NATO Science for Peace and Security Series - C:
Environmental Security

Decision Support for Natural Disasters and Intentional Threats to Water Security

Edited by
Tissa H. Illangasekare
Katarina Mahutova
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Springer

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Decision Support for Natural Disasters and Intentional Threats to Water Security

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Series C: Environmental Security

Decision Support for Natural Disasters and Intentional Threats to Water Security

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DEDICATION

These proceedings are dedicated to Prof. Dr. Dragutin Geres (1942–2008) of Hrvatske vode (Croatian Waters), an international expert and leader in water resources for many years, and a gracious host to all international scientists who participated in this Workshop.

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PREFACE

The NATO Advanced Research Workshop, "Decision Support for Natural Disasters and Intentional Threats to Water Security" was the result of close collaboration between environmental, security, water resource, and health officials in the United States and Croatia. The premise of the Workshop is that multiple, disparate threats to water security exist, and that shared decision support structures provide effective means for avoiding and responding to potential or actual situations.

The Workshop was co-directed by Professors Tissa Illangasekare of the Colorado School of Mines, and Dragutin Geres of Hrvatske vode.

The Workshop was organized into a series of case studies, presentation of management tools, or a combination of the two. Presentations were further organized as to (1) Natural Occurrences, (2) Anthropogenic Causes, and (3) Decision Support Tools.

Delegates from eleven countries assembled to explore these topics at the Hotel Dubrovnik President in Dubrovnik from April 22–25, 2007. A total of thirty delegates from NATO, Partner, Mediterranean Dialog, or other countries were in attendance. The final program included technical sessions using a presentation and dialog format, a field trip, and networking sessions. There were twenty five technical presentations supported by seventeen formal papers (many updated in late-2008 and 2009), and these form the basis for these proceedings.

ACKNOWLEDGEMENTS

The co-directors and organizers of this Advanced Research Workshop acknowledge the NATO Science Programme for major financial support and for providing detailed guidance on how best to organize and execute a meeting of this nature.

The NATO Science Programme also provided financial support for the publication of these proceedings, and for this the Co-directors and editors are grateful.

Substantial additional contributions were provided by Prof. Dr. Dragutin Geres and Ljudevit Tropan of the Water Management Institute, Hrvatske Vode, Dr. Aleksandra Fucic of the Institute for Medical Research and Occupational Health (IMI), and the US Environmental Protection Agency (USEPA). Drs. Geres, Tropan, and Fucic provided guidance on the science to be addressed, the importance of water security to health, and assisted with all host country logistics. They identified international scientist invitees and created a collegial environment during the Workshop that was conducive to thoughtful deliberation and inquiry.

John Barich of the USEPA was Workshop Manager. The USEPA organized the overall program, prepared pre-workshop materials, conducted the publicity program, and managed all activities throughout the four days of the Workshop. Colorado School of Mine’s Offices of Research Administration and Purchasing managed the NATO grant funds.

INTRODUCTION

Water resources are recognized as essential to security: a sufficient quantity of water at acceptable quality is needed to provide for health, welfare, ecosystems, and security. The extremes of too much water, as with hurricanes, tsunamis or floods, or too little, as with droughts or over-exploitation, present water security concerns. Scientists from the United States and Croatia recognized that water security is an important issue of common concern and that by sharing research and experience between themselves and with others in Europe, decision support related to water security would be advanced.

An Advanced Research Workshop (ARW) sponsored by the NATO Science Programme was identified by the organizers as a format for exploration of these important issues. Application was made, sponsorship secured, and an ARW was convened in April of 2007.

The goal of this workshop was to explore the relationship of decision support and environmental informatics as complementary tools to improve water security. Objectives included:

- Evaluation of "lessons learned" from recent natural disasters (hurricanes, tsunami, etc.)
- Delineation of how the use of state-of-science tools improves water security in relation to natural disasters and intentional threats
- Identification of research questions in the context of the workshop goal
- Cross-fertilization of ideas across disciplines and between countries, and to share experience
- Future collaborations between participants

The four-day workshop was organized around case studies that identified critical topics and explored how the technology and public policy fields are combined in the effective management of water. Topics that were covered include:

- Security concerns within the water sector
- Threats to water systems: demand, supply, chemical, biological, and radiological stressors
- Environmental health
- Comparative risk assessment based on population, water resources, and hydrogeologic settings
- Providing for infrastructure improvements while enhancing water security (multiple use)
- Decision support tools
- Environmental informatics in the water sector: security and environmental right-to-know
- Transfer of information on the combination of target technologies and public policy tools in water management

The Workshop included a series of lectures that were case studies, presentation of management tools, or a combination of the two. After the workshop, written papers were requested from the participants. Papers were reviewed and revisions were requested. The selected papers were assembled by the editors into these proceedings. The proceedings are divided into three parts that reflect the general subject matter addressed.

Part I, "Natural Stressors and Catastrophic Events," includes papers on catastrophic natural events like the 2004 South Asian tsunami and hurricane Katrina, and chronic threats of floods. Each had significant short-term impacts on the water supply to large numbers of people in affected communities. Both the natural sources of water supply and storage and distribution infrastructure were drastically affected.

In the *Illangasekare* paper, the consequences to water resources and water supplies in Sri Lanka following the tsunami generated by the December 26, 2004 magnitude 9.3 earthquake off the south coast of Sumatra is presented.

The tsunami caused extensive contamination of coastal aquifers across southern Asia and may have long-term implications on the availability of water to a large number of people in coastal communities. For example, it was estimated that over 40,000 drinking water wells in Sri Lanka were either destroyed or contaminated. Later estimates were close to 100,000.

A group of scientists from the USA and Denmark visited the affected areas in Sri Lanka for a first hand assessment of damage. They present the effects of the tsunami and the observations that elucidate the science and technology needs to support strategies and decision tools for recovery of water quality. The lessons learned and the knowledge generated will be of use in other coastal aquifers in Asia affected by the tsunami.

The *Reible* paper discusses the flooding of New Orleans by Hurricane Katrina. He emphasizes the lessons for the environmental and engineering communities and raises public policy questions about risk management. A summary of the primary engineering failures that led to the flooding and the consequences of those failures on the city, its people and the environment are examined.

Workshop participant *Kreizenbeck* provided a presentation on the US Environmental Protection Agency (USEPA) response to the hurricanes Katrina and Rita disasters. The USEPA utilizes a general decision support structure (DSS) to respond to a wide variety of environmental crises. This DSS enables the USEPA to respond to emergencies as diverse as these hurricanes, the Exxon Valdez oil spill, anthrax mail attacks, the World Trade Center cleanup, and the Space Shuttle Challenger disaster. In every case, preparation, execution, and adaptation (lessons learned) are keys to current and future success.

The overall structure is documented in national contingency and response plans. Preparation includes incident and unified command frameworks, data and information systems, work force capability and capacity through development of primary and backup teams, and training and readiness exercises. For hurricanes Katrina and Rita, the USEPA was directed pursuant to the national contingency plan to execute a series of missions including drinking water and wastewater assessments, collection and recovery of solid waste and hazardous materials, response to hazardous materials and oil spills, and monitoring water and other media. Lessons learned included the need to pre-deploy more resources, enlarge and strengthen the Response Support Corps, enhance preparedness by role-specific training, and by enhancing data and information applications, management and flow.

Participant *Suk* presented information on the “Environmental Health Sciences Data Resource Portal,” a new environmental health tool that was used in the public health response to Hurricane Katrina.

New technologies in information systems, data federation, grid systems, and spatial analytics hold great promise to enable integrated science teamwork while helping to disentangle genetic, environmental and other factors that contribute to the complex etiology of common human diseases. Such technology-driven translation of research provides effective means of knowledge and data sharing among scientists as well as rapid and efficient approaches for sorting through and analyzing large datasets. This supports both the scientific and policy processes, and accelerates the rate of knowledge production and discovery.

Of the series of devastating hurricanes that caused catastrophic damage to the Gulf Coast of the United States during 2005, Hurricane Katrina was especially severe. The human and environmental health impacts on New Orleans and other Gulf Coast communities will be felt for decades to come. To link and integrate data from basic and applied research and to support emergency preparedness, the US National Institute of Environmental Health Sciences (NIEHS) established the Data Resource Portal. It combines advances in Geographic Information Systems, data integration and visualization technologies through new forms of grid-based cyberinfrastructure. It provides decision-makers with the data, information and the tools they need to: (1) monitor the human and environmental health impacts of disasters, (2) assess and reduce human exposures to contaminants, and (3) develop science-based remediation, rebuilding, and repopulation strategies.

The scale and complexity of the problems presented by Katrina made it evident that no stakeholder alone could tackle them and that there is a need for greater collaboration. The NIEHS Portal provides a collaboration-enabling, information-laden base necessary to respond to environmental health concerns. It advances integrative multidisciplinary research. The NIEHS Portal is a model poised to serve as an international resource to track environmental hazards following natural and man-made disasters, focus medical and environmental response and recovery resources in areas of greatest need, and advance environmental health sciences research into the modern scientific and computing era.

The *Gramatikov* paper discusses water management and flood protection practices in Bulgaria. It illustrates that threats to water security occur at all scales.

Part I concludes with the *Hyndman* paper which discusses the potential impacts of climate change on natural hazards and water resources. Projections from the International Panel on Climate Change include alterations to the distribution of precipitation, the rate and timing of snow and glacial ice melting, sea level rises, and warming of lakes and rivers. These projected alterations pose significant risks to the quantity and quality of water resources and to natural hazard events in some regions. Rising sea levels are expected to affect millions of people through flooding in low lying regions. Generally, more precipitation is expected in high latitude regions while less is expected in most subtropical regions. Regions that experience less precipitation or less recharge from mountain snow and ice melting will have additional pressure on water resources, while those that experience more may have higher risk of floods, landslides, and rockslides.

Evidence also suggests that the warming of ocean waters will increase the intensity of hurricanes. This increases the risk of flooding and wind damage in coastal areas subject to such storms. Scientific research is beginning to address the complex interactions between climate change and the resulting impacts on water resources.

Part II, "Anthropogenic Stressors" includes papers that discuss a variety of anthropogenic threats to water security. These can be intentional as in a terrorist threat or unintended as in an unwanted consequence of economic or cultural activity.

The *Lukac* paper discusses flood hazards along the Slovak–Austrian section of the Morava River. Flood threats are both ameliorated and exacerbated by the utilization of dikes. A case study demonstrates how modern software simulation tools can improve prevention and response to floods. *Gurzau* discusses how anthropogenic sources of microbiological or chemical contamination threaten public drinking water supplies. Epidemic or endemic waterborne diseases are managed through proper source control and treatment, and that the public is a necessary and valued partner in improving water quality.

The *Galatchi* paper discusses a variety of anthropogenic threats to the Danube River/Black Sea. The Danube is subject to increasing pressure that affects drinking water, irrigation, industry, fishing, tourism, power generation, wastewater disposal, and navigation. These intensive uses have created severe problems of water quality and quantity, and reduction of biodiversity in the basin. The key activities required to support action for water security in the large international basin of the Danube River includes: (1) enhancing regional and international cooperation, (2) applying an integrated river basin approach, (3) mobilizing national financial and human resources, and (4) obtaining support from international organizations and financial institutions.

Lánczos identifies "industrial sites" defined as industrial, agricultural, military, waste deposits, and sites where dangerous chemicals are stored, produced, or used as threats to water security in Slovakia. A methodology developed in cooperation with the Danish Environmental Protection Agency identified and prioritized sites in relation to groundwater vulnerability and water management importance of the aquifer. The *Tserunyan* paper discusses the additional water security burdens of Armenia, the most upstream country in the Kura River Basin. Any pollution, hydrological extreme event, incidental or intentional chemical spill, mining, and ore-dressing discharges can become threats to water security. Development and putting into practice feasible early/emergency warning systems on the transboundary waters in Armenia will ensure environmental security and mitigate environmental pressures in the region.

Part III, “Decision Support Tools,” includes papers describing a variety of tools that are useful in addressing security threats from both natural and anthropogenic sources.

Participant *Herrmann* provided a presentation on protecting water infrastructure in the United States, setting priorities, conducting research, and delivering results.

Following the terrorist attacks against the United States in 2001, the US Environmental Protection Agency initiated a research and technical support program to protect water infrastructure. An Action Plan was developed through multiple stakeholder meetings with water utilities, public health officials, emergency and follow-up responders, and other federal agencies in late 2002 through early 2003. The Action Plan was reviewed by the National Academy of Sciences in May and July of 2003 and was fully implemented in October 2003. The Action Plan was informed by a thorough analysis of the threats to, and vulnerabilities associated with both drinking water and wastewater systems.

A review of the priority setting process and the results of the research program to date was presented. A discussion on the multiple benefits of the program was emphasized. Multiple benefits are those efforts under the research program that contribute to the water sector beyond just protection from terrorist threats and attacks. Multiple benefits may involve increased preparedness, response, and recovery from natural disasters. Multiple benefits may also involve the increased reliability of water systems in meeting everyday water quality requirements and customers’ routine needs for safe and clean water.A variety of potential threats to water systems are addressed. These include cyber attacks, physical attacks, and chemical, biological, and radiological contamination. Emphasis is placed on the research that is contributing to the water sector’s preparedness for, response to, and recovery from such threats or potential attacks. Examples of products that have been developed under the Action Plan were presented.

The *Geres* paper presents an overview of water management in Croatia, with an emphasis on what is at risk. It emphasizes the great breadth of responsibility for water managers at the national level and the importance of decision support structures to support their mission. *Ghazaryan* discusses the problems associated with transboundary water resource management in the South Caucasus region. Single-country oriented management of water resources does not solve the problems of transboundary water resources. Only integrated planning and management of water resources at the basin level can address the environmental and social-economic development needs in the region.

The *Hřebíček* paper discusses geoinformation support for water disaster situations. Cartographic visualization is an important feature of geoinformation support that plays an important role in crisis management. Visualization is not an isolated element of the information transfer process; it depends on the status of source databases, decision support models, and the requirements of the user of cartographic visualization tools in geographic information systems. *Banovec* and *Steinman* present information on the use of decision support systems (DSS) to implement the EU Drinking Water Directive. As it pertains to critical infrastructure, the DSS assists with the identification of infrastructure, risk analysis, counter-measures, and procedures implemented within the individual water system, of which there are more than 1,000 in the Republic of Slovenia.

Malik describes groundwater vulnerability assessments based on physical principles. Whereas groundwater vulnerability methodologies first developed in the 1970s were based on hydrogeological factors and subjective ratings, more recent assessments methodologies are based on contaminant spreading principles. These were applied to the Tisovec karst hydrogeological structure, Slovenske Rudohorie Mountains in Slovakia. The *Bobylev* paper addresses multiple criteria decision making in environmental security situations. Environmental security is defined as a subset of human security, and water is one of the key assets that provide human security. Water security can be jeopardized by many factors, including those caused by natural disasters. Multiple criteria decision making offers tools that can aggregate and prioritize environmental threats.

The *Pavlovič* paper proposes service-oriented decision support governance for water security applications. Service-oriented architecture evolved to deal with the needs of decision makers to have simple access to software applications, and for different software applications and their supporting databases to communicate with each other. Water security decision-makers are hindered when they must deal with different and perhaps incompatible decision support tools; instead they benefit if they can be provided with a single user-friendly portal to access all of the decision support structures and databases that are relevant to support a decision. The design, execution and maintenance of the portal, or enterprise portal, constitute the first step to service-oriented architecture, and require the involvement of computer specialists.

Kaplan presents ecological risk assessment using GIS-based decision support tools as an element of water security. Threats to the Gediz Delta ecosystem in western Turkey include urban encroachment, rural development, industry, wastewater treatment plant discharges, salt production, and agriculture. The GIS-based decision support tool which utilizes empirical “stressor-effect” summaries provides decision makers with the ability to include ecological risk assessment with traditional socio-economic based urban planning tools.

PART I:

NATURAL STRESSORS AND CATASTROPHIC EVENTS

IMPACTS OF THE 2004 TSUNAMI AND SUBSEQUENT WATER RESTORATIONS ACTIONS IN SRI LANKA

Tissa Illangasekare[1], Jayantha Obeysekera[2], David Hyndman[3], Lasantha Perera[4], Meththika Vithanage[5], Ananda Gunatilaka[6]

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Abstract: On December 26 2004, a magnitude 9.3 earthquake off the south coast of Sumatra generated tsunami waves that left over 280,000 people dead or missing in Asia and Africa. Hundreds of thousands of homes were destroyed resulting in a humanitarian crisis in the hardest hit countries. Lack of preparation to this unprecedented catastrophic event delayed response to meet immediate needs to provide shelter, food and water to millions who were displaced. In addition to widespread destruction of life and property, the tsunami also caused extensive contamination of coastal aquifers across southern Asia that may have long-term implications on the availability of water to a large number of people in coastal communities who rely on groundwater as the primary source of potable water. Seawater filled domestic open dug wells and also entered the aquifers via direct infiltration during the first flooding waves and later as ponded seawater infiltrated through the permeable sands that are typical of coastal aquifers. In Sri Lanka alone, it was estimated that over 40,000 drinking water wells were either destroyed or contaminated. Data collected immediately after the tsunami showed drastic rise in the salinity. Lack of information and appropriate knowledge produced actions with unexpected and undesirable results. Following the standard guidelines available at the time for decontamination, wells were pumped and bleach was applied as a disinfectant. This widespread pumping of wells by both governmental and non-governmental organizations for recovery of

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water quality was effective in some areas, but overpumping led to upconing of the saltwater interface and rising salinity and in the collapse of walls making the wells permanently unusable. The salination of the soil resulted in major damage to vegetation and lack of drainage made the coastal rice fields un-cultivatable for many years to come. A group of scientists from USA and Denmark visited the affected areas for the first hand assessment of the damage. The team visited damaged areas and met with the affected people, water managers, planners and researchers. A number of information exchange workshops were conducted. Some of the team members visited the field sites several times during the last 2 years and continued to collaborate with the local scientists who were conducting research and monitoring the wells. Groundwater-monitoring data at a selected set of field sites suggests that the salinity is still persisting at some locations. The expectation was that that the salinity should decrease with recharge from few seasonal rains associated with monsoons. Based on the findings and information gathered during the visits and the subsequent observations, the science and research needs to explain why the salinity is persisting in some locations have been identified. In this paper, we present the effects of the tsunami and the observations to evaluate science and technology needs to develop strategies and decision tools for recovery of water quality and management of coastal aquifers in Sri Lanka for long-term sustainability. The lessons learned and the knowledge generated will be of use in other coastal aquifers in Asia affected by the tsunami and decision making to recover the water quality in other coastal regions with potential threats of tsunamis.

Keywords: tsunami; Sri Lanka; ground water contamination; water restoration

1. INTRODUCTION

On December 26 2004, a 9.3M_w earthquake (United States Geological Survey Earthquake Information Network) off the south coast of Sumatra generated tsunami waves that left over 230,000 people dead or missing from Asia to Africa. Hundreds of thousands of homes were destroyed resulting in a humanitarian crisis in the hardest hit countries. Lack of preparation for this unprecedented catastrophic event delayed responses that could have met immediate needs to provide shelter, food and water to the nearly 1.7 million people who were displaced.

In addition to widespread loss of life and property, the tsunami also caused extensive contamination of coastal aquifers across southern Asia that may have long-term implications for water availability and security to a large number of people in coastal communities that rely on groundwater as the primary source of potable water. Seawater filled domestic open dug wells and also entered the aquifers via direct infiltration during the first flooding waves and later as ponded seawater infiltrated through the permeable sands that are typical of coastal aquifers. In Sri Lanka alone, it was estimated that over 40,000 drinking water wells were either destroyed or contaminated. Data collected immediately after the tsunami showed drastic increases in salinity.

Lack of information and appropriate knowledge produced actions with unexpected and undesirable results. Following the standard guidelines available at the time for decontamination, wells were pumped and bleach was applied as a disinfectant. This widespread pumping of wells by both governmental and non-governmental organizations for recovery of water quality was effective in some areas, but over-pumping led to up-coning of the saltwater interface and rising salinity. In some cases the pumping caused unlined well walls to collapse, making them permanently unusable. The salinization of the soil resulted in major damage to vegetation and lack of drainage will make the coastal rice fields un-cultivatable for years to come.

A group of scientists from the USA and Denmark visited the affected areas from February through September 2005 for the first hand assessment of the damage. The team visited damaged areas and met with the affected people, water managers, planners and researchers. A number of information exchange workshops were conducted. Some of the team members visited the field sites several times during the last 2 years and continued to collaborate with the local scientists who were conducting research and monitoring the wells. Groundwater-monitoring data at a selected set of field sites suggests that the salinity is still persisting at some locations. The expectation was that that the salinity should decrease with recharge from normal seasonal rains associated with monsoons. Based on the findings and information gathered during the visits and the subsequent observations, the science and research needs to explain why the salinity is persisting in some locations have been identified.

In this paper, we present the effects of the tsunami and the observations to evaluate science and technology needs to develop strategies and decision tools for recovery of water quality and management of coastal aquifers in Sri Lanka for long-term sustainability. The lessons learned and the knowledge generated will be of use in other coastal aquifers in Asia affected by the tsunami and decision making to recover the water quality in other coastal regions with potential threats of tsunamis.

The team of visiting water resource scientists and engineers surveyed the impacts of the tsunami on the coastal groundwater resources of Sri Lanka.

Sri Lanka was chosen for study as it was one of the hardest impacted by the tsunami. Further, the coastal aquifers found in Sri Lanka had some similarities to those found in parts of Indonesia, Thailand and India. The objectives of the survey team were to: (1) investigate the impacts of the tsunami on coastal groundwater resources and review well cleaning methods and their impacts, (2) develop a conceptual understanding of the seawater mixing phenomenon in coastal aquifers after the tsunami event, (3) investigate the medium and long-term impacts of the tsunami on coastal groundwater resources, (4) develop a joint program to study the regional aquifer hydrology and hydrogeology of Sri Lanka, and (5) to transfer knowledge about coastal aquifer vulnerability to other south Asian nations.

We begin with a brief review of the tsunami and its impacts in Sri Lanka along with a brief overview of Sri Lankan groundwater in the tsunami-impacted areas. We then discuss the major processes that occurred in the aquifers with an emphasis on salinity changes caused by the tsunami. We conclude with a preliminary estimate of the recovery and long-term sustainability of coastal aquifers in densely populated countries such as Sri Lanka.

2. SUMATRA TSUNAMI AND EFFECTS ON COASTAL AQUIFERS

The tsunami first impacted Sri Lanka along its eastern coastline and during a period of about 90 min, swept along the southern and southwestern and northern coasts. Inundation distances varied significantly due to the angle of wave incidence and the local shore and coast configurations, but in places wells up to 1.5 km inland were flooded (Villholth et al., 2005). The height of the tsunami waves in Sri Lanka ranged from 3 to 14 m, with run-up heights up to ~15 m (Figure 1) (Liu et al., 2005; Gunatilaka, 2009).

Although Sri Lanka is approximately 1,600 km from the epicenter, it still suffered catastrophic losses, including over 35,000 people known dead or missing. According to government sensors, more than 193,000 homes were destroyed, partially or severely damaged along the coast of Sri Lanka and ~160,000 families displaced. Over 400,000 jobs were lost as a result of the devastation (ADB et al., 2005). The magnitude of the tragedy continued to dominate the social and political structure of the region at the time this paper was written.

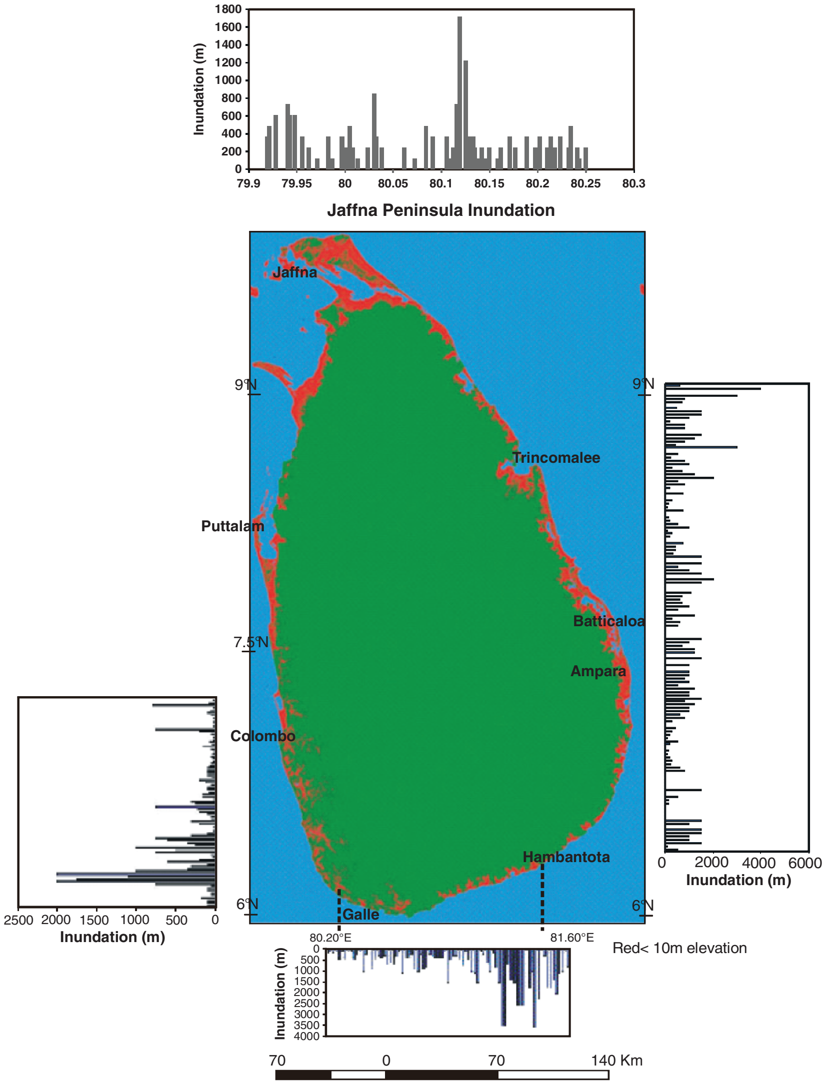

Figure 1. Estimated inundation distances (bar charts) in meters during the December 2004 tsunami. The areas shaded in red are less than 10 m above sea level

In most coastal areas of Sri Lanka, the availability of potable drinking water quickly became a critical factor for relief efforts, especially due to the potential for spread of waterborne diseases from contaminated water supplies.

Treated and piped surface and groundwater managed by the National Water Supply and Drainage Board (NWSDB) supplied the largest coastal urban communities of Sri Lanka. The primary damage to the treated water supply involved breaks in pipelines, which were completely destroyed at several river and estuary crossings. Additional leaks were caused when the force of tsunami waves sheared off the water connections to individual dwellings. Repairs to the distribution system started soon after the tsunami event, and as of September 2005, piped water service had been restored to most previously served areas and plans were underway to expand the distribution system to accommodate some impacted coastal areas.

While the NWSDB served about 30% of the country's general population via 287 water supply systems[1] using tube wells and surface water systems, many of the coastal areas rely on individual or community wells for potable water. Typically, these are large diameter (1–2 m) wells that are 3–8 m deep and are designed to tap the shallow parts of the fresh groundwater lens found in most of the coastal aquifers. These shallow wells are dug manually and/or with explosives and excavators, and are called "open dug wells" in this communication. The density of open dug wells in Sri Lankan coastal villages is very high in heavily populated or cultivated areas with approximately 90–125 wells/km^2 (Nadarajah, 2001; Villholth et al., 2006). At the coastal town of Maruthumunai on the eastern coast, the visiting team, noted the devastation of the tsunami and also the high density of domestic open dug wells (concrete cylinders and open excavations) typically used along the coast of Sri Lanka (Figure 2). Generally, each of the wells may have been used by several individual households that were totally destroyed by the tsunami wave. The local villagers reported that the water level reached close to the top of the coconut palm trees. Over a thousand lives were lost when the tsunami completely inundated this coastal village.

3. COASTAL HYDROGEOLOGY OF SRI LANKA

In order to better understand the nature of tsunami impacts on the coastal aquifers of Sri Lanka, the major aquifer characteristics are summarized below from the work of Panabokke (2001). While generalizations can be made, site-specific landscape and aquifer attributes produced a wide variety of responses to the tsunami.

Figure 2. Photograph of the coastal area near Maruthumunai, Sri Lanka, showing the near complete destruction of homes along the coast. The photographer is standing about 150 m from the coastline, and it was reported to the team that the maximum wave height at this site reached high into the palm trees shown in the background. Note the high density of domestic open dug wells (typically short vertical circular structures), many of which were not destroyed by the wave but were inundated and flooded by seawater and debris

Groundwater resources across most of the Sri Lankan coast are dominated by the "coastal sand" aquifers with the exception of a few confined Miocene age limestone aquifers that exist along the northern and northwest coast and throughout the Jaffna Peninsula (Lawrence and Dharmagunawardena, 1983). Coastal sand aquifers, which consist primarily of spits and bars, coastal dunes, raised beaches and paleo-beach deposits provide the most productive aquifers in Sri Lanka (Panabokke, 2001, 2008). They are distributed all round the island wherever the coastal geomorphology permitted build up of raised beaches and low sand dunes. The surface of such units usually lays 3.0–3.5 m above mean sea level and is related to the post-glacial global sea level rise resulting from the Holocene transgression. The raised beaches are usually more than 100 m wide and can be more than 2 km in length along the coast in well developed areas, with a total estimated area of 1,800 km^2 (Somasiri, 2001). These aquifers are tapped with shallow open dug wells and occasionally with deeper wells (termed "tube wells"). The shallow open dug wells are usually manually pumped whereas the deeper tube wells use electric pumps and are typically managed by the NWSDB or by private agricultural enterprises.

Although the configuration and hydrologic properties of the coastal sandy aquifers varies substantially, several broad generalizations can be made. The aquifers along the eastern coastline tend to be parallel to the coast and often have a brackish or saltwater lagoon just behind the beach ridge or rice paddy fields that extend inland from the coast. A freshwater lens is maintained above the seawater wedge as a result of recharge from northeast monsoon ("maha") rains (Villholth et al., 2005). Approximately 75% of the 1.0–1.7 m of annual coastal rainfall along this coastline occurs from October to February. The thickness of the freshwater lenses varies seasonally, and may range from as much as 10 m to as little as 10's of centimeters at the end of the dry season. Panabokke (2001) suggested that as much as 50% of the net precipitation may become recharge. Along the eastern coast, precipitation may be as low as 1.0 m/year, and assuming a typical sand porosity of 30%, a preliminary estimate of the seasonal fluctuation of the water table is between 1.5 and 2 m. The thickness of the vadose zone is poorly documented, but the study team typically observed water table depths of 2–6 m at most field sites visited in February and September of 2005.

Groundwater quality has been measured from coastal sand aquifers in a number of studies, which have shown that salinity in the coastal sand aquifers can range from a minimum of 400 μs/cm to as high as that of seawater (Panabokke, 2001, 2008). However, salinity in most wells used for drinking water or agriculture does not exceed 2,000 μs/cm. While there are no strict health-based drinking water quality standards for salinity, levels below 1,000 $\mu s.cm^{-1}$ are considered to be palatable, i.e. not having objectionable taste. Coastal aquifer wells have shown seasonal water quality variations, with an increase in salinity following the onset of the monsoon rains, believed to be the result of leaching of solutes from the vadose zone built-up during the dry season. Increasing salinity is generally observed during the dry season and has been attributed to the evapotranspiration and possible upconing of the fresh/saline water interface caused by pumping during this period. Panabokke (2001) reported that nitrate concentrations often exceed the World Health Organization standards of 10 mg/L, as nitrate-N and also showed a seasonal fluctuation, with maximum values occurring before or at the onset of rainy seasons. The likely sources of the elevated nitrate concentrations are domestic septic tank systems and fertilizer application.

4. INITIAL RESPONSE TO THE TSUNAMI

It has to be appreciated that the initial response to the tsunami catastrophe was taken in an atmosphere of total chaos and confusion, following catastrophic death and destruction. There was no anticipation of such a disaster, as tsunamis were unheard of in the recent history of the region. There was no disaster awareness or mitigation program for coastal hazards nor a regulatory framework for disaster management. Consequently, the initial responses were ad hoc and spontaneous. It was a tradition in Sri Lankan Society that at times of disasters people took refuge in nearby places of worship, irrespective of faith. In the absence of an early warning of the impending disaster, those who escaped congregated in temples, churches and mosques beyond the inundated zone, which put severe strains on the available water from local wells and sanitary facilities.

By design or sheer good civic sense, early responses to the disaster were taken by individuals, private organizations, local NGOs, and society groups to gather bottled water and dry foods (biscuits, bread etc.) from "supermarket" outlets by the truckload and transport them to the affected zones where large numbers of people had gathered. Many private companies released funds and their staff for several days for this task. News media had already highlighted the problem of contaminated water in wells, and this spontaneous response was a resounding success since a major health hazard from sewage contaminated groundwater was avoided. This effort was soon supplemented by international NGOs operating in the country. Almost immediately, the Department of Epidemiology of the Ministry of Health organized a program and sent medical personnel to the affected zones to prevent a potential epidemiological disaster. Not a single death has so far been reported in Sri Lanka from drinking polluted waters – an incredible achievement for a developing country. Adequate infrastructure and organizational networks were in place to prevent such a calamity.

The tsunami immediately inundated and contaminated more than 40,000 wells in Sri Lanka (ADB et al., 2005; UNEP, 2005), primarily close to the coastline. The coastal villages are no more than 10–15 m above sea level, thus an enormous area was affected by this inundation (see Figure by Gunatilaka attached). In most affected areas, the open dug wells were instantly filled with the seawater, forcing large volumes of saltwater into the freshwater lens as the tsunami receded. Many wells were also contaminated with organic and inorganic debris from the floodwaters, rendering them unusable until they were cleaned and disinfected. The seawater also inundated low-lying areas resulting in infiltration of saline water into broad areas of the aquifers.

During the post-tsunami clean-up, government, non-governmental organizations (NGOs), foreign and local voluntary groups and local citizens began pumping contaminated wells and treating them with chlorine for disinfection. However, most of the dug wells were not pumped and cleaned right after the tsunami. This allowed time to contaminate surrounding groundwater with seawater. Pumping was often conducted with high intensity and frequency, causing problems with the physical stability of some dug wells (Villholth et al., 2005). Fears of waterborne disease outbreaks were not realized in the inundated regions of Sri Lanka partly because the public was aware of the need for well disinfection and good hygiene. There were no guidelines for chlorination, which can increase the salinity in wells that had been subjected to high concentrations of chlorine. Although emergency well cleaning advice and instructions are now available from various sources, no widely distributed guidelines were available at the time for decontaminating wells affected by tsunami-related seawater, let alone guidelines relevant for conditions specific to coastal aquifers such as those found in Sri Lanka and other portions of south Asia. From the perspective of removing saltwater and restoring potable drinking water quality, the emergency procedures used may not have been effective. Excessive pumping may have caused saltwater intrusion from below as the lower density freshwater lens was removed during pumping. Compounding matters, the purged well water was often discharged on the land surface close to the wells, allowing the contaminated water to re-infiltrate into the aquifer through the vadose zone.

Government departments including the Social Services, Water Supply and Drainage Board, and Health Departments also quickly responded by setting up temporary camps, repairing damaged water transmission lines providing drinking water using hired water tankers on a daily basis. Although, people have been resettled in new areas, the high cost of supplying water to these temporary tsunami camps remains a major problem. Many people have rebuilt their original houses, mainly because state land is not available nearby. Basic water supplies have been temporarily restored, but a long term solution to water availability is required as cleaning and restoring wells will take time.

The rapid initial response prevented a health disaster, which easily could have followed with a poor public response – a lesson to keep in mind in future disasters. It is also imperative that attending to water requirements immediately in the manner mentioned above is a first step to coastal community resilience in future disaster scenarios. Restoration comes later as it takes time due to financial or bureaucratic constraints. Future organizational or state responses to coastal disasters should include standing buffer stocks (with adequate shelf life) of these basic requirements (like drinking water) that can be accessed immediately and transported to the affected areas. If properly planned, an efficient mechanism should be in place to achieve this, especially after new perspectives gained from the 2004 tsunami.

5. DISCUSSION AND LONG-TERM OUTLOOK

The short term impact of tsunami flood waves on coastal groundwater resources and supplies in much of Sri Lanka were severe. Thousands of open dug wells, a critical water-supply source for coastal communities, were made unusable. Although salinity in some wells declined rapidly within a few months after the tsunami, some wells in these locations remain unfit for drinking due to residual salinity.

The preliminary analysis and observations of this study support the conclusion that the 2004 tsunami produced a surcharged head and an unstable density contrast in the shallow coastal sandy aquifers leading to vertical mixing of saline water within the freshwater lens. Since March 2005, salinity levels have declined slowly, or at all, in many of the wells that continued to be pumped. In some wells, there is evidence that over-pumping occurred, drawing seawater up from below the freshwater interface and further contaminating the wells.

Many of the coastal areas that were most affected by inundation did not receive substantial rainfall for almost a year, thus aquifer recharge was very limited. Sri Lanka has received substantial monsoon rains during December of 2005, yet it is unclear how many monsoon seasons will be needed for to recover water quality in the aquifers. The magnitude of the salinity reduction each year will depend on the rate of recharge, the accumulation of salinity in the vadose zone, the permeability of the aquifers, and the pumping intensity. If we assume an aquifer porosity (n) of 30%, complete mixing of the upper 2 m of a freshwater lens, an initial residual salinity (S_{pre}) of the freshwater lens of 2,600 μs/cm before the rainy season (Villholth et al., 2005), and a recharge (R) of 0.5 m/year, the resulting salinity (S_{post}) of the 2 m lens after the monsoon recharge is:

$$S_{post} = S_{pre} \frac{Ln}{(Ln + R)} = 1420\, \mu S / cm \tag{1}$$

where L is the initial freshwater lens thickness. This simple mixing approach ignores residual salinity in the vadose zone and is provided only as a hypothetical example; however it indicates that aquifers may recover to pre-tsunami levels (<1,000 μs/cm) after a few monsoon seasons. While this is a positive outlook, other factors must be considered by the Sri Lankan government and water authorities for long-term use of these aquifers for potable water. As seen in Figure 1, the density of pre-tsunami housing on many coastal aquifers was high and there exists no central waste water collection in most areas. The combination of highly permeable sand, a shallow vadose zone, and dense developments makes these areas susceptible to groundwater contamination by nitrates and pathogens. Prior to the tsunami, coastal residents seemed well aware of this risk, and commonly chlorinated their open dug wells.

The long term sustainability of the coastal aquifers for private drinking water will continue to be a major concern. Planning efforts are currently underway to construct piped water systems in many coastal villages rather than rebuilding the reliance upon individual, open dug wells. Centralized sewage collection may also expand, but it is unlikely to be practical across the whole country. Legislation to require minimum setbacks from the sea for housing and buffer zones near the coast have been proposed to reduce the hazards of inundation; but the challenges of finding appropriate land for resettlement for the thousands of people who rely on coastal proximity to the for their livelihood are enormous. Sri Lanka has no formal permitting system for the private use of groundwater; hence limiting the use of coastal aquifers will be difficult. Long term sustainability of coastal aquifers is also impacted by the beach erosion which has been enhanced by lack of sand replenishment due to mining in both coastal areas and in the upland rivers as well as rising sea levels. The 2004 tsunami has highlighted the vulnerability of these aquifers to contamination and the need for conjunctive use of surface water and groundwater for sustainable water resources. New modeling tools available for integrated management of surface and groundwater systems, geophysical technologies for characterization and GIS tools for data analysis and interpretation should be valuable in this task. Introduction of these tools need to be coordinated with capacity building for training of scientists and engineers who should be versatile in the application of these tools.

As coastal populations continue to grow, devastating floods from sources other than tsunamis including storm surges, tropical cyclones, and rising sea level will continue to impact coastal areas. However, the hydrology community can participate in the development of emergency planning procedures that would considerably reduce unnecessary human suffering. This community should make an effort to carefully document and study the hydrologic problems associated with natural disasters. In the case of this tsunami, such results provide a foundation to develop internationally recognized emergency guidelines for the treatment and use of water supply wells and long term planning tools for managing groundwater in coastal areas affected by seawater inundation.

6. EFFECTS ON THE WATER RESOURCES/COASTAL AQUIFERS AND A CONCEPTUAL MODEL

Preliminary field investigations in the tsunami affected areas in Sri Lanka indicated that the tsunami waters entered and contaminated the shallow coastal unconfined aquifers via: (1) saltwater that traveled with the tsunami run-ups and deposited in ponds and depressions at considerable distances inland (2) infiltration of saltwater over the beach face and (3) deposition of saltwater inside the open wells (4) temporary inward moved salt water interface (Figure 3; Illangasekare et al., 2006). It is important to distinguish Sources 1 and 2 from Source 3 due to the residence time of the saltwater in the aquifer. It was assumed that the salt water deposited from Source-1 has a relatively short residence time; while Source-2 contaminants are located behind each face where the saltwater remains pooled and represents a continuous source to the aquifer (Illangasekare et al., 2006). Of these three mechanisms, infiltration through the vadose zone is likely to have injected the largest volume of seawater into the coastal aquifers due to their highly permeable sands and large areal extent of inundation, although direct injection into the open dug wells had the most rapid impact on the aquifer and water supplies.

The sudden surcharge of seawater into the open dug wells is analogous to an aquifer slug test, albeit with a slightly denser but miscible fluid. The height of the surcharge was highly variable, depending on the initial depth to the water table and other factors; but given that flood levels were as high as the tops of coconut palm trees in many places, it is probable that most inundated wells were completely filled with seawater. Due to the high permeability sediments, it is likely that the excess head of seawater in the open dug wells quickly dissipated through the aquifer.

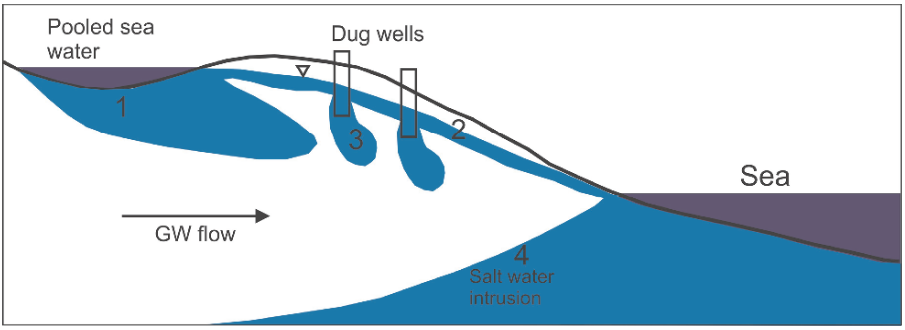

Figure 3. Salt water contamination sources; (1) slow infiltration/leakage from shallow depressions and lagoons located along the coastal zone; (2), direct infiltration from the land surface; (3) discharge through the open dug wells and (4), temporary inward moved salt water interface

There is additional concern over heavy metal contamination to affected aquifers, because the tsunami carried ocean sediments that commonly contain Hg, Cd, Ni, Pb and other heavy metals onshore. In this case elevated arsenic contamination has been reported and associated with the tsunami in Sri Lanka (Pilapitiya et al., 2006).

Mass burial sites can be a source of organic matter contamination to shallow ground water aquifers, which has not yet been studied in this case. In Sri Lanka, there were few places that were used as mass burial sites, and these were located within the tsunami affected areas.

7. LONG TERM MONITORING DATA

Several long-term studies have been monitoring salinity and other chemical parameters in coastal Sri Lanka. These include five field sites from eastern Sri Lanka and three field sites from southern Sri Lanka: (a) four eastern sites

Kinniya (Fig. 4-2), Kallady, Kaluthaweli and Olivil (Fig. 4-3); and (b) three Southern Sites located at Koggala (Fig. 4-4), and Peraliya and Weligama.

8. GROUNDWATER MONITORING STUDIES

Eastern Site – Before Tsunami

From July 2000 to July 2001, the Sri Lanka Water Resources Board conducted an agricultural well monitoring program to evaluate groundwater quality and quantity in the eastern coast from Nilaveli to Kumpuruppidy (Figure 4-1).

This study revealed that the water level in wells at the end of the rainy season is close to the surface, and at end of the dry season it is 2–4 m below ground surface. The better quality water, ranging 400–1,000 µs/cm, was found in wells situated at the higher elevation sites. Poor quality water, ranging from 1,000–2,000 µs/cm, is found close to the sea in an area south of Nilaveli and north of Uppuveli. The interpreted data shows that the sharp decline of EC values takes place in an aquifer following the northeast monsoonal rains. There was no salinity build up in this area before the Tsunami, and hopefully the rains received in this region will be sufficient to leach out the solutes that built up in the soil during the dry season following the tsunami.

Well Monitoring and Cleaning Program After the Tsunami 2004

Immediately after the December 2004 Tsunami, several teams of the Water Resources Board including hydrogeologists and technical officers, engaged in well cleaning and monitoring programs on the east coast. Kinniya is an East Coast Island with an extent of about 5 km^2 (Figure 4-2). Many people in this village rely on open dug wells for drinking water. The 2004 tsunami inundated nearly ¾ of the island and more than 2000 shallow wells were affected by sea water in this area. During the well cleaning and disinfection activities conducted in the island, information on well water quality and technical details of wells were collected. This program was conducted from late December 2004 to March 2005. In parallel to the well cleaning program 636 shallow wells were monitored for water quality and water level variations during a six-month period.

Figure 5 shows the percentage of wells falling into different specific conductance groups during the study period. (636 wells were considered for this analysis). It showed that the percent of wells with specific conductance between 1,001 and 2,000 μs/cm rapidly increased, while the percent with specific conductance over 10,000 after January 2005 rapidly decreased. It is likely that the north-west monsoon rains in January were relatively effective at diluting the salinity in this area.

Koggala Well Monitoring Program – Pre and Post Tsunami Monitoring

As discussed previously, the 2004 Tsunami adversely affected shallow groundwater quality in many coastal regions of Sri Lanka. The Koggala water supply is an example of a coastal aquifer that still has contamination. The annual rainfall in this area is typically bi-modal, with a long-term annual amount of 2.55 m. The wettest months tend to be May and October, while the driest are February and August. This water supply scheme operates from clusters of shallow tube wells and open dug wells that are 10 m deep on average. This water supply was established in 1991 by Water Resources Board (WRB) to supply groundwater to the Koggala FTZ (Free Trade Zone). At present 16 wells are intermittently pumping, supplying approximately 25 L of water per minute to meet the Board of Investment industrial enterprises requirements.

Water quality data have been collected monthly from a network of 24 wells since 1991. Unfortunately no data were collected from January to October 2006 due to lack of funds.

Based on the well pumping rates, data were grouped into eastern and western well clusters (Figure 4-4). Groundwater abstraction from the eastern well cluster is three times larger than from the western well cluster. At this point specific conductance in both well clusters has been not recovered to the initial level.

The moderate groundwater pumping from the western well cluster has allowed specific conductance values to approach their pre-tsunami levels fairly rapidly. In contrast, Heavy groundwater pumping from the eastern well cluster appears to have caused increasing specific conductance values in some wells even before the 2004 Tsunami (Figure 6). This was likely caused by upconing of the interface between saltwater and fresh water. Although conductivity values were declining, they rose in several wells during February 2007, likely due to upconing during the dry season (Figure 7).

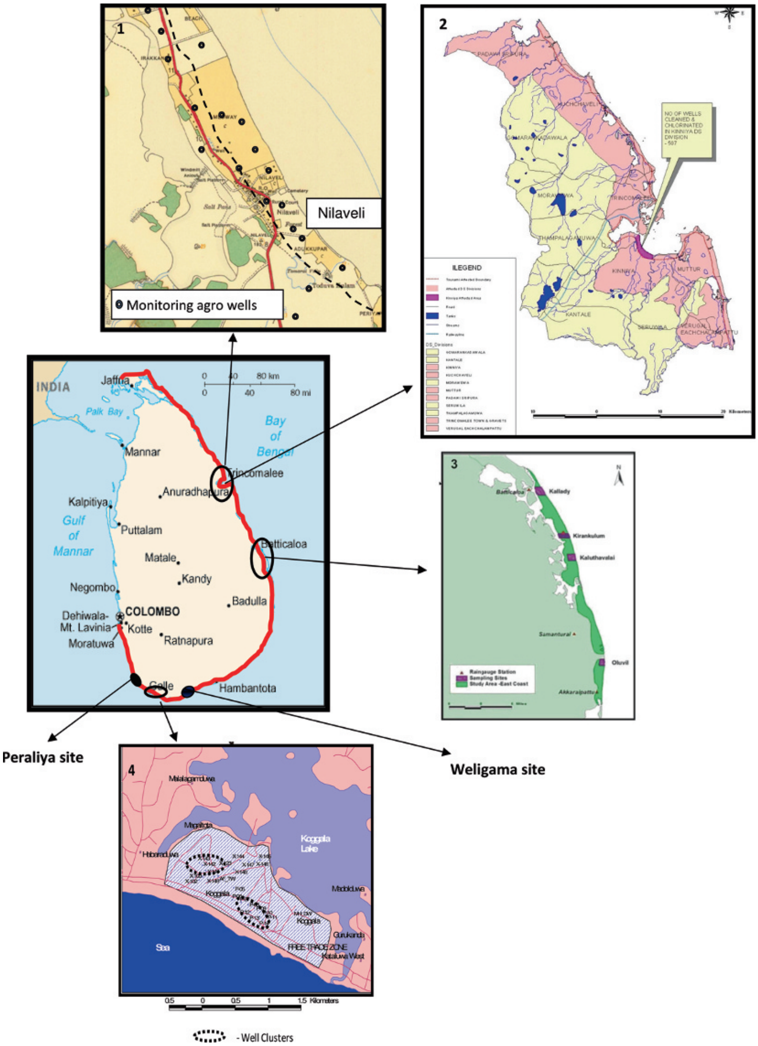

Figure 4. Long term groundwater monitoring sites; (1) Eastern site 1: Nilaweli (pre-tsunami salinity data); (2) Eastern site 2: Kinniya; (3) Eastern site 2, 3, 4, 5: Kallady, Kaluthaweli, Oluvil and Kirankulum; (4) Southern site 1: Koggala (eastern and western well cluster)

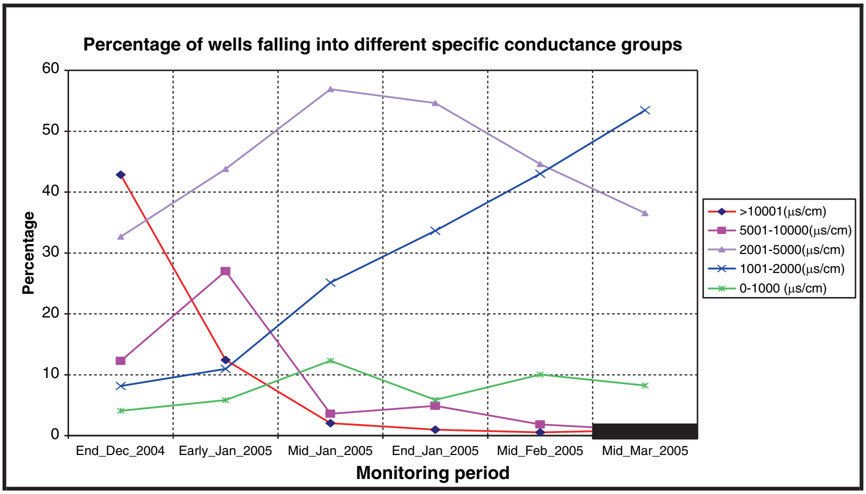

Figure 5. The percentage of wells falling into different specific conductance groups during the period from late December 2005 to mid March 2005

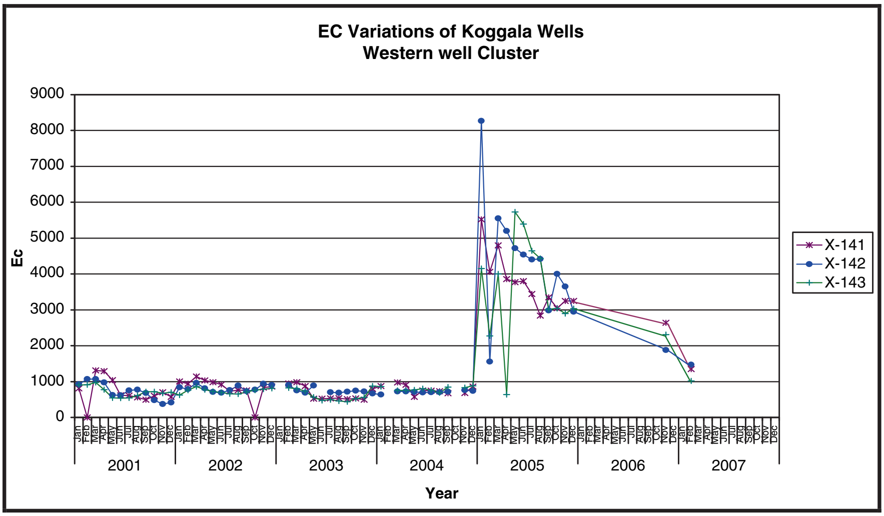

Figure 6. Temporal variation in EC values of tube wells located in the western cluster, Koggala, Sri Lanka

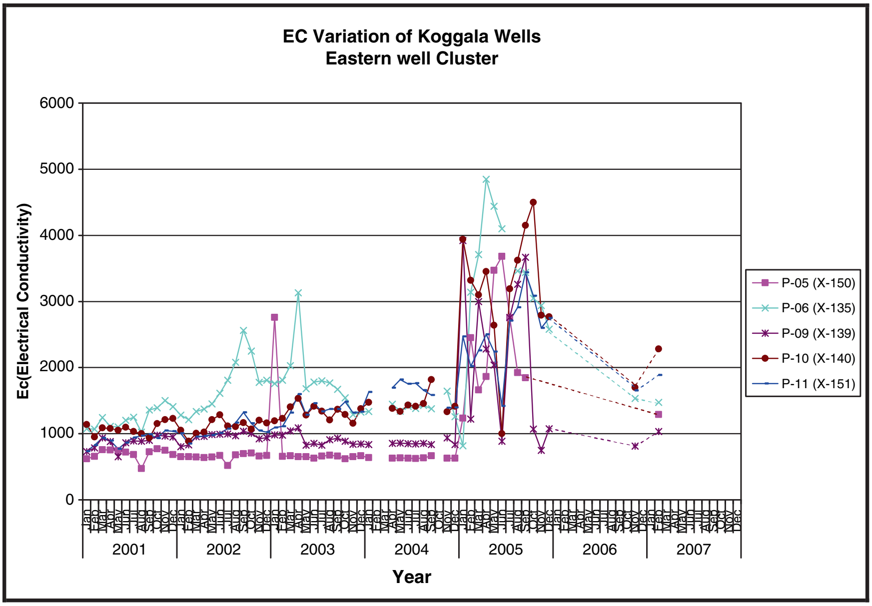

Figure 7. Temporal variation in EC values of tube wells located in the eastern cluster, Koggala, Sri Lanka

Eastern Field Site 2, 3, 4 and 5 – Post Tsunami Monitoring

The data from three different field sites in Eastern Sri Lanka showed a decrease of salinity after the tsunami contamination, likely related to the heavy monsoonal rainfall (Villholth et al., 2005). A field transect perpendicular to the coast in the same shows a general decline from October 2005 through September 2006 (Figure 8). This data shows a decrease in EC levels just after the monsoon rains in November. The increase in EC levels noted in January, 2006, may be due to dissolution and flushing of salts from the unsaturated zone. Twenty one months after the tsunami, the aquifer at this site had not recovered to its original state, since the EC in the non affected area is below 300 µs/cm.

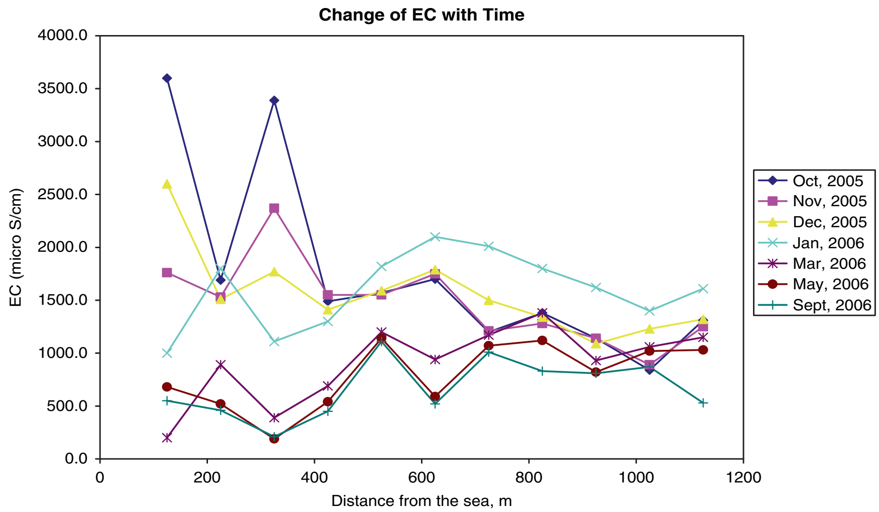

Figure 8. EC levels decreased after the monsoon rains in November, 2005

9. SCIENCE AND RESEARCH NEEDS

Tsunami impacts in Sri Lanka have highlighted a myriad of problems associated with water resources management. These problems can be separated into the following categories:

- Long Term Challenges
- Technology needs and Capacity Building
- Education and Outreach
- Data building

Long Term Challenges: Inadequate to nonexistent management of groundwater resources in coastal watersheds of Sri Lanka has resulted in an unsustainable situation for water supply for coastal communities. There is virtually no regulation of groundwater resources and there appears to be a significant impacts to the freshwater availability in coastal areas. Most coastal communities depend on groundwater from dug wells, many of which had already been impacted by saltwater intrusion prior to the tsunami. In addition to unmanaged utilization of freshwater sources in coastal regions, this vital resource has also been impacted by industrial point sources, and non-point sources including pesticides and fertilizers in agricultural areas, and septic tanks in densely populated villages. Given the already unsatisfactory state of the freshwater sources prior to tsunami, the fate of the tsunami imprint on the water supply wells is unknown. Data from the east coast from Sri Lanka suggests that disturbances due to well cleaning and pumping may delay the natural cleansing of the aquifer by recharge after precipitation events (Vithanage et al., 2007).

Research is needed to formulate a sustainable strategy to manage water resources in coastal regions of Sri Lanka. The strategy should be based on principles of integrated water resources management emphasizing conjunctive use of surface water and ground water. Groundwater withdrawals should be regulated to ensure sustainable utilization of the freshwater sources and avoid cumulative impacts. Research is also needed to investigate the impacts of septic tanks and to develop methods for their proper construction and management. Water quality impacts of stormwater, agricultural pollutants such as pesticides and insecticides, domestic waste, and illegal dumping of waste on living organisms and public health must be investigated. To minimize or avoid further water quality degradation, Best Management Practices (BMPs) suitable for local implementation must be developed.

Technology Needs and Capacity Building: Lack of technology and skilled professionals trained for managing water resources in coastal regions appear to have hampered the efforts to assess and develop recovery strategies for tsunami impacted water resources. Prior to the tsunami, regional scale assessments and management of water resources in coastal regions were virtually absent. There are serious deficiencies in aquifer characterization and the skilled personnel needed to develop simulation models. The monitoring of groundwater resources is sporadic with little focus on long term trend detection.

Research is needed to develop a comprehensive program for assessing and managing water resources in costal watersheds through implementation of appropriate technologies. Such a program should include, soil and hydrogeological studies, borehole geophysical investigations, aquifer characterization, and modeling interactions between surface water and groundwater. There is a clear need to develop an infrastructure and a mindset towards using groundwater models in Sri Lanka. Modeling will provide planners and managers with the tools to assess both the availability of water resources and sustainability and protection of existing sources. Clearly a program of capacity building to educate and train professionals in governmental agencies and academic institutions to effectively use surface water and groundwater modeling should be a high priority.

Research is needed to develop an accessible network for monitoring long term trends and short term variability surface water flows, groundwater levels, and water quality. Training of professionals for design of monitoring networks and their implementation should also be a priority. Although there appears to be widespread use of GIS for data visualization, professionals and academicians would benefit from training and technology transfer opportunities related to GIS tools in a broader context of data analysis and modeling. The use of such tools for developing Decision Support Systems (DSS) and analyzing regional water and environmental systems should be explored. Such tools can be valuable for decision makers and policy analysts.

Education and Outreach: Research is needed to assess the general awareness of the public regarding the value of water resources and the importance of protecting these natural resources for current and future generations. Through all outlets of media and other institutional mechanisms, programs need to be developed for public education and outreach. An emphasis on water quality is needed to better understand how freshwater sources in coastal communities may become contaminated and how they can be protected. Educational materials should be included in curricula of all school levels and universities.

Resources will be needed from both the State as well as donor agencies to educate the public in the following focus areas:

- Importance of water conservation and sustainability
- Current practices of water conservation in developing countries
- Water quality and public health impacts
- Handling of domestic waste and rules and regulations regarding illegal dumping

Data Building: Availability of data for general use by the public and internal and external institutions is seriously lacking in Sri Lanka, which is hampering resource assessment investigations. Although there have been many data collection efforts, the valuable information collected from such activities have not been archived in a centralized location for general use. Research is needed to design and implement a database for coastal watersheds which include, but are not limited to, aquifer delineation, hydrogeological characteristics, results of pumping tests, historical pumping rates, distribution of domestic and industrial wells, water levels, and water quality of both groundwater and surface water sources.

10. DECISION FRAMEWORK AND TOOLS

Sri Lanka is prone to floods, cyclones, landslides, droughts, coastal erosion and environmental related hazards (Government of Sri Lanka, 2006). The Indian Ocean tsunami of 2004 emphasized the need to establish an institutional setting for handling such natural disasters through joint efforts of central and local governments and non-governmental organizations. As discussed in the Initial Response section above, the response to the tsunami in the coastal communities may be characterized as chaotic because of the lack of an institutional structure to deal with such an unprecedented event. Since then, the Government of Sri Lanka has taken significant steps towards strengthening legislative and institutional arrangements for disaster management (Disaster Management Act, Government of Sri Lanka, 2006) and has developed a 'roadmap' to fund and execute several efforts to a new institutional setting for disaster management.

In May 2005, the Sri Lanka Disaster Management Act No. 13 was enacted to provide a legal basis for instituting a Disaster Risk Management (DRM) system in the country. This act calls for establishment of the National Council for Disaster Management (NCDM) and the Disaster Management Center (DMC) both of which fall under the purview of the newly created, Ministry of Disaster Management and Human Rights. Through assistance and consultation of state institutions and local governments, DMC has lead the effort to develop a holistic strategy known as the 'Road Map' to identify and coordinate multi-stakeholder efforts over the next 10 years. This strategy is focused on the following thematic areas (Government of Sri Lanka, 2006):

- Policy, Institutional Mandates, and Institutional Development
- Hazard Vulnerability and Risk Assessment
- Tsunami and Multi-hazard Early Warning Systems
- Preparedness and Response Plans
- Mitigation and Integration of Disaster Risk Reduction into Development Planning
- Community-based Disaster Risk Management
- Public Awareness, Education and Training

The ‘Road Map’ elaborates the project proposals for various activities under each of the above thematic areas.

As of September 2007, it appears that the DMC has been successful in its initial efforts to both implement aspects of the Disaster Management Act and act as the central coordinating agency for management of ongoing natural and man-induced disasters. Progress to date has included the establishment of institutional settings for coordination with local governments through appointment of disaster management coordinators. Depending on the funding availability, the plans are to implement various projects identified in the Road Map.

The implementation of the Disaster Management functions in Sri Lanka will certainly be a challenge because of the widespread distribution of critical functions among various ministries as well as the decentralization of local governments. After the September 2001 World Trade Center attacks the United States, much has been done to improve prevention, preparedness, response, recovery, and coordination across the United States during major disasters. A comprehensive national approach to incident management applicable to all jurisdictional levels has been developed. This approach, known as the National Incident Management System, or in short, NIMS, is designed to provide a consistent national approach for federal, state, and local governments to work effectively and efficiently together to prepare for, respond to, and recover from domestic incidents, regardless of cause, size, or complexity. NIMS includes a core set of concepts, principles, terminology, and technologies covering the incident command system; multiagency coordination systems; unified command; training; identification and management of resources (including systems for classifying types of resources); qualifications and certification; and the collection, tracking, and reporting of incident information and incident resources (http://www.nimsonline.com).

The newly created Disaster Management Institutions in Sri Lanka could develop a system similar to NIMS which makes effective use of the existing institutional frameworks and cater to the specific disasters that the country may face. This effort would require intervention at the highest level of the government to direct the relevant agencies distributed in many different agencies to train and provide staff to a centralized disaster management organization during common and more frequent disasters such as floods, droughts and landslides. A mandatory training program may have to be implemented to train technical and support staff in various ministries and develop an institutional arrangement for the Disaster Management Center to draw from a pool of trained professionals to participate during disasters. The primary components of NIMS such as the command structure and mechanisms for communication and information management will have to be developed to suite the local setting and implement throughout the government.

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HURRICANE KATRINA

Environmental and Engineering Concerns

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Abstract: The flooding of New Orleans by Hurricane Katrina provides many lessons for the environmental and engineering communities and raises serious public policy questions about risk management. A summary of the primary engineering failures that led to the flooding and the consequences of those failures on the city, its people and the environment will be discussed. The emphasis will be on the contamination and waste management issues that resulted from the flooding. The environmental consequences were of concern because of the many chemical plants, petroleum distribution and refining facilities, and contaminated sites, including Superfund sites, in the areas covered by floodwaters. Some 565 oil spills were noted in the wake of Katrina as a result of failures in the petroleum production and refining infrastructure. In addition, hundreds of commercial establishments, such as service stations, pest control businesses, and dry cleaners, use potentially hazardous chemicals that may have been released into the environment by the floodwaters. The potential sources of toxics and environmental contaminants included metal-contaminated soils typical of old urban areas and construction lumber preserved with creosote, pentachlorophenol, and arsenic. Compounding these concerns is the presence of hazardous chemicals commonly stored in households and the fuel and motor oil in approximately 400,000 flooded automobiles. Uncontrolled biological wastes from both human and animal sources also contributed to the pollutant burden in the city. Post-Katrina, we are still struggling with an unprecedented legacy of solid and hazardous wastes. This discussion will focus on successes and failures in responding to each of these concerns as well as lessons learned for future disasters.

Keywords: Katrina; floodwater contamination; waste management

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1. INTRODUCTION

Hurricane Katrina made landfall on August 29, 2005. The storm surge devastated the exposed coastline, including portions of the Louisiana and Mississippi coast. In addition, however, failures in the hurricane protection system around New Orleans led to extreme flooding in portions of the city. Much of the city was inundated by floodwaters 2–3 m deep and in some cases 5 or more meters deep. New Orleans is a city at-risk with much of city well below sea level. The city's protection against that risk includes levee structures that divide the city into a number of polders and large pumping stations that can be used to drain water from those polders. When portions of the levee system failed combined with failure or inability to activate the pumping systems, extensive flooding was the inevitable result. In some areas near catastrophic failures of the levees were noted and the ensuing rush of water destroyed homes and businesses immediately. In other areas floodwaters over-topped and undermined levee systems and slowly flooded portions of the city. The flooding led to other infrastructure failures such as the shutdown of power generation facilities necessary to operate the massive flood control pumping stations and the floating of a crude oil tank which led to further destruction in the community.

The flooding had a variety of impacts beyond direct or indirect destruction of homes and property. When Hurricane Katrina flooded the city of New Orleans and adjacent areas, one of many concerns in its wake was whether there was widespread chemical contamination associated with the flooding. There exist many potential sources of toxic chemicals in any city such as hydrocarbon fuel storage and distribution facilities and commercial chemical storage. Old inner city neighborhoods often exhibit elevated levels of metals such as lead and arsenic. Homes and vehicles are also sources of toxic contaminants with gasoline or diesel and crankcase oil from vehicles and toxic materials such as herbicides and pesticides that may be found in homes. In addition there are several large chemical and petroleum production facilities in and around New Orleans as well as old contaminated sites that have or are currently under going remediation. Figure 1 shows the potential petroleum-related release points, including refineries, oil and gas wells, and service stations near the city. Figure 2 shows the major hazardous-material storage locations, Superfund sites, and Toxic Release Inventory reporting facilities.

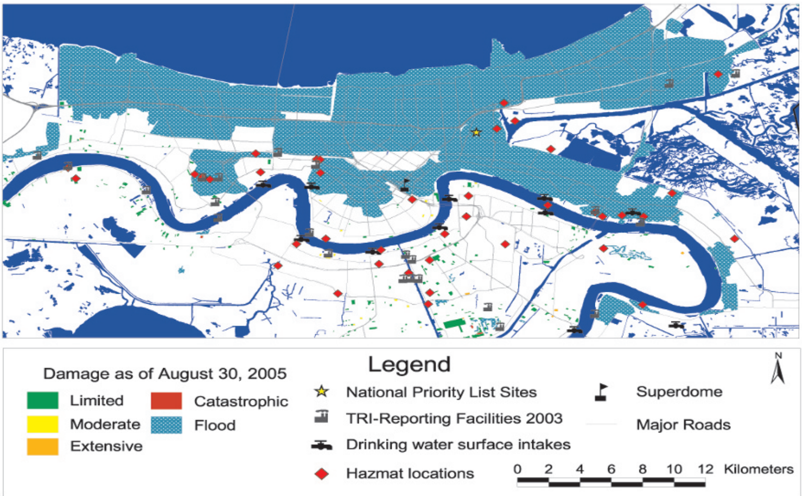

Figure 1. Map of New Orleans showing flooded area and petroleum and natural gas extraction, refining, and distribution facilities (NIEHS, 2005)

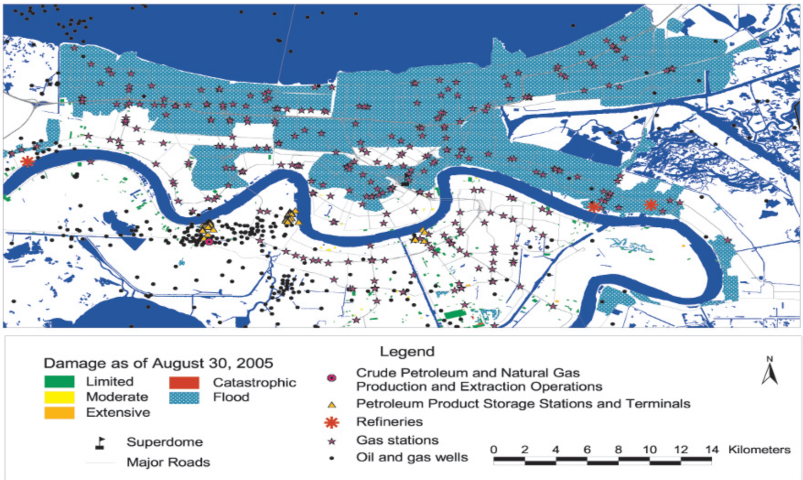

Figure 2. Map of New Orleans showing flooded areas and hazardous material release, storage, and disposal areas (NIEHS, 2005)

This combination of potential sources led to concerns that the flooding produced a "toxic gumbo" which would significantly impact emergency response and both short and long term rehabilitation by posing a risk to human health. A number of sampling efforts were initiated to understand and effectively respond to any potential concerns. In addition to concerns over the human health risks associated with floodwaters or any post-flood residual, another environmental concern was the solid waste and debris that was left in Katrina's wake. The extensive flooding resulted in significant amounts of waste that challenged the community's means of disposing of such wastes. Given limited secure land fill space and a desire to avoid large scale transportation of wastes, much of the wastes were disposed of in less secure landfills raising additional concerns about the long term environmental hazards posed by the flooding.

This paper will focus on an assessment of the environmental challenges posed by Hurricane Katrina and the implications of those challenges for both short and long term risks to the community.[1] The primary focus, however, is not to detail the events of Hurricane Katrina but to provide lessons for future similar disasters. This paper will raise questions that must be resolved when appropriately responding to and recovering from such a calamity. In addition, the failures that led to the human and economic disaster and the potential for more effectively avoiding such a disaster in the future will be a secondary focus of the paper.

2. CAUSES OF THE DISASTER

Although the hurricane was certainly the instigating event, only the catastrophic damages in the exposed Louisiana and Mississippi coasts can be considered largely unavoidable. The flooding in New Orleans has been found to largely be the result of a variety of human failures including

– Inadequate safety factors in the design of hurricane protection levees
– Different political jurisdictions responsible for construction and maintenance leading to uneven design and protectiveness
– Loss of wetlands in the surrounding area that could act as a buffer and mitigate hurricane effects

[1] The discussion here is largely excerpted from *The Bridge*, and that publication is gratefully acknowledged. Reible et al., *The Bridge (National Academy of Engineering)* 36, 1, 5–13 (2006).

- The presence of potentially aggravating factors including a navigational canal (the Mississippi River Gulf Outlet Canal, MRGO) that allowed the full storm surge to penetrate deeply into the New Orleans area

The causes of the catastrophe and the failure of the human response have been detailed in several studies and reports including those of the Interagency Performance Evaluation Task Force (IPET, 2007), ASCE External Review Panel (ASCE, 2007) and the NRC Committee on New Orleans Regional Hurricane Protection Projects (2006). In addition, both the coastal areas of Louisiana and Mississippi as well as New Orleans suffered from inadequate evacuation efforts which certainly contributed to the loss of life. Evacuation problems included failures on the part of citizens to heed the calls for evacuation as well as inadequate planning for citizens who had no convenient means of evacuating.

3. ENVIRONMENTAL IMPLICATIONS OF THE FLOODING

Several efforts were made during and after the flooding to monitor and quantify chemical and biological contamination and assess exposures to, and risks from, toxics and contaminants. Federal agencies, including the Environmental Protection Agency (EPA) and National Oceanographic and Atmospheric Administration (NOAA), collected environmental samples both in New Orleans and from the surrounding area impacted by Hurricane Katrina. Initial concerns in the city were focused on acute exposures for stranded residents and relief workers. Subsequent efforts have been focused on acute exposures for returning residents and initial assessments of chronic exposures. The results of independent sampling have been reported by Pardue et al. (2005), Presley et al. (2006), and the National Resources Defense Council (NRDC, 2005b).

Floodwaters were present in the city from the passage of the storm on August 29, 2005, until the city was declared dewatered by the US Army Corps of Engineers on October 11. Sampling showed elevated levels of inorganic and organic contaminants and biological constituents, including pathogens. The level of inorganic contaminants was generally low, even compared to drinking water standards. Presley et al. (2006) found no floodwater samples with concentrations higher than those designated for drinking water or acute and chronic threshold concentrations. Pardue et al. (2005) noted consistently high levels of arsenic in the floodwaters (mean of 30 μg/L compared to a maximum contaminant level in drinking water of 10 μg/L). Drinking water standards, however, are not an appropriate indicator of water quality for floodwaters because they are based on the assumption that a person drinks 2 L of water every day for 70 years, whereas much less floodwater is ingested or absorbed through dermal exposure.

Organic constituents in floodwaters were also at relatively low concentrations. This observation was initially met with some surprise because of the evident oil and hydrocarbon fuel spills in many locations. Soluble petroleum oils and fuel constituents, such as benzene, however, are typically volatile, leading to rapid release to the air; less-soluble constituents would partition to sediments left behind by the floodwaters. EPA concluded that inorganic and organic chemical concentrations in floodwater were generally below levels of concern for short-term (90 days) dermal contact and incidental ingestion (EPA, 2005b).

Bacterial contamination in the floodwaters was a source of great concern. Median concentrations of fecal coliform of approximately 104 MPN/100 mL were detected in the floodwaters (Pardue et al., 2005). This can be compared to a water quality standard for primary contact of 200 MPN/100 mL. The detection of human pathogens, such as Aeromonas spp., at concentrations on the order of 107 CFU/mL at two locations in the downtown area, raised even greater concern (Presley et al., 2006). Members of the genus Aeromonas, which have been associated with diarrhea and wound infections in humans (Janda and Duffey, 1988), have also frequently been isolated from soils and fresh water.

Another major concern was the immediate and long-term impacts of the discharge of floodwaters into Lake Pontchartrain. From September 6 to October 11, floodwaters, which had largely originated in the lake, were returned to their source. Lake Pontchartrain is a brackish, shallow lake with a surface area of approximately 1,630 km^2 and an average depth of about 4 m; there is an active commercial fishery on the lake. Pardue et al. (2005) detected low levels of dissolved oxygen in floodwaters and in discharged water, which likely resulted in low oxygen levels in the immediate vicinity of the discharge point but had a minimal impact on the lake as a whole. Similarly, the generally low levels of inorganic and organic contaminants in the floodwaters were unlikely to have significant impacts on Lake Pontchartrain.

The sediments at the mouth of the discharge canals contained some contaminants prior to the flooding as the result of normal wastewater and stormwater discharges from the city. The Katrina floodwaters were similar in character, although significantly larger in volume, to the normal stormwaters discharged into the lake (EPA, 2005b). Bacterial contamination of the discharge waters was typically an order of magnitude higher than prior to discharge (as measured by fecal coliform concentration). But in more than 100 samples collected by EPA in September and October, bacterial levels in the lake were within recreational limits (EPA, 2005b).

In summary, with the possible exception of biological pathogens, direct exposure to floodwaters either in the city or in Lake Pontchartrain appeared likely to have minimal toxic or contaminant impacts. Although direct exposure to flood waters appeared to have minimal long term consequences, the long period of exposure to floodwaters led to extensive mold growth in homes. Airborne exposure to the mold during storm cleanup and repairs is a potentially significant exposure. Unfortunately, little is known about exposure to airborne mold spores and the consequences of this exposure are unknown. NRDC (2005a) has identified some potential consequences.

4. ENVIRONMENTAL IMPLICATIONS OF RESIDUAL SEDIMENT

Although floodwaters were removed from the city by October 11, 2005, their legacy of contaminated soils, sediments, debris, and houses remained. In addition, sediment mobilized from storm surge through Lake Pontchartrain and the Mississippi River Gulf Outlet/Industrial Canal was deposited in the city. Additional sampling was done to assess the concentrations of chemical and biological contaminants in these media. Presley et al. (2006) found several inorganic constituents (arsenic, iron, and lead) and organic constituents (mostly PAHs) in sediments from New Orleans that exceeded EPA Region VI Human Health Specific Screening Levels for soils. The Region 6 Superfund Human Health Screening Levels are used to evaluate the “relative environmental concern for a site or set of environmental data. The values are not regulatory, but are derived using equations from EPA guidance and commonly used defaults” (EPA, 2005a).

The Screening Levels, which are “not generated to represent action levels or cleanup levels but rather as a technical tool,” (EPA, 2005a) are “chemical concentrations that correspond to fixed levels of risk (i.e., either a one-in-one million [10^{-6}] cancer risk or a noncarcinogenic hazard quotient of one, whichever occurs at a lower concentration) in soil, air, and water,” based on assumptions of lifetime exposures to generally, but not uniformly, exposure values at the upper end of the range of possible exposures (EPA, 2005c).

Of the 430 sediment samples collected by EPA between September 10 and October 14, a number exceeded screening criteria of the local regulatory authority, the Louisiana Department of Environmental Quality (LDEQ Risk Evaluation/Corrective Action Program or RECAP) (DEQ, 2006). These criteria were developed to meet objectives similar to those of the EPA Health Specific Screening Levels and are derived similarly. The constituents most often found to exceed the RECAP screening criteria were arsenic, lead, several PAHs (including benzo[a]pyrene), and diesel range organics.

On November 19 and 20, EPA resampled areas where previous sampling had indicated contaminant concentrations in excess of screening criteria and where sediment depth equaled or exceeded 0.5 in. (EPA, 2005b). Because of the complex nature of the storm surge and levee breaches and overtoppings, the amount of sediment deposited in flooded areas varied widely, and only 14 of the 145 locations had sufficient sediment depth. Three samples showed arsenic concentrations higher than 12 mg/kg (14.4–17.6 mg/kg); one sample showed benzo[a]pyrene concentration of 0.77 mg/kg; and one sample showed a concentration of diesel range organics of 2,100 mg/kg. Other samples were below applicable screening values.

Samples were also collected at specific sites where there were known or potential leaks of hazardous materials. Elevated concentrations of total petroleum hydrocarbons and a variety of crude oil associated contaminants were observed in the vicinity of the Murphy Oil crude oil tank failure and spill, which had a clearly identifiable source and could be easily differentiated from the general flooding-related contamination. This area is being managed separately from the rest of the flooded area and is not considered further here.

EPA also collected 74 soil samples at the site of the Agriculture Street Landfill, a closed Superfund site that was flooded by Katrina. The samples were collected immediately above the geotextile liner (12–24 in. below ground), which was installed as part of the site remedy. All samples were analyzed for lead, which was the contaminant of concern that defined the cleanup, but none showed concentrations that exceeded the lead cleanup standard or EPA screening standards for lead. EPA concluded that the flooding did not impact the effectiveness of the remedy (EPA, 2005d).

NRDC analyzed samples for other contaminants at the Agriculture Street site and found arsenic at levels similar to those found at other New Orleans sites and a variety of high molecular weight PAHs at somewhat elevated levels (NRDC, 2005c). They ascribed the presence of the high molecular weight PAHs to leachate from the landfill, although, because of the hydrophobic nature of these compounds, they would more likely be transported by resuspended soil from the site or elsewhere. Further assessment of this area might be warranted.

A third phase of focused sampling of soil and sediment ended in February 22, 2006 and involved taking 147 composite samples in 43 specific flood-impacted residential areas where previous sampling found concentrations of arsenic, lead, or petroleum indicators in excess of risk management screening levels. The purpose of this sampling was to determine whether the locations with the elevated levels of these chemicals were isolated, or whether they were representative of a larger contaminated area.

Arsenic levels did not exceed EPA's safe risk management level although apparently elevated concentrations were often noted. background The concentrations of arsenic throughout the Mississippi River Delta region of south Louisiana is on the order of 10 mg/kg (Gustavsson et al., 2001), and LDEQ has reported a background arsenic concentration of 7 mg/kg. Pre-Katrina concentrations of arsenic could be even higher in residential areas because of arsenic in lawn fertilizers (WSDA, 2001).

The only area with PAH contamination in excess of risk screening levels was an area near the Agricultural Street Landfill (a Superfund hazardous waste site that is still undergoing cleanup). Lead concentrations exceeded 400 mg/kg (the screening level) in 57 out 147 composite samples (38.1%). The 38% exceedances are similar to a pre-Katrina study of New Orleans indicated about 40% of nearly 5,000 soil samples with lead levels in excess of 400 mg/kg (Mielke et al. 2004; Pelley, 2006). Nationwide, approximately, 23% of privately owned homes in the U.S. built before 1978 have been estimated by EPA to contain soil-lead levels above 400 mg/kg. In 2000, 14% of the children tested in New Orleans had levels in excess of the federal advisory level of 10 μg per deciliter of blood, which is a city wide figure.

A fourth phase of sediment sampling in flood impacted areas (also in February 2006) involved taking 712 samples from 586 locations in Orleans and St. Bernard Parishes based on a 200 foot grid. EPA was unable to collect samples at another 1,090 locations because either no or insufficient sediment was present to sample or the location was in a commercial area, i.e., only 35% of the locations had sufficient sediment or were residential. Arsenic, lead, and B(a)P were each detected in only one sample in concentrations exceeding the risk management screening level (i.e., the one-in-one hundred thousand excess lifetime cancer risk level for arsenic and benzo(a)pyrene or the 400 mg/kg risk management screening level for lead), which equates to roughly 0.4% of the samples. The reduced frequency of elevated contaminant levels was associated with the random sampling rather than biasing sampling towards areas that had previously exhibited elevated levels as in phase 3.

The conclusion from the residual sediment sampling was that, on the whole, post-Katrina sediments contaminant levels did not differ significantly from pre-Katrina levels. There were specific areas in which contaminant levels were significantly impacted by the flooding, such as in the vicinity of the Murphy crude oil spill, but generally the flooding and deposition of residual sediments appeared to have little impact on exposure to contaminants. This does not suggest however, that the contaminant exposures were of no concern or inconsequential. There was significant concern over chronic contaminant exposures in the City of New Orleans before Hurricane Katrina and these persisted after passage of the Hurricane.

One area of special concern is that there exists limited evidence that indoor biological and chemical hazards may be far greater than suggested by generalized outdoor sampling and assessments. The sheltered environment indoors provides an opportunity for the growth of biological hazards including bacteria and mold but also is a source area for chemical hazards as a result of the storage of household hazardous materials. Further, as shown in Figure 3 for arsenic limited sampling of residual sediments indoors has suggested that these sediments may be significantly concentrated with respect to contaminants relative to outdoor soils and sediments (Ashley et al., 2007). This may be the result of the low energy indoor environment leading to the deposition of fine

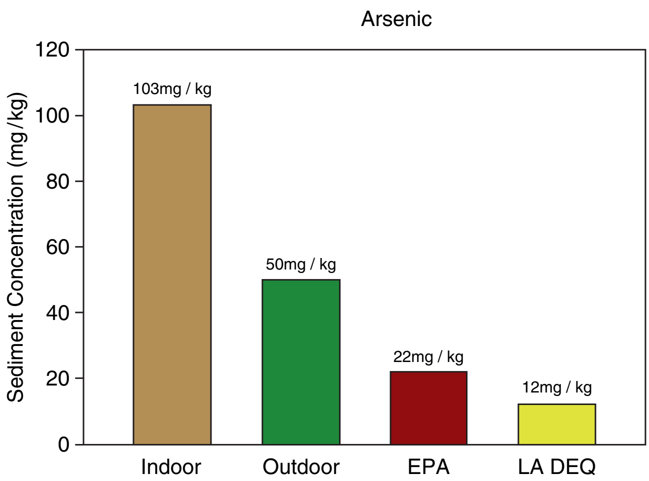

Figure 3. Indoor and outdoor arsenic concentrations in post Katrina New Orleans and EPA and LA screening levels (Ashley et al., 2007)

grained particles that are dispersed more widely outside. Fundamental research is needed to better understand the relationships between regional assessments of environmental exposure and local and individual exposures.

5. ENVIRONMENTAL IMPLICATIONS OF WASTE AND DEBRIS

Although most portions of the city did not exhibit substantially different contamination in soils or sediments after the hurricane, there was an unprecedented legacy of waste and debris. An estimated 120 million yd^3 of construction and demolition debris was generated by the storm and the flooding in its aftermath. In addition, approximately 350,000 automobiles were destroyed by the flooding as were some 750,000 white goods (washers, dryers, refrigerators). The volume of solid wastes was unprecedented and removal and disposal significantly delayed recovery and reconstruction.

Problems managing the wastes involved both problems with marshaling sufficient resources to pick up and transport the waste to a disposal site and problems with sufficient capacity at appropriate disposal sites. As with many other tasks in New Orleans, the availability of workers significantly constrained progress. Although no contractor could be expected to have the readily available capacity to address the volume of wastes, some firms that initially contracted to assist in the effort paved incapable of developing that capacity. Automobiles rendered worthless by the flooding, for example, sat for many months awaiting removal of crankcase oil and fuel and then destruction. Additional delays in managing the solid wastes were associated with the failure of many residents to return in a timely manner to conduct demolition. Waste and construction debris on private property generally could not be transported for disposal.

Disposal of these wastes posed other problems. The shear volume of waste required alternative disposal sites. Transportation out of the area to disposal sites elsewhere was not available, partially as a result of concerns abut Formosan termites that are quite common in the New Orleans area. Initial interest in open air burning of combustible debris was abandoned due to air quality concerns. Ultimately, much of the wastes were disposed of under the presumption that the wastes were solely construction and demolition wastes. Closed insecure landfills not meeting current design standards for household wastes such as the Chef Menteur landfill in eastern New Orleans were opened and used as disposal sites for the flood debris. The use of such landfills, however, depends upon the ability to adequately household and commercial hazardous wastes, however, and there is evidence that that separation was inefficient (Pardue and John, 2006). Concerns have been raised about the future environmental consequences of such disposal (Pardue and John, 2006). Even if household hazardous wastes were effectively separated from the wastes, however, components of construction and demolition wastes have also generated concerns (e.g., arsenic leaching from treated wood, Khan et al., 2006). Recognition and management of those problems should be an important role for city and regional managers in the years ahead.

6. BUILDING A MORE RESILIENT NEW ORLEANS

Recognition of the consequences of the impact of Hurricane Katrina and the subsequent flooding on New Orleans leads to obvious interest in avoiding a repetition of the events. A variety of responses are available depending upon the primary objective of any mitigation efforts. Perhaps the most obvious would be improvement in the hurricane protection system to insure its protectiveness in the face of likely hurricane events. This would aid avoidance of loss of human life as well as help protect property. Clearly, significant gains in protectiveness could be achieved by relatively modest improvements in the design, construction and integration of the hurricane protection systems. A variety of recommendations for such improvements can be found in IPET (2007). It should be noted, however, that the standard for protection against dam failure in the United States (USBR, 2003) is that risks that might lead to less than 1000 deaths in a million years provides "diminishing justification to take action to reduce risk". Conversely, risks that might lead to more than 1000 more often than once is 10,000 years provides "justification to take expedited action to reduce risk". By such a standard, the loss of 1000 lives by a storm that has an expected return frequency of less than once per 100 years is clearly unacceptable. But can New Orleans be protected sufficiently to avoid repetition of the events stemming from Hurricane Katrina on the basis of protection systems alone? There are a number of factors that suggest that this is not possible or a wise use of resources.

First, there exist a variety of risk factors in New Orleans that cause the city to be more vulnerable to hurricanes. Much of the city is well below sea level and is built in areas that are not possible to protect without extraordinary efforts such as massive pumping systems that are currently in use in the city. Making protection more difficult is the specter of global sea level rise and, more significantly, relatively rapid subsidence in and around the city of New Orleans. Sea level rise is currently of the order of 1 mm per year but local subsidence is 5–10 times greater (Dokka, 2006). Subsidence is likely caused by a combination of oil, gas and water extraction from the subsurface and the normal consolidation of South Louisiana sediments especially since channelization of the Mississippi River limits the introduction of new sediment to the area. It was in fact the deposition of these sediments that lead to the existence of South Louisiana. The levees and other flood control structures along the river, however, discharge most of this sediment to the Gulf of Mexico leading to severe declines in land mass and protective wetlands along the coast. Although efforts are underway to partially restore the natural flew of sediment, complete restoration without loss of flood protection function is unlikely.

Equally challenging is the fact that the variability of storm events in the Gulf of Mexico is quite high. The extensive flood control systems of the Netherlands have often been cited as a model for the protection of New Orleans but the storms of the North Sea are, by some measures, less intense the Gulf of Mexico. The ratio of wave height in a 10,000 year storm to that of a 100 year storm in the North Sea is about the same as that expected in a 1,000 year storm in the Gulf of Mexico. In addition, the Netherlands can be protected by construction of storm control structures between peninsulas that limit the size of the structures relative to the area protected. This is much more difficult in the "convex" coastline of the Mississippi River delta. Finally, a large fraction of the Netherlands gross national product depends upon the storm control structures put in place subsequent to the 1953 floods. By comparison, both the total economic impact and the proportion of the US economy that is dependent upon New Orleans is relatively small. It may not be possible to marshal the will and resources to adequately protect New Orleans to the "1,000 lives, million years" risk standard.

Alternatively, planning to more effectively respond to the consequences of a major storm and flooding event may be more fruitful. This could take the form of improved evacuation planning to reduce the loss of human life or in the form of rebuilding amore resilient city that could better weather the storm and for flooding as well as recover more quickly. Resiliency could be implemented by better land use restrictions which could discourage building in the most hazardous areas and improve design or construction in other areas. Design of especially important infrastructure (bridges, communication or other critical services infrastructure) could be designed and constructed for survivability, in much the same way that such structures are designed in earthquake prone areas.

Regardless of any efforts to improve the effectiveness of the hurricane protection infrastructure or the resiliency and survivability of the critical infrastructure, improved planning for recovery from the inevitable catastrophic storm and flood must be implemented. An examination of the aftermath of Hurricane Katrina and the slow and still incomplete recovery from that catastrophe provides a number of recommendations that could help guide future recovery efforts.

First, it must be recognized that the problems associated with a major natural disaster are not uniformly distributed throughout the community. There are, of course, problems in that individuals have different capacities to respond to the destruction caused by such a disaster. Decisions to equitably support reconstruction in the face of this uneven capacity should be made openly and adequately reflect the values of the community.

Although environmental contamination (which involves consideration of chemical and biological contamination, mold issues, and the potential for future floods) influences habitability and reconstruction decisions, it is likely that other factors (such as the potential for future floods) will control these decisions. As indicated previously, contaminant concentrations in soils in New Orleans are generally similar to those prior to Hurricane Katrina. Elevated concentrations, however, may be found in specific areas. The ability to translate community-wide impacts to exposure and risks to the individual homeowner should be improved.

Where these elevated concentrations are associated with a recognized source, both identification of the contamination and liability is relatively easy. More difficult are those situations leading to isolated areas of contamination. How can a homeowner be confident that their home and yard does not exhibit elevated contaminant levels? In the absence of assistance programs the cost of testing and cleanup would fall to the homeowner. Since reconstruction or other recovery efforts would likely be more important to the homeowner, environmental remediation and restoration may never be conducted. This is especially problematic in New Orleans when pre-Katrina conditions were not desirable. Should an event such as Hurricane Katrina be viewed as an opportunity to improve environmental conditions in the city? It is clear that the flexible sampling and expedited analyses that EPA and LDEQ utilized in the New Orleans area was effective at characterizing the general contamination characteristics, but it may need to be supplemented with low cost screening for individual properties. Moreover, future catastrophic events of a similar nature will likely result in similar needs suggesting that a national program of environmental screening analyses would be worthwhile. Such a program could be built on the model used for routine low-cost screening of soil physical and chemical properties for agricultural purposes. The extensive quality assurance and quality control programs that drive much of the cost of environmental analyses could be relaxed for such a screening program.

There were areas were the general environmental assessment post-Katrina were lacking. The habitability assessment should also address potential concerns posed by the presence of mold and airborne mold spores in homes and indoor sediment and dust concerns. Unlike air, water, and soil contamination, there is currently little scientific basis for evaluating the potential effects of mold and indoor dust on human health, or for developing risk-based action or cleanup levels. Airborne mold counts of 50,000 spores/m^3 are considered very high; yet spore counts as high as 650,000 spores/m^3 were observed by NRDC in a home in mid-city New Orleans after Katrina. Because there are no standards to which these mold counts can be compared, there is little guidance as to how to appropriately respond to such high mold counts. In addition, there is no clear regulatory responsibility among federal agencies for indoor air. High mold counts are cause for concern, however, and both NRDC and EPA recommended that returning residents remove all porous construction materials, including carpets and drywall, from flooded homes and use respiratory protection while doing so. The pervasive nature of mold contamination in New Orleans in the aftermath of Hurricane Katrina and the lack of knowledge on the risks of mold and airborne mold spores suggest that additional research is needed to improve our ability to respond to this problem.

The precise processes used to integrate the best scientific understanding of future flood risk, the risk of levee failure, the risk of mold contamination, and what, if any, chemical contamination in the redevelopment and habitability decisions is beyond the expertise of the authors or the scope of this paper. However, master reconstruction plans, zoning, and other mechanisms exist to integrate the actions of the federal, state, and local governmental entities and the private sector. The existing data suggest that the level of chemical contamination may be of lesser concern to stakeholders.

Future habitability decisions after these or similar events are likely to require input from a wide range of stakeholders. The criteria by which decisions are made should be uniform, transparent, and consistent with existing hazardous waste and natural disaster cleanup criteria. Fortunately, the sampling to-date suggests that only a very small number of locations, if any, contain chemical concentrations in soil that warrant remedial action.

The critical test of a legal process is not whether an agency chooses the alternative preferred by the public, but whether the public perceives that the process is fair. A necessary predicate to fairness is communication of the nature of such a process. The discrepancy between some of the concerns expressed by local residents and environmental groups versus the results of the EPA and LDEQ sampling efforts suggests that despite the unprecedented public involvement efforts (and challenges), even more efforts to maintain a dialogue with the public may be needed. The experience in New Orleans once again reflects the difficulty associated with calculating risks, communicating with the public about such risks, and building trust about risk, particularly in the midst and aftermath of an emergency.

A key policy issue facing New Orleans and likely to recur in other communities faced with major flooding is whether reconstruction should include clean up of pre-flooding contamination. EPA and LDEQ repeatedly note that the level of some isolated contaminants is the same as it was before Hurricane Katrina. Clearly these levels were not caused by the storm. However, the local residents and other groups, not surprisingly, demand that the soil be safe regardless of the cause or who pays. Thus, the question arises as to whether individuals might be willing to delay their return, and support governmental decisions about which neighborhoods might be rebuilt, based the levels of chemicals in the sediment or soil, even if these levels are the same or even reduced from the levels that existed prior to Hurricane Katrina.

The cleanup decision-making process that is ongoing might also be an opportunity to reduce exposure to toxics and other contaminants, regardless of whether the contamination was pre- or post-Katrina (e.g., ensuring that any soil contaminated from lead-based paint, or lead-based paint remaining in homes is removed). As a practical matter, such an approach is likely to require that the citizens of New Orleans accept a diversion of reconstruction funds to environmental cleanup.

Every effort should be made to put aside partisan concerns to solve real, significant problems concerning the way we process information in emergencies, and to make sensible, safe, and equitable cleanup/habitability decisions in an environment of great uncertainty. Because existing institutions were largely unprepared for a disaster of the scale of Katrina, it may not be possible to implement these principles in New Orleans. However, we can learn from Katrina and provide more effective responses to future catastrophes.

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SUSTAINABLE WATER MANAGEMENT AND FLOOD PROTECTION PRACTICES IN BULGARIA

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Abstract: The fresh water resources management in Bulgaria at the state and local levels is presented in this paper. Water resources of the country are estimated compared with the resources of other European countries. The present organizational structure and legislative basis of the network for flood monitoring, forecasting and warning, and the type of activities and division of work in this area are shown.

Keywords: water management; water resources; flood protection practices

1. INTRODUCTION

Water is one of the most precious substances for life on earth. It is indispensable in satisfying basic human needs, in safeguarding health, food and energy production, and for sustaining regional and global ecosystems. Recognizing the global importance of water resources for the future of the planet, the U.N. General Assembly declared 2003 to be the International Year of Fresh Water.

Fresh water problems are similar on a global scale – pollution, overuse, shortages or inadequate treatment. The problems in Bulgaria are also within this scope. As a country of limited water resources, Bulgaria regards fresh water as a crucial resource of paramount significance from an economic, social and environmental point of view. The root cause of water issues in the country is the unsustainable management model based on a sectoral rather than on an

T.H. Illangasekare et al. (eds.), *Decision Support for Natural Disasters and Intentional Threats to Water Security*,

integrated approach (Time Ecoprojects Foundation, Sofia, 2003). The government is aware of this fundamental flaw and has therefore laid down in the National Environment Strategy a provision to prepare a national policy or a programme with broad public participation based on the integrated philosophy of water management.

2. PRESENT WATER RESOURCES OF BULGARIA

Serious decrease of fresh water supplied by natural hydrological cycles has been witnessed during the last decades in Bulgaria. Based on climate patterns the weather forecast outlines a trend to global weather change of the planet and drought in the area of the Mediterranean region where Bulgaria belongs as well.

The drought forecast as well as the currently observed troubles in drinking and domestic water supply and the provision of water for irrigation in different regions, demand that urgent measures be undertaken to mitigate the consequences of the future decrease of fresh water. Because of the obsolete devices of the large part of the water supply networks, the water losses in the country are considerable. Not small parts of these losses are related to water theft and bad management of the water systems (Gerassimov G. Bulgaria, 2003).

Water management and control systems at present account only for pipe-end quantities. There is no information or systems that provide relevant public data about the quantities and the qualities of the water entering in to the system, which diminishes to a large extend the set up of practical measures and viable plans for improving fresh water management.

Bulgaria has quite specific geographic situation, being in the southeast outlying part of Europe, rather close to the Asian continent and near proximity to the subtropical Mediterranean region. It provides grounds for rapid change of climate from north to south. In climatic aspect the major part of the country belongs to the European moderate-continental zone. The southwest and south-east regions are under the strong influence of the Mediterranean continental-subtropical zone.

The Bulgarian river watersheds belong to three major basins (Figure 1)

- Danube river basin (most of the rivers in North Bulgaria)
- Black Sea basin (most of the rivers in East Bulgaria)
- Aegean Sea basin (most of the rivers in Central and South-West Bulgaria

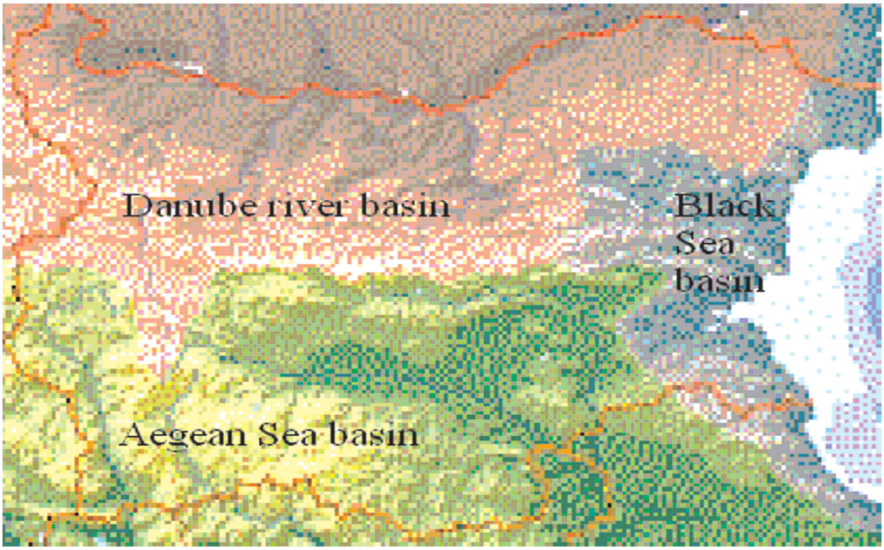

Figure 1. The major Bulgarian river basins

The precipitation is relatively well distributed annually between the high and low flow periods, mostly because of the evaporation conditions.

Generally the high flow of the rivers under the Mediterranean influence is in December–January. Those are the southernmost parts of the Aegean Sea basin. The low flow period of those rivers is quite dry because of the corresponding distribution of rainfall and better evaporation conditions.

The high flow period of the rivers under the Continental influence is during April–June. These are the rivers of the Danube river basin, at the North part of Bulgaria. The low flow of those rivers is higher than those in the South part.

Significant influence on the annual distribution of discharges is due to the permanent snow cover, which is formed in high mountains during the winter season. The snow pack is accumulating the winter precipitation thus transferring water from the winter season to late spring and early autumn.

The lowland areas are usually used for agriculture, while the mountain areas are covered by different types of forests. About 30% of the Bulgarian territory is covered by well karstified carbonate rocks. Only in the karstic areas the river may dry up during a hot spell. Another important issue is related to the artificial regulation of river flow. More than 60% of the total run-off is subject of different types of seasonal and annual regulation by dams, derivation channels and other hydrotechnical structures.

The Republic of Bulgaria does not enjoy abundant water resources compared to most European countries. From 9 to 24 billion m^3 of water are annually formed within the country's territory depending on precipitation. The average annual amount per citizen is roughly 2,300–2,500 m^3 per year. Figure 2 shows water availability data from across Europe as published in the FAO's information system AQUASTAT.

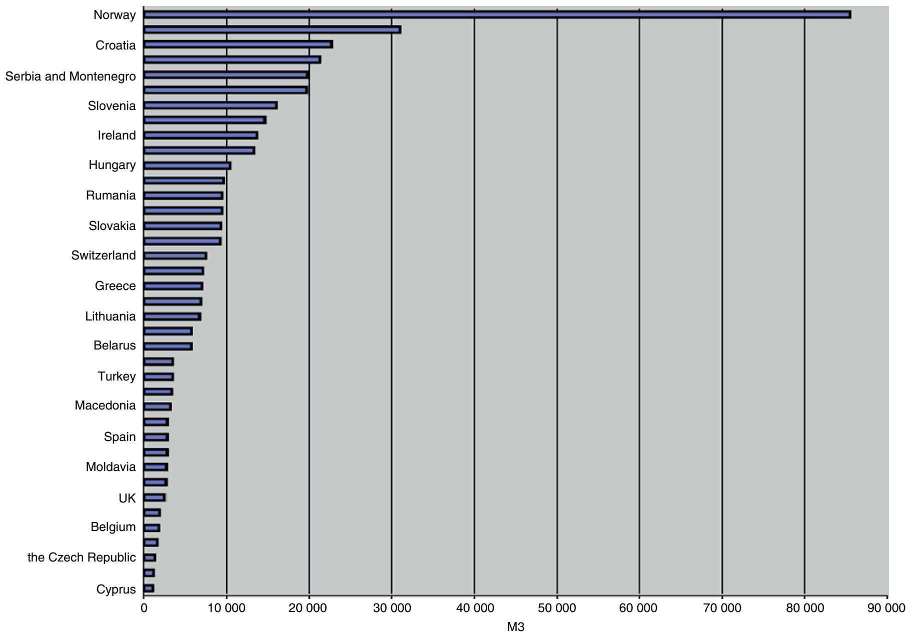

Figure 2. Water resources per head of the population in 2002

3. INSTITUTIONAL FRAMEWORK AND ORGANISATION OF WATER MANAGEMENT

Fresh water in Bulgaria is under the rule of the international legislation, the key European provisions, and the Bulgarian legislation.

The international legislation comprises all international conventions and agreements related to freshwater, which Bulgaria has officially acceeded to and ratified. Directly or indirectly fresh water is referred to by next international documents – the Danube River Convention, the Helsinki Convention, the Ramsar Convention and, in certain aspects, the Black Sea Convention, in its Art. 7, and the Protocol for protection of the Black Sea environment against pollution generated by land-based sources.

The key European provisions are laid down in the European Directives. Water management is chiefly governed by the Water Framework Directive (WFD) 2000/60/EC binding together all other water-related directives. This legislation still has no direct application in Bulgaria and needs to be transposed in the current national legislation.

The state Principal for all the issues related to water is the Ministry of Environment and Water. Waters in Bulgaria are state property and in this respect The Ministry is actually the owner of this national resource, it is giving permits to the water users, it is dealing with the short and long term planning in the field and keeps the national balance of the resource. There are several organizations in the field ensuring the ruling mechanism of the water affairs, which are given in the principle scheme on Figure 3.

The national governing bodies are the Council of Ministers, the Ministry of Environment and Water (MoEW), the Ministry of Regional Development and Public Works (MRDPW), the Ministry of Agriculture and Forests (MAF) and the Ministry of Energy and Energy Resources (MEER). A special consulting authority was also created with MoEW, the Supreme Consultative Water Council (SCWC). It is designed to assist MoEW in running its water management policy with the aim of achieving equilibrium of public interest, protection of public health and sustainable economic development.

The Bulgarian water legislation is mostly contained in the Water Act (Water Act, 1999) and 12 ordinances within the governance of the Act so far promulgated. The Water Act (1999) is the first integrated legal document on water in this country, which furthermore has largely approximated the WFD 2000/60/EC. The Act accommodates all the European principles and approaches of water management.

Water management in Bulgaria is regulated in Chapter 10 of the Water Act. The chapter stipulates the following key management principles:

- The river basin is the staple unit used for jointly managing surface and ground water in both quantity and quality terms in order to achieve sustainable water use and water and water ecosystems safety.
- Solidarity and safeguarding public interest by joint action and cooperation at all governance levels: central administration, municipal administration, water users and environmental groups.
- Polluter pays.

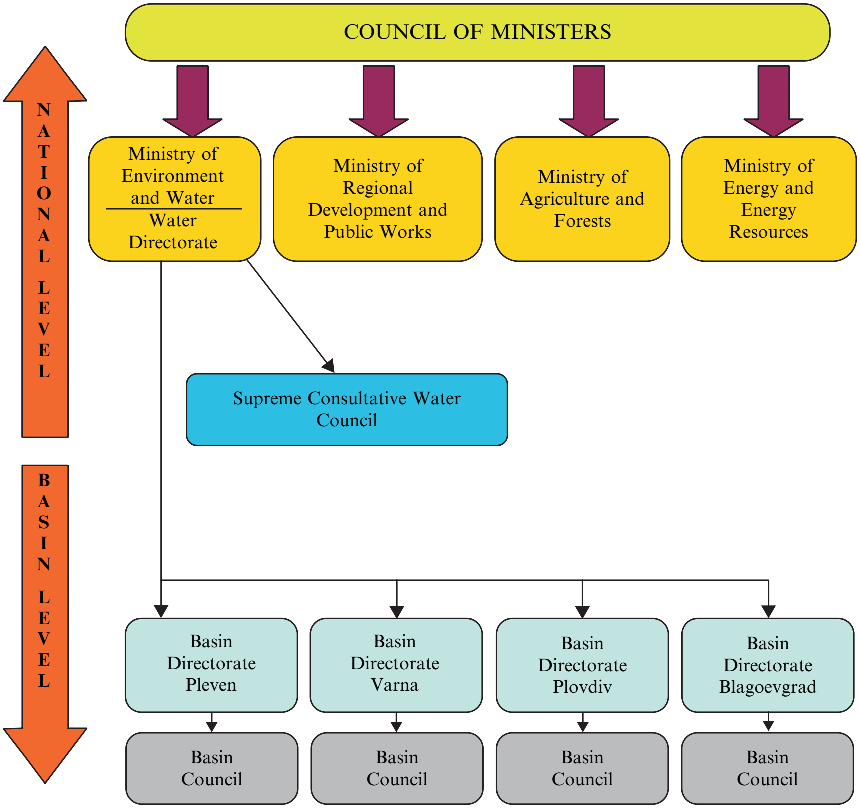

Figure 3. Water management institutional structure in Bulgaria

The Water Act prescribes managing national and basin waters on the basis of river basin plans and the National Water Economy Plan.

Four basin management areas have been identified in Art. 152 (1) of the Water Act – Danubian, Black Sea, East White Sea and West White Sea. Four basin directorates were set up within MoEW to match these areas (Order No. RD-27 of 17 January 2002 of the Minister of Environment and Water).

In order to provide support to the basin directorates, each one of them was coupled with a basin council in the form of state and public consultative commission. The basin councils are chaired by the directors of basin directorates, with their membership being shared among the state administration (up to

20%), the local administration (up to 30%), water users and owners of irrigation and other facilities (up to 30%) as well as by NGOs and research institutes related to water issues (up to 20%).

4. SUSTAINABLE WATER MANAGEMENT AT THE LOCAL LEVEL

Food safety and prevention the spread of infectious diseases are closely connected with the management of waters, and in the countries of Central and Eastern Europe (CEE) – with the construction of the necessary water supply and waste water treatment systems. For implementation of the common policy for reduction of the quantities of used and waste industrial waters it is necessary to carry out a debate with the business community as well.

For sustainable water management in the CEE countries have to design and implement urgent measures, both on national and local level, for finding out the most appropriate forms for involvement and public participation in the process of decision-making. The legal and executive documents on the national and local level in this area in CEE are almost lacking. Irrespective of that the local authorities, business sector and non-profit organizations could undertake the first steps in the direction of building partnerships on the local level among the different economic sectors and stakeholders. Such steps will guarantee the success of the process of development of river basin management plans along.

The major part of the construction of water supply stations in Bulgaria up to now is non-environmentally friendly, whereas the water supply facilities and systems were built and used in contradiction to the priority requirements in water supply. Even nowadays, there are still cases when water supply projects for a given industry or economic branch are being made, without having in mind the overall water needs. The facilities and equipment for water supply and sewerage are in general very expensive and the sole investor in their building is usually the state. Inadequate technical solutions directly affect the population in two directions: on one hand, the tax payers have to pay for expensive, ineffective and non-environmentally friendly sites and on the other – they pay high water consumption prices afterwards. The most striking example, however, is the loss of fresh water in the conduit system for water supply as the average figures for the country in this aspect are about 60%. At the same time, there is a lack of economic interest the Firms for Water Supply and Sewerage to minimize this loss. The design of sites for a complex usage of water, the finding of the cheapest, most effective and environmentally friendly solutions, the minimization of losses in the water supply systems are the motives that could and have to mobilize the specialists and all water users to participate actively in the process of decision-making. They could also attract other investors besides the state for the financing of such sites.

During the spring of 2001, the regional non-government association "Ecosouthwest" with the financial support of the Global Water Partnership established a Water Club in Blagoevgrad. It attracted as its member experts working in different sectors of the economy, and other local stakeholders. The uniting of the ideas, visions and efforts of these experts and water users was necessary with respect to the existing conditions in the region for complex water usage and its integrated management. Through uniting citizens and creating conditions for their gathering in a common focus, one of the aims of the water club initiative is to create the necessary management potential. In order to increase the knowledge of the club members, "Ecosouthwest" organizes discussions and distributes publications among them. Experts are engaged in the preparation of proposals dealing with improvement of the performance of water supply and waste water treatment facilities, as well as in developing solutions for overcoming problems in those facilities. The water club also attempts at creating conditions for integration at the operations level: between the water management organs and the other economic sectors that are directly dependent on water management decision-making process. Vision of the Water Club is that the State has to create a National Information Centre, which will collect and process the entire information for the country with respect to water management issues. At the local level have to be creating Consultative Councils of the respective institutions' managers from the sectors mentioned above.

In order to guarantee participation of the public in the preparation of the river basin management plans and sustainable water management, the "Ecosouthwest" suggests the following eight steps (Table 1) (Anastasov, 2003):

Proposed scheme for public information is shown on Figure 4.

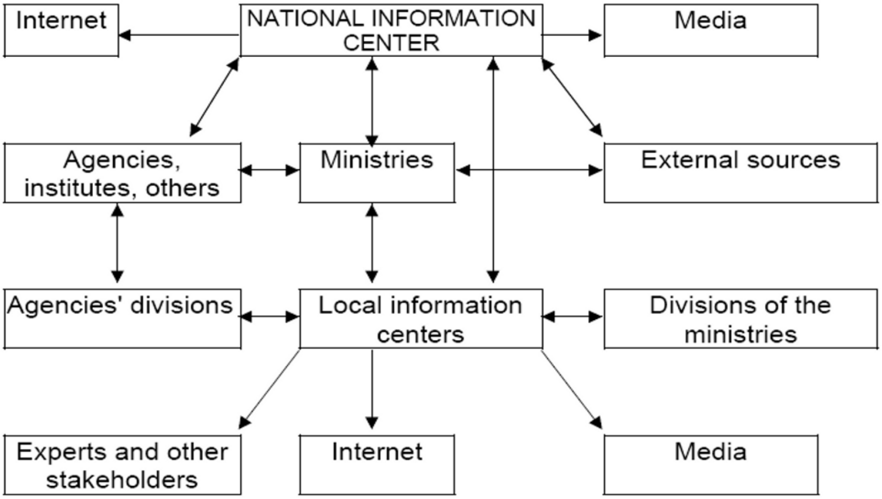

Figure 4. Scheme for public information

Table 1. Necessary Steps at the Local Level for Sustainable Water Management

Steps	Activity	Goals
STEP 1	Creating of independent information centers in the cities where the headquarters of the river basin directorates are situated. Their activities can be organized by non-for-profit organizations with experience and capacities to guide the process of informing the public and of its involvement in the process of decision-making.	Creating conditions for public information.
STEP 2	Collection of the necessary information materials for servicing interested users and experts.	Setting up of a database which creates premises for public involvement.
STEP 3	Creation of the necessary contacts at the local and national level for information update and requesting executive authorities at both levels to appoint contact persons.	Creating of a permanent and active partnership and mechanisms for guaranteeing regular supply of up-todate information.

(Continued)

(**Table 1.** Continued)

STEP 4	Setting up of water clubs with the participation of experts from the different sectors of the economy, business, citizens and NGO representatives who live and work on the territory of the river basin councils.	Creating of meeting loci where the activities of interested stakeholders will be united and organized by the water clubs.
STEP 5	Designing of a web site, uploading and regular update of the collected information on the site.	Spread of information and access by all interested citizens and organizations in the water basin region.
STEP 6	Organizing discussions with the members of the water clubs.	The interested citizens will meet to discuss and unite their efforts towards an improved water management in the borders of the water basin, to elect representatives in the basin councils, to prepare opinions and proposals to the executive authorities, to co-ordinate the common position of the representatives in the water basin councils.
STEP 7	Organization of round tables with the participation of representatives of all water users and members of the water clubs.	Searching of ways for overcoming of the existing problems, reaching of consensus over debated issues, etc.
STEP 8	Organization of educational seminars.	Increasing of the potential of the local experts from the different sectors of the economy, as well as of independent experts and non-for-profit organizations.

5. FLOOD PROTECTION ORGANISATION

The winter snowfalls are considerable in Bulgaria under the combine influence of Mediterranean cyclone and anticyclone or ridge from north. Combined with strong winds, the snowfalls often cause dangerous situations on the Northeast part of the country and in the high mountains as well. Intensive snowmelt due to the combined influence of warming and rainfall sometimes cause disastrous floods at certain Bulgarian rivers. Hailstorms quite often create dangerous conditions and significant economic losses. According to the climatic conditions certain parts of the country might be classified as semi-arid. Nevertheless there are nearly no rivers drying during the hot spell (except in the karsts areas), the low flow discharges are usually 50 times bigger than those of the high flow. So, droughts are among the dangerous phenomena in Bulgaria. Mostly because of the anthropogenic factors, certain regions suffer from insufficient drinking water resources.

Generally Bulgaria is situated in the semi-arid zone under the mixed continental and Mediterranean climate influence. Floods are generated on the Bulgarian territory under the following conditions (National Institute of Meteorology and Hydrology, www.hydro.meteo.bg):

- Intensive snowmelt mixed with rainfall at Springtime (this is usually the case at some Bulgarian tributaries of the Danube, e.g. Yantra and the plain regions in Northeast Bulgaria)
- Flush floods caused by relatively isolated heavy rainfalls at Summertime (this happens often at some river basins in Southeast and South Bulgaria like the tributaries of Arda, Maritza and Veleka rivers, as well as at some Danube tributaries like Yantra and Rusenski Lom rivers)
- High flows with long duration which might affect the stability of the levees and subsequent flooding (this is an issue only along the Danube)

The flood protection practices in Bulgaria comprise a range of activities, more or less intensive in different regions, depending on the level of the flood hazard there. These activities cover both short-term measures like flood forecasting and flood mitigation measures as well as long-term measures like prevention, legislation, infrastructure development, etc.

Short-term measures include flood monitoring and flood forecasting, made by the National Institute of Meteorology and Hydrology (NIMH).

In case of floods, flood mitigation and flood handling measures are:

- Planned (by the Civil Protection Agency)
- Implemented (by the local municipalities and Civil Protection Agency staff, in case of catastrophic flood, Police and Army forces as well as other resources are involved)
- Coordinated (by the Permanent State Commission for Civil Protection against Accidents and Disasters)

Long term measures include:

- Evaluation of the short term measures taken during flood periods, planning development activities, exercises, training, etc. This is mainly in the hands of the Civil Protection Agency and the local municipalities.

- Regular inspection and maintenance of flood protection facilities like levees, protection walls, retention reservoirs, cleaning river channels, bridges, etc. This work is coordinated at present by the Permanent State Commission for Civil Protection against Accidents and Disasters. The role of the newly established Basin Authorities at the Ministry of Environment and Waters should significantly increase according to the new Water Law.
- Issuing building permits, regulations, etc. Here the local municipalities and the newly established Basin Authorities at the Ministry of Environment and Waters are involved.

Most of the river cross-sections are monitored by observers through foot gauges and report water levels via telephone or telegraph. From the existing 210-river level measuring stations, 44 are reporting at real or semi-real time. Daily data collection is arranged for 12 of those 44 stations, while for the rest a weekly cycle of daily values for the past week is arranged. The nearest plans of NIMH are to equip 2–3 river level gauges at the most important Bulgarian tributaries of the river Danube with automatic telemetric facilities. Thus the input from the Bulgarian side will be elucidated by real time hourly data during floods. The stations and the frequency of data collection for the Danube region are given in the Table 2.

Table 2. Operational data used for flood forecasting services and transmitted operationally to the Romanian side

Station No.	River	Cross-section	Data collection
42070	r. Danube	Novo selo	daily
42073	r. Danube	Lom	daily
42075	r. Danube	Oryahovo	daily
42078	r. Danube	Svishtov	daily
42080	r. Danube	Rousse	daily
42083	r. Danube	Silistra	daily
16850	r. Ogosta	Misia	daily
18850	r. Iskar	Orehovitza	daily
21800	r. Vit	Tarnene	weekly
22800	r. Osam	Izgrev	weekly
23850	r. Yantra	Karantzi	daily
31830	r. Rusenski Lom	Bojichen	weekly

Nine of the river stations, located at Struma and Maritza river basins (South Bulgaria), are equipped by automatic river level gauges. Telemetric data transmission facilities are in operation at four of them as a result of a World Meteorological Organization (WMO)-World Bank project. NIMH is going to increase this number soon. For the above stations NIMH has computerized forecasting models able to give 24 h lead-time flood forecasts.

As the national hydrometeorological service, NIMH has framework agreements for real time data and flood forecasts/warnings exchange with relevant organizations as follows:

- *Greece* – under the PHARE and INTREG II, flood forecasting/warning system is maintained for the Struma river basin. That is under the cooperation agreement between the Bulgarian Ministry of Regional Development and Public Works and the Greek Ministry of Economy.
- *Turkey* – framework agreement between NIMH and Turkish competent institutions was adopted for data exchange and flood forecasting/warning for river Maritza. Project applications for further developments in the frame of some NATO programs are under preparation.
- *Romania* – under the umbrella of the WMO an agreement was signed in October 2001 for real time and flood forecasts/warnings exchange.

The dissemination of the forecasts is restricted to the NIMH clients and permanent users, while the warnings go free to the government bodies and especially the Civil Protection Agency, the Ministry of Environment and Waters, and especially to the press.

6. FLOOD FORECASTING AND WARNING SYSTEM

Natural disasters including floods were always part of the environment and humans were combating them. The ability of the human race to successfully mitigate them is a criterion for its development.

The basic characteristics of Systems for Emergency/Disaster Aid are:

- Rapid deployment by air, sea, land transport
- Medium water production volume (main priority is drinking water), small decentralised units
- Proven function and reliability

– Operability in remote locations with insecure supply chains (scarce fuel, no grid, and destroyed infrastructure)
– Deployment, operation and maintenance usually carried out by donor organizations

Information for flood forecasting and warning used presently in Bulgaria and necessity of improvements is (http://hydro.meteo.bg/en/floods/en/img0.html):

– *Satellite Information*. This year Bulgaria became a member of METEOSAT and has full access to the MSG satellite information;
– *Radar Information*. At present NIMH has one radar station near Plovdiv and exchanges information with Aero Traffic Service Authority. Their two radars are located near Sofia and Varna. The coverage is about 59%. Achieving full coverage will give the possibility for more precise evaluation of the processes and for prediction of the trajectories of clouds causing intense precipitation.
– *Ground Observations*. The full volume of data used in weather forecasts are supplied by 40 synoptic stations. Six of them belong to the Executive Agency for the Danube Navigation Maintenance. The approximate density is 60–70 km. The relevant evaluation of precipitation over the complex Bulgarian territory could be achieved if the density is 10–15 km. A supplementary automatic stations network will give this opportunity.

The operational issue of reports and forecasts is made in the Hydrological Forecasting Division, part of Hydrology Department of NIMH. The forecasts are based on:

– Operational observations of river levels and provisional rating curves for real time translation of levels into discharges
– Operational synoptic meteorological forecasts of precipitation and air temperature
– Operational forecasts of precipitation and air temperature coming from the High Resolution Limited Area meteorological forecasting model (ALADIN)

Most of the data processing work and calculations needed to issue the forecasts are computerized with relevant user interface and graphical visualization of the results. But NIMH has limited computational resources and the domain where the processes are calculated is small. To have the full capacity of the models for detailed forecast a more powerful mainframe is needed instead of the workstation used now. Another important problem is the reliability of the forecast for longer periods. NIMH should become a member of the European Centre for Middle range Weather Forecast (ECMWF) getting the possibility for access to the best middle range forecast in the world.

To improve further the accuracy and increase the lead time of the forecasts NIMH still needs:

– More sophisticated snowmelt/rainfall-runoff and routing models giving a possibility to use in detail the spatial variability of the runoff formation factors in the Bulgarian mountain landscape
– Precise cross-section information to allow calculating the flood risk at any location of the river lowland, determine alarm and danger levels at sensitive locations, and predict flooded areas and flood levels
– Real time automatic telemetric hydro-meteorological stations, high resolution satellite data giving a possibility for operational analysis of the temperature and precipitation fields
– More accurate air temperature and precipitation forecasting by non-hydrostatic Limited Area High Resolution Meteorological models

7. CONCLUSIONS AND RECOMMENDATIONS

1. The provision of drinking water should have higher priority because of the immediate relevance water has for life.
2. The quality of portable water is the issue of greatest concern. Water quality has both environmental and health implications. People would like to have more information on these aspects as well as on water quantity (sufficiency of supplies) and pricing.
3. The main problems are social, political and ideological in nature, not technological.
4. The public feels poorly informed on all issues related to water management. And this is especially true for the particular changes the country needs to introduce in its accession to the EU. This low starting point and the general shortage of information have to be taken into account in the context of the public awareness campaign.
5. The population ought to be drawn to participate in the water management processes locally, possibly through representation in committees. Passive ways of involvement, like receiving information, are preferred. In order to encourage a more active behaviour among the population as stakeholder

on the project, local information centres ought to be set up where people will be able to get advice on key water issues of interest to them. For the same purpose the local media can play a good part and should be actively engaged.

6. More solution oriented dialogue is required between natural/technical sciences and social sciences – perhaps we need to move from the information age to the communication age, ideally on a global scale and on all levels.

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CLIMATE CHANGES ON NATURAL HAZARDS AND WATER RESOURCES

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Abstract: Projected climate changes are expected to alter the distribution of precipitation, the rate and timing of snow and glacial ice melting, sea levels, and the temperature of lakes and rivers (IPCC, 2007). These projected alterations pose significant risks to the quantity and quality of water resources and to natural hazard events in some regions. More precipitation is expected in high latitude regions while less is expected in most subtropical regions. Regions that experience less precipitation or less recharge from snow and ice melting will have additional pressure on water resources, while those that experience more will likely have higher risk of floods, landslides, debris flows, and rockslides. Rising sea levels, due to both the thermal expansion of water and the melting of glaciers and ice sheets on land are expected to affect millions of people through flooding, especially in low-lying countries such as Bangladesh. Evidence also suggests that the warming of ocean waters will increase the intensity of hurricanes, which increases risks of flooding and wind damage in coastal areas subject to such storms. Scientific research is just beginning to address the complex interactions between climate changes and resulting impacts on water resources and hazards.

Keywords: climate change; natural hazards; water resources

1. INTRODUCTION

Humans are having clear impacts on climate, as recently summarized by the International Panel on Climate Change (IPCC, 2007). Direct expected changes

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include rising temperatures and alterations to the nature and distribution of precipitation. The temperatures of global air masses are expected to rise by several degrees Celsius over the next century, and the oceans are expected to warm by a smaller but significant amount. Annual precipitation is generally expected to increase in high latitudes, and decrease in subtropical regions.

In some regions, these projected climate changes will affect the sustainability of water resources both for human and ecological uses. In many areas of the world, there is already significant concern over the sustainability of water resources, and changes in climate and population growth will provide additional stresses to these already vulnerable water supplies. As humans compete with natural systems for water, additional stresses to aquatic ecosystems are also likely.

Climate changes will also affect the recurrence intervals and intensity of some natural hazard events due to changes in precipitation patterns and temperatures. Direct impacts include alteration of the extent and duration of floods and droughts, which are closely related to precipitation and temperature changes. Unfortunately, the general projections are that wet areas are expected to get wetter and dry areas are expected to become dryer. Thus, droughts are likely to be more extreme in arid regions, and floods are likely to become more severe in humid regions. Some scientists expect that extremes in climate events are more likely to occur with climate changes, since more moisture will be available in the atmosphere and there will likely be more contrast between warm and cold air masses.

2. OBSERVED CLIMATE CHANGES

There is strong evidence that humans have caused large changes in the concentrations of greenhouse gases in the atmosphere (IPCC, 2007). These concentrations began to dramatically rise during the industrial revolution when large-scale use of hydrocarbons intensified. Carbon dioxide concentrations have increased by roughly 30% in the last 100 years (Figure 1), and a simple comparison of measured carbon dioxide concentrations and carbon emissions over the last 1,000 years strongly suggests a causal linkage (Figure 1). Fortunately, the potential changes in our climate have been moderated since a significant portion of the emitted carbon dioxide and other greenhouse gases have been taken up by the oceans and the terrestrial environment. The rise in temperatures has also been moderated by anthropogenically generated aerosols in the atmosphere. The average atmospheric temperature has increased by about 0.9ºC over the last 100 years, roughly corresponding to the timing of dramatic increases in carbon dioxide (Figure 1).

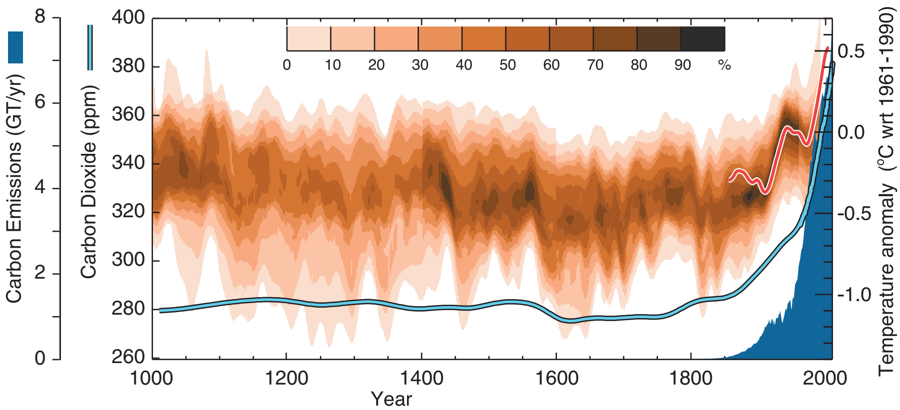

Figure 1. Carbon Dioxide concentrations from ice cores (Etheridge et al., 1988) and atmospheric measurements (Dr. Pieter Tans, NOAA/ESRL-www.esrl.noaa.gov/gmd/ccgg/trends) and globally averaged surface temperatures (IPCC, 2007) plotted over the last 1,000 years. The lower plot shows relative carbon emissions over the same time frame (Boden et al., 2009)

The relative impact of anthropogenic emissions can be evaluated by comparing recent changes in carbon dioxide concentrations with those from ice cores that span hundreds of thousands of years. Carbon Dioxide concentrations in the Vostok ice core, collected in Antarctica, have varied cyclically across a range from 182 to 299 parts per million, over the period from approximately 2,300 to 417,000 years before present (Figure 2b, data from Barnola et al., 2003). The longer term changes in carbon dioxide are driven by orbital changes of the Earth, and all three Milankovich cycles appear in this record. In contrast to the long term record, the rise over the last 150 years is rapid and unprecedented. Note that the concentration measured in 2005 was approximately 375 ppm (Figure 2b), which is 25% greater than any estimated value for the last 417 thousand years. Clearly humans are having a significant impact.

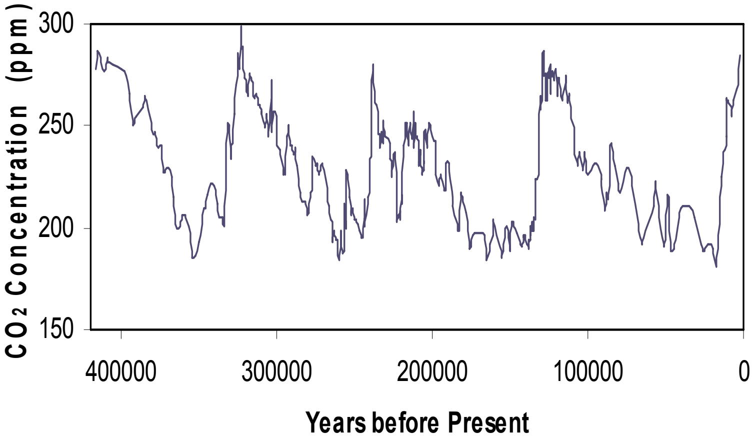

Figure 2a. Vostok Ice core data showing the natural cyclicity in carbon dioxide over the period from approximately 417,000 to 2,300 years before present (data from Petit et al., 2000)

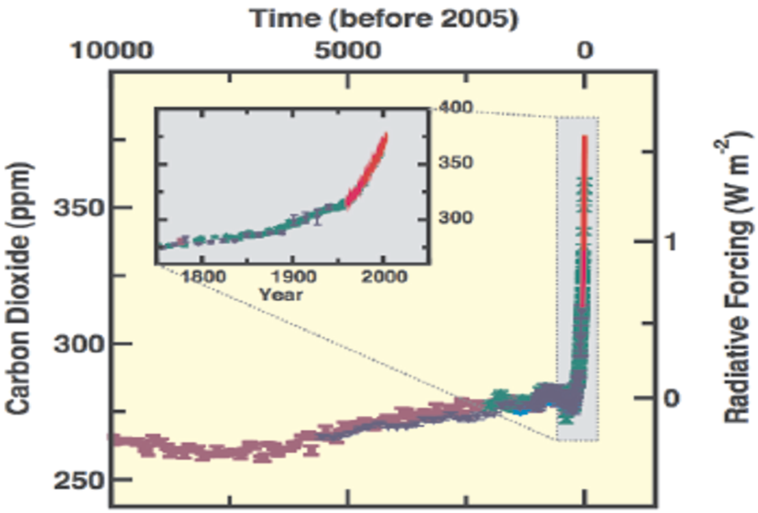

Figure 2b. Carbon dioxide concentrations over the past 10,000 years, with an inset of concentrations over the last 250 years (from IPCC, 2007)

Concentrations of carbon dioxide and other greenhouse gases are expected to increase substantially in the near future with rapid economic growth in developing economies such as China and India. The methane concentration in the atmosphere has more than doubled in the same timeframe. Although its greenhouse gas effect is greater than carbon dioxide, its total effect in terms of temperature increase is approximately one third of that provided by carbon dioxide (IPCC, 2007), due to the much smaller methane concentrations in the atmosphere. The United States remains the leading producer of greenhouse gases on a per capita basis, however, China recently exceeded US carbon dioxide emissions to become the world's largest emitter of this gas (Figure 3).

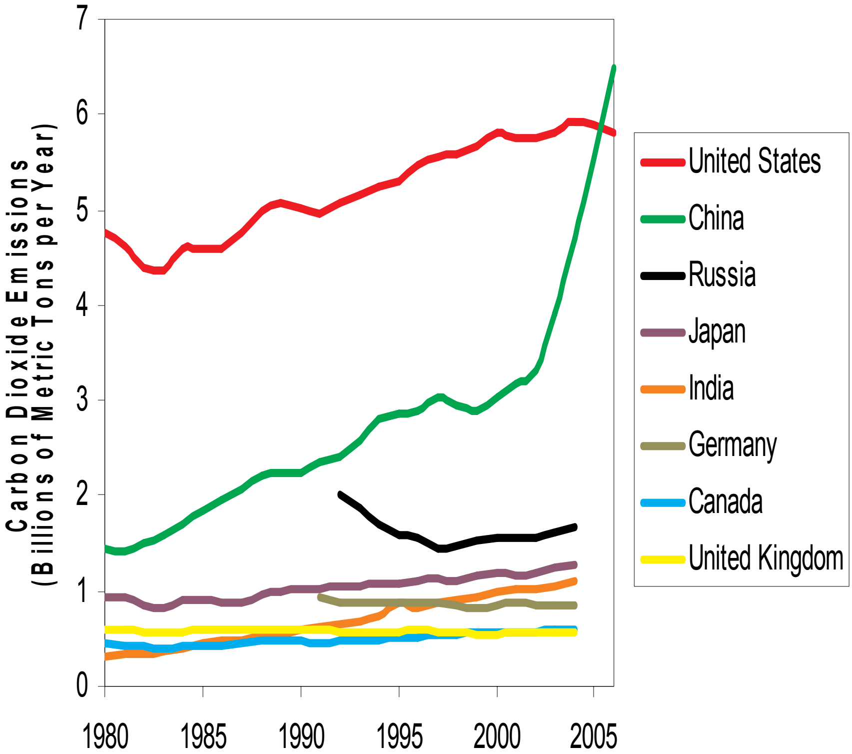

Figure 3a. The United States was the largest emitter of carbon dioxide in the world until the rapid acceleration in Chinese emissions recently caused it to overtake the U.S. (Data from Oak Ridge National Lab - CDIAC)

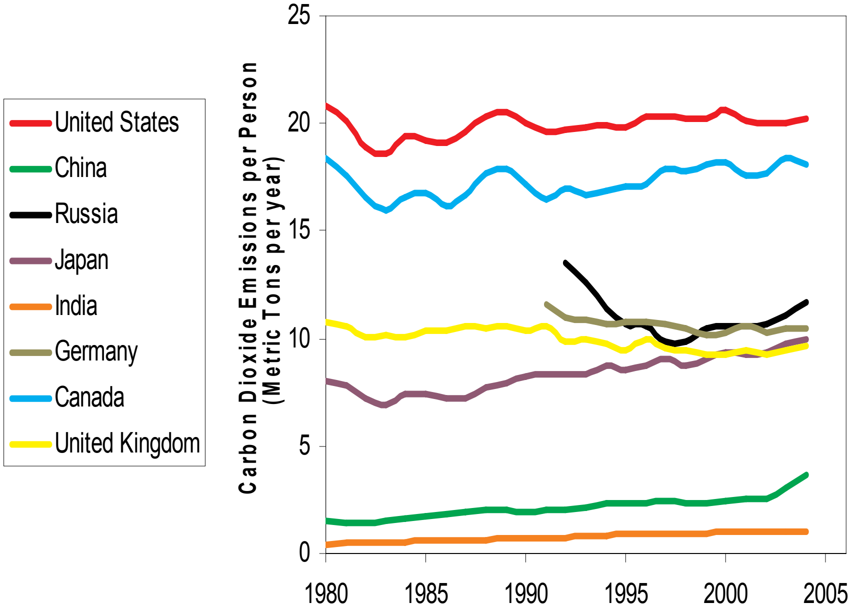

Figure 3b. The United States remains the largest emitter on a per capita basis followed by Canada. Population is clearly a critical factor, as illustrated by the striking contrast between emissions from China and the U.S. on a total vs. per capita basis (data from US Dept. of Energy, Carbon Dioxide Information Analysis Center)

The potential increases in emissions in countries such as China and India are immense as their economies continue to grow, and the impacts for climate change would be proportional.

3. PROJECTED CLIMATE CHANGES

Predicting the extent of climate change over the next century is a difficult task especially because it involves predicting human behavior, which is notoriously unpredictable. The socioeconomic decisions of humans drive the greenhouse gas inputs, primarily through the burning of fossil fuels. Global climate models simulate the response of Earth's complex climate system to changes in the atmosphere including changing levels of greenhouse gases and aerosols. These models also incorporate a series of feedback mechanisms to such changes. The simulations range from a baseline in which there are no additional greenhouse gas emissions, which still shows warming, to three different socioeconomic models that examine reasonable ranges of greenhouse gas emissions (IPCC, 2007). The most conservative of these three models in terms of the temperature increase (B1) assumes economies grow at an unreasonably slow rate with a rapid shift to a service orientation and far less material demand, and assumes that the countries of the world rapidly shift to clean technologies. The least conservative of the three models (A2) assumes that there is slow adaptation to new technologies, with rapid economic growth. In between these two extremes, is perhaps a more likely scenario (A1B) in which population peaks in the year 2050 with rapid worldwide economic growth, and a balance between use of fossil and non-fossil fuels (IPCC, 2007).

The projected rise in global atmospheric temperatures by the end of the century (2090–2099) relative to the 1980–1999 time period are rather dramatic for all of these scenarios (Figure 4; IPCC, 2007). Even for baseline simulations where greenhouse gases are fixed at levels observed in the year 2000, global air temperatures are projected to rise by 0.6°C ± 0.3°C. The B1, A1B and A2 scenario simulations project global temperatures to rise by 1.8 (1.1–2.9), 2.8 (1.7–4.4), and 3.4 (2.0–5.4)°C, respectively (IPCC, 2007).

Although the projected global average levels of warming are dramatic, the warming is expected to be even larger in the Arctic with 5.0 (2.8–7.8)°C of warming projected as the best estimate for the A1B scenario and 5.9°C for the A2 scenario with a similar across-model range.

The warming over land masses is projected to be approximately twice the average global values, due to less water being available for evaporative cooling and the smaller thermal inertia compared to oceans. For example, regional simulations for North America showed projected winter temperature rises of over 7°C for northern Canada and Alaska, and summer temperature rises of 4–6°C for much of the central and western United States (Christensen et al., 2007).

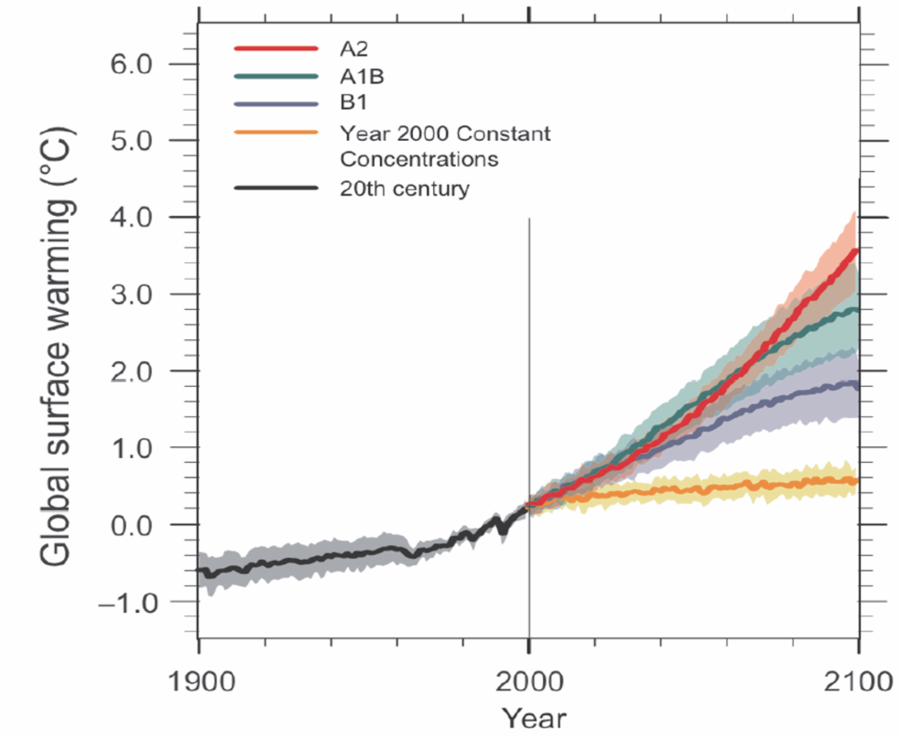

Figure 4. The measured increases in Earth's average surface temperature over the last century can be compared to modeled changes for the next century. Four simulations are shown, from the baseline case with year 2000 concentrations to three simulations that vary by factors including the levels of economic growth and technological advance and utilization (IPCC, 2007)

4. OBSERVED AND PROJECTED CONSEQUENCES

Sea Ice

The consequences of a warming climate are already being observed in many parts of the world. Perhaps the most dramatic example is the loss of Artic sea ice over the last three decades, where the annual average sea ice extent has decreased by approximately 8% over 30 years (ACIA, 2004). More dramatically, the extent of sea ice area at the end of summer has declined at an average rate of 7.4% (±2.7%) per decade over the period from 1978–2005 (Comiso, 2003;

Lemke et al., 2007), and the thickness of sea ice was reduced roughly in half (USGCRP, 2000). The Arctic climate is very complex due to non-linear interactions and substantial low-frequency variability. Many processes are still poorly understood and insufficient data exist to verify models. Nonetheless, these changes are indicative of a dire situation for this region, especially for animals such as polar bears that live on the ice. Positive feedback mechanisms contribute to melting once it begins; ice reflects roughly 90% of the incoming solar radiation while open water adsorbs about the same proportion. As a result, when ice melts, there is roughly a ninefold increase in absorbed solar radiation, which thus increases the rate of local warming. A similar mechanism occurs in areas where glaciers or ice sheets on land melt, as open ground again absorbs much more radiation than snow or ice.

The addition of fresh water to the oceans from melting glaciers and ice sheets is expected to have significant consequences by slowing down major ocean currents that affect the global and regional climate. Thermohaline circulation cells provide a global conveyer of heat from warm areas to cooler areas. Important examples are the Gulf Stream and the associated North Atlantic Current, which carry warm water from the Gulf of Mexico area towards Europe where it cools and sinks (Figure 5). The great deal of heat transported provides Northern Europe with an abnormally warm climate for its

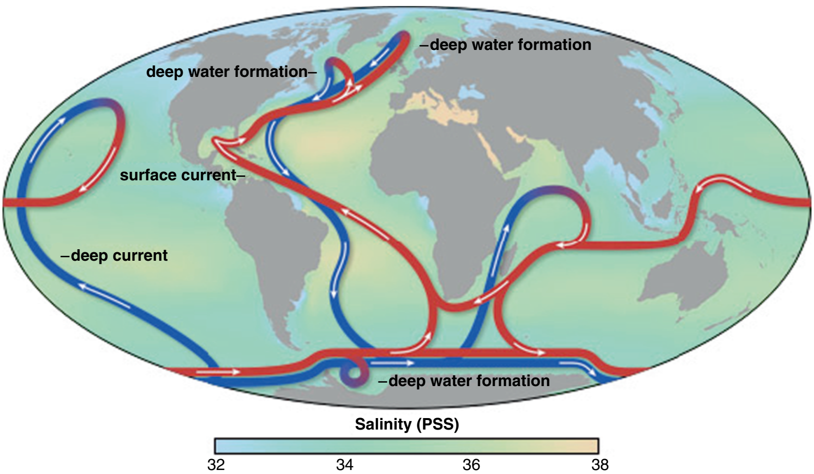

Figure 5. Map of the generalized currents that represent thermohaline circulation. The Gulf Stream is the red current moving from southeastern United States toward Europe (from National Geophysical Data Center)

northerly location. A major concern is that this addition of fresh water from melting sea ice has the potential to shut down, or greatly reduce the flow of this important Atlantic current. This could have major consequences for the climate in Europe, as temperatures could cool enough to freeze harbors and curtail agriculture, based on analysis of paleoclimate records. However, recent modeling studies indicate that overall increases in global warming are likely to counterbalance any changes in the Atlantic thermohaline circulation and are unlikely to change the trend from warming to cooling in Europe (Christensen et al., 2007; Gregory et al., 2005).

Snow Cover and Stream Discharge

Climate change is already causing significant melting of snow cover in the Northern Hemisphere (NH). Until 1980 the NH snow-cover area was relatively stable; in the late 1980s, it rapidly declined by 5%, largely due to increasing temperatures (Lemke et al., 2007). This has clear and significant implications for water resources in northern or mountainous regions, such as western North America, where snowmelt provides more than half of the annual flow in a large proportion of rivers flowing from this region (Stewart et al., 2004). This melt water is added to storage in reservoirs every spring, providing water that can be released from reservoirs during the dry summer and fall. Extended periods with low levels of snowmelt would greatly reduce the available water supplies during these critical periods for urban and agricultural users. Snowmelt also provides the largest annual pulse of groundwater discharge in Michigan streams (Jayawickreme and Hyndman, 2007; Hyndman et al., 2007) in part because most plants have low rates of evapotranspiration during spring. Any sustained reductions of this recharge pulse would significantly decrease the baseflow of streams.

Streams recharged by groundwater serve diverse purposes from agricultural, industrial, and urban supplies, to in-stream needs; thus the expected alterations to the timing of snow melt recharge are also of concern. The period of snow cover provides a delayed storage mechanism, which helps increase stream flows later in the spring and summer. Snow melt is occurring earlier and this trend is expected to continue (USGCRP, 2000). This has major implications for water resources in the western United States. These changes along with increases in temperature are expected to cause an increase in the extent and duration of droughts.

Projected declines of the area with snow cover are expected to be severe in the Sierra Nevada Range, the Pacific Northwest, and the Southern Rocky Mountains (Figure 6; USGCRP, 2000; Mote, 2003; Mote et al., 2005). By the end of the century, Canadian Model simulations show nearly complete loss of the snowpack in all four simulated areas, while the Hadley model shows roughly 50–90% declines in all but the Central Rocky Mountains.

Precipitation

Projected changes in the distribution of precipitation will also have direct impacts on water resources. The projections indicate that polar regions and areas near the equator will generally get wetter and the midlatitude areas will become dryer, thus wet regions will generally become wetter and dry regions will generally become dryer. Both of these changes would have adverse impacts. As Earth's surface warms due to climate change the oceans also warm, which increases the amount of evaporation and thus moisture available in the atmosphere. This increases the likelihood of extreme precipitation, which can cause flooding. The added moisture in the atmosphere is also a positive feedback mechanism. Since water vapor is a greenhouse gas, increase in its atmospheric concentrations heats the atmosphere further, accounting for perhaps half of the overall near-surface warming. Surface water bodies, from lakes and streams to wetlands, are also expected to get warmer. In many areas of the world, this will likely damage the suitability of existing aquatic habitats for various temperature-sensitive species.

Rising Sea Level

Melting of glacial ice and thermal expansion of the water is already causing sea level to rise (Figure 7). Thermal expansion accounts for roughly half of the total sea level rise from 1993 to 2003 (Bindoff et al., 2007). From 1870 to 2005, global average sea level rose by nearly 20 cm (IPCC, 2007). The recent rate of rise is even steeper, and projections are for sea level to rise between 22 and 50 cm in the next 100 years (Figure 7). This may not seem like a lot, but much of the world's population lives near sea level; as the oceans rise these people are at greater risk of flooding and enhanced coastal erosion.

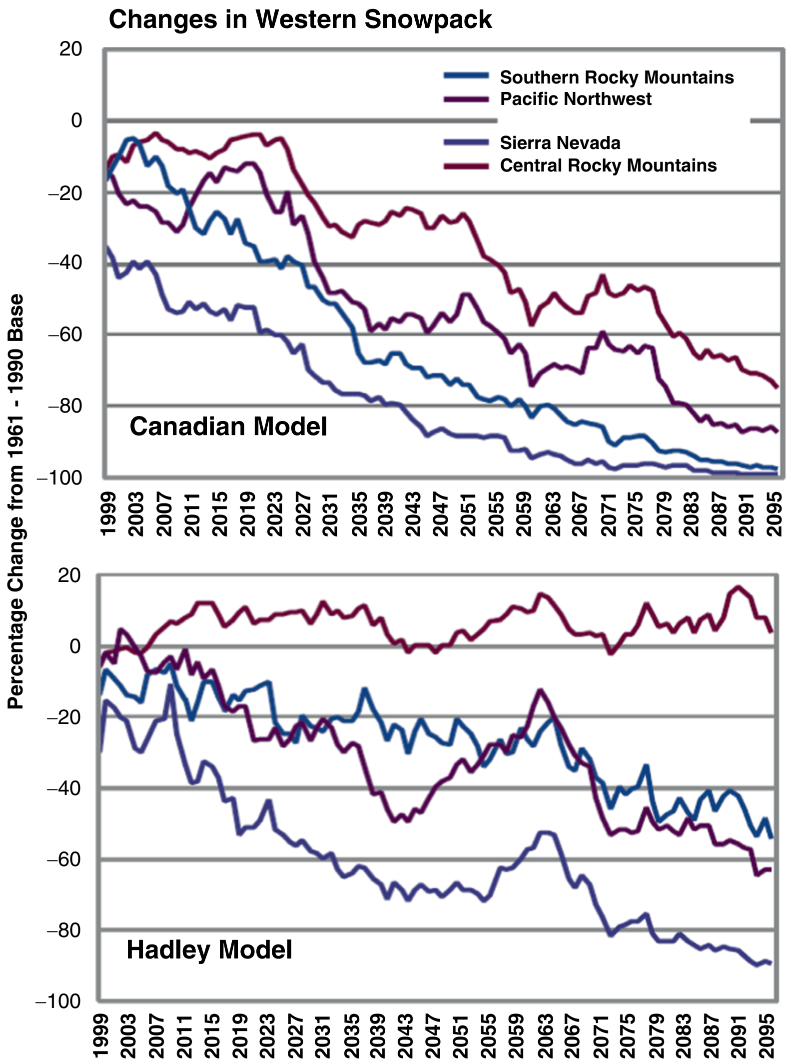

Figure 6. Simulated percentage changes in snow cover in four areas of the United States show large reductions in all but one simulation (from USGCRP, 2000)

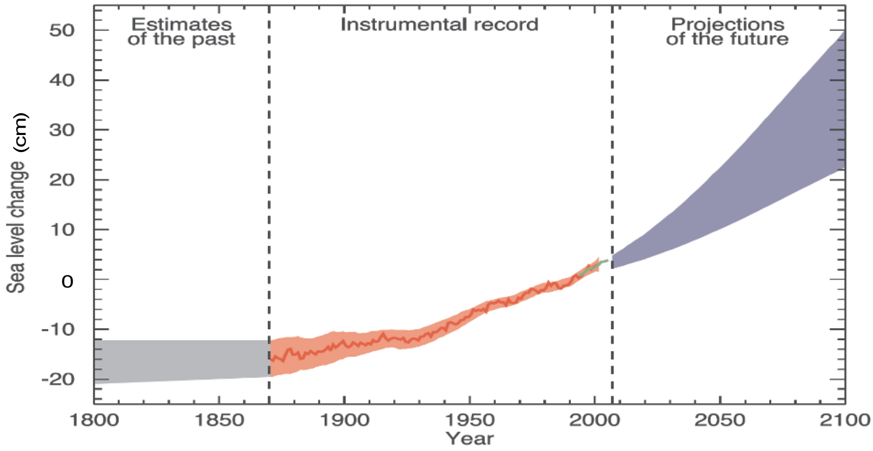

Figure 7. Sea level estimates and measurements since 1800, along with projections for future sea level rise based on projected temperature rises that cause thermal expansion of water and melting of glaciers and ice sheets (IPCC, 2007)

Rise in sea level is projected to cause significant coastal losses worldwide. Bangladesh is expected to have the largest impacted area, with an expected loss of nearly 20% of its land for 1 m of sea level rise. Any sea level rise at all puts this flood-prone country at higher risk of more damaging floods. A small island group, the Maldives, may lose the largest percentage of land, since 80% of its area is within 1 m of sea level (Asian Development Bank, 2007). There is also great concern in the United States since a large percentage of the US population lives on the coasts and the average East Coast beach is already retreating at a rate of nearly 80 cm for every centimeter of sea level rise (Zhang et al., 2004).

5. IMPACTS ON NATURAL DISASTERS

Projected changes in climate are likely to have significant effects on many types of natural hazards; feedback mechanisms, however, for both the recurrence intervals and intensity of natural disasters are generally poorly quantified. Hurricanes can form and strengthen when sea-surface temperatures are warmer than 25°C, thus warming the oceans will likely lead to stronger hurricanes (Figure 8; Emanuel, 2005). Warmer sea surface temperatures are also associated with an increase in the number of hurricanes (Mann and Emanuel, 2006), although modeling studies indicate that the number of storms may decrease in the future (Meehl et al., 2007). The size of hurricane-generated waves has also increased since 1980 (Komar and Allan, 2007); thus these storms will likely cause greater coastal erosion. After the recent devastating hurricanes of 2004 and 2005, and projections for even stronger hurricanes, insurance companies are reducing coverage and raising insurance rates to compensate for increased risk of large losses. There is insufficient record to accurately evaluate the impacts of climate change on the frequency or strength of tornadoes, partly because the record is affected by changes in detection technologies and increasing numbers of storm spotters.

Floods are expected be more frequent and more intense, due to the projected increases in frequency of heavy precipitation events. Mudflows and landslides are also likely to be more common, since the amount of water and hence pore-water pressure in the soils and rocks on slopes is a critical risk factor. The resulting devastation is compounded by increasing populations worldwide, which invariably leads more people to live in unsafe areas.

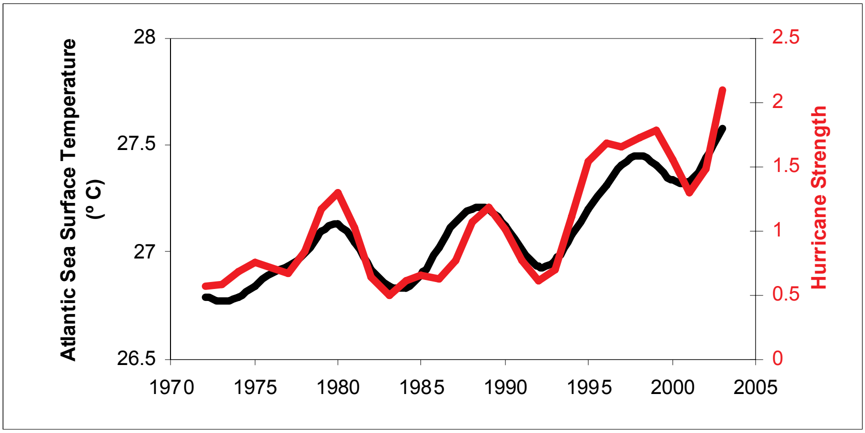

Figure 8. Hurricane strength shows a significant correlation with Atlantic Ocean sea-surface temperature (NOAA data; Emanuel, 2005)

Some of the most devastating effects of climate change are likely to be felt in the arid regions of the world. Droughts are expected to be more common and more severe. This is partly due to changes in precipitation patterns but also to increases in evapotranspiration rates related to increase in temperatures. Earlier melting of snowpacks, discussed above, will also increase the risk of droughts. A related effect, drier vegetation during drought periods, will likely lead to more forest fires, and in turn, more hillslope erosion and landslides following those fires. The incidence of heat waves and heat stress in people, is also on the rise, these events cause more deaths in the United States and Europe than floods, hurricanes, and tornadoes combined.

6. SUMMARY AND DISCUSSION

Earth's climate has been drastically altered over the past 150 years due to human activities, especially those associated with burning of fossil fuels. There has been a significant rise in the global average temperature, associated with increases in greenhouse gas concentrations in the atmosphere. As Earth's surface warms, the oceans also warm, leading to long-term heat storage in the oceans.

Warming of the oceans and atmosphere increases the evaporation rate, leading to more water vapor in the atmosphere and to an increase in the frequency of heavy rain events. Droughts are also expected to be more common and severe, especially in the mid-latitudes. Heat waves, one of the deadliest natural disasters in the U.S. and Europe, are also expected to be an increasing problem.

Climate changes have significant implications to water resources, especially in areas that rely on snowmelt for recharge to aquifers and reservoirs. There has already been a notable lengthening of the growing season, with earlier melting of snowpacks. Model projections indicate that the snow packs in the Western United States will be drastically reduced, or even eliminated in some areas.

Polar regions are expected to warm much more than the global average, causing further melting of the polar sea ice and the Greenland ice sheet. A positive feedback leads to rapid warming of the oceans as sea ice melts since much more of the suns energy is absorbed by open water or land rather than reflected from ice and snow. Melting of sea ice does not directly increase sea level but warming of ocean water is a significant contributor to sea level rise. Sea level is expected to rise at a faster rate than has been observed, leading to more coastal erosion and inundation of low lying areas.

Many natural hazards are expected to become more severe with climate change. Hurricanes and cyclones are expected to become stronger and perhaps more frequent as a result of increasing sea-surface temperatures, since these storms require warm water to form and grow. Floods are expected to be worse, in response to the increase in heavy rain events. Landslides, mudflows, and debris flows are also likely to be more common, since many of these events are triggered by abnormally wet periods that destabilize slopes. Wildfires are likely to be more common and perhaps more intense as droughts become more severe.

Despite the clear implications of climate change to water resources and natural hazards, little progress has been made in reducing greenhouse gas emissions. Industrialized nations continue to emit vast quantities of these gases, with the U.S. having the highest per capita emissions. China recently surpassed the U.S. as the largest overall emitter and its increase is likely to continue in the near future due to its rapid economic development. Rapid and decisive measures are clearly needed before the impacts of climate change reach a tipping point, beyond which it will be difficult to return.

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PART II:

ANTROPOGENIC STRESSORS

MAPPING OF FLOODS AT THE SLOVAK–AUSTRIAN SECTION OF THE MORAVA RIVER – TOOL TO IMPROVE DECISION SUPPORT IN CRISIS SITUATION

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Abstract: Water management activities in the Slovak part of the Morava River basin have increased significantly in the past 10 years, as a result of large floods occurrence (1997, 2006), as well as common trilateral (Czech, Slovak, Austrian) activities in the field of river restoration. Flood consequences in 1997 were not as catastrophic as in the Czech Republic, however they pointed at the weak points in the system and the need of complex approach application in the flood management. Modern software simulation tools can be efficiently used for the decision support in the flood management. The project "Conservation by restoration: Strategy and management of the lower Morava River system "has been finished at the Water Research Institute in Bratislava in the beginning of 2006. Numerical models have been applied for the evaluation of the current state of flood control in the model area (70 km long Slovak–Austrian river reach), assessment of the alternative flood control measures efficiency and determination of area endangered with possible dyke breaks The catastrophic consequences of real dyke breaks at the Austrian side of the river during the spring 2006 flood emphasized urgent need for the improvement of flood preparedness. Models prepared in the frame of project have been utilized during the flood for operational decision support. The flood maps for the vulnerable areas along the river were produced after the flood, in order to provide basis for effective management of future crisis situations.

Keywords: Morava River; floods; flood control; dyke break; numerical modeling; flood mapping; flood lines; decision support

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1. INTRODUCTION

The Morava River is the left-sided tributary of the Danube River. Its mouth is situated at Danube river 1,880 km, close to Bratislava – capital of the Slovak Republic. The river catchment area is 26,658 km^2. The river drains partial territories of three central European states – Czech Republic, Austria and Slovak Republic. It is a border river between Austria and Slovakia in the length of about 70 km in its lower part.

The basic river flow characteristics for the period of observations (1921–2007) in the gauging station Moravsky sv. Jan (67 km upstream from the mouth) are – minimum discharge $Q_{min} = 8\ m^3 \cdot s^{-1}$, maximum discharge $Q_{max} = 1573\ m^3 \cdot s^{-1}$, mean annual discharge $Q_a = 119\ m^3 \cdot s^{-1}$, 1% probability discharge $Q_{100} = 1{,}400\ m^3 \cdot s^{-1}$.

Morava is a typical lowland river in its lower part. Originally it was a strongly meandering river, in the Slovak–Austrian border reach. The river channel was straightened and lot of meanders cut-off, as a result of river training works (mainly after the World War II). Extensive system of flood protection dykes were constructed almost along the whole Slovak–Austrian river reach. Lower part of the river is influenced with the backwater effect of the Danube River, which can be evident almost 30 km upstream from the mouth during large Danube floods.

The Morava River basin suffered from a large flood in July 1997. The flood consequences were catastrophic mainly in the Czech Republic – more than 50 casualties, flood damages estimated to around 2 milliards €. The flood peak discharge was above Q_{500} in some parts of the river basin, mainly in the upper part. The flood peak in the Slovak–Austrian river reach was routed to 900 $m^3 \cdot s^{-1}$ in Moravsky sv. Jan, as a result of dyke breaks and controlled outflow from the reservoirs at the territory of the Czech Republic. Peak discharge was far from Q_{100} at the Slovak–Austrian reach of the river; however this flood pointed at the weak points in the flood protection of the territory. The maximum flood water level was close to the flood protection dykes crest in several locations.

The flood consequences were more serious in the spring 2006. Flood resulted from the combination of extreme volume of water in the snow pack and sudden rise of air temperature in the last decade of March. Rainfall, which hit large territory, accelerated snowmelt and excessive runoff in several parts of Central Europe, including the Morava River basin. The maximum observed water stages were recorded almost all along the Slovak–Austrian river reach. Emergency water level limits (highest 3rd degree of flood danger) were exceeded for more than 10 days. The return period of peak discharge – around 1,400 $m^3 \cdot s^{-1}$ was estimated to 100 years. The volume of flood wave was extreme, too. Critical situation resulted in several breaches of flood protection dykes at the Austrian side of the river. The first dyke break occurred close to Jedenspeigen village in the early morning on April 3rd. Extensive territory behind the flood protection dykes was flooded. The extent of flooded area grew very rapidly, in spite of intensive flood defense measures and activities. Flood consequences were catastrophic. Situation at the Slovak territory was dramatic, too. However, flood consequences were incomparable, thanks to improvement of flood protection in the Slovak side of the river in the beginning of the 21st century.

The Morava River floodplains, as well as adjacent territory situated behind the flood dykes, represent unique area from the ecological viewpoint. Relics of cut-off meanders, riparian forests, rare fauna and flora are valuable ecosystems, which require careful management of water resources. There are several Ramsar sites in the lower Morava River basin. The ecological value of the territory has decreased in the last decades, mainly due to antropogenous activities and lack of bilateral coordination of the river restoration measures.

The research projects aimed at the review of the current state and proposal of proper river restoration strategy started in the territory in the 1990s of the 20th century. The Water Research Institute in Bratislava coordinated the works, in the participation of river basin administration, Slovak Academy of Science, nature protection administration and local authorities. The introductory project focused at the definition of the current state in the fields of flow dynamics, sediment transport, groundwater regime and ecology in the area of interest – Holubova et al. (1997). The follow-up project – Holubova et al. (1999) focused at the evaluation of the first implemented measures and definition of more complex strategy in the river restoration at the Slovak side of the river. Selected project results, based at the modeling approach were presented in the Hydroinformatics 2000 conference – Holubova and Lukac, 2000. The project "Conservation by restoration: Strategy and management of the lower Morava River system" – Holubova et al. (2006), finished in the beginning of 2006, started bilateral cooperation with Austrian partners, which continues in present via INTERREG (EU) funded projects. The project consisted of several parts. One of them focused at numerical modeling of surface water flow in the area of interest – Lukac (2006). Numerical models, setup in the frame of above mentioned projects were utilized during the flood for rough prediction of flooding dynamics and for the mapping of potentially flooded areas after the flood. At present, models are applied for the evaluation of the effects of various proposed flood control measures, which should result in a common flood control strategy in this river reach.

The presented paper deals with the application and results of numerical modeling in the fields of flood control and emergency management.

2. APPLICATION OF NUMERICAL MODELS FOR FLOOD MAPPING

The river flow dynamics in the whole Slovak–Austrian border reach of the river was studied using a 1D numerical model MIKE 11 (DHI Water & Environment). The objectives of the 1D model application were as follows – evaluate current state of flood control, determine the efficiency of the intended flood control measures (polders) and provide a basis for the decision support in the emergency situations (dyke breaks). The basic model was designed to simulate flow dynamics for the current state and variety of hydrological conditions from minimum to flood discharges. Basic model was calibrated and validated, based at reliable data sets from the past. The longitudinal profiles of observed water levels were utilized, which covered both low and flood flow conditions. The differences between the observed and simulated water level did not exceed 10 cm for the main calibration event – already mentioned flood from July 1997.

The current state of flood control at the Slovak–Austrian border section of the Morava River was evaluated using the basic 1D model. Calibrated and validated model was applied for the computation of flood water level under the discharge conditions defined with bilateral Slovak–Austrian Commission on Border Rivers. This water level is governing for the determination of flood protection dykes freeboard. According to valid standards, freeboard of flood protection dykes should be in the range of 0.3–1.0 m, when protecting the area at the discharge Q_{100}. Based at the modelling results, it was stated that the actual freeboard of Slovak flood protection dykes is lower than minimum required at several locations. However, dykes should not be overtopped at the Q_{100} discharge. Analysis pointed at the critical situation in the Austrian side of the river. There were several locations, where calculated water levels of Q_{100} were higher (by up to more than 50 cm) than the altitude of dyke crest. The correctness of analysis was validated in reality during the 2006 flood. The first dyke break occurred at the location, which was identified as the most critical. The example of flood map for the case of hypothetical dyke break at the Slovak territory is given at the Figure 1.

The field measurements of the 2006 flood water level longitudinal profiles, as well as time series of recorded water stages in the gauging stations enabled comparison of model results with the reality. Differences were acceptable; it was therefore possible to utilize the model for the rough prediction of flooding dynamics after the dyke breaks during the flood. The maximum extent of flooding simulated with the model is given in the Figure 2. Comparison with real extent of flooding and flow dynamics proved, that model could be used for the decision support in the crisis situations. Inaccuracies were mainly caused by the short time available for model adjustment into the real situation and inaccuracies of terrain data.

After the flood, adjusted model was applied in the study of mapping the flooding extent for the cases of hypothetical dyke breaks in selected locations at the Austrian territory. Three locations were chosen and two different flood waves, which were used as the input model boundary. The situation of overtopping the dykes crest (not assuming dyke breaks) was simulated, too. Results were delivered to the clients in the shape files and finally processed into the printed form. Maps were presented to the regional (Land Lower Austria) authorities involved in the water management and emergency management, as well as to the representatives of local municipalities in the river basin. They were evaluated as very useful tool for the decision support in the crisis situations and for the improvement of flood management plans. The example of flood map for the dykes overtopping scenario is given at the Figure 3.

It was needed to extend basic hydrodynamic 1D model to the area situated behind the flood protection dykes, in order to simulate flow dynamics for the polders and dyke breaks. The digital terrain model (DTM) of the Slovak territory, as well as part of Austrian territory was obtained in the frame of project, by processing of aerial scanning realized in the spring 2004. Vertical and horizontal accuracy of DTM is ±0.25 m. Terrain was schematized in the irregular network of points in the distance of 5–50 m. More detailed DTM of the Austrian territory was obtained for the study of hypothetical dyke breaks.

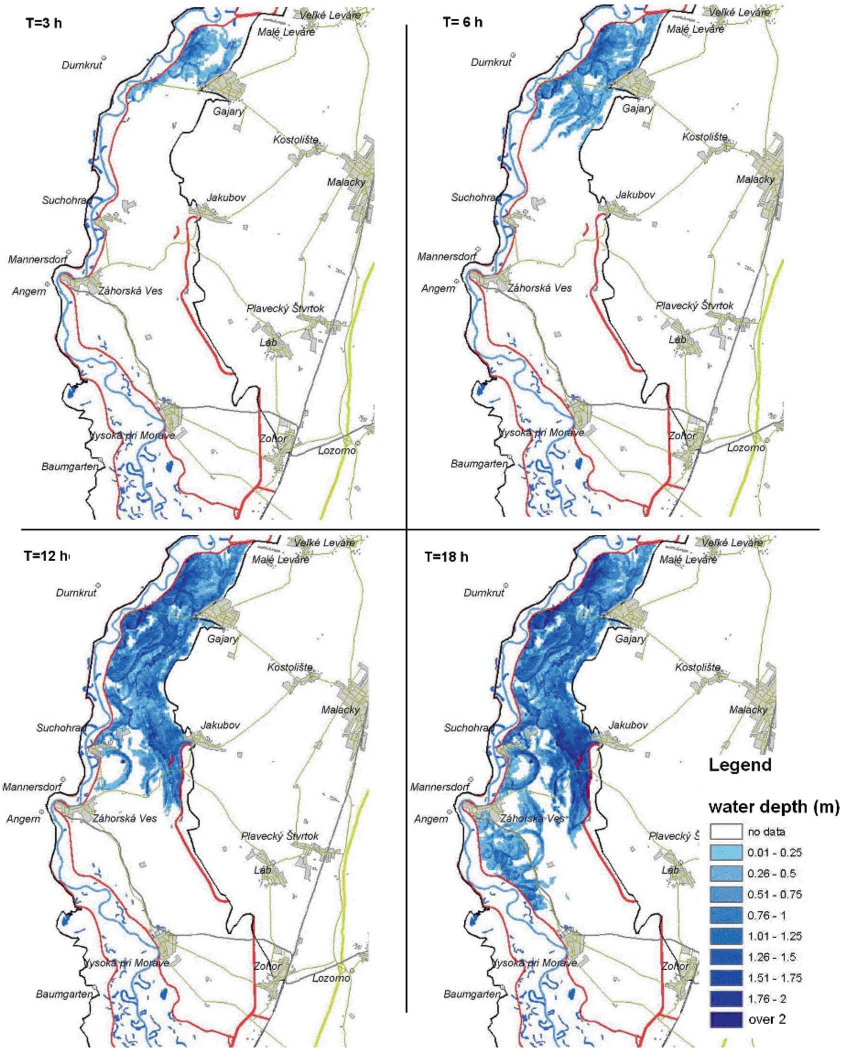

Figure 1. Simulated water depth in the Slovak territory behind the flood protection dykes for different time T after the dyke break

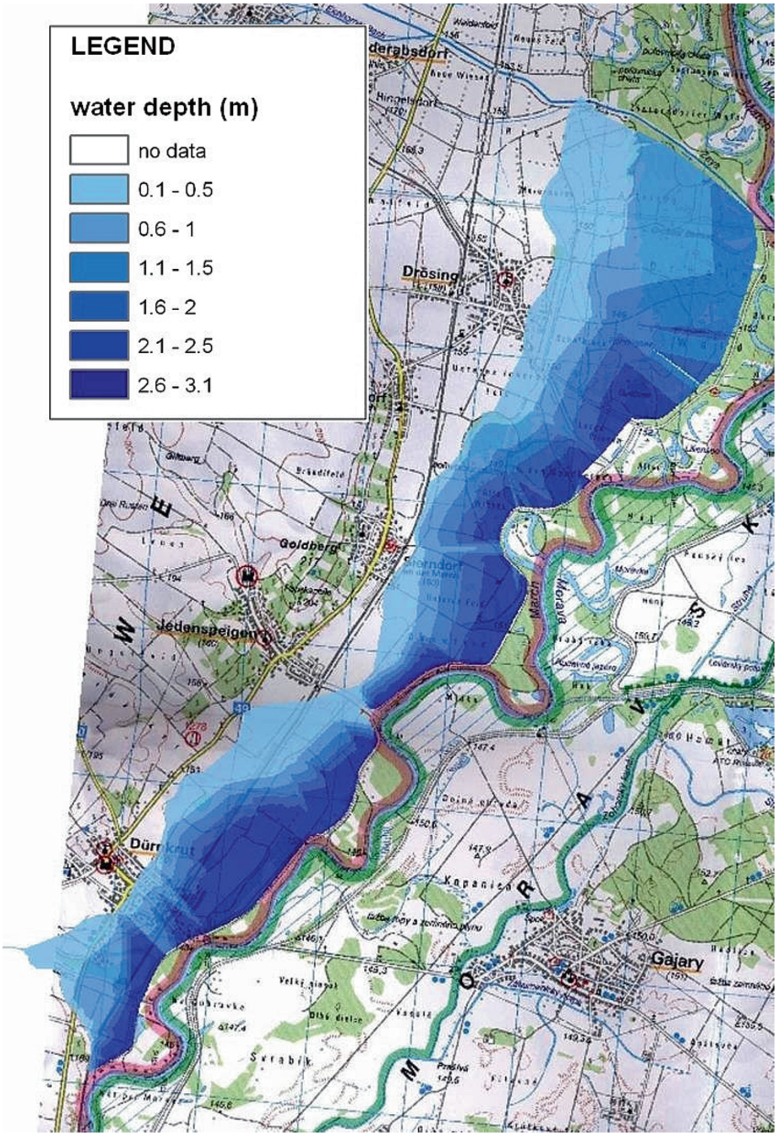

Figure 2. Map of flooding depth for the real dyke break at the Austrian side, prepared during 2006 flood

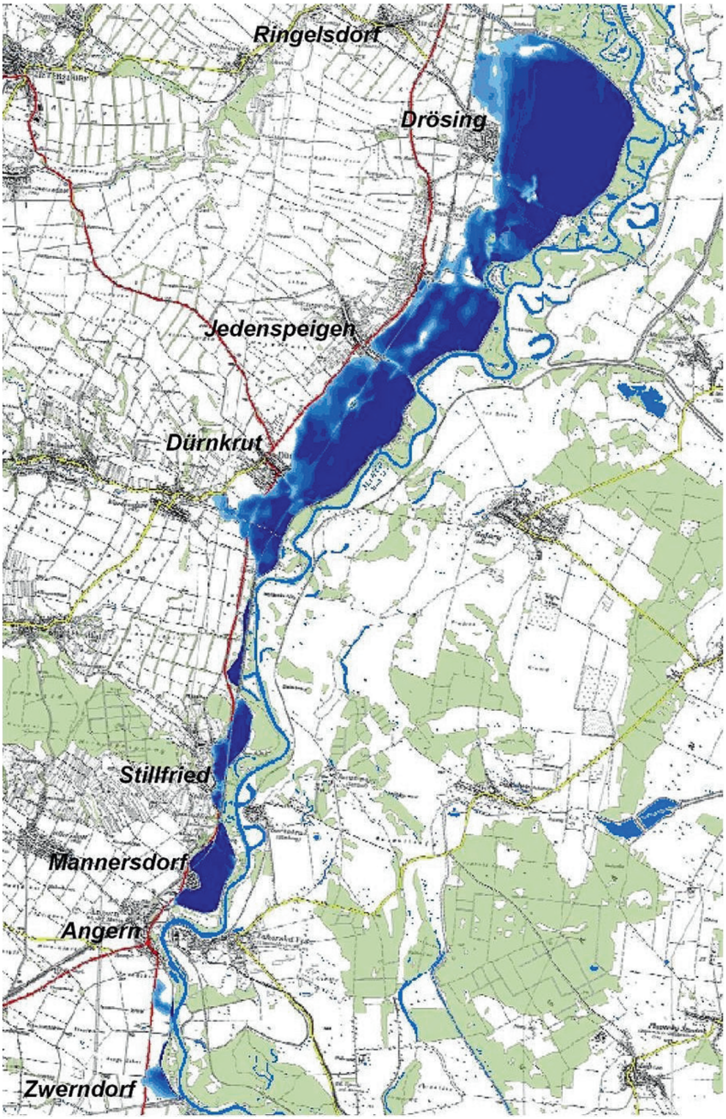

Figure 3. Austrian territory endangered with flooding for the case of overtopping the dykes at an extreme discharge

The cross sections of the terrain situated behind the flood dykes were extracted from the DTM in ArcView. Extracted cross sections were connected in model branches, which schematize water flow in a potentially flooded area. DTM was also used for the visualization of modelling results. The water levels simulated with hydrodynamic model were transformed into the DTM using the Flood mapping tool of MIKE 11, which enables direct export of ASCII files into ArcView.

Final visualization of modelling results was performed in ArcView, in the form of printed and electronic flood maps. Maps contain information on the water depth, water level altitude and flood extent (flood lines).

3. CONCLUSIONS

The numerical modelling and GIS tools were tested and applied in the frame of projects, as well as in the real situation for the elaboration of flooding maps for different hydrological inputs. The maps represent valuable tool for the analysis of dynamic processes, as well as for the decision support in the crisis situation. Applied methodology can be effectively utilized also in the evaluation of flood risk and modernization of flood management plans, in line with the prepared Directive of the EU on the flood risk management.

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DRINKING WATER SECURITY AND HEALTH IN TRANSYLVANIA, ROMANIA

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Abstract: The presentation concerns three central water supply systems which process conventionally the water from artificial reservoirs supplying drinking water for more than 750,000 people. Like in other many regions, these Transylvanian surface water sources face the microbiological and chemical contamination generated mainly by a poor management of wastes and municipal residual waters. Usually the quality of drinking water is negatively impacted by the source contamination (accidental or not), water treatment (its absence, low efficiency, interruption) and contamination in the distribution network due to the poor technical status of the distribution network. Those factors lead to lack of microbiological security maintenance and minimal changes of chemical parameters. The main health risk as a result of the improper drinking water quality is the microbiological one, and the means to keep this risk within acceptable limits involve each water treatment step and ask for specific actions.

Keywords: drinking water; safe water; water source; public health; water security

1. INTRODUCTION

From the public health point of view, water is a decisive environmental factor promoting health. The coverage of the population's needs for safe and sufficient drinking water is the most valuable indicator of the health status.

According to WHO (2004a, c), the poor water quality continues to pose a major threat to human health. Diarrhoeal disease alone amounts to an estimated 4.1% of the total DALY (the Disability Adjusted Life Year) global burden of

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disease and is responsible for the deaths of 1.8 million people every year. It was estimated that 88% of that burden is attributable to *unsafe water supply, sanitation and hygiene and is mostly concentrated on* children in developing countries.

Water resources are unevenly distributed between and within countries, leading to shortages in many areas. Romania is a poor country from the water resources point of view compared to other European countries, though it is not water stressed in the present; therefore, the proper selection and protection of water sources are essential in providing secure drinking water storage. Sometimes, one has to accept the actual and historical pollution of the water sources, and to take into account a water treatment technology according to them. Microbiological contamination remains the priority area of concern. The standard of treatment from source to tap varies widely across the European Region and in some areas does not always ensure safe water. Problems of chemical contamination occur locally, and can be circumscribed by appropriate techniques. Groundwater in the European Region is endangered and polluted by substances naturally present in harmful concentrations (e.g., lead, arsenic, fluoride, radon) or due to human activities, such as nitrate and pesticides.

The relationship between water and health arouses three essential problems:

- Quantitative restrictions related to water and their consequences upon human activities
- Maintaining the quality of water in terms of a growing demand for water
- Existence of direct link between water and health visible especially in case of diseases related to qualitative and quantitative shortage of drinking water and lack of proper waste waters treatment systems

Water security should be a priority for each community; in this regard the drinking water should have a quality which promotes and protects the public health, without a modification of natural resources or enforcing expensive treating and distributing technologies. The safe water expresses the accordance to the maximum admissible limits of the relevant water parameters for human health.

For centuries, the process of providing safe drinking-water has relied on the application of the “multiple barrier concept”. The concept of multiple barriers for water treatment is the cornerstone of safe drinking-water production (Mark W. LeChevallier and Kwok-Keung Au, 2004).

Traditionally, the barriers have included:

- Protection of source water (water used for drinking-water should originate from the highest quality source possible)
- Coagulation, flocculation and sedimentation
- Filtration
- Disinfection
- Protection of the distribution system

In Romania, 86% of the water sources are surface waters (lakes and rivers), which are preferable treated for drinking purposes because of the quantity advantage, despite their poor quality compared to the groundwater. The most important water sources in Transylvania for processing drinking water are the artificial lakes, both from the point of view of the water quantity delivered and number of consumers supplied. It is known that the health risk factors which can be associated with a drinking water treatment plant are related to the water contamination during treatment steps, the final disinfection efficiency, the distributed water quantity and the distribution continuity. This presentation concerns three central water supply systems in Transylvania which process conventionally (coagulation, decantation, rapid filtering, disinfection with chlorine) the water from artificial reservoirs supplying with drinking water more than 750,000 people.

2. METHODS

We made an information analysis of the surveillance data of the water sources, treatment process and water quality in the distribution networks, in order to identify the critical points and health risk factors. The analized central water supply systems are Cluj (Gilau water treatment plant), Zalau (Varsolt water treatment plant) and Hunedoara (Sanpetru water treatment plant), located in three different counties in Transylvania. We used the data for a period of 1 year of current chemical and bacteriological monitoring performed by the laboratory at the water treatment plant Gilau (the year 2005) and Varsolt (the year 2005) and expertise data resulted after a three consecutive days sampling for Hunedoara central supply water system (2004).

3. RESULTS AND DISCUSSIONS

Cluj Central Water Supply System

This system supplies the drinking water for more than 500,000 people from Cluj-Napoca town and other localities. The water source is Gilau artificial lake. Gilau artificial lake is built on Somesul Mic river following a system of artificial lakes on Somesul Cald river being supplied with water from Somesul Rece river and Agarbiciu creek.

During 2005, from the bacteriological point of view, the lake water quality was in accordance with A2 category for surface waters treated for drinking purposes (NTPA 013 quality of surface water used in water treatment plants). Generally, the analized chemical parameters permitted the framing in A1 category. In most situations a positive correlation was observed between the evolution of bacteriological, chemical indicators and turbidity.

On the whole it may be stated that Gilau water source frames in the A2 category for surface waters to be treated for drinking purposes (framing dictated by bacterial load). The water in Gilau lake has moderate variable characteristics concerning turbidity and organic load being influenced by the upstream hydrological system by the contribution of Somesul Rece river and Agarbiciu creek.

The following standard treatment technologies correspond to the A2 quality category: normal physical and chemical treatment and disinfection (pre-chlorination, coagulation, fluoridation, sedimentation, filtration and disinfection).

The water qualitative characteristics of Gilau accumulation are influenced by the downstream position of the lake in relation with a populated area with many utilizations, especially permanent residential and touristic. The pollution sources are mainly uncontrolled sources such as: domestic-faecaloid waste waters resulted from human agglomerations upstream of the lake which are not collected and spilled directly, or untreated uncontrolled storage of waste materials resulted inclusively from upstream touristic activities.

Gilau artificial lake has a rather unstable climatic stability as the change of the environmental factors has a direct influence upon it. Periods of prolonged drought may alter the quality of the lake water both from the physical chemical and biological points of view. On the other hand, during periods of heavy precipitation high floods occur (Agarbiciu creek and Somesul Rece river) which wash the soil and carry out big quantities of insoluble substances (suspensions) in water and as a result the water turbidity increases.

During the warm periods of the year (particularly) micro-organisms multiply, the content of organic matters increases originating from decomposition of vegetal or animal substances and besides the development of plankton biomass significant qualitative modifications of some physical indicators may appear.

The Gilau Water Treatment Plant

The Gilau water treatment plant is located ~18 km far from Cluj-Napoca, close to Gilau lake.

The bacteriological quality of the raw water entering the water treatment plant has the same progressive general characteristics of the parameters watched for the water from Gilau lake as presented above. However, by comparing the results of the bacteriological water analysis from Gilau lake with the water entering the water treatment plant it is obvious that in a short period of time (1–2 days) the quality of the water coming from Gilau lake may be significantly modified depending on the precipitations conditions.

On the whole, during the analized period, the raw water entering the treatment water plant framed in A2 category due to the bacteriological load with total and faecal coliforms in conditions of mainly small turbidities (maximum value 23 NTU daily average on 04.16.2005 and 180 daily average on 07.13.2005).

Starting with the daily average value for the raw water turbidity corresponding to the daily averages for decantated water turbidity the efficiency of the sedimentation step was calculated. Coagulation is not applied constantly because of the small turbidities of the raw water. An important inefficiency was observed and in rare cases corresponding or close to the recommended value (over 90%). It is common knowledge that Agarbiciu creek carries an important quantity of clay during precipitations periods or snow melting this substance preventing the process of coagulation/sedimentation with implications upon filtering efficiency and also the total efficiency of the station (most probably inadequate filters exploitation (clogging and inefficient washing). Rapid filtration which is not preceded by coagulation/sedimentation is not efficient, as the risk of bacteriological and parasitical contamination is maintained. The Ministry of Health recommends a minimum efficiency of 80% rapid filtration calculated based on turbidity and colimetry.

Disinfection efficiency was 100% in all cases, in conditions of hyper-chlorination (0.67–0.95 mg/L free residual chlorine compared to the standardized value of maximum 0.5 mg/L), thus correcting the inadequate bacteriological quality resulted after a filtration that is often not efficient.

The quality of the treated water going out the station was acoording to Law 458/2002 completed and modified by Law 311/2004 except for the free residual chlorine. Hyper-chlorination did not lead to excess development of secondary products (total trihalometanes 75% from the standardized value) due to the low content of organic matters.

Cluj-Napoca Drinking Water Distribution Network

At the level of the storage reservoires and the distribution network from Cluj-Napoca town water suffers minimum qualitative modifications compared to the water coming out from the treatment plant expressed by an inconstant increase of ammonia, nitrates and nitrites, without exceeding the standards for bacteriological contamination. Higher levels of nitrates, the presence of bacterial contamination and low values of free residual chlorine (0.1–0.15 mg/L) were observed inconstantly at the storage reservoires in Cluj-Napoca compared to the water quality at the emerging point from Gilau water treatment plant.

Analyses performed weekly in 26 points of the network in Cluj-Napoca pointed out the following aspects for the 2005 year:

– Bacteriological contamination reported by one or more indicators even at very small values in all sampling points and with preponderance during June and October
– Greater values for nitrates and nitrites than in the water coming out from the treatment plant, similar to those in the reservoires
– Ammonia traces

The free residual chlorine was measured at low levels in some points of the network, even below the microbiological safety value (0.25 mg/L), dangerous situation especially as the water in the reservoires presented bacteriological contamination.

Damages in the network (1.2 damages/km on pipe during June–December 2005) were concentrated in the low pressure area and are mainly in connection with the pipes wear. The total length of drinking water pipes in Cluj-Napoca is 451 km. Only 12% of the network pipes are less than 8 years old, while 41.71% of the pipes are 28–103 years old (cast iron pipes).

Zalau Central Water Supply System

It provides water for human consumption for Zalau and Simleul Silvaniei towns for a total of about 100,000 inhabitants.

Lake Varsolt represents the raw water source (accumulation on Crasna river).

The bacterial load characterized by the number of total coliforms and expressed as monthly average was greater during March–September 2005 being correlated with a very high level of precipitations.

On the whole Varsolt water source has moderate unstable characteristics regarding turbidity and the organic load. The period May–September 2005 is considered critical because of the organic load which required an increase of the treatment methods. From the comparison between the quality value indicators for the raw water in accordance with the legal stipulations resulted that the water source corresponds from the qualitative point of view at the place of sampling with the requirements of the application domain framing in the A1 and A2 quality categories. Framing in the A2 quality category results especially from the contamination of organic nature.

Similar to Gilau lake the qualitative characteristics of the water in Varsolt accumulation are influenced by the position of the lake upstream a populated area with many utilizations, especially agricultural even if big old live-stock farms do not function any more.

The main pollution sources are mainly not controlled sources (waste faecaloid-domestic waters, uncontrolled wastes deposits, etc.).

Varsolt barrier lake is a relatively small lake with an instable climatic equillibrium so that periods of prolonged drought and those with heavy precipitations may alter the quality of the lake water both from the psysical-chemical and biological point of view.

Varsolt Water Treatment Plant

The Varsolt water treatment plant is located 16 km far from Zalau, on the Varsolt lake shore.

Taking into account the daily averages of turbidity and total coliforms recorded in 2005 the total efficiency of sedimentation, filtration and dis-infection at the treatment plant was calculated.

The monthly averages of sedimentation efficiency calculated based on turbidity show values between 55% and 81%, but below the recommended ones (min 90%). Calculation based on colimetry shows higher values for efficiency (92–98%) as a result of pre-chlorination, especially during the warm period of the year. It is known that low temperatures favour water settling, bacteria survival in the external environment is longer while the disinfectant action of the chlorine is reduced.

Recommendations of the Ministry of Health stipulate a minimum efficiency of rapid filtration of 80% calculated based on turbidity and colimetry. Given this value the daily average efficiency of filtration calculated at Varsolt station based on turbidity during the analized period is generally smaller than the reference value. The calculation based on colimetry shows low values of efficiency with the mention that the bacterial load was significantly reduced as a result of pre-chlorination and sedimentation.

Although COD is not an usual indicator for calculating the efficiency it offers important information concerning the hygiene of decanters and particularly of filters. It was observed that efficiency of filtration was much lower than the efficiency of the sedimentation from this point of view. The cause consists in the fact that the sand blanket is maintained too long time in function so that the granules wear out, vegetal organisms colonization appears, clogging is more rapid, washing and filtration efficiencies decrease.

The total efficiency of the station was in all cases 100% (turbidity below 5 degrees and total coliforms below 50/100 mL). However the verification of the total efficiency through the calculation formula based on turbidity and colimetry showed values about 95% for turbidity and 99% for colimetry.

Disinfection efficiency was in all cases 100%, in conditions of hyperchlorination as shown above. The level of bound residual chlorine was in most cases 0.2 mg/L in the water going out the treatment plant. The proportion between the free residual chlorine and the total residual chlorine is in this case over 80.

The quality of the treated water going out the treatment plant is according to Law 458/2002 completed and modified by Law 311/2004 except for the free residual chlorine. Hyper-chlorination does not lead to form secondary products (trihalomethanes) in excess because of the efficient decrease of organic substances.

Zalau Distribution Network

In Zalau town at the level of the storage reservoires and in the distribution network water suffers qualitative modifications expressed by COD increase (without exceeding the standards) and decrease of the free residual chlorine in all distribution areas. Residual chlorine decreases substantially making uncertain the microbiological safety in some points of the network so much the more re-chlorination is made inconstantly with calcium hypochlorite at the level of the reservoires. Frequent damages in the network caused mainly by the pipes wear lead to appearance of ammonia and bacterial contamination of water in the network besides the qualitative modifications mentioned above (10.04.06). The pipes wear and intermittent chlorination with calcium hypochlorite at reservoires level is the cause for both fluctuating levels and most of the time insufficient or even not efficient of the free residual chlorine and of COD values. The total length of the drinking water network in Zalau is 102.6 km, from which ~50% are steel pipes and only 0.6% are crude iron pipes. 4.72 pipes damages/km were recorded during 2005.

Hunedoara Central Supply Water System

The Hunedoara central supply water system supplies with drinking water about 70,000 people.

The water source for this central supply water system is Hobita reservoir, situated upstream Hobita locality on Barbat River.

Water sampling (1–2 sample(s)/day) was performed on May 19 and May 20, 2004.

On May 19 at about 12 a.m. an accidental pollution occurred at 10 km upstream from the water captation point because of regularization works on the river upstream the captation point. That was the moment when pumping in the adduction pipe towards Sanpetru treatment plant was stopped. High water turbidity followed and water supply was restarted at about 6 p.m.

Although the turbidity was significantly higher the organic pollution indicators (chemical oxygen demand, nitrates, nitrites, ammonia, bacteriological indicators) had comparable values which indicated that the previous day pollution was not of organic faecal nature.

According to the NTPA 013 (quality of surface water used in water treatment plants) Hobita source is included in A1 category for which the simple psysical treatment and disinfection (rapid filtration) for obtaining drinking water is recommended – both from the psysical–chemical point of view and from bacteriological point of view.

Taking into account the distance of water transportation from Hobita captation to Sanpetru water treatment plant (~45 km) we compared the raw water quality entering the above mentioned plant and water quality at the captation point.

The raw water maintained the framing in A1 category. Some indicators suffered important modifications (chemical oxygen demand growth but not correlated to turbidity, diminution of ammonia, nitrites and nitrates growth). The chemical exam is correlated to the bacteriological water exam which shows discreet growth of the bacteria number due to the pollution accident.

Water transport from Hobita captation towards the water treatment plant is done at low pressure even if it is possible that pressure variations to occur as in any pipe system or even occurrence of a negative pressure followed by water contamination from the outside.

The calculated aggressivity index number shows that water is aggressive and it cannot form the protective layer of calcium carbonate but permits the pipe's colonization especially when the speed and implicit the water pressure are lower in the pipe. Thus it is most likely that the modifications of the water quality along the transport route to be produced from the inside of the pipe.

The Sanpetru Water Treatment Plant is designed to process conventionally the surface water from Hobita reservoir. Decantation is performed without previous coagulation. It has alternative water sources: Cincis reservoir and 2 drilled wells of medium depth (~40 m) which are used in case of high water turbidity at Hobita reservoir. It supplies the drinking water for Hunedoara town.

The raw water entering Sanpetru water treatment plant (source Hobita captation) is characterized by parameters framing category A1. As a result of the pollution accident at Hobita source on 19.05.04 starting from 12:30 p.m. the water supply from Cincis reservoir was used for the water plant (the water plant has the possibility to change the surface source and to mix it with water from drillings 2 and/or 4 as well as to use for processing only the water from drillings). At about 4:00 p.m. raw water turbidity (Cincis lake) increased over 70 UNT which imposed mixing the raw water with water from drillings. Sanpetru water plant does not coagulate the raw water before decantation.

Comparing the organic pollution indicators monitored in the raw and treated water from Sanpetru water plant highlighted higher values of ammonia, nitrates and nitrites in the treated water than in the raw water, even that all the values were within legal limits.

Two important aspects stand out: a pollution accident at the main source of raw water was followed also by alteration of the quality of the alternative surface source thus being necessary to mix water with underground water because the water plant cannot perform raw water coagulation; increasing the turbidity and organic load for raw water led to higher concentrations of substances indicating organic pollution in the treated water as a result of unsuitable filters washing and lack of coagulation previous to decantation.

In this 3 days of investigation period the free residual chlorine level was much lower at tanks outflow than in the reservoires of the water treatment plant at the distribution network inflow and at network ends/points where the values were much higher than the admitted limits. The average of free residual chlorine level recorded a decrease by 32% in the distribution network in Hunedoara in regard to the storage tanks of the town (from 0.97 to 0.66 mg/L).

In Hunedoara we face with hyper-chlorination at reservoires level and generally in the distribution network. Also, there is an important decrease of the free residual chlorine in the distribution network (network ends) correlated with distance increase (pipe length).

The main health risk as a result of the improper drinking water quality is the microbiological one, and essentially consists in epidemic or endemic waterborne diseases.

The official data reported by the Romanian Public Heath Authorities have not mentioned any waterborne outbreak disease in the population supplied with drinking water from these three presented central water supply systems in the last 15 years. Also, the incidences of diarroheal diseases and hepatitis A decreased starting with the year 2000 and were lower than at country level.

Water quality criteria for raw water used for drinking-water treatment and supply usually depend on the potential of different methods of raw water treatment to reduce the concentration of water contaminants to the level set by drinking-water criteria. Drinking water treatment can range from simple physical treatment and disinfection, to chemical treatment and disinfection, to intensive physical and chemical treatment. Many countries strive to ensure that the quality of raw water is such that it would only be necessary to use near-natural conditioning processes (such as bank filtration or low-speed sand filtration) and disinfection in order to meet drinking-water standards (Water Pollution Control, 1997).

There are many treatment options for eliminating pathogens from drinking-water. Finding the right solution for a particular supply involves choosing from a range of processes. Processes for removal of microbes from water include pretreatment; coagulation, flocculation and sedimentation; and filtration. For conventional treatment processes, chemical coagulation is critical for effective removal of microbial pathogens. Together, coagulation, flocculation and sedimentation can result in 1–2 log removals of bacteria, viruses and protozoa. The mechanism of disinfection within the distribution system differs from that of primary treatment. Factors important in secondary disinfection include disinfectant stability and transport into biofilms, disinfectant type and residual, pipe material, corrosion and other engineering and operational parameters (Mark W. LeChevallier and Kwok-Keung Au, 2004).

Water leaving water treatment plants should meet stringent criteria to provide assurance that pathogens are reduced to acceptable levels. The objective is not to provide sterile water to the consumer (which is neither practicable nor beneficial). Low levels of heterotrophic microorganisms indicate that the treatment and disinfection processes have been effective in removing or inactivating most pathogens (Pierre Payment and Will Robertson, 2004; September SM, 2007).

The microbial quality of water normally changes in a piped network. Although the changes often do not have health implications, there are many documented examples of serious contamination with pathogens occurring within the piped network (World Health Organization, 2004b). A drinking-water distribution system provides a habitat for microorganisms, which are sustained by organic and inorganic nutrients present on the pipe and in the conveyed water. A primary concern is therefore to prevent contamination from faecal material that might build up near pipes or contaminate surface or soil water. The traditional approach to verifying the microbial safety of piped public water supplies has relied on sampling strategies based on the tap water. Data from countries that have a surveillance system for waterborne diseases have provided numerous examples of the importance of a secure and well-operated distribution system in supplying safe drinking-water (AWWA, 1999; Pierre Payment and Will Robertson, 2004).

Current practice in many countries is to use disinfectant residuals to control the growth of microorganisms in distribution systems and to act as a final barrier, to help maintain the microbial safety of the water. Realistic residual concentrations only inactivate the least resistant microorganisms such as *E. coli* and the thermotolerant coliforms that are used as the main indicators of water safety (Payment, 1999). Absence of coliforms may create a false sense of security because many viral and parasitic pathogens are resistant to a low level of disinfectant. Therefore, the maintenance of a disinfectant residual or an increase in disinfectant dose should never be regarded as a substitute for the rigorous application of the operational and maintenance practices. However, the loss of chlorine residual can be used as an indicator of intrusion if an appropriate monitoring frequency is established, especially if continuous monitoring facilities are in place in the distribution system. In large systems, particularly where disinfectant residual is not maintained, nutrient levels should be controlled to reduce the potential for biofilm growth (Pierre Payment and Will Robertson, 2004).

Control of water pollution has reached primary importance in developed and a number of developing countries. The prevention of pollution at source, the precautionary principle and the prior licensing of wastewater discharges by competent authorities have become key elements of successful policies for preventing, controlling and reducing inputs of hazardous substances, nutrients and other water pollutants from point sources into aquatic ecosystems.

Water quality objectives provide the basis for pollution control regulations and for carrying out specific measures for the prevention, control or reduction of water pollution and other adverse impacts on aquatic ecosystems (Water Pollution Control, 1997).

In Romania water quality objectives play the role of a regulatory instrument and become legally binding. The water law in force since 2002 is in concordance with the European Directive.

Pollution in water supplies has always been a concern for water companies and with today's political climate the issue has never been more important. The requirements of Homeland Security and similar initiatives around the world require that water companies maintain detailed plans for how to react swiftly in the event of a pollution incident, whether accidental or malicious, and that they are ready to implement the plans effectively (Case Study, Environmental Expert, 2004). Source protection is particularly important when dealing with small, community-managed water supplies. Failures in source protection are likely to result in contamination of the water supply. Catchment protection has also been shown to be important in the control of pathogens in drinking-water supplies using treated surface waters (Hellard et al., 2001).

In fact, the treatment of drinking water has been acclaimed as one of the major public health achievements of the 20th century. Nevertheless, outbreaks associated with contaminated drinking water still occur in the United States, and a substantial fraction of waterborne illness may not be reported (Hauschild and Bryan, 1980; Bennett et al., 1987; Craun et al., 2006).

Recent estimates suggest that children younger than 5 years of age in developing countries experience a median of two to three diarrhea episodes per person–year. Moreover, children 6–11 months of age experience the highest median rate of diarrhea at five episodes per person–year (Snyder and Merson 1982; Kosek et al., 2003; Roy et al., 2006).

A water safety plan combines elements of a "hazard analysis and critical control point" (HACCP) approach, quality management and the "multiple barriers" principle, to provide a preventive management approach specifically developed for drinking-water supply. It can provide a framework for evaluating microbial control measures by helping to focus attention on process steps such as coagulation, filtration and disinfection, which are important for ensuring the microbial safety of water. Many current practices already employ some elements of a water safety plan, and this type of approach is likely to become more clearly defined in water treatment practices in the future (Mark W. LeChevallier and Kwok-Keung Au, 2004).

Dr. Lee Jong-wook, the General Director of WHO said: "Water and Sanitation is one of the primary drivers of public health. I often refer to it as "Health 101", which means that once we can secure access to clean water and to adequate sanitation facilities for all people, irrespective of the difference in their living conditions, a huge battle against all kinds of diseases will be won." (WHO, 2004).

4. CONCLUSIONS

Like in other many regions, these Transylvanian surface water sources face the microbiological and chemical contamination generated mainly by a poor management of wastes and municipal residual waters. Usually the quality of drinking water is negatively impacted by the source contamination (accidental or not), water treatment (its absence, insufficiency, interruption) and contamination in the distribution network due to the poor technical status of the distribution network. Those factors lead to lack of microbiological security maintenance and minimal changes of chemical parameters. The main health risk as a result of the improper drinking water quality is the microbiological one, and the means to keep this risk within acceptable limits refer to each water treatment step and ask for specific actions in order to maintain the water security.

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STRATEGIES FOR THE SUSTAINABLE DEVELOPMENT IN THE DANUBE DELTA IN ROMANIA, UKRAINE AND MOLDAVIA

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Abstract: Danube Delta is the largest humid zone in Europe. The diversified structure of the natural ecosystems, most of which were unaffected by human activity, have made the Danube Delta, together with the Razelm-Sinoe lagoon complex, a Biosphere Reserve. It has also been included on the list of International Natural and Cultural Heritage, and in the Ramsar Convention. As a direct effect of the flooding areas disappearance, the Danube Delta's capacity to retain nutrients has increased sharply since the 1980s. It is currently affected by eutrophycation, which has led to the reduction or loss of low water macrophitae, to changes in the range of periphytic and epiphytic algae, and to the spreading of rival species favoured by the nutrients in excess (for example, the blue–green bacteria *Cyanophyta*). Apart from the losses caused by eutrophycation, the Delta's biodiversity was and still is affected by the changes in (or destruction of) the habitats, by changes in the hydrological patterns. The latter are due to the creation of man-made channels or meander interruption, by transforming large areas into agricultural or fishing zones, or by the change in water quality (transformation of the Razelm lagoon into a fresh water lake).

Keywords: Danube river and delta; sustainable development; characteristics; biodiversity; ecology; ecological dynamics; anthropic impact; conservation; management

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1. INTRODUCTORY REMARKS

The value of the Danube Delta for biodiversity is broadly recognized in the level of protection afforded to them through international and national legislation. The Danube Delta has been designated as a Ramsar site. Other designations recognize the value for biodiversity. Of course, designation as protected areas alone does not guarantee the protection of the delta areas' biodiversity. Appropriate administrative structures to provide integrated management, appropriate management plans, and adequate resources for the implementation of management plans are all needed. It is notice that the main constraints on appropriate management are not, in the first place, scientific information, but personnel, the level of training, equipment, and last but not least, funds.

The Danube Basin

The Danube hydrographic basin of 817,000 km^2 stretches across the land of 17 countries. Of all, Romania is the greatest tributary to the river, its drained surface being of 228,580 km^2 (28% of the total Danube's drained surface). In fact, the Danube River drains 98% of Romania.

The Danube basin is divided in three sectors: upper basin, from the springs up to Devin Gate, middle basin from Devin Gate up to Iron Gates, in Romania and the lower basin: from Iron Gates to the Black Sea.

Romania is connected to the Danube River over a length of 1,076 (of which 166 km of the Danube Delta Biosphere Reserve borderline with today's Ukraine, actually an old Romanian land, the Southern Basarabia).

Once, in the Romanian Plains, next to the Danube, there were huge holms and sandbanks, with great environmental importance (being natural filters for any waste or polluting substances carried by the tributary rivers). It has as well a significant importance (fishing and wild life), that extended far beyond the needs of the nearby population. Unfortunately, between 1964 and 1985, the communist regime completely drained this area in order to obtain more farming land. The result was a disaster: in only a few years the soil was dry, salty, filled with chemical pesticides used to protect the crops, and the farming on the 435,000 ha drained became an illusion. The fish population and the wildlife were forever lost; the dams are continuously eroded by the strong current of the Danube or by floods and require a huge budget for maintenance and reinforcement. Across the whole Romanian Plains the drying of the underground reserves of water is obvious, thus leading to the death of the Plains' remaining forests and also to the continuous decrease in crops productivity. Could be a classical example of what can happen when the natural balance is perturbed.

Today, the Danube carries to the Black Sea 80 million tons of suspended substances every year, mainly bicarbonate, calcium, sulphur, sodium and potassium, chlorine, magnesium, but also nitrogen, phosphorus, oil by-products, metal residues; the average water mineralization being 324 mg/dm^{-3}. Another significant value is the biological oxygen demand (BOD 5), which is, on average 1–3 mg/dm^{-3}. The result is an obvious decrease of the Danube' fish population, both in quantity (100 times less today than in 1960) and in quality (the size of the fishes, the number of the species).

Regarding this drained area, it is probably more profitable and logical to flood the drained areas once again, in order to restore the natural balance of the region and that of the big Romanian Plains.

Regarding the Danube's polluting factors, it is most urgent to stop both the river's direct pollution and that of the tributary rivers – if not, within 20 years, the lower basin of the Danube will be lifeless.

Danube Delta

The Danube Delta is 75 km long EW and 75 km wide NS. Its total surface is 564,000 ha and until 1940 all belonged to Romania. Today 442,000 ha are Romanian land and 121,700 ha are Ukrainian land. Most of the surface is covered by water (65% permanently and up to 90% at flood time). The only firm lands are the two continental islands, but there are many major sand-banks, some of them with unique habitats (like the famous oak forest on Letea Sand Bank).

The reed-covered surface in the Delta is the biggest in Europe and other species are remarkable: oak, Turkestan ashtrees, aspen trees, crawling and climbing lianas). But the fame of Delta is due to its wealth in fish species (most important, the sturgeon family) and water birds.

Between 1878 and 1945 Romania invested in considerable channel and dam works so that navigation between the Black Sea and the Danube stream should be continuous.

After 1950, the Romanian communist regime (under some "friendly advice" from the soviets) came up with a plan for total and swift exploitation of the Delta, thus nearly destroying it.

– The first idea was of exploiting the reed for a paper factory built especially for that. The only result was the final and permanent destruction of 60,000 ha reed-covered surfaces and the knowledge that nobody can obtain paper using only reed.
– The second idea was that of changing a great part of the Delta into agricultural land. Many works have been achieved and in 1990 there were dams and drying installations for 50,000 ha. The result was pitiful.
– The third ecological attack on the Danube Delta involved changing part of the lakes and marshes into fishing ponds by surrounding them with dams. Exploiting them intensively in order to get huge fish production proved to be a disaster because the fish population didn't have time to recover and the biological (but also chemical) pollution of the waters increased to dangerous levels.

All these actions had two results: (1) considerable decreases of fishing production with 33%. (2) The quality of the fish also decreased, diminishing firstly the valuable species of fish (it is significant that the sturgeon production was reduced from 1900 to 1990 by more than 99%.

The whole fishing policy until now proved to be wrong and it must be ecologically reconsidered. Exploiting the forests is a real ecological attack, intensified especially after 1990, when the new regime gave the forests in Danube Delta to some private companies and not to Romsilva, an unique exception in the country. These companies executed massive deforestation without any concern for the future or for the natural balance.

Tourism also contributed to degrading the Delta especially by unrestricted hunting, which has led to some rare species of birds near extinction.

So, today's image of the economic – ecological situation of the Danube Delta is not satisfactory.

The Black Sea

The Black Sea is the eastern frontier of Romania over a length of 244 km and its continental platform of 200 km in North that gradually reduces to 100 km in South.

The shoreline presents three different aspects: (1) *low shoreline* of sandbanks; (2) *low shoreline* with sands; (3) *high shore* with vertical cliffs (mainly limestone).

The essential element of the sea's influence is a current, which moves sweeping the Romanian coast from North to South. The N–S coastal stream is the essential mechanism altering the Black Sea' shores, transporting the sand and mud brought by big tributaries (Danube, Don, Bug, Cuban, Nipru, Nistru) and depositing them along them coastlines, blocking the estuaries, deltas, and gulfs. But if dams block the rivers (like Danube and Nipru) the quantities of solid particles diminish and the stream erodes the coastal line.

The second effect of this circular stream is pollution of the seashore. This is a permanent action, due especially to local polluting agents.

For the sustainable development of The Black Sea (fishing, tourism, sea transport, etc.) the following measures to should be taken by every coastal country:

- To stop the pollution and filter the wastewater from cities, harbor and businesses placed on the coastal line
- For passing ships to strictly respect water pollution standards
- To create acquaculturing stations to regenerate the fish population
- To stop the pollution along the continental rivers tributaries to the Black Sea
- To find more efficient solutions of protection against the erosion of the shore

2. DANUBE DELTA AND ITS IMPORTANCE FOR GLOBAL NATURAL HERITAGE

The Danube Delta is Europe's greatest wetland, stretching over a vast area of more than 5,000 km^2 and channeling the water of the whole Danubian Basin into the Black Sea. Thus, Danube Delta is a vital center for biodiversity in Eurasia, a natural genetic bank with incalculable value for the global natural heritage but also an economic resource for Romania and for the adjacent countries (Ukraine and Moldavia).

For these considerations, the Romanian territory of Danube Delta has been declared a Biosphere Reserve in 1990.

The Program Man and Biosphere of UNESCO recognized the universal value of the reserve in 1990 through its inclusion in the international network of biosphere reserves. It was recognized with this occasion that the Danube Delta possesses unique and valuable features:

- It conserves examples of characteristic ecosystems of one of the world's natural areas.

- It is a land and coastal/marine area which people are an integral component, and which must be managed for objectives ranging from complete protection to intensive yet sustainable production.
- It is a regional center for monitoring, research, education and training on natural and managed ecosystems.
- It's a place where government decision-makers, scientists, managers and local people must cooperate in developing a model program for managing land and water to meet human needs while conserving natural processes and biological resources.
- It may serve as a symbol of voluntary cooperation to conserve and use resources for the well-being of people everywhere.

Having its legal basis established since 1930, when the first law to protect the natural monuments was passed, the study and the protection of the natural capital in Romania saw a steady development until the 1960s, thereafter falling into neglect and being completely abandoned in the 1980s. A few years after 1990, the conservation activity experienced a revival. The Danube Delta Biosphere Reserve was established, several international conventions regarding the conservation of the biological diversity were entered into, new environment protection projects and plans were drawn and the declaration of new protection areas was made. From 1993, though, the idea to conserve the biodiversity has again been abandoned and, as a result, no progress has been made in the field. Moreover, the objectives of the National Strategy for the Conservation of Biodiversity, elaborated in 1996, have not been achieved. Therefore, it is highly likely that due to the characteristics of the present period (confusing and contradicting legislation and overexploitation) and to the total lack of interest on the part of the institutions with responsibilities in the field, the situation of biological diversity in Danube Delta has worsened. It is difficult to know to what extent, as there is not enough information in this respect.

3. DEVELOPMENT AND PHYSICAL CHARACTERISTICS OF THE DANUBE DELTA

The Danube is the largest river in Europe; it runs through ten countries and with a catchment area of 805,300 km^2; it has by far the greatest impact on the Black Sea.

The Danube Delta can be divided into a number of discrete geographic units based on their morphological and biological characteristics. These are:

– Delta itself (including the three main river branches of the Chilia, Sulina and Sfantu Gheorghe channels)
– The secondary delta of Chilia channel in Ukraine
– The lakes from the North of Chilia channel, also in Ukraine
– The Razim – Sinoe lagoon complex
– The Black Sea coast out to 20 m depth
– The undivided Danube River East to Cotu Pisicii
– The Isaccea – Tulcea floodplain
– The Murighiol – Plopul saline plains

4. LOCAL HISTORY AND CULTURAL HERITAGE

Owing to its mild climate, natural richness and geographic location, people have been attracted to the Danube Delta and it has possessed economic, political and strategic importance since ancient times. The access to the river and sea made the region a major trading center and crossroad for human migration, even from the prehistoric period (Neolithic and Iron Age), then in the succeeding Dacian, Greek and Roman civilizations periods, in the Byzantine period.

As a result of wars with Russia and Turkey during the18th and 19th centuries, which meant that the delta region was under Russian administration until 1856 and then under Turkish rule until 1878, almost all evidence of preceding settlements was destroyed. Sulina town enjoyed a revival of economic and cultural importance between 1856 and 1940 that gave it a unique character among towns on the Danube; it born from the arrival and settlement of substantial Romanian, Russian, Ukrainian, Turkish, Greek and German ethnic groups, each of them with its own customs and religious practices. This diversity of culture is similarly reflected in all the smaller towns and villages in and around the delta at present time, in Romania, Ukraine and Moldavia.

5. LAND USE, PRODUCTION AND ZONATION OF THE DANUBE DELTA IN ROMANIA AND UKRAINE

The heterogeneous soils, landscape, climatic and hydrological conditions in the delta have played a major role in the land use of the Danube Delta. In Romania, local enterprises within the delta produce wide range of goods and services with a value of over USD 16 million per year (excluding shipping and industry). This same heterogeneity underlies the basis for the natural diversity, which led to the declaration of the biosphere reserve. The most extensive and important forms of natural resource use in the Danube Delta are fishing and reed harvesting, occurring over 3,306 km^2 (57%) of the reserve where there is a natural flooding regime. In Romania these areas are state-owned and controlled by the state, but the exploitation is carried out under license by both state-owned and private companies.

Fish farming takes place in custom – built polders, which occupy about 406 km^2 (7%) of the delta. They are operated by ten states-owned or joint venture companies (some of which also fish and harvest reeds outside the polders). The polders are state-owned and controlled by the regional council of Tulcea.

Agricultural land cover about 696 km^2 (12%) of the delta, comprising arable land (about 42%) that occur on the higher sandy soils and dry summer pastures. Of this land, 63% is state-owned under the control of regional council of Tulcea and use by six states-owned companies and several small companies and bodies operated by the regional council itself. A further 29% of the land is the regional council under the control of local councils represented by the mayors, and the remainder (8% is privately owned by the inhabitants, who generally raise livestock, grow vegetables and plant orchards and vineyards.

Among the land uses in the Romania's delta forestry is one of the more stable components in terms of land use. Forests occupy some 227 km^2 of which 187 km^2 are actually wooded (chiefly with poplars) and the rest are used for the other purpose or are not in productive use. Most of the planted forest (73%) has a protective function: to reduce erosion of levees and soils, to form windbreaks, and to provide shade and shelter for livestock.

Game hunting is an important activity for local people. It is carried out across 14 designated hunting zones occupying 1,435 km^2 of which 7% is in forestry land, 37% in agricultural land and 55% in the area used for fishing and reed harvesting. The local authorities are responsible for organizing and monitoring the hunting system.

Although the delta is an area which a high reputation in Europe and elsewhere in the world, the number of foreign visitors is very limited and use of accommodation is low. However, there is a great potential for developing environmental tourism if sufficient investment can be found for renovating and upgrading existing facilities to more modern standards.

6. VALUES AND RESOURCES UTILIZATION

The values of Danube Delta can be divided into products, functions and services. Each of the following aspects gives an overview of the relative importance of specific values in Danube Delta.

Let's look at products first. A wide variety of plants and animals, as well as mineral products and water, are harvested from Danube Delta, providing considerable economic returns to various stakeholders. Water-bird hunting occurs on almost the entire delta. In Danube Delta hunting is mainly recreational, although it also provides food for local people and considerable economic returns. For example, approximately 150,000 ducks are shot each year, increasingly by syndicated hunters from outside the area. The hunting of mammals occurs in a smaller proportion and is considered less important. The commercial exploitation of fish was recorded in all but one of the deltas studied. Fish is generally considered to be an important product. Extensive fish farming in the natural wetland areas occurs in several sites of Danube Delta. Exploitation of the vegetation occurs through:

- Grazing, which occurs in all of the deltas and is considered relatively important
- The cutting of reeds, particularly for thatching, is less widespread, but is important
- The extraction of wood for fuel or timber is not relevant in Danube Delta

The exploitation of the water resources was by far the most significant non-wildlife product, particularly water used for irrigation, but also domestic water supply. This exploitation was mentioned as a major threat to natural areas, due to unsustainable levels of abstraction.

Secondly, let's consider the functions of Danube Delta. The delta studies have a wide range of functions, including groundwater recharge and discharge, flood control, sediment, toxicant and nutrient retention, shoreline stabilization and storm control. Of these, the most important were considered to be groundwater recharge, toxicant and nutrient retention, shoreline stabilization and sediment retention.

Now let's consider the results about services on Danube Delta. It is also provide a wide range of services important to people. Amongst those identified the importance of Danube Delta for supporting biodiversity stand out. Other services were the recreation and tourism values, although eco-tourism was rather poorly developed in Danube Delta. The importance of deltas for research was also considered significant. Danube Delta had important culture or heritage values, reflecting the long history of settlements in the areas. Danube Delta provides important services for transport and trade, and for associated human settlements.

7. BIODIVERSITY AND ECOLOGICAL DYNAMICS IN THE DANUBE DELTA

The Danube Delta is Europe's largest delta and holds wetland areas that are among the least spoilt in the continent. It is internationally reputed for its bird populations, both in terms of sheer numbers using the area and in terms of rare species, including white pelican *Pelecanus onocrotalus*, pygmy cormorant *Phalacrocorax pygmaeus*, squacco heron *Ardeolla ralloides*, glossy *ibis Plegadis falcinellus* and red-breasted goose *Branta ruficollis*. Its mosaic of habitats is the richest in Romania Ukraine and Moldavia and supports a wide variety of interesting communities of plants and animals (so far numbering over 5,200 types), including many species that are important at regional and even global level. Fish biodiversity is very high with over 70 species (including several types of sturgeon). The majority of these (40) are specific to fresh water species, the others are migratory: they live both in the Black Sea and in the delta/Danube River for reproduction.

Over the last four to five decades, however, the delta has suffered deterioration in habitats and loss of species caused by the impact of a range of related factors, including:

- Construction of dams upstream which has subtly altered the flooding regime
- Creation of agricultural and fish polder in the delta which reduced the original natural area by over 20%
- Increased nutrient levels in the water (known as eutrophication) leading to dramatic losses of aquatic plants and changes in fish communities, due to the use of nutriments in agriculture in all the Europe
- Industrial pollution and effluents that accumulate in fish an then in the eggs of fish – eating birds like pelicans and cormorants, so reducing their breeding success
- Extension of canals for navigation that carries polluted and sedimented water all over the delta and reduces the overall drainage time during the flood period, leading to great changes in lake hydrology and poorer water quality both in Romania and Ukraine

- Mis-management of fish and reed resources that has lead to the development of a black market in fisheries and a collapse of reed harvesting both in Romania and Ukraine

In Romania the best remaining natural areas have been protected within core zones where biodiversity can be studied and from which local genotypes of species can be collected for habitat restoration in future. But these protected areas must extend in the Ukrainian and Moldavian zones of the Danube Delta.

In the present period, the main problems connected to the biological diversity and conservation in Danube Delta are:

(a) Specific diversity

- Although, unlike the fauna – where there are blank areas with respect to the number of species living on the territory of Danube Delta, due to the important number of insects species – the number of botanical species is known. In both categories only limited data regarding the present situation of the natural populations of the various species is available.
- The lack of information regarding the present state of most of the wildlife does not allow for the evaluation of the extent to which these species are threatened or nearly extinct and this is what makes them so difficult to protect.

(b) Ecosystem diversity

- There is no available data about the existing types of natural ecosystems, their distribution or their weight on the whole territory of Danube Delta. The programme of ecological zoning developed in the last decade was concluded at the level of the secondary eco-regions and therefore there is some data about the most endangered species.

(c) Conservation

- Since the 1950s, when there were 23 protected plant species and 24 protected animal species in the Romanian territory if Danube Delta, no further species have been placed under protection.

(d) Legislation

- There are numerous legal contradictions (Environment Act and the Forestry Code, Hunting Law and the Bern and Bonn Conventions, ratified by Romania).
- International conventions on the biodiversity conservation ratified by Romania, which, according to the Constitution, become an integral part of national law, are neither observed, nor put into practice.

8. THREATS TO BIODIVERSITY AND NATURALNESS

The threats to biodiversity can be divided into two groups: one that result from human action outside the delta territory, and another due to unsustainable human action within the delta.

Water Quantity

Humans have modified the river discharge to the Danube Delta, mainly by hydrotechnical works (particularly dams) in upstream river sections. Such interventions were generally considered the most important threat recorded. These changes affect many aspects of the functions of Danube Delta, but are particularly important for migratory fish species, and also flora and fauna, which depend on specific flooding patterns.

Increased drainage intensity and decreased water storage in the catchment cause increased amplitude and a shortened duration of floods. Storage lakes for hydropower production cause a leveling-off of the flooding regime in Danube Delta, especially of the minor floods outside the main flood season.

Sediment Supply

Regulation of the upstream sections of a river tends to reduce the sediment transported to delta. Most of the bed load, and part of the suspended sediment, are trapped in storage lakes. Sediment transported to the Danube Delta was reduced in the past decades by the construction of the Iron Gates Dam in the Danube itself and by numerous minor dams in the Danube at the apex of the Danube Delta was reduced by about 30%.

Sea Level Rise

Not only the upstream conditions influence the development of deltas – "downstream conditions" such as sea level rise have an influence as well. In fact, a relative rise in the sea level is a precondition for the development of a delta as a river's mouth. But a rapid acceleration in the rise of the sea level at least increased the wave action, causing erosion at the delta's marine margin. That is why the very famous and profitable beaches of the Romanian Black Sea coast narrowed in the last two decades, affecting the ecological equilibrium of the Romanian mediolitoral.

The Biosphere Reserve's Black Sea coastline, with a length of almost 200 km, is currently affected by an intensive and continuous degradation caused by marine erosion. *The shoreline is shrinking at an annual rate varying from a few meters to 15–20 m for the coastline of the delta (between Sulina and Cap Midia) and around 0.2–0.5 m for the coastline with sea cliffs (in South of Constanta).*

Erosion along the coastline is both natural and man-made. From among the human activities of great impact on the situation of the coastline one may mention the hydro-technical works on the Danube and its main tributaries, the ports, and coastal engineering works. The hydro-technical changes performed on the Danube and its main tributary have caused a fall in the inwash of sediments in the coastal area by over 50%, as compared to the values registered before the building of the dykes. Thus, a great sedimentary imbalance has been created in the coastal zone, which has in turn initiated the erosion process. The port facilities and other technical coastal engineering works such as the protection dykes for the Sulina navigation channel, the breakwater piers of the Midia, South Constanta and Mangalia ports, the coastline protection works on the tourist beaches, which also cause large environmental imbalance along the littoral.

Concerning the tendencies, I should say that considering the global climatic changes and the general rise in the sea level, as well as the regional geo-ecological conditions that characterise the Danube – Danube Delta – Black Sea geo-system, one can estimate that the medium-term erosion process will be at least as active as in the past two decades. The long-term predictions reveal an extension of beach erosion, especially because of the continuous decrease of sand material in the coastal area, because of the permanent rise in the sea level and an ever-higher energy level of the hydro-meteorological factors.

Many countries consider the problem of losing land by erosion of their coastline to be of national importance. Beach erosion leads to territory loss, but it especially compromises the tourist industry, causing significant losses to national economies. The process of erosion also disturbs at times the ecological state of the coastal area almost irreversibly.

Changes in the Land Use

One of the greatest threats to the biodiversity and naturalness of Danube Delta has been the conservation of natural areas for other purposes. This has been principally for agriculture, industrial zones, forestry, fish farms etc. The area of natural habitat (particularly wetlands) in Danube Delta has been greatly reduced in the past. In Danube Delta a portion of the delta remains as natural habitat, mainly due to strictly protection of the scientific interesting areas. Now, I can express optimism, due to the international designation of Danube Delta under the Ramsar Convention and European Directives would reduce the risk of further losses.

9. MAIN IMPACTS ON THE NATURAL ECOSYSTEMS OF THE DANUBE DELTA IN THE DANUBE BASIN

Over the last 50 years there has been an increasing rate of economic development and resource use within and around the Danube Delta. This trend has lead to a situation where the natural ecosystems and their resources are now under severe threat of collapse, particularly as a result of air and water pollution. Recent research into environmental quality has shown many sources of such pollution and human impacts (factories, agricultural chemicals, human waste), which is actually greater around the Danube Delta than it is within it. For example, while the human population living in the Romanian delta is less than 15,000, the population living in the towns and villages around its borders in Romania is over 145,000 (about the same number live along the Ukrainian stretch of the river).

The use of the main river branches by commercial shipping is one of the principal sources of air and water pollution, not only from the boats (exhaust fumes generate noxious gases and introduce sulphur, lead and vanadium into the water) but also from associated docks and shipyards where wastes (oil, metal ores, garbage, sewage and hot water containing detergents) are often discharged. Other impacts of navigation include bank erosion from wash due to use of unsuitable craft and high speeds, which then causes high water turbidity from the suspended sediments; disturbance of feeding and nesting places for fish and birds (from wash, noise and vibration); and direct destruction of aquatic plants and animals from propulsion systems.

Very little industrial activity takes place within the Danube Delta, but several factories exist close-by, particularly in Tulcea as a deliberate attempt to generate economic growth and provide local employment. The most significant of these are two factories which manufacture alloys for use in steel production and which do not have smoke filters. Wastes from these factories mostly comprise combustion products (at least 30% of the solids and 80% of the gases) which are transported into the territory of the Danube Delta by air or by water. The smoke issuing from the factories contains ash, coal dust, hydrocarbons, sulphur dioxide, chlorides, fluorides and many other toxic compounds. Moreover, the smoke particles are very fine and persist in the atmosphere for long periods; these are generally washed out by rain so that they have highly acidic episodic impact rather than a consistent, less harmful deposition. In addition, the solid wastes comprise ash with a high concentration of heavy metals, silica and titanium, which are dumped on the edge of the Danube Delta, where it is subject to windblown and leaching by rainwater.

There is another factory, which manufactures alumina, also causes a high degree of air and water pollution when its filters are not operating properly, or the processing of bauxite is not carried out correctly. The factory uses 12,960 m^3 of water per day, of which 10,366 m^3 is returned to the river with a high likelihood of chemical contamination. When the filters are not operating, very fine particles are released. RAACET Tulcea, which supplies the town hot water system, is the largest consumer of water in Tulcea, taking 73,440 m^3 per day, of which 51,840 m^3 is returned. It has no water treatment plant, so this effluent contains an increased level of dissolved materials.

The main sources of pollution arise from the overuse of chemicals, especially pesticides that persist in the soil and accumulate in the food chain. For example, in 1992 levels of the chlorinated hydrocarbon ppDDE found in the eggs of pygmy cormorant *Phalacrocorax pygmaeus* (up to 57 mg/g dry weight) and white pelican *Pelecanus onocrotalus* (up to 15 mg/g dry weight) are among the highest found anywhere. Such concentrations cause thin eggshells and embryo defects that greatly reduce breeding success. Today, the pesticides used in the Romanian Danube Delta Biosphere Reserve are biodegradable with low persistence. However, recent research shows that levels of persistent organochlorine pesticide residues derived from DDT and HCH remain high 10 years after they were prohibited. In fact, these residues are also present in the river water entering the Danube Delta, indicating transport from other sources.

The heavy use of fertilizers, especially in upper reaches of the Danube catchment, combined with a lake of sewage treatment facilities, has lead to very high concentrations of nitrogen and phosphorus in the waters entering the delta. These nutriments encourage the growth of algae, which displace other plant species and, through deoxygenation of water, cause the death of aquatic invertebrates and fish.

Arable farming in the Danube Delta involves pumping water for irrigation, which is another impact. Around the Lake Razim – Sinoe complex, for example, fish screens are not installed at the pump-house intakes so there is heavy mortality of fingerlings. Elsewhere, the pig-rearing units can cause serious damage from the discharge of untreated slurry.

With more than 1,000 km along an in the Romanian territory, the Danube, together with its overflow meadows and delta, has always represented an important part of our natural capital. As a result of the human activity upstream and in Romania (which has 98% of its territory in the Danube basin), changes have occurred in the hydrologic regime as well as in the quality of water. These have had a negative influence on the ecosystems found in the Delta and on the north-western coast of the Black Sea.

The embankment works executed in the 1960s on approx. 800 km along the Romanian border in order to obtain new land have practically led to the disappearance of the flooding areas. As it happens in large systems, the ensuing effects appeared much later and were obviated by

- Eutrophycation of Danube Delta waters, and partly of those in the north-west Black Sea, due to the elimination of the filtering effect caused by intensive agriculture and non-filtered streams from towns along the rivers (possible only in the presence of the flooding areas)
- Changes in the specific diversity of fish and the dramatic decrease in fish populations with great economic value (especially carp), due to a lack of shallow water zones in the flooding areas, which is needed for their reproduction

Another factor, whose detrimental effects were not initially considered, has been the building of dams and water reservoirs for the electric power supplies. Their appearance has led to changes in the flood patterns and to a fall in the quantity of alluvia carried by the Danube, due to water decantation. It has also caused major distortions in the Romanian coastal ecosystems. Another effect caused by dams was the disruption of migration paths for the reproduction of valuable sturgeon species.

Danube Delta is dynamic, changing structure. In its natural state it is permanently shaped and re-shaped by three different factors:

- Sediment input by the river
- Wave action from the sea and lakes
- Energy of tidal currents

Its position as a link between Black Sea, the river, and the mainland gave Danube Delta a major function in transport and trade. Its high biological productivity also made it an important source of food. Danube Delta is by nature highly open system. It is greatly influenced by all human interference in the upstream sections of the river. Its sensitivity to external influences forces those responsible for management of the Danube Delta to take various restrictions into account, and sometimes to deal with hazards resulting from actions beyond their control.

Danube Delta ecosystems sustain a rich and specific flora and fauna, which are in decline so long as the human interference will continue. Over the past decades, the specific value of the Danube Delta as a natural biome has become a point of increasing concern for those involved in delta management and development. Today, Danube Delta development has a deal with many, often contradictory objectives, of which the conservation of natural values is only one. How can biodiversity and naturalness be reconciled with the conservation of these delta resources? To put it in simpler words: *How to deal with nature in Danube Delta?*

10. LEGISLATION FOR CONSERVATION AND DEVELOPMENT IN THE DANUBE DELTA

In Romania the activities carried out within the Danube Delta are regulated by laws, government decisions, decrees and order of the Ministry of Water, Forests and Environmental Protection. This regulatory framework was established before and after the government reform of 1989 and largely covers the range of problems concerned with nature conservation and human development within the Danube Delta.

The most important act is the Law No. 82 of 1993, which confirmed the establishment of the biosphere reserve promulgated by Government Decision from 1990. It also sets out the arrangements for administering the reserve and managing human activities within it, mainly by the creation of the Danube Delta Biosphere Reserve Authority itself as a regional environmental agency. The low delineating the boundaries and internal zones of the reserve and authorizing the statutes of the Authority.

The Romanian legislation relating to nature conservation and natural resources use in the Danube Delta have the next scopes:

– Designation of the Danube Delta Biosphere Reserve (DDBR)
– Establishment of DDBR Authority
– Delimited borders and zones in DDBR

- Created statutes for the DDBRA and appointed Scientific Councilors
- Provisions for environmental protection in developments projects
- Establishes penalties for environmental damage
- Protection of waters
- Establishes penalties for polluting navigation waters by shipping
- Concerning fisheries and fish farming
- Hunting regulations
- Forest conservation and use
- Return of arable land to private owners
- Protection of crops and forest using chemicals

In addition, Romania is a Party to five international conventions that are applicable to the management of the Danube Delta:

- Biodiversity Convention (Rio de Janeiro, 1992)
- Convention for the Conservation of European Wildlife and Natural Habitats (Berne)
- Convention on the Prevention of Marine Pollution (London, 1973)
- Convention of the Protection of World Cultural and Natural Heritage (Paris, 1972)
- Convention on Wetlands of International Importance Especially as Habitat for Waterfowl (Ramsar, 1971)

11. ADMINISTRATION AND MANAGEMENT OF THE DANUBE DELTA

Administration and management in the Danube Delta is a complex process, which must be separate from but linked to the local government structure both in Romania, Ukraine and Moldavia. There must be lands under national control, lands under local government control, and land with a privately owned. The local district councils must take the lead for all decisions relating to land under their control, including development planning and control, public works, conserving historic monuments, and providing recreation facilities and protection and improvement of the environment to enhance the quality of life.

The superior level of government must coordinate various services on behalf of the district councils, as well as taking responsibility for land under its own control, town planning and maintaining and improving infrastructure such as roads and water supply. The district councils must control in these areas land comprising fish, agriculture and forestry polders, which may be use by companies in which the state has the majority ownership.

Also, must be establish in each country special administrative regimes for the conservation and protection of biological diversity in the natural ecosystems of the zones, to develop human settlements and to organize economic activities in accordance with the carrying capacities of those ecosystems. These special administrative regimes must have a range of duties, for examples:

- To assess that ecological status of natural resources, organize scientific research, elaborate a strategy for conservation and improvement and protection of the genofund and biodiversity
- Identify, delimit and propose the designation of functional zones of each area and mark them with signs and notices to avoid deleterious impact
- Act as a regional environmental agency and must issue licenses and permits for economic and social activities
- To establish and apply measures for restoring damaged delta's ecosystems
- To collaborate with local public authorities in order to protect the interests of the local population, to conserve their cultural heritage and to improve the quality of life and living standards
- To cooperate with international bodies and interested national and foreign institutions and promote cooperation in scientific research and exchange of information relating to the restoration of the Danube Basin, Danube Delta and Black Sea region
- In accordance with the specific legislation and based on the results of scientific research, to set up concessions for the use of renewable natural resources
- To propose for the approval of the district councils the fees for licenses for local people to use of renewable natural resources (farming, apiculture, grazing, hay – cutting etc.)
- To carry out actions for ecological education and public awareness
- To monitor and control the disposal of waste, especially toxic and dangerous materials, the treatment and neutralization of waste, or its removal from the Danube Delta, as well as removal of disused terrestrial and marine machinery
- To propose to the Governs the regulation for navigation and access for shipping and boats on the main river branches and on the smaller channels

For carrying out these duties, a series of communication and cooperation mechanisms must be establish with the order local government bodies and agencies operating within the Danube Delta.

12. MONITORING AND EVALUATION

The objectives of the monitoring and evaluation component of the strategy for sustainable development in Danube Delta should be to assist the decision-making process by ensuring the credibility of the proposed objectives and to supply the necessary corrections along the way. At the same time, the mobilisation of local and central governmental institutions is ensured by feedback mechanisms, so that the general public can make its contribution to the application of the strategy.

Fundamental characteristics of the monitoring and evaluation component in Danube Delta are:

- Interpretation, evaluation and integration of data at a high level in order to generate aggregate data
- Overview of the spatial and temporal trends
- Monitoring of the connections between the social-economic areas and the field of environmental protection in the context of sustainable development

In order to achieve these three fundamental objectives, the main questions that have to be asked in connection with the monitoring and evaluation of the Danube Delta's strategy for sustainable development the following:

- What is happening? *What are the conditions and trends of environmental changes?*
- Why is it happening? *What causes these changes?*
- Are the changes significant? *What are the implications for health, economy and environment?*

In addition to these basic problems, there are a number of objectives that must be anticipated by the monitoring and evaluation component. Therefore, this component must draw attention to the urgently needed steps to be taken for environmental protection, as well as identify the flaws existing in the domain of information and knowledge that have an impact on how the environmental conditions are interpreted. These objectives must contribute to the evaluation of society's answer to the environmental issue and encourage the integration of environmental considerations into economic and social development policies. Finally, the monitoring and evaluation component must contribute to the increase of institutional capability to honour international agreements.

The component for monitoring and evaluation is a need that results from Chapter 40 of the "Agenda 21" which requires the countries that participated at the United Nations Conference for Environment and Development to improve their monitoring, evaluation, and reporting system of the progress made, as a pre-requisite of sustainable development.

If a strategic monitoring, evaluation, and reporting component is established for sustainable development in Danube Delta, a set of guiding principles are needed.

– The most important step is to establish the role of the decision-makers, which includes governmental decision-makers, corporate executives, educators, and public decision-makers. This involves ensuring an intensive contact between participants in the process.
– Diversity within ecosystems must be taken into consideration; starting from the fact those natural systems are finite and have a limited capacity for sustainability.
– The integration and objective interpretation of data and information regarding the Danube Delta's environment represent the profit that can be derived from monitoring, evaluation, and reporting. The role of the monitoring, evaluation, and reporting component is a co-ordinating one. This component will transmit integrated and aggregate information to the existing organisations and will supply a coherent structure for a thorough, comprehensive report, credible and continuous in the sense of sustainability. This can be achieved only on the basis of a genuine partnership between institutions (governmental and non-governmental) that function at different administrative and private sector levels.
– It is important to base this component on a conceptual framework that will facilitate the development of an informational system able to respond to the main problems of Danube Delta Biosphere Reserve, and to connect the environmental and socio-economic factors.
– Regarding the territorial component, the supply of data and information to the administrative and institutional framework is desirable. This could be achieved by using, for instance, geographical information systems (GIS). Danube Delta's ecosystems, compared on a uniform scale, must be ranked

in a system that will make it possible to add and collect data. They must also be defined in the perspective of the entire ecological system, which includes climatic, geographical and geological, soil, wildlife, and water conditions, as well as the results of human activity. From the perspective of the time that it addresses, this dimension should lead to the analysis and interpretation of past, present and future trends, making and providing an environmental diagnosis and forecast. Until now, the practice was based only on retrospective analysis. However, forecasts regarding the state of the environment in Danube Delta are important decision-making factors in the process of sustainable development.

- The monitoring, evaluation, and reporting component must be based on ensuring a balance and completeness of data and indicators that will adequately reflect environmental conditions and trends as well a socio-economic development in a sustainable context.
- The niche of the monitoring, evaluation, and reporting component is reserved to scientists and experts as well as to decision-makers. A scientific base is needed in order to insure credibility, but the interpretation and analysis made by this sector only becomes efficient when scientific knowledge is transformed into useful information for the decision-making process.
- In order to be efficient, the monitoring, evaluation, and reporting component must be transformed into a product designed to satisfy the needs of a large spectrum of users. A simple periodic reporting is not enough to ensure the existence of a viable reporting system that will lead to an increase in the awareness of the local population, who will pressure Danube Delta Biosphere Reserve Authority to make decisions. Such products are maps, audio-visual and electronic products, as well as traditional publications. The dissemination of this information must be continuous and on a broad basis.

In order to ensure the success of the sustainable development in Danube Delta Biosphere Reserve, the clear defining of a system of indicators and the implementation of an adequate information system that will allow the monitoring and evaluation of human development in Danube Delta is needed. This evaluation will be accepted and useful as a basis for decision-makers involved in the process of sustainable development of the reservation. This includes decision-makers from the public, private, and non-governmental organisations sectors.

In this context, the monitoring, evaluation, and reporting component in the framework of the implementation of sustainable development ensures:

- Public awareness
- Education and motivation of the public
- Development of politics;
- Evaluation of achievements
- Improvement of the scientific basis of data integration and information and their aggregation.

In this perspective, it is obvious that this monitoring, evaluation and reporting component will extend its scope and concentrate on forecasting environmental conditions and social economic development, instead of merely focusing on past problems.

13. INTERNATIONAL MANAGEMENT OBJECTIVES AND PROJECTS FOR THE SUSTAINABLE DEVELOPMENT IN THE DANUBE DELTA

Therefore, Romania, Ukraine and Moldavia must elaborate common political and environmental strategies for the sustainable development in this region, materialized in common management objectives and projects, in the spirit of Agenda 21.

The general management objectives for these countries should focus on the improvement of the overall ecological status of the Danube Delta. It is therefore important to have good legislative framework and long perspectives plans for saving one of the world's most important wetland:

- Developing and implementing those measures required as a consequence of the international commitments assumed by Romania, Ukraine and Moldavia
- Developing and maintaining an integrated database comprising information necessary for management of biodiversity conservation and use of resource within their carrying capacity
- Protecting and maintaining populations of species and habitats with high ecological value on the whole the territory of the Danube Delta
- Identifying recently extinct and endangered species within the all Danube Delta and identifying suitable habitats in order to restore their populations

- Ensuring the proper management of reedbeds
- Carrying out research on the natural operations and functions of the natural delta's ecosystems
- Managing the circulation of water in the ensemble of Danube Delta in order to improve the ecological conditions in the lacustrine zones and adjacent areas
- Carrying out ecological restoration works where the natural or semi-natural character of areas has been lost as a result of human activity
- Improving the monitoring of the environment's quality in Danube Delta in each riparian country, its integrating with the each national monitoring system
- Identifying critical areas and sources of pollution, which have an important impact on the Danube Delta and develop zonal controls.
- Formulating a regional action plan to deal with cases of accidental pollution
- Encouraging economic activities but only as far as these do not cause damage to the delta's ecosystems or conflict with the objective of maintaining biological diversity
- Improving the quantity and quality of data available on tourism activity in the Danube Delta
- Facilitating tourism activity that is in harmony with the ecological objectives of the Danube Delta, in a particular to guide appropriate investments in the private sector
- Promoting sustainable development of agriculture in Danube Delta
- Investigating the potential for extending the boundary of Romanian Danube Delta Biosphere Reserve in Ukraine and Moldavia
- Cooperating with internationally organizations to generate support for the Danube Delta's preservation

The management objectives for the sustainable economic use of the wetland should ensure that the development of the economic activities does not affect the ecological equilibrium of the zone. One the other hand, the identification of new economic activities with less impact in the environment is important:

- Protecting and conserving the morphology of the Danube Delta coastal zone
- Institute a common system of management for the sustainable utilization of natural resources of the Danube Delta in Romania, Ukraine and Moldavia
- Developing and improve fish farming on the basis of economic efficiency

- Improving the marketing of products from the delta
- Developing of ecological tourism, producing handicrafts, growing organic food and other similar activities in which the local people are directly involved

For the buffer zones and strictly protected zones from the Danube Delta Biosphere Reserve (in Romania), special strategies should be designed in order to ensure the conservation of the existing natural heritage. In addition, habitat restoration measures are needed:

- Assess the effectiveness of existing buffer zones and, if necessary, recommend modifications to their management or their limits.
- Create an adequate legal frame in order to develop measures for conservation, protection and reconstruction of coastal/marine zone through establishing standards regarding the integrated management of coastal zone.
- Develop scientific methods for assuring the protection and conservation of the coastal morphology of the Danube Delta Biosphere Reserve.
- Strengthen the capacity for the control of the economic activities in the marine zone. Formulate criteria to stimulate mariculture in the marine zone, especially of organisms that have a role in biofiltration of water.
- Ensure the ecological integrity of strictly protected areas.

14. CONCLUDING REMARKS

The value of Danube Delta for biodiversity is broadly recognized in the level of protection afforded to them through international and national legislation. Danube Delta has been designated as a Ramsar site. Other designations recognize the value for biodiversity. Of course, designation as protected areas alone does not guarantee the protection of the delta areas' biodiversity. Appropriate administrative structures to provide integrated management, appropriate management plans, and adequate resources for the implementation of management plans are all needed. It is noticed that the main constraints on appropriate management are not, in the first place, scientific information, but personnel, the level of training, equipment, and last but not least, funds.

1. *An ecosystem-based approach is essential for a successful conservation of Danube Delta.* The most important threats to Danube Delta are changes in the quantity and quality of water reaching this delta from its upstream

catchments. Therefore conservation approaches will only succeed if they are accompanied by an integrated approach to catchment management. Such an approach will require the establishment of appropriate authorities, integrating the interests of the various stakeholders and taking biome needs into account when considering water allocations. Since Danube Delta has catchments that are shared between countries, this approach will also require a high degree of international co-operation.

2. *Management within delta should be undertaken within the framework of integrated land use and management plans.* The intense pressures for development in Danube Delta requires that the conservation of biodiversity and naturalness be put within the framework of an integrated land-use plan covering the whole delta. Within this, appropriate management decisions for the natural areas. These require the establishment of appropriate authorities on whole delta level, including the areas in Moldavia and Ukraine. Due to the reason that the Danube Delta is a transborder delta, special mechanisms to ensure the necessary international co-operation are needed.
3. *Adequate resources must be available for long-term and sustainable management plans.* There are numerous examples of management plans that have been developed for wetland areas, including deltas, which have failed to be implemented due to the lack of available resources in terms of training, personnel and equipment. A key priority in Danube Delta is to review those constraints and to assess how they can be addressed both at the national level and through international co-operation. The GEF projects for the Danube Delta Biosphere Reserve provide examples of how such co-operation can be arranged. Also, mechanisms for the financial involvement and responsibility of the private sector should be promoted.
4. *Coordinating mechanism should be established to exchange ideas and best practice between delta management experts in Europe.* The European deltas share many common values, threats and management constraints; therefore delta experts and managers can gain considerably from sharing expertise and information. Several initiatives to promote international co-operation between deltas already exist, of course. Some kind of coordinating mechanism would be helpful to integrate these initiatives. Activities would focus on training programs, international exchanges, specialist workshops, modern communications media, plus joint project initiatives. The exchange of ideas and learning from each other by bringing people together has to be very effective.

5. The fifth point is short but clear. *Not planning and decision-making* for *local people, but* with *local people.* Dealing with nature in Danube Delta in the end will only be successful if there is a strong commitment on the part of stakeholders and local communities to the planning and decision-making process.

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A DATABASE APPLICATION INTEGRATED WITH GIS AS A DECISION SUPPORT TOOL FOR POTENTIALLY POLLUTED SITES MANAGEMENT AS WELL AS AN OVERALL WATER MANAGEMENT

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Abstract: The presented system is based on preliminary risk assessment of industrial sites in relation to potential contamination of groundwater and surface water, as well as health risk for persons on the site. The system is implemented in Slovakia since 2001, further upgrades are required.

Keywords: risk assessment; database; GIS; environmental administration; potentially polluted site management

1. INTRODUCTION

The decision support tool assigned to environmental state and self-governmental administration bodies in Slovakia was developed within the Danish – Slovak bilateral co-operation supervised by the Danish DEPA – DANCEE (Danish Environmental Protection Agency – Danish Cooperation for Environment in Eastern Europe) agency. The system consists of four main components:

– Database of site-specific data concerning “industrial sites”, it means any industrial, agricultural, military or other sites including waste deposits where any dangerous chemicals or other materials are stored, produced or used for any purposes.

T.H. Illangasekare et al. (eds.), *Decision Support for Natural Disasters and Intentional Threats to Water Security*,

- Knowledge database regarding concerned chemicals, literature, legislation, remediation technologies, etc.
- Spatial data concerning relevant natural conditions and water management interests handled in GIS environment integrated with the database of industrial sites mentioned above and expressed as groundwater vulnerability maps, maps of groundwater classes defined by water management importance of the aquifer, and planning status of the surface waters.
- The method of prioritisation of the sites with respect to level of contamination based on a ranking system. The output of the ranking is forming a relevant portion of the information on which the decision making process within the environmental institutions is based.

2. THE BASIC CONCEPT

The presented system was developed within a time period 1998–2001 as one of the main tasks of the Danish – Slovak bilateral project "Remediation of Polluted Soil and Groundwater, phase 1 and 2" under supervision of the Danish DEPA – DANCEE agency. The system is based on the Danish System for the Prioritisation of Point Sources, as it was published by the DEPA (1995). As in the mentioned document is stated, the prioritisation is based on the investigations, which are the basis for registration of sites according to the Danish Waste Deposits Act. The purpose of the ranking system is:

- To set up a clear and simple system.
- To use existing data for assessments and calculations.
- The ranking shall be based on standard assessments and calculations of pollutant dispersal.
- The classification system shall be reproducible irrespective of the person who is working with the system.
- The scoring system shall be usable at three levels: National, regional and local.
- The time used to rank a single site shall be minimal.

The ranking concept is divided into three well defined sections, namely groundwater, land use and surface waters.

The review of site specific parameters is related to the fate and distribution of the contamination; to make an assessment of impact on ground water, land use and surface waters.

The groundwater assessment includes:

- Regional planning of groundwater use
- Groundwater vulnerability
- Mobility, toxicity and degradation of contaminants

The land use assessment includes:

- Site vulnerability
- Exposure of contamination to humans
- Hazards presented by the contaminants
- Site specific conditions
- Landfill gas risk

The surface water assessment includes:

- Actual impact on water quality
- Distance to the surface waters
- Mobility, toxicity and degradation of the contaminants
- Planning status of the surface waters

The assessment is based on standard questionnaires, allowing clear, reproducible and easy scoring of parameters.

The result is a ranking for each one of the three selected sections. During the adaptation and testing process the project team introduced and implemented numerous modifications in each part of the system to adapt the system to the specific natural, economical and legal conditions in Slovakia.

3. THE DATABASE

Both the site specific data and the knowledge database are handled by the GeoEnviron database application. The database application itself was developed as a result of international cooperation of private companies and institutions in Denmark, U.K. and Russia within the EUREKA project which started in 1994. The further development on commercial basis is recently provided by the Danish Geokon Ltd. Company (Geokon, 2001).

As a database engine the Sybase SQL Anywhere in version 5.5.04 is used. This database engine was in the time of its release (1997) a very advanced relation database management system (RDBMS) designed for personal computers, as shortly before the RDBMS where installed only on mainframe computers.

The data manipulation for the user is possible through the graphical user interface was developed in PowerBuilder version 6.5. Advanced data manipulation by SQL commands is possible through the use of the Interactive SQL interface.

The GeoEnviron application has modular structure. Two types of modules are present: the Basic Modules and Application Modules. The Basic Modules are a part of every installation and consist of the following modules (Geokon, 2001):

- InfoBase – the knowledge database is an important element of the scoring system. The InfoBase is built up by a chemical database containing essential information regarding potentially polluting chemicals used in different kinds of industries, the database of remediation technologies and custom data following the needs of the user.
- GeoView GIS – in fact it is not a "full" GIS, consists of scanned raster maps and point data visualized following their coordinates.
- GeoView pictures – module for storing raster data, e.g. photodocumentation, scanned schemes, plans, etc.
- System administration and user's documentation.

The customer can choose different Application Modules, like modules for waste management, IPPC, water supplies management, investigation data, etc., for the scoring system the only essential module is the Site Module, designed for storing data regarding industrial sites. The term "industrial site" is rather wide in this case, it could mean any site of running or past human activities connected with producing, storing or handling any dangerous chemicals, like factories, gas stations, warehouses, garrisons, schools, hospitals, landfills, etc. Although different important data are stored in this module, like historical data, different documentation, waste management, etc., for the scoring system essential are data about chemicals storing, handling and their amounts, together with land use data.

4. THE SCORING PROCESS

The ranking is based on the investigations and information (so-called the "preliminary risk assessment"), which are the basis for registration of potentially contaminated sites according to the Danish Soil Contamination Act.

The ranking concept is divided into three well-defined sections (DK-DEPA, 1995):

- Groundwater, i.e. the threats to groundwater contamination
- Land use, focused on the conflicts of using potentially; contaminated land for sensitive purposes
- Surface waters, as risks of direct or indirect pollution

The groundwater assessment includes knowledge of:

- Regional planning of groundwater abstraction, like groundwater protection zones, potential for groundwater abstraction; hydrogeological units, etc., expressed as groundwater classes
- Groundwater vulnerability, i.e. important properties of the topsoil and the unsaturated zone (thickness, character), the groundwater level and its regime
- Mobility, toxicity and anaeorobic degradation of contaminants

The land use assessment includes knowledge of:

- Vulnerability of the site, i.e. the risk of the site use in relationship toward the human beings potentially present on the site
- The exposure of contamination to humans
- The hazards presented by the contaminants, in terms of toxicity
- Site specific conditions, as the location of the contaminants on the site
- The explosion risk of landfill gas
- The landfill operation status

The land use assessment approach is different for landfills and other industrial sites.

The surface water assessment includes knowledge of:

- Actual impact on water quality
- Distance to the surface waters
- The mobility, toxicity and degradation of the contaminants
- The planning status of the surface waters, i.e. the possible or present use of the specific water body as a water supply, the water quality important for fish life conditions, etc.

Each of these parameters listed above are valued by a score. The sum of these scores gives a risk score of a section (groundwater, surface water and land use) for a particular site. The rank of the scores of the sites within a particular administrative/geographical area makes a basis for the prioritisation and decision for actions.

For the ranking purposes it is essential to gain information from maps of *groundwater vulnerability*, *groundwater classes* and *planning status of the surface waters*. The way of constructing these maps and defining the classes depends on the specific geological/geographical/hydrological situation and the state of the water management. Following the complicated geological and geographical situation in Slovakia it was needed to develop a different methodology of the map construction as it was applied in Denmark (Chriašteľ et al., 2001b). In spite of the rather complicated map construction methodology, the final maps are relatively simple as they contains only three types of area in accordance with three levels of groundwater vulnerability, groundwater classes and planning status of surface water. Assignment of the according partial score follows simply from the position of the site in one of the three areas representing one of the three levels of groundwater vulnerability, groundwater classes and surface water planning status. The ranking is performed within a GIS environment (Chriašteľ et al., 2001a).

The prioritisation system could be adapted for the local conditions and specific environmental risks, as happened in Slovakia, where it was needed to introduce some essential modifications. The significant modifications in the Slovak system were introducing the scoring of the amount of chemicals on the site, the technology of wastewater treatment and the landfill operation status and protection.

5. OPERATION OF THE SYSTEM

In 2001 the system was implemented for three levels of Slovak environmental state administration within the pilot area:

- Environmental department of the Michalovce County Office
- Environmental department of the Košice Regional Office
- Ministry of Environment

The next institution participation on the system is the Water Research Institute in Bratislava. All these institution installed the GeoEnviron database application with established connection to the database server maintained by the Slovak Hydrometeorological Institute. Except the Ministry of Environment, all the remote users were connected to the server by an ISDN connection, as the existing instant lines did not provide sufficient broadband needed to data transfer. The Ministry of Environment used the existing ZPNet network (Figure 1).

At present time the database is yearly updated by sending questionnaires to the industrial site owners and/or operators, after receiving fulfilled questionnaires the ranking is updated. Data are processed by the Slovak Hydrometeorological Institute and Water Research Institute in cooperation. One separate database of military sites was established for the Ministry of Defense as the part of the NATO PRENAME program. The maps needed for ranking are prepared and updated in cooperation between the Slovak Hydrometeorological Institute and the State Geological Institute of Dionýz Štúr in Bratislava.

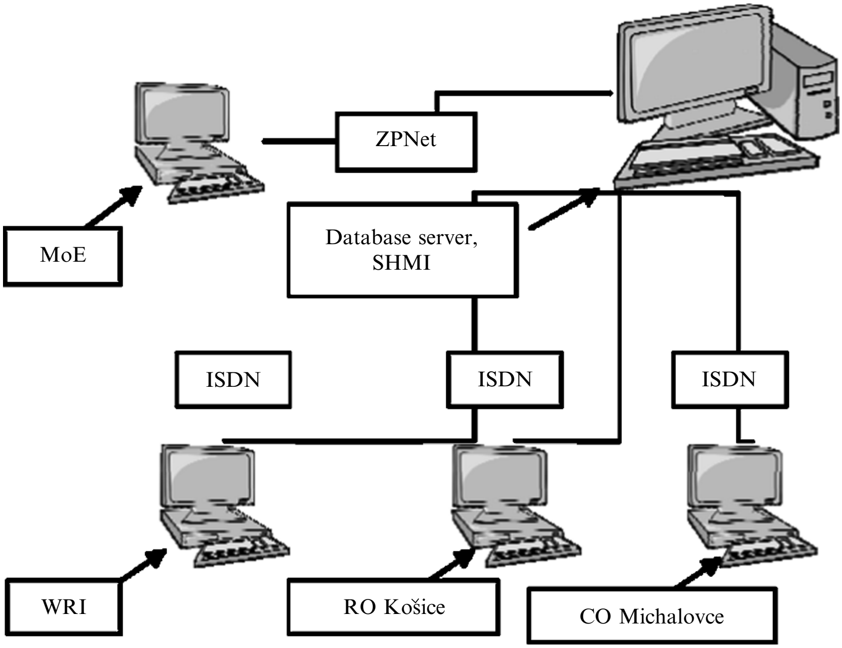

Figure 1. Scheme of the GeoEnviron network setup

After 5 years of operation it is clear that the system needs a radical update to make it more functional and flexible. The main reasons are listed below:

- Connection by ISDN to the database appeared not sustainable at all, as this connection is not maintained any more by the Internet connection providers, consequently the connection of the remote users does not work, moreover connection by ADSL or other technologies to the database server did not succeed using the installed version of Sybase SQL Anywhere database engine.
- To increase the functionality of the system it is needed to give an access to the system to all environmental institutions in the country.
- The ranking should perform automatically, immediately after inserting data to the database.
- For the surface water assessment it is needed to involve also a flooding risk, however the complete collection of the inundation area maps are missing.

The fact that most of the users cannot connect directly to the database and the connected users cannot perform the ranking process from their PCs and have a very limited possibility to manipulate the data, listed disadvantages are in fact seriously diminishing the usability the system as a decision support tool. In the future the direct connect of the user to the database will be requested, as well as to find a way to easily visualize spatial data and manipulate with them.

6. FURTHER DEVELOPMENT PROPOSAL

As it was described above, the most needed upgrade is regarding the database engine and the user's access. To solve this problem we have to focus on the following elements of the system:

- The database engine
- Working with spatial data
- User's interface
- Remote access

At present time there is a wide variety of database engines, but two of them seem to be best fitting the requirements: the Oracle and the PostgreSQL. These relational database management systems (RDBMS) are providing the best data integrity and safety, support, accessible manuals and tutorials. The most important feature of them is possibility to install extension for handling spatial data. It means that it is possible to perform most of GIS operations directly within the database (Oracle Spatial 10 g, PostGIS). The advantage of the Oracle is the support from the producer, the disadvantage is a high price and demanding hardware requirements. The advantage of the PostgreSQL/PostGIS is that it is an open source software (developed by the PostgreSQL Global Development Group under supervision of the University of California at Berkeley) and it does not have very demanding hardware requirements. Moreover, as the PostGIS extension can handle spatial objects (points, lines, polygons, 3D objects) as particular datatypes, it allows to define the industrial sites not only as point coordinates but also as polygons which results in more accurate site assessment.

To involve all the interested institutions to the system we need to find an easy and effective way of their connection to the database. The most proper way is to develop a PHP web interface communicating with the database engine. Also spatial data could be used and visualized through the web interface using the MapServer tool.

For working and visualisation of spatial data we need a GIS well integrated with the RDBMS, most modern GIS systems are able to do it easily. If we select the PostgreSQL/PostGIS RDBMS we can integrate it with other open source GIS software, like the GRASS and/or Quantum GIS. The GRASS (Geographic Resources Analysis Support System) was originally developed by the US Army Construction Engineering Research Laboratories (USA-CERL) and represents a very effective tool for advanced GIS operations (Dassau et al., 2005), however is not suitable for preparing maps for presentations. For this purpose is more suitable to use the Quantum GIS.

7. CONCLUSION

In the beginning of the 21st century we developed a decision tool designed for potentially polluted site management by environmental state institutions on all levels. To make this system fully functional today we need to perform a radical upgrade of the whole system, especially the software tools of the system. Selecting the PostgreSQL/PostGIS/GRASS/Quantum GIS/PHP/MapServer combination of open source software can help to evolve the system toward better functionality and accessibility for all interested institutions to improve the usability of the system as a decision support tool.

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FEASIBILITY OF EARLY AND EMERGENCY WARNING SYSTEMS FOR SAFEGUARDING THE TRANSBOUNDARY WATERS OF ARMENIA

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Abstract: Armenia, as the most upstream country in Southern Caucasus, is the major "exporter" of water to the neighboring countries, and therefore, any associated pollution or "natural emergencies" (hydrological extreme events, incidental or intentional chemical spills, mining and ore-dressing discharges, etc.) become part of the "parcel". Despite the regular stream-gauging and routine quality monitoring of the surface waters in the country (including the transboundary water bodies), the security of riparian communities downstream (across-the-border) is at risk due to the lack of early/emergency warning monitoring systems (EWS) in place, as well as adequate control measures upstream. Early warning monitoring systems can provide a means to monitor short-term and long-term changes in water quality, and are an important component of any rapid response program. This is relevant to the transboundary watercourses at risk, such as the rivers *Debed* (Armenia-Georgia), *Akhurian* (Armenia-Turkey), *Araks* (Armenia-Turkey-Azerbaijan), and *Voghji* (Armenia-Azerbaijan). Lake *Sevan*, being the largest freshwater body in Armenia and in Southern Caucasus, is a unique strategic reserve of fresh water in the region. It has interconnection with several freshwater aquifers (transboundary) used for drinking/irrigation abstractions. Overuse and man-made pollution caused widespread changes throughout the entire lake watershed and brought about abrupt drop in water levels, resulting in eutrophication and water quality deterioration. Regular monitoring of the lake's water quality with respect to early warning systems (e.g., phytoplankton), aimed to reveal man-made changes in Lake Sevan, will be beneficial for the whole region. Development and putting into practice of feasible EWS on the transboundary water bodies in Armenia, based on international best

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practices, will ensure water security and mitigate environmental pressures in the region, which is a high priority from EU-integration perspective of the South-Caucasian countries.

Keywords: natural emergencies; incidental or intentional chemical spills; mining/ore dressing discharges; transboundary water bodies; security of riparian communities; early/emergency warning systems

1. INTRODUCTION

Water bodies are vulnerable to degradation of water quality as a result of accidental, intentional or natural contamination. Transboundary water resources, particularly rivers, are subjected to a number of contaminants that can rapidly change in concentration. Rapid response to these sudden changes in the "source" water quality is necessary to protect water users and riparian communities downstream from potentially harmful contaminants, determine appropriate safety measures, and to the extent possible reduce the associated risks. Early warning monitoring systems can provide means to monitor short-term and long-term changes in water quality, and are an important component of any rapid response program.

Early warning systems can be used to reliably identify low probability/ high impact contamination events (e.g., spills), episodic events (e.g., floods, storm events, seasonal runoff of agricultural chemicals), and low levels of pollutants which are not normally monitored and may pose chronic health risks. Responses to identified contamination events can include shutting intakes or adjusting their location, switching to an alternate source, spill cleanup and containment measures, and increased monitoring (Gullick, 2001).

Armenia is the most upstream country in the Kura basin (Figure 1), neighboring with Georgia, Turkey, Azerbaijan and Iran, and a major "exporter" of water (and any associated pollution). Armenia is concerned about the financial liabilities resulting from the "polluter-pay" principle embodied in the Helsinki Convention on the *Protection and Use of Transboundary Watercources and International Lakes*, 1992. At the moment Armenia considers it impossible to join the Helsinki Convention due to the financial liabilities required for its accomplishment. Nevertheless, identification of the need for and scope of an early warning monitoring system should be guided by determination of potential risks (water vulnerability assessment), benefits and costs.

Figure 1. Map of the transboundary *Kura-Araks* basin

Design of the early and emergency warning systems for the transboundary water bodies should be conducted with security considerations for both the "exporter" and "importer" countries. Cooperation between the riparian countries (management authorities) is essential for the development and operation of a feasible early and emergency warning monitoring network and rapid-response program: "Comprehensive national and/or local surveillance and early-warning systems are established, improved or maintained which will identify outbreaks or incidents of water-related disease or significant threats of such outbreaks or incidents, including those resulting from water-pollution incidents or extreme weather events…" (UNECE Protocol, 1999). Prevention of, preparedness for and response to industrial accidents capable of causing transboundary effects, including the effects of such accidents caused by natural disasters, and to international co-operation concerning mutual assistance, research and development, exchange of information (Aarhus Convention, 1998, ratified by Armenia in 2001) and exchange of technology in the area of prevention of, preparedness for and response to industrial accidents (Helsinki Convention, 1992, ratified by Armenia in 1997). All three conventions try to assess impacts on the environment and options for adaptation. Activities common to all three conventions relate to predicting and monitoring impacts, and developing assessments and response measures, for example, early warning systems and adaptation strategies.

2. FEASIBILITY OF EARLY AND EMERGENCY SYSTEMS FOR RAPID RESPONSE

To reduce the impact of accidental pollution, steps should be undertaken towards an effective and coordinated early/emergency warning system. Emergency warning has two important features: warning for hydrological extreme events and warning/alarming in case of pollution incidents (e.g., industrial accidents).

According to the earlier studies (JRMP, 2004), the set up of a EWS in the *Kura-Araks* basin in a medium term is not feasible for a number of reasons:

- The rivers have a relatively high flow
- Possible places of accidental pollution and of water use are located close to each other
- The response time of the water users, being between 6 h and 4 days, is by far longer than the time the pollution takes to reach them, which could coordinate between the accident reporting and the water users
- Lack of operational capacity for rapid response
- Costs are far too high and the logistics cannot be solved in the near future

It was recognised and agreed that an early warning system based on permanent pollution measuring is beyond the scope of the countries (JRMP, 2004).

The design of an EWS network should be made based on specifics of the country, water body, type of the potential threats and indicative parameters, and proximity of the uptake points downstream, and should meet the following criteria:

- Covers the major potential threats.
- Provides warning in sufficient time for action.
- Gives minimal false positive or negative responses.
- Cost is affordable.
- Requires low skill level and training for operation.
- Is sensitive to water quality/quantity changes at regulatory levels.
- Is robust.
- Is reproducible and verifiable.

- Allows remote operation.
- Functions year-round.

Naturally, analysis of the relative system costs and benefits may reduce the number of these characteristics that are applicable to specific situations, but the list provides a framework for guidance in development of such systems. Feasible in the medium to longer term, are early and emergency warning systems based on accident or natural emergencies reporting (Gullick, 2001).

In the countries such as Armenia, it would be feasible to launch an EWS, based on already existing facilities and equipment. The simple EWS unit can be installed in the operating hydropost (gauging station), and can be comprised of the following functional components (Figure 2):

- Site-specific parameter online sensor(s)
- Datalogger
- GSM modem with General Packet Radio System (GPRS) wireless data communication system

Figure 2. Components of an automatic emergency warning unit proposed to be installed at the transboundary potential emergency points in Armenia

Considerably simple EWS could be effectively applied on some potential emergency points on the transboundary water bodies (rivers, reservoirs) of Armenia (Figure 3). Those are the high-risk points of:

- Natural floods and/or dam failure
- Accidental chemical spills
- Accidental ore-dressing discharges and/or failures of tailings storage facilities
- Accidental radioactive discharges (NPP)
- Intentional chemical spills (e.g., disposal of toxic chemicals, tanning and gold extraction effluents, etc.)

Figure 3. Map of Armenia with the major surface water bodies, groundwater aquifers, and potential transboundary "hot" points

For instance, assuming an accidental chemical spill has occurred in Vanadzor chemical plant on the transboundary *Debed* river (Armenia-Georgia), and it was "caught" by an online probe sensor (e.g., pH/conductivity, selective-ion, etc.) installed in the nearby hydropost. The radio-alarm system installed ~100 km downstream (beyond the border with Georgia) will immediately signal on the emergency. The response time of the water users (before the pollution flux takes to reach them), taking into account maximum annual velocity of the river, ~4.0 m/s, will be around 7 h. This is a reasonable time interval for operative decision making by the management authorities for immediate prohibition of water uptakes and other intended uses, and public notification on the emergency.

Table 1 represents the list of major transboundary water bodies in Armenia, type of potential emergency event(s) specific to each, the indicative monitoring parameter and applicable online detection method.

Table 1. Proposed EWS for potential transboundary "hot" points in Armenia

Transboundary water body	Potential accident/emergency threats	Indicative parameter	Online detection method
Debed river	Floods	water level (stage)	water level sensor
	accidental chemical spills	pH, conductivity, color, turbidity,	pH, conductivity, turbidity probes, color/optical sensor
	intentional chemical spills	pH, conductivity, color, turbidity, CN^-	pH, conductivity, turbidity probes, color/optical sensor, ion-selective probes
	Accidental or intentional discharges of tailings	pH, conductivity, turbidity	pH, conductivity, turbidity probes
Vorotan river/reservoir	floods/dam failure	water level (stage)	water level sensor
Aghstev river	Floods	water level (stage)	water level sensor
Akhuryan river/reservoir	flash floods/dam failure	water level (stage)	water level sensor
Metsamor river	accidental radioactive discharges from NPP	α/β radioactivity	online α/β radiometer
Hrazdan river	accidental chemical spills	pH, conductivity, color, turbidity	pH, conductivity, turbidity probes, color/optical sensor

(Continued)

(**Table 1.** Continued)

Voghji river	Accidental or intentional discharges of tailings	pH, conductivity, turbidity	pH, conductivity, turbidity probes
	intentional chemical spills	pH, conductivity, color, turbidity, CN^-	pH, conductivity, turbidity probes, color/optical sensor, ion-selective probes
Meghriget river	Accidental or intentional discharges of tailings	pH, conductivity, turbidity	pH, conductivity, turbidity probes

Economic Considerations. Limitations in resources dictate the necessity of designing a system (rugged, low maintenance and easy-to-operate) that is far from being ideal, but that still addresses the major concerns and objectives. Depending on the proposed scope, it is possible that substantial resources could be required for the development, installation, operation, and maintenance of an EWS. Despite the considerable high capital costs for setting up of an EWS in the countries such as Armenia, however, it is still feasible to launch within the scope of a pertinent donor-funded project, using already existing facilities and equipment. As such, practical decisions need to be made at each step of designing the scope and details of the early/emergency monitoring program.

3. ISSUE OF LAKE SEVAN

Lake Sevan, the largest freshwater body in Armenia and the whole South Caucasus region, is an enormous strategic source of drinking water. Lake Sevan is situated in the central part of the Republic of Armenia, about 1,900 m above sea level. The total area of the lake's basin is about 4,900 km^2, of which 3,650 km^2 constitutes the catchment area and approximately 1,250 km^2 constitutes the lake surface itself. The volume of the lake is 35,8 billion m^3. Twenty-nine rivers and streams are tributary to the lake, whereas the River Hrazdan is the only outflow from the lake. Lake Sevan (Figure 3), has a considerable contribution in formation of freshwater resources in the region.

Overuse and man-made pollution caused widespread changes throughout the entire lake watershed and brought about abrupt drop in water levels, resulting in eutrophication and water quality deterioration (Hovhannisyan, 1994).

In order to prevent the irreversible changes in the lake, the government has proclaimed the Lake Sevan as a national priority. In this respect, regular monitoring of the lake's water quality with respect to early warning indicators (bioalarms, e.g., phytoplankton, chlorophyll), rapid biotests using fish or bacteria to screen or warn for hazardous substances (LeGore and Tserunyan, 2002), aimed to reveal man-made changes in Lake Sevan, will be beneficial for safeguarding this strategic freshwater resource in the whole region.

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PART III:

DECISION SUPPORT TOOLS

WATER MANAGEMENT IN CROATIA: WHAT IS AT RISK

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Abstract: The paper highlights the status of the water management in Croatia. The basic source for water use in Croatia is surface water, followed by groundwater and marginal quantities of desalinized water. The current uses of sea and coastal areas are: fishing, mariculture, tourism, maritime transport, ports, etc. In Croatia, 38% of water is used for urban purposes, 60% in industry and energetic and 2% in agriculture. The quantity of water used for power production is not included in these indicators. The results of water quality monitoring shows that surface water is mostly of the categories II and III. The quality of groundwater is generally considered good throughout the country. Two government institutions have direct responsibility for water management in Croatia: Ministry of Regional Development, Forestry and Water Management–Water directorate, and Croatian Waters (Hrvatske Vode). Croatia is especially active with neighboring countries in issues related to cooperation in water management.

Keywords: Croatia; water management; water use; surface, ground and sea water; quality; institutions; cooperation

1. SOCIO-ECONOMIC AND GEOGRAPHIC CONTEXT

Croatia is located in southeastern Europe, with a land area of 56,538 km^2, territorial sea area of 31,071 km^2 and total area of 87,609 km^2, and has a total boundary length of 8,020 km, including 5,835 km of coastline. Croatia's territory includes 1,185 nearby islands in the Adriatic Sea, of which only 66 are inhabited, islands coastline account for 4,058 km. Croatia's population was 4.44 million in 2001. Less than half of the population (40%) lives in rural areas, Figure 1.

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Croatia consists of two distinct geographical regions: the Danube basin within the Black Sea catchment area (35,100 km^2 or about 62% of the total area) and the Mediterranean region (21,400 km^2 or 38%), which includes the Adriatic Sea coastline. Croatia's climate varies from mild, rainy winters and dry summers in the Mediterranean region, with precipitation ranging between 600 mm to 1,500 mm; to colder winters and more precipitation in the northern and eastern parts of Croatia reaching up to 3,000 mm. The average precipitation is 1,160 mm.

Due to the mountain chains the catchment area of the eastern coast is very limited so that only a small volume of freshwater from Croatia (20% of Croatia's rivers by the volume of water) drains into the Adriatic Sea.

Figure 1. Geographical regions in Croatia

Croatia (with a total area of 5.65 million ha) consists of two distinct geographical regions: the Danube basin within the Black Sea catchment area (3.51 million ha or about 62% of the total area) and the Mediterranean region (2.14 million ha), which includes the Adriatic Sea coastline. Mountains separate the two regions. Croatia's climate varies from mild, rainy winters and dry summers in the Mediterranean region, with precipitation ranging between 600 mm to 1,500 mm; to colder winters and more precipitation in the northern and eastern parts of Croatia reaching up to 3,000 mm. The average precipitation is 1,160 mm.

According to official statistics, Croatia's population was 4.44 million in 2001. Less than half of the population (40%) lives in rural areas (in settlements with less than 2,000 inhabitants). The tourism industry, whose success depends on the Adriatic Sea coastline and the offshore islands, contributes significantly to the economy and generates about 85% of Croatia's foreign exchange.

2. WATER RESOURCE BASE

For the purpose of water management, Croatian territory is divided into four water districts plus the Zagreb Metropolitan Area water district. These water districts are: (i) the Sava River basin; (ii) the Drava and Danube basin; (iii) the Dalmatian basin; and (iv) the Istrian and Littoral basin.

Surface and Groundwater Resources. Croatia can be considered a water-abundant country. Its overall renewable resources amount to 71.4 BCM or 14,900 m^3 per capita, out of which about 60% are generated within Croatia and the remaining from upstream countries (namely, Slovenia, Austria, Bosnia and Herzegovina and Hungary). Resources are unevenly distributed throughout the country. These figures don't account for flows from border rivers. When these flows are included, overall renewable resources amount to 156.3 BCM or 35,200 m^3 per capita.

The major water resource is surface water, which is found in 20 rivers, 26 natural and artificial lakes, and the Adriatic Sea. The major watercourses total 6,829 km. Most rivers flow into the Danube or one of its tributaries. The Danube River (coming from Hungary) flows through Croatia over a length of 188 km. The Drava and the Sava Rivers (both coming from Slovenia), which are the major tributaries of the Danube, flow through Croatia over 562 and 505 km, respectively. Many rivers serve as borders with neighboring countries, e.g., the Dragonja, the Mura and the Drava, the Danube, the Korana, the Kupa, the Sutla, the Sava and the Una. The only transboundary rivers are the Bosut and the Neretva. The largest rivers belong to the Black Sea catchment area and the shortest to the Adriatic catchment area. The karst rivers such as the Mirna, the Raša, the Lika, the Gacka, the Zrmanja, the Krka and the Cetina provide mean annual volumes of water of some 10 BCM.

There is a significant seasonal and annual variability in river runoff. The year-to-year variability of annual runoff is very high. In dry years, the annual runoff is less than one quarter (21%) of the average year flow. The situation is more severe in the Adriatic basin. In addition, because of its geomorphology and its climate, Croatia is very prone to water damages, namely floods. In order to address distributional and seasonal fluctuations and meet the demands of households, industry and tourism, storage reservoirs (1.53 BCM) and long transmission mains were constructed.

Croatia's coast on the Adriatic Sea is 5,835 km long, of which more than 1,000 of islands account for 4,058 km. Its territorial waters cover 31 km^2. The coastal regions are characterized by a large variety of flora and fauna, including numerous endemic species. Due to the mountain chains the catchment area of the eastern coast is very limited so that only a small volume of freshwater from Croatia (20% of Croatia's rivers by the volume of water) drains into the Adriatic Sea.

Groundwater resources are also abundant and represent about 20% of the total renewable resources. In the Sava and Drava basins, groundwater can be found in water-bearing strata in areas with alluvial formation. Karst formations predominate in the Dalmatian and the Istrian and Littoral basins. Water from underground fissures appears on the surface as karst springs. Despite the water abundance, there are quantity problems at key localities such as the Adriatic islands, which have poor water resources. They continuously experience water shortages during summer. In addition, a slightly decrease in the water table has been observed in the aquifer below Zagreb and an important one in the Drava River aquifer (4 m over 20 years).

Wetlands. Croatia has a wealth of wetland habitats particularly those of riverine origin. The most important areas are floodplains of the Sava, Drava, Danube and Neretva river basins, with numerous, mostly well-preserved wetland habitats significant for endangered species of migratory birds. Four locations in Croatia are listed as Ramsar sites – Lonjsko Polje, Crna Mlaka fishpond, Kopački rit and the Neretva River delta, which are thus designated as areas of global importance.

The Nature Park of Lonjsko Polje is situated in the central part of the country, bordering in the north with the slopes of the Moslovacka Gora mountain and the Zagreb-Slavonski Brod highway, and the Sava River in the south. It comprises an area of 506 km^2, and includes floodplains of the Sava River and its tributaries, namely, Lonja, Struga, Pakra, Ilova, Trebez, Cesma and other minor tributaries.

The Neretva delta is situated at the Neretva River mouth into the Adriatic Sea. The major part of the Neretva River (195 km out of a total length of 220 km) is in Bosnia and Herzegovina. The delta itself is shared by Croatia and Bosnia and Herzegovina. The delta wetlands cover 320 km^2 of which 120 km^2 is located within Croatia and the rest in Bosnia and Herzegovina. Along the entire Croatian part of the Adriatic coast, there are numerous smaller marshes.

Water Quality. Croatia has a systematic program for monitoring the quality of surface waters (rivers, lakes and storage reservoirs) and groundwater (water springs). In the year 2005, quality of surface waters (rivers, lakes and reservoirs) and springs was systematically monitored at over 270 measuring stations. Apart from the Central Authorized Water Management Laboratory of Croatian Waters, 12 authorized laboratories conduct systematic water quality monitoring, mainly the laboratory of the Public Health Institute in individual counties and some other institutions.

The results of systematic monitoring of water quality have shown that the highest deviations from water category for individual sections of rivers or lakes are caused by increased values of microbiological parameters, whereas biological parameters caused the slightest deviations. Increased values of microbiological parameters indicate a more permanent load by municipal wastewater. According to the monitored basic parameters, surface water in Croatia is mostly of the categories II and III, with the exception of microbiological parameters, according to which it belongs to categories III and IV. A comparison with earlier reports on water quality status, which were occasionally prepared, shows that in the previous period in Croatia there was no major deterioration of surface water quality. The results of the monitoring program also indicates that the areas exposed to the highest impact of diffuse pollution from agriculture are the water districts of the Drava and Danube river basins and the Dalmatian river basins.

The quality of groundwater is generally considered good throughout the country. Groundwater source in the western part of the Sava and Drava alluvial aquifer are exposed to anthropogenic pollution, although a certain improvement in water quality is noticeable. Groundwater quality of the Adriatic river basins continues to be high. Occasional occurrence of bacteriological contamination is the only significant problem in otherwise excellent water quality of mountainous region aquifers of the Pannonian plain.

In the Adriatic river basins, due to karst characteristics, it is virtually impossible to separate surface waters from groundwater. In general, it could be claimed that groundwater is of high quality – the main problem being sudden and relatively brief changes of quality in the wet season, when turbidity and contents of suspended solids multiplied several folds.

Reports on the state of the sea and its water quality (the northern Adriatic, the areas of Zadar, Šibenik, Split and Dubrovnik) indicate that a considerable part of the Croatian portion of the Adriatic Sea is still oligotrophic and clean. This is partly due to the fact that in the past decade there was a considerable decline in the industrial production in the Adriatic coastal region as a consequence of the transition process. At the same time the number of tourists went down considerably, thus reducing the amount of urban pollution. However, the ports of big cities and the industrial zones along the coast are often polluted by organic and inorganic substances of which *petroleum hydrocarbons* are the most noticeable pollutants. The sources of marine pollution are inhabitants (urban areas without full public sewerage systems), tourism, maritime transport, industry, agriculture, cattle breeding and discharges of polluted waters from rivers and ground waters.

Water quality monitoring system of surface waters and some springs has improved significantly during the past years, whereas the systematic monitoring system of groundwater quality in certain areas needs to be extended throughout the country. Special attention needs to be paid to improvement and standardization of the national bio-monitoring system.

3. WATER USE AND MANAGEMENT BY SECTOR

Total water use was estimated at 1.42 BCM in 1996, with water for industry and cooling accounting for 33%. Industrial water (0.26 BCM) is abstracted from surface sources, and the rest comes from the public supply system. Cooling water (0.2 BCM) goes mostly for electric production as well as the chemical and refining industries. Public water supply accounts for 37% or 0.53 BCM and is predominantly drawn from groundwater and springs. Irrigation is almost negligible, accounting for less 20 MCM. Fish and fish breeding in fishponds are well developed in Croatia and the related water use accounts for 29% of total water use.

Drinking Water and Sanitation Coverage. Between 1991 and 2000, the population with access to public water supply increased from 62% to 76%. There are significant differences in service delivery regionally. In addition, during the summer season, both areas in the high karst region and in the islands of the Adriatic Sea experience shortage of drinking water. Significant numbers of people still take water from local sources such as shallow wells, collect rainwater and during the summer are served by tanker trucks. About 50% of the shallow wells are at risk of microbial contamination.

Sewerage coverage is estimated at 52% countrywide, and shows considerable regional variation. Combined sanitary and rainwater systems predominate in the city centers with systems that are more than 50 years old. At present about 15% of the population is connected to primary and secondary treatment plants, compared to 10% in 1997. In rural areas wastewater flows to septic tanks. In 1997, only 20% of total municipal wastewater was treated of which about 81% was subject to mechanical treatment, about 6% was biologically treated and 13% was pre-treated industrial discharge (most recent statistics indicate that only 12% of wastewater is treated, of which only 4.4% receives secondary treatment). At present, there are 81 municipal wastewater treatment plants: 22 plants with preliminary treatment, 26 with primary treatment and 34 with secondary treatment. Along the coast, treated wastewater is discharged into the sea via long submarine outfalls. Despite significant investments in the construction of municipal sewerage systems and wastewater treatment plants, large quantities of untreated wastewater are still discharged directly into the sea and rivers, causing the contamination of recreational wasters. The level of health risk in the tourist areas along the coast is high.

Industry is supplied by water partly from the public water supply system and partly by its own water abstraction facilities. The volumes of water abstracted by the industry itself are estimated at about 260 MCM yearly. Due to the decline in industrial production, there has been a reduction of the water volumes abstracted for industrial purposes.

Floods. As a consequence of spacious mountainous areas with high precipitation and the presence of wide valley of lowland watercourses, some areas of Croatia are subject to frequent flooding, whether through flash floods, groundwater/overspill of water channels in river valleys, or flooding of poljes. Flash floods are most likely to occur during the season of high intensity precipitation, from May to September, groundwater floods from November to March, flooding of poljes in karst from October to April. It is estimated that floods endanger over 15% of the national inland territory.

Other areas which flood are: the town Karlovac on the Kupa River; Vukovar and Osijek on the Danube and Drava river; the Istria peninsula is subject to floods. Split, Rijeka, Šibenik and Dubrovnik are subject to frequent flash floods. The small karstic North Adriatic islands also flood: besides destruction to urban areas, one tourist lost his life during the flood of 1990.

The view of combining the multipurpose use of river streams with flood protection objectives tends to prevail in Croatia. Most of the protection works have been built following this view.

The analysis of the situation of Croatia with recent West European catastrophic floods in mind leads to the conclusion that floods risk in today's Croatia are exceptionally high. Moreover, the general public is not sufficiently aware of the danger posed by the floods. Something needs to be done to address the following shortcomings with the current flood management system:

- Existing protection systems along nearly all major Croatian rivers do not provide standard protection levels of the lowland from floods of a 100 year return period in many places
- Approximately 15% torrential basins are regulated
- Current water management has only about 65% necessary funds available for regular technical and economic management of watercourses, water estate and water structures
- Funds for improvement, reconstruction and further development of protection systems are non-existent
- Despite great efforts, war-related damages are still not fully repaired
- Financial insurance of property from uncovered flood risks is virtually non-existent
- Hydrological forecasting systems are insufficiently developed

4. WATER LEGISLATION AND POLICIES

Overall legislation on water management consists of two laws, the Water Act issued in 1995 and 2005, the Water Management Financing Act, and 38 regulations and secondary legislation.

The Water Act. It lays the institutional framework for water management activities, regulates the legal status of water and its ownership; the various means in which water is managed; assigns responsibilities to various levels of government, local authorities and legal subjects; and establishes a water agency, the Croatian Waters (Hrvatske vode).

The Water Act introduces the concept of managing water at the district level, by dividing Croatia into four water districts or territorial units for water management purposes (which contain one or more catchment areas and include both surface and groundwater) plus the city of Zagreb as an independent unit.

It also provides for the regulation of watercourses and the protection against adverse effects of flood and declares that the provision of drinking water to the population has absolute priority over any other water use. With regard to pollution protection, the Water Act regulates the protection of wells, aquifers and well-inflow areas by setting up sanitary protection zones around sources of water used for public supply. It declares that these sanitary zones are under the responsibility of the municipalities.

The Water Act requires the preparation of Water Management Plan of Croatia. The plan should specify the needed investments for integrated water management.

The Water Management Financing Act. This Act regulates and assigns responsibilities for financing water management activities. It covers the funds for the cost of the administration of water management, maintenance of existing facilities and planning and investment in new facilities. In addition, the Act identifies funding sources. The principle that the beneficiaries of water management activities should pay in relation to the benefits received is the foundation of the Act.

5. WATER MANAGEMENT INSTITUTIONS

The two government institutions that have direct responsibility for integrated water management in Croatia are: The Ministry of Regional Development, Forestry and Water Management – Water Directorate, and the Croatian Waters (Hrvatske vode). In addition, there is the National Water Council (the body of the Parliament), which was established by the 1995 Water Act to discuss policies, strategies, and implementation of laws regarding water management, Figure 2.

The Ministry of Regional Development, Forestry and Water Management–Water Directorate (WD). This body is responsible for administrative and other issues related to integrated management of water resources and water management systems and for incorporating water resources management and development issues within the overall economic development framework. Within the sphere of water pollution, the WD is responsible for the protection of water sources from pollution and the protection of the sea from land-based pollution sources. In addition, WD is responsible for planning and coordinating the development and construction of large water supply, sewage, and wastewater systems; and for the monitoring of water resources. The WD proposes to the Government the level of water use fee and water protection fee.

The Croatian Waters. It has overall responsibility for carrying out activities related to management of national and local water sources. Acts in close collaboration with municipal companies in water districts and coordinates and finances the implementation of water quality monitoring of surface waters by authorized laboratories. It performs public services and other tasks as defined in Water Act and Water Management Financing Act and Water Management Plan.

Other Institutions. The sectoral ministries that also have a role in water management and that should be included in any discussions related to integrated water management are:

– The Ministry of Environmental Protection, Physical Planning and construction is responsible for issues related to general environmental policy, for correlation of water issues with other environmental issues and for harmonization of regional physical development and planning.
– The Ministry of Health and Social Welfare is responsible for drinking water quality.
– The Ministry of Sea, Tourism, Transport and Development Economy, and Ministry of Finance also participate in discussions related to water demand and emission standards.
– On the local level, municipal and county governments are responsible for the design and implementation of infrastructure projects including water supply and sewerage/waste water treatment systems.

6. TRANSBOUNDARY ISSUES

Both points and non-point pollution sources in Slovenia, Hungary and Austria have transboundary effects on the Drava and Sava Rivers. Their water regimes are affected by the existing hydropower plans in Slovenia and Austria and other ongoing constructions. Hazardous waste disposal at Gyor in Hungary has transboundary impacts on the Lower Drava River and the Danube basin in general.

The Sava basin is polluted by wastewater and point and non-point sources of pollution in Bosnia and Herzegovina and Slovenia. The nuclear power plant on the border with Slovenia is another source of pollution. Croatia, in turn, contributes to the pollution of the Sava basin with loads of nutrients from industrial and municipal wastewater and agriculture runoff.

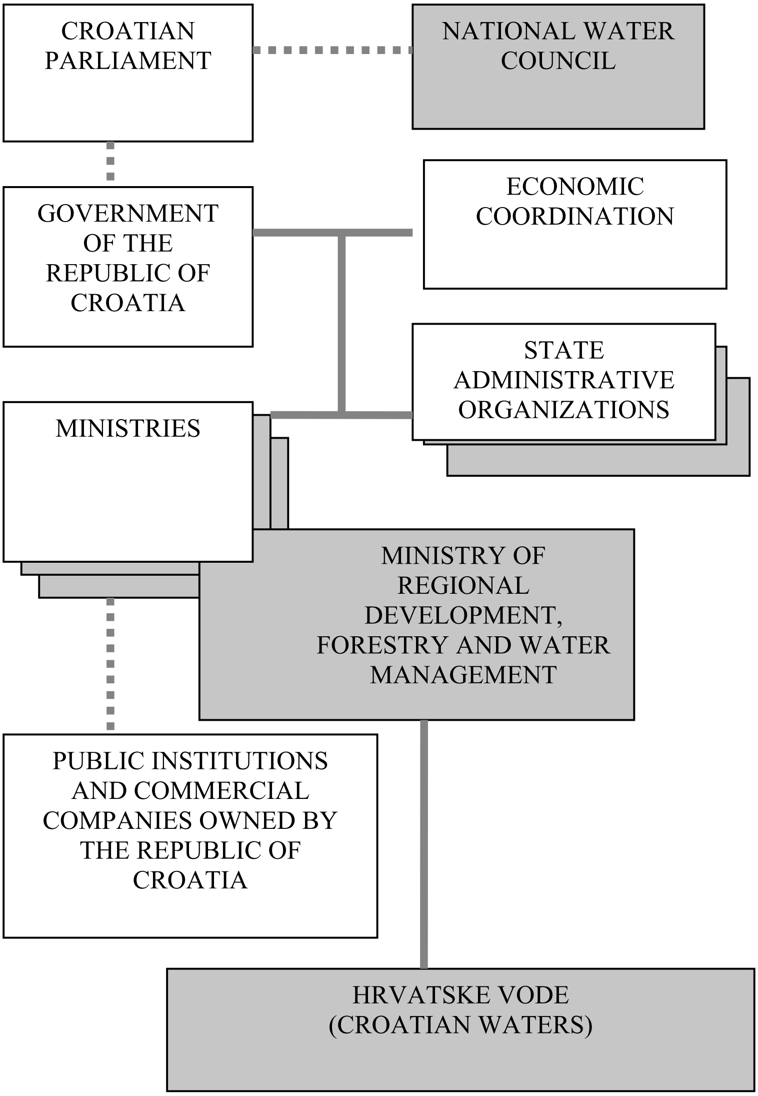

Figure 2. Water Management in the Republic of Croatia

Croatia is especially active with neighboring countries in issues related to cooperation in water management. Croatia is an active member of the International Commission for the Protection of the Danube River. In addition, Croatia has entered into bilateral arrangements with its neighbors to jointly manage shared waters. For example, a Permanent Croatian-Hungarian Commission on Water Management was established in 1994 to address water management issues in the Drava, Mura and Danube Rivers. Another example is the Permanent Croatian-Slovenian Commission on Water Management for the joint management of transboundary groundwater on the karst area between Croatia and Slovenia. Such agreement is also being established between the governments of Croatia and Bosnia and Herzegovina. Croatia has joined with its neighbors in the Sava River Commission.

7. KEY ISSUES AND CHALLENGES

The eastern region of the Adriatic is still one of the best-preserved coastal areas of the European part of the Mediterranean. However, at present mainland wastewaters are the major source of coastal pollution. The coastal waters near the mainland are more polluted with wastewaters than the island coastal waters. Preservation of the coastal water resources will be keyed to the growth of tourism in Croatia and will require substantial investment in wastewater treatment. There is however a shortage of funds for investments of this magnitude. Preservation of the Adriatic coast and its waters will also require transboundary cooperation in areas such as maritime transport, marine spills, and conservation of transboundary wetlands.

8. CONCLUSION

Analyses of the current status and developmental needs have shown that Croatia possesses sufficient quantities of water for its own needs, and that water resources, in terms of their quality and quantity, are not a restricting factor of economic development. However, due to marked temporal and spatial unevenness of the water regime, efficient and environmentally friendly water management requires systematic investment in the development and regular maintenance of the functionality of water management systems. Analyses have also shown that due to partly non-repaired war damage, as well as due to a longer period of insufficient investment in the development and regular maintenance of protective systems, the safety of the population and assets in many potentially flood-exposed areas has been significantly reduced.

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WATER RESOURCE MANAGEMENT PROBLEMS IN SOUTH CAUCASUS REGION

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Abstract: This is an attempts to reveal the main problems of the transboundary water resource management in the South Caucasus region taking into consideration that single country oriented management of water resources does not solve the problems of transboundary water resources. Only integrated planning and management of water resources at the basin level can address the environmental and social-economic development needs in the region.

Keywords: South Caucasus water resource management

1. INTRODUCTION

South Caucasus countries Armenia, Azerbaijan and Georgia rely heavily on Kura-Araks river system as a major source of water for all users. The basin covers almost all of Armenia and Azerbaijan territory, a big urbanized part of Georgia as well as of Iran and Turkey. The basic causes that hinder the sustainable integrated management of the Kur-Araks river basin have both local and global roots. The local inter-basin roots, are poor law enforcement and compliance, inadequate development planning, lack of transboundary cooperation mechanisms; and global root causes as undeveloped civil society, emergent economic mechanisms for water resources management.

The transboundary water resources management problems must be analyzed jointly with other national and international problems that exist in the basin, together with the needs and interests of different sectors and ecosystems, national and sustainable development priorities. In some cases, the political

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controversies among the countries make obstacles for collaboration. Water basin is a base for group effort for integrated water resources management, promoting environmentally sustainable development of each country in the region. It is worth mentioning that some progress has been made in these countries, but still significant difficulties and insufficiencies exist in terms of legal frameworks, implementation of transboundary agreements, and implementation of integrated management mechanisms.

2. OVERVIEW

Kura is the largest river of the South Caucasus, with a longitude of 1,515 km and the drainage basin of 188,000 km^2. The largest influx of the river Kura is the river Araks with a longitude of 1,072 km and the drainage basin of 102,000 km^2.

The water resources are distributed unevenly in the South Caucasus region. Georgia is the richest country in water resources in the region while Azerbaijan suffers from water shortage and reduced water quality.

Armenia totally lies on the Kura-Araks basin. The Araks basin only on the territory of Armenia is 22,790 km^2. The underground water resources that form on the territory of Armenia are 988 million km^3/annually. There are 9,500 big and small rivers in the republic with 6.2 km^3 flow annually. The average annual water consumption of the republic is 1.5–2.0 km^3 with a growing trend to 3–4 km^3 consumption level that was during Soviet period. Because of high mountainous position of the country, all the rivers of the republic flow to the neighboring countries.

Kura, Araks Rivers are the main source of drinking water for almost 70–75% of population of Azerbaijan. The longitude of Kura River in Azerbaijan is 915 km. The River inflows from Republic of Georgia to Azerbaijan. The major rivers of the republic originate outside Azerbaijan, in Turkey, Iran, Russia, Armenia and Georgia and reach the country with reduced quality. The underground water sources provide only 10% of annual water consumption of the republic.

3. LEGAL AND INSTITUTIONAL STRUCTURE

Environmental legislation and the institutional structure of the South Caucasus republics changed dramatically after the collapse of the Soviet Union. During the last 15 years New Independent States (NIS) of the region developed relatively new legal framework in addition to the inherited (According to the

Constitution of Georgia (adopted in 1995) agreements that were formed before 1995 are in power only if it were brought in accordance to the Constitution and legislation of Georgia and in 2 years after the adoption of the Constitution. As a cause of the above mentioned no one of the international agreements, which were formed before the adoption of the Constitution of the Georgia are in power.) from Soviet Union international agreements and conventions. Admitting and understanding the significance of the transboundary cooperation among the neighboring countries, most of the treaties adopted by the former Soviet Union are respected.

Thus, an agreement exists among Armenia, Azerbaijan (as successor states of Soviet Union) and Turkey for equally shared use of Araks River for irrigation and domestic use. This agreement was signed in 1927 and ratified in 1928 Three protocols detailing the implementation of the Convention were signed in 1953 and according to the Ministry of Nature Protection of Armenia an additional protocol was signed on 26.10.1973).

Another agreement between Armenia, Azerbaijan and Iran from 1957 provides the legal foundation for distribution of the transboundary River Araks in equal proportion for irrigation and power generation.

Additionally decisions and agreements were made between Armenia and Georgia on the use of Debed River (signed in 1971), an agreement on environmental protection (signed on 1997 and ratified on 1999). A number of agreements have been accepted by the former soviet states Armenia and Azerbaijan on the use of Arpa, Vorotan, Aghstev and Tavoush rivers. These agreements are being respected in practice.

Armenia, Azerbaijan, Georgia and Iran have signed a number of international environmental agreements and conventions. Table 1 shows the status of the international environmental agreements on transboundary environmental impact and water recourses in Kura-Araks basin countries. All three South Caucasus countries participate in the activities within the framework of the UN Convention on Transboundary Water Courses. However, only Azerbaijan ratified the Convention, while all South Caucasus countries ratified the protocol concerning health protection.

The overlapping local laws and treaties along with the gaps in the legal field hold back integrated effective transboundary water resource management of the Basin. Significant confrontation erases as implementation of the agreements and conventions moves forward. A major concern is the institutional insufficiency and/or duplications on the national level, consistent to different legal documents. The organizational structure of the Environmental Ministries of Caucasus NIS countries are being changed regularly, causing instability in the regional management and hindering integration of the management activities. There are no operating transboundary basin agencies (commissions) to manage the basin's water resources in an integrated manner. However, in some cases the transboundary commissions were established, it actually does not function effectively because of under-funding. In 2003 by the Decree of the Prime Minister of Armenia, a transboundary commission was established supervised by the Water Resource Management Agency of the Ministry of Nature Protection.

Table 1. International environmental agreements on transboundary water resourses, which the Kura-Araks Basin countries are party to

Name of Law or Convention	Date	Armenia	Azerbaijan	Georgia	Iran
Helsinki Convention on Protection and Use of Transboundary Watercourses and International Lakes	1992		Ratified on 03.08.2000		
Protocol on Water and Health of Helsinki Convention on Protection and Use of Transboundary Watercourses and International Lakes	1992		Ratified on 09.01.2003		
Espoo Convention on Environmental Impact Assessment in Transboundary Context	1991	21.02.1997	25.03.1999		
Convention on Transboundary Effects of Industrial Accidents	1992	21.02.1997	16.06.2004		
Aarhus Convention on Access to Public Information, Public Participation in Decision - Making and Access to Justice in Environmental Matters	1998	01.08.2001	23.03.2000	11.04.2000	

The other major derivative of the insufficient cooperation is lack of data exchange that is important constituent of management in general and for water resource management particularly.

There is a lack of river basin management specialists with experience in transboundary water resource management, lack of institutional structures in the different economic sectors for planning, coordinating of environmental activities.

4. ECONOMIC TOOLS

The economic mechanisms of water management on the national levels are emerging, however still missing on the regional level. Economic instruments are good tools for resource management; they increase the water use efficiency, generate revenues, offer constant incentives for usage and waist reduction, and stimulate innovation. The usage of the economic tools in the region is limited with water usage fee systems. The water usage fee (permitting) systems has different procedural structure in Armenia Georgia, Azerbaijan and Iran. The efficiency of implementation of this economic tool is low and there is an uncertain relationship between the charges and impact on water use. “The analyses of the payments associated with water use permitting shows that the current water resources fees system does not provide incentives in most of the Kura-Araks basin countries for the permit holders to meter water use, conserve water, or to reduce pollution” (Preliminary strategic action program (SAP) for the Kira-Araks Basin, September 2006). Thus, still the management costs are much higher than the revenues from the collected fees.

On the other hand significant increase in the price of water is socially not desirable, thus water prices are low compared to the value of water.

That the following steps have to be taken for improvement of the water resource management:

– The fees for the water use have to be set according to the actual used quantity, but not according to the quantity mentioned in the water use permit, except the cases when the used quantity is less than is mentioned in the permit.
– The fees have to reflect supply–demand relation for each water resource basin and for each category of the user.
– The fees for the water resources have to be steadily increased for pollution level reduction, better monitoring and management.
– The fees for the water pollution have to reflect the received water quality and quality.
– The nature protecting agencies has to set the list of polluting elements and set the system of fees accordingly.
– All types of fees (for water extraction, water use, water pollution and waste) have to be regulated according to the inflation level thus keeping their real value and creating base for effective water use and control over pollution.

- The new system of charges for the water resources have to be easily understandable, affordable for the less successful part of the population and has to be designed according to the timetable so that allow the population to take necessary steps for reduction of water use and pollution.
- As there is a real danger in the spare of agriculture that comes from the intensive use of fertilizers and pesticides, that could have an hazardous impact on the water resource quality, there is a need to implement special taxes and penalties that will allow and make intensives for using less polluting agricultural stuff and substances.
- The collected funds from the use of water resources have to be accumulated in a Nature Protection and Ecological Fund that will be used for fulfillment of the National Water Program as well as for water resource protection aiming programs.

Implementation of the economic instruments as a tool for transboundary water resources sustainable use and management promotion is currently restricted in Caucasus Region. The scarce economical data collected locally is mainly used for management system analysis and comparison.

Implementation of the regional economic mechanisms is politically sensitive and difficult to realize. The water resource crisis in the region is actually a crisis of water management and collaboration.

GEOINFORMATION SUPPORT FOR WATER DISASTER SITUATIONS

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Abstract: There is presented paper *Water Management Information Portal* of the Czech Republic for decision support for water disaster situations, and information about contemporary cartography with ubiquitous mapping. The project *Dynamic Geovisualization in Crisis Management* solved by the Masaryk University Brno is mentioned too.

Keywords: crisis management; dynamic geovisualization; ubiquitous mapping; hydro meteorological information; integrated warning service system

1. INTRODUCTION

Cartographic visualization plays an important role in decision support of emergency/crisis management for water disaster situations. Visualization is not an isolated element of the information transfer process; it depends on the status of source databases, decision-supporting models, and behavior of user of cartographic visualization tools in geographic information systems (GIS) (Bandrova and Konecny, 2006). GIS are often the core of the entire management systems that solves not just basic localization tasks, but can also be used for planning and solving complex crisis scenarios and applying their results into practice. An integral part is also visualization of all used information both in static and in dynamic modes and also transfer and processing of all updating information. Current solutions of crisis management employ static cartographic

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visualizations based on pre-prepared models of crisis situations (Konecny and Ormeling, 2005).

From the point of view of geoinformatics, emergency/crisis management units for water disaster situations utilize both spatial data infrastructures including systems for collection, processing, storing, and transfer of updating, usually dynamically changing data, and methods of cartographic visualization, which communicate data and information to user's consciousness (Hřebíček and Konečný, 2007). Decisions of users – especially of those in mobile workstations operating directly in the field – are based on visual perception of the given information.

The paper presents information about *Water Management Information Porta*l of the Czech Republic and *Integrated Warning Service System* which supplies warning information for the territory of Czech Republic from meteorological and hydrological risks point of view. It discusses research of ubiquitous mapping, adaptable cartography for decision support of water disaster situations and the project *Dynamic Geovisualization in Crisis Management* (http://geokrima.geogr.muni.cz/), which is solved at the Masaryk University Brno.

2. WATER MANAGEMENT INFORMATION PORTAL

The Czech Republic is inland country in the Central Europe which belongs to the area of temperate climate zone in the North hemisphere. Entire length of the Czech Republic state borders is 2,290.2 km. Seven hundred and thiry-eight kilometer is so-called wet border because it is formed by watercourses. The Czech Republic territory is important headstream of European continent and from the hydrological point of view we can call it a roof of the Europe. The Czech Republic is situated on the divide of tree seas: *the North Sea, the Baltic Sea* and *the Black Sea*.

All Czech important streams drainage of water at territories of bordering states, see Figure 1. The Czech Republic hydrological system creates three main hydrological basins: the *Elbe river basin*, the *Odra river basin* and the *Morava river basin* (the *Danube*). Spinal water streams are the Elbe river (370 km) with the Vltava river (433 km) in Bohemia, the Morava river (272 km) with the Dyje river (306 km) in the South Moravia and the Odra river (135 km) with the Opava river (131 km) in the North Moravia and the Silesia.

Figure 1. Czech Republic territory in European continent (WATER portal)

Monitoring of the hydrosphere of the Czech Republic is provided at about 500 stations of the surface water monitoring from which 70% are automated and at 1600 sites of the groundwater monitoring where 25% are automated. After the flood in 2002 damaged stations for surface water monitoring involved in the system of flood warning service were built or refurbished. Replacement about one third of observation boreholes for shallow waters and building or refurbishment of 22 stations for surface water quality monitoring was funded from the Cohesion Fund of the EU.

The forecasting meteorological and hydrological services in the Czech Republic are providing by the Czech Hydrometeorological Institute (CHMI). CHMI is incorporated into the system of integrated forecasting workplaces, daily discharge forecast for 100 river sites is issued, and 60 of them are presented on the Internet (http://hydro.chmi.cz/hpps/). It enables that the Ministry of Agriculture water management department in cooperation with other central water legal authorities of the Czech Republic (i.e. the Ministry of the Environment, the Ministry of Transport, the Ministry of Defense and the Ministry of Health) established *Water management information portal* (WATER) of the Czech Republic (http://www.voda.mze.cz/en/).

WATER portal presents current information on water levels in watercourses and water reservoirs, water quality in water reservoirs or current overview of precipitation rate at selected stations (Figure 2) as well as overviews on individual data bases from the Czech Republic water management fields. Through the uniform, well-arranged and easily available applications above mentioned departments present authentic information about water of Czech Republic to general public and conduce to better and timely informed ness.

WATER portal is related to clearness and presentation of individual information unique system and even according to all-European standards. There are secure reliable information from the water management field to the public at large and so contribute to her better and early awareness. You can find there water levels (in unit cm) and flow rates (in unit m^3/s) on watercourses at selected hydrometric stations in the state monitoring net operated by the CHMI and from inserted profiles of state enterprise *Povodí* (Figure 3). It is monitored each hour, every day in the year. It enables to obtain early information about floods threat to public and decision makers in emergency/crisis management of the Czech Republic (http://www.krizove-rizeni.cz/index.htm).

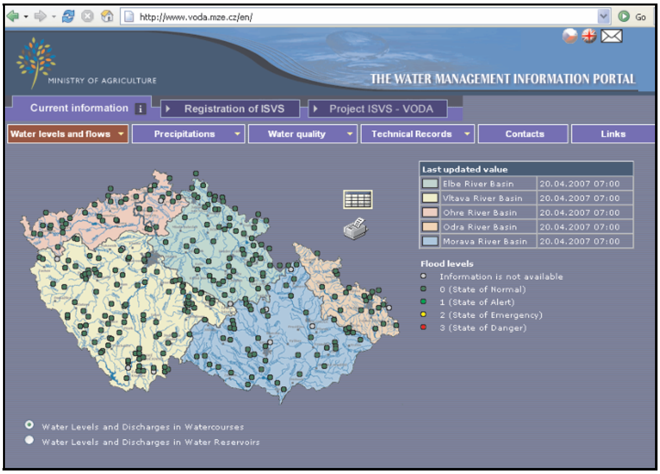

Figure 2. Water management information portal – WATER

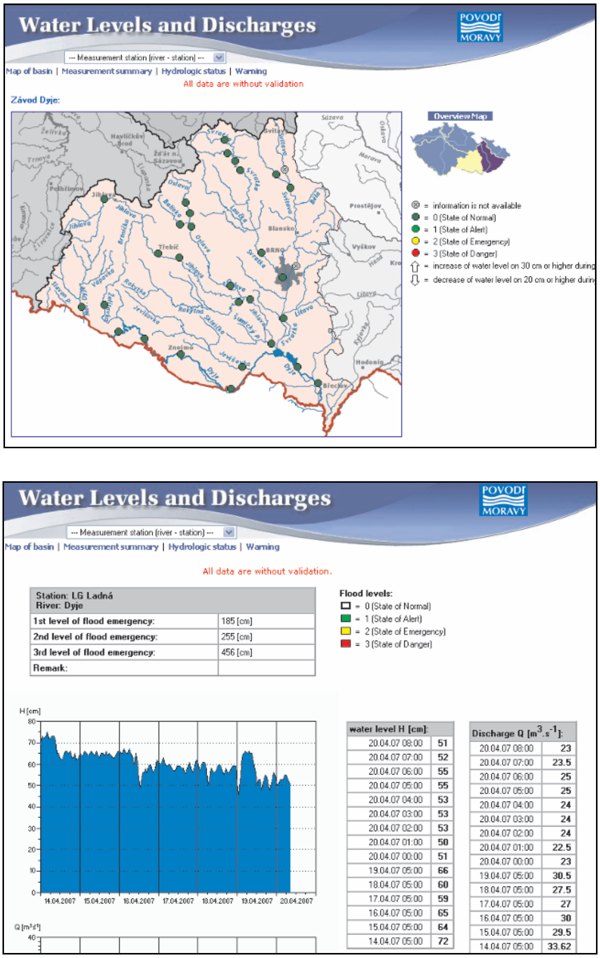

Figure 3. Water level and discharges application in WATER portal

Integrated Warning Service System (IWSS) is CHMI Warning Service (http://pocasi.chmi.cz) and this is a component of *Integrated Rescue System of Czech Republic* (IRC CR) which supplies issuing of warning information for the territory of Czech Republic from meteorological and hydrological risks point of view (Figure 4). *Integrated Warning Service System* issues directly (Obrusnik, 2006):

– Forecasting warning information (forecast for further development of flood situations, meteorological and hydrological hazards, smog warning (air pollution)
– Information of occurrence of extreme values (only for some hydro meteorological phenomena with extreme value of risk)
– Special warning for Flood forecasting and warning service

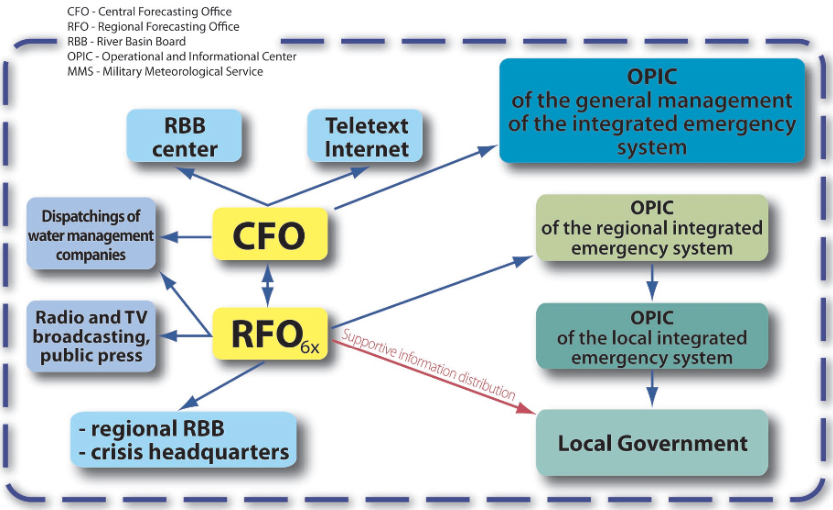

Figure 4. Data flow in the IWSS

The main stream of warnings, forecasts, and other information flowed from the CHMI Central Forecasting Office (CFO) to the Operations and Information Centre (OPIC) of the Prague-based Directorate General of the Fire Services, and thence to the OPIC of the Regional Directorates of the Fire Services, and thence to the districts, and, ultimately, to each of the communities and citizens. The CHMI's regional forecasting offices analogously communicated with the relevant OPIC at regional and district authorities (Nemec and Obrusnik, 2003).

A comparison of the 1997, 2002 floods and 2006 floods in the Czech Republic from the perspective of the water disasters management will indicate that the greatest pluses included the good working of the communication between the IWSS and the crisis management system and IRC CR, in compliance with the new crisis management laws that had been effective from the beginning of 2000.

Within the frame of the IWSS, warning information can be issued on a total of 26 dangerous phenomena divided into 7 groups. A different level of danger can be assigned to each of these phenomena. Based on its intensity, each phenomenon is attributed with one of the three levels of danger (low, high, extreme) distinguished by color in accordance with international projects dealing with presentation of warnings in web pages of national meteorological services (http://www.meteoalarm.eu). The level of attention required in the given situation from the user, including vulnerability and extent of involved area, is also taken into account.

3. ROLE OF CARTOGRAPHY IN CRISIS MANAGEMENT

As Konecny and Bandrova (2006) pointed out many questions asked during management of an emergency/crisis situation begin with the word WHERE – WHERE did something happen, WHERE are the rescue units, WHERE are the sources of danger, WHERE should the threatened people be relocated, etc. It is clear, that a natural answer to these questions is a map. The role of cartography in crisis management is therefore clear – simplify and well-arrange required spatial data. That makes the decision-making process quicker and better and leads to minimization of damage.

The International Cartographic Association (ICA) is active in the process of teaching people how to make and use maps created for early warning, natural risks and disasters, for emergency needs. ICA follows resolutions and agreements from World Summit on Sustainable Development (Johannesburg, 2002) and mainly United Nation World Conference on Disaster Reduction, held in Kobe, Hyogo, Japan, from 18 to 22 January 2005, (http://www.unisdr.org/wcdr/). The ICA and many cartographers work in this field of mapping phenomena connected with natural risks and disasters. Showing the way how to draw and read the maps, they are included in the processes of standardization. The way for data capture, collection, classification and visualization is proposed and many different ways for management with cartographic presented data are known. All efforts could be direct to the international standardization process. Konecny and Bandrova (2006) proposed a methodology of a standard in two directions: *symbol system and color representation* and the second one – *data classification in natural risks and disasters mapping*.

In order to realize new cartographic techniques, it is necessary to have available data, information, and knowledge. The attempts to interconnect a large amount of data stored often very far from one another have led to the idea of creating *Spatial Data Infrastructures* (SDI). Perhaps the best known definition of these infrastructures comes from one of the first executive orders of the former US President William J. Clinton (13 August 1994): *"Geographic information is critical to promote economic development, improve our stewardship of natural resources, and protect the environment. Modern technology now permits improved acquisition, distribution, and utilization of geographic (or geospatial) data and mapping. ... The executive branch [should] develop, in cooperation with State, local, and tribal governments, and the private sector, a coordinated National Spatial Data Infrastructure (NSDI) to support public and private sector applications of geospatial data in such areas as transportation, community development, agriculture, emergency response, environmental management, and information technology."*

NSDI contains – apart from actual data – also technologies, political, economic, and organizational policies, standards and human resources necessary for collection, processing, storage, distribution and improvement of use of geospatial data. US NSDI was the first world accepted approach to create SDI but looking back we have to say that it is mostly a collection of dataset catalogues and not really and integrated data infrastructure providing immediate access to data. It also does not really provide extensibility – i.e. ability to easily add new open data providers.

4. UBIQUITOUS MAPPING: MOBILE, SENSOR AND ADAPTABLE AREAS OF CARTOGRAPHY

We can see in contemporary digital cartography in crisis management a shift in the requests from base map to thematic map, to shape or develop new elements of Cartographic language, especially for mobile tools and as well as improvements of principles, rules and methods of visual communication are going on. Development of digital cartography is strongly influenced by Information and Communication Technologies (ICT) and vice versa digital cartography is enhancing efforts to play more important role in Information/Knowledge Society environment (Figure 5). There are evident integration of map makers and map users and new fields of cartography enhancing shift from analogue maps to

Ubiquitous Mapping. To solve a certain problem means to define it, make strategic planning how to solve it and how to derive a solution. Research agenda for this is specified by Morita (2004).

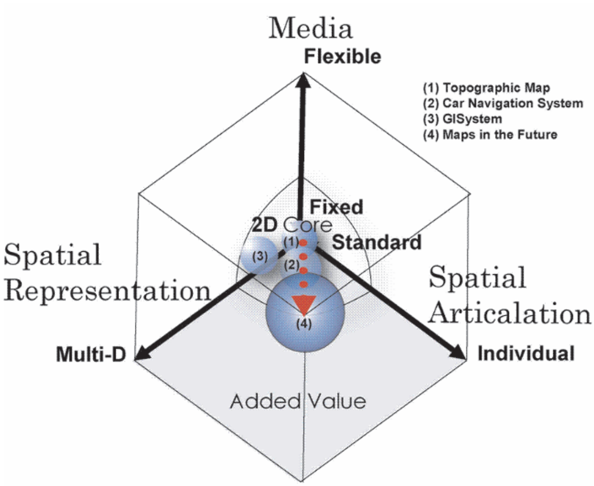

Figure 5. Contemporary Mapping World (according to by Morita, 2004)

In current cartography, we can recognize several development areas such as: *Internet Cartography; Mobile Internet/TeleCartography; Map based LBS; Navigation systems*. We can see new trends in Ubiquitous mapping: *Mobile, Sensor Cartography* and *Adaptable Cartography*.

- *Mobile Cartography* is more enhancing the technological part of the realization of the cartographical ideas mainly on small displays. A promising area that could utilize this approach is the area of spatial decision-making concerning specialists from different disciplines and with different educational and cultural backgrounds.
- *Sensor Cartography* intends to handle and elaborate specific data and information coming from various sensors (e.g. installed along rivers, the roads or in cars or on aircrafts), their transformation and integration with data and information prepared in databases. The target is real-time map derivation for users, e.g. decision-makers on the different level of public administration.

– *Adaptable (Adaptive) Cartography* is one of the most important directions of the contemporary cartography research (Friedmannová et al., 2006). Idea behind adaptable cartography is to automatically make proper visualization of geodata according to situation, purpose and user's background. Adaptable maps are still supposed to be maps, i.e. correct, well readable, visual medium for spatial information transmission, Figure 6 provides an example. All map modification processes are incorporated in electronic map logic. Users can affect adaptive map just indirectly by a context.

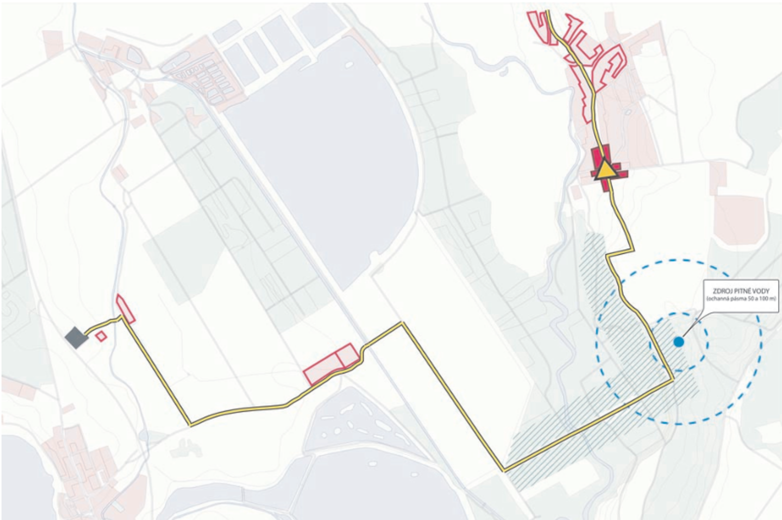

Figure 6. Example of dynamic visualization of the moving object with hazardous material (Friedmannová et al., 2006)

5. DYNAMIC GEOVISUALIZATION FOR CRISIS MANAGEMENT

The research project *Dynamic Geovizualisation in Crisis Management* of Ministry of Education, Youth and Sports of the Czech Republic started in 2006 (Konečný et al., 2005; http://geokrima.geogr.muni.cz). For the support of the crisis management by *intelligent* maps the research group based in Laboratory on Geoinformatics and Cartography at Masaryk University in Brno was established. Research group is composed from cartographers, geographers, mathematicians, psychologists and computer scientists. Implementation and evaluation of methods is provided in close collaboration with Crisis Management Centre of Southern Moravian region. Duration of the project is 7 years. In the actual stage is research focused on issues related to crisis situation related to hydrosphere and on hazardous material transport.

ACKNOWLEDGEMENT

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INCORPORATION OF THE CRITICAL INFRASTRUCTURE MANAGEMENT INTO THE DSS ON STRATEGIC WATER SUPPLY SYSTEM MANAGEMENT

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Abstract: There are more than 1,000 water supply systems (WSS) in the Republic of Slovenia due to the dispersed settlement pattern and more than 120 WSS operators managing them. In order to follow-up the performance of public service on all those systems and ensure the efficiency of the managing companies a complex regulative system (with decision support system - DSS) is under continuous development with a scope to ensure safe and quality water supply on short term as well on long term. The driving mechanism for DSS was implementation of the EU Drinking Water Directive.

A specific topic in this DSS is now addressing also the functionality of water supply system as critical infrastructure under terms of forthcoming EU Directive (proposed COM 2006/787) and national. Within the annex I of the proposed Critical Infrastructure Directive – Provision of drinking water and control of water quality water supply is identified as one of the explicitly listed sub-sectors. While the proposed directive is generally addressing the infrastructure that affects two or more member states it is also clearly expressing necessity of close harmonization with national systems of critical infrastructure.

In the article the applied approach on the DSS level to the critical infrastructure will be presented with key steps that are foreseen by the directive: identification of the infrastructure, risk analysis, counter-measures and procedures implemented in the system.

Keywords: management of critical infrastructure; DSS; water supply system

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1. INTRODUCTION

Dispersed settlement pattern as well as abundance of water resources has resulted in a specific distribution of water supply systems (WSS) in the Republic of Slovenia. Some 1,000, rather small WSS, are now under operation supplying more than 99% of the population. They are ranking in the wide spectrum from very small WSS, supplying about 20 inhabitants, to some large WSS systems supplying several hundred thousand inhabitants. The necessity to put all those system under systematic control, especially the systems supplying more than 50 inhabitants, was strengthened by the EU Drinking Water Directive. While the system of water quality supervision and control is already well established, it was recognized that the integration with other managerial aspects was necessary. Following managerial aspect were determined as a priority:

- Preparation of centralized registry of water supply systems
- Their supply area, in further context named agglomerations
- Centralized registry of public service providers
- Supervision system for water quality and preparedness/response measures
- Spatial registry of water supply infrastructure

In the following paragraphs some of the key aspects regarding determined priorities will be presented and discussed in the light of a specific task – management of WSS as a critical infrastructure.

2. CENTRAL REGISTRY OF WATER SUPPLY SYSTEMS AND WATER SUPPLY PROVIDERS

In order to improve the information on who is managing which of many water supply systems the internet based database was developed, providing along with the reporting scheme also detailed information on the managers of the water supply systems. In this manner it is possible to identify the public service provider for each individual agglomeration, and at the same level, the water supply system which is supplying water to each agglomeration.

Implemented registry is thus managing following key entities (Figure 1):

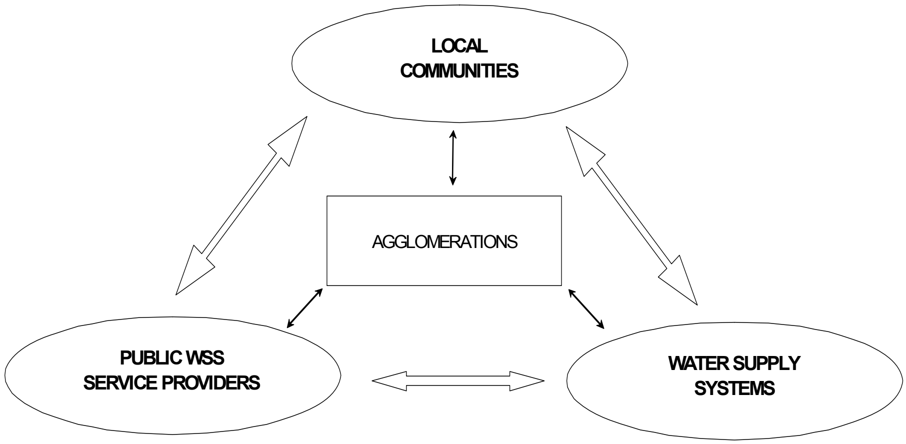


Figure 1. Entities managed in the central registry

The data on the entities are attributed in order to follow-up key information on each entity. Important attribute set to each water supply system is also link to the identified water resource used to supply each specific water supply system.

Findings on the registry which is implemented but still under development show that many small water supply systems (50 to 200 inhabitants, i.e. water users) in Slovenia are managed by the groups of owners/water user's associations, which have no legislative based forms, neither do they manage the systems by any specific operation and maintenance procedures.

Example of the spatial analysis on the data from the central registry is shown on the Figure 2. The dispersed settlement pattern of agglomerations, as shown on the Figure 2, and large number of separate water supply systems (different colors of agglomerations) are posing a specific challenge when trying to develop a structure that would enable follow-up of different strategic dimensions of the water supply systems.

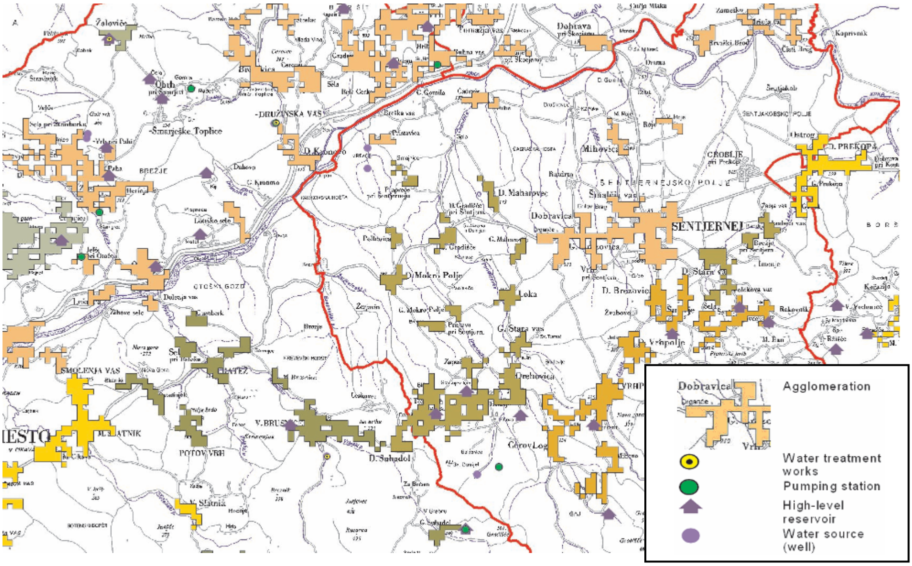


Figure 2. Agglomerations of different color are supplied by different WSS

3. NATIONAL REGISTRY OF SPATIAL INFORMATION ON WATER SUPPLY SYSTEM

With a scope of providing centralized information of all public information the project started to develop a centralized, maintained, spatial registry of all public infrastructures. The main scope of the project, which is already operational, was to determine the public infrastructure (roads, telecommunications, electricity, gas infrastructure, remote heating infrastructure, pipelines, sewerage network, and other) to determine the corridors already occupied by different types of infrastructure in order to lower the cost of maintenance of the infrastructures and prevent accidental damages to those. Other uses might be identified as spin-off effects.

The legal basis for this national registry of spatial information on public infrastructure is provided by the Spatial Planning Act with national surveying authority (GURS) in charge for the data collection and dissemination. All public service providers (water, sewerage, gas, electricity, telecommunications, etc.) are obliged to harmonize their GIS registry structures with the national registry in order to provide regular reporting.

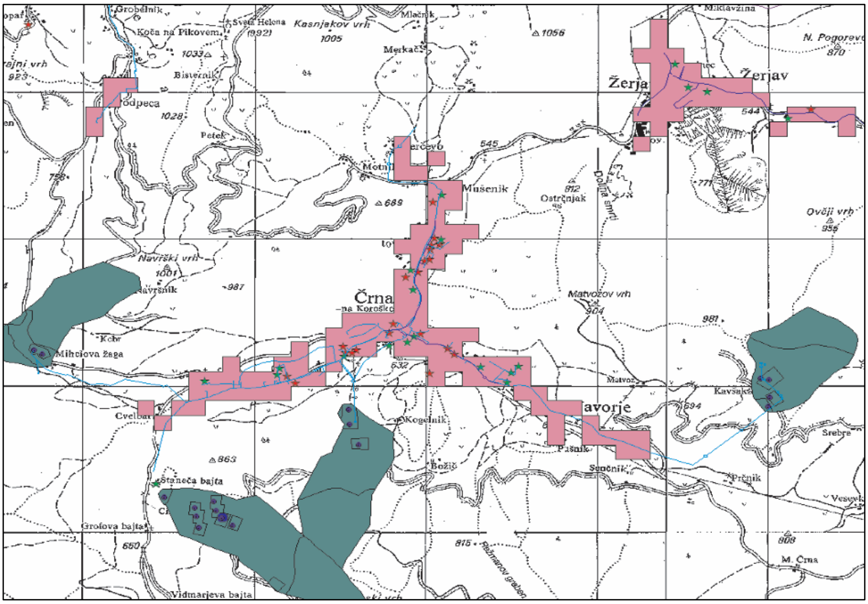
4. INTEGRATION OF SPATIAL INFORMATION ON DESEASES

Important part of the system, enabling the comprehensive monitoring of water supply system performance, is also information on spatial distribution of the registered water-borne diseases. Generally is the information on the diseases linked to the location of the ill person highly sensitive and should be approached with maximum awareness of necessary personal data protection. For the integration of the spatial information on the diseases in the central registry of water supply systems and water supply providers the test input scheme is under way. Within this scheme the physicians in the homogeneous water supply/ health service area are requested to enter the data on:

– Individual patient – age and gender
– Location of the patient – two locations are possible (home address, working place)
– Disease – according to the World Health Organization classification of diseases – selection of multiple diseases for one patient is possible

Example of the performed post-event analysis verifying the data necessity is shown on the Figure 3. The water supply system is supplied from different sources (blue dots). Yellow stars are showing the singular occurrence of the gastro-digestive disease while the red stars are standing for the locations of the multiple occurrence of the disease. It was identified on the basis of the hydraulic analysis, that the reason for the contamination of the water supply was the water source marked with circle.

It is expected that with this approach, requesting the minimum individual data necessary, a system on early identification of water-borne diseases could become operational enabling the identification of the spatial distribution of disease's spreading in water supply systems as it is shown in the post-event analysis for a local water supply system in Slovenia on Figure 3.



LEGEND:

Water source with protection zones

Agglomerations

Location of registered occurrence diseases

Figure 3. Example of the spatial distribution of the registered water-borne disease (post-event analysis)

5. REPORTING REQUIREMENTS AND WSS EMERGENCY MANAGEMENT PLANS

The information in the database is depending on the quality of reporting process from different stakeholders. The legislation is therefore important issue in order to provide institutional and procedural framework to provide a reliable and continuous source of the maintained information.

A specific attribute set that is already added to the entity – water supply system is also uploaded information on the emergency management plan for each specific water supply system. By this an important enhancement in the field of emergency management was achieved as:

- Regulatory institutions (Ministry of Environment and Spatial Planning – public service supervision; Ministry of Defense – civil protection activities, and Ministry of Health – drinking water quality) can control the contents of the emergency management plan and suggest for the improvements.
- In the case of the event under development all authorized stakeholders have an active access to the latest version of the emergency management plan.
- Revisions, testing and maintenance of the emergency management plan can be performed more easily.
- Other technical documents amending the management plan can be uploaded as well in order to improve the quality and management emergency operations.

The aggregated reporting system of water supply is a logical step in the system development necessary to provide information for supervision system and integration with services that are provided outside the internal system of Water Company. In the case of Slovenia, with more than 150 service providers for 2.0 million inhabitants such a system is an absolute necessity in order to assist and control the achievement of general supply standards for the population.

6. CONCLUSIONS

Integration of the data on water supply systems enables improved management of the water supply systems, but in the same time also provides improvement in the field of management of water supply systems as a critical infrastructure. Horizontal integration of different aspects goes along with the vertical integration of stakeholders with different roles in the process of water supply systems.

With the integration of monitoring data and improvement of the response mechanisms the security of the overall performance of the water supply systems in different loading conditions and operational statuses improve as well.

It is expected that the increased requirements regarding the obligatory reporting schemes requested by national legislation will gradually lead also to the reduction of WSS managers improving thus the economics of the operation of the WSS.

With the integration of the data on (critical) public infrastructure as water supply systems are, the question rises about the public availability, access and protection of those (public, private) data.

A major challenge in the field of strategic water supply system management is also the perspective of the climate change and its effects on the water supply. Foreseen perspectives for the Slovenia show a high possibility of longer drought periods, which could affect the reliability of water supply, depending predominantly on ground water resources. The efficient database which is already including data on water consumption, resource used and water losses from the WSS is of key importance in order to be able to develop a strategic planning process for this water use as well.

The next feature which is planned to be integrated in the central registry of water supply systems is a registry of events on water supply systems (with centralized reporting). Events, such as: pipe breaks, interrupted water supply, exceptional loads on WSS i.e. fire fighting, reported registered pollution of water and other could and should be centrally monitored in order to provide a long term reliable provision of drinking water and follow-up the quality of work of public service provides.

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GROUNDWATER VULNERABILITY ASSESSMENT USING PHYSICAL PRINCIPLES OF CONTAMINATION SPREADING

Theory Demonstrated on Tisovec Karst Hydrogeological Structure

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Abstract: Several methods of groundwater vulnerability assessment have been developed since 1970s in order to derive vulnerability maps, taking account of hydrogeological settings and field investigations. Majority of those relied on counting of points related to various hydrogeological factors with different, mostly subjective rating. More physical understanding to this topic was added by Brouyére et al. (2001) and Jeannin et al. (2001). Such definitions of groundwater vulnerability are based on contamination spreading principles. As the contamination evolves in the groundwater, it is affected by different intrinsic hydrodynamic and hydrodispersive mechanisms, altering progressively its spatial and temporal distribution. Main intrinsic hydrodispersive processes in underground are advection, hydrodynamic dispersion, physical retardation and dilution. For intrinsic groundwater vulnerability, three factors describing pollution by conservative contaminant are defined: contaminant transfer time, contamination duration and level of contaminant concentration. All three factors can be plotted on a "vulnerability cube" edges to help in the estimation of overall vulnerability. Such a groundwater vulnerability assessment methodology was applied at

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the site of the Tisovec Karst hydrogeological structure (Slovenske Rudohorie Mts., Western Carpathians – Slovakia). The potential target of contamination spreading was the groundwater table, so the final result in a map format can be called an "intrinsic groundwater resource vulnerability map" according to the "European definitions" (COST 620 project). For calculation of physically-based vulnerability parameters, the VULK software tool developed at the University of Neuchâtel in Switzerland was used. Simulations conducted using VULK tool provided contamination breakthrough curve parameters of potential contaminant transfer time, contamination duration and level of potential contaminant concentration. These were logarithmically plotted on the axes of the "vulnerability cube." Then the resulting vulnerability value V was calculated as the distance from the "zero point" of the "vulnerability cube." Results were used also as the first estimate of potential groundwater vulnerability influencing factors based on field data.

Keywords: groundwater vulnerability; groundwater attenuation; breakthrough curve; transfer time; duration of contamination; relative concentration

1. INTRODUCTION

Many methods of groundwater vulnerability assessment have been developed since 1970s in order to derive vulnerability maps (Aller et al., 1985; Foster, 1987; Moore, 1989; Van Stempvoort et al., 1993; Vrba and Zaporozec, 1994; Hölting et al., 1995; Doerfliger and Zwahlen, 1998; Daly et al., 2002; Zwahlen et al., 2004). Especially, development of GIS techniques after 1990s enabled easy handling and manipulation of spatial data, raster and vector map arithmetic calculations. Many groundwater vulnerability methods process many input layers, but manipulation with these layers usually relies on counting of scores. These scores are mostly related to estimates of functions of various hydrogeological factors with different, mostly subjective ratings. In such a case, groundwater vulnerability maps plotted on the same territory, using different groundwater vulnerability assessment methods can be seen in "contradictory colors", giving sometimes extremely high or very low vulnerability to the same spatial location in the field. This underestimating or overestimating of hydrogeological functioning, based on the partial experience, can never be removed using the mechanical extension of used principles, as human experience is every time partial.

2. PHYSICALLY BASED CONCEPT OF GROUNDWATER VULNERABILITY

Improved physical understanding to the topic of groundwater vulnerability was provided by Brouyére et al. (2001) and Jeannin et al. (2001). Their definitions of groundwater vulnerability were based on principles of contamination spreading. Basically, "vulnerability" as a parameter should reflect the capacity of the aquifer to reduce any type of contamination. This reduction can occur mainly in two ways: (a) a decrease of contaminant concentration or (b) a decrease of pollution duration. In the case of an accidental contamination event, there are three parameters, which define vulnerability: (a) how long does it take until the contamination reaches the target – groundwater table or groundwater source, (b) to what extent – at what concentration level will the target be contaminated, and (c) for how long will the contamination last. Thus, the three parameters should define groundwater vulnerability within rock media: (a) transit time, (b) concentration in polluting event and (c) duration time of concentration over threshold value (see also Figure 1).

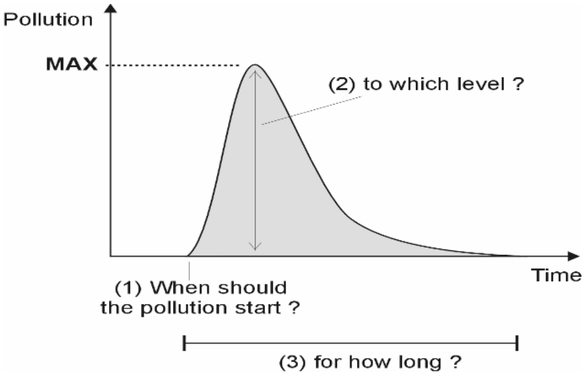

Figure 1. The three parameters which define groundwater vulnerability in the physically-based concept of intrinsic vulnerability (after Brouyére et al., 2001)

As a real (or potential) contaminant is released on ground surface, it is affected by different hydrodynamic and hydrodispersive mechanisms, altering progressively its spatial and temporal distribution. Main intrinsic hydro-dispersive processes in underground are advection, hydrodynamic dispersion, retardation and dilution. Other mechanisms are related to specific contaminant types (e.g. hydrocarbons or heavy metals). These processes act simultaneously, and can be simulated based on our knowledge of their physical (or chemical) character and based on available data on soil, rock and groundwater properties.

3. GROUNDWATER VULNERABILITY DATA PROCESSING

A method of vulnerability assessment should consequently take into account the properties, which control the transit time of a contaminant from the origin (land surface) of pollution to the target (groundwater table), the contaminant concentration and, in the case particularly of intermittent or sporadic pollution, the duration of the contamination at the target.

The transit time of contaminant in aquifer material mainly depends on the permeability, effective porosity, hydraulic gradient and thickness of the layers along the pathway. The contaminant concentration level depends on the attenuation capacity of the aquifer, and also on the dilutive effect of effective precipitation.

The 20.45 km^2 of the outcropping limestones and dolomites in the Tisovec Karst were covered by a 100 × 100 m grid, counting 12,644 cells. Values of four basic parameters (soil cover thickness “bs”, soil hydraulic conductivity “ks”, unsaturated zone (epikarst) thickness “be”, unsaturated zone (epikarst) hydraulic conductivity “ke”) were obtained from soil samplings, geological and hydrogeological maps and digital elevation model (DEM). For simplification of the number of VULK tool simulations, all the data were classified into coded categories. Resulting combination of categories occurring on the territory of Tisovec Karst gave 62 combinations from 72 that are theoretically possible. Input parameters of individual subsystems are shown in Table 1.

Breakthrough curves of a conservative contaminant were simulated using the VULK-tool (Cornaton and Perrochet, 2001; Jeannin et al., 2001). This 1-dimensional solver, developed at the University of Neuchâtel, simulates progress of contamination transport from the input point (point of infiltration) up to target (groundwater table). The tool calculates and converts the concentration to relative values (input/output relative concentrations).

Table 1. Input parameters of individual subsystems for contaminant breakthrough curve modeling in the Tisovec Karst

Code number	Description	Real parameter values
Soil thickness (m)		
0	Steep slope	0.1 m
1	Moderate slope	0.5 m
2	Plain	1.0 m
Soil hydraulic conductivity ($m\cdot s^{-1}$)		
0	Kambisoils	1E-05 m·s¯1
1	Kambisoils	1E-05 $m\cdot s^{-1}$
2	Luvisoils	3E-06 $m\cdot s^{-1}$
Epikarst thickness (m)		
0		50 m
1		50 m
2		150 m
3		250 m
4		350 m
5		450 m
6		550 m
7		650 m
Epikarst hydraulic conductivity ($m\cdot s^{-1}$)		
0	Non-carbonate rocks	3E-05 $m\cdot s^{-1}$
1	Limestones	3E-04 $m\cdot s^{-1}$
2	Dolomites	1E-04 $m\cdot s^{-1}$

VULK tool requires flow values of velocities, which were calculated by using hydraulic conductivity values and a hydraulic gradient set to 1. Single porosity of 0.1 (10%) was used; secondary porosity was neglected.

Dispersivity value was calculated as 1/20 of the flow distance (layer thickness), a common simplification when no field data on dispersivity is available. Because contaminant arrival was “recorded” on the groundwater table (resource vulnerability principle according to COST 620 classification, Zwahlen et al., 2004), zero dilution entered the simulation process as well. For all cases of simulated contaminant breakthrough (combinations of parameters listed in Table 1), input time interval of potential contamination release was set as 1 h. Shapes of typical simulated breakthrough curves are shown on Figure 2.

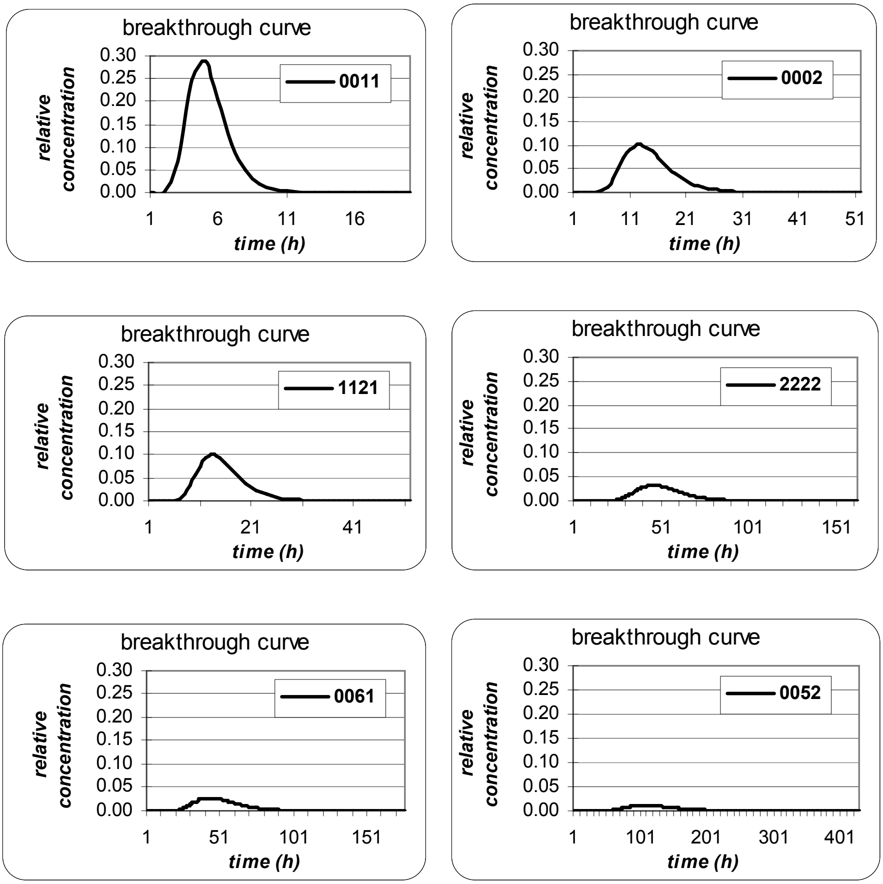

Figure 2. Shapes of typical breakthrough curves simulated by VULK for limestones (0011 – bs = 0.1 m, ks = 1E-05 m·s^{-1}, be = 50 m, ke = 3E-04 m·s^{-1}; 1121 – bs = 0.5 m, ks = 1E-05 m·s^{-1}, be = 150 m, ke = 3E-04 m·s^{-1}; 0061 – bs = 0.1 m, ks = 1E 05 m·s^{-1}, be = 550 m, ke = 3E-04 m·s^{-1}) and dolomites (0002 – bs = 0.1 m, ks = 1E-05 m·s^{-1}, be = 50 m, ke = 1E-04 m·s^{-1}; 2222 – bs = 1 m, ks = 3E-06 m·s^{-1}, be = 150 m, ke = 1E-04 m·s^{-1}; 0052 – bs = 0.1 m, ks = 1E-05 m·s^{-1}, be = 450 m, ke = 1E-04 m·s^{-1})

4. GROUNDWATER VULNERABILITY VALUE DEFINITION

It is clear that groundwater is more vulnerable, if a contaminant quickly arrives at the groundwater table, or its potential concentration (or relative concentration) is higher or if pollution of groundwater – duration of concentration over predefined threshold value – lasts longer. But to compare various parameters that control contaminant migration, a scheme should be introduced. According to the aforementioned definitions, any potential contaminant "breakthrough" can be presented using three dimensional graphics. The axes of these graphs hold transfer time, concentration level and duration criteria. Resulting transit time t_{break}, duration time $t_{duration}$ and relative concentration C_{max}/C_0 values – outputs from VULK tool simulation runs – are logarithmically plotted on the X_1, X_2 a X_3 axes of the "vulnerability cube" defined by Brouyére et al. (2001; Fig. 3). From the nature of the logarithmic plot describing parameters it is clear, that the final vulnerability value depends on the "zero point" – the point of maximal groundwater vulnerability plotted on the "vulnerability cube". Final vulnerability value V was then calculated as a position – distance – of a point determined by its X_1, X_2 a X_3 coordinates (or C_{max}/C_0, t_{break} and $t_{duration}$ values) from the "zero point" of a "vulnerability cube" according to the following equations (1, 2, 3 and 4).

$$V = (X_1^2 + X_2^2 + X_3^2)^{1/2} \quad (1)$$

$$X_1 = -\log (C_{max}/C_0) \quad (2)$$

$$X_2 = 5 - \log (t_{duration}) \quad (3)$$

$$X_3 = 2 + \log (t_{break}) \quad (4)$$

where:

V – final groundwater vulnerability value of the given point of the "vulnerability cube"

X_1 – position on the "relative concentration" axes of the "vulnerability cube"

X_2 – position on the "mean contamination duration time" axes

X_3 – position on the "mean contaminant transfer time" axes of the "vulnerability cube"

C_0 – relative input concentration on the surface [–]

C_{max} – maximal contaminant concentration in the evaluated point [–]

$t_{duration}$ – mean duration time of contaminant relative concentration over threshold value (D)

t_{break} – mean contaminant transfer time (D)

As can be seen also from the Eqs. (2, 3 and 4), the “zero”, i.e. the most vulnerable point of the “vulnerability cube” occurs for the case of the Tisovec Karst (on the contrary with the “vulnerability cube” zero point given by Jeannin et al., 2001), as $C_{max}/C_0 = 1$; $t_{break} = 1.10^{-2}$ day a $t_{duration} = 1.10^5$ days. For individual combination of rock and soil parameters in the Tisovec Karst, the “vulnerability cube” is shown on Figure 3.

Relative concentrations C_{max}/C_0 simulated for 62 combinations of the input parameters in the Tisovec Karst (Figure 3) are within the range of 0.002 to 0.290 with the mean value of 0.040. Plotted on the X_1 axes of the “vulnerability cube” using the Eq. (2), they are within the interval of 0.538–2.622 with the mean value of 1.721. As a threshold value for the relative concentration of contaminant the value of 0.01 (or 1%) was considered, taking into account typical situations and classical conservative contaminant (e.g. nitrates) scenario. Values of the mean contamination duration time $t_{duration}$ with the relative concentration >0.01 for 62 breakthrough curves, calculated by VULK-tool were within the range from 0.000 (no contamination) up to 45.973 h (1.92 days), with the average value of 22.641 h (0.94 days). Position of the mean contamination duration time on the X_2 axes of the “vulnerability cube” is within the interval of 4.718–7.000 (highest values were given to the zero contamination) with the average value of 5.476 (Figure 3). Values of the mean contamination transit time t_{break} for the case of the Tisovec Karst were from 5.33 to 601.41 h (0.22–25.0 days) with the average of 142.54 h (5.94 days). Position of the mean contamination transit time on the X_3 axes of the “vulnerability cube” is within the interval from 1.346 to 3.399 with the average of 2.498. Final groundwater vulnerability value for the Tisovec Karst V calculated according to Eq. (1) as a distance of the point determined by C_{max}/C_0, t_{break} and $t_{duration}$ from the “zero point” according to Eqs. (1, 2, 3 and 4) was ranging from 5.501 to 8.211 with the mean value of 6.281 (Figure 3).

When comparing different rock environments of limestones and dolomites and simulated breakthrough curve results, respectively, values of maximal relative concentrations C_{max}/C_0 for limestones are ranging from 0.23% to 29.0%, and for dolomites from 1.10% to 10.1% with mean values of 9.5% for limestones and 4.8% for dolomites. Mean contaminant transit time t_{break} for limestones was 0.22–2.57 days with 1.31 days average, for dolomites 0.61–5.65 days with the average of 2.53 days. Contamination duration time $t_{duration}$ over accepted threshold limit (>1%) was for limestones 0.32–1.82 days (average 1.11 days) and for dolomites 0.73–1.92 days (average 1.32 days). Such results support empirical knowledge on fast and concentrated contaminant arrival with shorter duration in limestones and less concentrated later contaminant arrival with longer duration in dolomitic rock environment (Figure 3). Large range of values within equal rock environments points to dominant influence of the unsaturated zone thickness on the groundwater vulnerability.

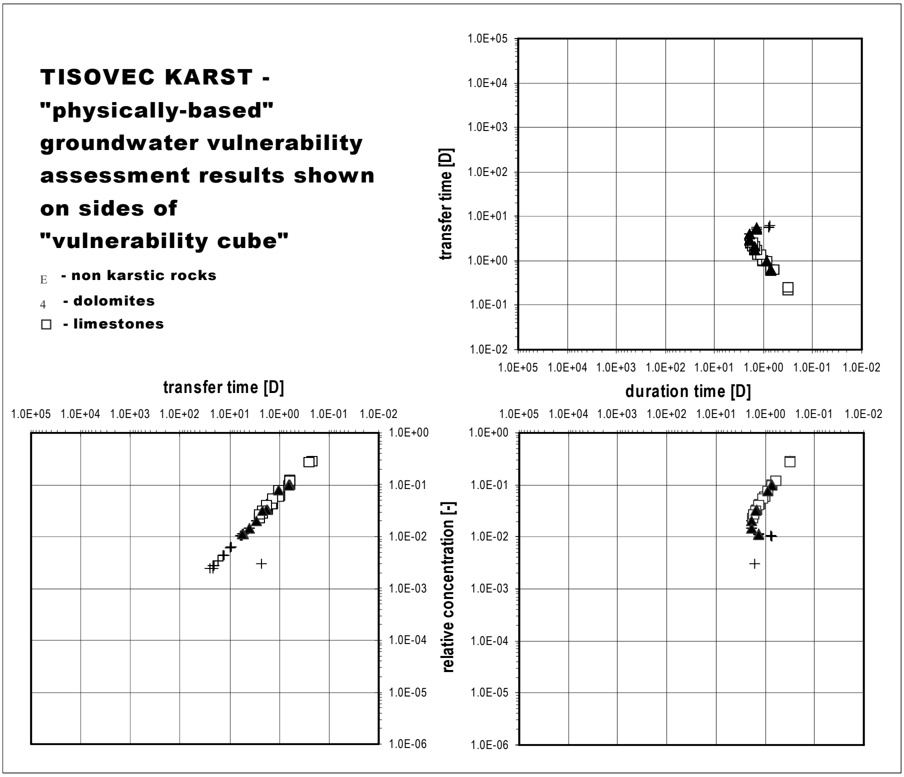

Figure 3. Plotting of simulated values of contamination breakthrough time (t_{break}), duration time ($t_{duration}$), and maximum relative concentration (C_{max}/C_0) for individual combination of parameters on the "vulnerability cube" for the Tisovec Karst

5. GROUNDWATER VULNERABILITY MAP

Based on physical values of theoretical contaminant spreading in the rock environment of the Tisovec Karst, simulated as breakthrough curves by the VULK-tool, final groundwater vulnerability map for the Tisovec Karst was then created by linking of V values ($V = (X_1^2 + X_2^2 + X_3^2)^{1/2}$) to the initial cells of the grid and by further re-classification of these values to five categories. Final classification of groundwater vulnerability of the Tisovec Karst was within the interval limits of – 5.6 – 5.8 – 6.0 – 6.2 – with names devoted to these categories: very low – low – moderate – high – very high vulnerability (Figure 4), respectively.

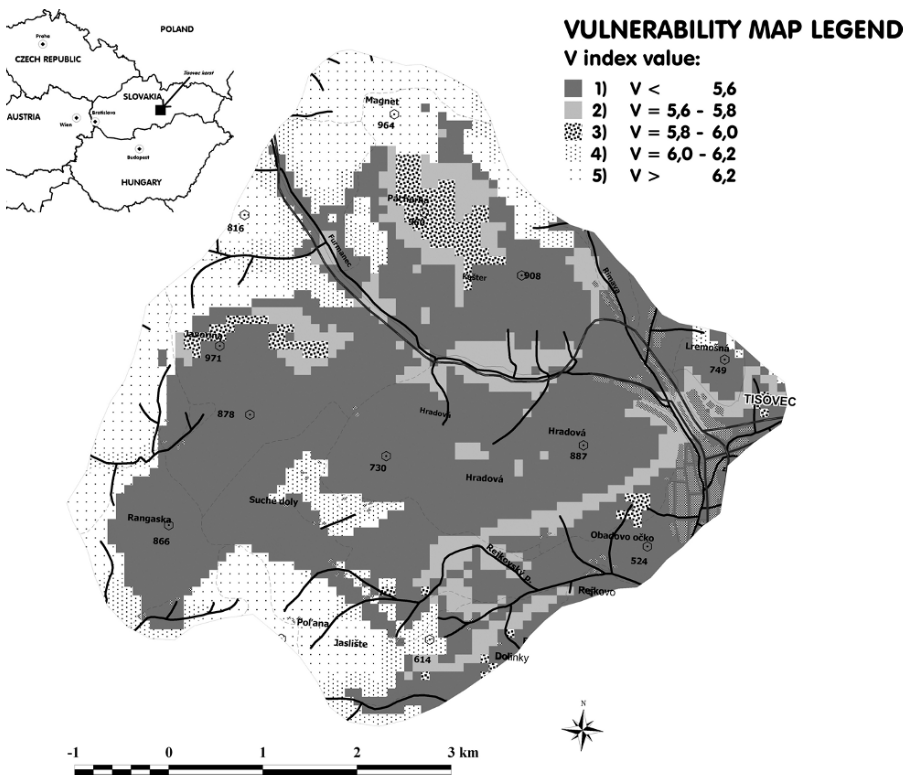

Figure 4. Physically-based intrinsic resource groundwater vulnerability map of Tisovec Karst. (1) – Very high vulnerability, (2) – high vulnerability, (3) – moderate vulnerability, (4) – low vulnerability, (5) – very low vulnerability

The final intrinsic groundwater resource vulnerability map of the Tisovec Karst was also plotted in the 1:50,000 scale afterwards. Three other Maps can also be compiled for the study area (map of maximal relative concentrations of the conservative contaminant, map of contamination mean breakthrough time and map of mean contamination duration time over accepted threshold limit). It is clear from the simplification of wide range of input data at the beginning (Table 1), that the final product, the intrinsic groundwater resource vulnerability map can characterize only limited number of simulated cases of a schematized environment. However, it brings into light the real possibilities of pollution spreading within the Tisovec Karst. The final intrinsic groundwater resource vulnerability map (Figure 4) shows, that groundwater is most vulnerable in the areas built by limestones in lower altitudes (areas of Hradová, Kášter and Rangaska), slightly less vulnerable is groundwater along the Furmanec stream in the area of the "Periodic spring" and Teplica spring, in the Rejkovský potok valley and in the NE part of the Tisovec surroundings. NE slopes of the Pacherka hill show moderate vulnerability values. The best natural groundwater protection (lowest vulnerability) is in the crystalline rim of the Tisovec Karst and in the Lower Triassic rocks of the Suché doly area. It is clear that a vulnerability map is, by definition, is independent from the contamination release scenario. It is not only be applicable for an accidental (instantaneous) point contamination, but also for diffuse and long-term scenarios. Whenever, it can be revised using better input data or contaminant spreading simulation techniques.

6. CONCLUSIONS

The applied concept of groundwater vulnerability assessment is based on physically based model of contamination spreading. However, this model was utilized only in the most simplified way, in order to cope with the number of model simulations, which had to be performed manually for 62 schematized cases – combinations of four parameters' ranges. In the future, it should be easier to run an automatic simulation process for the real parameters present in each grid cell. As for now, simulation is run only for the "worst case", i.e. fully saturated soil (e.g. after a heavy rain or snow melt), and only percolating part of water, excluding surface runoff. In the karstic environment, it often happens that a part of surface runoff flows into swallow holes and sinkholes, thus entering the underground water system in a concentrated manner. Such cases can be described by breakthrough curves as well, based again on physical principles of contamination spreading. These phenomena were not described in this paper, but the used approach is a very promising in building up a comparable (using defined physically defined parameters) vulnerability mapping methodology. As the use of several different “point-counting” methods can bring contradictory results for the same area, this physically-based method is worth of further development. The resulting groundwater vulnerability values should then depend only of the precision of knowledge of respective parameters in the field, and can be improved only by considering more precise data and data processing. The validity of the final groundwater vulnerability map can be checked by “simple” comparisons of modeled processes and the measured reality on available sites. Both results of tracing test, but also results of all experiments from which the unsaturated zone/aquifer properties can be obtained, can serve as a validation tool.

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MULTIPLE CRITERIA DECISION MAKING AND ENVIRONMENTAL SECURITY

Analytic Hierarchy Process Application for Water Resources Security Threats Identification and Management

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Abstract: Paper considers multiple criteria decision-making analytic hierarchy process application to assessment of environmental security, impacts on groundwater in urban areas in particular. Traditional role of groundwater as a strategic drinking water resource is complimented by importance of hydrogeological stability to the built environment. Emphases are put on describing approaches to hierarchy structures elaboration and the role of groundwater in urban environment.

Keywords: environmental security; multiple criteria decision-making; analytic hierarchy process; groundwater; urban areas; environmental impacts; environmental assessment, hierarchies, water security

1. INTRODUCTION

Environmental security concept falls into a broader notion of human security. Human security is viewed as a paradigm shifting from traditional notion of security related to military and political issues to environmental, public health, and quality of life issues. The most important components of environmental security concept are responsible use of environmental recourses, their equitable

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distribution, and quality of environmental services provision. Water is one of the key assets that provide human security.

Water has been always viewed as a renewable resource. However, such factors as surface water and sediments pollution, irreversible changes in water reserves recharge, deep groundwater horizons pollution threaten continuous availability of water.

Water security can be jeopardized by many factors, including those caused by natural disasters, and intentional man-made threats. Identification of water security status is a complex task, since not only multiple factors impact the status, but "ideal" security state depends upon functional purpose of water use. Multiple criteria decision making (MCDM) offers some tools that can help in problem structuring and thus tackling problem complexity. In the following sections MCDM process explanations will be accompanied by examples of its application to water security analysis.

2. MULTIPLE CRITERIA DECISION MAKING

Overview of MCDM Methods

MCDM is a method of decision analysis that involves the use of scoring and weighting systems based on criteria, in order to test and compare the impact of alternatives (Keeney and Raiffa, 1976). MCDM is applicable to a very broad range of interdisciplinary issues, and is widely utilised in economics, engineering, social science and environmental studies (French, 1996; Corner and Kirkwood, 1991; Beinat and Nijkamp, 1998). MCDM addresses situations where decisions are needed to handle complex problems involving alternative options evaluated along several conflicting criteria. MCDM helps stakeholders to effectively handle complex decisions in which the level of conflict between criteria is beyond intuitive solutions (Belton and Stewart, 2002).

MCDM embraces an array of different methods that can be classified according to aggregation rules (Holland et al., 2004), operative approaches (Roy, 1996), and a finite or infinite number of alternatives (Vooged, 1983). Comprehensive comparison of MCDM methods addressing their benefits and drawbacks can be found in Getzner et al. (2005). The most common MCDM methods are: multiple attribute value theory; analytic hierarchy process; evaluation matrix; electre; regime; novel approach to imprecise assessment and decision environments; multi-objective programming; goal programming.

Different MCDM methods can be viewed as competing ones, and the method choice mainly depends on the assessor's preferences. If time and resources are available, it is always an advantage to resolve same assessment problem using different methods and increase reliability of the outcome. However reliable and adequate input information and well-considered assessment problem structuring is a key to successful MCDM process and clear results.

Analytic Hierarchy Process Overview

Analytic hierarchy process (AHP) is an MCDM method that was developed by Tomas Saati (Saati, 1980) and encompasses three main steps: arrangement of a hierarchy structure, pairwise comparisons between elements of a hierarchy structure to establish priorities, and checking logical consistency of pairwise comparisons (Saati, 1980, 1994).

Hierarchies help to break down complex problems into a number of simple ones by constructing a framework of different independent elements that are connected logically. Establishing right interrelations between hierarchy elements is a key task for practical problem solving, such as water security assessment. Saati defines a hierarchy as a particular type of system, which is based on the assumption that the entities can be grouped into separate sets, with the entities of one group influencing the entities of only one other group, and being influenced by the entities of only one other group (Saati, 1980). Table 1 names and gives description of terms used in MCDM AHP. Table 2 describes steps of AHP.

AHP involves iteration, i.e. returning to previous steps after obtaining alternatives rating and conducting sensitivity analysis. Such iteration allows identifying possible inconsistencies in all the AHP steps, particularly a hierarchy structure composition and criteria weighting.

The next section will present AHP components that are most important in the context of environmental security (particularly assessment goal, alternatives, criteria, and a hierarchy structure). Analysis of these AHP components is based on AHP application to environmental issues; however ideas on e.g. hierarchy structure composition can be possibly applicable to a broader disciplinary area.

Table 1. AHP terminology

Term	Alternative terms	Explanations	Example related to water security
Hierarchy structure	Value tree	–	–
Assessment goal	Objective	Problem essence	Water quality in a particular reserve, sustainable drinking water supply
Elements of hierarchy structure	Sub-objectives, attributes, criteria	Smaller problems describing assessment goal	Groundwater dynamics, rate of organic contamination in a stream that flows into an assessed reserve
Criterion	Attribute	Lowest element of hierarchy structure, something to which value is given for different alternatives	Nutrients concentration
Alternatives	Decision alternative; options	–	State of water security in different time periods, or under different risks mitigation plans
Value function	Utility function	Function, which assigns value to criteria	–
Value of alternatives elicitation	Scoring	Assigning value to the lowest level elements, criteria, based on assessment of alternatives	Calculating of normalised difference between groundwater level deviation under two alternative water abstraction schemes
Weight of criteria elicitation	Weighting	Assigning weights to elements of hierarchy structure which are in one group	Expert assessment of relative importance of groundwater versus surface water group of elements for environmental security of a study area
Sensitivity analysis		Provides understanding on outcomes if weights or values were assigned differently	Finding out that a criterion organic contamination in groundwater is key to decide which alternative has less environmental impact
Result		Ranking of alternatives	A policy of diversification of water supply will improve human security in a study area

Table 2. AHP steps

Step	Explanations
Define the decision context	What is the decision needed to be made? Why it can not be made without conducting AHP? It is important to establish a brief problem description, specifying main conflicting criteria and possible trade-offs needed to be made.
Formulate an assessment goal	This step naturally derives out of the first one by more strict and clear formulation of the AHP objective. If the first step addresses more general questions about outcomes of AHP, the second step should provide solid base for structuring the AHP.
Identify alternatives	Usually some alternatives exist, if not they can be generated by analysis of the decision problem.
Specify criteria	This step is one of the most time-consuming, unless a set of criteria is available from other studies. Criteria are the measures of performance by which the alternatives will be judged.
Elaborate a hierarchy structure	Hierarchy structure resembles a tree at the top of which is an assessment goal and brunches are criteria. Criteria should be composed into groups; this allows prioritizing their impact on assessment goal. There are different approaches for elaborating a hierarchy structure (see Section 3).
Weight the criteria	Assign weights for each of the criteria to reflect their relative importance to the assessment goal. Pairwise comparisons between criteria are used.
Valuate the alternatives	Assess the expected performance of each alternative against the criteria. Pairwise comparisons between alternatives are used.
Combine the weights and values for each of the alternatives to rate alternatives	This step represents calculations using specific AHP equations, computer software is also available.
Conduct sensitivity analysis to examine how variation of the scores and weights affect the alternatives ratings.	This step allows analyzing alternatives performance using variation of scores and weights. Sensitivity analysis allows identifying how robust the decision-making model is and how ratings are sensitive to variation of particular criteria weights or scores.

3. ANALYTIC HIERARCHY PROCESS APPLICATION TO ENVIRONMENTAL SECURITY

Assessment Goal and Alternatives

Clear formulation of an assessment goal is very important. Assessment goals can be "positive" and "negative" by nature. Setting a "positive" assessment goal would mean that the best alternative would have the highest rating among all the options. Examples of a "positive" assessment goal are "water security", "water quality", and "water resources stability". Choosing "negative" assessment goal would mean that alternative with minimum score is the best. Examples of a "negative" assessment goal are "risk to water supply", and "water contamination". It is advisable to set a "positive" assessment goal, even if most of criteria would be "negative" by nature, e.g. risks. This advice is based on an observation that stakeholders involved in an assessment process are more comfortable considering postulates such as "provision of better security", "higher environmental quality", and assigning value to each criterion based on its positive contribution.

Formulation of an assessment goal should be done prior to other stages of AHP, modifying assessment goal according to elements of a hierarchy structure or assessment results is not advisable.

It is possible to suggest some assessment goals based on a concept of "environmental services", which has been introduced in the Millennium Ecosystem Assessment (2006). Such water related services would be drinking water supply, water as an amenity resource, fisheries, transport.

Unlike the assessment goal, modification and generating new alternatives during MCDM process is welcomed. It is a success of AHP if a new alternative (solution to the addressed problem) has been generated during the MCDM process. Different, sometimes even hypothetical alternatives allow decision-makers to gain a broader view of a problem.

Since AHP is a comparative analysis, minimum number of alternatives is two. In water security assessment these two alternatives would be the environmental baseline (existing environmental conditions, or some etalon environmental conditions) and state of the water environment after proposed policy, program, plan, project or security enhancement solutions being implemented. In environmental assessment, usual number of alternatives is between three and five (Dalal-Clayton and Sadler, 2005; Therivel, 2004; Sadler and McCabe, 2002). For water security problems comparison with environmental baseline should be sufficient.

Criteria

Criterion is the lowest element of a hierarchy structure, the element to which value is given for different alternatives. Criteria should reflect complexity of an assessment problem. In applications to water security most likely there will by many miscellaneous interdisciplinary criteria. Criteria are aggregated into groups. Table 3 gives some examples of possible criteria classifications.

Table 3. Examples of classifying threats to water security

Classification criteria	Examples of criteria groups
Scale	Local, regional, global
Origin	Natural, artificial technogenic, artificial intentional
Nature of impact	Contamination, disruption of hydrological mode, water resources over exploitation
Impact duration	Temporary, long-term, irreversible
Components of hydrosphere	Surface waters, groundwater
Signification of impact	Routine pollution, emergency threatening human health

Criteria can be quantifiable or assessed on the basis of expert judgments. It is possible to distinguish three groups of criteria: solely qualitative (e.g. water reserve amenity value), solely quantitative (concentration of suspended matter), and criteria that can be defined qualitatively or quantitatively depending on particular assessment objectives. The last group of criteria illustrates the complexity of input data, and often there are difficulties incorporating numerical data into AHP directly, although a wealth of data may be available. In this case expert judgment is needed and a criterion can be identified as a qualitative one, although the assessment was based on quantitative data. Let us examine this situation using an example of criterion "groundwater level". This criterion can be defined quantitatively as a deviation from a historically formed groundwater level in meters. This would be applicable only when the groundwater level is stable within the considered territory. If this is not the case, the criterion should be assessed using a number of measurements for representative, important points. Based on this quantitative information, experts can make qualitative judgments about the impact on groundwater level.

Hierarchy Structure

Elaboration of a hierarchy structure for assessment is the basic and most important step in MCDM AHP. Concept and philosophy of assessment depends on the way in which elements are arranged in a hierarchy structure. Criteria at the lowest hierarchy level are arranged in groups. These groups of aggregated criteria are elements of a hierarchy structure. Important is that pair wise comparisons are made just between criteria within their primary group, rather than with other groups, so there is a hierarchy structure with several priority levels.

Elaboration of a hierarchy can be based on two approaches: bottom-up or top-down.

The hierarchy structure arrangement in a bottom-up technique starts with obtaining criteria which would constitute the lower hierarchy level. These criteria are identified and listed during the problem analysis prior to MCDM process. The main task in the bottom-up technique is to aggregate these criteria into groups or nodes, depending on the nature of the criteria a number of hierarchy levels emerge. The aggregation process is governed by consideration of trade-offs that need to be made during assessment. It is important to keep in mind an assessment goal while aggregating criteria into nodes and linking nodes with each other. The bottom-up technique is effective when input data is clear, e.g. there are a number of well defined criteria which constitute the basis of the assessment process. One of the strong points of the bottom-up technique is the close link between all elements in the hierarchy structure with the input data, i.e. previously identified criteria. Figure 1 illustrates the bottom-up technique of a hierarchy structure composition.

The top-down hierarchy arrangement starts with defining groups of criteria at the highest level of the hierarchy table. In this case, elaboration of hierarchy elements is closely linked to the assessment goal. Detailed elaboration of lower hierarchy levels is governed by higher levels and can be seen as “induced”. This lack of clarity about lower level elements in the beginning of hierarchy elaboration is a weakness of the top-down technique. On the other hand, it allows starting with analytical considerations of water security problems. This approach allows creation of new criteria, that perhaps would be missed during bottom-up technique that is based on traditional, well-known criteria sets for addressing particular security issue.

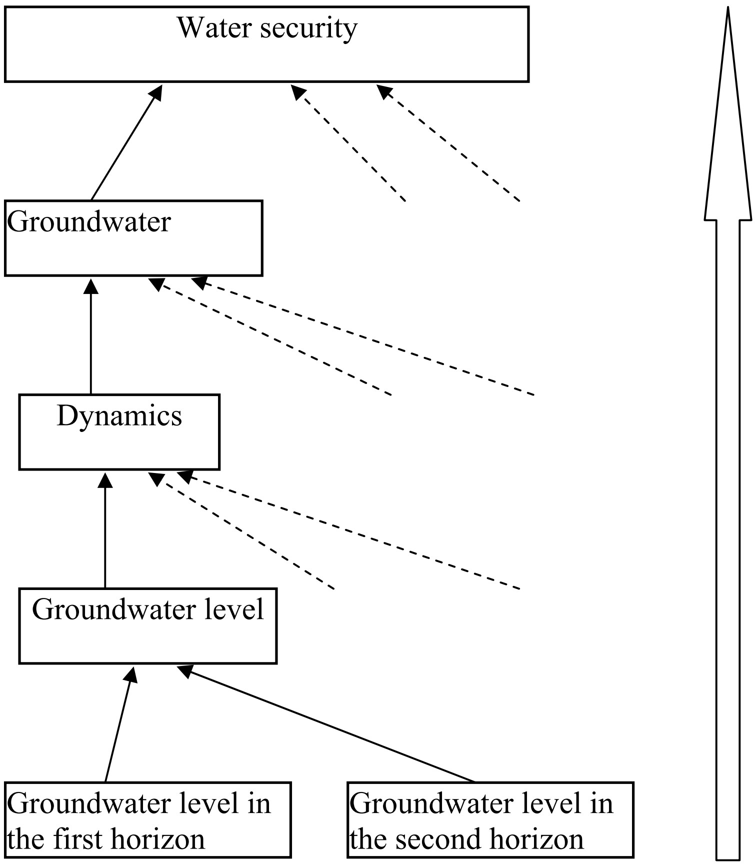

Figure 1. Hierarchy structure composition using the bottom-up technique

Figure 2 illustrates the top-down technique of hierarchy structure composition and Table 4 compares particular aspects of bottom-up and top-down techniques.

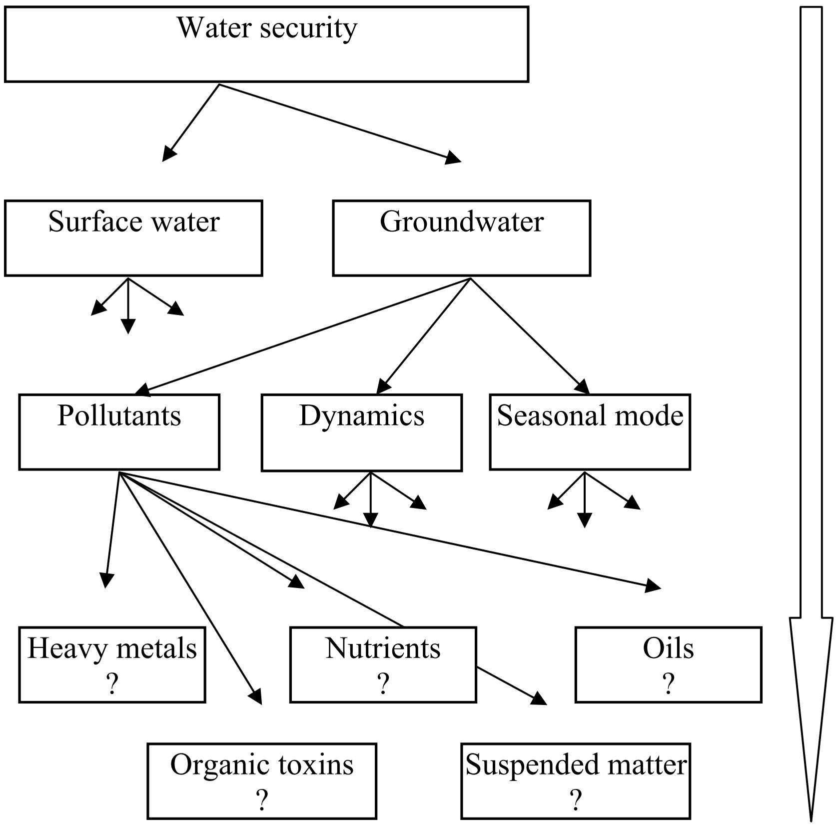

Figure 2. Hierarchy structure composition using the top-down technique

Weighting and Scoring

Weighting of a hierarchy structure elements and scoring criteria are based on pair-wise comparisons within a group. While scoring performance of each criterion is compared in different alternatives. Other elements of a hierarchy structure situated at the same hierarchy level are compared in their group and weights of relative importance are assigned. When weights are assigned, the relative contribution of each criterion to the overall assessment goal becomes fixed. Aggregation of criteria taking into account their weights will rank the alternatives. Criteria can be assessed qualitatively or quantitatively (direct data input with normalization (Bobylev, 2004). Weights are assigned on the qualitative basis.

Table 4. Comparison of particular aspects of hierarchy arrangement techniques

Particular aspect	Top-down technique	Bottom-up technique
Timing of hierarchy elaboration in the assessment process	Early stage	Later stage (after criteria are identified)
Acquisition of lower level elements (criteria or indicators)	Elicited during analysis of higher elements (elements description)	Obtained before MCDM assessment stages
Arrangement of nodes (grouping the elements)	Decomposition (description) of higher elements	Aggregation of lower elements (criteria or indicators as the first step)
Ability of a hierarchy to be changed	Liberal approach – easy to change	Strict approach – difficult to change
Main difficulty	Identification of criteria or indicators	Aggregation of elements
Main drawback	Initial lack of clarity about lower elements	Possibility of disagreements and uncertainty about nodes at the middle level (how to aggregate elements into groups)
Main strength	Goal-led approach allows strict adherence to purpose of assessment	Impact-led approach allows close-linked assessment to input data (criteria or indicators)
Underlying intentions	Enhancing positive impacts	Mitigating negative impacts

MCDM AHP Results, Sensitivity Analysis, and Software

The result of AHP is a numerical rating of alternatives against their contribution towards the assessment goal. Sensitivity analysis is the last step of AHP which allows decision-makers to check the logical consistency of decisions made with the overall accuracy of assessment. The results of MCDM AHP help to analyze complex problems of water security. Results of MCDM provide:

– Rating of the alternatives
– Show how assigned weights affect the assessment results
– Grouping alternatives according their impact on security

- Understanding which groups of criteria are the most significant ones
- Understanding trade-offs between groups of criteria
- Providing ideas for alternative solutions and mitigation measures

AHP can be repeated several times, making changes in the grouping of elements and reassigning weights to the elements, but normally conducting sensitivity analysis is sufficient to understand the impact of different criteria on the assessment goal.

MCDM can be conducted using different software packages, some of them are listed bellow:

- On Balance (http://www.krysalis.co.uk/)
- Expert Choice (http://www.expertchoice.com/)
- Decide Wise (http://www.decidewise.com/uk/default.htm)
- Hiview (http://www.catalyze.co.uk/)
- Logical Decisions (http://www.logicaldecisions.com/)
- HIPRE (http://www.hipre.hut.fi/)

As it has been previously stated, key element of MCDM process is problem structuring. Various software packages provide convenience to decision-maker in data input and representation of results.

4. GROUNDWATER SECURITY IN URBAN AREAS

Urban areas become increasingly important for human security considerations since more than half of the world's population lives in towns, cities, and megacities, and urbanization process advances all over the world (World Population Prospects, 2007), even in countries with negative population rate. Groundwater has always been considered as a strategic resource for drinking water supply. In urban areas groundwater provides more environmental services, these services are important for urban natural and artificial environment and sequentially for human security.

Figure 3 combines role of groundwater in urban areas, causes and consequences of impacts on groundwater.

Hydrogeological stability is important for surface waters, vegetation, and water discharge for human needs, including industrial, municipal, and drinking water supplies. These groundwater functions or environmental services can be generalized as water supply. Groundwater stability, especially chemical composition, groundwater level and mode is important for artificial built environment and soils (Bobylev, 2006). Disruptions can lead to above- and underground structures settlements, corrosion (including biocorrosion) of foundations.

Groundwater security can be threatened by many factors: routine pollution (leakages from conduits, infiltration through polluted surface cover and soils), natural disasters (earthquakes, floods), low surface cover permeability, contaminated recharge or over discharge from surface water bodies, artificial subsurface structures. On Figure 3 natural disasters and technogenic accidents boxes are combined, because in spite of different causes impact on groundwater can be similar. The same can be stated about intentional threats, perhaps excluding impact on seasonal mode. Key factor affecting aggregate impact on groundwater caused by natural disaster appears to be pre disaster state of the environment in terms of pollution. Natural disasters can seriously aggravate environmental security in areas that are under severe anthropogenic pressure. Impact of natural disasters on groundwater quality can be different, leading to perspective increase as well as decrease of pollutants concentrations.

The main threat to urban groundwater is routine pollution, mainly direct contamination from conduits leakages and indirect by infiltration of rainwater through polluted soil layers. Direct terror attack related to groundwater contamination (e.g. intentional leakage of dangerous chemicals) is unlikely to have an immediate impact, but rather postponed one due to time needed to reach water reserve of water pumping station. However negative impact can have long duration, leading to impossibility of groundwater use.

Intentional chemical groundwater contamination would represent threat to artificial underground structures, including wooden buildings foundations (especially historic buildings in downtown areas), and concrete underground structures. Facts of intentional contamination that would lead to uneven foundation settlements and buildings collapse are not known, but there are cases of contaminants (chemical and organic) leakages that lead to uneven buildings settlements resulting cracks on facade.

Demolition of deep underground structures or simply disruption of damp course due to explosion, structure failure, or earthquake can have serious negative consequences to an adjacent area due to water ingress in a cavern, lowering of groundwater level, suffusion, and possible uneven settlements of buildings. Such impact will not be immediate, but rather continuous and difficult to mitigate.

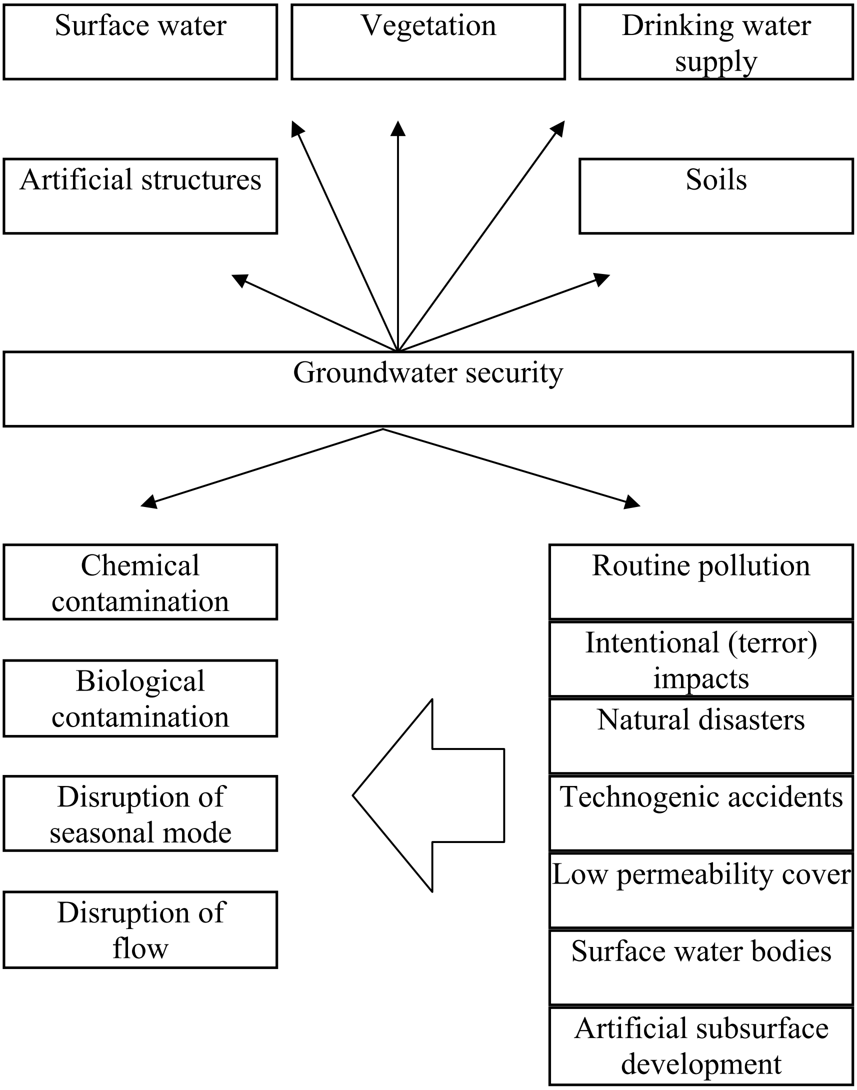

Figure 3. Groundwater security in urban areas: Impacts of groundwater are shown at the top. Below on the left are impacts on groundwater, and on the right are causes of these impacts

MCDM AHP can be successfully used for assessment of possible consequences of natural and man-made disasters to hydrogeological stability and groundwater security. The process would involve identifying criteria and elicitation of a hierarchy structure tailored to a particular problem in a particular setting.

5. CONCLUSION

MCDM methods can be successfully used in human security assessment, including environmental and water security problems. Advantage of MCDM methods is their ability to integrate quantitative and qualitative data, which is especially useful for security related problems given high uncertainty of input data. AHP is an appropriate instrument for assessment of vulnerability of natural and artificial environments and risks posed to them. Main task during MCDM AHP is to create a hierarchy structure that reflects an assessment problem complexity, all the factors impacting this problem and their interrelation. AHP results can be a good base for decisions on enhancing security and disaster mitigation measures.

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SERVICE-ORIENTED DECISION SUPPORT GOVERNANCE

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Abstract: This paper presents new approaches in service-oriented architecture domain area, focusing on technologies, which would be useful for interoperability among water decision support systems. Present demands on modern Information and Communication Technologies (ICT) infrastructure drive migration from the conventional n-tier systems to a service-oriented computing paradigm, described in terms of service-oriented architecture (SOA), infrastructure, process, and management. Environmental business process orchestration becomes an efficient way of combining security requirements on communication in crisis management structure. Furthermore, we mention how service-oriented portals integrate inflexible heterogeneous systems and thus help enterprises to unlock the functionality of existing legacy applications. Portals can leverage orchestration of underlying middleware components by being the single place where users interact with business processes using a standardized interface. Appropriate communication within the system in environmental decision support system is essential for minimization of disaster effects. Decision support systems finding the optimal strategies are mainly based on artificial intelligence computation technologies, which are extremely computations demanding. That is why we need to design interoperable structure in the context of service based communication. Case study of system structure providing evolution programming computation background for the environmental decision support tasks is presented in the paper.

Keywords: SOA; SOM; ESB; decision support; governance; enterprise portal

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1. ICT BACKGROUND FOR DECISION SUPPORT

This paper is focusing mainly on technical background aspect of environmental decision support systems and approaches in service-oriented architecture domain area.

The environmental business process orchestration becomes an efficient way of combining security requirements on communication in crisis management structure. Business process is a way of modeling and monitoring the system behavior, planning the priorities and establishing collaboration between involved systems.

2. NEW TRENDS IN SERVICE-ORIENTED ARCHITECTURE

Service-oriented architecture is an architectural style that utilizes methods providing for enterprises to dynamically communicate software applications between different business partners and platforms by offering generic and reliable services. This way it is possible to develop richer and more advanced applications and information systems (Kubásek, 2007).

Although Service-Oriented Architecture (SOA) is not a new concept, the new developments in this area bring about a new way of constructing software application architectures (Figure 1).

Enterprise portals are often referred to as “the first step to SOA”, which is true also from the Service-Oriented Infrastructure (SOI) perspective. Portals can leverage orchestration of underlying middleware components by being the single place where users interact with business processes using a standardized interface. This approach gains significant advantages of infrastructure services, including increased utilization of individual resources and increased service levels as applications do not depend on the availability of any individual resource.

The ESB principle represents a new way of looking at integration of loosely coupled and highly distributed integration network. An ESB is standardized integration platform for messaging, web services, and data transformation.

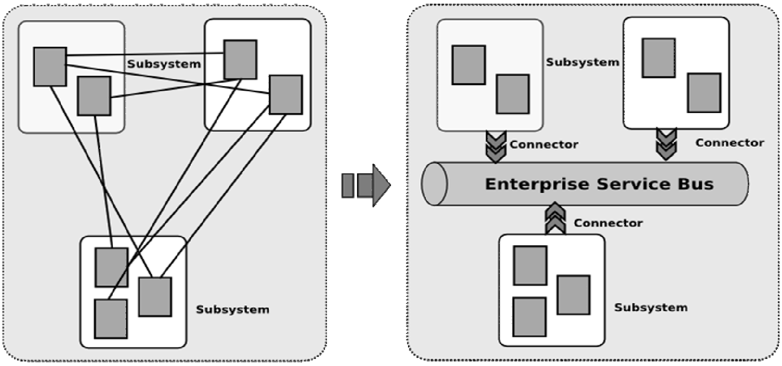

Figure 1. Evolution from spaghetti to real SOA

3. SERVICE-ORIENTED INFRASTRUCTURE

A Service-Oriented Infrastructure (SOI) is a very modular, flexible IT fabric based on standard building blocks, which are highly configurable to meet today's very rapidly evolving requirements. Looking at the Service-Oriented Enterprise as a multi-layered structure, the SOI layer focuses on the orchestration and virtualization of compute, network and storage resources. The SOI ensures resources are made available in the amount and location required by the SOA layer above it. Within the SOI abstraction, the physical details of a device are hidden by software on the platform. The device can then be managed through a more abstract software interface also defined as a service (Chang et al., 2006). SOI is optimized to handle the high volume XML traffic associated with Web-services applications. The SOI provides a way to manage computing resources in lockstep with application requirements both at initial deployment, and as the workload or requirements change, effectively enabling an integrated design, deployment, management life cycle. The standardized and loosely-coupled nature of SOI also reduces complexity and increases the potential for automation by enabling devices to do self-diagnosis and self-repair, with minimal involvement of higher levels (Figure 2).

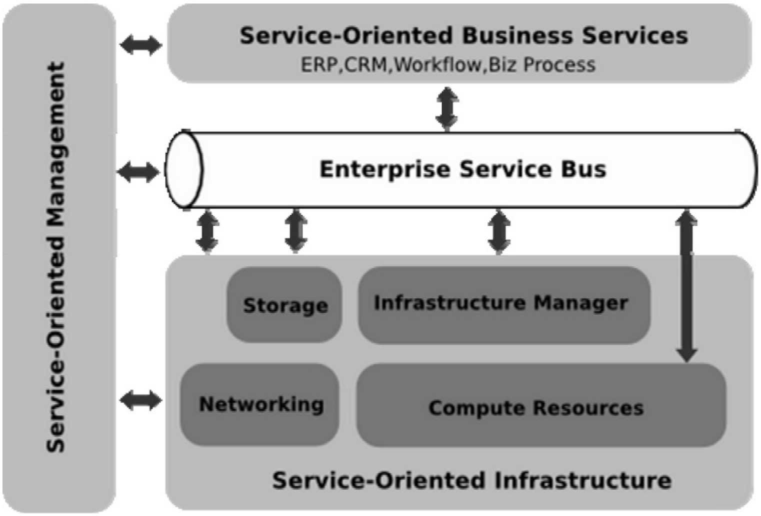

Figure 2. Service-oriented infrastructure example

4. SERVICE-ORIENTED PROCESS

Service-Oriented Process (SOP) represents a separate abstraction layer for business process definition and execution that leverages the capabilities of SOA. SOP provides a flexible approach towards implementing architectures that promote business agility. SOP includes orchestration, choreography, composition, workflow, transactions, and collaboration of Web Services (Figure 3).

The most used orchestration technology is the Business Process Execution Language (BPEL), created by IBM, BEA and Microsoft in 2002. With all the major players in the industry, BPEL will be the undisputed standard for the orchestration of XML Web Services (Schittko, 2003).

A BPEL process is an XML document typically generated with graphical design tools by business analysts rather than programmers. BPEL processes are executed by an execution engine. The engine can publish a process as a Web Services or react to trigger conditions set up inside the process itself.

Web Services are quickly becoming the standard development model for software applications. A BPEL orchestration language will be one of the enabling technologies for these architectures, while reducing the time and costs required for implementation.

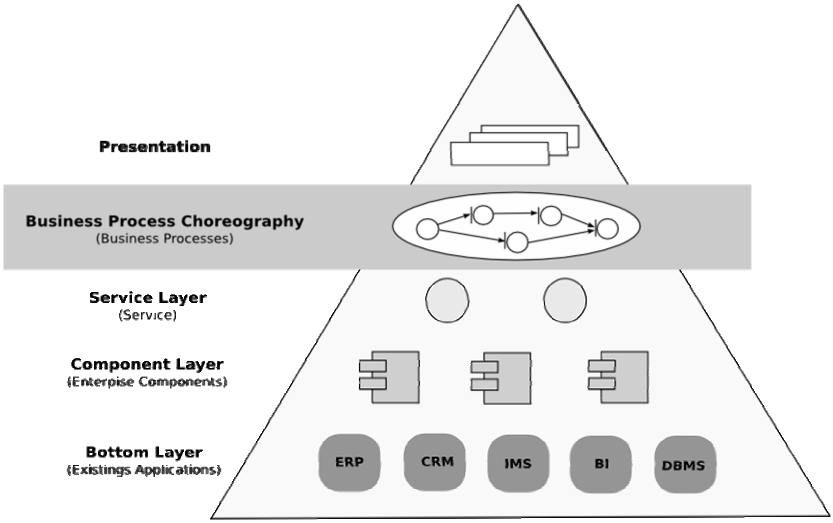

Figure 3. Role of businesses process choreography

5. SERVICE-ORIENTED MANAGEMENT

Service-oriented management (SOM) is a management of service delivery within the SOA. The primary objective of SOM is providing a differentiated service delivery capability, using business objectives to drive system behavior.

SOM tools are used to supervise and control the delivery of a service from a service provider to a service requester. A SOM solution should be able to manage services of any technology, without requiring special deployment, code changes or special development environments. SOM solutions are run-time solutions rather than development or deployment solutions (Allen, 2006).

Platforms that provide SOM capabilities typically offer several of the following functions: encapsulation and composition, web service instance management, dynamic routing, transport protocol translation, synchronous/ asynchronous conversion.

6. DECISION SUPPORT GOVERNANCE

ICT Governance can be considered as an establishing mechanism and politics used to measure and control the way ICT decisions are made and carried out. That's why we can take the decision support governance as an extension of ICT governance focused on the lifecycle of processes to ensure the value of decision support. The governance is a very important requirement for successful implementation of service-oriented system. The bigger the ICT structure is, the more it needs governance, and the governance roles and mechanisms need to be more comprehensive.

7. ENTERPRISE PORTALS

As organizations are looking for the way how to leverage service oriented architecture, many use portal products as the first step, says Gartner. Enterprise portals stand for a good tool for integrating web applications. They aggregate various types of information and provide users with consistent user experience. Portals are referenced as the single secure place where users meet enterprise data and business processes. Most of the enterprise portals are implemented using Java EE technology. In the SOA world, portals are the user front end to the underlying systems and infrastructure.

Portal pages are populated with portlets, standardized application components that provide some well-defined functionality. Portlets are independent of each other, so they naturally fit SOA patterns. Portlet typically consumes a service and provides users with GUI to such a service, allowing users to interact with business processes.

8. SOA COMPUTATION INFRASTRUCTURE CASE STUDY

With the collaboration with US EPA we developed an energy management decision support tool (Pavlovič and Mahutová, 2006). One of the results of this mutual collaboration is on-line ICT tool: Waste Site Energy Management Calculator available on a public web site (http://iris.fi.muni.cz/calculator).

Using this tool, domain experts can compare several remedial technologies according to input constraints. Each remedial technology is represented by an energy equation developed by US EPA. This decision support tool can find the optimal combination of remedial technologies that should be used in cleaning process. Since there exists a vast number of technology combinations we need to use Artificial Intelligence methods, e.g. Parallel Genetic Algorithms (Pavlovič and Hřebíček, 2006). We can not afford to design a solution that represents purchasing computer cluster only for this specific problematic. We need to use existing hardware and design upper software layer enabling reusing hardware capacity for AI.

The design of the system consists of several layers (Figure 4) (Kubásek et al., 2006). The first layer is the Knowledge Layer. This is represented mainly by Data Warehouse. Upon Knowledge Layer there is a hardware including clusters or a standalone computer. Individual SWS (Semantic Web Services) are mapped to this layer in M:N relationship. Next layer contains description units as UDDI and ontology.

With the SOA Bus Layer the system is encapsulated and client applications can consume the services. The Bus Layer can be easily realized using any implementation of Enterprise Service Bus. There is a possibility to add JMS server to increase performance. The type of visualization of the received knowledge is upon the clients.

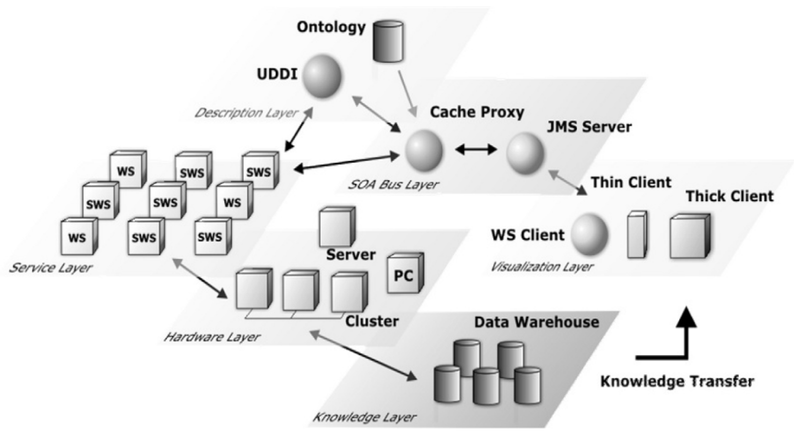

Figure 4. SOA computation infrastructure

9. CONCLUSION

The suggestion is that up-to-date enterprise technologies should be more intensively evaluated and incorporated into decision support systems infrastructure.

Since most decision support system applications rely on some kind of integration of information, which is generated, processed and consumed by multiple independent parties, it is essential that we realize the integration in a proper way.

As the whole IT industry gradually moves from data pipes and spaghetti patterns towards elaborated software architectures supporting smooth integration, the terms like SOA, ESB, and SOI gain more and more importance. Integration techniques and technologies at the application and presentation tiers definitely have potential to become the key architectural patterns of future decision support systems. In this context, we highlighted the integration ability of contemporary enterprise portals, which can speed-up the adoption of SOA even in decision support environment.

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AN EXAMINATION OF ECOLOGICAL RISK ASSESSMENT AT LANDSCAPE SCALE AND THE MANAGEMENT PLAN

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Abstract: This study primarily aimed to put forward some feasible measures over Gediz Delta derived from both our previous research on wetland functions-stressors context and the official management plan so that they could be utilized by decision-makers for the long term benefits of the delta. What has been suggested here is to make a comparative analysis between outcomes of the research on Ecological Risk Assessment (ERA) and the newly prepared management plan to strengthen and encourage implementation of the plan.

An ERA was carried out in the research based on 15 landscape types constituting the delta as coastal wetlands' system. Each landscape has been qualified with its wetland functions or values. Almost all landscapes have generally been ranked high in total wetland functions. However, some parts of landscapes under the impacts of natural and cultural stressors including land uses in varied degrees have been severely suffered.

Management of coastal wetlands at landscape level within the delta necessitates adoption of some scientific and concrete measures into the domain of either planning or management pursuits that is able to conserve or enhance natural processes and ecological stability.

Keywords: Gediz Delta; ecological risk assessment; landscape approach; management plan

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1. INTRODUCTION

Coastal wetlands are highly vulnerable ecosystems subjected to a wide variety of stressors or pressures that mostly result in different levels of natural and cultural degradations. It is crucial to underline that they support both their surrounding habitats and provide several environmental (water based) services such as supplying freshwater, purification of surface and underground waters, flood control. Therefore, ecological deteriorations of wetlands at landscape scale are quite capable of affecting adversely marina and terrestrial ecosystems (Kaplan et al., 2005). Moreover, landscape changes can alter one or several landscape attributes, which in turn may affect ecological attributes such as the hydrologic cycle, nutrient cycling or biodiversity (Leuven and Poudevigne, 2002). The resulting fragmentation of the landscapes surrounding aquatic ecosystems has received considerable attention (Brazner et al., 2004).

As one of the high ranking source of stressors, growth of urban areas and thus, expansion of impermeable surfaces alter landscape diversity and modify hydrological patterns. Such ecological relationships as interactions of human land use practices and wildlife population responses must be incorporated into ecological risk assessment (ERA) if resulting management decisions are to be relevant ecologically (Kapusta, 2003). In this context, in order to identify the existing and future stressors on wetlands towards guiding environmental management and decision-making processes ERA is becoming more and more common.

ERA as a new field of study for evaluating the risks associated with a possible eco-environmental hazard (Xu et al., 2004), has highlighted the need for flexible problem-solving approaches capable of linking ecological measurements and data with the decision-making needs of environmental managers (Hope, 2006). Risk assessment can provide an organizing framework, testable hypothesis, and eventually a method for evaluating management scenarios (Landis, 2003a). One of the classic problems is the matter of extrapolation from an effect to an individual organism and up to the regional or landscape scale (Landis, 2002). The ultimate challenge is the characterization and prediction of the risks due to multiple impacts at landscape scales. The characteristics of the landscape also affect the risk estimate at a regional scale (Hayes and Landis, 2004).

The management objectives for an ecosystem are important to defining the stressors, endpoints, and management options for which the conceptual model should be responsive. The step to delineate the spatial, temporal, and ecological scales and boundaries is essential in order to bind the problem (Gentilea et al., 2001).

Any research on ERA, such as Yücel (1997), is nowadays exceptionally important in the context of Gediz Delta since the existing and possible stressors of natural and cultural origin disturb overwhelmingly ecological order of the delta at the expense of high wetland functions. This resulted in noticeable loss or deterioration of freshwater sources. Most parts of landscapes in the region have been under the severe impacts of such stressors and largely conflicting land uses in varied degrees. Hence, in order to improve the qualitative nature of landscapes for wetland values and thereby mitigate negative effects of the stressors, the delta necessitates a comprehensive ERA at landscape scale. This study was undertaken to identify and examine the existing/possible stressors, their magnitude and effects on the delta through a risk assessment analysis, and to compare its findings with the newly prepared, but not approved yet management plan.

2. MATERIAL

Study Area; Gediz Delta

Gediz Delta is situated on the western cost of Türkiye (Turkey) with 40,000 ha. in size, and constitutes the large north-west tract of İzmir metropolitan city. 20,000 ha. of the delta embodies a wide variety of coastal wetlands including estuary, river, lakes, mudflats, salt marshes, reed beds, lagoons, saltpans, shallows, hills and farmland (Figure 1), and major part of it was designated as the Ramsar Site in 1998. Gediz River with a length of more than 400 km stretches out some intricate meanders westward to Aegean Sea passing by some major cities and many rural settlements. Gediz Delta is hereby a confluence of Gediz River and Ege (Aegean) Sea, involving brackish, salt and freshwaters. The content and biodiversity in major segments of almost these wetlands change dramatically depending upon seasonal flux of either freshwater or sea and river flows.

In this study, ArcView 3.2 was used along with satellite images [LANDSAT 7 ETM 4-5-3 bands combination (August, 2003) and ASTER (September, 2003)]. The data was also confirmed and supported by repeated field checks and expert opinions.

Figure 1. Geographical location of Gediz Delta and landscape types

Gediz Delta as a coastal wetlands system was analyzed at landscape scale, in terms of 15 landscapes or wetland types.

These landscape types are as follows:

1st Landscape:	Coastal marsh	9th Landscape:	Freshwater ecosystem
2nd Landscape:	Old river branches	10th Landscape:	Saltwater ecosystem
3rd Landscape:	Afforested area	11th Landscape:	Reedlake
4th Landscape:	Mudflat	12th Landscape:	Agriculture
5th Landscape:	Çilazmak Lagoon	13th Landscape:	Gediz estuary
6th Landscape:	Çamaltı Saltpan	14th Landscape:	Gediz River
7th Landscape:	Homa Lagoon	15th Landscape:	Temporal pasture
8th Landscape:	Kırdeniz Lagoon		

The Management Plan

The management plan for Gediz Delta was prepared to set up a balance between utilization and protection requirements of existing delta ecosystems. The plan was prepared officially based on the new guidance of Ramsar Convention along with the Regulation of National Wetlands. Participatory approach with relevant stakeholders was distinguished in planning process. The plan was aimed to be multi-functional and multi-dimensional at social, economical and ecological aspects. Thus, it provides a set of actions to be run through public and private initiatives under the Ministry of Environment and Forestry. Some guidance was addressed to protect and enhance a multitude of wetland ecosystems. In this way, a balance between ecosystem protection and demands of local people and of the city itself was envisaged to conceptualize the theme.

It is important to express that the plan was put into action for the next 5 years following the approval of the plan in draft by National Wetlands Commission. In 2012, it is going to be reviewed and revised in order to lead the plan for the second 5 years term (Turkish Republic of Ministry of Environment and Forestry, 2007). The plan is expected to be implemented right after the official approval in late April, 2007.

3. METHOD

The study addressed mainly our previous research (Kaplan et al., 2005) centered on ERA and a set of actions of management plan (Turkish Republic of Ministry of Environment and Forestry, 2007). It aims to provide possibly more concrete conservation policy and implementation, and to strengthen the efficacy of the official management plan in implementation phase.

Evaluation of Gediz Delta was mainly grounded into scrutinizing wetland functions or values of each landscape as well as surfacing the existing and potential stressors upon these landscapes that constituted coastal wetlands system of the whole delta.

In contrast to existing or potential challenges that the delta is subjected to, each landscape has been qualified with its wetland functions. A sum of both functions and stressors in quantity for each landscape and in this means the delta itself has been separately overlaid for launching a series of management guidelines so as to mitigate the current effects of a wide array of natural challenges and cultural interventions and to improve the wetland functionality of each landscape.

Framework of the methodology depicted in Figure 2 is stepped up below:

1. Identifying natural and cultural features of the delta and formulation of wetland functions or values to designate landscape types over the delta
2. Examining each landscape type for its functions
3. Ranking and mapping each function distinctly and subsequently total functions on every landscape (output 1)
4. Determining sources of stressors derived from internal and external parts of the delta
5. Analyzing and interrogating charges and impacts of these stressors over the delta
6. Ranking and mapping existing and possible impacts individually and totally (output 2)
7. Comparative analysis of outputs 1 and 2, on each landscape
8. Elaborating some actions of the management plan
9. Merging items 7 and 8 to increase and justify the efficacy of measures against the ongoing and potential impacts in policy and implementation

4. RESULTS AND DISCUSSION

Delta both as a whole body consisting of marine and terrestrial ecosystems and with its all landscapes have generally been ranked ‘high’ in total wetland functions (Figure 3). Functions or values of landscapes are as follows; creating habitat, recharge and discharge of (under)ground water, flood stabilization, stabilization in climate, recreation and tourism, sustaining food chain, buffer zone, species and habitat types, natural heritage and visual quality.

Landscapes adjacent to the sea and along the Gediz River were recorded very high in meeting wetland functions in total. In the meantime, some landscapes that undergo explicit influences of urban growth, rural, agricultural and industrial land uses match these functions in high or medium level whereas afforested and salty landscapes received relatively lower scores.

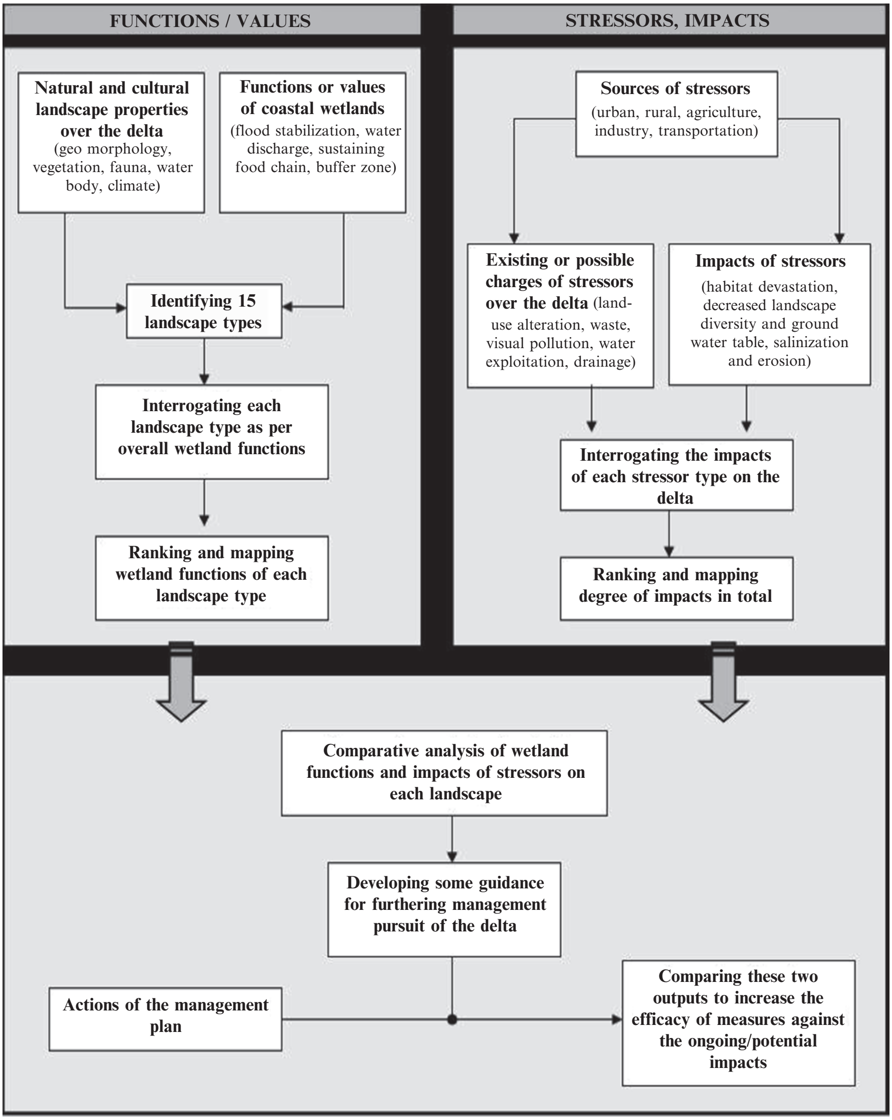

Figure 2. A procedure for the incorporation of the previous research with the management plan

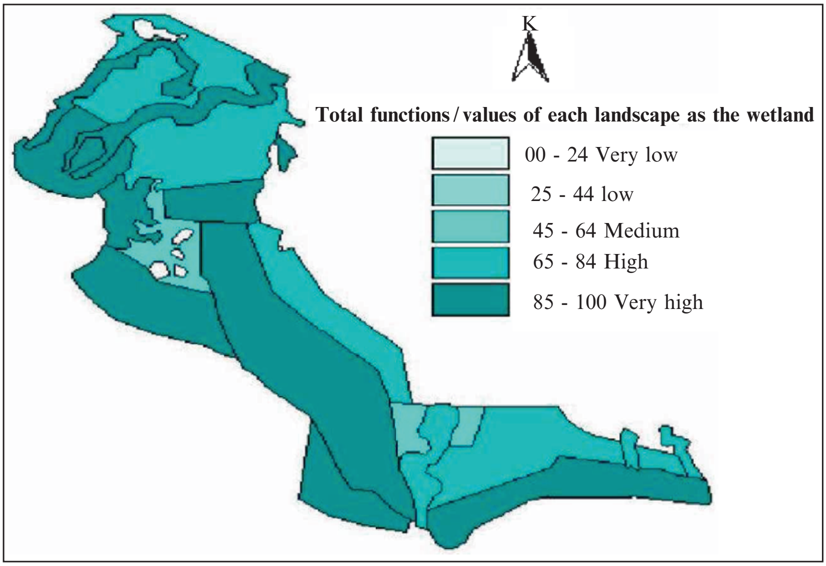

Figure 3. Ranking total wetland functions of each landscape

However, some parts of landscapes under the impacts of natural challenges (i.e. intrusion of sea inward freshwater bodies) and cultural interventions and land uses in varied degrees have been suffered severely from the existing or potential stressors or constraints, for instance; urban encroachments at city and rural development, industry, waste, salt production, agriculture, transportation, planning decisions (Figure 4).

These stressors resulted in some charges on the delta with fragmentation of landscapes, destruction of habitats, decreasing underwater table, disruption of coastal line, aggravation of soil and water salinization, land and soil erosion, exploitation of freshwater.

Stressors have unevenly distributed over the delta as well as each landscape, and thus their impacts could change not only between these landscapes but also within each landscape entity. This case is closely related to the sensitivity and absorption capacity of each landscape. Impacts addressed rather heavily on close to urban areas and in the vicinity of industrial plants besides on the estuary and freshwater landscapes. This is not correlated with the finding of Wolanski et al. (2004), indicating that the risk intensity decreases gradually from coast to inland, and from the delta's fan brim to the top.

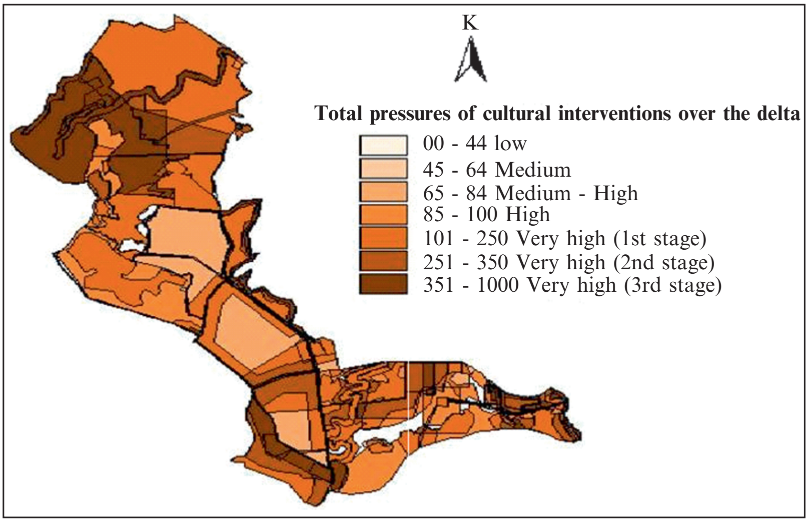

Figure 4. Ranking impacts of a number of stressors over the delta

Wetland functions and the impacts of each stressor have been compared with regard to landscape type, in which some traditional hypothesis referred that the more impacts decrease wetland functionality does not generally comply with each landscape (Table 1).

For instance; coastal marsh provides very high level wetland function although is subject to (very) high pressure. On the contrary, the afforested area matches somewhat the hypothesis. In general, even if some landscapes were rated (very) high in the functions, they experience (very) high level impacts. Ecological structure and stability of any landscape determine the sensitivity and capability of the delta against ongoing stressors with their impacts.

Figure 4 illustrates clearly most risky areas of necessitating due management and physical planning pursuits as Andersen et al. (2004) pointed out that such maps were produced for a set of feasible management alternatives as well as current land-use practices. These feasible management alternatives are spatially explicit representations of alternative distributions of the potential land uses over the study region.

Table 1. Comparing wetland functions with stressors as per the landscape type

Landscapes/wetland types	Wetland functions and/or values in total	Stressors in total on some parts of the landscapes
Coastal marsh	Very high	High, very high (1st stage, 2nd stage)
Old river branches	High	Very high (1st stage, 2nd stage, 3rd stage)
Afforested area	Medium	High, very high (1st stage, 2nd stage)
Mudflat	High	Low, medium-high, high, very high (1st stage, 2nd stage, 3rd stage)
Çilazmak lagoon	Very high	Very high (1st stage, 2nd stage, 3rd stage)
Çamaltı saltpan	Very high	Medium-high, very high (1st stage, 2nd stage)
Homa lagoon	Very high	High, very high (1st stage, 3rd stage)
Kırdeniz lagoon	Very high	High, very high (1st stage, 2nd stage)
Freshwater ecosystem	Very high	Very high (1st stage, 2nd stage, 3rd stage)
Saltwater ecosystem	Medium	Very high (1st stage)
Reedlake	Very high	Very high (1st stage, 2nd stage, 3rd stage)
Agriculture	Medium	Very high (1st stage, 2nd stage)
Gediz estuary	Very high	Very high (3rd stage)
Gediz River	Very high	Very high (3rd stage)
Temporal pasture	High	Medium-high, very high (1st stage, 2nd stage, 3rd stage)

The last stage of the procedure (Figure 2) involves two distinctive outputs of our previous research and of the management plan. The research has already developed some guidance for furthering and referencing management pursuit of the delta. In accordance with this, some actions of the management plan have recently been succinctly outlined in items for each landscape to compare with the findings of the research. Thus, the procedure has ended up with incorporation of the research with the management plan to increase the efficacy of actual measures against the ongoing/potential impacts over the delta (Table 2).

Table 2. Comparative analysis of wetland functions vs. stressors with the management plan

Threats or challenges	Outputs of our previous study	Outputs of the management plan
Freshwater	*Afforested area* Cutting off existing trees (Eucalyptus camaldulensis) to restore wetland again *Mudflat* Monitoring and reclamation works for conserving and circulating freshwater along the landscape Imposing limitations of underground freshwater uptake and consumption in industrial precincts *Saltwater ecosystem* Providing freshwater supply towards recreating freshwater ecosystem	The plan substantially stipulates supplying and circulating freshwater along the delta as well as some specific districts of importance.
Water contamination and depletion	*Lagoons* Preventing penetration of all kind of external wastes *Freshwater ecosystem* Introducing and circulating freshwater along the ecosystem especially in dry seasons *Agricultural area* Excessive water consumption resulted in a serious salinization. *Gediz Estuary* Determining sources of pollutions and comprehensive measures at Gediz Basin has to put in place to alleviate the contamination of the estuary.	Water contamination due to domestic and industrial wastes takes place a critical importance in water based challenges. Extensive agriculture and increasing residential growth besides industrial zones demand more water supplies. Contamination of Gediz River inflicts a key threat on agricultural areas.

(Continued)

Table 2. (Continued)

Landfill	*Coastal marsh and mudflat* Removing landfill barriers to provide access of (under)ground freshwater	Landfill composed of trash and garbage on the south east part of the delta is going to be strictly prohibited.
Waste	*Old river branches* Sources of pollutions should be connected to the waste treatment plant of İzmir metropolitan municipality. *Mudflat* Taking away sludge of the plant to convert the deposited place into a typical wetland.	The immediate municipalities and industrial plants are obliged to construct their own waste treatment plants for the disposal of contamination substances. To this end, effective monitoring program would put into action.
Salinization	*Freshwater ecosystem* Intrusion of sea water along with enlargement of saltpan cause a negative impact on freshwater body and its movement.	Some rural settlements are increasingly facing the salinization problem. This case has resulted in shortage of freshwater and subsequently decreasing agricultural productivity and furthermore migration of local people too.
Land use changes	*Lagoons* Shallow water, salinization and depositing sediments on the mouth of lagoons and particularly along the coastal environment modify somewhat coastal line across the delta.	Conversion of agricultural lands into urban and industrial disposal has commonly played an important role in land use changes.
Cultural interventions and physical planning	*Mudflat* Residential, commercial and industrial reserves should be put off to manage mudflat securely. *Saltwater ecosystem* Enlargement of the saltpan and shortage of freshwater are major challenges.	The management plan designated officially the boundary of coastal wetlands for conservation, and hence it will be incorporated with the development plan of İzmir metropolitan municipality (1:25,000) to provide environmental security of the delta as well as to mitigate cross boundary issues between the plan and urban or rural administrations.

5. CONCLUSION

İzmir metropolitan city is nowadays unable to enlarge its territory for physical development except its major north-west corridor covering the delta region. This situation has consequently triggered almost city-wide cultural based stressors upon the whole delta.

Towards improving the qualitative nature and functions of landscapes and decreasing ongoing negative effects of both natural and cultural challenges, some basic guidelines to each landscape have been introduced to support and encourage implementation of the newly prepared management plan. These all form spatial land-use strategies increasingly recognizing the need to reinforce the landscape approach for biodiversity and sustainable life.

This study primarily aimed to put forward some feasible measures derived from both our previous research on wetland functions-stressors context and the official management plan so that they could be utilized by decision-makers for the long term benefits of the Delta. By this means what has been suggested here is to make a comparative analysis between outcomes of the research and the management plan. The concept of this study is introduced to the management of coastal wetlands at landscape level within the delta by adopting some concrete measures to the domain of either planning or management pursuits that is able to conserve or enhance natural processes and ecological stability. Ohlson and Serveiss (2007) also underlined the importance of how the integration of ERA and decision analysis approaches can support decision makers in watershed management. Likewise, Landis (2003b) and Gaines et al. (2004) touched on that landscape and regional scale risk assessments will be necessary to develop approaches and tools to deal with these ranges of scope.

In conclusion, the experiences could inevitably push forward a citywide dilemma about whether to conserve and enhance the delta with its wetlands, rural settlements and agricultural lands or to endorse some basic and to an extent exaggerated requirements of political actors to reserve the delta for development. This paradoxical situation entirely requires implementation of the management plan that should address thoroughly the landscape-based ecosystem approach for the benefits of a self-sustainable coastal wetlands' system across the delta.

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