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Approaches to Managing Disaster

Assessing Hazards, Emergencies and Disaster Impacts

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APPROACHES TO MANAGING DISASTER – ASSESSING HAZARDS, EMERGENCIES AND DISASTER IMPACTS

Edited by **John Tiefenbacher**

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Meet the editor

Dr John P. Tiefenbacher (BS Carroll College, Wisconsin; MS University of Idaho; and PhD in Geography from Rutgers University) is currently Professor and Director of the James and Marilyn Lovell Center for Environmental Geography and Hazards Research in the Department of Geography at Texas State University in San Marcos, Texas. Dr Tiefenbacher's research has focused on Environmental Geography or the relationship between people and their natural environments. Dr Tiefenbacher has published on a diverse set of topics that examine perception and behaviors of people with regard to natural and technological hazards, environmental problems, and personal preconceptions about the places they inhabit. He has undertaken studies throughout the United States and in Mexico. His current research pertains to the challenges of urban hazards and evacuating cities, adaptation to climate change, and the responses of agricultural industries (particularly wine growing) and climate changes in several regions (principally South America, the U.S. and Europe) of the world.

Contents

Preface

Approaches to Managing Disaster is a collection of essays that demonstrate the array of types and forms of information critical for understanding the distribution of risk and hazards in the landscape and the evolution of emergencies that can potentially yield disasters. The organization of this book is intended to reflect management of components of the disaster continuum (the nature of risk, hazard, vulnerability, planning, response and adaptation) in the context of threats that derive from both nature and technology. The chapters include a selection of original research reports by an array of international scholars focused on specific locations or on specific events. The chapters are ordered temporally relative to the emergence of disaster. The first two chapters are assessments of risk or hazard in landscapes that provide disaster-prevention information that can be used for mitigation and/or emergency management planning. The next three chapters describe monitoring and information management systems that can be (and are) integrated in real-time emergency-response activities. The sixth chapter discusses methods that can be employed to evaluate the aftermath impacts of disasters, while the final chapter provides a framework for diagnosing the quality of disaster management through an after-the-fact evaluation of the responses and outcomes of disasters. Each of these chapters represent unique (but related) sets of scholarship from several disciplines that intend to contribute to safer environments and risk-averse behaviors. The over-arching goal of disaster management, of course, is to eliminate its importance to society by eliminating risk, hazard and vulnerability in the world; a goal that is by most unrecognized, unspoken and ambitious.

The first chapter is a study of landslides in Malawi by Msilimba. A very practical spatial assessment of past extreme events (landslides) in the Ntchenachena region provides insight into predicting future slides and adapting precautionary behaviors to reduce their impacts. Similarly, Chapter 2 by Shimada, Kitajima, Fuchino, and Takeda develops a management plan for the risks and hazards found within the lifecycle of an industrial facility. While the objects of their study are radically different in nature and scope, and one study is empirical and the other theoretical, they are both seeking to identify the “locations” of failures through a conceptualization of ongoing processes due manage the probabilities of “accidents.”

Information management is now recognised to be one of the most challenging aspects of emergency management as science has technologically enabled the epoch of information gathering. Being able to "know" the facts and being able to "act" on the knowledge gathered requires a very complex bridge process. For the actions to be useful, that bridge must be constructed (or simply crossed) with limited time for decisions to be made. Integrating the technology of monitoring with emerging technologies for analysis and decision making, remains a challenge to most disaster managers who are differentially trained. Three chapters by Houser, De Lannoy and Walker, Bröring, Lemmens and Jirka, and San Miguel-Ayanz, Schulte, Schmuck, Camia, Strobl, Liberta, Giovando, Boca, Sedano, Kempeneers, McInerney, Withmore, Santos de Oliveira, Rodrigues, Durrant, Corti, Oehler, Vilar, and Amatulli, detail the complicated nature of managing floods, wildfires and other dynamic events using "fluid" information in constantly evolving conditions in several settings. Bridging the information – action gap in the era of "smart" technology will only be achieved incrementally.

The penultimate chapter of this volume is by Petrucci who through analysis of the literature and a case analysis of damage reports provides a structure for an objective quantitative analysis of the social and economic impacts of disasters. Her discussion of the Natural Disaster Impact Assessment as it relates to extreme hydrological and geophysical events in Italy ,demonstrates the challenges and pitfalls associated with converting the experience of disaster into comparable quantifications. The ramifications of impact analyses for decision-making and financial prioritization in any country are somewhat obvious and the work she discusses is very important.

The final chapter by Lalonde assesses not the impacts of events but the outcome of management of disasters. Based on a reading of the disaster management literature, Lalonde develops a rubric for evaluating four components of management (planning and preparedness, coordination, leadership and civic (including the at-large public, grassroots leaders, and the media) behaviors). She examines emergency management in four specific disasters and assesses the successes and failures of management during those events. Her diagnostic model for assessment demonstrates that there is a major disconnect between the emergency-management theoreticians and practitioners. The principals and guidelines established in the literature by the scholars who constantly assess and reassess the processes, she concludes, are inevitably overlooked or ignored by the practitioners who either lack the time or training to follow them.

Indeed, this "separation" may be the greatest challenge to all risk, hazard and disaster management practices that may be called the disaster paradox: "we" (scholars) basically know what needs to be done, what people (the public and managers) should do, and where, when and how to do what should be done, but "we" (the public and managers in general) don't do what should be done. With all of the knowledge compiled and converted to useful guidance for disaster management (much like that which is found in these pages), we lack the practical capacity to integrate the lessons into wisdom to guide our actions. Disasters are complex problems for individuals and societies and individuals and societies are complex receivers of information. Perhaps disasters are inevitable because our actions exceed our capacity to understand their ramifications. The chapters in this book are “food for thought” in that regard.

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Landslide Inventory and Susceptibility Assessment for the Ntchenachena Area, Northern Malawi (East Africa)

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1. Introduction

Landslides are one of the causes of loss of life, injury and property damage around the world. In many countries socioeconomic losses due to landslides are great and increasing as human development expands under the pressures of increasing populations into unstable hill areas (Msilimba 2002; Huabin et al. 2005; Msilimba and Holmes 2005).

Similar to other parts of the world, landslides are not a new phenomenon in Africa. They have been reported in Cameroon, Kenya, Uganda, Rwanda, Tanzania, and Ethiopia (Moeyerson 1988; 1989a; 1989b; Davies 1996; Westerberg and Christiansson 1998; Ngecu and Mathu 1999; Ingang'a and Ucakuwun 2001; Muwanga et al. 2001; Knapen et al. 2006). The East African region which includes Malawi, is a heterogeneous in terms of physiography, geomorphology and rainfall, and has a high susceptibility to slope movement. The high annual rainfall, high weathering rates, deforestation and slope material with a low shear resistance or high clay content are often considered the main preconditions for landslides (Knapen et al. 2006).

The causes of landslides that have occurred in Malawi are similar to those of the countries in the East African region. Examples include the 1946 Zomba Mountain landslide, the 1991 Phalombe landslide and the 1997 Banga landslide (Poschinger et al. 1998; Cheyo 1999; Msilimba 2002; Msilimba and Holmes 2005).

This chapter is based on data from numerous landslides which occurred in 2003 in northern Malawi following heavy and prolonged precipitation. These landslides killed four people, destroyed houses and crops, flooded the Mzinga River and dammed the Lutowo River. The chapter presents and discusses landslide inventory for the Ntchenachena area of Rumphi District (northern Malawi). The inventory was prepared based on the analyses of aerial photographs, satellite images, and field observations. The inventory presents dating and the dimensions of the landslides, as well as the location, and distribution of the events. A simple classification of landslides is also given based on Coch (1995). It explains details of channel morphometry, materials involved in the movement, slope type and aspect. The chapter also discusses the causes and contributing factors of the landslides and describes a simple susceptibility appraisal procedure for the Ntchenachena Area.

2. Geographical characteristics of the Ntchenachena area

The Ntchenachena area is located in Rumphi District in the northern region of Malawi (**Fig 1**) and covers an area of 264 hectares. The area is comprised of six units identified by the spurs forming the area (**Fig 2**). It is a continuation of the East Nyika escarpments and is part of the Great African Rift Valley System (Kemp 1975). The area is a belt of rugged country, consisting mainly of deeply dissected spurs which are almost V-shaped. Elevation variesfrom 1295m to 1828m above sea level (GoM 1987). Flat areas are concentrated along the valleys.

Geologically, the region consists of a basement complex of Pre-Cambrian to Lower-Paleozoic rocks which is overlain by young sedimentary formations. In northern Malawi, the Pre-Cambrian rocks were affected by both the Ubendian and Irumide Orogenies (Kemp 1975). The resulting basement complex is largely composed of gneisses and muscovite schist of south easterly trend and structurally is a continuation of the Ubendian Belt of south-western Tanzania. The gneisses are of the Karoo Supergroup and experienced a long period of erosion that was followed by deposition, mainly in the Permian and Triassic times (Cooper and Habgood 1959). The Karoo Supergroup rocks comprise sandstones, siltstones and shale with some coal seams near the base (Bloemfield 1968; Kemp 1975). Within the Ntchenachena area, the geology consists of highly jointed muscovite schist and biotite gneisses, with a gneiss foliation trend varying between 278^0 and 114^0. The average dipping angle is 45^0. In some places, the lithology shows the presence of mica schists (GoM 1977; Kemp 1975). Fresh rock outcrops are rare due to rapid chemical weathering.

The soils in this area are derived from the deep chemical weathering of the muscovite schist, the gneiss and the Karoo sediments. The major soil group is ferrellic, of the soil family Luwatizi (Young 1972). The soils are very deep (>10m) and well drained. The surface stoniness is less than one percent. In the elongated valleys, ferrisols predominate. Red clays with a strongly developed blocky structure occur in association with leached ferralitic soils, but are less highly leached and more fertile than the latter. In the dambos, dark coloured or mottled gley or hydromorphic soils occur.

Areas of high elevation suffer less intense temperatures and thus weathering is less deep into the bedrock than lower elevations. The Ntchenachena area is over 1800m above sea level with mean monthly maxima ranging between 18.5^0C and 20^0C and mean monthly minima ranging from 7^0C to 10^0C. This is one of the wettest areas in Malawi, with only 1 or 2 months being considered as the dry period. Most rain occurs between November and April. The mean monthly rainfall is 200mm and the mean annual rainfall range is between 1200mm and 1600mm (Linceham 1972). Rainfall is primarily orographic, with convectional activity between November and April.

The vegetation of this area is classified as Afromontane, with scattered grass and shrubs. Most of the slopes are under cultivation, and this has resulted in large scale deforestation, although isolated patches of pine trees still occur along the ridges. The rate of deforestation has accelerated in recent years mainly due to increased seasonal burning of the trees, bushes and shrubs for shifting (slash and burn) cultivation and hunting. The increase in seasonal burning is due to growing population levels in the area.

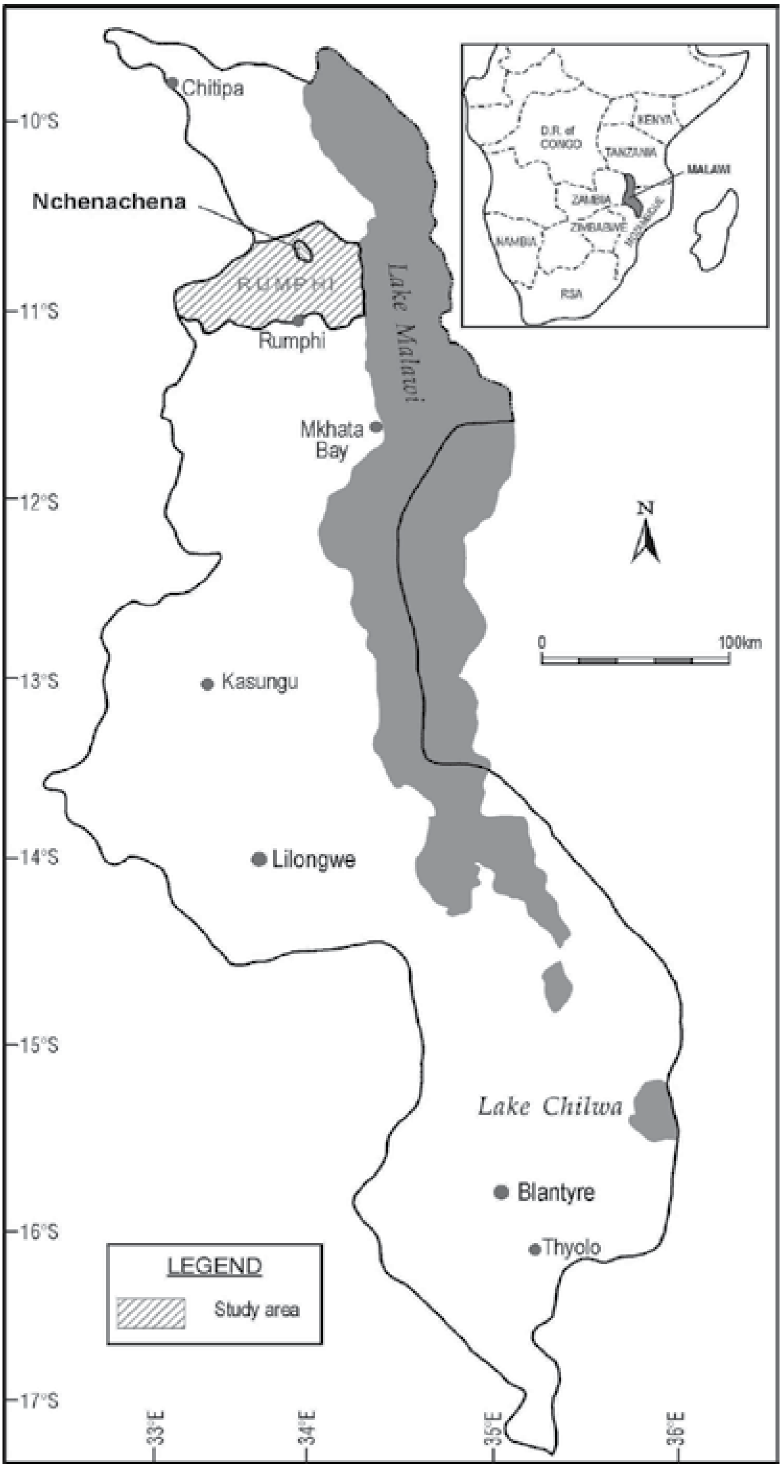

Fig. 1. Map of Malawi Showing Location of Rumphi District

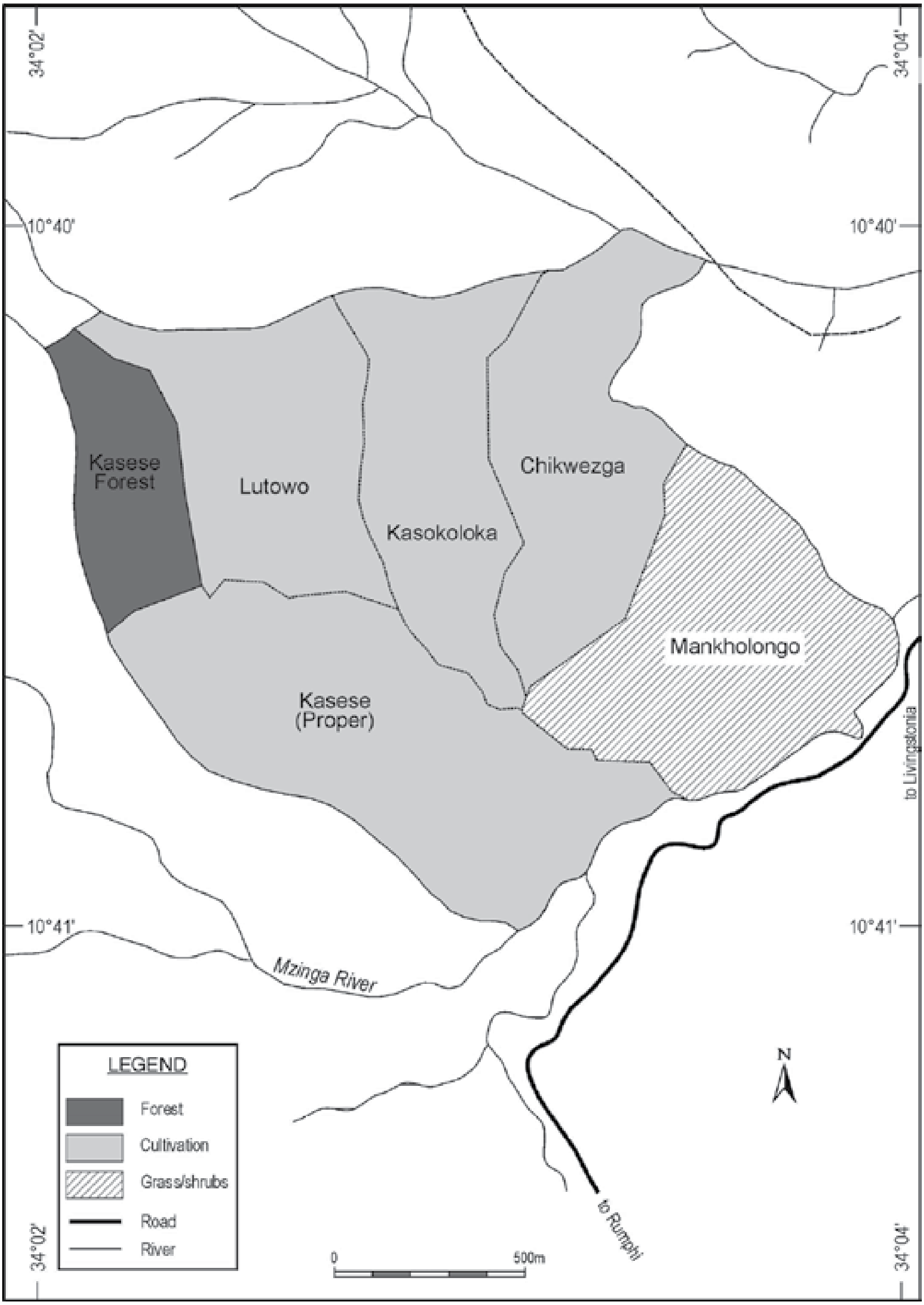

Fig. 2. Map of Rumphi District Showing Ntchenachena Area

Numerous streams originate in this area. Most of these are perennial due to the high rainfall of the area and the ability of the soil and weathered basement complex to absorb and store much of the precipitation. However, the perennial rivers show marked seasonal variation according to the amount of rainfall. Water tables are generally high. Human activities in the area are dominated by subsistence agriculture with a small amount of coffee grown as a cash crop and small scale lumbering of both indigenous and exotic timber species. Villages tend to be scattered and isolated with houses primarily built along ridges and slopes.

3. Work approach

Mapping the study area

Evidence of past landslides (scars and gullies), location of settlements, land degradation, and steepness of the slope were considered in delineation of the study area. Aerial photography and topographic map interpretations were used to delineate the areas. The 1995 aerial photographs at the scale of 1:25 000, and the topographic maps of Rumphi District at the scale of 1:50 000 were used.

As more recent maps and aerial photographs (after 1995) were not available, ground reference data and Landsat 7 ETM images were used to delineate the area. Reference data was used to correct errors caused by scale distortions on aerial photographs and topographic maps. Interpretation of aerial photographs was done following the standard procedures (Shaxson et al. 1996).

Ancient landslides inventory

Ancient landslides were identified on 1995 aerial photographs, at a scale of 1:25 000. 2003 Landsat 7 ETM images supplemented the data obtained from the 1995 aerial photographs. This involved the identification of scars and channels and depositional areas. Interpretation of the photographs was carried out using a pair of stereoscopes and a hand lens both of magnification 3X. Mapping of the coordinates for the identified landslides was done, using the Global Positioning System (Trimble Geo Explorer II GPS).

Ground reference data were acquired during fieldwork. These data were also used to verify landslide occurrences and to identify any scars not observed on the aerial photographs and satellite images. Fieldwork involved traversing the areas and inspecting all the spurs and slopes for scars, gullies, evidence of soil creeping and rock falls. Local people, especially those who were eyewitnesses to the landslides, provided information on the location of landslides and assisted with dating landslide events.

Measurements of average widths, depths and lengths of channels and diameter of the scars were carried out, using a 200-meter surveying tape. The angle at which the scar is located was determined by an Abney level while the actual location was determined by GPS. The classification of landslides was based on Coch (1995).

Collection of geological, vegetation and rainfall data

Fieldwork was carried out to determine the dipping angle, slope angle and foliation trends, using a Silva compass. The geological map of South Uzumara at a scale 1:100 000 was also used. (GoM 1977). Additional information was obtained from the Livingstonia Coalfield and the Geology of the Uzumara Area Bulletin (Bloemfield 1968; Kemp 1975). Fieldwork provided the bulk of geological data because at the scale of 1: 100 000, the geological map could not provide adequate details of the geology of the study area.

Rainfall data were obtained from the local meteorological stations located 500m from the study area. Records for a period of 30 years (from 1976 to 2006) were obtained with additional data being obtained from the Central Meteorological Services.

A vegetation survey was carried out to establish tree heights, canopy cover, and diameter at breast height (i.e. 1.3m above the ground) as a measure of plant density. Quadrants of 20m by 20m were constructed at a spacing of 50m. The vegetation survey was concentrated in the forested areas of the Ntchenachena area. The vegetation survey methodology which was followed is well discussed by several authors (Chutter 1983; Avery and Burkhart 2002).

Sampling rationale and laboratory analyses

Textural and physical properties of soils and sediments have an influence on the susceptibility of such material to failure (Bryant 1976; Msilimba 2002). Soil sampling was undertaken in order to assess physical characteristics that have a bearing on soil structural strength. Both core and clod sampling were carried out using standard procedures (GoM 1988; Fredlund and Riharjo 1993). Two undisturbed and two disturbed samples were collected for each sampling pit, using a core sampler and a soil auger. The sampling interval was 15m by 50m (based on the contour intervals 50m apart). Forty sampling points were identified in six units of the Ntchenachena area namely: Kasokoloka, Lutowo, Kasese Proper, Kasese Forest, Mankholongo and Chikwezga.

In areas where landslides had occurred, the samples were collected from the sides of the scar. Areas which were inaccessible due to thick forest, gullies and very rugged terrain were not sampled. The results from the rest of the spurs were generalised to include unsampled sites. In special cases, the selection of the sample locations was based on indications of slope instability, mainly soil creeping and cracking. The effective soil depth was determined using a screw soil auger, a surveying tape, measurements of the depth of recent landslides, and slope remodeling/cutting.

Samples were analysed using standard, acceptable soil analysis techniques to determine particle size distribution, hydraulic conductivity, particle density, bulk density, total porosity, aggregate stability and Atterberg limits (GoM 1988; Non-Affiliated Soil Analysis Working Committee 1990). Clay and silt percentages were determined using the hydrometer method (GoM 1988; Non-Affiliated Soil Analysis Working Committee 1990) and sand fraction was determined using standard sieving techniques (GoM, 1988). Hydraulic conductivity and bulk density were measured using standard methods (Punmia 1976). Liquid and plastic limits (Atterberg limits tests) were determined using the Casagrande method, following which plasticity indices were calculated (GoM, 1988; Non-Affiliated Soil Analysis Working Committee 1990).

4. Results and discussion

4.1 Landslides Inventory

A landslide inventory was carried out to give a measure of the past instability of the area. A total of 88 landslides were identified and mapped (**Table 1)**. Within the Ntchenachena area, there were 55 (62.5%) landslides recorded for Lutowo, followed by 14 (15.91%) for Chikwezga, 12 (13.64%) for Mankholongo, 6 (6.82%) for Kasese Proper and 1 (1.14%) for Kasokoloka.

Unit/area	**Number of landslides**	**Depth (m)**	**Length (m)**	**Width (m)**	**Slope angle^0**	**Impacts**
Kasokoloka	1	21	230	50	41	Crops destroyed, Maize granary swept away, Goats swept away, houses destroyed, four people killed
Lutowo	55	0.4 - 25	7 - 216	6 - 240	53	Crops destroyed, damming of Lutowo river, flooding of Mzinga river
Kasese Proper	6	0.5 - 13	31 - 99	6.7 - 95	58	Crops destroyed
Kasese Forest	Nil	-	-	-	58	-
Mankholongo	12	1.1 – 8.5	24 - 324	14 - 125	54	Vegetation removed
Chikwezga	14	0.4 – 4.2	21 - 406	9 - 57	54	Crops destroyed, pine trees swept away, houses destroyed

Table 1. Mapped landslides and their impacts

No landslides were recorded within the Kasese Forest of the Ntchenachena area. Seventy-nine landslides occurred in 2003 (contemporary) while 9 were undated (ancient) landslides (i.e. local people could not remember when they occurred). Within the study area, landslide dimensions vary enormously with length ranging from 7m (Lutowo) to 406m (Chikwezga). Width ranged from 6m (Lutowo) to 240m (Lutuwo). Depth ranged from 0.4m (Lutowo) to 25m (Lutowo). Slope angles for the mapped landslides were high, ranging from 41^0 (Kasokoloka) to 58^0 (Kasese Proper and Kasese Forest).

Fifty eight landslides (65.91%) occurred on concave slopes, 17 (19.32%) on convex slopes, and 13 (14.77%) on linear/rectilinear slopes. Within the individual units of the Ntchenachena Area; at Lutowo 35 landslides occurred on concave slopes, 12 on convex and 8 on linear/rectilinear; at Kasosokola the landslide occurred on a concave slope; At Kasese Proper, all the landslides occurred on concave slopes; at Mankholongo, 11 were on concave while 1 was on convex; at Chikwegza, 5 were on concave, 5 on convex while 4 were on linear/rectilinear. In terms of slope aspect, within the Ntchenachena Area, most of the landslides occurred on S, NE, E and SW aspects (29.55%, 17.04%, 21.59% and 15.91%, respectively).

4.2 Classification of the mapped landslides

All the landslides in all the units were rotational although some landslides quickly changed into mud/debris flows with increasing rainfall. The landslides involved curved surface ruptures and produced slumps by backward slippage. This is typical of the East Africa region (Davies 1996; Ngecu and Mathu 1999). Seventy nine landslides were classified as contemporary and the rest were ancient, although these were re-activated in 2003. In terms of degree of stabilisation, 81 landslides were still experiencing erosion and dissection (41 active and 39 partially stabilized) while 7 had been recolonised by grass/shrubs. Channel geometry varied enormously. Steep narrow valleys produced V-shaped channels while gentle wide valleys produced U-shaped channels. Forty-three landslides had U-shape, 33 had V-shape while 12 had irregular channel morphometry. Within the units of the Ntchenachena area, the material involved in the movement ranged from soil mass to soil mass/weathered rocks/quartz floats. The majority of the landslides (57) occurred on middle slopes. Upper slopes recorded 23 landslides while 8 were on the lower slopes.

In some areas, landslide material moved a limited distance before stopping. The motion was probably inhibited by the dilation of the soil and concomitant decrease in pore pressure. The soils, according to eyewitnesses, were looser and in a dilative state, having absorbed water from the continued rainfall or from water ponding behind the slump, as was the case at the Lutowo Unit. As the slump mass became re-saturated, pore pressure increased again, initiating a second failure. This mechanism contributed to the flooding of the banks of the Mzinga River and has been widely researched (Harp et al. 1989; Harp et al. 2002).

4.2.1 General synthesis of landslides Inventory

The Lutowo area recorded the highest number of landslide occurrences. This was due to the high degree of land disturbance caused by cultivation, settlement activities and slope remodelling. Deep channels were common in all the units of the Ntchenachena area due to the deep weathering of the basement which has produced deep soils. Deep weathering is due to relatively high temperatures and high precipitation (Msilimba 2007). However, the length of the channels depended on the initial point of failure, and the length of the individual slopes. This is particularly evident for the Mankholongo and Chikwezga landslides which started on the top of hills and had lengths of up to 324m and 406m respectively.

The role of slope type in determining the location and distribution of landslides is well documented (Crozier 1973; Knapen et al. 2006). The majority of the landslides in the study area were on concave slopes and were rotational which is in accordance with the findings of Knapen et al. (2006) in Uganda. Few landslides (13) occurred on linear and rectilinear slopes because there were few of these slopes in the study units. However, this does not indicate a diminished level of instability to deformation for such slopes. Such slopes (with shallow soils and a sharp contrast between solum and saprolite) are inherently more unstable (Westerberg and Christiansson 1998).

Studies have been carried out to correlate slope aspect and vegetation type and distribution, and also aspect and rainfall type and distribution (Crozier 1973; Sidle et al. 1985). Although rainfall is generally from the SE, E, NE and S in Malawi, there is no rainfall data to suggest that the distribution of landslides in an area is affected by aspect. The fact that most of the landslides occurred on NE, SW, E and S aspects, which coincide with rainfall aspect patterns in the country, could be an issue for further investigation.

Landslides in the Ntchenachena area were rotational which involved curved surface rupturing and produced slumps by backward slippage. Such failures are associated with deep soils as is the case with the Ntchenachena area (Msilimba, 2002; Msilimba and Holmes 2005; Knapen et al. 2006). Scars revealing curved rupture and flat planes are common. Within the Ntchenachena area, complex events started as slides and with increased water content changed into mud-flows and debris-flows.

Most of the landslides are undergoing dissection due to erosion and have not been re-colonised by vegetation. Evidence of instability such as cracking of soils, gullying, fissuring, soil creeping and the removal of basal support was observed. Some landslides had achieved 50% re-colonization by vegetation although erosion was still active in some parts of the channels. Those landslides which had achieved 90% or more of re-colonization were assigned to the stabilized category. Most of the landslides fall in the active and partially active categories because the events were fairly recent and slopes need time to rehabilitate.

The results of the determination of the initial point of failure, where the shear band developed, agree with the findings of Fernandes et al. (2006). According to Fernandes et al (2006), middle and lower slopes (18.6^{0} to 55.5^{0}) are the most frequent to fall, followed by upper slopes of greater than 55.5^{0}. Most of the landslides occurred on the middle and lower parts of the slope where the landslide potential index (LPI) is highest. LPI is based on the number of landslides recorded in a given segment of a slope (Fernandes, 2006). The index decreases with height due to excessive removal of slope material as the force of gravity increases with height and slope angle (Smith 1996; Fernandes et al. 2006). Within the Ntchenachena area, middle slopes had thick soil or weathered materials while the upper slopes had thin soils (< 1m deep).

4.3 Causes of landslides

The general literature on slopes, mass movement and landslides is vast and is not addressed here (see for example Summerfield 1991; Selby 1993). Rather, this study highlights and examines local factors which contributed to landslides and their mechanisms of generation. The study suggests a combination of natural and anthropogenic factors precipitated the occurrence of landslides in the Ntchenachena area. For the purpose of clarity, the factors are presented separately while in reality they interacted and were inextricably linked. The results from the routine analyses undertaken on soil samples from six units are presented in table form (**Table 2A and 2B**) and are explained below.

Topographic Unit	Clay%	Silt%	Sand%	Hydraulic Con. (cm/hr)	Remark	Porosity Index	Liquid Limit	Plastic Limit	Bulk Density	Aggregate Stability	Plasticity Index
Kasokoloka	29.00	16.75	54.25	5.88	Moderate	55.66	44.21	27.86	1.18	2.88	16.35
Lutowo	17.72	15.63	66.63	7.68	Moderately rapid	57.77	47.93	28.74	1.119	3.18	19.19
Kasese Proper	22.00	16.08	61.92	7.15	Moderately rapid	56.98	46.39	26.95	1.14	2.61	19.44
Kasese Forest	28.00	15.67	56.33	11.09	Moderately rapid	60.25	52.23	30.37	1.05	2.72	21.86
Mankholongo	22.53	17.53	59.92	8.73	Moderately rapid	59.12	47.72	28.40	1.08	2.67	19.32
Chikwezga	14.11	17.55	68.36	8.22	Moderately rapid	58.91	54.70	31.51	1.09	3.18	23.19

Table 2A. Particle size analysis, hydraulic conductivity, porosity, Atterberg limits and densities

Unit	**Slope angle ^{0}**	**Vegetation/Land-use**	**Disturbance of land surface**	**Degree of Weathering**
Kasokoloka	41	Cultivation/settlement	High	High weathered
Lutowo	53	Cultivation/settlement	High	High weathered
Kasese Proper	58	Cultivation/settlement	High	High weathered
Kasese Forest	58	Forest	Undisturbed	High weathered
Mankholongo	54	Grass/shrubs	Moderate	High weathered
Chikwezga	54	Cultivation/settlement	High	High weathered

Table 2B. Unit characteristics

Particle size analysis, hydraulic conductivity, porosity, atterberg limits and densities

The Atterberg limits determine the behaviour of soils before deformation occurs (Terzaghai 1950; Crozier 1984; Bryant 1991; Alexander, 1993). The mean values for liquid limit ranged from 44.21% to 54.70%. The mean values were found to be high in all the study units. However, in areas where human settlements occur, liquid limits were found to be low due to soil compaction. Plastic limit mean values for the units were moderately high ranging from 26.95% to 31.51%. Plasticity Index mean values were generally moderate, corresponding to moderate values of plastic limits

Hydraulic conductivity tests show moderately rapid hydraulic conductivity for all the units. The mean values range from 5.88cm/hr at Kasokoloka to 11.09cm/hr at Kasese Forest. Lower values were observed in areas disturbed by human activities such as settlement construction and deforestation. Soil aggregate stability mean values were high, ranging from 2.61mm (Kasese Proper) to 3.18mm (Chikwezga), indicating a strong structural stability (GoM 1988; Msilimba 2002). Therefore, slopes failures cannot directly be attributed to structural stability of the soils.

Bulk density tests were carried out to determine the degree of soil compaction, porosity, hydraulic conductivity and the packing of soil particles. The results were compared with the average of 1.33g/cm^3 for soil which is not compacted (GoM 1988). The results were below 1.33g/cm^3 which indicated that the soils were not compacted. These results agree with the moderately high porosity values observed in all the units ranging from 55.66% at Kasokoloka to 60.25% at Kasese Forest. In some isolated areas where human activities were observed, relatively higher values were obtained. Although porosity determines hydraulic conductivity and slope loading, the initial porosity may not necessarily always be a reliable indicator of soil instability (Yamamuro and Lade 1998). The results were, therefore, treated as an indirect measure of soil stability.

Particle size analyses were carried out to determine the percentages of total sand and medium to fine sand which are prone to liquefaction under prolonged precipitation (Alexander 1993; Finlayson and Statham, 1980). In general, in all units within the Ntchenachena area, the soils showed a high percentage of sand ranging from 54.25% (Kasokoloka) to 68.36% (Chikwezga). The proportion of silt was found to be low. The mean values ranged from 15.63% to 17.55%. Mean clay values ranged from 14.11% to 29.00% with Kasokoloka recording the highest value.

Rainfall data analysis

The contribution of rainfall to slope instability has been analysed by several authors (Crozier 1984; Aryamanya-Mugisha 2001; Ingag'a and Ecakuwun 2001; Msilimba 2002; Msilimba and Holmes 2005; Knapen et al. 2006). Rainfall measurements (**Figs 3 and 4**) indicate that the Ntchenachena area receives high precipitation. Annual rainfall ranges from 949mm (1988/9) to 2631mm (1987/8) with an average of 1472mm. Although annual totals for the 2003 period for the area are not available, the study area is one of the wettest areas in Malawi (Linceham 1972; Msilimba 2007). Daily rainfall analysis (Fig 4) shows that the landslides areas occurred after prolonged rainfall of 21mm on 26/27 March and 185mm on 27/28 March, 2003. Total rainfall for the two days was 206mm which was more than half the total for the month of March which was 402mm. Before these rainfall events, the area had received 192mm of rainfall during the month of March. This was also towards the end of the rainy season when the antecedent soil moisture was already high. The landslides occurred in March when the recorded rainfall of 402mm was significantly higher than the normal monthly average of 301.9mm. Eyewitnesses attest to prolonged rainfall of low intensity prior to the landslide events, suggesting inflow exceeded discharge, resulting in higher pore pressure and liquefaction.

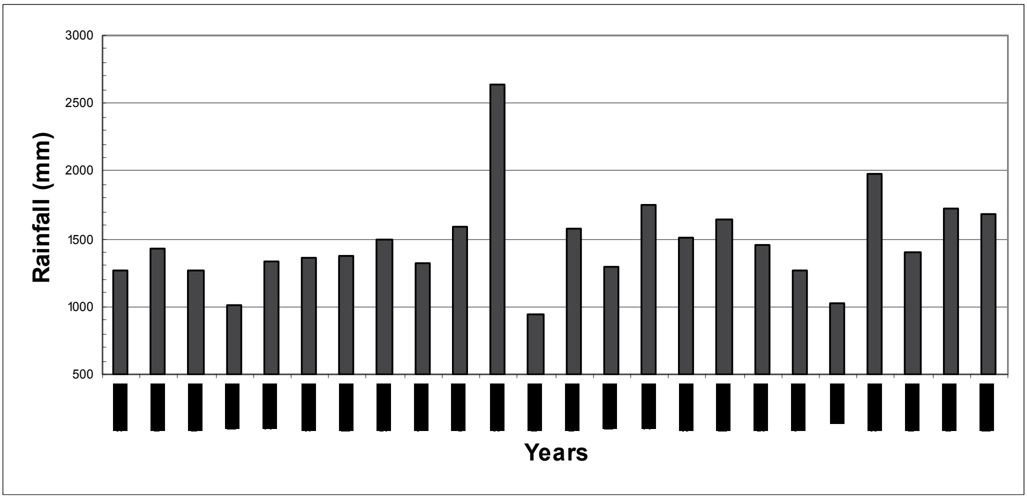

Fig. 3. Annual Rainfall Totals for the Ntchenachena Area from 1977 to 2001 (Note annual totals for years after 2001 were not available

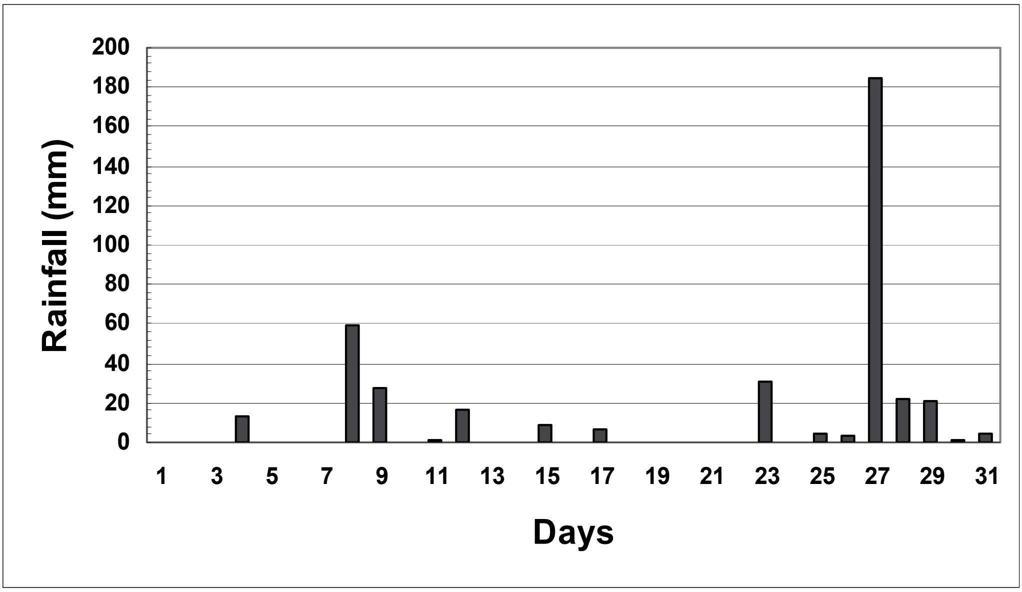

Fig. 4. Daily rainfall for March 2003 for the Ntchenachena Area. Note the critical rainfall that triggered the landslides

While high mean annual rainfall figures and moderate rapid hydraulic conductivity (>7 cm/hr) act as a prerequisite to occurrence by raising ground water tables and pore pressure, the critical factor in the case of 2003 landslides appear to have been prolonged, low intensity rainfall. It is important to note that out of six topographic units of Ntchenachena area (**Table 2A**), five registered hydraulic conductivity of greater than 7 cm/hr (moderate rapid hydraulic conductivity).

Slope angle analysis

The importance of slope angle in initiating landslides has been discussed by several authors (Hoek and Boyd 1973; Bryant 1991; Alexander 1993; Fernandes et al. 2006). All the landslides which occurred within the Ntchenachena area occurred on slopes of between 40^0 and 58^0. All the documented landslides elsewhere in Malawi have occurred on slopes steeper than 30^0 and have been triggered by prolonged precipitation, or high intensity rainfall (Gondwe and Govati 1991; Msilimba 2002; Msilimba 2007**).**

4.4 Mechanisms of landslides generation

Liquefaction of the soil

It was determined from the analysis of the data that the landslides were triggered by liquefaction of the sand and silt fractions of the soil. In all the units, the soils contained a high percentage of sand ranging from 54% to 68%. Medium to fine sand was abundant and the mean percentage exceeded 38.66% of the total sample. These sands satisfy the criteria for liquefaction; they are fine enough to inhibit rapid internal water movement, and coarse enough to inhibit rapid capillary action, while simultaneously displaying little cohesion (Bryant 1991; Msilimba 2002; Msilimba and Holmes 2005). Being unconsolidated, the angle of shearing resistance is low, and failure can occur at an internal angle less than that of the slope upon which the material rests (Finlayson and Statham, 1980)

Although some units within the Ntchenachena area showed a relatively high average percentage of clay (up to 29%), which would have reduced the rate of liquefaction (Finlayson and Statham, 1980), the strength of clay was reduced by high moisture content following 206mm of rainfall over two days. Though the plasticity indices were moderately high, the increased water content in 2003 meant that the soils easily crossed the threshold and liquefied. Evidence of liquefaction in this area is common (Msilimba and Holmes, 2005) However, it should be noted that liquefaction of the soils cannot be linked directly to soil aggregation. The high values of the calculated aggregate stability analysis indicate that the soils were structurally stable. This was supported by rainfall data which also showed high totals for other months in which there were no slope failures. Therefore, any slope instability cannot be attributed directly to the structural instability of the soil. However, since high aggregate stability values contribute to high porosity and permeability (Finalyson and Statham, 1980), the rate of hydraulic conductivity during the rain storms in March 2003, probably raised the water table, resulting in high pore pressure, possibly lowered aggregation and caused eventual liquefaction of the soils.

4.5 Triggering factors

Pore pressure

The mechanism of pore pressure accumulation is well discussed (Crozier 1973; 1984). The rainfall data show that the Ntchenachena area receives high annual precipitation (>1600mm per year). The antecedent moisture content prior to the landslide events was probably high. The 206mm of rain which fell in the Ntchenachana area, was unusual and above average. This unusually high rainfall coupled with high sand content, moderately high porosity, and moderately rapid hydraulic conductivity increased pore pressure between the soil particles contributing to the liquefaction.

Slope remodeling

It was observed that slope remodeling (cutting), though on a small scale, had negative effects on slope stability. Slopes had been remodeled for various purposes. Firstly, house building on steep slopes forced people to excavate large parts of the slope to create flat areas. The construction of foot paths also involved slope excavation. In addition, farmers often dig away parts of the slope in order to level their plots. Leveling was also done to construct irrigation channels. The creation of slope terraces for agricultural purposes and intensified natural processes removed the lateral support, caused water stagnation in some areas and increased slope loading, which led to increased pore pressure and landslide susceptibility. In the Manjiya area of Uganda, it was observed that numerous landslides occurred on slopes which had been remodelled for agriculture and settlement activities (Knapen et al. 2006).

Seismicity

Landslides caused by earthquakes have been reported in Malawi, and throughout the East African Region (Dolozi and Kaufulu 1992; Ingag'a and Ecakuwun 2001). Although the Ntchenachena area falls within the African Rift Valley System, with numerous observed and inferred faults, there is no conclusive evidence to suggest that the landslides were caused by earthquakes and tremors (Bloemfield 1968; GoM 1977). However, the location of these areas and the high percentage of sand indicate that there is a high probability for seismic-generated landslides.

4.6 Predisposing factors

Vegetation

Landslide occurrence as a response to land use change is well documented (Crozier 1984; Msilimba 2005). Field observations indicated that destruction of vegetation contributed to slope failures. The units, dominated by Afromontane grassland, and with poor ground cover of grasses and shrubs, recorded the highest number of landslides. For instance, the Lutowo unit where natural vegetation has been completely destroyed and the area is under cultivation recorded 55 landslides, the highest for the entire area. Within the Ntchenachena area, where the soils are very deep (> 10m), most of the landslides occurred beyond the root zone. This suggests that shallow rooted vegetation (grass/shrubs) did not provide maximum tensile resistance to the soil mass. In areas where vegetation was cleared for cassava cultivation, the instability has been increased because cassava has shallow roots and low root density (Msilimba 2002; Msilimba and Holmes 2005). It is suggested that grasses contributed to rapid infiltration, thereby increasing pore water pressure and slope loading. Grasses support high infiltration rates and have lower transpiration rates than deciduous forests (Scheichtt 1980; Msilimba 2002). It could therefore, be concluded that the rate at which the water infiltrated was greater than the rate at which the vegetation could transpire, thereby increasing both the load and the pore pressure.

Geology

It appears that the geology of the area did not contribute significantly to the slope failure. In all the occurrences mapped in this area, the basement was not involved in the movement. There were no pre-existing slide planes to suggest that geology contributed to the failures.

Most of the landslides were rotational which indicates that the soil mass was of significant depth. The basement which comprises muscovite schist and biotite gneiss has been reduced by rapid chemical weathering making it more porous and this probably contributed to moderately rapid hydraulic conductivity, thereby raising water pore pressure and reducing the strength of the material.

5. Susceptibility assessment

On the basis of the factors that contributed to and caused the landslides in the six units, an index of susceptibility for each of the units represented by the sample sites (**Table 2A and 2B**) has been calculated. This is a simple index, based on ten empirical, readily determinable variables (**Table 3**). Each variable is graded on a scale comprising three values: 1, 2 and 3. A value of 1 represents low susceptibility in terms of the variable contributing to landsliding, 2 represents intermediate susceptibility and 3 represents high susceptibility.

The sum of the gradings provides the susceptibility score for each site. The score for each site, derived from the data in **Table 2A and 2B** applied against the criteria in **Table 3**, is indicated in **Table 4A**. Areas with natural forests with little human interference are considered undisturbed; areas where forests have been cleared and are dominated by shrubs and grasses without cultivation are categorized as moderately disturbed, while areas under cultivation are considered highly disturbed.

Value	Slope 0	Disturbance of land surface	Vegetation	Sand %	Hydr. Con. (cm/hr)	Porosity index	Plasticity index	Bulk Density	Aggregate Stability	Degree of Weathering
1	≤45	Undisturbed	Forest	<60	≤6.25	<45	>15	>1.25	>2.00	Unweathered
2	45 - 50	Moderate	Grass/shrub	60 - 70	6.25 – 12.5	45 - 50	15 - 10	1.25-1.2	2.00 – 0.5	Partly weathered
3	≥50	High	Cultivation	>70	>12.5	>50	<10	<1.2	<0.5	Highly weathered

Table 3. Criteria used to determine susceptibility scores

Unit	Susceptibility score (see Tables 2B, 2C and 3	Susceptibility index (score ÷ 10)	Stability
Kasokoloka	20	2.0	Unstable
Lutowo	24	2.4	Unstable
Kasese Proper	24	2.4	Unstable
Kasese Forest	19	1.9	Potentially unstable
Mankholongo	20	1.9	Potentially unstable
Chikwezga	24	2.4	Unstable

Table 4A. Susceptibility scores and indices for six sample units

Susceptibility index	Stability
≤ 1.5	Stable
1.5 - 2	Potentially unstable
>2	Unstable

Table 4B. Degree of stability based on susceptibility index

The index of susceptibility (**Table 4A**) is simply the mean total score for variables indicated in **Table 3**. This is a crude index and no attempt has been made to weight the variables in terms of their relative significance in promoting instability. Initially, the midpoints between the variables on **Table 3** appeared to be logical divisions in terms of classifying areas as stable, potentially unstable, and unstable with regard to landslide susceptibility. Subsequently, taking cognizance of the danger of underestimating potential susceptibility, and erring on the side of a conservative classification, the criteria for identifying an area as stable was strengthened by reducing the critical value from 2.5 to 2. Therefore, an index of 1.5 or less indicates stability, between 1.5 and 2 indicates potential instability, and greater than 2 is regarded as unstable (**Table 4B**).

Further, detailed field observations and experimental work are required in order to assess the relative importance of the variables in promoting or retarding landsliding. Nevertheless, this technique provides an elementary, empirically based method which could be applied in the field to identify areas where the potential for landsliding is significant. The technique does not require sophisticated equipment or elaborate training of the practitioner and is, therefore, suited to developing countries which lack resources for high technology identification of vulnerable areas.

Using the susceptibility assessment index, the Ntchenachena area shows high susceptibility to landsliding. All the six units were classified as potentially unstable to unstable (Table 4A). No unit falls in the category of stable. Kasese Forest and Mankholongo areas are the only areas categorized as potentially unstable. Although all the parameters indicate instability, some stability is provided by vegetation. Kasese Forest is undisturbed forest while Mankholongo is dominated by shrubs/grass with no cultivation. Destruction of trees (Kasese) and shrubs/grass (Mankholongo) may soon render these areas unstable.

All the four other units were classified as unstable. A combination of steep slopes, land disturbance, lack of vegetation cover, high sand content, moderately rapid hydraulic conductivity and high degree of weathering of the basement, contributes to the instability.

6. Conclusion

This chapter has assessed the local factors that contributed to and have previously caused landslides in the Ntchenachena area of northern Malawi. Physical and anthropogenic factors contributed to the occurrence of landslides and rendered all the units of the Ntchenachena area susceptible to landslides. Partially unstable units are tenuously stabilized by vegetation. Continued destruction of vegetation may render Kasese Forest and Mankholongo units unstable. Therefore, improvement of public awareness of not only danger-prone areas but also the impacts of human activities is strongly recommended. This landslide inventory is an important step towards hazard reduction in the region and could also provide a framework for landslide inventories throughout Malawi and the region of East Africa region.

7. References

Alexander D (1993) Natural disaster. University College Library, London

Aryamanya-Mugisha H (2001) State of the environment report for Uganda 2000/1 technical report. National Environmental Management Authority, Kampala

Avery T, Burkhart H (2002) Forest measurements, 5th. McGraw-Hill Companies, New York

Bloomfield K (1968) The pre-karroo geology of Malawi. Geological Survey Department, Zomba

Bryant E (1991) Natural hazards. Cambridge University Press, Cambridge

Cheyo D (1999) Geohazard around the Michesi and Zomba areas. In the proceedings of the symposium on natural geological hazards in Southern Malawi, Zomba, 27th – 28th July, 1999

Chutter J (1983) Timber management, a quantitative approach. John Wiley and Sons, NewYork

Coch K (1995) Geohazards: natural and human. Prentice Hall Inc, New Jersey

Cooper W, Habgood F (1959) The geology of the Livingstonia coalfield. Department of Geological Survey, Zomba

Crozier M (1973) Techniques for the morphometric analysis of landslips. Zeitschrift fur Geomorphologie 17:78–101

Crozier M (1984) Field assessment of slope instability. In Brunsden D, Prior D (eds) Slope instability. John Wiley and Sons, New York pp 54 -156

Davies T (1996) Landslides research in Kenya. Journal of African Earth Science 4:541 – 549

Dolozi M, Kaufulu Z (1992) The Manyani hill landslide in north eastern Kasungu, Malawi. National Papers of the Malawi Department of Antiquities 1

Fernandes F, Guimaraes R, Vieira B (2006) Topographic controls of landslides in Rio de Janeiro: field evidence and modeling. J Catena 55:163 – 181

Finalyson B, and Statham I (1980) Hillslope analysis. Butterworth, London

Fredlund D, Riharjo H (1993) Soil mechanics for saturated soils. John Wiley and Sons Inc, New York

GoM (1977) Map of South Uzumara. Department of Geological Survey, Zomba

GoM (1987) Map of Livingstonia area. Department of Surveys, Zomba

GoM (1988) Soil laboratory analysis manual. Bvumbwe Research Station, Bvumbwe

Gondwe P, Govati C (1991) The stability status of Michesi Mountain. Department of Geological Survey, Zomba

Harp E, Wade G, Wells J (1989) Pore pressure response during failure in soils. Geological Society of America Bulletin 102:428 – 438

Harp E, Reid M, Michael J (2002) Hazard analysis of landslides triggered by typhoon Chata'an on July 2, 2002 in Chuuk State. Federal State of Micronesia, UGSS open file report 2004 .1348 US department of the Interior, Washington

Heok E, Boyd J (1973) Stability of slopes in jointed rocks. Journal of the Institution of Highway Engineers 4:1-36

Huabin W, Gangjun L, Weiya X (2005) GIS-based landslide hazard assessment: an overview. Progress in Physical geography 29:548-567

Ingang'a S, Ucakuwun E (2001) Rate of swelling of expansive soils: A critical factor in triggering of landslides and damage to structure. Documenta Naturae 136:93 – 98

Kemp J (1975) The geology of the Uzumara area. Geological Survey Department, Zomba

Knapen J, Kitutu M, Poesen J (2006) Landslides in densely populated county at the foot slopes of Mount Elgon (Uganda): Characteristics and causal factors. Journal of Geomorphology 73:149–165

Linceham I (1972) Climate 4; rainfall. In Agnew S, Stubbs G Malawi in Maps. University of London Press, London p23

Moeyerson J (1988) The complex nature of creep movements on steep sloping ground in Southern Rwanda. Journal of Earth Surface Processes and Forms13:511 – 524

Moeyerson J (1989a) La nature de l'erosion des versants au Rwanda. Annuals of the Royal Museum for Central Africa19: 396

Moeyerson J (1989b) A possible causal relationship between creep and sliding. Journal of Earth Surface processes and Landforms14:597 – 614

Msilimba G (2002) Landslides geohazard assessment of the Vunguvungu/Banga catchment area in Rumphi District, MSc. Environmental Science Thesis. University of Malawi, Zomba

Msilimba G, Holmes P (2005) A landslide hazard assessment and vulnerability appraisal procedure; Vunguvungu/Banga Catchment, Northern Malawi. Natural Hazards 24: 99 – 216

Msilimba G (2007) A comporative study of landslides and geohazard mitigation in Northern and Central Malawi, PhD Thesis. University of the Free State, Free State

Muwanga A, Schuman, A, Biryabarema M (2001) Landslides in Uganda: Documentation of natural hazards. Documenta Natuae136: 111 – 115

Mwenelupembe J (1999) Debris flow in Zomba and Michesi mountain slopes; their causes, mitigation and return period. Proceedings of the symposium on natural geological hazards in Southern Malawi, 27th – 28th July, 1999

Ngecu M, Mathu E (1999) The El-Nino triggered landslides and their socio-economic impact on Kenya. Journal of Environmental Geology 38: 277 – 284

Non-Affliated Soil Analysis Working Committee (1990) Handbook of standard soil testing methods for advisory purposes. Soil Science Society, Pretoria

Poschinger A, Cheyo D, Mwenelupembe J (1998) Geohazards in the Michesi and Zomba Mountain Areas in Malawi. technical cooperation report No. 96. 20915.5, Depratment of Geological Survey, Zomba.

Punmia B (1976) Introductory soil mechanics. Standard House, Delhi

Schiechtt H (1980) Bio-engineering for land reclamation and conservation., University of Albert Press, Edmonton .

Selbly B (1993) Hill-slope materials and processes. Oxford University Press, Oxford

Shaxson T, Hunter N, Jackson T et al (1996) A land husbandry manual. Ministry of Agriculture and Food Security, Lilongwe

Sidle R, Pearce A and O'loughlin (1985) Hill slope stability and land use. Water resources monograph series, No. 11, American Geophysical Union, Washington D.C

Smith K (1996) Environmental hazards; assessing risk and reducing disaster. Routledge, London

Summerfield M (1991) Global geomorphology. Burnt Mill, Longman

Terzaghai K (1950) Mechanics of landslides. Geological Society of America Berkey volume, pp83 – 123

Westerberg L, Christiansson C (1998) Landslides in East African highlands, slope instability and its interrelations with landscape characteristics and landuse. Advances in Geo-Ecology 31: 317 – 325

Yamamuro J, Lade P (1998) Steady state concepts and static liquefaction of silty sands. Journal of Geotechnical and Environmental Engineering 124:868 – 877

Young A (1972) Soils. In Agnew S, Stubbs M (eds) Malawi in Maps. London, Longman

Zoruba Q, and Mencl V (1969) Landslides and their control. Elsevier/Academia, Prague

2

Disaster Management Based on Business Process Model Through the Plant Lifecycle

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1. Introduction

There has been a recent surge in the number of disasters and incidents in occurring in the process industry (e.g. the petrochemical, chemical, food and pharmaceutical industries). The reasons include defects in process-safety management (PSM); inadequate safety management systems in companies; inadequate knowledge among managers and insufficient information about the tasks undertaken and resultant erroneous operation and/or misjudgement; no standardization for the PSM activity; and other engineering factors. Expecting that PSM will reduce the hazards and likelihood of disasters, OSHA in USA emphasizes PSM and requires that companies establish PSM systems and improve safety engineering techniques (OSHA, 1992).

Existing PSM guidelines, OSHA/PSM, Seveso II Directive (The Council of the European Union, 1996), AIChE/CCPS RBPS (Risk-based Process Safety) (AIChE/CCPS, 2007) and others, establish only minimum elements for safety management. They do not describe concrete actions to take within facilities. The importance of discussion of process/plant engineering activities based on business process modelling throughout a *'plant-lifecycle* (i.e. from process/plant design through construction and the active manufacturing period (incl. production and maintenance))' has been recognized for many years. Development of a systematized PSM framework should prevent disasters and ensure consistency within plant-lifecycle engineering (*Plant-LCE*).

To develop a plant- and site-specific PSM approach, it is important to clarify the relationship between management and individual activities, and to consider the technical and functional frameworks within the human-organization system. Traditionally, business-process analysis has been conducted according to organizational configurations and strives to clarify responsibilities (*'know-who'* and *'know-what'*) among employees and managers. However, companies have specific organizational frameworks, administrative structures, policies or strategies of operations management, and specialized engineering techniques (individual methods, procedures, tools, etc.), and therefore the standardization of business processes and the development of generic management frameworks to which companies can refer is very difficult. The first thing necessary for practical disaster management is to make hidden business knowledge (specifically the *'know-why'*) explicit by focusing on functional and logical structures of the business process (i.e. the causal relations and information flow among and between business activities).

This chapter aims to discuss what should be done to business functions (i.e. activities) and what should be done to operations at a plant-site. The focus of business process modelling is mainly on engineering activities in the process industry. These activities are organized hierarchically following a template in the form of the PDCA (Plan-Do-Check-Act) cycle. The business process model (BPM) of a Plant-LCE (including PSM) is presented as an example.

2. Plant-lifecycle engineering

As show in Fig.1, a plant-lifecycle consists of the following engineering stages: development, design, construction, production, maintenance, and scrap (or dismantlement). It may be more than 40 years from the beginning (or development) stage to the end (or scrap) stage. Over its lifetime, the product markets and the costs of raw materials and fuels may vary dramatically. During that time, changes of production rules or strategies and/or revamping of a plant's facilities are undertaken. Underlying hazards may be found while technology is improved or as a result of accidents that occur in the industry. Furthermore, degraded plants should be renovated to meet requirements for safety, because the quality of facilities is often diminished during their production tenures. Under these external and internal environmental conditions, changes of plant structure, processes, plant design, production and maintenance are necessary. For all changes, safety assessments and improvements are always needed. Process hazard analysis (PHA) and management of change (MOC) are perpetual and vital. Many activities are needed to achieve MOC. Modification of even a small part of a plant will affect many other stages in the plant-lifecycle. Stages in a plant-lifecycle are intricately connected.

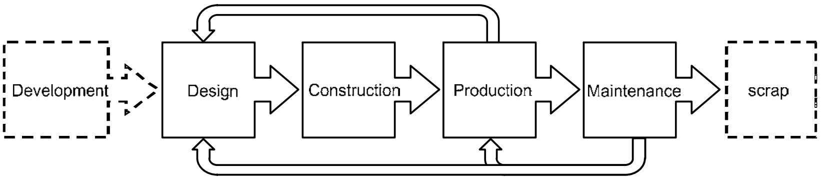


Fig. 1. Engineering stages through the plant-lifecycle

Most disasters occur during the production and maintenance stages of a plant-lifecycle. Researches during the development and design stages to improve safety during the production and maintenance stages help to prevent disasters. For example, plant equipment that is designed with low tolerance for operating conditions is difficult to operate safely and may lead to heightened risk, hazard and even disaster. If plant engineers can design for wider operating range, equipment is easier to operate safely and may produce few disasters. Furthermore, design based upon clear understanding of production and maintenance processes (*'design rationale'*) can also help to avoid disasters. If the proper design rationale (*'know-why'*) is incorporated into a facility, poor and dangerous decision making will be avoided. For systematic disaster management, a model-based engineering framework is needed so that information can be used to inform all stages of the plant-lifecycle. Constantly updated and revised data must be shared at each engineering stage in a transparent way in order to examine the impacts of safety decisions of all functions/activities of the plant. Such an information infrastructure is not currently available, so we have wasted enormous manpower to acquire or update proper information. To realize the engineering framework based on the information infrastructure, business activities and information flow among them should be represented explicitly.

3. Basis of business process modelling for plant-LCE

IDEF0 (Integrated DEfinition for Functional model standard, Type-zero) is adopted as a description format to develop the business process model. And a template has been proposed to generalize the modelling in IDEF0 format.

3.1 IDEF0 format

IDEF0 is a well-known standardized method for enterprise-resource planning or business-process (re)engineering. Fig. 2 shows the basis of the IDEF0 format. The rectangle represents an *'activity (function)'*, and the arrows describe information. The information is classified into four categories: '*Input*' which is changed by the activity, '*Control*' which constrains the activity, '*Output*' which is the result of the activity and '*Mechanism*' includes the resources of the activity. The information is collectively termed ICOM (Input, Control, Output, and Mechanism). Each activity can be further developed hierarchically to detail sub-activities as needed (NIST, 1993). Development of business process model using the IDEF0 format enables function-based discussions.

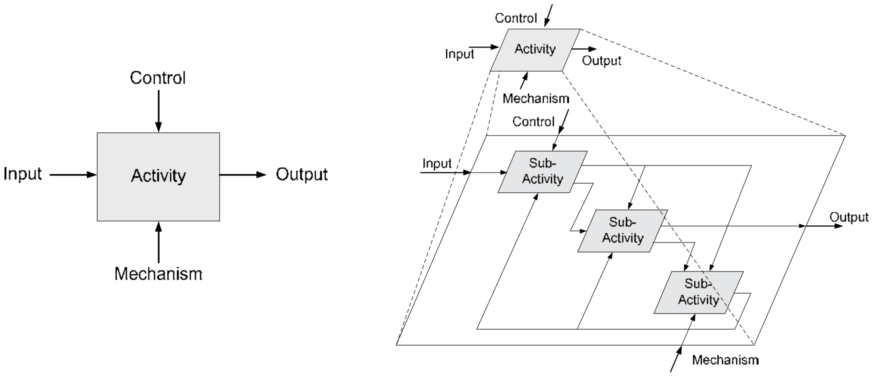


Fig. 2. Basis of IDEF0 format

3.2 Template for developing business process model

The PIEBASE (Process Industry Executive for achieving Business Advantage using Standards for data Exchange) was an international consortium to achieve a common strategy and vision for the delivery and use of internationally accepted standards for information sharing and exchange (ISO-STEP), and developed a business process model to represent the core business activity of the chemical process industry (PIEBASE, 1998). The

PIEBASE model uses a template approach across all principal activities. This template consists of three steps, (1) manage, (2) do, and (3) provide resources. The purpose of PIEBASE model is to provide a common understanding of the engineering and information requirements of processes throughout the lifecycle of a plant. However, the activities in the model were defined to reflect current practices.

On the other hand, as shown in Fig. 3, a template for business process modelling (*BPM-template*) of Plant-LCE has been proposed to generalize the modelling in IDEF0 format and enable a discussion of integrating each business process model for Plant-LCE (Shimada et al., 2009). This BPM-template consists of two functions; *'Performance in the form of a PDCA (Plan-Do-Check-Act) cycle'* and *'Resource provision'*.

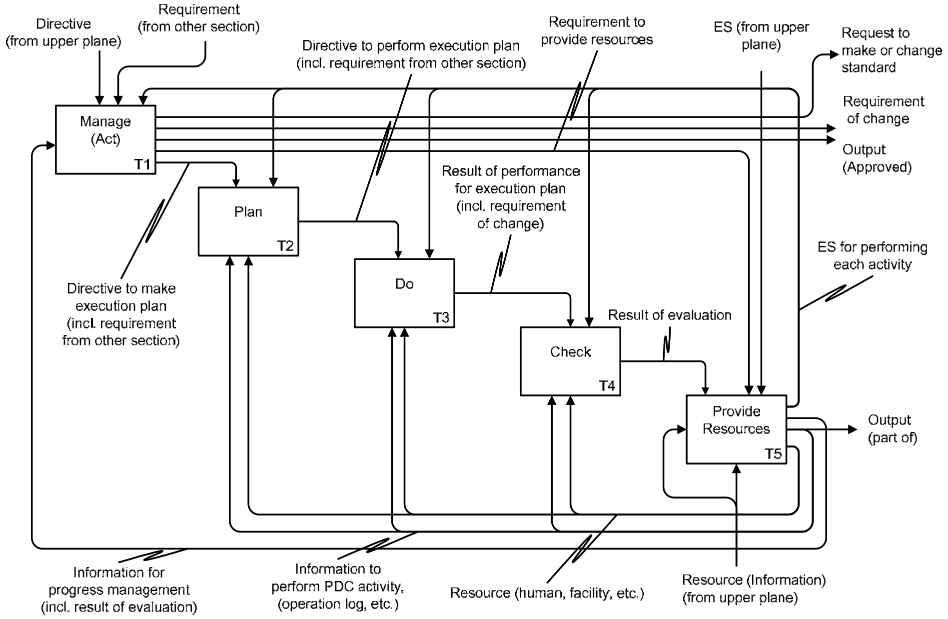


Fig. 3. BPM-template for business process modelling

1. Performance in the form of PDCA cycle (Deming, 2000): Each activity should be carried out according to engineering standards (or ESs; e.g. technical standards and control standards) complying with laws and regulations.

- The *'Manage'* activity manages the progress of overall activities within the same plane, including the requirement of resource provision, the improvement of engineering standard, and decision making of the next action for change requirement.
- The purpose of the *'Plan'* activity is to make an executable plan for a given specific directive.
- The *'Do'* activity executes a plan and yields requirements for administrative defect factors, if any.
- The *'Check'* activity evaluates the results and the performance of the previous activities to support these goals: a) performance and results for the directive and the plan, b) compliance with engineering standard, c) sufficient provision of resources, and d) validity of engineering standard itself.

2. Resource provision: *'Provide resources'* activity provides the resources to support and control *'Plan'*, *'Do'*, *'Check'*, and *'Act'* activities. These resources include: a) educated and trained people and organizations; b) facilities and equipment, tools, and methods for supporting activities; c) information to perform PDC activities; d) information for progress management; and e) engineering standard for controlling each activity, which are given from the activity of upper plane.

This BPM-template enables development of business process model to perform activity planning, execution, evaluation, and improvement at each sub-activity plane. That is, the model based on proposed BPM-template shows the implementation in the form of PDCA cycle and the uniform management of engineering standard with provision of just enough resources. And the developed model can make the purpose, the contents, and the relevant ICOM of individual activity clear.

Features of the business process model are:

- Business process activities with information and information flows at each stage of the plant-lifecycle are modelled in the form of PDCA cycle. The scope of each management plan becomes clear. The decision making, evaluation processes, resources, information, and engineering standard required for performing each process are expressed explicitly.
- All information needed to perform each activity (including the plans, the performance results and checked results) are collected, managed, and in the *'provide resource'* step in the framework. The *'Provide resources'* activity is to achieve consistency between engineering standards.
- Business processes are structured as activities or functions that are logically required regardless of a company's organization.
- Using the business process model as reference model should expose problems with the current process, activities that are not performed in the PDCA cycle, and any defects during information sharing and communication. The countermeasures of the problems, consolidation of technical requirements, and the processes centered on organization integration can be reviewed.

4. Business process modelling for disaster management

Business process model should be seen as a *'to-be'* model that represents the logical business process. The following points are required for a referenceable model.

- The definitions of business functions and the scope of them must be clarified before starting the development of model.
- Activities that develop technologies and activities that use technologies for engineering functions should be clearly distinguished.
- Activities must be categorized as *'Plan'*, *'Do'*, *'Check (Evaluate)'*, or *'Manage (Act)'* activities in order to develop a model that constitutes an activity framework in the form of a PDCA cycle.

Furthermore, two points must be kept in mind so as not to create a business process model that only represents a specific company's activities.

- The model should be considered separate from the company by assigning tasks based upon on organizational structure not specific workers in the specific company. That is, tasks should not be based on the question of "who should do them?", but rather on "what has to be done?"

- Specific activities in an individual company should not be the focus of the model. Widely-used and generalized structures of activities and information flow related to the activities should be developed.

Activities that are performed at actual companies (plant engineering companies, plant operation companies, etc.) have been compiled and examined, and business process models have been developed based on the BPM-template displayed in Section 3. Fig. 4 shows a business process model reflecting the activities of Plant-LCE. *'Do'* activities of this model are comprised of activities of development and design, construction, and manufacturing stages. Models for process and plant design, production, maintenance within manufacturing, and PSM are described in the following sections.

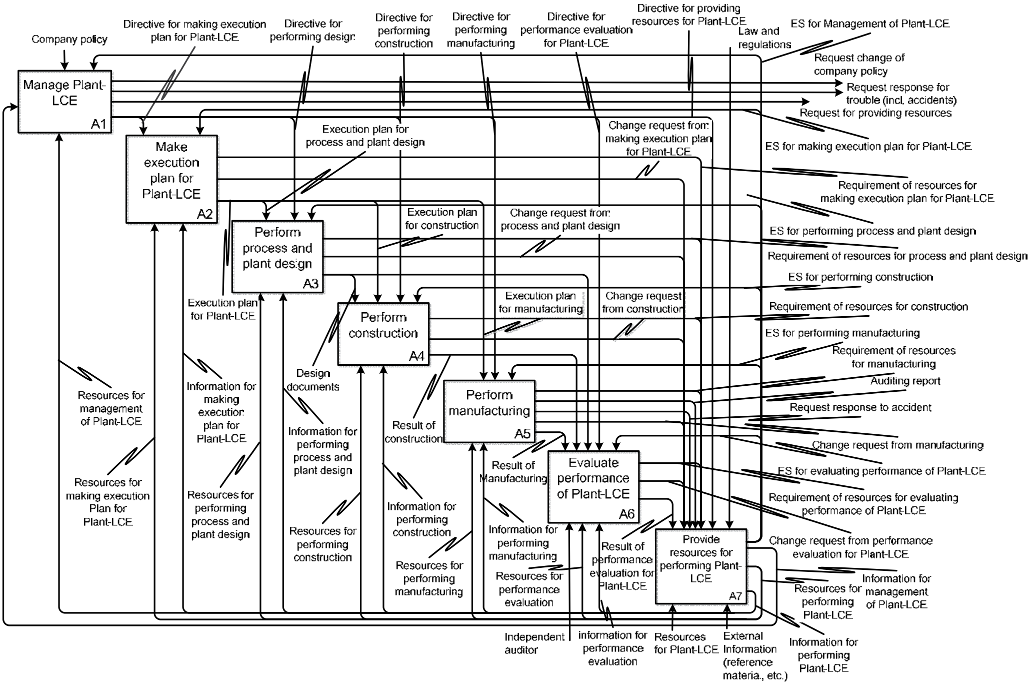


Fig. 4. Top activities of business process model of plant-LCE

4.1 Business process model for process and plant design

Chemical processes generate potential hazards, and these processes are designed to avoid hazards given that they can evolve into serious events. In general, the risk is controlled within a region of safety within normal operations. However, some initiating events that exceed the control capabilities of normal operations can cause abnormal deviations and hazardous events that can lead to human and physical damages. The purpose of using independent protection layers (IPLs) (AIChE/CCPS, 2001) is to prevent the occurrence of hazardous events by designing protective systems against failure sequences that might lead to disasters. Table 1 shows the most commonly encountered IPLs that should be considered for inclusion during process and plant design. In a typical plant engineering project, the analysis that precedes the IPL design and the IPL design itself are not incorporated in a systematic way with the process and plant design. This is related to the common lack of design rationales in the design of safety systems, and these result in alarm floods (ISA, 2007). To overcome these problems, a business process model is developed to provide a framework for process and plant design.

IPL No.	Countermeasures
1	Inherently safer process design
2	Basic process control system, process alarm and operator supervision
3	Critical alarms, operator supervision, and manual intervention
4	Automatic Safety Interlock System (SIS)
5	Physical protection (relief devices)
6	Physical protection (containment dikes)
7	Facility emergency response
8	Community emergency response

Table 1. Independent protection layers

A business process model for process and plant design that incorporates IPL design has been developed (Fuchino et al., 2011). This model is based on the previously discussed BPM-template across all principal activities, and the Plant-LCE approach was adopted as well. Fig. 5 shows a part of the node tree from "*(A3) Perform Process and Plant Design*" of business process model of the Plant-LCE. The process design activity consists of three phases: conceptual, preliminary, and final. The plant design is composed of two phases: preliminary and final. The conceptual process design phase *(A33)* corresponds to the inherently safer process design in IPL (1), including hazard elimination and substitution, inventory considerations, and plant location. The preliminary process design phase (*A34*) is related to the design of IPLs (2) to (6). In "*(A34) Develop Preliminary Process Design (IPL-2_6)*", the process design according to operational requirements of normal, abnormal, and emergency operations is executed. In designing process for normal steady state operation (*A343*), basic process control system is designed, so that the safety operating ranges should be assessed in *A3432* activity before *A3433* activity. *"(A344) Develop Preliminary Process Design for Startup (S/U) and Shutdown (S/D) operation"* evaluates the current plant design to verify that all the necessary equipment is available to perform startup and shutdown. As a result preliminary operating procedures are obtained along with information on operating limits and time-related data that can be used to configure state-based alarm algorithms. The synthesis of startup and shutdown operations takes place in *A3442* activity. To specify initial conditions and safety constraints in *A34423* activity, the hazardous conditions should be assessed in *A34422* activity. In "*(A345) Develop Preliminary Process Design for Abnormal Situation*" activity, PHA is necessary (*A34522*) and the operation category (fallback, partial shutdown, or total shutdown) is determined. This is because hazard analysis is used to identify possible hazard scenarios and its recommendations for additional sensors, alarms or other IPLs, some of which are addressed in activity *A34523*. Furthermore, because hazard scenarios contain information about causes, consequences, and corrective actions, they can also be used justify the design rationale for a given alarm. Operational responsibility should be estimated in *A34523* activity, and the operation category is decided in *A34524* activity. The activities to perform PHA are depicted in Fig. 5. It is clear that PHA and IPL design should be performed concurrently to generate rationalized process safety design. This makes it possible to manage the information on design rationale which can be useful for safety production management and effective maintenance and contributes to disaster prevention in process industry.

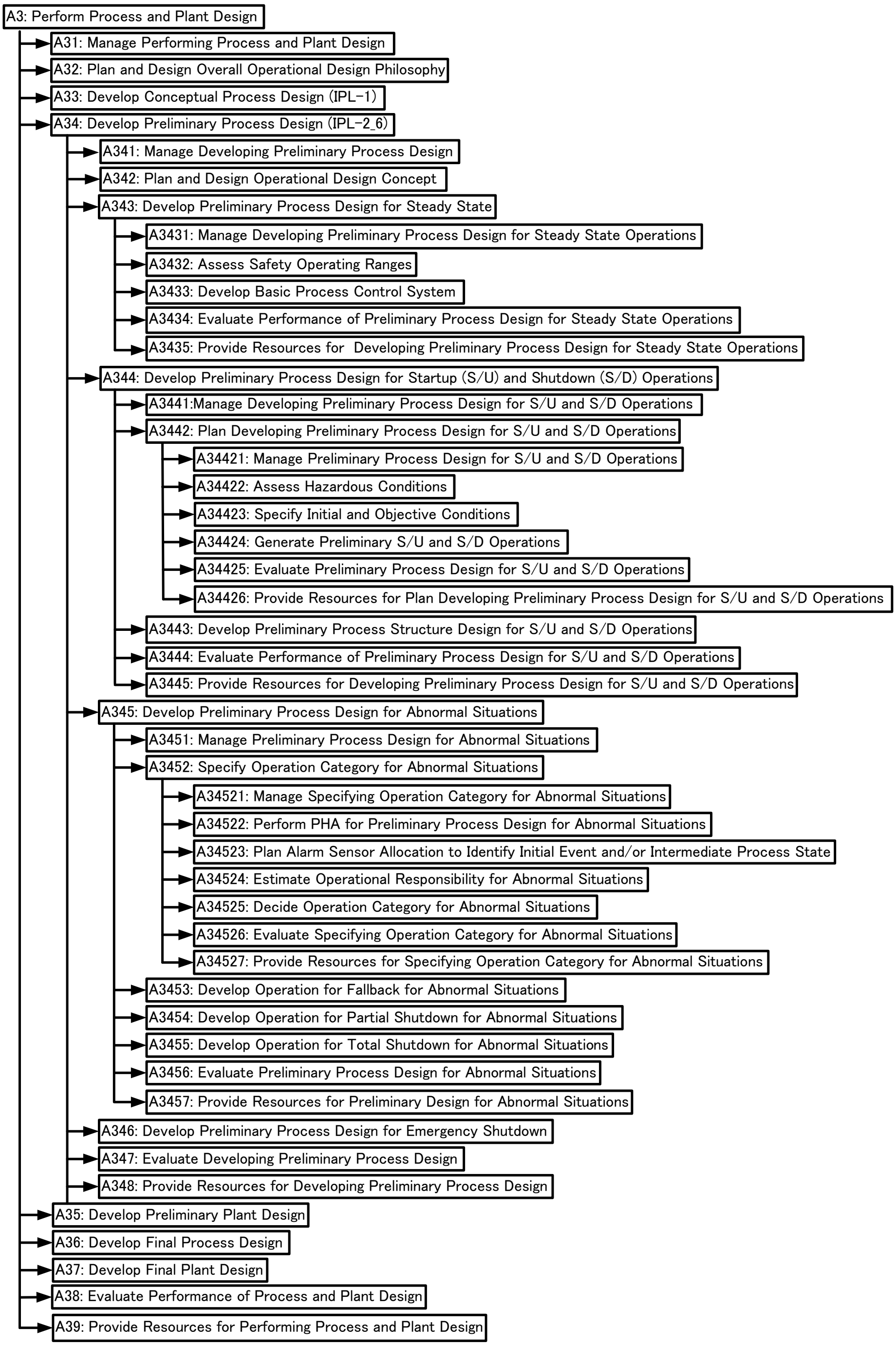


Fig. 5. Node tree from "*(A3) perform process and plant design*"

4.2 Business process model for production

It is essential to create the environment that can support purposeful management of safe operation and effective maintenance while performing normal manufacturing activities. The activities related to production and maintenance in the Plant-LCE are unified as manufacturing with production planning. This enables development of an integrated plan to manage production and maintenance activities together.

It is difficult to develop a unified business process model for manufacturing due to the differences with aspects of production management because of the organization of individual companies and the differences of operation philosophies of each type of plant (for instance, petroleum refineries compared to petrochemical plants and fine chemical plants). For these reasons, there have been no attempts to develop a business process model for production activities. To surmount this challenge, the following two principles have been established before starting the analysis of production: 1) The model is independent of organizational frameworks in specific companies, and 2) Specific production activities in specific companies will not be considered and only general activities and only the flow of information should be considered. Specific activities can be added to the BPM-template for use by specific companies to apply the model to real-world cases.

Business process model have been developed for production (Shimada et al., 2010a). Activities under *"(A53) Perform Production"*, which is a sub-activity of *"(A5) Perform Manufacturing"*, have been considered targets of business process modelling for production. At first, activities of production that are performed routinely at some companies have been listed and extracted by reference to international standard (IEC, 2003). Then, the activities and their relations have been generalized according to the BPM-template. Fig. 6 shows the node tree from *"(A53) Perform Production"* which consists of production scheduling, inventory control, and production execution. *"(A534) Execute Production"* activity consists of dispatching operations, preparation for operations, and execution of operations. Operation is comprised of operation for both normal and emergency situations, and normal operation has three main activities: operation-case execution, monitoring and diagnosis from the viewpoints of *SQEA (Safety, Quality, Environment, and Availability)*, and construction support under plant operation. As a second step, ICOM on production management is provided to for relation to production. As information related to mechanism, people, facilities and equipment, information, consistent engineering standards, etc. needed for performing production are clearly specified and managed in an integrated manner.

Fig. 7 shows the business process model for *"(A5344) Execute Operation"* as a part of production. The model shown in Fig. 7 do not mention about *'Plan'* activity explicitly, but directives from upper level activity that is *"Decided operating procedures"* and *"Directive of normal operation"* include each concrete execution plan.

The meanings of terms in the business process model and concrete examples of activities have been written down in the glossary, which is separate from the model. This glossary can help assist discussion of the model by clarifying what, how, and why steps are taken within the model specifically. At the same time, resources needed for executing each activity are also listed.

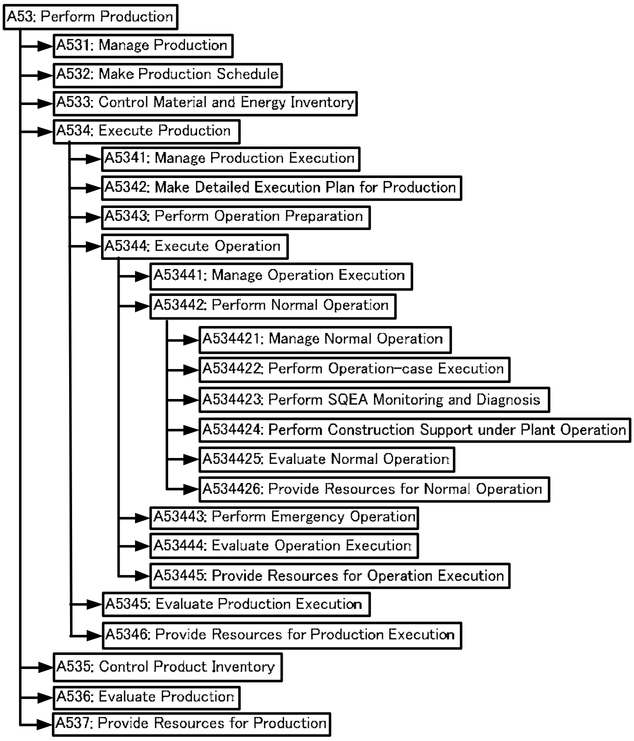


Fig. 6. Node tree from *"(A53) perform production"*

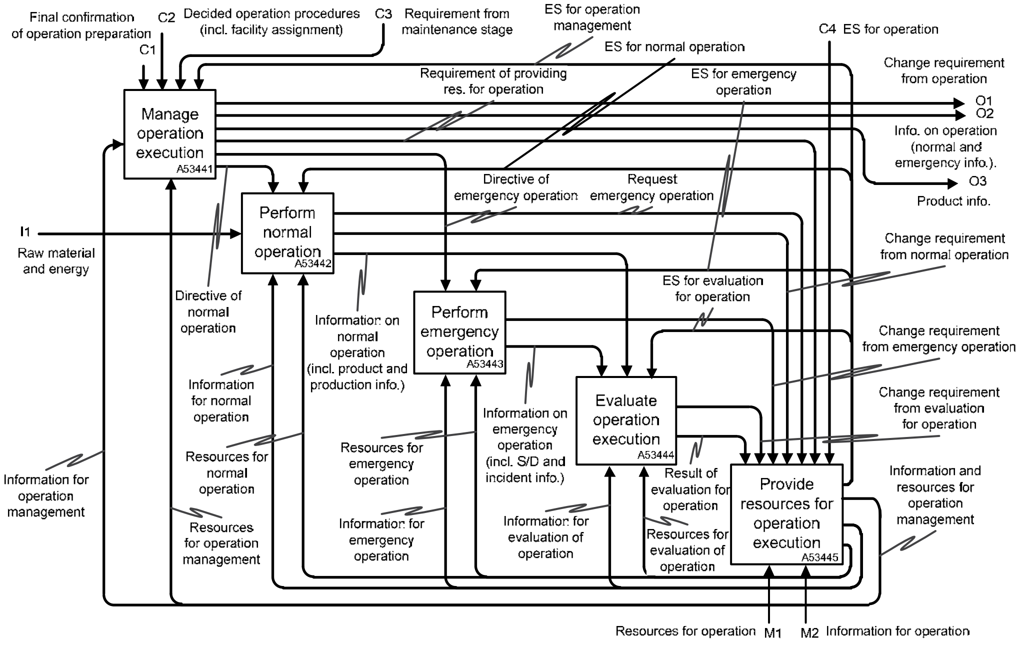


Fig. 7. Business process model for *"(A5344) Execute Operation"*

Developing a business process model for production provides following advantages:

- Development makes it possible to summarize the activities hierarchically and to clarify the required inputs, the constraining conditions, and the resources needed for each activity.
- Scope of safety operation management can be specified by extracting the structured activities of production.
- Performing production according to the developed model makes it possible to convey process-safety information positively and to enable the prevention of industrial accidents or disasters due to PSM difficulties.
- Introduction of a framework given as a model provides the basis of safety conscious production for the process industry.

4.3 Business process model for maintenance

Chemical plants employ a lot of flammable materials as raw materials, intermediates and products, so leakage is a serious problem that may lead to fire, explosion and/or disaster. Chemical plants are deteriorated by their production, and maintenance aims to restore the deteriorated plant into a safe condition. The mechanism, speed, and location of the deterioration vary with operating conditions (e.g. increasing flow rate in pipes sometimes change the location of sludge deposition, and the mechanisms of corrosion under the sludge). However, the deterioration (especially corrosion) is much more complicated by the chemical compounds and flows of process fluid, the plant structure (including the nature of the materials used in its construction), and electrochemical behavior. Therefore, the exact deteriorating location and level of deterioration (and/or residual life of the deteriorating part) cannot be expected from the beginning but can only identify the probabilities of deterioration locations.

In order to perform maintenance consistent with production and plant state through the plant-lifecycle, a mechanism not only to integrate the information of lifecycle activities (design, production and maintenance), but also to systematize the results of maintenance into technology is needed. Business process model have been developed for maintenance in order to define the framework of the processes (Fuchino et al., 2008, 2010). Fig. 8 shows the node tree from *"(A54) Maintain Plant"* of business process model of the plant-LCE. The model is based on the preceding BPM-template across all principal activities, and the Plant-LCE approach was adopted.

"(A54) Maintain Plant" activity receives directives and requirements for maintenance from *"(A51) Manage Manufacturing"*. The information from the production plan comes from *"(A52) Make Production Plan"* and any other information for maintenance including operational results and maintenance results is from *"(A56) Provide Resources for Manufacturing"*. Furthermore, engineering standard necessary to perform maintenance is delivered from *A56* to *A54* activities. *A54* activity developed into *"(A541) Manage Maintenance"*, *"(A542) Make Maintenance Plan"*, *"(A543) Perform Maintenance"*, *"(A544) Evaluate Maintenance Plan and Performance"* and *"(A545) Provide Resources for Maintenance"*. *A541* activity decides sub-directives for *A542* to *A544* activities on the basis of the directive, requirement and production plan from the upper hierarchical activities, and *A542* to *A544* activities are performed under the constraint of the sub-directives. The *A545* receives information and engineering standard for maintenance, and the information is delivered

to *A542* to *A544* activities. Making a maintenance plan is defined as deciding which parts and at what times to repair the plant, as well as selecting methods for inspection and repair.

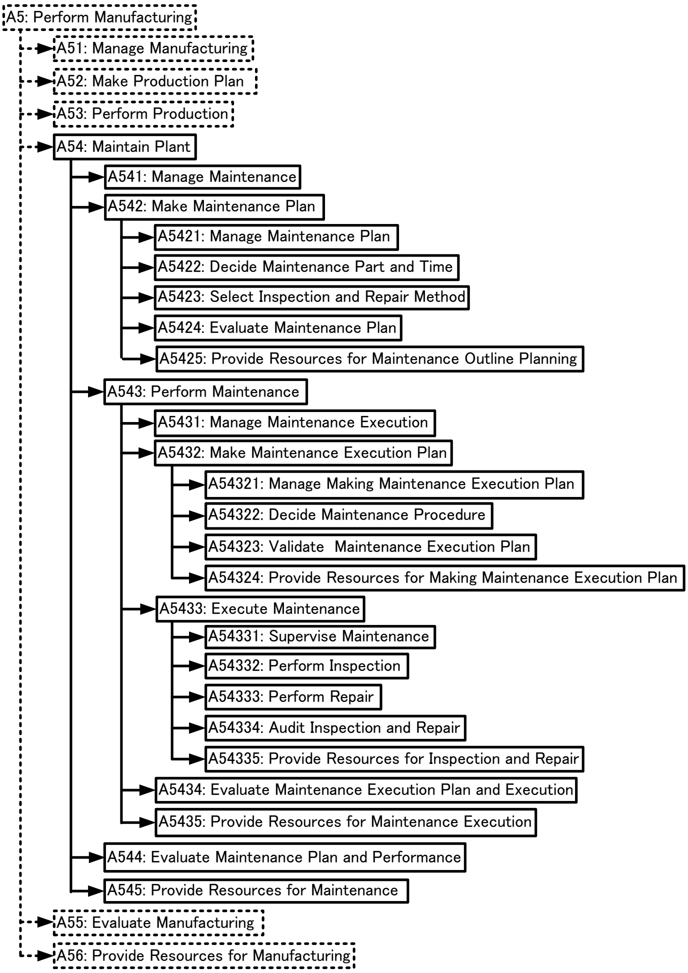


Fig. 8. Node tree from *"(A54) maintain plant"*

The *A5422* activity determines the part repaired and timing using the information from the production plan, production results and maintenance results. Repair and timing guide inspection and methods of repair from the inspection and repair data base in *A5423* activity. The results of such maintenance planning inform *"(A543) Perform Maintenance"* via *A5425* and *A5421* activities. To perform maintenance, maintenance procedure is planned in *A54322* activity which is a sub-activity of *"(A5432) Make Maintenance Execution Plan"*, and inspection and repair are carried out in *A54332* and *A54333* activities of *"(A5433) Execute Maintenance"*. The results of the maintenance execution plan, inspection and repair are stored in *"(A5435) Provide Resources for Maintenance Execution"* together with the result of maintenance execution plan. The stored information is transferred to *"(A7) Provide Resources for Performing Plant-LCE"* activity via activities that are compartmentalized in 'Provide resources' on several hierarchical nodes. The results of maintenance are group into technology and engineering standard in *A7* activity, and are reflected in activities at every hierarchical node. When some defects of technology and/or engineering standard are found, changes are required in upper hierarchical nodes. These changes are decided in the activities categorized as *'Manage'* on several hierarchical nodes. Therefore, the PDCA cycle within and across the hierarchy can be configured, and a *to-be* model for maintenance can be developed.

Fig.9 shows the business process model for *"(A54) Maintain Plant"*. The output information from *'Plan'*, *'Do'* and *'Check'* activities is standardized into *"Requirement of resources and engineering standards"*, *"Change Request"*, *"Progress"* and *"Certified Output"*, and is consistent within the hierarchies. This model can specify the system requirements for development of an environment to support knowledge management for maintenance.

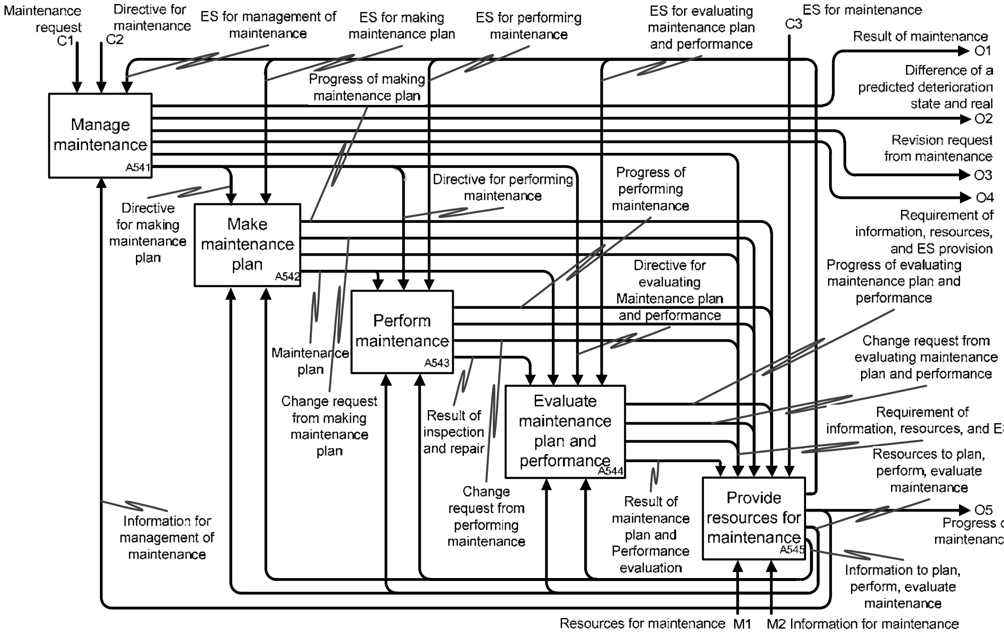


Fig. 9. Business process model for *"(A54) maintain plant"*

4.4 Business process model for PSM

4.4.1 Importance of systematic PSM

PSM is a management system that is focused on prevention of, preparedness for, mitigation of, response to, and restoration from catastrophic releases of chemicals or energy from a process plant. The main purpose of PSM is to maintain the safety of a production plant, and it could be realized by the Plant-LCE as shown in Fig. 10 (Shimada et al., 2010b). Plant development stage includes the periods of research and development (R&D), design, and construction of the facility. The manufacturing stage includes production and maintenance. PSM activities at the design stage are intended to design a safe process plant. Safe facilities are constructed through PSM activities during the construction stage. PSM activities at the maintenance stage are intended to maintain the integrity of the functioning of facilities throughout production. Furthermore, it is important to perform PSM activity in the form of a PDCA cycle, steps such as planning safety countermeasure based on risk assessments, execution of plans, evaluation of outputs and the sharing of process-safety information though the plant-lifecycle. And for the MOC, one of functions in the PSM system, it is also important to make decisions to respond to change by ensuring consistency among activities.

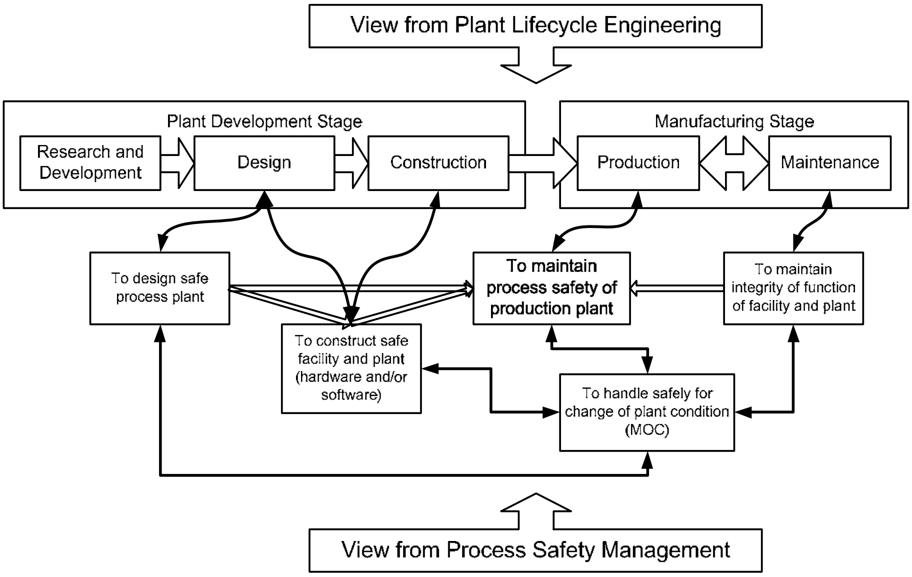


Fig. 10. PSM with plant-LCE

4.4.2 Business process model for PSM with Plant-LCE

Business process model have been developed for PSM. Fig. 11 shows an overview of PSM activities with Plant-LCE. A basic plan for PSM is considered based on a corporation's philosophy as PSM activity at the enterprise-level and PSM activities at the plant-site-level are performed to develop this basic plan. Activities at each level structure the PDCA cycle which clearly specifies planning, execution, evaluation, and improvement. *'Provide resources'* activities are added to clarify the resources needed and to define the environmental conditions it requires.

The business process model for PSM has been developed by extracting the essential activities and ICOM for maintaining process safety of production plant through the plant-lifecycle. Fig. 12 shows top activities of business process model for PSM. This model makes relationships among PSM activities clear. Aside from this model, the glossary and the list of typical tasks of PSM activities are summarized to help a user understand the model for PSM in a tabular form. In this table, resources such as process-safety information and engineering standard needed for accomplishing PSM activities are clearly specified. It becomes possible to understand the meanings and the contents of the activities and the information described in the model. And information sharing on PSM through the Plant-LCE can be achieved.

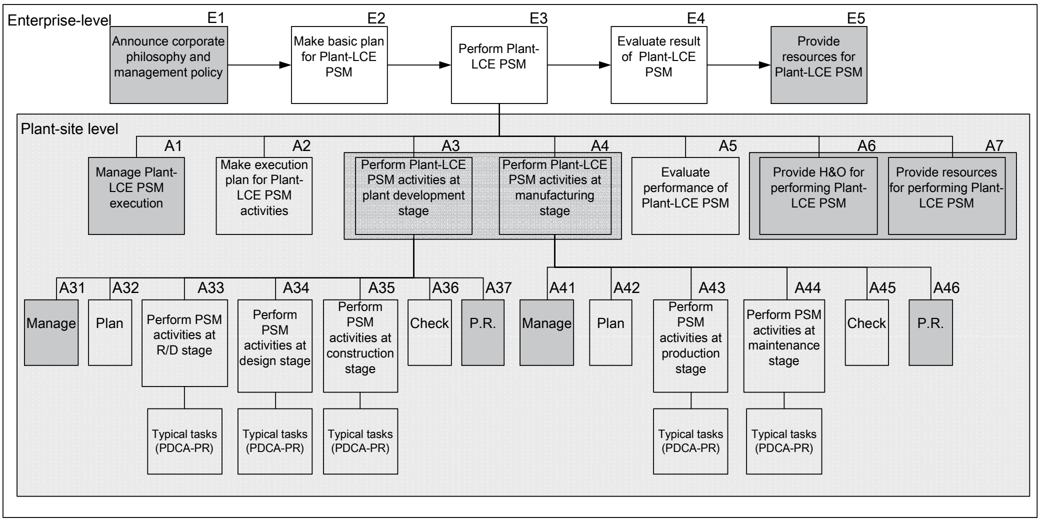


Fig. 11. Overview of PSM activities with plant-LCE

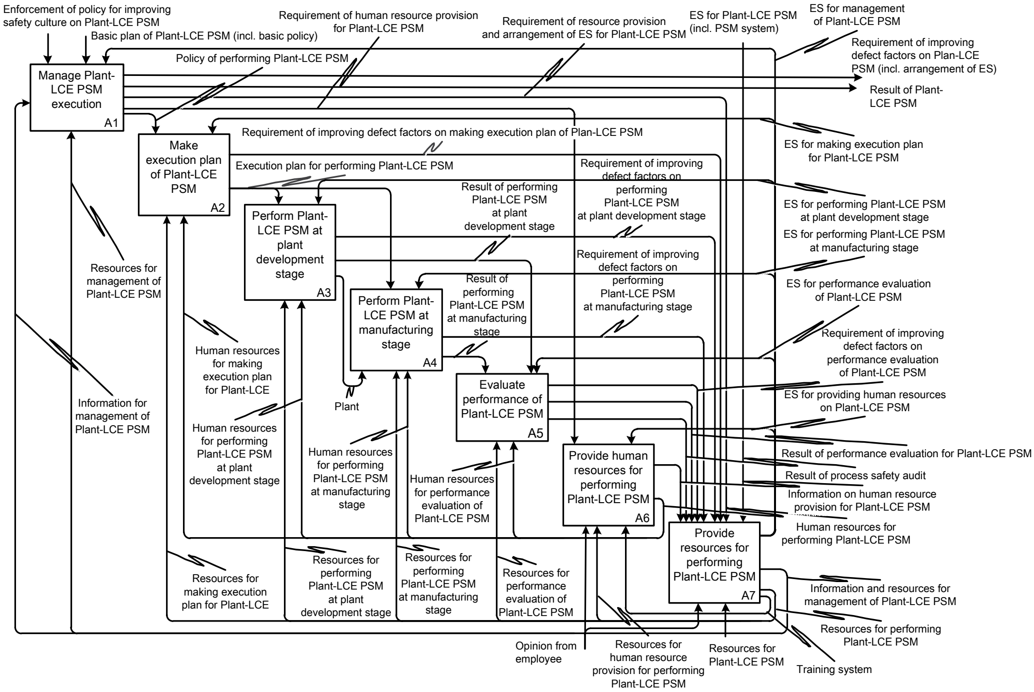


Fig. 12. Top activities of business process model for PSM with plant-LCE

Furthermore, a comprehensive framework structure for the PSM has been based on the business process model for PSM. The position of PSM elements can be defined by the more concrete activities for Plant-LCE. This makes it possible to specify how each PSM element should function in the PSM system. As a result, the proposed PSM framework can be applied to improvement of a company-specific PSM system to match a business's configuration.

To ensure that the PSM business process described above is nothing less than disaster management for the process industry.

5. Application of business process model as a reference model

The business process model clarifies business flow in the form of PDCA cycle and the provision of resources within an IDEF0 format sheet. The hierarchies' relationship between activities represents the superior and subordinate nature of activities. This can make explicitly how concrete activities at plant-site are directed by management and how the reporting of the results of activities generates suggestions for improvement to management. Business process model is used to drive logical and consistent business flow as a reference model. Two examples for actual analysis of problems are offered.

5.1 Derivation of company-specific business flow

The procedure to use the business process model at the plant-site consists of two steps:

1. For a company-specific instance of the business process model, the business flow is rewritten by replacing the generic names of activities and information within the model with real-world activities undertaken in the company.
2. Brainstorming compares the current activities with the business flow. This can expose the problems of management framework as well as those of the activities themselves.

The business flow can be used to analyze various activities. From a safety viewpoint, two types of discussion are enabled:

- Analysis of current activities, discussion of advanced countermeasures and precautionary action to prevent trouble/accidents,
- Identification of root causes of trouble/accidents that have already occurred and discussion of countermeasures to prevent similar troubles/accidents.

With regard to the first view-point, inexplicit problems can be found by comparing current activities with the specific business flow for the individual company. For example, problems such as *"activity of planning is not specified"*, *"environment to share the process-safety information is not developed"*, *"expert workers who have adequate skill for performing the activities are not assigned"*, can be clarified. Resulting safety countermeasures against them can be implemented preliminarily to prevent the troubles/accidents. With regard to the second view-point, root causes such as *"problem on defect of information sharing"*, *"insufficient operator training and improper assignment of personnel"* can be identified and safety countermeasures against them can be implemented to prevent the recurrences of trouble/accidents.

Fig. 13 shows an analysis based on a specific business flow. Specifically, the following points can be seen on it.

- Activities of PDCA cycle and resource provision are performed explicitly with the intents of follows; a) each role of activities of *'Plan'*, *'Do'*, *'Check'*, *'Act'* is clarified and performed certainly as well as the management framework of PDCA cycle is there, and b) provision of resources and information needed to perform the activities of *'Plan'*, *'Do'*, *'Check'*, *'Act'* and management of engineering standard such as technical and management standards are performed.

- Contents of information transferring by performing activities such as the direction for planning and executing activities, the result of performing activities, including information on defect factors are sufficient.
- Necessary resource, information, and engineering standard are provided in the referable form when needed from the *'Provide resources'* activity.

These ensure extraction of the problem on the contents of activity, the way information transfer ought to be, etc.

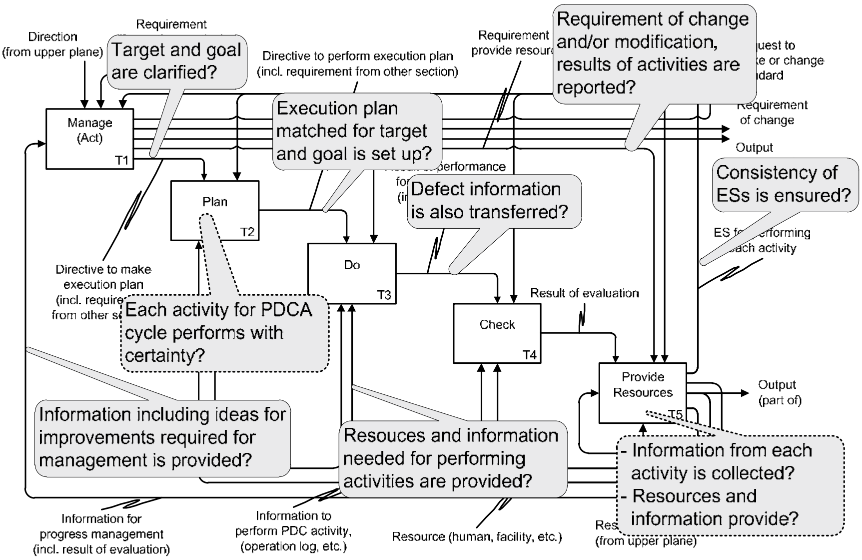


Fig. 13. Activity analysis based on business flow

5.2 Analysis for operation problems

An example of the use of business process model for production from a safety point of view is application for operation problems in *Fuji Oil Company, Ltd.* It is well known that the root causes of operation failures due to human-error include misdirection, lack of communication and information sharing, poor education, lack of technical knowledge, and so on. Business process model for production is used to analyze these root causes of operation accidents that happened on the plant-site.

Business process model is used to clarify the activities that comprise the PDCA cycle and the activities of resource provision. The generic identification of activities and information in the model for production were replaced by the actual activities undertaken in the Fuji Oil Company and other related ICOM was added to develop the specific business flow as an instance of the business process model. Fig. 14 shows a business flow for *'Grade 3 LGO-operation'*. The following points have been examined to identify the root causes of operation problems and to consider the countermeasures to be used in planning for prevention or recurrence.

- Each activity is performed according to engineering standards?
- ICOM is transferred with certainty?

- Performance results of the *'Manage (Act)'*, *'Plan'*, and *'Do'* activities are evaluated at *'Check'* activity?
- Workers are appropriately educated and/or trained?
- Resources including personal assignment were provided sufficiently?
- Other questions as shown in Fig. 13.

As results of them, advantages using business process model for case example have been reported as follows.

- Activities for safety management and/or quality management are not separated with usual manufacturing activities, but should be performed concurrently.
- Developed specific business flow clarifies the activities for *'Plan'*, *'Do'*, *'Check'*, and *'Act'*, and activity improvement based on it lead to implement certainly each activity which has been performed ambiguously in the past.
- It is understandable that the *'Provide resources'* activity is very important and can lead to develop the environment of information sharing.
- Definition of activity based on the model can make the role of organization and human resources clear, and lead the integration or reformation of organization.

These advantages lead to development of the environment of a logical PSM system, including a production support system, a maintenance system, and so on.

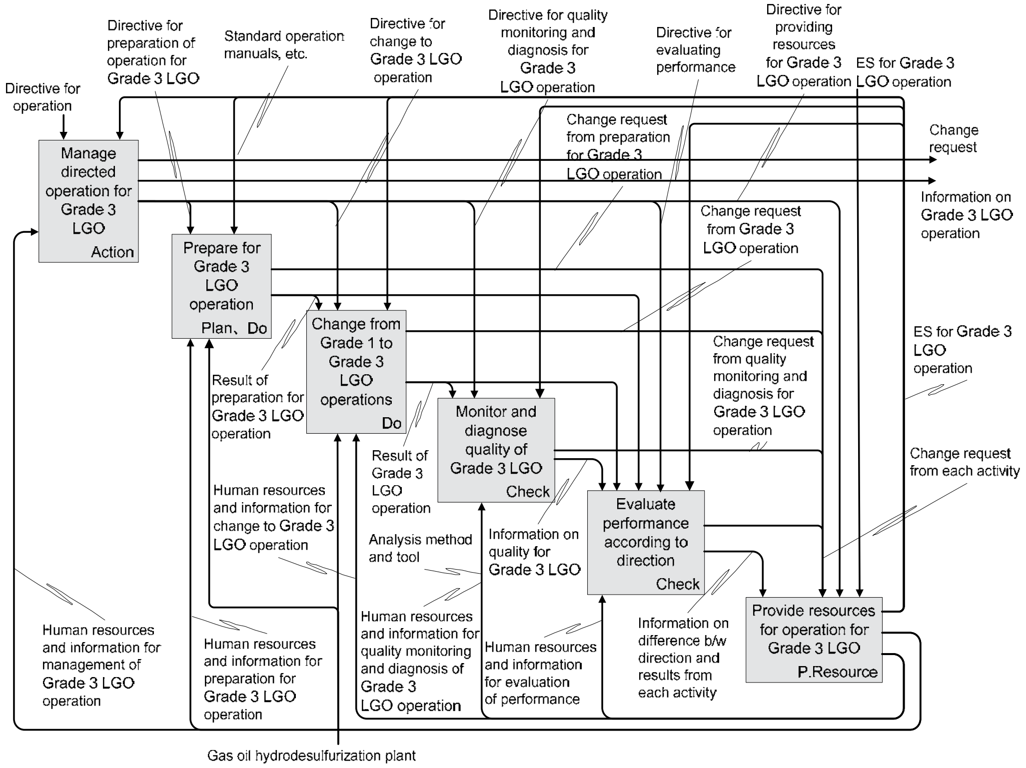


Fig. 14. Case example – A business flow for *'Grade 3 LGO operation'*

5.3 Analysis for maintenance problems

The developed business process model for maintenance is an ideal model to maintain plant-lifecycle safety. If the same mechanism as the model was used to perform maintenance, maintenance problems would not lead to accidents and/or disasters. Therefore, incidents related to maintenance would occur only if there were defects in the maintenance process. To uncover such defects, cases of malfunctions have been followed backward through the ideal business process model.

The incident case to be followed here is:

During shutdown maintenance of process plants, maintenance work for living H_2S service line in offsite facility was planned. The block valve located at downstream of the control valve was to be inspected. The blind plate insertion place, operation for block valves and disposition for the control valve, which were responsible for operation section, were not correct. When the bolts for the block valve flange were released for inspection, H_2S gas was released. Three workers were killed in this incident.

Fig. 15 shows the overview of activities for maintenance. To trace the malfunction backward on the business process model, this overview was used.

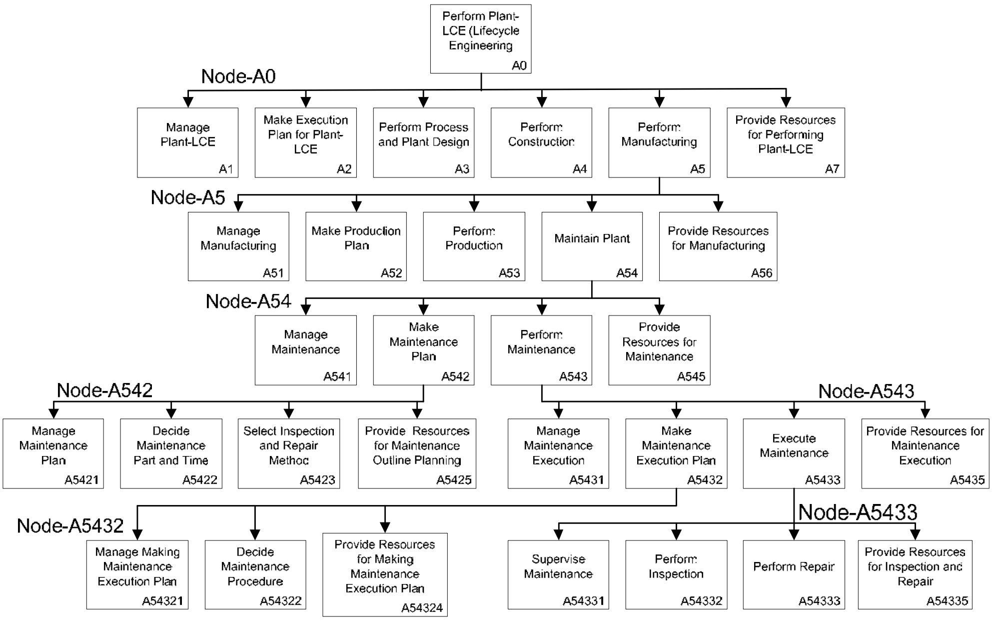
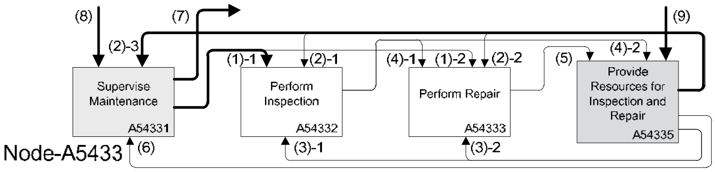
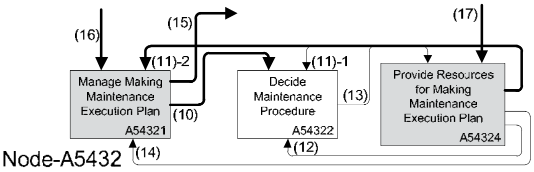


Fig. 15. Overview of activities for "*maintenance*"

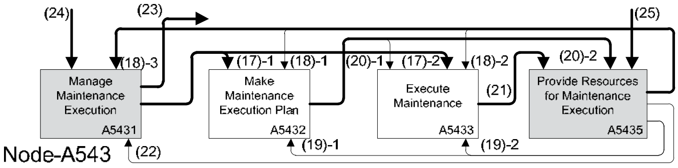
The incident occurred at inspection of the block valve, so that the analysis is started from *A54332* activity of *Node-A5433*. The information within *Node-A5433* is as shown in Fig. 16(a). *A54332* was carried out on the constraint of the directive from *A54331*, so that ICOM (1)-1 was incorrect directive. ICOM (8) included incorrect maintenance execution plan. *A54331* had responsibility for safe sub-directive (ICOM (1)-1), and the responsibility should have been clarified in engineering standard; i.e. ICOM (2)-3 and ICOM (9). *A54335* could not deliver sufficient engineering standard, and *A54331* did not inform change request of



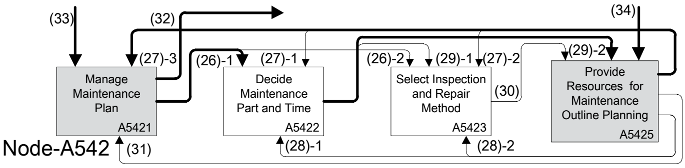
(a) Summarized node-A5433.



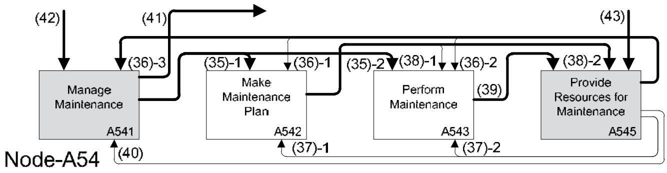
(b) Summarized node-A5432.



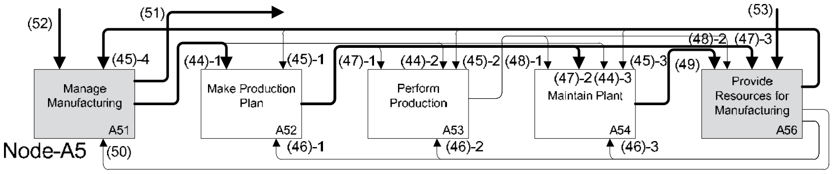
(c) Summarized node-A543.



(d) Summarized node-A542.



(e) Summarized node-A54.



(f) Summarized node-A5.

Fig. 16. Analysis by tracing the business process model for maintenance problems

maintenance execution plan to *A5436* (ICOM (7)). Therefore, the information described with heavy lines should have been incorrect, and the activities painted with gray (*'Manage'* and *'Provide resources'*) should have had error.

The *Node-A5432* is almost same as *Node-A5433* as shown in Fig. 16(b). The directive (ICOM (16)) from *A5431* and the sub-directive ICOM-(10) from *A54321* were incorrect. The ESs from A5435 (ICOM (17)) and from *A54324* (ICOM-(11)-2) were incorrect. *A54321* did not inform change request of maintenance execution plan to *A5435* (ICOM (15)). The information described with heavy lines should have been incorrect, and the activities painted with gray (*'Manage'* and *'Provide resources'*) should have had error.

As same as *Node-A5432* and *Node-A5433*, directive (ICOM (24)), sub-directive (ICOM (17)-1, (17)-2), engineering standard (ICOM (25), (18)-3, (18)-1, (18)-2)), change request (ICOM (20)-2, (21)) were incorrect. The change request (ICOM (23)) did not inform to the upper hierarchical node. Therefore, the information described with heavy lines should have been incorrect, and the activities painted with gray (*'Manage'* and *'Provide resources'*) should have had error as shown Fig. 16(c).

These analyses are continued up to *Node-A0*, and the results are as shown in Figs. 16(d) to (f). The information described with heavy lines should have been incorrect, and the activities painted with gray (*'Manage'* and *'Provide resources'*) should have had error.

This incident is categorized as problem of isolation, and is caused by the error in *"A52 Make Production Plan"* activity. However, it is obvious that it would be possible to prevent the incident, if the *'Manage'* and *'Provide resources'* activities are properly performed.

6. Conclusion

This chapter discussed a business process model of the Plant-LCE with the goal of creating an environment of logical disaster management. The importance of defining the business activities and information flow in the model as a reference model was described. The business process in the form of PDCA cycle throughout the plant-lifecycle as well as at each stage, and resource provision to share the process-safety information and to ensure consistency of engineering standard were also clarified.

Business process models developed for design, production, maintenance, and PSM were summarized. These models systematically showed the universal activities and information flow at each engineering stage. A logical and consistent business flow for each company can be developed by referring to these models. A specific business flow shows the framework, activity, information, etc. that are needed in order to prevent malfunctions and accidents and it is useful for the development of an environment for a systematic PSM. As a result, the number of accidents and hazards due to these defect factors will be reduced.

Further work is needed:

- To consider the practicable business process model for ensuring consistency in engineering standard.
- To consider the metrics for evaluating the result of activities at '*Check*' stage.
- To develop the framework of organization management based on the requirement of the framework of technical management which is represented in the business process model.
- And cases studies should be undertaken to review and consider these issues.

7. Acknowledgment

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8. References

AIChE/CCPS. (2001). *Layer of Protection Analysis*, AIChE/CCPS, ISBN 0-8169-0811-7

AIChE/CCPS. (2007). *Guidelines for Risk Based Process Safety*, WILEY, ISBN 978-0-470-16569-0

Deming, W.E. (2000). *Out of the Crisis*, The MIT Press, ISBN 978-0262541152

Fuchino,T.; Shimada,Y.; Miyazawa,M. & Naka,Y. (2008). Business Process Model for Knowledge Management in Plant Maintenance, *Proceedings of 18th European Symposium on Computer-Aided Process Engineering, ESCAPE-18*, Elsevier, pp.955-960 ISBN 978-0-444-53227-5, Lyon, France, June 1-4, 2008

Fuchino,T.; Shimada,Y.; Kitajima,T. & Naka,Y. (2010). Management of Engineering Standards for Plant Maintenance based on Business Process Model, *Proceedings of 20th European Symposium on Computer Aided Process Engineering, ESCAPE-20,* Elsevier, pp.1363-1368, ISBN 978-0-444-53569-6, Ischia, Italy, June 6 - 9, 2010

Fuchino,T.; Shimada,Y.; Kitajima,T.; Takeda,K.; Batres,R. & Naka,Y. (2011). Business Process Model for Process Design being Conscious of Independent Protection Layer, *Proceedings of 21st European Symposium on Computer Aided Process Engineering, ESCAPE-21*, Elsevier, Part A, pp.326-330, ISBN 978-0-444-53711-9, Chalkidiki, Greece, May 29 – June 1, 2011

IEC. (2003). *IEC 62264-1; 2003 Enterprise-control system integration - Part 1: Models and terminology*

ISA. (2007). *Alarm Management: Seven Effective Methods for Optimum Performance*, Instrumentation, Systems and Automation Society, ISBN 978-1-934394-00-7

NIST. (1993). *Integration Definition for Function Modeling,* Federal Information Processing Standards Publication, 183, National Institution of Standards and Technology, Available from: http://www.itl.nist.gov/fipspubs/idef02.doc.

OSHA, 29CFR 1910.119. (1992). *Process Safety Management of Highly Hazardous Chemicals*

PIEBASE. (1998). *PIEBASE (Process Industries Executive for Achieving Business Advantage using Standards for Data Exchange) Activity Model Executive Summary*, Available from: http://www.posc.org/piebase/

Shimada,Y.; Kitajima,T & Takeda,K. (2009). Practical Framework for Process Safety Management based on Plant Lifecycle Engineering, *Proceedings of 3rd International Conference on Integrity, Reliability & Failures, IRF'2009*, S1707_A0531, pp.501-502, ISBN 978-972-8826-2, Porto, Portugal, July 20 -24, 2009

Shimada,Y.; Kumasaki,M.; Kitajima,T.; Takeda,K.; Fuchino,T. & Naka,Y. (2010a). Reference Model for Safety Conscious Production Management in Chemical Processes, *Proceedings of 13th International Symposium on Loss Prevention and Safety Promotion in the Process Industries*, Vol.1, pp.629-632, ISBN 978-90-76019-291, Brugge, Belgium, June 6 – 9, 2010

Shimada,Y.; Kitajima,T. & Sumida,H. (2010b). Framework for Process Safety Management based on Engineering Activity through Plant Lifecycle, *Proceedings of Mary Kay O'Connor Process Safety Center International Symposium 2010*, pp.874-888, ISBN 978-0-615-38129-9, College Station, Texas, USA, October 26 – 28, 2010

The Council of the European Union. (1996). *Council Directive 96/82/EC of 9 December 1996 on the Control of Major-Accident Hazards involving Dangerous Substances*, Official Journal L 010, pp.13-33 (1997)

3

Hydrologic Data Assimilation

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1. Introduction

Information about hydrologic conditions is of critical importance to real-world applications such as agricultural production, water resource management, flood prediction, water supply, weather and climate forecasting, and environmental preservation. Improved hydrologic condition estimates are useful for agriculture, ecology, civil engineering, water resources management, rainfall-runoff prediction, atmospheric process studies, climate and weather/climate prediction, and disaster management (Houser *et al*. 2004).

While ground-based observational networks are improving, the only practical way to observe the hydrologic cycle on continental to global scales is via satellites. Remote sensing can make spatially comprehensive measurements of various components of the hydrologic system, but it cannot provide information on the entire system (*e.g.* evaporation), and the observations represent only an instant in time. Hydrologic process models may be used to predict the temporal and spatial hydrologic variations, but these predictions are often poor, due to model initialization, parameter and forcing, and physics errors. Therefore, an attractive prospect is to combine the strengths of hydrologic models and observations (and minimize the weaknesses) to provide a superior hydrologic state estimate. This is the goal of hydrologic data assimilation.

Data Assimilation combines observations into a dynamical model, using the model's equations to provide time continuity and coupling between the estimated fields. Hydrologic data assimilation aims to utilize both our hydrologic process knowledge, as embodied in a hydrologic model, and information that can be gained from observations. Both model predictions and observations are imperfect and we wish to use both synergistically to obtain a more accurate result. Moreover, both contain different kinds of information, that when used together, provide an accuracy level that cannot be obtained individually.

Figure 1 illustrates the hydrologic land surface data assimilation challenge to merge the spatially comprehensive remote sensing observations with the dynamically complete but typically poor predictions of a hydrologic Land Surface Model (LSM) to yield the best possible hydrological system state estimation. In this illustration, the LSM is a component of a General Circulation Model (GCM) or Earth System Model (ESM). Model biases can be mitigated using a complementary calibration and parameterization process. Limited point measurements are often used to calibrate the model(s) and validate the assimilation results (Walker and Houser 2005).

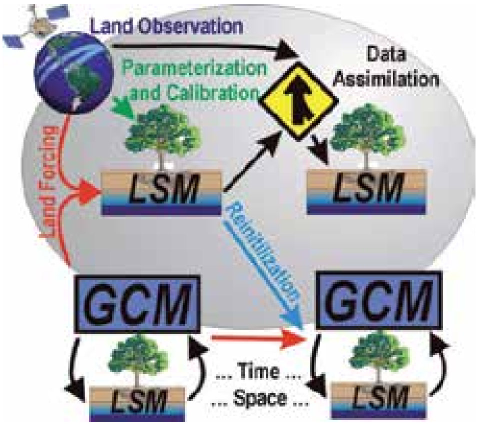

Fig. 1. Schematic description of the data assimilation process in a land surface model coupled to a general circulation model.

In this Chapter, we will first provide background on hydrologic observation, modelling and data assimilation. Next we will discuss various hydrologic data assimilation challenges, and finally conclude with several case studies that use hydrologic data assimilation to address disaster management issues.

2. Background: Hydrologic observations

Remote sensing has transformed our appreciation and modelling of the Earth system over, particularly in the meteorological and oceanographic sciences. However, historically, remote sensing data have not been widely used in land surface hydrology. This can be ascribed to: (i) a lack of focused hydrologic state (water and energy) remote sensing instruments; (ii) insufficient retrieval algorithms for deriving hydrologic information from remote sensing; (iii) a lack of distributed hydrologic models for incorporating remote sensing information; and (iv) a lack of techniques to objectively improve and constrain hydrologic model predictions using remote sensing. Remote sensing observations have been used in hydrologic models in several ways: (i) to assign parameter input data such as soil and land cover properties; (ii) to assign better atmospheric forcing conditions, such as precipitation, (iii) to set model initial conditions data, such as soil moisture; and (iv) as time-varying land state data, such as snow water content, to constrain model predictions.

The historic lack of remotely sensed hydrological missions and observations has been the result of an historical emphasis on meteorological and oceanographic operations and applications, due to the large scientific and mission communities that drive those fields. However, significant progress has been made over the past decade on defining hydrologically-relevant remote sensing observations through focused ground and airborne field studies. Gradually, remotely-sensed hydrological data are becoming available; land surface skin temperature and snow cover data have been available for many years, and satellite precipitation data are becoming available at increasing space and time resolutions. In addition, land cover/use maps, vegetation parameters (photosynthesis, structure, etc.), and snow observations of increasing sophistication are becoming available from a number of sensors. Novel observations such as saturated fraction and soil moisture changes, evapotranspiration, water level and velocity (*i.e.*, runoff), and changes in total terrestrial water storage are also being developed. Furthermore, near-surface soil moisture, a parameter shown to play a critical role in weather, climate, agriculture, flood, and drought processes, is currently available from non-ideal sensor configuration observations. Moreover, two missions targeted at measuring near-surface soil moisture with ideal sensor configuration are expected before the end of the decade (SMOS and SMAP; see Table 1).

Class	**Observation**	**Ideal Technique**	**Ideal Time Scale**	**Ideal Space Scale**	**Currently available data**
Parameters	Land cover/change	optical/IR	daily or changes	1km	AVHRR, MODIS, NPOESS
	Leaf area & greenness	optical/IR	daily or changes	1km	AVHRR, MODIS, NPOESS
	Albedo	optical/IR	daily or changes	1km	MODIS, NPOESS
	Emissivity	optical/IR	daily or changes	1km	MODIS, NPOESS
	Vegetation structure	lidar	daily or changes	100m	ICESAT
	Topography	in-situ survey, radar	changes	1m–1km	GTOPO30, SRTM
Forcings	Precipitation	microwave/IR	hourly	1km	TRMM, GPM, SSMI, GEO-IR, NPOESS
	Wind profile	Radar	hourly	1km	QuickSCAT
	Air humidity & temp	IR, microwave	hourly	1km	TOVS, AIRS, GOES, MODIS, AMSR
	Surface solar radiation	optical/IR	hourly	1km	GOES, MODIS, CERES, ERBS
	Surface LW radiation	IR	hourly	1km	GOES, MODIS, CERES, ERBS
States	Soil moisture	microwave, IR change	daily	1km	SSMI, AMSR, SMOS, NPOESS, TRMM
	Temperature	IR, in-situ	hourly-monthly	1km	IR-GEO, MODIS, AVHRR, TOVS
	Snow cover or SWE	optical, microwave	daily or changes	10m-100m	SSMI, MODIS, AMSR, AVHRR, NPOESS
	Freeze/thaw	radar	daily or changes	10m-100m	Quickscat, IceSAT, CryoSAT
	Ice cover	radar, lidar	daily or changes	10m-100m	IceSAT, GLIMS
	Inundation	optical/microwave	daily or changes	100m	MODIS
	Total water storage	gravity	changes	10km	GRACE
Fluxes	Evapotranspiration	optical/IR, in-situ	hourly	1km	MODIS, GOES
	Streamflow	microwave, laser	hourly	1m-10m	ERS2, TOPEX / POSEIDON, GRDC
	Carbon flux	In-situ	hourly	1km	In-situ
	Solar radiation	optical, IR	hourly	1km	MODIS, GOES, CERES, ERBS
	Longwave radiation	optical, IR	hourly	1km	MODIS, GOES
	Sensible heat flux	IR	hourly	1km	MODIS, ASTER, GOES

Table 1. Characteristics of remotely sensed hydrological observations potentially available within the next decade.

3. Background: Hydrologic modelling

Advances in understanding of soil-water dynamics, plant physiology, micrometeorology and the hydrology that control biosphere-atmosphere interactions have spurred the development of hydrologic Land Surface Models (LSMs), whose aim is to represent simply, yet realistically, the transfer of mass, energy and momentum between a vegetated surface and the atmosphere (Sellers et al., 1986). LSM predictions are regular in time and space, but these predictions are influenced by errors in model structure, input variables, parameters and inadequate treatment of sub-grid scale spatial variability. These models are built upon the analysis of signals entering and leaving the system; they predict relationships between physical system variables as a solution of mathematical structures, like simple algebraic equations or differential equations. Hydrologic processes are part of the total of global processes controlling the earth, which are typically represented in global general circulation models (GCMs). The major state variables of these models include the water content and temperature of soil moisture, snow and vegetation. Changes in these state variables account for fluxes, *e.g.*, evapotranspiration or runoff. Recently, coupling of hydrological models with vegetation models has received some attention, to serve more specific ecological, biochemical or agricultural purposes.

Most LSMs used in GCMs view the soil column as the fundamental hydrological unit, ignoring the role of topography on spatially variable processes (Stieglitz *et al.* 1997) to limit the complexity and computations for these coupled models. Increasingly, LSMs are being built with a higher degree of complexity in order to better represent hydrologic atmosphere interactions within GCMs or to meet the need for local state and process knowledge for use in conservation or agricultural management. This includes the treatment of more biological processes, the representation of subgrid heterogeneity and the development of spatially distributed or gridded models. Improved process representation should result in parameters that are easier to measure or estimate. However, more complex process representations results in more parameters to be estimated, and may lead to over-parameterized given the data available for parameter calibration.

Model calibration relies on observed data and can be defined as a specific type of data assimilation, as its goal is to minimize model bias using observations. For large scale hydrologic modelling, full calibration is nearly impossible. Some examples of widely used LSMs are the NCAR Community Land Model (CLM), the Princeton/U. Washington Variable Infiltration Capacity Model (VIC), and the NOAA-Noah Model.

4. Background: Hydrologic data assimilation

Charney *et al.* (1969) first suggested combining current and past data in an explicit dynamical model, using the model's prognostic equations to provide time continuity and dynamic coupling amongst the fields. This concept has evolved into a family of techniques known as data assimilation. In essence, hydrologic data assimilation aims to utilize both our hydrological process knowledge as embodied in a hydrologic model, and information that can be gained from observations. Both model predictions and observations are imperfect and we wish to use both synergistically to obtain a more accurate result. Moreover, both contain different kinds of information, that when used together, provide an accuracy level that cannot be obtained when used separately.

For example, a hydrological model provides spatial and temporal near-surface and root zone soil moisture information at the model resolution, including error estimates. On the other hand, remote sensing observations contain near-surface soil moisture information at an instant in time, but do not give the temporal variation or the root zone moisture content. While the remote sensing observations can be used as initialization input for models or as independent evaluation, providing we use a hydrological model that has been adapted to use remote sensing data as input, we can use the hydrological model predictions and remote sensing observations together to keep the simulation on track through data assimilation (Kostov and Jackson 1993). Moreover, large errors in near-surface soil moisture content prediction are unavoidable because of its highly dynamic nature. Thus, when measured soil moisture data are available, their use to constrain the simulated data should improve the soil moisture profile estimate, provided that an update in the upper layer is well propagated to deeper layers.

Data assimilation techniques were established by meteorologists (Daley 1991) and have been used very successfully to improve operational weather forecasts. Data assimilation has also been successfully used in oceanography (Bennett 1992) for improving ocean dynamics prediction. However, hydrological data assimilation has a smaller number of case studies demonstrating its utility and has very distinct features compared to atmospheric or oceanographic assimilation. Hydrological data assimilation development has been accelerated by building on knowledge derived from the meteorological and oceanographic data assimilation, with significant recent advancement and increased interdisciplinary interaction.

Hydrologic data assimilation progress has been primarily limited by a lack of suitable large-domain observations. With the introduction of new satellite sensors and technical advances, hydrologic data assimilation research directions are changing (Margulis *et al.* 2006). Walker *et al.* (2003) gave a brief history of hydrological data assimilation, focusing on the use and availability of remote sensing data, and stated that this research field is still in its “infancy”. Walker and Houser (2005) gave an overview of hydrological data assimilation, discussing different data assimilation methods and several case studies in hydrology. van Loon and Troch (2001) gave a review of hydrological data assimilation applications and added a discussion on the challenges facing future hydrological applications. McLaughlin (1995) reviewed some developments in hydrological data assimilation and McLaughlin (2002) transferred the options of interpolation, smoothing and filtering for state estimation from the engineering to hydrological sciences.

Soil moisture and soil temperature have been the most studied variables for hydrologic model estimation, because of their well-known impact on weather forecasts (Zhang and Frederiksen 2003; Koster *et al.* 2004) and climate predictions (Dirmeyer 2000). Besides these variables, also snow and vegetation properties have received attention. Hydrologic state variables are highly variable in all three space dimensions, so a complete and detailed assessment of these variables is a difficult task. Therefore, most studies have focused on data assimilation in one or two dimensions (*e.g.* soil moisture profiles or single layer fields) and/or relatively simple models.

Data assimilation was meant for state estimation, but in the broadest sense, data assimilation refers to any use of observational information to improve a model (WMO 1992). Basically, there are four methods for “model updating”, as follows:

- **Input:** corrects model input forcing errors or replaces model-based forcing with observations, thereby improving the model's predictions;
- **State:** corrects the state or storages of the model so that it comes closer to the observations (state estimation, data assimilation in the narrow sense);
- **Parameter:** corrects or replaces model parameters with observational information (parameter estimation, calibration);
- **Error correction:** correct the model predictions or state variables by an observed time-integrated error term in order to reduce systematic model bias (*e.g.* bias correction).

The data assimilation challenge is: given a (noisy) model of the system dynamics, find the best estimates of system states from (noisy) observations. Most current approaches to this problem are derived from either the direct observer (*i.e.*, sequential filter) or dynamic observer (*i.e.*, variational through time) techniques. Figure 2 illustrates schematically the key differences between these two approaches to data assimilation. To help the reader through the large amount of jargon typically associated with data assimilation, a list of terminology has been provided (Table 2).

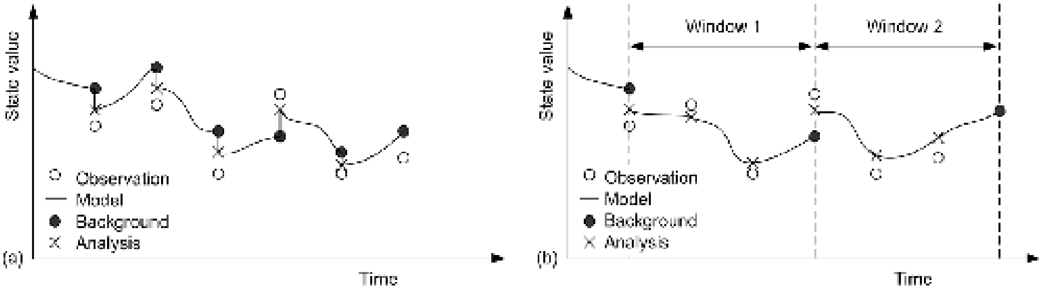

Fig. 2. Schematic of the (a) direct observer and (b) dynamic observer assimilation approaches.

State	condition of a physical system, e.g. soil moisture
State error	deviation of the estimated state from the truth
Prognostic	a model state required to propagate the model forward in time
Diagnostic	a model state/flux diagnosed from the prognostic states – not required to propagate the model
Observation	measurement of a model diagnostic or prognostic
Covariance matrix	describes the uncertainty in terms of standard deviations & correlations
Prediction	model estimate of states
Update	correction to a model prediction using observations
Background	forecast, prediction or state estimate prior to an update
Analysis	state estimate after an update
Innovation	observation-prediction, a priori residual
Gain matrix	correction factor applied to the innovation
Tangent linear model	linearized (using Taylor's series expansion) version of a non-linear model
Adjoint	operator allowing the model to be run backwards in time

Table 2. Commonly used data assimilation terminology.

Data assimilation has significant benefits beyond the improved state estimates, as follows (adapted from Rood *et al.* 1994).

- **Organizes:** By interpolating information from observation space to model space, the observations are organized and given dynamical consistency with the model equations, thereby enhancing their usefulness;
- **Supplements:** By constraining the model's physical equations with observations, unobserved quantities can be better estimated, providing a more complete understanding of the true hydrological system;
- **Complements:** By propagating information using observed spatial and temporal correlations, or the model's physical relationships, areas of sparse observations can be better estimated;
- **Quality control:** By comparing observations with previous forecasts, spurious observations can be identified and eliminated. By performing this comparison over time, it is possible to calibrate observing systems and identify biases or changes in observation system performance;
- **Hydrological model improvement:** By continuously confronting the model with real observations, model weaknesses and systematic errors can be identified and corrected.

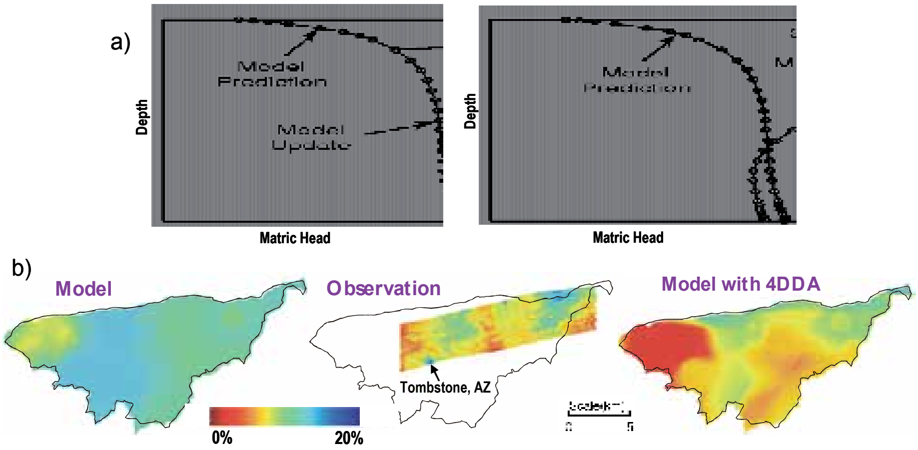

Fig. 3. Example of how data assimilation supplements data and complements observations: a) Numerical experiment results demonstrating how near-surface soil moisture measurements are used to retrieve the unobserved root zone soil moisture state using (left panel) direct insertion and (right panel) a statistical assimilation approach (Walker et al. 2001a); b) Six Push Broom Microwave Radiometer (PBMR) images gathered over the USDA-ARS Walnut Gulch Experimental Watershed in southeast Arizona were assimilated into the TOPLATS hydrological model using several alternative assimilation procedures (Houser et al. 1998). The observations were found to contain horizontal correlations with length scales of several tens of km, thus allowing soil moisture information to be advected beyond the area of the observations.

5. Hydrologic data assimilation techniques

Direct insertion. One of the earliest and most simplistic approaches to data assimilation is direct insertion. As the name suggests, the forecast model states are directly replaced with the observations. This approach makes the explicit assumption that the model is wrong (has no useful information) and that the observations are right, which both disregards important information provided by the model and preserves observational errors. The risk of this approach is that unbalanced state estimates may result, which causes model shocks: the model will attempt to restore the dynamic balance that would have existed without insertion. A further key disadvantage of this approach is that model physics are solely relied upon to propagate the information to unobserved parts of the system (Houser *et al.* 1998; Walker *et al.* 2001a).

Statistical correction. A derivative of the direct insertion approach is the statistical correction approach, which adjusts the mean and variance of the model states to match those of the observations. This approach assumes the model pattern is correct but contains a non-uniform bias. First, the predicted observations are scaled by the ratio of observational field standard deviation to predicted field standard deviation. Second, the scaled predicted observational field is given a block shift by the difference between the means of the predicted observational field and the observational field (Houser *et al.* 1998). This approach also relies upon the model physics to propagate the information to unobserved parts of the system.

Successive correction. The successive corrections method (SCM) was developed by Bergthorsson and Döös (1955) and Cressman (1959), and is also known as observation nudging. The scheme begins with an *a priori* state estimate (background field) for an individual (scalar) variable, which is successively adjusted by nearby observations in a series of scans (iterations, n) through the data. The analysis at time step k is found by passing through a sequence of updates.

The advantage of this method lies in its simplicity. However, in case of observational error or different sources (and accuracies) of observations, this scheme is not a good option for assimilation, since information on the observational accuracy is not accounted for. Mostly, this approach assumes that the observations are more accurate than model forecasts, with the observations fitted as closely as is consistent. Furthermore, the radii of influence are user-defined and should be determined by trial and error or more sophisticated methods that reduce the advantage of its simplicity. The weighting functions are empirically chosen and are not derived based on physical or statistical properties. Obviously, this method is not effective in data sparse regions. Some practical examples are discussed by Bratseth (1986) and Daley (1991).

Analysis correction. This is a modification to the successive correction approach that is applied consecutively to each observation s from 1 to s_f as in Lorenc *et al.* (1991). In practice, the observation update is mostly neglected and further assumptions make the update equation equivalent to that for optimal interpolation (Nichols 1991).

Nudging. Nudging or Newtonian relaxation consists of adding a term to the prognostic model equations that causes the solution to be gradually relaxed towards the observations. Nudging is very similar to the successive corrections technique and only differs in the fact that through the numerical model the time dimension is included. Two distinct approaches have been developed (Stauffer and Seaman 1990). In analysis nudging, the nudging term for a given variable is proportional to the difference between the model simulation at a given grid point and an "analysis" of observations (*i.e.*, processed observations) calculated at the corresponding grid point. For observation nudging, the difference between the model simulation and the observed state is calculated at the observation locations.

Optimal interpolation. The optimal interpolation (OI) approach, sometimes referred to as statistical interpolation, is a minimum variance method that is closely related to kriging. OI approximates the "optimal" solution often with a "fixed" structure for all time steps, given by prescribed variances and a correlation function determined only by distance (Lorenc 1981). Sometimes, the variances are allowed to evolve in time, while keeping the correlation structure time-invariant.

3-D variational. This approach directly solves the iterative minimization problem given (Parrish and Derber 1992). The same approximation for the background covariance matrix as in the optimal interpolation approach is typically used.

Kalman filter. The optimal analysis state estimate for linear or linearized systems (Kalman or Extended Kalman filter, EKF) can be found through a linear update equation with a Kalman gain that aims at minimizing the analysis error (co)variance of the analysis state estimate (Kalman 1960). The essential feature which distinguishes the family of Kalman filter approaches from more static techniques, like optimal interpolation, is the dynamic updating of the forecast (background) error covariance through time. In the traditional Kalman filter (KF) approach this is achieved by application of standard error propagation theory, using a (tangent) linear model. (The only difference between the Kalman filter and the Extended Kalman filter is that the forecast model is linearized using a Taylor series expansion in the latter; the same forecast and update equations are used for each approach.)

A further approach to estimating the state covariance matrix is the Ensemble Kalman filter (EnKF). As the name suggests, the covariances are calculated from an ensemble of state forecasts using the Monte Carlo approach rather than a single discrete forecast of covariances (Turner *et al.* 2007).

Reichle *et al.* (2002b) applied the Ensemble Kalman filter to the soil moisture estimation problem and found it to perform as well as the numerical Jacobian approximation approach to the Extended Kalman filter, with the distinct advantage that the error covariance propagation is better behaved in the presence of large model non-linearities. This was the case even when using only the same number of ensembles as required by the numerical approach to the Extended Kalman filter.

4D-Var. In its pure form, the 4-D (3-D in space, 1-D in time) "variational" (otherwise known as Gauss-Markov) dynamic observer assimilation methods use an adjoint to efficiently compute the derivatives of the objective function with respect to each of the initial state vector values. Solution to the variational problem is then achieved by minimization and iteration. In practical applications the number of iterations is usually constrained to a small number. While "adjoint compilers" are available for automatic conversion of the non-linear forecast model into a tangent linear model, application of these is not straightforward. It is best to derive the adjoint at the same time as the model is developed.

Given a model integration with finite time interval, and assuming a perfect model, 4D-Var and the Kalman filter yield the same result at the end of the assimilation time interval. Inside the time interval, 4D-Var is more optimal, because it uses all observations at once (before and after the time step of analysis), *i.e.*, it is a smoother. A disadvantage of sequential methods is the discontinuity in the corrections, which causes model shocks. Through variational methods, there is a larger potential for dynamically based balanced analyses, which will always be situated within the model climatology. Operational 4D-Var assumes a perfect model: no model error can be included. With the inclusion of model error, coupled equations are to be solved for minimization. Through Kalman filtering it is in general simpler to account for model error.

Both the Kalman filter and 3D/4D-Var rely on the validity of the linearity assumption. Adjoints depend on this assumption and incremental 4D-Var is even more sensitive to linearity. Uncertainty estimates via the Hessian are critically dependent on a valid linearization. Furthermore, with variational assimilation it is more difficult to obtain an estimate of the quality of the analysis or of the state's uncertainty after updating.

6. Assimilation of hydrologic observations

Estimation of the hydrologic state has mainly been focused on soil moisture, snow water content, and temperature. The observations used to infer state information range from direct field measurements of these quantities to more indirectly related measurements like radiances or backscatter values in remote sensing products. A few studies have also tried to assimilate state-dependent diagnostic fluxes, like discharge or remotely sensed heat fluxes. The success of assimilation of observations which are indirectly related to the state is largely dependent on a good characterization of the observation operator. This section presents examples of research in hydrologic data assimilation, but is not intended to be a comprehensive review.

Truly optimal data assimilation techniques require flawless model and observation error characterization. Therefore, recent studies have focused on the first and second order error characterization in hydrologic modelling. Typically, either model predictions or observations are biased. Studies by Reichle and Koster (2004), Bosilovich *et al.* (2007) and De Lannoy *et al.* (2007a, b) scratch the surface of how to deal with these hydrologic modelling biases. The second order error characterization is of major importance to optimize the analysis result and for the propagation of information through the system. Tuning of the error covariance matrices has, therefore, gained attention with the exploration of adaptive filters in hydrologic modelling (Reichle *et al.* 2008; De Lannoy *et al.* 2009).

Furthermore, it is important to understand that hydrologic data assimilation applications are dealing with non-closure or imbalance problems, caused by external data assimilation for state estimation. In a first attempt to attack this problem, Pan and Wood (2006) developed a constrained Ensemble Kalman filter which optimally redistributes any imbalance after conventional filtering. They applied this technique over a 75,000 km^2 domain in the US, using the terrestrial water balance as constraint.

7. Case studies

Significant advances in hydrological data assimilation have been made over the past decade from which we have selected a few case studies to demonstrate the utility of hydrological data assimilation in hazard prediction and mitigation.

7.1 Case study 1: Assimilation of water level observations

By providing predictions of flood hazard and risk over increasing lead-times, flood inundation models play a central role in advanced hydro-meteorological forecasting systems. As the cost of damage caused by flooding is highly dependent on the warning time given before a storm event, the reduction of its predictive uncertainties has received a great deal of attention by researchers in recent years (e.g., Montanari et al., 2009, Biancamaria et al., 2010). The predictive uncertainty originates from several causes interacting between each other, namely input uncertainty (i.e. inflows), model structure and parameter uncertainty. The predictive uncertainty can be reduced through a periodical updating of computed water surface lines by taking advantage of water level measurements. However, ground based data are spatially rather limited, numbers of hydrometric stations are in decline at a global scale and major parts of the world still remain largely ungauged to this date. Recent developments in remotely sensing-based measurement techniques potentially help overcoming data scarcity. For instance, the technique of water stage retrievals from satellite measurements with centimeter-scale accuracy (e.g. Alsdorf et al., 2007) can be seen as a promising alternative to hydrometric station data.

Matgen et al. (2010) demonstrated that the real-time assimilation of remote sensing-derived water elevation into 1D hydraulic models via a Particle Filter enables the correction of water depth from a corrupted hydraulic model. In their synthetic experiments they found that significant model improvements could be achieved with observation error standard deviations up to 5 m. Another interesting result from their synthetic experiments is the realization that it is crucial to adjust the fluxes at the upstream boundaries of the model in order to significantly and persistently improve the hydraulic model. In river hydraulics, the process time scale is relatively short, so that stock updates have a limited lifetime. As in Andreadis et al. (2007), the research of Matgen et al. (2010) has clearly demonstrated that because of the dominating effect of the upstream boundary condition merely updating the state variable of the model (water level and hence water storage), only improves the model forecast over a very short time horizon. Model predictions rapidly degrade after updating if the forcing data are not consistent with observed water levels. Updating the uncertain upstream boundary condition leads to more persistent model improvement.

Giustarini et al. (2011) recently tested the methodology with real event data using water level data obtained from ERS-2 SAR and ENVISAT ASAR during the January 2003 flood of the Alzette River (Grand-Duchy of Luxembourg). The retrieval of water elevation data from SAR is based on three steps (see Hostache et al., 2009 for a detailed description of the method). First, the flood extension limits with their respective geolocation uncertainty are derived from a SAR image using a radiometric thresholding-based procedure. Next, the resulting uncertain flood extent limits are superimposed on a digital elevation model (DEM) in order to estimate local water levels. The method takes into account the uncertainty stemming from the underlying DEM. The water level information is obtained as model cross-section specific intervals of the possible local water level. In the last step, the intervals of water levels are hydraulically constrained in order to reduce the estimation uncertainty (see Figure 4). The Particle Filter-based assimilation scheme consists in having a single particle with water levels at all cross sections as state vector. Hence, the likelihood that is computed for each particle is derived from its ability to correctly predict water levels along the entire river reach. In order to overcome the problem of non-persistent model improvements, the forcing of the hydraulic model is updated as well, using information on model error that is obtained during the analysis cycle. The approach works well if inflows are the main source of error in hydraulic modelling. However, when model behavior is non-uniform across the model domain, it is preferred to have the Particle Filter assign a separate particle set to each cross-section. Giustarini et al. (2011) further conclude that the analysis step is of major importance for carrying out an efficient inflow correction over many time steps as errors in the analysis will propagate through the inflow correction model, thereby potentially degrading the skill of the forecasts. The data assimilation experiments show the potential of remote sensing-derived water level data for persistently improving model predictions over many time steps (see Figure 5).

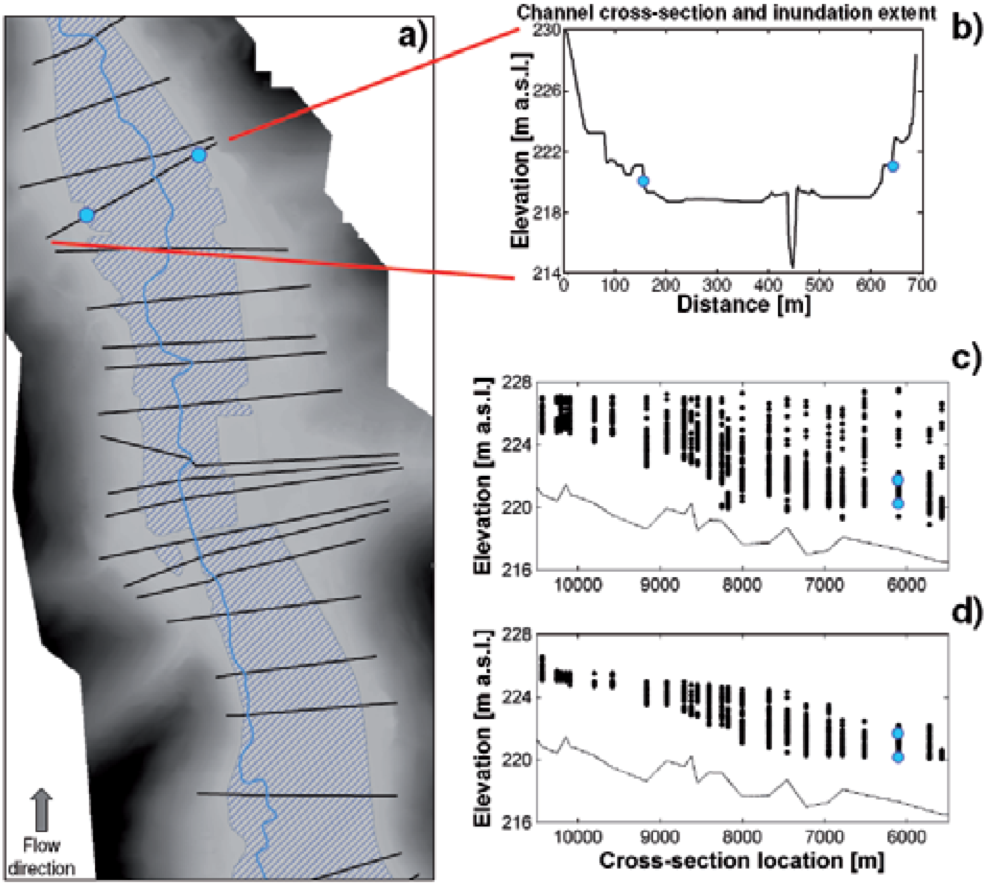

Fig. 4. Diagram showing an example of: (a) flood extent derived from a satellite image superimposed on the DEM and the river cross-section location, (b) illustration of water level values extracted for a given cross-section and c) the remote sensing-derived water elevation along a portion of stream (c) before and (d) after applying the hydraulic coherence constrain.

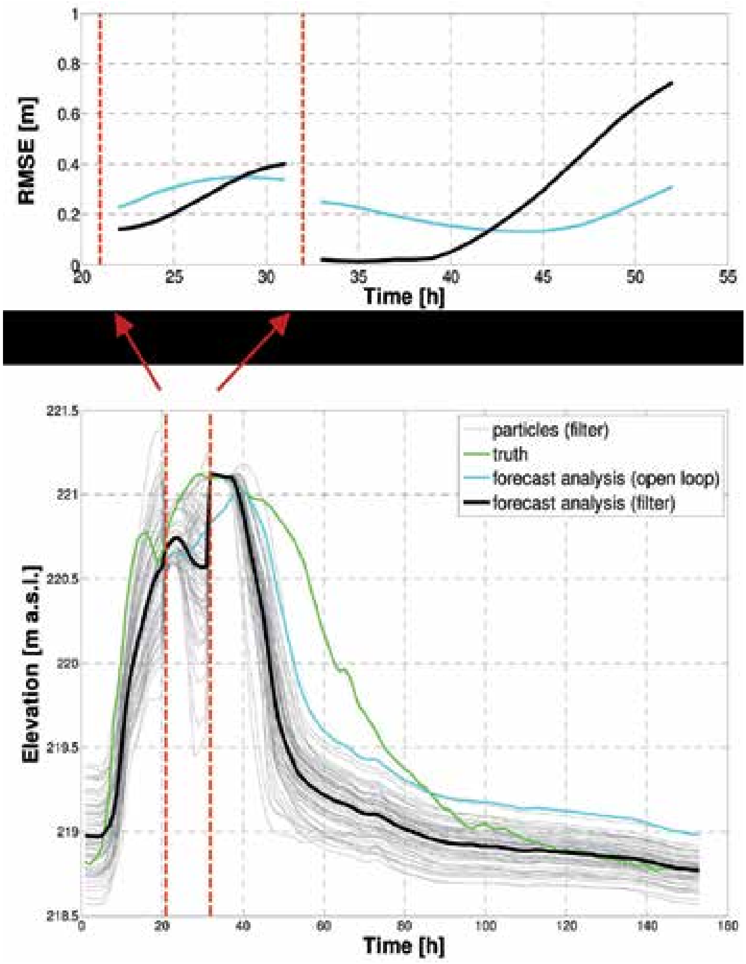

Fig. 5. Stage hydrographs at one river cross-section before and after assimilating remote sensing-derived water level intervals from two SAR images into the 1D hydraulic model (bottom panel). The forecasting performance is evaluated with the RMSE evolution in time (top panel). The cyan line represents the RMSE before assimilation and the black line displays the RMSE after assimilation.

7.2 Case study 2: Assimilation of snow water equivalent and snow cover fraction

Snowmelt runoff is of major importance to summer water supplies, and plays a considerable role in mid-latitude flood events. Snow alters the interface between the atmosphere and the land surface through its higher albedo and lower roughness compared to snow-free conditions, and by thermally insulating the soil from the atmosphere. Consequently, the presence of snow strongly affects the land surface water and energy balance, weather and climate. Moreover, snow has a high spatial and temporal variability which is very sensitive to global change.

Numerical simulation of snow processes is far from perfect (Slater et al., 2001), therefore snow data assimilation could provide a more accurate estimate of snow conditions. Satellite-based snow cover fraction (SCF) observations are available using visible and near-infrared measurements from sensors like the Moderate Resolution Imaging Spectroradiometer (MODIS, 2000 - present). While accurate, these observations have limitations (Dong and Peters-Lidard, 2010), such as the inability to see through clouds. Additionally, SCF observations only provide a partial estimate of the snow state, namely snow cover; in contrast, hydrologic modeling uses snow water equivalent (SWE, snow mass), so snow depletion curves are used to imperfectly translate SCF to SWE. These SCF issues can be overcome using SWE observations derived from passive microwave observations such as the Scanning Multichannel Microwave Radiometer (SMMR, 1978 − 1987), Special Sensor Microwave Imager (SSM/I, 1987-present) and Advanced Microwave Scanning Radiometer for the Earth Observing System (AMSR-E, 2002-present). These sensors do not suffer from cloud obscuration and allow SWE estimation by relating the microwave brightness temperature to snow parameters, but typically have a much coarser resolution and low precision (Dong et al., 2005).

Therefore, an improved snow analyses can be expected by combining the strengths of different snow observations and models. De Lannoy et al. (2011) examined the possibilities and limitations of assimilating both fine-scale MODIS SCF and coarse-scale AMSR-E SWE retrievals into the Noah LSM using an EnKF. Eight years (2002−2010) of remotely sensed AMSR-E snow water equivalent (SWE) retrievals and MODIS snow cover fraction (SCF) observations were assimilated into the Noah LSM over a domain in Northern Colorado using a multi-scale ensemble Kalman filter (EnKF), combined with a rule-based update. De Lannoy et al., 2011 discuss several experiments: (a) ensemble open loop without assimilation (EnsOL); (b) assimilation of coarse-scale AMSR-E SWE observations (SWE DA); (c) assimilation of fine-scale MODIS SCF observations (SCF DA), which involves a mapping from SCF to SWE; and (d) joint, multi-scale assimilation of AMSR-E SWE and MODIS SCF observations (SWE & SCF DA).

Figure 6 illustrates the spatial patterns of the satellite observations, the EnsOL estimates, and the assimilation estimates (without scaling) for a few representative days during the winter of 2009-2010. For this winter, the model and satellite observations have a similar SWE magnitude and no explicit bias-correction is needed to interpret the spatial patterns. The 3D filter performs a downscaling of the coarse AMSR-E SWE observations and shows a realistic fine-scale variability driven by the land surface model integration (De Lannoy et al., 2010). For example, high elevations maintain SWE values well above the observed AMSR-E SWE, which would not be the case if the AMSR-E pixels were a priori partitioned and assimilated with a 1D filter. Furthermore, areas without observations (swath effects) are updated through spatial correlations in the forecast errors. The 1D SCF filter imposes the fine-scale MODIS-observed variability, and locations without fine-scale observations (due to clouds) are not updated. The combined SWE and SCF assimilation shows features of both the SWE and SCF assimilation integrations. Assimilation and downscaling of coarse-scale AMSR-E SWE as well as MODIS SCF assimilation maintain realistic spatial patterns in the SWE analyses.

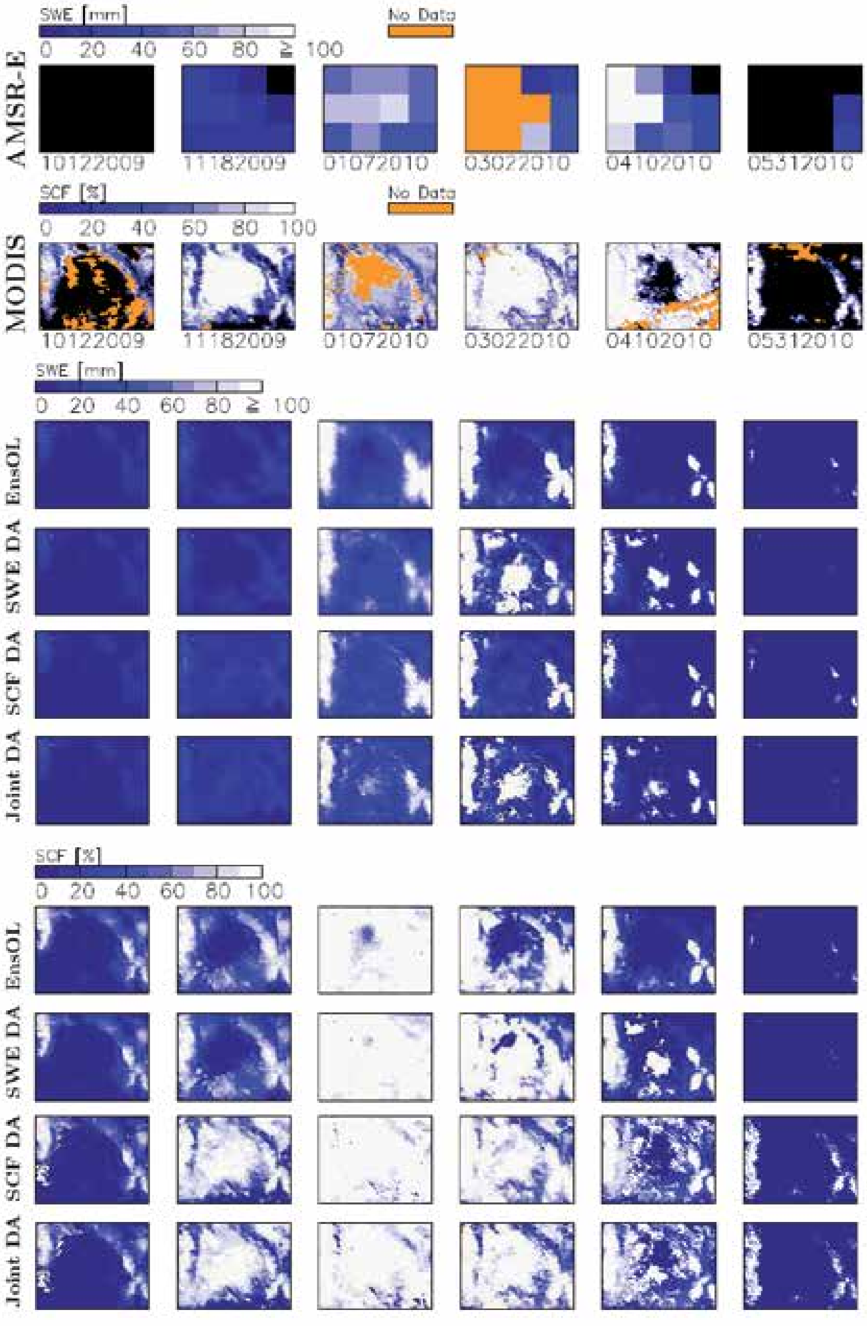

Fig. 6. SWE (at 8:00 UTC) and SCF (at 17:00 UTC) fields at 5 days in the winter of 2009-2010. The top 2 series show the assimilated observations, the other plots show SWE and SCF for the EnsOL forecast and 3 different data assimilation (DA) analyses. AMSR-E data are missing due to the swath effect and MODIS data are missing because of cloud contamination.

7.3 Case study 3: Assimilation of soil moisture observations

Soil moisture is an important initialization variable for large-scale weather forecasts and climate predictions. Smaller-scale soil moisture conditions have a great impact on agriculture, ecology and hydrology. The occurrence of droughts and flooding has a major impact on human lives and monitoring the soil moisture helps to prevent or mitigate disasters. Regional to global soil moisture data rely mostly on land surface model simulations forced by meteorological data or on satellite-based microwave observations. However, these satellite observations have coarse spatial resolution, only sense the top few centimetres of the soil and are only available for a specific area when the satellite happens to pass over. Through assimilation of these intermittent surface observations into a model, continuous and consistent soil moisture profile estimates could be obtained.

Liu et al. (2011) illustrated how land surface simulations can be improved by either improving the precipitation, or by assimilating surface soil moisture retrievals from the Advanced Microwave Scanning Radiometer (AMSR-E) with a 1-D ensemble Kalman filter into the NASA Catchment land surface model. The assimilated soil moisture products were either the operational NASA Level-2B AMSR-E "AE-Land" product (archived by NSIDC), or the Land Parameter Retrieval Model C-band LPRM-C product. The forcings were based on the atmospheric forcing fields from Modern Era Retrospective-analysis for Research and Applications (MERRA), but the precipitation is corrected with large-scale, gauge- and satellite-based precipitation observations from different datasets (CMAP, GPCP, and CPC). The soil moisture skill was defined as the anomaly time series correlation coefficient R of the model or assimilation results against in situ observations in the continental United States at 44 single-profile sites within the Soil Climate Analysis Network (SCAN). Figure 7 shows that the precipitation corrections and assimilation of satellite soil moisture retrievals contribute comparable and largely independent amounts of information to the assimilation results. Furthermore, it should be stressed that the satellite observations are only available for the surface soil layer and assimilation of these surface data clearly helps to improve the soil moisture estimates in the root zone.

The above example assimilated the coarse-scale AMSR-E data with a 1-D filter and focused on improving the temporal characteristics of the assimilation results for large scale applications. In another study by Sahoo et al. (2011), coarse-scale AMSR-E observations were assimilated with more focus on the fine-scale spatial variability by applying a 3-D spatial filter (Reichle and Koster, 2003, De Lannoy et al., 2010) to downscale the observations to the fine-scale model resolution over the Little River Experimental Watershed in Georgia. A correct assessment of the soil moisture pattern could largely impact flood predictions and may be crucial in the effective mitigation of droughts. Furthermore, as numerous previous studies (e.g., Walker et al. (2001b), De Lannoy et al. (2006), Liu et al. (2011)), it was reconfirmed that the assimilation of surface observations impact the deeper layer soil moisture and other water balance variables, but Sahoo et al. (2011) also illustrated that assimilation of surface observations helps the model to spin up faster to its balanced state, both in the surface and deeper layers. This is shown by the gray arrow in Figure 8, which indicates the time difference in model spin up without and with data assimilation. Data assimilation thus better prepares and balances the land surface models to provide improved short-term soil moisture forecasts.

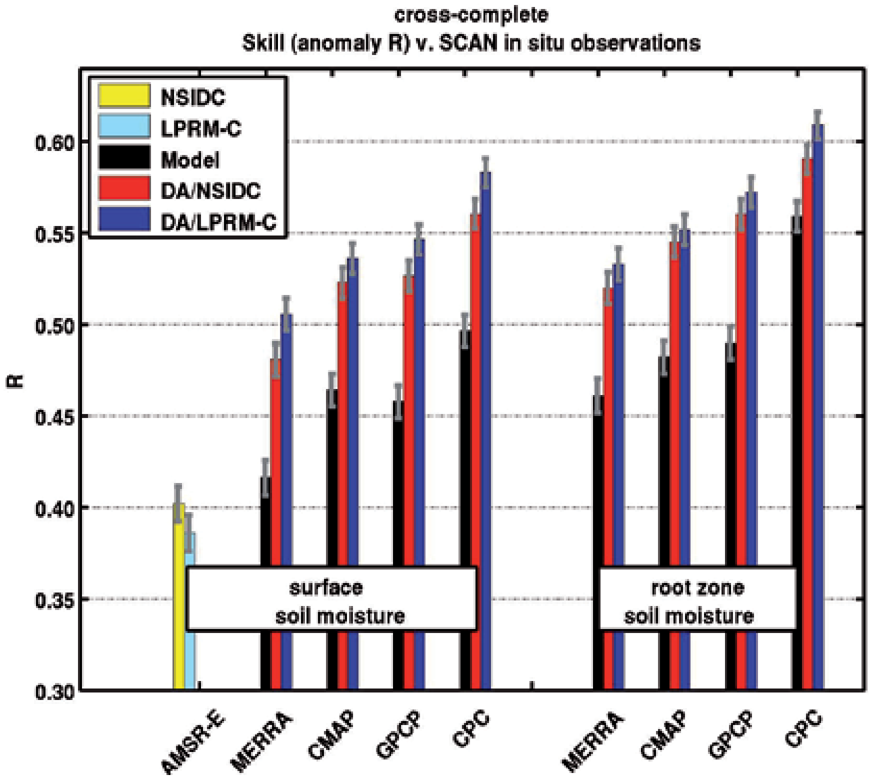

Fig. 7. Average time series correlation coefficient R with SCAN in situ surface and root zone soil moisture anomalies for estimates from two AMSR-E retrievals (NSIDC and LPRM-C), the Catchment model forced with four different precipitation datasets (MERRA, CMAP, GPCP, and CPC), and the corresponding data assimilation integrations (DA/NSIDC and DA/LPRM-C). Average is over 44 SCAN sites for surface soil moisture and over 42 sites for root zone soil moisture. Error bars indicate approximate 95% confidence intervals.

7.4 Case study 4: Soil moisture assimilation and NWP

Soil moisture can influence the development of the low-level atmosphere, by controlling the partition of incoming radiation into latent and sensible heat fluxes. In Numerical Weather Prediction (NWP) models, errors in the model forecasts (particularly from precipitation) tend to accumulate in the model soil moisture states, causing the modelled soil moisture to gradually drift away from reality. At many NWP centers this is prevented by applying simple nudging or Optimal Interpolation-based assimilation schemes that correct the model soil moisture to reduce errors in forecasts of low-level relative humidity and atmospheric temperature, based on screen-level (1.5 - 2m) observations from automatic weather stations. While this approach can effectively reduce low-level atmospheric forecast errors (of greatest concern to NWP) this is often achieved by degrading the model soil moisture, since it is `corrected' to compensate for screen-level errors unrelated to soil moisture, for example due to inaccuracies in the land surface flux parameterisations or the radiation physics (Drusch et al, 2007).

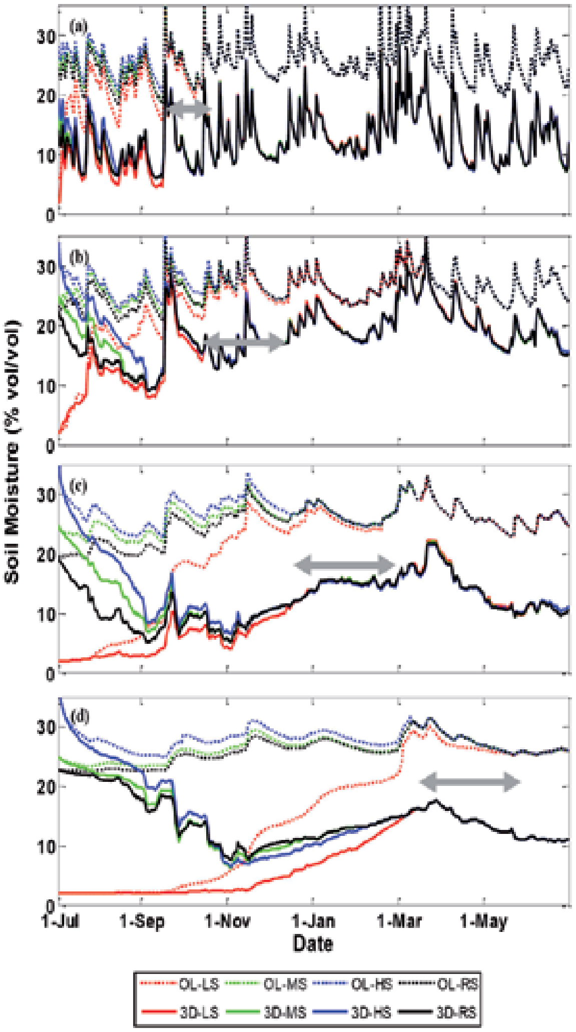

Fig. 8. Sensitivity results of the EnKF 3-D algorithm to the model initialization conditions and model spin-up for the Soil Moisture (a) Layer 1, (b) Layer 2, (c) Layer 3 and (d) Layer 4. The results are spatially averaged over 16 in-situ locations. OL (dashed) stands for the Open Loop model simulation without assimilation, started from different initial soil moisture wetness values. 3D (solid line) refers to assimilation results with L (low), M (moderate) and H (high) initial soil moisture. The simulations start in the summer (July 1, 2002 = S).

Ultimately, inaccurate soil moisture in an NWP model will lead to inaccurate atmospheric forecasts. Additionally, if accurate soil moisture states could be obtained from NWP models, these would be valuable for other operational applications, such as hydrological modelling, flood forecasting, and drought monitoring. A promising solution to improving the accuracy of the soil moisture in NWP models is to make use of novel remotely sensed observations of near-surface soil moisture, such as those available from AMSR-E. Within this context, a study by Draper et al. (2011) presents an Extended Kalman Filter (EKF) capable of assimilating both screen-level observations and remotely sensed near-surface soil moisture observations into an NWP model. This EKF, based on the Simplified EKF of Mahfouf et al (2009), was specifically designed to be computationally affordable within an operational NWP model, however the experiments presented here were conducted using an offline land surface model (with no feedback to the atmospheric model).

A series of assimilation experiments was conducted to compare the EKF assimilation of AMSR-E derived near-surface soil moisture and screen-level observations into Météo-France's NWP model over Europe. Figure 9 demonstrates how assimilating each data set influenced the fit between the subsequent model forecasts and each of the assimilated data sets. When the AMSR-E soil moisture and screen-level observations were assimilated separately, there was no clear consistency between the resulting root-zone soil moisture analyses, and so Figure 9 shows that assimilating one data set did not improve the model fit to the other data set. Hence, for these experiments the screen-level observations could not have been substituted with the AMSR-E data to achieve similar corrections to the low-level atmospheric forecasts, implying that the remotely sensed soil moisture may not be immediately useful for Météo-France's NWP model. However, for the experiments assimilating the screen-level observations the soil moisture innovations were dominated by a diurnal cycle that was not related to the model soil moisture, reinforcing the need to develop the assimilation of alternative data sets.

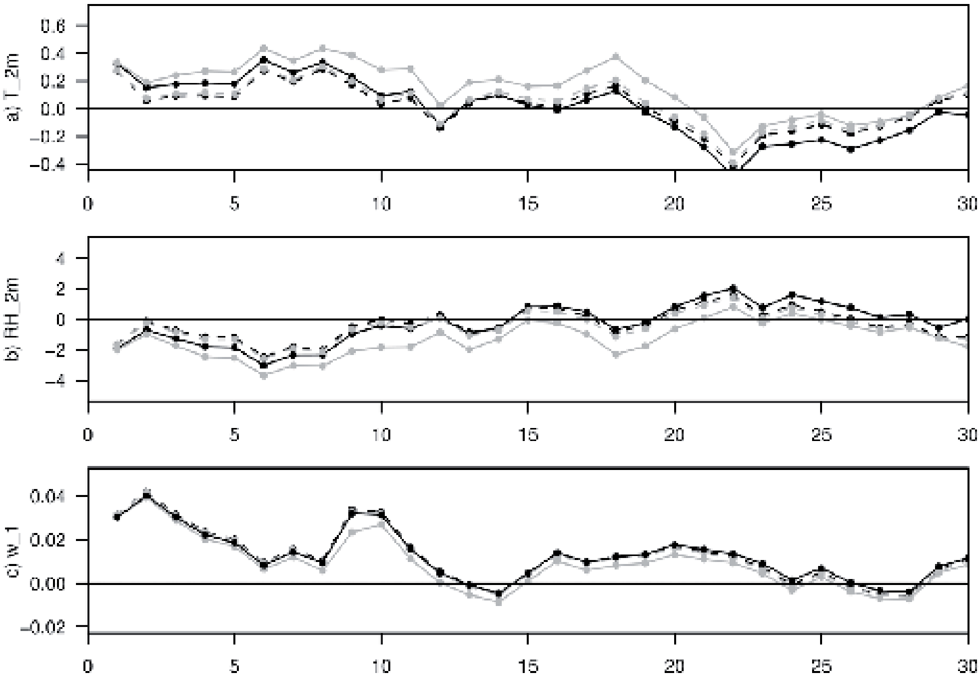

Fig. 9. Mean daily observation minus model forecast, averaged over Europe, for each day in July 2006, for a) temperature at 2m above the surface, T_2m (K), b) relative humidity at 2m above the surface, RH_2m (%), and c) surface soil moisture, w_1 (m3m-3), for an open-loop (no assimilation; black, solid), assimilation of screen-level variables (black, dashed), assimilation of AMSR-E soil moisture (grey, solid), and assimilation of both data sets (grey, dashed) experiments.

When the AMSR-E and screen-level observations were assimilated together, the EKF slightly improved the fit between the model forecasts and both observed data sets, although these improvements were very modest, and the root mean square difference over the one month experiment over all of Europe between the model forecasts and the assimilated observations was reduced by less than 5% of the open-loop values, for all assimilated variables. If this result can be substantiated with larger improvements by performing the assimilation in a fully coupled NWP model, this would confirm that assimilating remotely sensed near-surface soil moisture together with screen-level observations has the potential to improve the realism of the NWP land surface without degrading the low-level atmospheric forecasts.

8. Summary

Hydrological data assimilation is an objective method to estimate the hydrological system states from irregularly distributed observations. These methods integrate observations into numerical prediction models to develop physically consistent estimates that better describe the hydrological system state than the raw observations alone. This process is extremely valuable for providing initial conditions for hydrological system prediction and/or correcting hydrological system prediction, and for increasing our understanding and improving parametrization of hydrological system behaviour through various diagnostic research studies.

Hydrological data assimilation has still many open areas of research. Development of hydrological data assimilation theory and methods is needed to: (i) better quantify and use model and observational errors; (ii) create model-independent data assimilation algorithms that can account for the typical non-linear nature of hydrological models; (iii) optimize data assimilation computational efficiency for use in large operational hydrological applications; (iv) use forward models to enable the assimilation of remote sensing radiances directly; (v) link model calibration and data assimilation to optimally use available observational information; (vi) create multivariate hydrological assimilation methods to use multiple observations with complementary information; (vii) quantify the potential of data assimilation downscaling; and (viii) create methods to extract the primary information content from observations with redundant or overlaying information. Further, the regular provision of snow, soil moisture, and surface temperature observations with improved knowledge of observational errors in time and space are essential to advance hydrological data assimilation. Hydrological models must also be improved to: (i) provide more "observable" land model states, parameters, and fluxes; (ii) include advanced processes such as river runoff and routing, vegetation and carbon dynamics, and groundwater interaction to enable the assimilation of emerging remote sensing products; (iii) have valid and easily updated adjoints; and (iv) have knowledge of their prediction errors in time and space. The assimilation of additional types of hydrological observations, such as streamflow, vegetation dynamics, evapotranspiration, and groundwater or total water storage must be developed.

As with most current data assimilation efforts, we describe data assimilation procedures that are implemented in uncoupled models. However, it is well known that the high-resolution time and space complexity of hydrological phenomena have significant interaction with atmospheric, biogeochemical, and oceanic processes. Scale truncation errors, unrealistic physics formulations, and inadequate coupling between hydrology and the overlying atmosphere can produce feedbacks that can cause serious systematic hydrological errors. Hydrological balances cannot be adequately described by current uncoupled hydrological data systems, because large analysis increments that compensate for errors in coupling processes (*e.g.* precipitation) result in important non-physical contributions to the energy and water budgets. Improved coupled process models with improved feedback processes, better observations, and comprehensive methods for coupled assimilation are needed to achieve the goal of fully coupled data assimilation systems that should produce the best and most physically consistent estimates of the Earth system.

9. References

Alsdorf, D. E., Rodriguez, E., & Lettenmaier, D. P. (2007). Measuring surface water from space, Reviews of Geophysics, 45, doi:10.1029/2006RG000197.

Andreadis, K. M., Clark, E. A., Lettenmaier, D. P., & Alsdorf, D. E. (2007). Prospects for river discharge and depth estimation through assimilation of swath-altimetry into a raster-based hydrodynamics model, Geophys. Res. Lett., 34, L10403, doi:10.1029/2007GL029721.

Andreadis, K.M. and D.P. Lettenmaier, 2006. Assimilating remotely sensed snow observation into a macroscale hydrology model. *Adv. Water Resour.*, 29, 872–886.

Bennett, A.F., 1992. *Inverse methods in physical oceanography.* Cambridge University Press, 346 pp.

Bergthorsson, P. and B. Döös, 1955. Numerical weather map analysis. *Tellus*, 7, 329–340.

Biancamaria, S., Durand, M., Andreadis, K. M., Bates, P. D., Booneg, A., Mognard, N. M., Rodríguez, E., Alsdorf, D. E., Lettenmaier, D. P., & Clark, E. A. (2010). Assimilation of virtual wide swath altimetry to improve Arctic river modelling, Remote Sensing of Environment, doi:10.1016/j.rse.2010.09.008.

Bosilovich, M.G., J.D. Radakovich, A.D. Silva, R. Todling and F. Verter, 2007. Skin temperature analysis and bias correction in a coupled land-atmosphere data assimilation system. *J. Meteorol. Soc. Jpn.*, 85A, 205-228.

Bratseth, A.M., 1986. Statistical interpolation by means of successive corrections. *Tellus*, 38A, 439-447.

Charney, J.G., M. Halem and R. Jastrow, 1969. Use of incomplete historical data to infer the present state of the atmosphere. *J. Atmos. Sci.*, 26, 1160-1163.

Cressman, G.P., 1959. An operational objective analysis system. *Mon. Weather Rev.*, 87, 367–374.

Daley, R., 1991. *Atmospheric data analysis*. Cambridge University Press, 460 pp.

De Lannoy, G.J.M., P.R. Houser, N.E.C. Verhoest and V.R.N. Pauwels, 2009. Adaptive soil moisture profile filtering for horizontal information propagation in the independent column-based CLM2.0, *J. Hydrometeorol.*, 10(3), 766-779.

De Lannoy, G.J.M., P.R. Houser, V.R.N. Pauwels and N.E.C. Verhoest, 2006. Assessment of model uncertainty for soil moisture through ensemble verification. *J. Geophys. Res.*, 111, D10101.1-18.

De Lannoy, G.J.M., P.R. Houser, V.R.N. Pauwels and N.E.C. Verhoest, 2007b. State and bias estimation for soil moisture profiles by an ensemble Kalman filter: effect of assimilation depth and frequency. *Water Resour. Res.*, 43, W06401, doi:10.1029/2006WR005100.

De Lannoy, G.J.M., R. H. Reichle, K. R. Arsenault, P. R. Houser, S. Kumar, N. E. C. Verhoest, V.R.N. Pauwels, 2011. Multi-Scale Assimilation of AMSR-E Snow Water Equivalent and MODIS Snow Cover Fraction in Northern Colorado, *Water Resour. Res., in review.*

De Lannoy, G.J.M., R.H. Reichle, P.R. Houser, K. R. Arsenault, V.R.N. Pauwels and N.E.C. Verhoest, 2009. Satellite-scale snow water equivalent assimilation into a high-resolution land surface model, *J. Hydrometeorol.*, in press.

De Lannoy, G.J.M., R.H. Reichle, P.R. Houser, V.R.N. Pauwels and N.E.C. Verhoest, 2007a. Correcting for forecast bias in soil moisture assimilation with the ensemble Kalman filter. *Water Resour. Res.*, 43, W09410, doi:10.1029/2006WR00544.

De Lannoy, G.J.M., Reichle, R.H., Houser, P.R., Arsenault, K., Verhoest, N.E.C., Pauwels, V.R.N. (2011). Multi-Scale Assimilation of AMSR-E Snow Water Equivalent and MODIS Snow Cover Fraction in Northern Colorado, Water Resources Research, conditionally accepted.

Déry, S.J., V.V. Salomonson, M. Stieglitz, D.K. Hall and I. Appel, 2005. An approach to using snow areal depletion curves inferred from MODIS and its application to land surface modelling in Alaska. *Hydrol. Processes*, 19, 2755–2774.

Dirmeyer, P., 2000. Using a global soil wetness dataset to improve seasonal climate simulation. *J. Climate*, 13, 2900–2921.

Dong, J., and C. Peters-Lidard (2010). On the Relationship Between Temperature and MODIS Snow Cover Retrieval Errors in the Western U.S. IEEE Trans. Geosci. Remote Sens., 3(1), 132-140.

Dong, J., J.P. Walker and P.R. Houser, 2005. Factors Affecting Remotely Sensed Snow Water Equivalent Uncertainty. *Remote Sensing of Environment*, 97, 68-82, doi:10.1016/j.rse.2005.04.010.

Dong, J., J.P. Walker, P.R. Houser and C. Sun, 2007. Scanning multichannel microwave radiometer snow water equivalent assimilation. *J. Geophys. Res.*, 112, D07108, doi:10.1029/2006JD007209.

Draper, C. S., J.-F. Mahfouf, and J. P. Walker (2011), Root zone soil moisture from the assimilation of screen-level variables and remotely sensed soil moisture, J. Geophys. Res., 116, D02127, doi:10.1029/2010JD013829.

Drusch, M. and Viterbo, P. (2007). Assimilation of screen-level variables in ECMWF's Integrated Forecast System: A study on the impact on the forecast quality and analyzed soil moisture, Monthly Weather Review, 135, 300-314.

Giustarini, L., Matgen, P., Hostache, R., Montanari, M., Plaza, D., Pauwels, V. R. N., De Lannoy, G. J. M., De Keyser, R., Pfister, L., Hoffmann, L, & Savenije, H. H. G. (2011). Assimilatign SAR-derived water level data into a flood models: a case study, Hydrol. Earth Syst. Sci., 15, 2349-2365.

Hostache, R., Matgen, P., Schumann, G., Puech, C., Hoffmann, L., & Pfister, L. (2009). Water level estimation and reduction of hydraulic model calibration uncertainties using satellite SAR images of floods, IEEE Transactions on Geoscience and Remote Sensing, 47, 431-441.

Houser, P., M.F. Hutchinson, P. Viterbo, J. Hervé Douville and S.W. Running, 2004. *Terrestrial data assimilation*, Chapter C.4 in Vegetation, Water, Humans and the Climate. Global Change - The IGB Series. Kabat, P. et al. (eds). Springer, Berlin, pp 273-287.

Houser, P.R., W.J. Shuttleworth, J.S. Famiglietti, H.V. Gupta, K.H. Syed and D.C. Goodrich, 1998. Integration of soil moisture remote sensing and hydrologic modeling using data assimilation. *Water Resour. Res.*, 34, 3405-3420.

Hu, Y., X. Gao, W. Shuttleworth, H. Gupta and P. Viterbo, 1999. Soil moisture nudging experiments with a single column version of the ECMWF model. *Q. J. R. Meteorol. Soc.*, 125, 1879–1902.

Kalman, R.E., 1960. A new approach to linear filtering and prediction problems. *Trans. ASME, Ser. D, J. Basic Eng.*, 82, 35-45.

Koster, R.D., M. Suarez, P. Liu, U. Jambor, A. Berg, M. Kistler, R. Reichle, M. Rodell and J. Famiglietti, 2004. Realistic initialization of land surface states: Impacts on subseasonal forecast skill. *J. Hydrometeorol.*, 5, 1049–1063.

Kostov, K.G. and T.J. Jackson, 1993. Estimating profile soil moisture from surface layer measurements – A review. In: Proc. The *International Society for Optical Engineering, Vol. 1941*, Orlando, Florida, pp 125-136.

Liu, Q., Reichle, R.H., Bindlish, R., Cosh, M.H., Crow, W. T., de Jeu, R., De Lannoy, G.J.M., Huffman, G.J., Jackson, T.J. (2011). The contribution of precipitation forcing and satellite observations of soil moisture on the skill of soil moisture estimates in a land data assimilation system, Journal of Hydrometeorology, in press.

Lorenc, A., 1981. A global three-dimensional multivariate statistical interpolation scheme. *Mon. Weather Rev.*, 109, 701-721.

Lorenc, A.C., R.S. Bell and B. Macpherson, 1991. The Meteorological Office analysis correction data assimilation scheme. *Q. J. R. Meteorol. Soc.*, 117, 59-89.

Mahfouf, J.-F., Bergaoui, K., Draper, C., Bouyssel, C., Taillefer, F. and Taseva, L. (2009). A comparison of two off-line soil analysis schemes for assimilation of screen-level observations, Journal of Geophysical Research, 114, D08105.

Margulis, S.A., E.F. Wood and P.A. Troch, 2006. A terrestrial water cycle: Modeling and data assimilation across catchment scales. *J. Hydrometeorol.*, 7, 309–311.

Matgen, P., Montanari, M., Hostache, R., Pfister, L., Hoffmann, L., Plaza, D., Pauwels, V. R. N., De Lannoy, G. J. M., De Keyser, R., & Savenije, H. H. G. (2010). Towards the sequential assimilation of SAR-derived water stages into hydraulic models using the Particle Filter: proof of concept, Hydrol. Earth Syst. Sci., 14, 1773-1785.

McLaughlin, D., 1995. Recent developments in hydrologic data assimilation. In U.S. National Report to the IUGG (1991-1994). *Rev. Geophys.*, supplement, 977–984.

McLaughlin, D., 2002. An integrated approach to hydrologic data assimilation: interpolation, smoothing, and filtering. *Adv. Water Resour.*, 25, 1275–1286.

Montanari, M., Hostache, R., Matgen, P., Schumann, G., Pfister, L., & Hoffmann, L. (2009). Calibration and sequential updating of a coupled hydrologic-hydraulic model using remote sensing-derived water stages, Hydrol. Earth Syst. Sci., 13, 367-380.

Nichols, N.K., 2001. State estimation using measured data in dynamic system models, Lecture *notes for the Oxford/RAL Spring School in Quantitative Earth Observation*.

Pan, M. and E.F. Wood, 2006. Data assimilation for estimating the terrestrial water budget using a constrained ensemble Kalman filter. *J. Hydrometeorol.*, 7, 534–547.

Parrish, D. and J. Derber, 1992. The National Meteorological Center's spectral statistical interpolation analysis system. *Mon. Weather Rev.*, 120, 1747-1763.

Reichle, R.H. and R. Koster, 2003. Assessing the impact of horizontal error correlations in background fields on soil moisture estimation. *J. Hydrometeorol.*, 4, 1229–1242.

Reichle, R.H. and R. Koster, 2004. Bias reduction in short records of satellite soil moisture. *Geophys. Res. Lett.*, 31, L19501.1–L19501.4.

Reichle, R.H., D.B. McLaughlin and D. Entekhabi, 2002a. Hydrologic data assimilation with the ensemble Kalman filter. *Mon. Weather Rev.*, 120, 103–114.

Reichle, R.H., J.P. Walker, P.R. Houser and R.D. Koster, 2002b. Extended versus ensemble Kalman filtering for land data assimilation. *J. Hydrometeorol.*, 3, 728–740.

Reichle, R.H., W.T. Crow and C.L. Keppenne, 2008. An adaptive ensemble Kalman filter for soil moisture data assimilation, *Water Resour. Res.*, 44, W03423, doi:10.1029/2007WR006357.

Rood, R.B., S.E. Cohn and L. Coy, 1994. Data assimilation for EOS: The value of assimilated data, Part 1. *The Earth Observer*, 6, 23-25.

Sahoo, A.K., De Lannoy, G.J.M., Reichle, R.H. (2011). Downscaling of AMSR-E soil moisture in the Little River Watershed, Georgia, USA. Advances in Water Resources, in review.

Sellers, P. J., Y. Mintz, and A. Dalcher, 1986: A simple biosphere model (SiB) for use within general circulation models. J. Atmos. Sci., 43: 505-531.

Slater, A.G. and M. Clark, 2006. Snow data assimilation via an ensemble Kalman filter. *J. Hydrometeorol.*, 7, 478–493.

Stauffer, D.R. and N.L. Seaman, 1990. Use of four-dimensional data assimilation in a limited-area mesoscale model. Part I: Experiments with synoptic-scale data. *Mon. Weather Rev.*, 118, 1250-1277.

Stieglitz, M., D. Rind, J. Famiglietti and C. Rosenzweig, 1997. An efficient approach to modeling the topographic control of surface hydrology for regional and global climate modeling. *J. Climate*, 10, 118–137.

Turner, M.R.J., J.P. Walker and P.R. Oke, 2007. Ensemble Member Generation for Sequential Data Assimilation. *Remote Sensing of Environment*, 112, doi:10.1016/j.rse.2007.02.042.

van Loon, E.E. and P.A. Troch, 2001. Directives for 4-D soil moisture data assimilation in hydrological modelling. *IAHS*, 270, 257-267.

Walker J.P. and P.R. Houser, 2001. A methodology for initialising soil moisture in a global climate model: assimilation of near-surface soil moisture observations, *J. Geophys. Res.*, 106, 11,761-11,774.

Walker, J.P. and P.R. Houser, 2004. Requirements of a global near-surface soil moisture satellite mission: Accuracy, repeat time, and spatial resolution. *Adv. Water Resour.*, 27, 785-801.

Walker, J.P. and P.R. Houser, 2005. Hydrologic data assimilation. In *A. Aswathanarayana (Ed.), Advances in water science methodologies* (230 pp). The Netherlands, A.A. Balkema.

Walker, J.P., G.R. Willgoose and J.D. Kalma, 2001a. One-dimensional soil moisture profile retrieval by assimilation of near-surface observations: A comparison of retrieval algorithms. *Adv. Water Resour.*, 24, 631-650.

Walker, J.P., G.R. Willgoose and J.D. Kalma, 2001b. One-dimensional soil moisture profile retrieval by assimilation of near-surface measurements: A simplified soil moisture model and field application. *J. Hydrometeorol.*, 2, 356-373.

Walker, J.P., G.R. Willgoose and J.D. Kalma, 2002. Three-dimensional soil moisture profile retrieval by assimilation of near-surface measurements: Simplified Kalman filter covariance forecasting and field application. *Water Resour. Res.*, 38, 1301, doi:10.1029/2002WR001545.

Walker, J.P., P.R. Houser and R. Reichle, 2003. New technologies require advances in hydrologic data assimilation. *EOS*, 84, 545–551.

WMO, 1992. Simulated real-time intercomparison of hydrological models (*Tech. Rep. No. 38*). Geneva.

Zhang, H. and C.S. Frederiksen, 2003. Local and nonlocal impacts of soil moisture initialization on AGCM seasonal forecasts: A model sensitivity study. *J. Climate*, 16, 2117–2137.

4

Automated Integration of Geosensors with the Sensor Web to Facilitate Flood Management

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1. Introduction

It is predicted that severe flooding disasters will occur more and more often in the future, due to expanding land use and an increasing number of extreme meteorological events. For monitoring and managing large-scale floods efficiently, up-to-date information is crucial. Geosensors ranging from water gauges and weather stations to stress monitors attached to dams or bridges are used to gather such information. The various kinds of sensors need to be integrated into an interoperable infrastructure so that the measured data can be easily utilized by different disaster relief organizations. The standardized web service framework of the Sensor Web Enablement initiative (section 2.1) can be used as such an infrastructure, since it has shown its suitability in several projects and applications in past years. However, the integration of newly deployed sensors into the Sensor Web has not been straight-forward. That challenge is addressed by this work. A standards-based architecture enabling the on-the-fly integration of environmental sensors into the Sensor Web is presented. This new approach for an on-the-fly integration of geosensors is generic and can be applied to different types of sensors. We demonstrate and evaluate the developed methods by applying them to the real world use case of the German watershed management organization Wupperverband, where the mobile water gauge, G-WaLe, is used as an example for a new geosensor deployed in an ad-hoc manner to densify the measurement network.

The following section 1.1 introduces the topic of flood management and the need for the incorporation of geosensors into a coherent infrastructure to enable interoperable access to up-to-date information. Next, the problem of an interoperability gap between Sensor Web infrastructures and the used geosensors is outlined as the challenge addressed by this work (section 1.2). Section 2 describes the Sensor Web Enablement initiative as well as the mobile water gauge, G-WaLe, that is used to realize the case study in this work. Section 3.2 introduces the Wupperverband, its network of water gauge sensors, and emerging use cases in context of flood management. Next, section 4 presents the standards-based architecture which is applied to realize the case study, as described in section 5. This chapter closes with conclusions and an outlook to future work.

1.1 The need for geosensor infrastructures in disaster management

Two days of heavy rain in the mountains of the Erzgebirge in August 2002 caused a dramatic flooding along the German river Elbe. The disaster caused the death of twelve people and a financial damage of over one billion Euros (Elze et al., 2004). This is just one instance for a dramatic flooding disaster in the past years. The Annual Disaster Statistical Review 2007 (Scheuren et al., 2007) states that during the past twenty years seven million people were affected and almost two thousands were killed by flood disasters in Europe. During the last decade, Europe witnessed eight out of twenty of the largest floods ever recorded. Parry et al. (2007) forecast that such kind of flooding disasters will occur more often and more intensely in future. A reason for this is the still expanding land use within critical areas as well as the number of extreme meteorological events which has constantly increased over the past years as a consequence of climate change.

Another region endangered by floods is the drainage area of the river Wupper in the Northwest of Germany. The last floods in this region occurred in August 2007 and caused severe damages (Boch & Schreiber, 2007). Responsible for the watershed management of the Wupper region is the Wupperverband[1] organization. In this article, a flooding scenario in the Wupper region is used to illustrate and apply the developed approach (section 5).

To manage disasters such as large-scale floods, but also hurricanes, earthquakes, storms or wild fires, the supply with up-to-date information is crucial to provide decision support for the responsible organisations. In case of floods, information such as water level and precipitation measurements, weather forecasts as well as the state of dams, bridges and other structures along affected watercourses is required. Geosensors and geosensor networks (e.g., networks of stream gauges or weather stations) are valuable means for gathering precise and high resolution data to derive such information. As the National Science and Technology Council Committee on Environment and Natural Resources published in its report on grand challenges for disaster reduction (Subcommittee on Disaster Reduction, 2008), a key to minimize the damage of natural disasters is the provision of sensor data. This data has to be available in near real time, since disasters are time critical situations in which decisions have to be made ad-hoc. Heterogeneous information sources, e.g., different kinds of sensors, have to be integrated on-the-fly into a coherent infrastructure which can be easily utilized by different disaster relief organizations. This infrastructure has to serve as a basis for decision support systems to control and manage emergency situations. It has to enable discovery, browsing, querying and usage of geospatial information as well as processing capabilities.

Today, sensors are becoming smaller, cheaper, more reliable, and more power efficient. Sensors are increasingly used in early warning systems and disaster management (Shepherd & Kumar, 2005). The kinds of sensors utilized in these applications may be stationary or mobile, either on land, water or in the air and could gather data in an in-situ or remote manner. Due to this variety, a coherent infrastructure is necessary to integrate heterogeneous sensors and to enable interoperable access to their functionality. The idea of the *Sensor Web* describes such an infrastructure for sharing, finding and accessing sensors and their data across different applications (Nittel, 2009). The Sensor Web is to geosensors what the World Wide Web

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[1] `http://www.wupperverband.de`

(WWW) is to general information sources - an infrastructure allowing users to easily share their sensor resources. It encapsulates the underlying layers, the network communication details, and heterogeneous sensor hardware, from the applications built on top of it.

The Sensor Web Enablement (SWE) initiative of the Open Geospatial Consortium (OGC)[2] develops standards for Web service interfaces and data encodings which can be used as building blocks for a Sensor Web (section 2.1). SWE incorporates different models for describing sensors and representing sensor observations. Further, it defines Web service interfaces leveraging the models and encodings to allow accessing of sensor data, tasking of sensors and alerting based on gathered sensor observations. The SWE standards serve the functionality to integrate sensors into Spatial Data Infrastructures (SDI). The integration of sensor assets into SDIs makes it possible to couple available sensor data with other spatio-temporal resources (e.g., maps, raster as well as vector data) on the application level which maximizes the information effectiveness for decision support. Due to this integration, Sensor Webs and their comprised geosensors represent a real-time link of Geoinformation Systems (GIS) into the real world.

In recent years, these SWE standards have demonstrated their practicability and suitability in various projects (e.g., (Chung et al., 2009; Jirka et al., 2009; Schimak & Havlik, 2009)) and applications (e.g., (Aasa et al., 2008; Bröring, Jürrens, Jirka & Stasch, 2009; Foerster et al., 2009; Fruijtier et al., 2008)). However, there is still a fundamental challenge currently unresolved, the ability to dynamically integrate sensors in an on-the-fly manner. The integration of sensors into the Sensor Web with a minimum of human intervention is not possible with the given methods and designs. Especially in the above described disaster situations it is required to enable a live deployment of sensor networks and an ad-hoc integration of those sensors into the Sensor Web to allow multiple parties an easy access and usage of the geosensors. Those emergency scenarios require the incorporation of various sensor types. This article addresses the challenge of integrating geosensors on-the-fly towards a true *plug & play* of sensors with the Sensor Web.

1.2 The interoperability gap between sensors and the Sensor Web

Dynamically integrating geosensors on the Sensor Web requires advanced concepts. Generally, the SWE standards focus on interacting with the upper application level, since they are designed from an application-oriented perspective. The interaction between the Sensor Web and the underlying sensor layer has not yet been sufficiently addressed. In consequence, a gap of interoperability between these two layers arises. This interoperability gap results from the fact that both layers are designed with different objectives and approaches. The Sensor Web is based on the WWW and its related protocols. Geosensors, on the other hand, communicate based on lower-level protocols. These protocols follow rarely standards for instrument communication, such as IEEE 1451 (Lee, 2000), but instead are usually manufacturer dependent; see for example protocol specifications for typical oceanographic sensors from Sea-Bird-Electronics (2010), WETLabs (2010), or HOBILabs (2008).

From an application perspective, the SWE services encapsulate associated geosensors and hide their lower-level communication protocols. So far, the integration of a geosensor with the Sensor Web involves two major steps: first, driver software needs to be implemented which converts measured data from the native sensor protocol to higher level Sensor Web

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[2] `http://www.opengeospatial.org`

protocols, and second, the geosensor description has to be manually registered at a Sensor Web service. I.e., proprietary bridges have to be manually built between each pair of SWE service and sensor type (figure 1). This approach is cumbersome and leads to an extensive adaption effort for linking the two layers. Since the price of sensor devices is decreasing rapidly, these adaption efforts become the key cost factor in developing large-scale sensor network systems (Aberer et al., 2006). Besides those infrastructural deficits in the current Sensor Web design, there is a mismatch between low-level data structures used in sensor protocols and the high-level information models of the Sensor Web. This issue relates to semantic challenges which have to be tackled to enable an automatic integration of sensors as discussed in (Bröring, Janowicz, Stasch & Kuhn, 2009). The main difficulty lies in mapping the relationship between the different Sensor Web concepts used for modeling sensors, observations, and features to the constructs of the lower sensor layer. An example challenge is to guarantee that the output of a geosensor, e.g., a value symbol gathered by an *anemometer* for the observable *wind direction*, complies not only syntactically but also semantically with a certain characteristic of a real world entity's representation residing on the Sensor Web level. Currently, these matchings have to be established and maintained manually by an administrator. The Sensor Web is missing mechanisms which ensure a correct semantic matching without user interaction to enable an automatic registration of sensors.

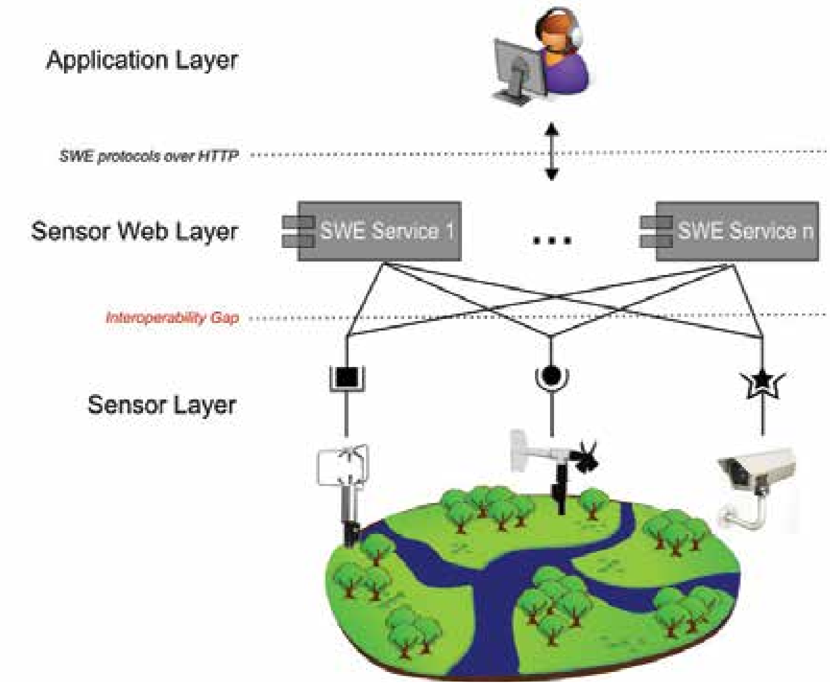

Fig. 1. The three layers of the geosensor infrastructure stack and the interoperability gap.

In future, Sensor Webs could be set up for certain geographic regions. SWE services, which build this Sensor Web, are only interested in sensors within that particular region, provide access to their data or enable their tasking. Various sensors of different type could register and upload their observations. Taking into account mobile sensors moving in and out of these regions, the above described problems become even more pressing. Methods enabling an automatic integration of sensors are needed to tackle those kinds of use cases.

Overall, the described obstacles are currently hindering an on-the-fly integration of sensors with minimal human intervention. In case of the Wupperverband's sensor network, serving as an application scenario in this article, these issues lead to a huge effort when integrating new geosensors or adjusting the existing infrastructure to optimize the monitoring of geo phenomena. To enable a timely reaction in disaster situations and to supply decision makers with necessary information, the demand for solutions coping with these problems is immense.

Hence, this work combines results of our previous work to design an architecture that facilitates the connection of the sensor layer and the Sensor Web layer. We apply this architecture here to enable the on-the-fly integration of a mobile water gauge, a sensor system that can be used to support flood management. The architecture incorporates first the Sensor Bus (Bröring, Foerster, Jirka & Priess, 2010), an intermediary layer that introduces a publish/subscribe mechanism between the Sensor Web and underlying geosensor networks. This is required to make services aware of new sensors appearing on the Sensor Web. Second, a *driver* mechanism for sensors is incorporated in our approach – the Sensor Interface Descriptor (SID) concept (Bröring, Below & Foerster, 2010). The SID model extends OGC's SensorML standard to describe the protocol of a particular sensor type in a declarative way. By means of a generic SID interpreter, the native sensor protocol can be translated to the SWE protocols.

2. Background

This section provides information on the Sensor Web Enablement initiative and its specifications (section 2.1). Further, the G-WaLe sensor system is described. These football-sized mobile buoys are capable of observing water level and are used in this work to demonstrate the developed architecture for an on-the-fly integration of geosensors (section 2.2).

2.1 Sensor Web enablement initiative

The goal of the Sensor Web is to allow Web-based sharing, discovery, exchange and processing of sensor observations, as well as task planning of sensor systems (Nittel et al., 2008). The Sensor Web Enablement (SWE) initiative of the Open Geospatial Consortium (OGC) defines standards which can be utilized to build such a Sensor Web (Botts et al., 2008). SWE standards make sensors available over the Web through standardized formats and Web service interfaces by hiding the sensor communication details and the heterogeneous sensor protocols from the application layer (Bröring, Echterhoff, Jirka, Simonis, Everding, Stasch, Liang & Lemmens, 2011).

The main Web services of the SWE framework are the Sensor Observation Service (SOS) and the Sensor Planning Service (SPS). The SOS (Bröring, Stasch & Echterhoff, 2010; Na & Priest, 2007) provides interoperable access to sensor data as well as sensor metadata. To control and task sensors, the SPS (Simonis, 2007) can be used. A common application of SPS is to define simple sensor parameters such as the sampling rate but also more complex tasks such as mission planning of satellite systems. Apart from these Web service specifications, SWE incorporates information models for observed sensor data, the Observations & Measurements

(O&M) (Cox, 2007) standard, as well as for the description of sensors, the Sensor Model Language (SensorML) (Botts, 2007).

SensorML specifies a model and encoding for sensor related processes such as measuring or post processing procedures. Physical as well as logical sensors are modeled as *processes*. The functional model of a process can be described in detail, including its identification, classification, inputs, outputs, parameters, and characteristics such as a spatial or temporal description. Processes can be composed by process chains.

O&M defines a model and encoding for *observations*. An observation has a result (e.g., 3.52 m) which is an estimated value of an *observed property* (e.g., water level), a particular characteristic of a *feature of interest* (e.g., the Wupper river at section 42). The result value is generated by a *procedure*, e.g., a sensor such as a water gauge described in SensorML. These four central components are linked within SWE.

2.2 G-WaLe - A mobile water gage

The G-WaLe sensor system consists of mobile buoys capable of observing the water level by measuring the position in three-dimensional space via satellite positioning systems. The key parts of the G-WaLe system (Beltrami, 2007) are the sensing devices, so-called floaters. These geosensors can be stationary anchored within a river or can be placed on demand within a flooded area. A floater is equipped with a satellite navigation receiver, a battery, memory, as well as a communication unit. The positioning data received from the satellites is internally stored and regularly transmitted via GSM or radio to a central receiver station (see figure 3). To increase the accuracy of the measurements, local reference stations can be incorporated in the positioning process, so that a positioning accuracy of around 10 cm can be achieved. In Germany, the SAPOS system[3] can be utilized for that. The water level is derived from the vertical component of the position measurement. Once the position data is transmitted from the G-WaLe floater to the receiver station, the data are accessible on an FTP server.

3. Flood management in the Wupper region

In the following, the Wupperverband and its role in flood management is outlined. Subsequently, an overview of the administered drainage area and potential flooding scenarios within that geographic region are outlined. Based on these considerations, the section finalizes with a presentation of different hypothetic applications for an on-the-fly integration of geosensors with regards to flood management. These example use cases serve as basis throughout the further work.

3.1 Existing water gage network

The Wupperverband is a statutory corporation whose members are for instance municipalities, water distribution companies, or industrial firms. The main responsibilities of the Wupperverband are the provision of drinking water, the operation of sewage treatment plants, the water level management including the backfilling in case of low waters, as well as the maintenance and ecological development of the river systems. Additionally, an important activity of the Wupperverband is the flood protection as well as the monitoring and warning in case of floodings. To accomplish these functions large amounts of measurement data

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[3] `http://www.sapos.de`

Fig. 2. Deployment of a G-WaLe floater in a river.

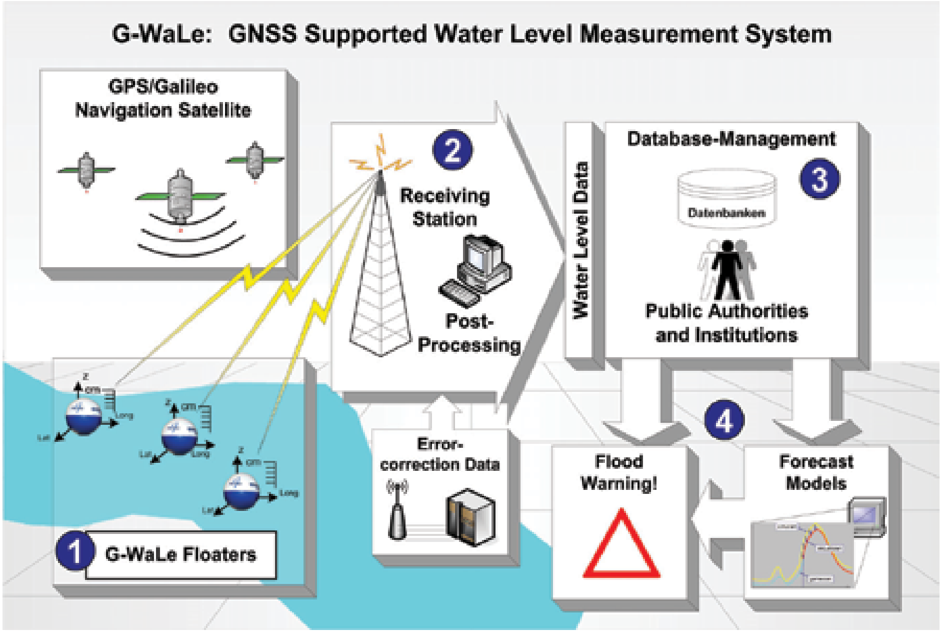

Fig. 3. The setup of the G-WaLe system (Beltrami, 2007).

have to be gathered, processed, analyzed and maintained. In the hydrology domain, the Wupperverband collects measurement parameters such as the stream flow amount, water level, groundwater level, or the amount of seeping water. Meteorological parameters which are of interest include precipitation data, air temperature, barometric pressure, humidity or wind direction and speed (Sat et al., 2005).

The Wupperverband is responsible for the management of over 3.000 bodies of water with an overall length of about 2.000 kilometers in the catchment area of the Wupper, which has a size of about 815 square kilometers (see Figure 4[4]). The terrain of the region rises from West to East which results in a heterogeneous precipitation distribution. With maxima of about 1.400 mm per year, the average annual precipitation in the Wupper drainage area can be considered as very high. Another important characteristic of the region is the population density, with 1.169 inhabitants per square kilometer, is around five times higher compared to the rest of Germany. The overall population of the region is 950.000 (Wupperverband, 2001). To monitor the parameters of interest within the catchment area of the Wupper, the Wupperverband operates over 50 weather stations and about 60 water gauge stations. Those water gauges are fixed installations and of various kind (e.g., staff gauges, ultrasonic gauges or radar gauges). At some gauges the water level needs to be looked up manually or a data logger needs to be read out on-site. Others support a remote transmission of the gathered data for example via telephone or GPRS .

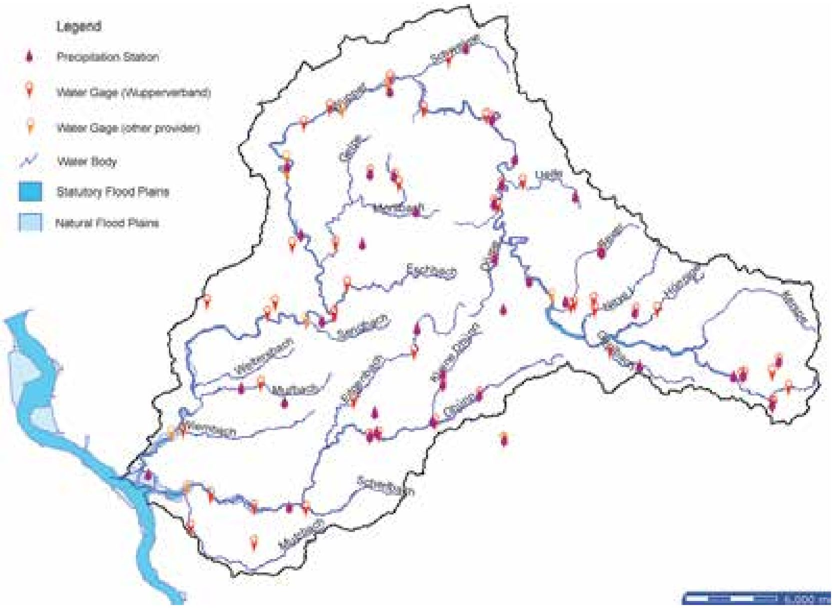

Fig. 4. The Wupper drainage area

Since the region is densely populated, large parts of the watercourses are channeled, the river banks within settlement areas are consolidated and partly outside of settlement areas, too. Thus, infrastructure objects, such as bridges or dams, reduce the discharge capacity

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[4] The maps in figure 4 and 5 have been created with the *fluggs* map client (`http://fluggs.wupperverband.de`)

considerably in places. The experiences of the disastrous flood at the watercourses of the Erzgebirge mountains in August 2002 have shown that such kinds of bottlenecks are often incapable of coping with the water volume of hundred-year floods (Elze et al., 2004). Thus, these objects are potentially endangered to get damaged which may cause further destructions.

In case of floodings, a potential risk goes out from industry facilities, such as plants or pipelines. Such facilities can particularly be found in the area of the lower Wupper and within the area where the Wupper empties into the Rhine. Other examples of endangered facilities are sewage treatment plants which are only capable of coping with a certain water level. These kinds of facilities demand a specific protection by technical emergency services. Also, gas storage tanks on the property of private households are at risk in flooding situations. These kinds of risks may result in subsequent water pollution, chemical spills, or industrial fires. The map in Figure 5 shows the region around the mouth of the Wupper into the Rhine. The turquoise areas show the floodplains of the river system officially determined by the public authorities. The plains endangered by regularly occurring floodings are drawn in light blue. To achieve an interoperable access to geosensors, e.g., water gauges and weather station, the Wupperverband has built up a local Sensor Web. The services of the SWE initiative have been used to encapsulate those sensor systems for seamlessly integrating them into the existing Spatial Data Infrastructure of the Wupperverband (Spies & Heier, 2008). Thus, the gathered hydrology and weather data are provided via Internet in a standardized way. The interoperable interfaces allow applications of the Wupperverband to work with internal as well as externally provided services. Hence, sensor data served by cooperating organizations (e.g., neighboring watershed management organizations) can be included into the decision making process. On the other hand, the information systems of third party organization are

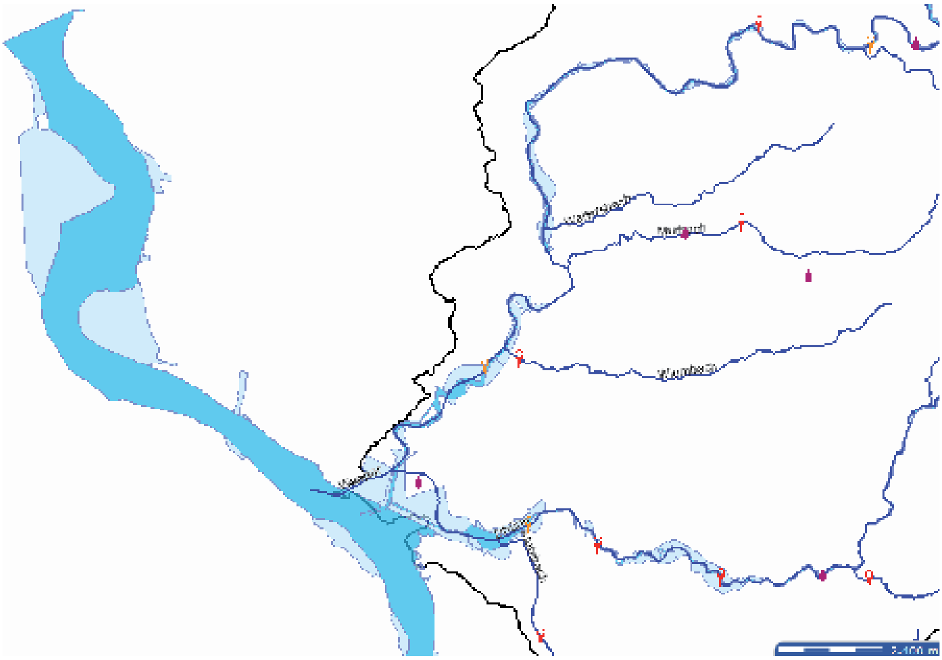


Fig. 5. Potential flooding zones of the lower Wupper

also enabled to work with the sensor data offered by the Wupperverband (Bröring & Meyer, 2008).

The central task of the Wupperverband in the context of flood protection is to create precipitation discharge models for the regional watercourse system. Based on those models, statistically possible flood scenarios (e.g., twenty-year or hundred-year floodings) and their consequences are simulated. The results of these simulations are the foundation for catalogs of countermeasures which aim at minimizing the damage in case of floodings. These are usually long-term measures. Real-time reactions on flood situations are currently not the focus of the Wupperverband. In fact, systems for the real-time management of disasters such as floods are still topic of research. An example for such a system has been developed within the SoKNOS project (Stasch et al., 2008). The objective of that project has been the research and development of concepts which effectively support governmental and industrial organizations in the area of public security. A service oriented approach for an emergency management system has been elaborated which helps technical services in handling disaster situations. The requirements for such emergency management systems are exceptional high, especially concerning scalability and reliability in disaster situations. The methods developed within this research support the development of such systems. However, a fully functional system fulfilling those extremely high requirements of emergency management is not the direct outcome.

3.2 Flooding use case

The following hypothetical scenario description is based on the real world flooding of the river Eschbach within the catchment area of the Wupper which happened in August 2007 and caused severe damages in the region (Boch & Schreiber, 2007).

Heavy rainfall is dominating the weather conditions over major parts of western Germany for the past days. This has lead to serious high waters especially along the Lower Rhine and its tributary rivers. During this tense situation, a massive local thunderstorm and heavy rainfalls occur over the greater region of the Wupper drainage area. With over 70 liters per square meter and hour, the measured precipitation amount is at certain weather stations statistically less frequent than every 100 years. Because the soil in the region has already contained much moisture, it is quickly saturated and incapable of absorbing further water. This leads to very high discharge rates along the watercourses of the Wupper region.

Of high importance is that emergency measures are conducted at the right places to assure the protection of critical objects such as dams, bridges or industry facilities. Up-to-date sensor data are the foundation for a sensible decision making. Therefore, the organization for disaster relief cooperates with the Wupperverband and requests water level measurements for all parts of the river basin. These data are necessary to compute the degree of danger of individual river reaches and to create exact situation awareness.

Certain parts of the river courses are not densely enough covered with pre-installed water level gauges. So, the emergency management decides to deploy new mobile geosensors on-the-fly at those reaches of the river. These geosensors increase the temporal and spatial density of precipitation, water level or stream flow measurements. The gathered data serve as input for exact stream flow models in order to compute risk estimations and forecasts. For this scenario, we assume that the Wupperverband is already capable of performing those computations in real-time.

As mentioned above, a local Sensor Web infrastructure is already in place and in productive use for the affected region. It is managed and maintained by the Wupperverband. This infrastructure enables the interoperable access to available water gauges and weather stations and their collected data. The information systems used by the emergency management rely on data provided by this Sensor Web. The newly deployed geosensors have to be made available within this infrastructure in an ad-hoc manner, so that operational applications of the emergency management can directly utilize their collected observations. Immediately after the deployment of the new geosensors in the field, they have to be accessible via the Sensor Web. The existing, persistent water gauges and precipitation sensors of the Wupperverband are partly not equipped with remote data transmission and require a manual readout of the last measured values. Other sensors report their data automatically but with a slow rate. Thunderstorms with heavy rain are short-term events which require a quick reaction time. So, an ad-hoc integration of suitable sensors deployed at endangered locations and transmitting data frequently to a base station can significantly enhance the monitoring and management of the flooding situation. An example for a mobile water gauge sensor, that can be used in the outlined scenario and serves as a test object within this work, is the G-WaLe sensor system as described in section 2.2.

Another example scenario, where an on-the-fly integration of new geosensors facilitates their usage, is construction site monitoring. Constructions built next to or in a water body have to be equipped with multiple kinds of sensors, e.g., to gain information about the quality of the water fed into the river. This use case is not as time critical as disaster management. The construction process is a priori known, at least several weeks before it starts. However, an easy and quick integration of new geosensors into a coherent infrastructure would also facilitate this scenario.

4. An architecture for the on-the-fly integration of geosensors

In this section, we present an architecture that enables the on-the-fly integration of sensors with the Sensor Web. We apply this architecture to the flood management use case and the G-WaLe sensor system in the following section 5.

4.1 Sensor Bus - A publish/subscribe mechanism for the Sensor Web

An automated on-the-fly integration of sensors and Sensor Web services requires a mechanism that enables a sensor to publish its availability as well as its measured data and enables a service to subscribe for sensors to subsequently receive their data. We realize such a publish / subscribe mechanism here by introducing an intermediary *sensor integration layer* between the sensor layer and the Sensor Web layer; see figure 6. This intermediary layer is externally designed as a logical bus - the Sensor Bus, as developed by Bröring, Foerster, Jirka & Priess (2010). In this article, we make use of the Sensor Bus and combine it with a generic driver mechanism (section 4.2) to apply it to the flood management use case and the G-WaLe sensor. In the following the concept of the Sensor Bus is outlined. Aligned with the *message bus pattern* (Hohpe & Woolf, 2003), the Sensor Bus incorporates (1) a common communication infrastructure, (2) a shared set of adapter interfaces, and (3) a well-defined message protocol. The common communication infrastructure is realized upon an underlying messaging technology. The Sensor Bus is independent of the underlying messaging technology which can therefore be exchanged. It can, for example, be realized

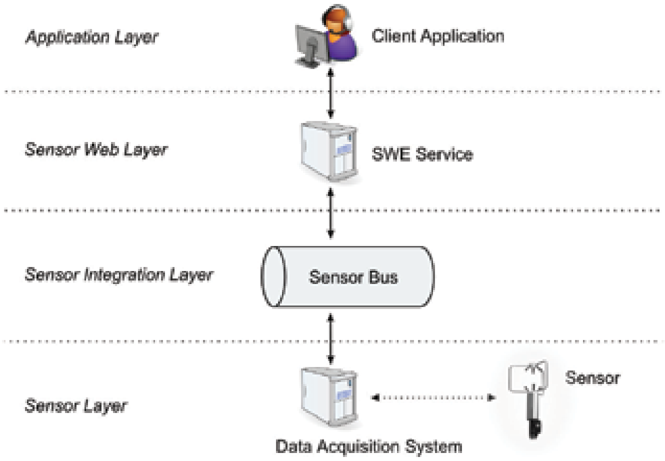


Fig. 6. The sensor infrastructure stack.

with instant messaging systems such as XMPP [5] or IRC [6], but also using Twitter as shown by Bröring, Foerster, Jirka & Priess (2010). Services as well as sensors can publish messages to the bus and are able to subscribe to the bus for receiving messages in a push-based communication style. The different components (i.e., sensors and Sensor Web services) can subscribe and publish to the Sensor Bus through *adapters*. Those adapters convert the service or sensor specific communication protocol to the internal bus protocol; see figure 7). A detailed analysis of interactions between the sensor layer and the Sensor Web layer, which emerge when introducing the Sensor Bus as an intermediary layer, is conducted by Bröring,

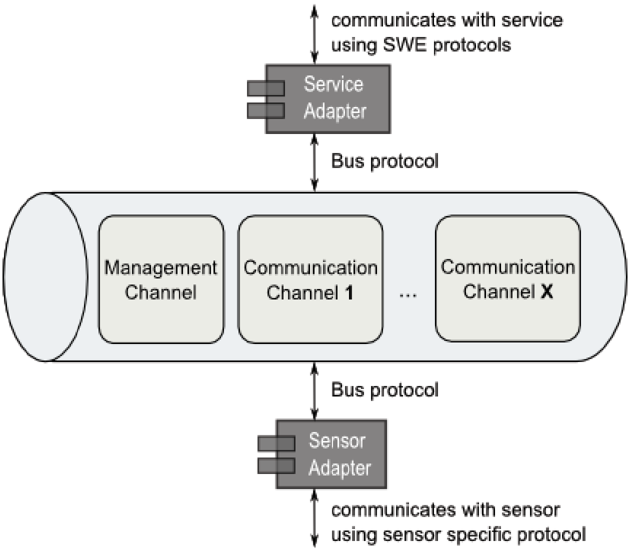


Fig. 7. Components of the Sensor Bus.

---

[5] `http://www.xmpp.org/`

[6] `http://www.irc.org/`

Foerster & Jirka (2010). Those interactions are realized through particular bus messages. The bus contains two different kinds of channels to exchange such messages (figure 7). First, the management channel is used to register a component at the bus and publish its metadata, i.e. sensor characteristics or service requirements. Second, there are communication channels, where sensors publish their measurements. Each communication is dedicated to a particular observed property (e.g., temperature or water level). The most important bus messages realize the following functionalities:

- *connecting a sensor* and passing a sensor description (encoded in SensorML)
- *subscribing a service* for specific sensors by defining required sensor characteristics
- *publishing data* measured by a sensor
- *directing* sensors / services to bus communication channels

A detailed description of the message protocol of the Sensor Bus and a proof-of-concept implementation can be found at Bröring, Foerster, Jirka & Priess (2010).

4.2 Sensor interface descriptors - A generic driver mechanism for geosensors

Before a geosensor can be integrated with the Sensor Web, a driver is required which understands the native sensor protocol and offers a well-defined interface that makes the functionality of the sensing device available to the outside. Since there are numerous kinds of environmental sensors with various interfaces available, we propose the usage of a generic driver mechanism for sensors. The Sensor Interface Descriptor (SID) model described in our previous work (Bröring & Below, 2010; Bröring, Below & Foerster, 2010) can be used to provide this functionality. The SID model supports the declarative description of sensor interfaces. It is designed as a profile and extension of OGC's SensorML standard (section 2.1). An instance of the SID model, designed for a particular type of sensor, defines the precise communication protocol, accepted sensor commands, or processing steps for transforming incoming raw sensor data. Based on that information, a so-called SID interpreter is able to establish the connection to the sensor and translates between the sensor protocol and a target protocol. For this work, we have developed a generic SID interpreter which acts as a sensor adapter and converts data received from a sensor in order to transfer it to the Sensor Bus; see figure 8. SID interpreters can be built independently of particular sensor technology since they are based on the generic SID model. Figure 9 depicts an excerpt of this model. The blue colored, SID specific classes extend the beige colored classes defined in SensorML. The SID is strictly encapsulated within the *InterfaceDefinition* element of a SensorML document. Since the SID is designed for a certain type of sensor and not for a particular sensor instance, this encapsulation makes the interface description independent of the rest of the SensorML document. Consequently, it is easily exchangeable and can also be reused in SensorML documents of other sensors of the same type.

The SID model extends the elements of the Open Systems Interconnection (OSI) reference model (ISO/IEC, 1996) which are already contained in SensorML and associated with the interface definition. The OSI model is the basis for designing network protocols and therefore consists of a number of layers. On the lowest layer, the physical layer, the structure of the raw incoming and outgoing sensor data stream is described. This includes the definition of block identifiers and separator signs within the data stream. Next, encoding and decoding steps can be applied to the raw sensor data. Therefore, according processes can be specified and attached to the data link, network, transport, and session layer. Such processing steps

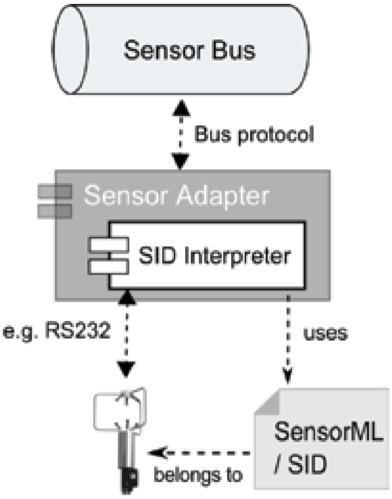


Fig. 8. SID interpreter as a sensor adapter for the Sensor Bus

are for example character escaping or checksum validation which are necessary for reliable communication with sensors. Finally, the application layer can be used to define commands accepted by a sensor, including their parameters, pre- and postconditions, as well as response behavior. Those command definitions can for example be used by a Sensor Planning Service (section 2.1) to provide an interoperable interface for tasking. A detailed description of the model can be found at Bröring & Below (2010); Bröring, Below & Foerster (2010). Sensor

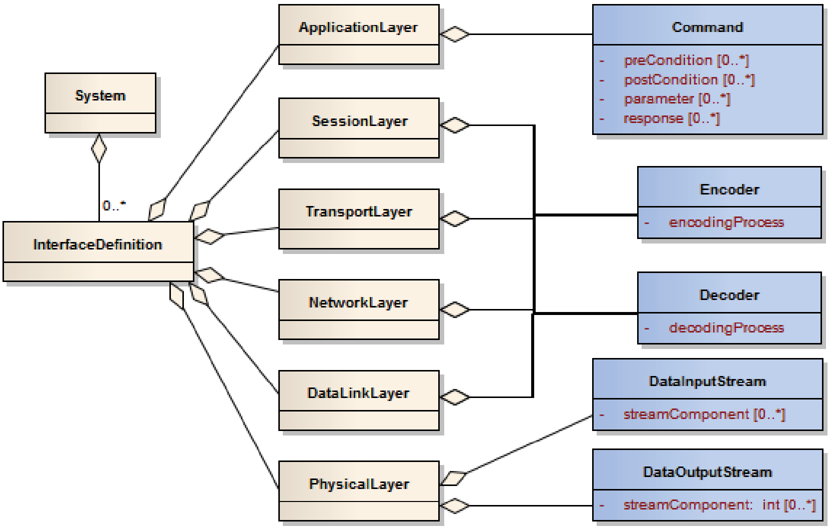


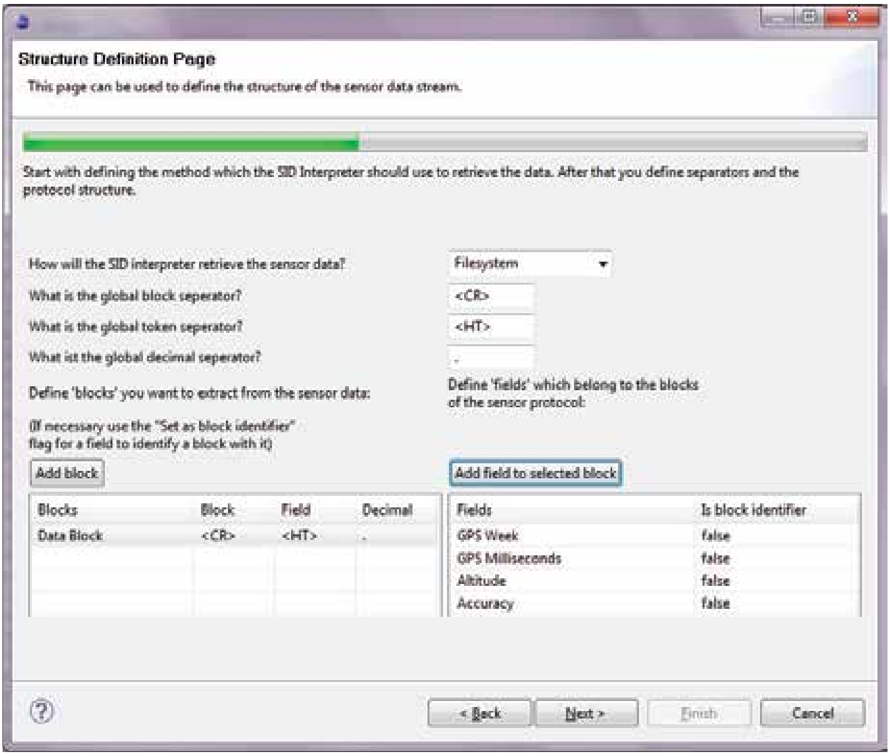
Fig. 9. Overview of SID extension to SensorML.

interfaces and communication protocols are often complex. Consequently, the design and manual creation of SID instances is not straightforward. Hence, a visual SID creator has been developed (Bröring, Bache, Bartoschek & van Elzakker, 2011). This graphical tool (see figure 10) supports users in describing the sensor interface and generate SID instances for their geosensors. The creator can be used by sensor manufacturers to create SIDs for their products and provide them to clients for an easy integration of their geosensors with the Sensor Web. Alternatively, this tool can help owners of sensors to create SIDs if they are not already available from the sensor manufacturer.

5. Application

This section applies the above presented architecture to the use case of a flood in the Wupper region where G-WaLe sensors need to be dynamically deployed to increase the density of the measurement network (section 3.2). A local Sensor Web infrastructure is already in place and built upon the Sensor Bus. New geosensors need to be integrated in an on-the-fly manner. As a proof-of-concept, we demonstrate in the following the integration of the G-WaLe sensor with a Sensor Observation Service.

To connect the G-WaLe sensor to the Sensor Bus we utilize the generic sensor adapter which incorporates an SID interpreter (section 4.2). The SID for the G-WaLe sensor has been designed using the SID creator tool that follows the wizard user interface pattern (Tidwell, 2006). Figure 10 shows the page of the wizard that allows to define how to physically connect to the sensor, e.g., via USB, serial connection, or with an indirect file system connection, as chosen here. The G-WaLe floater devices store measurements in a data file on an FTP folder. These measurement files are read out by the SID interpreter. To enable the SID interpreter to understand the structure of the data file, i.e. the sensor protocol, the page of the SID creator shown in figure 10 further allows to define the structure of the data file. A G-WaLe data file


Structure Definition Page

This page can be used to define the structure of the sensor data stream.

Start with defining the method which the SID Interpreter should use to retrieve the data. After that you define separators and the protocol structure.

How will the SID interpreter retrieve the sensor data? Filesystem

What is the global block seperator? <CR>

What is the global token seperator? <HT>

What ist the global decimal seperator? .

Define 'blocks' you want to extract from the sensor data:

(If necessary use the "Set as block identifier" flag for a field to identify a block with it)

Define 'fields' which belong to the blocks of the sensor protocol:

Blocks	Block	Field	Decimal
Data Block	<CR>	<HT>	.

Fields	Is block identifier
GPS Week	false
GPS Milliseconds	false
Altitude	false
Accuracy	false

Fig. 10. Sensor protocol defined in SID Creator.

contains a timestamp in GPS weeks and milliseconds, the measured elevation in meters, as well as the accuracy of the measurement in meters. Each row of the file represents a data block and ends with the carriage return. The fields of the block are divided by the tab character. An example is shown in listing 1. This structure is defined in the SID creator as shown in figure 10. The signs for block and field separation are specified in ASCII code, i.e., <*CR*> for a carriage return and <*HT*> for a tab character.

Listing 1. Example of a G-WaLe data file; each line contains tokens for measured *GPS week*, *GPS milliseconds*, *elevation (m)*, and *accuracy (m)*.

```
1570   547200000   93.831   0.04
1570   548100000   97.160   0.04
1570   549000000   93.804   0.04
1570   549900000   91.529   0.04
```

While other sensor protocols contain multiple kinds of data block structures, that can also be defined in the SID creator, the G-WaLe data file uses only one kind of data block structure that contains the four measurement fields. Those fields are named in the SID creator (e.g., the third field is called *Elevation*), so that they can be referenced during further processing of the data. Listing 2 shows the according SID code generated by the SID creator.

Listing 2. Excerpt of the generated SID file.

```
<sid:DataOutputStream>
  <dataOutputComponents>
    <ComponentList>
      <component name="Data Block">
        <swe:DataBlockDefinition>
          <swe:components>
            <swe:DataRecord>
              <swe:field name="GPS Week"/>
              <swe:field name="GPS Milliseconds"/>
              <swe:field name="Elevation"/>
              <swe:field name="Accuracy"/>
            </swe:DataRecord>
          </swe:components>
          <swe:encoding>
            <swe:TextBlock tokenSeparator="<HR>" blockSeparator="<CR>"
              decimalSeparator="."/>
          </swe:encoding>
        </swe:DataBlockDefinition>
      </component>
      ..
```

Once the sensor adapter is started, it sends the message for connecting the sensor to the Sensor Bus and advertises its characteristics. Depending on the phenomenon observed by the sensor, internal management components of the Sensor Bus direct the sensor to the appropriate communication channel. There, the sensor adapter publishes the data measured by the G-WaLe sensor.

Similar to the registration of a sensor, a service adapter subscribes a service, here a Sensor Observation Service (SOS), at the Sensor Bus and defines the sensor characteristics in which the service is interested. For example, a service can declare interest in geosensors which observe the property *Elevation*. Then, an internal management component of the Sensor Bus points the service to each sensor that matches the requested characteristics and directs the service to the communication channel used by the sensor. Subsequently, the service adapter registers the sensor at the SOS by calling the *RegisterSensor* operation.

As soon as the sensor adapter publishes measurements in the communication channel, the service adapter inserts that data as observations into the SOS. Therefore, the service adapter transforms the received data to *InsertObservation* requests and sends it to the SOS. An example of such a request is shown in Listing 3.

Listing 3. Example of a simplified SOS InsertObservation request.

```
<sos:InsertObservation service='SOS' version='1.0.0'>
  ...
  <Observation>
    <samplingTime>
      <gml:timePosition>
        2011-15-07T13:54:23
      </gml:timePosition>
    </samplingTime>
    <procedure xlink:href="http://myserver.org/sensor/G-WaLe-1"/>
    <observedProperty
      xlink:href="http://sweet.jpl.nasa.gov/1.1/property.owl#Elevation"/>
    <featureOfInterest>
      <sa:SamplingPoint gml:id="p1">
        <sa:sampledFeature xlink:href=""/>
        <sa:position>
          <gml:Point>
            <gml:pos srsName="urn:ogc:def:crs:EPSG:4326">52.64 7.12</gml:pos>
          </gml:Point>
        </sa:position>
      </sa:SamplingPoint>
    </featureOfInterest>
    <result xsi:type="gml:MeasureType" uom="m">
      93.831
    </result>
  </Observation>
</sos:InsertObservation>
```

Henceforth, the data is stored by the SOS and available to clients via its standardized interface. It can be accessed and retrieved in a pull-based manner. An example of such a client application which allows accessing and displaying sensor data from an SOS is shown in figure 11 and available as open source at 52°North[7].

Similarly to registering an SOS, a Sensor Alert Service or Sensor Event Service (section 2.1) can be subscribed at the Sensor Bus to provide data in a push-based manner. Those push-based services receive the incoming data, filter it by certain predefined criteria and forward it to interested clients.

Once available on the Sensor Web, the elevation measurements coming from the G-WaLe sensor can be related to the measurements of water gauges within the same river, and can be used for determination of the moment the wave of the flood passes the mobile water gauge.

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[7] `http://52north.org/thinSWEclient`

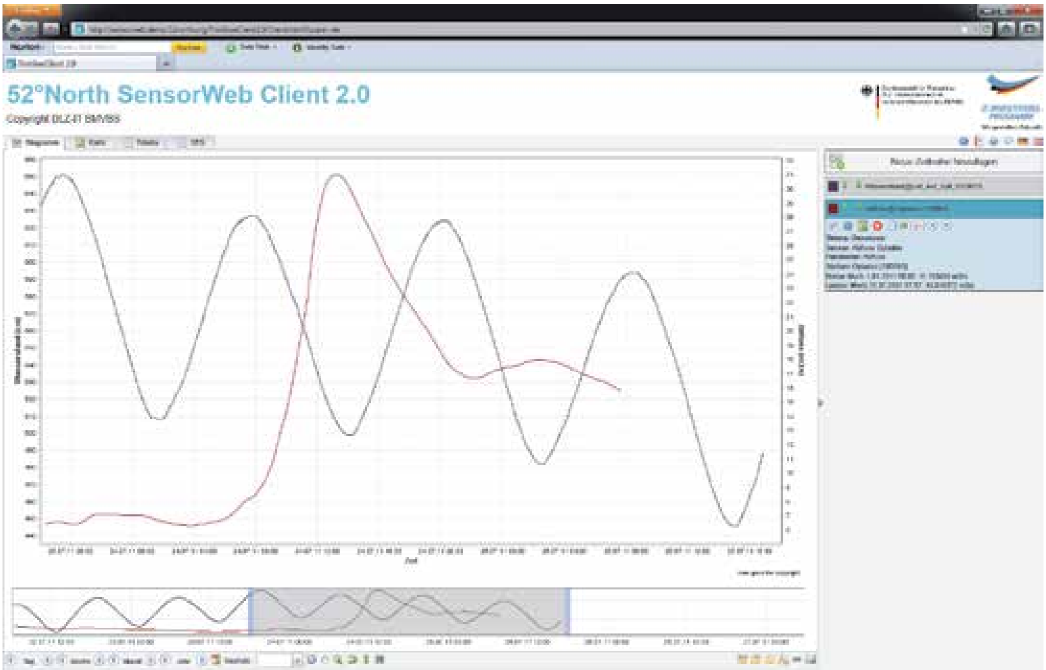

Fig. 11. 52°North SOS Web client application.

6. Conclusions & outlook

In this chapter, we stress the need for methods that enable an easy and flexible integration of geosensors with the Sensor Web, as a coherent information infrastructure. Thereby, an on-the-fly integration needs to be automated to minimize administration and configuration efforts. Such a facilitated integration of geosensors can support various use cases, in particular disaster management. Here, a flood management use case in the region of the German river Wupper is described, where heavy rain events have caused a local flood. Additional water gauges are needed to increase the measurement density and improve flood management. We demonstrate how the G-WaLe sensor, a mobile water gauge, can be used and dynamically integrated with the Sensor Web by means of the developed architecture.

The architecture consists of (1) the Sensor Bus, a message bus that realizes a publish / subscribe mechanism between sensors and web services and (2) the Sensor Interface Descriptor (SID) concept, a generic driver mechanism for geosensors. Both components are available as open source software at 52°North[8]. The presented approach is generic and in related articles we have shown that it can also facilitate the integration of radiation sensors (Bröring, Below & Foerster, 2010), a basis for managing nuclear disasters, or the integration of oceanographic sensors to fight oil spills or harmful algae plumes (Bröring, Maué, Janowicz, Nüst & Malewski, 2011).

The SID concept enables the operation of geosensors without the necessity of manually implementing a driver for the instrument. Instead, an SID file is created which describes the structure of the sensor's protocol. This SID creation is supported by the SID creator tool. Any

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[8] Sensor Bus: `http://52north.org/sensorBus`; SID concept: `http://52north.org/sid`

SID interpreter implementation that follows the SID specification (Bröring & Below, 2010) can execute the SID file and can communicate with the geosensor. Of course, the current design of the SID model does not accommodate every possible sensor protocol, but a broad variety of manufacturer specific protocols is already covered. Possible extensions of the SID specifications will broaden the range of supported protocols.

For the future, we are particularly interested in applying the developed approach in countries, such as Pakistan where floods have caused enormous damage in the recent past. In under-developed regions, where no static water gauge network is maintained by the state, a system that enables the on demand deployment and on-the-fly integration of water gauge sensors would significantly support flood management.

7. Acknowledgment

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8. References

Aasa, A., Järv, O. & Ahas, R. (2008). Developing a model to determine the impacts of climate change on the geographical distribution of tourists, *in* L. Kooistra & A. Ligtenberg (eds), *Sensing a Changing World 2008*, Wageningen University, pp. 55 – 58.

Aberer, K., Hauswirth, M. & Salehi, A. (2006). Middleware Support for the Internet of Things, *5. GI/ITG KuVS Fachgespraech - Drahtlose Sensornetze* pp. 15 – 19.

Beltrami, P. (2007). G-WaLe: GALILEO Supported Measurement of Water Level.
URL: *http://purl.oclc.org/sensor/G-WaLe*

Boch, B. & Schreiber, W. (2007). Hochwasser - Der Abend, als die Flut kam, *Westdeutsche Zeitung* .
URL: *http://www.wz-newsline.de/?redid=169454*

Botts, M. (2007). *OGC Implementation Specification 07-000: OpenGIS Sensor Model Language (SensorML)*, Open Geospatial Consortium.

Botts, M., Percivall, G., Reed, C. & Davidson, J. (2008). OGC Sensor Web Enablement: Overview and High Level Architecture, *in* S. Nittel, A. Labrinidis & A. Stefanidis (eds), *GeoSensor Networks, 2nd International Conference, GSN 2006*, Vol. 4540 of *Lecture Notes In Computer Science*, Springer, Boston, MA, USA, pp. 175–190.

Bröring, A., Bache, F., Bartoschek, T. & van Elzakker, C. P. (2011). The SID Creator: A Visual Approach for Integrating Sensors with the Sensor Web, *in* S. C. M. Geertmann, W. Reinhardt & F. Toppen (eds), *Advancing Geoinformation Science for a Changing World, The 14th AGILE International Conference on Geographic Information Science, Utrecht (Netherlands)*, Vol. 1 of *Lecture Notes in Geoinformation and Cartography*, Springer, pp. 143–162.

Bröring, A. & Below, S. (2010). *OGC Discussion Paper 10-134: Sensor Interface Descriptors*, Open Geospatial Consortium.

Bröring, A., Below, S. & Foerster, T. (2010). Declarative Sensor Interface Descriptors for the Sensor Web, *WebMGS 2010: 1st International Workshop on Pervasive Web Mapping, Geoprocessing and Services*, http://webmgs2010.como.polimi.it, Como, Italy.

Bröring, A., Echterhoff, J., Jirka, S., Simonis, I., Everding, T., Stasch, C., Liang, S. & Lemmens, R. (2011). New Generation Sensor Web Enablement, *sensors* 11(3): 2652–2699.

Bröring, A., Foerster, T. & Jirka, S. (2010). Interaction Patterns for Bridging the Gap between Sensor Networks and the Sensor Web, *8th IEEE International Conference on Pervasive Computing and Communications Workshops (PERCOM Workshops)*, IEEE, Mannheim, Germany, pp. 732 – 737.

Bröring, A., Foerster, T., Jirka, S. & Priess, C. (2010). Sensor Bus: An Intermediary Layer for Linking Geosensor Networks and the Sensor Web, *COM.Geo '10: Proceedings of the 1st International Conference on Computing for Geospatial Research and Application*, ACM, New York, NY, USA, pp. 1–8.

Bröring, A., Janowicz, K., Stasch, C. & Kuhn, W. (2009). Semantic Challenges for Sensor Plug and Play, *in* J. Carswell, S. Fotheringham & G. McArdle (eds), *Web & Wireless Geographical Information Systems, W2GIS 2009*, Vol. 5886 of *Lecture Notes in Computer Science*, Springer, Maynooth, Ireland, pp. 72–86.

Bröring, A., Jürrens, E. H., Jirka, S. & Stasch, C. (2009). Development of Sensor Web Applications with Open Source Software, *First Open Source GIS UK Conference (OSGIS 2009), 22 June 2009, Nottingham, UK.*

Bröring, A., Maué, P., Janowicz, K., Nüst, D. & Malewski, C. (2011). Semantically-enabled Sensor Plug & Play for the Sensor Web, *sensors* 11(8): 7568–7605.

Bröring, A. & Meyer, O. (2008). Bereitstellung und Visualisierung hydrologischer Zeitreihen mit Hilfe standardisierter Webdienste, *in* J. Strobl, T. Blaschke & G. Griesebner (eds), *Angewandte Geoinformatik 2008. Beiträge zum 20. AGIT-Symposium Salzburg*, Wichmann, Salzburg, Austria, pp. 354–364.

Bröring, A., Stasch, C. & Echterhoff, J. (2010). *OGC Interface Standard 10-037: SOS 2.0 Interface Standard; candidate standard*, Open Geospatial Consortium.
URL: *http://www.opengeospatial.org/standards/requests/73*

Chung, L.-K., Baranski, B., Fang, Y.-M., Chang, Y.-H., Chou, T.-Y. & Lee, B. J. (2009). A SOA based Debris Flow Monitoring System - Architecture and Proof-of-Concept Implementation, *17th International Conference on Geoinformatics 2009*, IEEE, Fairfax, VA, USA.

Cox, S. (2007). *OGC Implementation Specification 07-022r1: Observations and Measurements - Part 1 - Observation schema*, Open Geospatial Consortium.

Elze, R., Rieth, K., Walther, P., Mueller, U., Hegg, C. & Schmid, F. (2004). *Event analysis - August 2002 flood in the watercourses of the Osterzgebirge mountains*, Sächsisches Landesamt für Umwelt und Geologie.

Foerster, T., Bröring, A., Jirka, S. & Müller, J. (2009). Sensor Web and Geoprocessing Services for Pervasive Advertising, *in* J. Müller, P. Holleis, A. Schmidt & M. May (eds), *Proceedings of the 2nd Workshop on Pervasive Advertising - in Conjuction with Informatik 2009*, pp. 88 – 99.

Fruijtier, S., Dias, E. & Scholten, H. (2008). Geo Mindstorms: Investigating a sensor information framework for disaster management processes, *in* L. Kooistra & A. Ligtenberg (eds), *Sensing a Changing World 2008*, Wageningen University, pp. 50 – 54.

HOBILabs (2008). Hydroscat-4 spectral backscattering sensor - user's manual. URL: *http://purl.oclc.org/sensor/HOBILabs/Hydroscat4*

Hohpe, G. & Woolf, B. (2003). *Enterprise integration patterns: Designing, building, and deploying messaging solutions*, Addison-Wesley Longman Publishing, Boston, MA, USA.

ISO/IEC (1996). *ISO/IEC 7498-1: Information technology – Open Systems Interconnection – Basic Reference Model: The Basic Model*, ISO.

Jirka, S., Bröring, A. & Stasch, C. (2009). Applying OGC Sensor Web Enablement to Risk Monitoring and Disaster Management, *GSDI 11 World Conference, Workshop on Sensorweb Enablement: Strengthening the SDI*, GSDI, Rotterdam, Netherlands.

Lee, K. (2000). IEEE 1451: A Standard in Support of Smart Transducer Networking, *17th Instrumentation and Measurement Technology Conference*, Vol. 2, IEEE, pp. 525 – 528.

Na, A. & Priest, M. (2007). *OGC Implementation Specification 06-009r6: OpenGIS Sensor Observation Service (SOS)*, Open Geospatial Consortium.

Nittel, S. (2009). A Survey of Geosensor Networks: Advances in Dynamic Environmental Monitoring, *Sensors* 9: 5664 – 5678.

Nittel, S., Labrinidis, A. & Stefanidis, A. (2008). Introduction to Advances in Geosensor Networks, *GeoSensor Networks, 2nd International Conference, GSN 2006*, Vol. 4540 of *Lecture Notes in Computer Science*, Springer, Boston, MA, USA, pp. 1–6.

Parry, M., Canziani, O., Palutikof, J., van der Linden, P. & Hanson, C. (eds) (2007). *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press.

Sat, M., Müller, M. U. & Heier, C. (2005). Sensorweb in der Wasserwirtschaft - Untersuchung der Einsatzfähigkeit des SOS in der Wasserwirtschaft, *GI-Tage Münster*, Münster.

Scheuren, J.-M., le Polain de Waroux, O., Below, R., Guha-Sapir, D. & Ponserre, S. (2007). *Annual Disaster Statistical Review*, Center for Research on the Epidemiology of Disasters (CRED).

Schimak, G. & Havlik, D. (2009). Sensors Anywhere - Sensor Web Enablement in Risk Management Applications, *ERCIM News 2009 - The Sensor Web* 76: 40 – 41.

Sea-Bird-Electronics (2010). Sbe 37-smp microcat - conductivity and temperature recorder with rs-232 interface and integral pump. URL: *http://purl.oclc.org/sensor/Seabird37MP*

Shepherd, D. & Kumar, S. (2005). *Distributed Sensor Networks*, CRC Press, chapter Microsensor Applications, pp. 11–29.

Simonis, I. (2007). *OGC Implementation Specification 07-014r3: OpenGIS Sensor Planning Service*, Open Geospatial Consortium.

Spies, K.-H. & Heier, C. (2008). OGC Sensor Web in der Praxis - Bereitstellung von Sensordaten in Geodateninfrastrukturen und personalisierter Hochwasserwarndienst, *in* J. Strobl, T. Blaschke & G. Griesebner (eds), *Angewandte Geoinformatik 2008. Beiträge zum 20. AGIT-Symposium Salzburg*, Wichmann, Salzburg, Austria, pp. 721–725.

Stasch, C., Walkowski, A. C. & Jirka, S. (2008). A Geosensor Network Architecture for Disaster Management based on Open Standards, *in* M. Ehlers, K. Behncke, F. W. Gerstengabe, F. Hillen, L. Koppers, L. Stroink & J. Wächter (eds), *Digital Earth Summit on Geoinformatics 2008: Tools for Climate Change Research*, Wichmann, Potsdam, Germany, pp. 54–59.

Subcommittee on Disaster Reduction (2008). *Grand Challenges for Disaster Reduction (Second Printing)*, National Science and Technology Council - Committee on Environment and Natural Resources.

Tidwell, J. (2006). *Designing Interfaces: Patterns for Effective Interaction Design*, O'Reilly.

WETLabs (2010). Eco 3-measurement sensor (triplet) - user's guide.
URL: *http://www.wetlabs.com/products/pub/eco/tripletp.pdf*

Wupperverband (2001). Digitales Informationsmanagement zur Umsetzung der Wasserrahmenrichtlinie am Beispiel der Wupper, *Technical report*, Ministerium für Umwelt und Naturschutz, Landwirtschaft und Verbraucherschutz des Landes Nordrhein-Westfalen.

5

Comprehensive Monitoring of Wildfires in Europe: The European Forest Fire Information System (EFFIS)

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1. Introduction

Fires are an integral component of ecosystem dynamics in European landscapes. However, uncontrolled fires cause large environmental and economic damages, especially in the Mediterranean region. On average, about 65000 fires occur in Europe every year, burning approximately half a million ha of wildland and forest areas; most of the burnt area, over 85%, is in the European Mediterranean region. Trends in number of fires and burnt areas in the Mediterranean region are presented in Fig. 1.

Recent analyses of the available data in the European Forest Fire Information System (EFFIS) show that over 95% of the fires in Europe are human-induced. The split of causes shows that most of them are due to misuse of traditional practices of straw burning of shrub-burning to recover areas for cattle feeding.

Although European countries have collected information on forest fires since 1970s, the lack of harmonized information at the European level has prevented a holistic approach for forest fire prevention in the Region. The European Forest Fire Information System (EFFIS) has been developed jointly by the European Commission (EC) services (Directorate General Environment and the Joint Research Centre) and the relevant fires services in the countries (forest fires and civil protection services) in response to the needs of European bodies such as the Monitoring and Information Centre of Civil Protection, the European Commission Services and the European Parliament.

EFFIS is a comprehensive system covering the full cycle of forest fire management, from forest fire prevention and preparedness to post-fire damage analysis (see Fig. 2). The system is providing information to over 30 countries in the European and Mediterranean regions,

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and receives detailed information of forest fire events from 22 European countries. It supports forest fire prevention and forest fire fighting in Europe through the provision of timely and reliable information on forest fires.

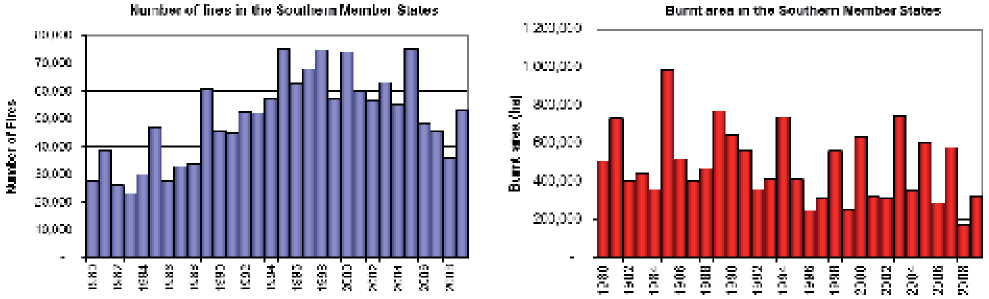

Fig. 1. Number of fires and burnt areas in the European Mediterranean region (source European Commission, 2010)

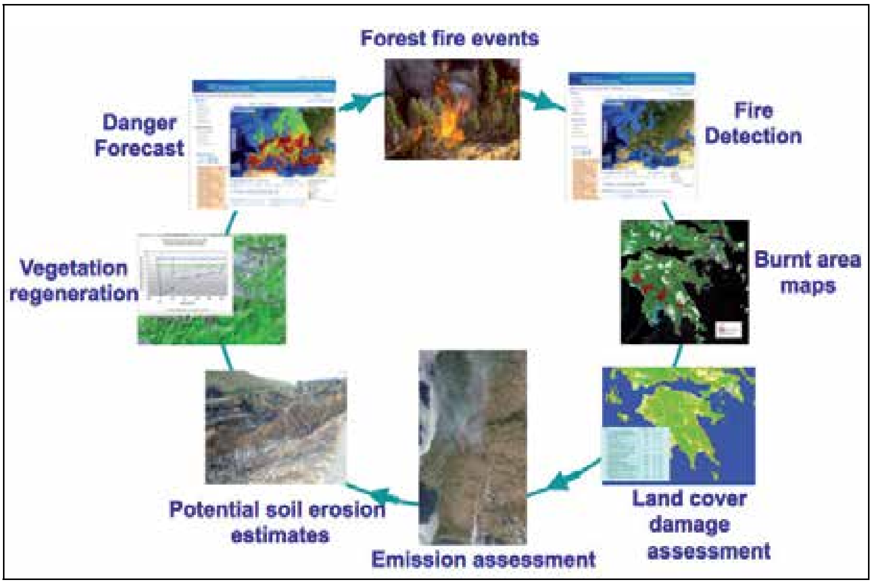

Fig. 2. Fire cycle monitored in EFFIS

This chapter presents the main components of EFFIS and the first steps towards establishing a comprehensive monitoring of forest fires in Europe and describes the different modules of the system. These include: Fire Danger Forecast, Active Fire Detection, Rapid Damage Assessment and post-fire modules dealing with the analysis of land cover damages, post-fire soil erosion, emissions estimates and dispersion of the smoke plume, and finally the monitoring of vegetation recovery in large burnt areas.

EFFIS core applications are based on the use of remote sensing and geographic information systems. Fire danger forecast is computed from two meteorological forecast models, handled by the French Météo-France and the Deutsche Wetter Dienst (DWD), the later providing weather forecast up to one week in advance. These data are used to compute a common European fire danger index based on the Canadian Fire Weather Index (FWI). Near-real time applications such as active fire detection and rapid damage assessment make use of data provided by the MODIS sensor, on board of the NASA TERRA and AQUA satellites for the detection of hot spots (active fires) and the mapping of burnt areas; two full mosaics of Europe are processed daily, providing information on burnt areas produced by large fires (over 40 ha). The system architecture is based on web data services that permit access to information in real time through web mapping and web feature services†; the EFFIS web interface is presented in Fig. 3.

WELCOME TO EFFIS

The European Forest Fire Information System (EFFIS) supports the services in charge of the protection of forests against fires in the EU countries and provides the European Commission services and the European Parliament with updated and reliable information on wildland fires in Europe.

CURRENT FIRE SITUATION

The most up to date information on the current fire season in Europe and in the Mediterranean area. This includes today meteorological fire danger maps and forecast up to 6 days, daily updated satellite images of the last 7 days, maps of the latest hot spots and fire perimeters also updated daily.

FIRE NEWS

A selection of news from the press on wildland fires in Europe updated daily by the EFFIS team. News can be browsed for specific countries selected by the user from the news map.

EFFIS ADVANCED VIEWER

The traditional EFFIS web mapping interface providing access to all main EFFIS modules, historical data and advanced analysis capabilities to experienced users.

MEMBER AREA

Private area for data and information exchange among the EC services, the fire protection services of the EU Member States and all the countries of the EFFIS network.

Fig. 3. EFFIS web interface

This information is then integrated into national geographic information systems for further analysis at the country level.

Despite the maturity of the system, the further development of EFFIS continues through the incorporation of new modules such as those that will be used for the assessment of socio-economic impact of forest fires as well as the harmonization of fire causes; it must be noted that over 95% of the fires in Europe are caused by humans.

The long time-series of fire data in EFFIS - over 25 years for Mediterranean countries – is used to model the potential effect of climate change regarding fire danger in the Mediterranean region and the expected impact in terms of burnt areas in the region.

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† http://effis.jrc.ec.europa.eu

2. EFFIS system architecture

EFFIS has been designed as a modular geographic information system. It consists of Web based modules, a data processing chain and spatial databases that store, process and disseminate forest fire information at a pan-European scale. The underlying system is driven by software tools that process meteorological and optical satellite image data on a daily basis to produce fire danger forecast and information on the perimeters of burnt areas. EFFIS also provides access to a historical spatial database of forest fire information in Europe that scientists and policy makers can use for retrospective analysis.

EFFIS can be considered to function as two inter-dependent systems within a GNU/Linux environment running on two 64-bit Red Hat Linux servers. The 'back-end' modules are scheduled to run on a daily basis to download and process spatial datasets to produce the forest fire information. The 'front-end' components of EFFIS consist of web-based mapping tools that publish the EFFIS layers and allow users to query and analyse the information through a web-browser. There are also tools to retrieve and aggregate forest-fire event news per country. These two main components are discussed in what follows.

2.1 Processing

All of the spatial and associated attribute data are stored in ORACLE Spatial, a relational database management system, while the MODIS satellite imagery are stored as flat files. Several Python and Bash Shell scripts that are based on the GDAL/ORG geospatial library (Anon, 2011) have been developed to pre-process and manage raster and vector spatial datasets that are updated on a daily basis or in some cases at a higher frequency.

Linux Bash scripts have been developed to download Moderate-resolution Imaging Spectroradiometer (MODIS) TERRA & AQUA satellite image data from the German AeroSpace Centre (DLR) receiving station. The satellite scenes are mosaicked to produce pan-European mosaics at 250 meters spatial resolution, which are then incorporated into the 'Current Situation' Web viewer. They are also used as a basis for the Rapid Damage Assessment (RDA) mapping, which is carried out by a fire expert on a daily basis during the fire season. This process involves the delineation of the extent of forest fire events based on the semi-automatic classification of MODIS satellite imagery using ancillary spatial datasets. The RDAs are stored directly in Oracle Spatial from where they are also published in a variety of formats. In addition, a fully automated processing chain is used to extract, store and publish the MODIS hot spots data (i.e. active fires, detected from satellite imagery as areas significantly hotter than the surrounding background. See paragraph "Active Fire Detection").

2.2 Web-based tools

The EFFIS website is developed within the Joomla! Content Management System. The web-mapping interface is the core tool of the EFFIS front end and in particular the 'Current Situation' Map Viewer[‡], which is a 'light' client, built using a number of JavaScript libraries that include OpenLayers, jQuery, along with Python and PHP/Mapscript on the server side.

[‡] http://effis.jrc.ec.europa.eu/current-situation

The viewer provides direct access to the FWI as WMS, the locations of the hot spots and Burnt Area as well as the daily MODIS mosaics. It also allows the user to query and retrieve attribute information from the datasets.

The EFFIS website also provides access to a fire news geolocated feed (GeoRSS). These fire news data are detected on a daily basis from a plethora of news feed on the web. The back end of EFFIS provides a section to geoparse, translate and archive the fire news in the database. The main aim of collecting the fire news data is to provide ancillary information to the fire expert that performs the rapid damage-assessment mapping, and a synoptic view of press information to forest fire managers.

GeoServer and UMN Mapserver are both used for the management and publication of the fire danger forecast and the other fire-related layers in a wide range of formats including INSPIRE and Open Geospatial Consortium (OGC) standards such as:

- Web Map Services (WMS) which render map data in a pictorial image format over the internet;
- Web Feature Services (WFS) that encode vector data using Geographic Mark-up Language (GML);
- Web Coverage Services (WCS) that disseminates gridded or raster data. ---

2.3 Future advances

Exploratory research is currently on-going to integrate Volunteered Geographic Information (VGI) and Web2.0 services into the EFFIS processing work flow. This has the specific aim to harness a new resource of spatially referenced information in the form of photographs from services such as Flickr and Panoramio, tweets from Twitter and potentially videos from YouTube. Although these services are relatively new, their use is increasing and they have the potential to provide contextual information that can provide news alerts and ancillary information during the fires and in post-fire events.

Other research aims to utilise in-situ meteorological data from meteorological sensors using the OGC Sensor Observation Service (SOS) specification. These sensor data can be used to produce more localized estimates of the Fire Weather Index and its related sub-indices.

3. The European Fire Database

The European Fire Database is the largest repository of information on individual fire events in Europe. It is the end product of a long collaboration between European countries and the European Commission on forest fires.

Since 1989 several regulations have supported the creation of forest fire information systems in the countries to monitor and evaluate the effectiveness of the measures taken at the European level. To this end the countries had to make available to the EC a minimum common set of data on forest fires. Thus a first fire database was established with information on forest fires, their size and causes. The systematic collection of a core set of data on each fire event started covering at that time six Member States of the Union: Germany, Portugal, Spain, France, Italy and Greece.

Since 2000, the forest fire data provided each year by individual EU Member States and other European countries have been checked, stored and managed by JRC within EFFIS. The database is now known as the European Fire Database, and the number of Member States and other participating European countries that contribute to it has been gradually increasing.

Today the database reflects the efforts of the 22 contributing countries that have been regularly supplying fire data: Bulgaria, Croatia, Cyprus, Czech, Estonia, Finland, France, Germany, Greece, Hungary, Italy, Latvia, Lithuania, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and Turkey, and contains over 2 million individual wildfire event records, of which about 1.66 million are classified as forest fires.

Each country has its own internal rules of reporting on individual fire events. Some store very detailed information and have complex databases for this purpose; others record only minimal and basic information. The European Fire Database therefore contains a number of commonly gathered characteristics of each fire, all of which can be supplied by all countries. The four main types of information collected are: time of fire, location of fire, size of fire, and cause of fire.

Time of fire

"Date and time of first alert" reflect the local date and time at which the official forest fire protection services were informed of the outbreak of the fire. The "Date and time of first intervention" are the local date and time on which the first fire-fighting units arrived on the scene of the forest fire. And, the "Date and time of fire extinction" are the local date and time on which the fire was completely extinguished (i.e. when the last fire-fighting units left the scene of the forest fire).

Location of fire

Wildand fires in Europe are traditionally geo-located by recording the administrative unit where they started. Two different administrative levels are requested to be specified in order to allow the maximum detail to be recorded for each fire event in the country.

A first administrative level is the province. The Nomenclature of Territorial Units for Statistics (NUTS) is a breakdown of territorial units established by the European Office for Statistics (EuroStat) for the production of regional statistics for the European Union. NUTS-3 level corresponds in most EU countries to the administrative level of provinces. The country provincial code and NUTS-3 code are requested. A second administrative level of information requested is that of the commune, corresponding to the Eurostat NUTS-5 level. This level is much more detailed than the province and is requested also in the Country nomenclature to facilitate the correct attribution of codes and the cross checking of codes with names.

With the widespread use of GPS devices, the location of the ignition point given as geographical coordinates (latitude, longitude) is becoming more widely applied on a routine basis in many countries. When the coordinates provided are projected, the projection parameters are also requested. The geographical coordinates do not replace the specification of the administrative units.

Size of fire

Fire size is broken down into burnt land cover categories whose definition can be found in the Forest Focus Regulation[§], which is compliant with FAO definitions.

Where possible, the burnt area is subdivided into the 4 land cover categories "*Forest*"," *Other Wooded Land*"," *Other Non-wooded Natural land*" and "*Agricultural and Other Artificial land.*" If this is not possible a hybrid category may be used.

The category "*agriculture and other artificial land*" should be excluded in the reported burnt area statistics. It was introduced to enable its separation from the other categories to produce comparable statistics. Thus, since a fire may cover more than one type of land, the reported "total area burnt" is calculated as the sum of the burnt areas of forest, other wooded land and other non-wooded natural land. The burnt area of agricultural and other artificial land burned is not included in the numbers reflecting the burnt area.

Cause of fire

The 4 EU categories for the presumed cause are the following: 1-Unknown; 2-Natural cause (e.g. lightening, volcano); 3-Accidental cause or negligence, meaning connection to a human activity but without any intention of causing the fire (e.g. accidents caused by power lines, railways, works, bonfires, etc.); and 4-Deliberate cause or arson.

Since the currently available information on fire causes in individual countries is much more detailed than simply the 4 classes given above, cause categories following the scheme adopted by the country are also requested in addition to the 4 EU cause codes, together with a full list of local cause codes and descriptions. Based on this, a new scheme to be eventually adopted as a common fire causes classification system in Europe has been proposed.

3.1 Status and content of the database

Information on individual fire events is recorded every year by individual countries and is provided to the JRC, which maintains the database. Contributions from the countries are voluntary, and back-dated data are also accepted if they can be supplied. The submitted data are then pre-processed and validated. The pre-processing includes, for example, changes in the data structure and formats to comply with the harmonized database.

The checks done in the validation phase include checks for temporal plausibility and consistency (extinction time must occur after alert time, for example), location details (correct NUTS codes) and size (plausible size of fire given the time taken to extinguish it). After being checked, requests for clarification may be sent to the country. After the quality checking phase has been finalized the data is transferred into the consolidated European Fire Database which is stored in an Oracle space.

[§] Regulation (EC) No 2152/2003 of the European Parliament and of the Council of 17 November 2003 concerning monitoring of forests and environmental interactions in the Community (Forest Focus), OJ L 324, 11.12.2003, p. 1-8.

The database currently contains about 1.66 million forest fire records. However, since also purely agricultural fires are stored if the country reports them, the total number of records including agricultural fires is just over 2 million records (Fig. 4).

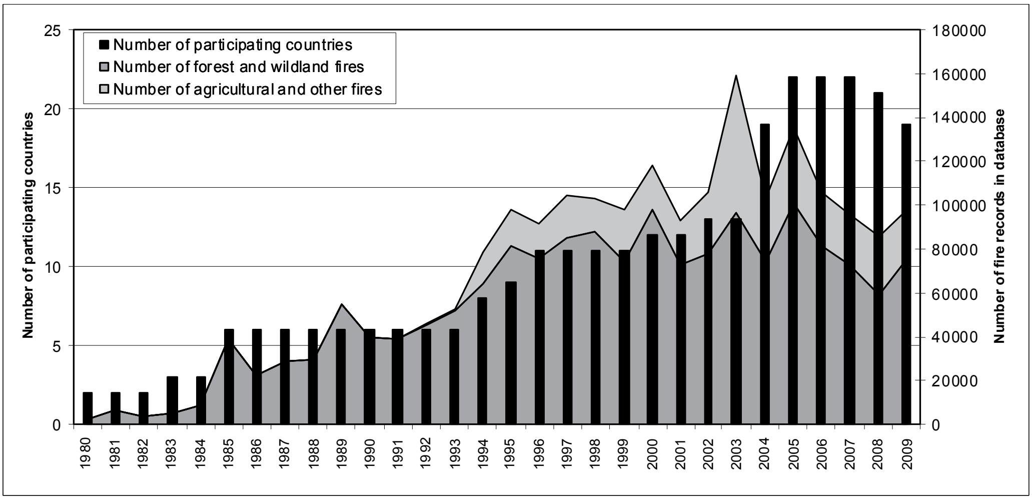

Fig. 4. Evolution of the European Fire database

The data are then ready to be used for further statistical analysis (Fig. 5). Key summary statistics are exported to the EFFIS web viewer and the information is made available to the public through the web interface**, which allows the users to retrieve general information such as maps of the number of fires, burnt area and average fire size for a selected year and for the countries for which data are available. The data can be displayed at different spatial aggregation level such as country, NUTS1, NUTS2 or NUTS3 and may be filtered to exclude fires below a certain size, while an interactive graphical facility allows the user to display the same fire statistics over time.

3.2 Analysis of spatial and temporal distribution of forest fires

The Mediterranean region of Europe, particularly the countries of Portugal, Spain, Italy and Greece and southern France, is by far the most affected by forest fires. From 1980 until 2009 fires have burnt an average of circa 480,000 ha of land per year in this region alone, with an annual average of 50,000 occurrences (European Commission, 2010). In this region, the majority of the fires (over 70%) occur between June and October, exhibiting different temporal trends in relation to the northern European countries, where the majority of fires occur in springtime.

The analysis of the spatial and temporal trends of forest fires is crucial to understand their underlying driving factors and the resulting environmental and socio-economic impacts, and for planning appropriate fire prevention and management. The analysis presented here focuses on the number of fires and burnt area in the European Mediterranean region (EUMed).

** http://effis.jrc.ec.europa.eu/fire-history

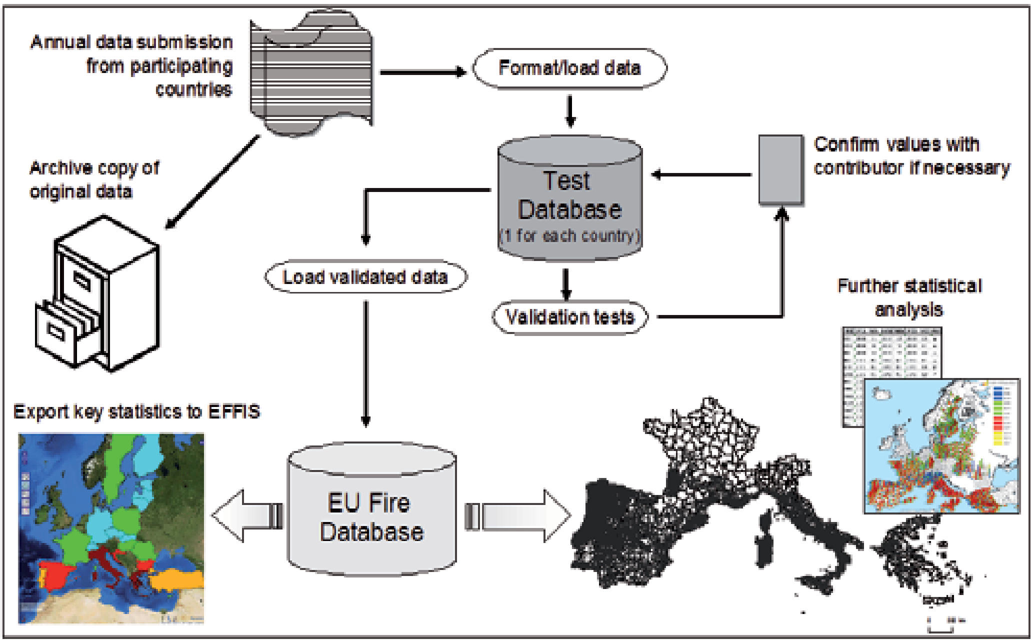

Fig. 5. Process control from data submission to storage, analysis and display

3.2.1 Analysis of number of fires and burnt area in the EUMed region

The general trend observed in the annual number of fires recorded between 1985 and 2009 is a slight increase, with strong fluctuations (Fig. 6). In the 90's a substantial increase can be observed, while in the last 10 years (i.e. since 2000), the number of fires tends to decrease, except for the years 2003 and 2005 which were affected by extreme weather events. The sharp increase recorded in the 90's might simply reflect changes in the reporting systems in the countries triggered by specific EC Regulations. In addition to this, many authors associate this trend with fuel accumulation related to land cover changes such as the expansion of shrublands and abandonment of agricultural lands (Carmo et al. 2011, Lloret et al. 2002, Romero-Calcerrada et al. 2010).

The burnt area, on the other hand, exhibits a decreasing trend since 1985, with strong annual fluctuations (Fig. 6). Besides the influence of weather conditions in fire spread and burnt area annually, this decrease can also be related to the implementation of fire prevention strategies and to the improvement in fire detection and fire-fighting techniques during the last years.

3.2.2 Seasonal trends

The months with higher number of fires and burnt area in EUMed between 1985 and 2009 were August, July and September (Fig. 7). Nearly 73% of the fires and nearly 85% of the burnt area occurred between June and October. March had the highest number of fires and burnt area among the spring months.

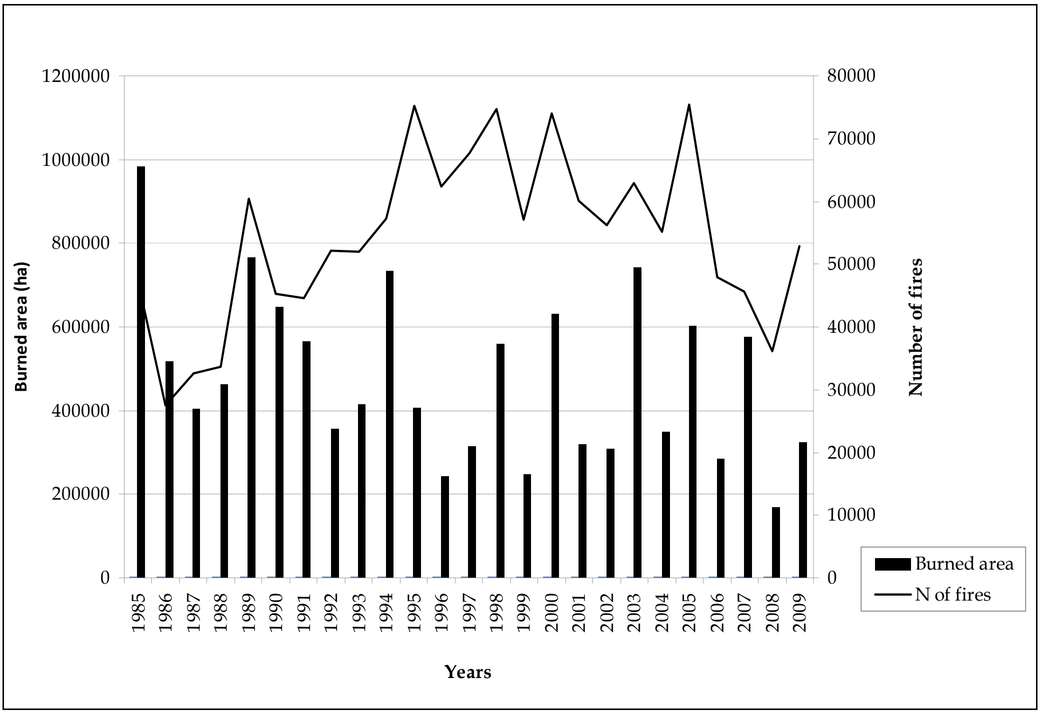

Fig. 6. Total annual number of fires and annual burnt area in the EUMed region from 1985 until 2009

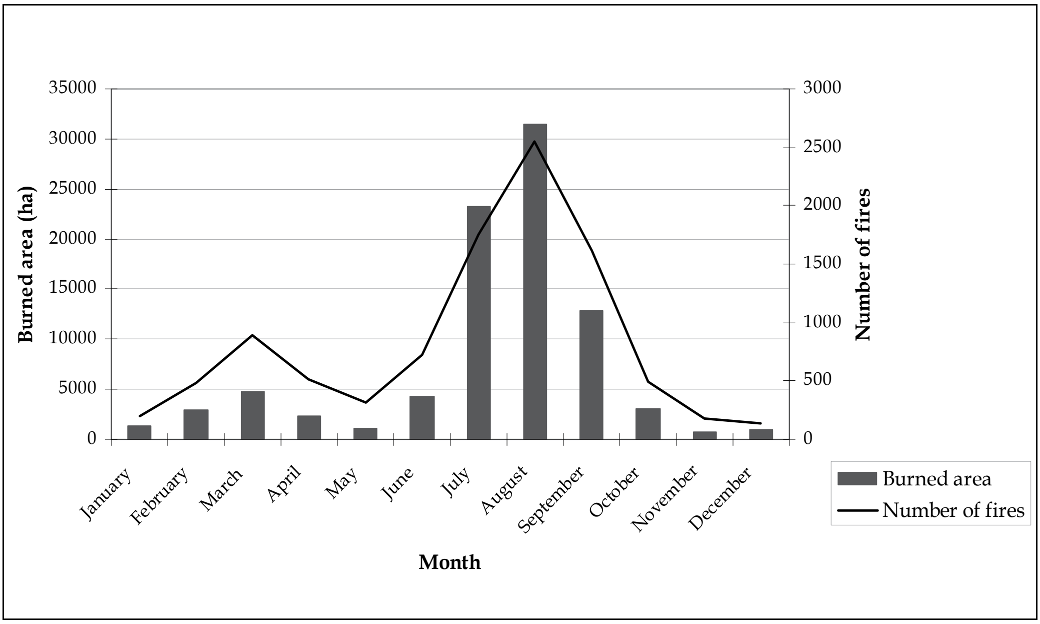

Fig. 7. Annual average (1985–2009) number of fires and burnt area per month in the EUMed region

4. Fire Danger Forecast

The Fire Danger Forecast module of EFFIS was initially established as a unified platform for the implementation of selected national fire weather indices throughout Europe. It enabled the extraction of coherent information for Europe and the inter-comparison of fire danger levels among European countries or regions. It has been designed to be a common reference for fire danger assessment, supporting cooperation among national services during major events or in case of trans-border fires.

Fire danger rating in EFFIS does not intend to replace the systems used by the countries, but to complement them by providing a harmonized European-wide assessment of fire danger. Fire danger assessment and forecast provided by EFFIS is therefore used as a reference information source which may be coupled with the other systems operated locally by individual countries or regions, which may be more or less advanced.

In addition to the daily support, the information is particularly useful in case of assistance requests by a country during major fires under severe conditions. The European maps of fire danger assessment and forecast are used a common baseline to evaluate the situation and its likely development.

4.1 Fire danger rating methods

During the first years of EFFIS, a number of selected national fire danger indices were implemented, and in 2007 a decision was taken to focus research and development efforts on components of the Canadian Fire Weather Index system (Van Wagner 1987), of the Canadian Forest Fire Danger Rating System, the national system of fire danger assessment in Canada (Stocks et al. 1989).

The FWI System has six components rating fuel moisture content and potential fire behavior in a common fuel type (i.e., mature pine stand) and in no slope conditions. Calculations are based on daily noon measurements of air temperature, relative humidity, wind speed and previous 24-h precipitation. The first three components of the FWI are numerical rating of the moisture content of forest floor layers with different drying rates and at various depths. The Fine Fuel Moisture Code (FFMC) rates the moisture of litter and other dead fine fuels at the top of the surface fuel layer; the Duff Moisture Code (DMC) rates the moisture of the loosely compacted organic layer of moderate depth; the Drought Code (DC) represents the moisture content of the deep layer of compact organic matter. The three moisture codes carry different useful information as indicators of the ease of ignition and flammability of fine fuels (FFMC), fuel consumption in medium-size woody material and moderate duff layers (DMC), fuel consumption in large logs and amount of smoldering in deep duff layers (DC) (Alexander 2008). The last three codes of the FWI are fire behavior indices rating the expected rate of fire spread (Initial Spread Index - ISI) from the combination of FFMC and wind speed, the fuel available for combustion (Build Up Index - BUI) from the combination of DMC and DC, and the fire line intensity (FWI), which is the final index that combines ISI and BUI and renders the energy output rate per unit length of the fire front according to Byram’s formulation (Byram 1959).

Each individual component of the FWI system is a fire danger index, revealing different aspects of fire danger which are finally difficult to synthesize with one single number

(Alexander 2008). It is important to keep in mind that the FWI output only depends on weather observations and does not consider differences in fuel types or topography. It provides a uniform, relative way of rating fire danger through fuel moisture and fire behavior potential (Van Wagner 1987). The FWI has a number of desirable properties (Fogarty *et al.* 1998). In particular, it is relatively simple to implement, is based on sound scientific principles and carries meaningful information to fire managers which can be directly correlated with fire behavior characteristics, and it is thereby easy to interpret.

Although the application of the FWI system in EFFIS during the last years has confirmed its robustness and validity for Europe, research work is still on-going to enhance its application in the European environment.

4.2 Data input

Fire danger assessment is done in EFFIS with weather forecasts and with observed synoptic weather data. Daily observations from a few hundreds synoptic weather stations are interpolated on a 50x50 km^2 grid over Europe. The database has been set up and is being primarily used by the project MARS (Monitoring Agriculture with Remote Sensing) of the JRC. Weather forecast data are received daily from Météo-France and Deutsche Wetter Dienst (DWD).

Daily forecast data of 0-24, 24-48, 48-72 hours from Météo-France are re-sampled on the EURAT5 grid of spatial resolution 0.5°x0.5°. The data are received daily and are used to calculate FWI values and generate EU maps of 1, 2 and 3 days forecast. DWD provides forecast data from the global model with spatial resolution of 0.36°x0.36° and up to 174 hours forecast with 3 hour time step. These data are received daily and used to generate maps of 1 to 6 days forecasts of FWI.

Weather forecast data are downloaded daily from the FTP servers of the meteorological services and stored with the results of the data processing in an Oracle workspace. Fire danger maps are updated daily from 1st of March until 31st of October. They are made accessible through the EFFIS Web interface and are also sent via email to the EC services and to the national fire services.

4.3 Fire danger classes

In the current EFFIS implementation of the FWI, 5 fire danger classes are defined with simple FWI thresholding, irrespectively of the fuel types. The FWI value for the highest fire danger class limit has been set on the basis of the analysis of fire danger conditions observed during about 2000 large fires of more than 500 hectares occurred in Europe during 20 years,. After that, the geometric progression described in Van Wagner (1987) has been applied to establish 5 lower danger classes. The lowest 2 classes have then been aggregated into one "Very Low" danger class. The resulting FWI ranges and classes are given in Table 1.

Efforts continue to enhance the operational use of the FWI system within EFFIS and to further refine the definition of the fire danger classes following alternative approaches (Camia and Amatulli 2010).

Fire Danger Class	*FWI ranges (upper bounds excluded)*
Very low	< 5.2
Low	5.2 - 11.2
Moderate	11.2 - 21.3
High	21.3 - 38.0
Very high	>= 38.0

Table 1. FWI ranges defining the fire danger classes in EFFIS

5. Active fire detection

The basis for the detection of active fires from satellite imagery is the identification of hot spots through the use of spectral-band thresholds or contextual fire-detection algorithms (San-Miguel-Ayanz et al. 2005). Contextual algorithms provide a more consistent performance for regional and global applications than simple thresholding algorithms. These contextual algorithms identify as hot spots (active fires) areas that are significantly hotter than the surrounding ones (i.e. the contextual background).

In EFFIS, active fire detection is based on the use of the MODIS thermal activity product (Justice et al. 2002b). The original contextual algorithm used for fire detection in the MODIS thermal activity product was improved by Giglio et al. (2003) allowing the detection of smaller and cooler fires, as well as the significant reduction of the rate of false alarms.

The MODIS active fire product is used for the automatic geo-location of active fires in EFFIS. This product is further filtered with the use of the CORINE land cover database and other ancillary datasets (e.g. digital elevation model, road and street maps) with the aim of reducing the number of false alarms coming from industrial and urban areas and distinguishing forest fires from other types of fires (e.g. agricultural fires). The EFFIS active fire product is also used as ancillary information for the mapping of burnt areas.

6. Burnt area mapping

6.1 Rapid Damage Assessment

The MODIS sensor on board of the TERRA and AQUA NASA satellites is used in EFFIS for continuous monitoring and mapping of fires of about 40 ha or larger in Europe. The module for the mapping of burnt areas and assessment of forest damages is referred to as Rapid Damage Assessment (RDA). Testing on the use of MODIS data for mapping burnt areas in Europe was performed between the years 2000 and 2002, and the first map of burnt areas using this imagery was obtained in 2003. Until then maps of fire perimeters (burnt areas) were obtained only at the end of the fire campaign, i.e. end of September/October. After 2003 the processing chain was further automated to process MODIS data in near-real time. Daily, two full image mosaics the European territory are processed in EFFIS to derive burnt area maps.

Currently, the processing chain includes a data pre-processing sub-system, which is operated by the German Aerospace Agency (DLR). Images are acquired year round, although the core of the real-time processing is carried out from May to the end October every year. The scheme of satellite imagery reception and transmission of the pre-processed products to JRC is presented in Fig. 8. These include radiometrically calibrated, geolocated and atmospherically corrected reflectances.

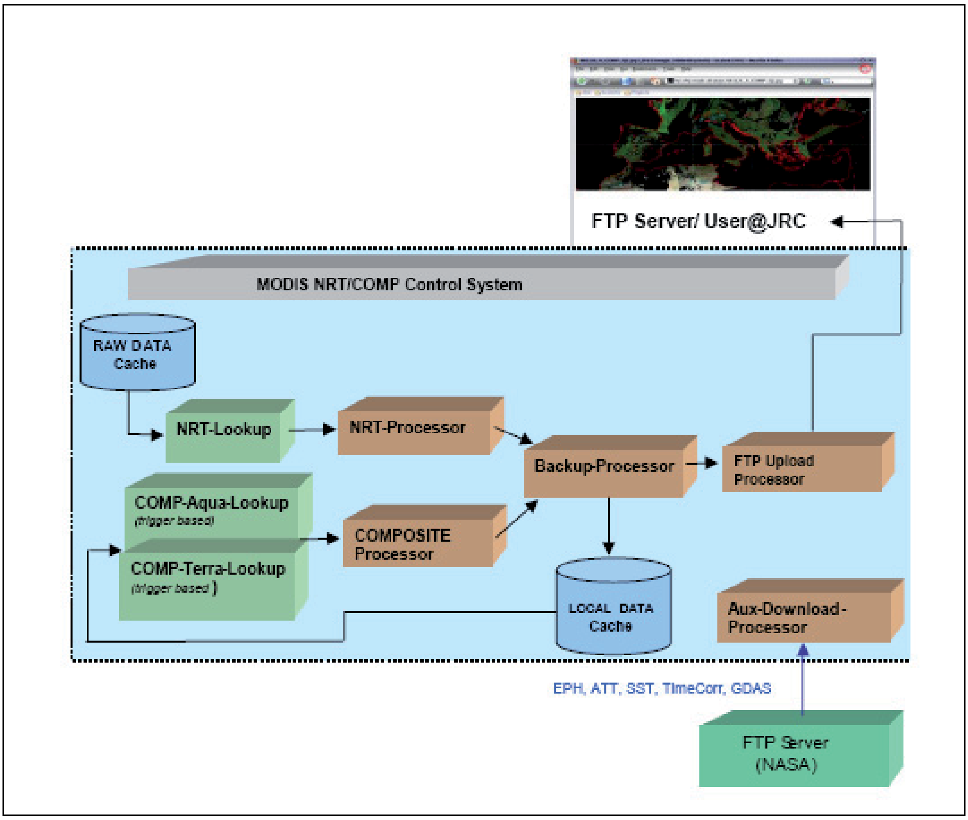

Fig. 8. Pre-processing of MODIS data for EFFIS (source: San-Miguel-Ayanz et al. 2009)

The spatial resolution of the MODIS data permits the accurate mapping of fires of approximately 40 ha or larger, although smaller fires are often detected and mapped. The information on the perimeters of these fires is updated twice daily and available in the "current situation' page of EFFIS.

Fires are mapped using a semi-automatic procedure. Fires are first mapped on the basis of an unsupervised procedure that uses a combination of band thresholds and ancillary information from the CORINE Land Cover, the active-fire detection product, and the news application, which are described in previous sections of this chapter. Fires that are mapped by the unsupervised procedure are visually verified, and the processing of the images continues for those true fires with the aid of a seeded region-growing algorithm (Salvador Civil et al. 2002).

Information from the RDA is published in EFFIS web site and transmitted to the Monitoring and Information Centre of EC Civil Protection Unit and to the civil protection and forest fire services in the European countries.

The acceptance of the RDA products by the scientific community and the final users in the EC and the countries required a thorough assessment of their quality. Although a validation exercise was performed in 1998, the validation of the EFFIS burnt area product is a continuous process that is still on-going, in conjunction with the validation of the global burnt area product of MODIS (Justice et al. 2002a). Specific validation of RDA was performed in the case of large fire events such as those in Portugal (2003), north-western Spain (2006), and Greece (2007) (Boschetti et al. 2008) and in the case of very large fires such as those in southern Spain and Portugal in 2004 that burnt approximately 25000 ha each.

The cumulative impact of burnt areas in the European Mediterranean region, as mapped in EFFIS from 2000 to 2009, is presented in Fig. 9.

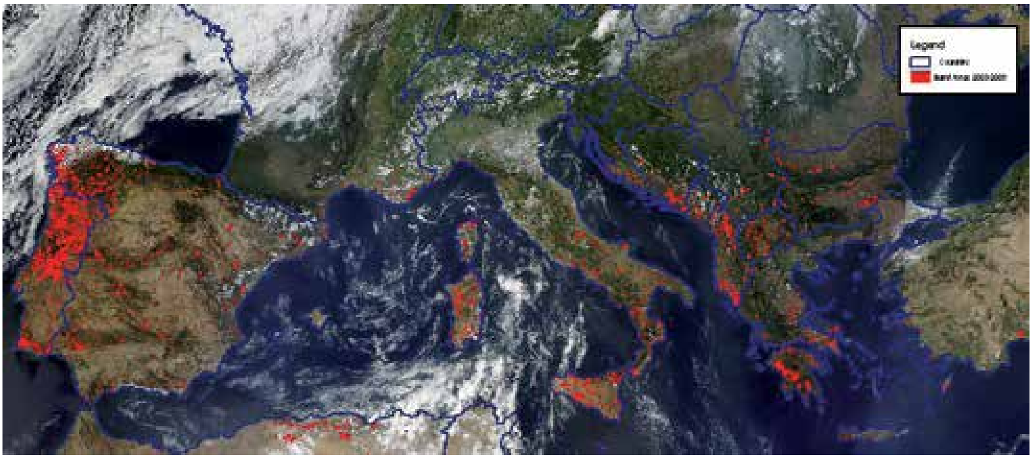

Fig. 9. Cumulative impact of forest fires in the 2000-2009 period

6.2 High resolution burnt area mapping

As mentioned in the previous section, the EFFIS Rapid Damage Assessment burnt area maps are based on 250-m spatial resolution bands from the Moderate Resolution Imaging Spectroradiometer (MODIS). The methodology and the spatial resolution of this sensor allows mapping burnt areas of about 40 ha or larger. This figure accounts for about 75% of the total area burnt every year in the Southern European Union (European Commission, 2008). Burnt areas smaller than 40 ha, however, make up a significant share of the total burnt area in the Europe. In regions such as the north-western Iberian Peninsula and Italy, these fires are frequent and highly relevant from ecological, social and economic perspectives. With this in mind, the European Parliament, in its resolution of 2006, called for the improvement of the burnt area assessments already provided by EFFIS. The improvement of remote sensing-based burnt-scar mapping capabilities in order to consistently map areas larger than 10 ha would imply the detection of nearly 90% of fires over Europe.

In this context EFFIS has explored the potential of higher spatial resolution remote sensing data for burnt-scar mapping. The rationale for estimating burnt areas at higher spatial resolution lays in the assumption that increased spatial detail could result in an improved capability for the detection of smaller burnt scars and a more precise delineation. Initial results using a bagged artificial neural network classifier (Sedano et al. in press) on IRS-AWIFS imagery acquired at the end of the fire-prone European summer season have shown that, in general, AWIFS-based burnt scars maps provide a more detailed delineation of burnt area polygons and non-burnt islands within the burnt perimeter. Fig. 10 shows the level of detail provided by MODIS as compared to that derived from AWIFS.

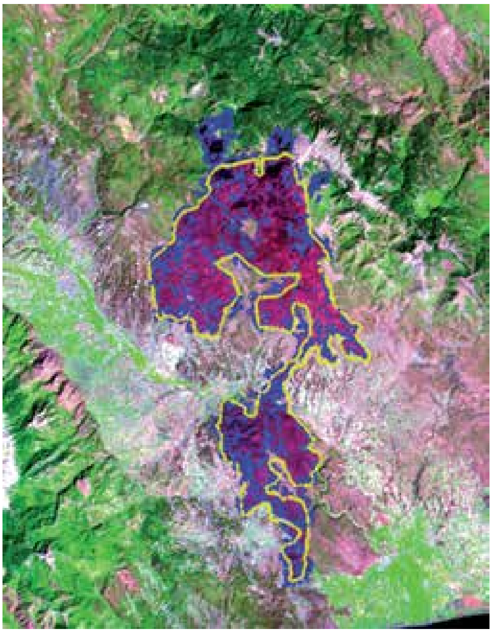

Fig. 10. Perimeter of burnt areas obtained from MODIS (yellow) and AWIFS (blue) in one of the large fires in the Peloponnese province, Greece in 2007

The results obtained so far in a full exercise of mapping burnt areas for the year 2009, however, do not clearly support the improved capability of AWIFS imagery for mapping smaller burnt scars. The acquisition of higher spatial resolution imagery generally implies lower revisit period and lower restricted spectral payloads. This trade-off imposes additional constrains. First the higher spatial resolution is obtained at the expense of a reduced spectral resolution and lower revisit period as compared to lower spatial resolution sensors. This limits the amount of available spectral information for automatic image classifications. Second, as a consequence of the lower revisit period, a continuous image acquisition plan is not feasible. Instead, image acquisition must be concentrated at the end of the fire season. This restricted acquisition period complicates obtaining full cloud free coverage over large study regions. It also increases the potential time lag between fire events and image acquisition, increasing the chance that the spectral signal of the burnt scar fades away over time. The lack of cloud free information, the time lag between forest fire and image acquisition date and the presence of fires after the image acquisition dates can results in the under detection of a considerable number of burnt-scars of various sizes. On the other side, the presence of undetected cloud shadows and shaded slopes can result in the overestimation of small burnt scars.

These present limitations are likely to be reduced as the availability of medium-resolution earth observation sensors increases, and the combination of images from different sensors give access to more complete and cloud free coverage at one or several periods during the fire season. Until this scenario becomes reality, initiatives relying on coarse resolution satellite data remain the most solid option for large-scale burnt scar mapping and monitoring.

7. Forest fire emissions

Combustion of fuels in forest fires emits gases and particles. These emissions do have an important effect on the local population, especially in the case of wildland-urban interface fires and may constitute a large portion of the country's emissions in case of large fire episodes such as those of Portugal in 2003 or Greece in 2007.

As mentioned in a previous section, the frequency and extent of fires in Europe varies greatly from year to year, reflecting year-to-year climatological variability, with an average of about half a million hectares in the last 20 years (this excludes fires in the European part of Russia). On average, during the period 2000 to 2009 about 60000 fires occurred annually in Europe and they, burned about half a million hectares of land every year. However, the areas burnt have exceeded 700000 ha in 2003 or nearly one million ha in 2007 (European Commission, 2009).

Emissions from forest fires depend on (1) the duration and intensity of the fire, (2) the total area burnt by the fire, and (3) the type and amount of vegetation that was burnt. This latter term is often referred to as fuel load. Of these three terms, the one that is best known is the total burnt area. EFFIS currently uses the state of the art in calculating emissions from open vegetation fires, which follows the work of Seiler and Crutzen (1980). The formula is:

$$E_x = A \cdot B \cdot C \cdot EF \quad (1)$$

Where:

- E_x emission of compound x
- A burnt area (m^2)
- B fuel load (g dry matter m^{-2})
- C burning efficiency
- EF emission factor (g g^{-1} dry matter burnt)

Each of the components of the fuel classes is attributed a specific burning efficiency and emission factor for gas-phase or aerosol compounds. These values depend upon whether the fire is flaming or smoldering, which is related with the diameter of the fuel type (Lenhouts, 1998). Emission factors for CO, CH_4, VOC, NO_x, N_2O and SO_x are taken from literature. If no local data on aboveground fuel load is available, default values can be applied. Values of total biomass for five biomes (boreal forest, temperate forest, Mediterranean forest, shrubland, grassland/steppe) and factors for each biome allow for the derivation of aboveground biomass as well as the assumed fraction of biomass burnt in a fire. The content of Carbon in a fuel is obtained by multiplying the value of biomass by the coefficient 0.45. The burning efficiency depends on the meteorological conditions and determines the type of combustion, which may lead to flaming or smoldering fire.

Depending on the available data, these factors can be computed with more or less detail. Burnt areas may be available as a geographic layer or as a global value for a country or a region. In the case of available geographical information of the burnt areas, the pre-fire vegetation can be classified into fuel types and distinctive fuel loads can be used for estimating emissions. The European Fuel Map available in EFFIS, which was derived from the combination of the CORINE Land Cover database and the Potential/Natural Vegetation Map of Europe (Sebastian-Lopez et al. 2002), is used for this purpose. The fuel categories in the map are those of the US National Fire Danger Rating System (NFDRS) (Burgan 1988). This allows for the allocation of above ground biomass to each fuel type. A conversion factor is subsequently used to determine the assumed fraction of biomass burnt in a fire. As mentioned above, the values of Biomass are converted into Carbon values through the multiplication by 0.45.

The series of burnt area statistics from the European Forest Fire Information System (EFFIS) provide a consistent database of burnt area perimeters that can be used for the calculation of emissions. As presented above, the maps of burnt areas in EFFIS have been systematically produced since the year 2000 and have been contrasted with national statistics.

Burning efficiency depends on the meteorological conditions during the fire. In EFFIS, average conditions for the summer time, when most fires in Europe occur, are used to derive the combustion efficiency. A new methodology has recently been developed for EFFIS (Liousse et al. 2011). This allows the precise estimation of emission on the basis of information on the time of the fire, the progression of the fire front and expansion of the fire perimeter, and the total fire duration. This will become operational in 2012.

According to EFFIS estimates (European Commission, 2008), the CO_2 emissions during catastrophic fires in Greece was in the range of 4.5 Mt until end of August 2007, representing some 4% of the total annual CO_2 emissions of this country. A similar share of fire emissions to total emissions of CO_2 was observed in Portugal during heavy fire campaigns in 2003 and 2005 (Barbosa et al. 2009). For August 2003, the contribution of forest fire emissions in Southern Europe to observed particulate levels of $PM_{2.5}$ appeared to be comparable to anthropogenic emissions, and they seemed to result in significant impacts on radiative properties of large areas of Europe (Hodzic et al. 2007). Fig. 11 presents the estimation of forest fire emissions in EFFIS in the last years.

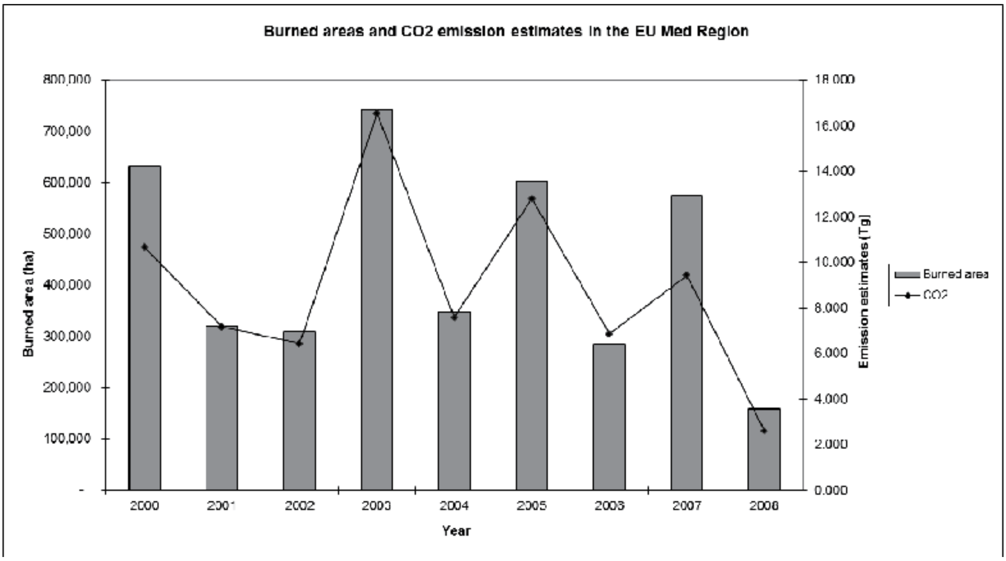

Fig. 11. Burnt areas (ha) and CO2 emission estimates (Tg) in the European Mediterranean region

8. Soil erosion estimation

Soil erosion is another major negative outcome of forest fires, particularly in the Mediterranean region. Furthermore, the damage represented by soil erosion is usually irreversible. This is why it is of utmost importance to assess the potential soil loss in fire-affected areas, and to identify areas where critical prevention measures should be applied after the fire season to avoid further damage.

The susceptibility of a burnt area to soil erosion depends on the intensity of the fire and the degree to which the vegetation cover is removed. The more intense the burning of the vegetation cover, the more the soil remains exposed to winds and rainfall. Within Europe, the risk of water-driven soil erosion is particularly high in the Mediterranean region where autumn rain storms often follow summer wild fires (Pausas and Vallejo 1999). Steep slopes not only favour the spread of wildfires, but are also most susceptible to soil erosion by water run-off when the soil lays bare after a fire.

While models assessing potential wind-induced erosion on a large scale do not exist yet, several methodologies to model water-driven soil erosion have been established. To estimate potential post-fire soil erosion, EFFIS is using the Revised United States Land Use Erosion (RUSLE) model which has been developed for the European scale. RUSLE is a physical process model built on three conceptual stages estimating daily total overland flow runoff, sediment transport and long-term average erosion rates. The output of the model is soil erosion estimate in tons per hectare per year, at a one kilometre grid resolution.

EFFIS offers the possibility of estimation of the potential for soil erosion for individual fire events grouped by their year of occurrence. This is done by summing the estimated potential soil erosion of all pixels within the burnt area perimeter.

9. Conclusions

The current chapter presented the fire monitoring in Europe through the European Forest Fire Information System (EFFIS). The system is the result of a long collaboration between the European Commission and the national fire services in the European countries. The monitoring of fires in Europe and the development of EFFIS paralleled trends marked by the development of environmental, forest protection, and civil protection policies in Europe (San-Miguel-Ayanz et al. in press). Its initial steps date back to 1998, when first discussions about its implementation took place between the EC and the national fire services. EFFIS became operational in 2000. Since then, new modules to enhance data processing and the dissemination of information, as well as the monitoring of forest fires were added to the system. These developments also paralleled the fast progress on information and communication systems, especially in the areas of remote sensing and geographic information systems.

EFFIS is a dynamic system that continues to be developed through the incorporation of subsystems for the monitoring of diverse phases of forest fires. EC services and the European Parliament (EP) have supported its development through time. The EP in its resolutions of 2006 and recently in 2011, (European Parliament 2006, 2011) has called for further enhancement and a continued legal basis for the operation and further development of EFFIS. Following the EP resolution of 2006, new modules in the areas of forest fire emissions, analysis and harmonization of fire causes, and the assessment of the socio-economic impact of forest fires were developed and will be shortly included in the system. Based on research activities of the EC Joint Research Centre, the system serves as repository of research findings in the field of forest fires, and acts as the means to incorporate those into operation.

The forest fire and civil protection services of the European countries are at the core of the system, as testers and critical users of it; they provide essential feedback on the usability of the information retrieved in EFFIS. As mentioned above, the system provides a basis for collaboration among the countries. Recently an agreement has been established with the Food and Agriculture Organization of the United Nations for the extension of the system to Northern African and near-East Mediterranean countries. The first steps for this will be taken already in 2011.

Future climate change scenarios combined with other factors such as land cover change and population exodus from rural areas may lead to increase fire activity in Europe. It is thus essential that the means be put in place for forest monitoring to enhance the collaboration of the countries on forest fire management.

10. References

Alexander, M.E. (2008). *Proposed revision of fire danger class criteria for forest and rural areas in New Zealand*. Christchurch: National Rural Fire Authority, Wellington, in association with the Scion Rural Fire Research Group.

Anon. (2011). *Open Source Geospatial Fundation (OSGEO). GDAL-OGR: Geospatial Data* Abstraction Library / Simple Features Library Software, July 2011. http://www.gdal.org.

Barbosa, P., Camia, A., Kucera, J., Liberta, G., Palumbo, I., San-Miguel, J., Schmuck, G. (2009). Assessment of Forest Fire Impacts and Emissions in the European Union Based on the European Forest Fire Information System. In: *Developments in Environmental Science*, Volume 8, 197, A. Bytnerowicz, M. Arbaugh, A. Riebau and C. Andersen (Editors), Elsevier.

Boschetti, L., Roy, D., Barbosa, P., and Boca, R. (2008). A MODIS assessment of the summer 2007 extent burned in Greece, *International Journal of Remote Sensing*, 29 (8), pp. 2433-2436.

Burgan, Robert E. (1988). *Revisions to the 1978 National Fire-Danger Rating System*. Res. Pap. SE-273. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 39 pp.

Byram, G.M. (1959). Combustion of forest fuels. In K.P. Davis (Ed.), *Forest Fire: Control and Use*. McGraw-Hill, New York, pp. 155-182.

Camia A., Amatulli G. (2010). Climatology of FWI over Europe: fire danger anomalies and index percentile rankings. In: Viegas D.X. (Ed.) *VI International Conference on Forest Fire Research*. Coimbra, Portugal.

Carmo, M., Moreira, F., Casimiro, P., Vaz, P. (2011). Land use and topography influences on wildfire occurrence in northern Portugal. *Landscape and Urban Planning* 100: 169–176.

European Commission, (2008). *Forest Fires in Europe 2007*. Office for Official Publications of the European Communities, Luxembourg, EUR 23492 EN, p. 77.

European Commission, (2009), *Forest Fires in Europe 2008*, Office for Official Publications of the European Communities, Luxemburg, EUR 23971 EN, p. 77.

European Commission (2010). *Forest Fires in Europe 2009*. Publication Office of the European Union, Luxembourg, EUR 24502 EN. p. 83.

European Parliament, (2006). *EP resolution on natural disasters (fires and floods) in Europe this summer*, OJ C 193E, 17.8.2006, p. 322–325.

European Parliament, (2011). *EP resolution on Commission Green Paper on forest protection and information in the EU: preparing forests for climate change*, P7_TA-PROV(2011)0226

Fogarty, L.G., Pearce, H.G., Catchpole, W.R., Alexander, M.E. (1998). Adoption vs Adaptation: lessons from applying the Canadian Forest Fire Danger Rating System in New Zealand. In *3rd Int. Conf. on Forest Fire Res. and 14th Conf. on Fire and Forest Met.* Luso-Coimbra, Portugal pp. 1011-1028.

Giglio, L., Descloitres, J., Justice, Ch. O., and Kaufman, Y.J. (2003). An enhanced contextual fire detection algorithm for MODIS, *Remote Sensing of Environment*, 87 (2-3), pp. 273-282.

Hodzic A., Madronich S., Bohn B., Massie S., Menut L., and Wiedinmyer C. (2007). Wildfire particulate matter in Europe during summer 2003: Meso-scale modeling of smoke emissions, transport and radiative effects, *Atmospheric Chemistry and Physics*, 7, pp. 4043–4064.

Justice, C., Lewis, P., and Roy, D. (2002a). Burned area mapping using multitemporal moderate spatial resolution data A-bi-directional reflectance model-based expectation approach. *Remote Sensing of the Environment*, 83, 263–286.

Justice, C.O., Giglio, L., Korontzi, S., Owens, J., Morisette, J.T., Roy, D., Descloitres, J., Alleaume, S., Petitcolin, F., and Kaufman, Y. (2002b). The MODIS fire products, *Remote Sensing of Environment*, 83 (1-2), p. 244-262.

Kirkby, M.J., Jones, R.J.A., Irvine, B., Gobin, A, Govers, G., Cerdan, O., Van Rompaey, A.J.J., Le Bissonnais, Y., Daroussin, J., King, D., Montanarella, L., Grimm, M., Vieillefont, V., Puigdefabregas, J., Boer, M., Kosmas, C., Yassoglou, N., Tsara, M., Mantel, S., Van Lynden, G.J. Huting, J. (2004). *Pan-European Soil Erosion Risk Assessment: The PESERA Map*, Version 1 October 2003. Special Publication Ispra 2004 No.73 (S.P.I.04.73). European Soil Bureau Research Report No.16, EUR 21176, 18pp.

Leenhouts, B. (1998). Assessment of biomass burning in the conterminous United States. *Conservation Ecology* [online] 2(1):1. http://www.consecol.org/vol2/iss1/art1

Liousse, C., San-Miguel-Ayanz, J., Camia, A., Guillaume B., (2011). A new methodology for the near-real time estimation of smoke plume emissions from forest fires in the European Forest Fire Information System. In: *Proceeding 8th International Workshop EARSeL, Special Interest Group on Forest Fires*, Stresa.

Lloret, F., Calvo, E., Pons, X., Diaz-Delgado, R. (2002). Wildfires and landscape patterns in the Eastern Iberian Peninsula. *Landscape Ecology* 17: 745-759

Pausas, J.G. and Vallejo, V. R. (1999). The role of fire in European Mediterranean ecosystems. In: Chuvieco, E. (Ed.) *Remote Sensing of large wildfires in the European Mediterranean Basin*, pp. 3 - 16. Springer Verlag, ISBN 3-540-65767-3 Berlin.

Romero-Calcerrada, R., Novillo, C.J., Millington, J.D.A., Gomez-Jimenez, I. (2008). GIS analysis of spatial patterns of human-caused wildfire ignition risk in the SW of Madrid (Central Spain), *Landscape Ecology* 23, pp. 341–354.

Salvador Civil, R. and San-Miguel-Ayanz, J., (2002). An extension of a non-parametric clustering algorithm to derive radiometrically homogeneous objects pointed by seeds, *International Journal of Remote Sensing*, Vol.23, No. 6, pp. 1197-1205.

San-Miguel-Ayanz, J., Pereira, J. M. C., Boca, R., Strobl, P., Kucera, J., Pekkarinen A. (2009). Forest Fires in the European Mediterranean Region: Mapping and Analysis of Burned Areas, in Chuvieco E. (Ed.), *Earth Observation of Wildland Fires in Mediterranean Ecosystems*, Springer, pp. 189-204.

San-Miguel-Ayanz, J., Ravail, N., Kelha, V. Ollero, A. (2005). Active fire detection for fire emergency management: Potential and limitations for the operational use of remote sensing, *Natural Hazards*, 35 (3), pp. 361-376.

San-Miguel-Ayanz, J., Schulte, E., Schmuck, G, Camia, A. (in press). The European Forest Fires Information System in the context of environmental policies of the European Union, *Forest Policy and Economics*.

Sebastian Lopez, A., San-Miguel-Ayanz, J., Burgan, R. (2002). Integration of satellite sensor data, fuel type maps, and meteorological observations for the evaluation of forest fire risk at the pan-European scale, *International Journal of Remote Sensing*, Vol. 23, No. 13, pp. 2713-2719.

Sedano, F., Kempeneers, P., Strobl, P., Vogt, P., San Miguel, J. (in press). Towards a pan-European burnt scar mapping methodology based on single date high resolution optical remote sensing data. *International Journal of Applied Earth Observation and Geoinformation*.

Seiler, W. and P. J. Crutzen (1980). Estimates of gross and net fluxes of arbon between the biosphere and the atmosphere from biomass burning, *Climatic Change* 2, pp. 207–247.

Stocks, B.J., Lawson, B.D., Alexander, M.E., Van Wagner, C.E., McAlpine, R.S., Lynham, T.J. Dubé D.E. (1989). The Canadian Forest Fire Danger Rating System: An overview. *The Forestry Chronicle* 65, 258-265.

Van Wagner, C.E. (1987). *Development and Structure of the Canadian Forest Fire Weather Index System*. Ottawa, Ontario: Canadian Forestry Service, p. 37

6

The Impact of Natural Disasters: Simplified Procedures and Open Problems

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1. Introduction

A *natural hazard* is a geophysical, atmospheric or hydrological event (e.g., earthquake, landslide, tsunami, windstorm, flood or drought) that has the potential to cause harm or loss, while a *natural disaster* is the occurrence of an extreme hazardous event that impacts on communities causing damage, disruption and casualties, and leaving the affected communities unable to function normally without outside assistance (Twig, 2007).

The definition of *natural disaster impact* (NDI) can change according to both the aim of the study and the scientist assessing it. It can be defined as constituting the *direct, indirect* and *intangible* losses caused on environment and society by a natural disaster (Swiss Re, 1998).

Direct losses include physical effects such as destruction and changes that reduce the functionality of an individual or structure. Damages to people (death/injury), buildings, their contents, and vehicles are included, as are clean-up and disposal costs.

Indirect losses affect society by disrupting or damaging utility services and local businesses. Loss of revenue; increase in cost; expenses connected to the provision of assistance, lodging, and drinking water; and costs associated with the need to drive longer distances because of blocked roads are included.

Intangible losses include psychological impairments caused by both direct and intangible losses that individuals personally suffer during the disaster.

The *Natural Disaster Impact Assessment* (NDIA) is crucial in helping individuals to estimate replacement costs and to conduct cost-benefit analyses in allotting resources to prevent and mitigate the consequences of damage (UNEP-ECLAC, 2000).

A general NDIA procedure has not yet been developed; several approaches are available in literature and their applicability depends on the accessibility of damage data.

Possible end users of NDIA include the following (Lindell & Prater, 2003):

1. Governments, with an interest in estimating direct losses to report to taxpayers and to identify segments of the community that have been (or might be) disproportionately affected
2. Community leaders, who may need to use loss data after a disaster strikes to determine if external assistance is necessary and, if so, how much.

3. Planners, who can develop damage predictions to assess the effects of alternative hazard adjustments. Knowing both the expected losses and the extent to which those losses could be reduced makes it possible to implement cost-effective mitigation strategies.
4. Insurers, who need data on the maximum losses in their portfolios to guarantee their solvency or even to undertake additional measures to alleviate the risk that they would face in case of a disaster (i.e., the use of catastrophe bonds which are risk-linked securities that transfer a specified set of risks from a sponsor to investors) (Noy & Nualsri, 2011).

Data availability and reliability, especially for old events, represent constraints in the NDIA context because of several issues of very different type:

1. Data availability, for current events, depends on the time at which data gathering started. It is impossible to decide a priori when data have to be gathered: it primarily depends on the type of phenomenon causing the disaster and its magnitude, and secondly on the scope of the assessment (for example, the assessment should not be delayed as there is an urgent need to elicit support from the international community) (ECLAC, 2003).
2. Long-term losses must sometimes be determined over a period of years. Slow landslides, for example, can cause damage over long periods. Intangible damage like disaster-related stress also requires years to be detected (Bland et al., 1996).
3. In most countries, there are no agencies responsible for gathering damage data. Damage caused by severest events can be mined from international databases, while data on less severe events can be obtained by means of specific historical studies.
4. Data on property damage can depreciate the value of property, thus they would not be available or not completely reliable (Highland, 2003).
5. For some type of disasters, as landslides or floods, the costs of damages to structures such as roads are often merged with maintenance costs and are therefore not labelled as damage. In addition, when heavy rains trigger both landslides and floods (Petrucci & Polemio, 2009), it is difficult to separate landslide damage from flood damage.
6. Developing countries have an incentive to exaggerate damage to receive higher amounts of international assistance; thus, in these cases, data may not be entirely reliable (Toya & Skidmore, 2007).

This chapter starts with a panoramic of the different approaches reported in the literature to assess the impact of natural disasters, and then presents some simplified approaches to perform a relative and comparative assessment of the impact caused by phenomena as landslides and floods triggered by heavy rainfall during events defined as Damaging Hydrogeological Events. Finally, some indices to assess the relative impact of landslides are presented.

2. A review of impact assessment literature

To identify recent literature concerning NDIA, a search was made using Google Scholar, a technical search engine that search across articles, theses, books and abstracts, from academic publishers, professional societies, online repositories, universities, international organizations and other web sites (Petrucci & Llasat, in press). According to their focus, the selected articles were sorted in three groups described in the next sub-sections.

2.1 Short-medium-term effects directly involving people and goods affected by a disaster

The articles included in this group employ the simplest approach: the impact is expressed by the list of damaged elements and neither monetary figures nor other assessment are performed (Ngecu & Ichang'i, 1999; Whitworth et al., 2006; Bilgehan & Kilic, 2008). Frequently used impact indicators include numbers of victims and damage to buildings, roads and agriculture. In these studies, damage data are obtained by state agencies or even collected by directly asking people involved in the disaster. Both the number of victims and the percentage of people affected are used to compare the impact of a disaster on various communities (Msilimba, 2010) or that of disasters that have occurred in different time and places. Some of these articles focus on damage to people, analysing the circumstances leading to loss of life and assessing them in relation to vulnerability factors (e.g., age, race, and gender) (Jonkman et al., 2009).

2.2 Medium- and long-term socio-economic effects

In these articles, after individuating the affected population and the pre-disaster situation, the researchers isolated effects on social sectors (the population, housing, health and education), service infrastructure (drinking water and sewage, communications, electricity and power), and production sectors (agriculture, industry and trade) in order to measure the disaster's impact on the macroeconomic indicators during a period of one to two years after the disaster (ECLAC, 1991).

Natural disasters are seen as a function of a specific *natural process* and *economic activity* (Raschky, 2008). The indicators used to detect the impact on national economies include a) long-term recovery businesses (Webb et al., 2002); b) changes in flow variables such as annual agricultural output (Patwardhan & Sharma, 2005); c) variations in fiscal pressure (Noy & Nualsri, 2011); and d) effects on the labour market (Belasen & Polachek, 2007; Zissimopoulos & Karoly, 2010).

The value of human life can be tentatively assessed using two approaches that assign different values to people in different income groups or in countries at different stages of development (AusAID, 2005):

1. The human capital approach involves calculating the average expected future income that the deceased would have generated assuming that he (or she) had achieved normal life expectancy.
2. In the willingness to pay (WTP) approach, surveys assess how much an individual is willing to pay to reduce the risk of death. Even environmental damage can be assessed using the WTP approach, either by asking people to state a WTP amount or by inferring this amount based on costs incurred for environmental services (Dosi, 2001).

Economically, disasters can act as a barrier to development, increasing poverty and having a small but significant negative effect on economic growth (Raschky, 2008). This effect can return a society to the level of human development it had achieved two years prior to the disaster (Rodriguez-Oreggia et al., 2010). Indirect societal effects such as decreases in productivity in people affected by disaster can influence economic growth (Popp, 2006). Human capital can be *directly* affected by these disasters through death or injury and *indirectly* affected when damage to schools decreases human capital accumulation (in poor countries, decreasing school attendance rates caused by reductions in family expenses can occur). Even demographic effects such as migration have been detected (Smith & McCarty, 1996).

Nevertheless, natural disaster can also produce positive effects. Disasters can create *Schumpeterian creative destruction* (Cuaresma et al., 2004), especially if there are injections of funds for assistance and/or reconstruction. They can represent an opportunity to update capital stock and improve an economy, thereby producing a long-term positive effect on the growth of the Gross Domestic Product (GDP) (Skidmore & Toya, 2002). Activities in the construction sector may reactivate the economy, and the demand for construction materials may generate windfall profits (ECLAC, 1991). Outside the disaster area, income increases can accrue for owners of commodities whose price is inflated by disaster-induced shortages (CACND, 1999). For instance, in the case of drought, when agricultural production decreases, farmers in affected areas experience the negative effects of the disaster, and the price of agricultural products increases. Then, farmers outside affected area, who are experiencing normal production, will reap the benefits of these higher prices (Wilhite et al., 2007). Even ways of thinking and acting can be modified by major disasters, resulting in personal and community growth (Birkmann et al., 2008).

Disasters are more costly for developing countries: as economies develop, there are fewer disaster-related deaths and damages/GDP (Toya & Skidmore, 2007). Nevertheless, increasing wealth causes relatively higher losses in high-income nations (Raskly, 2008). Increases in income increase the private demand for safety; higher income enables individuals (and countries) to employ additional, costly precautionary measures. Nevertheless, in countries that experience a concentration of assets that is larger than the counter-measures put in place, the income-vulnerability relationship can be inverted, especially in the case of disasters related to behavioural choices such as floods and landslides.

Disasters in South, Southeast, and East Asia are more costly than those occurring in the Middle East and Latin America. These results might be tied to the higher population density of Asian countries. Small island developing states are severely impacted by such events (Meheux et al., 2007): the number of victims and affected individuals and the degree of damage are twice as large on average as in any other region (Noy, 2009).

Normalization procedures are used to assess what the magnitude of economic losses over time would be if a past disaster took place today. It seems that societal change and economic development are the principal factors responsible for the increasing losses from natural disasters to date (Pielke et al., 2008; Barredo, 2009; 2010). For weather-related disasters, Bouwer (2011) pointed out no trends in losses - corrected for increases in population and capital at risk - that could be attributed to anthropogenic climate change.

2.3 Short-to-long-term physical and physiological effects on people

These articles focus on natural disasters and their effects on people's health from either a physical or a psychological point of view. Pre- and post-disaster conditions were compared in these studies to detect the onset of diseases and/or the worsening of pre-existing illness, and to assess if and when disaster-related symptoms appear/disappear. The data collection processes mainly involved standardized questionnaires used to collect self-reported information on symptoms quantified using numerical scores (Catapano et al., 2001; Cao et al., 2003) that could measure the disaster's impact.

Fig. 1. Damage caused to roads by landslides and floods in Calabria.

The risk of developing physical and/or psychiatric disorders is related to the extent of the losses suffered (Cao et al., 2003), and it is greater in families that have lost a family member in a disaster (Lindell & Prater, 2003), have experienced evacuation, or have worse finances (Bland et al., 1996). This probability can also be increased by a lack of information on the probability that the event will re-occur (Catapano et al., 2001). Two sub-sets of articles were isolated that focused on *psychological* and *physical* effects, respectively.

2.3.1 Psychological effects

According to the *Conservation Resource Model*, people try to protect resources such as objects (housing, possessions, etc.), social roles (employment, marriages, etc.), energy (time and monetary investments), and personal characteristics (e.g., self-confidence). The threatened or actual loss of these resources as caused by a natural disaster leads to psychological distress (O'Neill et al., 1999). Frequently observed conditions such minor emotional disorders seldom come to the attention of psychiatrists but may negatively affect social relationships and work performance. Commonly detected symptoms are fatigue (Lutgendorf et al., 1995), tics, and cognitive experiences such as confusion, impaired concentration, and attention deficit disorder. *Emotional* signs such as anxiety, depression, and grief, as well as *behavioural effects* such as sleep and appetite changes and substance abuse, were also reported (Lindell & Prater, 2003). Even effects on suicide rates were detected: earthquake victims (people who had lost family members residing with them, were injured, or experienced property loss) were 1.46 times more likely than non-victims to commit suicide (Chou et al., 2003).

All these effects can be mild and transitory or can lead to *Post Traumatic Stress Disorder* (PTSD). The mental states of victims can include three stages (Sadeghi & Ahmadi, 2008): a) an *immediate reaction* involving distressing symptoms accompanying adaptive stress; b) the *post-immediate phase*, which includes symptoms of maladaptive stress (confusion, agitation, and occasionally neurotic or psychotic reactions); and c) the *long-term sequel* phase, which involves a return to normal health or the onset of PTSD, which can sometimes yield a *chronic phase* that involves personality changes. These surveys make it possible to monitor the most fragile segments of the population, including people with pre-existing mental illness, racial and ethnic minorities, and children, in which symptoms may differ depending on age (Lazarus et al., 2002; Overstreet et al., 2011). Gender differences arise as well: for instance, after an earthquake, women report greater emotional distress and mental health problems than do men (Norris et al., 2002), but the occurrence of addiction disorders among women is much lower (Montazeri et al., 2005).

2.3.2 Physical effects

Physical effects encompass symptoms affecting people who have not been directly involved in a disaster. The deterioration of hygiene, housing, and basic services can induce the outbreak of diseases such as *leptospirosis* (AusAID, 2005) or increase the risk of morbidity and mortality caused by communicable diseases (Waring & Brown, 2005). In developing countries, for instance, contagious and non-contagious diseases are reported during the first weeks after floods. Moreover, in some environments, even the incidence of snake bites can increase (Shajaat Ali, 2007).

Disaster-related stress can have several secondary impacts on human health, such as effects on the human immune system (Solomon et al., 1997), diabetes (Ramachandran et al., 2006; Fonseca et al., 2009), and gastro duodenal ulcers (Suzuki et al., 1997). Also increases in serum leptin levels have been detected in subjects with PTSD, which explains the hyper-vigilance of people who have faced danger and uncertainty (Liao et al., 2004). In addition, after major earthquakes, the number of patients with Acute Myocardial Infarction (AMI) has been reported to increase 3.5-fold, and the part of women with AMI seems significantly greater than in the years preceding the disaster (Suzuki et al., 1997).

3. The impact of Damaging Hydro-geological Events (DHEs)

This paragraph focuses on climate-related damaging phenomena as landslides, floods, urban flooding, and storm surges which occur during periods of bad weather conditions, lasting from one to a few days, and characterised by intense rainfall and sometimes strong winds. These periods can be defined as Damaging Hydro-geological Events (DHEs) (Petrucci & Polemio 2003, 2009), and their impact can be assessed as the sum of the damage caused by all the damaging phenomena triggered through a selected DHE.

3.1 Data collection

Data on damage caused by DHEs which occur currently can be obtained from different agencies (civil protection, public works offices, etc.) or even by on-site surveys (interviews with people involved or local administrators). On the contrary, dealing with events that occurred in the past, for which no direct surveys can be performed, historical data have to be found. The availability of historical data changes from one country to another and over time, and it is related to event severity. Actually, information concerning older events is less plentiful than information pertaining to newer events and the greatest amount of data usually exists for the most severe events, whereas less severe cases are rarely mentioned. Historical data can be gathered mainly from non-technical sources (books, newspapers, etc.), and then phenomena are described by non-specialist observers, which often focus on the effects (damage) more than on their causes (landslides, floods and so on).

In Italy, for example, there is no public authority that systematically collects data on damage caused by DHEs. These data can eventually be found in several offices, but none of these offices focus exclusively on collecting them. Moreover, each office stores documents in its archive by using organization criteria that are designed according to the needs of the office itself and not planned for public use. In addition, the archives of some type of offices, as i.e. fire brigades and hospitals, which can contain data on damage to both people and properties, cannot be accessed because of laws ensuring the privacy of citizens. Other requests for both aid and damage reimbursement are usually sent to civil protection offices, but we mustn’t presume that these requests are systematically collected, and, this usually happens only for recently occurred phenomena; it is more difficult to find documents concerning damage that occurred several decades ago. Several authors gathered data from press archives (Cuesta et al. 1999, Devoli et al. 2007). Daily newspapers ensure continuity in information flow and, by-passing problems related to privacy, report detailed descriptions of human injuries, supply the age, sex, and names of the people involved and details of the causes of death or prognosis of injuries. However, this information source presents some disadvantages that must be clearly understood.

Fig. 2. Damage to houses caused by landslides and floods in Calabria.

1. The language of newspapers is not technical, so the articles must be carefully analysed to correctly classify the described phenomena. It is necessary to understand the reporter's perspective and familiarity with phenomena: adjectives to describe the size of a landslide, for example, must be assessed with caution because they are strongly affected by previous experience of the reporter with landslides.
2. Local newspapers are more detailed than national ones: until some decades ago, news coming from regions far from the editorial unit was only related to severe events, and thus, only the local newspaper allows a complete screening of both major and minor events occurred in a selected time-frame.
3. Articles tend to focus on damage, so details on phenomena can be scarce and must be inferred. Similarly, quantitative data on triggers (i.e., rain or wind intensity) are not provided, because newspaper articles focus more on the effects and less on their causes.
4. The articles must be checked in order to avoid duplication: often, newspapers report a damaging phenomenon in several editions (at least until major damage has been repaired). Also the number of victims must be carefully checked: newspapers may provide changing figures until the end of rescue operations.

Despite these disadvantages, especially in countries where there are no public authorities collecting these data, newspapers can be used as proxy data to establish a catalogue of damaging situations that can provide an indicator of the social impact of DHEs. In Italy, a systematic collection of data mined from newspapers was organised in an on-line database named AVI (http://sici.irpi.cnr.it/), and the use of newspaper data or, more recently, of internet-sourced news is a common practice to gather data (Kirschbaum et al., 2009).

3.2 Approaches to the assessment of damage caused by DHEs

The record of damage caused by DHEs in a selected region during a certain study period can be obtained by means of the systematic analysis of daily newspapers. Then, the damage caused by these DHEs can be assessed by various criteria, and the events can be classified according to their damage severity. In this way, data can be used for different types of analyses, as for example: a) the study of triggering rainfall thresholds, b) the comparisons between the severity of DHEs occurred in a selected area through the time, to understand if climatic change can modify their impact, and c) the comparisons between the severity of DHEs occurred in the same places but in different periods, to verify if and how the development of urbanised sectors can affect their impact.

The approaches to assess the impact of DHEs can be more or less complex; nevertheless, their applicability depends firstly on data availability and secondly on the scale of the study. The simplest damage classification, which can be applied at both local and regional scale, can be performed establishing *a priori* three damage levels (Petrucci & Versace, 2000):

1. **Level 1: high damage**. At least one of the following circumstances occurs:
    - breaking of bridges
    - damage to main roads and railway lines
    - serious blocking of roads and railways lines
    - damage to major life-lines
    - collapse of buildings
    - flooding of vast areas of land with great damage to agriculture
    - occurrence of victims and casualties

2. **Level 2: medium damage**. The circumstances of Level 1 do not occur but at least one of the following does:
    - some building rendered unusable
    - landslides and/or flooding that affect road and railways though with limited effects and brief duration
    - damage to secondary life-lines
    - flooding of limited areas of land with serious damage to agriculture
3. **Level 3: low damage**. The circumstances of Levels 1 and 2 do not occur and just one of the following happens:
    - damage to agriculture OR
    - flooding of inhabited areas OR
    - damage to life-lines

To perform an in depth analysis, further steps can be done, by defining some descriptive indices that can be used to summarize the effects of a DHE.

3.2.1 Index of Damaged Area (IDA)

This index represents the relative size of the area affected by floods or landslides during a DHE, and it is assessed in reference to small administrative units of the disaster region. In Italy, for example, we relate this index to the municipalities of a selected region.

The IDA is obtained by summing the area of municipalities hit during the DHE (S) and dividing the obtained value by the area of the regional surface (R).

$$\text{IDA (Index of Damaged Area)} = S / R \times 100 \tag{1}$$

S is greater than the area truly affected, but this simplification is necessary to by-pass the impossibility of precisely delimiting areas actually hit, because of the low technical level which can characterise historical data. IDA represents the percentage of a region’s area affected during each DHE; based on IDA, the DHEs that affected a region can be classified as:

$$\text{Local DHE} = \text{IDA} < 2.5\%$$

$$\text{Wide DHE} = \text{IDA: } 2.5 \div 10\%$$

$$\text{Regional DHE} = \text{IDA} > 10\%$$

3.2.2 Local Damage Index (LDI) and Local Damage Index Density (LDI_d)

The Local Damage Index is the sum of damage D_i caused in a municipality by the *i* phenomena that occurred there, and it is based on the concept that damage is the product of the value of damaged element and the level of loss that it suffered (Varnes & IAEG, 1984):

$$LDI = \sum Di \tag{2}$$

Where:

$$Di\ (Damage) = Vi \times Li \tag{3}$$

V_i is the *value of the damaged element*, ranging from 1 to 10 in an arbitrary scale (Figure 3), and L_i is the *level of loss* suffered, a measure of the percentage of loss affecting the element during the event, that can be High=L1 (1), Medium=L2 (0.5), or Low=L3 (0.25) (Petrucci et al. 2003).

By dividing the LDI by the municipal area, we can obtain an index that represents the density of damage in each of the hit municipalities:

$$\text{LDId (Local Damage Index Density)} = \text{LDI/Municipality area} \tag{4}$$

Obtained values can be sorted into a number of classes. For each event, a regional map of municipalities classified according to the LDId can summarise the regional pattern of damage, thus allowing use of a geographical analysis of the pattern of damage density pattern which can be used, i.e., to identify more intensely affected regional sectors. Moreover, by comparing LDI to the return period of rainfall which triggered the damaging phenomena, the proneness of an area to be damaged by DHEs can be classified as (Petrucci & Pasqua, 2008):

- **High**, if rainfall of low return periods causes severe damage.
- **Medium**, if return period of rainfall and induced damage show equal levels of exceptionality.
- **Low**, if rainfall having a high return period induces damage of low level.

4. The impact of mass movements

Mass movements, defined as the movements of masses of soil, rock, debris, or mud, usually occur because of the pull of gravity, and are a source of great concern because they can impact numerous victims and cause severe damage. Although many types of mass movements are included in the general term “landslide,” the more restrictive use of the term refers only to mass movements where there is a distinct zone of weakness that separates the slide material from more stable underlying material (USGS, 2009).

Only a low percentage (12%) of the articles analysed to perform the review presented in the paragraph 2 concern landslides. This low attention to landslides impact depends on two factors: a) if compared to earthquakes or hurricanes, landslides could be classified as minor disasters; b) landslides can be secondary consequence of major disasters such as earthquakes. Nonetheless, both the assessment of damage after landslides occurrence, and the appraisal of damage that could be caused by future landslides have practical usefulness.

Immediately after an event that triggered several landslides, a rapid relative damage assessment allows for the sorting of phenomena according to their relative impact, upon this assessment priorities for structural remediation can be set and the costs and benefits derived from the implementation of different defensive measures can be assessed.

On the other hand, pre-event assessment of the potential impacts of future mass movements can provide information to planners, who must evaluate the consequences of alternative hazard mitigation measures. If the landslide inventory of an area has been conducted, a “consequence analysis” can identify potential outcomes arising from the activation of each mapped landslide. In addition, estimating the potential damage from each landslide can enable preparedness and improve the capacity of governmental agencies to cope with the emergency phases.

5. The Support Analysis Framework

The Support Analysis Framework is a spread sheet used to appraise damage caused by past mass movements or to assess the probable damage related to future phenomena (Petrucci & Gullà, 2009, 2010). The SAF was organised on the basis of historical damage data available in the Historical Archive of CNR-IRPI of Cosenza which have been partially published (Petrucci & Versace, 2005, 2007; Petrucci et al., 2009).

Type	*Sub-Type*	*Vi*			*Level 1 (1)*	*Level 2 (0.5)*	*Level 3 (0.25)*
		Bridge	Tunnel	Roadway			
Road network	Highway	10	10	8	Prolonged traffic interruption due to road breakage	Temporary traffic interruption due to road breakage	Effects on road without traffic interruption
	State road	8	8	6			
	County road	6	6	4			
	Municipal road	5	5	3			
	Mule-track			1			
Railway network	State railway	10	10	8			
	Regional railway	8	8	6			
	Service railway	5	5	3			
Type	*Sub-Type*			*Vi*	*Level 1 (1)*	*Level 2 (0.5)*	*Level 3 (0.25)*
Housing areas				10	Building collapse	Building evacuation	Effects not involving evacuation
Public buildings	Hospital			10			
	City hall			10			
	School			10			
	Barracks			10			
	Fire station			10			
	Church			10			
	Airport			10			
	Cemetery			5	Collapse of a lot of construction	Collapse of some construction	Effects without collapses
Services networks	Electricity line			5	Prolonged service interruption in large areas	Temporary service interruption in large areas	Temporary service interruption in small areas
	Telephone line			5			
	Drainage system			5			
	Aqueduct			5			
Productive activities	Agriculture			4	Interruption of production and loss of productive system	Interruption of production and loss of products	Limited loss of products
	Farming			4			
	Commerce/business			5			
	Fishing			4			
	Industry			8			
Tourist and sport resorts	Hotel			10	Interruption of activity and loss of productive structure	Temporary interruption of activity	Effects without interruption of activity
	Campground			4			
	Bathing beach			2			
	Sport resorts			8			
Port equipment	Wharf			8	Collapse	Loss of efficiency	Effects not involving loss of efficiency
	Seafront			3			
	Breakwater			1			
Hydraulic works	Check dam			4	Collapse	Loss of efficiency	Effects not involving loss of efficiency
	Embankment			5			
	Retaining wall			6			
	Dam			10			

Fig. 3. Types and sub-types of damaged elements. For each type and sub-type, the value considered for damage assessment is V_i. The multiplying factors for assessing the Local Damage Index are 1, 0.5 and 0.25 for levels 1, 2 and 3, respectively.

The aim of the SAF is to convert (historical) data of landslide damage into numerical indices describing: direct damage, defined by the effects on 6 types of elements (*Buildings, Roads, Railways, Productive Activities, Network services, People)*, indirect damage, defined by the actions aiming to reinstate pre-landslide conditions, and intangible damage, defining psychological consequences caused to people by the landslide.

In dealing with an approach designed for historical damage data, the SAF does not require on-site surveys: damaged elements and levels of loss are obtained by analysing the available descriptive data. For this reason, the SAF can be filled by non-specialists who should simply be trained on the procedure to mine landslide damage data from historical documents.

5.1 Identification and direct damage sections

For each landslide, a SAF must be completed to obtain numerical indices representing its impact. The first part of the SAF is the identification section (**A**), which accounts for:

- location of the landslide (province, municipality, place name, coordinates) and map of the landslide area (if not available in analysed documents, we can roughly trace it on a topographic map with the available information);
- time of activation (year-month-day/s);
- document(s) from which data have been obtained (original title or type of document if no title is available);
- reliability of the document(s) from which data have been collected (ranging from low to high, according to the type of document and the skill of the author).

The part of the SAF assessing direct damage is made up of 6 sections (B to G) and it is divided into two parts: the elements (on the left side of the chart) and the levels of loss (on the right) (Figure 4). Each element is characterised by its value, set on an arbitrary scale (red numbers). The levels of loss (black numbers), are set as: L4: complete loss; L3: high loss; L2: medium loss; or L1: low loss. Depending on the section, these levels have different meanings, but they always reflect the aforementioned levels of loss.

In the working version of the SAF, the yellow cells are empty: by typing the letter x in a cell describing an element and another one in the cell of the suffered level of loss, formulas implemented in hidden columns multiply these two values to obtain dl, which is the contribution to damage of the line l. All the dl values are used to assess both direct and total damage indices.

The elements used for direct damage assessment are organised in the following sections:

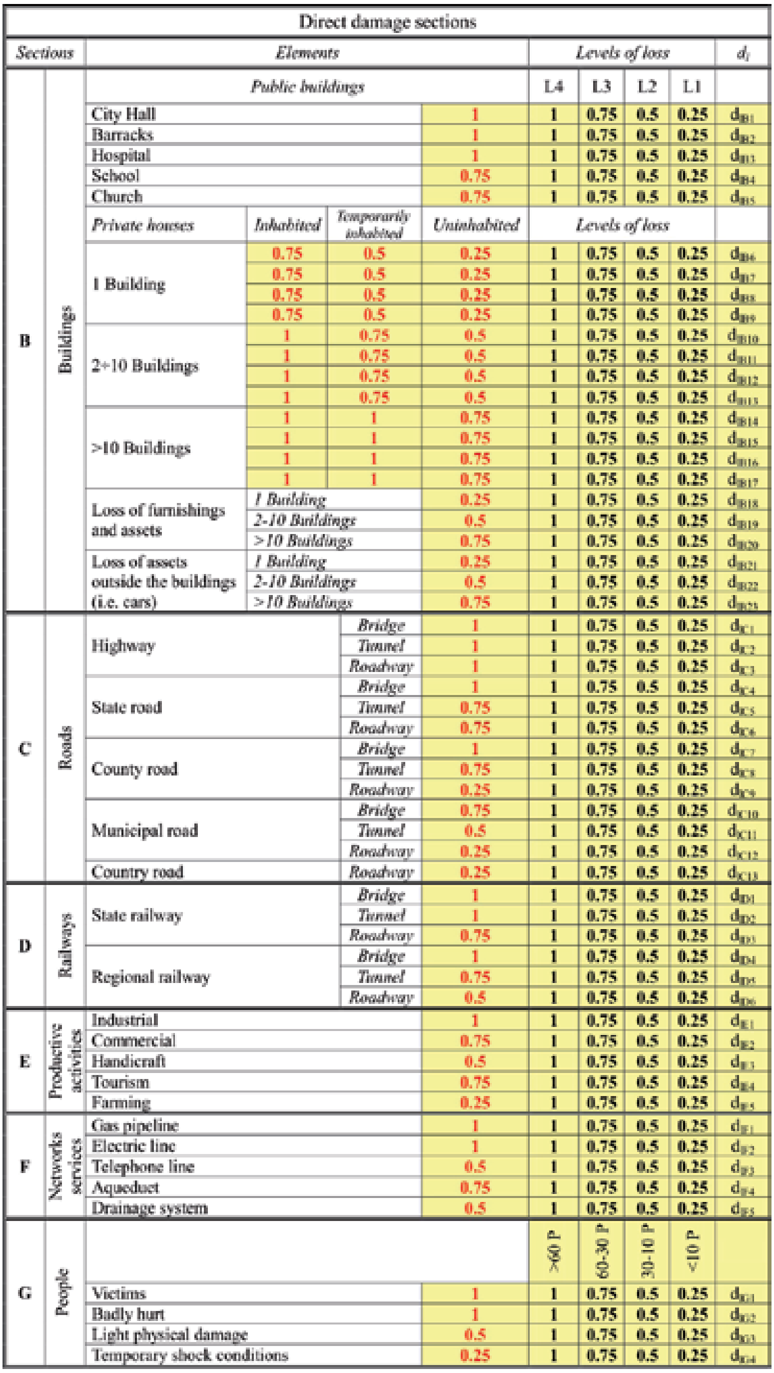
- **Section B: Buildings**. Buildings are classified as public or private. For public buildings, according to the social function, the strategic coordination role in emergency management and the number of people who can be inside during night and day, a unique value was set (city hall =1; barracks =1; hospital =1; school =0.75; church =0.75). For private buildings, two criteria were introduced to identify their value: the number of buildings (1 building; 2-10 buildings; >10 buildings), and whether they are inhabited, temporarily inhabited or uninhabited. The level of loss can be selected from: L4 (collapsed), L3 (unusable due to structural damage), L2 (unusable due to loss of functionality), and L1 (habitable with light damage). In this section, the loss of furnishing inside or outside the buildings is also included and classified according to the number of buildings involved (1 building; 2-10 buildings; >10 buildings).

- **Section C: Roads**. Roads are classified into five types according to relevance, traffic flow, and possible restoration costs: highway, state road, county road, municipal road and country road. Except for country roads, which are characterised by a simple structure, the damage can affect one or more of the following sub-elements: bridge, tunnel and roadway. Then, except for country roads, the value depends on the damaged sub-element(s). According to the degree and duration of inefficiency, the levels of loss were set as follows: L4: road breakage causing traffic interruption for months; L3: road breakage causing traffic interruption for days; L2: temporary interruption without breakage; L1: light damage without traffic interruption.
- **Section D: Railways**. According to the relevance and the traffic flow, we divided railways into state and regional railways. The value depends on the damaged sub-element(s), and the level of loss can be selected from: L4: railway breakage causing traffic interruption for months; L3: railway breakage causing traffic interruption for days; L2: temporary interruption without breakage; and L1: light damage without traffic interruption.
- **Section E: Productive activities.** These are divided into five types: industrial, commercial, handicraft, tourism and farming. The levels of loss were set as: L4: interruption of production and loss of productive system; L3: interruption of production and loss of products; L2: loss of products; and L1: light damage without loss of products.
- **Section F: Network services.** This category is divided into five types: gas pipeline, electric line, telephone line, aqueduct, and drainage system. The levels of loss were set according to the duration of the inefficiency and the extent of the suffering area (L4: prolonged service interruption of large areas; L3: temporary service interruption of large areas; L2: local and temporary inefficiencies; and L1: light damage without inefficiencies).
- **Section G: People.** Damage to people is described by the occurrence of four conditions: victims; badly hurt; light physical damage; and temporary shock conditions. The levels of loss were set according to the number of people concerned (>60 people; 60-30 people; 30-10 people; <10 people).

5.2 Indirect damage sections

The indirect damage analysis process includes two sections, H and I (Figure 5). Section H describes actions concerning the dislocation of people, for which the levels of loss are set according to the number of people involved (>60 people; 60-30 people; 30-10 people; <10 people). Section I accounts for the cost of remedial works, and the interruption and/or delay of economic activities caused by the mass movement. In this case, the level of loss depends on an appraisal of the economic cost of these works, sorted into four nominal intervals (>100,000 €; 100,000-20,000 €; 20,000-10,000 €; <10,000 €).

As for direct damage sections, the numbers in Figure 5 are hidden in the operating version of the SAF, because the yellow cells must be filled in. For each action, we have to select only one of the four levels of loss, by typing the letter *x* into the relative cell: in this way, the hidden value is placed in the correspondent d_l cell. All of the d_l values are used to assess both indirect and total damage indices.



Direct damage sections										
Sections		*Elements*				*Levels of loss*				d_i
B	Buildings	*Public buildings*				L4	L3	L2	L1	
		City Hall			1	1	0.75	0.5	0.25	d_{B1}
		Barracks			1	1	0.75	0.5	0.25	d_{B2}
		Hospital			1	1	0.75	0.5	0.25	d_{B3}
		School			0.75	1	0.75	0.5	0.25	d_{B4}
		Church			0.75	1	0.75	0.5	0.25	d_{B5}
		Private houses	*Inhabited*	*Temporarily inhabited*	*Uninhabited*	*Levels of loss*				
		1 Building	0.75	0.5	0.25	1	0.75	0.5	0.25	d_{B6}
			0.75	0.5	0.25	1	0.75	0.5	0.25	d_{B7}
			0.75	0.5	0.25	1	0.75	0.5	0.25	d_{B8}
			0.75	0.5	0.25	1	0.75	0.5	0.25	d_{B9}
		2÷10 Buildings	1	0.75	0.5	1	0.75	0.5	0.25	d_{B10}
			1	0.75	0.5	1	0.75	0.5	0.25	d_{B11}
			1	0.75	0.5	1	0.75	0.5	0.25	d_{B12}
			1	0.75	0.5	1	0.75	0.5	0.25	d_{B13}
		>10 Buildings	1	1	0.75	1	0.75	0.5	0.25	d_{B14}
			1	1	0.75	1	0.75	0.5	0.25	d_{B15}
			1	1	0.75	1	0.75	0.5	0.25	d_{B16}
			1	1	0.75	1	0.75	0.5	0.25	d_{B17}
		Loss of furnishings and assets	*1 Building*		0.25	1	0.75	0.5	0.25	d_{B18}
			2-10 Buildings		0.5	1	0.75	0.5	0.25	d_{B19}
			>10 Buildings		0.75	1	0.75	0.5	0.25	d_{B20}
		Loss of assets outside the buildings (i.e. cars)	*1 Building*		0.25	1	0.75	0.5	0.25	d_{B21}
			2-10 Buildings		0.5	1	0.75	0.5	0.25	d_{B22}
			>10 Buildings		0.75	1	0.75	0.5	0.25	d_{B23}
C	Roads	Highway		*Bridge*	1	1	0.75	0.5	0.25	d_{C1}
				Tunnel	1	1	0.75	0.5	0.25	d_{C2}
				Roadway	1	1	0.75	0.5	0.25	d_{C3}
		State road		*Bridge*	1	1	0.75	0.5	0.25	d_{C4}
				Tunnel	0.75	1	0.75	0.5	0.25	d_{C5}
				Roadway	0.75	1	0.75	0.5	0.25	d_{C6}
		County road		*Bridge*	1	1	0.75	0.5	0.25	d_{C7}
				Tunnel	0.75	1	0.75	0.5	0.25	d_{C8}
				Roadway	0.25	1	0.75	0.5	0.25	d_{C9}
		Municipal road		*Bridge*	0.75	1	0.75	0.5	0.25	d_{C10}
				Tunnel	0.5	1	0.75	0.5	0.25	d_{C11}
				Roadway	0.25	1	0.75	0.5	0.25	d_{C12}
		Country road		*Roadway*	0.25	1	0.75	0.5	0.25	d_{C13}
D	Railways	State railway		*Bridge*	1	1	0.75	0.5	0.25	d_{D1}
				Tunnel	1	1	0.75	0.5	0.25	d_{D2}
				Roadway	0.75	1	0.75	0.5	0.25	d_{D3}
		Regional railway		*Bridge*	1	1	0.75	0.5	0.25	d_{D4}
				Tunnel	0.75	1	0.75	0.5	0.25	d_{D5}
				Roadway	0.5	1	0.75	0.5	0.25	d_{D6}
E	Productive activities	Industrial			1	1	0.75	0.5	0.25	d_{E1}
		Commercial			0.75	1	0.75	0.5	0.25	d_{E2}
		Handicraft			0.5	1	0.75	0.5	0.25	d_{E3}
		Tourism			0.75	1	0.75	0.5	0.25	d_{E4}
		Farming			0.25	1	0.75	0.5	0.25	d_{E5}
F	Networks services	Gas pipeline			1	1	0.75	0.5	0.25	d_{F1}
		Electric line			1	1	0.75	0.5	0.25	d_{F2}
		Telephone line			0.5	1	0.75	0.5	0.25	d_{F3}
		Aqueduct			0.75	1	0.75	0.5	0.25	d_{F4}
		Drainage system			0.5	1	0.75	0.5	0.25	d_{F5}
G	People					>60 P	60-30 P	30-10 P	<10 P	
		Victims			1	1	0.75	0.5	0.25	d_{G1}
		Badly hurt			1	1	0.75	0.5	0.25	d_{G2}
		Light physical damage			0.5	1	0.75	0.5	0.25	d_{G3}
		Temporary shock conditions			0.25	1	0.75	0.5	0.25	d_{G4}

Fig. 4. Sections of the SAF assessing direct damage. The black numbers are the relative values of the elements. The levels of loss (red numbers) are set as follows: *L4*: complete loss; *L3*: high loss; *L2*: medium loss; *L1*: low loss. P stands for People.

Indirect damage sections						
S	*Actions*	*Levels of loss*				*dl*
		L4	L3	L2	L1	
		>60 people	60<people<30	30<people<10	<10 people	
H	Lodging for prolonged periods (>30days)	**1**	**0.75**	**0.5**	**0.25**	dl_{H1}
	Lodging for short periods (<30days)	**0.75**	**0.5**	**0.25**	**0.25**	dl_{H2}
	Arrangement of foodstuffs and basic necessities for displaced people	**0.25**	**0.25**	**0.25**	**0.25**	dl_{H3}
	Set up of sanitary conditions for displaced people	**0.25**	**0.25**	**0.25**	**0.25**	dl_{H4}
S	*Actions*	*Levels of loss*				*dl*
		L4	L3	L2	L1	
		>100,000€	*100,000 ÷ 20,000 €*	*20,000 ÷ 10,000 €*	*<10,000 €*	
I	Removal of debris in order to re-enable circulation	**1**	**0.75**	**0.5**	**0.25**	dl_{I1}
	Remedial works aiming to re-establish safety conditions for people (retaining walls, removal of unstable rock blocks)	**1**	**0.75**	**0.5**	**0.25**	dl_{I2}
	Studies, surveys and monitoring aiming to organise plans for emergency management and recovering	**1**	**0.75**	**0.5**	**0.25**	dl_{I3}
	Emergency works on unstable buildings	**1**	**0.75**	**0.5**	**0.25**	dl_{I4}
	Construction of new housing	**1**	**0.75**	**0.5**	**0.25**	dl_{I5}
	Opening of alternative roads to by-pass damaged areas	**1**	**0.75**	**0.5**	**0.25**	dl_{I6}
	Economic loss due to the decrease of traffic	**1**	**0.75**	**0.5**	**0.25**	dl_{I7}
Intangible damage section						
S	*Actions*	*Levels of loss*				*dl*
		L4	L3	L2	L1	
		>60 people	60<people<30	30<people<10	<10 people	
L	Psychological effects due to the prolonged condition of displaced people	**0.75**	**0.5**	**0.25**	**0.25**	dl_{L1}
	Psychological effects due to the temporary condition of displaced people	**0.5**	**0.25**	**0.25**	**0.25**	dl_{L2}
	Problems due to the delay of public transportation in the damaged area	**0.5**	**0.25**	**0.25**	**0.25**	dl_{L3}

Fig. 5. Sections of the SAF assessing the indirect (**H** and **I**) and intangible (**L**) damage. Basing on the combination of the action to be undertaken and the number of people involved (**H** and **L**) or the cost of the action (**I**), a value grid has been defined.

5.3 Intangible damage section

The intangible damage, assessed in section L, takes into account the psychological consequences affecting people who live in the damaged area. The levels of loss are set according to the number of people involved (>60 people; 60-30 people; 30-10 people; <10 people) (Figure 5). For each line of the indirect damage sections, by selecting a single level of loss, the appropriate numerical value is inserted in the corresponding cell of d_l. All of the d_l values are used to assess both intangible and total damage indices.

5.4 Assessment of damage indices

The values of d_l obtained from the lines of the SAF are converted into damage indices by means of the simple calculations summarised below. For each section, i.e., for the generic section *i*, we calculate the Damage of the Section *i* (D_{Si}) using equation 5:

$$Dsi = \sum dl \tag{5}$$

where d_l is the damage contribution of each of the *n* lines of section *I*.

For each section, the maximum value of D_{Si} ($MaxD_{Si}$) is calculated based on the occurrence of damage to all of the listed elements that are supposed to suffer the highest level of loss. Next, D_{Si} is normalised to $MaxD_{Si}$ to obtain the Normalised Damage of Section *i* (ND_{Si}), as in equation 6:

$$NDSi = DSi / MaxDSi \tag{6}$$

To obtain the Index of Damage of Section *i* (ID_{Si}), the values of ND_{Si} are classified as follows: D4: very high damage (1 < D4 ≤ 0.75); D3: high damage (0.75 < D3 ≤ 0.5); D2: medium damage (0.5 < D2 ≤ 0.25); or D1: low damage (D1 < 0.25).

The Normalised DIrect Damage (*N.DI.D*) is obtained using equation 7:

$$N.DI.D. = \sum NDSi / 32.5 \tag{7}$$

where the value 32.5, which is used to normalise the result, is the maximum ND_{Si} that can be obtained by summing the D_{Si} of all of the direct damage sections. The calculation is extended to all of the sections of direct damage, from B to G. The value of *N.DI.D.* is converted into the Index of DIrect Damage (*I.DI.D.*) by classifying it into one of the four classes listed above (D4, D3, D2, or D1). The Normalised Indirect Damage (*N.I.D.*) is calculated using equation 8: the sum is from i=H to i=I and 9.25 is the maximum indirect damage that SAF can assess. The Index of Indirect Damage (*I.I.D.*) is obtained by classifying the result according to the above-mentioned four classes.

$$N.I.D. = \sum DSi / 9.25 \tag{8}$$

Similarly, the Normalised INtangible Damage (*N.IN.D.*) can be assessed using equation 9, in which *L* is the intangible damage section and 1.75 is the maximum sum of D_{Si} of the L section. The Index of INtangible Damage (*I.IN.D.*) is determined by classifying the value obtained from equation 9.

$$N.IN.D. = \sum D_{Si} / 1.75 \tag{9}$$

The Normalised Total Damage (*N.T.D.*) is calculated using equation 10 (the sum is from i=B to L), and the Index of Total Damage (*I.T.D*) is obtained by classifying the value obtained from equation 10. In equation 10, 43.5 is the maximum value of total damage that can be assessed using the SAF.

$$N.T.D. = \sum DSi / 43.5 \tag{10}$$

Following the described procedure, the SAF allows to converts damage descriptions into numerical indices expressing – in a relative manner - the direct, indirect, and intangible damage. The procedure was tested in Calabria, on both historical landslides (Petrucci & Gullà, 2009, 2010) and more recent events (Petrucci et al., 2010).

Fig. 6. Damage caused to cars by DHEs in Calabria.

It must be pointed out that the procedure is based on a relative scale of values and not on monetary costs. Then it can be used for a) current events for which monetary assessments are not (or not yet) available, and for B) past landslides for which monetary assessments of costs are quite impossible to obtain. In both these situations, the SAF represents the *minimum amount of information* that can be used to define the impact caused by different landslides in order to perform impact comparisons.

6. Conclusion

The chapter showed a panoramic view of the assessment of the impact of natural disasters as presented in the scholarly literature. The numerous experiences of damage assessment performed in different economic frameworks show that developing countries are more strongly hit than developed ones: as economies develop, there are fewer disaster-related deaths and damages/GDP. Nevertheless, increasing wealth causes relatively higher losses in high-income nations. Increases in income increase the private demand for safety; higher income enables countries to employ additional, costly precautionary measures. Yet, in countries with a concentration of assets that is larger than the counter-measures, the income-vulnerability relationship can be inverted, especially in the case of disasters related to behavioural choices such as floods and landslides.

Two major constraints obstruct the assessment of the impact of disasters: the first is the lack of shared assessment methodologies. In the different literature sectors, several approaches are available, but, as far as academic research are restricted to the detailed discussion of one particular impact, or impacts in a single sector, the result is a somewhat fragmented coverage of impacts. On the other hand, conveying all the different assessments in a single methodological approach is objectively an extremely complicated task which can be handled exclusively by multidisciplinary staffs, having all the skills to cope with a multifaceted task as disasters impact assessment.

The second problem is related to data availability. It is impossible to decide a priori the most opportune time to gather data and to undertake impact assessment, as it will depend on the type of phenomenon causing the disaster, its magnitude and scope of the assessment. In addition, continuous data gathering also once the emergency phase has passed ensures detection of long-term effects, as either economic impacts or psychological consequences on people affected.

On the contrary, dealing with the impact of phenomena occurred in the past, data gathering becomes very complicated: both the amount of data available and their level of detail can be low and cannot be significantly increased, even by further research. In these cases, simplified approaches can be used to perform relative assessments based on a minimum amount of information. These approaches aim to supply quantitative indices expressing the impact of different disasters in order to make them comparable even if they occurred both at different time and in different areas.

Specifically for landslides, a structured approach aiming to collect data and transforming them into relative damage indices is presented. This approach can be used for a) current events for which monetary assessments are not (or not yet) available, and B) past landslides for which monetary assessments of costs are quite impossible to obtain. In both these situations, the approach focuses on the minimum amount of information that can be used to define the impact caused by different landslides in order to perform impact comparisons. It must to be understood when using this approach that one is dealing with relative assessments and their reliability strictly depends on the reliability of the data employed.

7. References

AusAID (Australian Agency for International Development) (2005). Economic impact of natural disasters on development in the Pacific, Volume 2: Economic Assessment Tools, http://www.ausaid.gov.au/publications/pdf/impact_pacific_tools.pdf, 2005, last access: June 2010

Barredo, J.I. (2009). Normalised flood losses in Europe: 1970–2006. *Natural Hazards and Earth System Sciences*, Vol. 9, pp. 97–104

Barredo, J.I. (2010). No upward trend in normalised windstorm losses in Europe: 1970–2008, *Natural Hazards and Earth System Sciences*, Vol. 10, pp. 97–104

Bilgehan, R. & Kilic, R.K. (2008). The landslides threatening Tasova town (Central Anatolia, Turkey) and their environmental impacts. *Environm. Geology*, Vol. 55, pp. 179–190

Birkmann, J., Buckle, P., Jaeger, J. Pelling, M., Setiadi, N., Garschagen, M., Fernando, N. & Kropp, J. (2008). Extreme events and disasters: a window of opportunity for change? Analysis of organizational, institutional and political changes, formal and informal responses after mega-disasters. *Natural Hazards*, Vol. 55 (3), pp. 637-655

Bland, S.H., O'Leary, E., Farinaro, E., Jossa, F. & Trevisan, M. (1996). Long-term psychological effects of natural disasters, *Psychosomatic Medicine*, Vol. 58, pp. 18-24

Bouwer, L.M. (2011). Have disaster losses increased due to anthropogenic climate change? *American Meteorological Society*, Jan 2011, pp. 39-46

CACND (Committee on Assessing Costs of Natural Disasters) (1999). The impacts of natural disasters: a framework for loss estimation. *The National Academy Press*, 80 pp.

Cao, H., McFarlane A.C. & Klimidis, S, (2003). Prevalence of psychiatric disorder following the 1988 Yun Nan (China) earthquake: the first 5-month. *Soc. Psychiatry Psychiatr. Epidemiol.*, Vol. 38, pp. 204-212

Catapano, F., Malafronte, R., Lepre, F., Cozzolino, P., Arnone, R., Lorenzo, E., Tartaglia, G. Storace, F., Magliano, L. & Maj, M. (2001). Psychological consequences of the 1998 landslide in Sarno, Italy: a community study. *Acta Psychiatr. Scand.*, Vol. 104, pp. 438–442

Chou, Y.J., Huang, N., Lee, C.H., Tsai, S.L., Tsay, J.H., Chen, L.S. & Chou, P. (2003). Suicides after the 1999 Taiwan earthquake. *Inter. Jour. of Epidemiology*, Vol. 32, pp. 1007–1014

Cuaresma, J.C., Hlouskova, J. & Obersteiner, M., (2004). Natural disasters as creative destruction: evidence from developing countries, http://www3.interscience.wiley.com/cgi-bin/fulltext/119397853 /PDFSTART, last accessed: June 2010.

Cuesta, M.J.D., Sanchez, M.J., & Garcia, A.R. (1999). Press archives as temporal records of landslides in the North of Spain: relationships between rainfall and instability slope events. *Geomorphology*, Vol. 30, pp. 125-132

Devoli, G., Morales, A., & Høeg, K. (2007). Historical landslides in Nicaragua-collection and analysis of data. *Landslides*, Vol. 4, pp. 5-18

Dosi, C. (2001). Environmental values, valuation methods and natural disaster damage assessment, Medio Ambiente y Desarrollo, CEPAL, United Nations, Santiago, Chile, 62pp.

ECLAC (Economic Commission for Latin America and the Caribbean's) (1991). Manual for estimating the socio-economic effects of Natural disasters. http://www.eclac.org.

ECLAC (Economic Commission for Latin America and the Caribbean's) (2003). Handbook for estimating the socio-economic and environmental effects of natural disasters, Section two: Social Aspects, Housing and human settlements, http://www.preventionweb.net/files/1099_Vol2[1].pdf, 2003, last access: June 2010.

Fonseca, V.A., Smith, H., Kuhadiya, N., Leger, S.M., Yau, C.L., Reynolds, K., Shi, L., Mcduffie, R.H., Thethi, T. & John-Kalarickal, J. (2009). Impact of a natural disaster on diabetes: exacerbation of disparities and long-term consequences, *Diabetes Care*, Vol. 32, pp. 1632-1638

Highland, L.M. (2003). An account of preliminary landslide damage and losses resulting from the February 28, 2001, Nisqually, Washington, Earthquake. USGS Open-File rep.03-211.

Jonkman, S.N., Maaskant, B., Boyd, E. & Levitan, M.L. (2009). Loss of life caused by the flooding of New Orleans after hurricane Katrina: analysis of the relationship between flood characteristics and mortality. *Risk Analysis*, Vol. 29 (5), pp. 676-698

Kirschbaum, D.B., Adler, R., Hong, Y., Hill, S. & Lerner-Lam, A. (2009). A global landslide catalog for hazard applications: method, results, and limitations. *Natural Hazards,* Vol. 52 (3), pp. 561-575

Lazarus, P.J., Jimerson, S.R. & Brock, S.E. (2002). Responding to natural disasters: helping children and families information for school crisis teams. www.nasponline.org. last accessed: June 2011.

Liao, S.C., Lee, M.B., Lee, Y.J. & Huang, T.S. (2004). Hyperleptinemia in subjects with persistent partial Posttraumatic Stress Disorder after a major earthquake. *Psychosomatic Medicine*, Vol. 66, pp. 23–28

Lindell, M.K. & Prater, C.S. (2003). Assessing community impacts of natural disasters. *Nat. Haz. Rev*. Vol. 4(4), pp. 176-185

Lutgendorf, S.K., Antoni, M.H., Ironson, G., Fletcher, M.A., Penedo, F., Baum, A., Schnelderman, N., & Klimas, N. (1995). Physical symptoms of chronic fatigue syndrome are exacerbated by the stress of hurricane Andrew. *Psychosomatic Medicine*. Vol. 57, pp.310-323

Meheux, K., Howes, D.D. & Lloyd, K. (2007). Natural hazard impacts in small island developing states: A review of current knowledge and future research needs. *Natural Hazards*, Vol. 40, pp. 429–446

Montazeri, A., Baradaran, H., Omidvari, S., Azin, S.A., Ebadi, M., Garmaroudi, G., Harirchi, A.M. & Shariati, M. (2005). Psychological distress among Bam earthquake survivors in Iran: a population-based study. *BMC Public Health*, Vol. 5(4), pp. 1-6

Msilimba, G.G. (2010). The socioeconomic and environmental effects of the 2003 landslides in the Rumphi and Ntcheu Districts (Malawi). *Natural Hazards*, Vol. 53, pp. 347–360

Ngecu, W.M. & Ichang'I, D.W. (1999). The environmental impact of landslides on the population living on the eastern foot slopes of the Aberdare ranges in Kenya: a case study of Maringa Village landslide. *Environmental Geology*, Vol. 38, pp. 259-264

Norris, F.H., Friedman, M.J., Watson, P.J., Byrne, C.M., Diaz, E. & Kaniasty, K. (2002). 60,000 disaster victims speak: Part I. An empirical review of the empirical literature, 1981–2001. *Psychiatry*, Vol. 65(3), pp. 207-239

Noy, I. & Nualsri, A. (2011). Fiscal storms: public spending and revenues in the aftermath of natural disasters. *Environment and Development Economics*, Vol. 16, pp. 113–128

Noy, I. (2009). The macroeconomic consequences of disasters. *Journal of Development Economics*, Vol. 88, pp. 221–231

O'Neill, H.K., Blake, A.E., Bussman, M.D. & Strandberg, D.K. (1999). Psychological distress during the Red River flood: predictive utility of the conservation of Resource Model. *Applied Behavioural Science Review*, Vol. 7(2), pp. 159-169

Overstreet, S., Salloum, A., Burch, B. & West, J. (2011). Challenges Associated with Childhood Exposure to Severe Natural Disasters: Research Review and Clinical Implications. *Journal of Child & Adolescent Trauma*, Vol. 4, pp. 52–68

Patwardhan, A. & Sharma, U. (2005). Improving the methodology for assessing natural hazard impacts. *Global Planet. Change*, Vol. 47, pp. 253–265

Petrucci, O. & Gullà, G. (2009) A Support Analysis Framework for mass movement damage assessment: applications to case studies in Calabria (Italy). *Natural Hazards and Earth System Sciences*, Vol. 9, pp. 315–326

Petrucci, O. & Gullà, G. (2010). A simplified method for landslide damage scenario assessment based on historical data. *Natural Hazards*, Vol. 52(3), pp. 539-560

Petrucci, O. & Llasat, M.C. (in press). Impact of disasters in Mediterranean regions: an overview in the framework of the HYMEX project. Proceedings of the Second World Landslide Forum, Rome, Italy, October 3-7, 2011

Petrucci, O. & Pasqua, A.A. (2008). The study of past Damaging Hydrogeological Events for damage susceptibility zonation. *Natural Hazards and Earth System Sciences*, Vol. 8, pp. 881–892

Petrucci, O. & Polemio, M. (2003). The use of historical data for the characterisation of multiple damaging hydrogeological events. *Natural Hazards and Earth System Sciences*, Vol. 3, pp. 17-30

Petrucci, O. & Polemio, M. (2009). The role of meteorological and climatic conditions in the occurrence of damaging hydro-geologic events in Southern Italy. *Natural Hazards and Earth System Sciences*, Vol. 9, pp. 105-118

Petrucci, O. & Versace, P. (2000). Conoscere il passato per prevedere il futuro. *DPC (Dipartimento Protezione Civile) Informa*, Vol. 29, pp. 25-26

Petrucci, O. & Versace, P. (2005). Frane e alluvioni in provincia di Cosenza agli inizi del '900: ricerche storiche nella documentazione del Genio Civile. I Quaderno dell'Osservatorio di Documentazione del Dipartimento di Difesa del Suolo (UNICAL). Editoriale Bios, Cosenza, 172pp. Available on Google Books, ISBN 88-7740-391-8

Petrucci, O. & Versace, P. (2007). Frane e alluvioni in provincia di Cosenza tra il 1930 e il 1950: ricerche storiche nella documentazione del Genio Civile. II Quaderno dell'Osservatorio di Documentazione del Dipartimento di Difesa del Suolo (UNICAL) Pubbl. GNDCI N. 2913, Nuova Bios, Cosenza, 247pp. Available on Google Books, ISBN 978-88-6093-029

Petrucci, O., Pasqua, A.A., & Gullà, G. (2010). Landslide damage assessment using the Support Analysis Framework (SAF): the 2009 landsliding event in Calabria (Italy). *ADGEO*, Vol. 26, pp. 13-17

Petrucci, O., Versace, P. & Pasqua, A.A. (2009). *Frane e alluvioni in provincia di Cosenza fra il 1951 ed il 1960: ricerche storiche nella documentazione del Genio Civile.* III Quaderno dell'Osservatorio di Documentazione del Dipartimento di Difesa del Suolo (UNICAL), Rubbettino, Soveria Mannelli (CZ), 316 pp. *Available on Google Books,* ISBN 978-88-95172-05-7

Pielke, R.A. Jr., Gratz, J., Landsea, C.W., Collins, D., Saunders, M.A. & Musulin, R. (2008). Normalized hurricane damage in the United States: 1900–2005. *Nat. Haz. Rev.* Vol., 9(1), pp. 29-42

Popp, A. (2006). The effect of natural hazard on long run growth, Major themes in economy, http://www.cba.uni.edu/economics/themes/popp.pdf, 2006, last access: June 2010

Ramachandran, A., Snehalatha, C., Yamuna, A., Bhaskar, A.D., Simon, M., Vijay, V. & Shobhana, R. (2006). Stress and undetected hyperglycemia in Southern Indian coastal population affected by tsunami. *JAPI*, Vol. 54, pp. 109-112

Raschky, P.A. (2008). Institutions and the losses from natural disasters. *Natural Hazards and Earth System Sciences*, Vol. 8, 627–634

Rodriguez-Oreggia, E., De la Fuente, A., De la Torre, R., Moreno, E. & Rodriguez, C. (2010). The impact of natural disasters on human development and poverty at the municipal level in Mexico. CID Working Paper No. 43, 34pp.

Sadeghi, N. & Ahmadi, M.H. (2008). Mental health preparedness for natural disasters in Iran. *Natural Hazards*, Vol. 44, pp. 243–252

Shajaat Ali, A.M. (2007). September 2004 flood event in SW Bangladesh: a study of its nature, causes, and human perception and adjustments to a new hazard. *Natural Hazards*, Vol. 40, pp. 89–111

Skidmore, M. & Toya, H. (2002). Do Natural Disasters Promote Long-Run Growth? Economic Inquiry, Oxford Univ. Press. 40, 4, 664-687.

Smith, S. & McCarty, C. (1996). Demographic effects of natural disasters: a case study of hurricane Andrew. *Demography*, Vol. 33(2), pp. 265-275

Solomon, G.F., Segerstrom, S.C., Grohr, P., Kemeny, M. & Fahey, J. (1997). Shaking up immunity: psychological and immunologic changes after a natural disaster. *Psychosomatic Medicine,* Vol. 59, pp. 114-127

Suzuki, S., Sakamoto, S., Koide, M., Fujita, H., Sakuramoto, H., Kuroda, T., Kintaka, T. & Matsuo, T. (1997). Hanshin-Awaji earthquake as a trigger for acute myocardial infarction. *Amer. Heart Jour.*, Vol. 134, (5)1, pp. 974-977

Swiss Re (1998). Floods-an insurable risk?, Zurich, 48 p.

Toya, H. & Skidmore, M. (2007). Economic development and the impacts of natural disasters. *Economics Letters*, Vol. 94, pp. 20–25

Twigg, J. (2007). Tools for Mainstreaming Disaster Risk Reduction, Social Impact Assessment. International Federation of Red Cross and Red Crescent Societies ProVention Consortium. http://www.proventionconsortium.org /mainstreaming _tools (latest access June 2011)

UNEP-ECLAC (2000): Panorama of the environmental impact of recent natural disasters in Latin America and the Caribbean, http://www.gdrc.org/uem/disasters/disenvi/Panorama-Envi-Impact.pdf. last accessed: June 2010.

USGS (2009). http://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html

Varnes, D.J., IAEG-Commission on Landslides (1984) Landslide Hazard zonation – a review of principles and practice, UNESCO, Paris, 63 pp.

Waring, S.C. & Brown, B.J. (2005). The threat of communicable diseases following natural disasters: a public health response. *Disaster Management Response*, Vol. 3, pp. 41-7

Webb, G.R., Tierney, K.J. & Dahlhamer, J.M. (2002). Predicting long-term business recovery from disaster: a comparison of the Loma Prieta earthquake and Hurricane Andrew. *Environ. Haz.*, Vol. 4, pp. 45–58

Whitworth, M.R.Z., Griffiths, J.S. & Lee, E.M. (2006). Evaluating risk in a rural environment; a case study; Sorbas, SE Spain, IAEG2006 Paper No. 535: 1-6.

Wilhite, D.A., Svoboda, M.D. & Hayes, M.J. (2007) Understanding the complex impacts of drought: A key to enhancing drought mitigation and preparedness. *Water Res. Man.*, Vol. 21, pp. 763–774

Zissimopoulos, J. & Karoly, L.A. (2010). Employment and self-employment in the wake of hurricane Katrina. *Demography*, Vol. 47(2), pp. 345-367

7

A Diagnostic Method for the Study of Disaster Management: A Review of Fundamentals and Practices

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1. Introduction

A diagnostic method for the study of disaster management, based on a synthesis of principles considered fundamental to successful crisis response, will be presented in this chapter. These principles can be grouped into four main categories: planning/preparedness, coordination, leadership and civil society behaviour (Lalonde, 2011). Several studies of disaster management have highlighted these categories separately, but they have seldom been considered together in a comprehensive perspective. This method of classification should allow researchers and managers to have a better overview of recurrent patterns that emerge from real cases and practices and provide avenues for resolving discrepancies with fundamental principles. This approach is based on a cross-sectional analysis of disasters, the method favoured by a number of researchers (Hart et al., 2001; Quarantelli, 2005). Based on reports from national inquiries and expert committees on four major disasters that occurred in Canada, France, the United States and Southeast Asia, this study presents a diagnosis for each of the four disaster management categories. The results show recurrent dysfunctional patterns of disaster management in each category: 1) public authorities have limited capacity and preparedness to cope with disasters; 2) the links between field responders and central administrations are dysfunctional, partly because administrators tend to operate in a vacuum; 3) grassroots leaders tend to demonstrate more key leadership skills than government officials; 4) citizenship behaviours are poorly integrated into formal response, so community inteventions tend to operate independently of official media channels. These results confirm numerous observations in the literature on the importance of several aspects of disaster preparedness and response: integrating disaster planning into the overall organization strategy on an ongoing basis, establishing networking structures, developing adaptive leadership skills at each phase of a disaster, and incorporating helping behaviour from civil society in disaster responses. The chapter conclusion will attempt to highlight the reasons that may explain the recurring deficiencies and problematic patterns in disaster management.

2. A diagnostic method based on major trends in the disaster literature

For many decades, the field of disaster management has been characterized by two main trends (Lalonde, 2007): organizational contingencies and planning/preparedness for a disaster. On one hand, the literature on organizational contingencies relies mostly on the sociology of disasters (Drabek & McEntire, 2003; Dynes, De Marchi, & Pelanda, 1987; Fischer, 1998). This field of inquiry has provided a wealth of data highlighting the complex and often disorganized dynamic amongst the responders themselves, as well as the roles and behaviours of citizens during crises (Helsloot & Ruitenberg, 2004; Perry & Lindell, 2003b). The research also draws attention to the political geometry of interventions, which varies depending on the missions of the responding organizations (Kreps & Bosworth, 2007), the strategies deployed (e.g., coalitions, alliances and disputes over control of resources; "garbage-can" approach), and the specific structural modalities or archetypes adopted to deal with the crisis (Lalonde, 2004; Macintosh & Maclean, 1999; Quarantelli, 1988). On the other hand, the disaster planning literature emphasizes formal or explicit knowledge and offers a number of normative pronouncements aimed at increasing the efficiency of disaster interventions. This often takes the form of recommendations which are presented as the correct way to cope with crisis situations. Authors in this field emphasize the need for emergency planning (Quarantelli, 1988, 1996); the identification and description of actions pertaining to various phases of a crisis, from detecting early warning signs to post-crisis activities (Mitroff, 1988); the need to promote preventive behaviour and the development of a culture of security, both within organizations and in the population at large (Denis, 2002); and the importance of training (Borodzicz & Van Haperen, 2002), developing communication skills and fostering leaders' awareness of their roles in times of crisis (Heifetz et al., 2009; James & Wooten, 2005; Wooten & James, 2008). In the disaster planning literature, the focus is on formalizing a set of rules, routines, techniques and general guidelines to follow in order to master the risks and dangers.

Together, these two major trends have contributed greatly to research in disaster management and knowledge development in the field. They are highly instructive for managers and policy makers and have contributed important insights to the discipline that can be used in the formulation of a diagnostic method capable of evaluating responses to disasters. The questions facing researchers are the degree to which organizations integrate this research-based knowledge, how it is actually implemented in practice, where the most common pitfalls can be found, and why they remain so commonplace. It is the aim of this chapter to respond to these questions. The next section will present the four frameworks that form the foundation of our diagnostic method for the analysis of disaster management. We will then present findings based on applying this diagnostic method to four major disasters that occurred in Canada, France, the United States and Southeast Asia. These implications of these findings are then discussed, concluding with the main reasons that dysfunctional patterns in disaster management persist.

3. Examination of disaster management based on four integrated frameworks

3.1 Framework for a diagnosis regarding planning and preparedness

Many authors argue that organizations can significantly increase the effectiveness of their crisis response by establishing an integrated and comprehensive risk management process and regularly updating their crisis preparedness (Alexander, 2005; Lagadec, 1996; McEntire & Myers, 2004; Perry & Lindell, 2003a; Quarantelli, 1988). This process should be part of the organization's overall strategy (Pauchant & Mitroff, 1995; Pollard & Hotho, 2006; Sapriel, 2003), should not be dealt with as an exceptional phenomenon (Roux-Dufort, 2007), and should be led by a senior manager acting as facilitator (Denis, 2002; Pauchant & Mitroff, 1995). Many authors deplore the fact that planning exercises are limited to establishing routines and formal plans that will rarely be put into practice (Comfort, 2005; McEntire & Myers, 2004; Perry & Lindell, 2003a) rather than situating planning within an ongoing process to improve the organization's intrinsic preparedness to cope with crises (Boin & Lagadec, 2000; Robert & Lajtah, 2003; Pearce, 2003). According to Perry and Lindell (2003a), a serious and rigorous approach to crisis planning and preparedness should be based on four major components: 1) evaluating the risks (vulnerability assessment); 2) evaluating the ability of the organization and community to cope with crises (capacity assessment); 3) developing and maintaining the skills of individual responders; and 4) establishing a flexible structure that can be deployed quickly when a crisis arises. In the same vein, Robert and Lajtah (2003) suggest that crisis management should be understood as a process that is continuously enriched by the knowledge, experience and training of managers, staff and other stakeholders who work closely with the organization, as well as by conducting regular simulations.

Because crisis preparation is never definitively completed, such knowledge and experience must be monitored and updated regularly, and should not be limited to drafting plans and designing emergency response protocols. Any number of situations can drive the need for regular updates, such as key people leaving the organization, taking valuable expertise with them; changes in resource availability (financial, material and human) which can impact the emphasis given to planning (Boin & McConnell, 2007; McConnell & Drennan, 2006); and variations in the nature of risks over time. Table 1 summarizes the components of the diagnosis that should be considered at the planning/preparedness level.

Components of the diagnosis	Yes	No
<u>Formal planning</u> 1. Is the plan (or plans) up to date? 2. Does the plan take into account community behaviour? 3. Does the plan include the coordination of the various responders? 4. Does the plan include personnel training?		
<u>Risk assessment</u> 5. Have the risks been evaluated in advance? 6. Does the organization have a multiple-risk plan? 7. Has the population been informed of the potential risks?		
<u>Capacity assessment</u> 8. The organization acts with diligence and purpose: a) Have the crisis managers verified that their interventions will not harm the population? b) Do the crisis managers regularly invest in the development of crisis intervention capabilities? 9. The organization shows flexibility in the application of response routines: a) Have the managers verified that responders act in a concerted manner? b) Have the managers adapted their interventions to the contingencies?		

Table 1. Diagnosis regarding planning/preparedness.

3.2 Framework for a diagnosis regarding coordination

Along with planning, coordination is one of the central themes in the disaster management literature (Drabek, 2007; Morris et al., 2007). Indeed, the lack of integration of activities among the various stakeholders has been identified by many authors as one of the major ongoing problems in crisis response coordination, highlighting as well the fragmented, even conflicting nature of their interventions.

The sheer number of stakeholders[1] involved adds to the complexity of coordination and can contribute to a lack of integration. The ability to create collaborative networks in times of crisis has been identified as an important factor in effective response (Wise, 2006). Many authors stress the importance of incorporating stakeholders, organizations, governments and local communities into a network of responders (Oloruntoba, 2005; Pearce, 2003; Waugh & Streib, 2006). In fact, in times of crisis, organizations and their stakeholders become more interdependent (Alvarado & Mendis, 2010; Kruchten et al., 2008) for a variety of reasons including the urgency to act in the absence of information normally considered essential for decision-making (Quarantelli, 1988), the increased uncertainty concerning what should be done, the possible negative effects on the reputations of those involved in the crisis, and the long-term impacts on the future of the organizations or their official representatives. Thus, during crises, organizations typically put diverse strategies into practice, most of which are based on forming alliances, alliances made on the basis of the personal contacts of the strategists and senior leaders involved. Unfortunately, these strategies are often imbued with political gamesmanship (Rosenthal, Charles & Hart, 1989). In most instances, however, they are not implemented blindly, as organizations tend to form alliances with others that are comparable in terms of status or legitimacy (Drabek & Hoetmer, 1991; Dynes, 1978; Wolensky, 1983), becoming similar to the "coalitions" described by Cyert and March (1963). According to several authors (Dynes, 1994; Morris et al., 2007; Quarantelli, 1997), there are two main models for defining coordination. The first is based on a traditional hierarchy in which relationships between the components of a system are clearly defined, including the distribution of authority. As these and other authors point out, while this model is very effective for routine and repetitive activities, it can result in inflexible structures that discourage adaptation and change (Takeda & Helms, 2006a, 2006b). The second model is based on networks of interdependent stakeholders that go beyond simple hierarchy and function through cooperation. This model assumes that relationships among organizations or individuals cannot be defined through formal ties alone, and that networks are formed among stakeholders who share values or beliefs. Yet, although the network model is based on greater structural flexibility and agility, it can prove difficult to implement, especially when the actors involved are not accustomed to working together or, worse, when they see each other as competitors. Morris and colleagues (2007) suggest that "contingent coordination", understood as a mix of traditional hierarchy (or the "command and control" model) and network-based coordination is a far better approach to solving the multifaceted problems usually associated with coordination. This approach combines the advantages of accountability and role definition associated with the classical

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[1] Tierney (2003), for example, noted that the Disaster Research Center counted at least 500 organizations involved in the first ten days after the attack on the World Trade Center on September 11, 2001.

top-down approach adopted by most public bureaucracies with the advantages of a flexible, negotiated and adaptable structure in order to deal with problems as they arise in the course of a disaster.

Insofar as one of the best predictors of effective coordination during crises is prior knowledge of potential collaborators (Dynes, 1994), a socio-ecological view of networks (Trist, 1983; Kapucu et al., 2010) may address the difficulties individual organizations face in dealing with complex or chaotic environments when attempting to operate in isolation. In the crisis management literature, the "crisis room" is often identified as the place for interaction among stakeholders from various organizations who are striving to act in concert in the heat of a crisis. In essence, the crisis room transcends the limiting particularities of each organization because, taken separately, each one is incapable or unable to solve the meta-problems generated by a crisis "because they lack the requisite variety" (Trist, 1983: 272). Beyond their inherent lack of flexibility, bureaucratic structures pose other intra-organizational issues that impact coordination during crises (Quarantelli, 1988). These issues concern: the modes of delegation and communication among units; the organization of work, such as the allocation and assignment of tasks; the ability of responders to demonstrate self-management, resourcefulness, imagination or improvisation (Lalonde, 2010); and the ways in which information is transmitted and communicated to maintain overall cohesion. Quarantelli (1988) provided an excellent summary of the principal challenges in coordination that he sees as revolving around three main elements: 1) communication, both internal and external, as well as with the public; 2) the exercise of authority; and 3) the development of cooperative structures. For each of these three aspects, the author defines the principal coordination issues to be considered in the context of crisis response. The main principles put forward by Quarantelli are summarized in Table 2.

Components of the diagnosis	Yes	No
Communication 1. Able to create new mechanisms to facilitate internal and external information flow? 2. Provides appropriate information to the population? 3. Integrates information from outside the formal decision-making mechanisms?		
Exercising authority 4. Authorizes the delegation and decentralization of certain decisions? 5. Demonstrates collegiality in the distribution of tasks? 6. Able to resolve conflicts between organizations? 7. Able to mobilize and motivate personnel and avoid burnouts?		
Developing cooperative structures 8. Works in collaboration with other leaders? 9. Integrates emerging local groups in the crisis response? 10. Maintains and strengthens harmonious relations with other leaders during normal (non-crisis) periods?		

Table 2. Diagnosis regarding coordination.

3.3 Framework for a diagnosis regarding leadership

When a crisis occurs, in addition to expecting their leaders to make critical decisions, citizens will turn to them for support, comfort and reassurance. As crises may take many forms and develop in very unexpected directions, crisis leadership must be highly adaptive (Heifetz et al., 2009; Ivanescu, 2011; Snowden & Boone, 2007). It not only requires rapid reactions, but also appropriate responses (Garcia, 2006; Lagadec, 1996), from implementing plans and creating tools to fostering a capacity for judgment and directing operations. Crisis leadership should not be strictly based on hierarchy and a centralized, command-and-control approach, but rather on collective sense making (Boin et al., 2005; Wooten & James, 2008), the construction of a shared legitimacy and the principles of continuity and cooperation (Dynes, 1983, 1994; Ivanescu, 2011; Lagadec, 1996; Quarantelli, 1988).

While effective crisis leadership entails the ability to mobilize and communicate adequately with people, it also requires a keen sensitivity to the external environment, such as the capacity to pick up on indications of an impending crisis, the ability to anticipate, the ability to view events in a systematic way, and the capacity to work in a network and with emerging actors (Boin et al., 2005; James, Wooten & Dushek, 2011; Watkins & Bazerman, 2003; Wooten & James, 2008). Of course, the skills required in times of crisis do not develop in a vacuum; they must be painstakingly cultivated beforehand through appropriate training, coaching and mentoring. According to many authors (Boin et al., 2005; Lagadec,1996; Smits & Ally, 2003; Wooten & James, 2008)[2], managers must develop certain specific abilities required in the various phases of a crisis. Boin et al. (2005) put forward five core tasks related to crisis leadership: sense making, decision making, meaning making, terminating and learning. These tasks punctuate the general process of crisis management — from the onset (in planning/preparedness, including detection of early warning signs) through the post-crisis period (when learning takes place). For their part, Wooten and James (2008) differentiate key skills for each phase. Thus, the capacities to give meaning to crisis warning signs and anticipate their potential impact on others are two key skills during the detection phase. In the prevention/preparation phase, the authors suggest that the capacity to convince organizational members of the importance of investing in crisis management planning is key. They argue that an agent of change who is skilled in issue selling is essential to bringing organizational leaders to pay attention to crisis preparation. Wooten and James (2008) also suggest that two additional skills are essential during the preparation phase: organizational agility (i.e., having detailed knowledge of the organization and a systemic view of the interaction dynamics likely to be deployed to face the crisis) and creativity (i.e., the capacity to imagine novel scenarios to deal with the contingencies of the crisis situation). At the height of the crisis, in the context of direct and active interventions, the capacity to make decisions under pressure, to ability to communicate effectively, and the courage to take needed risks is critical success factors. During the phase of reconstruction and returning to normal activities, promoting organizational resilience and adopting

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[2] Some of these authors, such as Boin et al. (2005), have focused on public leadership during crises, whereas others, such as James, Wooten & Dushek (2011), have focused primarily on business leadership. Despite this distinction, the results are largely in agreement.

ethical and responsible behaviour are two additional skills. On this point, the authors mention that organizations never completely return to how they were before the crisis. It is important that lessons be learned based on the strengths and weaknesses revealed during the crisis, with a concomitant review of any errors that can be avoided in the future. Even more importantly, the acknowledgement of these shortcomings will undoubtedly foster the support and confidence of stakeholders. Finally, adopting a learning approach encourages further reflection on improving crisis management practices outside the phases related to the crisis itself.

Components of the diagnosis	Yes	No
Before the crisis 1. Able to pick up on and make sense of early warning signals and the potential impacts they presage? 2. Uses persuasion and is skilled in communicating ideas? 3. Adopts a systemic view of the situation? 4. Demonstrates imaginative thinking?		
During the crisis 5. Maintains composure, enabling good decision-making under pressure? 6. Communicates effectively with entourage? 7. Takes "calculated" risks?		
After the crisis 8. Consolidates future interventions with a view toward resilience? 9. Regains the trust and confidence of other responders and employees? 10. Adopts a learning attitude?		

Table 3. Diagnosis regarding leadership.

3.4 Framework for a diagnosis regarding the behaviour of civil society

Civil society's behaviour in the face of crises is the subject of popular perceptions and myths, which a number of researchers have attempted to deconstruct (Drabek & McEntire, 2003; Dynes, 1983, 1994; Helsloot & Ruitenberg, 2004; Perry & Lindell, 2003b; Quarantelli, 1988; Tierney, 2003). As early as the 1960s, the sociologist Allen Barton (1969) was one of the first to introduce the notion of an "emergency social system" to convey the adaptive response of communities towards disasters likely to affect them. Far from giving rise to anti-social behaviour, disasters may bring about an "esprit de corps" or what Barton calls a "therapeutic community" composed of all the civic behaviours aimed at providing emergency assistance in the first moments following the destructive impact of a disaster (Drabek, 2007). Far from being a group of panicked and irrational actors, civil society can bring together citizens who are generally in control of themselves, make logical decisions, and provide initial help to their fellow victims. Dynes (1983), for example, uses the term "situational altruism" to characterize the expansion of civic roles in the form of mutual aid and expressions of solidarity towards victims.

The expansion of new roles and responsibilities among citizens can be a considerable challenge for organizations with more established and formal missions. In fact, the convergence of a large number of volunteers who lack training and knowledge of emergency procedures can impede proper coordination of response activities and block access routes to the disaster site (Drabek & McEntire, 2003). This observation, made notably by Helsloot and Ruitenberg (2004), is nonetheless counterbalanced by the advantages provided by help from citizens. In the opinion of many authors, it is in the best interests of governments to understand these advantages and integrate these civic behaviours into their coordination mechanisms. For example, in certain American cities, authorities have understood these advantages and have established civilian training programs (Tierney, 2003). The role of civil society may vary depending on the particular phase of the disaster, the type of disaster, and the characteristics of the affected communities.

Quarantelli (1993) thus argues that natural disasters usually bring about more consensual behaviour and empathetic gestures, whereas riots, environmental disasters or those resulting from manufacturing activities are more controversial. Regarding citizen involvement in different crisis phases, Helsloot and Ruitenberg (2004) point to the regrettable fact that the average citizen is little inclined to and not very interested in investing in preparing for a crisis. Citizens can, however, form organized groups after a crisis or disaster to make their voices heard. It is thus important to take into consideration the amount of information to which citizens have access before, during and after a disaster. The period leading-up to a crisis appears crucial, since the lack of time during the crisis will quickly prevent authorities from communicating relevant information to actors in civil society. Overcoming this obstacle is, furthermore, a real test of strength for those responsible for crisis management. In order to ensure that there is a clear understanding of what is happening, managers need to have strong communication skills and learn how to deal with the public nature and media coverage of most crises (Pollard & Hotho, 2006).

The role of civil society can also be examined from on the standpoint of citizens' views of their leaders and, more generally, of the reputation of response organizations during crises, particularly as represented in the media (Taylor, 2000; Alsop, Littlefield & Quenette, 2007). This can result in the search for guilty parties and the loss of confidence in leaders and institutions. In this regard, the role of the media during crises is also critical; they are viewed variously as probing, irritating and provoking or, conversely, as partners in communicating information to the public. According to several authors (Coppola, 2005; Littlefield & Quenette, 2007; Oloruntoba, 2005), the media can play a positive and constructive role, provided they act and behave like partners and allies in times of crisis. One critical role for the media would then be relaying information to the public. Coppola (2005) further asserts that journalists are not necessarily trained and prepared to fulfill this role, which is why the media must become aware of their impact on crisis management and especially in the management of perceptions. In summary, the need for a better understanding of community characteristics and civic behaviour in times of crisis is one of the guiding principles identified in the planning and coordination literature (Drabek & McEntire, 2003; Pearce, 2003). Altruistic acts give rise to activities that can be organized to a greater or lesser degree, an aspect that should be considered when coordinating crisis responses (Coate et al., 2006).

Components of the diagnosis	Yes	No
Civic behaviours 1. The population engages in: a) Altruistic acts? b) "Normal" panic behaviour? c) Delinquent acts such as looting or interference with public safety? d) Non-compliance with evacuation orders? e) Abdication of civic roles or lack of assistance to persons in danger?		
Emergence of grassroots leadership 2. Local and national actors — previously lesser known and/or less central to formal authority — act as consciousness-raisers?		
Role played by the media 3. Emphasize mostly what is dysfunctional? 4. Tend to focus on identifying the guilty parties? 5. Communicate useful information to the population?		

Table 4. Diagnosis regarding the behaviour of civil society.

4. A meta-analysis of four cases based on the diagnostic method

4.1 Choice of cases

In the last decade, many countries have experienced major disasters that have captured our collective imagination due to their very serious consequences in terms of death and material damage. These events involved mobilization of public services and the highest governmental authorities. They became the subject of a number of investigative reports by experts in the field and national commissions, and these reports now constitute invaluable sources of information for researchers (Quarantelli, 2005). This study thus employs a qualitative approach consisting of the content analysis of reports on four national disasters: Hurricane Katrina in the United States (2005), the tsunami in Southeast Asia (2004), the heat wave in France (2003) and the SARS outbreak in Canada (2003). Each of these disasters is treated as a case (Yin, 2009) and analyzed at a macro level. To properly describe each case, an exhaustive study of the national disaster inquiries was conducted to reconstruct a narrative of the events (Boje, 2008) that provides a thorough understanding of the context and the behaviour of the main actors. These four cases were chosen based on their high visibility, the fact that they were studied in depth by committees of experts or commissions of inquiry, their extensive coverage in the media, and the considerable upheaval they caused for the populations of these countries as a whole.

4.2 Review of two main sources of information

A meta-analysis of disaster management in the field for each case was conducted based on two complementary sources of information: the scientific community, in the form of research results (reliable data), and expert committees, in the form of recommendations[3].

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[3] After an initial classification of materials, "information holes" occurred mostly in the categories of leadership and the behaviour of civil society. Additional information to complete the analysis was therefore obtained from other sources, mainly newspapers, doctoral dissertations, and previously published articles focusing on the four disasters included in this study.

The study was conducted in two stages. First, a review of the academic research[4] on each of the four disasters studied in this paper was undertaken to identify recurring themes relating to disaster management practices. The results of this exercise, presented in the first part of the chapter, led to the identification of four major themes -- planning/preparedness, coordination, leadership and behaviour of civil society, as well as some guiding principles considered by researchers as the standard needed for effective disaster management[5]. The research design also enabled the classification of recommendations and lessons drawn from the four disasters, derived from the content analysis of the following expert committee reports (listed in references): for the SARS outbreak in Toronto, the report of the National Advisory Committee on SARS; for the public health impacts of Hurricane Katrina in New Orleans, the reports from the US House of Representatives (2006) and from the White House (2006); for the tsunami in Southeast Asia, the reports from International Federation of the Red Cross (2005) and United Nations (2005); and for the heat wave in France, the report from the National Assembly (2003, 2004). Classification of the main recommendations in these reports led to a diagnosis in each of the four areas of crisis management based on the precepts put forth in the academic literature.

4.3 Creation of a meta-matrix

The most pertinent data from research papers and from expert and/or public reports were collected, classified and recorded in a meta-matrix as described by Miles and Huberman (1994). The meta-matrix was organized into sub-themes, which were developed based on quotations drawn from the various reports[6]. For each case, both the head researcher and a research assistant read and classified relevant data, in accordance with the principle of double coding, thus increasing the consistency and internal validity (Yin, 2009). A preliminary document was prepared identifying the main information points and the sub-themes. A second document was then prepared in which the most relevant quotes were grouped into the four major themes identified from the literature review (planning/preparedness, coordination, leadership and behaviour of civil society). Some quotes were removed to avoid redundancy[7]. The quotes and sub-themes were added, modified or removed using an inductive approach and were contingent.

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[4] Articles published between 2000 and 2008 in specialized journals such as *Disasters,* the *Journal of Disaster Policy, Research and Management*, the *Journal of Contingencies and Crisis Management*, *Disaster Prevention and Management* and the *International Journal of Emergency Management* provided the basis for this review.

[5] The work of Perry and Lindell (2003a), Alexander (2005) and McEntire and Myers (2004) has been key in the development of guiding principles in planning and preparedness. The work of Dynes (1983, 1994) and Quarantelli (1988) has provided the basis for statements about coordination. For leadership, the recent work of Wooten and James (2008) as well as the work of Boin and colleagues (2005) have identified the key skills required in times of crisis. Finally, considerable research from the Disaster Research Center as well as that of Helsloot and Ruitenberg, 2004 and Perry and Lindell, 2003b were used to identify the main principles concerning the behaviour of civil society.

[6] Each quote or excerpt specified the source (page and report name).

[7] There was considerable redundancy in the diagnosis provided in the various reports selected for analysis. The method of classification used was in accordance with the saturation principle for qualitative methods (Corbin & Strauss, 2008). In addition, other authors have reached the same conclusion with regard to a strong convergence in the diagnosis of the management of these crises (Boudes & Laroche, 2009).

5. Overview of the main results

Table 5 summarizes the principal results of the application of the diagnostic method to each case. The next section presents the details of the diagnosis for each category (planning/preparedness, coordination, leadership and the behaviour of civil society).

5.1 Diagnosis regarding planning and preparedness

Public authorities in three of the four regions studied had crisis management plans. Prior to the SARS outbreak, the government of Ontario did not have a plan in effect to fight a pandemic. This situation significantly impeded the effectiveness of preventive interventions and the coordination of various actors in the health system, not least because they had to actually create a plan from the ground up in the midst of the ongoing crisis. The need for such planning, however, was well-known and had been brought to their attention on a number of prior occasions, including the report of the Krever Commission's inquiry into the contaminated blood scandal. As early as 1997, six years before the SARS outbreak, Justice Krever had stipulated that chronic under-financing of public health services was harmful to the population. In Ontario, Justice O'Connor, who also delved into questions concerning the financing of the provincial public health system, noted that the Health Minister had broadened the responsibilities of public health agencies without providing the necessary additional funding. In short, well before the arrival of SARS, it was clear that the public health system did not have sufficient capacity to cope with emergencies or crises:

> It is troubling that Ontario ignored so many public health wake-up calls from Mr. Justice Krever in the blood inquiry, Mr. Justice O'Connor in the Walkerton inquiry, from the Provincial Auditor, from the West Nile experience, from pandemic flu planners and others. Despite many alarm calls about the urgent need to improve public health capacity, despite all the reports emphasizing the problem, the decline of Ontario's public health capacity received little attention until SARS. SARS was the final, tragic wake-up call. To ignore it is to endanger the lives and the health of everyone in Ontario. *(SARS Report, 2006, 4:40)*

Similarly, in the Indian Ocean region, a number of experts (Kelman, 2006; Oloruntoba, 2005; Schaar, 2005) had pointed out serious deficiencies in national planning, basic support infrastructure and risk evaluation. Indeed, studies conducted since the 1980s had demonstrated the importance of being better prepared to deal with a tsunami, but the Indian government in particular considered that this threat was not the most dangerous or significant one for the country:

> In 1967, the issue of a tsunami warning system for India was raised at the Indian Institute of Science in Bangalore. The idea was supported in principle, but with frequent and severe droughts, river floods, and cyclones causing known levels of destruction, tsunamis were considered to have a lower priority. (*Kelman, 2006: 183*)

In Indonesia, the government had started to develop a national tsunami detection system to warn the population of danger, but this system was far from ready at the time the quake struck in December 2004. Thus, in contrast to countries in the Pacific Ocean, several Southeast Asian countries did not have any modern technology at their disposal to protect the population, such as sensors capable of precisely detecting earthquakes or tsunami waves and transmitting vital information to governments. It appears that prior to the 2004 tsunami:

> […] some agencies were actively trying to develop tsunami warning systems in some sectors of the Indian Ocean. For example, the Intergovernmental Oceanographic Commission (IOC), the Indian government, and the Indonesian government were pursuing an Indian Ocean tsunami warning system, but were unable to obtain adequate resources. *(Kelman, 2006: 182)*

It goes without saying that the regions that were devastated by the tsunami less than 15 minutes after the earthquake, such as the province of Aceh in Indonesia, would not have been able to benefit efficiently from a warning system. But those that were hit later, such as Sri Lanka, India, the Maldives and Thailand, would have had time to respond and should have received a warning:

> A tsunami bulletin was transmitted within 15 minutes of the earthquake from the Pacific Tsunami Warning Center (PTWS), but no Asian country directly received that warning. What was missing was an organized emergency communication plan beyond the Pacific region. (*Annunziato & Best, 2005: 7*)

Indeed, even though a warning would not have prevented the physical and material devastation in Southeast Asia, "[…] the information may have allowed people to escape to higher ground or take other emergency actions" (Martin, 2007: 191). On December 26 2004, "[t]here was no Tsunami early warning system which would have saved many lives" (Munasinghe, 2007: 10). Munasinghe (2007) and Rodriguez (2006) add that for the moment, there is simply no detection system able to warn the population of an impending threat. The communities hit by the tsunami did not possess any warning system whatsoever of the sort necessary and essential to saving the lives of their inhabitants.

Finally, while France and the United States had crisis management plans in place at the time of the heat wave of 2003 and Hurricane Katrina in 2005, respectively, their limitations were quickly revealed.

In the case of France, the danger associated with a heat wave was not among the concerns of society at large and public health organizations in particular, nor was it a priority for surveillance or crisis management organizations such as the *Institut national de veille sanitaire (InVS*; institute for public health surveillance*)* or the *Centre Opérationnel de Gestion Interministériel des Crises* (COGIC; interministerial crisis management operations centre). This omission indicates that the risk analysis and vulnerability assessment were not conducted thoroughly:

> […] what emerges clearly from the hearings of the commission of inquiry is that the consequences of intense heat on the population had not been fully analyzed or anticipated by the public health and safety services prior to last summer's tragic episode. Several ministers agreed on this point. *(*translation; *Assemblée nationale, 2004a: 51)*

Thus, during his hearing, Gilles Brücker, the director of the *InVS*, indicated that climate risks had not been included in the aims and means contract in effect; consequently, the organization was not concerned about them (Jacquat 2003; 14). Moreover, the report produced by the commission headed by Claude Evin mentions that in 1993 the health and biometeorology commission had initiated a discussion of the impacts of climate events on certain categories of the population judged most vulnerable, such as the elderly, but that "the INVS representative had not attended the meetings for years even though the INVS was a member" (Létard, 2004: 57). This was corroborated by the Health Minister Jean-François Mattei's additional comments, who explained to the Inquiry members:

[…] in 2003, while preparing the public health bill [...], the directorate-general for health called upon 140 French, European and international experts with the goal of developing a list of 100 priority public health objectives. Not one of them mentioned problems related to climate." *(Létard et al., 2004)*

It seems possible to say that the risks related to the dangers were not well known and not integrated into a global vision of risk. As a result, the system erred by not anticipating or picking up the warning signs. This led to a plethora of cascading problems, including the death of 15,000 people, most of whom were elderly, due to the delay in interventions.

At the time Hurricane Katrina hit the Gulf of Mexico in the United States, the American administration was in the midst of revising its crisis planning, so the lessons drawn from simulation exercises were not yet fully integrated into the plan.[8] Following the September 2001 attacks, the crisis planning was oriented towards strengthening a military command and control system, a direction a number of observers considered ill-suited to natural catastrophes. The constitutional foundations of the Stafford Act, according to which the Federal Government intervenes only at the request of the states, are also poorly adapted to incidents on a national scale.

Furthermore, the meteorological forecast had given a general forewarning. The director of National Oceanic and Atmospheric Administration, David L. Johnson, as well as director of the National Hurricane Center (NHC), Max Mayfield, both declared in May of 2005 that the Atlantic hurricane season was going to have above normal activity and that planning and preparation were going to make a difference in responding to any related emergency situations. In view of this alarming forecast, the two directors urged residents and government agencies in at-risk areas to prepare themselves and make planning efforts well before the hurricanes would hit (Bipartisan Committee, 2006: 21). Thus, Hurricane Katrina was not in itself a surprise. The probable force of the hurricane season had been predicted. Moreover, the importance of preparing efficiently had been emphasized by several experts. "Federal, State, and local plans were inadequate for a catastrophe that had been anticipated for years" (Bipartisan Committee, 2006: 60). Consequently, the deficiencies in preparation could have been avoided or at the very least attenuated.

Similarly, it is unfortunate that in spite of all the warnings, the Gulf states were not better prepared, the result of an unfortunate gap between government policy and actual practices (Comfort, 2005). In fact, these states initiated emergency action by activating parts of their emergency response plans only a few days before Katrina hit the coast. Neither government nor private sector organizations seemed adequately prepared to face a disaster on the scale of Katrina. In addition, emergency alert systems were not used in any of the three states at risk. The outcome of this ambivalent planning was that "[s]till, tens of thousands, many of them the region's most vulnerable, remained in areas most threatened by the approaching hurricane" (Bipartisan Committee, 2006: 29).

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[8] The Hurricane Pam Exercise was a simulation created following reports from all levels of government regarding the potential danger of a level four or five hurricane in New Orleans. Leading officials from approximately 50 organizations participated in the exercise in July 2004. Even though the simulation was assessed to plan for disasters like Hurricane Katrina, "[…] the exercise also highlighted lessons learned that were not implemented and did not anticipate certain weaknesses that Katrina exposed" (White House Committee, 2006: 81).

Overall, the initial findings on the planning/preparedness dimension corroborate previous research to the effect that having a plan is a necessary but insufficient condition to dealing with a crisis. Crisis planning is a process that must be based on a multi-risk approach in order to improve preparation, an aspect which was absent in all four of the crisis cases we examined.

5.2 Diagnosis regarding coordination

Coordination problems were also prevalent in all four disasters. The issues identified and mentioned in the post-crisis reports included: the cumbersome, halting nature of bureaucracy; the tendency to isolate the different actors; the gap between actors on the ground (or those intervening directly with the population) and administrators; the tendency towards organizational hierarchy and centralized decision-making; the multiplicity of actors generating confusion and sometimes duplication of efforts; and the inefficiency in managing donations and international aid.

The fight against SARS was hindered by problems associated with the collection of funds and the analysis and sharing of information. In addition, tense relations among various levels of government and between the provincial public health authorities and local offices did not help to resolve the crisis efficiently. Justice Campbell, who presided over the SARS Commission in Ontario, reported that numerous local offices thought management had high expectations but provided neither support nor timely and accurate information to doctors and public health officers in the field. The lack of planning for information systems and data collection likewise had harmful repercussions on interventions. The inadequate systems, combined with a crushing number of disorganized requests, made it impossible for public health and hospital staff to efficiently coordinate their efforts. "Confusion, duplication and an apparent competition prevailed in the work of those in the central apparatus who sought information from local public health units and hospitals" (SARS Commission, 2006, 4: 132). However, no system had been implemented to respond to the discrepant needs of the various responders. In fact, requests were coming in from everywhere and in large numbers. "There was no order or logic in the frenzied, disorganized, overlapping, repetitious, multiple demands for information from hospitals and local public health units" (SARS Commission, 2006, 4: 135). This duplication of efforts was caused by poor coordination and by the fact that, due to the absence of a pre-established plan and structure, each office created their own data collection system during the SARS outbreak. Considerable time and effort was needed to verify the discrepancies, inquire about the condition of patients and determine which of several reports was indeed correct. This lack of coordination increased the stress felt by both responders and victims.

In France during the heat wave, the *Institut de veille sanitaire* (public health surveillance institute) and the *Direction générale de la santé* (DGS; public health division of the health ministry) operated in seclusion from the situation on the ground. No representative of these institutions visited hospitals to take stock of the situation, and it was only very late in the crisis that they discussed possible measures for curbing the crisis with responders from the hospital sector. In terms of coordination, there was an evident gap between the upper and lower echelons. This lack of integration was responsible for the discrepancy between the mobilization of hospitals and the central administration. On the whole, mobilization was rather efficient at the local level (health services, hospitals, retirement homes, emergency medical services and fire departments), in spite of some degree of physical and psychological exhaustion on the part of the personnel. But that the response of the central administration was rather laborious and late. Thus the DGS and INVS in particular worked in an information vacuum. Interactions between the two institutions and the other actors were infrequent and very formal. No representative of these institutions went to hospitals to observe the extent of the situation and it was late in the crisis before members of local hospital administrations were included in consultations with the central institutions. In fact, no one seemed to know who was really in charge of managing this crisis. Consequently, it is difficult to speak of formal structures in charge of crisis management because all the actors seem to have taken part in it, without any actual structure being in place. Similarly, it is difficult to assess whether the principle of decentralization and delegation in decision-making was respected, because the first emergency actions were organized and carried out in the field and only gradually came under centralized coordination.

In the case of Hurricane Katrina, the "pull system" maintained an extremely hierarchical and vertical relationship between levels of government and inevitably led to delays in responding to the crisis. Certain responders attempted to by-pass problems in applying the National Response Plan by taking initiative on their own while simultaneously handling the tasks assigned by the Federal Emergency Management Agency (FEMA). Search and rescue activities were among those most severely compromised by this situation as, all too often, a number of rescue teams were deployed to the same place, leaving many other victims stranded. Hence, the Federal administration had to face several major challenges. In fact, the Secretary of the Department of Homeland Security, Michael Chertoff, seems to have had great difficulty coordinating the disparate activities of the various Federal agencies and departments. This lack of coordination at the Federal headquarter-level reflected confusing organizational structures in the field. *(Bipartisan Committee, 2006: 53).*

Moreover, the confusing and ambiguous demands resulting from poor coordination in managing requests exceeded the capacities and procedures of the Federal Emergency Management Agency (FEMA).In addition:

Due to the communications problems, officials from national leaders to emergency responders on the ground lacked the level of situational awareness necessary for a prompt and effective response to the catastrophe. *(Bipartisan Committee, 2006: 41).*

These difficulties and others resulted in an ineffective and inefficient response from the Federal authorities. In addition, there seem to have been a too varied and too numerous contingent of Federal coordinators involved, frustrating local and state officials. More specifically, the Federal command, control and authority structure was complex and difficult to understand. Communication and coordination was also lacking at the Federal level and led to incorrect information on available resources. There was an enormous gap between what was necessary in the field and what was sent. According to the expert assessment, considerable amounts of aid and assistance were not used due to a lack of coordination and the excessively complicated procedures from the National Response Plan (NRP). Among other issues, the NRP procedures are too bureaucratic and time-consuming to respond effectively to a catastrophe. Many agencies took action under their own independent authorities while also responding to mission assignments from the FEMA, creating further process confusion and potential duplication of efforts. *(Bipartisan Committee, 2006: 52).* The private sector did make a concerted effort to coordinate its assistance with the Federal government and did so in spite of a plethora of constraints and difficulties.

In the case of the tsunami, despite more than six billion dollars in international assistance, donations were not managed efficiently and only a portion was used to assist communities in need. The absence of functioning cooperative structures thus diminished the efficacy and consistency of the response (Rodriguez, 2006), as each organization had a tendency to operate independently of the others.

In the U.N. Economic and Social Council report, the experts declared that during the crisis, the available resources sometimes exceeded the capacity to administer them efficiently. *(Clinton, 2005 in Trigueros, 2006 : 40)*

Rodriguez (2006) demonstrated how local groups had made a major difference in the response to the tsunami. According to the author, local NGOs helped meet most primary community needs. In both India and Sri Lanka, these organizations were involved at various levels in reconstruction projects, including the development of public-private partnerships to better assist the crisis victims. By involving local community leaders with local and international NGOs to coordinate the distribution of aid and assistance efforts, the reconstruction was facilitated while demonstrating the great resilience of the affected population. Although efforts were made to involve local groups, it appears that the various communities were not fully and sufficiently integrated in the response process (Houghton, 2005). According to Oloruntoba (2005), in managing this crisis, the responders did not sufficiently understand the roles of each:

[…] longer term coordination and partnership with the victims themselves and the local authorities and actors would be required for a successful relief and reconstruction effort […] Intra- and inter-organisational coordination is crucial at all stages of this response; in functions such as asset usage, incident management, search and rescue, division of labour, public information management amongst others. There must be clarification of organisational roles in disaster management. *(Oloruntoba, 2005: 512).*

With regard to the tsunami, the lack of flexibility of the response structures in place — whether international, federal or municipal — had a negative impact on the efficiency of the supply chain and support mechanisms in response to the crisis.

5.3 Diagnosis regarding leadership

The main criticisms of national leaders in the crises we examined concerned the delay in taking action following warning signs of an impending crisis, as well as their lack of visibility during the crisis itself. For example, *The Globe and Mail*, Toronto's daily, reported the absence of then-Prime Minister, Jean Chrétien, and the low profile maintained by the Canadian Minister of Health, Anne McLellan, leaving the public to believe that the SARS crisis was not a federal government priority. Under the headlines "Where are the Leaders When They're Needed?" and "Chrétien Criticized for Lack of Involvement in Crisis," the journalist Bruce Cheadle (2003) wrote "a political leadership vacuum has made a bad situation much worse and helped fan domestic and international perceptions that containing SARS is not a high priority." The same issue was raised by the press with respect to the Premier of Ontario, Ernie Eves, who, after having declared a state of emergency, remained on the sidelines throughout the crisis. Under the headline "Premier Offers Too Little, Too Late in SARS Crisis," columnist Murray Campbell (2003) of *The Globe and Mail* wrote:

[…] from the early days of the SARS outbreak four weeks ago, the Premier said he wanted to keep a low profile on the issue. He certainly has succeeded […] It's one thing to let the professionals handle the SARS outbreak. But the Toronto area desperately needs a politician who understands the symbolism of such a crisis. Mr. Eves has shown he's no Rudy Giuliani.

The same criticism — slowness to act and a failure to be proactive — was directed at then-Prime Minister of France, Jean-Pierre Raffarin, as well as the Minister of Health, Jean-François Mattéi, during the heat wave of the summer of 2003. In an article in *l'Express*, Jean-Marc Biais (2003) reported:

[…] at a minimum we could blame the Prime Minister and his Minister of Health for having led a poorly timed public relations campaign from the top. In the course of this, Jean-François Mattei had the bitter experience of visiting the Pitié-Salpêtrière hospital services (Paris). A nurse did not want to shake his hand. 'It is shameful,' she told him. 'We needed much faster action.'

As the journalist continued:

Jean-François Mattei was, before being named to government, head of the Timone hospital services in Marseille, one of the largest French hospital establishments. As such, he was familiar with the heat wave that struck the Phocaean city in 1983. Also, he would have to have been more sensitive to alarming information.

In the case of the heat wave, it appears that the individuals who had developed the traits considered most important for effective leadership were not the ones heading the administrations, but rather those heading organizations in the field. The public judged the ministers directly concerned with the crisis very harshly for waiting until late in the crisis to interrupt their holidays and return to work, displaying a lack of proactivity in appropriating the crisis and in decision-making. The acting national health director at the time, Dr. Yves Coquin, did not demonstrate any ability to exert influence or persuasion. In fact, messages he addressed to the health minister's office indicating that the situation was under control prevented the heat wave from becoming a priority for the ministry. It thus appears that government leaders remained largely passive and did not at any time seek to go beyond their defined duties in order to understand and interpret the signals coming from the field. As for then-Prime Minister Jean-Pierre Raffarin, he clearly did not make the crisis a priority before August 14, at which time he interrupted his vacation. According to expert opinion from several commissions, the main deficiencies in crisis leadership were the long delays before intervention from the leaders which were related an inability to give meaning to the early warning signs.

The lack of preparedness was also stressed by the four main leaders involved in crisis management after Hurricane Katrina: Secretary of Homeland Security Michael Chertoff, FEMA director Michael Brown, Louisiana governor Kathleen Blanco and New Orleans mayor Ray Nagin (Olejarski & Garnett, 2010). First, Secretary Chertoff undermined public confidence in his abilities by making questionable decisions, such as naming Brown to the post of Principal Federal Officer. Establishing confidence in a leader is an crisis-management asset that Chertoff appears to have been unable to garner, largely because he did not carry out the responsibilities incumbent upon his status:

[…] critical response decision points were assigned to the Secretary of Homeland Security. Secretary Chertoff executed these responsibilities late, ineffectively, or not at all. *(US House, Bipartisan Committee, 2006: 131)*

In addition, the four leaders should have tried to identify potential vulnerabilities and risk. It would have been necessary for the leaders to plan and anticipate potential threats while anticipating certain crisis scenarios. On the one hand, the four leaders, Chertoff, Brown, Blanco and Nagin, all had knowledge of the situation and its probable dangers, but their ability to anticipate future developments was terribly lacking. Furthermore, these supposed leaders did not act proactively. They did not adapt their leadership to the particular circumstances of the crisis and did not act with sufficient diligence considering the context. For example, Blanco and Nagin only ordered a mandatory evacuation very belatedly (US House, Bipartisan Committee, 2006).

In the case of the tsunami, leadership shown by Indonesian Prime Minister, Susilo Bambang Yudhoyono, and that of Thai Prime Minister, Thaksin Shinawatra, were very different. Whereas the Indonesian Prime Minister failed miserably, the Thai Prime Minister emerged from the crisis fairly honourably. According to the media, Prime Minister Thaksin Shinawatra was able to benefit from the crisis. His repeated appearances at the disaster site transformed him into a hero for the affected population and for the various responders at the site. According to Parry (2005) in *The Times,* "most Thais revere him as a man of practicality and action, a welcome change after 72 years of weak civilian governments punctuated by military coups." Some criticism was nevertheless directed towards Shinawatra's leadership saying that he was putting on a role for the occasion. "Thaksin has managed to reinvent himself as a leader of compassion… Will he stay the same or become a democratic leader or a dictator intolerant of dissent?" (Parry, *The Times*, 2005). In addition, it is important to note that as Prime Minister he failed somewhat in his duties by neglecting to emphasize the need for tsunami detection and warning systems. In this regard, he was more reactive than proactive. As for Prime Minister of Indonesia, Susilo Bambang Yudhoyono, he did not meet the public's expectations. In fact, some critics compared him to President Bush at the time of the 9/11 attacks. "Like Mr. Bush, the newly installed Mr. Yudhoyono will be judged in large measure on his response to a momentous national crisis that found him woefully unprepared" (*Financial Times*, 2005). For that matter, the Indonesian leader had a reputation for being very indecisive. He did not react rapidly to a disaster which had enormous repercussions for his country. By being neither proactive nor actively involved, he developed an image as an incompetent man whose lack of leadership led to a loss of life that could have been avoided.

After-crisis leadership is most often relegated to experts who are given responsibility for leading national commissions of inquiry. Aside from the impressive number of recommendations issued by these commissions — recommendations that are usually based on strengthening and increasing formal crisis procedures — it is practically impossible to determine the degree to which public authorities will follow through on them. Crisis management that has been judged inadequate by the public and the media also results in a search for those responsible or scapegoats, such as Michael Brown (Director of FEMA) for Katrina, Dr. Lucien Abenheïm (Director of Health) during the heat wave, and Dr. Collin Cunha (Director of Public Health in Ontario) during the SARS outbreak.

5.4 Diagnosis regarding the behaviour of civil society

The participation of civil society, through expressions of support and solidarity, was carefully described in the crisis reports we examined. The role of religious and charitable organizations during the Katrina disaster was underscored in the report from the committee established by the American House of Representatives:

[…] countless numbers of charities provided billions of dollars in relief to those in need […] The efforts of charitable organizations in the Gulf Coast represent the largest disaster response effort in U.S. history. *(U.S. House, Bipartisan Committee, 2006: 343)*

In the response to Hurricane Katrina, the presence of organizations outside the government was a significant element. Among others, non-governmental organizations (NGOs), religious organizations and private-sector companies contributed substantially to the response and brought a more human and compassionate aspect to the crisis interventions. However, government agencies did not efficiently coordinate operations with these diverse organizations, the private sector and other volunteers. Among other groups, the American Red Cross played a major role in managing the Katrina response, with 45,000 active volunteers at the height of the crisis. Like other organizations, the Red Cross had to deal with many challenges due to the extent of the crisis, inadequate logistical capacities, and a disorganized procedure for providing emergency shelter. In addition, certain charity officials, like those of the Red Cross, were refused access to certain locations. In spite of these difficulties, experts believe that the Red Cross and a plethora of other charitable organizations played an essential role in the response to Hurricane Katrina. Their actions during the crisis thus had a direct impact on its management. Indeed, these organizations helped the government by creating, among others structures, centres to help volunteer groups manage their resources and to connect them with needs in the field. Nevertheless, there was room for improvement regarding integration of their intervention capacity into the disaster response.

We must recognize that NGOs play a fundamental role in response and recovery efforts and will contribute in ways that are, in many cases, more efficient and effective than the Federal government's response. *(Bipartisan Committee, 2006: 63).*

The commission experts also thought it important to mention that there were stories of courage, determination and compassion that made a difference in the response to Hurricane Katrina. More specifically, some citizens spontaneously provided assistance after the storm. Certain doctors acted independently by providing assistance and medical supplies. Dr. Carrie Oliver, from Texas, is one of these doctors; she opened a temporary clinic and paid for all the medical supplies herself. Importantly, she consistently communicated and cooperated with local officials to rapidly and appropriately serve the affected population. Many other examples of citizen interventions that had a definite impact on crisis management were pointed out. Contrary to popular belief, a majority of the threatened population acted responsibly by evacuating in time and without excessive panic. As for those who became disaster victims, some acted proactively by creating mutual aid networks. Moreover, there was very little looting. The stories of courage, determination and compassion were thus far more numerous than crimes.

The rigid governmental response model was unable to respond and adapt to these spontaneous citizen intervention strategies. For instance, in their efforts to survive, many disaster victims sought refuge in places that had not previously been considered emergency shelters. Consequently, despite the fact that civil society had acted relatively rationally and responsibly, certain behaviours were not sufficiently taken into account while managing the crisis. For example, some people did not possess the physical or financial means to evacuate. Others, having already lived through other hurricanes, decided not to evacuate, thinking they would be spared. The likelihood of these types of behaviours should be taken into consideration during disaster planning.

In France, expert reports on the heat wave, while revealing the isolation of senior citizens, particularly those living in institutions[9], also showed that victims' families mobilized to come to their aid. The press, having reported the cases of isolated victims or abandoned elderly, let the idea take hold that these cases represented the general rule, whereas the fact-finding missions and inquiries demonstrated that they were isolated occurrences. The intense media attention on these instances played on the emotions, distorting reality, placing blame on governments, and make the society as a whole feel guilt-ridden. The report also identified two individuals who played major roles in communications and decision-making during the heat wave crisis, namely Patrick Pelloux and Pierre Carli. Although they were not part of the central administration or official authorities, these two men demonstrated emerging leadership and contributed to managing the crisis. Each demonstrated an ability to detect crisis signals, by conducting research on the effects of the heat wave, in the case of Pierre Carli, and by communicating with colleagues to verify the status of the situation, in the case of Patrick Pelloux. The two men went above and beyond their duties as emergency physician and doctor in order to understand what was happening and to warn and mobilize people to respond to the crisis. Creativity was also central to the actions of these two emergent leaders, both in defining the appropriate methods of patient management and in their drive to understand the events and warnings.

Rodriguez (2006) reports that, in a number of communities in India and Sri Lanka, citizens actively engaged in activities to comfort the victims and began to rebuild. Tight-knit fishing communities demonstrated remarkable altruism. Munasinghe (2007) highlighted the initiatives undertaken by a group of some one hundred leaders from diverse backgrounds. More specifically, a People's Consultative Meeting was organized only ten days following the disaster with the goal of sharing and encouraging development of a network to address all aspects of managing the crisis. Through this meeting, these leaders paved the way to better coordination of the various interventions carried out by many organizations in the field. Munasinghe (2007:10) concludes:

In summary, civil society in Sri Lanka proved remarkably resilient and helped to hold the country together especially during the first few weeks — apparently, the social capital embedded within traditional communities in affected areas and throughout the nation played a crucial role.

Similarly, the SARS Commission report places great emphasis on the courage, exceptional dedication and heroism of frontline healthcare workers who did everything possible to counter the risks of a SARS pandemic. At the same time, most experts deplore the fact that the official assistance systems did not effectively coordinate these unseen efforts on the part

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[9] The mission established by the National Assembly (Jacquat Mission) noted a number of bodies that were never claimed.

of civil society. Furthermore, the Campbell Commission and the Health Canada Report both praised the efforts of numerous local medical officers who assumed substantial roles in managing the SARS outbreak. In the absence of provincial leadership, many established their own networks in order to plan and organize interventions, and they were essentially left on their own without any guidelines or support.

Dr. Sheela Basrur is one of the people who devoted themselves fully to managing the SARS outbreak.

[…] the real leader of the city's increasingly confident struggle with the disease was even more obvious to all. It was Dr. Sheela Basrur. She has become a household name not just in Toronto and in Ontario but really across Canada. […] They appreciate the clarity, the integrity and the straightforwardness of her presentation of the disease. […] Toronto medical officer of health Sheela Basrur and her colleagues have worked diligently on the main task of containing it and calming irrational fears. *(Barber,2003).*

Civil society as a whole reacted well. However, the lack of information about the spread of the epidemic gave rise to regrettable behaviours which could have been avoided.

SARS has highlighted how communicable diseases, particular those caused by hitherto unknown agents, can tap primal anxieties, prompt enormous interest on the part of the media, and provoke some unsavoury public responses (e.g., incidents of harassment and scapegoating of the Asian community in Toronto). (*Health Canada*, 2003 : 64).

Among other acts committed in the absence of definitive guidance, some citizens harassed others and sought out scapegoats within the Asian community of Toronto. Access to accurate and reliable information as well as confidence in credible leadership would certainly have increased public trust and calmed the fears of Toronto residents.

Cases of looting are mentioned in most reports, notably those on Katrina and the tsunami[10], although it is it difficult to assess the extent of these occurrences. In fact, the regrettable lack of information and late or inaccurate communication of information have been pointed out by experts in all the crises studied. Rodriguez (2006) mentions that a month after the disaster, a number of members of local fishing communities remained in a state of uncertainty about their families, their savings, and where they would live. Plans for relocation proposed by the state suffered from a lack of participation by the affected communities. These groups had the impression that their needs, cultures and interests, which would allow them to return to a normal life, were being neglected.

6. Discussion and conclusion

In light of the results discussed above, it appears that the guiding principles put forward in the literature to orient and inspire effective crisis management were neither followed nor respected in these four disasters. Shortcomings appeared at all levels — in terms of planning and capacity for preparation, in coordination, and at the level of leadership, as well as in understanding the behaviour of civil society. The next section explores some possible reasons for the common pitfalls and recurrent patterns observed during disasters.

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[10] The question of looting was not germane to the heat wave or SARS case.

Guiding principle	Katrina (USA)	Heat wave (France)	Tsunami (Southeast Asia)	SARS (Canada)
Planning/Preparedness				
Formal Planning[11]	Yes[12]	Yes[13]	No	No
Capacity Assessment	Weak	Weak	Weak	Weak
Risk Assessment	No	No	No	No
Coordination				
Exercise of Authority	Conflicting	Centralized	Confusing	Centralized
Communication	Difficult	Difficult	Difficult	Difficult
Cooperative Structures	Ineffective	Ineffective	Variable	None
Leadership				
Before the crisis	Weak	Weak	Weak	Weak
During the crisis	Problematic	Problematic	Problematic	Problematic
After the crisis	Unknown[14]	Unknown	Unknown	Unknown
Civil Society				
Civic Behaviours	Mixed assessment[15]	Mixed assessment[16]	Mainly positive[17]	Fear, stigma, Misunderstanding
Emergence of spontaneous leaders	Yes	Yes	Yes	Yes

Table 5. Diagnosis regarding disaster management practices concerned with planning/preparedness, coordination, leadership and civic behaviour.

The analytical framework presented in this chapter has two principal objectives. The first is to propose a method for preparing a diagnosis regarding the principal areas of crisis management which brings to light elements that should be consolidated or reviewed. The second is to indicate more promising avenues for crisis managers to pursue in order to improve the management of future crises, based on research in this field. It is therefore hoped that the diagnostic methods explored here will allow stakeholders to refocus on the fundamental principles of effective disaster management.

Furthermore, considering the state of knowledge in the field, we must question why the same deficiencies in crisis management tend to recur. In this regard, two main types of explanations drawn from the literature — which may serve as warnings for stakeholders — can be put forward: (1) the inadequacy of a strict and unnuanced application of the classic crisis management model based on a "command and control" structure and (2) the difficulties related to real organizational learning.

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[11] Written plans, procedures, emergency routines, jurisdictional specifications.

[12] Stratford Act (generic).

[13] “Plan Blanc” which is generic and not specifically for a heat wave crisis.

[14] Leadership undertaken mainly by experts.

[15] Evacuation was a major problem.

[16] The indifference of families has been noted.

[17] Positive due to help from NGOs and humanitarian groups. See Munasinghe (2007)

With regard to coordination, it appears that the classic model inherited from Fayol, which is still quite dominant in management circles (Carroll & Gillen, 1987), tends to be transposed more or less intact into crisis management in the form of the "command and control" model. This is the model most commonly known to administrators and it provides the illusion of being in control of events. However, research has shown that this model proves to be too rigid and centralizing, leaving little room to integrate spontaneous responders who emerge within communities affected by disaster. This tends to create discord and, in the end, to be detrimental to crisis mitigation efforts.

In terms of learning, several factors that seem to impede real integration of knowledge within organizations have been identified. First, the time constraints or temporal framework for learning is too limited (Bourrier, 2002); the issue does not remain a priority once the immediate crisis has passed (Petak, 1985; Lagadec, 1996; Rosenthal and Kouzmin, 1996; Nathan, 2000); or alternatively, the issue is too sensitive for discussion after the organization has gone through a crisis (Lagadec, 1996; Bourrier, 2002).

Moreover, the pressure of managing day-to-day affairs resurfaces and tends to eclipse the period which could be devoted to post-crisis reflection (Rosenthal et al., 1989; Rosenthal and Kouzmin,1996). Second, the manager responsible for integrating learning may be shirking these responsibilities (Lagadec, 1991, 1996), may tend to pass the responsibility off to the experts (Rosenthal and Kouzmin, 1996; Bourrier, 2002), or may use them for political ends (Hart et al., 2001). Third, managers and responders do not view crisis experiences as transferable to routine practice (Roux-Dufort, 2000; Bourrier, 2002). Such experiences are seen as eminently contingent on the idiosyncrasies of the crisis itself (March et al., 1991). Thus, very little sharing of crisis management experience occurs across organizations (Bourrier, 2002), between sectors of activities, or amongst countries (Hart et al., 2001). The classical response to these shortcomings is to add new procedures to the old ones, in the expectation that this will help manage the next crisis. However, empirical research suggests that organizations may not use all of their planned procedures during a crisis and may prefer to adapt their response to the contingencies of the situation (Espedal, 2006; Lalonde, 2004, 2010; Quarantelli, 1998; Schneider, 1992). We believe that in order to avoid the recurrence of dysfunctional patterns in crisis management, it behoves managers and responders to take these warnings into account.

7. Ackowledgments

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8. References

Alexander, D. (2005). Towards the development of a standard in emergency planning. *Disaster Prevention and Management*, Vol. 14, No. 2, pp. 158-175, ISSN 0965 3562

Alsop, R.J. (2004). Corporate reputation: Anything but superficial – the deep but fragile nature of corporate reputation. *Journal of Business Strategy*, Vol. 25, No. 6, pp. 21-29, ISSN 0275 6668

Alvarado, J. & Mendis, P. (2010). New Multilateralism in Action for Peace: A Case Study of the US-Led Operation Unified Assistance in the Asian Tsunami Disaster. *Democracy and Security*¸ Vol. 6, No. 1, pp. 97-108, ISSN 1555 5860

Annunziato, A. & Best, C. (2005). The tsunami event, analyses and models. European Commission, Joint Research Center, Available from http://tsunami.jrc.it/.

Barber, J. (2003). Toronto's SARS Star Medical Officer of Health Sheela Basrur has proved the city's real leader in the fight against the virus. *Globe and Mail*, April 26th, F3.

Barton, A. (1969). *Communities in Disaster: A Sociological Analysis of Collective Stress Situations*, DoubleDay and Company, Garden City, ISBN 101 281 477 New York, USA.

Biais, J.-M. (2003). Pourquoi la canicule a tué" [Why the heat wave killed], *L'Express*, see: http://www.lexpress.fr/actualite/sciences/sante/pourquoi-la-canicule-atue_495546.html.

Boin, A. & Lagadec, P. (2000). Preparing for the Future: Critical Challenges in Crisis Management. *Journal of Contingencies & Crisis Management,* Vol. 8, No. 4, (December 2000), pp. 185-191, ISSN 0966 0879

Boin, A.; Hart, P.; Stern, E. & Sundelius, B. (2005). *The Politics of Crisis Management. Public Leadership under Pressure*, Cambridge University Press, ISBN 978 0 521 60733 9 New York, USA

Boin, A., McConnell, A. (2007). Preparing for Critical Infrastructure Breakdowns: The Limits of Crisis Management and the Need for Resilience. *Journal of Contingencies & Crisis Management,* Vol. 15, No. 1, (March 2007), pp. 50-59, ISSN 0966 0879

Boje, D. (2008). *Storytelling Organizations*. Sage Publications, ISBN 978 141 2929 776 Thousand Oaks, CA, USA

Borodzicz, E. & Van Haperen, K. (2002). Individual and Group Learning in Crisis Simulations. *Journal of Contingencies and Crisis Management*, Vol. 10, No. 3, (September 2002), pp. 139-147, ISSN 0966 0879

Boudes, T. & Laroche, H. (2009). Taking off the Heat: Sensemaking and Narration in Post Crisis Inquiry Reports. *Organization Studies*, Vol. 30, No. 4, (April 2009), pp. 377-396, ISSN 0170 8406

Bourrier M. (2002). Bridging Research and Practice: The Challenge of 'Normal Operations' Studies. *Journal of Contingencies and Crisis Management*, Vol. 10, No. 4, (December 2002), pp. 173-180, ISSN 0966 0879

Campbell, M. (2003). Premier offers too little, too late in SARS crisis. *The Globe and Mail*, Toronto, p. A6

Carroll, S.J. & Gillen, D.J. (1987). Are the Classical Management Functions Useful in Describing Managerial Work. *Academy of Management Review,* Vol. 12, No. 1 (January 1987), pp. 38-51, ISSN 0363 7425

Cheadle, B. (2003). Chrétien criticized for lack of involvement in crisis. *The Hamilton Spectator*, p. B07.

Coate, B.; Handmer, J. & Choong, W. (2006). Taking Care of People and Communities. Rebuilding Livelihoods Through NGOs and the Informal Economy in Southern Thailand. *Disaster Prevention and Management*, Vol. 15, No. 1, pp. 135-145, ISSN 0965 3562

Comfort, L. (2005). Fragility in Disaster Response: Hurricane Katrina, 29 August 2005. *The Forum*, Vol. 3, No. 3, pp. 1-8, ISSN 0015 8356

Corbin, J., Strauss, A. (2008). *Basics of Qualitative Research*. Sage Publications, Third Edition, ISBN 978 1 4129 0644 9 Thousand Oaks, California, USA

Crichton, M.T.; Flin, R. & Rattray, W. (2000). Training Decision Makers – Tactical Decision Games. *Journal of Contingencies and Crisis Management*, Vol. 8, Vol. 4, (December 2004), pp. 208-217, ISSN 0966 0879

Denis, H. (2002), *La Réponse aux catastrophes. Quand l'impossible survient*. Presses internationales Polytechnique, ISBN 2 553 01022 2, Montréal, Canada

Drabek, T.E., Hoetmer, G.J. (1991). *Emergency management: Principles and practice for local government*. International City Management Association, ISBN 0 87326 082 1, Washington, D.C., USA

Drabek, T., McEntire, D. (2003). Emergent Phenomena and the Sociology of Disaster. Lessons, Trends and Opportunities from the Research Literature. *Disaster Prevention and Management*, Vol. 12, No. 2, pp. 97–112, ISSN 0965 3562

Drabek, T. (2007). Community Processes: Coordination. In: *Handbook of Disaster Research*, H. Rodriguez, E.L. Quarantelli, E.L. & R.R. Dynes (Eds.), Springer, ISBN 978 0 387 73952 6, New York, pp. 217-233.

Dynes, R.R. (1978). Interorganizational relations in communities under stress. In: *Disasters: Theory and Research,* E.L. Quarantelli (Ed.), Sage Publications, ISBN 0803998511, Oxford, UK, pp. 50-64.

Dynes, R.R. (1983). Problems in Emergency Planning. *Energy*, Vol. 8. No. 8-9, pp. 653-660, ISSN 0360 5442

Dynes, R.R. (1987). The concept of role in disaster research. In: *Sociology of disasters: Contributions of sociology to disaster research,* R.R. Dynes, B. DeMarchi & C. Pelanda (Eds.), Franco Angeli, ISBN 978 882 0422 677, Milan, Italy, pp. 71-102

Dynes, R.R. (1994). Community Emergency Planning False Assumptions and Inappropriate Analogies. *International Journal of Mass Emergencies and Disasters, Vol.* 12, No. 2, pp. 141-158, ISSN 0280 7270

Dynes, R.R.; De Marchi, B. & Pelanda, C. (1987). *Sociology of Disasters. Contribution of Sociology to Disaster Research*. Franco Angeli Press, ISBN 978 882 0422 677, Milan, Italy

Espedal, B. (2006). Do Organizational Routines Change as Experience Changes? *Journal of Applied Behavioral Science*, Vol. 42, No. 4, pp. 468-490, ISSN 0021 8863 1552 6879

Fischer, H. (1998). *Response to Disaster. Fact Versus Fiction & Its Perpetuation. The Sociology of Disaster*. University Press of America, ISBN 0 7618 1183 4, Lanham, Maryland, USA

Garcia, H.F. (2006). Effective Leadership response to crisis. *Strategy & Leadership*, Vol. 34, No. 1, pp. 4-10, ISSN 1087 8572

Hart, P. (1997). Preparing Policy Makers for Crisis Management: The Role of Simulations", *Journal of Contingencies and Crisis Management*, Vol. 5, No. 4, pp. 207-215, ISSN 0966 0879

Hart, P.; Heyse, L. & Boin, A. (2001). Guest Editorial Introduction. New Trends in Crisis Management Practice and Crisis Management Research: Setting the Agenda. *Journal of Contingencies and Crisis Management*, Vol. 9, No. 4, pp. 181–188, ISSN 0966 0879

Health Canada (2003), *Learning from SARS. Renewal of Public Health in Canada,* National Advisory Committee on SARS and Public Health, Canada, http://www.hc-sc.gc.ca/english/protection/warnings/sars/learning.html, (Accessed March 2011)

Heifetz, R.; Grashow, A. & Linsky, M. (2009). Leadership in a (*Permanent*) Crisis. *Harvard Business Review*, Vol. 87, No. 7/8, pp. 62-69, ISSN

Helsloot, I. & Ruitenberg, A. (2004). Citizen Response to Disasters: a Survey of Literature and Some Practical Implications. *Journal of Contingencies and Crisis Management*, Vol. 12, No. 3, pp. 98–111, ISSN 0966 0879

Ivanescu, I.M. (2011). Leadership and Crisis. *Romanian Economic and Business Review*, Vol. 6, No. 1, pp. 37-42

Jacquat, D. (2003). Rapport d'information sur la crise sanitaire et sociale déclenchée par la canicule. Assemblée Nationale Française, Paris, France.

James, E. & Wooten, L. (2005). How to Display Competence in Times of Crisis. *Organizational Dynamics,* Vol. 34, No. 2, pp. 141-152, ISSN 0090 2616

James, E., Wooten, L., Dushek, K. (2011). Crisis Management: Informing a New Leadership Research Agenda. *The Academy of Management Annals*, Vol. 5, No. 1, pp. 455-493, ISSN 1941 6520

Kelman, I. (2006). Warning for the 26 December 2004 Tsunamis. *Disaster Prevention and Management*, Vol. 15, No. 1, pp. 178-189, ISSN 0965 3562

Kapucu, N.; Arslan, T. & Demiroz, F. (2010). Collaborative emergency management and national emergency management network. *Disaster Prevention and Management,* Vol. 19, No. 4, pp. 452-468, ISSN 0965 3562

Kreps, G.A., & Bosworth, S.L. (2007). Organizational Adaptation to Disaster. In: *Handbook of Disaster Research,* H. Rodriguez, E.L. Quarantelli & R.R. Dynes (eds.), Springer, ISBN 978 0 387 73952 6, New York, USA, pp. 297-315

Kruchten, P., Woo, C., Monu, K., Sottodeh, M. (2008). A conceptual model of disasters encompassing multiple stakeholders domains. *International Journal of Emergency Management*, Vol. 5, No. 1/2, pp. 25-56, ISSN 1741 5071 1471 4825

Lagadec, P. (1996), "Un Nouveau Champ de Responsabilité pour les Dirigeants", *Revue Française de Gestion*, 108 *Disasters,* Vol.34, No. 2, (March/ April/ May), pp. 100-109, ISSN 0338 4551

Lalande F. (2004), Mission d'expertise et d'évaluation du système de santé pendant la canicule 2003, Ministère de la santé, de la famille et des personnes handicapées, Paris, France.

Lalonde, C. (2004). In Search of Archetypes in Crisis Management. *Journal of Contingencies and Crisis Management*, Vol. 12, No.2, (March 2004), pp. 76-88, ISSN 0966 0879

Lalonde, C. (2007). The Potential Contribution of Organization Development to Crisis Management. *Journal of Contingencies and Crisis Management*, Vol. 15, No. 2, (March 2007) pp. 95-104, ISSN 0966 0879

Lalonde, C. (2010). Organisation socialisation in a crisis context. *Disasters*, Vol. 34.No. 2, (April 2010), pp. 360-379, ISSN 1467 7717 0361 3666

Lalonde, C. (2011). Managing Crises Through Organisational Development. A Conceptual Framework. *Disasters*, Vol. 35, No. 2, (April 2011), pp. 443-464, ISSN 1467 7717 0361 3666

Létard, V.; Flandre, H. & Lepeltier, S. (2004), "La France et les Français face à la canicule : les leçons d'une crise". Rapport d'information fait au nom de la commission commune d'information Sénat, 195, Séance du 3 Février 2004.

Littlefield, R.S. & Quenette, A.M. (2007). Crisis Leadership and Hurricane Katrina: The Portrayal of Authority by the Media in Natural Disasters. *Journal of Applied Communication Research*, Vol. 35, No. 1, pp. 26-47, ISSN 1479 5752 0090 9882

MacIntoch, R. & MacLean, D. (1999). Conditioned emergence: a dissipative structures approach to transformation. *Strategic Management Journal,* Vol. 20, No. 4, pp. 297–316, ISSN 1097 0266 0143 2095

March, J.G.; Sproull, L.S. & Tamuz, M. (1991). Learning from samples of one or fewer. *Organization Studies*, Vol. 2, No. 1, pp. 1-13, ISSN 0170 8406

Martin, Nigel. (2007). The Asian tsunami: An urgent case for improved government information systems and management. *Disaster Prevention and Management*, Vol. 16, No. 2, pp. 188-200, ISSN 0965 3562

McConnell, A. & Drennan, L. (2006). Mission Impossible? Planning and Preparing for Crisis. *Journal of Contingencies and Crisis Management*, Vol. 14, No. 2, pp. 59-70, ISSN 0966 0879

McEntire, D. & Myers, A. (2004). Preparing communities for disasters: issues and processes for government readiness. *Disaster Prevention and Management,* Vol. 13, No. 2, pp. 140-152, ISSN 0965 3562

Miles, M. & Huberman, A. (1994). *Qualitative Data Analysis. An Expanded Source Book.* Sage Publications, ISBN 0803946538, Beverly Hills, California, USA

Morris, J.C.; Morris, E.D. & Jones, D.M. (2007). Reaching for the Philosopher's Stone: Contingent Coordination and the Military's Response to Hurricane Katrina. *Public Administration Review*, Vol. 67, No. S1, pp. 94-106, ISSN 1540 6210 0033 3352

Munasinghe, M. (2007). The importance of social capital: Comparing the impacts of the 2004 Asian Tsunami on Sri Lanka, and Hurricane Katrina 2005 on New Orleans. *Ecological Economics*, Vol. 64, No. 1, (October 2007), pp. 9-11, ISSN 0921 8009

Oloruntoba, R. (2005). A wave of destruction and the waves of relief: issues, challenges and strategies. *Disaster Prevention and Management*, Vol. 14, No. 4, pp. 506-521, ISSN 0965 3562

Parry, R. L. (2005). Thai disaster turns leader into a hero of the people. *The Times*, Available from http://www.timesonline.co.uk/tol/news/world/article510270.ece

Pauchant, T.C. & Mitroff, I. (1995), *La gestion des crises et des paradoxes: Prévenir les effets destructeurs de nos organisations* [*The management of crises and paradoxes: Prevent destructive effects of our organizations*], Québec/Amérique Editions, ISBN 2890378624, Montreal, Canada

Pearce, L. (2003). Disaster Management and Community Planning, and Public Participation: How to Achieve Sustainable Hazard Mitigation. *Natural Hazards*, Vol. 28, No. 2, pp. 211-228, ISSN 0921 030X

Perry, R. (2004). Disaster Exercise Outcomes for Professional Emergency Personnel and Citizen Volunteers. *Journal of Contingencies and Crisis Management*, Vol. 12, No. 2, (March 2002), pp. 64-75, ISSN 0966 0879

Perry, R. & Lindell, M.K. (2003a). Preparedness for Emergency Response: Guidelines for the Emergency Planning Process. *Disasters,* Vol. 27, No. 4, (December 2003), pp. 336-350, ISSN 1467 7717 0361 3666

Perry, R.W. & Lindell, M.K.(2003b). Understanding citizen response to disasters with implications for terrorism. *Journal of Contingencies and Crisis Management,* Vol. 11, No. 2, (March 2002), pp. 49–60, ISSN 0966 0879

Pollard, D. & Hotho, S. (2006). Crises, Scenarios and the Strategic Management Process. *Management Decision*, Vol. 44, No. 6, pp. 721-736, ISSN 0025 1747

Quarantelli, E.L. (1988). Disaster Crisis Management: A Summary of Research Findings. *Journal of Management Studies*, Vol. 25, No. 4, pp. 373-385, ISSN

Quarantelli, E.L. (1993). Community Crises: An Exploratory Comparison of Characteristics and Consequences of Disasters and Riots. *Journal of Contingencies and Crisis Management*, Vol. 1, No. 2, pp. 67-78, ISSN 0966 0879

Quarantelli, E. (1996). The Future is not the Past Repeated: Projecting Disasters in the 21st Century from Current Trends. *Journal of Contingencies and Crisis Management*, Vol. 4, No. 4, pp. 228–240, ISSN 0966 0879

Quarantelli, E. L. (1997). *Research Based Criteria for Evaluating Disaster Planning and Managing*. Preliminary Paper # 247, Disaster Research Center, University of Delaware.

Quarantelli, E. (2001). Another Selective Look at Future Social Crises: Some Aspects of Which We Can Already See in the Present. *Journal of Contingencies and Crisis Management*, Vol. 9, No. 4, pp. 233-237, ISSN 0966 0879

Quarantelli, E. (2005). A Social Science Research Agenda for the Disasters of the 21st Century: Theoretical, Methodological and Empirical Issues and their Professional Implementation. In: *What Is A Disaster? New Answers to Old Questions*, R.W. Perry & E.L. Quarantelli (Eds), Xlibris Corporation, ISBN 141347983, Philadelphia, USA

Robert, B. & Lajtah, C. (2002). A New Approach to Crisis Management. *Journal of Contingencies and Crisis Management*, Vol.10, No. 4, (December 2002), pp. 181-191, ISSN 0966 0879

Rosenthal, U.; Charles, M.T. & Hart, P.T. (1989). *Coping with crises: The management of disasters, riots and terrorism*, Charles C. Thomas Publisher, ISBN 0 398 05597 1, New York, USA

Roux-Dufort, C. (2007). Is Crisis Management (Only) a Management of Exceptions? *Journal of Contingencies and Crisis Management*, Vol. 15, No. 2, (March 2007), pp. 105-114, ISSN 0966 0879

Sapriel, C. (2003). Effective crisis management: Tools and best practice for the new millennium. *Journal of Communication Management*, Vol. 7, No. 4, pp. 348-355, ISSN 1478 0852 1363

Smits, S.J. & Ally, N.E. (2003). Thinking the Unthinkable. Leadership's Role in Creating Behavioral Readiness for Crisis Management. *Competitiveness Review*, 13(1), pp. 1-23, ISSN 1059 5422

Snowden, D.F. & Boone, M.E. (2007). A Leader's Framework for Decision Making", *Harvard Business Review*, Vol. 85, No. 11, (2007), pp. 68-76, ISSN 0017 8012

Takeda, M. A. & Helms, M.M. (2006a), "Bureaucracy, meet catastrophe". Analysis of the tsunami disaster relief efforts and their implications for global emergency governance, *International Journal of Public Sector Management*, Vol. 19, No. 2, pp. 204-217, ISSN 1758 6666 0951 3558 0951 3558

Takeda, M.A. & Helms, M.M. (2006b). Bureaucracy, meet catastrophe. Analysis of hurricane Katrina relief efforts and their implications for global emergency governance. *International Journal of Public Sector Management*, Vol. 19, No. 4, pp. 397-411, ISSN 1758 6666 0951 3558 0951 3558

Taylor, M. (2000). Cultural Variance as a Challenge to Global Public Relations: A Case Study of the Coca-Cola Scare in Europe. *Public Relations Review,* Vol. 26, No. 3, pp. 277-293, ISSN 0363 8111

Tierney, K. (2003). Disaster Beliefs and Institutional Interests: Recycling Disaster Myths in the Aftermath of 9/11. *Research in Social Problems and Public Policy*, Vol. 11, pp. 33-51, ISSN 0196 1152

Trist, E. (1983). Referent organizations and the development of inter-organizational domains. *Human Relations*, Vol. 36, No. 3, pp. 269-284, ISSN 1741 5071 1471 4825

US House. Select Bipartisan Committee to Investigate the Preparation for and Response to Hurricane Katrina (2006), A Failure of Initiative, Government Office, Washington, DC, USA, Available from
http://www.katrina.house.gov/full_katrina_report.htm

Waugh, W.L. & Streib, G. (2006). Collaboration and Leadership for Effective Emergency Management. *Public Administration Review*, Vol. 66, No. S1, pp. 131-140, ISSN 1540 6210 0033 3352

Watkins, M.D. & Bazerman, M.H. (2003). Predictable Surprises. The Disasters You Should Have Seen Coming. *Harvard Business Review*, Vol. 81, No. 3, pp. 72-80, ISSN 0017 8012

Webb, G.R., Chevreau, F-R. (2006). Planning to improvise: the importance of creativity and flexibility in crisis responses. *International Journal Emergency Management*, Vol. 3, No. 1, pp. 66-72, ISSN 1741 5071 1471 4825

Weick, K.E. (1993). The Collapse of Sensemaking in Organizations: The Mann Gulch Disaster. *Administrative Science Quarterly*, Vol. 38, No., pp. 628-652, ISSN 001 8392

White House (2006), The Federal Response to Hurricane Katrina: Lessons Learned, Office of the Assistant to the President for Homeland Security and Counterterrorism, Washington, DC., USA Available from
http://www.whitehouse.gov/reports/

Wise, C.R. (2006). Organizing for Homeland Security After Katrina: Is Adaptive Management What's Missing? *Public Administration Review*, Vol. 66. No. 3, pp. 302-318, ISSN 1540 6210 0033 3352

Wolensky, R.P. (1983). Power Structure and Group Mobilization Following Disaster : A Case Study. *Social Science Quarterly*, Vol. 64, No. 1, pp. 97-110, ISSN 0038 4941 1540 6237

Wooten, L.P. & James, E.H. (2008). Linking Crisis Management and Leadership Competencies: The Role of Human Resource Development. *Advances in Developing Human Resources*, Vol. 10, No. 3, pp. 352-379, ISSN 15234223

Yin, R.K. (2009). *Case Study Research. Design and Methods*. Sage Publications, Fourth Edition, ISBN 978 1 4129 6099, Thousand Oaks, California, USA

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