ROLE OF CLIMATE CHANGE IN VULNERABILITY ASSESSMENTS

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1. INTRODUCTION

According to the Environmental Protection Agency (EPA, 2013), over one third of the total U.S. population get some or all of their drinking water from public drinking water systems that rely, at least in part, on intermittent, ephemeral or headwater streams. The provision of safe and acceptable drinking-water of adequate quantity frequently represents a challenge to small-scale water supplies. Furthermore, experience has shown that small water systems are more vulnerable to breakdown and contamination than larger utilities, and that they require particular attention due to their administrative, managerial, and potential social impact in case of disaster (Rickert and Schmoll, 2011).

Quantitative vulnerability assessment methods are often used to characterize exposure and sensitivity of water systems, but have difficulty in addressing several physical and societal concerns. Alternatively, focus meetings of stakeholders delivering qualitative risk ranking, supply explicit knowledge of system sensitivity and adaptive capacity. They can also address issues related to climate change, but fall short in the specifics needed for practical decision making.

Timely adoption of climate model projections by decision makers can be severely limited by this inability of both quantitative and qualitative vulnerability assessments to properly account for changing trends in distribution and severity of hazards. Therefore, an attempt is being made to use ontology and semantic web applications as cross-domain technologies that can enable the development of comprehensive vulnerability assessment methodologies.

Since the development of the NOAA Community Vulnerability Assessment Tool (Watson, 2009) several attempts were made to apply information technologies to qualitative and quantitative vulnerability assessments. However, besides specific limitations intrinsic to the objectives of the individual studies, most of the attempts provide support for the discovery of past local events and limited support for estimating risks related to future trends of natural environments.

A preliminary review is made on the role natural hazards play on the systems, services, and management related to water resources. The review indicates that decision support systems can be significantly improved with the integration of a climate change model and a climate trend forecast for natural hazard related information.

Experiments made providing focus groups of water system stakeholders with on-line quantitative information on environmental hazards demonstrated that focus groups can deliver vulnerability rankings verifiable against historical records. These findings hint to the possibility that as long as the technical information is maintained at a level appropriate for all the participating stakeholders, the quantitative information on hazards, vulnerabilities, and values of losses could be equally effective.

From this preliminary analysis, it appears that the need for statistical data on natural hazards (Hunt et al. 2009) remains a promising area for development of decision support systems. They are both relevant to all major areas of interest, are generally available, and they baseline locally possible climate change trends (Milly, et al. 2008).

An expansion of the use of new information technologies to linking information of past hazards to their projected trends could make assessment support tools considerably more useful for small operators and general users (Dozier and Gail, 2009).

2. A DELIBERATIVE RISK RANKING EXPERIMENT

During a recent experiment (Coletti, et al., 2012), focus groups identified and discussed some thirty-five risks affecting community water systems (CWS) in two coastal communities of

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the East coast of the US. The experiment, conducted under a NOAA Climate Program Office grant measured the advantages that on-line Vulnerability Assessment Support Systems (VASS) could provide to focus groups.
During a first phase of the experiment, the stakeholders prioritized each risk by frequency and severity using an ordinal ranking process. During a second phase, the stakeholders were presented with past records of local natural hazards and with demographic analysis of vulnerable groups. The data were presented on a dedicated web-site that included historical records, which dated back twenty years, of severe storms gathered from the NOAA NCDC database. The website provided the stakeholders with the ability to refer to individual environmental events whenever they were recollecting events of systems operations under adverse conditions.

Data records facilitated the discussion of the relevant events during the recollection of the local contextual experiences. The discussions reviewed water quality monitoring practices in use by the community and evaluated vulnerable safety rules adopted during recovery phases following system failures and repairs.

2.1 Risk Types and Vulnerability Assessment Methodologies

The set of risks identified by the two separate stakeholder groups during the VASS experiment resulted in having several similarities. Regardless of the differences in the levels of severity and probability of occurrences, the risks addressed by both groups of stakeholders can be considered representative of those experienced by several coastal communities in the United States consolidates the risks identified by the two groups of stakeholders in one single list obtained eliminating duplicates. The table shows how, in addition to the risks of water plant failures, the stakeholders addressed vulnerabilities caused by ill prepared management, maintenance services, and water quality monitoring practices. Several risks addressed problems with quality and availability of water resources due to demographic changes, sharing of water resources, distribution services across systems (risk 1,3,4,25,26,27 in the table), as well as water quality and flow rates of the aquifers (risk 1, 2, 3, 5, 8,9,10, 17, 20 in the table). Other risks addressed vulnerabilities related to power distribution, essential supplies, and suitability of allocation of funding in case of emergency (risk 6, 13, 14, 22, 30 in the table).

Therefore, even though the VASS demonstrated that the availability of well selected climate and weather data can help in validating vulnerabilities and priorities, still as shown in Figure 1, they are of little help when the majority of high priority risks originate from hazards related to human and social behaviors (labeled with M in the table). Interestingly also, contrary to weather and climate, there are no applicable statistical data collections for human and social behaviors.

The risk listed by the stakeholders during the VASS experiment, identified vulnerabilities of critical elements in water systems such as pumps, storage tanks, water conditioning units, and distribution lines. Generally, these vulnerabilities are well defined during quantitate risk assessments. Due to their different nature and scope, quantitative risk assessments require detailed identification of the critical assets of a system, such as the threats or hazards that can cause them to fail or malfunction.

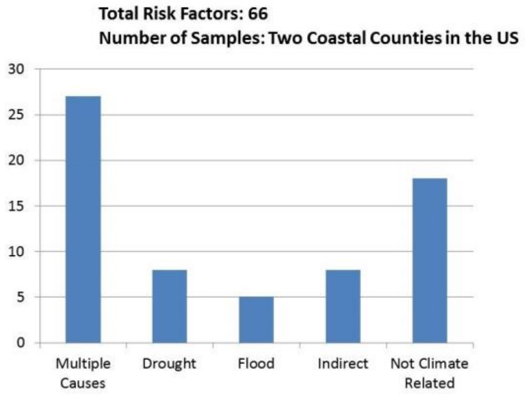

Figure 1 Risks of CWS measured during the VASS Experiment. The figure compares the Weather and Climate related risks to those due to other causes. The histogram reports data extracted from the original risk descriptions gathered during the two focus groups.

For this reason, quantitative risk assessments provide verifiable results in the case of risks related to physical components or assets, but results are hard to validate in the case of socially related threads like vandalisms, mismanagement of resources, and human errors in operating procedures.

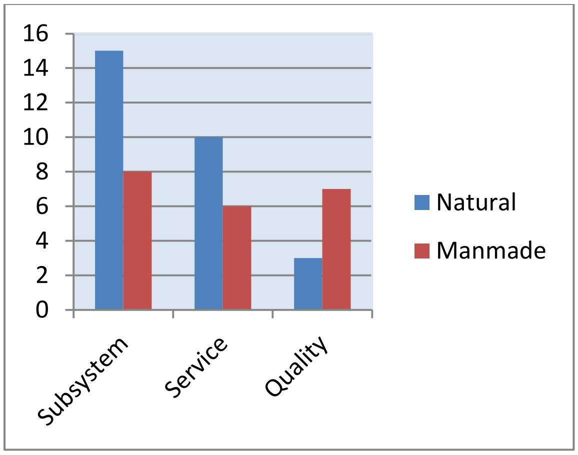

Figure 2 Number of risks observed during the experiment divided according to broad categories of impacted system modules (system components, system service, and service requirements) for natural and manmade hazard (threads) sources.

Figure 2 plots the number of all the risks in Table 1 that are related to subsystem components, services, and quality standards. It shows that the number of risks that can be assessed by quantitative methods on the basis of weather related statistics is around 30% of the total. The total of amount of risks related to natural hazards involving systems, services and quality control is instead greater, and in our experiment of the order of 60%.

3. CLIMATE AND WATER SYSTEMS VULNERABILITY

The breakdown of the risk categories in Figure 2 confirms some well-known facts about vulnerability assessments and some broad concepts relative to water system vulnerability assessments. The data objects associated to these concepts are those needed by stakeholders and planners in the decision making process.

Creating parametric relationships between data points and concepts is an important phase of several of the on-going semantic web development efforts. The process is schematically represented in Figure 3, and the technology can be used to enable stakeholders to share a common formal specification of related concepts in water systems. These specifications are illustrated in the ontology layer of Figure 3 where the concepts are the dots and the lines connecting the dots are the relationships. Therefore, the ontology model defines the set of concepts and their relationships so that the data objects on the information layer can be organized according to the same criteria simply by inheriting relationships and concepts. For example, natural hazards can be defined as the objects that exploit some system vulnerability, and vulnerability as the object contributing to a risk. Since natural hazards include weather and climate model as children in the information layer, severe weather events and model predictions can also exploit individual exposure, sensitivity and adaptive capacity weaknesses of water system components, services, and quality parameters (Coletti et al., 2014).

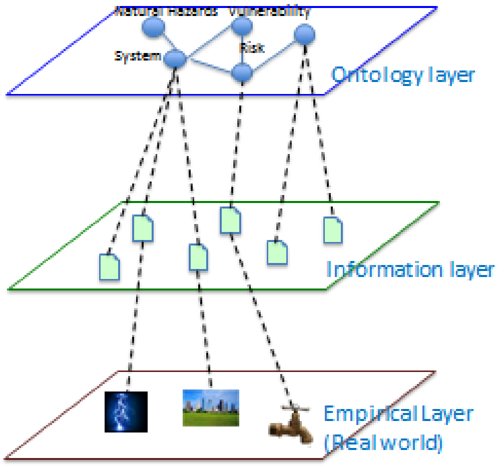

Figure 3 Schematic representation of how the semantic web can organize data and information to make them more easily accessible to stakeholders.

These types of ontologies offer the opportunity for making easily accessible information already available on-line, and to substantiate relationships between different risk elements such as local weather extrema and projected climate trends.

4. CONCLUSIONS

The majority of small water system operators is aware of the local vulnerabilities and has some understanding of the associated risks. For the most part, their difficulties arise from limitations in the predictive models useful for planning components upgrades, improving water management methods, and updating water quality monitoring methods.

New ontology based information technologies could be used to enable users to access similar subject matters according to related knowledge bases. For example, weather and climate effects could be related to their effects on services and critical infrastructures or quality control practices could be related to climate trends. Such technologies could also be used to facilitate comparisons between the performance of climate predictive models and projections in other fields such as demographic trends and water availability and quality.

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Table 1 List of risks, associated vulnerable system and hazards. Vulnerable systems considered are Vulnerable subsystem (HW), Vulnerable Support Services (Se), and Exceeded/Inadequate Quality Standards (Q). Hazards considered are M= Man and Natural hazard (N)

Risk Definition	**HW, Se, Q**	**M, N**	**Risk Definition**	**HW, Se, Q**	**M, N**
1. Shortage due to drought	HW	N	19. Returning the water system to normal after a disaster	Se, Q	M
2. Taste, Temperature and odor of finished water	Se, Q		20. Plan for and ability to implement emergency testing	Q	M
3. Climate change impacts on groundwater system and aquifers	HW		21. Well-head protection	HW	M
4. Demand due to population growth or construction	Q	M	22. Physical damage of water storage tanks	HW	M
5. Salt water intrusion	HW	N	23. Amount of storage capacity of treated water	HW	N
6. Hurricane impacts on water systems and management	HW, Se		24. Physical, Chemical, and Biological Conditioning of Water	HW	M
7. Wind and flooding affects power distribution lines	HW	N	25. Back feeding from contaminants	HW	N
8. High water surges contaminating distribution system	HW		26. Integrity of transmission lines of raw water	HW, Se	N
9. Levels of natural deposits (arsenic, fluorides.etc.)	HW	N	27. Distribution system deterioration (age, maintenance)	Se, Q	M
10. Water system potability and pressure	HW, Se	N	28. Number of connections and ability to isolate most/least critical	Se	M
11. Contamination of wells	HW	N	29. Pressure to extend CWS	Q	M
12. Ability to get staff to come to work in a disaster	Se	M, N	30. Disgruntled employee action	HW	M
13. Disrupted delivery of treatment and process chemical	Se	M	31. Vandalism to infrastructure	HW	M
14. Ability to maintain emergency power	HW, Se	N	32. Telemetry system vandalism	Se	M
15. Emergency power supply	Se	N	33. Lack of funding for maintenance and repair	Q	M
16. Process for notifying regulators/ public of compromised supply	Se, Q	N	34. Emergency funding	Q	M
17. Ability to produce and distribute water at minimum potability standards	Se ,Q	N	35. Ability to supply water to critical infrastructures	HW	M, N
18. Cascading impacts of private and public systems	HW	N			