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USE OF VOLUNTEERS' INFORMATION TO SUPPORT PROACTIVE INSPECTION OF HYDRAULIC STRUCTURES

Vivian Juliette Cortes Arevalo

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Para mis padres Yolanda y Ricardo.
Para mi cielito, Yared

Summary

Proactive management is particularly important to deal with the increasing occurrence of hydro-meteorological hazards in changing environments. Mountain areas are one example of changing areas were threats are often caused by multiple and sudden onset hazards such as debris flows. Sudden onset hazards give a short lead-time to communicate warning signs or to implement emergency response measures. However, natural hazards do not automatically lead to disasters if their impacts can be mitigated, especially if proactive and adaptive management is pursued. Proactive inspections are one way of combining non-structural and structural measures towards adaptive risk management approaches. Citizen volunteers can be involved in inspecting structural measures to support technicians on checking the structures' functional status. Such collaborative effort between managing organizations and local volunteers becomes more important under limited resources.

Citizen science offers opportunities for involving local volunteers in support of proactive inspections. Volunteers' involvement may contribute to self-awareness and may provide managers with insights about local impacts and changes. Research on citizen science encompasses a variety of aspects such as motivations of volunteers, data quality requirements, and coordination between the varieties of actors involved. In this research, I refer to citizen science through the involvement of volunteers in support of first level or prescreening visual inspections about the functional status of structures that protect against debris flows. Thereby, I developed a methodology applicable in day-to-day risk management to consider volunteers' information in support of proactive inspection of hydraulic structures. To that end, I addressed the following scientific objectives: i) identify requirements for citizen science approaches based on existing literature and the specific context of the study area; ii) develop a data collection approach that can be performed by volunteers taking into account data quality requirements of technicians; iii) develop a methodology to evaluate first level inspections in support of decisions about the functional status of hydraulic structures; and; iv) design a Web-GIS decision support framework to assist technicians in evaluating inspection reports of hydraulic structures.

The methodology focuses on check dams' inspections in the Fella basin, which are key structures in the system of protection works against debris flows. The Fella is a mountain basin located in the North-eastern Italian Alps of the

Friuli Venezia Giulia region (FVG). It is prone to multiple flash floods and debris flows. Although structural measures are in place, such measures may not be efficient under all possible hazard and exposure scenarios and, if they are not in optimal state. Proactive inspection is of high priority. Design choices for the citizen science application of this thesis follows a conceptual framework analysis. I propose this conceptual framework to review the requirements and design considerations for citizen science approaches. From the framework analysis in the FVG, I list a variety of in-practice examples of citizen science approaches. Overall, volunteers' involvement in the study area responds to a collectivism motivation, which has been supported via citizen volunteer groups of Civil Protection. Specific organizational requirements beyond existing volunteers' involvement includes simplified procedures for inspecting implemented protection measures and decision support methods accounting for limitations in data quality.

I developed, in collaboration with technicians-in-charge, a data collection approach for first-level or pre-screening visual inspections that can be performed by volunteers. Methods comprise of a data collection exercise, inspection forms and a learning session based on existent procedures in the FVG region and neighbouring regions. Eleven technicians and 25 volunteers attended the data collection exercise divided into a learning and control group. Participants appreciated the activity for promoting the proactive inspection of the structures with preventive scope. Collected reports do not have high statistical significance due to the limited number of participants per group. I used this exercise to evaluate data quality. The results from this analysis shows that volunteers' reports had higher variance than technicians' reports. To cope with the differences in precision, I generalized rating scales to calculate the mode response according to the questions and rating options provided in the form. Although the generalization brought forth some improvements, the reports of both volunteers and technicians showed limited reproducibility. Iterative design and testing of the inspection form was required. Moreover, a method was required to support technicians in systematically evaluating the inspection reports to support decisions about proactive inspections and management actions.

To systematically evaluate the individual inspection reports, I designed a support method by means of a multi-criteria method with fuzzy terms. The method allows the technicians-in-charge to categorize the reports in one of three levels, each corresponding with a course of action. I organized a workshop with technicians in the study area to test the decision support method based on their inspection reports. Fourteen participants took part of the workshop, including technicians who were not involved in previous research activities. I looked at the effect of the quality of their input reports on the output of the decision support method. In addition, I compared the differences in the participants' advice during the inspection and the output from the decision support method. The individual reports were aggregated into two values at parameter level, an index to indicate the functional status and a completeness ratio. To calculate the index, I summed the reported ratings per parameter while using equal weights for all questions to isolate the effect of data quality. A weighted aggregation should be used with caution because it influences the outputs considerably, especially if inspectors err by overestimating or underestimating the structures' condition. The use of expert-based rules limiting the minimum acceptable index and worst reported condition was helpful to evaluate the reports. In addition, complementary data from historical inspections or remote sensing data can be useful to initiate specific actions following these inspections.

To facilitate the evaluation of inspection reports, I transformed the decision support method into a prototype Web-GIS application. The design process followed a user-centered approach. The conceptual design of that framework incorporates four modules for managing the inspection reports: 1) Registered users, 2) Inspection planning; 3) Available reports and 4) Evaluation of reports. The development of the prototype focused on the evaluation module. The prototype architecture was implemented using OpenGeo Suite SDK, which is a web-GIS platform based on standard and interoperable open source tools. Ten technicians used the prototype application for evaluating their own inspection reports. Besides the involvement of technicians that participated in previous research activities, the involvement of new technicians was important due to their fresh perspectives. Participants' feedback led to a set of suggested improvements in the decision support method and the Web-GIS application.

This research contributes to the use of citizen science in support of inspections by technicians. I hope that the knowledge, theory and concept behind this decision support method can be developed into a full-scale Web-GIS application. The advantage of using this decision support method is that it allows inspections to be carried out by either skilled volunteers or technicians while ensuring technicians-in-charge that they can systematically evaluate the collected reports. The Web-GIS application can be further promoted as a tool to support cooperation between different management organizations. Relevant actors for managing volunteers' inspections include organizations dealing with emergency preparedness and risk prevention at regional and local level as their management activities could potentially benefit from the outputs of first level inspections.

Based on the experiences of the Fella basin application, I provide recommendations for further research. The methodology developed in this thesis can be adapted to other study areas with different volunteering traditions and to other types of hydraulic structures. The selection of hydraulic structures should have limited complexity and sufficient accessibility to be inspected with volunteers.

Decisions following the proactive inspections require hazard and exposure information to define risk assessment scenarios and maintenance strategies. Moreover, working with technicians and volunteers in a collaborative research approach requires trade-offs between motivations of participants, scientific and management goals. Finally, volunteers can become skilled inspectors by teaming up with technicians for the inspection of hydraulic structures. Technicians can become more aware about local impacts and changes in the structures' status by teaming up with volunteers.

Vivian Juliette Cortes Arevalo
Delft, April 2016

SAMENVATTING

Proactief beheer is van bijzonder belang voor een goed beheer van toenemende hydro-meteorologische gevaren in veranderende leefomgevingen. Berggebieden zijn voorbeelden van veranderende gebieden waar bedreigingen vaak veroorzaakt worden door verscheidende plotseling optredende gevaren, zoals puinstromen. Bij plotseling optredende gevaren is er weinig tijd om waarschuwingen te geven of noodmaatregelen te treffen. Natuurlijke gevaren leiden echter niet altijd tot een ramp als de gevolgen gemitigeerd kunnen worden, in het bijzonder als er proactief en adaptief beheerd wordt. Proactieve inspecties zijn één manier om structurele en niet-structurele maatregelen te combineren en zo het beheer meer adaptief te maken. Vrijwilligers kunnen betrokken worden bij de inspectie van structurele maatregelen ter ondersteuning van experts die de functionele status van de structuren controleren. Dergelijke samenwerking tussen beheersorganisaties en lokale vrijwilligers is vooral belangrijk als de middelen beperkt zijn.

Zogenaamde “citizen science” biedt mogelijkheden om lokale vrijwilligers actief te betrekken bij proactieve inspecties. Actieve betrokkenheid kan bewustwording van de vrijwilligers bevorderen en kan de beheerders inzicht geven in lokale gevolgen en veranderingen. Onderzoek naar citizen science richt zich op verscheidene aspecten, zoals de motivatie van de vrijwilligers, de kwaliteit van de data, en coördinatie tussen de verschillende typen actoren. Citizen science in dit onderzoek heeft betrekking op de ondersteuning van niveau-1, pre-screening visuele inspectie van de functionele status van dammetjes ter voorkoming van puinstromen. Hiervoor heb ik een methodologie ontwikkeld, toepasbaar in de dagelijkse praktijk van het risicobeheer, om de informatie van vrijwilligers mee te laten wegen bij proactieve inspectie van deze dammetjes. De wetenschappelijke doelen hierbij zijn: i) het identificeren van de vereisten die aan citizen science benaderingen gesteld kunnen worden, gebaseerd op de huidige literatuur en de specifieke context van het studiegebied; ii) het ontwikkelen van een benadering voor data-verzameling door vrijwilligers, rekening houdend met de kwaliteit die de technici nodig hebben; iii) het ontwikkelen van een methodologie om de niveau-1 inspecties te evalueren ter ondersteuning van besluiten over de functionele status van hydraulische structuren, en iv) het ontwerpen van een beslissingsondersteunende Web-GIS ter ondersteuning van de evaluatie van de inspectierapporten door technici.

De ontwikkelde methodologie richt zich in het bijzonder op inspecties van dammetjes in het stroomgebied van de Fella, de belangrijkste kunstwerken tegen puinstromen. Het stroomgebied van de Fella is gelegen in de Noordoostelijke Italiaanse Alpen in de Friuli Venezia Giulia regio (FVG). Het is gevoelig voor snel-optredende overstromingen en puinstromen. Hoewel er structurele maatregelen genomen zijn, zijn deze niet efficiënt voor alle mogelijke gevaren in alle mogelijke scenario's als zij zich niet in een optimale staat bevinden. Proactieve inspectie heeft daarom een hoge prioriteit. Ontwerpkeuzen voor de citizen science toepeassing in dit proefschrift zijn gebasseerd op een conceptueel-kader. Dit is bedoeld om de vereisten en ontwerpoverwegingen voor citizen science benaderigen te evalueren. Gebruik maken van dit kader voor FVG, kom ik tot een lijst van praktische voorbeelden van citizen science benaderingen. Alles bij elkaar genomen beantwoord de betrokkenheid van vrijwilligers in de regio aan een collectieve motivatie, die ondersteund wordt via vrijwilligersgroepen van de Bescherming Burgerbevolking. Specifieke organisatorische vereisten die uitgaan boven de huidige betrokkenheid van vrijwilligers, zijn onder andere versimpelde procedures voor de inspectie van uitgevoerde beschermingsmaatregelen en beslissingsondersteunende methoden die rekening houden met de beperkingen in de kwaliteit van de data.

Samen met de verantwoordelijke technici heb ik een benadering voor dataverzameling ontwikkeld voor niveau-1 visuele inspectie door vrijwilligers. Methoden binnen deze benadering zijn een dataverzamelingsoefening, inspectieformulieren en een leersessie die gebaseerd is op bestaande procedures in FVG en de buurregio's. Elf technici en 25 vrijwilligers, gesplitst in een leer- en een controlegroep, namen deel aan de dataverzamelingsoefening. Deelnemers waardeerden de activiteit ter bevordering van proactieve inspectie van de dammen met als doel preventie. De verzamelde rapporten laten geen hoge statische significantie zien vanwege het beperkte aantal deelnemers per groep. Ik gebruikte de oefening om de kwaliteit van de data te evalueren. De resultaten laten zien dat de variantie van de rapporten van de vrijwilligers hoger is dan de variantie van de rapporten van de technici. Om beter om te kunnen gaan met de verschillen in nauwkeurigheid, heb ik de beoordelingsschalen die gebruikt worden om de responsmodus te berekenen op basis van de vragen en antwoordopties in het formulier, algemener gemaakt. Hoewel dit tot enige verbetering leidde, zijn de rapporten van zowel de vrijwilligers als de technici beperkt reproduceerbaar. Iteratief ontwerp en testen van de inspectieformulieren was nodig. Verder was er een methode nodig om de technici te helpen bij de systematische evaluatie van de inspectierapporten ter ondersteuning van besluitvorming over proactieve inspecties en beheersmaatregelen.

Om de individuele inspectierapporten systematisch te kunnen evalueren, heb ik een ondersteunende methode ontwikkeld in de vorm van een multi-criteria methode die gebruik maakt van vage termen. Met deze methode kunnen de verantwoordelijke technici de rapporten classificeren op drie niveaus, elk met bijbehorende acties. Ik organiseerde een workshop met de technici in het studiegebied om deze beslissingsondersteunende methode te evalueren op basis van hun eigen inspectierapporten. Er waren veertien deelnemers, waaronder technici die niet eerder bij het onderzoek betrokken waren geweest. Ik bestudeerde het effect van de kwaliteit van hun inputrapporten op de output van de beslissingsondersteunende methode. Verder vergeleek ik de verschillen tussen het advies van de deelnemers tijdens de inspecties met de resultaten van de beslissingsondersteunend methode. De individuele rapporten werden geaggregeerd tot twee waarden op parameterniveau: een index voor de functionele status en een compleetheid ratio. Om de index te berekenen, sommeerde ik de gerapporteerde ratings, waarbij ik alle vragen evenveel gewicht gaf, om het effect van datakwaliteit te isoleren. Aggregatie gebruik makende van gewichten moet zeer voorzichtig toegepast worden omdat het de uitkomsten sterk kan beïnvloeden, vooral als inspecteurs de toestand van de kunstwerken over- of onderschatten. Voor de evaluatie van de rapporten bleek het nuttig om regels ontleend aan experts te gebruiken die beperkingen stellen aan de minimale acceptabele index en de slechts gerapporteerde toestand. Daarnaast kunnen data van inspecties uit het verleden en remote sensing data nuttig zijn bij besluitvorming over vervolgacties naar aanleiding van de inspecties.

Om de evaluatie van de inspectierapporten te vergemakkelijken, heb ik de beslissingsondersteunende methode omgewerkt tot een prototype Web-GIS applicatie. Het ontwerpproces stelde de gebruiker centraal. Het conceptuele ontwerp bevat vier modules voor de verwerking van de inspectierapporten: 1) Geregistreerde gebruikers, 2) Planning van de inspectie; 3) Beschikbare rapporten en 4) Evaluatie van de rapporten. De ontwikkeling van het prototype had vooral betrekking op de evaluatiemodule. De architectuur van het prototype werd geimplementeerd met behulp van OpenGeo Suite SDK, een web-GIS platform dat gebaseerd is op standaard en interoperabele open source instrumenten. Tien technici hebben het prototype gebruikt om hun eigen inspectierapporten te evalueren. Betrokkenheid van technici die niet eerder bij het onderzoek betrokken waren geweest, was belangrijk omdat zij een frisse kijk hadden. De terugkoppeling van de deelnemers leidde tot een aantal gesuggereerde verbeteringen in de beslissingsondersteunende methode en de Web-GIS applicatie.

Dit onderzoek draagt bij aan het gebruik van citizen science ter ondersteuning van inspecties door technici. Ik hoop dat de kennis en theorie en het concept achter deze beslissingsondersteunende methode verder uitgewerkt kan worden tot een volledige Web-GIS applicatie. Het voordeel van deze beslissingsondersteunende methode is dat hij inspecties mogelijk maakt door kundige vrijwilligers of technici, die de verantwoordelijke technici dan systematisch kunnen evalueren. De Web-GIS applicatie kan ook gepromoot worden als een middel om de samenwerking tussen verschillende beheersorganisaties te bevorderen. Relevante organisaties die inspecties door vrijwilligers kunnen coördineren en potentieel profijt hebben van de resultaten van niveau-1 inspecties, zijn onder andere organisaties op regionaal en lokaal niveau met als taak voorbereiding op crises en risicopreventie.

Op basis van de ervaringen met de applicatie voor het stroomgebied van de Fella doe ik verschillende aanbevelingen. De methodologie die in dit proefschrift ontwikkeld is, kan aangepast worden voor andere studiegebieden met andere tradities op het gebied van vrijwilligerswerk en voor andere kunstwerken dan dammetjes. De te selecteren kunstwerken moeten toegankelijk zijn voor de vrijwilligers en niet te complex zijn. Om op basis van proactieve inspecties risicobeoordelingsscenario's en beheersstrategieën te ontwikkelen is er verder informatie nodig over gevaren en kwetsbaarheid. Werken met technici en vrijwilligers in collaboratief onderzoek vereist afweging tussen de motivaties van de deelnemers, wetenschappelijke doelen, en beheersdoelen. Ten slotte: als vrijwilligers en technici voor de inspectie van kunstwerken een team vormen, dan kunnen de vrijwilligers kundige inspecteurs worden en kunnen de technici meer bewust worden van de lokale gevolgen en veranderingen van de status van de kunstwerken.

CONTENTS

List of Figures

List of Tables

1

INTRODUCTION

Part of this chapter (Section 1.2) are based on Prenger-Berninghoff et al. (2014):

Prenger-Berninghoff, K., Cortes, V. J., Sprague, T., Aye, Z. C., Greiving, S., Głowacki, W. and Sterlacchini, S.: The connection between long-term and short-term risk management strategies for flood and landslide hazards: examples from land-use planning and emergency management in four European case studies, *Nat. Hazards Earth Syst. Sci.*, 14(12), 3261–3278, doi:10.5194/nhess-14-3261-2014, 2014.

1.1. WHY A PROACTIVE APPROACH TO THE INSPECTION OF HYDRAULIC STRUCTURES?

Over the last years, European and worldwide directives have called for more proactive and collaborative approaches for climate change adaptation (EC, 2013; Pachauri et al., 2014) and disaster risk mitigation (EC, 2007; UN, 2005). Proactive approaches are particularly important to deal with the occurrence of hydro-meteorological hazards in a changing world (Merz et al., 2010). A proactive approach involves the individual and organizational capacity of being aware and acting ahead of the build-up of hydro-meteorological hazards to better prepare and adapt (McFadden et al., 2009).

Mountain areas are an example of changing socio-economical environments where threats are often caused by multiple and sudden hydro-meteorological hazards such as flash floods and debris flows (Jäger et al., 2014). Debris flows are one of the most destructive water-sediment processes in Alpine areas. A debris flow consists of water, sediment and debris rushing down a stream channel with intermediate behaviour between flash floods and mudflows (Gaume et al., 2009). The occurrence of such water sediment processes requires a significant water discharge and abundant source of sediments to be mobilised. Thereby, debris flows can be triggered by intense rainfall, snowmelt or the combination of both. Debris flows can also be initiated by the combined effect of multiple hazards such as floods and landslides (Badoux et al., 2008). Due to their sudden initiation and fast flowing, debris flows are difficult to predict. Debris flows give a short lead-time to communicate warning signs or to implement emergency response measures (Molinari and Handmer, 2011). Moreover, where structural mitigation measures are in place, the performance of protecting measures is being challenged by the complexity of changing socio-economical, environmental and climatic patterns (EEA, 2010; UNISDR, 2011).

Structural measures comprise hydraulic structures, which are designed and built to protect society against hydro-meteorological hazards. However, the functional status of hydraulic structures can be affected by their state of maintenance and the increasing influence and frequency of water-sediment processes (Mazzorana et al., 2014). Risk due to hydro-meteorological hazards can be assessed through the relationship between hazard, vulnerability and exposure (van Westen et al., 2014). Hazard assessment accounts for the temporal and spatial probability of hazard occurrence as well as the relation between hazard magnitude and frequency (van Westen et al., 2008). Vulnerability addresses multiple dimensions of the elements at risk, which should be assessed according to the risk management measures under consideration (cited in Ciurean et al. (2013) referring to O'Brien et al. (2008)). Exposure is a component of vulnerability that refers to the amount and type of elements at risk in a hazard prone area. In addition, elements at risk have hazard specific vulnerabilities (Merz et al., 2010); for example, the degree to which a system of elements at risk can be damaged. Elements at risk and relevant protective structures also have a physical susceptibility or predisposition to be damaged due to, for example, the age and maintenance status (Uzielli et al., 2008).

Hydraulic structures such as check dams are important structural measures to mitigate hazards. Proactive inspection and maintenance should be planned and performed during the life cycle of the structures (Bontempi et al., 2008). Information about the functional status of such structures is essential to define risk scenarios and maintenance strategies. The limited resources and the increasing complexity of hazard events and elements at risk urge for a better coordination of inspections and collaborative efforts to increase the frequency and spatial coverage of inspection activities.

1.2. Collaborative efforts to combine structural and non-structural risk management measures

Proactive inspections of hydraulic structures with support of volunteers are one way of combining structural and non-structural measures. Risk management measures are often referred to as structural and non-structural measures. According to UNISDR terminology (2009, p.28), structural measures distinguish physical constructions or engineering applications from more organizational and institutional measures.

Huebl and Fiebiger (2005, p.446) highlight the active role of structural measures. Protecting measures actively influence the magnitude and frequency of events by reducing the probability of their occurrence or by managing the event itself. Holub and Hübl (2008, p.83) further distinguish active from passive structural measures. Passive measures aim to separate elements at risk from the hazard itself or to reduce vulnerabilities, for example, by adapting the building design and constructing local protection works. Instead, according to Linnerooth-Bayer et al. (2015, p.5) non-structural mitigation is neither an active or a passive measure. Non-structural measures comprise policy and organizational interventions to reduce risk exposure. Such measures account for education and awareness raising and collaborative efforts between scientific, management and community organizations.

1

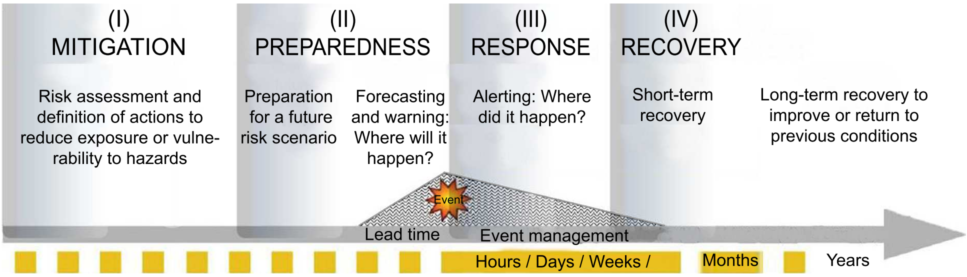

Figure 1.1: Timeline of disaster risk management (Source: adapted from the timeline for humanitarian aid, EUGENE, 2010, p.11)

Risk management measures are implemented in all phases of the disaster risk management cycle: mitigation, preparedness, prevention and recovery (**Figure 1.1**). However, measures are taken on long and short-term basis by taking into account the imminent probability of hazard and the available time for event management. **Table 1.1** summarizes some examples of structural and non-structural measures according to their long or short-term period of implementation. In that context, proactive management promotes joint-actions by supplementing long-term with short-term actions that are combined into structural and non-structural measures (Tingsanchali, 2012). This is opposite to reactive management that focuses on short-term actions to reduce casualties and damage when or just before an event takes place (Adger et al., 2007). Inter-organizational coordination and pooling of resources between organizations dealing with emergency preparedness and risk prevention are important mechanisms to combine structural and non-structural measures (Prenger-Berninghoff et al., 2014; Watson, 2004).

Moreover, the strategic identification of proactive and adaptive risk management strategies implies a learning process based on monitoring and evaluating the effects of implemented measures (Pahl-Wostl, 2008; Smit and Wandel, 2006). In that process, mechanisms to facilitate multi-stakeholder collaboration are necessary to ensure the integration of complementary data, information, knowledge, experience and preferences of relevant stakeholders. Relevant stakeholders comprise persons or organizations that influence decisions about risk management actions or may be affected by a particular action or guidelines towards achieving a risk management strategy (cited in Aye et al. (2016) referring to Baede et al. (2007, p.87)). **Figure 1.2** illustrates the steps of a collaborative adaptive management process (Pratt Miles, 2013). Collaborative efforts generally vary according to the purpose, methods and level of stakeholder participation (Lesen, 2015). Collaborative efforts to enhance the organizational capacity of management organizations are especially important under limited resources, in remote settings and under the increasing complexity of hydro-meteorological events.

Table 1.1: Examples of risk management measures classified into structural and non-structural, long and short-term implementation (Source: compiled from examples listed on Brilly et al., 2011; Holub and Hübl, 2008; Ranzi et al., 2011)

	Structural	Non-Structural
Long-term	• Works for water level regulation (e.g. dikes); • River channel works (e.g. enlargement of cross section); • (Bio)-land engineering works (e.g. terraces); • Temporal or permanent storage and retention basins; • Local structural measures and adapted building design (e.g. flood proofing); • Cleaning and maintenance of engineering measures	• Spatial and land-use planning; • Shared loss through private insurance schemes; • Establishment and management of protected or relocation areas
Short-term	• Operation of protection works (e.g. floodwalls and removable floodwalls)	• Early warning; • Education and awareness raising for self-protecting behaviors; • Contingency and emergency plans

1.3. VOLUNTEERS' INVOLVEMENT AND THEIR KNOWLEDGE

Active involvement of local organizations such as volunteer groups is especially important to manage sudden-onset hazards. This holds not only during the build-up or recovery of the hazard but also in preparedness and mitigation phases. Natural hazards do not automatically lead to disasters if their impacts can be mitigated, especially if proactive and adaptive management is pursued (ISDR, 2008). Efforts to enhance the adaptive capacity of communities at risk, and management organizations, should consider the following aspects (Berkes, 2007; Folke et al., 2003): learning to live with change and uncertainty while building a memory of past events; fostering diversity in management options; creating opportunities for self-organization in the face of crises and disaster; and combining different types of knowledge for learning.

Citizen science offers important opportunities for involving local communities in support of proactive and adaptive management. According to the specific goal and context of implementation, there are multiple definitions and categories of citizen science approaches that generally consist but are not limited to

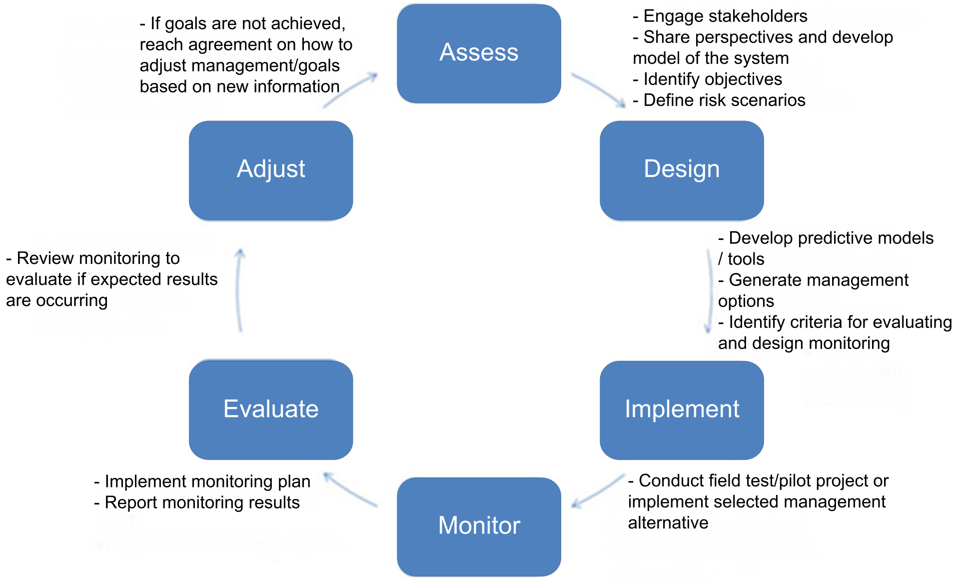

Figure 1.2: Steps of a collaborative adaptive management process (Source: Pratt Miles, 2013, p.2)

data collection (Wehn and Evers, 2015). Working definitions account for volunteers or public involvement in citizen science activities, for example, volunteer geographic information (Goodchild, 2007). This research particularly refers to citizen science to distinguish the involvement of volunteers in data collection activities that require training to support management needs (Devictor et al., 2010). SABO, 2007 suggested the following types of information that can be potentially collected by volunteers in support of management strategies for hydro-meteorological hazards:

- information about the status of streams and mitigation structures that can be observed before and after the occurrence of hydro-meteorological hazards and related events;
- information about hazard occurrence or impacts to built infrastructure, particularly relevant infrastructure for emergency management such as shelters and evacuation roads;
- information after a hazard event such as field investigations including information about the impacts from witnesses of the event;

In conclusion, volunteers' involvement may provide managers with insights about the local impacts. It may also contribute to volunteers' awareness and more proactive behaviour against water-sediment processes (Folke et al., 2003;

Lara et al., 2010). Despite potential advantages, research on citizen science addresses a variety of challenges such as data quality control, evaluation and interpretation, motivational aspects of volunteers' engagement and long-term coordination between the varieties of actors involved. The use of volunteers' knowledge into management practice is a difficult proposition (Failing et al., 2007). According to (Gaillard and Mercer, 2012, p.9), knowledge in a broad sense includes information and/or skills acquired through education and experience. Edelenbos (2005) further distinguishes between expert, institutional and local knowledge. Expert knowledge is based on scientific models and rigorous methods. Institutional knowledge refers to the strategic use of knowledge according to administrative and governmental practices. Local knowledge, for example, volunteers' information is grounded in experiences, or related to the volunteers' context or location. Unless the combination of different types of knowledge leads to management actions to reduce local hazards, exposure or vulnerability, it rarely contributes to effective mitigation (Holcombe et al., 2013).

This research addressed the need for developing data collection and data evaluation procedures for supporting technicians on the inspection of hydraulic structures with the involvement of volunteers. Frequent inspections of hydraulic structures are important for proactive risk management. Collaborating with volunteers becomes important to increase the frequency and spatial coverage of inspection activities, especially when hydraulic structures are dispersed and resources to carry out frequent inspections are limited.

1.4. MOTIVATION AND RESEARCH CONTEXT: THE CHANGES PROJECT

This research was carried out in the framework of the CHANGES project, an acronym that literally stands for Changing Hydro-meteorological Risks as Analyzed by a New Generation of European Scientists[1]. The CHANGES project focused on floods, debris flows and landslides in the mountain areas of four European case studies (**Figure 1.3a**). Those study areas included the case study in the north-eastern Italian Alps where this PhD research was performed. The research was part of the Marie Curie ITN Changing Network funded by the European Community's 7th Framework Programme FP7/2007-2013 under Grant Agreement No. 30 263953 with a total duration of three years, from January 2011 to December 2014. The research activities were developed in close collaboration between the National Research Institute of Padova (CNR-IRPI, Padova) and the Water Management Department of the Technical University of Technology (TUDelft). In this context, this PhD thesis examined the use of volunteers' infor-

[1] `http://www.changes-itn.eu/`

1

mation in support of proactive inspection of hydraulic structures such as check dams which are key components in the system of protection works against debris flows. This research contributed to the study of proactive risk management strategies in mountain catchments (WP4 in Figure 1.3b).

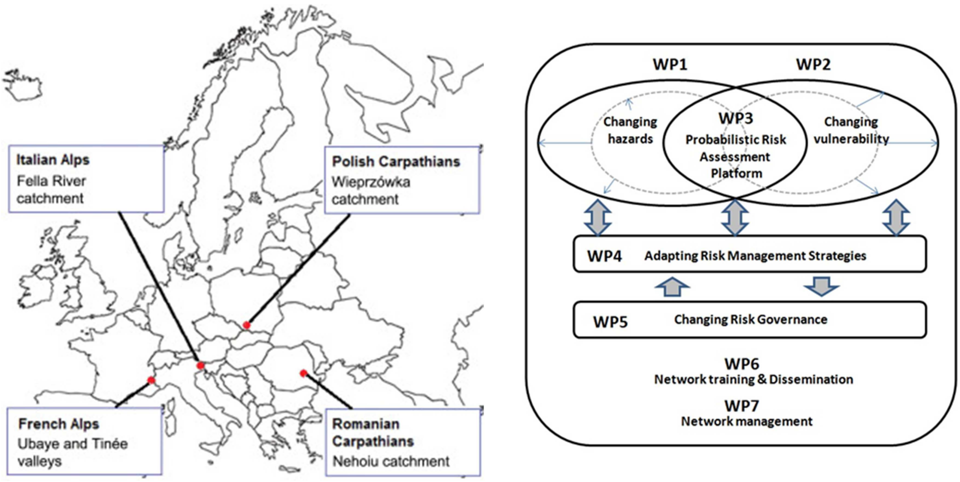

Figure 1.3: a) Left: Case study sites of the CHANGES project (Source: Prenger-Berninghoff et al., 2014, p.3262) and b) Right: Work Package organization and methodological framework of the CHANGES Project (Source: `http://www.changes-itn.eu/`)

1.5. RESEARCH OBJECTIVES AND RESEARCH APPROACH

As described before, the use of volunteers' information can support proactive management approaches. However, volunteers' information has limitations with respect to data quality that poses challenges for data evaluation and interpretation. Hence, the overall aim of this research is to *"develop a methodology applicable in day-to-day risk management to use volunteers' information to support proactive inspection of hydraulic structures"*.

To do so, the specific objectives of this research are to:

i) identify requirements for citizen science approaches based on existing literature and the specific context of the study area;

ii) develop a data collection approach that can be performed by volunteers considering data quality requirements of technicians;

iii) develop a methodology to evaluate first level inspections in support of decisions about the functional status of hydraulic structures;

iv) design a Web-GIS decision support framework to assist technicians in evaluating inspection reports of hydraulic structures.

This research has both scientific and societal significance. Scientifically, it contributes to understanding data requirements, evaluation procedures and decision support requirements in order to include volunteers' information into risk management practices. The societal contribution concerns with the development of a methodology that can be applicable in day-to-day risk management to promote collaborative efforts for proactive inspections and maintenance.

In order to fulfil the objectives above, the research methods comprised a literature study of citizen science in water resources management. A conceptual framework was proposed for getting an overview from the literature about the general considerations and specific requirements in the study area, which is located in the north-eastern Italian Alps of Friuli Venezia Giulia (FVG). Thereby, the insights from the literature were complemented by empirical observations obtained from field visits and meetings in the context of stakeholder activities of the CHANGES project. In the Fella basin, there is a strong tradition of volunteers' involvement. Structural measures are in place and proactive inspection of such structures has high priority for both emergency preparedness and risk prevention organizations at regional and local level.

A data collection approach for first-level or prescreening inspections was developed in collaboration with technicians-in-charge. The data collection approach comprised inspection forms and a training session based on existent procedures in the FVG region and neighbouring regions. A data collection exercise was carried out in a municipality of the Fella basin with participation of volunteers and technicians. The main interest with this research activity was to identify data quality and evaluation requirements for the use of volunteers' information. The participation of technicians and volunteers since early stages enabled a better understanding of the actual context of implementation of this research in day-to-day risk management practices.

On one side, the technicians group consisted of regular inspectors and technicians-in-charge for the inspection of hydraulic structures in the study area. Technicians-in-charge were from both preventive and emergency management organizations. On the other side, the volunteers group mainly consisted of citizen volunteer groups already enrolled by the Civil Protection in the municipalities of the study area. Participant volunteers attended the invitation of Civil Protection to collaborate with our research activities. Furthermore, students from the University of Trieste were invited through university colleagues to widen the volunteer groups.

A decision support method was proposed to systematically evaluate reports of first-level inspections that can be carried out either by technicians or skilled volunteers. The method was transformed into a Web-GIS prototype application as a proof of concept to evaluate inspection reports. Finally, the decision support method and prototype application was introduced to technicians during a testing workshop in the study area. The workshop included a second data collection exercise to collect inspection reports and to test the decision support method. Technicians involved in previous research activities but also new participant technicians attended the workshop. The main interest here was to get feedback about the usefulness of the methods for decision-making and related considerations for further research.

1.6. THESIS STRUCTURE/OUTLINE

The thesis outline is divided into six chapters (see **Figure 1.4**). Chapter 1 contains a brief explanation of the relevance and background of this research. In Chapter 2, we developed the conceptual framework to review the requirements and design considerations of citizen science approaches. In Chapter 3, we developed a data collection approach to understand the quality issues of volunteers' information in the inspection of hydraulic structures. In Chapter 4, we designed and tested a decision support methodology to evaluate first level inspections that can be carried out either by skilled volunteers or technicians. Chapter 5 contains the web-GIS framework we proposed to support managing organizations on the evaluation of first level inspection reports. Chapter 6 brings all previous chapters together into the synthesis and recommendations of this research.

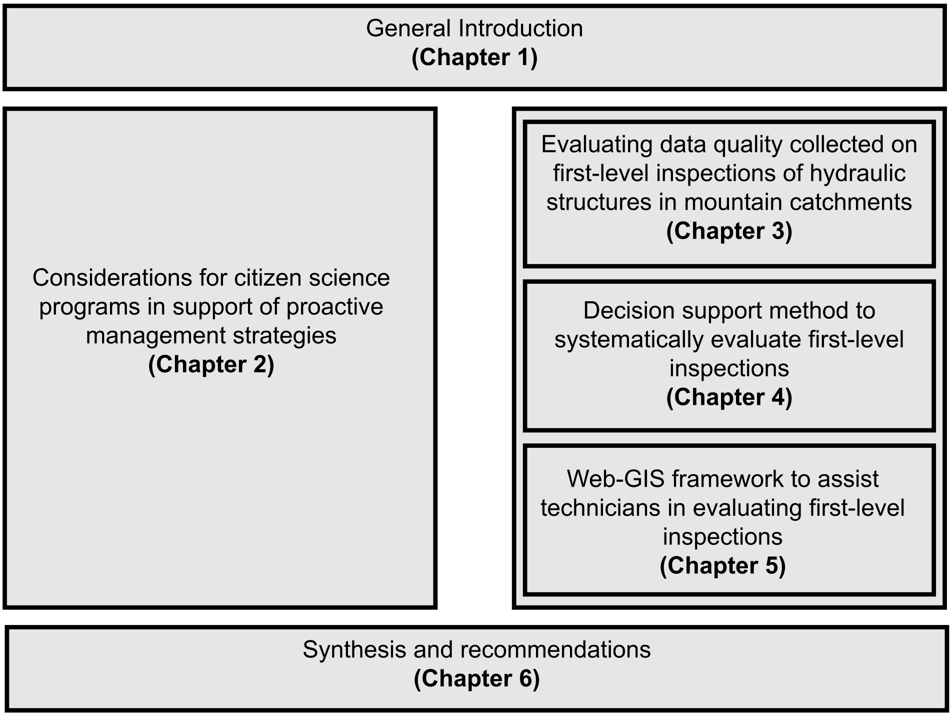

Figure 1.4: Thesis structure

2

CONSIDERATIONS FOR CITIZEN SCIENCE PROGRAMS IN SUPPORT OF PROACTIVE MANAGEMENT STRATEGIES

I can do things you cannot,
you can do things I cannot;
together we can do great things.

Mother Teresa

The study area description of this chapter (Section 2.4) is partially based on: Aye et al. (2016):

Aye, Z. C., Sprague, T., Cortes Arevalo, V. J., Prenger-Berninghoff, K., Jaboyedoff, M., & Derron, M. H. (2016). A collaborative (web-GIS) framework based on observations of three case studies in Europe for risk management of hydro-meteorological hazards.*International Journal of Disaster Risk Reduction*, 15(March), 10–23. http://doi.org/10.1016/j.ijdrr.2015.12.001

2.1. INTRODUCTION

Risk management of hydro-meteorological hazards is faced by ever more limiting resources while the need to better prepare and mitigate increases due to changing environments. Policy guidelines deriving from European and worldwide directives (EC, 2007; UN, 2005) have required active involvement of local communities in support of proactive management strategies. Policy guidelines have also emphasized on the need of combining structural (e.g. engineering works) and non-structural mitigation measures (e.g. organizational measures). Proactive risk management should include efforts for monitoring and evaluating the effects of implemented measures towards adaptive management approaches (Pahl-Wostl, 2008; Simonovic, 2012).

Citizen science programs represent one way of actively engaging local communities such as volunteer groups in collecting relevant data for risk management organizations. In this research, we particularly refer to citizen science to distinguish the involvement of volunteers in data collection activities that require training to support management needs (Devictor et al., 2010). Both scientists and authorities are increasingly recognizing the potential contribution of volunteer knowledge into management practices (Rinaudo and Garin, 2005). Volunteers' knowledge can be tacit, implicit or explicit according to the extent to which knowledge is conscious, articulated, formalized and accessible to others (Raymond et al., 2010). Collected information can be embedded into the experiences and volunteers' practices (Shirk et al., 2012). Rossiter et al. (2015) distinguish the following information potentially provided by volunteers: tacit and traditional knowledge, protocol-guided information, geospatial data, physical measurements, observations made by volunteers according to the opportunity (e.g. videos, photos, etc).

In risk management of hydro-meteorological hazards, examples of volunteers' involvement vary from training volunteer emergency responders to more supportive roles for mitigation strategies. The active volunteers' involvement in data collection may encourage their awareness and willingness to take actions in support of proactive risk management strategies (Lara et al., 2010). Examples of active involvement often respond to a volunteering tradition that in some cases is also recognized and promoted by the administrative and legal context of implementation (Waugh Jr. and Streib, 2006). In addition, the geographical and socio-economical setting of implementation may influence such volunteering traditions. For example, the different land use and population density between urban and rural areas may affect volunteers' participation, their interaction and motivations (Flint and Stevenson, 2009). In risk management, volunteers' involvement relies on the willingness of volunteers to participate, available organizational resources and importance that authorities place on the phases of the disaster management cycle: mitigation, preparedness, response and recovery (Scolobig et al., 2015; Wehn et al., 2015). Changing management approaches are increasingly recognizing the volunteers' role beyond reactive or emergency phases for enhancing the adaptive capacity of communities to deal with future disasters (Enders, 2001).

In water monitoring for management, examples of well-recognized projects exist particularly for data gathering of ecological and water quality variables (Conrad and Hilchey, 2011). Water monitoring projects are mostly running at large scale (e.g. national) in developed countries, such as the Water Alliance (Riverkeeper, Lakekeeper, Baykeeper, and Coastkeeper programmes) and Creek watch in USA, Coral watch in Australia (Marshall et al., 2012), OpenAir laboratories in UK (Starkey and Parkin, 2015), among other projects in Europe (Liu et al., 2014). This geographic bias can be related to the dissemination efforts of well-recognized citizen science projects as compared to more local or regional projects following similar principles under different denomination.

Efforts to use volunteers' information raises questions on how to effectively achieve that goal in support of proactive actions for the management of water resources and hydro-meteorological hazards (Wehn et al., 2015). Despites the potential advantages of volunteers' involvement, there is a need to better understand the limitations of their information. Moreover, citizen science projects should aim at long-term volunteers' engagement and effective communication and coordination between the relevant actors (Scolobig et al., 2015).

This chapter gives a literature review and links to the actual situation in the study area. Section 2.2 introduces the conceptual framework guiding the literature review. Thereby, Section 2.3 highlights the general considerations and design requirements for citizen science programs. Section 2.4 gives an overview on the need for proactive management strategies in the Fella basin. This is a mountain basin in the north-eastern Italian Alps, which is located in the Friuli Venezia Giulia region (FVG). The section also lists in-practice examples of volunteers' information in the study area, which were derived from discussions with stakeholders and researchers in activities of the CHANGES[1] project (**Appendix A**). Section 2.5 concludes this chapter by summarizing the needs identified in the study area to introduce the application of this PhD work.

[1]Changing Hydro-meteorological Risks as Analyzed by a New Generation of European Scientists, (`http://www.changes-itn.eu/`)

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2.2. CONCEPTUAL FRAMEWORK

Some frameworks already exist for identifying appropriate mechanisms and tools for engaging, collecting or using volunteers' information into management organizations. For example, Raymond et al. (2010) proposed a framework for integrating volunteer and scientific knowledge starting from the identification of the management problem. That framework follows steps towards knowledge integration through a series of questions to assist the identification, engagement and evaluation of different knowledge types (e.g. traditional, personal experience and professional). Liu et al. (2014) revealed five sequential aspects for designing and implementing citizens science approaches. Those are the identification of what volunteers want and can offer; exploration of the additional value that participating to the citizen science project can provide to volunteers; engaging and supporting participants for collecting data, and providing tools to access data collected in a way that is easily understood and useful for potential users.

Referring to Fung (2006), Wehn et al. (2015) introduced a framework for analysing, from a governance perspective, the impact of citizen science approaches in decision-making. The framework comprises three dimensions: participants, authority and power; communication; and decision mode. Wehn et al. (2015) also specified that volunteers' information can be collected in an explicit or implicit way, according to the awareness of participants on their contribution to the decision-making process. Moreover, technological developments in web-based and geospatial tools have facilitated the use of information and communication technologies (ICT) in citizen science. Tang and Liu (2015) proposed a framework based on the identification of participant groups, objectives of data collection and actual contribution of participants to citizen science approaches that are mediated by ICT tools.

The conceptual framework of this study (questions guiding the literature review) follows a decision-focused approach to use volunteers' information (Raymond et al., 2010). Similar to Liu et al. (2014), we used a step-wise approach. However, we distinguish volunteers' motivations from organizational requirements. The questions in **Figure 2.1** (conceptual framework) were used to identify: citizen science approaches, motivations of volunteers' groups, organizational requirements and specific data requirements as well as the tools supporting the use of volunteers' information. Thereby, we highlight strengths and weakness of volunteers' information for water management and the use of ICT tools for data collection and data management.

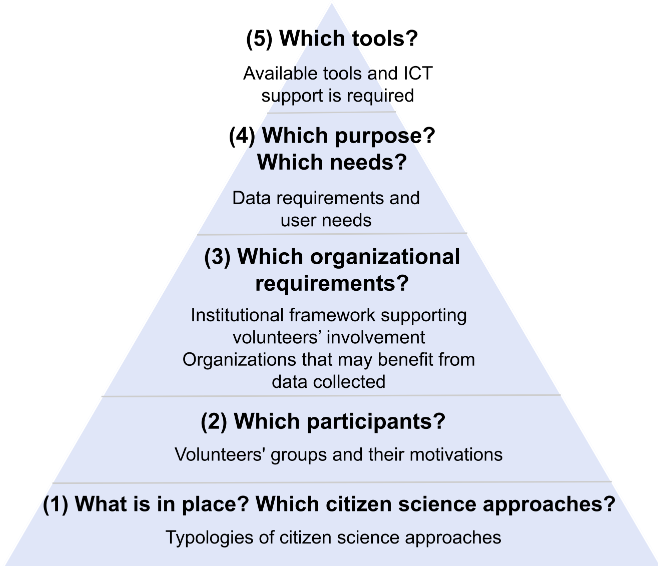

Figure 2.1: Framework for designing citizen-science projects in the context of this research

2

2.3. General considerations for designing citizen science projects

The following sub-sections comprise the steps of the conceptual framework (**Figure 2.1**). Section 2.3.1 highlights the different typologies and definitions related with citizen science approaches. Section 2.3.2 highlights motivations of volunteers' groups. Section 2.3.3 highlights general organizational requirements. Section 2.3.4 addresses specific data-collection requirements for managing water resources and related hydro-meteorological hazards. Finally, Section 2.3.5 acknowledges the potential usefulness of designing ICT tools to assist those requirements.

2.3.1. Background on citizen science approaches

In this research, we refer to citizen science by the involvement of volunteers mainly in data-collection activities. Their involvement implies simplified procedures and training according to management needs (Devictor et al., 2010). Beyond this consideration, scientific literature relate the involvement of volunteers and general public with a variety of terms that are often related with citizen science without strict distinction (Ferster and Coops, 2013). **Table 2.1** lists the most common typologies, which can be grouped into the following categories according to differences in the engagement level and the skills of participants.

2

Table 2.1: Typologies of citizen science projects according to categories proposed by Ferster and Coops (2013) and Haklay (2013)

Typology	Description	Categories	Reference
Collaborative science	Local organizations are engaged to collaborate with management organizations. According to goals of collaboration, involvement can take different forms including direct input in decision-making processes	Collaborative science	(Bäckstrand, 2003; Haklay, 2013)
Community-based monitoring	A variety of stakeholders collaborate to monitor, track and respond to issues of common community concern	Participatory science or citizen science	(Whitelaw et al., 2003)
Citizen science	Active non-scientist engagement mainly in data collection activities, from which participants may also benefit either intrinsically or extrinsically		(Buytaert et al., 2014; Devictor et al., 2010)
Citizen observatories	Citizens' participation in monitoring the environment they live in, with the help of mobile sensors, qualitative or quantitative observations	Distributed intelligence or basic interpreters	(Liu et al., 2014)
Volunteered Geographic Information	Geographic data provided voluntarily by participants for updating geographic databases		(Goodchild, 2007; Haklay, 2013; Seeger, 2008)
Participatory Sensing	Remote sensing where citizens participate by operating sensors	Citizens as sensors or crowdsourcing	(Burke et al., 2006)
Crowdsourcing	Open monitoring or data processing tasks that are entirely mediated by ICT tools. Tasks are outsourced to a large number of participants with different knowledge and demographic characteristics		(Wiggins et al., 2011; Yang and Lee, 2013)
Opportunistic Sensing	Remote sensing using devices that are not necessarily designed to collect data		Lane et al. (2006)
Crowd science	Open participation to a large number of potential contributors. and open sharing of data collected		Franzoni and Sauermann (2014)

Referring to the volunteers' awareness of their contribution for decision-making, Wehn et al. (2015) further differentiated implicit from explicit data collection approaches. Implicit data collection refers to data mining from, for example, social media. Explicit data collection refers to intended and volunteer information that is collected according to the specific purpose. However, some typologies in **Table 2.1** may comprise both explicit and implicit data collection methods. According to the context of implementation, this could be the case of citizen observatories, participatory sensing, crowdsourcing and opportunistic sensing.

The multiple typologies and categories related to citizen science denote the plurality of views and working definitions. Citizen science collectively describes a range of diverse approaches dealing, but not limited to volunteers' participation in monitoring activities. The volunteer term refers to the variety of participants that can be engaged such as, citizens, students and other participants that may not be directly related to a study area. The participation term refers to the different levels of volunteers' involvement in support of data collection, analysis and interpretation. However, volunteers may also be involved in the definition of monitoring variables which can be initiated from scientific and management requirements; and also in response to more local concerns (Fernandez-Gimenez et al., 2008). In this research, we particularly refer to citizen science in data collection activities that require training to support management needs. Scientists and/or management agencies establish those campaigns in response to local concerns about the management of water resources or hydro-meteorological risks, without necessarily involving volunteers in analyzing the data collected.

2.3.2. Volunteers' groups and their motivations for engagement

Volunteers can be categorized according to the target groups to be engaged such as citizens, students, regular volunteers and skilled volunteers. Volunteers can also be categorized according to their preliminary knowledge and skills into neophytes, interested amateurs and skilled amateurs. According to (Coleman et al., 2009, p5.), neophyte is *"someone with no formal background in a subject, but possessing the interest, time, and willingness to offer an opinion on a subject"*. Interested amateur is *"someone who has 'discovered' their interest in a subject,(...), is experimenting with its application, and is gaining experience in appreciating the subject"*. Expert amateur is *"someone who may know a great deal about a subject, practices it passionately on occasion, but still does not rely on it for living"*.

Public engagement is usually, but not necessarily, a target of citizen science projects (Riesch and Potter, 2014). The citizen term is often referring to the involvement of non-scientists with some level of stewardship in the study area (Ferster and Coops, 2013). Volunteers can also be people interested in participating without necessarily living in the study area. According to Cohn (2008), volunteers' involvement may be driven by personal interest or community involvement. However, it can also be facilitated by a management organization (Overdevest et al., 2004). Students' involvement is generally facilitated by schools or universities and their involvement is given at different levels as participants or trainers (Savan et al., 2003).

Batson et al. (2002) distinguished four motivational categories for volunteers' involvement. Those are personal interests to increase own welfare; collectivism to increase communities' welfare; altruism to increase others' welfare; and principalism to follow some moral principle. Rotman et al. (2012) suggested that the volunteers' decision to be engaged is also affected by the trust in relevant organizations and mutual apprehension of motivational factors. This can be, for example, referring to the relationship between and with other volunteers; facilitating organizations of volunteers' involvement; and other organizations that may benefit from collected data. Moreover, Rotman et al. (2012) highlighted that the motivational factors may change over time. Then, initial involvement is generally driven by personal interests such as improvement of technical skills, knowledge and experience gained through volunteer contributions. Active collaboration between volunteers and management organizations is further facilitated by adequate communication between relevant actors, and by acknowledging volunteers' role. Finally, continued involvement can be facilitated by attribution of volunteers' information and shared improvement of a common resource.

In addition, recent research has also investigated main drivers and barriers for volunteers' participation in collecting and sharing weather data via web-platforms. Gharesifard and Wehn (2016) analyzed behavioral determinants such as attitudes, social pressures and perceptions about influencing factors that encourage or impede participation in citizen science projects via web-platforms. **Table 2.2** lists their findings from qualitative empirical research in case studies in the Netherlands (Delftland), United Kingdom (Doncaster) and Italy (Vicenza):

Riesch and Potter (2014) argued that citizen science projects should promote win-win situations about the objectives and expected outcomes from volunteers' engagement. Not all objectives of volunteers' engagement directly influence management aspects. According to Tulloch et al. (2013), the most representative and contributing objectives are certainly focused on knowledge-gain to improve or develop monitoring approaches. However, education and awareness objectives are also important to increase participants' self-awareness about the impacts of monitored aspects. Other objectives with indirect influence in management activities are to explore and uncover unexpected environmental events; to address volunteers' interests through recreational objectives; and to support research to understand volunteers' motivations to participate and take proac-

Table 2.2: Motivational factors to share personally-collected weather data (Source: List of findings referred in Gharesifard and Wehn, 2016, Figure 3, p.6)

Attitudes: Expectations about the outcomes	Tangible personal outcomes	• Usefulness of the collected data for personal purposes; • Privacy and security issues;
	Intangible personal outcomes	• Belonging to a community of friends with share interests/ visions; • Learning from each other; • Recognition; • Interest in the weather;
	Social outcomes	• Risk prevention applications; • Creating knowledge about the weather;
	Interpersonal trust	• Competence and reliability; • Intentions;
Social Pressure: Others' expectations and their (dis)approval	(Non)governmental organizations	• Variety of weather related commercial actors and inter-governmental organizations;
	Scientific community	• Scientists, educational institutes;
	Weather enthusiast community	• Weather enthusiasts individuals, weather networks and related hobby-club;
	Other society members'	• Citizen science (Big data) projects; • (Anti) Environmentalist community; • Family and peers;
	Moral norms and altruism	• Risk prevention; • Benefit for society;
Perceived behavioral control: Perceptions about influencing factors	Knowledge self-efficacy	• Meteorology Science; • Data collection methods;
	Technical skills	• Setting up, maintenance and IT skills;
	Resource control	• Equipment, internet connection, time and usability of web-platforms apps;
	Opportunities	• Incentives provided; • Gain and exchanging knowledge;

tive actions. We conclude from this section that trade-offs between motivations of volunteers, scientific and management goals should be taken into account to ensure (long-term) commitment of volunteers. These trade-offs imply the mutual apprehension of motivational and orgainizational aspects during the planning, implementation and follow up of citizen science programs. Motivations may change in time according to the trust and effective communication between relevant actors.

2.3.3. ORGANIZATIONAL REQUIREMENTS OF CITIZEN SCIENCE PROJECTS

Citizen science can be categorized into top-down, bottom-up, and collaborative approaches based on the organizations initiating and funding the citizen science project (Bonney et al., 2014; Conrad and Hilchey, 2011; Cooper et al., 2006). The top-down approach initiates participants' engagement driven by scientist or institutional organizations. However, the continuous engagement of participants is an important challenge for long-term implementations. The bottom-up approach initiates from volunteer organizations. Long-term implementations can be threaten by lack of funding and lack of technical and organizational support from scientists and authorities. Therefore, collaborative approaches emerge from trade-offs between volunteers and management organizations to agree on project goals (Fraser et al., 2006). To that end, project design requires understanding the organizational context of project implementation while acknowledging the importance of volunteers' engagement.

Organizational requirements should account for the legal framework supporting volunteers' involvement as well as the available resources in terms of staff and funding. Resources also include existing protocols for data-collection and training, available tools for collecting, managing using volunteers' information and organizational commitment to support citizen science involvement. Previous experiences and continued collaboration between the organizations involved may facilitate the alignment of organizational requirements and pooling of resources in support of citizen science (Gouveia et al., 2004).

Pocock et al. (2014) argued that the suitability of citizen science increases according to the clarity of monitoring goals (aim or research question). The monitoring goals drive decisions about data-collection protocols and sampling scale. Sampling can be ad-hoc or at a fixed site, repeated or sporadic, at a specific temporal or spatial resolution, etc. Protocols should generally meet ease, safety, and reliability criteria (Rossiter et al., 2015). Ease refers to the limited training that volunteers can receive according to the monitoring goals, engagement period and number of participants. Safety refers to the consideration of accessibility and safety conditions to carry out the monitoring activities. Reliability requires that volunteers follow a data-collection protocol including meta-data that, in turn, is required for data interpretation and quality control of monitoring procedures.

Implementation and follow up of citizen science programs also require sufficient resources for long-term implementations. If resources are not sufficient, collaboration with other institutions should be initiated as early as possible to promote pooling of resources (Whitelaw et al., 2003). Accounting for mutual benefits for scientists, authorities and volunteers can increase the long-term feasibility of the project (Shirk et al., 2012). **Table 2.3** presents an overview of organizational requirements of citizen science projects along planning, implementation and follow-up stages to be considered into the design process.

2

Table 2.3: General considerations for the design of citizen science projects according to the project stage. (Source: Summary of stages and modules of a participatory monitoring project Pilz et al., 2006, Table 1, p. 6)

Planning	Implementation	Follow-up
• Characterizing the context of project implementation and relevant organizations; • Determining monitoring goals (aim or research question); • Documenting project plan; • Determining data to be collected, scale of sampling and complexity of protocols; • Selecting participant groups; • Understanding motivations, concerns and anticipated benefits; • Obtaining and allocating funds, resources, and support; • Involving participants in project design; • Evaluating the usefulness and goals of collaboration; • Making systematic and collaborative decisions about project planning	• Design data collection protocols and procedures; • Providing participants with requisite training; • Ensuring safety of participants; • Planning field activities; • Ensuring quality and quality evaluation of collected data; • Making arrangement for handling, storing and using data	• Arranging data analysis and interpretation; • Periodic review and interpretation of project outcomes; • Reporting project outcomes; • Evaluating and improving the project; • Ensuring the project is rewarded and widely appreciated

2.3.4. DATA-COLLECTION REQUIREMENTS FOR CITIZEN SCIENCE PROJECTS

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Data-collection aims at gathering systematic observations within a given temporal and/or geographical scale (Danielsen et al., 2009). However, volunteers' information can also be referred to volunteers skills in support of tasks such as problem-solving or data-processing (Wiggins et al., 2011). Concerns about data quality should acknowledge limitations in the data-collection approach. Moreover, in this research we particularly refer to explicit data-collection (Wehn et al., 2015). Such approaches should account for requirements before, during and after the implementation of monitoring campaigns (e.g. training, data filtering and validation).

MONITORING VARIABLES, TASKS AND DATA TYPE

Technological advancements in remote sensing techniques, mobile personal computing and the widespread use of internet have fostered important opportunities for citizen science; for example, in developing low-cost sensors and alternative data sets for validation (Ferster and Coops, 2013). Thereby, use of volunteers' observations is being promoted to better understand the impacts of water resources management and related hydro-meteorological hazards (Stem et al., 2005). Specific challenges for measurement and observation of monitoring variables include (Buytaert et al., 2014):

- variety of uncontrolled boundary conditions and sensitiveness of observations;
- intrinsic variability over time and space;
- safety and accessibility conditions to carry out observations;
- frequent sampling and long-term measurement requirements;
- complexity of volunteers' training and engagement level;
- different approach for data analysis from a larger volume of potentially lower quality data;
- integration with official monitoring networks which have historically shifted from human to automatic observations to support organizational requirements;

Examples of well-recognized projects exist particularly for data gathering of ecological and water quality variables (Conrad and Hilchey, 2011). **Table 2.4** highlights strengths and weakness of commonly measured variables in hydrology and water resources management for the use of volunteers' information (Buytaert et al., 2014; Starkey and Parkin, 2015). In addition, we list some example applications of citizen science per monitoring variable. The overview of applications does not pretend to be exhaustive, but to give some peer-reviewed examples.

Table 2.4: Example of monitoring variables in water resources management. Strengths and weakness for the use of volunteers' information. (Source: Extended version of Buytaert et al. (2014, Table 2, p.7) with additional variables referred in Starkey and Parkin (2015, p10-12))

Variables	Strengths	Weakness	Example applications
Precipitation and weather data	• Variety of measurement techniques, low low-cost devices and portable devices; • Advancements on combined analysis of different data sources and remote sensing techniques;	• Long-term measurements; • Strong influence of local environmental conditions; • Proper installation of measuring devices; • Long-term data collection and quality control;	(SnowTweets: Bonnan-White and Bielecke, 2014) (MPING: Elmore et al., 2014) (CrowdHidrology: Lowry and Fienen, 2013) (SHAVE: Ortega et al., 2009) (CoCoRaHS: Reges et al., 2008) (Review in crowdsourcing: Muller et al., 2015)
Streamflow	• Cheap and robust water level measurements that allow for data calibration; • Advancements in remote sensing techniques for stage and flow measurements;	• Influence of local environmental conditions; • Proper installation and maintenance of devices; • Long-term datasets for data inference;	(Wet/Dry mapping: Turner and Richter, 2011) (Remote sensing flood: Schnebele and Cervone, 2013)
Water quality	• Cheap measurement and analysis equipment; • Automatic measurement of proxy data; • Largest experience with volunteers' data;	• Influence of sampling strategy; • Some parameters remain costly, poorly documented and difficult to analyze;	(Ecological stream conditions: Engel and Reese, 2002) (Waterwatch: Nicholson et al., 2002) (Coliforms monitoring: Au et al., 2000)

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Table 2.4 Continued:

Variables	Strengths	Weakness	Example applications
Soil moisture	• Advancements in remote sensing techniques and automatic measurements;	• Strong influence of other soil properties; • Spatial variability;	(Sensing with boots and trousers: Rinderer et al., 2012)
Vegetation dynamics	• Diverse technologies and remote identification can be applied;	• Systematic processing depends of the local vegetation patterns;	(Stream visual assessment protocol: Bjorkland et al., 2001; Yetman, 2002) (Stream monitoring: Fore et al., 2001) (Leafsnap: Kumar et al., 2012)
Hydraulic structures status	• Hydraulic structures status Datasets of citizen complaints can be exploited;	• Accessibility and complexity of monitoring protocols; • Rapidly changing (morphologically active) river systems;	(Trash delivery to culverts: Wallerstein and Arthur, 2012) (Automatic classification of municipal call data: Rodríguez et al., 2012; ten Veldhuis et al., 2011)
Human activities impacting water resources	Potential monitoring variables relevant for water management • Waste release; • Deforestation; • Farming and irrigation; • Water use; • Land use change	• Heavily modified and used for a variety of activities;	(CreekWatch: Kim et al., 2011) (Collaborative mapping damage: Kerle and Hoffman, 2013) (Soil and land cover mapping: Comber et al., 2013; Rossiter et al., 2015) (Space4Agri: Kliment et al., 2014)

QUALITY: DATA STANDARDIZATION, SOURCES OF ERROR AND BIAS

According to Gouveia et al. (2004), volunteers tasks comprise identifying the occurrence of an event or impact, reporting observations via rating scales, sampling and measuring physical characteristics via sensors or portable devices, surveying and mapping variables of interest, and using specific human abilities. Data types include opinions, qualitative and factual information based on human senses (vision, odor, hearing and taste) as well as quantitative estimations. In addition, the geospatial component of volunteers' information can be either a primary aspect as a mapping entity or a secondary aspect in the interpretation of a geographic reference (Gouveia et al., 2004).

Standardization bodies of geospatial information such as the Open Geospatial Consortium (OGC) define indicators for geospatial quality through the positional accuracy of the geographic entry (Goodchild and Li, 2012) and available metadata (Devillers et al., 2002). Devillers et al. (2005, p. 210) gave an example of quality indicators for geospatial data. However, volunteers' collected datasets do not necessary follow a unique standard. Data quality is often defined according to extrinsic, pragmatic, and intrinsic factors (**Figure 2.2**). Perceived usefulness of volunteers' information is from the perspective of data users. Their needs influence choices in data formats, referring standards and minimum acceptable quality (Sheppard and Terveen, 2011).

Extrinsic factors are related to the heterogeneity of expertise and commitment of volunteers (Bordogna et al., 2014a). Pragmatic factors refer to the "fitness of data for an intended purpose" (Wiggins et al., 2011). Those are, for example, related to the data definition, coverage, origin, acceptable precision, official recognition and facilities for data accesibility (cited in Gervais et al. (2009, p. 102) referring to Bédard (1995)). Intrinsic quality (EPA, 1997, p19-20) is related to its expected value or conformity to the reality (accuracy); repeatability of values in presence of same contextual conditions (precision); lack of data comparability, representativeness and completeness.

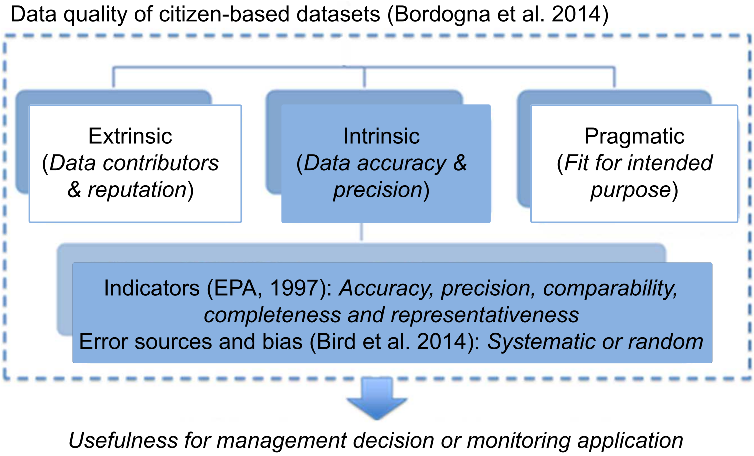

Figure 2.2: Quality of citizen-based datasets

Accuracy and precision comprise aspects such as the granularity of numerical scales and ordinal scales. The latter is often referred with a set of labels or linguistic ratings (Bordogna et al., 2014a). However, data quality also depends on the ability and expertise of the data contributor. In addition, comparability of data collected is generally possible by following protocols for collecting data in the same way. Representativeness in time or space depends of project goals, volunteers' commitment and monitoring procedure. Examples of monitoring procedures are given by the use of sensors or visual inspections, manual or automatic observations (Bordogna et al., 2014b). Pocock et al. (2014) relate completeness with the implicit effort in filling the monitoring protocols. The sampling scheme may also account for pre-selected sites where inspections are carried out during relatively long visits on a repeated basis. In other cases, volunteers can select their own sites without requiring repeated visits or staying long time at the site.

For volunteers' datasets (Bird et al., 2014), data inferences at specific location or time span often describe aspects related to a monitoring variable or condition that is relevant for water resources management and related hydro-meteorological hazards **Table 2.4**. That is for example by identifying conditions such as the only-presence, presence or absence, ratings about presence of monitoring variables and some quantity measurement. In addition, sources of error and variations can be systematic or random. Systematic errors may occur when despite of using the same survey protocol, data collected is similar but not conform to the 'reality'. Random errors refer to variations not explicitly included on how the measurement was performed at given location or time. Variations (bias) can be either systematic or random according to the consistent or imperfect variation, for example, under or overestimation of collected values. To understand influencing sources of error and potential bias, quality control mechanisms should consider contextual conditions to deduce indicators about reliability, credibility and performance of volunteers (Bordogna et al., 2014a; Tulloch et al., 2013).

QUALITY CONTROL MECHANISMS AND DATA ANALYSIS METHODS

For geospatial data, Goodchild and Li (2012) proposed quality control mechanisms based on crowdsourcing, social and geographic approaches. Crowdsourcing approach refers to the ability of the crowd to converge on the 'reality' (e.g. Xintong et al., 2014). The social approach tracks volunteer contributions to calculate metrics of performance, identify contributions from spammers and cheats (e.g. Foody, 2014). The geographic approach defines semantic rules governing what can occur on a given location (e.g. Vandecasteele and Devillers, 2013). For volunteers' collected datasets, inferences are generally made from comparisons with data collected by experts or alternative data sources (e.g. remote sensing, sensors, models) to understand variations and limitations (Fowler et al., 2013). **Table 2.5** summarizes some quality control mechanisms at multiple stages of the data-collection process, for example, protocol design, training, validation, filtering procedures and data analysis. Generally the earlier control mechanisms are applied the better (Sheppard and Terveen, 2011).

Table 2.5: Overview of control mechanisms at different data collection stages (Source: synthesis prepared from Gouveia et al., 2004; Sheppard and Terveen, 2011; Wiggins et al., 2011)
Note: B, D and A denote before, during and after the data collection stage respectively

Stage	Control Mechanism	B	D	A	Comments/Recommendations
Protocol design	Uniform protocol and/or calibrated equipment	X			Follow standard procedures
	Repeated sample tasks		X		Collect data by multiple participants for the same task
	Data documentation		X	X	Collect photo record and comments
Training	Participants' training	X			Set as pre-requisite for participation
	Doing pre/post tests		X		Reinforce participants' training
	Having a coordinator per participants' group		X		
	Providing feedback to participants			X	
Validation	Comparison with training datasets or resample of known areas	X	X		Identify potential sources of error or bias
	Automatic submission and data synchronization		X		Limit data entry errors
	Complementary data from in-built sensors		X		Compare with available datasets
	Providing instant feedback		X		Use data validation algorithms during submission
	Tracking corrections done to the data		X	X	Support decisions about data validation
	Tracking data validation status		X	X	Provide additional options for data filtering
	Flagging of potential outliers or erroneous data			X	Identify contributions from spammers or misleading data
	Computing data quality metrics			X	Give overview of data quality indicators for data contributors and coordinators
	Data triangulation			X	Corroborate with data from other sources
Data filtering	Classification			X	Highlight features from datasets

2

Table 2.5 Continued:
Note: B, D and A denote before, during and after the data collection stage respectively

Stage	Control Mechanism	B	D	A	Comments/Recommendations
	Clustering			X	Compare different measures of similarity as they may lead to different results
Analysis and interpretation	Easy to understand data analysis reports			X	Support data sharing and feedback to contributors
	Rating of participants' performance			X	Require a record of historical contributions per participant
	Automatic data analysis techniques		X	X	Facilitate instant feedback to participants
	Data standardization			X	Facilitate data inferences according to the analysis requirements (eg. only presence, presence/abscence, etc)
	Data mining			X	Facilitate inferences from large volume of data that is for example gathered at a given time and/or location from variety of sources
	Multi parties review (e.g. data analysts or data contributors)			X	Rely on the ability of multiple parties to validate and correct the errors that a participant might make

Compiled by synthetizing the requirements for quality control provided in Gouveia et al. (2004) and Sheppard and Terveen (2011). We clustered the recommendations according to stages from study design to data interpretation (Wiggins et al., 2011, Table 1, p2)

In addition, the estimation of a 'true' value representing the 'reality' relies on the available validation procedures or alternative datasets to determine true positives against false positives or miss-identifications. Often validity is assessed by mean or standard deviations of available observations or simply by the proportion of accurate results (Bordogna et al., 2014a). However, when enough data is available to detect patterns or trends, more analytical methods and novel approaches can be used (**Table 2.6**). Such analysis can be done, for example, by analysing potential bias according to the expertise level of contributing volunteers; or by looking at changes at time and space of volunteers' collected data (Bird et al., 2014).

Table 2.6: Overview of data analysis methods for citizen-based datasets. Summarized from (Bird et al., 2014, p146-151). Overview includes the methods proposed by Koch et al. (2013) and Bordogna et al. (2014a)

Methods	Strengths	Weakness	Example applications
Linear and additive models	Relate volunteers' collected data with predictors such as location, time and observer	Assume that the observed variable (e.g. presence or absence) follows normal distribution, which is not true in all cases	(Invasive species case study: Crall et al., 2011) (Detection of nocturnally active mammals: Sunde and Jessen, 2013)
Generalized linear models	Extend the previous category beyond normal distributions	Datasets with a large number of zero counts may violate assumptions of alternative distributions (e.g. Poisson or binomial)	
Mixed approach	Clustering of collected data to better fitting of the modelling approach	May induce over parametrization with the clustering procedure	(Land cover identification: Comber et al., 2013)
Hierarchical models	Bayesian approaches could be consider as a type of hierarchical model. Describe relational parameters as function of predictor variables	Requires a specific data collection protocol design to accurately describe the sampling process of data collected	(Complain calls about urban flooding: ten Veldhuis et al., 2011)
Machine learning approaches	Useful to explore the relative importance of large number of predictor variables in explaining volunteers' information	Computationally challenging to quantify the confidence intervals of the machine learning output	(Wild bird species: Caruana et al., 2006)
Linguistic variables & multi-criteria methods	Observed variables are represented with linguistic indicators of distinct granularity	The distinct granularity is still subjective and specific to the pplication	(Glaciers monitoring: Bordogna et al., 2014a)

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Table 2.6 Continued:

Methods	Strengths	Weakness	Example applications
Agent-based modelling	Outputs of agent based modelling can be compared with data collected by volunteers	Difficulties to estimate the norms and rules influencing the volunteers' collected data and accordingly consider them into the agent-based model	(Sentient City: Koch et al., 2013)

2.3.5. TOOLS SUPPORTING CITIZEN-BASED APPROACHES

Data-collection, storing, access and analysis of volunteers' data can be facilitated through information and communication technologies (ICT). ICT tools can also facilitate data exchange and integration with available institutional datasets (Bedrina et al., 2012), for example, through the use of information and decision support systems (Gouveia et al., 2004). However, the variety of potential users have posed challenges for the usage and adoption of ICT tools and related systems. Potential users comprise data contributors, data users and occasional users. Specific requirements for the design of supporting tools should be defined according to the type of citizen science project (Section 2.3.1), level of volunteers' engagement (Section 2.3.2), organizational (Section 2.3.3) and data requirements (Section 2.3.4).

In citizen science, ICT applications can be generally categorized into (Roy et al., 2012): front-end tools for data collection (**Table 2.7**), front-end tools for data visualization (**Table 2.8**) and back-end tools for data management, sharing and data analysis (**Table 2.9**). For selecting the appropriated technologies, developers should consider (Gouveia et al., 2004): lack of familiarity with the technology of potential users, development of easy-to-use tools to manage volunteers' data, and to promote effective collaboration between the variety of actors involved. Thereby, user-centered design approaches are increasingly promoted to better understand user needs (Haklay and Tobón, 2003).

Table 2.7: Examples of front-end tools for data collection (Source: summarized from examples listed on Roy et al., 2012)

Tools	Strengths	Weakness	Opportunities
Websites	• Relatively easy to implement; • Flexible content and widespread access; • Variety of services for data visualization and exploration	• Some participants' groups may have limited access (e.g. older age and lower income participants);	• wider number of participants; • big datasets when technological resources are available
Smart-Phone and mobile applications	• GPS geographic location; • Flexible attachment of photo with tag and geo-location; • Flexible data submission;	• Limited size screen; • Usage is restricted by signal strength, internet coverage and availability of the device; • Require user friendly design and branded application;	• Advancements on open source applications for mobile devices; • Data validation can be based on location of contributors; • Asynchronous or synchronous connection with central database;
In-built or plugin sensor devices	• Automatic data collection when device is synchronized with central-server;	• Data collection is sensible to location (mobile or static sensor) and type of sensor;	• Increasing development of plug-in and low-cost sensors;

Table 2.8: Examples of front-end tools for data visualization (Source: summarized from Bowser et al., 2013; Roy et al., 2012)

Tools	Strengths	Weakness	Opportunities
Real-time visualization	Useful for data comparison and to provide immediate feedback for participants	Very sophisticated visualization can become unstable and distracting for participants	New insights in complex data with customizable and simple visualizations
Mapping tools	Wide and increasing usage through open source projects for data visualization, exploration and aggregation	High resolution and too detailed maps can create high demands on the server-side	Customizable layout, zooming, and download options
Graphs	Useful to identify trends and interpret data	Limited use as stand-alone visualization option	Combined with maps allow easier data interpretation
Serious gaming elements	Elements such as interest in technology, rewards and competitions may benefit volunteers' motivation and engagement	Challenge is to align interests of casual gamers with requirements of citizen science	Tools to engage non-traditional audiences

Table 2.9: Examples of back-end tools for data management. (Source: summarized from Roy et al., 2012)

Tools	Strengths	Weakness	Opportunities
Data management and data sharing	Open access, documented metadata and data management standards may increase usage of volunteers' collected data	Increasing complexity according to requirements for data management (e.g. data accessibility)	Open source solutions with common standards facilitate interoperability
Cyber infrastructures	Centralize efforts may support small running projects	Loss of independence of individual projects and concerns about data sharing	Encouragement of collaborative and coordinated efforts
Virtual communities	Volunteers' participation can be facilitated by social networks (e.g. Facebook, twitter, blogs, etc.)	Dependent on the commitment of the community, few active participants and many silent observers	Interaction within the community can be either project-based or peer to peer
Crowd sourcing tasks	Distributions of tasks, variety of contributions and volunteers	Limited standardization increase complexity for data analysis	Participation is open to all interested

Table 2.9 Continued:

Tools	Strengths	Weakness	Opportunities
Image and sound analysis	Pattern matching algorithms to support data quality evaluation Results from data analysis are innovative for participants	Limiting connectivity and processing capacity according to available resources on the server or client side	Volunteers as collector of samples from which data can be extracted in a systematic way

2.4. THE NEED FOR PROACTIVE MANAGEMENT STRATEGIES IN THE FELLA BASIN

The Fella is a mountain basin comprising the valleys of Canal del Ferro and Val Canale and is a left tributary of the Tagliamento river. The geomorphological features and rainfall patterns make the basin prone to landslides, flash floods and debris flows (Borga et al., 2007; Norbiato et al., 2007). The basin of about 700km^2 is located in the northeastern Italian Alps of FVG bordering with Austria and Slovenia. Administratively the basin overlaps with eight municipalities (**Figure 2.3 Left**): Chiusaforte, Dogna, Malborghetto-Valbruna, Pontebba, Resia, Resiutta and Mogio-Udinese. Tarvisio is the nearest settlement to the study area over 4000 inhabitants. The location is remote and population number is rather low. The area has experienced highest depopulation and decreasing in economic activities. Since the 90's population density has decreased by 10%. However, built areas have increased around 12% (see Malek et al., 2014, p.54). Due to its alpine landscape and strategic location, development in the area is being promoted from regional and national authorities through tourism activities, traffic and energy infrastructure (Vinci, 2014).

Regarding the management of hydro-meteorological hazards, Aye et al. (2016) give an overview of the managing responsibilities. The mayor has the legally defined responsibility to support risk management strategies through emergency plans and restrictions in local land-use plans. At regional level, sectorial planners comprise the Soil Defense Services, Forestry Services, as well as the Geological Service. The interregional level is represented by the Water Basin Authority of the Isonzo, Tagliamento, Livenza, Piave, and Brenta-Bacchiglione. In addition, the Regional Civil Protection coordinates organizations supporting emergency management (e.g. local volunteer organizations and specialized groups such fire brigades, alpine rescue, first aid, etc). Beyond the short-term focus, Civil Protection also supports preventive measures that tend to remain after the recovery phase.

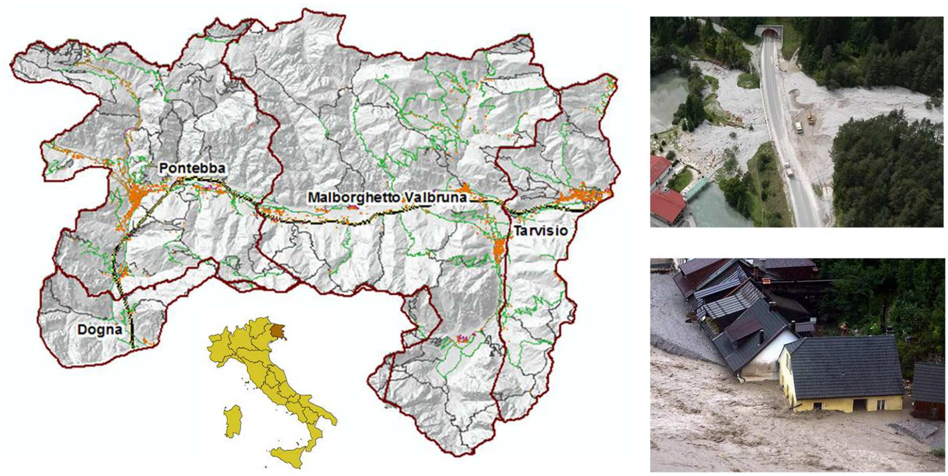

Figure 2.3: (Left) The Fella River Basin Study area; (right) damages caused by the 2003 event in the study area (Source: Ciurean et al., 2014, p2)

The latest severe flood event occurred on 29 August 2003 (**Figure 2.3 Right**) exceeded the 500 years return period of rainfall intensity (Marchi et al., 2009). Such flash flood induced debris flows creating gullies and expanding existing riverbeds (Borga et al., 2007). Tropeano et al. (2004) estimated that during the event a total of 1 million cubic meters of debris and sediments were mobilized in the Val Canale valley. Deposit heights exceeded 2m and caused the interruption of the traffic and railway infrastructure. Severe damages and human casualties mainly occurred in the municipalities of Malborghetto Valbruna and Pontebba. Approximately EUR40 million were spent on restoration works to private and business infrastructure. In the affected areas, Civil Protection also realized several structural measures such as check dams and stream channelization (Prenger-Berninghoff et al., 2014).

Recent analysis of future hazardous scenarios indicates some influence of mitigation measures on reducing the debris flow characteristics (Hussin et al., 2014). However, those structural measures may not be completely efficient (Boccali et al., 2015). Therefore, proactive risk management and non-structural measures are especially required. Proactive measures comprise cleaning and maintenance of streams and existing structural mitigation works. Proactive approaches include measures to reduce vulnerability such as adaptive building design. Proactiveness should further account for land management measures, spatial and land-use planning, shared-loss through private insurance-schemes. Finally, measures include public education and awareness raising of self-protecting behaviours.

All in all, the 2003 event demonstrated the importance of aligning land development and risk management goals in the study area (Malek and Boerboom, 2015). Although progress has been made to update the hazard maps (ADBVE, 2012), the current available hazard information already has to be used in local spatial planning (Prenger-Berninghoff et al., 2014). To that end, coordination and cooperation between organizations dealing with risk prevention and emergency preparedness is specially required both at local and regional level. Moreover, promoting collaborative efforts between the varieties of actors involved is important.

2.4.1. IN-PRACTICE EXAMPLES OF VOLUNTEERS' INFORMATION

Regarding risk management of hydro-meteorological hazards, there is a strong involvement of citizens from each municipality in volunteer groups such as Civil Protection and fire brigades. Therefore, in-practice examples of volunteers' information mainly rely on the Civil Protection. However, some collaborations with universities and technical authorities were also identified. Thereby, volunteers' involvement is not only in support of preparedness and response activities but also for raising awareness activities or cooperating with management organizations. **Table 2.10** summarizes in-practice examples from the active involvement of volunteers in FVG, which may also account for the involvement of teenagers and children through educational campaigns.

2.4.2. VOLUNTEERING TRADITION

In the FVG, volunteers can be categorized in citizen volunteers groups and specialized groups. At every municipality, the mayor directly coordinates citizen volunteer groups. Thereby, citizens can enrol to participate in the Civil Protection activities of the place they live in. Upon admission, Civil Protection supports volunteer groups by providing equipment, insurance coverage as well as formative and informative training. Specialized training is provided upon request or according to the needs of specialized groups. Those are for example fire brigades, alpine rescue groups, first aid, logistics and communication.

According to observations from stakeholders meetings of the CHANGES project, the volunteering tradition seems to follow a collectivism motivation supported by the institutional framework. Furthermore, Bianchizza et al. (2011) refers to this collectivism motivation coming as tradition from the Austro-Hungarian empire. Tradition that was later on strengthened by the devastating effects of the earthquake of 1976. Unfortunately, such volunteering tradition is being challenged by the depopulation of alpine areas. Therefore, institutional efforts also aim at engaging and transferring this tradition to new generations.

2

Table 2.10: In-practice examples of volunteers' information in FVG

In practice-example	Goal	Related typology
Laboratory experiment in the transboundary basin of Vipacco at the border with Slovenia	Understanding local preferences to receive warning and forecasting information	Collaborative science to support behavioral research
"Ecological days" along the streams and workshops in the schools	Participation of volunteers in support of activities to raise awareness of local communities	Collaborative science with educational purposes
Geo-location of hydrants in the urban area of Udine in collaboration with the University of Trieste	Volunteers involvement to update available databases	Volunteer geographic information
Monitoring campaigns organized on October 10th, 2010 for the extraordinary surveillance of 70km of levees along the coast and the lagoon in the Province of Trieste	Signalize and geo-localize the alteration of dikes due to the presence of aquatic species such as Nutria, Gambero rosso della Louisiana that traditionally live in that coastal environment and affect those structures	Citizen science
Deployment of volunteers to inspect the upper and lower part of the dikes. The use of uniform, radio, mobile phone, torches and cartography is compulsory for the volunteers to inspect	Inspection of dikes as part of the monitoring strategies activated by Civil Protection	Citizen science
Minor cleaning of streams due to undesired vegetation or obstruction of materials	Preventive activities with support of volunteers and specialized groups	Community-based monitoring
Reports about the impact of hydro-meteorological events in critical infrastructure and buildings	Informational input on the occurrence of events that technical agencies could validate later on	Volunteer geographic information
The so called, traditional weather stations are still operating by local people that may also be rewarded for it	Informational input about water level and precipitation on a daily basis	Citizen Observatories

Regardless of the involvement in volunteer organizations, a wider involvement of public in support of the identification of proactive management strategies is an increasing demand (Scolobig et al., 2008).

2.4.3. ORGANIZATIONAL REQUIREMENTS

Organizations initiating and funding volunteers' involvement follow a top-down approach but the origin of volunteer organizations respond to a bottom-up tradition. The institutional recognition of volunteer organizations was almost parallel to the institution of the Civil Protection *(Regional Law 64/1986).* Moreover, interactions of regional and local authorities with volunteer organizations, for emergency management, were recognized at national level (*Legislative Decree No 225/1992*). **Figure 2.4** presents an overview of the legal framework and events influencing the volunteer organizations in FVG with special focus in the Fella basin.

Regarding emergency management, warning thresholds are activated based on the intensity of rainfall events and not with reference to water levels. According to Civil Protection representatives, some rainfall thresholds are used operatively in the Fella basin. However, those thresholds are not established from detailed historical analysis but mainly from the experience of managing previous events. Warning messages are then sent by the meteorological office to the relevant operational group (e.g. mayor, Civil Protection, volunteers' organizations, etc). Alert zones are established based on the location of critical infrastructure and places in which previous events have occurred. Specifically referring to Civil Protection activities, this operative scheme is supported with spatial data infrastructures and information systems centralized at regional level in the operative room of Palmanova, FVG.

Due to the flash events common in mountainous catchments, there is limited time to communicate warning signs or to implement emergency response measures. Therefore, managing organizations should promote self-awareness and precautionary actions of local communities. Although structural measures are in-place, risk management organizations in the Fella basin should enhance the implementation of non-structural measures and maintenance of mitigation works. The last flood event in 2009 did not occur as intense as the 2003 event. However, the implemented mitigation works might not be enough in all possible scenarios (Boccali et al., 2015; Hussin et al., 2014).

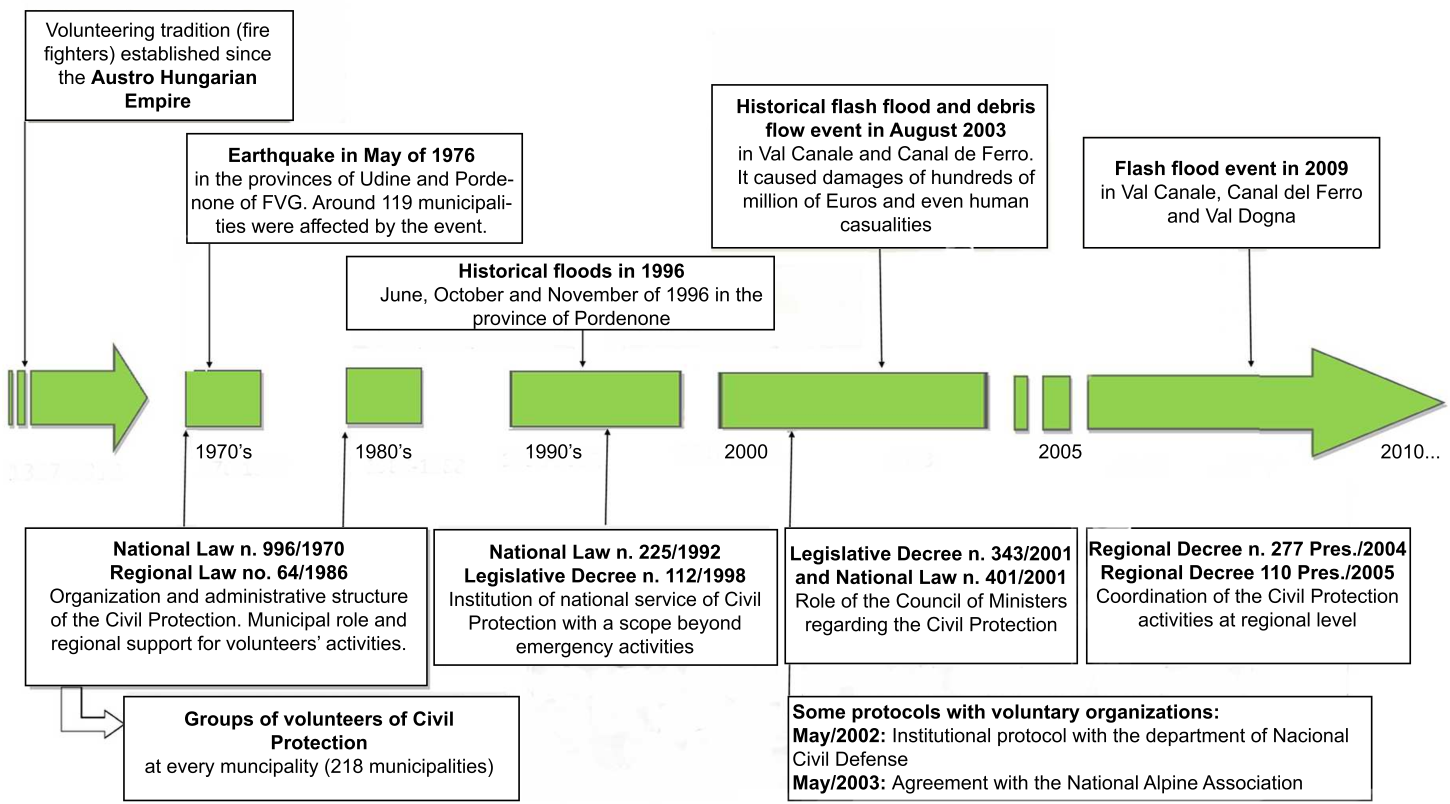

Figure 2.4: Overview of the legal framework and events influencing volunteers' organizations in FVG and particularly in the Fella basin (Source: based on `http://www.protezionecivile.fvg.it/ProtCiv/default.aspx/32-quadro_normativo.htm`)

2.4.4. DATA-COLLECTION REQUIREMENTS

In FVG, technical and Civil Protection organizations have already involved volunteer groups in monitoring activities in a variety of ways (**Table 2.10** in Section 2.4.1). One specific example is the traditional weather stations operated by local people, who may be rewarded for their involvement. Currently, such stations are being replaced by real-time sensors. According to operators of the Hydraulic Service, the quality of those volunteers' measurements generally varies. Moreover, Civil Protection supports the inspection of protection works (e.g. dikes) and cleaning of minor streams with the involvement of volunteer groups. However, there is a need to standardize volunteers' information; to establish mechanisms to evaluate the quality of data-collected; and to further coordinate roles, responsibilities and resources between organizations that are in charge of inspection and maintenance of hydraulic structures.

2.4.5. TOOLS SUPPORTING THE USE OF VOLUNTEERS' INFORMATION

In FVG, there are variety of ICT tools supporting the use of volunteers' information. The primary source of information is the Civil Protection website (`http://www.protezionecivile.fvg.it/`). Standard volunteer training is complemented with a virtual center (`http://formazione.protezionecivile.fvg.it/`). As mentioned in Aye et al. (2016), the region has been developing some web information systems for exchanging risk management information.

For emergency management, a web-based information system assists the design and implementation of emergency plans at municipal level. This platform is called "Aree di emergenza" and is coordinated by the Civil Protection. Responsible authorities and citizens can access hazard maps, the location of critical infrastructures and emergency procedures according to different accessibility rights. In addition, such platform has a complementary mobile application to facilitate the access and informational input of citizens and volunteers to report relevant information for emergency management (RiMaComm, 2013).

Additional efforts are being carried out to support the exchange of information between the regional agencies and municipal authorities that are involved in preventive risk management activities. These efforts include the informational input of citizen calls and volunteer' reports. That is particularly the case of the *"Sistema Informativo Territoriale per la Difesa del Suolo"* (SIDS), which literally stands for Informative System for the Soil Defense. Through that system, regional technicians from Civil Protection upload reports coming from citizen's alerts or calls. The Geological Service, Forestry Services and IRDAT (the cartography institution of the region) integrate information about elements at risk and hydraulic structures databases. Within this platform, the Geological Service cross-validate and follow-up the documentation process of hydro-geological events being reported by the Civil Protection. Finally yet important, the technical services (i.e. Forestry Service) are also updating on that system their inventories of hydraulic structures with the support of mobile devices specially designed for technicians.

2.5. FINAL REMARKS

The conceptual framework (**Figure 2.1**) comprises the questions we used to identify requirements for citizen science approaches. The links to the actual situation in the study area were derived from meetings between stakeholders and researchers in the CHANGES project. In Friuli Venezia Giulia, risk management against debris flows is particularly complex due to the abundant presence and variety of protecting structures. In locations where structural measures are in place, mitigation measures along the catchment, channel track or deposition area may not be fully efficient. This especially applies under dynamic hazard conditions (Boccali et al., 2015; Hussin et al., 2014). It also applies in mountain environments in which the frequency and influence of flow and sediment processes affect the functional status of hydraulic structures, and vice versa (Holub and Hübl, 2008). Then, proactive inspection and maintenance are of high priority (Mazzorana et al., 2014).

Particularly in the Fella basin, risk management organizations have expressed their interest to increase monitoring activities in support of preventive maintenance of protection works. However, responsibilities and resources between risk management organizations should be coordinated. Volunteers' involvement could widen the geographic area and the frequency of inspections, that would not be possible otherwise. That is for example due to the limitated staff and relatively large number of protection works. Furthermore, the volunteering tradition (**Table 2.10**) and supporting institutional framework (**Figure 2.4**) can facilitate the training and communication with volunteers. The inspection on the status of hydraulic structures is based on the function for which such structures were designed and built. Starting from organizational requirements, there is a need to standardize and assess the data quality of volunteers' information. Therefore, the focus of this PhD research is to *"develop a methodology applicable in day-to-day risk management to use volunteers' information in support of proactive inspection of hydraulic structures"*.

3

EVALUATING DATA QUALITY COLLECTED BY VOLUNTEERS FOR FIRST-LEVEL INSPECTION OF HYDRAULIC STRUCTURES IN MOUNTAIN CATCHMENTS

Volunteers have been trained to perform first-level inspections of hydraulic structures within campaigns promoted by Civil Protection of Friuli Venezia Giulia (Italy). Two inspection forms and a learning session were prepared to standardize data collection on the functional status of bridges and check dams. In all, 11 technicians and 25 volunteers inspected a maximum of six structures in Pontebba, a mountain community within the Fella Basin. Volunteers included Civil-Protection volunteers, geosciences and social sciences students. Some participants carried out the inspection without attending the learning session. Thus, we used the mode of technicians in the learning group to distinguish accuracy levels between volunteers and technicians. Data quality was assessed by their accuracy, precision and completeness. We assigned ordinal scores to the rating scales in order to get an indication of the structure status. We also considered performance and feedback of participants to identify corrective actions in survey procedures. Results showed that volunteers could perform comparably to technicians, but only with a given range in

This chapter has already been published on: Cortes Arevalo et al. (2014):

Cortes Arevalo, V. J., Charrière, M., Bossi, G., Frigerio, S., Schenato, L., Bogaard, T., Bianchizza, C., Pasuto, A. and Sterlacchini, S. (2014). Evaluating data quality collected by volunteers for first-level inspection of hydraulic structures in mountain catchments. Natural Hazards and Earth System Science, 14(10), 2681–2698. http://doi.org/10.5194/nhess-14-2681-2014

precision. However, a completeness ratio (question / parameter) was still needed any time volunteers used unspecified options. Then, volunteers' ratings could be considered as preliminary assessments without replacing other procedures. Future research should consider advantages of mobile applications for data-collection methods.

3.1. INTRODUCTION

There is an increasing interest in the use of citizen-based approaches to better understand the environment and hazard related processes. To that end, there are different data collection approaches according to the citizens' skills and time of involvement, e.g., crowdsourcing (Hudson-Smith et al., 2008), volunteered geographic information (Goodchild, 2007) or facilitated-volunteered geographic information (Seeger, 2008). Moreover, scientists have increasingly considered management approaches based upon the broader concept of citizen science (Bonney et al., 2009). Thereby, volunteers are enlisted and trained according to survey and management needs (Devictor et al., 2010).

In disaster risk management, citizen science is linked to European and worldwide directives, such as the Hyogo framework (EC, 2007; UN, 2005). Such directives promote citizen involvement to build a culture of resilience before, during and after a disaster strikes[1]. Therefore, modern approaches for emergency management promote exchange of information between local authorities and volunteer groups to support preparedness and preventive actions (Enders, 2001).

Hydro-meteorological events in mountain areas are often caused by multiple and sudden onset floods and debris flows. Traditionally, hazard mitigation in the European Alps is mainly organized by implementing structural measures. However, the increasing frequency and influence of flow and sediment processes also affect the functional status of hydraulic structures, and vice versa (Holub and Hübl, 2008). The impact (i.e., damage) is evident to structures for debris-flow control, such as check dams. Evidence is also found in the potential aggravation of flood hazard at the location of bridges and culverts due to blocking material such as debris, large wood and other residues (Mazzorana et al., 2010). Stability of protection works is often threatened by the erosion level at stream banks.

The need to enhance data-collection approaches to support risk-management strategies is widely acknowledged (e.g. Molinari and Handmer, 2011). Besides situations where financial and human resources are limited, scientific monitoring may be subject to additional complexity under dynamic environmental conditions or remote settings (de Jong, 2013). Moreover, frequent inspection of hydraulic structures is especially important in mountain basins.

[1] http://ec.europa.eu/echo/files/civil_protection/civil/prote/cp01_en.htm

Therefore, opportunities in promoting citizen science projects stem from the increasing frequency, timeliness and coverage of surveillance activities (Flanagin and Metzger, 2008). To be useful, survey procedures should be tested and adapted according to quality requirements of decision-makers (Bordogna et al., 2014a; EPA, 1997; Goodchild and Li, 2012; Gouveia and Fonseca, 2008).

Experiences of citizen science include data collection regarding water quality and biological aspects (Engel and Reese, 2002; Fore et al., 2001; Nicholson et al., 2002); forestry and ecosystem rehabilitation (Brandon et al., 2003; Gollan et al., 2012); biodiversity (Snäll et al., 2011); stream monitoring (Bjorkland et al., 2001; Yetman, 2002) and hydrological processes (Cifelli et al., 2005; Rinderer et al., 2012). Despite the variety of projects, limited research has been devoted to evaluating the quality of citizen-based data (Danielsen et al., 2005). Furthermore, scientists and decision-makers have a general lack of confidence due to the limited accuracy, non-comparability and incompleteness of citizen-collected data (Conrad and Hilchey, 2011; Riesch and Potter, 2014).

In spite of the challenges for citizen involvement, precision and completeness of largely collected data depends on the exhaustiveness of the inspection procedures (Galloway et al., 2006). Therefore, training activities are often required before starting the inspection campaigns. However, the extension of these training sessions should consider available time, number and type of participants (Tweddle et al., 2012). To that end, Jordan et al. (2011) suggested that identification of technical data should be restricted while more general indicators can still be accurately obtained. Those indicators may be quantitative and qualitative aspects that are easily recognizable from visual inspections (Gommerman and Monroe, 2012; Gouveia et al., 2004). Then, qualitative field methods are generally based on rating scales to report inspected conditions.

This study considers regular inspections with citizen volunteer groups that are promoted by Civil Protection and local authorities of Friuli Venezia Giulia (FVG), Italy. We involved eleven technicians and 25 volunteers on a data-collection exercise. Participants were invited according to their location. Thus, 15 out of 25 volunteers were members of Civil Protection groups in neighbouring municipalities. In all, ten university students were also volunteers within a supplementary academic activity.

In this chapter, we evaluate data quality on preliminary inspections of bridges and check dams. Therefore, we address the following research questions: (1) how well were participants able to report on the functional status by distinguishing between available rating classes? (2) How effectively were data collected by volunteers compared to those collected by technicians? (3) How can survey procedures be improved? To that end, Section 3.2 describes the methodology for data collection. In Section 3.3, we evaluate data quality by their accuracy, precision and completeness. Finally, we highlight in the discussion's and conclusion's (Sections 3.4 and 3.5) key points for the practical use of citizen-based data.

3.2. METHODS

In the first step of the methodology, we defined target groups. The participants' groups comprised of volunteers and technicians to evaluate the data quality. In the second step, two inspection forms were designed for bridges and check dams. The forms were created to carry out inspections with trained volunteers.

Despite available procedures for technicians, the volunteers' involvement demands more structured and simpler forms to inspect the functional status. Similar to Yetman (2002), we used rating scales to standardize collected data in distinguishing minor problems from more serious concerns. The rating scales included visual schemes to guide inspectors. In addition, the latter were required to take a photo to support their choices.

Finally, we organized a data-collection exercise to carry out first-level inspection of six structures, hereafter referred to as "inspection tests". There was 1 day for the training session and 1 day for the inspection tests. Participants were divided between control and learning groups to identify potential improvements in survey procedures.

3.2.1. PARTICIPANTS' GROUPS

Citizens were involved in the form of Civil Protection volunteers due to safety limitations and accessibility to hydraulic structures in mountain catchments. Citizens enrolled as Civil Protection volunteers traditionally received formative, informative and safety procedures while specialized training is selectively provided (Protezione Civile della Regione FVG, 2012)[2]. In addition, we widened the range of participants with students to account for assumed differences in preliminary knowledge to fill the form. Then, volunteers included geology students and students from a master's course on cooperation, both from the University of Trieste. The technicians were employees from regional services with competences for the inspection of hydraulic structures in the mountain community.

Volunteers (Vs) and technicians (Ts) joined the activity according to their time-availability (**Table 3.1**). The control group (CG) carried out the inspection tests without attending the learning session. Most citizen-volunteers were present in the learning group (LG) as they are the target group of campaigns promoted by Civil Protection. Students of geosciences were only available for the inspection tests during the first day. Their involvement was important to facilitate

[2] http://www.protezionecivile.fvg.it/ProtCiv/default.aspx/PianoRegionaleEmergenze.aspx

knowledge exchange during outdoor learning. Then, they were equally divided into a volunteers' learning group (VLG) and a volunteers' control group (VCG).

During registration to the data-collection exercise, participants were asked to fill a questionnaire to characterize participants' groups (**Table B.1** in **Appendix B**). Gathered information included demographics such as age, gender and level of education, as well as period of residence in the Fella Basin and FVG region. In addition, we measured the experience with hydro-meteorological hazards (i.e., floods, debris flows and landslides). The questionnaire also included 20 questions to assess a prior knowledge of participants of debris-flow phenomena, functionality of check dams and culverts, as well as emergency security guidelines.

Table 3.1: Participants' distribution between Learning (LG) and Control groups (CG).

Participants' number		Two-days LG	One-day CG
Civil Protection volunteers	15	8 from Pontebba 2 from Chiusaforte 2 from Dogna	1 from Pontebba (Date 1) 1 from Dogna (Date 3) 1 from Malborghetto (Date 4)
Geo-sciences students	8	4*	4
Social science students	2	2	No participants
Volunteers (Vs)	25	18-Learning (of which 14-Testing)	7-Testing
Civil Protection (CP) Forestry Service (FS) Geological Survey (GS)	11	3 and 1* from CP 1 from FS 1 from GS	1 from CP (Date 3) 1 from FS (Date 1) 3 from GS (Date 2)
Technicians (T)	11	6-Learning (of which 5-Testing)	5-Testing
Total Participants	36	24-Learning (of which 19-Testing)	12-Testing

* LG participants that attended only one-day

3.2.2. DESIGN OF THE INSPECTION FORMS

Table 3.2 summarizes the forms' layouts divided by sections. We defined the latter with four risk managers of Civil Protection, the Geological Service and the Forestry Service of FVG. Section I identifies the inspector. Section II comprises simplified information on location, type, use and presence of connected structures, if available. Section III accounts for the level of accessibility, presence of stream water, occurrence of rainfall and snow. Thus, section III becomes relevant for comparing between campaigns carried out at different periods. Thereafter, section IV of the form refers to the functional status of the inspected structure. Functional status is the susceptibility or physical conditions of the structure that may affect the function type for which it was designed or built (Uzielli et al., 2008). Furthermore, the functional status is inspected by looking at three parameters, according to the structure type.

Table 3.2: Form's layout for bridges and check dams

Sections	Aim of each section
I. Inspector's name and period of the inspection	Identify person responsible for form compiling Identify time and inspection period based on rainfall conditions during last 24 h, if known
II. Structure and function type	Precompiled with data available from regional databases of hydraulic structures
III. Inspection conditions	Distinguish conditions of regular inspections from those to intensify surveillance
IV. Functional status: A) Condition of the structure; B) Level of obstruction at the structure; C) Presence of protection works and erosion level at the stream bank	Distinguish among the following possible actions: • No action is required; • Requires routine cleaning of blockages by hand with a maximum group of 10 volunteers; • Requires cleaning with support of equipment; • Second level inspection; actions other than cleaning are required
V. Presence of anthropic elements	Refer critical infrastructure next to the structure
VI. Synthesis of the inspection	Provide general recommendation from available options

Parameters in section IV are comprised of a maximum of four questions. For example, questions for check dams in parameter A are: (1) is the stream flow passing where it should be? (2) What is the status of the check dam? (3) How visible is the basis of the structure? (4) Is there any protection for scouring at the downstream bottom of the check dam? Questions, rating options and visual schemes were defined according to inspection procedures for technicians. Those were mainly for check dams (Huebl and Fiebiger, 2005; Province of British Columbia, 2000; Provincia Autonoma di Bolzano, 2006; von Maravic, 2010) and bridges (Engineering, 1999; Ohio Department of Transportation, 2010; Servizio Forestale FVG, 2002). The inspection forms adopted in this study are available in **Figures B.1-B.4** in **Appendix B**).

For the case of bridges, parameter A focuses on the opening for the water flow and erosion of the pillar or abutments. Parameter B assesses levels of lateral obstruction, either at the structure location or at the stream channel. Therefore, questions for these parameters were aimed at identifying morphological changes immediately upstream, downstream and at the structure location. Such changes relate to either local erosion at protection structures and abutments, deposition phenomena that is somehow perennial with presence of vegetation, or clogging of critical flow sections. Finally, it accounts for additional elements, such as pipes, when they reduce the stream cross section.

We also included a question referring to the maximum free height of the structure. However, it was, in the end, not considered due to safety limitations for citizen volunteers when accessing the stream channel. Limitations are based on the dynamic distribution of deposits and eroding surfaces along steep mountain channels (Remaître et al., 2005). Therefore, volunteers should follow safety procedures according to the environmental and meteorological conditions during the inspection period.

For check dams, the focus of parameter A is on the status of the structure itself and downstream scouring. Parameter B distinguishes between consolidation and open check dams. Then, upstream obstruction is limited to the open check dam type. That distinction is due to the relevance of open check dams for retention of sediments, if there is a retention basin connected to the structure. Therefore, we included a "Does not apply" option for inspecting consolidation check dams.

In contrast, parameter C addresses the same questions for bridges and check dams. It refers to the worst condition while looking at the presence of protection works and erosion level at the stream banks. Then, we established a control distance of 20m upstream and downstream of the structure. This distance was defined to reduce variability of assessments during the inspection. The 20m allow inspectors to observe and to take pictures, even if accessibility to the structure is restricted. Section V of the form reports the critical infrastructure within the same control distance. Finally, section VI distinguishes required actions to follow up the inspection based on the options provided in the form.

Data-quality evaluation focuses on sections IV and VI of the inspection form. **Table 3.3** summarized the rating scales we used. When the question itself did not specify the location to report, a multiple choice was included by specifying the problem's location: right, left or in correspondence with the structure. In addition, all questions had alternative options to report unspecified answers such as "I don't know" and "Could not be answered". The latter represents conditions at the structure location (e.g., water level) that did not allow inspectors to provide an assessment. In addition, we assigned ordinal scores to the rating classes to get an indication on the functional status. For the data quality evaluation, we aggregated scores according to the given range in precision while generalizing the rating scales.

Table 3.3: Rating scales used in the inspection form

Rating classes	Criteria	Scores' meaning *(Scores)*	Generalized classes *(Precision range)*	Questions
Five classes (*1,2,3,4* and *5*)	Minimum to maximum concerns	*1:* Best condition *5:* Worst condition	Three classes (*1-2, 3* and *4-5*)	Bridges: B1 & B2 Check dams: A2, A3 ,B1 & B3 Both: C2-1, 2, 3 & 4
Three classes (*1, 3* and *5*)	Differences are not for five classes	*1:* Best condition *3:* Medium *5:* Worst condition	Three classes (None)	Check dams: A4 & B1
Three classes (*1, 4* and *5*)	Relevance to present aspects	*1:* Total absence *4:* Presence *5:* Presence beyond reference aspect	Two classes (*1* and *4-5*)	Bridges: A1* Check dams: A1* Both: C1-1, 2, 3 & 4
Two classes (*1* and *5*)	Yes/No	*1:* Absence *5:* Presence	Two classes (None)	Bridges: A2*, A3 & B3*
Synthesis (*1,2,4* and *5*)	Management options for synthesis of the inspection		Two classes (*1-2* and *4-5*)	Section VI of the form

*Includes multiple choice to specify the problem's location

3.2.3. DATA-COLLECTION EXERCISE

The data-collection exercise was carried out in the municipality of Pontebba (FVG, Italy) within the mountain community in the Fella Basin **(Figure 3.1a)**. The only settlement with over 4000 inhabitants is Tarvisio, bordered by Austria and Slovenia. The Fella catchment has an area of 700 km^2, with a mean altitude of 1140 m.a.s.l. It consists mostly of limestone and it is characterized by steep slopes and high tectonic grade. The area is prone to landslides, flash floods and debris flows.

The latest severe alluvial event was on 29 August 2003. The total rainfall amount of the event was equal to 389.6 mm. Detected intensities were particularly strong for values corresponding to 3 and 6 h (Borga et al., 2007). The event caused severe damage, created gullies and expanded existing river beds. The most affected villages were Ugovizza, Valbruna, Malborgehtto and Pontebba (Calligaris and Zini, 2012).

After the 2003 event, technical services updated the inventory of debris flows. Civil protection realized several mitigation measures in the affected areas. The basin authorities produced an updated version of the Fella hazard maps, so called "Piano stralcio di assetto idrogeologico" (P.A.I-FELLA ADBVE, 2012). Thus, 22% of total check dams and 50% total of bridges within Fella Basin are accounted at the different hazardous areas defined in the P.A.I. upstream of the Pontebba location. That corresponds to 230 and 115 structures respectively.

Civil Protection selected the structures for the inspection tests **(Figure 3.1b)**.

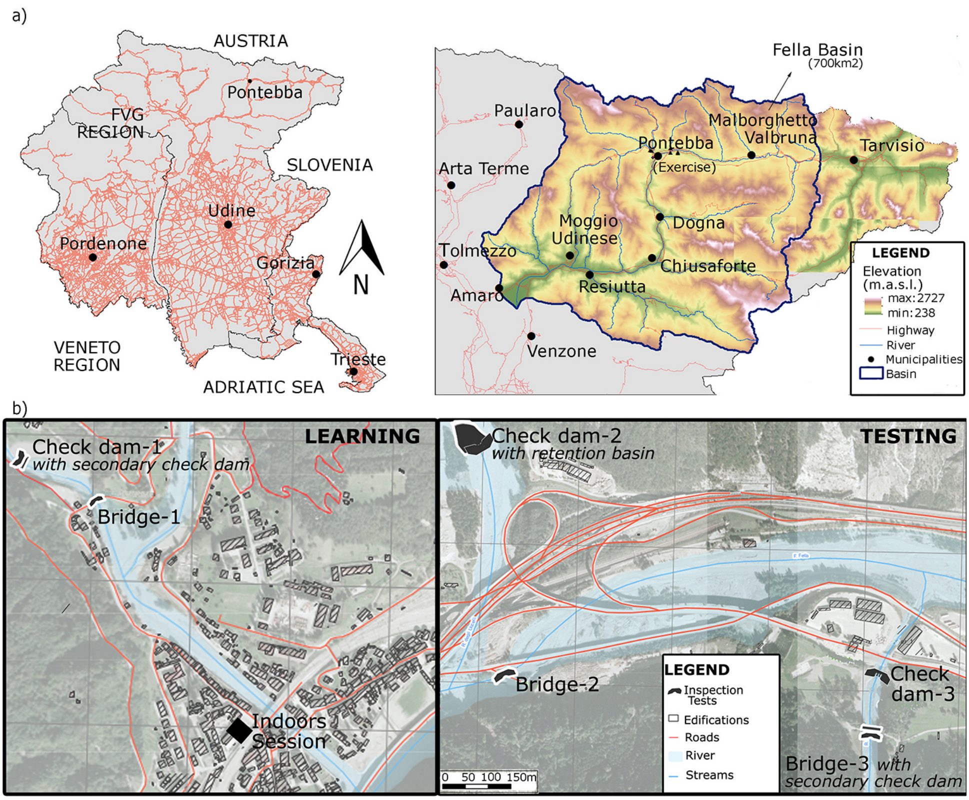

Figure 3.1: Study area: (a) overview of the study area and Fella Basin. (b) Map indicating the location of the structures for the inspection tests

The complexity of the inspection tests differed according to the functional status of the structures. Then, structures for the inspection tests accounted for a range from minimal to serious concerns. Structures also included connected elements, such as retention basins and secondary check dams for scouring protection.

Finally, **Table 3.4** describes the organization of the exercise, divided by sessions and inspection tests. The registration questionnaire was open until the exercise day, which took place on May 2013. See the website of the activity[3] for more details on the questionnaire and training material. After a common introductory session, participants inspected the same structures according to the CG or LG program. Every test took 15 min on average, which was actually faster than expected. First, all participants carried out an indoor pretest by looking at

[3]Website of the activity: `https://horatius.irpi.pd.cnr.it/changes-fella/changes-fella/index.php/relazione-dell-attivita`

a poster. Then, the CG initiated inspections directly in the field without attending the learning session. The CG program was on different dates based on the participants' availability.

Table 3.4: Description of the data collection exercise

	Session *(Duration)*	Inspection Test *(Structure)*	Description of activities: Two-days LG	Description of activities: One-day CG
(1)	Registration *(1 month)*	Filling the registration questionnaire		
(2)	Introduction *(1 hour)*	Pre-test with a poster *(Bridge-1 and Check dam-1)*	• Scope of the activity; • Safety advice and recommendations for form compiling; • Pre-test to establish the initial understanding of participants to fill the form	
(3a)	Indoors Learning *(3 hours)*	Presentations of 45 min separated by breaks in-between		
(3b)	Outdoors Learning *(3 hours)*	Test-1 *(Bridge-1 and Check dam-1)*	• Participants divided in two teams guided by a senior technician; • Individual form compiled for two structures; • Team divided in five sub teams of five participants; • Group form compiled per sub team	• Participants divided in four groups. Each group made the test in one of three optional dates; • Individual form compiled for six structures
(4)	Testing *(3 hour)*	Test 2 and 3 *(Bridge-2 and 3) Check dam-2 and 3)*	• Participants divided in two teams to minimize interaction; • Individual forms compiled for four structures	
(5)	Feedback	Feedback form 15 min and during learning sessions		

Instead, the LG continued their first-day with the learning session. The learning had an indoor program followed by an outdoor session that included the structures of the pretest. In the outdoor session, the LG was divided into teams with representatives of each participant's group (one technician, Civil Protection volunteers and one student). At first, each participant compiled the test 1 for check dams and bridges. Then, they filled it out by teams for knowledge exchange. Senior technicians clarified further aspects, if needed. On the second day, the LG continued with test 2 and 3, divided in two groups to reach the structure location. At the end, all participants provided feedback and submitted the pictures they took during the inspections, if any.

3.3. EVALUATION ON THE QUALITY OF COLLECTED DATA BY VOLUNTEERS

Tables 3.5 to **3.6** summarize results according to the component questions per parameter. Mean ordinal scores ($\overline{X}$) and standard deviations (S.D.) were calculated from the ratings that participants reported in test 1, 2 and 3. Then, we evaluated how effectively data were collected by Vs as compared to that collected by Ts. **Figures 3.2** to **3.6** summarize results according to the pretest, tests 1, 2 and 3. Distinction was done between Vs and Ts within participants of the learning and control groups. For that purpose, a frequency analysis was applied to the ordinal scores that **Table 3.3** defines. This consideration was based upon the relatively low sample, size and difference in number between the groups. We referred to the mode score for the data evaluation as it represents the class with the highest frequency. In addition, we used the following criteria to assess the quality of collected data (EPA, 1997, pp. 19–20):

- Accuracy is a "degree of agreement between the data collected and the true value on the condition being measured". Then, we referred to as "true value" as the mode score for Ts in the learning group. **Figures 3.2** to **3.6** aggregate the relative frequencies in four frequency classes with reference to the true value: equal to or larger than 90, 70–90 and 50–70%, and smaller than 50%. We chose this aggregation to distinguish different accuracy levels for each group. In addition, we assumed agreement among group members when a question had a relative frequency of at least 70 %. Then, the overall agreement per parameter was calculated by the ratio question / parameter, i.e., the number of questions with frequencies of at least 70% between total questions per parameter.

- Precision "refers to how well data collected are able to reproduce the result on the same group". For all participants, we represented precision by using the standard deviation (SD) in **Tables 3.5** to **3.6**. Instead, in **Figures 3.2** to **3.6**, we compare each group while looking at the mode scores and the mode-off by one level. The mode-off is a range in precision given by generalizing the extreme scores of the rating classes. For example, according to **Table 3.3**. Rating scales used in the inspection form, we generalize rating scales from five to three classes by grouping: very low to low concerns, medium concerns and high to very high concerns. Those are ordinal scores 1 and 2 on one side; scores 4 and 5 on the other. Mode-off by one level in

Figures 3.2 to **3.6** only distinguished questions where the scale generalization brought forth increments to the relative frequencies.

- Completeness is the "measure of the amount of valid data actually obtained vs. the amount expected to be obtained". In **Tables 3.5** to **3.6**, completeness is evaluated by the amount of answers obtained between the rating scales as compared to the selection of unspecified answers. In **Figures 3.2** to **3.6**, we evaluated completeness by distinguishing questions with relative frequencies larger than 14% in the options: "I don't know", "Could not be answered" and "No answer". We chose a threshold of 14% to highlight questions with the lower completeness. It corresponds approximately to an absolute frequency of one participant in the control group or two participants in the learning group.

Other criteria, such as comparability and representativeness, were only considered in designing the form. "Comparability represents how well data from one form can be compared to data from another. Representativeness is the degree to which collected data actually represent the structure being inspected." (EPA, 1997, pp. 19–20). Then, we referred to comparability by using a standard form for bridges and check dams. For representativeness, we required a photo record from the inspector to support their choices and to provide additional information for the later examination of inspections. Finally, we used comments provided by participants during the sessions and the comments provided in the feedback form to define corrective actions (**Table 3.7**). Following subparts present results according to specific aspects for bridges and check dams, then into common aspects for both structures.

Table 3.5: Evaluation of scores for the data collected in the inspection tests for bridges

Participants' number		36			31			31	
Questions per parameter (Rating classes: *assigned scores*)		TEST-1 Bridge-1			TEST-2 Bridge-2			TEST-3 Bridge-3	
	$\overline{X}$	S.D.	%Us	$\overline{X}$	S.D.	%Us	$\overline{X}$	S.D.	%Us
(A) Condition of the structure									
A1. Erosion at the pillar or abutment 3 classes: *1, 4 and 5*	1.3	±**1.0**	3 %	2.5	±**1.6**	***19 %***	1.0	–	3 %
A2. Natural jumps created by the stream (2 classes: *1 and 5*)	1.2	±0.9	–	1.7	±**1.5**	***13 %***	1.1	±0.7	3 %
A3. Other damages at the foot of the structure (2 classes: *1 and 5*)	1.0	–	3 %	1.9	±**1.7**	***13 %***	1.0	–	***10 %***
(B) Level of obstruction at the structure									
B1. Obstruction upstream (5 classes: *1, 2, 3, 4 and 5*)	1.3	±0.5	–	1.7	±0.9	3 %	1.8	±0.9	–
B2. Obstruction downstream (5 classes: *1, 2, 3, 4 and 5*)	1.3	±0.5	–	1.7	±0.8	3 %	1.5	±0.6	3 %
B3. Islands with vegetation (shrub) or other man-made obstructions (2 classes: *1 and 5*)	1.7	±**1.5**	–	2.9	±**2.0**	–	1.8	±**1.6**	–
(C-1) Presence of protection works within 20 m upstream and downstream									
C1-1. Left Bank upstream (3 classes: *1, 4 and 5*)	4.9	±0.7	3 %	1.6	±**1.3**	***13 %***	4.4	±**1.2**	–
C1-2. Left Bank downstream (3 classes: *1, 4 and 5*)	4.8	±0.7	–	1.6	±**1.4**	3 %	4.4	±**1.0**	3 %
C1-3. Right Bank upstream (3 classes: *1, 4 and 5*)	5.0	±0.2	6 %	3.5	±**1.9**	3 %	3.1	±**1.8**	3 %
C1-4. Right Bank downstream (3 classes: *1, 4 and 5*)	4.8	±0.7	–	4.2	±**1.4**	***10 %***	4.5	±0.8	–
(C-2) Level of erosion at the stream bank within the same distance									
C2-1. Left Bank upstream (5 classes: *1, 2, 3, 4 and 5*)	1.1	±0.3	***19 %***	1.6	±0.6	***19 %***	1.6	±0.9	3 %
C2-2. Left Bank downstream (5 classes: *1, 2, 3, 4 and 5*)	1.1	±0.3	***14 %***	2.4	±**1.3**	***16 %***	1.7	±**1.0**	3 %

3

Table 3.5 Continued:

Participants' number	36			31			31		
Questions per parameter (Rating classes: *assigned scores*)	TEST-1 Bridge-1			TEST-2 Bridge-2			TEST-3 Bridge-3		
	$\overline{X}$	S.D.	%Us	$\overline{X}$	S.D.	%Us	$\overline{X}$	S.D.	%Us
C2-3. Right Bank upstream (5 classes: *1, 2, 3, 4 and 5*)	1.1	±0.2	***17 %***	1.3	±0.5	***10 %***	2.0	±0.9	3 %
C2-4. Right Bank downstream (5 classes: *1, 2, 3, 4 and 5*)	1.1	±0.3	***22 %***	2.0	±0.8	6 %	2.3	±**1.3**	–
Synthesis of the inspection (4 classes: *1, 2, 4 and 5*)	1.5	±**1.1**	***19 %***	2.6	±**1.5**	6 %	3.2	±**1.8**	6 %

($\overline{X}$): average ordinal score; SD: standard deviation; %Us: relative frequency of unspecified answers.
Note: The values in bold distinguish the lowest performance

Table 3.6: Evaluation of scores for the data collected in the inspection tests for check dams

Participants' number	35			31			31		
Questions per parameter (Rating classes: *assigned scores*)	TEST-1 Check dam-1			TEST-2 Check dam-2			TEST-3 Check dam-3		
	$\overline{X}$	S.D.	%Us	$\overline{X}$	S.D.	%Us	$\overline{X}$	S.D.	%Us
(A) Condition of the structure									
A1. Stream flow passing where it should be (3 classes: *1, 4 and 5*)	1.1	±0.7	–	2.0	±**1.5**	–	2.0	±**1.4**	–
A2. Status of the check dam (5 classes: *1, 2, 3, 4 and 5*)	2.2	±**1.5**	9 %	1.0	±**0.2**	6 %	1.1	±0.3	–
A3. Visibility of the basis of the structure (5 classes: *1, 2, 3, 4 and 5*)	***2.2***	±1.7	***23 %***	1.3	±0.6	3 %	1.3	±0.6	3 %
A4. Protection for dowmstream scouring (3 classes: *3, 1 and 5*)	***4.7***	±0.9	***11 %***	3.2	±0.6	***32 %***	1.9	±1.0	***16 %***
(B) Level of obstruction at the structure									
B1. At the opening of the check dam, if any (5 classes: *1, 2, 3, 4 and 5*)	1.0	–	***26 %***	***4.4***	±0.8	–	2.1	±0.5	3 %
B2. Upstream in the retention basin, if any (3 classes: *1, 3 and 5*)	1.2	±0.8	***26 %***	***4.0***	±1.4	***13 %***	1.2	±0.5	***16 %***

Table 3.6 Continued:

Participants' number	35			31			31		
Questions per parameter (Rating classes: *assigned scores*)	TEST-1 Check dam-1			TEST-2 Check dam-2			TEST-3 Check dam-3		
	$\overline{X}$	S.D.	%Us	$\overline{X}$	S.D.	%Us	$\overline{X}$	S.D.	%Us
B3. Downstream obstruction (5 classes: *1, 2, 3, 4 and 5*)	1.1	±0.2	9 %	2.5	**±1.3**	3 %	1.8	±0.9	–
(C-1) Presence of protection works within 20 m upstream and downstream									
C1-1. Left Bank upstream (3 classes: *1, 4 and 5*)	1.7	**±1.5**	6 %	1.3	±0.9	***13 %***	4.4	±0.8	6 %
C1-2. Left Bank down stream (3 classes: *1, 4 and 5*)	4.9	±0.3	3 %	4.5	±0.8	3 %	4.6	**±1.0**	–
C1-3. Right Bank up stream (3 classes: *1, 4 and 5*)	4.6	**±1.2**	6 %	1.1	±0.6	***16 %***	4.0	**±1.3**	–
C1-4. Right Bank down stream (3 classes: *1, 4 and 5*)	4.9	±0.3	3 %	2.9	**±1.7**	3 %	4.6	±1.0	3 %
(C-2) Level of erosion at the stream bank within the same distance									
C2-1. Left Bank upstream (5 classes: *1, 2, 3, 4 and 5*)	1.4	±0.7	***26 %***	1.8	**±1.2**	***39 %***	1.3	±0.4	3 %
C2-2. Left Bank down stream (5 classes: *1, 2, 3, 4 and 5*)	1.2	±0.5	***11 %***	1.5	±0.9	***19 %***	1.3	±0.4	–
C2-3. Right Bank up stream (5 classes: *1, 2, 3, 4 and 5*)	1.1	±0.3	***14 %***	1.9	**±1.2**	***39 %***	1.6	±0.8	6 %
C2-4. Right Bank down stream	1.1	±0.3	***17 %***	2.6	**±1.4**	***23 %***	1.3	±0.5	–
Synthesis of the inspection (4 classes: *1, 2, 4 and 5*)	3.1	**±1.9**	***11 %***	**4.3**	**±0.4**	**19 %**	2.7	**±1.4**	**10 %**

($\overline{X}$): average ordinal score; SD: standard deviation; %Us: relative frequency of unspecified answers

Note: The values in bold distinguish the lowest performance

Table 3.7: Feedback of participants to initiate corrective actions in survey procedures.

Feedback form	Comments received	Corrective actions
Was the inspection form clear enough to carry out the inspection?	• Protection works for scouring should be inspected not only for check dams but also for bridges when it applies; • For bridges, obstructions in the floodplain should be also reported; • Upstream obstruction should be reported for open and consolidation check dams.	• Rating classes and schemes will be adapted according to participants' comments and recommendations from the results section • Brief guidelines and glossary must be provided together with the inspection form.
Did you find useful the options provided in the form to answer the questions?	• When possible, rating scales with three or two classes should be extended to rate all possible status; • Presence of human infrastructure should be open question to report other infrastructure besides roads and buildings.	• To avoid misunderstandings, the question regarding the presence of protection works will better refer to their length within the control distance; • The form will emphasize to report the infrastructure that may be affected in case of high water levels.
Which aspects you did not like from the activity?	• All structures to inspect should have available information for the function type; • Participants with technical background considered the indoor session long while citizen-volunteers requested more time to better understand the theory and to carry out the inspections; • - The inspection in front of the poster could be better used after both theory and practice have been explained.	• Information regarding the type of structure will be always precompiled in the form; • The learning should start directly with the outdoor session and finishes with the indoor session; • The indoor session will be carried out separately for each group of participants; • Interaction between groups will be limited to the outdoor session.

FUNCTIONAL STATUS OF BRIDGES FOR A AND B PARAMETERS

Table 3.5 shows that A and B parameters in test 1 have mean scores between 1 and 2 in the functional status. Lower ordinal scores represent the best condition for inspected aspects (**Figure 3.3a**). Despite Ts in the control group, **Figure 3.2** presents overall agreement near to one for parameter A. That is the ratio question / parameter for parameter A and test 1. For parameter B, overall agreement was reached only in the mode-off by one level. That represents lower precision in the B ratings indistinctly of the groups.

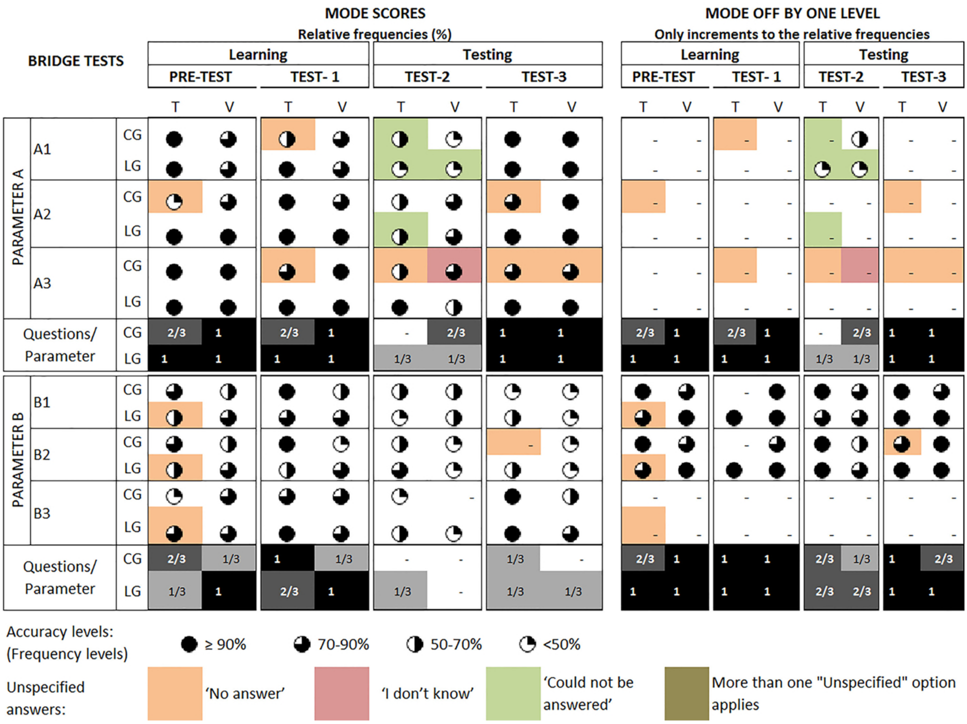

Figure 3.2: Relative frequencies for Vs and Ts of learning groups (LGs) and control groups (CGs). Parameters A and B in inspection tests for bridges

However, performance in test 1 contrasts with the one in test 2. Inspection complexity of bridge 2 was higher due to stream water flowing along the structure's pillars and abutments (**Figure 3.3b**). For parameter A, **Table 3.5** highlights higher frequency of unspecified answers and ordinal scores with standard deviations larger than 1. For Parameter A, **Figure 3.2** shows accuracy levels below the relative frequency of 70%. Consequently, there is disagreement in the mode score between Vs and Ts, indistinctly of the groups. The presence of erosion in test 2, i.e., question A1, was mostly rated by participants as "Could not be answered", "No answer" or "No erosion". Moreover, those who reported erosion in the pillar and abutment did not distinguish among erosion presence with or without the stream water along the basis.

Figure 3.3: Photo record of the structures inspected: (a) upstream view of bridge 1: pretest and test 1. (b) Upstream view of bridge 2: test 2. (c) Upstream view of bridge 3: test 3. (d) check dam 1: pretest and test 1. (e) Opening of check dam 2: test 2. (f) Upst Upstream to downstream view of check dam 3: test 3

For parameter A, in test 3, **Figure 3.2** shows better performance for the TLG and VLG as compared to the TCG and VCG. The difference in performance could represent some influence of the learning session. However, it also denotes the need for adjusting questions to avoid misunderstandings. That is the case of question A3, which should explicitly address the status of protection works for downstream scouring in bridges (**Figure 3.3c**). For parameter B, Ts and Vs only reached accuracy levels above 70% when looking at the mode-off by one level, indistinctly of the test. However, question B3 (presence of islands with shrubs or man-made structures that reduce the opening for the flow) had the lowest precision in **Table 3.5** and **Figure 3.2**. Then, question B3 should be split for better distinguishing presence of islands with vegetation from man-made obstructions.

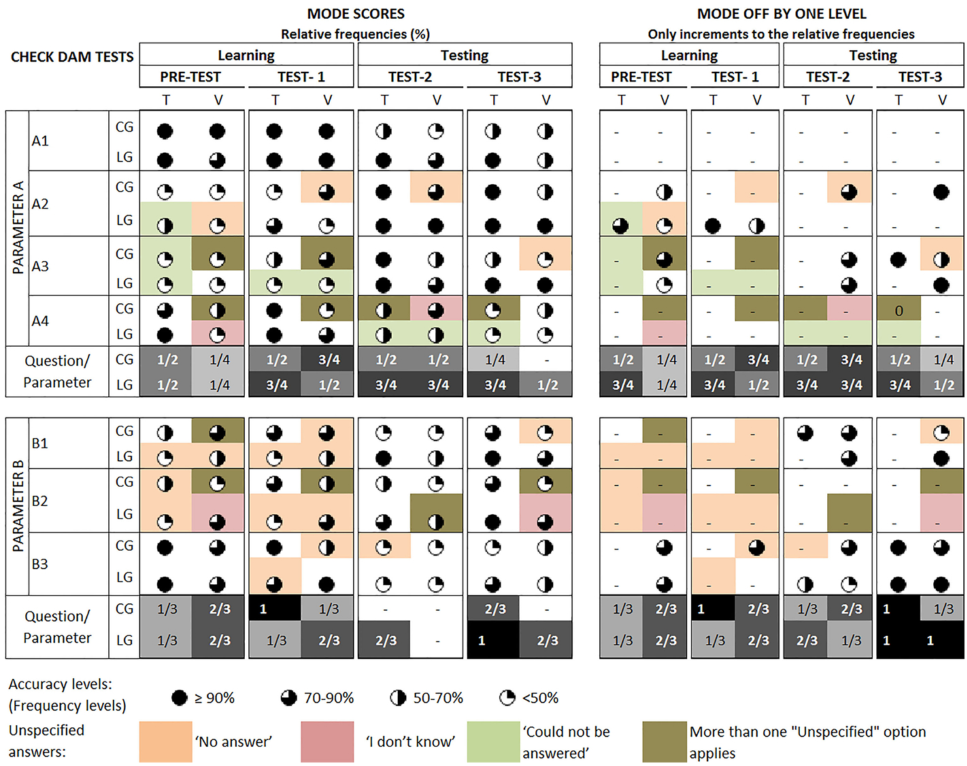

Figure 3.4: Relative frequencies for Vs and Ts of learning groups (LGs) and control groups (CGs). Parameter A and B in inspection tests for check dams

FUNCTIONAL STATUS OF CHECK DAMS FOR PARAMETERS A AND B

Table 3.6 highlights the questions with more serious concerns and standard deviations above 1. Despite the functional status, the presence of connected elements to the structures contributed to larger standard deviations. Thus, complexity in the inspection was higher due to the presence of a secondary structure in check dam 1 and a retention basin in check dam 2 (**Figure 3.3d** and **e**). **Figure 3.4** shows the lower accuracy levels and overall agreement ratio for parameter A in test 3. Then, question A1 was the least accurate for Vs in test 2 and 3. Those results may be explained on the rating scale we used, (see **Figure B.3** in Appendix B). For question A1, rating classes did not distinguish slight deviations from the strong ones. Then, medium concerns were not explicitly within the available options.

In addition, **Figure 3.4** shows higher frequencies of unspecified answers for questions A2 and A3 in test 1 and 2. In test 1, unspecified answers were due to the water level at the basis of the structure. "Could not be answered" was even the preferred option for the TLG. In test 2, visibility at the basis of the structure was limited due to the sediment accumulation. Finally, question A4 denoted higher frequencies of unspecified answers for all structures (**Table 3.6** and **Figure 3.4**). Description of question A4 should be reviewed to avoid misunderstanding with question A2. That is the case of connected structures for protection of downstream scouring. Classes to report in question A4 should be extended to consider all possible functional conditions. For parameter B, questions B1 and B2 have the lowest completeness in pretest and test 1. Those questions were not relevant for the consolidation check dam. Despite the "Does not apply" option, VLG and TLG still preferred not to answer.

COMMON ASPECTS FOR THE FUNCTIONAL STATUS: PARAMETER C AND SYNTHESIS

In questions C1 and C2 for bridges and check dams, participants only distinguished the upstream and downstream location from the field inspection (test 1). That is comparing to the pretest results, which was the preliminary inspection test to the learning session. For the pretests, mode scores were only assessable during the field inspections (test 1) due to the participants' difficulty in compiling the form in front of a poster (pretest). Similar performance of the pretests holds for check dam 1 and bridge 1, indistinctly of the parameter inspected (**Figures 3.2** to **3.6**).

When looking at the overall agreement (**Figures 3.5** and **3.6**), the most subjective aspects were the level of erosion at the stream bank (parameter C) and synthesis of the inspection. For the first one, the description coming along with the rating classes should be improved. The scheme that supports this aspect should also be adjusted in order to minimize misunderstandings between the left and right bank. For the latter, the synthesis should remain optional for volunteer inspectors. However, Ts did not agree for all structures. Then participants still require a short handout which can be taken with them to the field to support their choices.

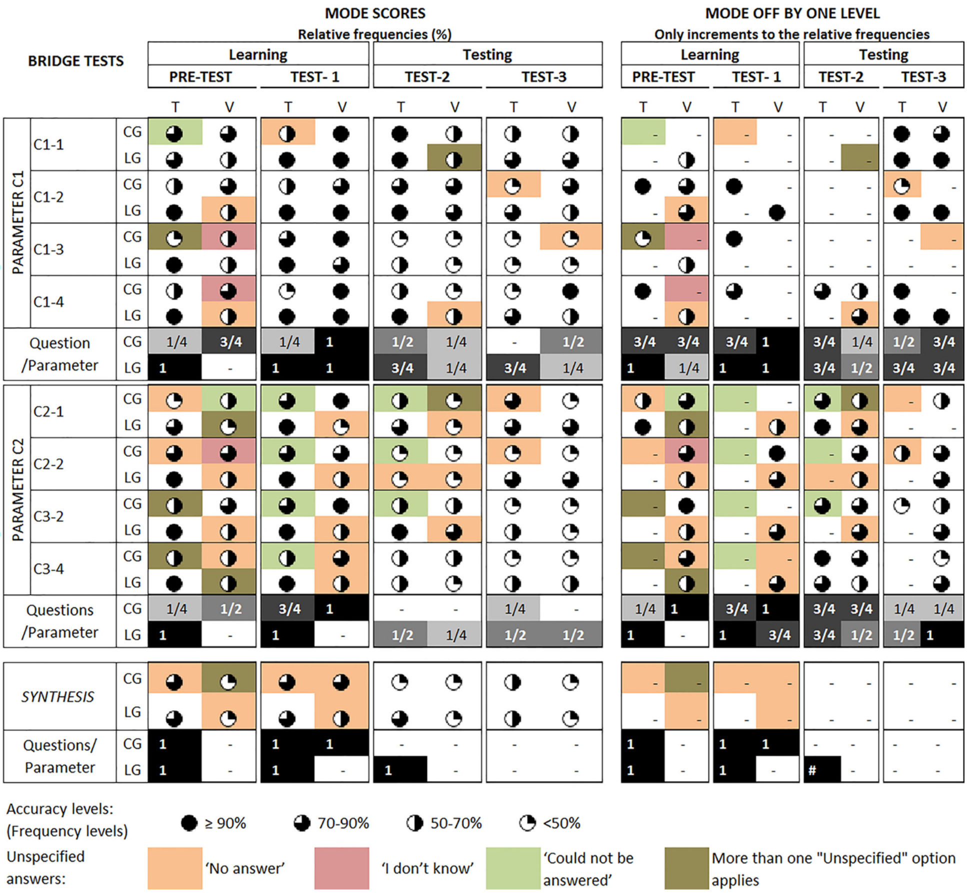

Figure 3.5: Relative frequencies for Vs and Ts of learning groups (LGs) and control groups (CGs). Parameter C and Synthesis of the inspection tests for bridges

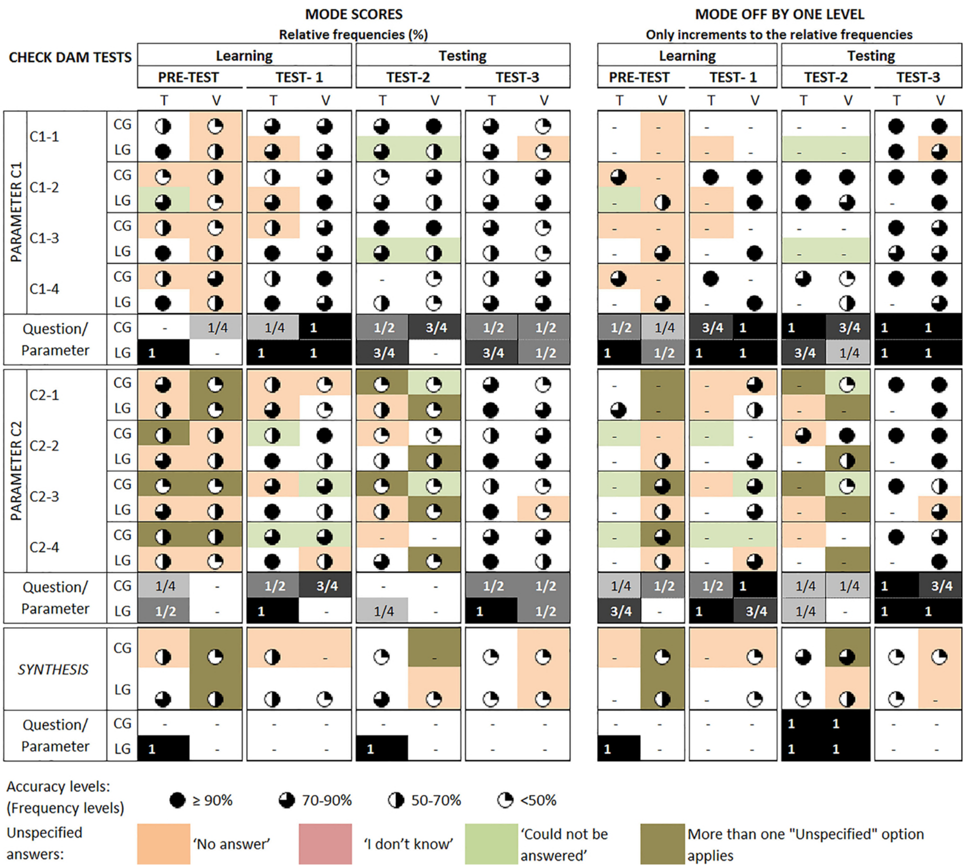

Figure 3.6: Relative frequencies for Vs and Ts of learning groups (LGs) and control groups (CGs). Parameter C and Synthesis of the inspection tests for check dams

3.4. DISCUSSION

First-level inspection of hydraulic structures is a citizen science project that aims to support decisions about obstructions of hydraulic structures, or to pre-screen problems for more technical and detailed inspections. Potential use especially holds on dynamic environments with a large number of hydraulic structures or where financial and human resources are limited (Danielsen et al., 2005; de Jong, 2013; Holub and Hübl, 2008).

In this research, we combined rating scales with ordinal scores to get an indication on the functional status. However, we still acknowledge the usefulness of photo and videos to support detailed descriptions (Dirksen et al., 2013; Yetman, 2002). Regardless of their importance, not all volunteers took photographs. They expressed difficulties to relate the photo record in the form. Then, we made distinction among volunteer data with those obtained by professional staff. Referring to participants' characteristics, both the Ts and Vs were mostly adult men. However, Vs were younger participants, as groups included students. Ts generally had higher level of education than Vs. This can be explained again by the presence of students but also by the fact that volunteering for Civil Protection does not require high level of education. Most Ts and half of the Vs were local inhabitants of the Fella Basin. Vs who do not live there were mostly the students who live largely in the FVG region.

Compared with data collected by Ts, Vs often had higher variance. Differences in accuracy can be explained from their hazard experience and preliminary knowledge for the inspection of hydraulic structures. The experience with natural hazards varied greatly for all the groups, some participants had never experienced natural hazards when some had more than 10 times. Not surprisingly, Ts had very good a prior knowledge for debris-flow phenomena, functionality of check dams and culverts, as well as on emergency security guidelines. Vs scored lower especially in the VLG.

Survey procedures were discussed with the LG. Thus, forms may be differently interpreted when comparing between the TLG and TCG. Similarly, the preliminary knowledge of geosciences students may also influence their performance in the VCG. That is by comparing with the VLG, which were mostly composed of citizen volunteers of Civil Protection. Differences between Vs and Ts can evidenced lack of training and unfamiliarity with survey protocols.

We found that the use of rating scales with a range in precision of one level could cope with some variance. Previous studies indicated the advantages of rating classes (Yetman, 2002) and the combination of classes depending on the questions to be answered (Rinderer et al., 2012). However, visual inspections are subjected to various sources of biases, both for the volunteers and technicians.

For example, limitations on the accuracy for the recognition of defects, precision to describe defects according to a rating scale and completeness of the inspection reports (Dirksen et al., 2013; Gouveia et al., 2004). Therefore, it was useful to include unspecified options distinguishing limitations such as water level and inspection conditions, which are also complementary information to analyse the reports.

Furthermore, we referred to potential improvements in survey procedures. Rating scales should consider all possible functional conditions, only when distinction among different concerns is possible. Improvements in the forms are still required. For example, a separated form could be defined for culverts to address specific aspects of such structures (Najafi and Bhattachar, 2011). However, surveys procedures should remain as simple as possible.

Despite the needs for improvement, several comments proved the utility of the activity: "as a good initiative to instruct volunteers on the observation of the territory with preventive scope, it joined theory and practice together on the field, it helped to understand and inspect the functionality of the structure". Nevertheless, iterative design and additional testing is required before making a perennial activity from this pilot. First, improvements on the inspection procedures should be separately tested with technicians to improve robustness of methods. Thus, we could validate the iterative design within the reference group. Then, we could discuss procedures with the technicians for later examination of data and the use for decision-making.

The involvement of a mixed group of participants was interesting for knowledge exchange, particularly in the outdoor session. However, it also facilitated interaction during the inspection tests, which was ideally not desired. Then, replication exercises should be carried out on a separate day for each participant's group to improve consistency on the methods. Finally, participants should have feedback on the quality evaluation following every inspection campaign. It may contribute to maintaining data quality during the design phase but also on a long-term basis.

Moreover, citizen-based approaches require the effective combination of two practical aspects in order to be fully useful: recruiting and training strategies. Then, quality assurance methods for data collection, comparison and examination Crall et al. (2010); Riesch and Potter (2014). From the social perspective, a cornerstone beyond our research scope is the increasing volunteers' awareness of the water-sediment processes being addressed (Couvet et al., 2008). From the technical perspective, geoinformatic tools and mobile devices could facilitate data collection, access and validation (Newman et al., 2012). Data management systems could support technicians to compare and use collected data for later examination.

In addition, participants could exploit smartphone applications for form compiling, completeness checking, data transferring and photo record. Additional tools could be included, such as an embedded glossary or a systematic tag. GPS signal coverage of mobile devices is especially limited in mountain catchments. Therefore, a known ID of the structure may still be relevant. Future research using such applications should address data-quality requirements. Usability should explore advantages for the diversity of volunteers getting involved (Newman et al., 2010).

3.5. CONCLUSIONS

Results showed that citizen volunteers could carry out first-level inspections with comparable performance to technicians. Differences among the 11 technicians and 25 volunteers do not have a high statistical significance when distinction is done among control and learning groups. However, key points can still be extracted from this data set. Those considerations are relevant for the use of volunteers' data on the functional status of hydraulic structures. It may also provide some guidance to researchers and practitioners interested in citizen-based data.

1) Volunteers could carry out first-level inspections with comparable performance to technicians, but with a pre-required range in precision. However, survey procedures that are clear enough require iterative design and testing to avoid uncertainty and misunderstandings;

2) In spite of the need to standardize reports, unstructured data such as comments and pictures are still required by managers to validate completeness and precision of volunteers' data. Then, the systematic tagging and referencing of that data is crucial;

3) Unspecified answers may persist according to the complexity of connected elements to the structure, and the unexpected conditions for the inspection. Rating classes should specify when water or sediment did not allow the assessment. However, other options should be limited to facilitate the later examination of data;

4) Volunteer ratings should be considered as first-level assessment. Managers could combine these ratings to get indexes on the status of the structure at parameter level. However, an indication of the overall completeness per parameter would still be needed for the later examination;

5) The use of scores to convert volunteer ratings is important for getting an indication of the functional status. Since the rating scales are expressed in

linguistic terms, ratings could be converted into numbers by using a fuzzy set theory instead of ordinal scores. Conversion of the volunteers' data using scales of fuzzy terms could handle the pre-required ranges in precision (e.g., from low to very low).

Important considerations to improve and promote citizen science projects are firstly related to limitations on citizen involvement due to different traditions of volunteer activities and interest in participating. Secondly, training is relevant for the performance of volunteers, but also for increasing awareness and preparedness on the causes and consequences of hydro meteorological hazards (Enders, 2001). For the first one, students are an alternative approach for the citizens' recruitment, where there is limited volunteer culture. Universities could involve students of geosciences or social sciences to gain practical knowledge or better understand their territory (Savan et al., 2003).

For the latter, future research should test the effectiveness of the learning session according to differences in preliminary knowledge of participants. In the study area, volunteer groups offered opportunities to carry out first-level inspections. However, replication exercises are still needed in other study areas to improve the consistency and robustness of the data evaluation. In addition, survey procedures could be adapted to other target groups, e.g., last-year high school students who are not aware/involved in management activities. That could be an alternative approach to enhance their awareness of hydro-meteorological hazards.

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4

Decision support method to systematically evaluate first-level inspections

First-level inspections could be provided by skilled volunteers or technicians to pre-screen the functional status of check dams. This paper discusses the design and testing of a support method in collaboration with the responsible technicians in evaluating inspection reports. Reports are based on linguistic rating scales that are systematically aggregated into indices by means of a multi-criteria TOPSIS method with fuzzy terms. The aggregation procedure is carried out for three parameters representing the structure's status while highlighting any lack of completeness of inspection reports. The method was evaluated using inspection reports collected during a workshop in the Fella basin in the Italian Alps. The method allows the responsible technicians to set rules to categorise the aggregated indices in one of three levels, each corresponding with a course of action. Rules were useful to categorise the aggregated indices according to the structure's status. Disagreements on rating defects suggest that a weighted aggregation procedure to calculate the indices might lead to overestimating or underestimating defects. Complementary data from historical inspections or remote sensing are required to initiate specific actions. The method can be applied to pre-screen different types of hydraulic structures after adaptation to the local conditions and functional requirements.

This chapter has already been published on: Cortes Arevalo et al. (2016):

Cortes Arevalo, V.J., Sterlacchini, S, Bogaard, T.,Junier, S. and van de Giesen, N. (2016): Decision support method to systematically evaluate first-level inspections of the functional status of check dams, Structure and Infrastructure Engineering.

4.1. INTRODUCTION

Check dams and other stabilisation structures aim to reduce the risks of debris flows (Holub and Hübl, 2008). Without appropriate inspection and maintenance, the functional condition of structures often declines (Huebl and Fiebiger, 2005). For planned maintenance, pre-screening inspections are fundamental (van Riel et al., 2014). The frequency and type of inspections depend on local circumstances and available financial resources (Holub and Hübl, 2008; Mazzorana et al., 2014).

Collaboration between relevant authorities and community organisations (Failing et al., 2007) can take the form of visual inspection campaigns with volunteers in support of technicians (Cortes Arevalo et al., 2014). To evaluate inspections performed by skilled volunteers or technicians, a method is proposed that combines a well-established approach for multi-criteria evaluation with linguistic inputs and expert-based rules. This method aggregates ratings into indices and indicates reports' completeness. Indices fall in one of three levels, each corresponding with follow-up advice. This paper discusses the design and testing of the support method in collaboration with the intended users.

4.2. OVERVIEW OF CRITERIA FOR INSPECTION AND MAINTENANCE PLANNING OF CHECK DAMS

Proactive maintenance strategies are based on the assessment of the vulnerability of check dams (Suda et al., 2009), which results from the hazard intensity and the susceptibility of the structure itself due to, for example, the state of maintenance (Uzielli et al., 2008). No straightforward relationship exists between the susceptibility of a single check dam and other components of the protection system (Dell'Agnese et al., 2013). In addition, inspection and maintenance planning should address the different functions that structures have and the value of what is being protected (Mazzorana et al., 2014). **Table 4.1** lists the system criteria for sustainable maintenance planning (Sahely et al., 2005).

In decision support methods, actions can be modelled as a set of alternatives for the decision-makers that are evaluated against a set of criteria. According to Serre et al. (2009), decisions about maintenance planning imply sorting the set of structures by applying pre-established rules. Support methods for the management of infrastructure are often based on multi-criteria methods such as the weighted sum approach (Kabir et al., 2014). A variety of examples exist for structures such as bridges (e.g. Dabous and Alkass, 2010; Rashidi and Lemass, 2011), dams (e.g. Curt and Gervais, 2014) and sewage systems (e.g. Tagherouit et al., 2011).

Table 4.1: Review of system criteria for the inspection and maintenance planning of check dams.

Criteria	Sub-criteria	Indicator	References
Engineering	Structure and function type	• Type of standard and key structures • Energy dissipation level through presence of grade control structures. • Available retention volume for solid material	Suda et al. (2009)
	Functional condition	• Structural and environmental factors affecting functionality and stability • Changes in the functional status	Dell'Agnese et al. (2013)
	Torrent processes and stress over the stream system	• Relevant inflow at the upstream boundary • Natural stability of the streambed • Rainfall patterns at sub-basin level	Cavalli et al. (2013); Mazzorana et al. (2012); Valentinotti et al. (2012)
	Geomorphic characteristics	• Mean channel slope • Variation of stream power index and sediment connectivity • Channel confinement ratio • Erodibility of the banks	
Economical	Operation and maintenance	• Initial investment • Resource allocation for inspection and maintenance.	Pardo-Bosch and Aguado (2015)
	Consequences on the built environment	• Exposed people and infrastructure at the structure location and the affected area • Occupancy type, buildings exposed, essential services affected and other land use types	Holub and Hübl (2008); Mazzorana et al. (2015)
Social	Awareness of socio-institutional organisations	• Competences and institutional requirements • Involvement of community organisations	Holub and Fuchs (2009)

The analytical hierarchy process method (AHP) Saaty (1987) facilitates pairwise comparisons in order to set the relative importance (weight) of criteria or actions (e.g. Najafi and Bhattachar, 2011; Sun and Wenjun, 2011). In addition, indicator schemes are often required to aggregate knowledge and information about the performance of a given set of criteria. Curt et al. (2011) used such a scheme to represent and aggregate measurements, sensory evaluations and expert knowledge on dam conditions. The uncertainty embedded in the indicators is generally handled with fuzzy logic theory and expert-based rules (Janssen et al., 2010).

To improve the use of decision support methods, active involvement of potential users helps refine the initial requirements for designing and testing decision support methods McIntosh et al. (2011). (Rhee and Raghav Rao, 2008, Chapter 51) (also suggest involving persons external to the design process to supply fresh perspectives. A combination of ease of use, perceived usefulness and validity of decision support methods contribute to actually being used (Díez and McIntosh, 2009; Junier and Mostert, 2014).

4.3. The design process of the decision support method

Our method was developed in collaboration with decision-makers working in the Fella basin, in the Friuli Venezia Giulia (FVG) region, located in the north-eastern Italian Alps (**Figure 4.1a**).The Fella basin (**Figure 4.1b**) is a mountainous basin prone to landslides, flash floods and debris flows, where the management of inspection and maintenance is a priority due to the increased number of protection works. After the debris flow event in 2003, the Regional Civil Protection suggested involving their volunteers to support the technicians in pre-screening visual inspections.

Cortes Arevalo et al. (2014) describe the collaborative design and testing of inspections forms with support of technicians and volunteers, followed by a data collection exercise (**Figure 4.1c** in Dec and May/2013). The form's content and layout were developed in collaboration with decision-makers from the relevant management organisations in the FVG region. Questions, rating options and visual schemes to guide the inspection (see example in **Figure 4.2**) were based on existing procedures in FVG (Servizio Forestale FVG, 2002) and neighbouring regions (Provincia Autonoma di Bolzano (2006); as referred to in von Maravic (2010)). During the data collection exercise, inspections were carried out both by technicians and volunteers. The results from that exercise showed that volunteers' reports had higher variance than technicians' reports. To cope with the differences in precision, we generalised rating scales to calculate the mode according to the questions and rating options provided in the form. For a five-option rating scale, we simply generalised into three options, namely: very low-to-low concerns, medium and high-to-very-high concerns. However, the reports of both groups were comparable in their limited reproducibility. Therefore, a method was required to support the decision-making of technicians by system-

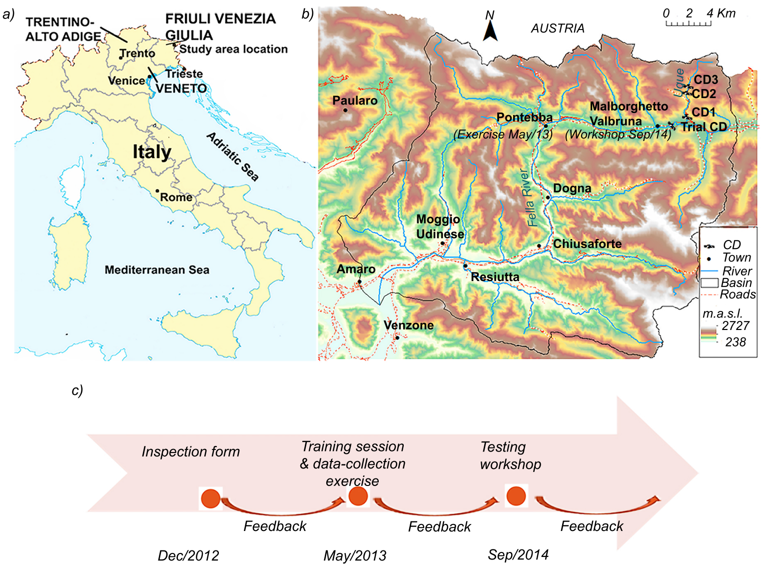

Figure 4.1: (a) FVG and neighbouring regions; (b) the study area and location of the check dams (CD) inspected during the workshop; and (c) summary of the method design process.

atically evaluating the inspection reports.

In order to test the proposed decision support method, a workshop was organised in September 2014 (**Figure 4.1c** in Sep/2014). The method was evaluated by comparing the participants' inspection reports of each of the three check dams that were selected by the technicians of Civil Protection (**Figure 4.1b**). Check dam 1 (**Figure 4.3a and b**) is a consolidation check dam with a secondary dam for downstream scouring protection. Its function as part of a series of structures along the stream channel is to reduce flow and sediment processes, and to control channel erosion. Check dam 2 (**Figure 4.3c and d**) is located downstream along the same channel and is meant mainly for the retention of wood and debris. Check dam 3 is located downstream in the alluvial fan near the Ugovizza town. Check dam 3 (**Figure 4.3e and f**) is a key check dam as it retains large amounts of wood and debris.

Fourteen participants attended the workshop. They formed two equal groups: users and new-users. The users consisted of six decision-makers of the FVG region who had participated in the design stages and a scientist. The new-users were a mixed group of two technicians of FVG, one from the intrabasin authority, two from neighbouring regions and two final-year students of geo-sciences. The workshop consisted of outdoor and indoor activities in a one and a half-day programme. During the first day, a trial check dam inspection

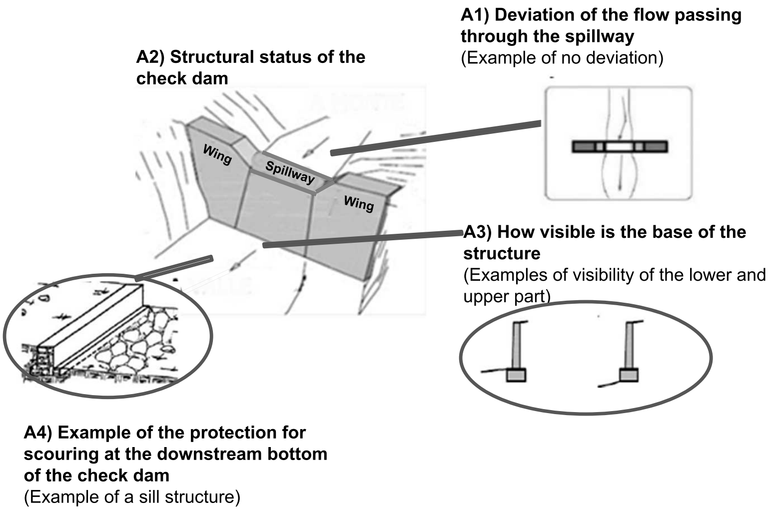

Figure 4.2: Example of questions and visual schemes to guide the inspection for parameter A, damage level of the structure. Source: adapted from existing procedures in (Servizio Forestale FVG, 2002, p.27) and neighbouring regions (Dell'Agnese et al., 2013, p.13); EF30-Vulnerability evaluation form as cited in (von Maravic, 2010, Annex 2)) referring to (Provincia Autonoma di Bolzano, 2006)

(trial CD in **Figure 4.1b**) introduced the inspection procedures to all participants (**Figure C.1 to C.2** in **Appendix C**). Subsequently, all participants inspected the three check dams of **Figure 4.3**. Next, the prototype – web-based – decision support method (Chapter 5) was introduced to the participants. During the second day, 10 participants applied the decision support method using their field data, and provided feedback afterwards.

The effect of data quality on the final condition of the check dams was assessed as follows: no defects, unclear conditions and defect(s). The most frequent rating was assumed the 'true condition' (modal rating). The agreement on the modal rating was the accuracy indicator for each question at parameter level. For each question, the following accuracy levels were used: equal to or larger than 90%, 70–90%, 50–70% and smaller than 50%. The precision was evaluated through the maximum and minimum rating that participants reported, while a completeness ratio accounted for unanswered questions. False positives (FP) are reported defects or unclear conditions that were not present. False negatives (FN) are defects or unclear conditions that were not reported. The consistency of the outputs was analysed through comparing the aggregated indices calculated using the decision support method with the expert advice after the field inspection.

Figure 4.3: Photos of the structures inspected: (a) downstream view of check dam 1; (b) check dam 1 and sill structures located in series; (c) downstream view of check dam 2; (d) level of obstruction in check dam 2; (e) upstream deposit in check dam 3; and (f) level of obstruction in check dam 3.

4

4.4. THE DECISION SUPPORT METHOD TO SYSTEMATICALLY SCREEN STRUCTURES' STATUS

After the visual inspection (**Figure 4.4**), the reported ratings were aggregated and indices were calculated using the multi-criteria TOPSIS method, representing the functional status for three parameters:

1. damage level of the structure,
2. obstruction level at the structure and
3. erosion level in the stream banks.

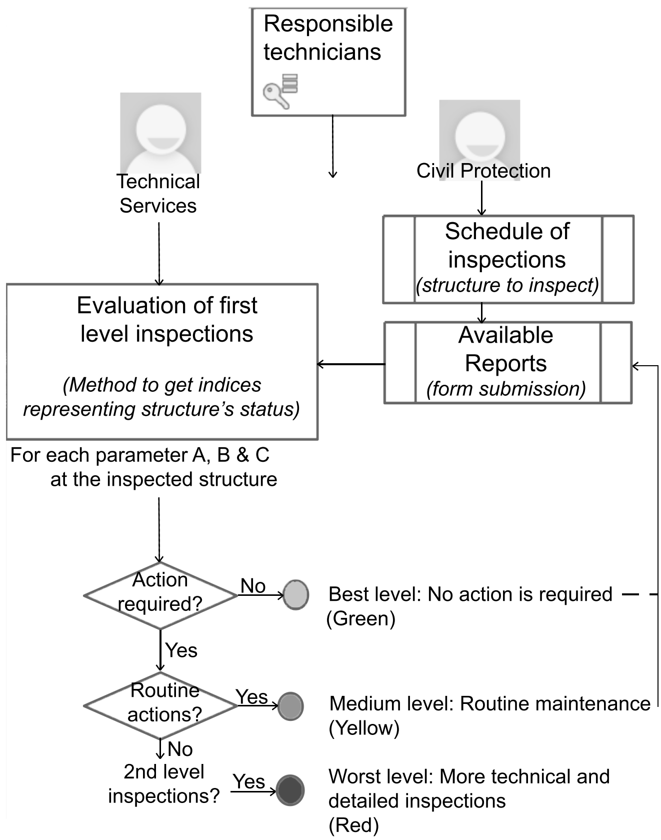

Figure 4.4: Flow diagram for inspections actions to be implemented.

The technicians set rules to assess the three indicators determining the functional status of the structure and, with that, an advised action. The best functional level requires no action, the medium level signifies routine maintenance and the worst level requires a second level or more detailed inspection to determine the type of maintenance or repairing.

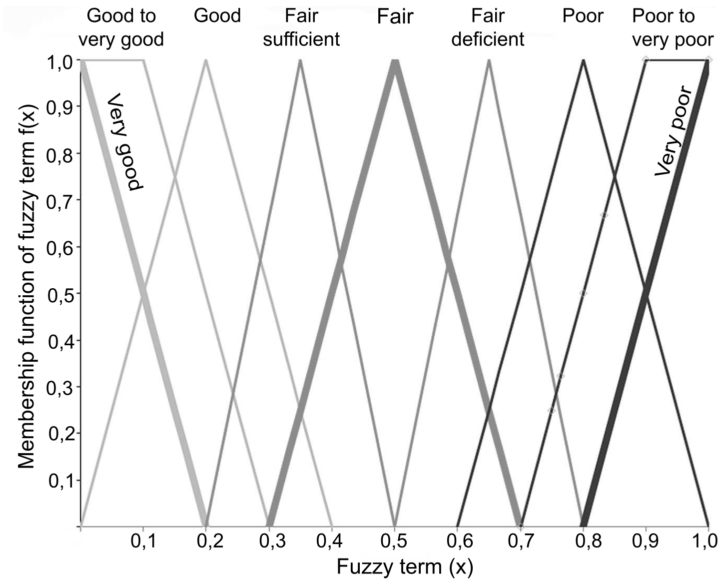

Figure 4.5: Nine fuzzy terms scale for the systematic conversion of rating options based on Chen and Hwang (1992) and adapted from Jonoski (2002).

4.4.1. CONVERSION OF RATING OPTIONS INTO SCORES

To convert the ratings into scores, fuzzy terms were assigned to the rating options for each question and subsequently systematically converted into scores. The membership functions of Chen and Hwang (1992) were chosen (**Figure 4.5**) because they include fuzzy terms (e.g. poor to very poor) that account for the differences in precision between the rating options provided in the form. **Table 4.2** presents the conversion scores assigned to all rating options. For example, for parameter A and question A3, the option 'The base of the structure is covered with sediment' was qualified as 'Good'. Decision-makers can use the report plot (**Figure 4.6**) to compare the reported conditions with the best and worst possible ratings for each question.

Table 4.2: Scores assigned to all rating options for each question per parameter on the inspection form.

Rating options per question at parameter level	Rating condition	Conversion score
A) Damage level of the structure		
A1) Deviation of the flow passing through the spillway	eight options	
4-Outside of the structure to the left	Very poor	0.917 (Sc-)
3-On the left wing	Poor to very poor	0.875
2-Slight deviation to the left wing.	Fair sufficient	0.370
1-Through the spillway	Good	0.250 (Sc+)
2-Slight deviation to the right wing.	Fair sufficient	0.370
3-On the right wing	Poor to very poor	0.875
4-Outside of the structure to the right	Very poor	0.917 (Sc-)
There is now flow, I can't assess it	Fair	0.500
A2) Structural status of the check dam	six options	
1-Structural elements are in good status, "in order"	Good to very good	0.125 (Sc+)
2-Elements have slight deterioration without cracks	Good	0.250
3-Elements have visible deterioration with cracks	Fair deficient	0.630
4-Elements have deep erosion with missing parts	Poor	0.750
5-Structural damage that compromise the stability of the structure	Poor to very poor	0.875 (Sc-)
Not assessable, the structure is covered by sediment or water	Fair	0.500
A3) How visible is the base of the structure	six options	
1-The base of the structure is covered with sediment	Good	0.250 (Sc+)
2-The upper part of the base is visible	Fair sufficient	0.370
3-The lower part of the base is visible	Fair sufficient	0.370
4-There is an opening path below the base of the structure	Poor to very poor	0.875
5-Scouring at the base of the structure	Very poor	0.917 (Sc-)
Not assessable to much water	Fair	0.500
A4) Status of the protection for scouring at the downstream bottom of the check dam	six options	
1-Not visible protection, it's covered with sediment.	Good to very good	0.125 (Sc+)
2-Protection present in good status	Good	0.250
3-No protection but there is no erosion	Fair sufficient	0.370
4-No protection but there is deep erosion	Poor to very poor	0.875
5-Protection with strong erosion or missing parts	Very poor	0.917 (Sc-)
Not assessable, too much water	Fair	0.500
B) OBSTRUCTION LEVEL AT THE STRUCTURE		
B1) Obstruction level at the open check dam	six options	
No obstruction	Good to very good	0.125 (Sc+)

Table 4.2 Continued:

Rating options per question at parameter level	Rating condition	Conversion score
<20%	Good	0.250
20-40%	Fair deficient	0.630
40-60%	Poor	0.750
>60%	Poor to very poor	0.875 (Sc-)
Not assessable (consolidation check dam)	Fair	0.500
B2) Level of sedimentation in the retention basin	four options	
> 66%	Poor to very poor	0.875 (Sc-)
33-66%	Fair deficient	0.630
< 33%	Good to very good	0.125 (Sc+)
Not assessable (consolidation check dam)	Fair	0.500
B3) UPSTREAM lateral obstruction		
B4) DOWNSTREAM lateral obstruction	six options	
No obstruction	Good to very good	0.125 (Sc+)
<20%	Good	0.250
20-40%	Fair deficient	0.630
40-60% with deviation of the flow	Poor	0.750
>60%	Poor to very poor	0.875 (Sc-)
Not assessable too much water	Fair	0.500
C) EROSION LEVEL IN THE STREAMBANKS WITHIN 20M UPSTREAM AND DOWNSTREAM OF THE STRUCTURE		
C1) LEFT bank downstream/ C2) RIGHT bank downstream/ (C3) LEFT bank upstream/ C4) RIGHT bank upstream	six options	
1-Bank in good status "in order"	Good to very good	0.125 (Sc+)
2-Bank with slight erosion or slight irregularities in the protection works	Good	0.250
3-Bank with visible erosion or visible irregularities in the protection works	Fair	0.500
4-Erosion with opening flow path below the bank or protection work	Poor to very poor	0.875
5-Important drift of the bank or missing parts in the protection works	Very poor	0.917 (Sc-)
Not assessable too much water	Fair	0.500

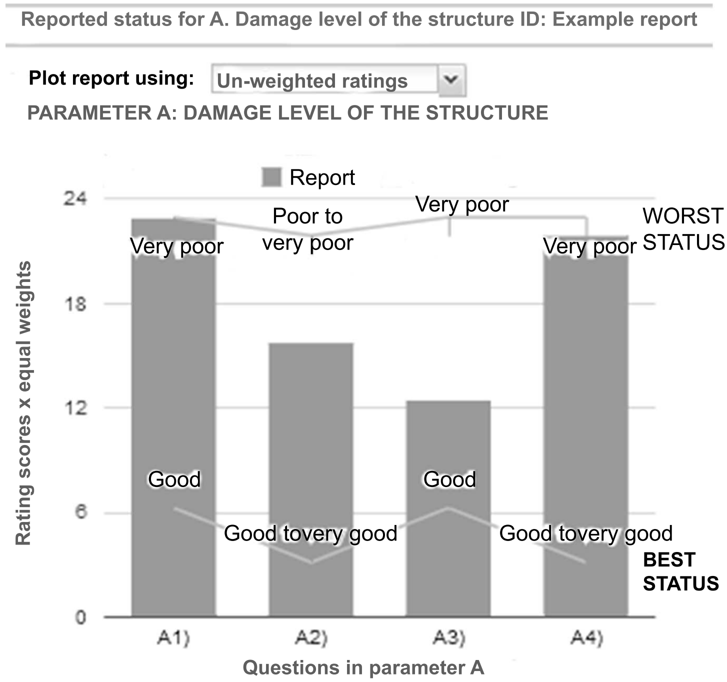

Figure 4.6: Example report plot to compare reported status (bars) against the reference best (lower line) and worst conditions (upper line).

4.4.2. AGGREGATION INTO INDICES AT PARAMETER LEVEL

The scores were aggregated into indices at parameter level using the multi-criteria method TOPSIS with fuzzy inputs (Hwang and Yoon, 1981). The TOPSIS method has been originally applied for the ranking of management alternatives (e.g. Almoradie et al., 2015). As adopted here, an index is derived from Equation (4.1), according to the relative distances to the best and worst conditions. The best functional status is defined as close to 100 and the worst as close to 0.

For each question i, the difference was calculated between the reported conditions (Sc_i) and the best (Sc_i^+) and worst (Sc_i^-) reference conditions. Equation (4.2) was used to calculate the distance(D^+) to the best rating score (Sc_i^+) and Equation (4.3) for the distance (D^-) to the worst one (Sc_i^-). The term W_i accounts for the relative importance of each question i. Setting weights can change the outcomes considerably; therefore, decision-makers should set these weights with great care. To support the weights elicitation, we suggested the pairwise comparisons of the AHP method (Saaty, 1987). Thereby, decision-makers can assess the relative importance between questions at parameter level, based, for instance, on the structure's design criteria or their expert knowledge of check dams (e.g. Dell'Agnese et al., 2013). In this study, equal weights (un-weighted ratings) were used to specifically evaluate the effect of the quality of the input data on the output of the method. By including the weights, we would have clouded the effect of the input data quality by introducing additional factors in the evaluation of inspection reports.

The reported ratings (**Figure 4.7**) were aggregated into two values at parameter level, the functional status and the completeness ratio of Equation (4.4). Where conditions were reported as unspecified, or questions were unanswered, the index was calculated assuming a 'fair' condition. An alternative option for the analysis of incomplete reports may have been by neglecting unanswered questions, assigning them a zero weight in Equations (4.2) and (4.3) for the index calculation. However, this will also alter the weights for other questions and therefore it would increase the complexity for decision-makers and limit the comparability of reports. Overestimations may be introduced, for example, by assuming a poor condition to remain on the safe side. Thus, we opted for maintaining the same weights and assuming a 'fair' condition to limit the effect on the calculated index. Furthermore, the completeness ratio calculated by Equation (4.4) draws the decision-maker's attention to unanswered questions. Lastly, decision-makers can modify the rating condition and corresponding score for unspecified or unanswered questions according to their assessment of the functional requirements of the structure itself (see **Table 4.2**). The aforementioned equations are defined as follows:

4

$$Idx_{A,\ B\ or\ C\ parameter} = \frac{D^-}{D^+ + D^-} \times 100\% \tag{4.1}$$

$$D^+_{A,\ B\ or\ C\ parameter} = \sqrt{\sum_{i=1}^{n} (Sc_i - Sc_i^+)^2 W_i^2} \tag{4.2}$$

$$D^-_{A,\ B\ or\ C\ parameter} = \sqrt{\sum_{i=1}^{n} (Sc_i - Sc_i^-)^2 W_i^2} \tag{4.3}$$

$$Completeness(\%)_{A,\ B\ or\ C} = \frac{\#questions - \#Unspecified\ ratings}{\#questions} \tag{4.4}$$

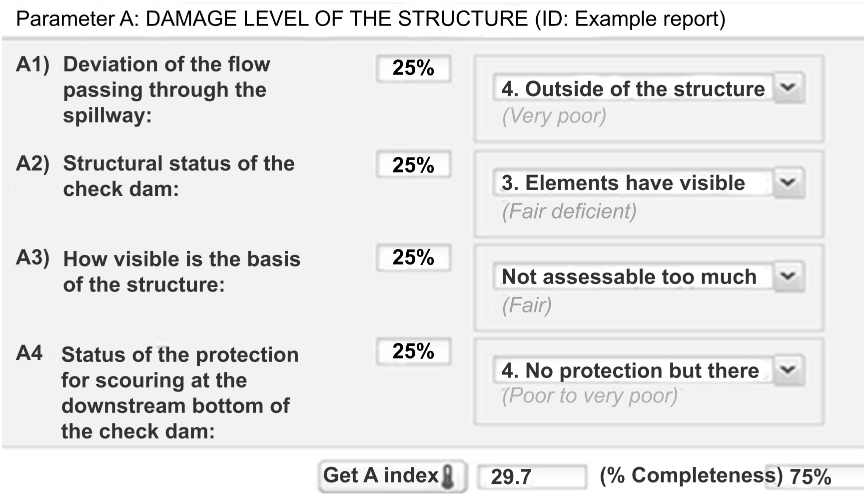

Figure 4.7: Example report illustrating the aggregation of rating scores including very poor conditions and unspecified answers.

4.4.3. RULES TO IDENTIFY LEVELS OF FUNCTIONAL STATUS PER PARAMETER

To arrive at an advised action, decision-makers define a status that is acceptable, by setting two rules at the parameter level: the lowest acceptable aggregated index Idx and the worst acceptable rating $condition$. To be assigned the worst level, the aggregated index has to be smaller than Idx and the worst rating score has to be larger or equal to the given $condition$. Idx can range from 0 to 100. A $condition$ can be selected from fair deficient (FD), fair (F), poor (P), poor to very poor (PVP) and very poor (VP). The combination of the two rules leads to the assigned functional status at parameter level (**Table 4.3**).

Table 4.3: Levels of functional status at parameter level.

Functional level	Proposed Action	Rule combination
Best	No action is required	The rules for the acceptable index AND the worst rating are FALSE
Medium	Need for routine maintenance	Either the acceptable index OR the worst rating rule is FALSE
Worst	Second level inspection or more detailed engineering procedures are required to take a decision about the maintenance type	The rule for the acceptable index AND the worst reported rating are TRUE

In this study, Idx was set to 70 and $condition$ to Poor. This leads to an outcome space with four areas according to their functional levels. A report results in the worst functional level when the combination of the two rules is true (**Table 4.3**). In the example of the index comparison plot (**Figure 4.8**), the dark grey dots are the aggregated indices for all possible rating combinations horizontal axis) against the average scores (vertical axis). The white dots indicate the aggregated indices (horizontal axis) against the worst rating of every possible combination (vertical axis). As an example, in **Figure 4.8**, the report (R) is given by the combination of ratings of 'very poor' for question A1, 'fair deficient' for A2, 'fair' for A3 and 'poor to very poor' for A4 that leads to an index of 29.7. In **Figure 4.8**, (R) is indicated as a dark grey dot with the index (29.7) and the average score of reported ratings (18.3). The index of the report (R) is also plotted as a white dot against the worst reported rating (22.9). In addition, other possible rating combinations leading to the same index are indicated within the index annotations.

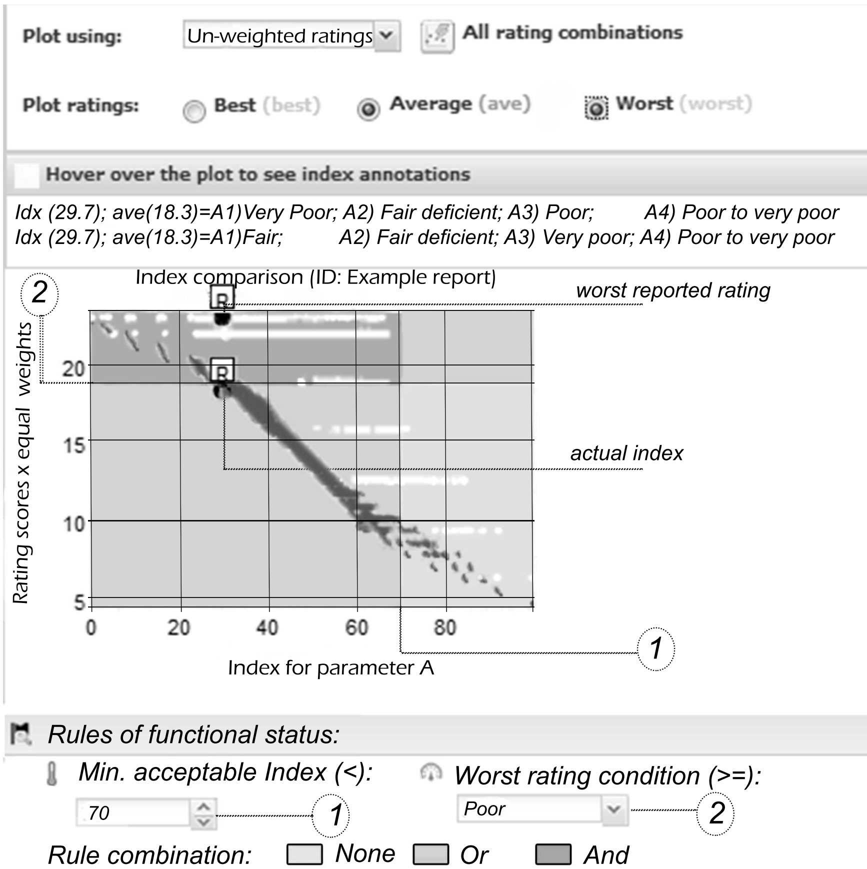

Figure 4.8: Example of index comparison plot for parameter A.

To further assist decision-makers in defining the acceptable minimum index and the worst acceptable rating, the cumulative frequency of the occurrence of a given index $F[Idx]$ was analysed for all possible rating combinations. For example, indices were calculated for all 1728 possible rating combinations according to the rating options listed in **Table 4.2** for parameter A. In this frequency analysis, $F[Idx]$ shows the cumulative frequency of calculated indices and the position of a given index in the outcome space of the method, Idx range. **Table 4.4** presents as an example the frequency analysis regarding parameter A.

Table 4.4: Cumulative frequencies of aggregated indices for each possible rating combination according to the index range and worst rating condition for Parameter A.

			Cumulative frequency of indices given the set worst rating condition				
Idx Range		$< F[Idx]$ (%)	$\geq F[Idx\|F]$ (%)	$\geq F[Idx\|FD]$ (%)	$\geq F[Idx\|P]$ (%)	$\geq F[Idx\|PVP]$ (%)	$\geq F[Idx\|VP]$ (%)
0-10	[<10]	2				100	88
10-20	[<20]	3				100	88
20-30	[<30]	7				100	85
30-40	[<40]	23				100	76
40-50	[<50]	52			100	100	67
50-60	[<60]	78	100	100	98	96	58
60-70	[<70]	91	100	97	93	89	53
70-80	[<80]	97	11	4			
80-90	[<90]	100	8				
90-100	[<100]	100					
100	[=100]	100					

Notes: Idx range: the outcome space of the method.
$< F[Idx]$: cumulative frequency of occurrences of indices that are lower than the upper limit of the Idx range.
$\geq F[Idx|condition]$: cumulative frequency of indices, given the set worst rating condition.
$condition$ can take the values: f: fair; fd: fair deficient; P: Poor; P-VP: Poor to very poor; and VP: Very poor.

As all questions are weighted equally, all possible rating combinations (**Table 4.4**) have a normal cumulative frequency distribution ($F[Idx]$). In addition, the column $\geq F[Idx|condition]$ indicates the cumulative frequency of rating combinations provided, given that at least one question was reported worse or equal to the $condition$ selected for the worst rating. For column $F[Idx|condition]$, the $condition$ was set as fair (F), fair deficient (FD), poor (P), poor to very poor (PVP) and very poor (VP). $F[Idx|condition]$ presents the cumulative percentage of occurrences below the index range ($< F[Idx]$) for each possible condition. In this study, the acceptable index and the worst rating were set at 70 and at poor. Thus, this example shows that from all 1728 possible rating combinations, 91% have a cumulative frequency of indices lower than 70 (see column $< F[Idx]$ and Idx range 60–70 in **Table 4.4**. From that 91%, 93% have at least one rating worst or equal to poor ($F[Idx|P]$). If the decision-maker sets the worst acceptable condition at very poor (VP), then 53% of that 91% will be in very poor condition for at least one question ($\geq F[Idx|VP]$). Moreover, **Table 4.4** illustrates the cumulative frequencies below the index range when varying the worst rating condition (see columns $[Idx|F]$, $[Idx|FD]$, $[Idx|P]$, $[Idx|PVP]$ and $[Idx|VP]$).

4.5. RESULTS OF USING THE DECISION SUPPORT METHOD

This section presents the results of applying this method in the September 2014 workshop. To see whether there is a positive effect of being involved in the design process, users that were and those that were not involved before the workshop were compared. First, the results of the method will be assessed in terms of differences in the decision outcomes within groups and between groups. Next, the perceived usefulness of the inspection form and the proposed method according to participants will be discussed. The reported ratings and the aggregated indices for the three check dams inspected are available in **Appendix C** (**Tables C.1 to C.3**) together with an overview of the feedback provided by participants (**Tables C.4 to C.5**).

4.5.1. DIFFERENCES IN THE DECISION OUTCOMES DUE TO DIFFERENCES IN INDIVIDUAL REPORTS

The individual reports consisted of ratings for questions at the parameter level together with a synthesis advice for further action that inspectors gave in the field by selecting one of the following management actions: (1) no action required; (2) routine maintenance with support of volunteers; (3) routine maintenance using equipment; and (4) second-level inspection. After a comparison of inputs (ratings) and outputs (advice) per individual inspections and structures, the following issues were addressed:

- Differences in the reported ratings for each question depending on the accuracy, precision and completeness of inspection reports.
- Differences in the aggregated indices and comparison of the inspectors' advice with the functional levels that were assigned in the decision support method.

DIFFERENCES IN THE REPORTED RATINGS FOR EACH QUESTION

Figure 4.9 summarises the reported ratings for each question by participants' group and check dam. The scores in the upper area represent a reported defect and correspond to ratings between very poor (VP) and poor (P). The middle area stands for ratings in which a defect is not clearly recognisable or information is limited. Those are ratings between fair deficient (FD) and fair sufficient (FS). The lower area stands for no defects with ratings between to very good (VG) and good (G).

Table 4.5: Frequency of errors for all inspected check dams at parameter level.

Parameter	Error type(%)	All Participants(%)	Users(%)	New-users(%)
A	FP	8.33	4.76	11.91
	FN	13.69	17.86	9.52
B	FP	14.29	12.86	15.71
	FN	7.86	5.71	10.00
C	FP	19.05	19.05	19.05
	FN	0.00	0.00	0.00

Notes: False positives (FP): answers reporting defects or unclear conditions that were not present. False negatives (FN): present defects or unclear conditions that were not reported.

The modal score of users and new-users were the same in most cases (**Figure 4.9**), despite the differences in precision (maximum and minimums reported ratings). By aggregating the results of all participants, only the modal score of one question resulted in assigning a 'poor' status (A1 for check dam 3). The mode for five questions resulted in an 'unclear' status (A1 for check dam 1 and 2, A3 for check dam 2 and 3 and B1 for check dam 2). The other questions resulted in a 'good' status, for example, the modal scores for parameter C. In addition, regarding the probability of errors, **Table 4.5** summarises the frequency of false positives (FP) and false negatives (FN) at parameter level. For parameter A, for all participants, the frequency of FN is somewhat higher than the FP. In contrast, for parameters B and C, the error frequencies of FP are higher.

DIFFERENCES IN THE AGGREGATED INDICES AND COMPARISON OF THE INSPECTORS' ADVICE WITH THE CALCULATED FUNCTIONAL LEVELS

To compare the outcomes of the users and new-users groups, the individual inspection reports were aggregated at parameter level. **Figure 4.10** shows the differences in the calculated indices at parameter level for each check dam. The relative frequencies of resultant indices (bars) are plotted for each group, whereas the cumulative frequencies (line) are plotted for all participants.

Regarding check dams 1 and 2, the range of calculated indices for parameter A is mostly above 70. Regarding check dam 3, the most frequent indices are in a wider range between 60 and 70 and 80 and 90. It turned out to be unclear whether the sectional barriers in the open check dams were to be reported in question A2 (condition of the structure). Some technicians only reported the damage of the bars in the comments and did not include them in answering question A2.

Regarding check dams 2 and 3, calculated indices for parameter B had a larger variability (between 40 and 70). Parameter C comprised most unanswered questions of all parameters. However, the indices were calculated by assuming 'Fair' conditions and indicating the completeness ratio, Equation 4.2 in Section 4.4.2. Despite the lack of completeness, the range of calculated indices for parameter C was mostly above 70 with some outliers for both check dams 1 and 2.

To analyse the consistency of the outputs, the inspectors' advice was compared with the outcome of the decision support method (**Figure 4.11**). The inspectors' advice varied, but the majority considered check dam 1 in good condition, requiring no action. The majority of inspectors considered check dam 2 in need of cleaning of sediments using equipment. Regarding check dam 3, the majority was divided between the need of a routine cleaning and one with support of equipment.

As a result of the calculations by the decision support method, check dam 1 was assigned the best level for parameters A, B and C, although the results were divided for parameters B and C. Check dam 2, was assigned the best level for parameters A and C. The result for parameter B shows a medium level, which implies cleaning of obstructions. In comparison, for check dam 3, parameters B and C were mostly rated the best level and parameter A shows a divided opinion between best and worst levels. The results of the inspector's advice and the output of the decision support method correspond fairly well. In both cases, some ratings resulted in assigning low functional levels, slightly more so for the new-users group.

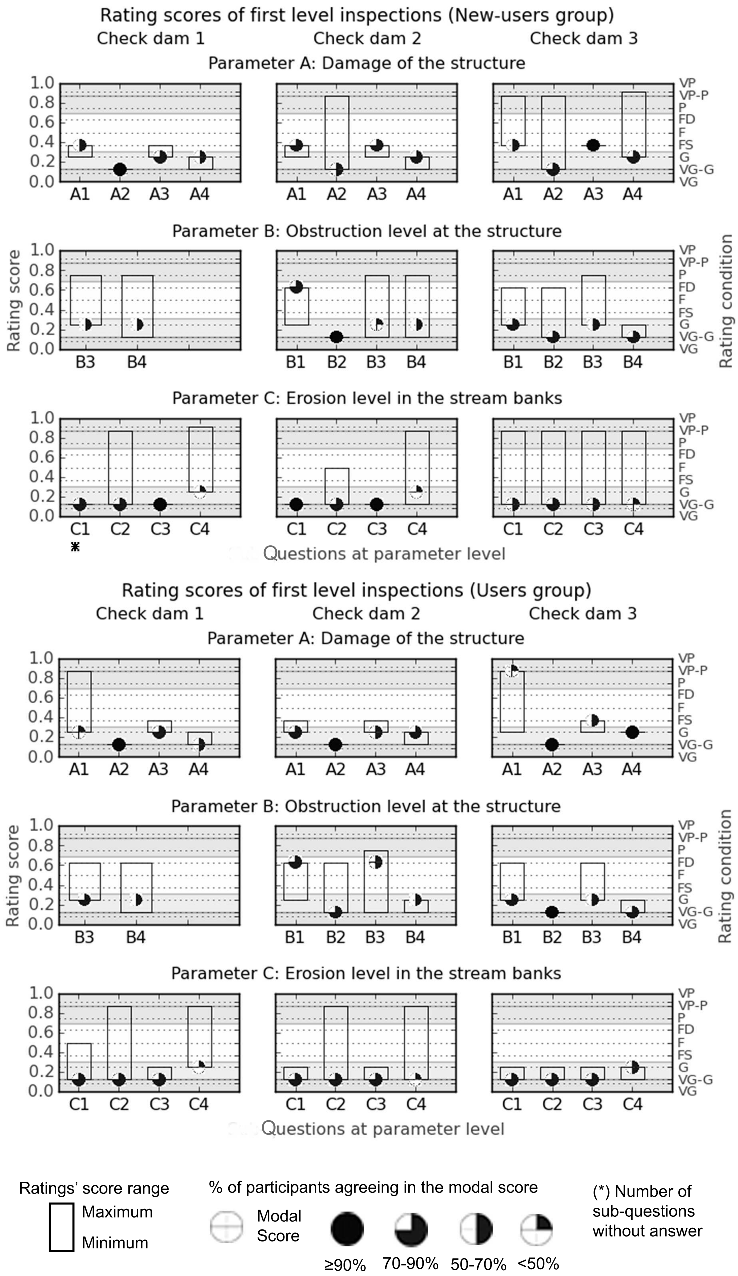

Figure 4.9: Differences in the reported ratings for (a) users and (b) new-users groups.

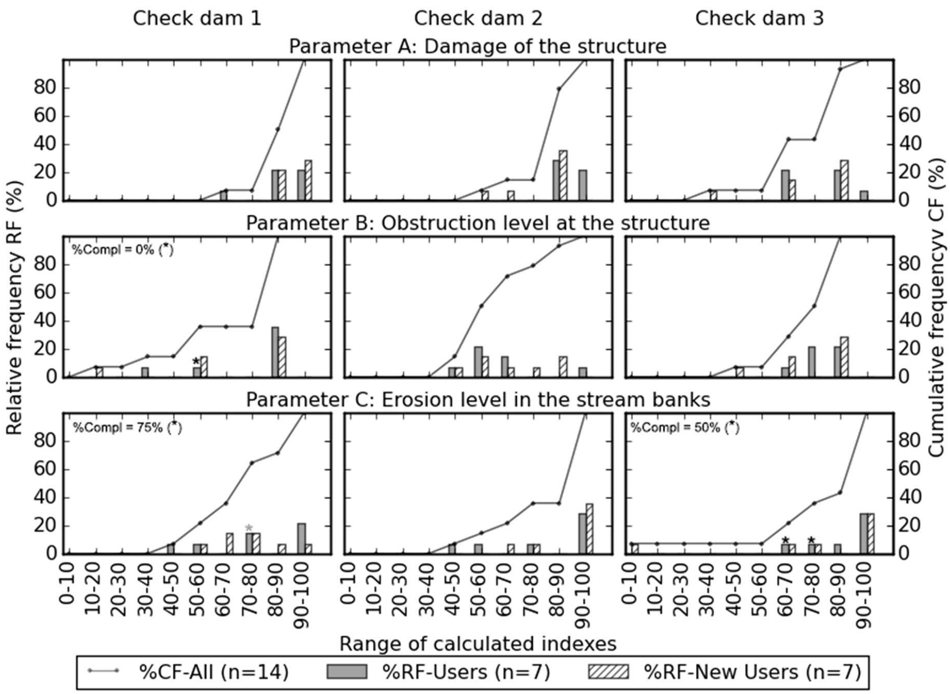

Figure 4.10: Frequency analysis for the calculated indices at parameter level per inspected check dam. the percentages are calculated referring to the total number of participants. (*) indicates indices calculated for incomplete reports

4.5.2. PARTICIPANTS' PERCEPTION OF THE USEFULNESS OF THE METHOD

Figure 4.12 depicts the views of both groups on: (a) rating options and conditions in the design of the inspection form and (b) perceived clarity, reliability and usefulness of first-level inspections. Participants rated their level of agreement from -3 (full disagreement) to +3 (full agreement) and provided comments to explain their judgement. Feedback from new-users on the inspection form was particularly relevant as they had a fresh perspective.

Figure 4.12a shows the level of agreement regarding the fuzzy terms assigned to the rating options (**Table 4.2**). To that end, participants checked the fuzzy terms assigned for each question for all parameters. Although the mean agreement level was positive for both groups, the users group was more positive, which may be due to their previous involvement. All participants provided suggestions for improvements of the inspection form as summarised in **Table C.5** (see **Appendix C**).

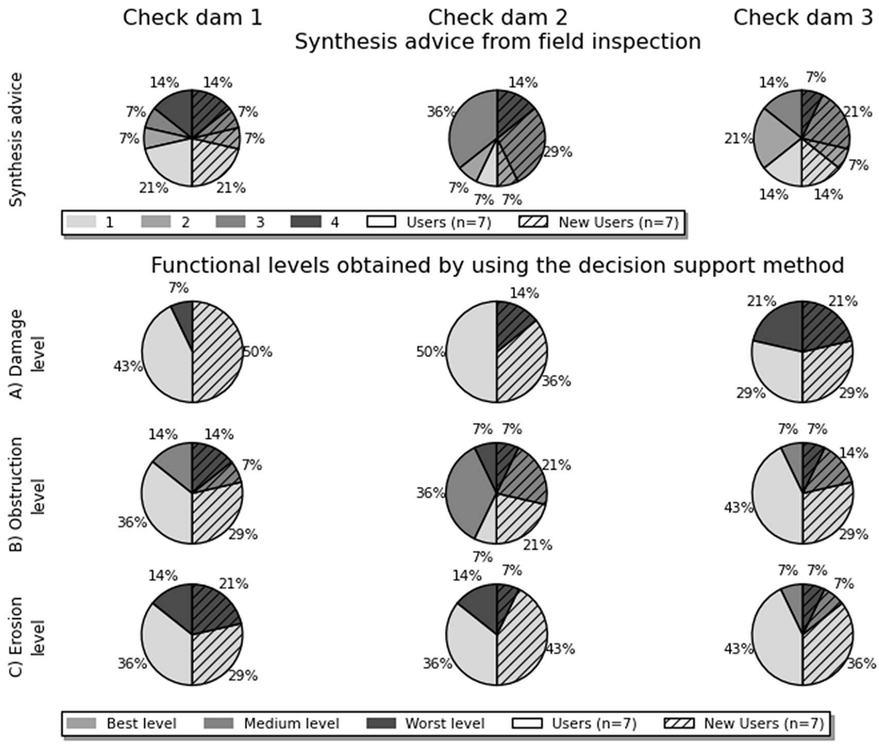

Figure 4.11: Comparison of the assigned advice in the synthesis from the field inspection and the calculated functional levels. Note: the advice distinguishes four levels, but the decision support method distinguishes three, merging the two middle categories.

Figure 4.12b depicts the results regarding the perceived clarity, reliability and usefulness of first-level inspection reports. The participants specifically judged the following statements:

- The questions and options to report are clear enough.
- Reliable information can be collected with these questions.
- The information collected this way is useful to set priorities for the maintenance of hydraulic structures.

Figure 4.12 reflects the need for improvements **Table C.5** (see **Appendix C**). Concerning the reliability, participants remarked upon the need for training and instructions with photo examples that can be taken to the field. The inspectors, whether volunteers or technicians, should always supplement their ratings with the photo record of the inspection and compare these with available previous inspections. The users group suggested carrying out first-level inspections after an important rainfall event to establish the check dams' status.

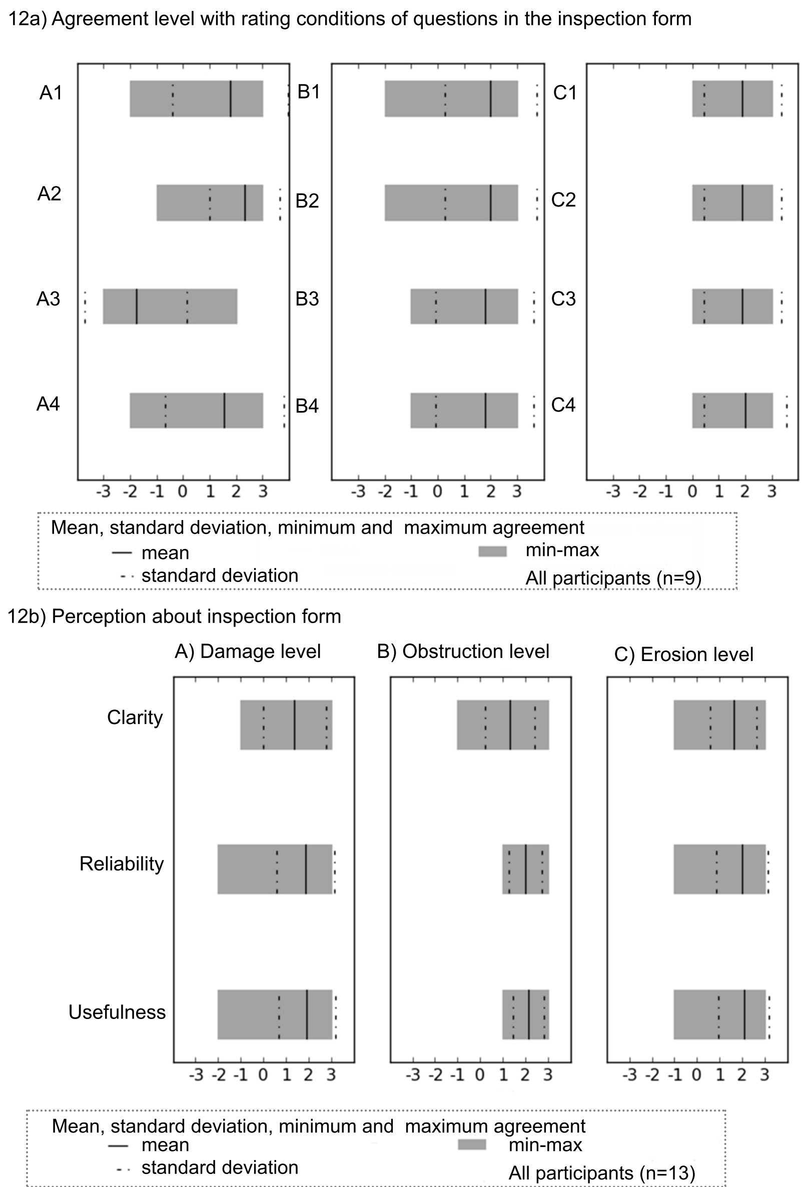

Figure 4.12: Overview of participants' level of agreement (Table A4 in appendix1). The difference in the participants' number was because not all users group attended the second-day programme.

4.6. DISCUSSION ON THE USE OF FIRST-LEVEL INSPECTION REPORTS FOR DECISION-MAKING

The usefulness of methods proposed depends on how well the limitations of rating systems are understood and handled by decision-makers (Swets, 1988). In our study, an undisputed 'True condition' cannot be established, but the modal result was defined as true and the disagreement can be seen as a lack of precision or an error. Thus, the differences in outcomes, resulting from the disagreements in the reports, were analysed (**Figure 4.9**) and explored to improve the inspection form. Based on the categories distinguished by van der Steen et al. (2014), the following causes for disagreement can be distinguished:

1) Questions or support schemes did not clearly specify the condition to observe. For example, question A1 asks about the deviation of the flow in the spillway. Although there was no deviation in the spillway of check dam 1, a deviation was reported (**Figure 4.3a**), mainly by the new-users group, because there was a deviation of the stream flow downstream of the check dam. To avoid misunderstandings, participants suggested transferring this question to parameter B.

2) Observed conditions could not be reported through the options provided. This is illustrated by parameter B for check dams 2 and 3 (**Figure 4.3c** and **e**). The accumulated debris was deposited in the retention basin after recent rainfall events. Some participants did not report them because sediments may be washed away in future rainfall event.

3) The difference between the rating options was unclear. This is derived from the accuracy levels and range in precision presented in **Figure 4.9**. A larger range in precision indicates a difficulty to distinguish differences between the rating options, but a smaller range increases the accuracy error. Regardless of who performs the inspection, technician or volunteer, a supporting manual regarding how to fill out the form is useful to clarify differences between rating options. Overall, the precision of the users group was slightly better than new-users. The lack of completeness was mainly the result of unanswered questions by users. The completeness ratio was slightly better for the new-users than the users group.

As shown in **Table 4.5**, disagreements can be due to an inspector failing to recognise a defect (FN) and a defect being reported, although there is none (FP). Dirksen et al. (2013) indicated for visual inspections in sewage infrastructure that the probability of FN is significantly larger that the probability of FP. In our case, FN was somewhat higher only for parameter A (Damage level). Inspectors may have erred on the side of caution when it was not possible to distinguish between rating options. Such could be the case for parameters B (obstruction level) and C (erosion level). The rated defects are higher than reality demands (see also Curt et al., 2011) and the probability of FP increases. Training and longer experience of participants using the form may reduce the number of FP.

By facilitating the definition of expert-based rules to categorise the indices, some flexibility in the application of the method is introduced. In this study, we used equal weights at parameter level to evaluate the effect of the input data quality on the output of the method. By applying the same relative importance for all questions, errors within the data equally affected all calculated indices. The findings regarding the probability of errors (**Table 4.5**) suggest that using different weights for the aggregation of ratings lead to underestimating or overestimating defects. Weights may still be relevant for the damage level (parameter A) to distinguish the effect of damages in different parts of the structure, but perhaps not for erosion and obstruction levels (B and C parameters). In either case, we suggest that assumptions for setting up the method (i.e. weights and treatment of unanswered questions) are made only once for every structure inspected. Changing assumptions will affect the comparability of all future reports of the same structure. A statistical analysis of the weights for different types of structures would be required to understand their effect in the evaluation of reports and priorities of interventions.

The effect of errors on the output of the method also depends on the pre-established rules to classify the indices into functional levels. The analysis of the cumulative occurrence of a given index $F[Idx]$ (**Table 4.4**) suggests that combined rules become necessary to choose between the worst and medium functional levels. In this study, worst functional levels were assigned by $Idx < 70$ and condition ≥ Poor. Using $Idx < 70$, (too) many combinations were considered in the worst level (**Table 4.4**). Decision-makers can decrease the acceptable index or increase the limiting worst condition.

Regarding the differences between inspection advice and outputs of the decision support method, most parameters were categorised as having the best or medium status requiring only cleaning. However, both users and new-users show a bias to the lower functional levels (**Figure 4.11**). Advice from new-users (mainly technicians from other regions and students) were generally lower than the users. New-users had less knowledge of the inspected structures and the study area, which probably led to (overly) cautious ratings.

To validate the inspections and set expert-based rules, additional information is required that can come from the photo taken to support the reports or from previous inspections reports. It is important to maintain and update the database of hydraulic structures of first-level inspections carried out at different periods. The imperfections and limitations of visual inspections can be countered using remote sensing techniques and vice versa. Some studies are already using multi-temporal data-sets for the impact analysis of check dams and hydrogeological mapping at sub-basin level (Raghu and Reddy, 2011). The morphometric analysis of remote sensing data can support the susceptibility analysis of the system of protection works at sub-basin level rather than limiting it to the individual structures (e.g. D'Agostino and Bertoldi, 2014; Patel et al., 2013).

The decision support method provides options to set rules distinguishing the functional status at parameter level. According to Vuillet et al. (2012), multi-criteria methods may be useful for intermediate aggregations about the performance of relevant criteria, but expert-based rules are more suitable to get an overall judgement about the functional status. By indicating the functional status at parameter level instead of aggregating the parameters score in a global index, compensation of extremes or errors in one parameter by the other two parameters is avoided. A sorting of inspected structures is required for prioritising management actions. The sorting (see **Figure 4.4**) could be based on the assessment of each of the three parameters. Alternatively, sorting could consider the completeness ratio of inspection reports.

The focus was on the functional status because it is a preliminary, but essential, criterion towards a proactive management approach (Mazzorana et al., 2014). Other important criteria that should be further investigated to set priorities for maintenance planning are (**Table 4.1**): for example, changes in the functional status at different periods; dominant water–sediment processes in the system; functional type of the check dam within the system; and type and relevance of exposed elements that are being protected by the check dam. Moreover, the outputs of this method could be further evaluated with alternative approaches such as Bayesian inference (Schweckendiek et al., 2014) and fault tree analysis (ten Veldhuis et al., 2013) to analyse changes of the functional status over time.

Finally, the collaboration with the responsible technicians was key to addressing the user requirements for decision support from the early stages. A group of 14 participants attended the organised workshop; half of them were involved in the design process. Involvement of users and new participants in the process was valuable to analyse differences in decision outcomes and to identify the need for improvements or further research.

A combination of usefulness and validity is particularly important (Junier and Mostert, 2014). Balancing those aspects required less complex scientific methods in favour of the users' understanding of underlying assumptions behind the support applications (Rao, 2007). In our application, the use of fuzzy terms was limited to systematically converting inputs to the support method. The conversion of scores could perhaps be improved by modelling the membership functions for the fuzzy terms with experts and by carrying out a sensitivity analysis on the effect of the gradient and shifting of membership functions (Chou and Yuan, 1992). To enable the assessment of the effect of choosing certain rules, the decision-makers need to be provided with easy to interpret information. Weighing of individual questions may introduce more complexity. Another possibility to give some flexibility for setting the rules without necessarily introducing more factors (weights) would be, for example, instead of using the worst condition from at least one question to two or more reported questions.

4.7. CONCLUSIONS

The presented decision support method used the multi-criteria TOPSIS method to provide an indication of the functional status of check dams by aggregating the reported scores into indices. Check dams can have different functions in the system of protection works due to their influence on flow and sediment processes. Management organisations can optimise their use of human resources by, for example, having skilled volunteers inspect complementary check dam structures, while regular technicians teamed up with volunteers inspect more critical check dams. Regardless of these management choices, an important advantage of the decision support method is that it allows inspections by either skilled volunteers or technicians, while ensuring that responsible decision-makers can systematically evaluate the reports.

Participants in the workshop considered it fundamental for all volunteers to be well-trained. We suggest that quality control campaigns should be regularly carried out to evaluate the data that are being collected; for example, by asking at least three inspectors to inspect the same structure. In addition, technicians can carry out inspections campaigns teamed up with volunteers. In that way, technicians can benefit from understanding the local stream patterns from volunteers' knowledge and volunteers can get additional training and experience on carrying out the inspections themselves.

By indicating the functional status at parameter level instead of a global index that aggregates the result of A, B and C parameters, compensation of extreme conditions or errors into an overall judgement for all parameters is avoided. Moreover, a sorting of structures is required to prioritise management actions. For such sorting, additional consideration should be given to combine outputs of preliminary inspections with other available knowledge about the relevant criteria at pre-screening level (**Table 4.1**). Thereby, decision-makers can assess the results of the individual parameters from a broader perspective and then choose what action is to be taken. However, a balance between complexity and user-friendliness should be maintained for further development stages in the decision support method.

It is expected that the steps of the method as described in the design section can easily be adapted to other situations where an evaluation of qualitative data is required. Certainly, for other structures or in other regions, other questions will become relevant and it is suggested to develop the inspection form together with the users. However, the translation of the answers to indexes and the combination with expert-based rules can be applied in many situations. Future research should evaluate the use of this method for other types of hydraulic structures that may be relevant within a system of protection works. That is, for example, the case for culverts and box culverts in mountain basins, where blocking materials such as debris, large wood and other residues can aggravate flood hazard. An integrated monitoring approach based on the combination of visual inspections with available information from high-resolution images and sensors can be useful to handle limitations of the different methods.

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5

A WEB-GIS DECISION SUPPORT FRAMEWORK FOR ASSISTING TECHNICIANS IN EVALUATING FIRST-LEVEL INSPECTIONS

This paper presents a decision support framework to assist technicians, responsible for the inspection and maintenance of protection works, in a first-level inspection to evaluate the functional conditions of check dams. We followed a user-centred design approach by engaging technicians in the Fella basin (north-eastern Italian Alps) since early design stages. First-level inspections can be carried out by regular technicians or skilled volunteers to identify possible degradations in the status of the structure itself or surrounding area. Technicians-in-charge evaluate the functional status of inspected check dams based on available reports. Therefore, the conceptual design of our decision support framework incorporates four modules for managing the inspection reports: 1) Registered users, 2) Inspection planning, 3) Available reports, 4) Evaluation of reports. The framework was developed on a web-GIS platform using Opengeo Suite. In this paper, we show the full implementation of the evaluation module for the evaluation of check dam inspection reports. Feedback from potential users was collected during a testing workshop organized in the study area. Participants perceived the evaluation module as useful and innovative and highlighted aspects to refine its capabilities. The conceptual design of the decision support framework can be further adapted to evaluate inspections reports of other type of hydraulic structures.

This chapter is based on: Cortes Arevalo et al. (Under Review):

Cortes Arevalo, V.J., Aye, Zar Chi., Frigerio, S., Schenato, L., Bogaard, T., Pasuto, A., Sterlacchini, S. (Under Review). A Web-GIS decision support framework for assisting technicians in evaluating check dams inspection reports, Water Resources Management.

5.1. INTRODUCTION

Decisions about inspection and maintenance planning of mitigation structures against debris flows such as check dams are usually under the responsibility of specialized technical agencies. Here, competent technicians decide about the functional status of such structures based on tier-level inspections (Rudolf-Miklau and Suda, 2013). Tier-level inspections start with a prescreening level, hereafter referred as first-level inspections. Technicians-in-charge generally assign inspectors to fill in reports and take pictures as complementary data to the inspection. More frequent or larger coverage of inspection campaigns can be possible by involving skilled volunteers in support of regular inspector technicians. However, using visual inspections requires systematic evaluation procedures to support maintenance decisions about the inspected structures (Dirksen et al., 2013). Moreover, the use of such inspections for proactive inspection and maintenance strategies require efforts for coordination and collaboration between the different management organizations (Prenger-Berninghoff et al., 2014; Watson, 2004) that may benefit from the use of the collected data.

The use of web Geographic Information Systems (GISs) and decision support systems (DSSs) has become increasingly prevalent for the management of environmental resources and related hydraulic structures (Matthies et al., 2007). The increasing availability of open-source data, web-based applications and geospatial technologies (e.g. Botts et al., 2008) has simplified the exchange, processing and visualization of geospatial information that is relevant for decision-making (e.g. Chang and Park, 2004; Frigerio et al., 2014; Gkatzoflias et al., 2013; Turconi et al., 2014). One of the advantages of web-based applications is it makes information interoperable between management organizations (e.g. Awad et al., 2009), which has increased the preference of web-based over desktop-based applications (e.g. Nogueras-Iso et al., 2005). Web applications further facilitate the use of a variety of data sources and technologies following standard formats for data collection and processing (Horsburgh et al., 2011). Moreover, a growing community of open-source research has facilitated the application of web-GIS technologies into the development of decision support frameworks, for example in the field of natural hazards and water management (Aye et al., 2015b; Delipetrev et al., 2014; Stefanovic et al., 2015).

Despite potential advantages of DSSs and web-GIS applications, differences in expectations and expertise level of the variety of intended users have created a gap between design and use (Bhargava et al., 2007). Laitenberger and Dreyer (1998) stated that users tend to use a system according to the extent they believe it is useful to perform their activities and the system is appropriate for the context of use. Díez and McIntosh (2009) suggest that factors influencing the use and usefulness of DSSs include users' participation and perception of the system, user computer experience, quality in use, top management support and training or support to adopt the system.

McIntosh et al. (2011) summarise the challenges for developing DSSs into engagement, adoption, cost and technology, testing and validation. Thereby, engagement challenges require having strategies according to available resources to work collaboratively with users since early stages of the development. Adoption challenges require starting with simple implementations, developing tools incrementally and having a strategy to facilitate the future adoption of the designed application. Cost and technology challenges require re-using software components to overcome up-front development and ensuring funding for the long-term maintenance. Finally, testing and validation challenges are not only about using the designed application but also about analysing the support capabilities, for example in decision-making.

To address design challenges, user-centered design approaches (UCD) are being widely considered in software engineering (McIntosh et al., 2011; Wallach and Scholz, 2012). UCD originates from the usability aspects of designing software user interfaces (Gould and Lewis, 1985). Therefore, ISO/IEC. 9241-14 (1998) standards define usability by the extent to which a designed product can be used to achieve specified goals in a context of use (effectiveness), optimizing the resources expended (effectivity) and generating a positive attitude towards the use of the product (satisfaction). An extended view of usability can be the quality in use of a designed product for its intended purpose (Bevan, 1999). In so doing, UCD aims at better understanding usefulness, usability and appropriateness requirements by engaging users since early design stages (van Velsen et al., 2008). In this paper, we present a prototype of a decision support framework for assisting technicians in evaluating check dam inspection reports. We evaluate the usefulness of such framework following a UCD approach as implemented in a pilot study area.

5.2. User requirements for the evaluation of first-level inspections

The Fella basin, located in the northeastern Italian Alps of Friuli Venezia Giulia Region (FVG), was chosen as pilot study area due to the existing collaborations between potential users and scientists. After severe floods and landslides occurred in 2003, Civil Protection of FVG implemented several mitigation measures such as check dams as an immediate reaction to the disaster (Prenger-Berninghoff et al., 2014). In addition, for planned inspection and proactive maintenance of implemented works, Civil Protection suggested skilled volunteers in support of technicians to carry out first-level inspections in the Fella basin. Consequently, technicians-in-charge required systematic inspection procedures to use volunteers' reports for decision making on check dams maintenance.

Preliminary research included a data-collection exercise with technicians and volunteers to better understand the context of use and issues about the quality of first-level inspections Cortes Arevalo et al. (2014). We focused on the inspection of check dams due to its relevance, number and often remote location in the mountain basin of the pilot study area. Potential decision-makers are technicians who are in-charge of planning inspection and maintenance of mitigation works. In our study, skilled volunteers are mainly Civil Protection volunteers from the municipalities of the pilot study area. Such volunteers traditionally received the training on formative, informative and safety procedures Protezione Civille della Regione FVG (2009) and were further interested in supporting inspection campaigns.

Technicians-in-charge further required the decision support for getting an indication from collected reports about the functional level of inspected structures. Therefore, a decision support framework for systematically evaluating reports became an important prerequisite for increasing frequency and amount of inspections with the support of skilled volunteers. **Figure 5.1** and **Table 5.1** illustrate the modules we proposed for such framework: 1) Registered users, 2) Inspection planning, 3) Available reports, 4) Evaluation of reports. The workflow-input information to the framework are inspection reports that are collected either by skilled volunteers or regular technicians to be systematically evaluated by technicians-in-charge. The workflow-outputs are functional levels (e.g. best, medium, worst), each corresponding to a course of action.

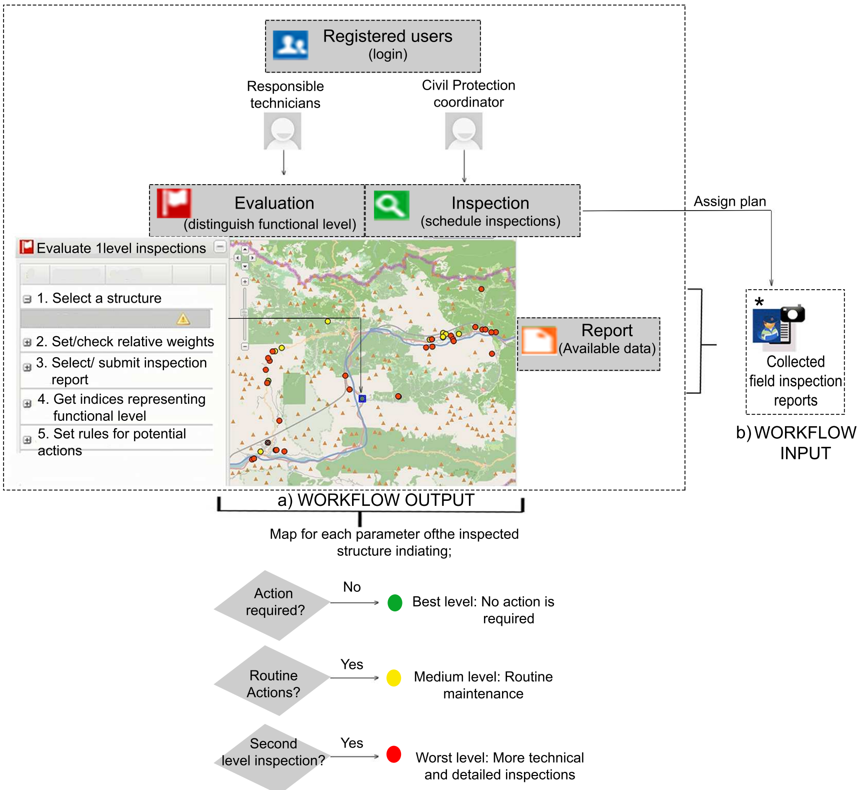

Figure 5.1: Workflow describing the input and output information for the decision support framework. *Volunteer icon (©Civil Protection of FVG region, Italy)

5.3. CONCEPTUAL DESIGN AND SYSTEM ARCHITECTURE OF THE WEB-GIS PLATFORM

The conceptual design tracked a modular architecture consisting of four modules (**Figure 5.1**), each of them providing a group of capabilities for the framework. We focused on the evaluation module as a proof-of-concept for using inspection reports in

Table 5.1: Modules comprising the decision support framework

Module	Capabilities	Implementation stage
Registered Users	• Login of technicians-in-charge. • Explore the database of available inspectors among technicians and skilled volunteers.	Mock-up interface
Inspection planning	• Create and assign an inspection plan to an inspector. • Select maximum number of structures to inspect (e.g. 10) according to available structures and technician-in-charge. • Define a period to carry out the inspection plan.	Mock-up interface
Available Reports	• Submit first-level inspection reports. • Visualize available reports of structures inspected for each section of the form: i) Inspector ii) Structure to inspect iii) Inspection conditions iv) Functional conditions A) Damage level, B) Obstruction level and C) Erosion level v) Human infrastructure vi) Synthesis advice	Mock-up interface
Evaluation of reports	• Systematic aggregation of first-level inspection reports into indices representing the structure status. • Categorizing the indices into functional levels according to rules defined by technicians.	Core functionalities

decision-making. Registered users, inspection planning and available reports were implemented as a mock up interface within the web-GIS platform for illustrating the conceptual design.

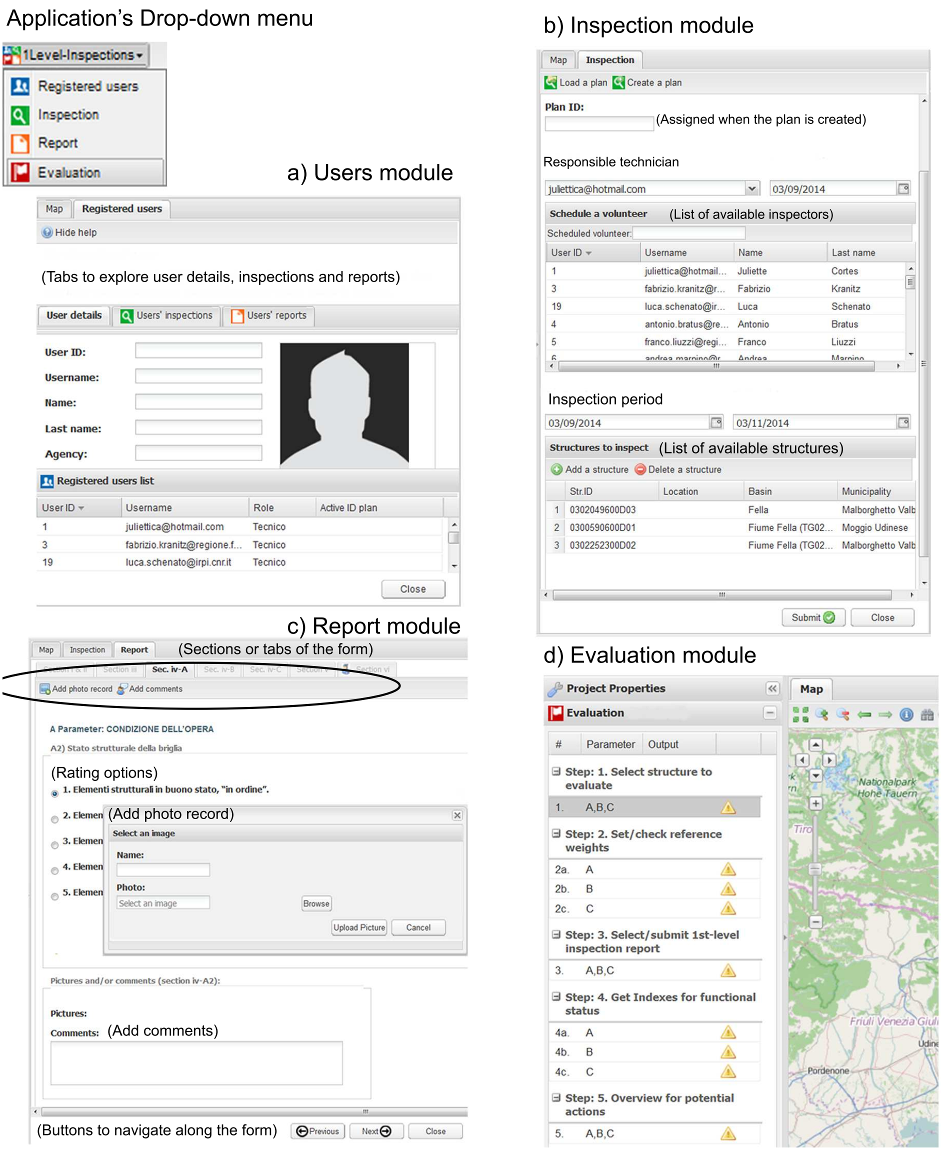

Figure 5.2: Conceptual design for a) registered users, b) inspection planning, c) available reports and d) Evaluation of reports

5.3.1. CONCEPTUAL DESIGN

Table 5.1 summarizes the modules comprising the conceptual design. The first module (Registered users) accounts for capabilities to explore user details, inspections and reports (**Figure 5.2a**). The second module (inspection planning) considers capabilities for creating inspection plans (**Figure 5.2b**). The third module (available reports) accounts for capabilities to submit or load reports in the database (**Figure 5.2c**). The report module comprises a sub-tab for each section in the form. It accounts for capabilities to report using rating options, add comments and photo records. The last module (evaluation of reports) focuses on the responses of the inspection form to get an indication of the functional status, which are represented by the three parameters referred in **Table 5.1**. Responses of other sections are only available as background information for the inspection. The module implements a step-wise approach (**Figure 5.2d**) to aggregate the reports of inspected structures into indices that are further categorized as functional levels, each corresponding to a course of action. Component sections and figures in the inspection form were adapted from existing procedures in FVG (Servizio Forestale FVG, 2002) and neighbouring regions (Provincia Autonoma di Bolzano, 2006).

5.3.2. SYSTEM ARCHITECTURE OF THE WEB-GIS PLATFORM

The platform uses a typical multi-tier client-server architecture of web-based applications (**Figure 5.3**). State of the art applications integrating decision support and geospatial capabilities have system architecture that often comprises a back-end tier including the relational database, a middle tier for managing geospatial data and a front-end tier for managing specialized services and other software components of the user interface (Aye et al., 2015a; Delipetrev et al., 2014). In the client or front-end-side, visualization functions and requests to the server side are provided through the user interface (browser). According to Zhao et al. (2012), basic data processing can be performed in the client-side to minimize requests to the server and improve user interactions. Instead, complex processing and submission/retrieval should be carried out in the server-side. In this work, data processing (i.e. evaluation of collected reports) is mainly in the client-side as proof of concept of the core-capabilities for decision support.

The implementation is based on the Boundless (OpenGeo Suite) framework. **Figure 5.3** illustrates the system architecture that is running on Debian as operating system and Tomcat 7 as web-server. Data storage is done through the database management system (DBMS) and application server. On the server-side, OpenGeo Suite allows interoperability between Tomcat server and the DBMS. The DBMS comprises the relational tables to store first-level inspection reports and GIS data. **Figure D.1** in the **Appendix D** illustrates the conceptual design of the data model. A Geoserver instance is deployed in the server as part of middle tier to connect the geo-spatial components of the database with the web-GIS user interface. In the client-side, we use the software development kit (SDK and GXP template) of OpenGeo Suite, which also includes plug-ins and mapping tools to explore the geospatial data. SDK deploys the mapping application that can be extended and customized from the GXP template using JavaScript libraries such as ExtJs, GeoExt and OpenLayers. The possibility to develop such customized plugins facilitates the re-use of available mapping tools and functionalities (Aye et al., 2015b).

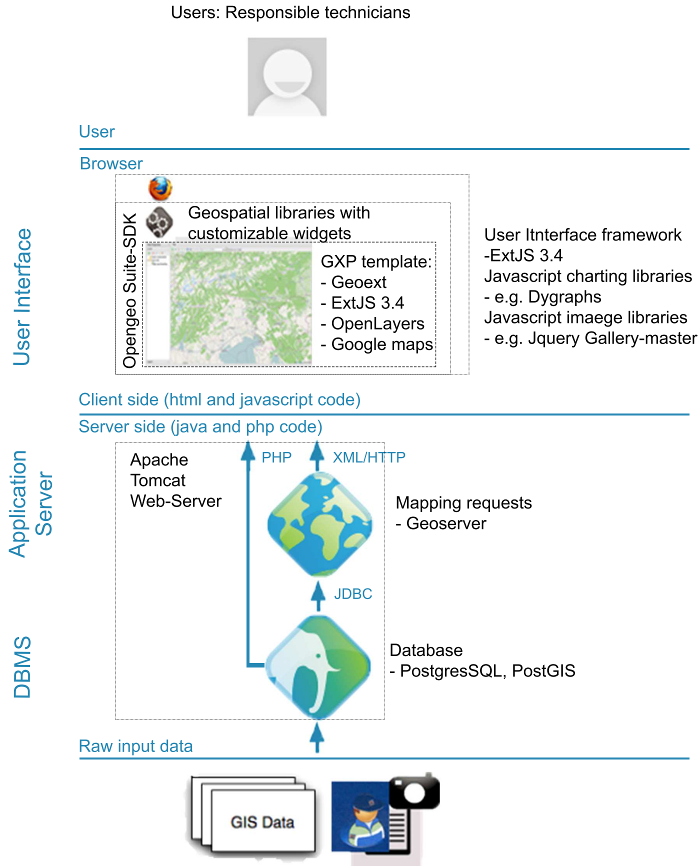

Figure 5.3: System architecture of the web-GIS platform based on Opengeo Suite. *Volunteer icon (©Civil Protection of FVG region, Italy)

The user interface uses JavaScript libraries and open source projects for creating charts and data visualizations (e.g. Dygraphs) as well as providing photo gallery capabilities (e.g. JQuery Gallery master). ExtJs 3.4 provided options to create and update temporary stores in the client-side (browser). The logic behind the user interface includes the model and knowledge base implementation (**Figure 5.3**), which at this development stage demonstrates the evaluation module. Although a strict Model-View-Controller (MVC) architecture is not fully supported in ExtJS 3.4, the scripts coded follows the MVC pattern to support its migration and to facilitate further development stages. **Figure 5.4** presents the components of the MVC paradigm: Model (data stores), View (outputs) and Controllers (Functions) which is being increasingly supported in web technologies (Mikkonen and Taivalsaari, 2007).

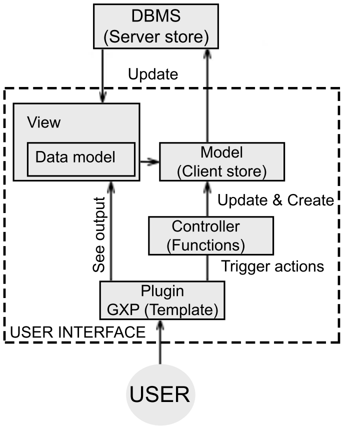

Figure 5.4: MVC components and illustration of the local client and server stores (adapted from Sencha, 2014)

After login to the platform[1], technicians-in-charge (users) can access the modules (**Figure 5.5**) through a plug-in the top toolbar of the view. The four modules of the framework are available in a drop down menu and are deployed in the central tab-panel next to the map tab. The right tab-panel deployed the help content and subtabs of the modules sharing the map-view for mapping interaction. Left tab-panel provided an overview of the user's selections on each module. User interaction triggers actions and/or displays outputs to follow the steps of the evaluation module.

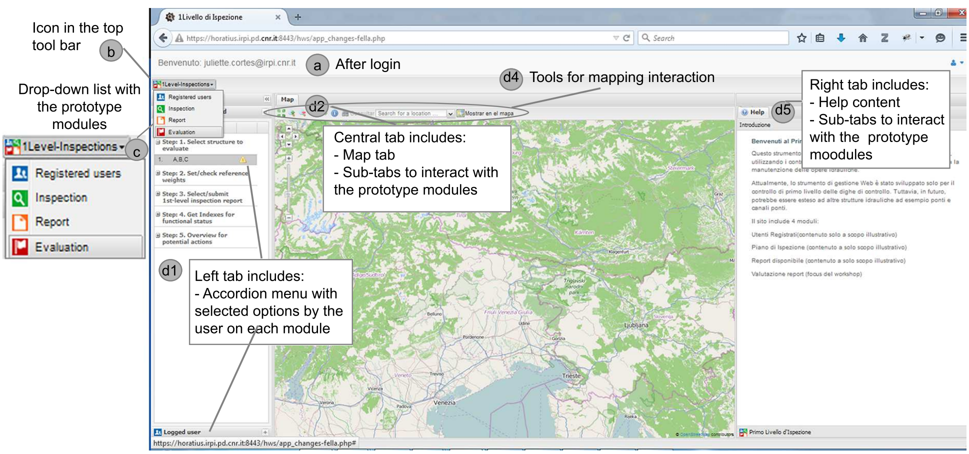

Figure 5.5: Web-GIS platform interface indicating a) Registered user; b) Decision support prototype; c) Drop down list to access the modules; d) Content in the left, central and right tab-panel. The central tab-panel includes the tools for mapping interaction

[1]website of the platform: `https://horatius.irpi.pd.cnr.it:8443/hws/index.php`

5.4. CONCEPTUAL DESIGN AND SYSTEM ARCHITECTURE OF THE WEB-GIS PLATFORM

The decision support framework starts when registered users such as technicians of Civil Protection or technicians-in-charge for the management of mitigation works login to access the web-GIS platform. Registered users should assign a functional level to available inspection reports that are collected either in a paper-based form (as carried out in this study) or through a complementary mobile application to be designed as future research. The evaluation module comprises a method to aggregate available inspection reports into indices that are further categorized in a functional level based on rules defined by technicians.

To that end, the evaluation module includes five steps that technicians should go through once an inspection report has been filled in for a given check dam. The inspection form is based on linguistic rating scales mainly to report about three parameters indicating the functional status. Those parameters are: A) Damage level, B) Obstruction level and C) Erosion level. Each parameter is inspected by means of four sub-questions, which were agreed with technicians-in-charge (Cortes Arevalo et al., 2014). When reported ratings become available, the evaluation module systematically aggregates them into indices at parameter level by means of multi-criteria Technique for Order of Preference by Similarity to Ideal Solutions (TOPSIS) method with fuzzy inputs (Chen and Hwang, 1992).

In addition, the module provides options to allow users formulating rules for categorizing the aggregated indices in one of the three levels, each corresponding to a course of action. The highest functional level (green) corresponds to no required actions. The medium level (yellow) denotes the need for a routine maintenance or additional information to validate functional level. Finally, the lowest level (red) indicates that a second level inspection or a more detailed engineering procedure is required before making the decision about the maintenance. In Cortes Arevalo et al. (2016) further details about the methodology behind this module are provided. Screenshots of an example report, hereafter listed, illustrates all steps through the platform interaction.

5.4.1. SELECT A STRUCTURE TO EVALUATE (CHECK DAM)

Figure 5.6 illustrates the database of structures (spatial layers) and available information about their properties, dimensions and photo record as presented in the right tab-panel. When available, inspectors can also visualize the images from photo records or previous inspections, which can be filtered according to the inspection ID (i.e. a unique identifier of the inspection report). The functional level is the actual field to be updated after getting the output of the evaluation module. For illustration purposes, **Figure 5.6** also highlights the location of the pilot study area with the location of check dams inspected during the workshop.

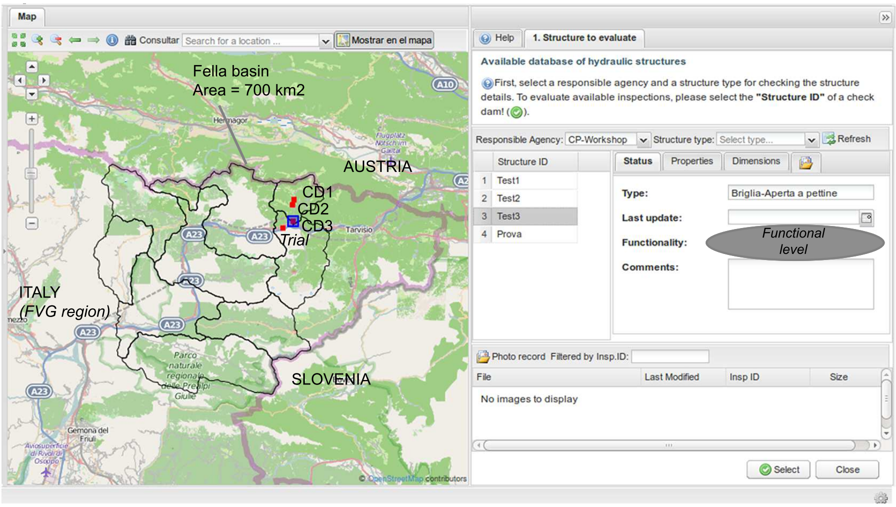

Figure 5.6: a) Exploring available databases of structures and b) Selecting one of the structures (CD) inspected in the workshop to continue with next steps. The layer of the study area location was added to the figure for illustration purposes

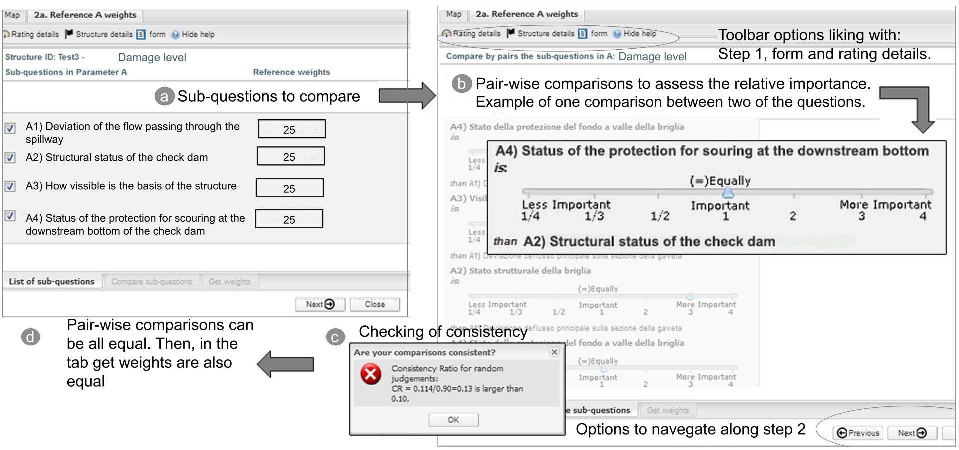

Figure 5.7: Setting reference weights for the index calculation at parameter level. User sets weights by interacting with tabs: a) Sub-questions to compare b) compare sub-questions c) check of the consistency of comparisons and d) get weights

5.4.2. REFERENCE WEIGHTS

For a selected structure, for example check dam 3 (CD3 in **Figure 5.6**), options are given so that users can compare the relative importance of sub-questions at parameter level (**Figure 5.7a**). **Figure 5.7b** illustrates the pairwise comparisons of sub-questions in A) parameter "Damage level" using the Analytic Hierarchy Process (AHP) method (Saaty, 1987). The AHP method allows checking the consistency of a comparison (**Figure 5.7c**). By doing the comparisons, technicians can derive the weights that will be used in the aggregation of reported ratings (**Figure 5.7d**). Weights should be set for sub-questions on each A, B and C parameter. Technicians can base their comparisons, for example, on the design criteria when building the structure. For the evaluation workshop, the relative importance was set equal for all questions to evaluate the outcomes of the module based on the quality of input reports (Cortes Arevalo et al., 2016).

5.4.3. SELECT/SUBMIT FIRST-LEVEL INSPECTION REPORT

A mock up report coming from the inspection module was automatically listed to access the evaluation module (**Figure 5.8**). At the current development stage, users should select that report to type the data collected from the paper-based form directly into the user interface of the next step (**Figure 5.9**). The connection to the DBMS, based on specific requests of users, will be matter of a future development to load available reports that will be systematically evaluated in the following steps.

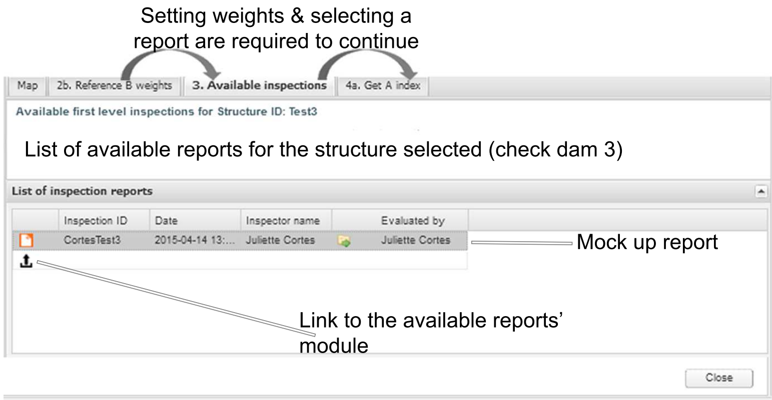

Figure 5.8: Selecting between available first-level inspect reports to evaluate

5.4.4. DERIVE INDICES

By interacting with this step, users can first aggregate the reported ratings into three indices at parameter level (**Figure 5.9a**). Indices are calculated by means of the TOPSIS multi-criteria method with fuzzy terms (Chen and Hwang, 1992). The fuzzy terms are the ratings reported for the structure inspected. The equal weights defined in Section 5.4.2. are used for aggregating the ratings into indices. A completeness ratio is calculated to highlight when participants report unspecified conditions.

Then, users can use the plot in **Figure 5.9b** to compare the reported ratings (bars in the plot) against the reference best and worst possible conditions (upper and lower lines in the plot). To go to the advised action, users should finally set rules to define a status of the structure that is acceptable. For example, to be assigned in the worst level (red), the aggregated index for the report has to be smaller than an acceptable minimum index and has to be larger or equal than the worst acceptable rating condition. The rules (acceptable index and worst rating) were fixed for the testing workshop but can still be modified by the user. **Figure 5.9** presents the evaluation for an example report of parameter A (Damage level). The same process is repeated for all parameters.

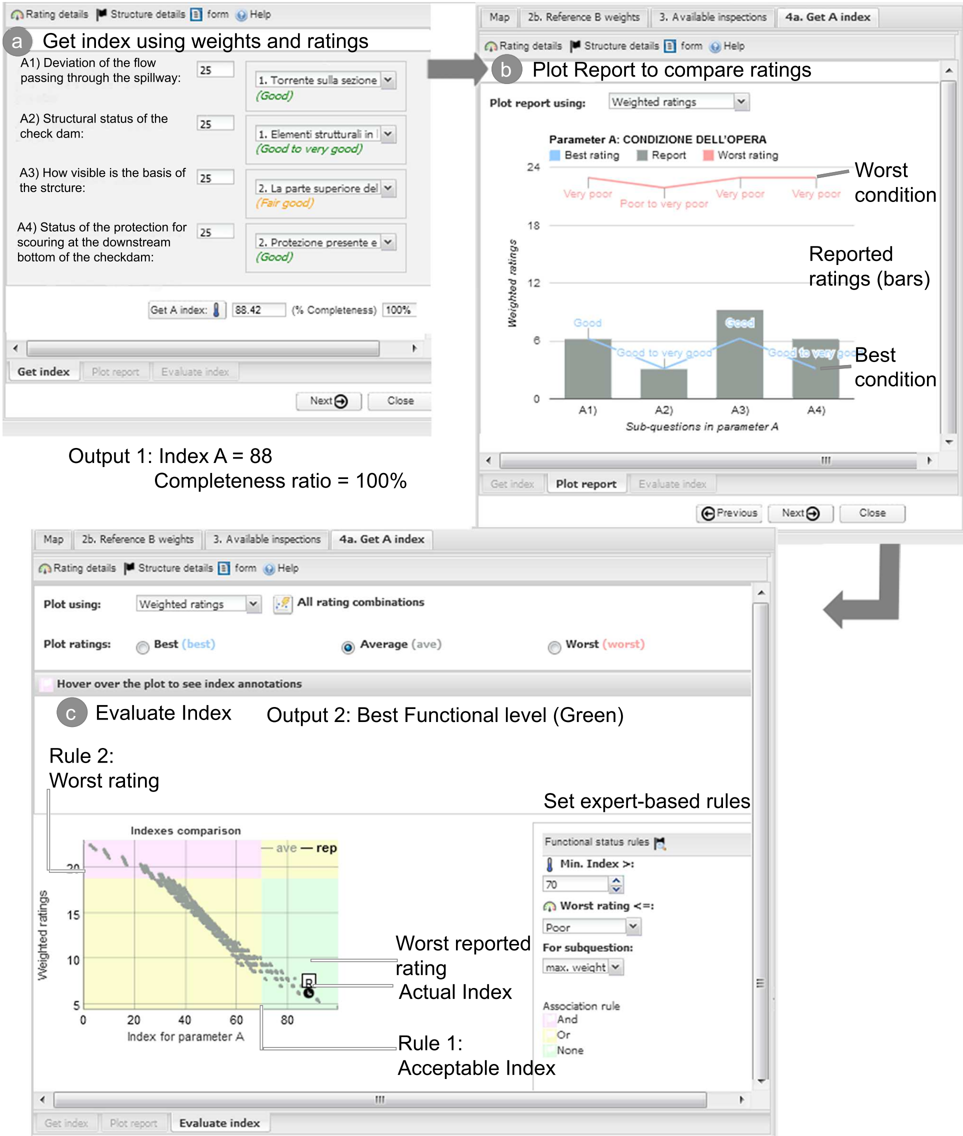

Figure 5.9: Outputs from the evaluation module: a) Index and a completeness ratio indicating the reported ratings. b) Report plot to compare ratings with reference conditions. c) Functional category of the parameter according to expert-based rules

5.4.5. OVERVIEW OF POTENTIAL ACTIONS

The last step gives an overview of the outputs and functional level assigned for parameter A, B and C (**Figure 5.10**). The green color indicates that, according to the reported ratings, the structure was at the best functional level and no action needs to be carried out. The medium level (yellow) indicates that one of the expert-based rules was not true and additional information needs to be considered coming from photo records or previous inspection reports. The worst level (red) indicates that the structure may have been at the worst functional level and thus, a second level inspection needs to be carried out towards maintenance planning.

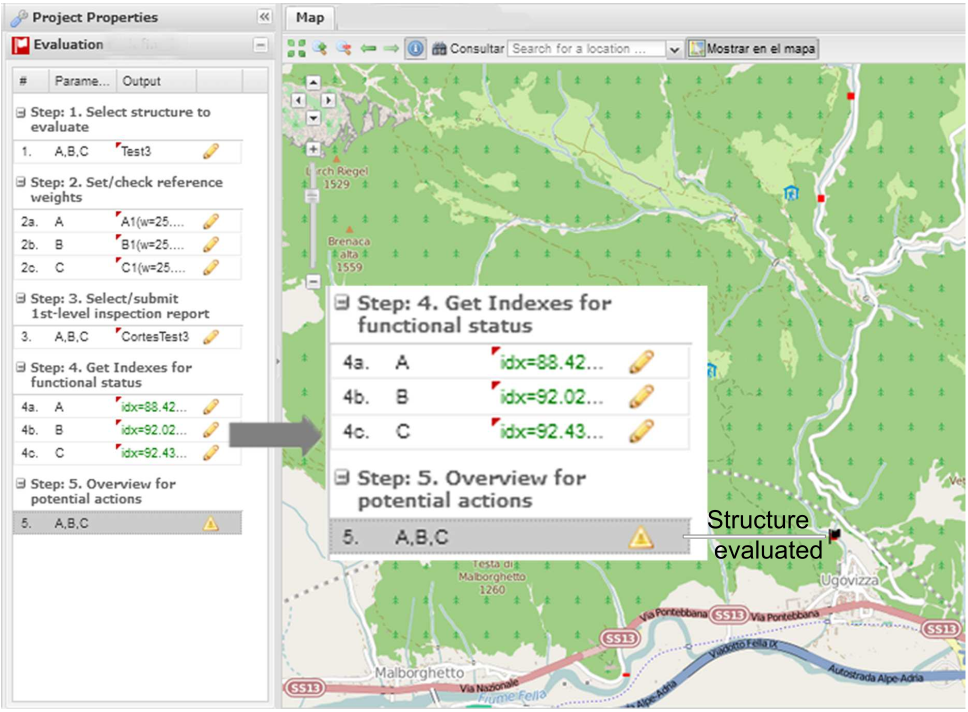

Figure 5.10: Overview of the derived indices and functional level for each parameter

5.5. WORKSHOP AND FEEDBACK OF THE EVALUATION MODULE (USE CASE)

To introduce the web-GIS application and obtain feedback about the usefulness of the evaluation module, a workshop was organized in the study area with ten participants. Participants comprised of four technicians of FGV that had participated in the user requirement stage (Section 5.2). Six newcomers participated: a mixed group of two technicians of FVG, two technicians of neighboring regions and two last-year students of geosciences.

During the first day, attendants carried out individual inspections for three check dams in the Fella basin (**Figure 5.6**) that were collected in a paper-based format. The field inspections were carried out to use real data for using the module. The first-day program (inspection session) was finalized with the introduction of the decision support framework. During the second day, participants interacted with the evaluation module by using one of the reports collected during the inspection session. At the end, feedback was collected in a questionnaire form.

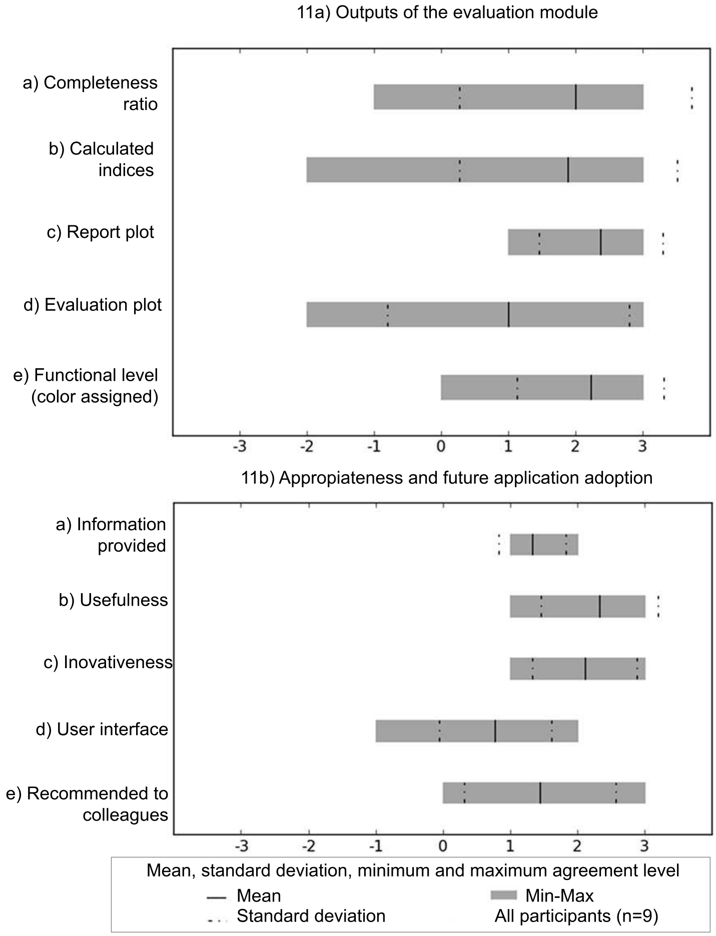

Figure 5.11: Agreement level about the outputs of the evaluation module, the usefulness and appropriateness for future application adoption. The difference in participants' number is because one participant did not fill in the feedback form

Participants rated their levels of agreement with statements in the feedback questionnaire using a Likert rating scale from -3 (full disagreement) to +3 (full agreement); which is a scale used for getting indication about users' attitudes (e.g. Arciniegas et al., 2013; Inman et al., 2011). When preferred, participants provided comments to explain their judgments. Participants rated the following statements about the usefulness of the evaluation module for one of the check dam inspections that they carried out themselves (**Figure 5.11a**):

a) In the Get Index tab, the completeness ratio is a useful indicator for the quality of volunteers' ratings

b) In the Plot report tab, the calculated indices (e.g. 70) for parameters A, B and C are useful and informative to support decision advice

c) In Plot report tab, the plot is useful and informative to understand the weighted-aggregation of rating scores into indexes for parameters A, B and C

d) The comparison plot for different combinations of rating options is clear enough to support your decision advice for the part A, B and C

e) In the evaluate index tab, the level assigned to the structure for parameters A, B and C, as indicated with the red, yellow, green color represents my preferences for the decision advice

We also asked participants about the appropriateness of the decision support module and future application adoption. To that end, participants rated their agreement to the following statements (**Figure 5.11b**):

a) The information provided is sufficient to follow each step (evaluation module)

b) The web-management application is useful

c) The web-management application is innovative

d) The user interface is clear and easy to follow

e) I would recommend my colleagues to use the evaluation module to support the interpretation of volunteer' inspections

We finally ask them about additional comments or capabilities to the module. According to **Figure 5.11a**, the most appreciated aspect of the evaluation module was the report plot and the possibility to define a functional level based on expert-based rules. Although the evaluation module was considered useful and innovative (**Figure 5.11b**), participants found some features not straightforward to understand, e.g., the completeness ratio, calculated indices and evaluation plot. That is probably due to lack of documentation beforehand to the testing session and the needs for improvement in the user interface. In **Table 5.2**, we list the comments that participants provided to refine the prototype. A full implementation of the system together with users' manual will allow for a more extensive evaluation of the platform.

Table 5.2: Overview of participants' comments for refining the evaluation module

Aspects to improve	Participants' comments
Information provided	• Clarify the instructions to interact with the different steps, special attention to the explanation about the weights
User interface	• The user interface is not clear enough yet • The user interface may benefit from the support of professionals
Appropriateness	• It is a nice idea • The evaluation of the indexes (weights) should be optional and it should be located at the end of each step. As default the weights should be equal and modified only for a choice about the priority of the intervention (second level inspection) • The weights should be adjusted when the questions are not to be compiled
Future application adoption	• To test the outcome of the evaluation module, it would be useful to have the statistical analysis of the different structure types • To make a more comprehensible and simple interface. Maybe with a step-by-step tutorial to help technicians that will be in charge of using the program • To give feedback to volunteers that will compile the form

5.6. DISCUSSION AND CONCLUSIONS

This study proposed a decision support framework implemented into a web-GIS platform to assist technicians in managing first-level inspections reports about protective structures in the mountain basin of the pilot study area. At the current development stage, we introduce an evaluation module to test how to get an indication of the functional status of check dams based on the field reports. Following a UCD approach, the outcomes of the user requirement stage lead to the conceptual design, implementation and usage of the decision support framework. Therefore, collaborations with responsible technicians of the FVG Region, local municipalities as well as other stakeholders were important not only to understand user requirements but also to evaluate its first implementation.

The module architecture of the Web-GIS platform facilitated the development of the core-capabilities for decision support and the conceptual design of the complementary modules. The system architecture was developed using GXP library backed up by OpenGeo Suite SDK, which facilitate the re-use of available mapping tools and extension of functionalities. The interface's scripts were coded based on the logical MVC that will support and facilitate the upgrading of the platform to a more recent version following such logic.

To test the functionalities of the platform, a proof-of-concept evaluation module was implemented. The testing workshop focused on users' perception about the usefulness for decision support. The weighing procedure to aggregate questions in the inspection reports was met with scepticism (Section 5.4.2). The pair-wise comparisons included the Consistency Ratio (CR) that were proposed by Saaty (1987) as indication of the consistency of comparisons (**Figure 5.7c**). Such ratio should be used only to warn users about inconsistencies but not to limit the experts' choices. Moreover, weighted aggregation should be used with caution because can change the outputs considerably especially if inspectors err by overestimating or underestimating defects (Cortes Arevalo et al., 2016). Participants suggested that the weighting option should be optional and located at the end of the evaluation process. For a more extensive evaluation of the platform, participants also required the evaluation of inspection reports from a larger number of structures to support statistical analysis of the module outcomes.

This is an initial prototype for the development of a full-scale system later on by transferring knowledge, theory and concept behind this decision support framework. Workshops to evaluate a full-scale system will require longer interaction with the Web-GIS platform focusing on a comprehensive evaluation of usability (Bastien, 2010; Hornbæk, 2006). Thereby, qualitative evaluation methods (e.g. questionnaires) can be further combined with quantitative indications (e.g. data log analysis) to explain user interaction van Velsen et al. (2008). Future developments will consist of a full implementation of all the modules of the platform (Table 5 1) that could be further extended to other type of hydraulic structures, for example culverts. Consideration should also be given to include into the web-GIS platform a crosschecking feature to compare the outputs of the evaluation module with complementary information, such as photo record of the inspection and previous reports for the same structure. In addition, the overview of derived indices (**Figure 5.10**) should be provided for all check dams reports that were evaluated. Further options should consider sorting the structures according to the functional level of all three parameters and visualizing in the map the functional level assigned for each parameter. Future research may also consider a mobile application to extend the capabilities of the report module into a portable device to support data-collection and to provide feedback to inspectors.

To conclude, the web-GIS decision support framework consists of a systematic procedure for the evaluation of first-level inspection reports that facilitates the use of inspections collected by skilled volunteers or technicians. The platform can be further developed as a tool to support coordinated and collaborative efforts between different management organizations involved in preparedness and prevention with interest in inspection and maintenance planning. For example, that is the case of Civil Protection, technical agencies and basin authorities in FVG. Thereby, the framework can also complement spatial data infrastructures that centralize relevant information about the inspected structures and other preventive works or hydraulic structures besides check dams.

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6

Synthesis and Recomendations

Be the change you wish to see in the world.

Mahatma Gandhi

6.1. BRINGING IT ALL TOGETHER

In this conclusive chapter, I reflect on the contributions of my work and provide recommendations for further research. I hope it will motivate more efforts to involve volunteers in support of proactive inspections. This research proposed a methodology applicable in day-to-day risk management to use volunteers' information in support of proactive inspection of hydraulic structures. I tested the methodology in a mountain basin in the north-eastern Italian Alps. The mountain basin is prone to flash floods and debris flows and is threated by depopulation and increasing built areas for tourism. Structural measures are in place along the basin, in the stream channel or in the deposition area to mitigate the debris flows hazards. Such measures may not be efficient if they are not in optimal state. Proactive inspection has high priority. Of course, such proactive approach may not overcome all possible debris flows and exposure scenarios. However, it can and should uphold the standard function for which such measures are in place. Collaborative efforts to inspect implemented structural measures such are one way to support proactive risk management.

In this context, tier-level inspections of hydraulic structures have an essential role in the system of mitigation works. First-level or pre-screening inspections aim at documenting defects and disruptions on the functional condition of relevant hydraulic structures such as check dams. In mountain catchments, check dams are a key component for debris flow control. Such structures slow water-sediment processes and control channel erosion. Inspections should be planned from the structure design to be performed during the life cycle of the structure (Bontempi et al., 2008). Risk assessment scenarios and maintenance strategies may be also updated from the outputs of proactive inspections.

First-level inspections are visual inspections to identify possible degradations of the functional status of the structure. More frequent first-level inspections can be done by involving skilled volunteers in support of regular inspector technicians. However, volunteers' information requires quality control and evaluation mechanisms to better support decisions about the functionality of structures. The main contribution of this research is the development of a decision support method that allows inspections to be carried out by either skilled volunteers or technicians while ensuring that technicians-in-charge can systematically evaluate the reports. In this chapter, I highlight the extent of that contribution in terms of the scientific objectives of this thesis. I further synthesize the research design choices and its implications for the mentioned contribution. Based on the experiences of the Fella basin application, I provide recommendations for further research in working with volunteers, inspecting hydraulic structures and decision-making about proactive risk management.

6.2. MAIN CONTRIBUTIONS OF THIS THESIS

Research on how to develop a citizen science method useful in day-to-day risk management practices addresses a variety of aspects such as data quality requirements, volunteers' engagement and coordination between the variety of actors involved. In that context, this thesis focuses on four scientific objectives: i) to identify requirements for citizen science approaches based on existing literature and the specific context of the study area; ii) to develop a data collection approach that can be performed by volunteers considering data quality requirements of technicians; iii) to develop a methodology to evaluate first-level inspections in support of decisions about the functional status of hydraulic structures; and; iv) to design a Web-GIS decision support framework to assist technicians in evaluating inspection reports of hydraulic structures.

i) *identify requirements for citizen science approaches based on existing literature and the specific context of the study area*

In Chapter 2, a conceptual framework was developed to identify the context of implementation of citizen science projects. This framework followed a decision-focused approach to use volunteers' information. I focused on reviewing applications for water resources management due to their relevance in proactive management (**Table 2.4**). The framework analysis supports the design choices of Chapter 3 to 5. **Table 6.1** summarizes these design choices and related assumptions.

Table 6.1: Sub-questions of the conceptual framework, research design choices and related assumptions

Questions of the conceptual framework	Research design choices	Related assumptions
What citizen science approach?	Volunteers' involvement using simplified inspection procedures and training	Explicit and dedicated data-collection methods for volunteers' involvement can support decision-making
Which participants and motivations?	Citizen volunteers of Civil Protection at the location of the study area	Volunteers of Civil Protection can become capable inspectors of hydraulic structures
Which organizational requirements?	Evaluation and quality control of data collected	Standardization of data collection can result in comparable inspections
Which needs? Which purpose?	Proactive inspection and maintenance of hydraulic structures	Systematic evaluation of the collected data is possible by aggregating reports and setting expert-based rules for action
Which tools?	Decision support tools to manage and evaluate data collected	Collaborative and user-centered design can enhance the usefulness of supporting tools

First, the different typologies of citizen science approaches and working definitions were identified (**Table 2.1**). In the Friuli Venezia Giulia (FVG), there are a variety of in-practice examples of citizen science approaches (**Table 2.10**). Volunteers' involvement seems to follow a collectivism motivation. The volunteering tradition is promoted by regional and local authorities and it is further recognized in the legal framework (**Figure 2.4**).

I particularly refer to citizen science to distinguish the involvement of volunteers in data collection using simplified protocols and training according to management needs (Devictor et al., 2010). I also distinguished volunteers' motivations from organizational requirements. I recognize (review in Section 2.3.2) the importance of studying the volunteer motivations for the inspection of hydraulic structures. This is not only important for citizen volunteers of Civil Protection but for alternative groups (e.g. university students). However, I did not elaborate on the volunteers' motivational aspects in this research.

The pilot implementation mainly involved citizen volunteer groups of Civil Protection that were already engaged and enrolled in the municipalities of the study area. However, I recognize that the interpersonal trust and mutual apprehension of volunteers' involvement may change from project design, implementation and follow up. This could be the case, for example, if the inspections are not followed up by management organizations or if the data quality is not controlled. My focus was on the organizational aspects of data collection and the evaluation of data collected. This consideration is important to provide technicians-in-charge with methodologies to evaluate and to use those inspections.

Organizational requirements were important to define the type of structures to inspect and the data-collection protocols. Protocols should generally meet ease, safety and reliability (Section 2.3.3). Data quality and evaluation procedures should account for the requirements of data users (Section 2.4.3). I address these requirements by simplifying procedures for inspecting implemented protection measures in the Fella basin (Chapter 3) and providing a decision support method to systematically evaluate inspection reports (Chapter 4).

User centered approaches are important to design ICT tools supporting data management requirements (**Tables 2.7**, **2.8**, and **2.9**). Finally, yet important, volunteers' engagement and coordination efforts should consider the planning, implementation and follow up stages (**Table 2.3**). If resources are insufficient, collaboration with relevant organizations should be initiated as early as possible. The assumption that explicit and dedicated methods of data collection can support decision-making (see **Table 6.1**) requires further research on two complementary aspects: i) methodological efforts to ensure data quality and ii) systematic review of interpersonal trust and motivational aspects of relevant actors. The long-term feasibility of a citizen science project can be promoted by addressing benefits and constraints of collaboration between scientists, authorities and volunteers since early stages.

ii) *develop a data collection approach that can be performed by volunteers considering data quality requirements of technicians*

Chapter 3 presents the first experiment to evaluate the quality of first-level inspections of hydraulic structures by technicians and volunteers. Civil protection selected six structures such as bridges and check dams to be inspected (**Figure 3.1a**). The data collection approach comprised of two inspection forms, a learning session and a data collection exercise about the functional status of hydraulic structures using the inspection forms. Questions, rating options and visual schemes to guide the inspections were a simplified version of existing procedures in FVG and neighboring regions. The forms content and layout (**Table 3.2**) were discussed with technicians-in-charge from the regional Civil Protection, Geological Survey and Forestry Service. In May 2013, a data collection exercise was performed - one day for the learning session and another day for the inspection tests - in the municipality of Pontebba (**Table 3.1**).

Eleven technicians and 25 volunteers attended the program. In contrast to the control group, those ones attending the learning session were referred to as learning group. The volunteers group included Civil Protection volunteers and university students. All inspectors, whether technicians or volunteers, looked at damages and obstructions of the structure as well as bank erosion 20 meters upstream and downstream of the structure. The inspectors reported on each parameter via questions and rating options. Although the inspectors were requested to supplement their report with a picture, this was not often the case. Besides sections about the functional status, inspections included complementary sections to document the inspection conditions and provide synthesis advice from their report (**Table 3.2**). The latter, I recommend only to be filled in by inspector technicians.

Overall, the activity was appreciated for promoting the proactive inspection of the structures with preventive scope. However, the collected reports do not have high statistical significance due to differences in distribution and number per participants' group (**Table 3.1**). The study area has experienced significant depopulation and decreasing in economic activities in the last three decades (Malek et al., 2014). Despite the strong volunteering tradition, the number of participants was rather low due to the low population density and the remote location of the study area (Italian Alpine area bordering with Austria and Slovenia). As stated in Section 3.2.1, I widened the range of participants by inviting students from the University of Trieste. Nevertheless, the remoteness of the study area also limit their number and involvement in the data-collection activities.

I used this exercise to understand considerations for data quality evaluation. To do so ordinal scores were assigned to the rating scales to calculate the accuracy, precision and completeness of collected reports. A modal score was calculated for each participants group and the mode of technicians in the learning group was used as indication of the 'true value'. The results from that exercise showed that volunteers' reports had higher variance than technicians' reports. To cope with the differences in precision, I generalized rating scales according to the questions and rating options provided in the form (**Table 3.3**). For example, for a five options rating scale, I generalized into three options namely very low-to-low concerns, medium and high-to-very-high concerns. The generalization of the medium class is not straightforward and depends on the ranges of precision in the rating options. Although the generalization brought forth some improvements in volunteers' performance, the reports of both groups were comparable in their limited reproducibility (e.g. **Figures 3.2 to 3.6**).

The low number of volunteers is not necessarily a disadvantage in day-to-day risk management as long as the frequency of inspection increases. However, the assumption that volunteers of Civil Protection can become capable inspectors of hydraulic structures (see **Table 6.1**) is not easy to proof with the data I have gathered with the experiments. The inspection form requires iterative design and should be separately tested with each participant group. Unspecified answers may persist; for example, due to the complexity of the structure to inspect (e.g. number of connected elements) and the unexpected conditions of the inspection. Therefore, a completeness ratio was useful to indicate when not all questions in the form were possible to inspect. To test the capability of inspector volunteers, repeated data collection exercises considering additional quality control procedures (see **Table 2.5**) and extended training are still required.

The essence of the approach is the standardization of data collection to facilitate comparable inspections either by inspectors or skilled volunteers. The approach comprised collaborative design of inspection reports with technicians-in-charge, a pilot training and data-collection exercise. Before increasing the frequency and spatial coverage of data-collection, the management organization required support on evaluating inspection reports (Chapter 4). A prototype Web-GIS tool further illustrates how to manage and evaluate collected reports (Chapter 5).

iii) *develop a methodology to evaluate first-level inspections in support of decisions about the functional status of hydraulic structures*

Chapter 4 discusses the design and testing of a support method to systematically aggregate individual inspections according to the reported ratings. Instead of using the ordinal scores as done in Chapter 3, fuzzy terms were used to systematically convert the linguistic rating options into scores (**Table 4.2**). I also refer to the fuzzy terms to define the best and worst reference conditions for each question (**Figure 4.6**). The aggregated sum of questions per parameter was done by means of a multi-criteria method with fuzzy terms (TOPSIS method) while using equal weights for all questions to isolate the effect of data quality. The reports were aggregated into two values at parameter level: an index to indicate the functional status and a completeness ratio (**Figure 4.7**). To distinguish the functional level (output), the method allows technicians-in-charge to define low, medium and high functional levels based on two rules at parameter level. Those are the acceptable index and the worst rating score (condition), which for this study were set at 70 and at poor condition (**Table 4.3**).

In September 2014, a workshop was organized specifically for technicians in the study area (municipality of Malborghetto) to test the decision support method. To do so, I evaluated the effect of the quality of input reports on the output of the method. Chapter 4 comprises the results of the second experiment for evaluating data quality, which was done primarily with technicians. In a first day, fourteen participants including technicians-in-charge, a scientist and two final-year geoscience students inspected three check dams that Civil Protection selected (**Figure 4.3**). Participants synthesized their inspection by selecting in the field one of the following management options: 1) no action required; 2) routine maintenance with support of volunteers; 3) routine maintenance using equipment; and, 4) second level inspection. The day ended by introducing to all participants the prototype – web-based – decision support (Chapter 5). During the second day, ten participants applied the decision support method using field data.

To see whether there is a positive effect in data quality of being involved in the design process, I invited technicians that were and those that were not involved before the workshop (i.e. users versus new-users). New-users involvement was important due to their fresh perspectives. From the collected reports, I looked at the accuracy, precision and completeness of collected reports (**Figure 4.9**). According to Dirksen et al. (2013), the following disagreement causes were distinguished in collected reports: i) Questions or support schemes did not clearly specify the conditions to observe. ii) Observed conditions could not be reported through the options provided. iii) The differences between the rating options was unclear. In addition, I calculated the frequencies (**Table 4.5**) of an participant failing to recognize a defect (False Negative, FN) and a defect being reported although there is none (False Positive, FP). Lastly, I compared the differences in the participants' advice (synthesis of the inspection form) and the output functional levels from the method (**Figure 4.11**).

Results of the quality evaluation confirmed difficulties to assess obstruction and bank erosion whereas the damages at the structure could be inspected. Most parameters were consistently classified into high and medium level by the participants' advice and the decision support method (**Figure 4.11**). However, some users and new-users erred on the side of caution and choose the lower functional levels. Overall, the multi-criteria method was helpful for intermediate aggregations of collected reports while expert-based rules supported technicians in distinguishing functional levels. The sensitivity analysis on the frequency of occurrence of a given index (**Table 4.4**) can assist technicians on setting the expert-based rules. Thereby, technicians can set the minimum index and worst acceptable condition based on the frequency analysis of all possible rating combinations at parameter level (**Figure 4.8**). Finally, feedback results reflect recommendations of participants for improving the clarity, reliability and usefulness of methods.

iv) *design a Web-GIS decision support framework to assist technicians in evaluating inspection reports of hydraulic structures*

Chapter 5 transforms the decision support method into a Web-GIS application. The conceptual design of that framework incorporates four modules for managing the inspection reports (**Figure 5.1** and **Table 5.1**): 1) Registered users, 2) Inspection planning; 3) Available reports and 4) Evaluation of reports. The development of the Web-GIS prototype platform focused on evaluating reports while demonstrating the conceptual design of the complementary modules (**Figure 5.2**). The design process followed a user-centered approach. User requirements were identified by inviting potential users to the data collection exercises and asking for feedback.

The prototype architecture (**Figure 5.3**) was developed using OpenGeo Suite SDK, which is a Web-GIS platform based on standard and interoperable open source tools. The development options of OpenGeo allows reusing available mapping tools while customizing its functionalities. To test the prototype application, a proof-of-concept of the evaluation module was implemented based on the method of Chapter 4. Hence, the evaluation module was tested during the last part of the same workshop. Screenshots of an example report illustrates all evaluation steps through the Web-GIS platform (**Figure 5.6** to **Figure 5.10**). Those steps include selecting the structure to evaluate; setting or checking reference weights; typing the input reports in the user interface; getting indices based on reports collected; and getting an overview of the outputs.

After participants used the prototype application for evaluating their own inspection reports, I asked their perception on the usefulness of the evaluation module. I also asked participants about their intention of adopting a future application of the module. Although the evaluation module was considered innovative (**Figure 5.11b**), not all features were straightforward to understand. This is probably due to the needs for improvements in the user interface of the prototype application and the lack of documentation before the testing workshop. Besides the involvement of technicians that participated in previous research activities, new technicians involvement was important due to their fresh perspectives. This led to a set of suggested improvements (**Table 5.2**). Participants also required the evaluation of inspection reports from a larger number of structures to support a more extensive evaluation of the module outcomes. In addition, when testing future developments of the Web-GIS application, I recommend the combination of users' perception with quantitative indications of users' interaction with the Web-GIS platform.

The collaborative research supported the extensive participation of technicians-in-charge and the volunteers' involvement. The user centered design approach allowed to understand requirements for day-to-day risk management in the study area. Important requirements for standardization were a simplified version of technical procedures, iterative design of inspection forms, volunteers' training and evaluation by technicians-in-charge. This made early involvement of technicians-in-charge essential. The involvement of participants also implied trade-offs in the timeline of the research.

I hope that the knowledge, theory and concept behind this decision support framework can be developed into a full-scale Web-GIS platform. The prototype application can also complement spatial data infrastructures that centralize information about the inspected check dams and other preventive works or hydraulic structures. Section 2.4.5 provides some examples of the available information systems in the study area. In addition, this prototype can be further promoted as a tool to support cooperation efforts between the Civil Protection and technicians-in-charge for the management of preventive works.

6.3. ARE VOLUNTEERS' INSPECTIONS USEFUL?

In this research, a data collection approach and a decision support method were developed to carry out inspections by either skilled volunteers or technicians. The methodology should be adapted to other study areas that may have different volunteering traditions. The methodology should be further applied to other types of hydraulic structures and systems of structural measures by tuning its applicability. Moreover, working with volunteers and technicians in a collaborative research approach implies trade-offs between motivations of participants and scientific and management goals. Volunteers' involvement also implies some other organizational and logistical efforts to coordinate activities between relevant actors and to provide feedback to the contributing volunteers. The selection of hydraulic structures should have limited complexity and sufficient accessibility to be inspected with volunteers. Decisions about the proactive inspection and maintenance require the considerations of more aspects beyond the functional status. Based on the experiences of the Fella basin application, I have the following recommendations for further research.

6.3.1. RECOMMENDATIONS FOR WORKING WITH VOLUNTEERS

In many places, citizens' involvement is traditionally limited to report interruptions in the system of hydraulic structures, via for example complaints. Although the analysis of citizen complaints support the risk assessment and the development of maintenance strategies (e.g. Rodríguez et al., 2012; ten Veldhuis et al., 2013), citizens' involvement is mainly reactive. This research is a first step towards the use of volunteers' first-level inspections in support of proactive inspections. The value of working with volunteers relies on adapting the methodology to local contexts. The major recommendation is the need to follow-up scientific research for improving the methodology to evaluate volunteers' data quality. I also recommend training sessions harnessing both volunteers' knowledge and willingness to take proactive actions. Finally, the use of volunteers' information relies on the understanding of motivational aspects while accounting for data evaluation, organizational and logistical requirements.

6

- *On scientific methodological issues for evaluating quality of volunteers' hydraulic inspection structures*

  The methodology was tested through data collection exercises in the study area. A collaborative research approach was useful to understand the actual context of implementation of volunteers' information. This is influenced by participants' availability and logistical constraints that it can never be fully simulated in an experimental setting. Volunteers and technicians were primarily involved in a first data collection exercise to identify data quality requirements Chapter 3. The mixed group of technicians and volunteers in the first exercise was interesting for knowledge exchange beyond the training session. However, the quality evaluation was hindered by participants' interactions during the inspection tests. To overcome this methodological limitation, replication exercises to evaluate data quality should be on a separate day for each participant's group.

  In the data collection second exercise (Chapter 4), technicians previously involved and new participants (also technicians) attended a testing workshop of the decision support method. From the analysis of the second data collection exercise, suggestions are that inspection campaigns should benefit from teaming up volunteers and technicians. In that way, technicians can get insights in the local stream conditions from volunteers' knowledge. Meanwhile, volunteers can become skilled volunteers through their extended training and experience with carrying out inspections. To identify skilled volunteers, future research should test the influence of learning sessions and accumulated experience in inspection campaigns. Quality evaluations should be carried out at the beginning and at the end of each campaign. Feedback and notification about the quality of reports and the management actions following the inspections may contribute to maintaining data quality in long-term basis. Participants also recommended the evaluation of inspection reports from a larger number of structures to support a more extensive evaluation of the outcomes of the decision support method.

- *On the different volunteering tradition*

  In the case study area, citizen-volunteers of Civil Protection and university students were involved. Those volunteers were willing to participate in a training session without necessarily having the specific background or accumulated experience for inspecting hydraulic structures. Such volunteers' involvement was possible due to the existing collaborations of volunteers with scientific, Civil Protection and technical agencies in FVG (Chapter 2). Civil Protection and municipal administrations actively promote volunteer involvement and transfer of this tradition to new generations is actively pursued. Moreover, the institutional framework of management organizations recognize the role of volunteers beyond a reactive scope.

  However, this is not the case in many regions. In places with different volunteering traditions, students are an alternative for volunteers' engagement as also mentioned by Savan et al. (2003). Buytaert et al. (2014) argue that in developing regions, volunteers very often derive their income from such engagement. In any case, goals of volunteers' involvement should include awareness and promotion of more proactive and self-protective behavior. Whenever possible, rewarded engagement should be translated into in-kind contributions. In addition, research to understand the volunteering traditions and conflicting motivations may guide the necessary trade-offs between scientific, management and volunteer goals. That is important to promote long-term involvement and promote proactive actions beyond the inspections.

- *On data evaluation, organizational and logistical efforts to use volunteers' information*

  Besides calculating the relative frequencies of data collected, alternative methods can be used for evaluating citizen science datasets (**Table 2.6**). However, data evaluation choices depend on the data type, frequency and spatial resolution of inspections. It also relies on the numbers of volunteers contributing and the availability of alternative datasets for validation. In this study, a relatively small number of volunteers participated in the first-level inspections. This is not necessarily a limitation when considering that the number of volunteers contributing and the quality of the data is not linear (Haklay et al., 2010). For specialized tasks, a small but skilled number of volunteers can provide information that is more reliable.

  Volunteers can become skilled by teaming up with technicians for the inspection of hydraulic structures. Technicians can be aware about local impacts and changes in the structures' status by teaming up with volunteers. Thereby, inspection campaigns including skilled volunteers could widen the inspection frequency of management organizations. This organizational support is important, for example, due to remote locations, the increasing number of protection works or limited resources to carry out frequent inspections. However, the use of volunteers' information also implies other organizational efforts for planning, implementing and follow up citizen science programs (Brudney and Gazley, 2006; Roy et al., 2012). If resources are not sufficient, coordination and pooling of resources should be pursued with organizations that may benefit from volunteers' involvement.

- *On increasing awareness, proactive and self-protective behavior*

  Although recent studies are devoted to measure increasing awareness (Charrière et al., in preparation), for citizen science this is a knowledge gap. Previous researches argue that the increasing awareness and expertise of volunteers may not necessarily influence proactive and self-protective behavior (Jordan et al., 2011; Toomey and Domroese, 2013). Further research is required to understand whether participants' involvement results in proactive and self-protective behaviour. Training sessions should both address inspection goals and promote specific proactive and preventive actions. Examples of such actions are collaborative campaigns for cleaning streams, information on adapted building design or disseminating restrictions of land use according to municipal spatial planning. Moreover, first-level inspections could also be adapted to support alternative educational goals for other community groups; for example, last-year high school students that are not aware/involved in management activities.

6

6.3.2. RECOMMENDATIONS FOR INSPECTING HYDRAULIC STRUCTURES

In both experiments (Chapter 3 and 4), Civil Protection selected the structures for the inspection tests. The complexity of the inspections differed according to the functional status of the structures. Structures also included connected elements, such as retention basins and secondary check dams for protection against scouring. In Chapter 3, first-level inspections were initially proposed for bridges and check dams due to their role for the potential aggravation of hydro-meteorological hazards in mountain basins. The aggravation of hazards can occur due to blocking material such as debris, large wood and other residues. However, in Chapter 4, I focused on check dam inspections. This choice was motivated by the constraint to limit the complexity and type of structures to inspect. However, innovative approaches are still required to handle the limitations of first-level inspections. Moreover, the use of web-GIS tools and mobile applications for data collection can support both inspections and evaluation procedures of inspection reports.

- *On structures to be inspected with volunteers' support*

  The hydraulic structures should have limited complexity and enough accessibility to be inspected with volunteers. This research demonstrated difficulties to distinguish obstructions and bank erosion whereas damages in the check dam itself were better to inspect. For inspection campaigns beyond this research, I think that management organizations can optimize their efforts and volunteers support. For example, skilled volunteers can inspect complementary and remote check dam structures while regular technicians (teamed up with volunteers) can inspect more critical check dams.

Regardless of these management choices, an important advantage of the decision support method is that it can be adapted to other types of hydraulic structures. For example, culverts and box culverts are often complementary structures that can be inspected well with volunteers. Of course, for other structures or in other regions, other questions will become relevant and I suggest to develop the inspection forms together with potential users.

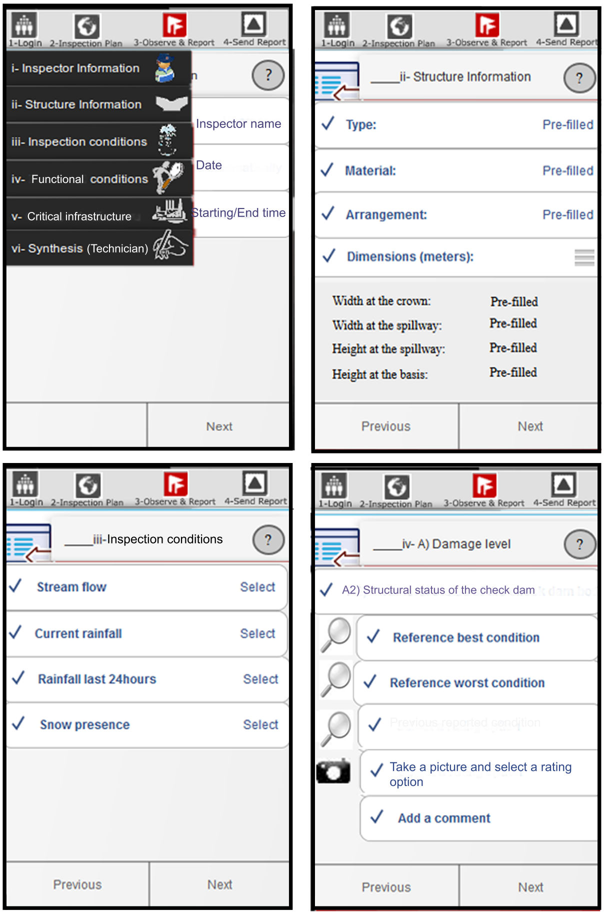


Figure 6.1: Schematic representation of the inspection form in a mobile application. The scheme also illustrates the use of references pictures and previous reported conditions. (Icons for login, inspection plan, observe and report and submit are of Civil Protection of FVG region, Italy)

- *On inspections campaigns at different periods*

  I recommend to organize sequential inspection campaigns and to build-up temporal datasets based on the first-level inspections. Promoting such temporal datasets contributes to build a database on the hydraulic structure. One advantage of such approach is that, for example, inspectors could report only if changes were detected with reference to the previous inspection (see the schematic representation in **Figure 6.1**). Such time-series are also beneficial for the evaluation of reports and the decisions about interventions. For example, damages in a check dam structure may be persistent without necessarily affecting the functional status. Sediment deposition behind check dams can be temporary and in some cases can be washed away during next rainfall events. However, permanent deposits without maintenance affects check dam functionality. Temporal analysis of first-level inspection reports can be done, for example, by using alternative methodologies such as Bayesian inference (Schweckendiek et al., 2014) or fault tree analysis (ten Veldhuis et al., 2011).

- *On handling the limitations of first-level inspections*

  First-level inspections are subject to the limitations of visual inspections some of which were discussed in this research (Chapter 4). In this thesis application, an option for unspecified conditions was included into the rating scales to calculate a completeness ratio. In addition, **Figure 6.1** schematizes the use of reference images to carry out the inspections in a schematic representation of a mobile application. A set of reference pictures could be assigned to the best and worst reference conditions. Volunteers could refer to those images to compare changes in the status of the structure, if any. Then, volunteers could report by labeling the photo record with the applicable rating option. Instead of limiting their contribution by taking picture, asking volunteers to relate a rating condition to the photo record might be useful to handle limitations of both rating options and photo record.

- *On the use of Web-GIS tools and mobile applications for supporting both inspections and evaluation procedures*

  In this research, I focused my efforts on developing a Web-GIS framework to support management of volunteer inspections by technicians-in-charge. The prototype application was a proof of concept for the decision support method to evaluate inspections reports. Future research should also consider a mobile application to extend the capabilities of the report module. Difficulties to relate the photo record to the inspection form can be supported by using mobile devices including camera and geo referencing capabilities. **Figure 6.1** shows a schematic representation of the inspection form in a mobile application. Such applications could support data-collection.

  Research efforts could account for the improvements in data quality of inspections and the capability of such tools to support long-term involvement of contributing volunteers (Tang and Liu, 2015). Future research should also combine qualitative evaluation methods (e.g. questionnaires about users experience) with quantitative indications (e.g. data log analysis) to explain the user interactions with the designed tools (van Velsen et al., 2008).

- *On breaking inspections into smaller volunteers' tasks*

  For other types of hydraulic structures, in cases in which visual inspections are not possible, volunteers could provide insights about human activities or land use changes that may influence the functional status of hydraulic structures. The latter could be an alternative to breaking inspections into smaller tasks that appeal wider volunteers' involvement (Franzoni and Sauermann, 2014). Moreover, elements of gaming environments may be useful for volunteers interested in technology, rewards and competitions. However, the influence of gaming in data quality remains an issue for further research.

- *On decision-making about proactive maintenance*

  In addition to the functional status, other criteria should be considered for risk assessment and for planning maintenance of structures (see Section 4.2). **Figure 6.2** provides a schematic representation of the different locations of protecting structures and the exposure of what is being protected. When many structures require maintenance, priorities are driven not only by the status and function of the structures. Decision-making about proactive maintenance should also asess the consequences for the infrastructure is being protected, according to their exposure to debris flow and flood hazard levels.

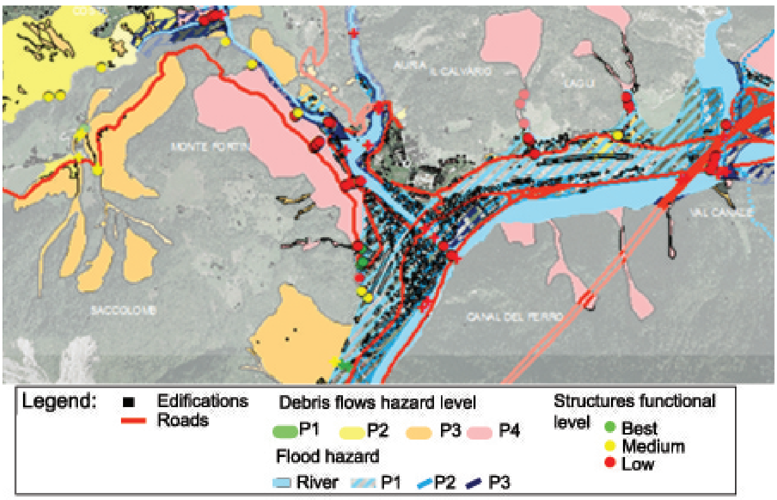


Figure 6.2: Schematic representation of relevant criteria on the sorting of structures for proactive maintenance.

- *On the evaluation method we proposed*

  The evaluation method proposed in 4 is a weighted additive model based on fuzzy inputs. I used equal weights to isolate the effect of data quality and made a frequency analysis of the cumulative occurrence of indices according to the expert-based rules that technicians-in-charge can set (**Table 4.4**). A weighted aggregation should be used with caution because it influences the outputs considerably, especially if inspectors err by overestimating or underestimating defects. Participants to this research suggested that, if used, the weighting option should be optional and located at the end of the evaluation process. Due to the limitations of visual inspections, I suggest setting the expert based rules without necessarily introducing more factors (weights). For example, functional levels can be defined based on a minimum acceptable index and a limiting worst condition from at least two reported questions per parameter.

- *On the sorting of structures for proactive maintenance*

  By indicating the functional status at parameter level (Section 4.4), compensation of extreme conditions or errors into an overall judgement for all parameters is avoided. To set priorities for management actions (**Figure 6.2**), a sorting of structures could be first based on the damages of the structure itself. Then, on the presence of obstructions and erosions due to the limited data quality for those factors. Alternatively sorting procedures could also consider limitations of data quality such as the completeness ratio. In any case, outputs of preliminary inspections should be combined with other available knowledge on relevant criteria at pre-screening level (**Table 4.1**). Those are for example, the different flood and debris flow hazard level, function type of the check dam within the system of protection works, type and relevance of exposed elements that are being protected. In that way, decision-makers can assess the inspection results of individual parameters from a broader perspective and then choose what action is to be taken. However, a balance between complexity and user-friendliness should be maintained for further development stages in the decision support method.

Proactive risk management should go beyond inspection of individual structures by assessing the residual risk of a system of protection works, designing a strategy to combine structural and non-structural measures to reduce that risk, and developing guidelines to put those measures into effect (Simonovic, 2012). Frequent inspections of relevant hydraulic structures can be useful information to update risk assessment scenarios and maintenance strategies in a system of protection works. However, the pooling of resources and collaboration between emergency preparedness and risk prevention organizations should be pursued. Joint efforts could promote the long-term implementation of volunteers' inspections and the use of collected data in proactive management.

References

ADBVE, (Autorità di bacino dei fiumi dell'Alto Adriatico) (2012), Progetto di Piano Stralcio per l'Assetto Idrogeologico del bacino idrogeografico del fiume Fella, PAI–FELLA, Technical report, ADBVE.
URL: *http:// pai.adbve.it/PAI_Fella/index_fella.html*

Adger, W., Agrawala, S., Mirza, M., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit, B. and Takahashi, K. (2007), Assessment of adaptation practices, options, constraints and capacity, *in* M. Parry, O. Canziani, J. Palutikof, P. van der Linden and C. Hanson, eds, 'Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change', Vol. 129, Cambridge University Press, Cambridge, UK,, pp. 717–743.

Almoradie, A., Cortes, V. and Jonoski, A. (2015), "Web-based stakeholder collaboration in flood risk management", *Journal of Flood Risk Management* , Vol. 8, p. 19–38.
URL: *http://onlinelibrary.wiley.com/doi/10.1111/jfr3.12076/pdf*

Arciniegas, G., Janssen, R. and Rietveld, P. (2013), "Effectiveness of collaborative map-based decision support tools: Results of an experiment", *Environmental Modelling & Software* , Vol. 39, pp. 159–175.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S1364815212000801*

Au, J., Bagchi, P., Chen, B., Martinez, R., Dudley, S. and Sorger, G. (2000), "Methodology for public monitoring of total coliforms, Escherichia coli and toxicity in waterways by Canadian high school students", *Journal of Environmental Management* , Vol. 58, pp. 213–230.
URL: *http://www.sciencedirect.com/science/article/pii/S0301479700903232*

Awad, M., Khawlie, M. and Darwich, T. (2009), "Web based meta-database and its role in improving water resources management in the mediterranean basin", *Water Resources Management* , Vol. 23, pp. 2669–2680.
URL: *http://link.springer.com/10.1007/s11269-009-9402-9*

Aye, Z. C., Jaboyedoff, M., Derron, M.-H. and van Westen, C. J. (2015a), "Prototype of a web-based participative decision support platform in natural hazards and risk management", *ISPRS Int. J. Geo-Inf.* , Vol. 4, pp. 1201–1224.
URL: *http://www.mdpi.com/2220-9964/4/3/1201/htm*

Aye, Z. C., Jaboyedoff, M., Derron, M. H., van Westen, C. J., Hussin, H. Y., Ciurean, R. L., Frigerio, S. and Pasuto, A. (2015b), "An interactive web-GIS tool for risk analysis: a case study in the Fella River Basin, Italy", *Natural Hazards and Earth System Sciences Discussions* , Vol. 3, pp. 4007–4057.
URL: *http://www.nat-hazards-earth-syst-sci-discuss.net/3/4007/2015/*

Aye, Z. C., Sprague, T., Cortes Arevalo, V. J., Prenger-Berninghoff, K., Jaboyedoff, M. and Derron, M. (2016), "A collaborative (web-gis) framework based on observations of three case studies in europe for risk management of hydro-meteorological hazards", *International Journal of Disaster Risk Reduction* , Vol. 15, pp. 10–23.

Badoux, A., Graf, C., Rhyner, J., Kuntner, R. and McArdell, B. W. (2008), "A debris-flow alarm system for the alpine illgraben catchment: design and performance", *Natural Hazards* , Vol. 49, pp. 517–539.
URL: *http://www.springerlink.com/index/10.1007/s11069-008-9303-x*

Baede, A., van der Linden, P. and Verbruggen, A. (2007), Annex ii. glossary of synthesis report, Fourth assessment report, Intergovernmental Panel on Climate Change (IPCC). "https://www.cbd.int/doc/pa/tools/Intergovernmental%20Panel%20on%20Climate%20Change.pdf".

Bastien, J. C. (2010), "Usability testing: a review of some methodological and technical aspects of the method", *International Journal of Medical Informatics* , Vol. 79, pp. e18–e23.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S1386505608002098*

Batson, C. D., Ahmad, N. and Tsang, J.-A. (2002), "Four motives for community involvement", *Journal of Social Issues* , Vol. 58, pp. 429–445.
URL: *http://onlinelibrary.wiley.com/doi/10.1111/1540-4560.00269/abstract*

Bäckstrand, K. (2003), "Civic science for sustainability: Reframing the role of experts, policy-makers and citizens in environmental governance", *Global Environmental Politics* , Vol. 3, pp. 24–41.

Bédard, Y., V. D. (1995), Qualité des données 'a référence spatiate dans un contexte gouvernmental, Rapport de rechche pour le plan g'eomatique du gouvernement du qu'ebec, Université Laval, Québec, Canada. 55p.

Bedrina, T., Parodi, A., Quarati, A. and Clematis, A. (2012), "ICT approaches to integrating institutional and non-institutional data services for better understanding of hydro-meteorological phenomena", *Natural Hazards and Earth System Science* , Vol. 12, pp. 1961–1968.
URL: *http://www.nat-hazards-earth-syst-sci.net/12/1961/2012/*

Berkes, F. (2007), "Understanding uncertainty and reducing vulnerability: lessons from resilience thinking", *Natural Hazards* , Vol. 41, pp. 283–295. 00316.
URL: *http://link.springer.com/10.1007/s11069-006-9036-7*

Bevan, N. (1999), "Quality in use: Meeting user needs for quality", *The Journal of Systems and Software* , Vol. 49, pp. 89–96.

Bhargava, H. K., Power, D. J. and Sun, D. (2007), "Progress in web-based decision support technologies", *Decision Support Systems* , Vol. 43, pp. 1083–1095.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S0167923605001016*

Bianchizza, C., Scolobig, A., Pellizzoni, L. and del Bianco, D. (2011), 2nd CapHaz-Net regional hazard workshop: social capacity building for Alpine hazards Gorizia (Italy), WP 8 D.8.1., Institute of International Sociology (ISIG).
URL: *http://caphaz-net.org/outcomes-results/CapHaz-Net_WP8_RHW-Alpine-Hazards.pdf*

Bird, T. J., Bates, A. E., Lefcheck, J. S., Hill, N. A., Thomson, R. J., Edgar, G. J., Stuart-Smith, R. D., Wotherspoon, S., Krkosek, M., Stuart-Smith, J. F., Pecl, G. T., Barrett, N. and Frusher, S. (2014), "Statistical solutions for error and bias in global citizen science datasets", *Biological Conservation* , Vol. 173, pp. 144–154.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S0006320713002693*

Bjorkland, R., Pringle, C. and Newton, B. (2001), "A stream visual assessment protocol (svap) for riparian landowners", *Environmental Monitoring and Assessment* , Vol. 68, pp. 99–125.

Boccali, C., Calligaris, C., Zini, L., Cucchi, F. and Lapasin, R. (2015), *Engineering Geology for Society and Territory - Volume 2: Landslide Processes*, Springer International Publishing, Cham, chapter Comparison of Scenarios After Ten Years: The Influence of Input Parameters in Val Canale Valley (Friuli Venezia Giulia, Italy), pp. 525–529.
URL: *http://dx.doi.org/10.1007/978-3-319-09057-3_87*

Bonnan-White, J. and Bielecke, A. (2014), "Snow Tweets: Emergency information dissemination in a US County during 2014 winter storms", *PLoS Curr.* , Vol. 6.
URL: *http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4323415/*

Bonney, R., Cooper, C. B., Dickinson, J. L., Kelling, S., Phillips, T., Rosenberg, K. V. and Shirk, J. (2009), "Citizen Science: A developing tool for expanding science knowledge and scientific literacy", *BioScience* , Vol. 59, pp. 977–984. 00199.
URL: *http://bioscience.oxfordjournals.org/content/59/11/977.full.pdf+html*

Bonney, R., Shirk, J. L., Phillips, T. B., Wiggins, A., Ballard, H. L., Miller-Rushing, A. J. and Parrish, J. K. (2014), "Next steps for citizen science", *Science* , Vol. 343, pp. 1436–1437.
URL: *http://science.sciencemag.org/content/343/6178/1436*

Bontempi, F., Gkoumas, K. and Arangio, S. (2008), "Systemic approach for the maintenance of complex structural systems", *Structure and Infrastructure Engineering* , Vol. 4, pp. 77–94.
URL: *http://www.tandfonline.com/doi/abs/10.1080/15732470601155235*

Bordogna, G., Carrara, P., Criscuolo, L., Pepe, M. and Rampini, A. (2014a), "A linguistic decision making approach to assess the quality of volunteer geographic information for citizen science", *Information Sciences* , Vol. 258, pp. 312–327.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S0020025513005240*

Bordogna, G., Carrara, P., Criscuolo, L., Pepe, M. and Rampini, A. (2014b), "On predicting and improving the quality of Volunteer Geographic Information projects", *International Journal of Digital Earth* , pp. 1–22.
URL: *http://www.tandfonline.com/doi/full/10.1080/17538947.2014.976774*

Borga, M., Boscolo, P., Zanon, F. and Sangati, M. (2007), "Hydrometeorological analysis of the 29 August 2003 Flash Flood in the Eastern Italian Alps", *Journal of Hydrometeorology* , Vol. 8, pp. 1049–1067.
URL: *http://journals.ametsoc.org/doi/abs/10.1175/JHM593.1*

Botts, M., Percivall, G., Reed, C. and Davidson, J. (2008), OGC sensor web enablement: Overview and high level architecture, *in* 'Geosensor networks', Springer-Verlag, Berlin Heidelberg, pp. 175–190.

Bowser, A., Preece, J. and Hansen, D. (2013), Gamifying Citizen Science: Lessons and Future Directions, *in* G. R. Network, ed., 'CHI 2013 Workshop Designing Gamification: Creating Gameful and Playful Experiences, Apr 27-May 2, Paris, France'.
URL: *http://gamification-research.org/wp-content/uploads/2013/03/Bowser_Hansen-_Preece.pdf*

Brandon, A., Spyreas, G., Molano-Flores, B., Caroll, C. and Ellis, J. (2003), "Can Volunteers provide reliable data for Forest vegetation surveys?", *Natural Areas Journal* , Vol. 23, pp. 254–262.
URL: *http://plsa.inhs.uiuc.edu/publications/Brandon_et_al.pdf*

Brilly, M., Rusjan, S., Mikoš, M., Horvat, A., Kryžanowski, A., Schnabl, S., Vidmar, A., Koprivšek, M., Bogaard, T., Baldassarre, G. D., Ferri, M., Ranzi, R., Bacchi, B. and Balistrocchi, M. (2011), Critical review of structural measures for water-related risks, Report D-4-1, KULTURRisk, Delft, The Netherlands.
URL: *http://www.kulturisk.eu/results/wp4*

Brudney, J. L. and Gazley, B. (2006), "Moving ahead or falling behind? Volunteer promotion and data collection", *Nonprofit Management and Leadership* , Vol. 16, pp. 259–276.
URL: *http://onlinelibrary.wiley.com/doi/10.1002/nml.106/pdf*

Burke, J., Estrin, D., Hansen, M., Parker, A., Ramanathan, N. and Reddy, S. (2006), Participatory sensing, *in* 'Proceedings of the International Workshop on World-Sensor-Web (WSW'06), Oct-31, Boulder, CO, USA', UCLA: Center for Embedded Network Sensing, ACM, Boulder, CO, USA.
URL: *http://escholarship.org/uc/item/19h777qd*

Buytaert, W., Zulkafli, Z., Grainger, S., Acosta, L., Tilashwork C, A., Bastiaensen, J., De Bievre, B., Bhusal, J., Clark, J., Dewulf, A., Foggin, M., Hannah, D. M., Hergarten, C., Isaeva, A., Karpouzoglou, T., Pandeya, B., Paudel, D., Sharma, K., Steenhuis, T., Tilahun, S., van Hecken, G. and Zhumanova, M. (2014), "Citizen science in hydrology and water resources: opportunities for knowledge generation, ecosystem service management, and sustainable development", *Front. Earth Sci.* .
URL: *http://journal.frontiersin.org/Journal/10.3389/feart.2014.00026/full*

Calligaris, C. and Zini, L. (2012), Debris Flow Phenomena: A Short Overview?, *in* 'Earth Sciences', imran ahmad dar edn, InTech, pp. 72–90.
URL: *http://www.intechopen.com/books/earth-sciences/debris-flow-phenomena-a-short-overview-*

Caruana, R., Elhawary, M., Munson, A., Riedewald, M., Sorokina, D., Fink, D., Hochachka, W. M. and Kelling, S. (2006), Mining citizen science data to predict orevalence of wild bird species, *in* 'Proceedings of the 12th ACM SIGKDD International Conference on Knowledge Discovery and Data Mining, Aug 20-23, 2006, Philadelphia, PA, US', KDD '06, ACM, New York, NY, USA, pp. 909–915.
URL: *http://doi.acm.org/10.1145/1150402.1150527*

Cavalli, M., Trevisani, S., Comiti, F. and Marchi, L. (2013), "Geomorphometric assessment of spatial sediment connectivity in small Alpine catchments", *Geomorphology* , Vol. 188, pp. 31–41.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S0169555X12002267*

Chang, Y.-S. and Park, H.-D. (2004), "Development of a web-based Geographic Information System for the management of borehole and geological data", *Computers & Geosciences* , Vol. 30,

pp. 887–897.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S0098300404001335*

Charrière, M., Junier, S., Bogaard, T., Mostert, E., Van de Giesen, N. and Malet, J.-P. (in preparation), "The impact of an exhibition on general public's risk awareness of mountainous hazards".

Chen, S. and Hwang, C. (1992), *Fuzzy multiple attribute decision making: methods and applications.*, Lecture Notes in Economics and Mathematical Systems, Springer-Verlag, New York.
URL: *http://link.springer.com/book/10.1007%2F978-3-642-46768-4*

Chou, K. C. and Yuan, J. (1992), "Safety assessment of existing structures using a filtered fuzzy relation", *Structural Safety* , Vol. 11, pp. 173–189.

Cifelli, R., Doesken, N., Kennedy, P., Carey, L. D., Rutledge, S. A., Gimmestad, C. and Depue, T. (2005), "The Community Collaborative Rain, Hail, and Snow Network: Informal education for scientists and citizens", *Bulletin of the American Meteorological Society* , Vol. 86, pp. 1069–1077.
URL: *http://journals.ametsoc.org/doi/abs/10.1175/BAMS-86-8-1069*

Ciurean, R., Chen, L., Hussin, H., van Westen, C., Glade, T., Frigerio, S. and Pasuto, A. (2014), Quantitative vulnerability assessment of buildings to debris-flows in Fella River Basin using run-out modeling and damage data from the 29th of August 2003 event, *in* 'International Conference Analysis and Management of Changing Risks for Natural Hazards, Nov 18 –19, Padova, Italy', Padua, Italy.

Ciurean, R., Schroter, D. and Glade, T. (2013), *Examining the Implications of Hazards, Emergencies and Disasters*, InTech, chapter Conceptual Frameworks of Vulnerability Assessments for Natural Disasters Reduction, pp. 3–32. ISBN: 978-953-51-1093-4.
URL: *http://www.intechopen.com/books/approaches-to-disaster-management-examining-the-implications-of-hazards-emergencies-and-disasters/conceptual-frameworks-of-vulnerability-assessments-for-natural-disasters-reduction*

Cohn, J. P. (2008), "Citizen science: Can volunteers do real research?", *BioScience* , Vol. 58, pp. 192–197.
URL: *http://bioscience.oxfordjournals.org/content/58/3/192.full.pdf+html*

Coleman, D. J., Georgiadou, Y. and Labonte, J. (2009), "Volunteered geographic information: The nature and motivation of produsers", *International Journal of Spatial Data Infrastructures Research* , Vol. 4, pp. 332–358.
URL: *http://kfrichter.org/crowdsourcing-material/day3/coleman09.pdf*

Comber, A., See, L., Fritz, S., Van der Velde, M., Perger, C. and Foody, G. (2013), "Using control data to determine the reliability of volunteered geographic information about land cover", *International Journal of Applied Earth Observation and Geoinformation* , Vol. 23, pp. 37–48.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S0303243412002358*

Conrad, C. and Hilchey, K. (2011), "A review of citizen science and community-based environmental monitoring: issues and opportunities", *Environmental Monitoring and Assessment* , Vol. 176, pp. 273–291.
URL: *http://dx.doi.org/10.1007/s10661-010-1582-5*

Cooper, T., Bryer, T. A. and Meek, J. W. (2006), "Citizen-centered collaborative public management", *Public Administration Review. Special issue: Emergency Management: A Challenge for Public Administration* , Vol. 66, pp. 76–88.

Cortes Arevalo, V. J., Aye, Z., Frigerio, S., Schenato, L., Bogaard, T., Pasuto, A. and Sterlacchini, S. (Under Review), "A web-GIS decision support framework for assisting technicians in evaluating check dams inspection reports", *Water Resources Management* .

Cortes Arevalo, V. J., Charrière, M., Bossi, G., Frigerio, S., Schenato, L., Bogaard, T., Bianchizza, C., Pasuto, A. and Sterlacchini, S. (2014), "Evaluating data quality collected by volunteers for first-level inspection of hydraulic structures in mountain catchments", *Natural Hazards and Earth System Science* , Vol. 14, pp. 2681–2698.
URL: *http://www.nat-hazards-earth-syst-sci.net/14/2681/2014/*

Cortes Arevalo, V. J., Sterlacchini, S., Bogaard, T. A., Junier, S. and van de Giesen, N. (2016), "Decision support method to systematically evaluate first-level inspections of the functional status of check dams", *Structure and Infrastructure Engineering* , pp. 1–18.
URL: *http://dx.doi.org/10.1080/15732479.2016.1144619*

Couvet, D., Jiguet, F., Julliard, R., Levrel, H. and Teyssedre, A. (2008), "Enhancing citizen contributions to biodiversity science and public policy", *Interdisciplinary Science Reviews* , Vol. 33, pp. 95–103.
URL: *http://www.maneyonline.com/doi/abs/10.1179/030801808X260031*

Crall, A. W., Newman, G. J., Jarnevich, C. S., Stohlgren, T. J., Waller, D. M. and Graham, J. (2010), "Improving and integrating data on invasive species collected by citizen scientists", *Biological Invasions* , Vol. 12, pp. 3419–3428.
URL: *http://link.springer.com/10.1007/s10530-010-9740-9*

Crall, A. W., Newman, G. J., Stohlgren, T. J., Holfelder, K. A., Graham, J. and Waller, D. M. (2011), "Assessing citizen science data quality: an invasive species case study", *Conservation Letters* , Vol. 4, pp. 433–442.
URL: *http://onlinelibrary.wiley.com/doi/10.1111/j.1755-263X.2011.00196.x/full*

Curt, C. and Gervais, R. (2014), "Approach to improving the quality of data used to analyse dams - illustrations by two methods", *European Journal of Environmental and Civil Engineering* , Vol. 18, pp. 87–105.
URL: *http://www.tandfonline.com/doi/abs/10.1080/19648189.2013.850188*

Curt, C., Talon, A. and Mauris, G. (2011), "A dam assessment support system based on physical measurements, sensory evaluations and expert judgements", *Measurement* , Vol. 44, pp. 192–201.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S0263224110002381*

Dabous, S. A. and Alkass, S. (2010), "A multi-attribute ranking method for bridge management", *Engineering, Construction and Architectural Management* , Vol. 17, pp. 282–291.

D'Agostino, V. and Bertoldi, G. (2014), "On the assessment of the management priority of sediment source areas in a debris-flow catchment", *Earth Surface Processes and Landforms* , Vol. 39, pp. 656–658.
URL: *http://onlinelibrary.wiley.com/doi/10.1002/esp.3518/pdf*

Danielsen, F., Burgess, N. D. and Balmford, A. (2005), "Monitoring Matters: Examining the potential of locally-based approaches", *Biodiversity and Conservation* , Vol. 14, pp. 2507–2542.
URL: *http://link.springer.com/10.1007/s10531-005-8375-0*

Danielsen, F., Burgess, N. D., Balmford, A., Donald, P. F., Funder, M., Jones, J. P., Alviola, P., Balete, D. S., Bromley, T., Brashares, J., Child, B., Enghoff, M., Fjeldsa, J., Holt, S., Hubertz, H., Jensen, A. E., Jensen, P. M., Massao, J., Mendoza, M. M., Ngaga, Y., Poulsen, M. K., Rueda, R., Sam, M., Skielboe, T., Stuart-Hill, G., Topp-Jorgensen, E. and Yonten, D. (2009), "Local participation in natural resource monitoring: a characterization of approaches", *Conservation Biology* , Vol. 23, pp. 31–42.
URL: *http://onlinelibrary.wiley.com/doi/10.1111/j.1523-1739.2008.01063.x/pdf*

de Jong, C. (2013), "Linking ICT and society in early warning and adaptation to hydrological extremes in mountains", *Natural Hazards and Earth System Science* , Vol. 13, pp. 2253–2270.
URL: *http://www.nat-hazards-earth-syst-sci.net/13/2253/2013/*

Delipetrev, B., Jonoski, A. and Solomatine, D. P. (2014), "Development of a web application for water resources based on open source software", *Computers & Geosciences* , Vol. 62, pp. 35–42.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S0098300413002525*

Dell'Agnese, A., Mazzorana, B., Comiti, F., Von Maravic, P. and D'Agostino, V. (2013), "Assessing the physical vulnerability of check dams through an empirical damage index", *Journal of Agricultural Engineering* , Vol. 44, pp. 9–16.
URL: *http://www.agroengineering.org/jae/article/view/jae.2013.e2/pdf*

Devictor, V., Whittaker, R. J. and Beltrame, C. (2010), "Beyond scarcity: citizen science programmes as useful tools for conservation biogeography", *Diversity and Distributions* , Vol. 16, pp. 354–362.
URL: *http://dx.doi.org/10.1111/j.1472-4642.2009.00615.x*

Devillers, R., Bédard, Y. and Jeansoulin, R. (2005), "Multidimensional management of geospatial data quality information for its dynamic use within GIS", *Photogrammetric Engineering & Remote Sensing* , Vol. 71, p. 205–215.
URL: *http://dx.doi.org/10.14358/PERS.71.2.205*

Devillers, R., Gervais, M., Bédard, Y. and Jeansoulin, R. (2002), Spatial data quality: from metadata to quality indicators and contextual end-user manual, *in* 'OEEPE/ISPRS Joint Workshop on Spatial Data Quality Management, Mar 21-22, Istanbul, Turkey', pp. 45–55.
URL: *http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.460.4972&rep=rep1&-type=pdf*

Díez, E. and McIntosh, B. S. (2009), "A review of the factors which influence the use and usefulness of information systems", *Environmental Modelling & Software* , Vol. 24, pp. 588–602.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S1364815208001916*

Dirksen, J., Clemens, F. H., Korving, H., Cherqui, F., Le Gauffre, P., Ertl, T., Plihal, H., Müller, K. and Snaterse, C. T. (2013), "The consistency of visual sewer inspection data", *Structure and Infrastructure Engineering* , Vol. 9, pp. 214–228.
URL: *http://www.tandfonline.com/doi/abs/10.1080/15732479.2010.541265*

EC, European Commission (2013), An eu strategy on adaptation to climate change, Technical Report COM 2013 216 final, European Commission, Brussels.

EC, (European Council)) (2007), 'Directive 2007/60/EC of the european parliament and of the council of 23 october 2007 on the assessment and management of flood risks', European Council.
URL: *http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:288:0027:0034-:en:pdf*

Edelenbos, J. (2005), "Institutional implications of interactive governance: insights from dutch practice", *Governance: An International Journal of Policy, Administration, and Institutions* , Vol. 18, pp. 111–134.
URL: *http://onlinelibrary.wiley.com/doi/10.1111/j.1468-0491.2004.00268.x/epdf*

EEA, European Environment Agency (2010), Mapping the impacts of natural hazards and technological accidents in europe – an overview of the last decade, Technical Report No 13/ 2010, European Environment Agency, Copenhagen.
URL: *http://www.eea.europa.eu/publications/mapping-the-impacts-of-natural*

Elmore, K. L., Flamig, Z. L., Lakshmanan, V., Kaney, B. T., Farmer, V., Reeves, H. D. and Rothfusz, L. P. (2014), "MPING: Crowd-sourcing weather reports for research", *Bulletin of the American Meteorological Society* , Vol. 95, pp. 1335–1342.
URL: *http://journals.ametsoc.org/doi/abs/10.1175/BAMS-D-13-00014.1*

Enders, J. (2001), "Measuring community awareness and preparedness for emergencies", *Australian Journal of Emergency Management* , Vol. 16, pp. 52–58.
URL: *http://apo.org.au/node/49193*

Engel, S. R. and Reese, Jr, V. (2002), "Volunteer Biological Monitoring: Can it accurately assess the ecological condition of streams?", *American Entmologist* , Vol. 48, pp. 164–177.
URL: *http://dx.doi.org/10.1093/ae/48.3.164*

Engineering, B. (1999), *Indiana Drainage Handbook. An administrative and technical guide for activities within Indiana streams*, (CBBEL), Burke Engineering, Christopher B Ltd, Indianapolis, Indiana.
URL: *http://www.in.gov/dnr/water/files/allhbook.pdf*

EPA (1997), *Volunteer Stream Monitoring: A Methods Manual*, number EPA 841-B-97-003, United States Environmental Protection Agency (EPA), Office of Water 4503F, Washington, DC. 227 pp.
URL: *http://water.epa.gov/type/rsl/monitoring/upload/2002_08_13_volunteer_stream-_stream.pdf*

EUGENE (2010), Status quo report disasters, Report Work package 3000, Eugene. "`http://www.eugene-fp7.eu/docs/EUGENE_Disasters_Status_Quo_Report_Issue_1.pdf`".

Failing, L., Gregory, R. and Harstone, M. (2007), "Integrating science and local knowledge in environmental risk management: A decision-focused approach", *Ecological Economics* , Vol. 64, pp. 47–60.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S0921800907002017*

Fernandez-Gimenez, M. E., Ballard, H. L. and Sturtevant, V. E. (2008), "Adaptive management and social learning in collaborative and community-based monitoring: a study of five community-based forestry organizations in the western usa", *Ecology and Society* , Vol. 13, p. 4.
URL: *http://dlc.dlib.indiana.edu/dlc/handle/10535/3213*

Ferster, C. J. and Coops, N. C. (2013), "A review of earth observation using mobile personal communication devices", *Computers & Geosciences* , Vol. 51, pp. 339–349.
URL: *http://www.sciencedirect.com/science/article/pii/S0098300412003184*

Flanagin, A. J. and Metzger, M. J. (2008), "The credibility of volunteered geographic information", *GeoJournal* , Vol. 72, pp. 137–148.
URL: *http://link.springer.com/10.1007/s10708-008-9188-y*

Flint, C. G. and Stevenson, J. (2009), "Building community disaster preparedness with volunteers: Community emergency response teams in illinois", *Natural Hazards Review* , Vol. 11, pp. 118–124.
URL: *http://ascelibrary.org/doi/abs/10.1061/(ASCE)NH.1527-6996.0000014*

Folke, C., Colding, J. and Berkes, F. (2003), *Navigating social – ecological systems: Building resilience for complexity and change*, number ISBN: 0-5218-1592-4, Cambridge University Press, Cambridge, UK, chapter Synthesis: Building resilience and adaptive capacity in socio-ecological systems, pp. 352 – 387.
URL: *http://dx.doi.org/10.1017/CBO9780511541957.020*

Foody, G. M. (2014), "Rating crowdsourced annotations: evaluating contributions of variable quality and completeness", *International Journal of Digital Earth* , Vol. 7, pp. 650–670.
URL: *http://www.tandfonline.com/doi/abs/10.1080/17538947.2013.839008*

Fore, L. S., Paulsen, K. and O'Laughlin, K. (2001), "Assessing the performance of volunteers in monitoring streams", *Freshwater Biology* , Vol. 46, pp. 109–123.
URL: *http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2427.2001.00640.x/full*

Fowler, A., Whyatt, J. D., Davies, G. and Ellis, R. (2013), "How reliable are citizen-derived scientific data? assessing the quality of contrail observations made by the general public", *Transactions in GIS* , Vol. 17, pp. 488–506.
URL: *http://onlinelibrary.wiley.com/doi/10.1111/tgis.12034/pdf*

Franzoni, C. and Sauermann, H. (2014), "Crowd science: The organization of scientific research in open collaborative projects", *Research Policy* , Vol. 43, pp. 1–20.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S0048733313001212*

Fraser, E. D., Dougill, A. J., Mabee, W. E., Reed, M. and McAlpine, P. (2006), "Bottom up and top down: Analysis of participatory processes for sustainability indicator identification as a pathway to community empowerment and sustainable environmental management", *Journal of Environmental Management* , Vol. 78, pp. 114–127.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S0301479705001659*

Frigerio, S., Schenato, L., Bossi, G., Cavalli, M., Mantovani, M., Marcato, G. and Pasuto, A. (2014), "A web-based platform for automatic and continuous landslide monitoring the rotolon (Eastern Italian Alps) case study", *Computers & Geosciences* , Vol. 63, pp. 96–105.

Fung, A. (2006), "Varieties of participation in complex governance", *Public administration review* , Vol. 66, pp. 66–75.
URL: *http://onlinelibrary.wiley.com/doi/10.1111/j.1540-6210.2006.00667.x/full*

Gaillard, J. and Mercer, J. (2012), "From knowledge to action: Bridging gaps in disaster risk reduction", *Progress in Human Geograph* , Vol. 37, pp. 93–114.
URL: *http://phg.sagepub.com/content/37/1/93.full.pdf+html*

Galloway, A. W. E., Tudor, M. T. and Haegen, W. M. V. (2006), "The Reliability of Citizen Science: A case study of Oregon White Oak stand surveys", *Wildlife Society Bulletin* , Vol. 34, pp. 1425–1429.
URL: *http://doi.wiley.com/10.2193/0091-7648(2006)34[1425:TROCSA]2.0.CO;2*

Gaume, E., Bain, V., Bernardara, P., Newinger, O., Barbuc, M., Bateman, A., Blaskovicová, L., Blöschl, G., Borga, M., Dumitrescu, A. et al. (2009), "A compilation of data on european flash floods", *Journal of Hydrology* , Vol. 367, pp. 70–78.

Gervais, M., Bedard, I., Levesque, M.-A., Bernier, E. and Devillers, R. (2009), *Geographic Data Mining and Knowledge Discovery*, Chapman & Hall/CRC Data Mining and Knowledge Discovery Series, CRC Press, chapter Data Quality Issues and Geographic Knowledge Discovery, pp. 99–116. 486 pp.

Gharesifard, M. and Wehn, U. (2016), "To share or not to share: Drivers and barriers for sharing data via online amateur weather networks", *Journal of Hydrology* , Vol. 535, p. 181–190.

Gkatzoflias, D., Mellios, G. and Samaras, Z. (2013), "Development of a web GIS application for emissions inventory spatial allocation based on open source software tools", *Computers & Geosciences* , Vol. 52, pp. 21–33.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S0098300412003512*

Gollan, J., Bruyn, L. L., Reid, N. and Wilkie, L. (2012), "Can volunteers collect data that are comparable to professional scientists? A study of variables used in monitoring the outcomes of ecosystem rehabilitation", *Environmental Management* , Vol. 50, pp. 969–978.
URL: *http://link.springer.com/10.1007/s00267-012-9924-4*

Gommerman, L. and Monroe, M. C. (2012), "Lessons learned from evaluations of Citizen Science Programs", *School of Forest Resources and Conservation. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida* .
URL: *http://edis.ifas.ufl.edu/fr359*

Goodchild, M. (2007), "Citizens as sensors: the world of volunteered geography", *GeoJournal* , Vol. 69, pp. 211–221.

Goodchild, M. F. and Li, L. (2012), "Assuring the quality of volunteered geographic information", *Spatial Statistics* , Vol. 1, pp. 110–120.
URL: *http://www.sciencedirect.com/science/article/pii/S2211675312000097*

Gould, J. D. and Lewis, C. (1985), "Designing for usability: Key principles and what designers think", *Communications of the ACM* , Vol. 28.

Gouveia, C. and Fonseca, A. (2008), "New approaches to environmental monitoring: the use of ICT to explore volunteered geographic information", *GeoJournal* , Vol. 72, pp. 185–197.
URL: *http://dx.doi.org/10.1007/s10708-008-9183-3*

Gouveia, C., Fonseca, A., Câmara, A. and Ferreira, F. (2004), "Promoting the use of environmental data collected by concerned citizens through information and communication technologies", *Journal of Environmental Management* , Vol. 71, pp. 135–154.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S0301479704000428*

Haklay, M. (2013), *Crowdsourcing Geographic Knowledge: Volunteered Geographic Information (VGI) in Theory and Practice*, Springer Netherlands, Dordrecht, Netherlands, chapter Citizen Science and Volunteered Geographic Information: Overview and Typology of Participation, pp. 105–122.
URL: *http://dx.doi.org/10.1007/978-94-007-4587-2_7*

Haklay, M. M., Basiouk, S., Antoniou, V. and Ather, A. (2010), "How many volunteers does it take to map an area well? the validity of linus' law to volunteered geographic information", *CARTOGR J* , Vol. 47, pp. 315 – 322.
URL: *http://discovery.ucl.ac.uk/150404/2/150404.pdf*

Haklay, M. and Tobón, C. (2003), "Usability evaluation and PPGIS: towards a user-centred design approach", *International Journal of Geographical Information Science* , Vol. 17, pp. 577–592.
URL: *http://www.tandfonline.com/doi/abs/10.1080/1365881031000114107*

Holcombe, E., Anderson, M. and Holm-Nielsen, N. (2013), *Landslide Science and Practice: Volume 7: Social and Economic Impact and Policies*, Springer Berlin Heidelberg, Berlin, Heidelberg, chapter Learning by Doing: Community Based Landslide Risk Reduction, pp. 297–302.
URL: *http://dx.doi.org/10.1007/978-3-642-31313-4_39*

Holub, M. and Fuchs, S. (2009), "Mitigating mountain hazards in Austria - legislation, risk transfer, and awareness building", *Natural Hazards and Earth System Sciences* , Vol. 9, pp. 523–537.

Holub, M. and Hübl, J. (2008), "Local protection against mountain hazards - state of the art and future needs", *Natural Hazards and Earth System Sciences* , Vol. 8, pp. 81–99.
URL: *http://hal.archives-ouvertes.fr/docs/00/30/17/04/PDF/nhess-8-81-2008.pdf*

Hornbæk, K. (2006), "Current practice in measuring usability: Challenges to usability studies and research", *International Journal of Human-Computer Studies* , Vol. 64, pp. 79–102.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S1071581905001138*

Horsburgh, J. S., Tarboton, D. G., Maidment, D. R. and Zaslavsky, I. (2011), "Components of an environmental observatory information system", *Computers & Geosciences* , Vol. 37, pp. 207–218.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S009830041000275X*

Hudson-Smith, A., Batty, M., Crooks, A. and Milton, R. (2008), Mapping for the masses: accessing Web 2.0 through crowdsourcing, *in* 'Working paper series - University College of London for advanced spatial analysis', number Paper 143 - Aug 08, Centre for Advanced Spatial Analysis University College London, London, UK, pp. 1–18.
URL: *http://eprints.ucl.ac.uk/15198/1/15198.pdf*

Huebl, J. and Fiebiger, G. (2005), Debris flow mitigation measures, *in* M. Jakob and O. Hungr, eds, 'Debris Flow Hazards and Related Phenomena', number 445–487 *in* 'Springer', Praxis, Chichester, UK, chapter 18.

Hussin, H. Y., Ciurean, R., Frigerio, S., Marcato, G., Calligaris, C., Reichenbach, P., Westen, C. and Glade, T. (2014), *Landslide Science for a Safer Geoenvironment: Volume 2: Methods of Landslide Studies*, Springer International Publishing, Cham, chapter Assessing the Effect of Mitigation Measures on Landslide Hazard Using 2D Numerical Runout Modelling, pp. 679–684.
URL: *http://dx.doi.org/10.1007/978-3-319-05050-8_105*

Hwang, C. and Yoon, K. (1981), *Multiple Attribute Decision Making - Methods and Applications A State-of-the-Art Survey*, Vol. 186 of *Lecture Notes in Economics and Mathematical Systems*, Springer Verlag, Berlin, New York.

Inman, D., Blind, M., Ribarova, I., Krause, A., Roosenschoon, O., Kassahun, A., Scholten, H., Arampatzis, G., Abrami, G., McIntosh, B. and Jeffrey, P. (2011), "Perceived effectiveness of environmental decision support systems in participatory planning: Evidence from small groups of end-users", *Environmental Modelling & Software* , Vol. 26, pp. 302–309.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S1364815210002331*

ISDR, International Startegy for Disaster Reduction (2008), Indigenous knowledge: Disaster risk reduction, Policy note, International Startegy for Disaster Reduction, Kyoto.
URL: *http://www.unisdr.org/files/8853_IKPolicyNote.pdf*

ISO/IEC. 9241-14 (1998), ‘Ergonomic requirements for office work with visual display terminals (VDTs) – part 11: Guidance on usability’.

Janssen, J., Krol, M., Schielen, R., Hoekstra, A. and de Kok, J.-L. (2010), “Assessment of uncertainties in expert knowledge, illustrated in fuzzy rule-based models”, *Ecological Modelling* , Vol. 221, pp. 1245–1251.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S0304380010000505*

Jäger, J., Moser, S., Arnott, J. and Schaller, M. (2014), Adaption to climate change in mountain & coastal areas Building an interface between providers and users of climate change knowledge – insights from a transatlantic dialogue, Report 22, Climate Service Center, Germany.
URL: *http://www.climate-service-center.de/imperia/md/content/csc/report_22.pdf*

Jonoski, A. (2002), *Hydroinformatics as socioetchnology: promoting individual stakeholder participation by using network distributed decision support systems.*, PhD Dissertation, UNESCO-IHE, Delft and Sweets and Zeitlinger, Lisse, Lisse, The Netherlands.

Jordan, R. C., Brooks, W. R., Howe, D. V. and Ehrenfeld, J. G. (2011), “Evaluating the performance of volunteers in mapping invasive plants in public conservation lands”, *Environmental Management* , Vol. 49, pp. 425–434.
URL: *http://link.springer.com/10.1007/s00267-011-9789-y*

Junier, S. and Mostert, E. (2014), “A decision support system for the implementation of the Water Framework Directive in the Netherlands: Process, validity and useful information”, *Environmental Science & Policy* , Vol. 40, pp. 49–56.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S1462901114000689*

Kabir, G., Sadiq, R. and Tesfamariam, S. (2014), “A review of multi-criteria decision-making methods for infrastructure management”, *Structure and Infrastructure Engineering* , Vol. 10, pp. 1176–1210.
URL: *http://www.tandfonline.com/doi/abs/10.1080/15732479.2013.795978*

Kerle, N. and Hoffman, R. R. (2013), “Collaborative damage mapping for emergency response: the role of Cognitive Systems Engineering”, *Natural Hazards and Earth System Science* , Vol. 13, pp. 97–113.
URL: *http://www.nat-hazards-earth-syst-sci.net/13/97/2013/*

Kim, S., Robson, C., Zimmerman, T., Pierce, J. and Haber, E. M. (2011), Creek watch: Pairing usefulness and usability for successful citizen science, *in* ‘Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, May 7-12, Vancouver, BC, Canada’, CHI ’11, ACM, New York, NY, USA, pp. 2125–2134.
URL: *http://doi.acm.org/10.1145/1978942.1979251*

Kliment, T., Bordogna, G., Frigerio, L., Stroppiana, D., Crema, A., Boschetti, M., Sterlacchini, S. and Brivio, P. A. (2014), “Supporting a regional agricultural sector with Geo & mainstream ICT–the case study of Space4agri Project”, *AGRIS on-line Papers in Economics and Informatics* , Vol. 6.
URL: *http://online.agris.cz/files/2014/agris_on-line_2014_4_kliment_bordogna_frigerio-_stroppiana_crema_boschetti_sterlacchini_brivio.pdf*

Koch, F., Cardonha, C., Gentil, J. M. and Borger, S. (2013), *Citizen in Sensor Networks: First International Workshop, CitiSens 2012, Montpellier, France, August 27, 2012, Revised Selected Papers*, Springer Berlin Heidelberg, Berlin, Heidelberg, chapter A Platform for Citizen Sensing in Sentient Cities, pp. 57–66.
URL: *http://dx.doi.org/10.1007/978-3-642-36074-9_6*

Kumar, N., Belhumeur, P. N., Biswas, A., Jacobs, D. W., Kress, W. J., Lopez, I. C. and Soares, J. V. B. (2012), Leafsnap: A computer vision system for automatic plant species identification, *in* A. Fitzgibbon, S. Lazebnik, P. Perona, Y. Sato and C. Schmid, eds, 'Computer Vision – ECCV 2012: 12th European Conference on Computer Vision, Proceedings, Part II, Oct 7-13, Florence, Italy', Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 502–516.
URL: *http://dx.doi.org/10.1007/978-3-642-33709-3_36*

Laitenberger, O. and Dreyer, H. M. (1998), Evaluating the usefulness and the ease of use of a web-based inspection data collection tool, *in* 'Proceedings of Fifth International Software Metrics Symposium, 20-21 Nov, Bethesda, MD, USA'.

Lane, S. J., Heddle, N. M., Arnold, E. and Walker, I. (2006), "A review of randomized controlled trials comparing the effectiveness of hand held computers with paper methods for data collection", *BMC medical informatics and decision making* , Vol. 6, p. 23.
URL: *http://www.biomedcentral.com/1472-6947/6/23*

Lara, A., Saurí, D., Ribas, A. and Pavón, D. (2010), "Social perceptions of floods and flood management in a mediterranean area (costa brava, spain)", *Natural Hazards and Earth System Science* , Vol. 10, pp. 2081–2091.
URL: *http://www.nat-hazards-earth-syst-sci.net/10/2081/2010/*

Lesen, A. E. (2015), *Scientists, experts, and civic engagement : walking a fine line*, Ashgate studies in environmental policy and practice., Ashgate. 166 p.

Linnerooth-Bayer, J., Scolobig, A., Ferlisi, S., Cascini, L. and Thompson, M. (2015), "Expert engagement in participatory processes: translating stakeholder discourses into policy options", *Natural Hazards* .
URL: *http://link.springer.com/10.1007/s11069-015-1805-8*

Liu, H.-Y., Kobernus, M., Broday, D. and Bartonova, A. (2014), "A conceptual approach to a citizens' observatory–supporting community-based environmental governance", *Environmental Health* , Vol. 13, p. 107.
URL: *http://www.biomedcentral.com/content/pdf/1476-069X-13-107.pdf*

Lowry, C. S. and Fienen, M. N. (2013), "CrowdHydrology: Crowdsourcing hydrologic data and engaging citizen scientists", *Ground Water* , Vol. 51, pp. 151–156.
URL: *http://doi.wiley.com/10.1111/j.1745-6584.2012.00956.x*

Malek, i. and Boerboom, L. (2015), "Participatory scenario development to address potential impacts of land use change: An example from the Italian Alps", *Mountain Research and Development* , Vol. 35, pp. 126–138.
URL: *http://www.bioone.org/doi/10.1659/MRD-JOURNAL-D-14-00082.1*

Malek, i., Scolobig, A. and Schröter, D. (2014), "Understanding land cover changes in the Italian Alps and Romanian Carpathians combining remote sensing and stakeholder interviews", *Land*

, Vol. 3, pp. 52–73.
URL: *http://www.mdpi.com/2073-445X/3/1/52*

Marchi, L., Cavalli, M., Sangati, M. and Borga, M. (2009), “Hydrometeorological controls and erosive response of an extreme alpine debris flow”, *Hydrological Processes*, Vol. 23, pp. 2714–2727.
URL: *http://doi.wiley.com/10.1002/hyp.7362*

Marshall, N. J., Kleine, D. A. and Dean, A. J. (2012), “Coralwatch: education, monitoring, and sustainability through citizen science”, *Frontiers in Ecology and the Environment*, Vol. 10, pp. 332–334.
URL: *http://www.esajournals.org/doi/abs/10.1890/110266*

Matthies, M., Giupponi, C. and Ostendorf, B. (2007), “Environmental decision support systems: Current issues, methods and tools”, *Environmental Modelling & Software*, Vol. 22, pp. 123–127. 00173.
URL: *http://www.sciencedirect.com/science/article/pii/S1364815205001726*

Mazzorana, B., Comiti, F., Scherer, C. and Fuchs, S. (2012), “Developing consistent scenarios to assess flood hazards in mountain streams.”, *J Environ Manage.*, Vol. 94, pp. 112–124.

Mazzorana, B., Hübl, J., Zischg, A. and Largiader, A. (2010), “Modelling woody material transport and deposition in alpine rivers”, *Natural Hazards*, Vol. 56, pp. 425–449.
URL: *http://link.springer.com/10.1007/s11069-009-9492-y*

Mazzorana, B., Simoni, S., Kobald, J., Formaggioni, O. and Lanni, C. (2015), Material intrusion as a key factor for the physical vulnerability of the built environment to debris flows, *in* ‘Engineering Geology for Society and Territory’, Vol. 5, Springer International Publishing, pp. 747–751.

Mazzorana, B., Trenkwalder-Platzer, H., Fuchs, S. and Hübl, J. (2014), “The susceptibility of consolidation check dams as a key factor for maintenance planning”, *Österreichische Wasser- und Abfallwirtschaft*, Vol. 66, pp. 214–216.

McFadden, L., Penning-Rowsell, E. and Tapsell, S. (2009), “Strategic coastal flood-risk management in practice: Actors’ perspectives on the integration of flood risk management in london and the thames estuary”, *Ocean & Coastal Management*, Vol. 52, pp. 636–645.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S0964569109001355*

McIntosh, B. S., Ascough II, J. C., Twery, M., Chew, J., Elmahdi, A., Haase, D., Harou, J. J., Hepting, D., Cuddy, S., Jakeman, A. J., Chen, S., Kassahun, A., Lautenbach, K., Matthews, K., Merritt, W., Quinn, N., Rodriguez-Roda, I., Sieber, S., Stavenga, M., Sulis, A., Ticehurst, J., Volk, M., Wrobelr, M., van Delden, H., El-Sawah, S., Rizzoli, A. and Voinov, A. (2011), “Environmental decision support systems (EDSS) development - challenges and best practices”, *Environmental Modelling & Software*, Vol. 26, pp. 1389–1402.
URL: *http://www.sciencedirect.com/science/article/pii/S1364815211002076*

Merz, B., Hall, J., Disse, M. and Schumann, A. (2010), “Fluvial flood risk management in a changing world”, *Natural Hazards and Earth System Science*, Vol. 10, pp. 509–527.
URL: *http://www.nat-hazards-earth-syst-sci.net/10/509/2010/nhess-10-509-2010.pdf*

Mikkonen, T. and Taivalsaari, A. (2007), Web applications: Spaghetti code for the 21st century, Technical report, Sun Microsystems, Inc., U.S.A.
URL: *http://dl.acm.org/citation.cfm?id=1698200*

Molinari, D. and Handmer, J. (2011), "A behavioural model for quantifying flood warning effectiveness", *Journal of Flood Risk Management*, Vol. 4, pp. 23–32.
URL: *http://onlinelibrary.wiley.com/doi/10.1111/j.1753-318X.2010.01086.x/pdf*

Muller, C., Chapman, L., Johnston, S., Kidd, C., Illingworth, S., Foody, G., Overeem, A. and Leigh, R. (2015), "Crowdsourcing for climate and atmospheric sciences: current status and future potential", *Int. J. Climatol.*, Vol. 35, pp. 3185–3203.
URL: *http://onlinelibrary.wiley.com/doi/10.1002/joc.4210/pdf*

Najafi, M. and Bhattachar, D. V. (2011), "Development of a culvert inventory and inspection framework for asset management of road structures", *Journal of King Saud University - Science*, Vol. 23, pp. 243–254.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S1018364710001540*

Newman, G., Wiggins, A., Crall, A., Graham, E., Newman, S. and Crowston, K. (2012), "The future of citizen science: emerging technologies and shifting paradigms", *Frontiers in Ecology and the Environment*, Vol. 10, pp. 298–304.
URL: *http://www.esajournals.org/doi/abs/10.1890/110294*

Newman, G., Zimmerman, D., Crall, A., Laituri, M., Graham, J. and Stapel, L. (2010), "User-friendly web mapping: lessons from a citizen science website", *International Journal of Geographical Information Science*, Vol. 24, pp. 1851–1869.
URL: *http://www.tandfonline.com/doi/abs/10.1080/13658816.2010.490532*

Nicholson, E., Ryan, J. and Hodgkins, D. (2002), "Community data-where does the value lie? Assessing confidence limits of community collected water quality data", *Water Science & Technology*, Vol. 45, pp. 193–200.

Nogueras-Iso, J., Zarazaga-Soria, F., Bejar, R., Alvarez, P. and Muro-Medrano, P. (2005), "OGC catalog services: a key element for the development of spatial data infrastructures", *Computers & Geosciences*, Vol. 31, pp. 199–209.

Norbiato, D., Borga, M., Sangati, M. and Zanon, F. (2007), "Regional frequency analysis of extreme precipitation in the eastern italian Alps and the August 29, 2003 flash flood", *Journal of Hydrology*, Vol. 345, pp. 149–166.
URL: *http://www.sciencedirect.com/science/article/pii/S0022169407004313*

O'Brien, K., Sygna, L., Leichenko, R., Neil Adger, W., Barnett, J., Mitchell, T., Schipper, L., Tanner, T., Vogel, C. and Mortreux, C. (2008), Disaster risk reduction, climate change adaptation and human security, Technical Report GECHS Report 2008:3, Norwegian Ministry of Foreign Affairs.

Ohio Department of Transportation (2010), Manual of Bridge Inspection, Technical Report ORC 5501.47, Ohio Department of Transportation. Federal Highway Administration, Ohio.
URL: *http://www.dot.state.oh.us/Divisions/Engineering/Structures/News%20Document-/Manual%20of%20Bridge%20Inspection_2010.pdf*

Ortega, K. L., Smith, T. M., Manross, K. L., Scharfenberg, K. A., Witt, A., Kolodziej, A. G., Gourley, J. J. et al. (2009), "The severe hazards analysis and verification experiment", *Bulletin of the American Meteorological Society*, Vol. 90, pp. 1519–1530.

Overdevest, C., Orr, C. H. and Stepenuck, K. (2004), "Volunteer stream monitoring and local participation in natural resource issues", *Human Ecology Review*, Vol. 11, pp. 177–185.
URL: *http://ww.humanecologyreview.org/pastissues/her112/overdevestorrstepenuck.pdf*

Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., Church, J. A., Clarke, L., Dahe, Q., Dasgupta, P. and others (2014), “Climate change 2014: Synthesis report. contribution of working groups i, ii and iii to the fifth assessment report of the intergovernmental panel on climate change”.
URL: *http://epic.awi.de/37530/*

Pahl-Wostl, C. (2008), *Adaptive and Integrated Water Management: Coping with Complexity and Uncertainty*, Springer Berlin Heidelberg, Berlin, Heidelberg, chapter Requirements for Adaptive Water Management, pp. 1–22.
URL: *http://dx.doi.org/10.1007/978-3-540-75941-6_1*

Pardo-Bosch, F. and Aguado, A. (2015), “Investment priorities for the management of hydraulic structures”, *Structure and Infrastructure Engineering* , Vol. 11, pp. 1338–1351.
URL: *http://dx.doi.org/10.1080/15732479.2014.964267*

Patel, D. P., Gajjar, C. A. and Srivastava, P. K. (2013), “Prioritization of Malesari mini-watersheds through morphometric analysis: a remote sensing and GIS perspective”, *Environmental Earth Sciences* , Vol. 69, pp. 2643–2656.
URL: *http://link.springer.com/10.1007/s12665-012-2086-0*

Pilz, D., Ballard, H. L. and Jones, E. T. (2006), Broadening participation in biological monitoring: Handbook for scientists and managers, General Technical Report PNW-GTR-680, United States Department of Agriculture (USDA), Forest Service, Northwest Research Station, Portland, OR. 131 p.
URL: *http://www.fs.fed.us/pnw/pubs/pnw_gtr680.pdf*

Pocock, M. J. O., Chapman, D. S., Sheppard, L. J. and Roy, H. E. (2014), *Choosing and using citizen science: a guide to when and how to use citizen science to monitor biodiversity and the environment*, isbn: 978-1-906698-50-8 edn, NERC/Centre for Ecology & Hydrology, Wallingford. 28pp.

Pratt Miles, J. D. (2013), “Designing collaborative processes for adaptive management: Four structures for multistakeholder collaboration”, *Ecology and Society* , Vol. 18, p. 5.

Prenger-Berninghoff, K., Cortes, V. J., Sprague, T., Aye, Z. C., Greiving, S., Głowacki, W. and Sterlacchini, S. (2014), “The connection between long-term and short-term risk management strategies for flood and landslide hazards: examples from land-use planning and emergency management in four European case studies”, *Natural Hazards and Earth System Science* , Vol. 14, pp. 3261–3278.
URL: *http://www.nat-hazards-earth-syst-sci.net/14/3261/2014/*

Protezione Civile della Regione FVG (2012), ‘Note Illustrative sull’individuazione dei punti da monitorare nei “Presidi Territoriali” a livello Comunale’, http://www.protezionecivile.fvg.it/ProtCiv/default.aspx/PianoRegionaleEmergenze.aspx.
URL: *http://www.protezionecivile.fvg.it/ProtCiv/GetDoc.aspx/111125/Note%20illustrative-%20presidi%20territoriali.pdf.*

Protezione Civille della Regione FVG (2009), ‘Formazione’.
URL: *http://www.protezionecivile.fvg.it/ProtCiv/default.aspx/81-formazione.htm*

Province of British Columbia (2000), *Flood Protection Works Inspection Guide*, number C00-960101-5, Water Management Branch. Public Safety Section. p.44.
URL: *http://www.env.gov.bc.ca/wsd/public_safety/flood/pdfs_word/fld_prot_insp_gd.pdf.*

Provincia Autonoma di Bolzano (2006), 'Bestandsaufnahme von wasserbauwerken der wildbachverbauung - EF 30 [Evaluation of check dam vulnerability EF 30 - Quick & Full Version].'.

Raghu, V. and Reddy, M. K. (2011), "Hydrogeomorphological mapping at village level using high resolution satellite data and impact analysis of check dams in part of Akuledu Vanka Watershed, Anantapur District, Andhra Pradesh", *Journal of Indian Geophysical Union* , Vol. 15, pp. 1–8.
URL: *http://igu.in/15-1/1raghu.pdf*

Ranzi, R., Maurizio, M., Luca, M., Marco, P., Michele, F., Fabio, G., Gero, M., Timothy, F., Paul, B., Jeffrey, N., Giuliano, D. B., Thom, B., Mitia, B. and Matjaž, M. (2011), Critical review of non-structural measures for water-related risks (mapping, planning and risk transfer), Report D.3.1, KULTURRisk, Delft, The Netherlands.
URL: *http://www.kulturisk.eu/results/wp3*

Rao, R. V. (2007), A logical approach to fuzzy MADM problems, *in* 'Decision making in the manufacturing environment: using graph theory and fuzzy multiple attribute decision making methods', Vol. 1 of *Springer Series in Advanced Manufacturing*, Springer London, pp. 43–49.

Rashidi, M. and Lemass, B. (2011), "A decision support methodology for remediation planning of concrete bridges", *Journal of Construction Engineering and Project Management* , Vol. 1, pp. 1–10.

Raymond, C. M., Fazey, I., Reed, M. S., Stringer, L. C., Robinson, G. M. and Evely, A. C. (2010), "Integrating local and scientific knowledge for environmental management", *Journal of Environmental Management* , Vol. 91, pp. 1766–1777.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S0301479710000952*

Reges, H. W., Cifelli, R. C., Doesken, N. J. and Turner, J. (2008), COCORAHS (The Community Collaborative Rain, Hail and Snow Network)—The accidental network: evolving collaborations, *in* 'Proceedings in 17 th Symposium on Education, American Meteorological Society, Apr 21-25, Denver/Boulder,CO, USA'.
URL: *http://www.cocorahs.org/Media/docs/AMS2008_Reges_CoCoRaHS-_17Education1.3.pdf*

Remaître, A., Malet, J.-P. and Maquaire, O. (2005), "Morphology and sedimentology of a complex debris flow in a clay-shale basin", *Earth Surface Processes and Landforms* , Vol. 30, pp. 339–348.
URL: *http://eost.u-strasbg.fr/omiv/Publications/Remaitre_et_al_2005_ESPL_A.pdf.*

Rhee, C. and Raghav Rao, H. (2008), Chapter 51. Evaluation of decision support systems, *in* 'F. Burstein, C. Holsapple (Eds): Handbook on Decision Support Systems 2', Springer Berlin Heidelberg, pp. 313–327.

Riesch, H. and Potter, C. (2014), "Citizen science as seen by scientists: Methodological, epistemological and ethical dimensions", *Public Understanding of Science* , Vol. 23, pp. 107–120. 00003.
URL: *http://pus.sagepub.com/content/23/1/107.full.pdf+html*

RiMaComm (2013), Risk Management and Communication on Local and Regional Level, Rapporto Finale, Rip. 26 Protezione antincendi e civile della Provincia Autonoma di Bolzano Alto Adige (Eds), Bolzano, Italy. Ch02.
URL: *http://www.protezionecivile.fvg.it/ProtCiv/GetDoc.aspx/102352/Rimacomm-%20pubb%20finale.pdf*

Rinaudo, J. D. and Garin, P. (2005), "The benefits of combining lay and expert input for water-management planning at the watershed level", *Water Policy* , Vol. 7, pp. 279–293.
URL: *http://test.iwaponline.com/wp/00703/0279/007030279.pdf*

Rinderer, M., Kollegger, A., Fischer, B. M. C., Stähli, M. and Seibert, J. (2012), "Sensing with boots and trousers — qualitative field observations of shallow soil moisture patterns", *Hydrological Processes* , Vol. 26, pp. 4112–4120.
URL: *http://dx.doi.org/10.1002/hyp.9531*

Rodríguez, J. P., McIntyre, N., Díaz-Granados, M. and Maksimović, e. (2012), "A database and model to support proactive management of sediment-related sewer blockages", *Water Research* , Vol. 46, pp. 4571–4586.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S0043135412004514*

Rossiter, D. G., Liu, J., Carlisle, S. and Zhu, A.-X. (2015), "Can citizen science assist digital soil mapping?", *Geoderma* , Vol. 259-260, pp. 71–80.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S0016706115001548*

Rotman, D., Preece, J., Hammock, J., Procita, K., Hansen, D., Parr, C., Lewis, D. and Jacobs, D. (2012), Dynamic changes in motivation in collaborative citizen-science projects, *in* 'Proceedings of the ACM 2012 conference on Computer Supported Cooperative Work, 11-15 Feb, Seattle, WA, USA', ACM, New York, NY, USA, pp. 217–226.
URL: *http://dl.acm.org/citation.cfm?id=2145238*

Roy, H., Pocock, M., Preston, C., Roy, D., Savage, J., Tweddle, J. and Robinson, L. (2012), Understanding citizen science and environmental monitoring, Final report on behalf of uk environmental observation framework, NERC, Center for Ecology & Hidrology, Wallingford, UK. 173pp.
URL: *http://nora.nerc.ac.uk/20679/*

Rudolf-Miklau, F. and Suda, J. (2013), Design criteria for torrential barriers, *in* 'Dating Torrential Processes on Fans and Cones', number 47 *in* 'Advances in Global Change Research', Springer, Dordrecht, pp. 375–389.

Saaty, R. (1987), "The analytic hierarchy process - what it is and how it is used", *Mathematical modelling* , Vol. 9, pp. 161–176.

Sabo, (Erosion and Sediment Control Department) (2007), Sediment-related disaster warning and evacuation, Guidelines, Erosion and Sediment Control Department Ministry of Land, Infrastructure, Transport and Tourism.
URL: *http://www.sabo-int.org/guideline/pdf/sediment_02.pdf*

Sahely, H. R., Kennedy, C. A. and Adams, B. J. (2005), "Developing sustainability criteria for urban infrastructure systems", *Canadian Journal of Civil Engineering* , Vol. 32, pp. 72–85. 00159.
URL: *http://www.nrcresearchpress.com/doi/abs/10.1139/l04-072*

Savan, B., Morgan, A. J. and Gore, C. (2003), "Volunteer environmental monitoring and the role of the universities: The case of citizens' environment watch", *Environmental Management* , Vol. 31, pp. 561–568.
URL: *http://link.springer.com/10.1007/s00267-002-2897-y*

Schnebele, E. and Cervone, G. (2013), "Improving remote sensing flood assessment using volunteered geographical data", *Natural Hazards and Earth System Science* , Vol. 13, pp. 669–677.
URL: *http://www.nat-hazards-earth-syst-sci.net/13/669/2013/*

Schweckendiek, T., Vrouwenvelder, A. and Calle, E. (2014), "Updating piping reliability with field performance observations", *Structural Safety* , Vol. 47, pp. 13–23.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S0167473013000799*

Scolobig, A., Castan Broto, V. and Zabala, A. (2008), "Integrating multiple perspectives in social multicriteria evaluation of flood-mitigation alternatives: the case of Malborghetto-Valbruna", *Environment and Planning C: Government and Policy* , Vol. 28, pp. 1143–1161.
URL: *http://epc.sagepub.com/content/26/6/1143.abstract*

Scolobig, A., Prior, T., Schröter, D., Jörin, J. and Patt, A. (2015), "Towards people-centred approaches for effective disaster risk management: Balancing rhetoric with reality", *International Journal of Disaster Risk Reduction* , Vol. 12, pp. 202–212.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S2212420915000084*

Seeger, C. J. (2008), "The role of facilitated volunteered geographic information in the landscape planning and site design process", *GeoJournal* , Vol. 72, pp. 199–213.
URL: *http://dx.doi.org/10.1007/s10708-008-9184-2*

Sencha (2014), Making sense of application architecture choices, Technical report.
URL: *http://cdn.sencha.com/whitepaper/Whitepaper-MVVM-MVC.pdf?mkt_tok=3RkMMJWWfF-9wsRoluajPZKXonjHpfsX54%2BstXaGyhYkz2EFye%2BLIHETpodcMTcFlMK%2BTFAwTG5tozi-V8R7PCKM1338YQWhPj*

Serre, D., Peyras, L., Maurel, P., Tourment, R. and Diab, Y. (2009), "A spatial decision support system aiding levee managers in their repair and maintenance planning", *Journal of Decision Systems* , Vol. 18, pp. 347–373.
URL: *http://www.tandfonline.com/doi/abs/10.3166/jds.18.347-373*

Servizio Forestale FVG (2002), 'Catasto Opere Idraulico Forestali. Manuale Tecnico. Allegato A. Schede di Rilevo [Cadastral of Forestry Service's hydraulic structures. Technical manual. Annex A. Inspection forms]'.

Sheppard, S. A. and Terveen, L. (2011), Quality is a verb: the operationalization of data quality in a citizen science community, *in* 'Proceedings of the 7th International Symposium on Wikis and Open Collaboration, 3-5 Oct, Mountain View, CA, USA', WikiSym '11, ACM, New York, NY, USA, pp. 29–38.
URL: *http://dl.acm.org/citation.cfm?id=2038565*

Shirk, J. L., Ballard, H. L., Wilderman, C. C., Phillips, T., Wiggins, A., Jordan, R., McCallie, E., Minarchek, M., Lewenstein, B. V., Krasny, M. E. and Bonney, R. (2012), "Public participation in scientific research: a framework for deliberate design", *Ecology and Society* , Vol. 17, p. 29.
URL: *http://www.ecologyandsociety.org/vol17/iss2/art29/*

Simonovic, S. (2012), *Floods in a Changing Climate: Risk Management*, number isbn: 9781107018747 *in* 'International Hydrology Series', Cambridge University Press, UK. 194 pp.

Smit, B. and Wandel, J. (2006), "Adaptation, adaptive capacity and vulnerability", *Global Environmental Change* , Vol. 16, pp. 282–292.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S0959378006000410*

Snäll, T., Kindvall, O., Nilsson, J. and Pärt, T. (2011), "Evaluating citizen-based presence data for bird monitoring", *Biological Conservation* , Vol. 144, pp. 804–810.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S0006320710004805*

Starkey, E. and Parkin, G. (2015), A review of current knowledge community involvement in uk catchment management, Technical Report FR/R0021, Foundation for Water Research, UK.
URL: *http://www.fwr.org/Catchment/frr0021.pdf*

Stefanovic, N., Radojevic, I., Ostojic, A., Comic, L. and Topuzovic, M. (2015), "Composite web information system for management of water resources", *Water Resources Management* , Vol. 29, pp. 2285–2301.
URL: *http://link.springer.com/10.1007/s11269-015-0941-y*

Stem, C., Margoluis, R., Salafsky, N. and Brown, M. (2005), "Monitoring and evaluation in conservation: a review of trends and approaches", *Conservation Biology* , Vol. 19, pp. 295–309.
URL: *http://dx.doi.org/10.1111/j.1523-1739.2005.00594.x*

Suda, J., Strauss, A., Rudolf-Miklau, F. and Hübl, J. (2009), "Safety assessment of barrier structures", *Structure and Infrastructure Engineering* , Vol. 5, pp. 311–324.
URL: *http://www.tandfonline.com/doi/abs/10.1080/15732470701189498*

Sun, L. and Wenjun, G. (2011), "Pavement condition assessment using fuzzy logic theory and analytic hierarchy process", *Journal of Transportation Engineering* , Vol. 137, pp. 648–655.

Sunde, P. and Jessen, L. (2013), "It counts who counts: an experimental evaluation of the importance of observer effects on spotlight count estimates", *European Journal of Wildlife Research* , Vol. 59, pp. 645–653.
URL: *http://link.springer.com/10.1007/s10344-013-0717-8*

Swets, J. A. (1988), "Measuring the accuracy of diagnostic systems", *Science* , Vol. 240, pp. 1285–93.
URL: *http://www.sciencemag.org/content/240/4857/1285.long*

Tagherouit, W. B., Bennis, S. and Bengassem, J. (2011), "A fuzzy expert system for prioritizing rehabilitation of sewer networks", *Computer-Aided Civil and Infrastructure Engineering* , Vol. 26, pp. 146–152.
URL: *http://onlinelibrary.wiley.com/doi/10.1111/j.1467-8667.2010.00673.x/pdf*

Tang, Z. and Liu, T. (2015), "Evaluating internet-based public participation gis (PPGIS) and volunteered geographic information (VGI) in environmental planning and management", *Journal of Environmental Planning and Management* , pp. 1–18.
URL: *http://www.tandfonline.com/doi/full/10.1080/09640568.2015.1054477*

ten Veldhuis, J. A., Clemens, F. H. and Van Gelder, P. H. (2011), "Quantitative fault tree analysis for urban water infrastructure flooding", *Structure and Infrastructure Engineering* , Vol. 7, pp. 809–821.
URL: *http://www.tandfonline.com/doi/abs/10.1080/15732470902985876*

ten Veldhuis, J. A., Harder, R. C. and Loog, M. (2013), "Automatic classification of municipal call data to support quantitative risk analysis of urban drainage systems", *Structure and Infrastructure Engineering* , Vol. 9, pp. 141–150.
URL: *http://www.tandfonline.com/doi/abs/10.1080/15732479.2010.535543*

Tingsanchali, T. (2012), "Urban flood disaster management", *Procedia Engineering* , Vol. 32, pp. 25–37.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S1877705812012647*

Toomey, A. H. and Domroese, M. C. (2013), "Can citizen science lead to positive conservation attitudes and behaviors?", *Human Ecology Review* , Vol. 20, pp. 50–62.
URL: *http://www.academia.edu/6128458/Can_citizen_science_lead_to_positive-_conservation_attitudes_and_behaviors*

Tropeano, D., Turconi, L. and Sanna, S. (2004), Debris flow triggered by the 29 August 2003 cloudburst in Val Vanale, Eastern Italian Alps, *in* 'Proceedings of the 10th Internationales Symposion, May 24-28, Riva/ Trient, Italy', Riva/ Trient, pp. 121–132.
URL: *http://www.interpraevent.at/palm-cms/upload_files/Publikationen-/Tagungsbeitraege/2004_1_I-121.pdf*

Tulloch, A. I., Possingham, H. P., Joseph, L. N., Szabo, J. and Martin, T. G. (2013), "Realising the full potential of citizen science monitoring programs", *Biological Conservation* , Vol. 165, pp. 128–138.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S0006320713001754*

Turconi, L., Nigrelli, G. and Conte, R. (2014), "Historical datum as a basis for a new GIS application to support civil protection services in NW Italy", *Computers & Geosciences* , Vol. 66, pp. 13–19.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S0098300413003063*

Turner, D. S. and Richter, H. E. (2011), "Wet/Dry Mapping: Using citizen scientists to monitor the extent of perennial surface flow in dryland regions", *Environmental Management* , Vol. 47, pp. 497–505.
URL: *http://link.springer.com/10.1007/s00267-010-9607-y*

Tweddle, J., Robinson, L., Pocock, M. and Roy, H. (2012), *Guide to citizen science: developing, implementing and evaluating citizen science to study biodiversity and the environment in the UK*, UK Environmental Observation Framework, Natural History Museum, Wallingford. 29pp.
URL: *http://nora.nerc.ac.uk/id/eprint/20678*

UN, (United Nations)) (2005), Hyogo framework for action 2005–2015: Building the resilience of nations and communities to disasters, *extract from the final report of the world conference on disaster reduction (a/conf.206/6), United Nations, Kobe, Japan.
URL: *http://www.unisdr.org/2005/wcdr/intergover/official-doc/L-docs/Hyogo-framework-for-action-english.pdf*

UNISDR, United Nations International Strategy for Disaster Reduction (2009), UNISDR terminology on disaster risk reduction, Technical report, United Nations International Strategy for Disaster Reduction, Geneva, Switzerland. "`http://www.unisdr.org/files/7817_UNISDRTerminologyEnglish.pdf`".

UNISDR, United Nations International Strategy for Disaster Reduction (2011), Global assessment report on Disaster Risk Reduction: Revealing risk, redefining development, Open file rep, United Nations International Strategy for Disaster Reduction, Geneva, Switzerland. 178 pp.
URL: *http://www.preventionweb.net/english/hyogo/gar/2011/en/home/index.html*

Uzielli, M., Nadim, F., Lacasse, S. and Kaynia, A. M. (2008), "A conceptual framework for quantitative estimation of physical vulnerability to landslides", *Engineering Geology* , Vol. 102, pp. 251–256.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S0013795208001889*

Valentinotti, R., Grisotto, S. and Pinamonti, V. (2012), A spatial decision support system to assess debris-flow hazard and risk, *in* '12th Congress INTERPRAEVENT, 23-26 Apr, Grenoble, France', Interpraevent, Grenoble, France.
URL: *http://www.studiogrisotto.it/articles/Grisotto_Valentinotti_Pinamonti-_INTERPRAEVENT%202012.pdf*

van der Steen, A. J., Dirksen, J. and Clemens, F. H. (2014), "Visual sewer inspection: detail of coding system versus data quality?", *Structure and Infrastructure Engineering* , Vol. 10, pp. 1385–1393.
URL: *http://www.tandfonline.com/doi/abs/10.1080/15732479.2013.816974*

van Riel, W., Langeveld, J., Herder, P. and Clemens, F. (2014), "Intuition and information in decision-making for sewer asset management", *Urban Water Journal* , Vol. 11, pp. 506–518.
URL: *http://www.tandfonline.com/doi/abs/10.1080/1573062X.2014.904903*

van Velsen, L., van der Geest, T., Klassen, R. and Steehouder, M. (2008), "User-centered evaluation of adaptive and adaptable systems: a literature review", *The Knowledge Engineering Review* , Vol. 23, pp. 261–281.

van Westen, C. J., Castellanos, E. and Kuriakose, S. L. (2008), "Spatial data for landslide susceptibility, hazard, and vulnerability assessment: An overview", *Engineering Geology* , Vol. 102, pp. 112–131.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S0013795208001786*

van Westen, C., Kappes, M. S., Luna, B. Q., Frigerio, S., Glade, T. and Malet, J.-P. (2014), *Mountain Risks: From Prediction to Management and Governance*, Springer Netherlands, Dordrecht, chapter Medium-Scale Multi-hazard Risk Assessment of Gravitational Processes, pp. 201–231.
URL: *http://dx.doi.org/10.1007/978-94-007-6769-0_7*

Vandecasteele, A. and Devillers, R. (2013), "Improving volunteered geographic data quality using semantic similarity measurements", *ISPRS-International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* , Vol. 1, pp. 143–148.
URL: *http://www.int-arch-photogramm-remote-sens-spatial-inf-sci.net/XL-2-W1/143/2013/isprsarchives-XL-2-W1-143-2013.pdf*

Vinci, I. (2014), *The spatial strategies of Italian regions*, number 1a edizione *in* 'Urbanistica', franco angeli edizioni edn, Milano, Italy. pp. 176.

von Maravic, P. (2010), Evaluation of the physical vulnerability of check dams exposed to the impact of torrential processes through experimental analysis, Msc.Thesis, University of Padua. Faculty of Agriculture. Departments of Land and Agro-forestry Systems.

Vuillet, M., Peyras, L., Serre, D. and Diab, Y. (2012), "Decision-making method for assessing performance of large levee alignment", *Journal of Decision Systems* , Vol. 21, pp. 137–160.
URL: *http://www.tandfonline.com/doi/abs/10.1080/12460125.2012.680354*

Wallach, D. and Scholz, S. C. (2012), User-centered design: Why and how to put users first in software development, *in* A. Maedche, A. Botzenhardt and L. Neer, eds, 'Software for People', Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 11–38.
URL: *http://link.springer.com/10.1007/978-3-642-31371-4_2*

Wallerstein, N. and Arthur, S. (2012), "Improved methods for predicting trash delivery to culverts protected by trash screens", *Journal of Flood Risk Management* , Vol. 5, pp. 23–36.
URL: *http://onlinelibrary.wiley.com/doi/10.1111/j.1753-318X.2011.01122.x/pdf*

Watson, N. (2004), “Integrated river basin management: a case for collaboration”, *International Journal of River Basin Management*, Vol. 2, pp. 243–257.
URL: *http://www.tandfonline.com/doi/abs/10.1080/15715124.2004.9635235*

Waugh Jr., W. L. and Streib, G. (2006), “Collaboration and leadership for effective emergency management”, *Public Administration Review*, Vol. 66, pp. 131–140.
URL: *http://onlinelibrary.wiley.com/doi/10.1111/j.1540-6210.2006.00673.x/pdf*

Wehn, U. and Evers, J. (2015), “The social innovation potential of ICT-enabled citizen observatories to increase eParticipation in local flood risk management”, *Technology in Society*, Vol. 42, pp. 187–198.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S0160791X15000421*

Wehn, U., Rusca, M., Evers, J. and Lanfranchi, V. (2015), “Participation in flood risk management and the potential of citizen observatories: A governance analysis”, *Environmental Science & Policy*, Vol. 48, pp. 225–236.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S1462901114002457*

Whitelaw, G., Vaughan, H., Craig, B. and Atkinson, D. (2003), “Establishing the Canadian community monitoring network”, *Environmental monitoring and assessment*, Vol. 88, pp. 409–418.
URL: *http://link.springer.com/article/10.1023/A:1025545813057*

Wiggins, A., Newman, G., Stevenson, R. D. and Crowston, K. (2011), Mechanisms for data quality and validation in citizen science, *in* ‘Computing for Citizen Science workshop at the IEEE eScience Conference, 5-8 Dec, Stockholm, Sweden’, Stockholm, Sweden, pp. 14 – 19.
URL: *http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6130725*

Xintong, G., Hongzhi, W., Song, Y. and Hong, G. (2014), “Brief survey of crowdsourcing for data mining”, *Expert Systems with Applications*, Vol. 41, pp. 7987–7994.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S0957417414003984*

Yang, H.-C. and Lee, C.-H. (2013), *The 3rd International Workshop on Intelligent Data Analysis and Management*, Springer Netherlands, Dordrecht, Netherlands, chapter Toward Crowdsourcing Data Mining, pp. 107–110.
URL: *http://dx.doi.org/10.1007/978-94-007-7293-9_12*

Yetman, K. T. (2002), “Using Maryland’s stream corrido survey to prioritize watershed restoration efforts”, *JAWRA Journal of the American Water Resources Association*, Vol. 38, pp. 905–914.
URL: *http://dx.doi.org/10.1111/j.1752-1688.2002.tb05533.x*

Zhao, P., Foerster, T. and Yue, P. (2012), “The geoprocessing web”, *Computers & Geosciences*, Vol. 47, pp. 3–12.
URL: *http://linkinghub.elsevier.com/retrieve/pii/S0098300412001446*

A

APPENDIX

Selected list of meetings in the framework of stakeholder activities of the CHANGES Project

- *December 13/2011, Pontebba, FVG region, Italy:* Kick-Off meeting with representatives of the Civil Protection and PhD students dealing with risk assessment and decision support in the Fella basin;
- *April 2-3/2012, Pontebba, FVG region, Italy:* Stakeholder meeting of PhD students of the project with representatives of municipal offices of Pontebba and Malborghetto, volunteer and professional fire brigades, Civil Protection, Geological Service, Water Basin Authority, University of Trieste and International Sociology Institute of Gorizia;
- *July 24 and 25/2012, Udine, FVG region, Italy:* Meeting with representatives of the Hydraulic Service to identify weakness and strengths of data collection, validation and dissemination from the monitoring network of hydro-meteorological variables;
- *August 6/2012, Palmanova, FVG region, Italy:* Meeting with representatives of the Civil Protection to identify in-practice examples on the use of volunteers' information in prevention and preparedness activities;
- *August 23/2012, Bolzano, Province of Bolzano, Italy:* Meeting with a representative of the Hydraulic Service of the Province of Bolzano to identify existing protocols for inspecting hydraulic structures;
- *September 4/2012, Udine, FVG region, Italy:* Meeting with representatives of the Geological Service to identify existing protocols for inspecting hydraulic structures and to introduce the first level inspection activities of this research;
- *December 3/2012, Udine, FVG region, Italy:* Meeting with representatives of the Forestry service to identify existing protocols for inspecting hydraulic structures and to introduce the first level inspection activity of this research;
- *January 23/2013, Venice, Veneto region; Italy:* Meeting to introduce the first level inspection activity to representatives of the Water Basin Authority;
- *February 25/2013, Palmanova, FVG region, Italy:* Meeting to introduce the first level inspection form to the Civil Protection representatives;
- *March 4/2013, Udine, FVG region, Italy:* Meeting to introduce the first level inspection form to the representative of the Forestry Service

B

APPENDIX

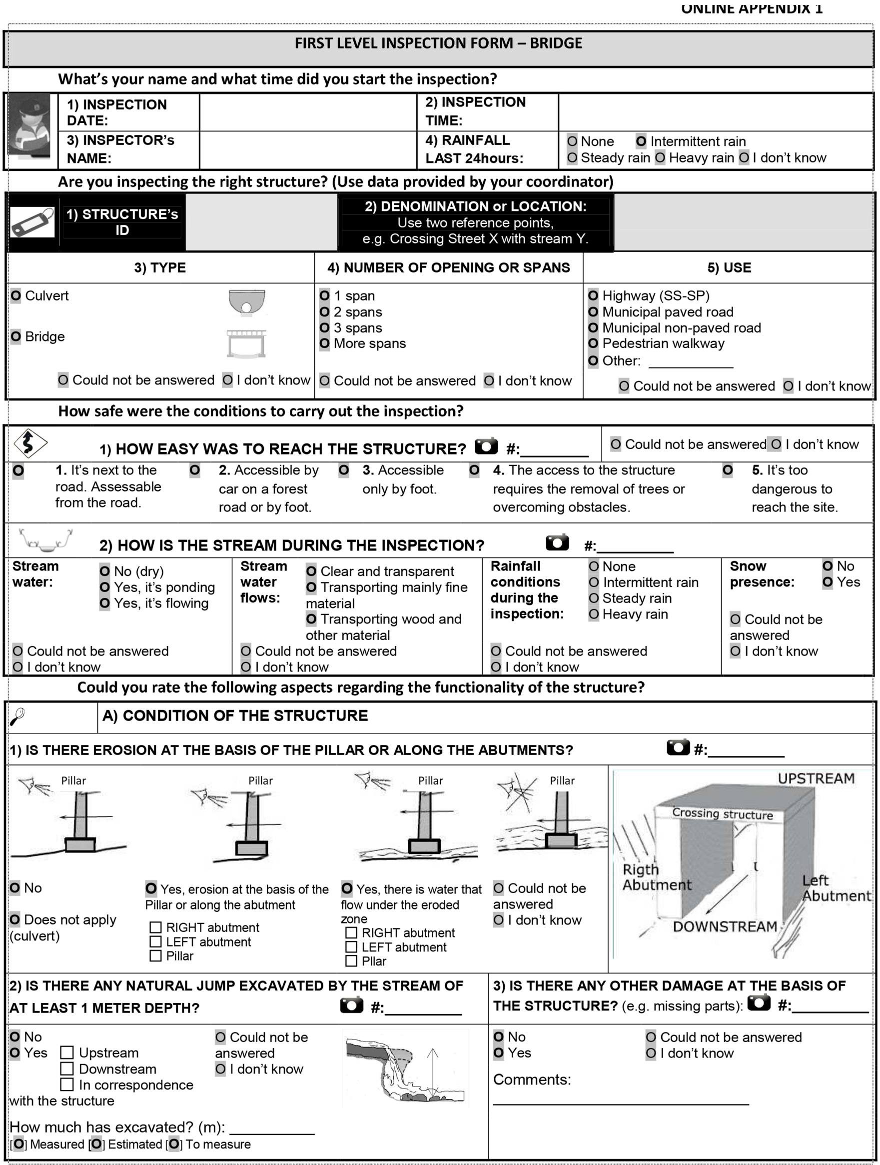
Table B.1: Participants' characteristics for Vs and Ts of Learning (LG) and Control Groups (CG)

Participants' number	T-LG 4*	T-CG 5	V-LG 18	V-CG 7
Age (years)				
16-24	-	-	7	4
25-44	2	2	7	2
45-64	2	3	4	1
Gender				
Female	-	1	3	2
Male	4	4	15	5
Highest level of education				
Primary school	-	-	2	-
College	-	-	4	2
High school	1	1	10	3
Technical degree	-	-	2	2
Master degree	2	3	-	-
PhD	1	1	-	-
Period of residence in the Fella basin				
More than 20 years	3	4	7	5
Never	1	1	11	2
Period of residence in the FVG region				
Less than a year	-	-	2	-
1-5 years	-	-	1	1
More than 20 years	4	5	14	4
Never	-	-	1	2
Experiences with floods				

Table B.1 Continued:

Participants' number	T-LG 4*	T-CG 5	V-LG 18	V-CG 7
Never	1	1	6	3
Once	-	-	1	1
2-5 times	2	2	8	3
6-10 times	-	-	1	-
More than 10 times	1	2	1	-
NoData	-	-	1	-
Experiences with debris flows				
Never	1	1	8	4
Once	-	-	-	-
2-5 times	2	2	4	3
6-10 times	1	1	4	-
More than 10 times	-	1	1	-
NoData	-	-	1	-
Experiences with landslides				
Never	-	2	7	3
Once	-	-	2	2
2-5 times	2	1	3	2
6-10 times	-	1	3	-
More than 10 times	2	1	2	-
NoData	-	-	1	-
A priori knowledge (% of correct answers on 20 questions)				
0-25%	-	-	1	-
26-50%	-	-	3	-
51-75%	-	-	8	6
76-100%	4	5	6	1

*2 T-LG did not fill the questionnaire. Table summarize data for 34 participants



ONLINE APPENDIX 1

FIRST LEVEL INSPECTION FORM – BRIDGE

What's your name and what time did you start the inspection?

1) INSPECTION DATE:		**2) INSPECTION TIME:**	
3) INSPECTOR's NAME:		**4) RAINFALL LAST 24hours:**	O None O Intermittent rain O Steady rain O Heavy rain O I don't know

Are you inspecting the right structure? (Use data provided by your coordinator)

1) STRUCTURE's ID		**2) DENOMINATION or LOCATION:** Use two reference points, e.g. Crossing Street X with stream Y.

3) TYPE	4) NUMBER OF OPENING OR SPANS	5) USE
O Culvert O Bridge O Could not be answered O I don't know	O 1 span O 2 spans O 3 spans O More spans O Could not be answered O I don't know	O Highway (SS-SP) O Municipal paved road O Municipal non-paved road O Pedestrian walkway O Other: ___________ O Could not be answered O I don't know

How safe were the conditions to carry out the inspection?

1) HOW EASY WAS TO REACH THE STRUCTURE? #:________ O Could not be answered O I don't know

O **1.** It's next to the road. Assessable from the road.
O **2.** Accessible by car on a forest road or by foot.
O **3.** Accessible only by foot.
O **4.** The access to the structure requires the removal of trees or overcoming obstacles.
O **5.** It's too dangerous to reach the site.

2) HOW IS THE STREAM DURING THE INSPECTION? #:_________

Stream water:	**Stream water flows:**	**Rainfall conditions during the inspection:**	**Snow presence:**
O No (dry) O Yes, it's ponding O Yes, it's flowing O Could not be answered O I don't know	O Clear and transparent O Transporting mainly fine material O Transporting wood and other material O Could not be answered O I don't know	O None O Intermittent rain O Steady rain O Heavy rain O Could not be answered O I don't know	O No O Yes O Could not be answered O I don't know

Could you rate the following aspects regarding the functionality of the structure?

A) CONDITION OF THE STRUCTURE

1) IS THERE EROSION AT THE BASIS OF THE PILLAR OR ALONG THE ABUTMENTS? #:_________

Pillar / Pillar / Pillar / Pillar

O No
O Does not apply (culvert)

O Yes, erosion at the basis of the Pillar or along the abutment
☐ RIGHT abutment
☐ LEFT abutment
☐ Pillar

O Yes, there is water that flow under the eroded zone
☐ RIGHT abutment
☐ LEFT abutment
☐ Pllar

O Could not be answered
O I don't know

UPSTREAM
Crossing structure
Rigth Abutment
Left Abutment
DOWNSTREAM

2) IS THERE ANY NATURAL JUMP EXCAVATED BY THE STREAM OF AT LEAST 1 METER DEPTH? #:_________

O No
O Yes ☐ Upstream
☐ Downstream
☐ In correspondence with the structure
O Could not be answered
O I don't know

How much has excavated? (m): __________
[O] Measured [O] Estimated [O] To measure

3) IS THERE ANY OTHER DAMAGE AT THE BASIS OF THE STRUCTURE? (e.g. missing parts): #:_________

O No
O Yes
O Could not be answered
O I don't know

Comments: ______________________________

Figure B.1: Inspection form for bridges used during the data collection exercise - Front side (Source: Questions, rating options and visual schemes were defined from the following inspection procedures for technicians: Servizio Forestale FVG (2002); Burke Engineering (1999); Ohio Department of Transportation (2010); EF30-Vulnerability evaluation form which is cited in Von Maravic (2010, Annex 2) referring to Provincia Autonoma di Bolzano – Alto Adige (2006)

B) LEVEL OF OBSTRUCTION AT THE STREAM CHANNEL AND STRUCTURE'S LOCATION:

Obstruction of wood, sediments or other waste

1) UPSTREAM #:_______	O **1.** No obstruction	O **2.** <20%	O **3.** 20-40%	O **4.** 40-60% with deviation of the flow	O **5.** > 60% or buried by sediment	O Could not be answered O I don't know
2) DOWNSTREAM #:_______	O **1.** No obstruction	O **2.** <20%	O **3.** 20-40%	O **4.** 40-60% with deviation of the flow	O **5.** > 60% or buried by sediment	O Could not be answered O I don't know

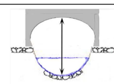
3) Is there any island with vegetation (shrub) or other man-made structures that reduce the opening section for the flow? #: _______

O No
O Could not be answered
O I don't know
O Yes, **Comments:**
(e.g. pipes or elements attached to the structure) ____________________

If yes, where?
☐ Upstream
☐ Downstream
☐ In correspondence

4) What is the height of the structure from the lowest point of the stream? #: ________

Maximum height: ________(m)
[O] Measured
[O] Estimated
[O] To measure



O Could not be answered
O I don't know

C) LEVEL OF EROSION OF THE BANK WITHIN 20 meters UPSTREAM AND DOWNSTREAM OF THE STRUCTURE?
Use the scale to assess the erosion level with reference to the worst case in each section of the bank.

1. Minimum erosion	2.	3.	4.	5. Maximum erosion
Structural elements are in good status "in order" or continuous presence of vegetation in the bank.	Elements with slight erosion or slight irregularities in the vegetation of the bank.	Elements with visible erosion or visible irregularities in the vegetation of the bank.	Parts are eroded by the stream flow with an opening below the protection of the bank.	Parts are missing, there us an important drift. Bank without vegetative protection.

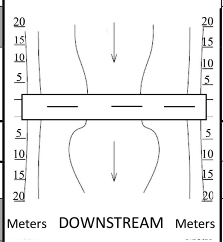
1) LEFT BANK 20m UPSTREAM #:_________

Presence **of walls or protection works**	**Erosion level in the bank**
O No O ≤ Less 20m. O > More than 20m. O Could not be answered O I don't know	O 1. O 2. O 3. O 4. O 5. O Could not be answered O I don't know

2) RIGHT BANK 20 m UPSTREAM #:_________

Presence **of walls or protection works**	**Erosion level in the bank**
O No O ≤ Less 20m. O > More than 20m. O Could not be answered O I don't know	O 1. O 2. O 3. O 4. O 5. O Could not be answered O I don't know

Mark on the scheme where the erosion level is equal or larger than 3.



3) LEFT BANK 20m DOWNSTREAM #:_________

Presence **of walls or protection works**	**Erosion level in the bank**
O No O ≤ Less 20m. O > More than 20m. O Could not be answered O I don't know	O 1. O 2. O 3. O 4. O 5. O Could not be answered O I don't know

4) RIGHT BANK 20m DOWNSTREAM #:_________

Presence **of walls or protection works**	**Erosion level in the bank**
O No O ≤ Less 20m. O > More than 20m. O Could not be answered O I don't know	O 1. O 2. O 3. O 4. O 5. O Could not be answered O I don't know

Is there any anthropic element within the same control distance?

Presence within 20m distance from the stream:	1) 20m UPSTREAM Left	1) 20m UPSTREAM Right	2) 20m DOWNSTREAM Left	2) 20m DOWNSTREAM Right	**Comments:** Infrastructure details
Road infrastructure	O No O Yes	O No O Yes	O No O Yes	O No O Yes	
Buldings	O No O Yes	O No O Yes	O No O Yes	O No O Yes	

Could an ordinary intervention with volunteers of CP improve the functionality of the structure? Comments: ______________________

O Could not be answered
O I don't know

O No action is required	O Requires routine cleaning of blockages by hand (maximum with 10 volunteers)	O Requires cleaning with equipment support.	O Other action than cleaning is required (Need for a second level inspection)

Figure B.2: Inspection form for bridges used during the data collection exercise - Back side. (Source: same as **Figure B.1**)

ONLINE APPENDIX 2

FIRST LEVEL INSPECTION FORM – CHECK DAM

What's your name and what time did you start the inspection?

1) INSPECTION DATE:		**2) INSPECTION TIME:**	
3) INSPECTOR'S NAME:		**4) RAINFALL LAST 24hours:**	O None O Intermittent rain O Steady rain O Heavy rain O I don't know

Are you inspecting the right structure? (Use the data provided by your coordinator)

1) STRUCTURE's ID:		**2) DENOMINATION or LOCATION:** Use two reference points, e.g. Crossing Street X with stream Y.	

3) TYPE	**4) CONNECTED STRUCTURES**
O Open check dam O Consolidation check dam O Could not be answered O I don't know	O No connected structure ☐ Structures to deviate water from the stream ☐ Bridge or culvert ☐ Retention basin (immediately upstream) O Could not be answered O I don't know

How safe were the conditions to carry out the inspection?

1) HOW EASY WAS TO REACH THE STRUCTURE? #:__________ O Could not be answered O I don't know

O **1.** It's next to the road. Assessable from the road.
O **2.** Accessible by car on a forest road or by foot.
O **3.** Accessible only by foot.
O **4.** The access to the structure requires the removal of trees or overcoming obstacles.
O **5.** It's too dangerous to reach the site.

2) HOW IS THE STREAM DURING THE INSPECTION? #:_________

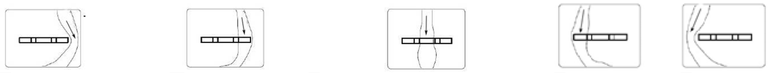
Stream water:	**Stream water flows:**	**Rainfall conditions during the inspection::**	**Snow presence:**
O No (dry) O Yes, it's ponding O Yes, it's flowing O Could not be answered O I don't know	O Clear and transparent O Transporting mainly fine material O Transporting wood and other material O Could not be answered O I don't know	O None O Intermittent rain O Steady rain O Heavy rain O Could not be answered O I don't know	O No O Yes O Could not be answered O I don't know

Could you rate the following aspects regarding the functionality of the structure?

A) CONDITION OF THE STRUCTURE

1) Is the stream flow passing where it should be? #:__________ O Could not be answered O I don't know

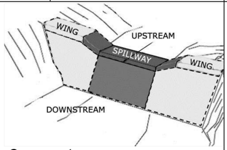
Stream flow deviated to the LEFT — **Normal condition of the stream** — **Stream flow deviated to the RIGHT**



O Outside of the structure O On the wing O Through the section of the spillway O On the wing O Outside of the structure

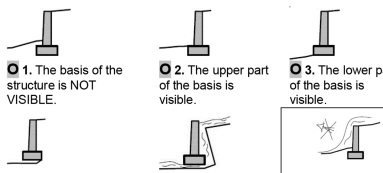
2) What is the status of the check dam itself? #:__________ O Could not be answered O I don't know

O **1.** Structural elements are in good status, "in order".
O **2.** Elements have slight deterioration without cracks.
O **3.** Elements have visible deterioration with cracks.
O **4.** Elements have deep erosion with missing parts.
O **5.** Structural damage that compromise the stability of the structure.



Comments: ______________________

3) How visible is the basis of the structure? #:__________

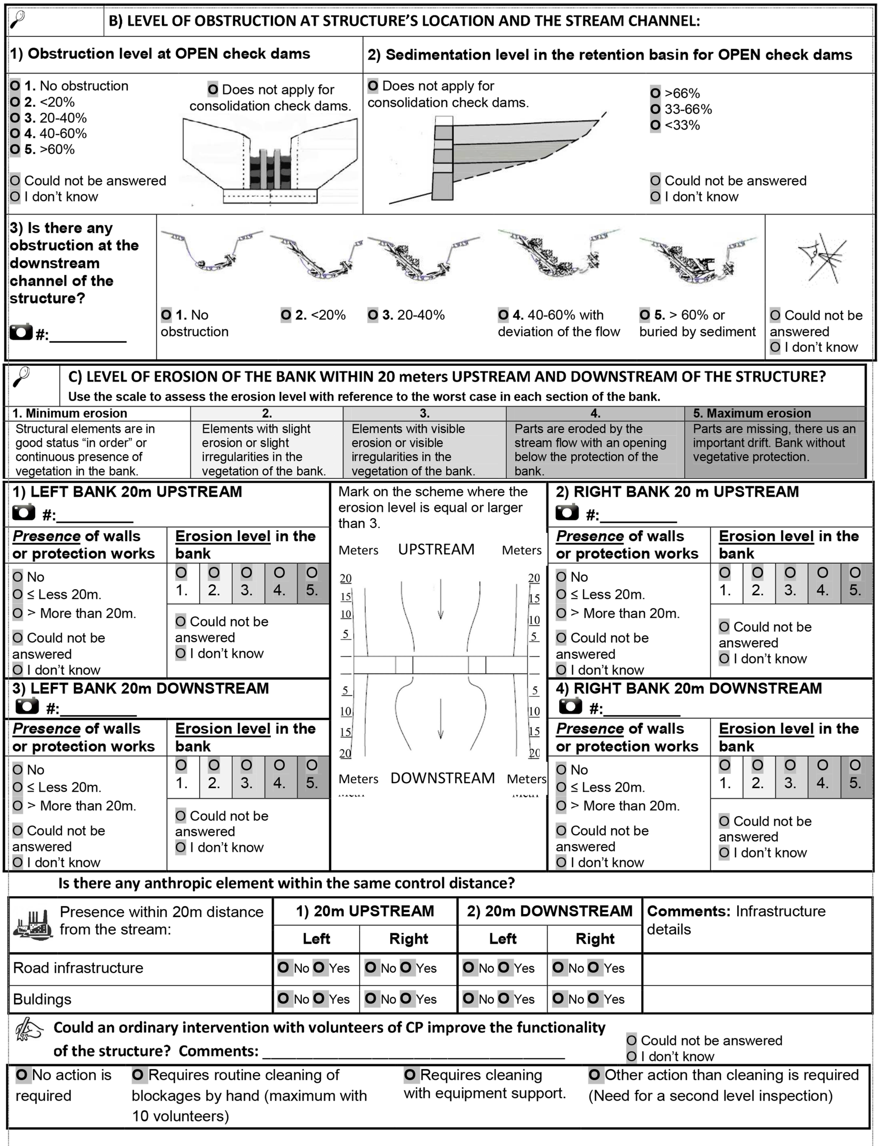


O **1.** The basis of the structure is NOT VISIBLE.
O **2.** The upper part of the basis is visible.
O **3.** The lower part of the basis is visible.
O **4.** There is an opening path below the basis of the structure.
O **5.** Scouring at the basis of the structure.
O Could not be answered
O I don't know

4) Is there any scouring protection? #:__________ O No. O Yes, in good condition. O Yes but not in good condition O Could not be answered O I don't know

Alcuni immagini sono da Bestansaufnahme -EF30 – Provincia autonoma di Bolzano, Von Maravic, P (2010).

Figure B.3: Inspection form for chec kdams used during the data collection exercise - From side (Source: Questions, rating options and visual schemes were defined from the following inspection procedures for technicians: EF30-Vulnerability evaluation form which is cited in Von Maravic (2010, Annex 2) referring to Provincia Autonoma di Bolzano – Alto Adige (2006); Dell'Agnese et al., (2013); Servizio Forestale FVG (2002); Province of British Columbia (2000) and Huebl and Fiebiger (2005)



B) LEVEL OF OBSTRUCTION AT STRUCTURE'S LOCATION AND THE STREAM CHANNEL:

1) Obstruction level at OPEN check dams

O **1.** No obstruction
O **2.** <20%
O **3.** 20-40%
O **4.** 40-60%
O **5.** >60%

O Does not apply for consolidation check dams.

O Could not be answered
O I don't know

2) Sedimentation level in the retention basin for OPEN check dams

O Does not apply for consolidation check dams.

O >66%
O 33-66%
O <33%

O Could not be answered
O I don't know

3) Is there any obstruction at the downstream channel of the structure?

#:_________

O **1.** No obstruction
O **2.** <20%
O **3.** 20-40%
O **4.** 40-60% with deviation of the flow
O **5.** > 60% or buried by sediment
O Could not be answered
O I don't know

C) LEVEL OF EROSION OF THE BANK WITHIN 20 meters UPSTREAM AND DOWNSTREAM OF THE STRUCTURE?

Use the scale to assess the erosion level with reference to the worst case in each section of the bank.

1. Minimum erosion	2.	3.	4.	5. Maximum erosion
Structural elements are in good status "in order" or continuous presence of vegetation in the bank.	Elements with slight erosion or slight irregularities in the vegetation of the bank.	Elements with visible erosion or visible irregularities in the vegetation of the bank.	Parts are eroded by the stream flow with an opening below the protection of the bank.	Parts are missing, there us an important drift. Bank without vegetative protection.

1) LEFT BANK 20m UPSTREAM #:_________

2) RIGHT BANK 20 m UPSTREAM #:_________

3) LEFT BANK 20m DOWNSTREAM #:_________

4) RIGHT BANK 20m DOWNSTREAM #:_________

For each bank section:

Presence **of walls or protection works**
O No
O ≤ Less 20m.
O > More than 20m.
O Could not be answered
O I don't know

Erosion level in the bank
O 1. O 2. O 3. O 4. O 5.
O Could not be answered
O I don't know

Mark on the scheme where the erosion level is equal or larger than 3.

Meters UPSTREAM Meters
20 15 10 5 — 5 10 15 20
Meters DOWNSTREAM Meters

Is there any anthropic element within the same control distance?

Presence within 20m distance from the stream:	1) 20m UPSTREAM Left	1) 20m UPSTREAM Right	2) 20m DOWNSTREAM Left	2) 20m DOWNSTREAM Right	**Comments:** Infrastructure details
Road infrastructure	O No O Yes	O No O Yes	O No O Yes	O No O Yes	
Buldings	O No O Yes	O No O Yes	O No O Yes	O No O Yes	

Could an ordinary intervention with volunteers of CP improve the functionality of the structure? Comments: ___________________________________

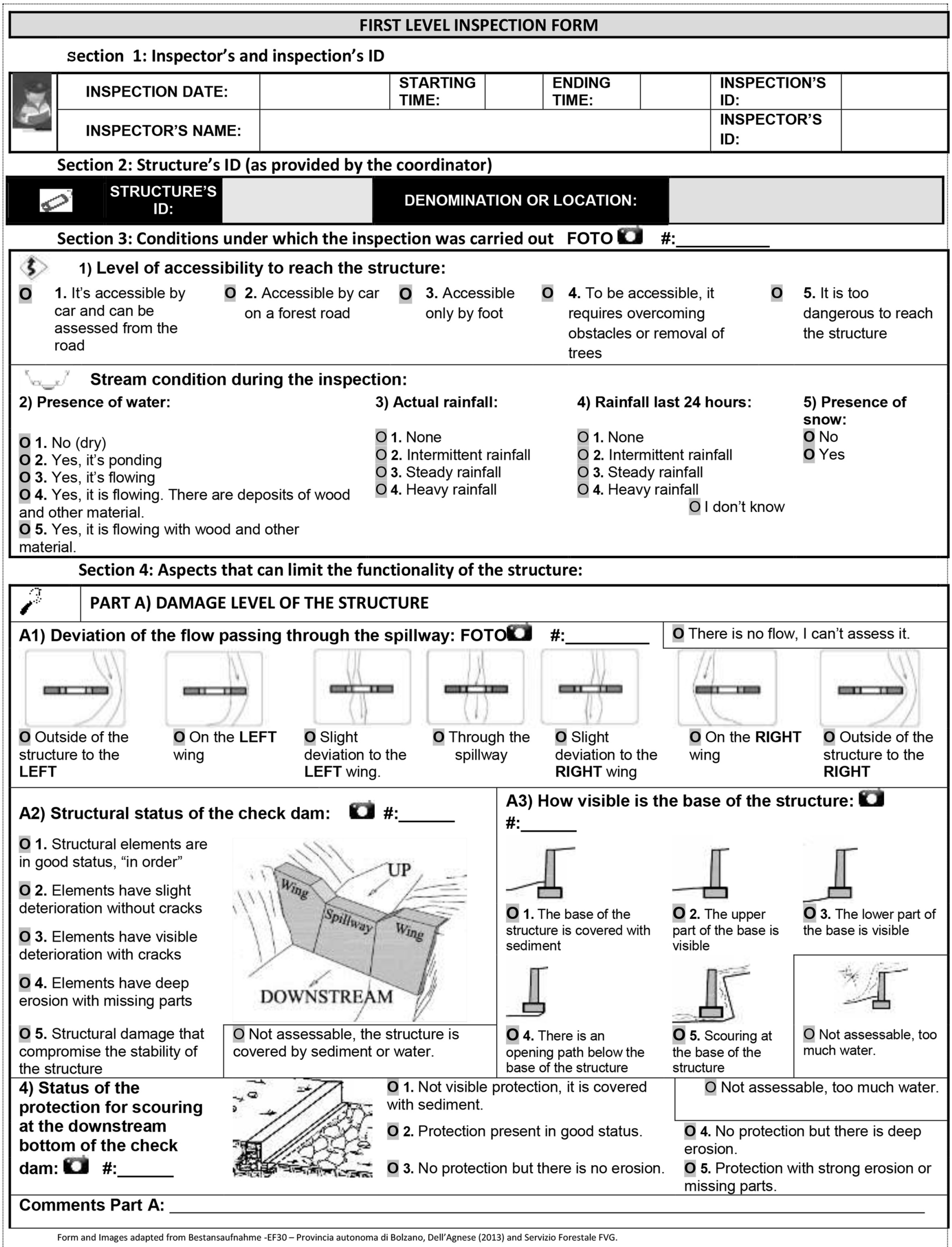
O Could not be answered
O I don't know

O No action is required
O Requires routine cleaning of blockages by hand (maximum with 10 volunteers)
O Requires cleaning with equipment support.
O Other action than cleaning is required (Need for a second level inspection)

Figure B.4: Inspection form for check dams used during the data collection exercise - Back side (Source: same as **Figure B.3)**

C

APPENDIX



FIRST LEVEL INSPECTION FORM

Section 1: Inspector's and inspection's ID

INSPECTION DATE:		STARTING TIME:		ENDING TIME:		INSPECTION'S ID:	
INSPECTOR'S NAME:						INSPECTOR'S ID:	

Section 2: Structure's ID (as provided by the coordinator)

STRUCTURE'S ID:		DENOMINATION OR LOCATION:	

Section 3: Conditions under which the inspection was carried out FOTO #:__________

1) Level of accessibility to reach the structure:

O **1.** It's accessible by car and can be assessed from the road
O **2.** Accessible by car on a forest road
O **3.** Accessible only by foot
O **4.** To be accessible, it requires overcoming obstacles or removal of trees
O **5.** It is too dangerous to reach the structure

Stream condition during the inspection:

2) Presence of water:
O **1.** No (dry)
O **2.** Yes, it's ponding
O **3.** Yes, it's flowing
O **4.** Yes, it is flowing. There are deposits of wood and other material.
O **5.** Yes, it is flowing with wood and other material.

3) Actual rainfall:
O **1.** None
O **2.** Intermittent rainfall
O **3.** Steady rainfall
O **4.** Heavy rainfall

4) Rainfall last 24 hours:
O **1.** None
O **2.** Intermittent rainfall
O **3.** Steady rainfall
O **4.** Heavy rainfall
O I don't know

5) Presence of snow:
O No
O Yes

Section 4: Aspects that can limit the functionality of the structure:

PART A) DAMAGE LEVEL OF THE STRUCTURE

A1) Deviation of the flow passing through the spillway: FOTO #:_________
O There is no flow, I can't assess it.

O Outside of the structure to the **LEFT**
O On the **LEFT** wing
O Slight deviation to the **LEFT** wing.
O Through the spillway
O Slight deviation to the **RIGHT** wing
O On the **RIGHT** wing
O Outside of the structure to the **RIGHT**

A2) Structural status of the check dam: #:______
O **1.** Structural elements are in good status, "in order"
O **2.** Elements have slight deterioration without cracks
O **3.** Elements have visible deterioration with cracks
O **4.** Elements have deep erosion with missing parts
O **5.** Structural damage that compromise the stability of the structure
O Not assessable, the structure is covered by sediment or water.

A3) How visible is the base of the structure: #:______
O **1.** The base of the structure is covered with sediment
O **2.** The upper part of the base is visible
O **3.** The lower part of the base is visible
O **4.** There is an opening path below the base of the structure
O **5.** Scouring at the base of the structure
O Not assessable, too much water.

4) Status of the protection for scouring at the downstream bottom of the check dam: #:______
O **1.** Not visible protection, it is covered with sediment.
O **2.** Protection present in good status.
O **3.** No protection but there is no erosion.
O Not assessable, too much water.
O **4.** No protection but there is deep erosion.
O **5.** Protection with strong erosion or missing parts.

Comments Part A: ____

Form and Images adapted from Bestansaufnahme -EF30 – Provincia autonoma di Bolzano, Dell'Agnese (2013) and Servizio Forestale FVG.

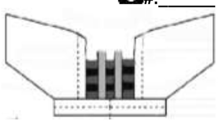
Figure C.1: Inspection form used in the testing workshop - Front side (Source: same as **Figure B.3**)

B) OBSTRUCTION LEVEL AT THE STRUCTURE

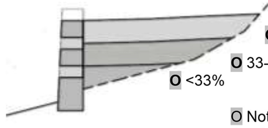
B1) Obstruction level at the OPEN check dam #:______

- O **1.** No obstruction
- O **2.** <20%
- O **3.** 20-40%
- O **4.** 40-60%
- O **5.** >60%

O Not assessable (consolidation check dam)



2) Sedimentation level in the retention basin (OPEN check dam) #:______



- O >66%
- O 33-66%
- O <33%

O Not assessable (consolidation check dam)

Lateral obstruction with wood, debris or other material						
						
3) UPSTREAM #:______	O **1.** No obstruction	O **2.** <20%	O **3.** 20-40%	O **4.** 40-60% with deviation of the flow	O **5.** > 60% or buried by sediment	O Not assessable too much water.
4) DOWSNTREAM #:______	O **1.** No obstruction	O **2.** <20%	O **3.** 20-40%	O **4.** 40-60% with deviation of the flow	O **5.** > 60% or buried by sediment	O Not assessable too much water.

Comments Part B: ____

C) EROSION LEVEL IN THE STREAMBANKS WITHIN 20M UPSTREAM AND DOWNSTREAM OF THE STRUCTURE

Use the following scale to assess the each bank and make a mark in the scheme with reference to the worst case.

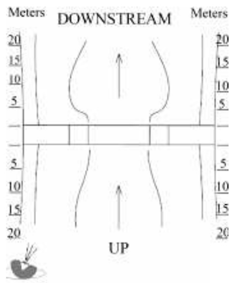
1. Minor erosion	**2.**	**3.**	**4.**	**5. Major erosion**
1-Bank in good status “in order”, continuous presence of vegetation in the bank	Bank with slight erosion or slight irregularities in the protection works or the vegetation in the bank	Bank with visible erosion or visible irregularities in the protection works or the vegetation in the bank	Erosion by the flow with opening path below the bank or important irregularities in protection works or vegetation	Important drift of the bank or missing parts in the protection works

1) LEFT BANK within 20 meters UP #:_______

Worst erosion level in the bank	Extension of the alteration
O 1. O 2. O 3. O 4. O 5.	O Between 0-10 m O Between 10-20 m O More than 20 m
O Not assessable too much water.	

2) RIGHT BANK within 20 meters UP #:______

Worst erosion level in the bank	Extension of the alteration
O 1. O 2. O 3. O 4. O 5.	O Between 0-10 m O Between 10-20 m O More than 20 m
O Not assessable too much water.	



Comments: ____________________

3) LEFT BANK within 20 meters DOWN #:_______

Worst erosion level in the bank	Extension of the alteration
O 1. O 2. O 3. O 4. O 5.	O Between 0-10 m O Between 10-20 m O More than 20 m
O Not assessable too much water.	

4) RIGHT BANK within 20 meters DOWN #:_______

Worst erosion level in the bank	Extension of the alteration
O 1. O 2. O 3. O 4. O 5.	O Between 0-10 m O Between 10-20 m O More than 20 m
O Not assessable too much water.	

Section 5: Elements that could be affected in case of flood in the stream.

Road, services or communication infrastructure, buildings.	**1) 20 m UPSTREAM FOTO #:______**		**2) 20 m DOWNSTREAM FOTO #:______**	
	L.B.	**R.B.**	**L.B.**	**R.B.**

Section 6: Synthesis advice:

O In the actual conditions no routine maintenance is required.	**O** Requires routine maintenance with support of max. of 10 volunteers	**O** Requires routine maintenance with support of equipment.	**O** Need for a second level inspection to define the maintenance type.

Specify the maintenance type:

Figure C.2: Inspection form used in the testing workshop - Back side (Source: same as **Figure B.3)**

Table C.1: Reported ratings and aggregated indices for check dam 1.

	New-user group							User group						
	Inspector ID													
Questions	4	5	6	8	11	12	13	1	2	3	7	9	10	14
A1	FS	G	FS	G	FS	G	FS	FS	FS	G	FS	G	G	P-VP
A2	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG
A3	G	G	G	G	G	G	FS	G	FS	FS	G	G	G	G
A4	G	G-VG	G-VG	G	G	G	G-VG	G-VG	G-VG	G	G	G	G-VG	G-VG
B3*	FD	P	G	G	G	G	P	G	G	N/A	G	G	G	FD
B4*	G	P	G	G-VG	G-VG	G	G	G	G	N/A	G-VG	G	G	FD
C1-1	G-VG	G-VG	N/A	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	F	G-VG	G-VG	G-VG	G
C1-2	G-VG	P-VP	G-VG	G-VG	G	G-VG	G-VG	G-VG	G-VG	F	G-VG	G-VG	G-VG	P-VP
C1-3	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G	G-VG	G-VG	G-VG	G-VG	G
C1-4	G	P-VP	G	F	G	VP	VP	G	F	P-VP	G	G	N/A	P-VP
Inspector's advice	1	3	2	1	1	4	4	3	4	1	2	1	1	4
IdxA	88,4	100,0	92,1	91,7	88,4	91,7	88,7	92,1	88,7	88,4	88,4	91,7	100,0	67,2
%ComplA	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Fun_LevelA	Best	Best	Best	Best	Best	Best	Best	Best	Best	Best	Best	Best	Best	Worst
IdxB	56,3	16,7	83,3	88,7	88,7	83,3	50,0	83,3	83,3	50,0	88,7	83,3	83,3	32,7
%ComplB	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%	100%	100%	100%	100%
Fun_LevelB	Medium	Worst	Best	Best	Best	Best	Worst	Best	Best	Medium	Best	Best	Best	Medium
IdxC	92,4	51,4	77,5	79,3	89,2	63,4	63,4	92,4	77,6	51,8	92,4	92,4	79,3	46,8
%ComplC	100%	100%	75%	100%	100%	100%	100%	100%	100%	100%	100%	100%	75%	100%
Fun_LevelC	Best	Worst	Best	Best	Best	Worst	Worst	Best	Best	Worst	Best	Best	Best	Worst

Notes: **Table 4.2** provides details about the questions and rating code.

VG: Very good; G-VG: Good to very good, FS: Fair sufficient; F: Fair; FD: Fair deficient; P: Poor; P-VP: Poor to very poor; and VP: Very poor.

* For a consolidation dam (Check dam 1), questions B1 and B2 do not apply.

Table C.2: Reported ratings and aggregated indices for check dam 2.

	New-user group							User group						
	Inspector ID													
Questions	4	5	6	8	11	12	13	1	2	3	7	9	10	14
A1	G	FS	FS	FS	FS	G	FS	G	FS	G	FS	G	G	G
A2	G	G-VG	G-VG	G-VG	G-VG	P	P-VP	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG
A3	FS	FS	FS	FS	G	FS	FS	G	FS	FS	G	G	G	FS
A4	G	G	G	G	G	G	G-VG	G-VG	G	G	G	G	G	G
B1	G	FD	G	FD	FD	FD	FD	FD	FD	G	FD	FD	FD	FD
B2	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	FD	G-VG	G-VG	G-VG
B3	G-VG	P	G	G	FD	G	FD	FD	FD	G-VG	FD	G	FD	P
B4	G	P	G-VG	G-VG	G	G	G	G	G	G-VG	G-VG	G	G-VG	G
C1-1	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G
C1-2	G-VG	F	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	P-VP	G-VG	G-VG	G-VG	P-VP
C1-3	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G
C1-4	G	F	G	G	G-VG	G-VG	P-VP	G-VG	G-VG	P-VP	G	G-VG	N/A	P-VP
Inspector's advice	2	3	3	3	3	4	4	3	3	2	3	3	1	3
IdxA	85,5	85,7	85,7	85,7	88,4	62,9	59,0	100,0	85,7	88,4	88,4	91,7	91,7	88,4
%ComplA	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Fun_LevelA	Best	Best	Best	Best	Best	Worst	Worst	Best	Best	Best	Best	Best	Best	Best
IdxB	88,7	44,3	88,7	70,7	58,8	68,9	58,8	58,8	58,8	92,0	49,6	68,9	61,0	55,5
%ComplB	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Fun_LevelB	Best	Worst	Best	Best	Medium	Medium	Medium	Medium	Medium	Best	Medium	Medium	Medium	Worst
IdxC	92,4	70,5	92,4	92,4	100,0	100,0	64,7	100,0	100,0	51,4	92,4	100,0	79,3	46,8
%ComplC	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	75%	100%
Fun_LevelC	Best	Best	Best	Best	Best	Best	Worst	Best	Best	Worst	Best	Best	Best	Worst

Notes: **Table 4.2** provides details about the questions and rating code.
VG: Very good; G-VG: Good to very good, FS: Fair sufficient; F: Fair; FD: Fair deficient; P: Poor; P-VP: Poor to very poor; and VP: Very poor.

Table C.3: Reported ratings and aggregated indices for check dam 3.

	New-user group							User group						
	Inspector ID													
Questions	4	5	6	8	11	12	13	1	2	3	7	9	10	14
A1	P-VP	FS	FS	FS	FS	P-VP	P-VP	P-VP	FS	G	P-VP	G	P-VP	FS
A2	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	P-VP	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG
A3	FS	FS	FS	FS	FS	FS	FS	G	FS	FS	G	G	FS	FS
A4	G	G	G	G	G	G	VP	G	G	G	G	G	G	G
B1	G	G	FD	G	G	G	FD	G	G	G	G	G	G	FD
B2	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	FD	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG
B3	FD	G	FD	G	G	G	P	G	FD	FD	FD	G	G	G
B4	G	G-VG	G-VG	G-VG	G-VG	G-VG	G	G-VG	G	G-VG	G-VG	G-VG	G	G-VG
C1-1	G-VG	F	G-VG	G	G-VG	G-VG	P-VP	G-VG	G-VG	G-VG	G-VG	N/A	G-VG	G
C1-2	G-VG	G-VG	G-VG	G-VG	G-VG	G-VG	P-VP	G-VG	G-VG	G	G-VG	N/A	G-VG	G-VG
C1-3	G-VG	F	G-VG	G	G-VG	G-VG	P-VP	G-VG	G-VG	G-VG	G-VG	G-VG	N/A	G
C1-4	G-VG	G	G-VG	F	G-VG	G	P-VP	G	G-VG	G-VG	G	G	N/A	G
Inspector's advice	2	1	3	3	1	3	4	3	2	2	3	2	1	1
IdxA	63,8	85,7	85,7	85,7	85,7	63,8	30,3	65,4	85,7	88,4	65,4	91,7	63,8	85,7
%ComplA	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Fun_LevelA	Worst	Best	Best	Best	Best	Worst	Worst	Worst	Best	Best	Worst	Best	Worst	Best
IdxB	68,9	88,7	61,0	88,7	88,7	88,7	43,1	88,7	68,9	70,7	70,7	88,7	85,9	70,7
%ComplB	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Fun_LevelB	Medium	Best	Medium	Best	Best	Best	Worst	Best	Medium	Best	Best	Best	Best	Best
IdxC	100,0	68,6	100,0	75,8	100,0	92,4	5,3	92,4	100,0	92,4	92,4	68,6	70,5	86,6
%ComplC	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	50%	50%	100%
Fun_LevelC	Best	Medium	Best	Best	Best	Best	Worst	Best	Best	Best	Best	Medium	Best	Best

Notes: **Table 4.2** provides details about the questions and rating code.
VG: Very good; G-VG: Good to very good, FS: Fair sufficient; F: Fair; FD: Fair deficient; P: Poor; P-VP: Poor to very poor; and VP: Very poor.

Table C.4: Participant's agreement about the usefulness of the method.

Participant ID		1	2	3	4	5	6	7	8	9	10	11	12	13
a) Rating conditions of questions in inspection form	A1	3	3	–	3	3	3	3	–	–	–	-2	-2	2
	A2	3	3	–	3	3	3	3	–	–	–	-1	2	2
	A3	-3	-3	–	-3	-3	-3	-3	–	–	–	0	0	2
	A4	3	3	–	3	3	3	3	–	–	–	0	-2	-2
	B1	3	3	–	3	3	3	3	–	–	–	-2	1	1
	B2	3	3	–	3	3	3	3	–	–	–	-2	1	1
	B3	3	3	–	3	3	3	3	–	–	–	0	-1	-1
	B4	3	3	–	3	3	3	3	–	–	–	0	-1	-1
	C1	3	2	–	3	3	3	3	–	–	–	0	0	0
	C2	3	2	–	3	3	3	3	–	–	–	0	0	0
	C3	3	2	–	3	3	3	3	–	–	–	0	0	0
	C4	3	–	–	3	–	3	3	–	–	–	–	0	0
b) Inspection form at parameter level														
Clarity	A	2	2	3	2	2	2	2	2	2	-1	-1	-1	2
	B	2	1	1	1	1	0	1	2	3	3	-1	1	2
	C	2	2	2	3	1	2	1	3	1	2	1	-1	2
Reliability	A	2	2	2	2	2	2	2	2	3	3	3	-2	1
	B	2	2	2	2	2	1	3	2	3	2	3	1	1
	C	2	2	3	3	1	2	2	3	2	3	3	-1	1
Usefulness	A	2	2	2	2	2	2	3	3	2	2	3	-2	2
	B	2	2	3	2	2	1	3	3	2	2	3	1	2
	C	2	2	3	3	1	2	3	3	2	2	3	-1	2

Notes: **Figure 4.12** provides an overview of participants' agreement.
Participants rated their level of agreement from −3 (full disagreement) to +3 (full agreement).
The difference in participants' number was because not all participants attended the second-day programme and one participant did not fill in the second-day feedback.

Table C.5: Overview of participants' suggestions for improvements in the inspection form.

Aspects of the inspection form	Participants' comments
Section 1*: Inspector's ID	–
Section 2*: Structure's ID	Simplified information about the structure type, if available in the database
Section 3*: Conditions of the inspection	New-users from neighboring regions suggested to keep only the question 2 about the condition of the stream during the inspection e.g. dry, ponding, flowing.
Section 4: Aspects that can limit the functional status of the structure	
Question A1	Questions A1 (Deviation of the flow passing through the spillway), B2 and B3 (level of obstruction upstream and downstream) should be integrated into one within Parameter B.
Question A2	Question about the condition of the structure could be further divided according to the wings and the body of the structure.
Question A4	The option "protection present but slight deterioration without missing parts" is missing. When the protection for scouring is a secondary check dam or a sill, the question is rated. Even so such structures should have their own first level inspection report.
Question B1 and B2	Have a different format for open check dams in which these questions do not appear.
Question B3	Level of sedimentation in the retention basin should include an additional option to report the presence of consolidated vegetation in the deposit.
Rating scale about parameter C	Add in the description for option 1, when the bank is naturally a rock or bare bank. In such cases, there is not a specific option to report.
Questions Parameter C	The extension of the erosion level should be referred to in the provided scheme and not as independent question.
Section 5*: Elements that could be affected in case of flood	New users suggested that if available in the database we could omit this part.
Section 6: Inspector's advice	It is relevant only when technicians carry out the inspection not for volunteers.
Paper-based format and recommendations for data-collection	Adjust the format to 4 sides (2 pages) to have the information clearer and more readable. However, data collection may benefit from an ICT application for acquiring pictures in an automatic way and visualize minimum information about the structure. Have a manual portable to the field to carry out the inspections with some reference pictures serving as example. To fill in the form is fundamental a training course.

Note: *The decision support methodology considers only the responses to the questions about the functional status (see **Table 4.2**). Other sections were only used as background information for the inspection

D

APPENDIX

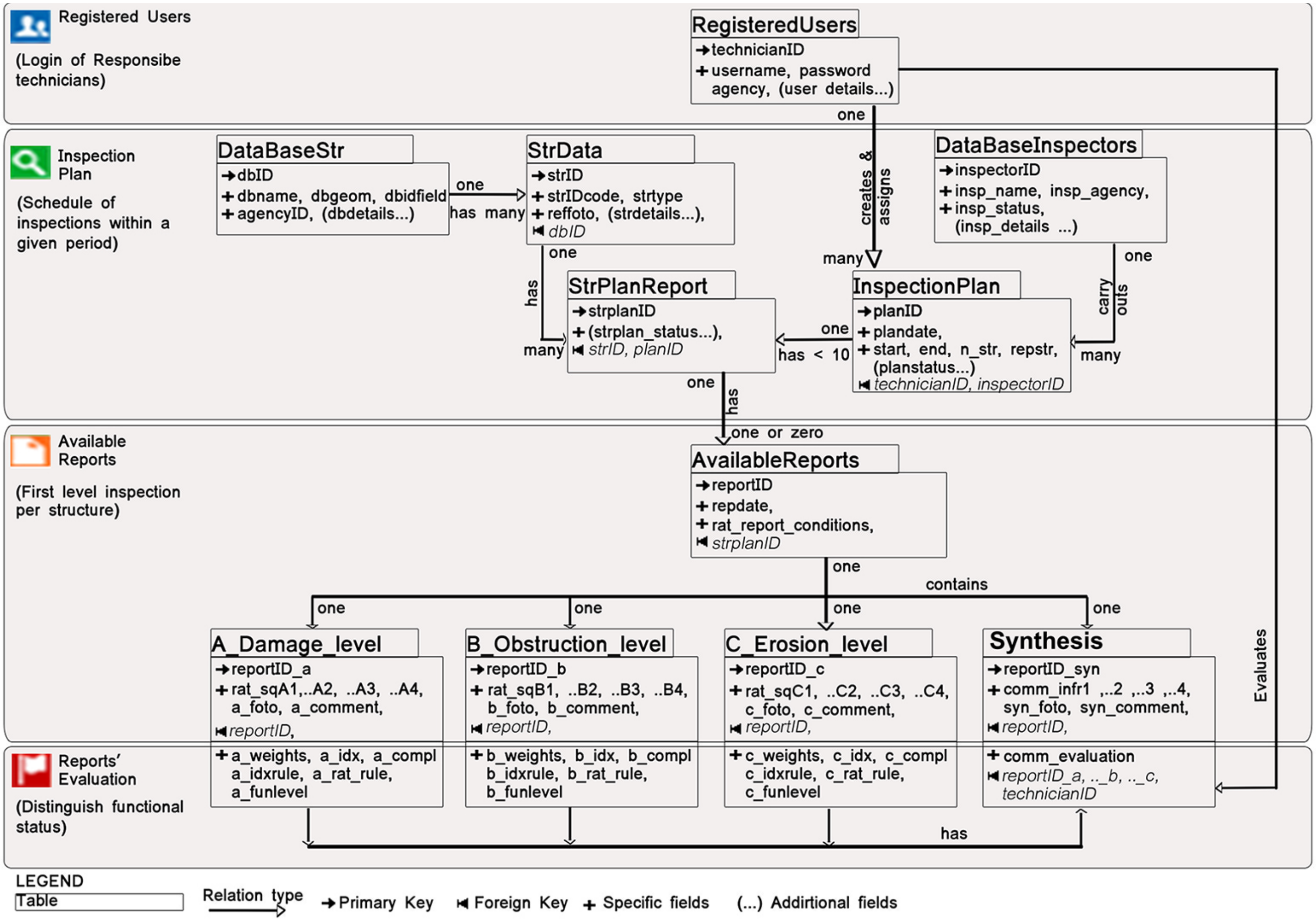


Figure D.1: Conceptual design of the data model behind the web-based application

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ABOUT THE AUTHOR

Juliette Cortes was born in Bogota, Colombia on 11 September 1983. She obtained her B.Sc. in Civil Engineering, in 2005 from the Faculty of Engineering, Universidad Nacional de Colombia in Bogota. Since her studies, she demonstrated interest on water resources by being student assistant and doing her BSc. Thesis on a related topic. After her graduation she became a project engineer in Hidroconsulta Ltda., where she worked about three years. First, she was assistant engineer for the design of the hydraulic drainage in national highways. Then, she worked as field engineer to supervise the construction of protection works against erosion and sedimentation of rivers along main national highways. Finally, she collaborated in the preparation of proposals for tenders in the design and supervision of hydraulic studies. During that three-years working experience, she carried out some inventories of hydraulic structures to assess the needs for maintenance with support of local workers and junior engineer students. She also attended a flood emergency in La Mojana, (Magdalena , Colombia), where she interacted with local communities living in the floodplain.

In 2009, she was awarded with a Nuffic scholarship for 18 months by which she obtained her master degree in Water Science & Engineering at Unesco-IHE, Delft, the Netherlands. She did her MSc. thesis in the framework of the DIANE-CM project, which had two case studies one in Hamburg (Germany) and another in London (UK). During her research, she participated in the design of web-based tools to support collaborative modelling approaches in flood risk management. The performance during her master study gave open the opportunity for a three-years scholarship to as PhD student in the EU Marie Curie project CHANGES (`http://www.changes-itn.eu/`).

In October 2012, she started working on her PhD research in close cooperation between the Italian National Research Council, Institute for Geo-hydrological Protection (CNR-IRPI, Padua) and the Department of Water Management at TUDelft. She performed her three-years research on the Fella Basin in the north-eastern Italian Alps (Friuli Venezia Giulia). Moreover, the CHANGES project involved several European partners and PhD researchers with case studies in four mountain European study areas. Thereby, she participated in the network activities, workshops and conferences from the different partners. Since May 2015 and parallel to the last-stage of her PhD research, she is working at the University of Twente, in the RiverCare project. She is currently researching on the potential of web-collaborative platforms. The aim is to support knowledge exchange between actors with different perspectives to better identify the effects of riverine measures being implemented in Dutch study sites.

List of Publications

Journal papers

- **Cortes Arevalo, V. J.**, Charrière, M., Bossi, G., Frigerio, S., Schenato, L., Bogaard, T., Bianchizza, C., Pasuto, A. and Sterlacchini, S. (2014). Evaluating data quality collected by volunteers for first-level inspection of hydraulic structures in mountain catchments. *Natural Hazards and Earth System Science*, 14(10), 2681–2698. `http://doi.org/10.5194/nhess-14-2681-2014`.
- **Cortes Arevalo, V.J.**, Sterlacchini, S, Bogaard, T.,Junier, S. and van de Giesen, N. (2016): Decision support method to systematically evaluate first-level inspections of the functional status of check dams, *Structure and Infrastructure Engineering*.
- **Cortes Arevalo, V.J.**, Aye, Zar Chi., Frigerio, S., Schenato, L., Bogaard, T., Pasuto, A., Sterlacchini, S. (Under Review). A Web-GIS decision support framework for assisting technicians in evaluating check dams inspection reports, *Water Resources Management.*
- Aye, Z. C., Sprague, T., **Cortes Arevalo, V. J.**, Prenger-Berninghoff, K., Jaboyedoff, M., & Derron, M. H. (2016). A collaborative (web-GIS) framework based on observations of three case studies in Europe for risk management of hydro-meteorological hazards.*International Journal of Disaster Risk Reduction*, 15(March), 10–23. `http://doi.org/10.1016/j.ijdrr.2015.12.001`.
- Prenger-Berninghoff, K., **Cortes, V. J.**, Sprague, T., Aye, Z. C., Greiving, S., Głowacki, W. and Sterlacchini, S.: The connection between long-term and short-term risk management strategies for flood and landslide hazards: examples from land-use planning and emergency management in four European case studies, *Nat. Hazards Earth Syst. Sci.*, 14(12), 3261–3278, `doi:10.5194/nhess-14-3261-2014,2014`.

Conference papers

- **Cortes, V.J.**, Sprague, T., Frigerio, S., Bogaard, T., Sterlacchini, S. (2014) The role of community knowledge and participation for hydraulic-structure inspections: Combining knowledge with action trough citizen-science projects. International Conference Analysis and Management of changing risks for natural hazards. 18-19 November 2014. Padova, Italy.
- **Cortes, V.J.**, Frigerio, S., Schenato, L., Pasuto, A & Sterlacchini. S. (2013), Review of the current risk management strategies in Europe for hydro-meteorological hazards at protection and emergency level.Comprehensive Flood Risk Management – Klijn & Schweckendiek (eds). 2013 Taylor & Francis Group, London, ISBN 978-0-415-62144-1.
- **Cortes, V.J.**, Frigerio, S., Schenato, L., Sterlacchini, S., Bogaard, T., and Pasuto, A (2014), Setting priorities for management of hydraulic structures in mountain catchments. HIC 2014 – 11th International Conference on Hydroinformatics "Informatics and the Environment: Data and Model Integration in a Heterogeneous Hydro World" New York, USA August 17 – 21, 2014.