8N  99.9W 1931Z  0.62M /  2.0FT  26MIN
 DART SAN DIEGO 4641 32.2N 120.7W 1931Z  0.06M /  0.2FT  24MIN
 LOTTIN PT NZ        37.6S 178.2E 1934Z  0.15M /  0.5FT  10MIN
 RAROTONGA CK        21.2S 159.8W 1918Z  0.32M /  1.0FT  06MIN
 CABO SAN LUCAS MX   22.9N 109.9W 1833Z  0.36M /  1.2FT  12MIN
 DART TONGA 51426    23.0S 168.1W 1844Z  0.04M /  0.1FT  30MIN
 HIVA OA MARQUESAS    9.8S 139.0W 1741Z  1.79M /  5.9FT  12MIN
 PAPEETE TAHITI      17.5S 149.6W 1810Z  0.16M /  0.5FT  10MIN
 NUKU HIVA MARQUESAS  8.9S 140.1W 1745Z  0.95M /  3.1FT  04MIN
 MANZANILLO MX       19.1N 104.3W 1705Z  0.32M /  1.0FT  24MIN
 DART MANZANILLO 434 16.0N 107.0W 1611Z  0.07M /  0.2FT  24MIN
 RIKITEA PF          23.1S 134.9W 1559Z  0.15M /  0.5FT  22MIN
 DART MARQUESAS 5140  8.5S 125.0W 1531Z  0.18M /  0.6FT  18MIN
 QUEPOS CR            9.4E  81.2W 1416Z  0.24M /  0.8FT  52MIN
 BALTRA GALAPAGS EC   0.4S  90.3W 1452Z  0.35M /  1.2FT  14MIN
 EASTER CL           27.2S 109.5W 1205Z  0.35M /  1.1FT  52MIN
 ANCUD CL            41.9S  73.8W 0838Z  0.62M /  2.0FT  84MIN
 CALLAO LA-PUNTA PE  12.1S  77.2W 1029Z  0.36M /  1.2FT  30MIN
 ARICA CL            18.5S  70.3W 1008Z  0.94M /  3.1FT  42MIN
 IQUIQUE CL          20.2S  70.1W 0907Z  0.28M /  0.9FT  68MIN
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Message Content 2: Tsunami warning issued at the occasion of the Chile earthquake (February 2010), part 2

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LAT  - LATITUDE (N-NORTH, S-SOUTH)
LON  - LONGITUDE (E-EAST, W-WEST)
TIME - TIME OF THE MEASUREMENT (Z IS UTC IS GREENWICH TIME)
AMPL - TSUNAMI AMPLITUDE MEASURED RELATIVE TO NORMAL SEA LEVEL.
       IT IS ...NOT... CREST-TO-TROUGH WAVE HEIGHT.
       VALUES ARE GIVEN IN BOTH METERS(M) AND FEET(FT).
PER  - PERIOD OF TIME IN MINUTES(MIN) FROM ONE WAVE TO THE NEXT.

EVALUATION

SEA LEVEL READINGS CONFIRM THAT A TSUNAMI HAS BEEN GENERATED
WHICH COULD CAUSE WIDESPREAD DAMAGE. AUTHORITIES SHOULD TAKE
APPROPRIATE ACTION IN RESPONSE TO THIS THREAT. THIS CENTER WILL
CONTINUE TO MONITOR SEA LEVEL DATA TO DETERMINE THE EXTENT AND
SEVERITY OF THE THREAT.

A TSUNAMI IS A SERIES OF WAVES AND THE FIRST WAVE MAY NOT BE THE
LARGEST. TSUNAMI WAVE HEIGHTS CANNOT BE PREDICTED AND CAN VARY
SIGNIFICANTLY ALONG A COAST DUE TO LOCAL EFFECTS. THE TIME FROM
ONE TSUNAMI WAVE TO THE NEXT CAN BE FIVE MINUTES TO AN HOUR, AND
THE THREAT CAN CONTINUE FOR MANY HOURS AS MULTIPLE WAVES ARRIVE.

FOR ALL AREAS - WHEN NO MAJOR WAVES ARE OBSERVED FOR TWO HOURS
AFTER THE ESTIMATED TIME OF ARRIVAL OR DAMAGING WAVES HAVE NOT
OCCURRED FOR AT LEAST TWO HOURS THEN LOCAL AUTHORITIES CAN ASSUME
THE THREAT IS PASSED. DANGER TO BOATS AND COASTAL STRUCTURES CAN
CONTINUE FOR SEVERAL HOURS DUE TO RAPID CURRENTS. AS LOCAL
CONDITIONS CAN CAUSE A WIDE VARIATION IN TSUNAMI WAVE ACTION THE
ALL CLEAR DETERMINATION MUST BE MADE BY LOCAL AUTHORITIES.

BULLETINS WILL BE ISSUED HOURLY OR SOONER IF CONDITIONS WARRANT.
THE TSUNAMI WARNING WILL REMAIN IN EFFECT UNTIL FURTHER NOTICE.

THE WEST COAST/ALASKA TSUNAMI WARNING CENTER WILL ISSUE PRODUCTS
FOR ALASKA...BRITISH COLUMBIA...WASHINGTON...OREGON...CALIFORNIA.
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Message Content 3: Tsunami warning issued at the occasion of the Chile earthquake (February 2010), part 3

In the case of near-field sources the disadvantage of having short warning times is compensated with the possibility to directly feel the earthquake shocks and to directly see the eventual anomalous retreat of the sea. In such cases the population should be trained properly in their behaviour. When the near-field sources are local earthquake events, the risk of devastation prior to the arrival of tsunami waves is not marginal and appropriate considerations for rescue and escape organisation as well as for shelter selection should be taken.

1.2 Evacuation plan: objectives and goals

While even in tsunami-prone regions the risk can be quite small, the vulnerability can nevertheless be extremely huge. Managing this risk focuses upon reducing the vulnerability to a satisfactory extent. Hence the primary objective is to save lives.

Saving lives means to reduce the heavy impact of incoming waves (hitting persons onto objects, hitting debris onto persons, drowning persons), the risk of being swept out into open sea waters, and the risk of becoming trapped in a collapsing house.

While mitigation measures may be installed to reduce the waves' impact (e.g. breakwater), the other main issue remains to evacuate the potentially affected population in time towards safe places. Usually, in rather populated areas, detailed planning is necessary in order to make evacuation as efficient as possible; hence an evacuation plan has to be set up, implemented and monitored by local decision makers.

1.3 What is an evacuation plan?

A tsunami evacuation plan (TEP) is a plan that will be invoked if a tsunami alarm has been triggered. Hence a TEP will affect a variety of preparedness measures to be activated in the case of tsunami alert[1].

The purpose of a TEP is to save the life of those persons that might be affected by the incoming tsunami waves. Primary aim of a tsunami

[1] *With tsunami alert, usually, an audio-visual signal or a telecommunication-based message is meant. In some cases, however, especially in the context of near-field earthquakes, the warning may occur only a few minutes before the arrival of the tsunami waves; therefore the feeling of the earthquake is the first non-ambiguous signal even if no tsunami will take place or a tsunami alarm may be issued.*

evacuation plan should therefore be to guide all affected persons along the evacuation routes

a) Towards safe places (which are supposed to be outside the reach of tsunami waves), also called assembly facilities or emergency shelters;

b) In time (time span between alarm and arrival of first wave taking into account for each person the distance to the next emergency shelter).

In addition, an evacuation plan should foresee that a single assembly facility that matches criteria a) can cope with the

c) expected number of persons that are supposed to use this assembly facility.

Consequently a TEP is generated on the basis of the following two groups of parameters:

1)
- number of people affected (including special handicaps like young, disabled or elderly) per location
- Locations, roads and distances, the accessibility of these, the safety of these after a preceding earthquake

2)
- Basic assumption on maximal expected wave height
- Basic assumption on time lap until arrival of first wave.

1.4 Evacuation plan as part of a strategy including early warning, preparedness, awareness

The existence of a TEP is crucial for evacuation and life-saving measures. However, it will not work properly if it is not embedded within a strategy that fulfils the following criteria:

1. TEP invocation, early warning system installation: A TEP does not make very much sense unless an early warning system is installed. Usually, some audio/visual/ telephone communication networks may be used to issue a general tsunami warning (e.g. sirens, alarm lights, SMS's).
2. Early warning system integration: In general, local communities do not have sufficient means to get an early warning system installed and have it run properly. Hence a superior system (e.g. regional, national) may be of great help.
3. Tsunami scenarios elaboration for tsunami impact understanding: Evacuation plans should always be derived from information such as the expected sources, propagation of the waves and inundation inland, vulnerability and expected damages, in a way similar to the approach developed in SCHEMA project [Tinti, 2010].
4. Community preparedness: Communities in tsunami-prone areas should be prepared in any case despite low probabilities and/or negligible effects to be expected.
5. People's awareness: It is important to raise awareness within the population without creating panic. People should be informed about the general risk and should know the basic link of a preceding earthquake and a tsunami invoked by it.

A typical framework of an overall strategy has been undertaken by UNESCO-IOC for the Indian Ocean region [UNESCO-IOC 2009].

1.5 Current practice in other countries

1.5.1 Practice of evacuation planning in Japan

Evacuation planning in Japan has a long tradition: as for earthquakes, the occurrences of tsunamis have been incorporated into the Japanese culture. Many community-based preparedness measures exist as all the coasts of Japan are exposed to the tsunami threat.

In near history, the Hokkaido coast earthquake-induced tsunami from 1993 allowed an evacuation time of 3–5 minutes; the maximum height of wave observed was 10m [Nagao, 2005]. Also for these reasons, in Japan, a trend towards the use of existing and the construction of (artificial) vertical shelter buildings (Figure 1 and Figure 2) can be observed.

Japanese signboards provide the direction to escape, the distance to the next shelter, and the name of the shelter; many signboards are written in Japanese and in English. Assembly point signs are rectangular showing a tsunami wave and optionally a green cross. Possibly, signs are posted along roads indicating for this specific location the height (of the expected wave) above sea level, i.e. 3.3m.

Most of the evacuation preparedness is done through the work of voluntary rescue or disaster preparedness organisations; over 28 million people are organised in such a way.

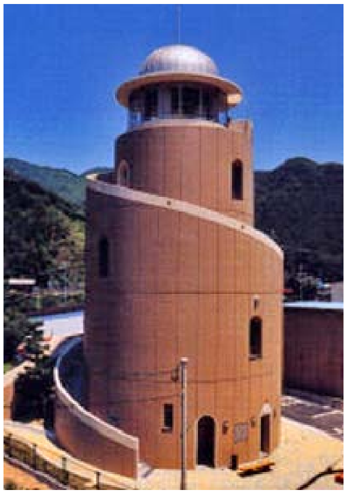

Figure 1: Emergency shelter building (Mie prefecture, Japan, Info courtesy of http://www.webmie.or.jp)

- **Okushiri Island**

After the devastating tsunami in 1993, artificial vertical shelters have been built along the beaches. Holiday resorts seem to have disadvantages due to the evacuation of a high number of temporarily residing persons; however these disadvantages can easily be compensated with construction of vertical shelters which could well be used as panorama platforms.

Figure 2: Elevated platform used on Okushiri Island (http://ioc3.unesco.org/itic/printer.php?id=20)

In addition, on Okushiri one can also see the construction of Watergates (see Figure 3).

Figure 3: Water gate used on Okushiri Island.* Courtesy of ITIC *(http://ioc3.unesco.org/itic/printer.php?id=20)

1.5.2 Practice of evacuation planning in USA

The Disaster Mitigation Act 2000 (DMA 2000) [FEMA 2003] reinforced the importance of mitigation planning and emphasized planning for disasters before they occur. As such, DMA 2000 establishes a pre-disaster hazard mitigation program and new requirements for the national post-disaster Hazard Mitigation Grant Program (HMGP). Section 322 of DMA 2000 specifically addresses mitigation planning at state and local levels. This section identifies new requirements that allow HMGP funds to be used for planning actions, and increases the amount of HMGP funds available to states that have developed a comprehensive, enhanced mitigation plan prior to a disaster. States, tribes, and communities must have an approved mitigation plan in place before receiving HMGP funds. Local and tribal mitigation plans must demonstrate that their proposed mitigation actions are based on a sound planning process that accounts for the risk to and the capabilities of the individual communities.

State governments have certain responsibilities for implementing Section 322, including:

- Preparing and submitting a standard or enhanced state mitigation plan;
- Reviewing and updating the state mitigation plan every three years;
- Providing technical assistance and training to local governments to assist them in developing local mitigation plans and applying for HMGP grants; and

- Reviewing and approving local plans if the state has an approved enhanced plan and a managing state is designated.

DMA 2000 is intended to facilitate cooperation between state and local authorities. It encourages and rewards local, tribal, and state pre-disaster planning and promotes sustainability as a strategy for disaster resistance. This enhanced planning network will better enable local, tribal, and state governments to articulate their needs for mitigation, resulting in faster allocation of funding and more effective risk reduction projects.

- ## West Coast States

Many communities along West Coast States in the US and Canada have excellent tsunami evacuation plans. Typically, they issue leaflets that contain town/city maps showing the hazard zones, the evacuation routes and evacuation shelters. Very often additional locations are marked, such as schools, hospitals, police and fire departments.

Brochures are printed on two pages and can be folded twice thus producing a handy leaflet which can be brought elsewhere or which can be put on frequently accessed locations. Typically, a leaflet describes the hazard, very often with a relationship to a felt earthquake. The brochures contain the evacuation signs used in that area as well as contact points in order to obtain further information.

Hawaii has a state-wide warning system based on sirens that are radio-controlled and partly solar-powered. The special Emergency Alert System combines all Hawaiian Islands and broadcasts alarms on all available media. The system is tested weekly. Emergency Operation Centres (EOC) activate and alert emergency response agencies. The EOC do siren soundings and coordinate school closures. Tsunami evacuation maps for all major localities are located in the front of telephone white pages. About 2 hours prior to the expected arrival time of the first wave schools and other public buildings should start the evacuation procedure. About 30 – 45 minutes prior to the expected arrival time of the first wave police should put roadblocks on roads entering the tsunami hazard zone; bus drivers will be informed to use (pre-established) alternate routes that will avoid tsunami hazard zones; designated emergency response staff should arrive at the tsunami shelter sites or on other sites of duty. [UNESCO IOC Tsunami Programme, 2005]

Figure 4: Parts of the evacuation map for the town of Depoe Bay (left) and Brookings (right), Oregon, USA (from www.oregon.gov)

1.5.3 Practices of evacuation planning in Indian Ocean since 2004

Some awareness has definitely been raised in most of the countries that had been affected by the 2004 South-East Asia tsunami. Among the most intriguing publications issued recently is a manual edited by the IOC with special focus on tsunami risk assessment and mitigation for the Indian Ocean [UNESCO-IOC 2009].

- ## Thailand

Thailand is definitely among those countries that have installed the most advanced measures in order to educate its population and to elaborate on thorough preparedness measures. Along the Indian Ocean coastline, signposts have been installed indicating the evacuation route and its length; these signposts are written in Thai and in English. In addition, markers are installed making people remember the height of the flooding during the Dec-2004 tsunami [Scheer, 2008] and inhabited areas along the vulnerable coastlines are supervised by a radio-wave controlled early-warning system.

Several brochures have been issued explaining the tsunami risk and discussing local observations (during the 2004 tsunami) together with potential mitigation strategies [e.g. Norwegian Geotechnical Institute, 2006].

1.5.4 Practice of evacuation planning in Europe

Very little information is available on tsunami evacuation and relevant plans in Europe. With regard to the SCHEMA-based tsunami test sites it can be stated:

For the region of Setúbal there aren't any specific evacuation plans or specific structures for an event like a tsunami. The alert systems and the procedures, in case of a natural disaster, are coordinated by the Portuguese National Authority of Civil Protection. There is a main office that relays down the procedures to the local civil protection offices and local search and rescue teams. The rescue teams consist mainly of fire departments and the Red Cross. In the specific case of Setúbal, the local fire department has recently completed a study about flooding in the city which shows the potential flooding areas according to the intensity of the rain. The action to be taken in these cases is to go to higher ground areas, and this study indicates:

- Which places are the best choice to go;
- The best route to access to those places;
- The places where the warning and guiding signs would be;
- Which places could be accessible to the rescue teams and what type of equipment could be used in these specific areas?
- This study also contemplates other secondary hazards, like fire, and for this there would be specific places with fire fighting equipment [Ribeiro J., 2008]

Stromboli Island, where several local tsunami disasters had happened, is equipped with a network of signposted evacuation routes. Apparently the signs are quite different from other internationally used signs. In the Stromboli case it should also be mentioned that – despite of the continuous hazard (regular volcanic eruptions → landslides into the sea → tsunami waves) – the authorities intentionally try to "hide" the risk, mainly due to the important tourism industry.

Other municipalities in nearby Calabria and Sicily had adopted local emergency plans due to anomalous waves provoked by the Stromboli volcano activities (mainly in 2002). As an example, the municipality of Rometta (Sicily) has edited an emergency plan also containing a description of the competences of the various local and regional actors as well as a map indicating along the municipality-owned coastline those areas which may become flooded (Figure 5). In addition, this map shows the general direction of escape, the escape routes, the "waiting" areas and particular buildings, like schools that lie within the inundation zone.

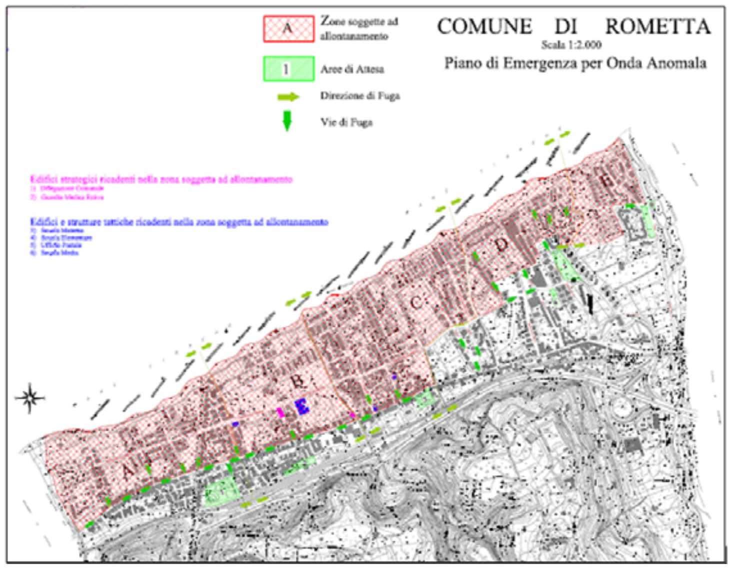

Figure 5: Emergency scenario elements map [Comune di Rometta, 2008]

1.6 UNESCO – IOC

In the aftermath of the 2004 South-East Asia tsunami, the Intergovernmental Oceanographic Commission (IOC) of UNESCO was given a mandate to facilitate the expansion of global coverage of tsunami warning systems, including and/or coordinating various early warning systems in major regions of the world. For the European/Mediterranean region an early warning (NEAMTWS, North Eastern Atlantic, the Mediterranean and Connected Seas) is going to be finalized [UNESCO-IOC Tsunami Programme, 2005].

UNESCO-IOC has also produced a couple of publications readable by the general public, among which the tsunami glossary [UNESCO IOC, 2008] can be used to gain detailed information on the tsunami hazard and on preparedness and evacuation principles.

1.6.1 NEAMTWS

The structural elements of NEAMTWS are Regional Tsunami Watch Centres (RTWCs), Tsunami Warning Focal Points (TWFPs) and National Tsunami Warning Centres (NTWCs) [see also http://www.ioc-tsunami.org/content/view/287/1123/]. Each member state should also nominate a Tsunami National Contact (TNC).

Regional Tsunami Watch Centres (RTWCs)

- Collection, recording, processing and analysis of earthquake data for the rapid initial assessment (locating the earthquake, its depth, its magnitude and its origin time) as a basis for the alert system.
- Computing the arrival time of the tsunami in the forecasting points listed in the Communication Plan.
- Collection, recording, processing and analysis of sea level data for confirming and monitoring the tsunami or for cancelling elements of the alert system.
- A decision making process in accordance with the Communication Plan to elaborate messages.
- Dissemination to the Member States focal points (and national warning centres) of the messages in accordance with the Communication Plan, including tsunami travel time, amplitude and period of the measured tsunami, and cancellation messages .

Up to now, five countries have offered to host RTWCs: France, Greece, Italy, Portugal and Turkey; Germany has offered to provide a backup for data collection and processing.

National Tsunami Warning Centres (NTWCs)

- Collection, recording, and processing of earthquake data for the rapid initial warning (locating the earthquake, its depth, its magnitude and its origin time)
- Computation of the arrival time of the tsunami in the national forecasting points
- Collection, recording, and processing of sea level data for confirming or cancelling the warning.

These national warning centres strive to be:

- Rapid, by providing warnings as soon as possible after a potential tsunami generation
- Accurate, by issuing warnings for all destructive tsunamis while minimizing false warnings
- Reliable, by making sure they operate continuously, and that their messages are sent and received promptly and understood by the users of the system.

Tsunami National Contact (TNCs)

The person designated by an ICG Member State government to represent his/her country in the coordination of international tsunami warning and mitigation activities. The person is part of the main stakeholders of the national tsunami warning and mitigation system program. The person may be the Tsunami Warning Focal Point, from the national disaster management organization, from a technical or scientific institution, or from another agency with tsunami warning and mitigation responsibilities.

Tsunami Warning Focal Point (TWFPs)

The Tsunami Warning Focal Point (TWFP) is a 24/7 contact person, or other official point of contact or address designated by a government, available at the national level for rapidly receiving and issuing tsunami event information (such as warnings). The Tsunami Warning Focal Point either is the emergency authority (civil defence or other designated agency responsible for public safety), or has the responsibility of notifying the emergency authority of the event characteristics (earthquake and/or tsunami), in accordance with national standard operating procedures. The Tsunami Warning Focal Point receives international tsunami warnings from the NEAMTWS or other regional warning centres.

- Reception of the messages transmitted by the Regional Tsunami Watch Centres

- Evaluate and issue national warnings in accordance with the National Emergency Plan
- Transmission of warning messages to the National Emergency Authorities
- Operating in a 24/7 mode.

Current recommendations by the NEAMTWS working group

The NEAMTWS working group confirmed [NEAMWTS working group, 2008] to maintain two levels of threat thus having an alert-triggering decision matrix as mentioned in Table 1.

Table 1: Decision Matrix (alert level) as suggested by the ICG working group

	Advisory	**Watch**
Run-up	< 1m	> 1m
Amplitude	0.2m – 0.5m	> 0.5m
Impact	Currents, bore, recession, damage to harbours, small inundations along beaches	Advisory impact + coastal inundation

1.6.2 Indian Ocean Region

For the Indian Ocean region, UNESCO-IOC has developed a comprehensive handbook [UNESCO-IOC, 2009] mentioning all tsunami-hazard related aspects and providing with detailed advice for enhancing communities' preparedness and planning the various phases of evacuation. This handbook gives many hints and advices on how preparedness could be achieved; in the chapter on how to manage the tsunami risk, communities are taught the various steps and procedures to follow in order to prepare for evacuation.

1.7 Specific evacuation plan generation concepts

Beyond the general concepts for evacuation plan generation issued by UNESCO-IOC, the outcome of FP6 SCHEMA project incorporates some particularities that may influence the construction of a tsunami evacuation plan. These concern:

1. the results of local tsunami scenarios (based on historical events and/or assumed near and far distance sources): in alignment with the IOC document [UNESCO-IOC 2009] a selection of "representative scenarios" are provided. Usually, for the evacuation planning the scenario providing a maximum of expected impacts will be selected for further analysis. A variety of tsunami scenarios should also raise the awareness on a local level showing the extent of damage in case that a similar event may strike again.
2. the computed maximum wave height, the inundation zone as well as the approximate arrival time of the first wave: thus the tsunami hazard zone is known (determining safe areas) as well as the maximum time available for evacuation. See for example Figure 6.
3. the computed damage level to local houses (based on wave height). The SCHEMA-based scenarios give clear hints on the to-be-expected damage level (Figure 7); as an implication, the number of affected people to be evacuated may be less than originally expected.
4. a specific time-cost algorithm adapted to local infrastructure and residing population: this algorithm studies the movement of evacuees over available space (escape routes) onto safe areas (horizontal shelters on safe ground, buildings serving as vertical shelters). The algorithm calculates time spans needed for a full evacuation.
5. In addition, the SCHEMA-based evacuation plan generation procedure proposes a three-phases intervention with the possibility of iteration within each step and the necessity to step back (recursion) towards a previous phase: the first phase produces a fully-valid evacuation scenario (based on the outcome of point 2., using the algorithm of point 4., and taking into consideration the results of point 3.); the second (mid-term) phase serves to implement the evacuation plan on site and to arrange the necessary procedures of maintenance; within a third (long-term) phase, the evacuation plan is continuously monitored and updated, amended or re-written if certain indicators make it necessary.

Among the main outputs of SCHEMA project there is the production, for each project test site, of an "Atlas of the areas exposed to tsunami risk". These Atlases contain maps showing the computed impact of selected tsunami scenarios (expected maximum wave height, inundation extension, arrival time, sea retreat, currents velocity) as well as maps depicting the vulnerability of the buildings in the area of interest and the level of damage expected on them. All this information can be used as input parameters for the generation of evacuation plans, as detailed in the next section.

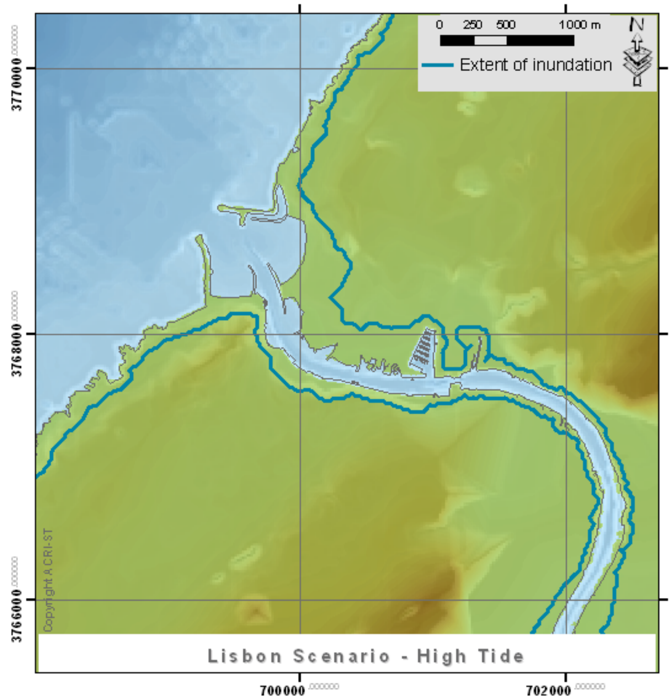

Figure 6: Extent of inundation (Rabat test site)

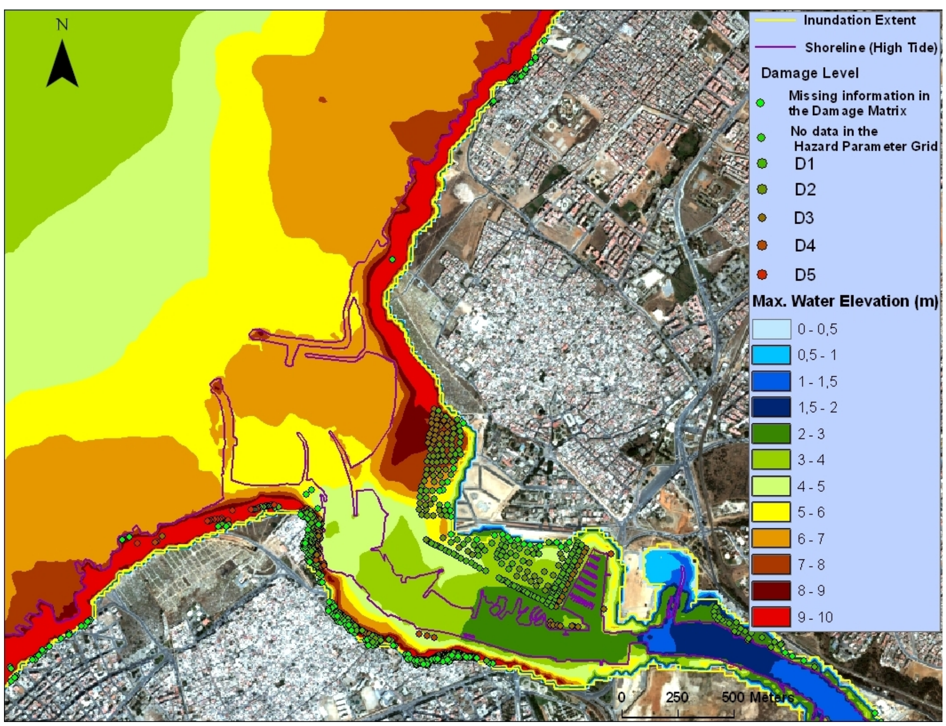

Figure 7: Damage assessment on buildings and maximum water elevation for 1755 Lisbon earthquake scenario (Rabat test site) – Copyright Quickbird image, 2008-09-28, res: 0.63m.

2 Methodology of evacuation plan generation

2.1 General aspects

2.1.1 The various stages and functions

An evacuation plan has to be generated, using a fact-finding and analytical (risk) approach, and subsequently developed in three iterative steps. Moreover the deployment and the integration of the evacuation plan within a regional level are additional important tasks. The validity of an evacuation plan has to be checked continuously, appropriate updates generated and the overall maintenance guaranteed [FEMA, 2003].

Within the first main step basic calculations are undertaken as classical risk and impact analysis. The result should be to reveal the location and the number of potentially affected people, the number and the location of shelter sites. Based on to-be-defined assumptions, maximum wave height and minimal wave arrival time, appropriate maps will be generated showing whether existing escape routes will be sufficient or not.

Further steps of the overall evacuation plan generation process comprise *signage* of the escape routes and emergency shelters, response instructions to local communities and threatened people, routine exercises for maintaining public awareness, evacuation and rescue training, resource allocation, maintenance of the escape routes and the control of the basic assumptions over the years. Hence the second main step means evacuation plan production and dissemination. This second step deals with overseeing the development and monitoring the implementation of an existing plan on a daily/monthly basis. In case variations to the concepts of the plan will be encountered, an iteration of the first step might be necessary.

Thus the third main step refers to the deployment of the evacuation plan, meaning that an existing tsunami evacuation plan should be monitored over time; variations to the basic inputs or to fundamental concepts of the overall plan should be considered for analysis, examining potential consequences to the existing plan and therefore decide whether iterations of the first or second step above might be required.

Consequently the evacuation plan generation process is an iterative process with three in-built iterations: 1. a start-up iteration to optimize an existing network of escape routes and emergency shelters, 2. a medium-term iteration when putting the evacuation concept into force, 3. and a long-term iteration on the overall plan due to new insights or additional information concerning tsunami hazard or land-use.

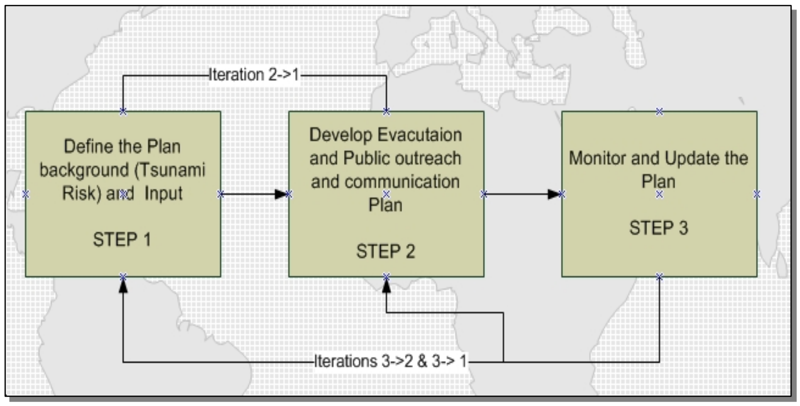

Figure 8: Stepwise approach for evacuation planning

2.2 Risk and impact analysis for the definition of the plan background and input (step 1)

An initial risk and impact analysis will help documenting how a network of escape routes and tsunami safe shelters (or buildings) could be built up in frame of lifesaving activities in a high-risk area. Risk and consequence analysis will also serve in order to tune an existing network of routes and shelters with view on further optimization. This task has to be entrusted to the local authorities in charge of civil protection.

The outcome of this task in context of the tsunami evacuation planning will be the designation of a valid network of escape routes and safe locations to be used during a warning or an emergency for guiding the population at risk timely and safely.

2.2.1 Basic input

Context and vulnerability data

The following basic thematic layers may serve as basic spatial input for the analysis required and thus they should be made available:

- **Digital elevation model** (DEM). This is one of the input data to compute the expected inundated area and thus for assessing the potential safe locations.
- **Population distribution map**: This map shows how the population is usually distributed within an inhabited area. For practical reasons, a maximum of persons (including temporarily residing as people at work or tourists) is taken as basis. The population distribution map will indicate the magnitude of evacuees potentially to be expected. For this purpose, potentially affected town areas are sub-divided into districts, quadrants or segments. On the population distribution map, every such subdivision will be presented as a class of population size indicated by a specific colour.
- **Road and major paths map**: This map will show selected roads, paths or routes that can realistically serve as escape routes. Additionally, these roads could be classified according to their capacity and colour-coded for comprehensive presentation of their content. For practical reasons only roads or paths having a minimum size should be considered in this map.
- **Classified buildings map**: This map shows the classification of all buildings (within the probably to be evacuated areas) according to the vulnerability classification scheme worked out in SCHEMA (WP 3.3, D3.1, see in the Annex): A, B, C, D, E, F, G, among which the categories A – E will usually be considered as unusable (unsafe).
- **Map of special places**: This map shows all those places and buildings that may be subject of special care procedures. In particular, schools and hospitals, very frequented places (e.g. markets), highly vulnerable places (e.g. harbours, beaches, estuaries) but also buildings of concern for the emergency response.
- **Hazardous and dangerous areas**: All industrial facilities or installations that are located within the area of concern may be marked separately in a map. The reason is that NATECH events may happen to the destruction or inundation of those areas. It should be separately assessed whether there could be an impact on such installations, whether this could lead to a hazardous situation, and consequently evacuation shelters and escape routes could be affected.
- **Map showing evacuation-hindering particularities**: There are particularities that can be decisive for efficient evacuation and that for these reasons should be marked separately in a map: 1. barriers, (wired) fences that may inhibit inland evacuation, 2. stairs and other bottlenecks at the edge between beaches and the hinterland, 3. extremely crowded roads (people, cars, shops, etc.) in the immediate neighbourhood of beaches. In addition, extremely located areas may accumulate water after the flooding and may therefore be detrimental to vertical evacuation.

Hazard and physical impact of waves

Furthermore, basic assumptions have to be made concerning the following factors:

- **Expected arrival time of the first wave**: The shortest expected arrival time of the first tsunami wave is a key input to the overall calculation procedure since it defines the response time the evacuation deployment has to achieve. For practical reasons it is the time interval between a warning was issued and the arrival of the first wave.

  For obvious reasons, extremely short "Expected Tsunami Wave Arrival Times" (ETWATs) - i.e. below 5 minutes- can be neglected since an orderly evacuation procedure will hardly work well. Similarly, ETWAT values above 1 hour must be considered critically. People often ignore how dangerous the situation is and they try to avoid evacuation or they tend to return back before the "All clear" statement is given by the Emergency Management Officials.

  Lack of knowledge or the unavailability of appropriate calculation tools has to be compensated with an assumed default value. In SCHEMA it has been indicated that a mean ETWAT value of 15 minutes can be used as default.

- **Maximum expected wave height:** Though there are several wave heights to be considered, it is probably the maximum wave height which – for practical reasons – provides the most important value as it gives a clear indication up to which distance (from the sea shore) an area may become flooded and persons may be hit by the waves.

  Similar to the ETWAT, expected wave heights up to 1m may be neglected unless there are clear reasons found in the terrain map (e.g. very flat beaches) or in the local infrastructure (e.g. exposed harbour constructions, roads very close to the beach) to care for.

Lack of knowledge or the unavailability of appropriate calculation tools has to be compensated with an assumed value. In SCHEMA it has been indicated that a mean value of 10m could be used as default.

- **Currents' velocity map**: Within the inundated area this map shows the various consolidated velocities of the incoming waves. Different velocities may arise as a single wave may find its whole way through or may find obstacles that will reduce its energy.

On basis of the two key parameters (ETWAT, wave height) and with the support of the previously elaborated maps, the following calculations could be done:

- **Inundation & safe areas map**: The inundation map is calculated by merging the digital elevation model with the expected wave height. Since the estimated inundated area is subsequently considered as "The evacuation zone" or "tsunami hazard zone", in principle all non-inundated land (i.e. areas out of the tsunami hazard zone) could consequently be considered as safe location. Further restrictions may apply to this consideration, upon investigation of the single case, such as:
    - safe areas that are completely surrounded by inundated land can be excluded from further calculations, and/or
    - land that, although not flooded, is extremely flat, could be excluded from further calculations, too.

  Results following the calculations have to be analyzed in order to validate and confirm that the depths are reasonable for the respective tsunami height and topography set. A range of maps of scale 1:25.000 to 1:10.000 has to be prepared with a grid of 100m and of 20m, respectively, expressed as colour-coded inundation depth lines of 1m.

  Horizontal shelters are designated locations on safe areas which satisfy to host in a safe way a sufficient amount of evacuees for the time of inundation. Those shelter sites are specifically defined as assembly points. Some restrictions may apply to these sites including the requirement of being easily accessible, also placed at rational distance from the point of departure, while they should have substantial capacity for allowing appropriate number of persons to fit in. Ideally, horizontal shelter sites should have access to lifelines, like drinkable water, phone, electricity, emergency kits, etc. to the choice of those sites should take into account the response phase, as access routes to horizontal shelters could remain flooded.

- **Vertical shelters map**: Buildings classified as E2 according to their vulnerability to tsunamis (i.e., reinforced concrete structures, residential or collective, with more than 3 storeys, see the Annex) and resistant to earthquakes can be considered as potential vertical shelters within the tsunami hazard zone. They may remain surrounded by water for some time and horizontal shelters may remain inaccessible due to inundation. Moreover buildings selected as vertical shelters must also be able to withstand severe damages created by floating debris and huge objects carried forward with the incoming waves or brought back during the backwash.

  In addition, these selected buildings must have a height sufficiently above the maximum water height. Usually this additional height is set to 5m. An empirical formula for estimating the height above which vertical evacuation is considered safe is the following:

  Safe height = (Max Wave height x 1.30) +1 m.

  A vertical shelter does not necessarily have to be a closed building. Especially, artificially built vertical shelters are of type open-platform shelters or of type artificial mound, as long as these vertical shelters are built with the same strength and resilience as E2 classified buildings. The use of multi-storey reinforced concrete or structural steel buildings or of artificial mounds as vertical shelters is an appropriate policy for all near-source tsunamis or for remote-source tsunamis in densely populated areas where horizontal evacuation is not possible.

  Some common restrictions might apply to vertical shelters. They should be accessible easily, and the access routes should have appropriate capacity. The shelters themselves should not be crowded a-priori thus making them useless to host a huge number of additional persons. Ideally, vertical shelter sites should have access to lifelines, like drinkable water access, phone, lights, emergency kits, etc.

- **SCHEMA-type amendment to vertical shelters**: In deviation from the above mentioned criteria for vertical shelters, other, less resistant buildings may be taken into consideration as well as long as their resistance to the incoming waves reveals sufficient results. This analysis is done through a joint calculation taking into account the inundation depth, the waves' velocity, and the buildings classified according to their vulnerability.

The purpose of this amendment is to reduce the number of potential evacuees.

As a result the vertical shelter map may contain more elements.

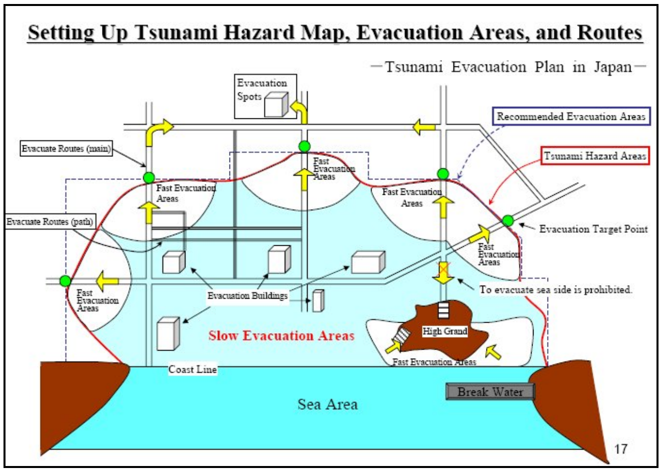

Figure 9: Generalized scheme of evacuation planning

Figure 9 [Nagao, 2005] displays a generalized scheme of evacuation planning showing the basic concepts (even with different naming) of tsunami hazard zone, horizontal and vertical shelters and escape routes.

2.2.2 Evacuation mapping

Tsunami evacuation maps should be used by emergency managers in order to support decision making in the frame of evacuation planning. Hence evacuation simulation maps are neither printed nor produced as composite maps (as the evacuation maps for the public used to be) but rather dynamic maps are created ad hoc for supporting managers to take proper decisions during evacuation operations. These maps result following spatial analysis of existing data in order to identify and analyze problems and elaborate relevant potential solutions. This analysis is a very efficient GIS technique of type cost-path analysis.

During evacuation planning for addressing a tsunami emergency, several problems can be considered including blockage of the evacuation routes, reduction of the flow capacity of the evacuation roads network, etc. Solutions for addressing such problems can relate to the definition of alternative routing or development of additional vertical shelters.

The evacuation maps can be produced on basis of the expected tsunami wave arrival time, the exposed population map layer and on information concerning the following additional information:

1. The direction to escape
2. The availability of roads and/or major paths (evacuation routes) in this direction
3. The number of people that will use these evacuation routes simultaneously
4. The minimum travel speed (of the evacuees) to take into account
5. The distance towards the next safe destination (including locations of horizontal and vertical shelters).

Evacuation mapping will provide emergency managers evacuation routing options, assessment of the performance of implementing the existing evacuation plan, the capability of overlaying layers of data regarding assembly points, position of the vertical shelters and evacuation routes.

Mobilization time (or preparation to evacuate) needs also to be considered in the evacuation (simulation) planning. Appropriate mobilization curves can be used for this purpose representing the time in which evacuees are expected to start evacuating, after reception of a tsunami alarm. Mobilization times are highly variable and seem to depend on the level of urgency to respond [Lindell et al, 1985]. For rapid onset events such as tsunamis (in particular originating from near-field sources) the curves are fairly steep. In slower events, such as a hurricane, departure times are more spread out, but can vary by location. A weak point of most evacuation plans is that they do not integrate properly (under-emphasis) the response capacity [Gruntfest and Huber, 1989].

Clearance time is the sum of the time a warning is received, mobilization time, and trip travel time (time from evacuation trip departure to reaching the destination shelters).

As major outcome, the map will provide the managers information on a time series of the population distribution during the evacuation in those districts that will be flooded and finally a result (R1 or R2) showing either:

(R1) The efficiency of the evacuation plan (if all affected people could be evacuated within the clearance time)

or

(R2) Those districts with inadequate time for evacuation (i.e., flooded without the possibility of evacuating all the residing people within the clearance time).

Obviously, this last case will reveal the issue that the evacuation plan has to be improved. As the evacuation simulation exercise has to be redone on a modified basis, an iteration of this step (step 1) has to be undertaken (see chapter 4.2.4).

There are two ways (indicated by the codes *EvacR* and *VertSh*) for making such improvements:

(EvacR) Increase the throughput (of evacuees) along the directions of escape by:

1. enlarging existing routes

   and/or

2. creating additional routes.

(VertSh)Diminish time to reach the next vertical shelter through an augmentation of the system of vertical shelters by:

1. increasing the capacity of existing shelters

   and/or

2. creating additional vertical shelters [Nagao, 2005].

When the operating environment is characterized by inhabited areas at seaside, improvements of type EvacR will be difficult to tackle. In addition, an improvement as suggested by VertSh-1 seems rather theoretical; hence the search for VertSh-2 solutions will be the most straightforward ones with some possibilities with regard to EvacR-2-type solutions.

Particular problems dealing with human behaviour can greatly alter the results of evacuation implementation and therefore the relevant simulation. In case of vertical evacuation, two different behaviours can occur: seeking to go up (people who receive and understand the warning, know what to do and they do it), and seeking to get outside (people who want to get out the building for whatever reason). A relevant vertical evacuation model developed at the Pacific Disaster Center, Kihei Maui HI tech, in 2007, demonstrated how individual behaviours may slow down the overall movement, create traffic jams and block access to safe zones during vertical evacuation [Jul, 2007].

2.2.3 Evacuation simulation analyses and mapping using GIS

Evacuation simulation analysis aims at identifying whether an existing network of escape routes (towards horizontal and vertical shelters) and vertical shelters may satisfy the needs of a full evacuation within the demanded time. Hence evacuation simulation analysis assesses the performance of evacuation plans and as such it is an excellent tool for decision support. As an objective, problematic areas (districts, escape routes, etc.) may be identified.

The geographic data together with other important information[2] that may play a decisive role during the evacuation simulation are analyzed spatially using GIS, in order to produce a series of maps which can provide the decision makers with answers on:

- General coverage of vertical shelters in the inundation area
- Elaboration of the performance (i.e. throughput of evacuees) of the existing network of streets/roads to be used for accessing the horizontal and vertical shelters considered in the evacuation plan
- Assessing the distribution of the residents against the network of shelters established (taking into account the capacity of the shelters)
- Assessment of the overall adequacy of the network of shelters (number / positioning / capacity) and identification of inadequacies and gaps.

On basis of the "Roads and Major Paths Map", the "Inundation and Safe Areas Map", and the "Vertical Shelters Map" an evacuation of the exposed population is simulated. Thus, for all districts (or quadrants or sub-divisions) of the tsunami hazard zone the residing[3] population is assessed in order

1. To run to the nearest road or path segment and follow the escape routes up to the nearest horizontal or vertical shelter,

or

2. To stay (and move up[4]) in the building in case the building is part of the vertical shelters network.

For practical reasons the following assumptions are adopted:

1. The capacity of every escape route segment does not play a significant role unless for particular cases (e.g. if too many persons arrive at an escape route segment at the same time and start running). Nevertheless, this situation should be handled properly, especially in the case of very short clearance time. The authors suggest an "indirect" solution: a drastic increase of time to next shelter for those evacuees.

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[2] *This can be places of special attention or interest, known bottlenecks, fences, walls, or roads full with parking cars.*

[3] *Usually a maximum of temporarily residing population is assumed thus including workers, school children, tourists, even if these live elsewhere.*

[4] *In general, as a minimum, the third floor should be reached.*

2. Not all persons per district/quadrant/sub-division will present themselves at the same time (i.e. within the first minute of evacuation) on the nearest escape route segment, thus allowing for some flexibility with respect to the necessary segment capacity. See also comments in section 2.2.1.
3. An average human speed as of 1m/sec is taken as granted; a reduction of this will be taken up within the cost-surface layer (see below). For example, on difficult ground like on beaches, an average human speed as of 0.5m/sec is granted.
4. Only pedestrian evacuation is considered thus excluding the use of cars[5].
5. People with special needs are not considered in this simulation exercise; however, they have to be considered separately by the authorities (see chapter 4.3.5).

Creation of evacuation simulation maps

The methodology for creating the aforementioned specific layers/maps for Pedestrian evacuation is implemented according to the following steps (A to G):

A) Definition of a cost surface layer

All further GIS analyses require the introduction of a fundamental thematic layer, the "cost surface" layer. The cost surface layer is a raster layer which represents the time-cost of the travelling element (evacuee) for crossing a distance unit (one meter) of the raster layer.

The cost surface layer considers only those areas in which the pedestrians are expected moving during an organized evacuation process (i.e. road network, beach zone). All the other areas (mainly buildings, rivers, fields, etc.) are excluded from further consideration.

In order to create, as much as possible generic (unit-independent) evacuation maps/layers, the time-cost value, assigned to each cell of the cost surface layer, represents a unit-less size that derives its meaning in relation to the costs assigned to other cells.

Thus, in the analyses which follow, for expressing a time-cost for each cell, the concept of non-specific "time-unit" is introduced instead of real units of time (seconds, minutes, etc.).

B) Definition of evacuation shelter points

The "Vertical Shelters Map" (see also chapter 4.2.1) shows suitable buildings in the flooded area that could temporarily host a sufficient number of evacuees.

On the other hand, horizontal shelters are indirectly defined through an analysis of the "Inundation and Safe Locations Map" (see chapter 4.2.1 as well). As these horizontal shelters may be located far outside the flooded area, it is for calculation purposes more convenient to mark the interfaces of escape routes with the flooded area boundary as "horizontal shelter locations".

C) Definition of the time map

Using the layers of the "Cost Surface" and the "Evacuation Shelter Points", a Cost-Weighted Distance map can be calculated using the appropriate GIS tools. In this map the value of each cell represents the cost needed to go to the nearest (in terms of cost) source point, following the costless (i.e., with a minimum of costs) path.

With regard to the SCHEMA approach, the evacuation shelter points are considered as the source points and the cost values will be expressed in terms of time: each cell will report the time necessary to go from there to the nearest shelter following the fastest (costless) path.

In general, this map will reveal those parts of the area considered by the evacuation plan that need more time to be evacuated [Laghi et. al 2007; Graehl and Dengler, 2008].

D) Definition of the area/zone covered by each shelter point (allocation of shelters/region)

The aim of this analysis is to delineate the area/neighbourhood which can be assigned to the shelters (refuges) which have been selected for inclusion in the evacuation plan.

The "time-cost surface" is used in the GIS "cost allocation" analysis and it is further combined with the "shelters" layer in order to compartmentalize the whole area into small zones, which represent the borders of the neighbourhoods within the whole area that could be served by the respective shelter buildings. Each zone is assigned a unique ID which is relative to and identical to the Building ID (Figure 10) considered as a vertical shelter in the context of the tsunami evacuation plan.

E) Time-distance from closest shelter

The purpose of this analysis is to provide an indication of the proximity of each shelter to the respective road/street segment. Such an indication is an indicator of the performance of the shelter for the evacuation

[5] *Pedestrian evacuation is considered as the most effective way of evacuation as the massive of cars can be detrimental to fast evacuation. In some circumstances the use of cars may be allowed: availability of very long warning times, availability of extremely good road infrastructure, very reduced number of evacuees. For example, in some (less inhabited) places in the USA, vehicle-based evacuation is consented.*

purpose. The analysis is based on the "Shelter/streets allocation" map presented above.

The "Time Distance from closest Shelter" map (e.g. Figure 11) represents the time units needed to reach the closest shelter from any point on the road/street network.

The analysis identifies road segments and locations that are distant from shelters and where special attention should be paid during evacuation, since people from these areas won't have enough time to evacuate. This map can be combined with the Tsunami Risk maps (maps visualizing the time of arrival of the first wave, flow depth, maximum water elevation), in order to estimate the available time for the evacuation procedure at each point of the area of interest and to identify vulnerable areas (according to the tsunami scenario adopted for the simulation) due to time limitations for the residents in reaching safe places/buildings (insufficient time for evacuation).

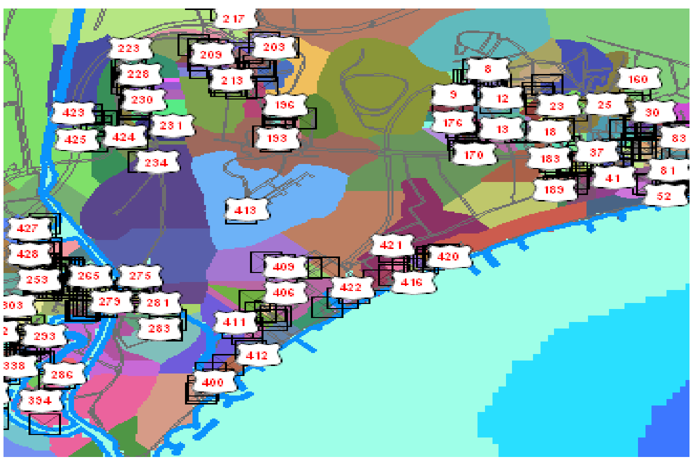


Figure 10: Subdivision of the territory in zones, each one served by a vertical shelter (Mandelieu test site)

Figure 11: Map of distance classes from closest shelter (Mandelieu test site); yellow to red coloured areas are the most distant road segments in this example

F) Definition of the area served by exit/escape points (allocation of exits/region)

The following analysis is conceptually similar to the definition of the area/zone covered by each shelter point, presented above; the focus is put on the most critical zones (e.g. beaches) where there are no shelters and where residents have to be evacuated as a priority because they are in greater danger. The geographic features (e.g. stairs, underpasses, ramps etc) that lead outside of this critical zone are considered as exit or escape points. All the other area is considered as obstacles (i.e. fences or walls).

The results of this analysis show the division of the critical zone into sub-areas that correspond to the closest escape point. Additionally, each sub-area has a unique ID which is identical to the escape point ID. In Figure 12a, for example, the corresponding road segment is divided between exit points 2 and 3, while the nearby beach segment, on its right, is attributed entirely to exit point 2, simply because of the lack of stairs (i.e. violet bullet points) towards the beach-side road.

G) Time distance to reach the closest escape point

The "Time Distance from closest escape point" also focuses on the most critical zones for tsunami evacuation (e.g. beaches, roads near the beach) where there are no shelters and which need to be prioritized for evacuation because residents there are in greater danger. This analysis calculates the time units required for reaching the closest point/location which can be considered as exit point from the endangered area towards the inner and safer area. The legend (colour code) expresses time-units in seconds based on the assumption of an average walking-speed of 3600 m/hour (1m/sec) on the road surfaces, and a speed of approximate 1800 m/hour (0.5 m/sec) on the roughest (i.e. difficult) surfaces (e.g. beach, stairs etc).

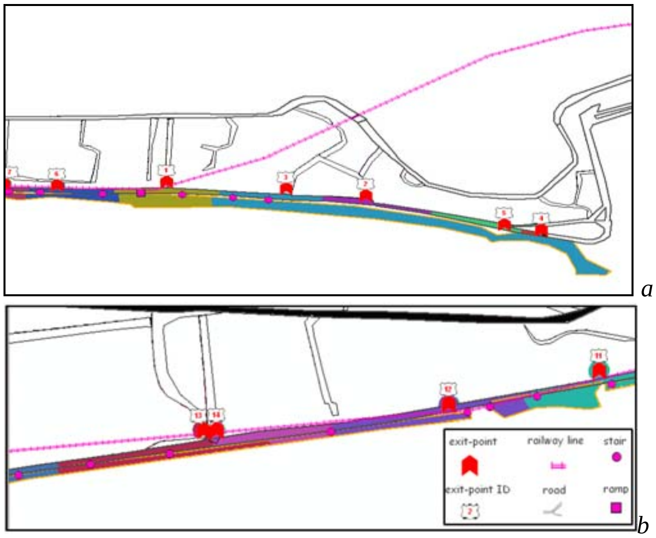


Figure 12 (a, b): Allocation of sub-zones within a critical zone to be served by each escape point (Mandelieu test site – Each sub-zone is represented by a different colour)

The analysis in Figure 13, for example, identifies sub-areas that are distant from escape points. This is particularly the case for the yellow and red-coloured areas (see also explanation for Figure 12a).

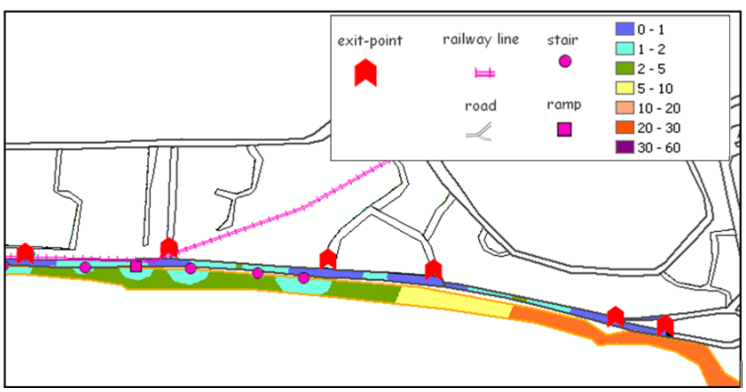


Figure 13: Map of time-distance (minutes) on a critical zone from closest escape point (Mandelieu test site)

2.2.4 Iteration of step 1

The step 1 of evacuation plan generation procedure has to undergo an iteration using the functionalities of the evacuation simulation map. In fact, a first instance of an evacuation map is valid if the simulation reveals that all affected population[6] will be evacuated in time. Consequently, the above mentioned improvements should be followed in order to reach this goal.

Improvements with respect to EvacR (see 4.2.2) should be prioritized, as it is still the best (and probably cheapest) option to evacuate people towards safer grounds in nature. Evacuation towards horizontal shelters is the most straightforward way: no further inspections on vertical shelters have to be done; the facilitation of response measures could be fostered.

VertSh-type improvements could be foreseen if the possibilities of EvacR-type evacuation are saturated. Improvements with respect to VertSh-1 will probably have the least chance to be realized, while VertSh-2-type interactions could sometimes make sense; for example, beach-situated vertical construction platforms could be an excellent and easy-to-reach safe location for crowded beaches.

Once one or more interactions have been worked out, the evacuation simulation map (of chapter 4.2.3) should be calculated again.

2.3 Evacuation plan production and implementation (step 2)

A network of escape routes, assembly points and emergency shelters has to be marked and reproduced in paper and in electronic format in order to disseminate this critical information to all potentially affected people. Hence the findings of the evacuation simulations should be integrated into the evacuation plan which has to be communicated efficiently to the public.

The more appropriate actors for managing the dissemination of the Public Evacuation Plan are the local authorities in charge of civil protection. Apparently, the use of TV and radio spots, press and the internet have to be considered as the means for communicating the elements of the Tsunami evacuation plan.

The outcome of this task ("step 2") is that of producing and communicating a tsunami evacuation plan in which the escape routes, assembly points, safe locations and the emergency shelters will be clearly marked. The implementation of an evacuation plan foresees also that the meaning of evacuation is incorporated by the potentially affected population through training exercises and by the public administrations through the definition of tasks and allocation of resources in order to keep a valid evacuation plan "alive".

[6] In the context of this work, the term "affected population" means the maximum of temporarily residing/working people per area.

2.3.1 Signposting

The most visible way to educate the public about escape routes and shelters is to post signs. Selected outcomes of "step1", such as escape routes, safe sites, assembly points, etc. should be marked on the ground within the Tsunami Evacuation Zone. Escape routes should be marked along their entire course. Evacuation route signs have to be placed well in advance of the actual need and maintained properly in order to educate people as to the available routes and paths that will guide them away from high risk areas (Figure 16 to Figure 15).

The tsunami hazard zone as a whole should be marked thus providing additional information to those entering and leaving the tsunami hazard zone. Thus any person, particularly those non-residents, can be warned properly. Additional signs should be placed within tsunami hazard zones, especially in places where many people congregate, as beaches, parks and developed water fronts. This would have a repeating effect.

Moreover, all identified shelters – horizontal and vertical shelters – should be marked accordingly. The horizontal shelters indicate a person running away from a wave towards hill, platform or berm; on the other hand, the vertical shelter signs indicate a person running away from a way towards a building (with entrance and windows).

There seem to be many different tsunami signs available around the world, such as tsunami hazard zone, tsunami evacuation route, tsunami evacuation site, and entering/leaving tsunami hazard zone. Since 2008 UNESCO/IOC is encouraging its member states to develop and to use ISO-compliant tsunami signage and symbols in order to promote consistency in understanding and action across local, national, and international jurisdictions. It had been agreed to add three basic signs (hazard / evacuation zone, horizontal shelter, vertical shelter; Figure 14) within ISO 20712 standard which provides specifications and guidance on safety signs for aquatic hazards.

Figure 14: ISO approved signs showing tsunami evacuation zone, horizontal shelter and vertical shelter

These three signs symbolize a minimum standard; where localization is necessary, it is suggested that additional supplementary signage or text be added to the standard sign. Complementing signage that advise populations in the warning zone on what to do and what directions to take may also be needed [Kong, 2000]. The round-type evacuation route sign (e.g. Figure 16), as it had been implemented in the 1990's or before, could become obsolete; following the UNESCO/IOC suggestions [ISO Tsunami Signs, 2008] the evacuation route could be marked in its entire course by showing the evacuation sign (each with an arrow underneath) with the type of shelter an escaper may expect at the end of the evacuation route (Figure 14) or even with the name of location serving as shelter (Figure 15).

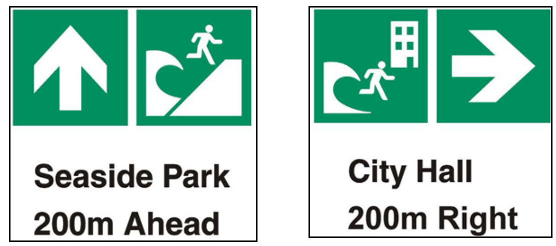


Figure 15: ISO approved evacuation signs along a specific evacuation route

Likewise any other evacuation route, a tsunami evacuation route should be marked in such a way that its course is immediately visible, memorable and unmistakable. Signs should be placed along roads designated as tsunami evacuation routes. Escapers from building, once reached the escape course on ground, should immediately know in which direction to escape. In addition, it is useful to indicate the locations of the various signs within the tsunami evacuation map (see chapter 4.2.2).

Figure 16: Permanent evacuation route signs in USA (outdated signs)

2.3.2 Instruction and dissemination

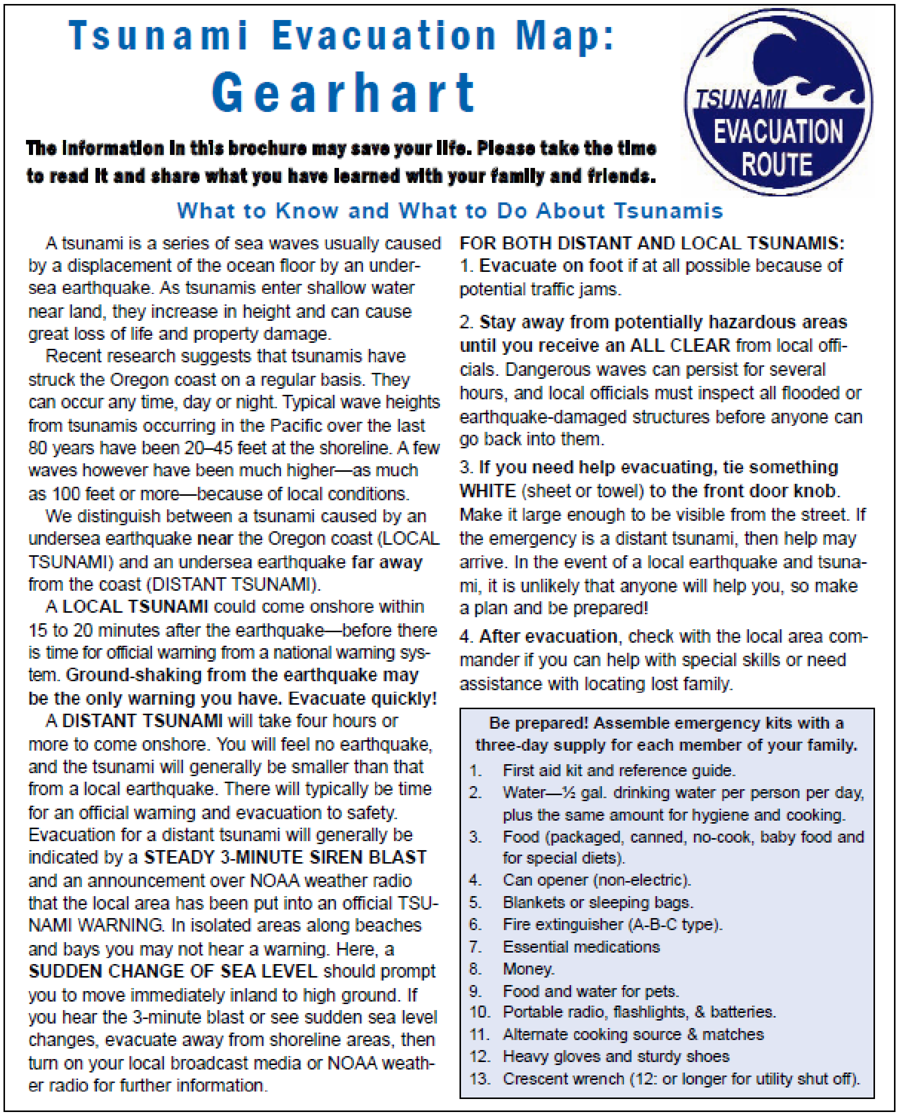
The creation of leaflets and/or brochures is fundamental for communicating general instruction to the public. People living/working in tsunami-prone regions must be aware about the hazard, the correlated risk and the way they have to react in case of a warning. The usual way of providing information to the various groups of the population is by distributing leaflets and/or brochures which – in a summarised way – include and explain the following:

- What is a tsunami
- What is the tsunami-related hazard and risk
- Which are the basic precautions
- How to be prepared (emergency kit)
- Which way an alarm or warning will be communicated
- A map of
  - the hazard zone including the risky zones and the safe zones
  - the locations of assembly points, shelters and safe sites
  - the evacuation routes
- Examples of the tsunami hazard zone ISO sign
- Examples of the evacuation shelter ISO signs
- What to do when there is a warning/alarm
- What to do after an alarm.

It is preferable to combine the various maps into one composite map and to make such a map as easy to understand as possible. Figure 17 and Figure 18 show possible texts and graphics which could be parts of a composite brochure.

Leaflets and/or brochures should be disseminated according to a predefined dissemination plan ensuring that it includes proper instructions for all members of households. Temporarily living people (external workers and employees, tourists, etc.) should not be excluded from being informed. Attention must be paid also to road network users (car drivers), passengers in train stations, and passengers at harbours or even in airports. Proper dissemination of the specific evacuation plan is crucial to make everybody aware of the hazard and of the necessary instructions on how to react in case of an alarm. Hence, well-elaborated brochures should be distributed in key places (public buildings, work areas/offices, tourist resorts and facilities, hotel rooms, beaches, etc.), communication of warning messages should be enabled (road posters, traffic electronic screens, etc.), and other channels of dissemination should be kept up-to-date (internet, mobile phones, etc.).

Leaflets have the advantage that they are something concrete which can be given to a person directly. People can put them at home on a directly and frequently visited location. Other important ways of information dissemination should be done through TV spots, messages transmitted through radio channels. The leaflets prepared can be available or distributed also through Internet by publishing them on the website of Local Authorities or Civil Protection Agencies. Web sites of tsunami-prone communities should mention the risk and should put focus on the evacuation procedures in force. The particular advantage of internet is that interactive maps can be made available allowing to identify for a specific location the risk [Merati et al., 2004], the vulnerability and the foreseen evacuation route. Users can insert their exact location and get an immediate answer about their personal situation.



Tsunami Evacuation Map: Gearhart

TSUNAMI EVACUATION ROUTE

The information in this brochure may save your life. Please take the time to read it and share what you have learned with your family and friends.

What to Know and What to Do About Tsunamis

A tsunami is a series of sea waves usually caused by a displacement of the ocean floor by an undersea earthquake. As tsunamis enter shallow water near land, they increase in height and can cause great loss of life and property damage.

Recent research suggests that tsunamis have struck the Oregon coast on a regular basis. They can occur any time, day or night. Typical wave heights from tsunamis occurring in the Pacific over the last 80 years have been 20–45 feet at the shoreline. A few waves however have been much higher—as much as 100 feet or more—because of local conditions.

We distinguish between a tsunami caused by an undersea earthquake **near** the Oregon coast (LOCAL TSUNAMI) and an undersea earthquake **far away** from the coast (DISTANT TSUNAMI).

A **LOCAL TSUNAMI** could come onshore within 15 to 20 minutes after the earthquake—before there is time for official warning from a national warning system. **Ground-shaking from the earthquake may be the only warning you have. Evacuate quickly!**

A **DISTANT TSUNAMI** will take four hours or more to come onshore. You will feel no earthquake, and the tsunami will generally be smaller than that from a local earthquake. There will typically be time for an official warning and evacuation to safety. Evacuation for a distant tsunami will generally be indicated by a **STEADY 3-MINUTE SIREN BLAST** and an announcement over NOAA weather radio that the local area has been put into an official TSUNAMI WARNING. In isolated areas along beaches and bays you may not hear a warning. Here, a **SUDDEN CHANGE OF SEA LEVEL** should prompt you to move immediately inland to high ground. If you hear the 3-minute blast or see sudden sea level changes, evacuate away from shoreline areas, then turn on your local broadcast media or NOAA weather radio for further information.

FOR BOTH DISTANT AND LOCAL TSUNAMIS:

1. **Evacuate on foot** if at all possible because of potential traffic jams.

2. **Stay away from potentially hazardous areas until you receive an ALL CLEAR** from local officials. Dangerous waves can persist for several hours, and local officials must inspect all flooded or earthquake-damaged structures before anyone can go back into them.

3. **If you need help evacuating, tie something WHITE** (sheet or towel) **to the front door knob.** Make it large enough to be visible from the street. If the emergency is a distant tsunami, then help may arrive. In the event of a local earthquake and tsunami, it is unlikely that anyone will help you, so make a plan and be prepared!

4. **After evacuation**, check with the local area commander if you can help with special skills or need assistance with locating lost family.

Be prepared! Assemble emergency kits with a three-day supply for each member of your family.

1. First aid kit and reference guide.
2. Water—½ gal. drinking water per person per day, plus the same amount for hygiene and cooking.
3. Food (packaged, canned, no-cook, baby food and for special diets).
4. Can opener (non-electric).
5. Blankets or sleeping bags.
6. Fire extinguisher (A-B-C type).
7. Essential medications
8. Money.
9. Food and water for pets.
10. Portable radio, flashlights, & batteries.
11. Alternate cooking source & matches
12. Heavy gloves and sturdy shoes
13. Crescent wrench (12: or longer for utility shut off).

Figure 17: The "What to know and what to do about Tsunamis" section of a brochure (outdated sign)

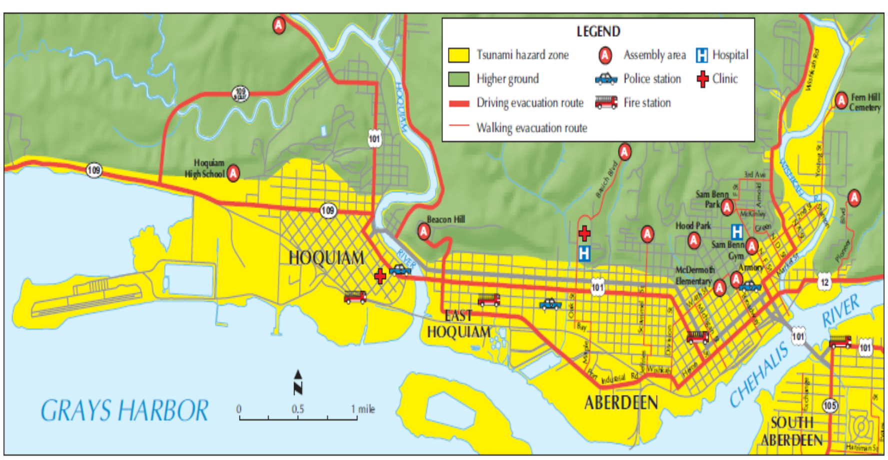


Figure 18: Evacuation map in a brochure of Aberdeen and Hoquiam counties along the Washington coast

2.3.3 Training

Local communities have to be educated and trained on a regular basis concerning the existing tsunami evacuation plan. The communication plan, the equipments included in the evacuation plan and the response level of the evacuees has to be tested in context of evacuation drills. Particular attention has to be paid to organizing evacuation drills in public buildings, workshops for hotel Associations in coastal regions and information campaigns for minorities and vulnerable groups. In addition, specific evacuation drills have to be planned for specific groups such as:

- Schools/students (see Figure 19)
- The elderly and disabled
- Health care facilities personnel
- Hotel Staff
- Business-Industry workers
- Non Governmental Organizations (Example: Red Cross).

Exercises have to be organized by Local Authorities and Civil Protection services. For organizing such exercises the following issues have to be considered:

- Identify stakeholders and host meetings
- Discuss and agree on objectives of exercise
- Roles and responsibilities
- Level of participation by stakeholders
- Select date and time for evacuation
- Develop script for controllers to follow and to provide input
- Public Notification (see Figure 20, bottom).

Figure 19: Evacuation drill of school students (La Push County, Washington, USA)

Evacuation exercises as well as training could refer to a complete evacuation gathering everybody at the designated assembly points within the time interval set necessary for safe evacuation (see Figure 20, left). Alternatively, semi-operational evacuation training could be envisaged; in that training the exercise stops when affected people reach their escape routes. An escape exercise along the escape routes will be ignored. Hence, it simulates only the beginning of an evacuation.

Coordination is a key issue to during evacuation drills since the local authorities have to consider

- how local services (e.g. public transport, schools etc.) may be affected during the drill
- how local businesses and public administration may be affected
- what (independent) organisation could serve as observer and assessment body
- whether the press and the media could be involved effectively.


(a)

(b)

Figure 20: Evacuation exercise in (a) La Push (Washington Coast) and (b) Andaman (Thailand)

2.3.4 Tasks for the authorities during evacuation

Proper evacuation requires also significant intervention on behalf of the local authorities in order to guarantee fastest evacuation for everybody. Therefore, those authorities have to generate own operation schedules for a variety of specific tasks after a tsunami alert has been issued:

- Local authorities have special responsibility for the evacuation of public buildings and for controlling local traffic during evacuation. In particular, the eventual evacuation of schools, hospitals and houses of elderly people should be analysed and appropriate allocation of resources be granted. Also, it would be of great advantage to know where people with special needs are located so that their evacuation can be ensured.
- Local authorities should consider the evacuation of near-shore areas that could be crowded, especially in summer season. Particular emphasis should be put on the evacuation of harbours as they may be the working place for many employees.
- Authorities may have to set up a list of potential bottlenecks during evacuation which could make it necessary to foresee special supervision. Such bottlenecks could be narrow parts of escape routes or any other obstacle that diminishes drastically a throughput of evacuees. For example, the identification of so-called “escape points”, as mentioned in 2.2.3.G, is such a case.
- Ready-made plans for road blockage should be elaborated. In a first step, the tsunami hazard zone is closed for incoming private travel; then further on, in a second step, also public transport is going to be deviated.

2.3.5 Maintenance of escape routes / shelter Sites

Local decision makers must ensure that, once an evacuation plan has been issued, it should regularly be maintained verifying for the evacuation routes:

- State of accessibility
- Changes to their capacity.

For the emergency shelters to be used in the evacuation plan, it should be considered:

- Accessibility to emergency shelter(s)
- Availability of additional (new) shelters
- Change in capacity of the emergency shelter(s).

Evacuation routes could become inaccessible, either permanently or temporarily due to road works, which could become a problem in maintaining the standard in the evacuation plan. Furthermore, roads could become altered having possibly recurrences on the capacity as it had been assumed in the original plan. Additionally putting road dividers could, for example, reduce the road capacity.

Local decision makers must ensure regularly that basic constituents of an existing evacuation plan are valid. Roads that serve as evacuation routes must be kept free so that the intended capacity for evacuation remains unaltered. Similarly for emergency shelters: they must be kept available so that they can provide safe places to the planned number of evacuees. In the case that emergency shelters provide facilities (e.g., water access, emergency kits, etc.), these should be kept in order as well.

2.3.6 Organizational tasks for authorities

The maintenance of an evacuation plan needs the active involvement of specialised and authorised persons, as well as the allocation of resources for accomplishing this task. Hence part of developing a tsunami evacuation plan should be the a-priori allocation of human and financial resources for ensuring its maintenance. This permanent staff allocation should be reinforced with more specialists in case of an emergency.

All permanent and emergency staff must undergo training in order to properly perform all the tasks assigned to them.

Reliable implementation and steady maintenance of the evacuation plan shall anticipate any significant deviation from its objectives and its effective deployment. Regular inspections should be recorded in a table with annexed decision matrix; such a matrix could reveal necessary actions to be taken in order to re-establish a desired state.

2.3.7 Iteration of step 2

An existing tsunami evacuation plan and its implementation have to be closely monitored on a regular[7] basis. The evacuation plan may undergo revisions in case:

- Signs have to be removed, replaced or substituted
- Leaflets and brochures may have to be reproduced
- New residents should be informed as well
- Escape routes have to be supervised and continuously kept free of obstacles

[7] Obviously it is up the local decision makers how often these checks are undertaken; daily, monthly, yearly.

- Shelters should stay accessible and in a good shape
- The basis for authority-own tasks has changed: significant change of human and financial resources.

Authorities should continuously be informed regarding persons needing specific care, staying in public buildings or hospitals.

Evacuation drills have to be periodically organized, their outcome has to be evaluated and potential necessary modifications to the existing plan must be proposed. Briefing with exposed population has to be constant in order to familiarize them with the existing evacuation plan.

Deteriorations in the state of escape routes (non-accessibility or permanent blockage; reduced capacity) and/or in shelter sites (non-accessibility; reduced capacity) should be taken into account to found proper alternatives. Table 2 gives an overview of regular checks to be done by local authorities

Table 2*: Issues at stake and to check within step-2*

Issue at stake / controls	*Suggested frequency*
Control state of evacuation signs	monthly
Control state of escape routes	monthly
Control state of shelters	monthly
Undertake evacuation training	Bi-annually for full training exercise; yearly for semi-operational (special) exercise
Control continuous use of escape routes (whether there are obstacles placed, etc.)	Daily to weekly
Inform new residents	During registering
Check (public) evacuation map (new roads, new public buildings, etc.)	yearly
Check state of resource allocation plan	monthly

Table 3, on the other hand, provides with a suggested[8] decision table of whether to revise an existing evacuation plan within a step-1 iteration[9] or within a step-2 iteration. For example, it is obvious that major changes in the road network make an existing evacuation plan invalid. Hence the system of shelters and escape routes has to be revalidated through iteration of the whole process on the basis of the new realities.

Alternatively, step-2 iterations are due to minor modifications in signposting, occupancies in public buildings, road traffic, and shifts in resource allocations.

Table 3: Suggested decision table to revise an existing evacuation plan either within a step-1 iteration or within a step-2 iteration

Issue at stake	*Step-1 iteration (suggested)*	*Step-2 iteration (suggested)*
Signs missing or in bad shape		Replace signs
Changes in road network (used for escape routes)	Mandatory in case of substantial change (loss of accessibility, decrease of capacity, layout change, e.g. road dividers)	Advisable to look for adjustments in case that capacity drop < 5%
Downgrading of horizontal (inland) shelters	Mandatory in case of substantial change (loss of accessibility, decrease of capacity > 10%,) encountered	Otherwise: Restore horizontal shelter
Downgrading of vertical shelters	Mandatory if principal change (inexistence, capacity drop > 2%, loss of accessibility)	Otherwise: Restore vertical shelter
New requirements for training		Revise training plan
Outdated instructional and communication material (leaflet, internet)		Revise existing material (leaflet, internet)
New residents		Individual instruction
Outdated resource allocation		Revise resource allocation. plan

[8] *These suggestions provide a hint and as such they are not binding; especially the mentioned values of percentages could be interpreted differently by local decision makers.*

[9] *It should be clear that a step-1 iteration implies a repetition of step-2 as well; for example, a modified or new escape route implies an alteration of the signage system.*

2.4 Evacuation plan deployment, monitor and update (step 3)

Once a tsunami evacuation plan is fully operational there are still a couple of external factors to be looked at in more detail. First, the overall assumptions, expected tsunami wave height, expected wave arrival time related to all known potential sources, may undergo revisions due to new insights or scientific achievements. Other issues to consider are the overall integration of the local evacuation plan into an early tsunami warning system, into the regional emergency plan, and to evacuation procedures associated with additional hazards. The task of evacuation plan deployment is also to think about common adaptations and/or limitations to the overall approach or to re-evaluate acceptance issues.

2.4.1 Integration with an early warning system

Basic assumption of developing a tsunami evacuation plan is to have a triggering point: an alarm issued which starts an evacuation process. Also, the expected arrival time of first wave is calculated from the time an alarm is formally issued. An early warning system can be operating on a hierarchical basis thus receiving alarms from national level which, in turn, may receive an alarm from a regional or even supra-regional early warning system. In any case an early warning system triggers alarms that come from a superior system. Hence local connectivity to the superior system must be given and appropriately implemented. Incoming alarms must be correctly interpreted on a local level and properly fed to the local warning communication procedure.

Local authorities must continuously supervise the functioning of the alarm triggering. In the absence of a fully operational connectivity to a supra-regional warning system, communities could also work out a local alarm activation plan.

2.4.2 Integration with other emergency plans

Communities may have more than one emergency plan available, probably pointing at other hazards that may occur on the communities' territories. Hence an existing tsunami evacuation plan could further be modified or adapted towards its integration with other emergency plans. In the case of having also a wider-deployed regional action plan that is in charge of risk reduction issues in general, appropriate adaptations should be foreseen.

Typical disasters which tsunami-prone regions can have to cope with are:

- Earthquakes
- Landslides
- Floods or incessant rains
- Fires
- Storms.

In particular, earthquake disasters could well precede a tsunami disaster; hence earthquake preparedness measures have to be integrated into a general tsunami evacuation plan. Usually, alert times differ significantly (close to zero in case of earthquakes). Hence the evacuation objectives are different, too. Common points to be considered regard the following:

- The selected vertical shelters (buildings with a vulnerability level classified as E2 and a sufficient height; see the Annex and section 2.2.1) should in any case "survive" a preceding earthquake.
- People that succeed in leaving a building should evacuate in direction of the tsunami evacuation route.

Communities may have a local or be part of a regional action plan regarding risk reduction and disaster resilience/recovery as such. Interaction on behalf of a community should cover all phases of disaster management: prevention, preparedness, response and recovery. Activities that arise during the various phases refer to early warning, implementation of mitigation measures, training and capacity building, and also the distribution and management of those tasks.

2.4.3 Feasibility and acceptance review

Most of the analysis done so far considered more theoretical aspects than practical ones. It could happen that specific issues in the plan would better be implemented in a different way. Usually, there should be contact points that gather in long-term comments, complaints and suggestions for improvements wherever possible.

Setting a tsunami evacuation plan into operation means also to convince the involved people regarding the importance and the need of such a plan. Therefore it is crucial to know whether the plan has reached all stakeholders and whether the plan is understood by everybody involved. Accordingly acceptance issues should be gathered over time and analysed by the responsible authorities.

The local (and/or regional) authorities are strongly encouraged to assess the level of preparedness and understanding of the underlying risk with the affected population. Important contributions towards evacuation planning may be collected from people affected regarding the usability of escape routes and shelters as well as information deployment and general acceptance of the evacuation procedures.

Hence the co-involvement of the population should not be seen as detrimental to the whole evacuation planning process but rather as a valuable source of information that helps to improve details of an existing evacuation plan.

2.4.4 Long-term maintenance

Independently of issues regarding the integration into other emergency plans, an existing tsunami evacuation plan and its current implementation should be revised regularly, for example on an annual or at least bi-annual basis. The reasons for doing this could be manifold:

1. New insights into tsunami hazard could reveal a new maximal wave height or a new expected arrival time of first incoming wave;
2. Significant changes in number of affected people could mean that the capacity of identified escape routes or shelters is no more sufficient[10];
3. Changes in the road network due to new roads thus having an effect on possibly incorporating new escape routes;
4. New constructions that could serve as additional vertical shelters;
5. Modified legal bindings could mean that new standards (e.g. layout of escape routes, signposting, etc.) have to be followed;
6. Adaptations to other emergency plans could mean that synergy effects or redundancy aspects have to be analysed;
7. Evaluation of feasibility and acceptance issues could mean that decisive parts of the existing evacuation plan are hardly accepted and that they should better be altered.

Actions on evacuation plan modification deriving from alterations of that kind should be assessed by the local authorities and undertaken according to the decision matrix displayed in Table 3.

2.4.5 Revision (long-term or step-3 iteration)

Maintenance work under step-3 is, per se, an iteration taking place over many years. First, regular inspections concerning the functioning of the early warning transmission system and of the basic assumptions with respect to the tsunami hazard have to be done annually. Second, concerns on legal issues and on the integration of other emergency plans will come up when necessary. Third, acceptance and feasibility issues should also be analysed on a regular basis. Typically, step-3 iterations concern fact findings and preparatory work for eventual step-1 or step-2 iterations. In the case of identification of major changes or discrepancies of fundamental parameters or factors, other types of iterations, mostly step-1 iteration, will have to be done. Step-2 iterations, which do not question the fundamental elements of the plan, might be undertaken if minor changes regarding signposting and shelters are encountered. Similarly, necessary light modifications in publications (leaflets, internet) could be done within a step-2 iteration.

The following Table 3 presents issues at stake and suggested stepping back actions (towards step-1, step2, or a repetition of step-3) according to the SCHEMA project approach.

[10] Also the other way round is possible: if the number of affected people dropped significantly, the layout of escaper routes and shelters may be modified accordingly.

Table 3: Issues at stake during step-3 and suggested iterations to be done

Issue at stake	*Step-1 iteration (suggested)*	*Step-2 iteration (suggested)*	*Step-3 iteration (suggested)*
New tsunami wave height identified	Mandatory if Δh > 50cm		
New tsunami wave arrival time identified	Mandatory if Δt > 5 min.		
Increase in affected population	Mandatory if Δn > 2% in one district		
Newly constructed roads	Advisable if system of escape routes could be changed significantly	Advisable if changes are minor (e.g. local changes)	
Newly built facilities that could serve as horizontal shelters	Advisable if significant change possible	Advisable if changes are minor (local changes)	
Newly built facilities that could serve as vertical shelters	Advisable if significant changes may be expected	Advisable if changes are minor (local changes)	
Change in legal bindings	Advisable if too many changes regarding basic calculations; Mandatory for modified implications on assumptions (e.g. wave height, arrival time)	Mandatory for change in signposting, facilities in shelters, outlay of shelters, layout of escape routes; Mandatory for new requirements in dissemination (leaflet, internet) or training	Advisable for fact-finding (if current evacuation plan is within the legal bindings) & preparation for future step-1 or step-2 iterations
Overlap / integration with other emergency plans	Mandatory if existing network of escape routes and shelters is not enough	Advisable if signposting and shelters could be re-used; advisable if common dissemination (leaflet, internet) and training could be organised.	Advisable for fact-finding (adjustments, redundancies) and to optimize the use of common resources; advisable for preparation for future step-1 or step-2 iterations
Suggestions coming out of feasibility and acceptance issues		Advisable if clear improvements could be achieved in signposting, layout of escape routes, dissemination (leaflet, internet) and training	Advisable for fact-finding & preparation of future step-1 or step-2 iterations

3 Sociologic aspects of hazard acceptance and evacuation: analysis on the SCHEMA test site at Setúbal (Portugal)

3.1 Context and presentation of the study

Consideration on human factors in the hazard and evacuation acceptance management is a main issue for people in charge of evacuation plan elaboration. It is an important step for a *local implementation* of evacuation plan. At Setúbal, the study was done according to a psychosocial approach.

Main topics are group behaviour, social perception, mental representation, spatial perception, attitudes and the links between these factors and observed behaviours.

Because it is impossible to test everyone, psycho-social research is usually conducted on a small sample of persons from the wider population. Studies results tend to be specific and focused, rather than global and general.

The survey conducted on the site of Setúbal involves a qualitative study, applied to a selected sample of population and specific key actors interviews.

Main lines of the research were:

- Impact of environmental, economical and social contexts on capacity of population and key actors to react to an evacuation warning,

- Level of risk perception, spatial representation and risk representations; impacts of them on intended and observed behaviours.

- Level and capacity of interactions between keys actors (internal interactions) and population (external interactions)

The results provide for good insights into opinions and intended behaviours of potentially affected users of the area at risk at Setubal.

While the results are not representative for any other tsunami affected sites, similar studies have to be implemented before elaboration of an evacuation plan. Such a plan must take into account the population and key actors perceptions and awareness of the tsunami risk. Used methods are explained hereunder and questionnaire is presented in annex.

3.2 Impacts on behaviours of the specific contexts at Setubal

3.2.1 Environmental and social factors

Setubal, a medium sized town, is situated 40 km from Lisbon. It is a harbour town of 118.696 inhabitants, built along the coast.

The whole area is prone to earthquakes; during the earthquake and tsunami of 1755 the town had been destroyed. In December 2009, lastly, a small earthquake occurred and was felt by the population.

Photo 1: Sea front of Setubal (source: Port Authority of Setubal); behind on the right, the Troia peninsula with tourist facilities

- The historical town centre (the commercial and tourism zone) has been rebuilt after the 1755 earthquake and tsunami without implementation of anti-seismic norms. It is made of very small and narrow streets; the general level of maintenance is poor for economical reasons. This crowded area is well-known for its “shopping streets”. At day time, the streets are crowded; at night they are nearly empty.
- The principal Avenue Luisa Todi has been rebuilt from the wasted materials left behind by the 1755 disaster; the avenue creates a sort of dam between the port area and the old town. A large number of restaurants and business activities are situated alongside creating a “zone of accumulation of risks”.

- The traffic problem in general, combined with anarchic parking, public works, and narrow streets, creates frequent traffic jams and limits the access for emergency vehicles. Permanent flow of trucks has to be added to the important traffic on the narrow coastline road (trucks, car parks and bicycles or bus).
- Newly built high and modern buildings are located in the higher parts of the town, on the bed of small rivers coming down to the sea through the town, thus inducing floods. The sanitary net is insufficient to disperse water when joined with seasonal high tides.

3.2.2 Economical context

- The industrial port spread over 12kms, along the coastal line, built up with port installations.
- The industrial area behind the port includes five plants classified "Seveso II" (classified dangerous according to European criteria by EU. Seveso II Directive 1996).
- The fisher port is decreasing in activities. Most of the boats are more than 30 years old; they keep on ancient equipments. Fishermen population is also aging; the profession is no more attractive for young people.
- Recent disappearance of activities of the ancient fish canning factories (115 units fifteen years ago; 0 today) affected employment.
- Tourism is expected to give a new dynamism to the local economy. It means an important change of image of the town and improvement of the beaches and tourism installations.
- For the town, the challenge is to retain tourists at Setúbal from going to Troia on the opposite located peninsula (see Photo 1).

From the above description, the site shows most of the difficulties for implementing an evacuation plan as described by the handbook.

Furthermore, at daytime a large part of the population at risk (living near the seaside) is working, either in the plants, the harbor, or in the offices or shops in the center of Setubal; at night they are living near the sea side or in the higher part of Setubal. Evacuation plan must take into account accordingly the people places and the feasibility of evacuation.

3.3 Methods of the survey used at Setúbal

In order to understand the institutional and social inputs, two enquiries on the site have been conducted[11] as described in the following sub-sections.

3.3.1 A qualitative survey on a definite panel of population

The survey has been built from a grid of interviews after a pre-survey, and basing on crossed methodologies of words' association, open and closed questions, mental maps and observed redundancies in the collected responses. All the interviews were made face to face.

Mental maps were used for measuring sample awareness of space and intended means of evacuation.

During the questioning, the interviewees were presented with a map of Setúbal. They had to indicate their place of living and working, their representation of the zone at tsunami risk, the safe places, and to choose a route for potential evacuation, etc.

The mental maps constitute a base for spatial choices and decisions. The spatial preferences of the individual are linked to the level of attraction exercised by the place, combined with the memorized distance which separates him/her from this place and the familiarity he/she has with this place. This information leads to the construction of a mental map of the environment.

3.3.2 Institutional actors face-to-face interviews

The questioning of the risk mitigation major actors aimed to overview their awareness, preparedness and concern toward tsunami risk and evacuation and how they could interact between themselves in case of a tsunami occurrence. The goal was to meet major representatives of the economical local life, the different sectors of activities that would play role in case of evacuation linked to a tsunami warning. Focus of the analysis was put on the articulation between the actors.

[11](1) A keys actors enquiry on fifteen people and (2) a population survey on a total of 42 persons (20 male, 22 female); all persons could be considered as "affected" as they were all either living and/or working within the tsunami hazard zone.

3.4 Results from both enquiries underline specific vulnerabilities

3.4.1 Structural vulnerability linked to the lack of systematic links between the major actors of risk mitigation

From the actors' interviews, we underlined that an adequate risk perception is useless when professional activities and duties limit its integration at day-to-day decisional level.

In the graph of the existing links between the actors, represented in Figure 21, it is obvious that some of the actors are isolated. In case of a tsunami, it seems that a warning will not reach every service or local actors.

In the present state of things, the local Civil Protection will not receive immediate warning from the scientists. On 17/12/2009, the local Civil Protection had to phone to the National Institute of Meteorology to get information on the earthquake.

According to the actors, the first information will come from the field, as a result of people's experience on earthquakes. But, the link earthquake / tsunami will not be automatically made if we refer to what has been said by teachers, technical services, etc.

A new communication system with the population is in progress. New radio connecting terminals, located in the historical centre, will allow an immediate communication with the emergency services.

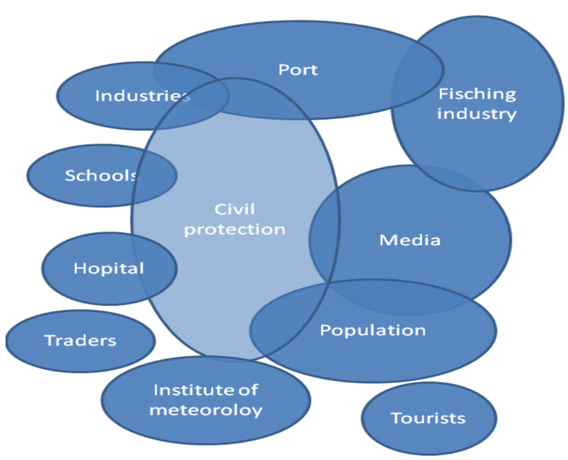


Figure 21: Interaction between the actors

The graph in Figure 22 provides with a visual summary of the results of the interviews with the key actors according to their various sectors of activities.

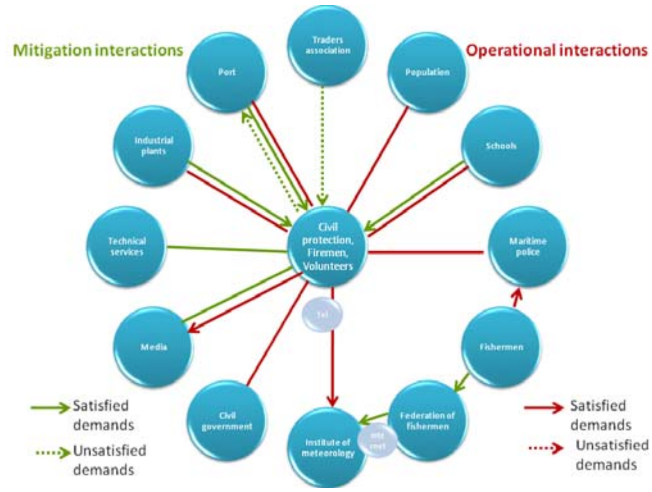


Figure 22: Communication between actors and satisfaction

3.4.2 Social vulnerabilities linked to a low level of tsunami risk awareness

Analysis of the sample interviews shows that, today, risk perception and knowledge are disconnected from behaviour (experienced/intended).

1) Representation of a safe place

Thinking of a tsunami occurrence, the sample had to give its own definition of "a safe place".

The sample is coherent with its knowledge of instructions: a safe place is far from the ocean and located at an elevated place. Analyzing the mental maps, it is confirmed that the height is an element massively considered for the identification of safety zones. Once drawn the zone of probable impact of a tsunami, we could expect that the safety zones will be located quite near the border. In fact, on the map, the majority of the sample locates it far beyond the impact zone.

This refers to an intention of maximum avoidance behaviour, combining horizontal and vertical distance with regard to the wave. A safe place is understood as a place located as far as possible from the tsunami wave. Trying to access a far safe place, however, increases the exposure to be hit by a tsunami wave.

The item "easy to reach from where you are" is quoted by few persons. The item "one place where you can group together" is quoted only by three persons and the fact to be at a certain distance from buildings is discarded.

The identification of safe zones is based on adequate information: vertical and horizontal distances from the wave.

When having to draw on the Setúbal map the limits of a possible tsunami, most of the sample appears to refer to the worst scenario, the 1755 scenario. But from the general mood of the answers, the reference is more topographic and linked to the good knowledge of the town.

2) Involvement in protective behaviours

Individual involvement in risk mitigation depends upon three functions: the individual risk assessment (is that risk important for me or only for other people?), the understanding of risk proximity (will that risk have an impact on my own values and goods?) and the capacity to react (have I an opportunity of action and control on that risk?).

At Setubal several actors told us: "the secret for saving people is to rely on them and to have them prepared" or: "for efficient warning in case of emergency, people have to know what to do and that we will rely on them".

In the enquiry**,** preparedness for tsunami is refused by one third of the sample, either because they think that preparedness cannot be of any use in such a situation, or they think that a tsunami will not occur.

3) Mobilization at local level and participation to elaboration of an evacuation plan

Most of the interviewees wish to participate in the meetings in their borough for elaboration of an evacuation planning. Gender does not seem to influence the wish of participation.

Wish of participation is always a means to keep control on the decision process, to get more information, to understand mechanisms at stake. It is also a sign of openness to learning and must be put in balance with the refusal of preparedness for coping with a tsunami, quoted above.

The sample was also questioned on the persons or organizations involved in the preparation of an evacuation plan. It was an open question; interviewees could give the name of community leaders or specific people known for their involvement in the natural hazards domain.

For the panel, confidence and effectiveness are granted to Civil Defence at first, then to Town-Hall. District, Port authority, experts or Army are quoted by two persons each.

The choice, by the panel, of the institutional and official service in charge of emergency can be seen as the wish to leave the question of evacuation plan to specialists; if they agree to participate, they do not want to be on the front line; it is a passive attitude. At the same time, the local fame of the Civil Defence service, (the Director), and of the firemen team received, here, some sort of acknowledgement from the inhabitants.

The sample explains its choice: Civil Defence agency has capacity, knowledge and responsibility, when the Town-Hall is situated on the side of power, responsibility and coordination.

Interestingly, the item "protection" is not quoted in correlation with Town-Hall and Civil Defence: the results can be correlated with the perception of a low preparedness of the city and the need to protect oneself (see questionnaire results).

Even if the interest for tsunami prevention and evacuation planning exists, the mobilisation of the population is not yet organised and is still considered as the matter of public services. No one emerges as referent or a leader at the borough level except the operational public services.

4) Observed and intended behaviours

The earthquake of December 17, 2009 (Mw 5.5 at 1:37 UTC) appeared as a chance for the study: it was assumed that recent experience of earthquake will lead people to acknowledge their own exposure to the risk; in the questionnaire the interviewees were requested to describe what they have felt and what have been their first actions or request of information.

More than half of the panel stated to have experienced the earthquake of December 2009 and to know about the earthquake and tsunami of 1755 at Setúbal; only one person quoted an earthquake in the eighties stronger than the one of 2009. Furthermore, the sample gave a frightening description of the potential consequences of an earthquake.

Nevertheless, experience of the earthquake of December 2009 (Mw 5.5) appears to have had no influence on risk perception; knowledge is present or latent among the panel but does not imply a feeling of risk. Furthermore, most of the people can quote the instructions to apply in an earthquake situation, but only three persons did it in the real occurrence. It can be said that knowledge is disconnected from behaviour; the image of an earthquake is too abstract to be integrated into concrete behaviour.

In December 2009, in the sample, only people having specific knowledge or training as a nurse, or a fisherman made an immediate link between the earthquake and a potential tsunami. Preparedness to risks plays clearly an essential part in the adequate reaction.

It seems that most of the time, the link between an earthquake and a tsunami exists at a theoretical or knowledge level; but in the Setúbal sample, that link was not activated spontaneously by a real situation.

One can say that the information on tsunami risk exists through stories and memories of the past; it created an image of "the worst flooding" of the city; but that image is insufficient to induce adapted behaviour.

The questionnaire reveals also an intention to use vehicles rather than to escape walking during the evacuation process. It might be explained by the localization of the remote safe zones and their height, but this choice reveals potential problems to come up when considering the traffic jams and the possible obstruction of roads by the collapses of buildings due to an earthquake.

3.5 Conclusions

Generally speaking the authorities imagine that people will wait for instructions or apply instructions when the lay man without specific formation will assess the situation by himself and according to several factors based on his experience, his knowledge or culture.

Formation should be given for learning to protect oneself immediately and keep in touch with the channels of information as far as the people in charge can give it quickly enough.

The factors impeding the set up of tsunami warning and evacuation procedures and the factors aiming at facilitating the preparation of coastal communities for a tsunami are summarized in the table hereunder. They are organized according three axes. The first one, "representation and knowledge", refers to the mental context and the level of knowledge about risk. The second one, "responsibility", is about the personal acceptance of involvement in protective behaviour toward risk. The last one, "capacity", is related to the likeliness to adopt adequate protective behaviour and mobilize existing means or tools.

At Setúbal, at the beginning of the enquiry, there was not enough contact between the organizational and the societal aspects. But before its end, new measures were developed by the City and the Civil Defence agency; the study played as a trigger and the usefulness of its results must be emphasized.

Table 4: *Building resilience with population*

	Facilitating factors	Impeding factors
Representations and knowledge	Knowledge of potential tsunami (except for young people). Relatively good knowledge of instructions to apply in case of earthquake and tsunami occurrence. Knowledge of the town topography and of the places. Affective attachment to the town. Good representation of what is a safe place.	Lack of link between earthquake and tsunami. Reflex action to fly away as far as possible with risk to cross the flooded area. Trying to reach a far safe place increasing the exposure to danger. Unrealistic idea of using car for escaping tsunami. Lack of spontaneous adoption of instructions in real occurrence linked to low level of perception.
Responsibility	Protection of myself and my family depends on me. Wish of participation to elaboration of an evacuation plan at local level.	Transfer of responsibility to public services (duty). Low perception of a need for collective action.
Capacity	Modern means of communication. Confidence in authorities.	Bad identification of the communication channel likely to be used (T.V.). Not interested in being prepared for coping with tsunami.

Nevertheless, the knowledge of guidelines does not guarantee the adoption of appropriate behaviours. Though the 2009 earthquake occurred three months only before the investigation had been undertaken, it did not induce protective behaviour. It should be kept in mind that, in case of an earthquake, the first move of human being is reflexive and often to freeze in paralysis. Experimentations and blank exercises may create a body's memory that can help in adopting an adequate behaviour.

It was stated that an active involvement in the preparation and generation of the local evacuation plan was requested by most of the interviewees. It underlined that the evacuation plan had to take into account the often non realistic views of people thinking to escape by car, taxi and even bus. Chances of evacuation in case of tsunami are poor for the population living at the seaside, unless a better alert system is implemented.

Experiences all over the world, as in Chile in 2010, provide for interesting and efficient lessons. The Chilean tsunami of 2010 (triggered by the Maule earthquake, M 8.8, occurred on February 27) caused little human damages because of a very well integrated previous experience (1960) and preventive policy. For instance, all the coastal cities have implemented an area-wide marking "at risk", and have signposted the evacuation roads towards safe places.

This Chilean example demonstrates the efficiency of the integration of the operational behaviour to abstract knowledge. From this integration, adequate behaviour may spontaneously merge, according to the specific situation, for successful evacuation.

4 Difficulties and limitations

The SCHEMA approach provides with a full-range methodology allowing for a community to prepare for a tsunami disaster. The methodology is based on scientific insights providing with basic input on expected tsunami characteristics so that any further calculation can be applied on top of that. In theory this requires the use of certain techniques and the availability of particular tools. In addition, connectivity to an early warning is somehow crucial. Nevertheless the methodology has been designed to provide workable solutions even in the case of lacking necessary information and/or resources.

4.1 Absence of early warning system

Despite the increasing number of modern early warning systems (EWS) installed or currently under development there are still several coastal areas that remain out of coverage of such systems. In these areas "alternative" indices can be used as sign of potential tsunami occurrence. Such indices include:

1. felt or reported ground shaking
2. abnormal rapid retreat or draw-down of the sea.

The first index is not reliable in the sense that it does not necessarily lead to tsunami waves. Nevertheless it can be taken as "input" for tsunami warning; this is particularly the case at locations known as tsunami-prone. On the other hand, rapid retreat (i.e., few minutes up to 20 minutes) or draw-down of the sea is considered a valid sign of potential tsunami occurrence. In this case the time of arrival of the wave can be indeed very short. However, depending on the type of the source and on the location of the area of interest with respect of the source, the first manifestation of a tsunami can be an abnormal increase of the sea-level without previous sea retreat.

The difficulty to trigger an alarm without being connected to a (supra-) regional early warning system could only be addressed through the interaction of specially appointed and authorised (and fully responsible) persons who immediately trigger local alarm once they observe or report a "natural" warning sign. This is mostly the case in less equipped countries or remote regions. Many of the envisaged measures and precautions following this particular warning identification can be identical to those considered where EWS exist and are operational.

4.2 Absence of analysis tools

Beyond the absence of an operational Early Warning System (EWS), the absence of appropriate analysis tools may be often the case in many parts of the world and/or remote areas. There are communities that want to quickly set up emergency plans for their population which won't be conditional to the existence or presence of experts. In this case computer-based calculation of inundation maps and the subsequent determination of shelter sites cannot be implemented [Ministry of Home Affairs, Gov. of India, 2005].

Rudimentary risk analysis can be performed by assuming a certain tsunami wave height thus selecting those safe places which are sited above such a threshold, e.g. from the third floor onwards. The assessment of the impact of the waves on constructions could be done by an on-spot analysis taking into account constructions' features such as strength, foundation as well as a building's position towards the waves. The location of a construction plays also a role since first-row constructions, obviously, are much more exposed to incoming waves compared to second-row constructions.

A valid scenario for working out solutions in case analysis tools are not available is assuming a maximal evacuation time of 15 minutes and a wave height of up to 10m.

4.3 Absence of shelter sites

The methodology described assumes that shelter sites (vertical shelters and, with priority, also horizontal shelters/assembly points on safe ground[12]) will somehow be available. While the availability of vertical shelters is more a fact of urbanization or of explicit intention (dedicated platforms), the availability of horizontal shelters absolutely depends on higher grounds on nearby terrain. In nature, in particular along extremely flat coastal regions, this could be a problem. Experience has proved that tsunami waves, if not heavily stopped by elevated beach crests, could enter far inland thus making it problematic for evacuees to reach safe sites in flat coastal areas.

In such cases, construction of vertical shelters has to be fostered. These shelters can have the form of concrete

[12] *In practice, a 20m high elevation is sufficient while in case of very large tsunami this could go up to 50m.*

platforms or even earth mounds. More importantly, they should be resistant to wave impact, undercutting, etc. In the case that even this alternative fails, for example due to high construction costs, other mitigation measures should be taken into account, e.g. the installation of onshore wave breakers or sea gates.

The worst case (no shelter sites, no other mitigation measures affordable) discloses running to inland as the only evacuation practice. In this context, a distance of 3km from the sea shore is usually considered to be sufficient.

4.4 Lack of acceptance by population

It can be understood from many observations and official reports that the importance of tsunami evacuation procedures is badly perceived or scarcely accepted by local population. Various factors may contribute to that: first of all, the tsunami hazard is not perceived thoroughly because of its relatively low probability, especially in Europe and along the Mediterranean Sea. Secondly, people use to overestimate their own capabilities to address a tsunami wave. Many persons think seriously that they may cope with being flooded or being caught by a tsunami wave.

As in many similar cases regarding safety issues no human being can be forced towards safe behaviour. The minimum that local authorities can do is to perform consistently their tasks (instruction, dissemination and training) along with the application of enforcement procedures. In particular, authorities could enforce evacuation of public buildings and apply traffic control measures (road deviation / blockage etc). Information deployment to temporary residents (in hotels, at work place, on roads, on beaches) should be enforced and properly controlled. An example of plans for informing and practicing mitigation and evacuation in case of a tsunami event is given by the Tsunami Ready Program (www.tsunamiready.noaa.gov).

Sensitivity towards safety should constantly be deployed through instruction and information providing via internet and via publications. Local residents should drastically be informed about the huge impact generated by tsunami waves.

4.5 Lack of acceptance by decision makers

Huge problems could be generated if local or regional decision makers deny the importance of tsunami early warning and relative evacuation procedures. This is particularly the case in tourist areas where local authorities – being afraid that the installation of warning signs or evacuation plans could be detrimental to economic development – use to lessen the importance of properly marking the hazardous area and setting up valid safety procedures.

While the overall methodology described here is addressed to local decision makers, it could be necessary to employ enforcement procedures on behalf of national decision makers. They may define the responsibility of the local decision makers for evacuation invocation in front of higher administrative structures of civil protection.

4.6 Evacuation of special population

Special parts of population are those groups of people who, because of their special situations or needs, require different planning strategies from those of general evacuation planning [Vogt, 1990 and 1991]. The term "special population" is somewhat misleading in the sense that populations of institutions or special facilities are frequently considered homogeneous when in reality they exhibit many characteristics that differ by physical or geographical constraints [Lindell et al., 1985]. While some populations may be concentrated in institutions such as schools, prisons or hospitals, other will be widely dispersed. These institutions have individual evacuation plans in case of an emergency which have to be integrated within the community evacuation plans. Among the dispersed individuals that make up such special groups are the hearing or visually impaired, the foreign speaking, transients such as motorists passing through the area, tourists or other temporary visitors such as day workers, and the non-ambulatory confined to residences either temporarily or permanently.

The reason why these groups may fail to respond to warnings to take protective actions is that they may require special transportation while others require different types of technologies to receive a warning. Some groups must rely on care-givers (such as schools and day-care centres) to hear the warning and respond. Populations of nursing homes or assisted-care facilities may combine various aspects related to mobility and mental competence that makes evacuation the last resort in protective action planning. Lack of mobility may be imposed as in the case of prisons where continued constraints must be respected during the evacuation process.

Suggestions for special groups are as follows:

Hospitals, houses for elderly or handicapped persons, nursery homes, prisons: Usually evacuation is difficult unless with a long warning period. As such facilities are extremely critical, strict preparedness measures should be applied beforehand thus constructing them either on safe locations or as E2 classified buildings (see the Annex). In this latter case, nevertheless, it remains the problem of evacuating the first two floors.

<u>Schools, kindergartens and similar</u>: An individual evacuation plan, though in line with the general evacuation plan, could be worked out; usually there should not be problems in performing the evacuation. It could be useful to organize regular drills.

<u>Handicapped or elderly people dispersed in various houses</u>: In general, either these people already live in houses with low vulnerability to tsunamis (E2 vulnerability class) or the authorities should know about specific necessities and try to allocate staff for special evacuation.

4.7 Tsunami warning limitations

Notwithstanding their potential of devastation, tsunamis are still rather rare disasters; it remains difficult to predict their propagation precisely. Hence tsunami warning as such could find certain limitations (see also [UNESCO IOC Tsunami Programme, 2005]).

4.7.1 Low probability

The biggest problem in raising tsunami awareness is the low probability of its occurrence, especially in Europe and along the shores of the Mediterranean Sea; tsunamis are rare events, sometimes it may take decades for a tsunami striking a coastline. People use to underestimate the tsunami risk, simply due to the fact that it may take several years for a tsunami to hit the same area.

As done for big earthquakes, rarely happening in earthquake-prone regions, local population must be instructed to consider the risk of having huge but rare events. Authorities must raise awareness by constantly informing the population on new (scientific) insights, new developments concerning the network of escape routes, and organizing training evacuation drills. See also under chapter 6.4 (lack of acceptance by population).

4.7.2 False alarms

Early warning systems issue tsunami alarms on basis of certain parameters: essentially earthquake parameters, but also wave height measurements on open seas, etc. Each of these parameters or measurements could trigger an alarm which, at the end, turns out to be false. Repeated false alarms, however, can lead to "cry-wolf" effects which refer to non-compliance with warnings behavior that might be observed by residents who have responded previously to too many false alarm warning messages.

The sensitivity of an alarm system is definitely a delicate feature: is it better to produce more false alarms than real alarms? Having too many false alarms issued could become detrimental to the persons' alarm perception; on the other hand, having a tsunami wave arriving onshore without prior detection by an (existing) early warning system, could even be perceived worse.

On one hand, responsible authorities must optimize their procedures that will trigger a tsunami alarm in order to drastically reduce the number of false alarms. Another step to "mitigate" effects of false alarms would be to optimize the closing down of such a false alarm in order to reduce the consequences (leaving homes, leaving work places, chaotic situation on roads, etc.). However, it will also be the task of the authorities to promote to the population the risk and self-protection culture which considers that a false alarm is much more preferable than a missed real alarm.

Local authorities could also experiment with color-coded warning schemes (see also 4.7.3) allowing issuing different levels of warnings. The advantage of this approach could be the flexibility of refraining from a warning without creating too many disturbances to the population.

Another feasible way of handling this problem to differentiate between the expected levels of impact; thus different levels of warning will be addressed to different recipients: a level with only information for the (local) authorities (as advisory level), and a level of alert or warning for the public.

4.7.3 Extreme warning times

Problems will arise from extreme warning times until a tsunami wave is striking. It can take hours until the arrival of the first tsunami waves, or in the contrary, only a couple of minutes. The case of extremely short warning times is much more difficult to handle; similarly to an earthquake shock there is nearly no time to evacuate. Preparedness measures should rather concentrate on having a sufficient number of vertical shelters nearby or other mitigation options (e.g. seawalls etc.) to prevent the effects of tsunami wave hitting.

With regard to extremely short warning times, it should be mentioned that the warning response is a sequential process including [Mileti and Sorensen, 1988]:

<u>Hearing</u> the warning;

<u>Understanding</u> the contents of the warning message;

<u>Believing</u> the warning is credible and accurate;

<u>Personalizing</u> the warning to oneself;

<u>Confirming</u> that the warning is true and others are taking heed

<u>Responding</u> by taking a protective action.

All the above instances can increase the warning response time according to the group of population [Mayhorn, 2004], the season of the year, the time of the day, etc. One frequent response to a warning is to confirm the original message received [Drabek, 1969]. Confirmation increases with longer lead-time to impacts [Perry et al., 1981], for warnings received from the media [Dillman et al., 1983; Sorensen, 1992] and for alerts received by sirens [Sorensen, 1992]. Confirmation levels decrease with the specificity of information in the first warning received [Cutter and Barnes, 1982] and when the initial warning is heard from police and fire personnel going door-to-door or using loudspeakers [Sorensen, 1992]. These issues could be communicated to all stakeholders and in particular to the population when being informed of the tsunami risk.

In the case of an extreme long warning time, the problem is negligence by the evacuees: they simply tend to return to their working places or to their homes. If possible, a colour-coded warning system could be useful allowing gradually preparing for tsunami evacuation. The colour codes could be displayed on huge panels and should, ideally, be connected with a gradual audio warning scheme through sirens. In some publications it is reported that a yellow-orange-red colour-code can be used. In the first case (delay above 9 hours) civil defence or high-level authorities may be warned. The orange case means that a severe danger of tsunami has not yet been confirmed. The red case, then, means an imminent danger (delay below 3 hours) which will launch the “official” alarm to the population.

4.7.4 Not identified tsunamis

There is the possibility to not being informed of a tsunami wave. Probably this could be triggered due to landslides into the sea or by underwater landslides.

Handling such a situation comes close to what is mentioned under 4.1 (absence of early warning system). Unless a local early warning system is closely connected with a landslide detection system (as it is for example the case on Stromboli Island in Italy) the detection of tsunami waves in this case becomes extremely difficult. Nevertheless one can rely on one’s own awareness (e.g. retreat of sea water) and on one’s own preparedness measures (e.g. having a vertical shelter nearby, knowing well the escape routes, etc.).

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6 Annexes

6.1 SCHEMA project presentation

The **SCHEMA** project aims at initiating, designing, developing and validating a stand alone methodology to assess the potential impacts of tsunamis that may occur in the Mediterranean basin, on the Atlantic coast and in the Black Sea. As source of a potential tsunami both earthquakes and underwater landslides are considered.

Its key ambition is to demonstrate that Earth observation data allows defining generic rules to calculate vulnerability maps, when, for instance, seismic and tsunamis events are combined. The key features of this research and development work are:

- the clarification of concepts such as vulnerability, hazards, scenarios, in order to produce documents and maps accessible and understood by end-users (civil protection, rescue planners);
- an analysis of mathematical modelling limitation to reproduce reality in order to assess the degree of uncertainty when risk is estimated on models and not on real past events;
- the development of a generic methodology, validated by end-users, to produce scenarios for tsunami and related phenomena hazard impact;
- the extraction of vulnerability and hazard level indicators, as used in the generic methodology, from Earth observation data;
- a first validation of the methodology on real life cases as observed during the recent tsunami in Asia;
- a thorough validation of the resulting prototype methodology on 5 test cases typical of different environments (Portugal: Setúbal, Morocco: Rabat, France: Mandelieu, Italy: Catania, and Bulgaria: Balchik).

The main achievements of this research work are the followings:

for civil security organisations: a comprehensive and homogeneous technique to assess tsunami and related phenomena risk levels based on intrinsic vulnerability variables (building heights, building types, inhabitant description) and environment variables (density of buildings per unit area, road width…) and, thus, a technique capable of helping them to develop generic preventive emergency measures.

for rescue planners: a clear cut description of accessible areas in case of tsunami occurrence, to help rescue planners design effective rescue operations since they are able to evaluate vulnerability variables under crisis organisation modes.

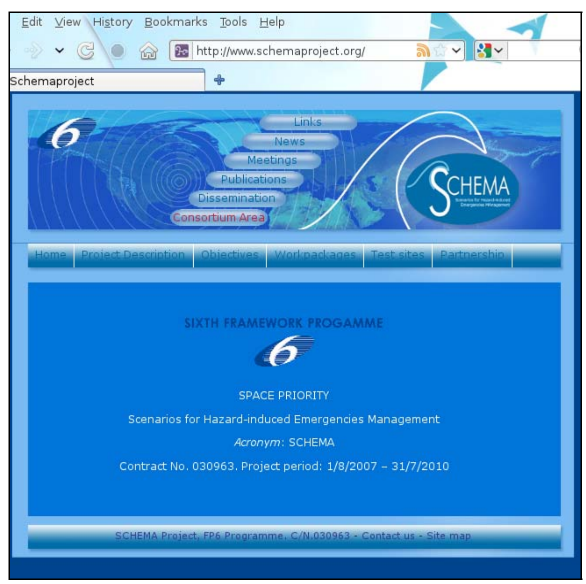
for public safety policy makers: a set of policy recommendations to standardise data collection and preparation for vulnerability studies, based on tsunami simulation scenarios that concentrate prevention and education efforts within the most exposed areas.

for insurance companies: useful spatial data related to potential maximum building damages within potentially flooded zones, thus allowing them to answer questions such as: what level of premiums should be set for buildings, contents loss and business interruption loss insurance in risky areas ? What is the potential level of claims for a particular portfolio of insured assets in a given location?

for land management and planners: the approach combining models, field survey and vulnerability assessment should be used as an input in the planning of coastal management and taken into consideration when building or modifying a coastal zone exposed to a tsunami hazard.

Additional material on the project is available at:

www.schemaproject.org



6.2 SCHEMA Consortium

Logo	Short name	Country	Expertise	Role in SCHEMA project
	GSC	France	All natural hazards, vulnerability assessment, damages assessment, Earth observation. Mitigation measures and vulnerability reduction	**Coordinator** Methodology to build up GIS mapping of natural hazard and damages. Work on the French test site
	ALGOSYSTEMS	Greece	GIS, management of natural hazards, multirisk assessment	Dissemination and user feed back. Work on evacuation simulation
	HIDROMOD	Portugal	Wave propagation modelling, emergency response planning	Tsunami modelling, work on the Portuguese test site
	UNIBOL	Italy	Tsunami observations, generation mechanism, modelling, hazard and risk assessment	Methodology build up, tsunami modelling, work on the French and Italian test sites
	UNICOV*	United Kingdom	Risk/vulnerability/ capability assessment, scenario development	Tsunami vulnerability assessment, crisis management, users feed back
	NOA-GI	Greece	Earthquake monitoring, seismic and tsunami hazard assessment, studies on seismic and tsunami sources, tsunami modelling and risk mapping	Methodology build up, tsunami modelling, work on the Bulgarian test site
	CRTS	Morocco	Morocco Earth observation in charge of hazard mapping for Morocco, vulnerability assessment	Vulnerability assessment, work on the Moroccan test site
	ACRI-ST	France	Fluid dynamics, geophysics, ocean modelling, surveillance and forecast of the Earth environment, integrated on-line Earth observation systems	Methodology build up, tsunami modelling, work on the Moroccan test site, contributing to work on the French test site
	SRI-BAS	Bulgaria	Earth remote sensing, onboard systems, geoinformatics	Vulnerability assessment, work on the Bulgarian test site
	JRC-IPSC	European Commission	Hazard assessment and prevention, vulnerability assessment, users needs assessment	Dissemination and feedback from user panel. Work on evacuation plans.
	TUBITAK – MRC-EMSI	Turkey	Earthquake and tsunami hazard mapping and assessment, geophysical monitoring, natural processes modelling	Exchange of experience on on-going work related to earthquake and tsunami in Turkey. Feedback from local users

* Partner withdrawn in the course of the project

6.3 Buildings classification according to their vulnerability

In order to assess the vulnerability of buildings, the first step consists in adopting a standardized building types description to qualify all or almost all constructions on the coasts exposed to tsunami hazard. After the tsunami of the December 26, 2004, various authors (Leone et al., 2006; Garcin et al., 2007; Reese et al., 2007) have proposed typologies of buildings in order to elaborate vulnerability functions. The building typology proposed by SCHEMA project Consortium is principally derived from Leone et al. (2006), but has been completed and enlarged in order to be more general, and to include at least all constructions present in the five test sites of the SCHEMA project.

Four main classes of buildings (divided in sub-classes) have been defined on the basis of their structural characteristics of resistance, as is given in

Table 5:

- I. Light constructions;
- II. Masonry construction and not reinforced concrete constructions;
- III. Reinforced concrete constructions;
- IV. Other constructions.

Table 5: *Vulnerability classes of buildings*

Class		**Building types**	**Height & storeys**
I. Light	A1	Beach or sea front light construction of w*ood, timber, clay*	0 to 1 level, Rarely 2
	A2	Very light constructions without any design. Very rudimentary huts, built using *wood or clay, timber, slabs of zinc*	1 level only
II. Masonry, and not reinforced concrete	B1	*Brick not reinforced, cement, mortar wall, fieldstone, masonry*	1 to 2 levels
	B2	Light and very concentrated constructions: *wooden, timber and clay materials*	1 to 2 levels
	C1	Individual buildings, villas: *Brick with reinforced column & masonry filling*	1 to 2 levels
	C2	Buildings with walls realized with *lava stones*, usually squared-off, alternating with *clay bricks*	1 to 2 levels
	D	Large villas or collective building, residential or commercial buildings: *Concrete not reinforced*	1 to 3 levels
III. Reinforced concrete	E1	Residential or collective structures or offices, car parks, schools: *reinforced concrete, steel frame*	0 to 3 levels
	E2	Residential or collective structures or offices, car parks, schools, towers: r*einforced concrete, steel frame*	> 3 storeys
IV. Other	F	Harbour and industrial buildings, hangars: r*einforced concrete, steel frames*	Undifferentiated
	G	Other, administrative, historical, religion buildings	Undifferentiated

6.4 Classification of buildings' damages

The damage level on buildings may be classified through a discrete qualitative scale with increasing severity, from no damage to total collapse. A 6-degree scale was adopted by SCHEMA basing on the works by Leone et al. (2010), Peiris (2007) and Garcin et al. (2007) and is given in Table 6. The possible utilisation of the building in the immediate post-disaster emergency period is also suggested (column 3) as well as how effective satellite observation techniques are expected to be in detecting and assessing the damage level (column 4).

Table 6: *Damage levels on buildings (scale adopted by SCHEMA project)*

Damage Level	Damage on Structure	Use as shelter / post crisis use	Detection by Earth observation
D0 No damage	No significant damage	Shelter / immediate occupancy	No sign of damage visible on building and surrounding environment. The absence of damage cannot be only proved from space imagery.
D1 Light damage	No structural damage - minor damage, repairable: *chipping of plaster, minor visible cracking, damage to windows, doors.*	Shelter / immediate occupancy	Barely visible
D2 Important damage	Important damage, but no structural damage: *out-of-plane failure or collapse of parts of wall sections or panels without compromising structural integrity, leaving foundations partly exposed.*	Evacuation / Unsuitable for immediate occupancy, but suitable after repair	Damage on roof hardly visible. Other damage not visible.
D3 Heavy damage	Structural damage that could affect the building stability: *out-of-plane failure or collapse of masonry, partial collapse of floors, excessive scouring and collapse of sections of structure due to settlement.*	Evacuation / Demolition required since unsuitable for occupancy	Not or hardly visible if roofs have not been removed
D4 Partial failure	Heavy damages compromising structural integrity, partial collapse of the building	Evacuation / Complete demolition required	Visible
D5 Collapse	Complete collapse: *foundations and floor slabs visible and exposed.*	Evacuation	Very visible

Examples of damage caused to buildings by tsunami waves and the association to the damage level defined in Table 6 is provided through the pictures assembled in Figure 23. They refer to the effects of the disastrous 2004 tsunami in the Indian Ocean.

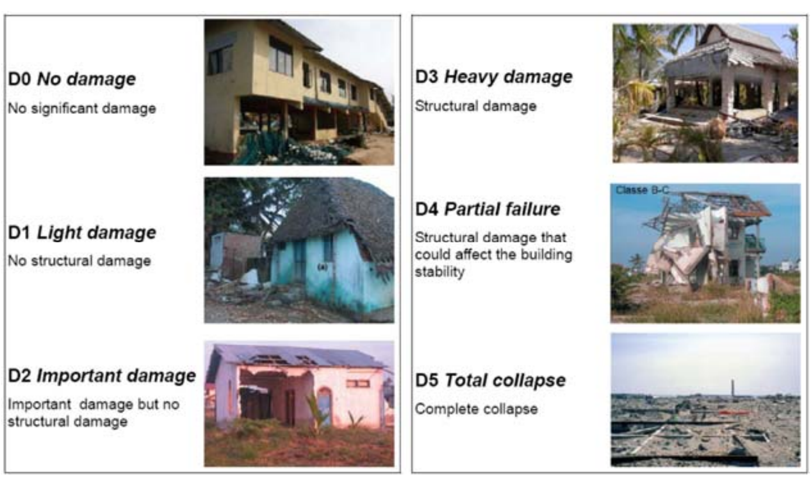


Figure 23: *Examples of damage to buildings associated with the damage matrix proposed in Table 6. Figures are from the 2004 Indian Ocean tsunami (sources: Leone et al. 2010, Peiris 2006 and Garcin et al. 2007)*

6.5 Questionnaire developed and used for the Setúbal case study

In the course of an European Program, the Schema team would like to study the impact of a potential tsunami at Setúbal.
The questionnaire you are requested to answer intend to analyse the risk perception and the knowledge of the phenomenon by local population.
Answers to the questions are confidential and anonymous
Your collaboration will permit to the public authorities to integrate your opinion upon the subject.
If you would like some more information on the Schema Program, you can visit the site: www. schemaproject.org

1. In your opinion, what are the environmental risks at Setúbal?
____

2. Did you experience the earthquake of December 17, 2009? 1. Yes □ 2. No □
3. What was your reaction? What did you do?
____

4. At that time, do you think at a possible tsunami? 1. Yes □ 2. No □

5. According to you, could an earthquake generate damages or other negative consequences at Setúbal?
1. Yes □ 2. No □

6. What sort of consequences could occur? ____________________
____
(building collapse, injury or deaths social disorder, tsunami, economic problems) ,

7. After an earthquake, of what could you be the most frightened?
____

8. According to you, the city of Setúbal is well prepared to cope with:

8.1 A flooding 1.Yes □ 2.No □ 3. More or less □ 4.don't know □
8.2 An earthquake 1.Yes □ 2.No □ 3. More or less □ 4.don't know □
8.3 A tsunami 1.Yes □ 2.No □ 3. More or less □ 4.don't know □

9. Do you know instructions to be adopted in case of
9.1 earthquake? 1. Yes □ 2. No □ Which ones? ____________________
9.2 tsunami? 1. Yes □ 2. No □ Which ones? ____________________

10. Today, for you, a tsunami is:
10.1 Something possible 1.Yes □ 2.No □ 3.Don't know □
10.2 A subject of talking between us 1.Yes □ 2.No □ 3.Don't know □
10.3 An event to be prepared for 1.Yes □ 2.No □ 3.Don't know □1 □

11. Please, look at that map, and tick with coloured pencils on the map the following places
C. Where you live ("C")
T. Where you work or spend most of your days ("T")
R. Places you are used to go (shopping, school, beach, etc.) ("R")

12. According to your experience, what are the frequently flooded places that you know (draw them with a grey pencil)?

13. Can you draw the limits of areas that would be flooded by a potential tsunami? (draw them with the green pencil)

14. A tsunami-safe location is one that enables people to protect themselves against the wave. In case of tsunami threat, what is the location that you consider as safe? (draw it in blue)

14.1 Why? ____

15. With the blue pencil, can you draw the ways that you will take in order to get a safe place if you are
at home (C)
at work (T)
at place number (R)

16. What transportation means do you think you could use to get this safe place? and how long will it take?
16.1. C :……………. And minutes………………..   **16.2.** T :…………… minutes………………..
16.3. R :……………. minutes………………..

17. Imagine that an earthquake occurs. What you do?
(immediate answer and two choices only in the list hereunder)

1.□ get out the building where you are
2.□ feel confident in the building you are in
3.□ try to protect yourself according the official instruction
4.□ phone to your relatives
5.□ go to your children's school (make your way immediately towards your children school)
6.□ stare and feel paralysed till the stroke stop
7.□ think about the possibility of a tsunami
8.□ listen to the radio
9.□ wait for official instructions
10.□ other.

18. Protecting my family and myself from a tsunami depends on:

1.□ Me

2.□ A warning given in time

3.□ Anticipated actions from the public authorities

4.□ God

5.□ The place where we are

6.□ The building quality

7.□ A previous family planning

8.□ The support of local organisations

9.□ We cannot do anything

19. According to you, a safe place:

1.□ Is one where you can group together	Yes /_/	No /_/	Not important /_/
2.□ Is one that is easy to reach from where you are	Yes /_/	No /_/	Not important /_/
3.□ Is one that is far from the ocean	Yes /_/	No /_/	Not important /_/
4.□ Is one that is far from buildings	Yes /_/	No /_/	Not important /_/
5.□ An elevated place	Yes /_/	No /_/	Not important /_/

20. What is the channel the most used at Setúbal? ____________________________

21. What is the usual channel on which you are connected most of the time?
____

22. In an emergency situation such as an earthquake, or flooding, or tsunami, the means of information that you would check right away are:
____

23. According to you, which media could be the most efficient for warning the greatest number of persons?

1. □ Radio? If yes, which one? ________________
2. □ Mobile
3. □ Phone
4. □ Loudspeakers
5. □ VHF Radio
6. □ An immediate information at my working place
7. □ Sirens
8. □ Other:

24. What information could be the most useful to you in case of tsunami warning?
1 .□ the location of a sheltering place?
2 .□ the time left before the wave impact?
3 .□ the state of traffic?
4 .□ the dangerous areas to avoid?

25. Do you wish to participate to local meeting in order to plan for evacuation in case of tsunami?
1. Yes □ 2. No □

26. According to you, and in reference to its capacity and duty, what organisation should be in charge of the elaboration of an evacuation plan in case of tsunami?
____

27. Why? ____

28. In your own borough, because the effectiveness or the confidence you have in, which person or organisation should be involved in the preparation of an evacuation plan?
____

Please, answer the last following questions:

29. You are: 1.❑ a man 2.❑ a woman

30. Your age: _________ years old

31. What do you do for living **?** Your profession? ____________________________

32. At which floor do you live? 1.❑ ground-floor 2.❑ 1º 3.❑ 2º 4.❑ 3º 5. ❑ other

33. Do you work: 1. ❑ inside a building 2. ❑ outside of a building

34. At what level? 1.❑ ground-floor 2.❑ 1º 3.❑ 2º 4.❑ 3º 5.❑ other

35. Are you living:

1.❑ alone 2.❑ in couple 3. ❑ alone with children

4.❑ in couple with children 5.❑ with other people

36. Do you usually go to pick up your children from school? 1. Yes □ 2. No □

37. For how long have you been living at Setubal? ____________

38. For how long have you been living in this neighbourhood? ____________

7 List of Figures

8 List of Tables

European Commission

EUR 24707 EN – Joint Research Centre – Institute for the Protection and Security of the Citizen
Title: Handbook of Tsunami evacuation planning
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Abstract
This handbook is dedicated to provide thorough and hands-on information and a fully-comprehensive methodology of tsunami evacuation plan generation. Hence community-employed decision makers or similar stakeholders are supplied with a detailed guideline to implement a fully-fledged evacuation plan within three stages: set-up of valid first instance of evacuation plan, mid-term revision, and long-term revision and integration.

Local tsunami risk assessment and all subsequent implications on evacuation planning are based on (1) knowing the to-be-expected tsunami wave height, and (2) the to-be-expected arrival time of the first devastating tsunami wave. The first parameter helps to calculate the area at risk; the second parameter gives an indication of how fast the evacuation has to take place. Evacuation has to take place on a given network of suitable roads or paths. In this context, if necessary, the methodology foresees also the inclusion of additionally to be built escape routes and/or safe places.

Moreover, the methodology explains how to implement a valid instance of evacuation plan by marking the identified escape routes and shelters in reality, and how to disseminate all information to the affected population. Within a mid-term review the evacuation plan has to be maintained constantly and appropriate authority-own measures have to be guaranteed. The long-term review, finally, keeps track of all other information needed to run the evacuation plan properly: integration with early-warning systems, integration with other emergency plans, checking of legal obligations.

The handbook also presents the results gathered during interviews with potentially affected persons (Setúbal case study) and concludes mentioning the difficulties and limitations that may arise during the generation of evacuation plans.
This work has been realized in the framework of the FP6 European co-funded SCHEMA project (SCenarios for Hazard-induced Emergencies MAnagement, www.schemaproject.org).

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