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Integrated disaster risk management strategy to prevent exposure to hazardous substances due to inundation triggered releases: a concept for Japan

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ABSTRACT

An integrated approach to prevent inundation-triggered releases of hazardous chemicals from facilities is introduced. The concept integrates data from the recently available Pollutant Release and Transfer Register (PRTR) in Japan, inundation scenarios and agricultural land use into an information scheme within a real-time disaster response strategy. It is shown how recent available mobile communication systems using a newly developed system for dissemination of maps and disaster relevant information can be used within this strategy to prevent or mitigate consequences of released hazardous substances. The approach distinguishes three steps: risk assessment, disaster response and disaster mitigation. The introduced concept is exemplarily discussed using an inundation scenario occurred during the 2000 Tookai flood in Nagoya, where 16 facilities dealing with hazardous substances were inundated. Consequences for planning and policies, based on the introduced concept are discussed.

1. INTRODUCTION

The Nobi plain in Aichi Prefecture is exposed to multiple hazards, like inundation, typhoons and earthquakes. One serious threat is given by typhoon-triggered inundation as happened in the year 2000 during the Tookai-flood. This threat increased in the last decades because of land subsidence triggered by exhaustive ground water withdrawal in the mid of the 20th century (Yamamoto, 1984).

Several facilities handling hazardous substances were inundated during this event. It is unknown if hazardous substances were released. Similar cases suggest that this is highly probable. E.g., during the 2002-Elbe-flood in Germany large amounts of contaminants like heavy metals were flushed into the Elbe river. This resulted in chemical loadings, up to three magnitudes higher than the normal river load. The total delivered load of lead was 2500 times higher than the annual average load. The origin of those chemicals were determined to be inundated chemical facilities located in the Czech-Republic (Schiemeier, 2002). This example shows that not only the loss of property and life is of concern to disaster managers, also consequences by inundation-triggered events, like releases of hazardous substances have to be considered (Christou, 2000; Cruz et al., 2001; Schiemeier, 2002; Cruz et al., 2004).

Today new data are available in Japan, allowing the identification and risk assessment of sites handling hazardous substances (Hartmann et al., 2004; Ministry of Environment, 2004). In the year 2003 the "Law Concerning Reporting, etc. of Releases to the Environment of Specific Chemical Substances and Promoting Improvements in Their Management" (Cabinet Order No. 138, March 29, 2000) was put into effect. Based on this law a Pollutant Release and Transfer Register (PRTR) was established. The database lists all facilities in Japan dealing with certain hazardous chemical substances. These data can be used to conduct a risk assessment based on future inundation scenarios for each considered site.

The mentioned experiences from former inundations give rise to the question of how releases of contaminants from industrial or commercial facilities can be prevented, or better, if those facilities can be protected from inundation using an integrated approach of disaster response strategies and preliminary risk assessment as e.g. proposed in Okada et al. (2004). This study aims to introduce a concept for a possible future integrated disaster risk management for this objective, based on the available databases and information technologies. A recently developed system for dissemination of inundation relevant information using mobile communication technologies (Ushiyama & Takara, 2002) allows integrating knowledge from the proposed risk assessment into disaster response management strategies to protect threatened facilities handling hazardous substances or prevent releases from these sites. The significance of the approach is discussed in an example inundation to enlighten advantages and problems of the presented approach. The concept presented herein may influence preparedness, disaster response strategies and post-disaster hazard mitigation, focusing on human health and ecosystem integrity endangered by hazardous substances release triggered by inundation.

KEY WORDS: PRTR, disaster risk management, inundation, contaminants, Japan

2. BACKGROUND TO THE TOOKAI FLOOD

On September 11th and 12th, 2000 the typhoon No. 14 impacted Aichi Prefecture in Japan. As consequence, Nagoya and the surrounding areas received 600 mm of extreme rainfall within two days. As a result, 10 river embankments were breached and many communities in the area were inundated (Zhang et al., 2003). One broken river embankment at the river Shinkawa resulted in the inundation of Nishibiwajima town and parts of Nishi-ku, Nagoya city. This area is located between the rivers Shinkawa and Shonaigawa (**Fig. 1**).

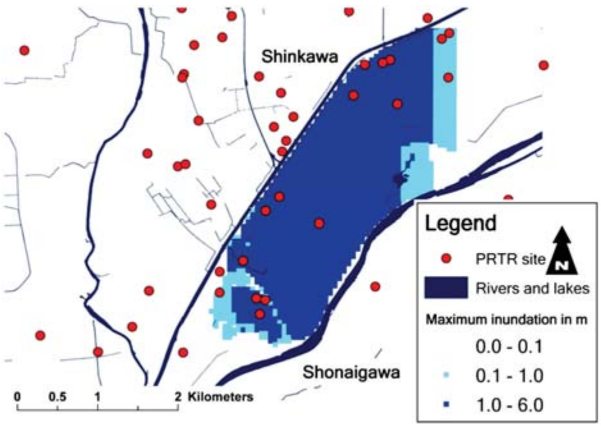


Fig. 1 Inundation scenario after Zhang et al. (2003). The area between the rivers Shinkawa and Shonaigawa were inundated during the Tokai flood. The figure shows 16 inundated facilities handling hazardous substances after the Japanese PRTR.

The area is characterized by a heterogeneous land use (**Fig. 2**), where agricultural areas are located beside commercial and industrial areas. The heterogeneous land use pattern is partially caused by the fast economic growth in the last decades, where land use planning was often neglected; partially because areas within the town are traditionally used for farming of rice, vegetables and tea (**Fig. 2**).

The river embankment at Shinkawa (**Fig. 1**) broke on a length of 100 m and more than 2900 buildings were inundated in Nishibiwajima town, the south-western part of the inundation area (Zhang et al., 2003).

There are 16 facilities located in this area, which deal with hazardous chemicals listed in the Japanese PRTR-law. A memorial place at the location where the river embankment broke, mentions that the inundation resulted in the deposition of industrial matters all over Nishibiwajima. It cannot be neglected that inundation triggered accidental releases of chemicals from industrial facilities, unpublished or unknown, occurred. Such kind of releases are described in detail, e.g. in Christou (2000) or Cruz et al. (2001). The consequences of a release would be infiltration of contaminants on agricultural areas or the contact of humans with contaminants, resulting in the exposure of human health to hazardous substances, carried by the inundating water. A study by Ishihara et al. (2001) about rice consumption in Japan showed that the morbidity can increase if contaminants are carried by contaminated water into the food chain. To prevent probable releases with harmful consequences to pulic health and the environment in the future, preparedness and response management is needed.

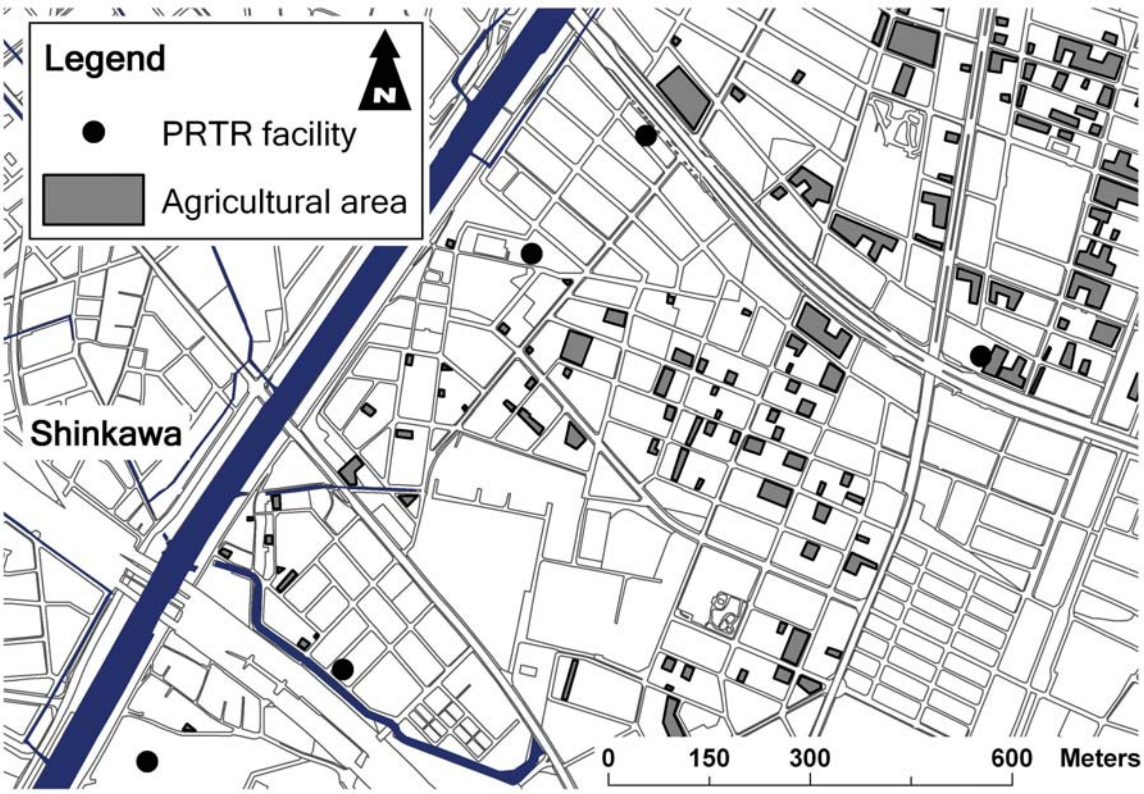


Fig. 2 Agricultural used areas are often close to PRTR-facilities. The agricultural used areas were mapped during field research. The facilities A and B are shown in detail in **Fig. 3**.

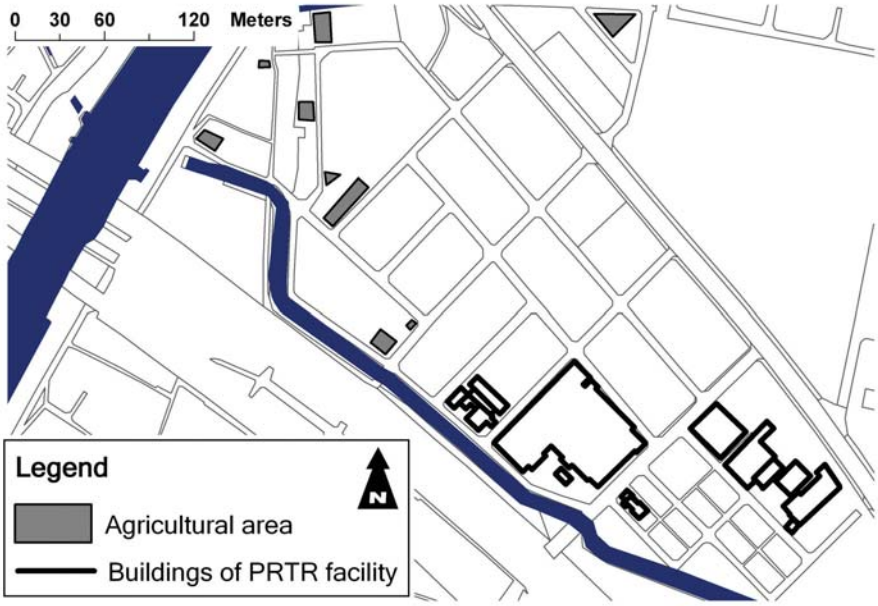
3. APPROACH

The proposed concept, based on available new data and technologies, is divided into three steps: a) risk assessment, b) disaster response management and c) disaster mitigation. The risk assessment is carried out for planning measures (land use and buildings) and preparedness within the disaster response management in facilities dealing with hazardous substances. **Fig. 3** presents the typical settings of considered facilities in the neighbourhood of agricultural used areas. Facilities dealing with hazardous substances are normally composted by several buildings.

4. RISK ASSESSMENT

The recently available PRTR (Pollutant Release and Transfer Register) in Japan (published in April 2003) provides the possibility to identify facilities, which are handling specified hazardous chemical substances. The addresses of such facilities can be geocoded for a spatial evaluation of the sites, e.g. with the geocoding tool provided by the Center of Spatial Information Science, Tokyo University. This enables the user exactly to locate the facilities handling hazardous substances.

The Administration of Aichi Prefecture has developed a software tool capable of giving information on frequencies and inundation height and also flow velocity for each region in Aichi



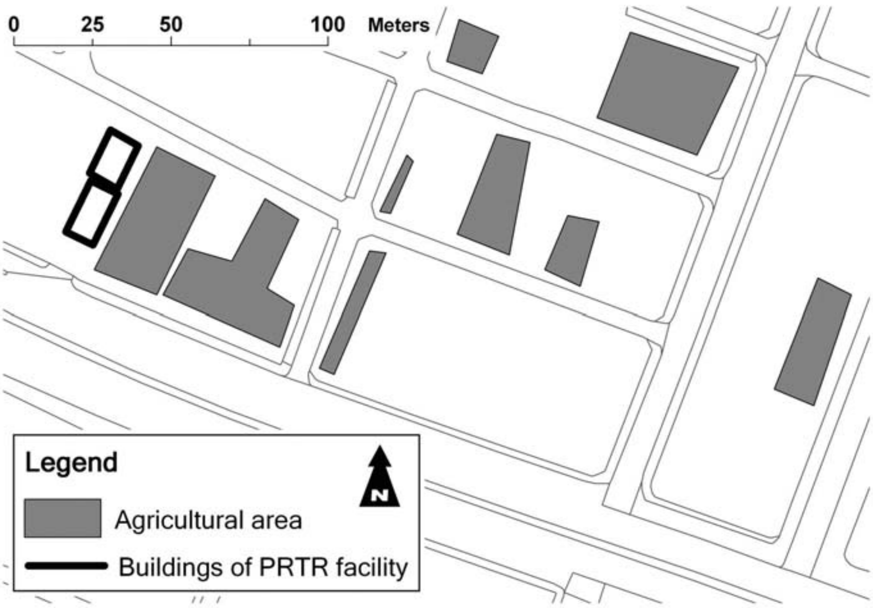


Fig. 3 The grund of two PRTR facilities marked in **Fig. 3** are shown. In the first case (A) a chemical factory consists of several buildings, whereas the second case (B) shows a facility storing chemicals besides rice fields.

Prefecture. The information gained from the georeferenced facilities and inundation scenarios can be combined to assess the risk of inundation for each facility handling hazardous substances. Information gained from this integration, are e.g. maximum or average inundation height and frequency of inundation for each facility handling hazardous substances. For further discussion of the concept, the inundation scenario of the Tookai-flood in the year 2000 between the rivers Shinkawa and Shonaigawa, Aichi Prefecture, is adapted after Zhang et al. (2003).

Based on this information a detailed analysis of each site (e.g. building structure) considering the risk of inundation and the evaluation of consequences to their surrounding is possible. **Fig. 3** gives some typical examples for the shape of building complexes. The gained information from the risk assessment can be integrated into a cross media disaster information system, such as the one recently developed by Urukawa et al. (2004) and Kugai et al. (2004).

Cross media disaster information systems are a research support information infrastructures (RSII). They catalog, locate, and retrieve support information sources regardless of their format: spreadsheet data, reports, geospatial databases, multi-resource type including video, images, audio files, web pages and data about people, organizations, and events (Kugai et al., 2004). One objective of a cross media disaster information system is to provide online-access to essential data for decision makers. In addition, stored data can be integrated into a disaster response strategy.

5. DISASTER RESPONSE MANAGEMENT

An appropriate disaster response management needs the integration of the results from the risk assessment (Okada et al., 2004), using information about a) which facilities are endangered by inundation, exposing certain parts of the considered area (**Fig. 1**), b) the probability of inundation and the inundation height, c) the minimum/maximum time until probable inundation impacts (**Fig. 4**) and d) the types of hazardous substances handled.

To prepare facilities and employees dealing with hazardous substances a concept for disaster response is needed. The herein introduced disaster response management concept is based on the use of new internet-based technologies for dissemination of spatial information to mobile devices and response by individuals in charge. The use of internet based technologies seems appropriate in the future, as fast response due to probable impacts is needed, because the time for response is often less than an hour as the used scenario implies. In case of inundation events the infrastructure for mobile communication should not be harmed, as the essential infrastructure is located on the top of buildings or surrounding areas, not impacted by inundation. This should provide the needed resources for mobile communication in the disaster case.

I) Alarm system

Once a critical situation is detected a prepared alarm system should be used. Such an alarm system should disseminate emergency information using phone and e-mails to responsible local and regional disaster response coordinators. They should start a task chain for preventing endangered sites for the impact or start protection measures if possible. The inundation scenarios suggest that response time is limited (**Fig. 1** and **4**).

II) Information technology

Ushiyama and Takara (2001) presented an internet based technological system, which allows distributing spatial information of heavy rainfall to interested individuals on their mobile devices. For this purpose software was developed for the widely used i-mode technology in Japan. The software is capable to display desired spatial information on a mobile device. They used data from the Japanese Meteorological Association (JMA), distributed by the Japanese Weather Association (JWA).

This system can be enhanced with information from the inundation scenarios provided by the software tool of Aichi Prefecture and the proposed risk assessment. The principle setup of such a disaster response information system using internet-based technology is shown in **Fig. 5**. Based on monitoring (rainfall, water height, integrity of river embankments as shown in **Fig. 6**) the risk for inundation is evaluated. In case inundation is probable or inevitable, risk assessment previously conducted for the area is used to start the alarm chain. Sites at risk are informed of the current situation by the disaster headquarters. The information gained by the risk assessment, the calculated inundation predictions and the monitoring information, is used to coordinate tasks.

All information about available resources should be included in a cross media disaster information system. This enables the efficient coordination of disaster response forces, while using updated information. Technologies for dissemination of disaster response relevant information should be based on disaster-cross-media-databases.

For supporting the disaster response or preparation onsite, wireless mobile devices should provide task forces and staff at

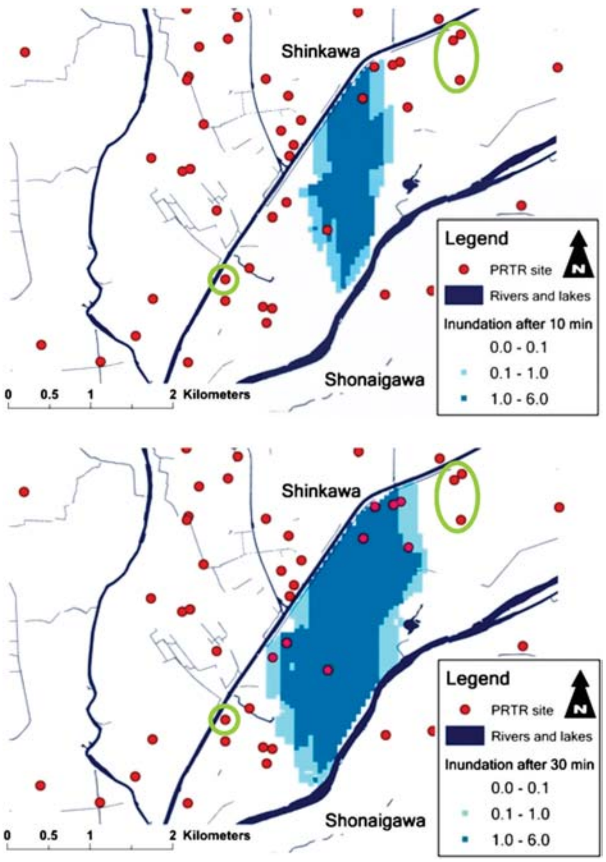


Fig. 4 The marked PRTR-facilities had more than one-hour time for preparation and were inundated with less than one meter height. Compare with **Fig. 1**.

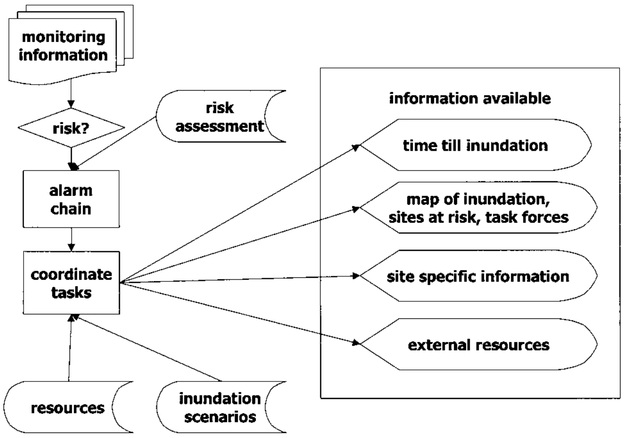


Fig. 5 Information structure for the Disaster Response Management.

Fig. 6 A typical online monitoring device at a Shonairiver in Nagoya.

facilities with the following information:

a) probable time till inundation

b) map of inundation, sites at risk, task forces location

c) site specific information (e.g. **Fig. 3**)

d) information about external resources, mainly disaster response teams coordinated by the disaster response headquarters.

Equipment and information dissemination:

The needed equipments are especially mobile communication tools, capable of displaying maps. This requires a powerful server structure. A server should provide information fast from password secured mobile web sites. For this coordination of data providers, local sites involved (including employees in charge), and also disaster response forces is necessary. A possible data dissemination structure for the presented problem is presented in **Fig. 5**. How such a information dissemination has to be designed and implemented is explained in Ushiyama and Takara (2001).

III) Response

Two kinds of disaster response are possible to prevent an inundation triggered release of hazardous substances from a facility: a) establish active protection systems to prevent inundation of the considered site or b) prepare the facility for an unavoidable impact (passive action). This may be the shut-down of production, secure stored hazardous substances or other actions preventing possible releases of hazardous substances. With modern mobile dam systems it is possible to protect facilities if the expected inundation height is less than a meter. Modern systems can be built up in decaminutes.

In any case, to prepare a site for the impact, measures should be taken in advance, which ensure that releases of hazardous substances are less probable. Possible measures are e.g. safe storage of substances in containers capable of sustaining the water pressure or the shut-down of production before impact, to avoid chain reactions leading to a release (Cruz et al., 2001).

IV) Organisational needs

A disaster response strategy needs some organisational preparation. It is important that staff in facilities endangered by the inundation is educated concerning prevention or protection measures. This needs first the awareness of the risk by employees at the site. If regional task forces, capable dealing with mobile real-time protection measures are available, they need to be trained and including a system coordinating employees of considered facilities at threat. It may happen that some sites cannot be protected because the preparation time for inundation is to short or the expected height is to high for the used mobile protection measures.

V) Education

The employees of each site have to be educated about the necessary tasks to be taken before inundation impact. This is the case if production has to be shut down fast or stored substances need to be prepared for the impact. Site-independent task forces, like civil protection teams, need knowledge how to handle mobile protection equipment and how to use mobile coordination devices. The population in the threatened area should know about the threat of hazardous substances in case of inundation, the health risks concerning consumption or handling of agricultural goods from these sites and about prevention of protection measures that can be taken. Information dissemination to the population should be coordinated by local administrations. Another advantage of such education efforts is that the local administration and potentially affected population is up to date on the local situation.

6. DISASTER MITIGATION

In Japan, traditionally heterogeneous land use patterns are the normal case. Agricultural, housing and commercial areas in flood plains are located side by side, as indicated in **Fig. 2**. Because of this, released contaminants may enter the food chain, if contaminated water after an accidental release infiltrates the ground (**Fig. 2**).

The many small parcels for farming, especially rice, vegetables and tea are often used by the neighbours. In case that inundation triggered releases of chemicals occur, users of inundated land have to be warned. Further analysis of the soil and plants might be necessary after an inundation event, to examine the risk that hazardous substances are entering the food chain and harm population, as shown e.g. in Ishihara et al. (2001).

7. INTEGRATION OF RISK ASSESSMENT AND DISASTER RESPONSE MANAGEMENT

As described before, the risk assessment can be integrated into a disaster response management strategy to prevent inundation triggered releases. The successful integration and the implementation of the disaster response strategy need the following efforts.

Policy needs:

One possibility is to consider that the endangered facilities self-organise their protection measures due to risk of inundation. But as mentioned, the population is also involved due to the possible consequences. This results in the need of an appropriate information strategy, including about potential risks from the sites considered, and information flow to affected stakeholders after an inundation event.

A clear policy strategy should be worked out by the local or prefectural administration. This depends on the wished participation grade of involved stakeholders.

Local preparation

One crucial point is the education of employees at each considered site. A coordination of educational measures including the employees of several sites might improve the preparedness and build the possibility for an information network, capable for improving response by information exchange. This has an additional effect on the response effectiveness of employees at each site. Local and regional information networks are suitable to discuss the training of measures for prevention of releases or prevention measures. Public administration may have a coordination function to push developments.

Advantage and disadvantages of the concept

The proposed concept needs some logistic and infrastructural background, which has to be financed. The financing of such measures might be a cost factor, which may be seen as inadequate by industry. In addition, the distribution of information also needs a physical investment.

Advantages by the introduced concept are that the exposure of people and eco-systems can be reduced. Further more, informational networks are easy to set up to distribute and exchange information .

8. DISCUSSION OF THE CONCEPT BASED ON THE 2000 INUNDATION IN NISHIBIWAJIMA

Fig. 1 shows the inundation scenario with its maximum extent during the Tokai flood in the year 2000. Sixteen facilities handling hazardous substances and listed in the Japanese PRTR were inundated during this event. Four of these facilities were inundated with less than 1 m. The heterogeneous land use in this area (**Fig. 2**) increases the probability that released hazardous substances probably enter the food chain.

Fig. 1 implies that for several facilities during the inundation event the possibility was given to shut down production or to prepare for the coming impact, if the introduced concept with mobile information dissemination of crucial information is given. For at least four of the facilities a preparation time of more than an hour was given (marked in **Fig. 4**). Facilities can be composed by several buildings. **Fig. 3** shows two examples of typical building complexes. Their locations are marked in **Fig. 2**. The structure of the complexes, in this case one larger facility, makes clear that a detailed knowledge of each facility is necessary to protect them. Employees knowing their sites in detail can do the necessary tasks. This is a hint that facility employees should be consulted for an integrated strategy. To the knowledge of the authors no studies were conducted to analyse this matter.

An integrated risk assessment within a disaster response strategy can reduce risks to human health. The exposure of the area of Nagoya within the Nobi plain, where most of the area is on river level or below makes future inundation of facilities dealing with hazardous substances probable.

Since the needed technology for the introduced concept exists (Ushiyama and Takara, 2002), it needs only an extension to integrate the additional information introduced within this study. Educational and organisational needs can be conducted within the mentioned framework.

Because Nagoya city and their surrounding communities are exposed to multiple hazards, efforts for reducing risks and involving stakeholders (exposed population, disaster reduction forces, employees in facilities) are continued (Shidawara, 1999, Ushiyama and Takara, 2002). Shidawara (1999) concluded that the dissemination of risk related information to the population alone is not enough. Stakeholders should be involved actively in integrated disaster risk management. Coordinated programs are needed to aim at informing and increasing the sensibility of the population to the risk of floods, and their consequences should be considered by coordinating administrations.

9. CONCLUSION

It was shown how information from a risk assessment of areas with heterogeneous land use including facilities dealing with hazardous substances given by the recently published PRTR in Japan can improve the disaster response strategy of the region. In addition this knowledge can be used to enhance disaster response strategies to protect human health from exposure to hazardous substances releases. Recently available mobile communication technology for dissemination of information supports these efforts.

The mobile information system developed by Ushiyama and Takara (2002) can serve as the basis for such a strategy which involves the distribution of spatial information needed for the coordination of task forces or to evaluate appropriate actions on sites dealing with hazardous substances during an inundation event. Nevertheless, coordination of local or regional administrations to conduct preliminary risk assessment for probable inundation scenarios and to integrate the results into a disaster response strategy is needed.

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