D3.3 END-USERS RELEVANT OPERATIONAL RESEARCH AND STUDIES

DESCRIPTION OF RESEARCH AND STUDIES PERFORMED BEFORE THE PROJECT, THAT ARE CONSIDERED RELEVANT FOR THE END-USER SCENARIOS

EMMON

Agreement Ref.: *100036*

Date: *2009-08-31*
Pages: *48*
Status: *Approved*
Dissemination Level: *PU*
Reference: *FP7-JU-EMMON-2009-DL-WP3-028-D3.3*
Version: *1*

Customer:

SEVENTH FRAMEWORK PROGRAMME

D3.3 End-Users Relevant Operational Research and Studies

EMMON

Authors and Contributors			
Name	**Contact**	**Organization**	**Description**
Pedro Braga	plbraga@criticalsoftware.com	Critical Software, S.A.	Author
Rui Mónica	rs-monica@criticalsoftware.com	Critical Software, S.A.	Author

Dissemination Level
Public
The contents of this document are under copyright of ARTEMIS JU. it is released on condition that it shall not be copied in whole, in part or otherwise reproduced (whether by photographic, or any other method) and the contents therefore shall not be divulged to any person other than that of the addressee (save to other authorized offices of his organization having need to know such contents, for the purpose for which disclosure is made) without prior written consent of submitting company.

Revision History				
Version	**Revision**	**Date**	**Description**	**Author**
1	1	2009-08-03	First draft	Pedro Braga
1	2	2009-08-24	Final Draft for internal review	Pedro Braga
1	3	2009-08-31	Version 1, For approval	Pedro Braga
1	4	2010-06-04	Approved version according to the results of the Technical Review Report, ref: ARTEMIS-ED-21-09, of 2010-06-04.	Pedro Braga

Change Traceability:			
Paragraph or Requirements Number	Paragraph or Requirements Number	Description & Comments	Reference
Version 01	Version 02		

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

1. Introduction

1.1 Objective

The objective of this document is to present relevant operational research and studies in the field of the monitoring scenarios considered by the EMMON project, performed before the project kick-off.

Another objective of this document is to present existing technological solutions that address the monitoring needs of each scenario.

This information will serve to create awareness amongst the EMMON team about the scenarios' operational particularities (specific domain business rules and constraints) and about the problems already solved by existing technological solutions that will drive the research and development of EMMON.

1.2 Scope

The EMMON project is an European R&D project presented under the Embedded Computing Systems research programme, handled by the public-private partnership ARTEMIS Joint Undertaking (JU), and sponsored by the following entities: European Union (EU) Seventh Framework Programme (FP7) Information & Communication Technologies (ICT) research programme, the participating ARTEMIS Member States and the Industry.

The EMMON project is composed of eight (8) Work-Packages:

- WP1 – Project Management, Procedures and Communication;
- WP2 – Exploitation, Dissemination and standardization;
- WP3 – Study of user environment and definition of requirements and needs;
- WP4 – Research activities on Protocols & Communication Systems;
- WP5 – Definition of HW platforms and sensors;
- WP6 – Research on Embedded Middleware;
- WP7 – Implementation and System Integration;
- WP8 – Operational Testing & Validations.

This document is produced under the scope of Work-package 3 (WP3), "Task 3.1 Consolidation of operational scenario requirements" and is identified as D3.3.

The research and studies presented in this document are focused on end user monitoring scenarios, and existing solutions for those scenarios, presenting its weaknesses and strengths.

The studies referred in this document were provided or referenced by the end users. Other studies referred by the original studies were also referred in this document when thought necessary to help better express the scenarios' specificities.

The existing technological solutions were identified by the end-user, using Internet searches and EMMON's team knowledge. Some technological solutions are currently being used by the end users. Information about other solutions was obtained by developers and/or manufacturers web sites, catalogues, technical datasheets, articles and studies.

This document is not meant to be a thorough and detailed technical analysis of all studies and solutions related to the EMMON end user scenarios. It should be used as starting point to drive future research work, and therefore assumes that there are studies and solutions not identified and not presented in this document.

The monitoring scenarios are:

- Water Quality and Quantities monitoring
- Urban Quality of Life
- Maritime Environment
- Civil Protection (Fire prevention and detection and others)
- Event Propagation Simulation (Fire, Pollution, etc.)

It is not in the scope of this document to present scientific research and studies in specific technologies like wireless telecommunication protocols or embedded systems.

1.3 Audience

The target audiences of this document are:

- ARTEMIS JU and the Commission Services;
- WSN research groups;
- EMMON consortium participants;

More specifically, and within the EMMON consortium, WP4, WP5 and WP6 will use this document as input for driving their research work (by analyzing existing technological solutions), whilst, WP5, WP7 and WP8 will use it to better understand and implement the specific business rules, requirements, and constraints for the real world functional prototype.

1.4 Definitions and Acronyms

Table 1 presents the list of acronyms used throughout the present document.

Acronyms	Description
AD	Applicable Document
BSH	Federal Maritime and Hydrographic Agency (Germany) (“*Bundesamt für Seeschifffahrt und Hydrographie*”)
CAMS	Continuous Ambient Monitoring Stations
CETESB	Brazilian Technical State Company for Basic Sanitation and Environment Protection (“*Companhia Estadual Técnica de Saneamento Básico e Defesa do meio Ambiente*”)
EEA	European Environment Agency
EPA	USA Environmental Protection Agency
EU	European Union
GIS	Geographic Information System
GOOS	Global Ocean Observing System
GPRS	General packet radio service
GPS	Global Positioning System
INPE	Brazilian National Institute for Space Research (“*Instituto Nacional de Pesquisas Espaciais*”)
IOW	Leibniz Institute for Baltic Sea Research (“*Leibniz-Institut für Ostseeforschung Warnemünde*”)

Acronyms	Description
IQA	Brazilian Water Quality Index (“*Índice de qualidade das águas*”)
NOAA	National Oceanic and Atmospheric Administration, USA
PM2.5	Particulate Matter - 2.5 Micrometers
RD	Reference Document
TBC	To Be Confirmed
TBD	To Be Defined
TCEQ	Texas Commission on Environmental Quality (USA)
UEG	Goiás State University (Brazil) (“*Universidade Estadual de Goiás*”)
UNESP	São Paulo State University (Brazil) (“*Universidade Estadual Paulista*”)
USA	United States of America
USP	São Paulo University (Brazil) (“*Universidade de São Paulo*”)
VANET	Vehicular ad hoc networks
WHO	World Health Organization
WSN	Wireless Sensor Network

Table 1 - Table of acronyms

Definitions	Description
PM2.5	Particulate matter is the term used for a mixture of solid particles and liquid droplets found in the air. PM2.5 refers to particulate matter that is 2.5 micrometers or smaller in size.
Transect	It consists of a path along which occurrences of a specific phenomenon under study are recorded and counted.

Table 2 - Table of definitions

1.5 Document Structure

Section 1, Introduction, presents a general description of the contents, pointing its goals, intended audience and structure.

Section 2, Documents, presents the documents applicable to this document and referenced by this document.

Section 3, EMMON Project Overview, presents an overview of EMMON project.

Section 4, Studies Performed on Water Quality Monitoring, presents studies and conclusions related to Water Quality scenarios.

Section 5, Studies Performed on Urban Quality of Life Monitoring, presents studies and conclusions related to Urban Quality of Life scenarios.

Section 6, Studies Performed on Maritime Environment Monitoring, presents studies and conclusions related to Maritime Environment scenarios.

Section 7, Studies Performed on Civil Protection - Forest Fire Scenarios, presents studies and conclusions related to Civil Protection scenarios.

Section 8, Studies Performed on Event Propagation Simulation, presents studies and conclusions related to Event Propagation Simulation.

2. Documents

This section presents the list of applicable and reference documents as well as the documentation hierarchy this document is part of.

2.1 Applicable Documents

This section presents the list of the documents that are applicable to the present document. A document is considered applicable if it contains provisions that through reference in this document incorporate additional provisions to this document [ECSS-P-001B].

[AD-1] "Technical Annex", EMMON Project, ARTEMIS Joint Undertaking Call for proposals ARTEMIS-2008-1, Grant agreement no. 100036, 2009-03-23.

2.2 Reference Documents

This section presents the list of reference documents. A document is considered a reference document if it is referred but not applicable to this document.

The following documents are referenced within this document:

[RD-1] "ESA PSS-05-03 Guide to the software requirements definition phase", ESA, ISSN 0379-4059, Issue 1, May 1995.

[RD-2] "Impact of precipitation on Purus river water quality" (original title: "Influência da precipitação na qualidade da água do Rio Purus"), INPE, Ana Elisa Pereira Silva, Carlos Frederico de Angelis, and Luiz Augusto Toledo Machado, 2007.

[RD-3] "Water Quality Variables" (original title: "Variáveis de qualidade das águas"), CETESB, http://www.cetesb.sp.gov.br/Agua/rios/variaveis.asp (accessed on 2009-08-04).

[RD-4] "EnviroMapper for Water", EPA, http://map24.epa.gov/emr/ (accessed on 2009-08-04).

[RD-5] "ANA Telemetric Stations", ANA, http://www.ana.gov.br/telemetria (accessed on 2009-08-04).

[RD-6] "Estimating Estuarine Pollutant Loading From Atmospheric Deposition Using Casco Bay, Maine as a Case Study", Maine Department of Environmental Protection, EPA, Casco Bay Estuary Project, May, 2003.

[RD-7] "Influence of Cattle Ranching and Agricultural Activities on Physical Chemical Parameters of Water", Adriana Rosa Carvalho (UEG), Flávio Henrique Mingante Schlittler (UNESP), and Valdemar Luiz Tornisielo (USP), 2000.

[RD-8] "Water Quality Index" (original title: "*IQA - Índice de qualidade das águas*"), CETESB, http://www.cetesb.sp.gov.br/Agua/rios/indice_iap_iqa.asp (accessed on 2009-08-05).

[RD-9] "National Hydrologic Network" (Original title: "Rede Hidrológica Nacional"), ANA, Maurício Cezar Rebello Cordeiro, 2009.

[RD-10] "Continuous Water Quality Monitoring Stations and Data", TCEQ, http://www.tceq.state.tx.us/assets/public/compliance/monops/water/wqm/tx_realtime_swf.html, (accessed on 2009-08-07).

[RD-11] "Devils River Downstream of Baker's Crossing Continuous Water Quality Monitoring Project Plan", TCEQ, Continuous Water Quality Monitoring Network Quality Assurance Project Plan, Appendix S, 2008.

[RD-12] "HidroWeb – Hydrologic Information System" (original title: "*HidroWeb – Sistema de Informações Hidrológicas*"), ANA, http://hidroweb.ana.gov.br/ (accessed on: 2009-08-07).

[RD-13] "Guidelines for Drinking-water Quality", WHO, ISBN 92 4 154696 4, 2006.

[RD-14] "Real-Time Remote Monitoring of Drinking Water Quality", EPA and Shaw Environmental, Inc., Srinivas Panguluri (Shawn), Roy C. Haught (EPA), Craig L. Patterson (EPA), E. Radha Krishnan (Shawn), and John Hall (EPA).

[RD-15] "Wireless Sensor Network: Water Distribution Monitoring System", Min Lin, Yan Wu and Ian Wassell, Computer Laboratory, Cambridge University, UK, 2008.

[RD-16] "WISE-WAI – Wireless Sensor networks for city-Wide Ambient Intelligence" project, DEI-UP, http://cariparo.dei.unipd.it/ (accessed on 2009-08-11).

[RD-17] «The "Wireless Sensor Networks for City-Wide Ambient Intelligence (WISE-WAI)" Project», Paolo Casari, Angelo P. Castellani, Angelo Cenedese, Claudio Lora, Michele Rossi, Luca Schenato and Michele Zorzi, Department of Information Engineering, University of Padova, Italy, May 2009.

[RD-18] "Sensor networks on the road: the promises and challenges of vehicular ad hoc networks and grids", Maziar Nekovee, Mobility Research Centre, UK, 2005.

[RD-19] "Traffic Surveillance by Wireless Sensor Networks: Final Report", Sing Yiu Cheung and Pravin Varaiya, California Path Program, Institute Of Transportation Studies, University of California, USA, April 2007.

[RD-20] "A Cohort Study of Traffic-Related Air Pollution Impacts on Birth Outcomes", Michael Brauer, Cornel Lencar, Lillian Tamburic, Mieke Koehoorn, Paul Demers, and Catherine Karr, The University of British Columbia, Canada and University of Washington, USA, 2008-01-23.

[RD-21] "Impacts of Ambient Air Pollution on Infant Bronchiolitis in Puget Sound and the Georgia Air Basin", Catherine Karr, University of Washington, USA, 2008-03-28.

[RD-22] "Correlation Between Co-Exposures To Noise And Air Pollution From Traffic Sources", J. Vlaanderen (UU), H. Davies, S. Henderson, and M. Brauer (UBC), University of Utrecht (UU), the Netherlands, University of British Columbia (UBC), Canada, 2008-11-18.

[RD-23] "PM 2.5 Objectives and History", EPA, US, http://www.epa.gov/region4/sesd/pm25/p2.html (accessed on 2009-08-13).

[RD-24] "WHO air quality guidelines for Europe", WHO, 2nd edition, 2000.

[RD-25] "WHO air quality guidelines", WHO, global update, 2005.

[RD-26] "The Urban Audit — measuring the quality of life in European cities", Eurostat, Berthold FELDMANN, 2008-09-18.

[RD-27] "Ensuring quality of life in Europe's cities and towns", EEA report, 2009.

[RD-28] "Sensorized waste collection container for content estimation and collection optimization", F. Vicentini, and A. Giusti (LRPM), A. Rovetta, X. Fan, Q. He, M. Zhu, and B. Liu (CIMRI), Laboratory of Robotics, Politecnico di Milano, Milan, Italy (LRPM), Computer Integrated Manufacturing Research Institute (CIMRI), Shanghai Jiao Tong University, Shanghai, China, 2008-10-21.

[RD-29] Research Vessel "Professor Albrecht Penck" Monitoring cruise report, Cruise No. 07 / PE / 09 / 12, 5th – 13th May 2009, Leibniz Institute for Baltic Sea Research, Warnemünde, Germany.

[RD-30] National Environmental Satellite, Data and Information Service (NESDIS), NOAA, http://www.ncdc.noaa.gov/ (accessed on 2009-08-17).

[RD-31] Observing the Earth, ESA, http://www.esa.int/esaEO/ (accessed on 2009-08-17).

[RD-32] MarCoast – Marine and Coastal Environment Information Services, ESA, http://www.gmes-marcoast.com/ (accessed on 2009-08-17).

[RD-33] IOW-MARNET Monitoring Stations, IOW, http://www.io-warnemuende.de/marnet-en.html, (accessed 2009-08-17).

[RD-34] “Economics of Australia’s sustained ocean observation system, benefits and rationale for public funding”, Australian Academy of Technological Sciences and Engineering and the Western Australian Global Ocean Observing System Inc., August 2006.

[RD-35] “Global Ocean Observing System”, http://www.ioc-goos.org (accessed on 2009-08-18).

[RD-36] “Upper Ocean Climate Ship-of-Opportunity Programme of BSH – A Status Report”, BSH, Alexander Sy, Jürgen Ulrich and Hans-Joachim Weichert, 2002.

[RD-37] “Forest fires: behavior and ecological effects”, Edward A. Johnson, University of Calgary, Kiyoko Miyanishi, University of Guelph, Canada, ISBN 0-12-386660-X, 2001.

[RD-38] “Variation in Forest Fire Ignition Probability in Finland”, Silva Fennica 38(3): 253–266, Markku Larjavaara, Timo Kuuluvainen, Heidi Tanskanen and Ari Venäläinen, University of Helsinki, Finland, 2004.

[RD-39] “A fire probability model for forest stands in Catalonia”, José Ramón González and Marc Palahí, Centre Tecnològic Forestal de Catalunya, Spain, Antoni Trasobares, ForEco Technologies, Spain, Timo Pukkala, University of Joensuu, Finland, October 2005.

[RD-40] “The Speed of a Fire Front and Its Dependence on Wind-Speed”, International Journal of Wildland Fire 3(4) 193 – 202, T. Beer, 1993.

[RD-41] “Voltree Power LLC”, http://www.voltreepower.com/ (accessed on 2009-08-20).

[RD-42] “First Experiences Using Wireless Sensor Networks for Noise Pollution Monitoring”, Silvia Santini and Benedikt Ostermaier, Institute for Pervasive Computing, Switzerland, Andrea Vitaletti, University of Rome La Sapienza, Italy, 2008-04-01.

[RD-43] “On large scale forest fires propagation models”, O. Séro-Guillaume and S. Ramezani, LEMTA, France, J. Margerit, Université de Liège, Belgium and D. Calogine, Université de La Réunion, France, June 2007.

[RD-44] “Automatic Fire Detection: A Survey from Wireless Sensor Network Perspective.”, Technical Report TR-CTIT-08-73, Centre for Telematics and Information Technology, University of Twente, Enschede. ISSN 1381-3625, Bahrepour, M. and Meratnia, N. and Havinga, P.J.M., 2008.

[RD-45] “Analysis of signature patterns for discriminating fire detection with multiple sensors.” Fire Technology 31(2): 120-136, Milke, J. A. and T. J. McAvoy, 1995.

[RD-46] “Real-time forest fire detection with wireless sensor networks”, Wireless Communications, Networking and Mobile Computing, Yu, L., N. Wang, et al., 2005.

[RD-47] “Efficient K-Coverage Algorithms for Wireless Sensor Networks and Their Applications to Early Detection of Forest Fires”, Computing Science, Simon Fraser University, MSc: 75., Bagheri, M., 2007.

[RD-48] “Mine Fire Detection System Based on Wireless Sensor Network”, Information Acquisition, ICIA '07, 2007.

[RD-49] NOAA, N. O. a. A. A. "National Fire Danger Rating System ", http://www.wrh.noaa.gov/sew/fire/olm/nfdrs.htm (accessed on 2009-08-20).

[RD-50] "CFS - Canadian Forest Service", http://www.nrcan.gc.ca/cfs (accessed on 2009-08-20).

[RD-51] “Fire Management Tech Tips: The Osborne Fire Finder”, T. R. 1311-SDTDC, USDA Forest Service, Fleming, J. and R. G. Robertson, 2003.

[RD-52] "Autonomous forest fire detection", Third International Conference on Forest Fire Research and Fourteenth Conference on Fire and Forest Meteorology, Luso, Portugal, Breejen, E., M. Breuers, et al., 1998.

[RD-53] "NASA - National Aeronautics and Space Administration", USA, http://modis.gsfc.nasa.gov/ (accessed on 2009-08-20).

[RD-54] "Advanced Very High Resolution Radiometer - AVHRR", National Environment Satellite, D., and Information Service (NESDIS), http://noaasis.noaa.gov/NOAASIS/ml/avhrr.html (accessed on 2009-08-20).

[RD-55] "The Advanced Very High Resolution Radiometer" (AVHRR), CRC Press, Cracknell, A. P., 1997.

[RD-56] "A Directionality Based Location Discovery Scheme for Wireless Sensor Networks", proceedings of the 1st ACM international workshop on Wireless sensor networks and applications Atlanta, Georgia, USA ACM New York, NY, USA, Nasipuri, A. and K. Li, 2002.

[RD-57] «Experience from a Pilot Implementation of an "In-Situ" Forest Temperature Measurement Network», Personal, Indoor and Mobile Radio Communications (PIMRC2007), Vescoukis, V., T. Olma, et al., 2007.

[RD-58] "Fire Detection in the Urban Rural Interface through Fusion Techniques", Mobile Adhoc and Sensor Systems (MASS 2007), Zervas, E., O. Sekkas, et al., 2007.

[RD-59] "Early Forest Fire Detection with Sensor Networks: Sliding Window Skylines Approach", University of Zagreb, Faculty of Electrical Engineering and Computing, Department of Telecommunications, Pripužic, K., H. Belani, et al., 2008.

[RD-60] "D-FLER – A Distributed Fuzzy Logic Engine for Rule-Based Wireless Sensor Networks", Springer Berlin Heidelberg, Mihai Marin-Perianu and P. Havinga, 2008.

[RD-61] "AmbientRT - Real Time System Software Support for Data Centric Sensor Networks", Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP): 61-66., Hofmeijer, T., S. Dulman, et al., 2004.

[RD-62] "Prisma Electronics SA", http://www.prisma.gr (accessed on 2009-08-20).

[RD-63] "PREMFIRE – Fire Combat Management and Control System", Critical Software S.A., http://www.premfire.net/ (accessed on 2009-08-20).

[RD-64] "SITHON: A Wireless Network of in Situ Optical Cameras Applied to the Early Detection-Notification-Monitoring of Forest Fires", Sensors 2009, 9(6), pp. 4465-4482, Tsiourlis G., Andreadakis S. and Konstantinidis P., April 2009.

[RD-65] "Performance of a Protected Wireless Sensor Network in a Fire. Analysis of Fire Spread and Data Transmission", Sensors 2009, 9, pp. 5878-5893, Thierry Antoine-Santoni, Jean-François Santucci, Emmanuelle de Gentili, Xavier Silvani and Frederic Morandini, 2009-07-24.

[RD-66] "A Design and Implementation of Forest-Fires Surveillance System based on Wireless Sensor Networks for South Korea Mountains", IJCSNS International Journal of Computer Science and Network Security, VOL.6 No.9B, Byungrak Son, Yong-sork Her, and Jung-Gyu Kim, September 2006.

[RD-67] "A Distributed and Self-Organizing Scheduling Algorithm for Energy-Efficient Data Aggregation in Wireless Sensor Networks", Transactions on Sensor Networks 4(4), Article 20, S. Chatterjea, T. Nieberg, N. Meratnia, and P.J.M. Havinga, 2008.

[RD-68] "The Global Sensor Networks middleware for efficient and flexible deployment and interconnection of sensor networks", LSIR Report 2006-006, K. Aberer, M. Hauswirth, A. Salehi, 2006.

[RD-69] "A Cellular Automata and Intelligent Agents use to Model Natural Disasters with Discrete Simulation", Environmental Modelling and Simulation (EMS 2004), P. Fonseca, J. Casanovas, and J. Montero, 2004.

[RD-70] “A Fire Perimeter Expansion Algorithm-Based on Huygens Wavelet Propagation”, International Journal of Wildland Fire 3(2) 73 – 84, I. Knight and J. Coleman, 1993.

[RD-71] “Forest Fire prediction. The GIS Simulation Model”, Centre National des Techniques Spatiales, Division Géomatique, Ahmed Saidi, A. Missoumi, Chercheur en Géomatique, 2004.

[RD-72] “Elliptical fire front speed function”, Building and Fire Research Laboratory, National Institute of Standards and Technology, R. McDermott and R. Rehm, 2008.

[RD-73] “Specification of Discrete Event Models for Fire Spreading”, SIMULATION, Vol. 81, No. 2, 103-117, Alexandre Muzy, Eric Innocenti, Antoine Aiello, Jean-François Santucci and Gabriel Wainer, 2005.

[RD-74] “Computer vision techniques for forest fire perception”, Image and Vision Computing, Volume 26 , Issue 4, Pages 550-562 , J.R. Martinez-de Dios, B.C. Arrue, A. Ollero, L. Merino and F. Gómez Rodríguez, April 2008.

[RD-75] “Algorithms for Semi-Automated Dispatching in FOMFIS System”, International Workshop on "Improving dispatching for forest fire control", David Caballero, December 6-8, 2001.

[RD-76] “Latest algorithms and scientific developments for forest fire detection and monitoring using MSG/SEVIRI and MODIS sensors”, Proceedings of 2nd International Conference on Recent Advances in Space Technologies, Pages 118 – 123, A. Calle, J.L. Casanova, C. Moclan, A.J. Romo, E. Cisbani, M. Costantini, M. Zavagli, B.Greco, 9-11 June 2005.

[RD-77] “Active-DEVS: a computational model for the simulation of forest fire propagation”, 2004 IEEE International Conference on Systems, Man and Cybernetics, E. Innocenti, A. Muzy, A Aello, J.-F. Santucci, D. Hill, October 2004.

[RD-78] “A Semi-empirical Cellular Automata Model for Wildfire Monitoring From a Geosynchronous Space Platform”, College of William & Mary, Department of Applied Science, D. Brian, J. Killough, 2003.

[RD-79] “Forest Fire Detection and Monitoring by Means of an Integrated MODIS-MSG System”, Remote Sensing Laboratory of University of Valladolid ,LATUV, J.L. Casanova, A. Calle, A. Romo, J. Sanz, 2006.

[RD-80] “An elliptical growth model of forest fire fronts and its numerical solution”, International Journal for Numerical Methods in Engineering, Volume 30 Issue 6, Pages 1163 - 1179, Gwynfor D. Richards, Jun 2005.

[RD-81] “Geographic Information Systems and Cellular Automata: a New Approach to Forest Fire Simulation”, In Proceedings of The European Conference on Geographic Information Systems (EGIS), Paris (France), P.P. Goncalves, P.M. Diogo, 1994.

[RD-82] “On elliptical model for forest fire spread modeling and simulation”, Mathematics and Computers in Simulation, Volume 78, Issue 1, Pages 76-88, J. Glasa, L. Halada, June 2008.

[RD-83] “FARSITE: Fire Area Simulator -- A model for fire growth simulation”, Fire management notes. 59(2):13-15, Finney, M.A. and P.L. Andrews, 1998.

[RD-84] “Assessing the Effectiveness of Landscape Fuel Treatments on Fire Growth and Behavior”, Journal of Forestry. Pp 32-40, Stratton, Rick D., 2004.

[RD-85] “FireFamily Plus user's guide, Version 2.0”, Gen. Tech. Rep. RMRS-GTR-67WWW. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Bradshaw, Larry; McCormick, Erin, 2000.

[RD-86] “BehavePlus fire modeling system: Past, present, and future”, Proceedings of 7th Symposium on Fire and Forest Meteorological Society, Andrews, P. L., October 2007.

[RD-87] The Essence of Chaos. University of Washington Press. Lorenz, E. N., 2001.

[RD-88] A New Kind of Science. Wolfram Media, Inc. Wolfram, S., 2002.

[RD-89] Complex Adaptive Systems. Princeton University Press. Miller, J. H and S. E. Page, 2007.

[RD-90] Deep Simplicity of Complex Systems. InteSys Ltd. Jankovic, L, 2009. http://www.e-intesys.com/complexitycourse/index.htm (accessed on 2009-08-27).

[RD-91] “Environment and Sustainable development. Donostia - San Sebastian” (original title: “Medio ambiente y desarrollo sostenible. Donostia – San Sebastián”), City council of San Sebastian, http://www.agenda21donostia.com/cas/corporativa/areas/aire.htm (accessed on: 2009-08-27)

[RD-92] “Online indexes for pollution in San Sebastian”, City council of San Sebastian, http://www.agenda21donostia.com/cas/indicadores/panel/index_conta.htm (accessed on: 2009-08-27)

3. EMMON Project Overview

The EMMON project is an European Research and Development (R&D) project, sponsored by the 7th Framework Programme (7FP), ARTEMIS Joint Undertaking (JU) initiative and integrated in the Industrial Priority "Seamless connectivity and middleware".

EMMON motivation is originated from the increasing societal interest and vision for smart locations and ambient intelligent environments (smart cities, smart homes, smart public spaces, smart forests, etc). The development of embedded technology allowing for smart environments creation and scalable digital services that increase human quality of life.

The project goal is to perform advanced technological research on large scale distributed Wireless Sensor Networks, including research and technology development activities in order to achieve the following specific objectives:

- Research, development and testing of a functional prototype for large scale WSN deployments;
- Advance the number of devices by one order of magnitude, by real world validation (10 thousand to 100 thousand nodes);
- Advance the number of devices by two orders of magnitude, by simulation (100 thousand to 1 million nodes);
- Improve reliability, security and fault tolerance mechanisms in WSN;
- Identify and capture end-user needs and requirements, as well as operational constraints;
- Determine a path for exploitation of project results;

EMMON's main objective is the development of a functional prototype for the real-time monitoring of specific natural scenarios (related to urban quality of life, forest environment, civil protection, etc) using Wireless Sensor Network (WSN) devices. The goal of the project is to develop the technology to effectively monitor and control an area of 50 square km.

Areas of application for the project include a multitude of physical environments where continuous, large scale monitoring and situation analysis are of great interest, such as hydrographical systems (rivers and dams), urban areas quality of life monitoring (pollution and noise), regional climate/marine monitoring, civil protection (forest fires, pollution propagation, etc), natural resources monitoring, energy production prediction, industrial plant monitoring, personal health monitoring and precision agriculture, just to name a few.

The increased environment awareness and detection of abnormal variations, allied with the possibility to rapidly broadcast alarms and alerts, improves human quality of life and sustainability.

Project main results include:

- Large scale deployment of a fully-functional system prototype in a real world scenario (composed of thousands of nodes);
- New WSN embedded middleware with better overall energy efficiency, security and fault-tolerance;
- New efficient and low power consumption WSN multilevel communication protocols and reliable middleware for large scale monitoring;
- Simulation models for WSN behaviour analysis;

- Centralized C&C Centre for easy and centralized monitoring;
- Mobile C&C station or device for local access, diagnosing, viewing and troubleshooting of the network;

EMMON is structured on eight (8) work-packages (WP1 to WP8):

- WP1 and WP2 include management, dissemination, exploitation and standardization activities;
- WP3, WP4 and WP6 include the main RTD activities;
- WP5, WP7 and WP8 aggregate all integration, implementation and testing activities.

Figure 1, illustrates the work-packages distribution within project areas and how they are related.

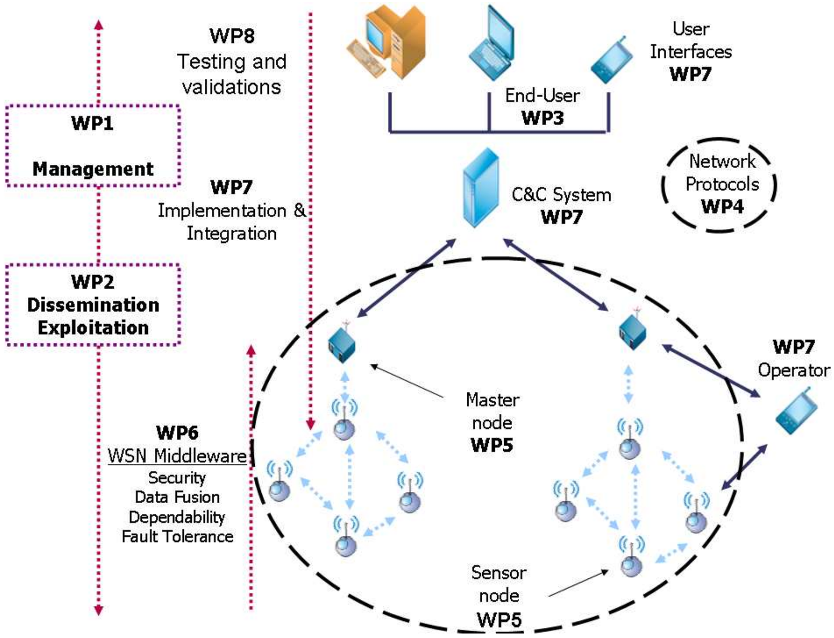

Figure 1 - EMMON system overview and work package decomposition

3.1 Work-Package 3 Overview

WP3 "User environment requirements and needs" objective is to systematically identify the end-user needs and requirements that should be taken into account in the project for each application operational scenario. The WP is split into six (6) Tasks, each focusing on a particular application scenario for the technology:

- T3.1: Consolidation of operational scenarios requirements;
- T3.2: Water quality scenario;
- T3.3: Urban quality of life scenario;
- T3.4: Marine environments scenario;
- T3.5: Civil protection scenario;
- T3.6: Event propagation (Fire, pollution, etc) simulation.

4. Studies Performed on Water Quality Monitoring

This section presents results of studies related with water quality monitoring.

4.1 Operational Studies

In “Water Quality Variables” [RD-3] from CETESB, variables pertinent to Water Quality are presented and the impact on the ecosystem by the variance of each is detailed.

In order to quantify the overall quality of the water, CETESB created a Water Quality Index (IQA) [RD-8] adapted from previous studies performed in 1970 by the "National Sanitation Foundation" from the United States of America.

The IQA was based in researches that gathered Water Quality specialists’ judgments. A set of curves for each variable was set up to quantify each water quality variable and a mathematical formula to aggregate it into the index (see Figure 2 for two example curves). The index has a value between zero and one hundred (0-100). The index also makes it easier to communicate the quality level to non water quality experts by establishing a textual qualification by range of IQA as shown on Table 3.

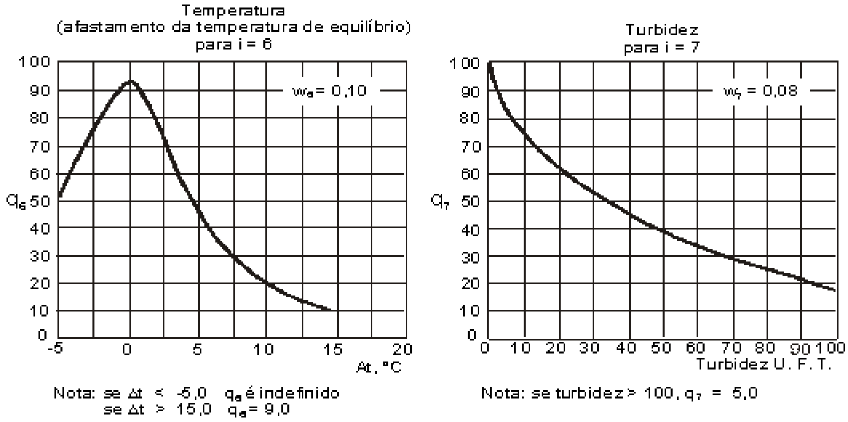

Figure 2 - IQA curves for Water Temperature (left) and Turbidity (right)

Category	Range
Excellent	79 < IQA <= 100
Good	51 < IQA <=79
Acceptable	36 < IQA <= 51
Bad	19 < IQA <= 36
Very Bad	IQA <= 19

Table 3 - IQA qualifications

Studies have been made to correlate natural and human made phenomena and the impact they have on water bodies.

The impact of precipitation on a river’s water quality was studied in the river Purus, Brazil. The study [RD-2] correlates the occurrence of rain in the hydrographical basin of the river and the quality parameters of the river’s water. The quality parameters monitored were: water temperature, turbidity, pH, electrical conductivity, dissolved Oxygen concentration, and suspended solids.

Carvalho et al. (2000) [RD-7] also realised a correlation between precipitation and several water quality variables. The strongest correlation is between precipitation and water pH. The pH tends to increase with higher amounts of rain.

In [RD-6] the Casco Bay Air Deposition Study Team, from the United States of America, composed by elements from Maine Department of Environmental Protection, from Environmental Protection Agency (EPA), and from Casco Bay Estuary Project (CBEP), estimate the annual rate of direct atmospheric deposition of pollutants to an estuary when little or no local monitoring data is available. The estimation approach is a useful starting point for understanding the sources of pollutants entering water bodies that cannot be accounted for through run-off or point source discharges. Casco Bay is used as a case study. The CBEP and other National Estuary Programs have sought to identify and quantify sources of contamination to water bodies.

The estimation techniques described in the article [RD-6] are presented as a useful and inexpensive way to understand the impact of atmospheric pollution source and can help to pinpoint the locations where future field measurements are needed to support management decisions.

For drinking water, the World Health Organization (WHO) produced “Guidelines for Drinking-water Quality” [RD-13] with the primary purpose of protection of public health. This is a comprehensive set of guidelines for drinking water quality.

4.2 Technological Research and Solutions

Currently the data for water quality monitoring is mainly collected manually ([RD-9]). The data collected is later introduced in computerised data bases. This process is done either also manually or with some automatic data transfer. The latter one is possible when the data collecting equipment is fully digitalised. Sometimes the data is telecommunicated immediately after the collection (e.g.: GPRS [RD-9]).

One of the reasons a great effort is done manually, is that automatic stations do not measure all the variables needed for a full assessment of the water quality ([RD-3]).

Automatic telemetric stations (Figure 3) are also used to provide information from water bodies with difficult access. These automatic stations provide near real-time information (usually ranging from every hour to every day). From all the solutions analysed, every automatic telemetric station communicates directly to a central computerised Information System. Usually this communication is through Satellite communications ([RD-5], [RD-9] and [RD-10]). No implemented solution resembling WSN has been found on this kind of scenario.

The use of WSN for water quality monitoring has been found only on academic studies like [RD-15] where the authors propose a WSN based solution to monitor water distribution pipes for leakage detection.

For automatic telemetric stations, the data provided is usually validated by a human operator. Usually there is a concern in maintaining the data quality and identifying problems in the stations.

Figure 3 - Telemetric station from ANA

According to [RD-9], the Brazilian Water Agency (ANA) main data collection is made manually with analogical equipments. 969 rivers are monitored this way. Four data collection campaigns are performed per year. Data collected manually is mainly with regards to precipitation, water level, water flow, water quality and sediments. Figure 4 shows some examples of manual data collection.

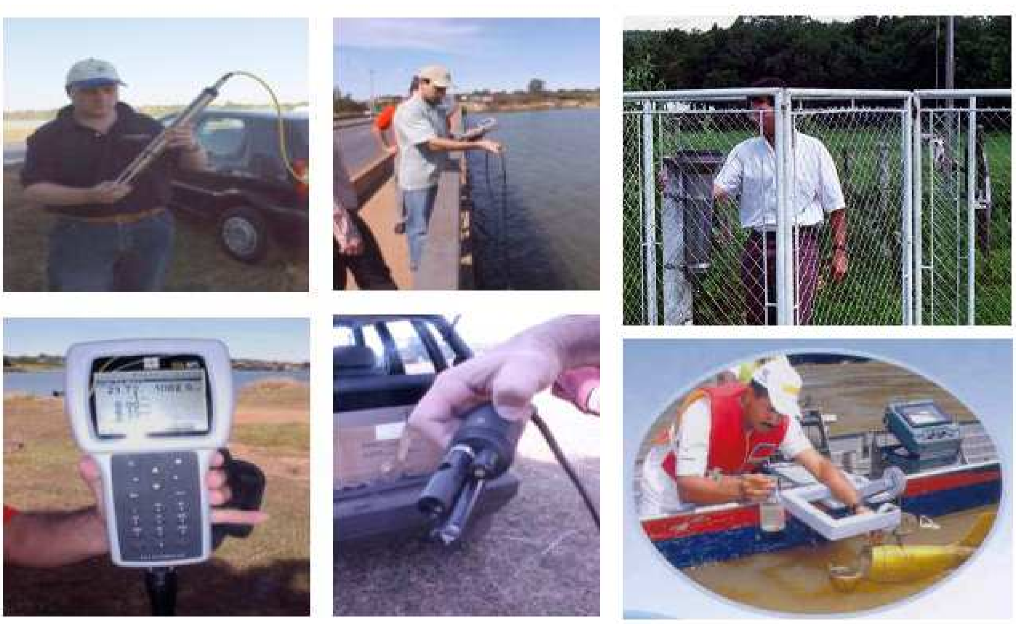

Figure 4 - ANA manual data collection

The data collected manually is afterwards uploaded into a central database. This database is accessible by everyone to perform studies, analysis or as a long term monitoring.

Data collected manually includes more then 2.600 points of measurement, involves around 3.600 people spread through 37 operational bases, using 180 different routes, and mobilizes means such as airplanes and boats.

Besides the manually collected data, ANA also has 313 remote telemetric stations. The stations are deployed in the main Brazilian basins. They provide data every hour through INPE satellite communications. The data provided includes water level (pressure), precipitation, and water temperature. Besides environmental data, the stations also provide important information for the station maintenance: internal humidity, internal temperature, battery condition and solar panel electrical current flow.

The data collected by the telemetric stations – because in normal operation provides data every hour – serves as a near real-time monitoring tool, providing current hydrologic status and an alarm system through automatic data analysis. The data is also provided to the electric sector to help on resource management decisions.

Another kind of solution is used for a high population density region. Three of the Brazilian states with highest population density have 10 points of monitoring. These points are monitored by portable sensors, handled by an operator, and transmit the data through cellular network (GPRS), as illustrated by Figure 5.

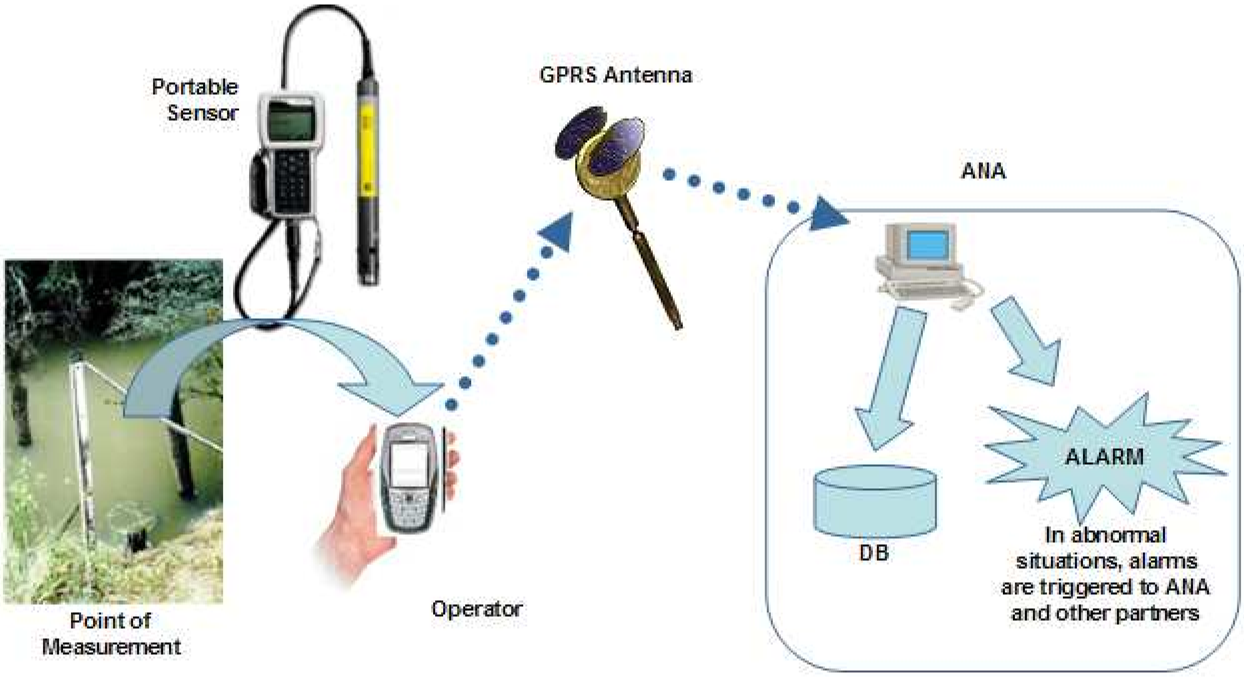

Figure 5 - ANA GPRS portable sensors

Other solutions include a special national telephone number to report measurements. Each measurement provider has an identification code. The person reporting a measurement uses the telephone equipment's numeric keys to provide the identification code and to report the values. This system has a very low investment and maintenance cost, and allows for technicians based on distant locations without sophisticated communications equipment or infrastructure, to report measurements ([RD-9]).

The USA Texas Commission on Environment Quality (TCEQ) operates continuous environmental monitoring sites that measure both air and water parameters. TCEQ calls it CAMS, Continuous Ambient Monitoring Stations. This includes water quality automatic telemetric stations based on satellite communications (see an example in Figure 6). Currently it has around 80 stations in water bodies spread by the Texas state ([RD-10]), and new monitoring projects are being developed using satellite communications based automatic telemetric stations ([RD-11]).

Figure 6 - TCEQ Dickinson Bayou continuous ambient monitoring station

Manufacturers providing projects from TCEQ ([RD-11]) are presenting solutions to allow for a wider area of measurement. SUTRON has a solution based on slave sensors communicating readings to a master sensor up to 1 mile (approximately 1,600 meters) that will communicate all the slaves' readings and his own through satellite. An example is illustrated on Figure 7.

Figure 7 - SUTRON's SDI-LINK solution

Data Publication

Solutions to publicly provide comprehensive data to users, usually through web-based access, are based on Geographic Information Systems (GIS). Basic functionalities provided in most solutions are to navigate through maps (pan and zoom) with different kinds of data overlapped, print maps, and generate reports based on area and with specified water quality information.

The maps have several different layers of data that can be shown or not according to the user's need. The data varies from reference points, like cities and borders, to water quality (like impaired water points) or water level.

The Brazilian National Water Agency (ANA) has publicly available on the Internet the data collected by automatic telemetric stations [RD-5]. The data encompasses precipitation, water level and water flow. The user can click on the map basin regions to zoom in into the basin, and then into sub-basins and rivers.

The data is presented with colour codes that represent the current situation. The data is considered outdated if no new reading is available in the last 24 hours. Figure 8 is a snapshot of this application. It is an example of a sub-basin with two telemetric stations. The data shown is precipitation and the colours are grey for no current information, white for no rain, and blue for raining. In this example the two stations present a raining situation and a not raining situation.

Figure 8 - ANA telemetric stations snapshot

ANA also provides access to historical data. This is mainly the manually collected data. The user can specify the data to access by basin, sub-basin, region, etc. The data can be visualised on-line as a Web page list or downloaded in text format or Database (Access) format ([RD-12]).

The United States of America Environmental Protection Agency (EPA) has publicly available in the Internet, the EnviroMapper for Water [RD-4]. As described in the EPA institutional web site, "*EnviroMapper for Water is a web-based Geographic Information System (GIS) application that dynamically displays water quality and other environmental information about bodies of water in the United States. This interactive tool allows you to create customized maps that portray the nation's surface waters along with a collection of water quality related data from the national level down to community level. The redesigned tool provides the ability to:*

- *Geographically display a variety of EPA water program data*
- *Pan, zoom, label and print maps*
- *Link to water program web reports after identifying specific features of interest*
- *Generate specific water quality related reports based on an area of interest*"

TCEQ also makes their sensors readings available on the Internet ([RD-10]). The access to the readings is also provided through a sequence of maps, as illustrated on Figure 9. The data can also be accessed by selecting the site (reading location) from a list with all sites. The data is shown in a tabular from for a whole day, as illustrated in Figure 10, highlighting the maximum and minimum values for the day. The user can select other days from the past.

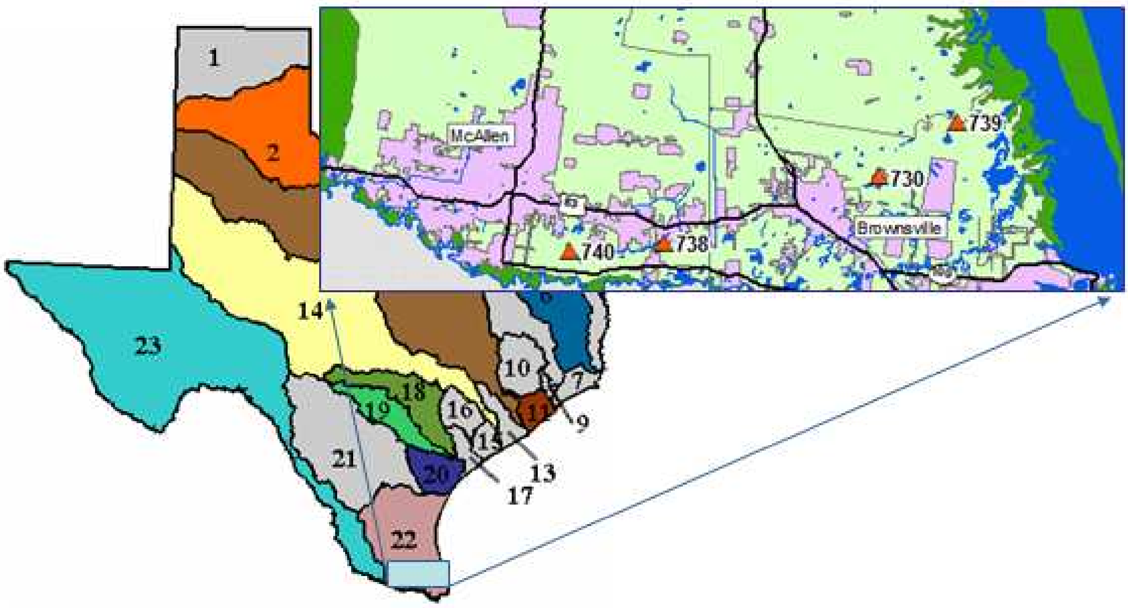

Figure 9 - TCEQ web interface for selecting sensor

Use the controls below to select a different date or time format. Click on the Generate Report button once you have made your selections.

CAMS 736 Anzalduas Dam Near Pier 7 C736 **Select a different site**

Month: **Day: Year: Time Format:**

May 6 2009 24 Hour Generate Report

☑ Highlight validated data

The table below contains hourly averages for all the pollutants and meteorological conditions measured at Anzalduas Dam Near Pier 7 C736 for **Wednesday, May 6, 2009**. All times shown are in CST.

Parameter Measured	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	
Reservoir Water Elevation	**104.36**	104.36	104.32	104.32	104.31	104.34	104.32	104.30	104.26	***104.26***	104.26	104.27	104.32	104.34	1
Parameter Measured	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	
	Maximum values for each parameter are **bold** within the table. Minimum values are ***bold italic***.														

PLEASE NOTE: This data has not been verified by the TCEQ and may change. This is the most current data, but it is not official until it has been certified by our technical staff. Data is collected from TCEQ ambient monitoring sites and may include data collected by other outside agencies. This data is updated hourly. All times shown are in Local

Figure 10 - TCEQ web interface for daily report

4.3 Conclusions

It is evident that water is a priceless valuable resource. Life depends on it. Its use ranges from drinking and hygiene, to agriculture and even electrical production.

Degradation on water quality highly impacts on public health directly or indirectly.

The concern on monitoring water resources in water bodies is present in most countries. In a simple search on the Internet one can find national water institutes or similar in a huge number of countries and internationals institutions.

From the studies, it was understandable that to fully assess the quality of a water sample it is necessary to perform laboratory tests. There are a high number of parameters that must be measured. The current solutions that automatically measure water parameters, only measure a few important parameters like pressure (for water depth), temperature, electrical conductivity and turbidity. These parameters might indicate some kind of bad quality that can be further assessed by manual samples for a more complete analysis.

Water leakages from distribution pipelines are one kind of water monitoring that has been studied to be addressed by WSN.

The solutions addressing water quality monitoring are summarized on Table 4.

Solution	Technical Solution	Strengths	Weaknesses
Manual Water Samples Collection	- Transportation for personnel and samples (by plane, boat, car and on feet.) - Laboratory	- Complete assessment on water quality	- Expensive cost-per-measurement (involves human resources and travels for each measurement campaign) - Not real-time
Manual Onsite Water Measurements	- Transportation for personnel and instruments - Manual measurement instruments - GPRS	- Faster results than water sample collection (near real-time when GPRS is used to report data)	- Expensive cost-per-measurement - Transportation of instruments (proportional to the amount of different measurements)
Automatic Telemetric Stations	- Satellite communication - Automatic measurement instruments - Solar panel for energy harvesting	- Real-time - Inexpensive cost-per-measurement	- Expensive installation
WSN for monitoring water distribution.	- WSN	- Real-time - Fast deployment - Inexpensive installation - Inexpensive cost-per-measurement	- Just a study (immature solution) - Underground communications still presents a challenge - High node density with low range communication is not required, thus technology does not seem suitable for this purpose
SDI-LINK, by SUTRON	- Satellite communications - Wireless low power radio communication	- Increased area of measurement (several close reading points for one satellite communication)	- Expensive installation

Table 4 - Water quality monitoring technologic solutions summary table

5. Studies Performed on Urban Quality of Life Monitoring

This section presents results of studies related with urban quality of life monitoring.

5.1 Operational Studies

In the 27 countries composing the European Union, 74% of the population lives in cities or towns with more than 5.000 inhabitants ([RD-26]). Thus, it is considered important by EUROSTAT to understand what is happening economically and socially in the European cities. A good quality of life is important to retain and attract population into a city. Furthermore, business, tourists, students, skilled labour force are also important assets for a city and are attracted by the cities' quality of life.

But what is "quality of life"? It is not a consensual definition. Two different persons might give radically different importance to the same thing regarding its impact on their quality of life; i.e., their perspective of quality of life might be different. One might consider heath care one of the most important aspects while another might consider air quality much more important then health care.

The report [RD-27] joins together opinions and perspectives about quality of life from different partners all across Europe, with different backgrounds on urban issues. This report aims to increase awareness of the different perspectives of quality of life. It also presents global and European drivers of change in relation to quality of life. It considers demographic development, changing consumption patterns, and urbanisation; and highlights related environmental challenges critical to quality of life like air pollution, noise, and climate change.

Air quality is one of the factors that impacts on quality of life, namely for health reasons.

Air quality guidelines are defined by the World Health Organization (WHO) ([RD-24] and [RD-25]). [RD-24] is a thorough guideline containing health risk assessments for 28 chemical air contaminants. As an example, Table 5 resumes the values provided by the global update [RD-25].

Pollutant	Averaging time	AQG value
Particulate matter PM2.5	1 year	10 $\mu g/m^3$
	24 hour (99th percentile)	25 $\mu g/m^3$
Particulate matter PM10	1 year	20 $\mu g/m^3$
	24 hour (99th percentile)	50 $\mu g/m^3$
Ozone, O3	8 hour, daily maximum	100 $\mu g/m^3$
Nitrogen dioxide, NO2	1 year	40 $\mu g/m^3$
	1 hour	200 $\mu g/m^3$
Sulfur dioxide, SO2	1 year	20 $\mu g/m^3$
	1 hour	500 $\mu g/m^3$

Table 5 - World Health Organization Air Quality Guideline (AQG) values

PM2.5 and PM10 are terms to refer to solid particles and liquid droplets that exist suspended in the air and that have 2.5 micrometers or less and between 2.5 and 10 micrometers respectively.

In [RD-24], chapter 7.3, Particulate Matter is defined as "*Airborne particulate matter represents a complex mixture of organic and inorganic substances*" and that "*Mass and composition tend to divide into two principal groups: coarse particles mostly larger than 2.5* *μm in aerodynamic diameter, and fine particles mostly smaller than 2.5 μm in aerodynamic diameter (PM2.5).*"

There are several studies on how urban air pollution impacts on public health.

The study [RD-20] evaluates the impact of air pollution on Small for Gestational Age birth weight, Low full-term Birth Weight, and preterm birth using spatiotemporal exposure metrics. Associations between traffic-related air pollution and birth outcomes were observed.

[RD-21] presents the results of a study on the impact of ambient air pollution on Infant bronchiolitis in Puget Sound and the Georgia Air Basin. This study suggests a correlation between bronchiolitis hospitalization and PM2.5 exposure.

Also, the noise pollution has been studied on how it impacts on public health or even the conjunction of air and noise pollution ([RD-22]).

5.2 Technological Research and Solutions

[RD-17] presents a technical overview on activities carried out in the context of the project WISE-WAI [RD-16]. The project has a testbed setup in the department of Information Engineering at University of Padova.

In [RD-91] the city council of San Sebastian presents a study of the environmental pollution of this city in the previous months. In this report a set of statistical data is stated and analysed in order to assess the air quality according to the thresholds established for the State legislation. The traffic and the parking places are compared and correlated in this assessment. This report has two major goals: the first one is to study and present statistical data about environmental pollution in the city, and the second is to try to promote the use of alternative means of transportation (such as public transportation or bicycles), in order to reduce the emission of pollutants.

Moreover, [RD-91] and [RD-92] present the main indexes regarding the air quality in San Sebastian, monitored on a weekly basis. The monitored pollutants are sulphur dioxide, ozone, suspended particulates, nitrogen dioxide and carbon monoxide as Figure 11 shows.

Figure 11 - Online air quality indexes in San Sebastian

[RD-92] uses data originating from 4 monitoring stations. One of these stations is located in Irun, a city near San Sebastian. The remaining 3 stations are strategically located in San Sebastian, taking into account the distance between them. Figure 12 illustrates the station located in Easo, a zone in the midtown of San Sebastian, next to a local train station.

Figure 12 - Easo station for air quality monitoring in San Sebastian

[RD-18] discusses the challenges and features for vehicular ad hoc networks (VANET). These networks define not only inter-vehicle communications (IVC), but also vehicle-to-roadside communication (VRC). VRC impacts the way sensors can be distributed on a city to monitor traffic, both for active vehicles – that perform VRC – and for passive vehicles.

[RD-19] presents a thorough report about sensors for traffic monitoring. In it, different kinds of sensors are analysed. The report divides the sensors into intrusive, non-intrusive and the WSN solution presented. The intrusive ones require direct installation onto the pavement. The non-intrusive ones do not require such installation (e.g.: a video camera). The WSN ones do not need cables and are placed on top of the pavement (glued and/or screwed). Issues related with battery types, node lifetime, and even signal processing are addressed in this report. Manufacturers and existing solutions are referenced.

The solution presented in this report has sensor nodes and an access point that will relay the information to central operation information systems. Figure 13 illustrates two possible layouts to monitor the passage of vehicles, with the position of sensors and access points.

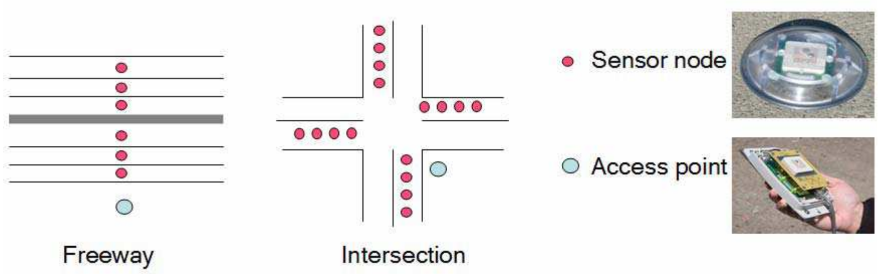

Figure 13 - A sample wireless sensor network layout for traffic surveillance ([RD-19])

The WSN sensor node has a built-in magneto-resistive sensor that measures changes in the Earth's magnetic field caused by the presence or passage of a considerable mass, like the vehicles, in the proximity of the node. The sensor is deployed embedded on the road pavement with glue. This solution is presented as being more cost effective, easy of installation and with flexibility of deployment, when compared with existing solutions to monitor traffic (inductive loop, video, radar detector systems, etc.).

Monitoring noise with Wireless Sensor Network (WSN) was tested with a sensor node prototype based on *Tmote invent* prototyping platform ([RD-42]). The study's objective was to depict the potential and limitations of currently available wireless sensor networks prototyping platforms to be used as noise pollution sensors. The study concluded that current commercial available platforms for collecting noise pollution data are limited. Un-calibrated nodes' microphones produce misaligned acoustic responses. But in general, they conclude that WSN are suited to monitor noise pollution, at least to the extent of the number of nodes used on the experiment.

The trash collection on a city, everyone would agree, is directly related with quality of life. No one would like to live on a city where the trash would easily increase due to lack of trash collection. Furthermore, besides the visual and olfactory impact, the spread of plagues and diseases would have better chances to occur. [RD-28] presents a solution to estimate the amount of trash in trash containers to optimize trash collection.

5.3 Conclusions

From the data provided by the studies, one can infer that factors that people consider important for urban quality of life and that might be able to be automatically monitored using WSN are:

- Environmental factors:
  - Air Quality
  - Sound Pollution
  - Beach Water Quality (when applicable)
  - Urban Trash Collection and Differentiation
- Mobility
  - Average Speed on Private Transportation
  - Average Speed on Public Transportation
  - Average Available Parking Spaces
  - Traffic Jams

The solutions addressing urban quality of life monitoring are summarized on Table 6.

Solution	Technical Solution	Strengths	Weaknesses
Vehicular ad hoc networks (VANET). (For monitoring traffic in cities)	- Dedicated Short Range Communication (radio) - GPS	- Distributed System (cars are part of the system) - Cost (transmitted to car owners)	- All vehicles must be equipped with the system - System relies on the vehicles system (car owner might not repair malfunctioning system)
Wireless Sensor Networks for Traffic Monitoring, from Sensys Networks and University of California	- magneto-resistive sensor (Earth magnetic field micro-variations) - low-power radio - Two-layer architecture (Sensors and Access Point)	- Sensors easily deployable	- Need for two or more sensors in the direction of traffic flow to efficiently detect vehicle presence, count and velocity. - Collaborative signal processing needed (between sensors, and sensors and AP)
Wireless Sensor Network for Noise Pollution Monitoring, studied by [RD-42]	- WSN - COTS Motes (Tmote invent)	- WSN (ad-hoc network; no previous infrastructure needed)	- Reliability of noise sensors - Just a study (immature solution)

Solution	Technical Solution	Strengths	Weaknesses
Waste collection container with sensor for content estimation prototype ([RD-28])	- Video camera - LED lights - Ultrasounds - Strain gauge - Pressure sensors - GPRS/Internet - GPS (For collecting trucks)	- Allows to determine density of each drop into the trash container (weight vs volume)	- Prototype (immature solution) - Complex system

Table 6 - Urban quality of life technologic solutions summary table

6. Studies Performed on Maritime Environment Monitoring

This section presents results of studies related with maritime environment monitoring.

6.1 Operational Studies

Monitoring the oceans' temperature and salinity allows determining the oceans' impact on weather. Global climate change studies depend highly on these data. Monitoring ocean water levels also allows for early warnings in case of tsunamis.

The Australian Academy of Technological Sciences and Engineering, and the Western Australian Global Ocean Observing System Inc., estimate in a thorough report ([RD-34]), the benefits for the Australian Economy by having a greater use of climate forecasting in the agriculture industry. The report presents a rationale for the public funding on marine environment monitoring by demonstrating that "*investing in the Global Ocean Observing System (GOOS) project represents value for money in terms of the considerable and diverse benefits to communities and industries*."

The Global Ocean Observing System (GOOS) ([RD-35]) is an effort to produce a comprehensive, sustained, operational and international ocean observing system. It consists of a network made by the aggregation of several institutional networks from all over the world. UN sponsorship and UNESCO assemblies assure that international cooperation is always the first priority of the Global Ocean Observing System. Temperature and salinity are measured from space, moored instruments, free floating buoys and profilers.

6.2 Technological Research and Solutions

Maybe one of the first maritime monitoring solutions was vessel cruises to collect measurements in open sea.

The Leibniz Institute for Baltic Sea Research (IOW) performs 4 to 6 cruises per year to perform measurements in the Baltic Sea. The research vessels measure water temperature, salinity and Oxygen saturation. [RD-29] is a report of one of these cruises.

Besides scientific specific vessels, merchant vessels equipped with thermosalinographs or contact thermometers also collect measurements during their regular cruises. This takes advantage of the fact that ships would have to take the cruise independently of the measurement needs, as well as the fact that the measurement equipment doesn't impact the normal operation of the ship. The measurements are automatic and the power consumption to transmit the data is residual compared with the power consumption of the ship. Another advantage is that merchant ships have common routes, making the same route for years. This practice of using regular merchant ships to collect the data is called "ship of opportunity" ([RD-36]).

Besides the cruises, buoys spread in the sea are also used. An example of an IOW monitoring station belonging to the MARNET network is shown on Figure 14 publicly available in the IOW site, section MARNET ([RD-33]).

Figure 14 - IOW-MARNET monitoring station (Oder Bucht)

Another technique used to obtain real-time data is through satellites observing earth.

Data from weather satellites like the USA NOAA series ([RD-30]) and the European ENVISAT from ESA ([RD-31]) are used by IOW. Using image processing techniques, the satellite images can provide information on ice distribution and surface temperatures. As an example, Figure 15 shows a well visible water temperature difference. Warmer waters show up darker than cooler waters. This image is a sample image provided in the NOAA web site. It was processed by Ralph E. Meiggs, Physical Scientist, NCDC-NOAA.

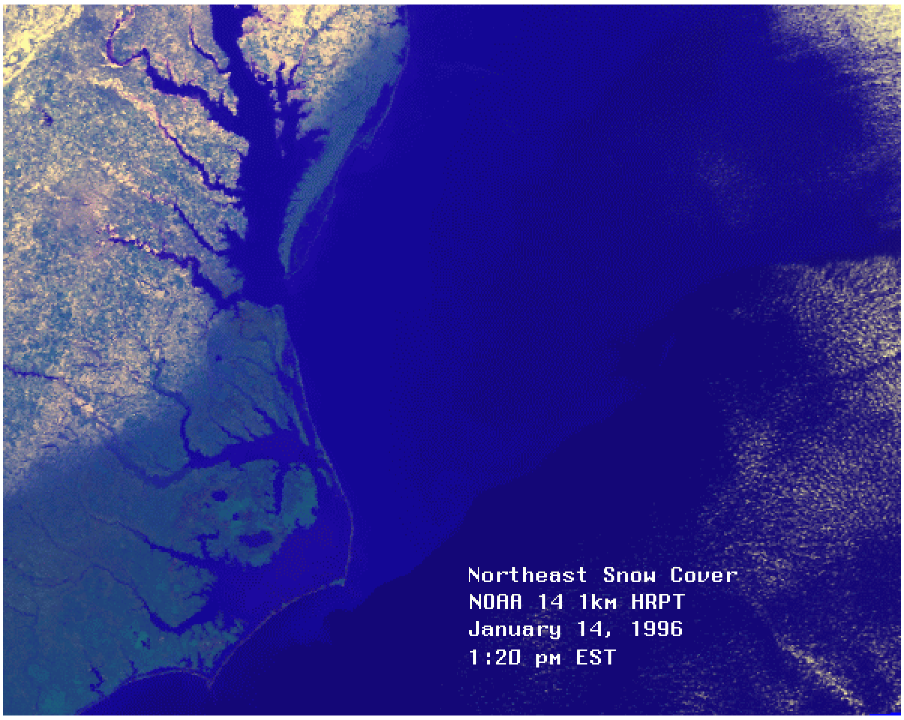

Figure 15 - NOAA sample image

6.3 Conclusions

Climate changes and marine environments are tightly correlated. Observing marine environments allows determining and alerting in advance in case of drastic climate changes. Nowadays, more then ever, this is a critical issue for mankind.

Furthermore, having measurement stations providing real-time information on sea water level and waves, allows preventive alerting for tsunamis.

From the studies, the main parameters that need to be measured are:

- At surface:
  - Waves' weight and frequency
- Both at surface and under surface
  - Temperature
  - Water flow (direction and speed)
  - Salinity

The solutions addressing marine environment monitoring are summarized on Table 7.

Solution	Technical Solution	Strengths	Weaknesses
Scientific vessel cruises	- Scientific measurement instruments - GPS	- Devoted ship - Wide range of measurements	- Expensive cost-per-measurement
Ship-of-opportunity	- Thermometer - Thermosalinographs - GPS - Satellite communication	- Takes advantage of existing commercial routes	- Depends on existing commercial routes
Sea Monitoring Stations	- Buoys - Satellite communication	- Real time	- Expensive installation
Earth observation satellite	- Satellite observation - Optical cameras	- Large coverage	- Lack of detail - Lack of measurements

Table 7 - Maritime environment monitoring technologic solutions summary table

7. Studies Performed on Civil Protection - Forest Fire Scenarios

This section presents results of studies related with civil protection monitoring, namely in forest fires scenarios.

7.1 Operational Studies

The need to understand forest fire behaviour has been present and has driven a considerable number of studies. Understanding fire behaviour allows a better planning regarding forest management and also aids decision-making. The goal is to protect the forest from fire hazards and to minimize fire impact when fire occurs.

The behaviour of the fire and the probability of fire depend on forest characteristics, such as tree size, density, structure and species composition; land characteristics, such as elevation and slope; and weather conditions, such as temperature and wind speed ([RD-37] and [RD-39]).

The land characteristics can be considered static. Geological modifications on the Earth's surface occur in a completely different time scale. Only human intervention can perform light modifications on land characteristics in a short time.

The forest characteristics can be planned. The species and spatial distribution can be selected to minimize the probability of fire ignition and the Impact of a fire occurrence. This plan shall consider land characteristics and region climate.

Climate characterizes the region's weather profile: average weather conditions in each time of the year. Climate has a strong correlation with the forest fire ignition probability, even for small differences on climate in two relatively close regions, as the example of north and south of Finland, according to [RD-38].

The weather conditions are the most dynamic influence on fire behaviour and ignition probability. The weather has a predictable variation throughout the year, obtained by statistical data from past years that defines the climate. But weather is highly stochastic and variations occur and differently in different regions of the same civil protection operational area.

The main dynamic factors that highly increase the probability of ignition and fast fire spread are: low humidity (dry terrain and air), high wind speed ([RD-40]), and high temperature. A major research study consists in defining exactly what is considered normal values for these physical parameters, and what constitutes abnormal values, denoting emergency situations.

Currently, there is no generic solution for the efficient supervision of an area, in terms of fire detection. Cooperative surveillance of the forest is recommended. The paper [RD-44] presents a survey of previous studies regarding the best approaches for early fire detection. The most important concerns in automatic fire detection are with regards to sensor combinations and adequate techniques for quick and noise-tolerant detection. To try and find solutions for these problems, researchers have been studying fires taking place in many places, such as residential areas [RD-45], forests [RD-46], [RD-47] and mines [RD-48].

Many decades of forestry research have resulted in several advances in the field of forest fire monitoring. Examples of such advances are the National Fire Danger Rating System (NFDRS) developed by the National Oceanic and Atmospheric Administration [RD-49], [RD-46] and the Fire Weather Index (FWI) system, developed by the Canadian Forest Service [RD-50], [RD-47].

The Fire Weather Index (FWI) is represented in Figure 16.

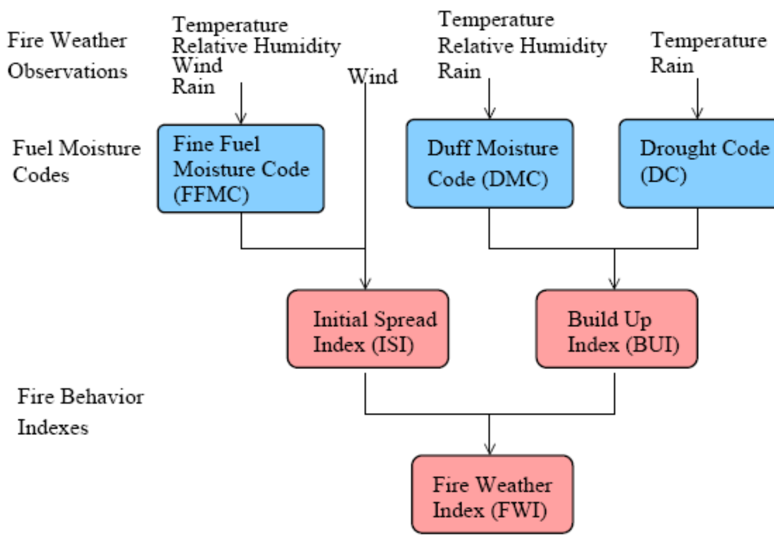

Figure 16 - Structure of the FWI system [RD-47]

The breakdown of the FWI indices is as follows:

- **FFMC** – takes four sensory inputs (temperature, relative humidity, wind and rain), and generates ignition potential of fire.
- **DMC** – takes three sensory inputs (temperature, relative humidity and rain), and calculates the fuel average consumption in duff layers, the first layer of the forest soil, and medium-size woody materials.
- **DC** – takes two sensory inputs (temperature and rain), and calculates the average humidity for deep, compact, organic layers.
- **ISE** – takes as inputs the FFMC and wind sensory information, and produces the expected rate of fire spread.
- **BUI** – takes as inputs the DMC and the DC, and produces the total amount of fuel for combustion.
- **FWI** – takes as two inputs the ISI and the BUI, and calculates the potential fire danger.

The National Fire Danger Rating System (NFDRS) Index is represented in Figure 17.

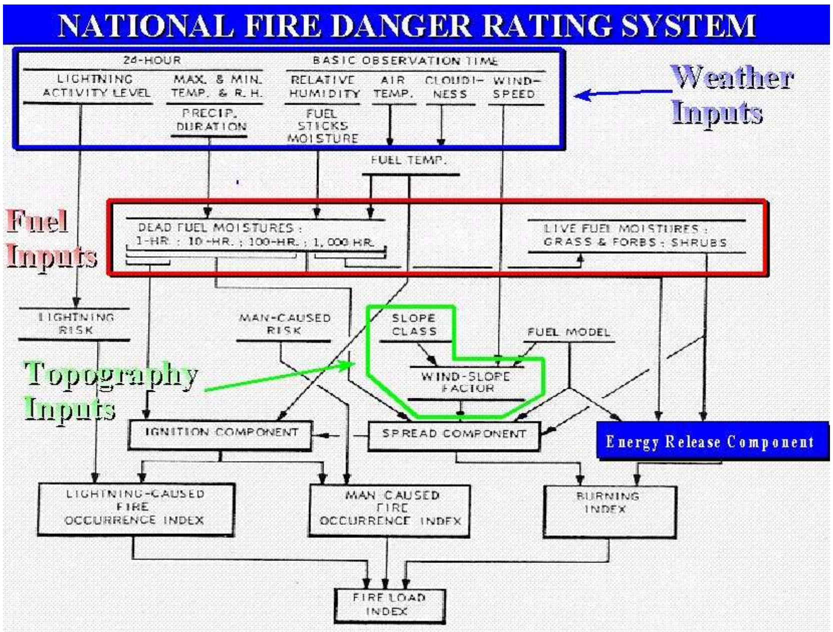

Figure 17 - National fire danger rating system [RD-49]

The NFDRS indices are as follows:

- **Occurrence Index** – indicates the potential of fire incidence.
- **Burning Index** – specifies the possible amount of effort required to control a single fire in a particular fuel type, within a rating area.
- **Fire Load Index** – shows the total amount of effort needed to surround all probable fires within the rating area during a particular period of time.

Forest fires have traditionally been detected by having some personnel perform the monitoring activities in a lookout tower, standing in a strategically chosen location (usually a high place) [RD-51]. In fact, many countries still use this technique nowadays, such as USA, Canada, Australia and Portugal.

Nevertheless, there are some big disadvantages in using this approach: life conditions are hard in the lookout towers and human observations are error prone. This has lead to the development of alternative vision techniques, such as Automatic Video Surveillance Systems (AVSS) [RD-52] or even satellite imagery, like the Advanced Very High Resolution Radiometer (AVHRR) and the Moderate Resolution Imaging Spectroradiometer (MRIS) [RD-53], [RD-54], [RD-55]. However, these also present some disadvantages: the AVSS system was developed for small forests, and the low spatial and temporal resolution of the satellite imagery can compromise the timeliness of the fire detection.

Sensor networks allow a more comprehensive and finer grained (better spatial and temporal resolution) monitoring [RD-47]. Not only that, but sensors can be used in regions where satellite signals are not available [RD-56].

Researchers at the University of Corsica (http://www.univ-corse.fr/) have been working on performing fire front tracking with a WSN [RD-65]. In order to achieve this goal, they developed a protection to avoid having the sensors destroyed by the fire, which they called "Firesensorsock". The objective of this protection is to reduce the thermal impact of fire when in contact with the sensors. However, the shield has to allow a continuous emission of data as well as temperature and humidity inside the package to vary on a short time scale, in order for the sensors to be able to correctly locate the fire's position.

The Firesensorsock is composed of several layers of thermal insulation materials: a simple Zetex fibre layer, a ceramic wool layer and an aluminized Zetex fibre layer. All these layers are fixed to each other with Kevlar thread. This allows the sensors to sustain prolonged exposure to fire while still allowing wireless communications with disturbances. The following figure shows the composition of the Firesensorsock technology:

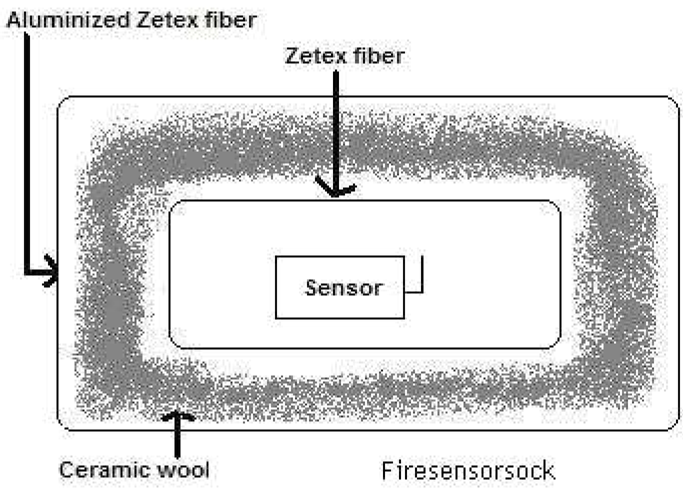

Figure 18 – Fire resistant sensor node proposed by [RD-65]

7.2 Technological Research and Solutions

In section 7.1, the paper [RD-44] presents a short description of several interesting technological solutions related to fire detection using wireless sensor networks, such as:

- **An "In-Situ" Forest Temperature Measurement Network** [RD-57]

  A sensor network was used to monitor the temperature in a real-life forest. Each sensor was equipped with a thermometer and a GPS device. The sensors were placed on trees, at a distance of no less than 3.5m from the ground. As sensors might be destroyed by the fire, a dynamic routing protocol was proposed. The conclusion was that a sensor node with the structure presented in Figure 19 could sense and transmit data more accurately, and that if three nodes were used to monitor the same location, the fire could be more accurately detected.

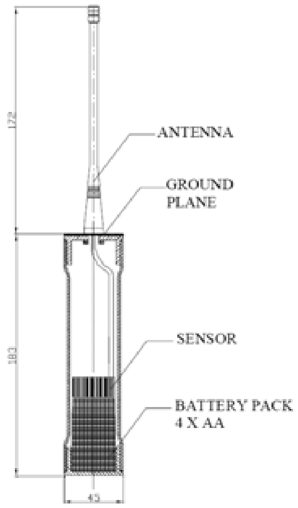

Figure 19 - Sensor node type proposed by [RD-57]

- **Fire Detection in the Urban Rural Interface through Fusion techniques** [RD-58]

  The author proposed a sensor network for early fire detection in jungles as well as urban areas. The system used temperature sensors and a likelihood algorithm to fuse the sensory information. The architecture, which can be seen in Figure 20, is composed of three parts: a sensing sub-system, a computing sub-system and a localized alerting sub-system.

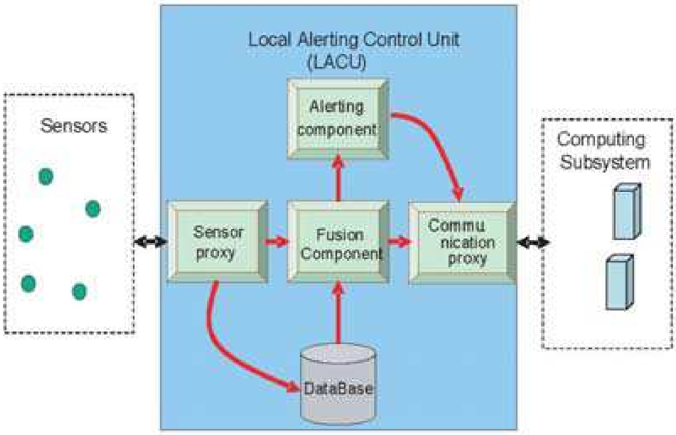

Figure 20 - System architecture proposed by [RD-58]

- **Early Forest Fire Detection with Sensor Networks: Sliding Window Skylines Approach** [RD-59].

  An approach using a "skyline" concept was used for early fire detection. The term "skyline" was given to those sensor readings with large temperature and wind speed. Only the data above the skyline is sent to sink nodes, reducing the number of communications needed as well as the amount of overall data transmitted. The sink nodes process the data according to the implemented algorithms, thus providing quick and energy efficient fire detection. Figure 21 shows the proposed skyline.

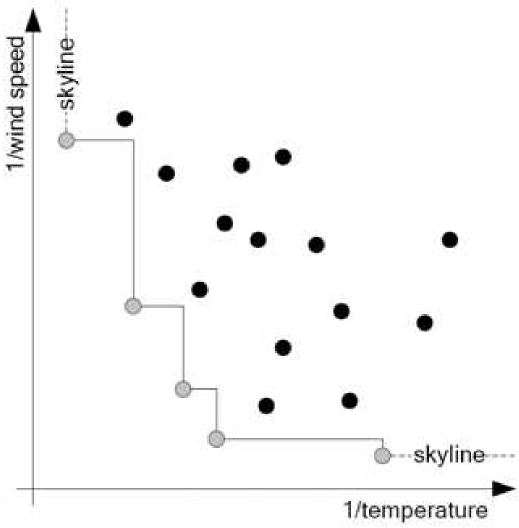

Figure 21 - Skyline for sensor readings [RD-59]

- **D-FLER – A Distributed Fuzzy Logic Engine for Rule-Based Wireless Sensor Networks** [RD-60]

  A fuzzy inference engine in a wireless sensor network was proposed by the authors, called "D-FLER", for event detection. In their work using smoke and temperature sensors for residential fire detection, they studied fire detection. D-FLER uses a distributed fuzzy logic engine, combining sensor inputs with neighbourhood observations. A prototype was implemented using the "Ambient μNode 2.0" platform [RD-61]. Figure 22 shows the structure of the D-FLER.

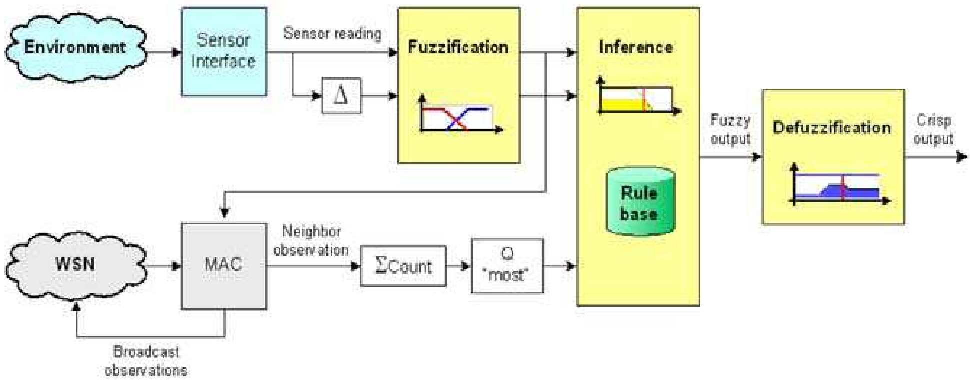

Figure 22 - D-FLER structure [RD-60]

In [RD-66], a Forest Fire Surveillance System (FFSS) was developed based on Wireless Sensor Networks. The FFSS consists of WSN, middleware and a web monitoring application. As a result, the FFSS monitors forests in real-time. The WSN measure temperature and humidity, and detect smoke. The middleware program and the web application analyze the collected data and information.

Collection of raw data poses a challenge to WSN as very large amounts of data need to be transferred through the network. This not only leads to high levels of energy consumption and thus diminished network lifetime but also results in poor data quality as much of the data may be lost due to the limited bandwidth of present-day sensor nodes.

In [RD-67] this problem is alleviated by allowing certain nodes in the network to aggregate data by taking advantage of spatial and temporal correlations of various physical parameters and thus eliminating the transmission of redundant data. Simulation results indicate a reduction in message transmissions of up to 85% and an increase in network lifetime of up to 92% when compared to collecting raw data.

The lack of standardization and the continuous introduction of new sensor network technologies have made their deployment the main factor of manpower consumption, considerably complicating the interconnection of heterogeneous sensor networks, and making portable application development a challenging and time-consuming task. In [RD-68] these problems are addressed by a Global Sensor Networks middleware which supports the rapid and simple deployment of a wide range of sensor network technologies. It facilitates the flexible integration and discovery of sensor networks and sensor data, enabling fast deployment and addition of new platforms, providing distributed querying, filtering, and combination of sensor data, and supporting the dynamic adaption of the system configuration during operation.

The company Voltree Power [RD-41] has developed a solution called EWAN (Early Wildfire Alert Network), to monitor forests for wildfires and provide an accurate, day-to-day fire hazard prediction. This solution consists of thousands of humidity and temperature nodes, with wireless transceivers, distributed along the forest. Although most of the technology used in this project is inexpensive and has been around for several years, the need to replace the batteries of devices placed in hard-to-reach locations has limited the use of this kind of technology.

Voltree Power solved this problem by creating a chemical energy generation mechanism, allowing the nodes to harvest metabolic energy from the trees, converting it to electricity. This “bioenergy converter” is part of a power module that does not depend on wind, light, heat gradients or mechanical movement, and does not harm the environment. Consequently, the lifetime of the nodes only depends on the lifetime of the host trees where they are placed.

Prisma Electronics [RD-62], a Greek company, has developed a solution called EWFiD (Early Warning Fire Detection). This solution uses light, temperature and humidity sensors to monitor a specific area, providing awareness of overheated areas using multisensory networks and communicating managers. The system continuously monitors the status of the selected area, collecting, translating, processing and transmitting data regarding fire/smoke detection, to a base work station (whether nearby or at a distant location).

Its main functionalities are: warning generation in case of fire/smoke detection, fire progress monitoring, decision making support and data tracking.

SITHON is a thermal imaging system, using a network of digital cameras linked to a GIS database, to provide early detection, notification and monitoring of forest fires [RD-64].

The system is designed to ensure automatic fire detection. It can be mounted on an airborne platform and can be operated within 15 to 20 minutes after the fire was first detected. SITHON has a fully automated control system to manage the frame acquisition, the radiometric image calibration and threshold setting, as well as the dynamic identification of the fire front (or hot spot) and geo-positioning within 50 to 100 metres error with the lack of any operating GPS station on the ground.

A significant reduction of fire detection time was achieved (reaching less than 2 minutes for the majority of cases), as well as an automatic calculation of the fire ignition point coordinates within less than 5 minutes in most cases.

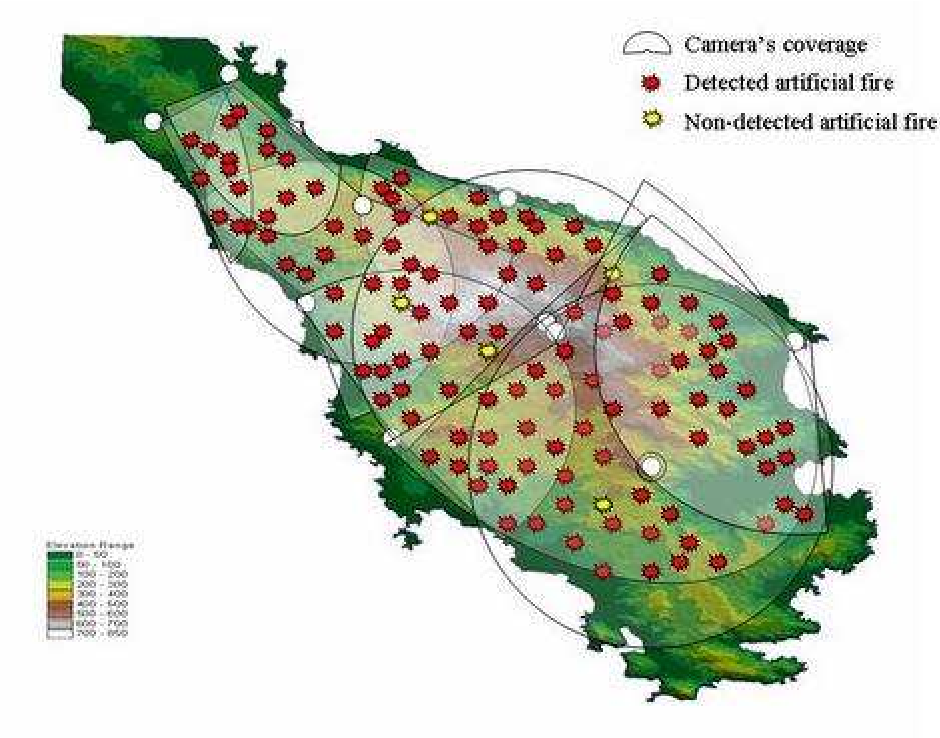

Figure 23 – The SITHON system [RM21]

PREMFIRE is a combat management and control system. An integrated Command and Control (C&C) and decision support system. PREMFIRE allows for C&C and operational combat forces on the field to share information and create awareness on the situation to the whole team.

PREMFIRE is based on three-level architecture, adapted to the different stakeholders and profiles involved in fire-fighting (Figure 24). This architecture perfectly adapts to processes, roles and activities to be execute, through very user-friendly interfaces.

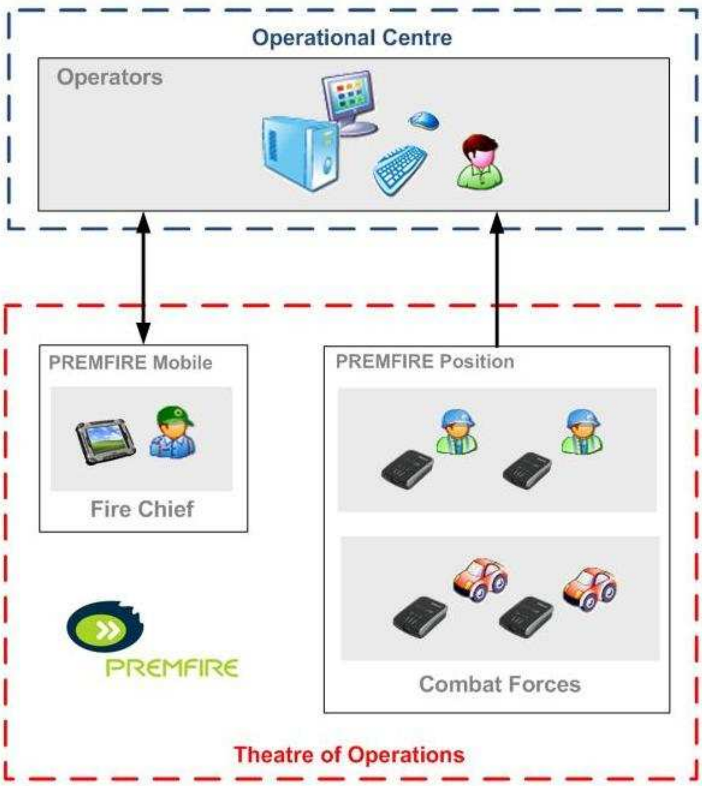

Figure 24 - PREMFIRE structure (from http://www.premfire.net/)

PREMFIRE is a framework to manage vital information that allows the teams on the field and the command and control to share information and commands as if they were sitting on the same C&C room. Mobile devices with graphical capabilities will serve as a remote monitoring screen with all of the combat information, like geographical, team distribution, attack plan, etc. (Figure 25)

Figure 25 - PREMFIRE shared information

7.3 Conclusions

Several conclusions arise from the analysis of previous research and studies regarding civil protection monitoring.

Although temperature sensors are cheap and probably the most obvious choice to use in fire detection systems, it has been seen that this type of sensors alone is not enough to quickly and accurately detect fires. Humidity and gas (CO and CO2) sensors as well as vision techniques (such as AVSS, AVHRR or MRIS, mentioned previously) can and should also be used in combination with temperature sensors, to make early fire detection much more effective.

The distance between the sensors must be carefully considered. If it is too large, a fire might only be detected when it is too late, as the sensors will only detect it when the fire is relatively close to them. If the distance is too short, we might be using many more sensors than we might need, which can render the whole system too expensive. A compromise has to be reached regarding the amount of sensors to use and the distances between them.

Several indexes have risen from decades of experience in forest fire research. This is the case of the NFDRS and the FWI. These indexes can be used as strong indicators for forest fire detection.

Most of the current operational challenges regarding civil protection monitoring with WSN are related to power autonomy issues, data transmission, loss of nodes due to fire and fire detection accuracy (including the detection and tracking of the fire front). Some of these challenges are common to all scenarios.

The solutions addressing civil protection monitoring are summarized in Table 8:

Solution	Technical Solution	Strengths	Weaknesses
In-Situ Forest Temperature Measurement Network	- Sensors equipped with thermometers and GPS devices (placed on trees, at least 3.5m above ground), to monitor temperature in a forest	- Self-organized network - Real-time measurements - Predict the evolution of fires	- Sensors might be destroyed by fire - Temperature is the only monitored parameter - Some lack of accuracy detecting fires
SCIER project	- Sensor network composed of temperature sensors, using a likelihood algorithm to fuse sensory information - Network deployed at the “urban-rural-interface” (URI)	- Fusing techniques enhance performance - Self-organizing, self-healing and re-configurable	- Solution developed specifically for “urban-rural-interface” areas
Sliding Window Skylines Approach For Early Forest Fire Detection	- Data suppression technique using sliding window “skylines” - Only sensor readings above the “skyline” are sent to sink nodes	- Reduced number of communications - Reduced overall data transmitted - Energy efficient operation	- Not a complete solution for forest fire detection
D-FLER – A Distributed Fuzzy Logic Engine For Rule-based Wireless Sensor Networks	- Wireless sensor network with a distributed fuzzy inference engine for event detection - Combines sensor inputs with neighbourhood observations - Uses temperature and smoke sensors	- Improves overall detection time and reliability - Robust against sensor errors - Effective and feasible to run on resource-constrained nodes	- Not a complete solution for forest fire monitoring
EWAN, Early Wildfire Alert Network, Voltree Power	- Thousands of humidity and temperature nodes with wireless transceivers distributed along the forest	- Highly automated - Long-lived - Maintenance-free - Cheap technology	- As a commercial product, little information is available regarding the technology behind it, which makes it hard to understand its limitations

Solution	Technical Solution	Strengths	Weaknesses
EWFiD – Early Warning Fire Detection, Prisma Electronics	- Light, temperature and humidity sensors to monitor a specific area - Uses multisensory networks and communicating managers	- Independent sensor operation (robust against sensor errors)	- Not known, as there is not much information available regarding this product
SITHON System	- Fully digital thermal imaging system, integrating INS/GPS and a digital camera - Designed to provide timely positioned and projected thermal images and video data streams rapidly integrated in the GIS operated by Crisis Control Centres	- Provides real-time monitoring	- Depends on airborne platforms (airplanes) - Issues related to the establishment of air-ground communication links
PREMFIRE, Critical Software	- Integrated C&C and decision support system for prevention and combat of forest fires - Allows C&C and operational combat forces on the field to share information with the whole team	- Distributed C&C tool, supported by OpenSource tools - Track resources such as the positions of fire-fighters, vehicles and other, in real-time - Integrates several communication standards, such as HF Radio, TETRA Radio, or Satellite	- Slightly different scope than the EMMON project (does not deal with the monitoring of physical parameters)

Table 8 – Civil protection technologic Solutions Summary table

8. Studies Performed on Event Propagation Simulation

This section presents results of studies related with event propagation simulation.

8.1 Operational Studies

Event propagation is extensively researched subject in the field of complexity science. A well-known butterfly effect was introduced by Edward Lorenz in his talk entitled “Predictability: does the flap of a butterfly's wings in Brazil set off a tornado in Texas?” This talk is published in his book “The Essence of Chaos” ([RD-87]). Lorenz worked on weather prediction at Massachusetts Institute of technology where he created one of the first event propagation models, looking into how air pressure changes propagate through the atmosphere.

Event propagation in complexity science is simulated using cellular automata machines which are described extensively by Stephen Wolfram in his book “A New Kind of Science” ([RD-88]). The best known event propagation model that is based on cellular automata is Forest Fire Model (FFM). This model is described by Miller and Page in “Complex Adaptive Systems” ([RD-89]) and a working model of Forest Fire using cellular automata machines was created by Jankovic in his course on the Deep Simplicity of Complex Systems ([RD-90]).

The key to event propagation model in the work by Jankovic ([RD-90]) is that the system consists of many interacting components (up to 250000) and it evolves in time. Each component represents a site which can be in one of the three following states: a tree, a burning tree, or an empty site. Trees will grow certain probability on empty sites and lightning events will occur randomly and with much lower probability. When a tree is struck by lightning it will burn and it will pass the fire on to the neighbouring trees. When the model starts the density of trees is very low and fire caused by lightning does not propagate through the system. However as the system evolves and is the density of the forest increases, each burning tree will have more neighbours and the fire events will propagate more easily through the system. When a system reaches a critical state with density of trees approximately equal to 60% large fire fronts will occur in the system and sweep through the system leaving the Forest completely burnt. This cycle will then repeats as new trees grow with certain probability and new lightning events occur with a lot lower probability.

8.1.1 Fire Propagation Models and Cellular Automata

In [RD-37] models for forest fire behaviours are presented. Trying to model exactly and mathematically the fire behaviour using conservation of mass, momentum, and energy is very difficult. Instead, the book presents an approximate semi-empirical fire front propagation model ([RD-40]).

Another simpler model is presented in [RD-43]. This modelling takes into account the effects of wind and slope. The article states that this type of modelling is the simplest generalization of the empirical ones.

Several pieces of research work focus on cellular automata as a solution to model propagation in general.

Fonseca et al. [RD-69] model natural disasters using smart agent and cellular automata techniques. Although they do not specifically focus on fire or pollution propagation, their models are created based on continuous data collection of the system under observation and the critical parameters, which shall be considered to forecast the future system state.

Knight and Coleman [RD-70] developed a model based on the Huygens–Fresnel principle, arguing that every point in the front of the fire is a new starting point of the fire. Each point advances as a small eclipse with its own characteristics (landscape slope, temperature, humidity, wind speed and direction, flammability of the undergrowth, etc.).

Saidi and Missumi [RD-71] developed a model that describes every point in the perimeter of the fire assuming knowledge of wind characteristics, undergrowth flammability. A WSN system forecasts the direction of the fire by utilizing GIS information.

A very simple model using only wind characteristics for forecasting the perimeter and the speed of the fire is given by McDermott and Rehm in [RD-72].

Muzy et al. [RD-73] describe two modelling methods based on Discrete Event System Specifications (DEVS) and Cell-DEVS and provide simulation results with well-controlled lab experiments.

Martinez-de Dios et al. [RD-74] provide a 3D representation of the fire perimeter based on captured videos from cameras and information from sensors, thus improving the knowledge of fire propagation characteristics.

Innocenti et al. [RD-77] developed a computational model called Active-DEVS for the simulation of forest propagation. The model is based on cellular automata and DEVS.

Killough [RD-78] developed a model based on semi-empirical cellular automata for monitoring wildfire. A geosynchronous space platform is used together with an ellipsis based model.

Casanova et al. [RD-79] investigated the ability of MSG/SEVIRI sensors to detect the fire perimeter by calculating the density and the temperature focusing at the differentiation between true events and false alarms.

Some analytical results using numerical analysis of an elliptical growth model of forest fire fronts is provided by Richards [RD-80].

Goncalves and Diogo [RD-81] combine GIS and cellular automata methods for forest fire simulation. The simulation takes place by using a software package called FIREGIS. It compares the results of the GIS with cellular automata with classic models (Rothermel).

A new approach for the derivation of an elliptical model for steady-state forest fire spread in time based on classical envelope theory is described in [RD-82]. The derivation of this model known in the literature is based on the introduction of a special transform of the co-ordinate system, which allows the use of geometrical properties of points lying on common tangent lines of two circles. However, the use of this transform means that there is a need to apply some specific assumptions onto the model. The proposed new procedure allows us to derive the model without the use of this transform. The new approach enables to better explain the internal coherence of the studied problem, assumptions and limitations of the model, as well as to suggest its further generalizations.

8.1.2 Forest Fire Simulators

The forecasting of wild fire propagation for different scenarios (different parameter values) is a very valuable tool in order to estimate the risk over time for particular forest areas. Several of tools have been developed for this purpose. We evaluate some of them in this section.

FARSITE (Fire Area Simulator) [RD-83] is a two-dimensional program for spatially and temporally simulating the spread and behaviour of fires under heterogeneous conditions.

FARSITE incorporates existing fire behaviour models of surface fire spread, crown fire spread, spotting, point source fire acceleration, and fuel moisture with spatial information on fuels, weather, and topography. FARSITE is an important simulator since it provides several features: it is a stable tool and it is one of the most popular among the researchers. Other tools have been also developed that use outputs of FARSITE (e.g. FlamMap). FARSITE users must have the support of a geographic information system (GIS) to use FARSITE because it requires spatial landscape information to run. FARSITE can simulate both air and ground suppression actions.

FlamMap [RD-84] is a spatial fire behaviour mapping and analysis program that requires landscape, fuel moisture and weather data. Unlike FARSITE, FlamMap makes independent fire behaviour calculations for each location of the raster landscape (e.g., about fire line intensity or flame length). There is no predictor of fire movement across the landscape (weather and wind conditions are constant). FlamMap output augments in landscape comparisons and to identifying hazardous fuel and topographic combinations, thus aiding in prioritization and assessment.

FireFamily Plus (FFP) [RD-85] is a fire climatology and occurrence program that combines the functionality of the PCFIRDAT, PCSEASON, FIRES, and CLIMATOLOGY programs into a single package with a graphical user interface. It allows the user to summarize and analyze weather observations, associate weather with local fire occurrence data, and compute fire danger indices.

RERAP - Rare Event Risk Assessment Process (http://www.fs.fed.us/fire/rerap/indexz.htm) is a program used to estimate the risk that a fire will reach a particular point of concern before a fire-ending event occurs. RERAP consists of three modules: Term, Spread, and Risk; and it incorporates weather, fuels, topography, and Rothermel's surface spread and crown fire models with two waiting-time distributions: i) a distribution for the fire-ending event and ii) a distribution for "critical" spread events. The goal is to produce probabilities along a straight-line transect. A fire-ending or fire-stopping weather event occurs when sufficient moisture results in the termination of the fire spread. A season-ending weather event consists of a fire-ending event followed by a persistent combination of environmental factors that end the fire season.

The BehavePlus [RD-86] fire modelling system is a collection of models that describe fire and the fire environment. It produces tables and graphs which can be used for a multitude of fire management applications. BehavePlus is the successor to the BEHAVE fire behaviour prediction and fuel modelling system. Many of the fire models in BehavePlus are the same as those in the FARSITE fire area simulator and the FlamMap fire behaviour mapping and analysis system. The primary modelling capabilities of BehavePlus include surface fire spread and intensity, safety zone size, size of a point source fire, fire containment, spotting distance, crown scorch height, tree mortality, probability of ignition from fire brands or from lightning, transition from surface to crown fire and crown fire spread.

Some additional libraries have been developed for making the development of fire simulators easier (and can be found at http://www.fire.org/). fireLib is a C function library for predicting wild land fire behaviour using the BEHAVE algorithms. fireLib is for programmers who need a highly optimized application programming interface for developing fire behaviour growth simulators. The Fire Behavior Software Development Kit (FBSDK) is a collection of C++ functions and classes implementing the algorithms used in BEHAVE, BehavePlus, FARSITE, and FlamMap. FOFEM (a First Order Fire Effects Model) is a tool for predicting tree mortality, fuel consumption, smoke production, and soil heating caused by prescribed fire or wildfire. NEXUS is a spreadsheet linking surface and crown fire prediction models. NEXUS is useful for evaluating alternative treatments for reducing crown fire risk and assessing the potential for crown fire activity.

8.2 Technological Research and Solutions

Apart from the academic studies presented on the previous section, which try to address mathematical or empirical models that might be used as a solution to forecast specific events (such as the fire front), some technological solutions have also been developed.

Caballero in [RD-75] focuses on algorithms for taking down fires by the full utilization of various means for doing so, in the FOMFIS system. He uses methods such as semi-automated dispatching for forecasting the risk of fire.

Calle et al. [RD-76] use a WSN to detect forest fire. Using some thresholds on some critical relevant parameters, it provides decisions on whether a fire occurred or not. The system uses MSG/SEVIRI and MODIS sensors.

8.3 Conclusions

Fire front propagation prediction is very difficult to achieve with a good degree of certainty. Furthermore, by the existing studies ([RD-37], [RD-39] and [RD-40]), it might be deduced that a solution that would provide such information would have a great effort of parameterization. The model would have to “know” the forest characteristics for each area. Land characteristics might be known from previous cartography, weather characteristics might be known from real-time monitoring, but tree sizes, density, structure and species would have to be provided and updated when forest characteristics had changed considerable. Nevertheless, many studies have been conducted on this field, and there are a few commercial solutions that provide such propagation simulation. Some libraries have even been developed, to help developers build their own simulators easier, providing them a framework to work on.