

**DEMONSTRATING THE CAPACITY OF ONLINE CITIZEN SCIENCE
MAPPING SOFTWARE TO COMMUNICATE NATURAL HAZARDS AND
ENGAGE COMMUNITY PARTICIPATION**

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Dedication

For my family.

Abstract

OpenStreetMap (OSM) is an online citizen science mapping software program that can be used to empower communities and encourage participation in natural hazards planning. This is a multi-disciplinary thesis demonstrating OSM's effectiveness as a tool in this capacity through a literature review, in depth case study, and functional application. The literature review and case study focus on applications of OSM in other contexts, like the Nepal earthquakes in 2015. The functional application addresses the impacts of climate change in the Elk River watershed. Flooding here has become more frequent and intense as a result of climate change. The Flood Solution Strategy is prepares people for extreme flooding events in Fernie, B.C. This research utilized a unique methodology in using OSM as both a tool for engaging the community and communicating the risk of flooding. The result is a flood hazard map created through a science-policy-stakeholder partnership complimenting a larger initiative.

Preface

When I first began my Master's Degree in January of 2015, I had intentions of studying populations vulnerable to the impacts of climate change in developing countries. As my studies progressed, however, certain opportunities arose that led me to studying OpenStreetMap and applying it towards collaborative efforts for the Elk River in Fernie. Firstly, I was granted an excellent internship with Geoff Haines-Stiles during which I researched citizen science for the upcoming documentary, the Crowd & the Cloud. It was through this work that I became well versed in the diverse and various applications of OSM, and wrote the case study on the Nepal earthquakes.

When the internship was complete, I became available to begin working with the Elk River Alliance, an organization dedicated to the health of their watershed, and in particular preparing the community for extreme flooding events. Through many field trips to Fernie, meetings with the collaborative group and community workshops, I gathered experience working together with stakeholders, policy makers, and researchers. Together, we agreed that OSM would be an excellent tool for empowering and engaging the community.

While pursuing my degree I became knowledgeable in many subjects, thanks to both courses, graduate teaching assistantships, and research experience. The courses I participated in were Graduate Research Methods, Global Populations, Advanced Geographical Information Systems, and Climate Change: Science, Impacts and Solutions. I assisted in teaching fourth year Current Events in Environmental Science, Introduction to Geography, Weather and Climate, and Natural Hazards. I also participated in running a student group, the Global Citizen Cohort, in which I mentored first year students. With my research experience I've gained knowledge in topics including renewable energy,

natural resources, environmental policy, disasters and risk, water resources and management, spatial analytical technologies (ArcMap, GIS, etc.), community engagement and education, and of course, citizen science.

During my degree, I had the privilege of attending the American Geophysical Union Fall Meetings of 2014 and 2015 in San Francisco to present posters on my research. Throughout my studies I also volunteered with the Southern Alberta Council on Public Affairs as a session moderator and was introduced to many great academics, people in government, and high ranking community members. I also served at a restaurant and trained for many half marathons and long distance obstacle races.

This thesis represents the culmination of my experiences throughout my degree, and although it took turns in unexpected directions, I'm very proud of the progress I've made and the lessons I've learned. This study is multi-interdisciplinary and intertwines humanitarianism with community hazard planning. In my future studies, I will certainly be following my passion of working with vulnerable peoples in developing countries, as they are the most unjustly affected by the impacts of climate change.

Acknowledgements

Firstly, I'd like to thank my advisor, Dr. James Byrne, for recognizing my potential when I did not, and providing me with exceptional opportunities to grow. Thank you for treating me like family and always showing me compassion and understanding during the twists and turns.

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I owe much gratitude to Lee Anne Walker and Ayla Bennett of the Elk River Alliance, for accepting me into the collaborative flood strategy. I always looked forward to your hospitality and experiencing first hand your passion for the Elk River communities.

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List of Abbreviations

ENSO – El Nino / Southern Oscillations
EPA – Environmental Protection Agency
ERA – Elk River Alliance
GIS – Geographic Information Systems
HOT – Humanitarian OpenStreetMap Team
IPCC – Intergovernmental Panel on Climate Change
KLL – Kathmandu Living Labs
NOAA – National Oceanic and Atmospheric Administration
OSM – OpenStreetMap
PDO – Pacific Decadal Oscillations
UNISDR – United Nations International Strategy for Disaster Reduction
USGS – US Geological Survey
VGI – Volunteered Geographic Information

Chapter 1: Introduction

Research Goal

The goal of this thesis is to demonstrate the various capacities for which OpenStreetMap is utilized in communicating natural hazards through the use of maps by means of a literature review, detailed case study, and functional application in a study area. The literature review and case study aim to validate the known effectiveness of OSM, while its application in a study area highlights a unique approach that has yet to be explored in the scientific literature. This work is significant in that it applied the strengths of local engagement through online citizen science software to empower a community to participate in its own flood hazard mapping. The products of this thesis are an in-depth case study of OSM work in Nepal, and a flood hazard map created through a science-policy-stakeholder partnership, which complements a larger initiative. The partnership was established through several meetings with academics, community members, and municipal policy makers often sitting at the same table and collaborating on solution measures. Whether or not these policies are acted upon, is another debate entirely.

Summary

Natural hazards are a reality that all people face. In Canada, most disasters are the result of geophysical and meteorological processes that produce floods, fires, landslides, earthquakes, etc. Climate change is an increasing threat that exacerbates the risk of flooding in particular. The most resilient communities have shifted towards incorporating integrated disaster risk research that focuses on including vulnerability and adaptability in the face of climate change. Research in this area can help vulnerable populations to be prepared for extreme events through the communication of knowledge to be used in decision-making. One of the most effective means of communicating hazards is the

creation of visuals, such as maps, which can be easily understood by the public. Even more powerful, is the involvement of the public in creating a map.

Chapter two contains the literature review which first comprises a conceptual analysis, outlining the importance of understanding vulnerability to natural hazards; essential to establish when seeking solutions. It then introduces citizen science and OSM, delving into its virtues and vices. Several examples of the use of OSM online mapping software in hazard planning are provided to give background and insight into the program. An in depth case study on the Nepal earthquakes of 2015 is included as proof of OSM's already established success in responding to a natural disaster. Furthermore, the case study demonstrates the versatility of the program in that it can be utilized in response to various hazard and risk scenarios.

The Elk River study is introduced in Chapter three as a practical application of OSM in disaster preparedness, which is preliminary to effective disaster response. The history of flooding in the Elk River Valley and the impacts of climate change are highlighted, along with flood modelling and mapping techniques. Population demographics and socio-economics of the City of Fernie, located along the Elk River and vulnerable to flooding, are outlined and discussed. Finally, the Elk River Alliance (ERA) is reviewed, partner organization with the University of Lethbridge and producer of the Elk River Flood Solution Strategy.

Complementing the Flood Solution Strategy is a flood hazard map created by a research group. The map includes key city features added by community members, making this work unique. It is unique in that the map could be used as an interactive community engagement tool that is intentionally updated by the members of the community themselves through OSM software. While the flood extent map features are

updated by scientific sources via the ERA and other partners, the city's basemap is constantly updated by locals in Fernie. Two community workshops were held to initially populate the map with city features. The methodologies for creating the map both on the scientific and community side are presented.

The discussion is intended to interpret the results of the mapping workshops held in the community as well as challenges in creating the final map product. Adaptation strategies for responding to the hazard of flooding are also reviewed, focusing mainly on the need for local participation in the preparation of extreme events. The conclusion is Chapter four and it addresses future possible applications of the work done and reiterates findings pertinent to the research goal along with its significance in contributing to the literature.

Chapter 2: Review of Literature

Summary

Online mapping is not a new concept, nor is using OSM basemaps for communicating hazards with mapping. What is unique in this thesis is the participation of the community in purposefully populating the OSM basemap with city features specifically to be used as an online interactive engagement tool in preparation for an extreme flooding event. Research of the current literature has revealed a gap here, though there are examples of OSM basemaps being used in hazard mapping that are briefly reviewed. Furthermore, an extensive review of the Humanitarian OpenStreetMap Team's response during the Nepal earthquakes in 2015 is provided as an example of the power of citizen science in hazards communication.

Conceptual Analysis

Vulnerability to Natural Hazards

Natural hazards are any potentially damaging physical event, possibly causing the loss of life, injury or life disruption, property damage, social, economic, or political disruption, or environmental disturbance [1]. This thesis focuses on those hazards classified into geological, hydro-meteorological, or climatological events. A disaster in any of these classifications refers to a serious disturbance of normal functioning society which causes a variety of widespread losses exceeding the resources of the affected community to respond [1]. According to the Intergovernmental Panel on Climate Change 2007 (IPCC) [2], disaster risk is the likelihood over a specified time period of adverse impacts due to extreme events interacting with vulnerable social conditions. The

management of current disaster risk from natural hazards is the key to future management and building community resistance.

Risk has two properties: the source (i.e. flooding) and the nature of the risk in context (high or low consequences) based on probability estimates concerning frequency of occurrence [3]. The potential for hazard is dependent on several factors including environmental vulnerability and population demographics. Furthermore, hazards can be chronic or acute, enveloping contrasting social contexts and diverse approaches to solving problems [3]. Hazard potential is a function of risk and mitigation which are influenced by geographic and biophysical contexts, place-based vulnerability, and social factors [3].

Meteorological disasters from climate induced events, such as floods, impose great socio-economic, livelihood, and environmental impacts, with severity dependent on exposure and vulnerability [1, 2]. Exposure is defined by the location of people, assets, and infrastructure in areas at risk of hazard [1], while vulnerability is more difficult to describe. It tends to be an emergent phenomena in that it remains underlying until a population is stressed, at which point it emerges from a combination of socio-economic and environmental factors. There are several definitions of vulnerability put forth by various authorities. The UNISDR considers vulnerability as the degree to which people, assets, and infrastructure are susceptible to damage, relating it to exposure [1]. The IPCC 2007 [2] simply defines exposure as a population's "propensity" to be severely affected.

Vulnerability factors in risk and hazard exposure with social response. No matter which definition is utilized, each identifies the potential for loss from the interactions of society and physical conditions affecting the resiliency of a population and its environment to respond to a disaster [3]. Assessments of vulnerability should be multi-disciplinary, place specific, consider several interacting stressors, study adaptive capacity,

and be both historical and future focused [4]. Techniques for assessment can include historical narratives, contextual analyses, case studies, statistical analyses, Geographic Information Systems (GIS) and mapping techniques [3].

Citizen Science and OSM

Citizen science, or crowdsourcing, as defined by Goodchild [5] is a collection of individuals acting and responding to the needs of local communities. Online citizen science not only lessens information gathering costs, but it develops a link between citizens and researchers, as well as increasing public scientific knowledge [6]. This method has fundamentally changed the nature of scientific investigation and has led to several new scientific discoveries [7]. The main principle is that a large group of non-experts can contribute a small amount of information as individuals to solve a problem that is otherwise too large an effort for experts [8]. Particularly through web-based contribution, individuals participate in scientific activities that address local problems by volunteering information that is often costly and labor intensive [6]. There are four components of crowdsourcing: (1) an organization with a project; (2) a voluntary community; (3) an interactive, online environment; and (4) a mutual benefit for the organization and the community [9].

Crowdsourcing has emerged as an effective means of empowering communities; traditional top down approaches are often not feasible with many community planning needs [10]. When conducted through a technological medium, crowdsourcing can develop a sense of community which generates shared ownership and also increases the likelihood of future collaboration [10]. Strengthened social ties from volunteering allow for citizens to be civic-minded rather than passive in community development and planning that stimulates cultural capacity [9, 10]. Smith, et al. [10] assert that access to

information and other people through technology strengthens the resilience of a population due to the creation of social networks that increase resource robustness and adaptive capacity. Volunteered Geographic Information (VGI) is a form of citizen science by which the public contributes, maintains, and utilizes geo-spatial data for a variety of purposes [7, 11]. One of the most successful forms of VGI is OpenStreetMap which is a free, online, editable map of the whole world built by over a million public contributors [12].

OpenStreetMap successfully incorporates the two pillars of online citizen science as outlined by Nov et al. [6]. These include technologies managed by computer systems designed to retain and distribute resources, and the ability to attract motivated volunteers willing to dedicate skills and time to a greater good [6]. There are several factors motivating participants, all of which are demonstrated through OSM. Motives for participation may include collective motives reflecting the importance of the goals of the project; social motives concerning a participant's expectations of their community's reaction; and reward motives such as making new acquaintances or other potential benefits [6]. The retention of volunteers is a challenge in online citizen science, however research suggests that motivation is enhanced when they have control over their participation [6]. This function is fulfilled by OSM as it allows for volunteers to be flexible and responsible for their own engagement, producing results as the need arises.

Community Engagement in Online Mapping

Outlined in the following section are examples of community engagement in online mapping found within the scientific literature. Looking first through a broad lens, an internet-based geospatial tool was developed for the purpose of storm water

management and planning in coastal areas by Lathrop, et al. [13]. As with Elk River, key infrastructure, populations, and natural resources in coastal regions are impacted by flooding enhanced by climate change. Lathrop et al. [14] uses guidelines set by NOAA for developing decision support tools concerning coastal flooding. The guidelines can be made applicable to inland flooding as well and are as follows [14]:

1. Tools should incorporate information ascertained through scientific research and modeling that can be easily applied by local governments and large landowners when planning future land use and deciding on policy and regulations that affect resources;
2. Tools should forecast expected habitat changes, especially the potential loss of habitats important for ecological services;
3. Tools should be easy to translate to decision-makers;
4. Tools should enable easy understanding of potential risks to people and development due to future flooding and related hazards.

The work done with Elk River relates closely to these guidelines, with the use of OSM providing an environment that is easily understood to both decision makers and lay community members.

Initially the study looked at two options for the distribution of GIS information to potential users, one being through conventional GIS software, the other through a customized interactive map server interface [13]. While the conventional approach offers advantages to the geospatial provider with access to the GIS software, the customized, interactive map was determined to be more appropriate for reaching a wider assortment of potential map users with no need for them to have GIS knowledge [13]. Lathrop, et al. [13] utilized a Google Maps API basemap, rather than OSM, which does not allow for end users to contribute to basic map layers such as buildings and streets. Still, using the Google Maps server as opposed to relying on their own server capacity, enabled them the advantage of reliable, updated map imagery, as with OSM.

Focus groups found that flooding scenarios in increments of measurement (i.e. 1 meter depth) rather than probability (high, medium, low) were more straightforward and easy to understand [14], therefore measurement has been adopted in the Elk River case study, rather than probability.

Through the use of an online customized map, Lathrop, et al. [13] sought to develop trust with their end users, effectively demonstrate new technology, and communicate successfully with their target audience (especially non-GIS users). One of the benefits of site-specific geospatial information communicated with a target population is equity, or community empowerment, [13] which is also an outcome of the work accomplished in Elk River with OSM. Lathrop et al. [13, 14] conclude that through making geospatial information more easily accessible, a wider and more diverse community of stakeholders will benefit and that broadens public involvement in decision making. It is not enough to have the information available online, but to have it understood and applicable in the context of preparing for a hazard, in this case flooding [14]. Lathrop et al. [14] applied the results of focus groups that revealed a tool should be “easy to use”, “user friendly”, have “current information/content” and be a “one stop shop” [14]. They also ensured that the geospatial information they used was from reliable, science backed sources [14]. The Elk River hazard map applies similar concepts.

Knight, et al. [15] provides another example of the application of a “web-based geospatial decision support tool” for flood risk, though unlike Lathrop, et al., they utilize an OSM basemap for their interface. Their tool allows for users to explore areas and infrastructure at risk, the extent to which flood hazard changes with sea level rise, and thresholds where policy options are “no longer viable for locations at high risk of flooding” [15]. Similar to Lathrop et al., however, is the intention for non-GIS users to

benefit from the tool, with special emphasis on an empowered community's ability to reduce losses. With the use of OSM as a basemap, their map's basic features can be mended as they change over time. The Elk River study actively enlisted community members to mend the basemap, while Knight, et al. [15] did not.

A master's thesis produced in 2014 by Xhou [16] asserts that VGI may create a link between community participation and storm water management, concluding it provides a more localized understanding of planning issues. There were three key functions of the application; firstly, to "receive green infrastructure knowledge and information"; use personal mobile devices to report green practices, building an online virtual photo library of green infrastructure sites; and lastly to communicate green infrastructure issues [16]. It was found that once more people added to a VGI system, the green infrastructure culture became more prominent in the storm water planning process which increased the input of social efforts in communities through VGI [16].

Advantages and Disadvantages of OSM

Web 2.0 technology is constantly evolving to satisfy the continually changing needs of users including the creation of online communities, and contribution and flow of knowledge through these communities [7, 17]. The creation of Wikipedia and its use of crowdsourcing has immensely influenced the development of user-generated GIS applications like OSM, which uses citizens as "sensors" [5]. The emergence of open source geospatial data has had an immense impact on the GIS and digital mapping community. One critical advantage to OSM and its use of VGI is the increase in the quantity of spatially referenced data which is used for a variety of purposes. Furthermore, as new data availability increases, older data becomes more freely available, increasing

opportunities for user-generated GIS applications to be utilized towards various objectives. Old data can be utilized together with new data for analysis.

User-generated GIS applications appeared as a result of improvements in GPS, accessibility to “capture devices” like mobile phones and computers, decreased data storage costs, increased bandwidth, and decreased purchase cost [17]. The development of VGI and crowdsourcing has made applications like OSM possible; providing free access to current digital geographic information [18]. The accessibility of current information is especially imperative in crisis response and the success of hazard mapping, as natural disasters can drastically alter basic map elements in a very short period of time.

OpenStreetmap has provided many benefits compared to those of commercial mapping agencies. This includes increased productivity and earlier response time, localized knowledge, and a free platform to access current spatial data [18]. The use of OSM has provided an enormous increase in the productivity of digital mapping, vastly exceeding the potential progress for a single individual in similar timeframes [17]. Crowdsourcing geographic data distributes time consuming and tedious mapping tasks amongst hundreds to thousands of users.

Arguably one of the biggest advantages of OSM data is that it is often the cheapest, and *sometimes the only source* of geographic information [12]. Access to a free network of geographic information provides practical service to various OSM users, from personal uses like route calculations and trip planning, to communal uses that include city planning and disaster prevention and relief. When mapping phenomena, such as natural disasters, it is very important to have evolving data in order to accurately visualize damage extent.

User-generated data can be updated very quickly, similar to the functions of Wikipedia [17]. Some areas of the world regard access to geographic information as an issue of national security, in which case OSM may be the only source of publicly available geographic information [18]. OpenStreetMap provides users with a greater availability of knowledge in the form of place based data, images and other relevant information [18]. Another one of the more important advantages is the use of localized expertise and current information about local conditions. Often time, the most knowledgeable responders to a crisis are the locals.

There are several intrinsic methods through which VGI ensures data quality. Firstly, crowd sourcing the data allows multiple contributors to edit and revise the geospatial data. Another approach is social measures which highlight the “assessment of contributors themselves as a proxy measure for the quality of their contributions” [11]. Furthermore, geographic consistency is easily detected through analyzing contextually implausible entities such as the presence of a building in the middle of a lake [11].

Although OSM does not have a standardized procedure or data quality specifications, its intrinsic value is added to by a consistent tagging system. The system acts as an informal standard and allows for the combination of elements as well as the creation of new elements for feature classification. Primary features are classified into buildings, roads, amenities, land use, and so on [19].

Despite its many advantages, OSM is not without disadvantages. One flaw associated with user-generated data is the credibility and reliability of VGI. Data supplied from a VGI-generated system lacks the strictly regulated standards and specifications that govern professional mapping agencies [18]. The users creating and editing data in OSM are rarely qualified or trained cartographers, which can render map data unreliable in

some cases. Some argue that OSM data may be biased by opinion or perspective, thus forfeiting scientific credibility through the prioritization of other influencing factors [18].

Data quality is defined as the fitness for purpose, or ability for a dataset to satisfy certain requirements for solving a particular problem [4]. In the case of citizen science, data quality is measured as “a degree of excellence of what is produced” [6]. Nov, et al. [6] found that quantity of data contributed correlates to a community’s commitment to the project, and in the case of OSM, greater quantity correlates with greater quality. Data accuracy refers to the closeness that particular data represents compared to the true or real values [4]. This is important because when using digital representations of real world objects there is always going to be a certain level of associated distortion. Despite the importance of data quality and accuracy, the importance of accessibility and cost of acquiring data cannot be understated; without affordable and accessible data the use of digital models and maps would be difficult to utilize in underfunded operations [4]. Data can have a high level of accuracy while having a low level of data quality; the acceptance of data depends on its specific purpose. Due to its rising popularity and increasing usage, there have been a number of investigations into the quality and accuracy of OSM, which has been found to be quite high [20].

The use of OSM software requires a method of assessing the quality of geographic data provided by volunteers. Haklay, et al. [21] compared data produced by OSM to commercially generated data via a “buffer analysis”. Haklay analyzed the spatial correlation between a user-generated map through OSM and a professionally generated map by overlaying the two layers, ‘buffering’ out the areas that didn’t overlap and calculating the percent of overlap. The study determined the “positional accuracy” of the data and found that the road networks had roughly 80% overlap, leaving only 20% of the

network misrepresented from a total of 109 roads and 328km of roadway [22]. They concluded that VGI accuracy was quite comparable to that of commercially generated data, furthermore that it is faster at digitizing areas of constant change [22].

Another study by See, et al. [7] assessed quality by comparing volunteer results with expert produced results at certain control points. It was found that there was “little difference” between the results given to identify human impacts while experts were better at identifying land cover [7]. Overall however, the study concluded that volunteers were as reliable as experts and that the information they provided actually improved proficiency to a greater degree than that provided by the experts [7]. Furthermore, research by Swain et al. [8] demonstrated that the great majority of citizen science participants contribute honest, accurate responses, indicating that volunteering is motivated by interest in and knowledge of the project’s goals.

The importance of attribute information cannot be understated in hazard mapping. With VGI, the accuracy of attribute data increases as the number of contributing users increases [22]. The more attribute data available, the more detailed a map becomes and thus more useful to its users. As the popularity of OSM grows and access increases, the quality of geographic information will increase. Since OSM accuracy increases with the number of OSM users it is important to establish a reliable community of users for the area of interest before using this data for spatial analysis. The benefits of VGI in OSM heavily outweigh the disadvantages when this is considered alongside its open-source status, and has proven invaluable in disaster response. This is true for both developed and developing countries [9], both of which are demonstrated in this thesis.

Privacy and Security: OSM Potential for Abuse or Misuse?

Could OSM be used in a negative capacity, for example terror or military purposes? It could be surmised that drone strikes could be carried out by simply looking at the map. There is, of course, no readily apparent record of such an abuse for OSM. Furthermore, questions of privacy may be invoked at the availability of the spatial location of someone's home on a map on an open source website. The OSM basemap, however only depicts what can already be surmised from satellite photos, and private information (i.e. number of people in a dwelling living with a disability), is not available through the online platform. Users are also protected in that they do not provide any private information when they sign up for the program. The only conceivable way that OSM could be used in a negative fashion is if its basemap were to be uploaded into a software program that is used in a negative fashion. The OSM basemap on its own does not contain any information besides basic map data that could also be found on Google Maps, or any other basic mapping program.

Case Review: Nepal

Summary

Crowdsourcing includes networks of ordinary people acting as sensors, observing and recording information for science. The Humanitarian OpenStreetMap Team (HOT) is one such sensor network working to empower citizens to collaboratively produce a global picture from free geographic information. The success of such open source software is extended by the development of freely used open databases for the user community. Participating citizens do not require a high level of skill. Final results are processed by professionals following quality assurance protocols before map information is released.

OpenStreetMap is not only the cheapest source of timely maps in many cases but also often the *only* source. This is particularly true in developing countries. Emergency response to the 2015 Nepalese earthquakes illustrates the value for rapidly updated geographic information. This includes emergency management, damage assessment, post-disaster response, and future risk mitigation. Local disaster conditions (landslides, road closings, bridge failures, etc.) were documented for local aid workers by citizen scientists working remotely. Satellites and drones provided digital imagery of the disaster zone and OSM participants shared the data from locations around the globe.

For the 2015 Nepalese earthquakes, HOT provided a team of volunteers on the ground which contributed data to the disaster response through smartphones and laptops. This, combined with global citizen science efforts, provided immediate geographically useful maps to assist aid workers, including the Red Cross Society, Canadian Disaster Assistance Response Team (DART), and the Nepalese Army.

Background

Every year since 1990, over 200 million people have been severely impacted by natural disasters around the world [23]. Nepal is a country regularly distressed by earthquakes due its position on the constantly shifting Main Himalayan Thrust fault system [24]. Kathmandu, Nepal's capital city, is considered the world's most earthquake vulnerable city [25]. With this knowledge, OSM and its affiliated arm HOT, contributed to the preparation and response of the devastating 2015 Nepalese earthquake. Working in partnership with several global partners including the United Nations (UN), Red Cross, and Canadian Disaster Assistance Response Team (DART), OSM created maps which enabled aid workers to appropriately distribute their services to people in need. The maps themselves were produced by a massive army of volunteers from around the world.

The earthquakes that occurred in Nepal on April 25 and May 12, 2015, killed more than 8,600 people and left over 22,000 people injured [23, 26, 27]. The first was of 7.8 magnitude and struck approximately 81 kilometers northwest of Kathmandu [23] while the second was of 7.3 magnitude 40 kilometers west of the capital [27]. Early relief efforts were disrupted as damaged buildings that withstood the first quake were reduced to rubble by the second event. The most affected districts were Bhaktapur, Dhadhing, Dolakha, Kathmandu, Lalitpur, Gorkha Lamjung, Rasuwa, Ramechhap, Nuwakot, and Sindupalchowk [28]. It was estimated that 8 million people in Nepal had been affected, including 2.8 million displaced survivors [29]. The UN was immediately emphasizing the need for shelter and food from the international aid community. The disaster highlights the importance of effective disaster and risk mitigation strategies from "humanitarian cooperation mechanisms" [25] to respond efficiently to those in greatest privation.

Nepal required a variety of goods and services stemming from immediate safety requirements, access to emergency services, basic life subsistence necessities, and psychological support. According to a situation report filed on April 30th by the UN's Office of Coordination for Humanitarian Affairs (UNOCHA) [28], the focus of aid agencies was on providing shelter, food, security, and health for the displaced Nepalese. The question, however, for any disaster response, is where to send the goods and services. Which areas are most heavily affected? Who needs the most help? Aid organizations struggle to assess these questions when they first arrive. That's when citizen science initiated its efforts towards Nepal. Using maps created by OSM/HOT crisis mappers, UNOCHA organised a UN Disaster and Assessment Coordination team to provide timely, crucial assistance.

The Humanitarian OpenStreetMap Team are the 'feet on the ground'. OpenStreetMap is considered by the US Geological Survey (USGS) to be "one of the most ambitious efforts at producing a basemap of the world" [30]. With the development of open data, OSM has collaborated with the US government as well as several humanitarian organizations to bring citizen scientists an open-source mapping platform. As the availability of geospatial data becomes available to civilians with hand held access to "geo-enabled mobile devices", an increasingly "mature" map-based platform is produced [30].

People that consider themselves members of a global society are not content with simply donating money to help with aid relief but rather they want to actively participate. Most OSM members are stay-at-home citizen science cartographers. Given the history of the country, scientists had been expecting the earthquakes before they even happened. Working in partnership with Kathmandu Living Labs (KLL) in Nepal, the organization

had already been collaborating on the Open Cities Project funded by the World Bank [31]. They were in the process of digitally mapping the city, and that advanced work made quick relief efforts much more timely and effective when the instance came for mobilizing. For the Nepal “task”, virtual volunteers traced roads, buildings, and open spaces over aerial imagery while in-situ volunteers filled in the finer details. Altogether, this information was used in order to generate maps to assist aid workers.

Once the disaster struck, adding details to online maps in real time, OSM/HOT generated valuable information using open data input from satellite pictures, drones, social media, and orthotic photos. This geographic information was used to identify passable roads, collapsed buildings and bridges, and potential helicopter landing sites. The volunteers onsite in Nepal verified the maps for use by first responders: the Red Cross Society, the Nepali Army, and UN affiliates. The OSM/HOT organizational platform allows for a huge number of global participants to contribute, which increases situational awareness and improves data management [32, 33] throughout the crisis period and beyond. Quality control measures are taken but the driving force behind this ‘big’ data collection is Linus’ Law – given enough eyeballs, all bugs are shallow [30], meaning the more participation the better the quality.

HOT Response in Nepal

It used to be that mapping with OSM was a “by nerds, for nerds” project [34], however with the expansion of user friendly GIS capabilities, it has grown into a community of citizen scientists. OpenStreetMap was conceived in 2005, but HOT did not flourish until the Haiti earthquake in 2010, revealing the organization’s disaster response capacities to the global aid community. To be clear, OSM and HOT, while closely

affiliated, are separate entities. Humanitarian OpenStreetMap team is responsible for the mobilization of volunteers towards humanitarian efforts, disaster response, and economic development [31]. It is an NGO that trains, coordinates, and organizes OSM mappers [31]. The “core humanitarian mission” of HOT is “to serve as a bridge between the OSM community and humanitarian responders on the ground” [35]. It is the interface between the OSM citizen science community and humanitarian agencies. For Nepal, HOT volunteers did the actual damage assessments in situ, and that data was stored using OSM online software [36].

When the first earthquake hit, the International Federation of Red Cross and Red Crescent Societies coordinated with KLL’s Nama Raj Budhathoki, HOT Board of Directors member. Once a “situation room” [26] was established, coordination of the mapping response could commence. According Kuncce [37], American Red Cross relies “heavily on OSM data to do [their] assessments and planning”. Their role in the disaster response was to provide “remote mapping and information management support” so as to attain an accurate evaluation of the devastation [37, 38]. The American Red Cross, working closely with the Nepal Red Cross Society, analyzed 2011 Nepal Census data and defined where the most people were most likely affected. The Humanitarian OpenStreetMap Team then assembled a specific task manager online which split the areas into grids allowing multiple edits at once (Figure 1) [31]. The gridded system of mapping allowed remote crisis mappers to perform tasks without the problem of overlapping.

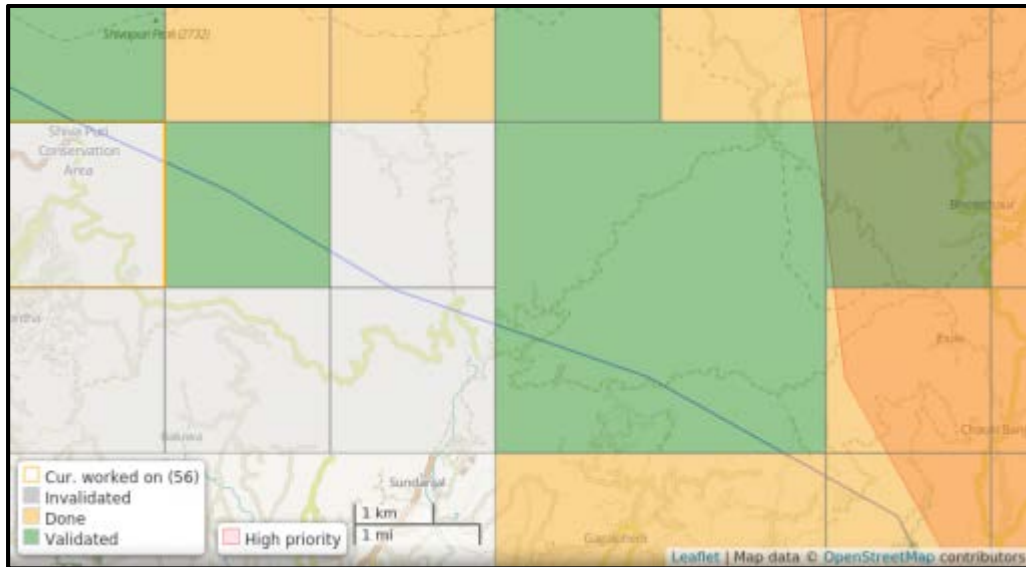


Figure 1: HOT/OSM task grid for mapping Nepal (Source: hotosm.org).

Humanitarian organizations were able to provide various services in cooperation with HOT and OSM crisis mapping volunteers. The provision of an accurate road map is fundamental towards the most urgent needs in any relief effort. Therefore, the first task of volunteers was to map the road networks of Nepal that had not already been previously mapped by HOT and KLL. Most of these roads were rural and outside Kathmandu's dense city area [39].

Budhathoki [38] asserts that the Nepali Army used the maps of road blocks and displaced people for effective response. The army, in addition to supplying forty helicopters towards the relief effort, also used drones to provide imagery which was uploaded for the production of digital maps [39]. Kathmandu Living Labs was called upon to facilitate mapping potential helicopter landing sites as well as to identify paths with water sources to accommodate aid relief using mule transportation [26]. Health facilities in Kathmandu had already been previously mapped by OSM participants [38], expediting the relief process and thus saving more lives. Figure 2a shows a map of Nepal

displaying all categories of reports made by HOT volunteers, while Figure 2b shows relief needs that can be further broken down into various categories.

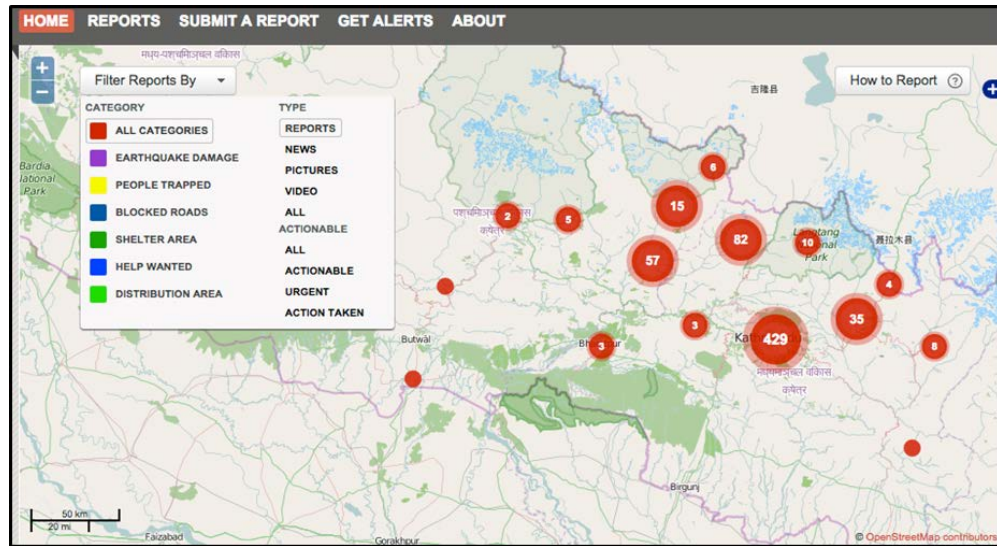


Figure 2a: Reports made by HOT crisis mappers across Nepal; numbers in red circles indicate the numbers of reports made in all categories (Source: Kathmandu Living Labs, 2015 [26]).

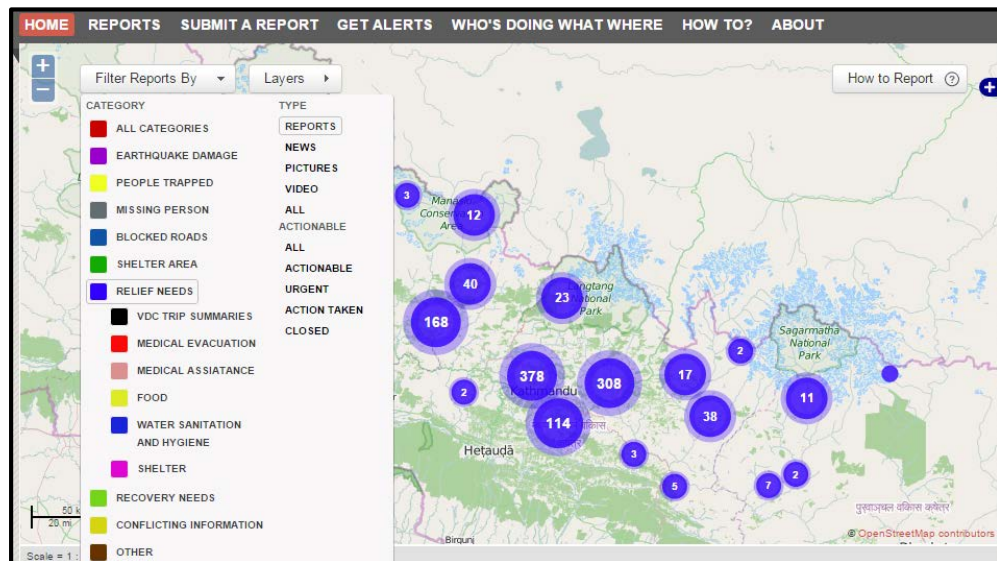


Figure 2b: Relief needs identified by HOT crisis mappers across Nepal; the numbers in the blue circles indicate the number of reports made for relief efforts needed (Source: Kathmandu Living Labs, 2015 [26]).

Volunteer members of OSM are referred to as crisis mappers. Their work involves remote mapping, or armchair mapping as participants do not have to leave their homes. They simply download the OSM software, trace information from satellite or drone imagery, and upload contributions that create map data to be used in the field. While mistakes are unavoidable, HOT verifiers on the ground are capable of identifying and adjusting misinformation. Moreover, in times of crisis, mapping that is 90% accurate is infinitely better than 0% available. Armchair, or crisis, mapping happens in the following manner [40]:

1. An administrator selects an area requiring updating in OpenStreetMap. The administrator ensures there is suitable satellite imagery available for remote mappers to trace, and creates a project covering the area. The level of detail required and the urgency are specified within the project together with any other information the remote mapper will require. When satisfied, the administrator publishes the project within the Tasking Manager tasks.hotosm.org, although they may also make changes later if required.
2. A remote mapper selects a task square, completes the mapping, and marks the square as complete.
3. A second remote mapper checks that the square is completed to a satisfactory level and marks the square as 'validated'
4. Progress of the mapping of the project can be monitored from within the "stats" tab of the project, and the project can be downgraded or archived as required by an administrator.

As described above, the process is quite simple and validated by administrative verifiers. The degree of reasonable accuracy depends on the existing data, which is increased as more crisis mappers contribute. The verifiers use a range of quality assurance tools to edit OSM data, which include bug reporting tools, error detection tools, visualization tools, monitoring tools, assistant tools, and tag statistics [41]. The error detection tools, for example, contains *Keep Right* which displays automatically detected potential errors such as a stream intersecting a roadway where technically a feature is needed like a bridge or culvert [42]. Another useful quality control measure is the

monitoring tool *User Activity* which generates reports that detect vandalism using statistics of map user activity [42]. Editing tools that the administrative verifiers use create OSM maps of higher quality than several commercial maps available [41].

The rapid response of volunteers provides a detailed map of road networks and buildings that supports the relief work of humanitarian organizations, expediting the provision of goods and services. Some maps show a visualization of deaths and injuries, as seen in Figure 3, which was “updated each time the Nepali Government publishes new data” [26]. One of the major benefits of mapping with OSM is its open data license, utilized by smartphones which can access the maps offline [43]. During critical days of the crisis, OSM map data was published in offline formats every hour for android phones to download thus leveraging volunteer efforts as much as possible [26]. The Nepali Government’s Health Emergency Operations Center was assisted by KLL team members who directly uploaded maps to the phones of relief workers.

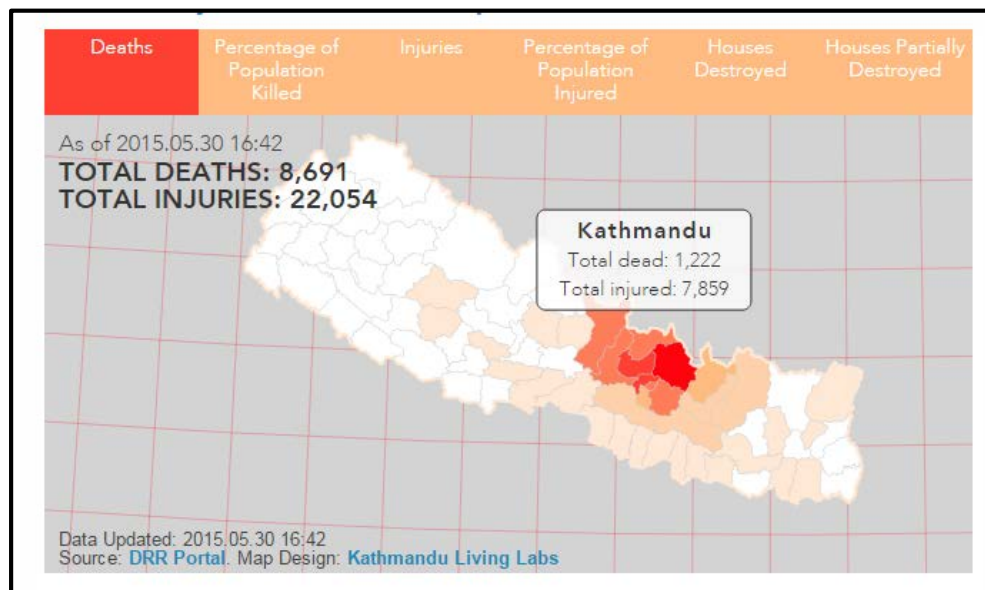


Figure 3: Deaths and injuries due to earthquake; Kathmandu region (Source: Kathmandu Living Labs [26]).

Offline mapping support was essential in the rescue and aid efforts. In remote areas of Nepal where relief workers had no access to the internet, current maps with updated details of the situation were essential. The DART applied the maps to “draw upon millions of points of continually updated crowdsourced data as well as satellite imagery and existing topographical maps” [44]. For this, they relied on OSM geospatial data generated by active, remote crisis mappers obtained through HOT members stationed at KLL. Data quality is increased as more people join in the mapping effort to improve the ability of aid workers to operate effectively. The collaboration of “old school tactics” in combination with “new technology” [44] ensures the advancement and stability of humanitarian aid.

As of April 30th, only days after the first earthquake struck, over 3,500 OSM volunteers were actively mapping Nepal [26]; classifying road networks and conditions, evaluating damaged buildings and identifying open spaces where displaced refugees were converging. Damage assessment was determined by comparing pre-imagery and post-imagery of buildings [36]. Quite simply, if a building appeared in the pre-imagery and not in the post-imagery, it was classified as damaged. Within the first 48 hours, 3 million edits had been made by over 2,000 crisis mappers [37]. During the following five weeks of the response, 1.4 million buildings were traced, with volunteers contributing 500-600 edits which added up to 75 buildings per hour (Figure 4) [45].

Contributors mapped over 13,199 miles of new road [46]. Figures 5a and 5b show the mappers road contributions before and after the earthquake, respectively. Figure 5b clearly displays a larger network of roads than in Figure 5a that had been added by crisis mappers. There are also more polygons (buildings, spaces, etc.) mapped in Figure 5b which had been classified more finely than in Figure 5a. A fine classification gradient is

important to relief workers because it allows them to identify areas of use, like helicopter landing spaces or refugee camps, as previously mentioned. According to Radford [35], the HOT response averaged almost 1 million map edits by 1000 volunteers per day in the first 10 days of the crisis.



Figure 4: Building edits made for Kathmandu. Green polygons were added after the earthquake (Source: Kathmandu Living Labs [26]).

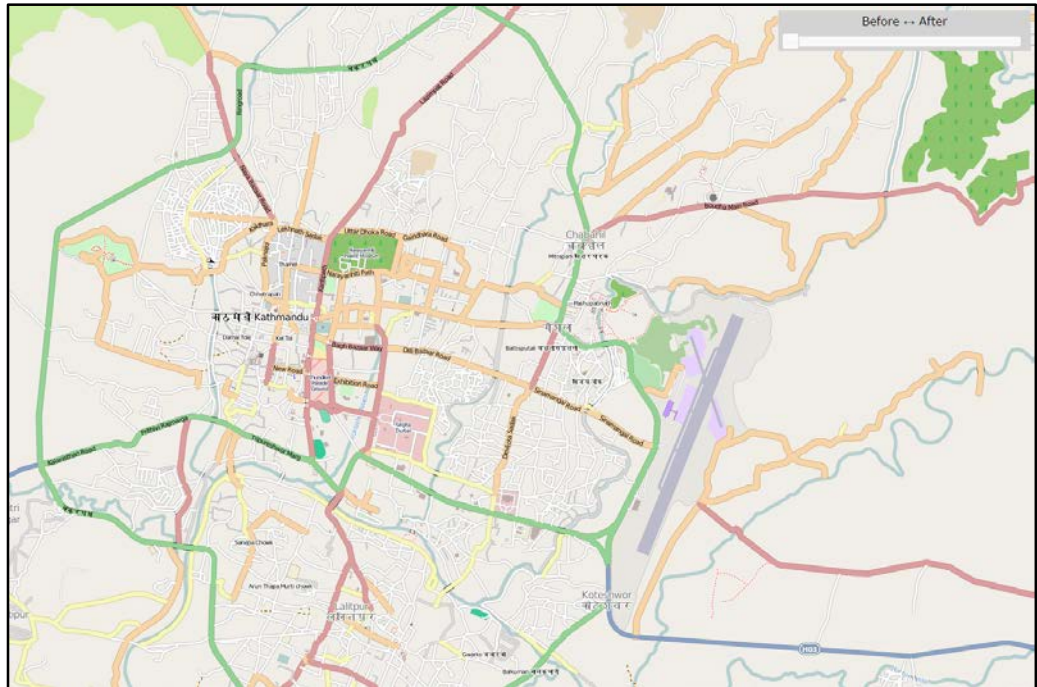


Figure 5a: Roads of Kathmandu mapped before the event (Source: Wood, 2015 [43]).

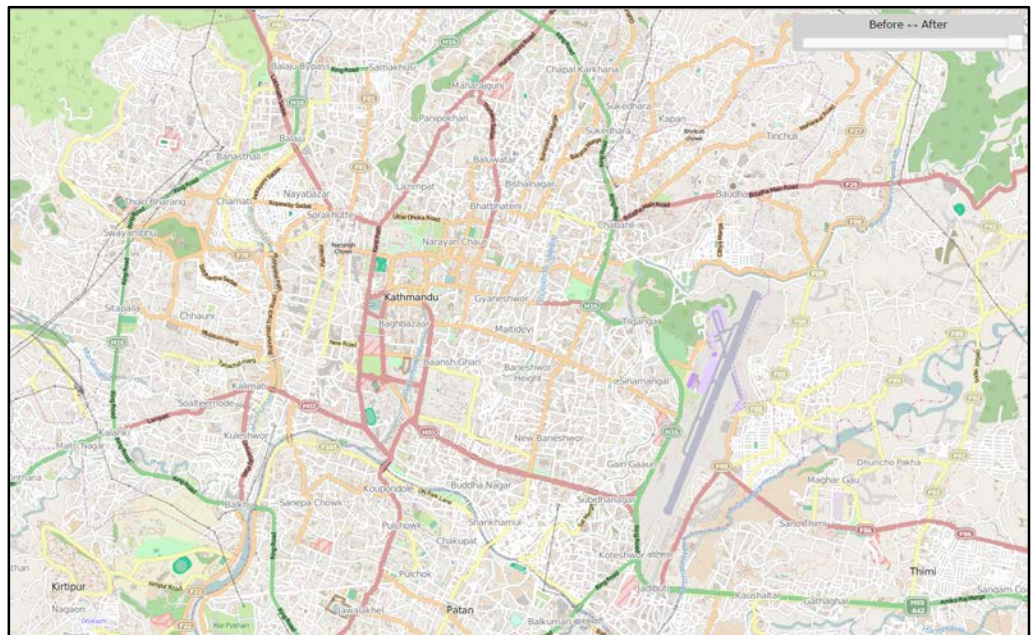


Figure 5b: Roads of Kathmandu mapped after the event (Source: Wood, 2015 [43]).

Post-quake Lessons from Haiti and Nepal

The capacity of the Humanitarian OpenStreetMap Team was truly challenged during the Haiti earthquake of 2010, the event in which many of the difficulties of crisis mapping were amended for effective response to the Nepal earthquakes. Unlike Kathmandu, which had been in the process of being mapped in preparation for an event, half of the capital city of Haiti was missing from the map altogether when the 7.0 magnitude quake struck in 2010 [47]. Lessons from the Haiti response were applied to the mapping process in Nepal five years later, which included gaining access to satellite imagery and beginning the mapping process prior to a disaster event, thus saving valuable time, as well as using a finer classification gradient. The crisis in Haiti resulted in greater availability and access to geocoded data [48], information which HOT understood to be valuable in future disaster events and from this lesson began work in Nepal where major earthquakes are certain to strike. In 2010, the National Society for Earthquake Technology estimated that “a large-scale earthquake in mid-Nepal would displace more than 1.8 million people, kill in excess of 100,000, and injure a further 300,000” [49], predicting more devastating earthquake events, than that experienced in 2015, to come.

It is evident that OSM techniques used in Nepal utilized a much finer classification gradient than that of the Haiti map when Figures 5b and 6 are compared, respectively. This is evident in that Figure 5b has more colors and patterns representing various classes of roads, buildings or spaces, where Figure 6 has fewer, indicating that simply recording the features was of greater importance. The aggregation of detailed crowdsourced data is leveraged to provide the maximum benefit to aid workers so that rescue efforts could focus on response rather than researching and cataloging data [48]. This lesson was clearly applied to the Nepal response in 2015.

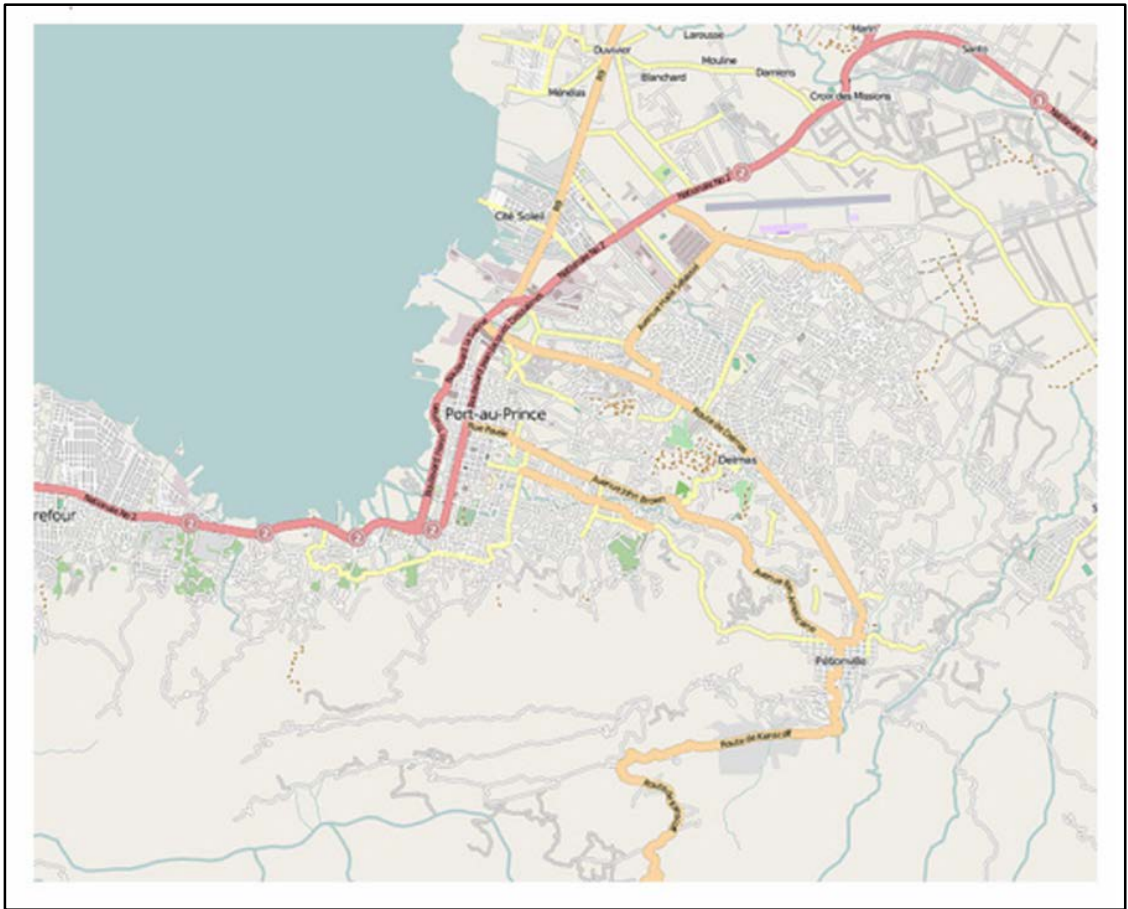


Figure 6: Road and building edits made by OSM contributors for Port-au-Prince, capital city of Haiti (Zook et al., 2010 [48]).

A finer classification, as mentioned previously, improves the effectiveness of aid responders to achieve their goals which is ultimately to save lives. This is done so by increasing and improving their access to information about the locality of the disaster's impact [50]. Including factors such as population demographics, roads and routes for emergency access and evacuation, damaged infrastructure as well as landmarks and street names for navigation and context [50]. The online community was also responsible for classifying buildings into hospitals and schools for possible locations of relief agencies along with open fields like sports stadiums for the convergence of refugees. If the polygons were simply mapped and unclassified, responders would waste valuable time

trying to find the information elsewhere. Furthermore, the “common operational picture” [50] created by the OSM volunteers, enabled relief workers to minimize searching the same areas twice. This was a lesson learned from the Haiti earthquake which had a more haphazard approach to the use of volunteer built maps. Centralized information increases the response time of the agencies which translates into more lives saved.

Another key message from Haiti was that disaster relief efforts should not be restricted to the city alone, rather it should include rural areas [49]. Relief workers addressed this by providing assistance to inhabitants surrounding Kathmandu, thus rural refugees did not have to travel into the city for aid. This was clearly demonstrated in the mapping of vulnerable rural areas prior to the earthquake by KLL and HOT, which were vital in providing information for the relief workers as to where efforts should be directed.

The humanitarian response in Haiti highlighted the importance of using citizen science crisis mapping in a disaster setting and paved the way for HOT’s presence in Nepal. Several months after the Haiti earthquake, the UNOCHA actively sought collaborations with volunteer networks and new technologies [47], such as OSM. The use of digital technologies to engage in two way communication with affected communities is a fast evolving sector in the humanitarian response [51]. “Humanitarianism in the Network Age” presented by UNOCHA in 2012 posits that aid agencies need to access collaboratively produced data from a holistic range of partners; information is intrinsically a life-saving need for people in crisis [51]. The success of the response of relief agencies to the 2015 earthquakes can be partially attributed to the involvement of OSM/HOT volunteers and the lessons applied from Haiti. However, much was still

learned from the Nepal crisis, including the need for even more geographic data for future disasters.

Drawing on the lessons learned, HOT collaborated with KLL to create a “roster” of trained, dedicated volunteers to take on various roles during future activations [26]. The partner organizations were inspired by the global army of volunteers to educate an ‘elite’ class of mappers to assist in future earthquake relief responses. Workshops in Dar es Salaam and Jakarta encouraged crisis mappers that had been involved in the 2015 earthquake “activation” to train with HOT mentors [26]. The increased education of crisis mappers may contribute to more accurate information in the field at the time of a disaster thus improving the response of aid workers.

There are several areas of mapping applications that need to be addressed. This includes needs assessment mapping, post disaster needs, casualties and damage, and early recovery and reconstruction [52]. The use of publicly available information in initial assessment and mapping in order to create an “integrated disaster geodatabase” requires data acquisition, availability and harmonization issues, data availability and access, national actors and international actors [52]. OpenStreetMap is one of the essential elements in the process of creating an integrated disaster geodatabase that can be used by relief agencies, along with census data, topographical data, and satellite imagery [52].

Additionally, in seeing the value of OSM in response to the earthquake, KLL is building on their on-going mapping work utilizing the program. They are collecting exposure data for individual buildings in the Kathmandu Valley which will be shared in OSM and enable the disaster response community to more accurately assess building damage [26]. As of 2015, wards 4 and 5 of Kathmandu had already been assessed for building exposure and typology [26]. Kathmandu Living Labs [26] asserts that this

exposure data will enable disaster preparation agencies to effectively mitigate building structures thus reducing the number of casualties and potentially saving many lives. In the case of Kathmandu, a dense urban center, critical infrastructure and services play a major role and mapping them in their proximity to operational centers is crucial in a disaster situation [49].

In post-quake Nepal, start-up tech-companies are taking the example of OSM/HOT and leveraging the crowd sourcing dynamic for solutions based coordination in an effort to grow the economy [53] for disaster resilience. The evidential power of voluntarily contributed geographic information in response to disaster is shifting communities towards similar innovation-based entrepreneurial responses to gaps and issues in civic planning [53]. Such responses to gaps in urban planning, for example, would include enhancing access for emergency vehicles by building wider streets as well as legislating more open spaces left for evacuation [49].

After the earthquake in 2015, NGOs and ‘civil society’ began utilizing OSM and other crowdsourcing solutions for the coordination of future disaster assistance strategies. Enhancing preparedness for disasters must involve a holistic approach from government and community combined to develop risk awareness, and coordinate the capacity for humanitarian response [49]. This involves the adoption of new partnerships and technologies in order to prepare for a range of possible disaster events [47, 49, 53]. Kathmandu Living Labs and HOT contribute crowdsourced geographic information and collect vital information through OSM. This information, mainstreamed and systematically gathered [51], contributes to a well-informed humanitarian community and helps build a disaster resilient Nepal with the goal of saving lives and livelihoods.

The Future Role of Citizen Science and HOT

The integration of new mobile applications and citizen science shows promise for advancing risk mitigation and disaster response. The engagement of broad audiences in humanitarian responses owes much to emerging technologies that revolve around open data. If appropriately utilized, scientists may be capable of integrating “continental-scale citizen science datasets with professional datasets” that can be verified by local observation [54]. As people become more aware of the impact of their contribution, they will respond accordingly and increase their involvement.

The Red Cross Society and other major humanitarian aid organizations have the capacity to encourage citizen engagement when volunteers’ efforts are rewarded with results. Most people have never heard of HOT or OSM, therefore it is the responsibility of the users of the resulting maps to communicate in detail how their efforts were made successful by armchair mappers. Such efforts will encourage more people to become global citizens through the participation of citizen science that is used, in the case of HOT, for humanitarian efforts.

Traditionally, online maps were used for simple navigation by the average driver, for example. However, advances in open-source data, mapping technology, and camera equipped drones have increased disaster response capacity. Online mapping now has an important emerging role in “coordinating emergency responses at ground zero” of a disaster [39]. The HOT response to the 2015 Nepalese earthquake is an excellent case in which the principle of crowdsourced data was successfully applied to real-world disaster response and preparation efforts.

The maps produced by OSM volunteers are a wealth of evolving information that cannot otherwise be produced. Using OSM, citizen scientists build continuously updated

maps that can be used online or downloaded into navigation devices. Humanitarian OpenStreetMap Team leverages an advantage through social media and networks to provide relief agencies with necessary real-time data.

The Red Cross has teamed up with HOT and OSM on an ambitious project to map the entire globe in anticipation of future disasters [37, 55]. Preparedness accelerates crisis mapping at the time of a disaster and thus improves the reaction response of relief agencies. The role of citizen science in future risk mitigation will not be an acute post-disaster reaction, but a broad component of a comprehensive pre-disaster action plan.

Chapter 3: Community Engagement Using OSM

Summary

Flooding in the Elk River Valley is a natural hazard for which vulnerable communities must prepare. The study area is first identified, along with flood hydrology and history, and the partnership between the Elk River Alliance and University of Lethbridge is identified as well. A flood hazard map was created through the use of ArcGIS, OSM, and community participation. The results are discussed as well as challenges in creating the map and its limitations.

Elk River Study Area

Study Area Extent

The City of Fernie lies in the Elk River Valley watershed, part of the Rocky Mountain expanse of the East Kootenay Basin located in British Columbia (B.C.), Canada (Figure 7a). The East Kootenay Basin is part of the Elk Valley Eco-section of the Northern Continental Divide Ecoregion and contains bio-zones home to several species of tree [56] including Engelmann Spruce (66.1%), Montane Spruce (21.1%), Interior Douglas Fir (9.3%), Interior Mountain Heather Alpine (3.2%) and Interior Cedar Hemlock (0.3%) [57]. There are over 6000 km of rivers and streams, with lakes making up 448 hectares and wetlands spreading over 768 hectares of the basin. One of four watersheds in the East Kootenay Basin is the north-south orientated Elk River watershed with a drainage area of 3110 km² [58] (Figure 7b). The Elk River bisects the watershed forming a valley ranging from 1 kilometer to 6 kilometers wide [59].

The Elk River, as it runs through Fernie, is a single sinuous channel formed from braided channels upstream and is laterally “quite active”, making for variations in local

flood profiles as the channel naturally shifts over the valley floor [56, 58]. The river bed material is predominantly coarse gravel [58] and prone to bank erosion in the areas where the active channel is confined by railroads and roads, placing this infrastructure in further danger of flooding as well as erosion [56].



Figure 7a: Provincial boundaries of British Columbia, Canada, emphasising the City of Fernie in the south east (Source: Columbia Basin Rural Development Institute [60]).

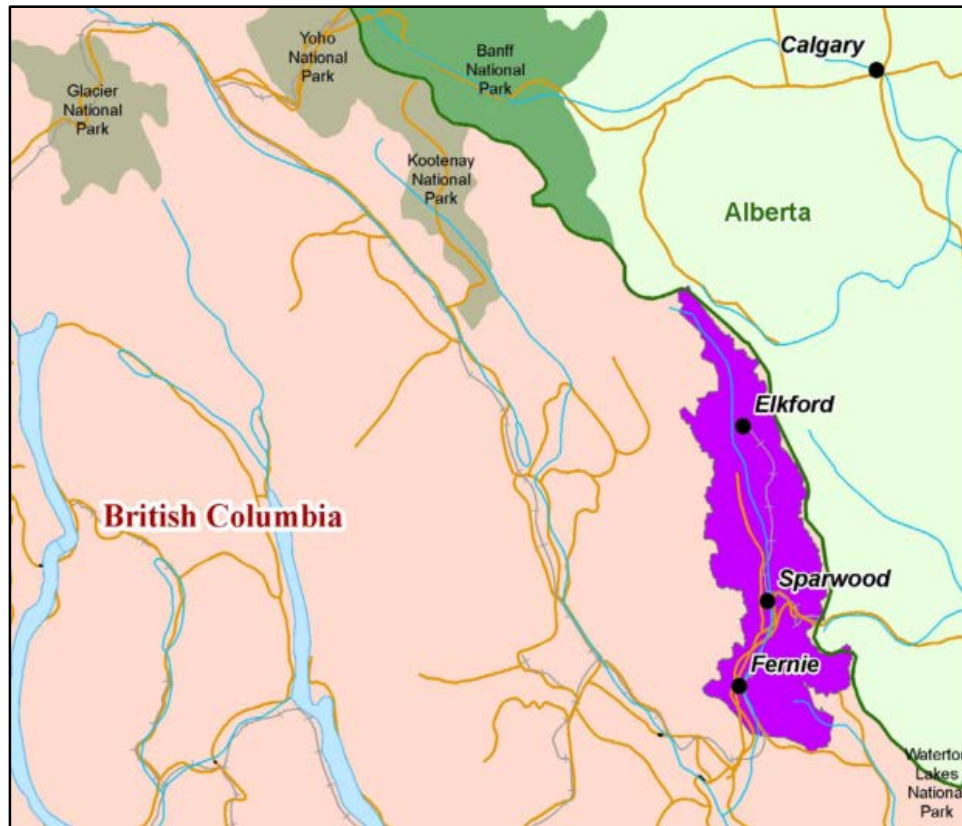


Figure 7b: Elk River watershed shown in purple, encompassing Elkford, Sparwood, and Fernie (Source: B.C. Oil and Gas Commission [57]).

The Elk River watershed is characterized by a humid continental climate with predominantly Pacific frontal storms [59]. Precipitation in the region occurs from orographic lifting of maritime air masses that are moist and stable, producing long lasting but low intensity storms [59]. Synoptic scale storms formed by cold low pressure systems yield heavy rainfall in late spring and early summer [59]. The hydrology regime is determined by snowmelt resulting in annual maximum flows in late May and into June [58, 61]. The amount and type of precipitation that watershed receives affects the volume and timing of discharge from the river [61].

Streamflow in the Elk Valley is defined by a discharge peak in the late spring which coincides with peak snowmelt [72]. Large rain events have a great impact streamflow, with average monthly rainfall exceeding 100 mm in June at Fernie, peaking

with snowmelt [72]. Precipitation data for May and June display a statistically definite increase from 1970-2014 ($p=0.039$, 0.006) for Fernie [72].

Fernie, located on the banks of the Elk River, was established in 1904 and is prone to extreme flooding events in several sections of the city [58]. Historical analysis performed by Northwest Hydraulic Consultants in 2006 revealed that the active channel and channel zone widths of the Elk River have considerably narrowed since the 1970s [58]. Dykes, and other bank protective measures have encroached into the former channel zone, which may result in an elevated flood profile when the river experiences high channel flow again [58].

City of Fernie Population Characteristics

Population Demographics

This section will simple outline the population demographics of Fernie, while the following section will explain why they are important to natural hazards planning. Fernie hosts a population of 4,528 according to 2014 B.C. Stats, with a median age of 39.9 for both males and females which is slightly lower than the provincial average at 41.9 years of age [60]. The Canada Revenue Agency stated average personal income for 2012 to be \$49, 700 CAD annually, greater than the provincial average of \$42, 453 CAD [60].

Fernie has 115 occupations in recreation and associated roles, 110 occupations relating to natural resources, and 70 occupations in utilities [60]. This accounts for 9% of the total occupations in Fernie. According to Statistics Canada (2011), a high school diploma is the highest level of educational attainment for a majority of the population, with 1090 people, however trades and college diplomas combined account for 1,145 [60].

Health Indicators from Stats Canada (2013) report that the percentage of the population living in the East Kootenay that have a somewhat or very strong “sense of community belonging” was 69.2% [60]. There are many recreational activities available to residents and tourists of Fernie. These include but are not limited to skiing or snowboarding, golfing, sight-seeing, tours, exhibitions, workshops, historic sites and shops, snowmobiling, snow shoeing, cross-country skiing, skating, curling, eco-tours, hiking, fishing, horseback riding, swimming, rafting, kayaking, canoeing, mountain biking and zip lining [60]. In fact, municipal expenses are largest in recreation, with parks, recreation, and culture requiring \$2,761,877 CAD annually, according to Local Government Stats (2013) [60].

Role of Socio-Economics in Hazard Adaptation

This thesis utilized the adoption of online mapping software, considered an “innovative form of information and communication technology” [62]. A range of socio-economic variables affect apprehensions and confidences of internet use including age, education, income, and occupation, but not gender [62]. A study in 2007 found that there was a positive correlation to internet use with income, educational attainment and employment status, while there was a negative correlation with age [62]. Not all the socio-economic variables were effective in distinguishing users from non-users, the study concluded that the adoption of online technology is ultimately dependent on the “nature and utilities” of individual technologies [62]. Support tools, such as online hazard maps, must recognize that decisions are made not only within environmental contexts but economic and social contexts as well [15].

The use of an online interactive map can be used as a mitigation and adaptation tool, in response to increased flooding risk due to climate change and other factors. Whether or not a population is willing to adapt may be influenced by social-psychological variables like age, education, and income, as well as psychographics such as environmental attitudes, concern, values and motivations, and knowledge [63]. The behavioral engagement of a population needs to be greater and broader in addressing the impacts of climate change, and personal engagement is dependent on the aforementioned socio-demographics [63]. The community in Fernie has a perfect population for using online methods as an engagement tool as its mean age is under the provincial average, and younger persons may be more inclined towards online activity. It is well educated, with a large number of individuals holding diplomas and degrees thus enabling them to learn new methods quickly. The average household income suggests the population is ‘well-off’ and not considered low-income, and research suggests these populations are better equipped to mitigate floods in the form of flood warnings, protection works, and flood proofing [64]. Finally, as a community that draws a large portion of income from recreation, it is surmised that it has strong environmental values which may motivate individuals to take an active role in city hazard planning.

Influence of Major Industries

With a vast expanse of forested land there is much forestry activity, mining, and some scattered farming on the east side of the valley [56, 58]. In light of challenges facing both the forestry and mining industries, the Kootenay Region is shifting much of its economic focus on recreation and amenities by building on strengths such as parks [65]. Increasing demand for recreation has led to the increase of development in the valley,

mostly on the floodplains which are susceptible to erosion and flooding [58]. Impervious surfaces, such as parking lots and sidewalks, that come with urban development typically increases storm water discharge as well as erosion in a watershed [66]. The decrease in infiltration significantly increases peak flow in times of heavy precipitation [66]. This requires the increased focus on flood protection for these developments.

Hydrologic processes impacting the amount of precipitation available for runoff in the watershed are interception, evaporation, transpiration, and changes in water storage (Figure 8) [61]. Both transpiration and evaporation are affected directly by forest cover as well as patterns of snow accumulation and melt, therefore any change in forest structure influences runoff in the watershed [61]. Increased forestry and mining in the Elk River watershed has led to the removal of forest cover and road construction This causes reduced soil moisture capacity that results in more runoff to the river and thus impacting flood regimes [61].

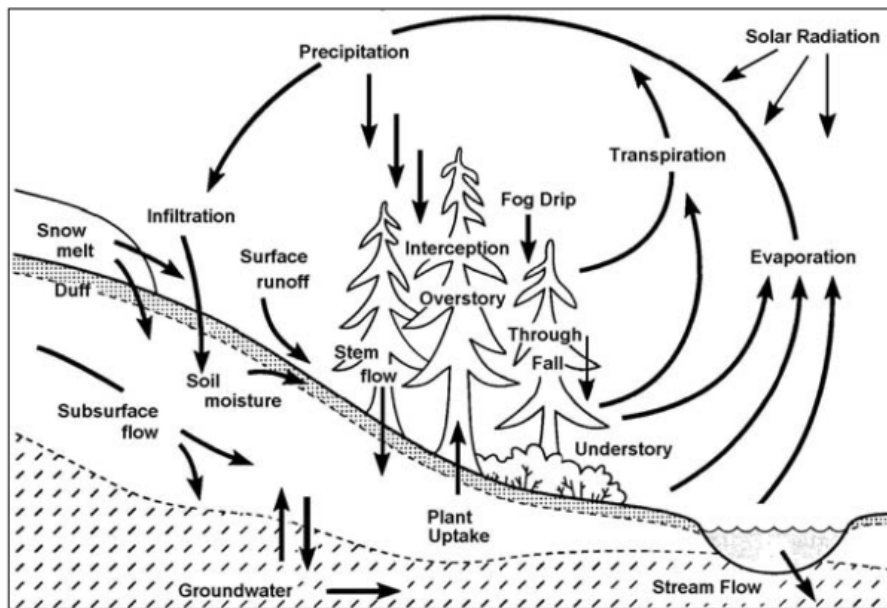


Figure 8: Forest hydrologic cycle (Source: Scherer et al. [61])

Communities along the Elk River thrive on these industries, as the population characteristics mentioned previously suggest. Therefore, despite the negative impacts that forestry and mining may have on the watershed, there are economic benefits. These economic benefits increase the capacity for vulnerable populations to respond to flooding. Additionally, most companies have established programs within the community that encourage conservation and environmental stewardship.

Flooding in the Elk River Valley

Climate Change

The effects of climate change are increasingly noticeable at global and regional scales. The most convincing evidence of climate change is derived from observations of the atmosphere, land, oceans and cryosphere, according to the IPCC 2007 [67]. Whether climate change is the product of anthropogenic [63] or natural forces, it has led to changes in both the frequency of occurrence and severity of extreme weather and climate events [1]. Extreme precipitation events, in particular, have been attributed with greater than 90% confidence to anthropogenic forcing [68]. In North America, it is expected that the “annual maximum 1 day precipitation” event that occurred approximately every 20 years in the early 1950s, has developed into a 15 year event in the early 2000s [68] due to human influence.

There are several indicators that the climate is changing. Figure 9 demonstrates that there has been an increase in meteorological, hydrological, and climatological events while geological events have remained relatively stable. The most commonly cited indicator is the rise of average global temperatures, variable over both short term and decadal scales, and influencing precipitation on a regional scale [58]. Ice core records

show that the atmospheric concentrations of greenhouse gases CO₂, CH₄, and N₂O have substantially increased over the past 200 years [67], with CO₂ driving long term global climate change [58]. With rising temperatures as a result of these gas emissions, the world’s glaciers are melting and contributing to sea level rise and coastal flooding. This is due to changes in atmospheric circulation patterns generating prolonged weather changes resulting from stagnation of the polar front jet stream ensuing protracted snow storms, heavy rains, and other severe weather events [1]. The frequency, intensity, and magnitude of flooding, particularly in British Columbia, is projected to increase in drainage basins that are dominated by “short-period runoff events” [69] such as the Elk River Watershed.

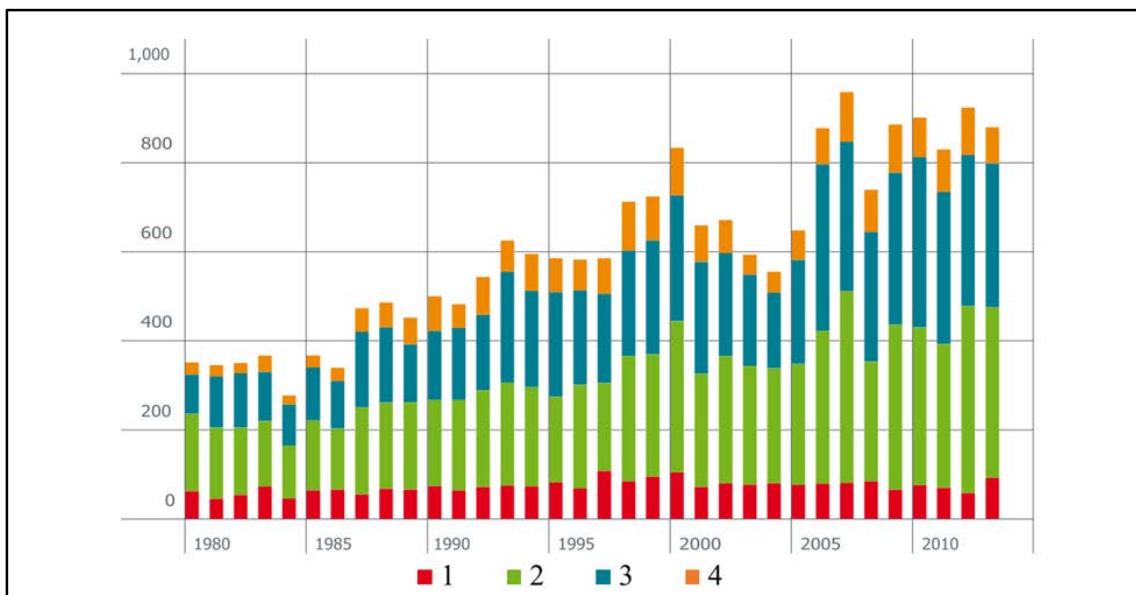


Figure 9: Annual number of natural disasters globally from 1980 to 2013. 1: red represents geological events; 2: green meteorological events; 3: blue hydrological events; and 4: orange climatological events (Source: Munich Re [1]).

In the case of flooding, periods of “above-average” floods are expected due to climate change and as part of quasi-periodic and multi-decadal oscillations [4, 58, 70]. Precipitation, temperature, stream flows and other flood-impacting conditions in B.C. are affected by the Pacific Decadal Oscillations (PDO) and El Niño Southern Oscillations

(ENSO) [58]. Rivers that drain the Rocky Mountains are greatly impacted by these oscillations as well as regional precipitation patterns, according to long-term discharge records [70].

Church et al. (2012), summarizes the climate change impacts in B.C. relating to hydrology and hydrogeomorphic processes that are expected over the next several decades [69]:

- Average temperatures are predicted to rise by 2.8C.
- Average annual precipitation is predicted to increase 6 – 17%, primarily during the winter in the mountainous regions.
- Surface runoff is predicted to increase during the winter, with the expectation of an earlier spring freshet and drier conditions prevailing during the summer.
- Rain-dominated floods are predicted for smaller watersheds with the chance of higher peak flows resulting from the increased intensity of storm precipitation.
- Snowpack at higher elevations may increase in depth due to wetter conditions of warmer winters.
- Glaciers will reduce in mass, mostly by frontal retreat in Southern B.C.
- Increased incidence of pest infestations resulting from species distribution shifts.
- Increased likelihood of forest fires resulting from rising temperatures, more frequent lightning strikes, and droughts in the summer.

Climate change may affect natural resources that generate tourism which may result in a decrease in recreational attractiveness, thus leading to decreased tourist activity [4]. This is particularly true in the Elk River Valley where tourism accounts for a large portion of revenue for its inhabitants. These impacts may come in the form of a decrease in tourist numbers due to environmental degradation [4].

Flood Hydrology

Regional scale floods are not only influenced by meteorological conditions, such as the amount, intensity, and distribution of precipitation, but through a combination of several physical processes including soil saturation, snow cover, infiltration, and river routing [71]. While the amount of runoff is primarily determined by precipitation and

infiltration, the speed at which it travels is determined by slope, length of flow path, depth of flow, and surface roughness [66]. Considering physical processes, floods in a spatial-temporal context can be thought of in terms of “flood event description, classification into flood types, and linkage of flood occurrence to atmospheric circulation patterns” [71]. Descriptions of floods are generally qualitative or quantitative and limited to extreme flooding events, while flood type classification concerns diverse magnitudes of flooding events [71]. The linkage of flood occurrence to atmospheric circulation patterns characterize the “modes of variability” by observing individual weather situations [71]. For the purpose of this study, flood event descriptions as well as atmospheric circulation patterns support the use of hydrology and hydraulic models to predict the occurrence of a 1:200 year flood in the Elk River Valley. Furthermore, the B.C. government has standardized its flood hazard legislation to reflect 1:200 year floods [69]. This means that B.C. has based its standard flood response and preparation practices on floods of 1:200 year probabilities.

Discussing floods in a spatial-temporal context most accurately frames the nature of floods occurring in the Elk River Valley. The spatial flood extent refers to the distribution of the flood over geographic space. A flood of small extent may be caused by a convective storm, while a flood of large extent may result from a frontal system [71]. Flooding of the Elk River occurs at both ends of the scale. Seasonality also affects floods [71], with the Elk River experiencing its 3 largest floods on record in the month of June [72].

Flooding can be greatly impacted by snow cover, air temperature, precipitation and weather patterns, length of “build-up period”, and soil moisture [71, 73]. Flood type is linked to soil moisture and weather patterns but predominantly defined by season,

snowpack, and atmospheric conditions during the build-up period [71]. Precipitation in the form of snow is stored in the winter and the resulting snowpack at the time of a rain-on-snow event in the spring may contribute to the severity of a flood [58]. Air temperature affects the type of precipitation that occurs, and is utilized in estimating the incidence of snowfall or rainfall [71]. Climate change has the most measurable impact on temperature and thus the type of precipitation that can be expected (i.e. warmer temperatures may lead to the prevalence of rain rather than snow). The amount and spatial distribution of precipitation is a parameter of the hydrology/hydraulic models [72]. The length of the build-up period, or time in between events, in the watershed indicates runoff processes in the river's tributary sources; the longer the build-up period the larger the flood [71].

Fernie receives 1,227 mm in average annual precipitation, consisting of both snow and rain [72]. The daily mean annual temperature is 5.3°C, with an average high of 11°C and average low of -1°C [72]. The numerical meteorological and hydrometric data, such as runoff, collected for the creation of the hydraulic model is not available to the public yet, as it is part of a collaborative partner's PhD dissertation. For the purpose of this thesis, streamflow data is sufficient in providing proof of future flooding events. The streamflow data, collected from the Water Survey of Canada, and meteorological data was combined with watershed features (soil, vegetation, geology, etc.) to create Hydrologic Response Units [72]. These were used to model GENESYS (discussed below) hydrological processes, to be used in the hydraulic model created by engineers.

The above stated flooding variables are both interdependent and interactive. Peak discharges rely on the relationship between the parameters on the drainage area of the watershed as well as the location of flood control methods or industrial development [66].

For example, changes to the climate or landuse may influence soil moisture, and changes to the atmospheric conditions may alter weather patterns [71]. This is why it is important that flood management strategies be aware and inclusive of climate change as well as changes to landuse by local industry [69].

Two climate change scenarios were used by the hydraulic engineers to simulate future streamflow from 2011 to 2041; RCP 4.5 and RCP 8.5 [72]. The climate change scenarios represent greenhouse gas concentration pathways based on when greenhouse gas emissions will stabilize [72]. RCP 4.5 assumes radiative forcings will stabilize at 4.5 Watts per square meter while RCP 8.5 assumes radiative forcings will stabilize at 8.5 Watts per square meter, each by the year 2100 [72]. Both scenarios predict air temperature and precipitation will increase, hence the importance of their involvement in the modelling.

Flood Hazard Mapping

The variables affecting flooding are often uncertain, from hydrological models to river discharge and corresponding flood scenario predictions [73]. Meteorological rainfall predictions, for example, are often inconsistent thus rendering a hydraulic model instantly obsolete the moment it's created [69]. There is, however, a strong correlation between climate variables and river discharge, implying that precipitation records are dependable in flood forecasting where flow records are limited or unavailable [70]. Such is the case with missing stream flow gauge data among some of the tributaries of the Elk River.

The use of models in flood forecasting adopts a level of acceptable error that is continually reduced as more accurate data are acquired closer to the season of flooding. The most reliable flood forecast modeler allows sufficient time for such appropriate

actions and must exercise caution when interpreting results [73]. Conditions are always changing, incorporating new information strengthens the model and thus the corresponding action plan [74]. These changes include not only climatic or meteorological changes but also developments on the flood plain, channel planform (shape of the river), and channel geomorphic processes [69].

A flood hazard is defined as “the potential for loss of life or injury and potential damage to property resulting from flooding” [69]. The purpose of a flood hazard map is to display potential future flooding events to be used in determining how to address mitigation and adaptation strategies such as flood proofing and community awareness. Flood risk refers to the combination of the likelihood of flooding occurring and the possible consequences to humans, the environment, and economics [69]. In the province of B.C., and all of Canada in fact, there is no standardized flood risk map [69]. This thesis utilizes a flood hazard map rather than a flood risk map because the map produced does not combine the consequences of the flood with the flood hazard. The consequences may be inferred from the hazard map however. Consequences include damage to buildings, utilities, infrastructure, and agricultural assets, from which economic losses are also incurred due to loss of jobs, business, as well as repair and reconstruction costs [69]. There are also social and environmental impacts from the loss of recreational space or wild habitat.

Simply mapping a hazard results in a basic delineation of the likely exposure or vulnerability of a population [3]. Many different stakeholders can utilize flood hazard maps in order to prevent developing future risks, reduce existing risks, and adapt the changing risks [69]. They can also be used for raising community awareness [69] which is the primary function of the flood hazard map created for the ERA. It should be noted

that a 1:200 year flood does not mean the return period for a flood is 200 years, this may instill a false sense of security. In the case of the Elk River, a 1:200 year flood has been found to occur roughly every 20 years in accordance with the 3 most recent major flooding events. This is evidence for climate change, change in landuse, or both. The use of a 1:200 year flood map is considered a “medium” probability according to the European example [69], which leaves room for the more probable small floods (1:50 – 1:100 year).

The hydrologic conditions for a 1:200 year flood on the Elk River were assessed through the use of a hydrological and hydraulic model. The hydrological model utilized was the Generate Earth Systems Science Input (GENESYS) modelling tool which simulated the hydrologic processes of the Elk River watershed [72]. The hydraulic model was a one-dimensional, steady state model called “HEC-RAS” from the U.S. Army Corps of Engineers, and was developed using LiDar survey data in 50 meter cross sections along the river, perpendicularly [72]. The model parameters accounted for channel roughness and slope, as well as bridge crossings and road elevations [72].

For disaster risk reduction to be effective, information needs to be properly communicated to those at risk so they can be prepared. Better models of spatial hazard information can deliver science based knowledge, in this case in the form of a flood hazard map, for social engagement, policy development and implementation [1, 75]. The facilitation of preparedness involves making practical information and resources available as well as developing the social capacity to interpret the information [1]. The use of the online interactive map, through the website as well as workshops, is a community engagement strategy which increases the resiliency of the population at risk. Through a grass-roots approach to enhancing people’s ability to express their sense of involvement

by reframing the message in a meaningful way, community engagement is empowering [1].

Justification of Study Area

There is debate over the cost of climate change, although the literature is inundated with evidence that most outcomes have a negative impact for human beings as well as other biota. Evidence of human vulnerability to climate change in water, land, and food systems is demonstrated through the “interaction of non-climatic forces” and “climatic forces” [5]. Examples of non-climatic forces include “overcrowding, urbanization, changing land use, and shifting cultural norms”, while climatic forces refer to drought, flood, change in sea levels, extreme weather events, and changing ocean chemistry [5]. Studies undertaken in South Eastern B.C. have examined impacts of long-term climate change on water resources including flooding, water use, supply and the management of water resources [3]. Between 1975 and 2001, floods were the most common natural disaster and, although they kill fewer people than earthquakes, they affect a larger number of people [64].

Throughout a long term observation of data from 1914 – 2005, it is surmised that flood regimes are variable. The available flood record for the Elk River displays flood magnitudes were less than the long term average from 1914 – 1945 [58]. The following 30 years of records (1946 – 1976), however, presented floods that were above average in magnitude [58]. From 1977 – 2005, despite the occurrence of a major flood in 1995, the floods were once again below the long term average [58]. The fluctuating trend in peak flows aligns with coinciding ENSO patterns with which there was a higher occurrence of El Niño years that displayed flood magnitudes less than the long term average [58]. As

the impacts of climate change become more evident in the flooding regime, the long term pattern may shift towards floods of greater magnitude and frequency [2].

As the literature suggests, the Elk River Valley is and will be subject to flooding which requires the involvement of all occupants in the affected communities. Climatic changes, industrial impacts, and man-made changes in the Elk River watershed may alter the hydrology and thus flood profiles as a consequence [56]. Furthermore, floodplain inhabitants may be at risk for floods of higher magnitude due to man-made changes to the river which instill an overestimation of flood protection [64]. Managers and officials responsible for the City of Fernie consulted “professional associations” as well as the “scientific community” for suggestions concerning future strategies in light of flood risk [1]. The resulting submissions are as follows [1]:

1. Potential increases in mean air temperatures, rainfall precipitation and rain-on-snow events could increase the magnitude and alter the timing of flood peaks on the Elk River. The current 200-year flood flow may be influenced by more frequent and larger flood events.
2. Structural flood protection or flood hazard mitigations (e.g. diking and bank protection) should incorporate potential related changes beyond those forecast by climate and hydrological modelling alone. For example, future flood hazard assessments should also include the potential for increased debris floods, sediment and geomorphic change.
3. Non-structural flood protection (i.e. land-use regulation, zoning, etc.) should be considered in conjunction with existing structural protection (i.e. dykes) as part of a flexible, risk adverse strategy for flood hazard risks.

In light of the first submission, referring to 1:200 year floods becoming larger and more frequent, the flood hazard map produced for the ERA displays the extent of a 1:200 year flood resulting from the hydraulic model [72]. There are no updated provincial government issued flood hazard maps for the region as the BC Floodplain Development Control Program was discontinued in 2003 [69] presumably due to lack of funding.

The Elk River Alliance Partnership

The Elk River Alliance is a grassroots community group that aims to “connect people to the Elk River” and ensure the river remains clean and productive for the benefit of all watershed inhabitants [76]. Following the 2013 flood, a meeting of government, industry and community representatives determined to collaborate on a holistic plan for the watershed to address flood preparedness and mitigation [77]. The ERA conducted a survey of watershed inhabitants in the summer of 2015 and found that 52% of participants were concerned about flooding while 61% feel safe when it floods [76]. Safety was clearly not of great priority and the survey revealed that most participants were concerned about infrastructure damage and environmental impacts. Figure 10a displays the results of the survey question “What about flooding is a concern for you?”, showing personal safety to be of lowest concern. The results in Figures 10b and 10c, respectively, show that participants were most interested in access to a flood hazard map, emergency response plan, and flood solution options available via a website. Web sites have become standard practice for communicating public information to stakeholders [78].

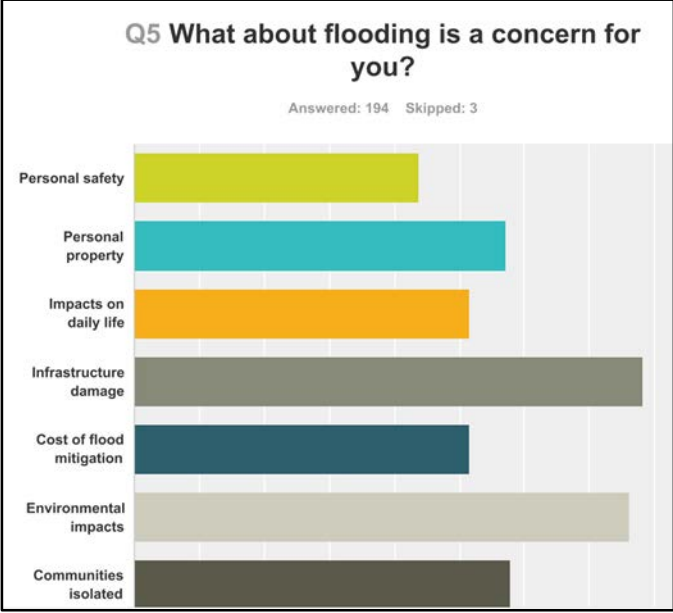


Figure 10a: Results from the question "What about flooding concerns you?" as put forward to Elk River watershed inhabitants by the ERA [76].

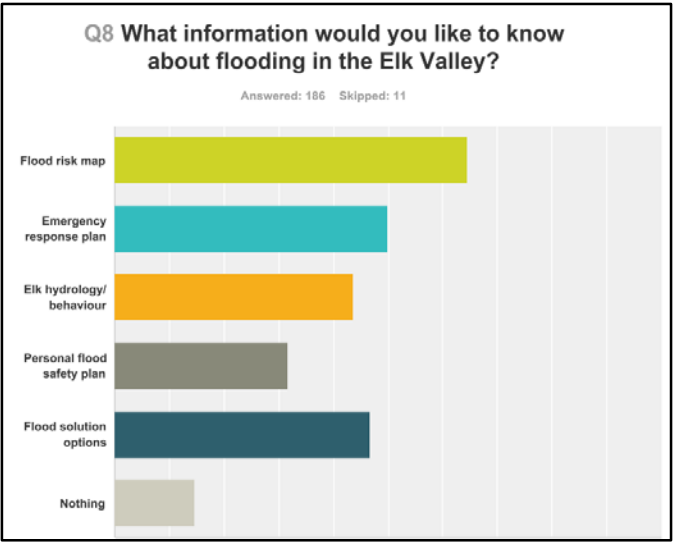


Figure 10b: Results from the question "What information would you like to know about flooding in the Elk Valley?" as put forward to Elk River watershed inhabitants by the ERA [76].

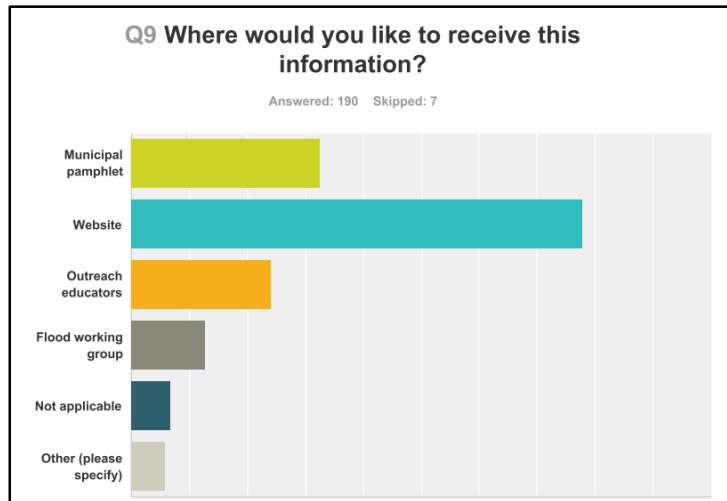


Figure 10c: Results from the question "Where would you like to receive this information?" as put forward to Elk River watershed inhabitants by the ERA [76].

In response to the concerns expressed in the survey, the University of Lethbridge partnered with the ERA to collaborate on a flood hazard map as part of their project entitled "Elk River Flood Solution Strategy". The goals of the strategy are as follows [77]:

1. Achieve a better understanding of Elk River hydrology.
2. Model future scenarios of flood frequency/severity and the effects on communities.
3. Conduct a cost/benefit analysis of flood preparedness and mitigation options in order to identify alternatives that protect urban infrastructure and human safety/property, as well as protect and enhance both natural watershed function and wildlife habitat.
4. Promote a watershed approach to flood mitigation to encourage the integration of government policies, industrial practices and community efforts.
5. Support decision makers to implement the best flood mitigation practices throughout the Elk River watershed.
6. Increase community watershed literacy of the past, current and future impacts of flooding.

The Elk River segment of this thesis aims to address a few key aspects of the aforementioned project goals. The model of the flood scenarios was that which was utilized in creating the interactive flood hazard map. The creation of the map itself involved engaging community members so as to increase watershed literacy of the future

impacts of flooding. The resulting flood hazard map may be used to support community, government, and industrial decision makers. Figure 11 depicts a flow chart demonstrating the author's role in the Flood Solution Strategy. The model produced files that displayed the flood extent of a 1:200 year flood in the Elk River Valley from Fernie to Hosmer (Figure 15) and were used by the author to create an interactive flood hazard map. The map was posted on the ERA website and is both utilized and contributed to by community members and planners.

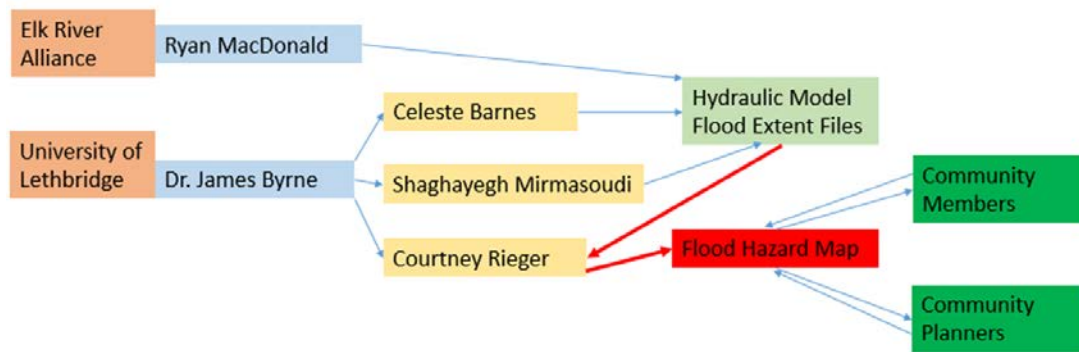


Figure 11: Flowchart emphasising the author's role in the Flood Solution Strategy.

Methodology

Community Workshops

Two consecutive workshops were held through the ERA for the purpose of populating the OSM basemap with City of Fernie features. The first of the workshops was with a group of youth and the second was with a small group of adults. Before March 31 2016, OSM reported that only 4 users had contributed to the city of Fernie basemap. After this date over 30 users had been reported to edit the basemap.

Youth Workshop

On March 31 2016, a group of 18 co-ed grade 8 students from the Fernie Academy participated in a workshop in partial fulfillment of a “Know Your Watershed Student Action Project” through partners with the ERA. After a brief introduction as to the purpose of the workshop, students were divided into three equal groups by their teacher and instructed to collect data with Garmin eTrex handheld GPS units. Group 1 mapped the east side of the Elk River between the West Fernie Bridge and the end of the dyke trail in James White Park. Group 2 mapped the west side of the Elk River between West Fernie Bridge and the end of the dyke trail in West Fernie. Group 3 mapped the main and secondary dykes in Annex Park between the West Fernie Bridge and the North Fernie Bridge. Each group had two GPS units marking the same tracks and waypoints for improved accuracy. Instructions were given to map the length of the dykes by creating tracks on the hand held GPS units as per sections A and B of Appendix 2: Instructions for Youth Workshop. Students were also instructed to mark waypoints along the dykes to indicate erosion, erosion control methods, and storm water outfall culverts. The

examination of flood mitigation structures are important in flood hazard mapping [69].

Instructions were given as per section C of Appendix 2.

After the field portion of the workshop, students returned to their classroom and were instructed to upload their GPS data in the form of .gpx files into laptops provided by the school. Instructions were given as per section D of Appendix 2. They then traced their tracks and way points using the tools available in OSM in accordance with Appendix 1: Instructions for editing in OpenStreetMap. The results of the youth workshop are shown in Figures 12a and 12b of the results section.

Community Mapathon

On March 31 2016, a group of 12 adults of varying age and gender participated in a group workshop, or 'mapathon', to contribute city features to the OSM basemap.

Participants were recruited from the ERA website on a volunteer basis and the workshop took place in the office of the ERA in Fernie. After a brief introduction as to the purpose of the workshop, participants were given instructions as per Appendix 1: Instructions for editing in OpenStreetMap. They used smart phones and laptops. The workshop was held over a two-hour period where participants were able to ask questions about the program and be corrected if errors were encountered. Refreshments and snacks were provided throughout the course of the workshop.

Creation of Interactive Community Engagement Tool

Using a raster data set derived from a model output provided by hydraulic engineers [72] partnered with the ERA, layers from a 1:200 year flood were extracted in ArcMap 10.2 and exported as KMZ files. The KMZ files were then used to extract KML files for import into UMap where the layers were made cartographically pleasing for the final map. The embedding code of the final map was provided to the ERA for display on their webpage. All figures are in Appendix 3.

Extraction of KML Files from Raster Data Set

The initial raster data set was added to a new map and contained values from 81.3243 to 5.14661 meters (Figure 15, left). Figure 15 (left) also contains the Map Algebra expression in *Raster Calculator* used to remove negative values from the data set. The result was values from 0 to 5.1488 meters (Figure 15, right). Negative values were removed because 0 meters represents the river bottom, the lowest elevation, and any negative values from the model output are considered anomalous.

The raster data set containing no negative values was then used to define 11 distinct sets of depths using the *Raster Calculator*. The set of depths (in meters) were 0 – 0.25, 0.25 – 0.5, 0.5 – 0.75, 0.75 – 1, 0 – 1, 1 – 3, 1 – 2, 2 – 3, 3 – 5, 3 – 4, and 4 – 5. The Map Algebra expressions for each depth are shown in Table 1, while Figure 16a and 16b displays the results of the calculation for all depths on the map separately.

Table 1: Map Algebra expressions deriving depth.

Depth (m)	Math Algebra Expression
0 – 0.25	Con(("fldextnoneg" > 0) & ("fldextnoneg" <= 0.25),"fldextnoneg")
0.25 – 0.5	Con(("fldextnoneg" > 0.25) & ("fldextnoneg" <= 0.5),"fldextnoneg")
0.5 – 0.75	Con(("fldextnoneg" > 0.5) & ("fldextnoneg" <= 0.75),"fldextnoneg")
0.75 – 1	Con(("fldextnoneg" > 0.75) & ("fldextnoneg" <= 1),"fldextnoneg")
0 – 1	Con(("fldextnoneg" > 0) & ("fldextnoneg" <= 1),"fldextnoneg")
1 – 3	Con(("fldextnoneg" > 1) & ("fldextnoneg" <= 3),"fldextnoneg")
1 – 2	Con(("fldextnoneg" > 1) & ("fldextnoneg" <= 2),"fldextnoneg")
2 – 3	Con(("fldextnoneg" > 2) & ("fldextnoneg" <= 3),"fldextnoneg")
3 – 5	Con(("fldextnoneg" > 3) & ("fldextnoneg" <= 5),"fldextnoneg")
3 – 4	Con(("fldextnoneg" > 3) & ("fldextnoneg" <= 4),"fldextnoneg")
4 – 5	Con(("fldextnoneg" > 4) & ("fldextnoneg" <= 5),"fldextnoneg")

Each depth was then converted from a 32 bit raster to a 16 bit raster. This was necessary to accomplish before moving on to creating polygons because the ArcMap 10.2 tool *Raster to Polygon* does not accept 32 bit raster data sets as the input raster. The *Copy Raster* tool converted each individual depth raster data set into a 32 bit raster data set with a “16 bit unsigned” pixel type, Figure 17 gives an example.

Once each of the 11 defined depths were converted into 16 bit raster data sets, they were converted into shapfiles using the *Raster to Polygon* tool, Figure 18 gives an example. Note that “Simplify Polygons” is checked for a smoother appearance of the

resulting polygon shapefiles. Figures 19a, 19b, and 19c display the depth layers as simplified polygons in ArcMap 10.2.

The resulting shapefiles were converted using the *Layer to KML* tool, Figure 20 gives an example of the tool converting a single layer. The file type resulting from this tool is KMZ which cannot directly be imported into UMap. The KMZ files were ‘unzipped’ in 7Zip in order to render them KML files. The program 7Zip is an open-source file archiver which can be used to manipulate and extract files.

Creation of Online Map

The online tool used to create the final map for the ERA was UMap, an open source software that uses OSM layers and allows for other layers to be imported and displayed together. A new map was generated on the umap.openstreetmap.fr website and the Fernie OSM basemap, as edited by community members from the workshops, was utilized. There are several different versions, or backgrounds, of the basemap available that display select features for various purposes. The layer chosen for Fernie was simply called “OpenStreetMap” which is the same basemap displayed in openstreetmap.com and shows all features.

In editing mode, 3 flood depth layers were imported to the map using the *Import Data* tool. These layers (in meters) were 0 – 1, 1 – 3, and 3 – 5. The remaining 8 layers were not imported into the final map due to software limitations using the free account, but they were provided to the ERA for use in a future, more detailed map. The software is limited to a certain number of polygons. When using a fine classification gradient, there can be over 3500 polygons per depth layer, which is too numerous. The free account was used for the final map because it demonstrates the capabilities of the software that are

available to users with low resources. The ERA has the option to upgrade their account and add the remaining 8 layers to the map as resources become available.

The KML files produced through ArcMap 10.2 and 7Zip were imported into new, individual layers which can be turned on or off by community members utilizing the map from the ERA webpage. The first depth layer shown in Figure 22a, was labelled “Waist deep (0 – 1 m)” and colored “Aqua” as per Figure 21. The second depth shown in Figure 22b, was labelled “Above waist to way above your head! (1 – 3 m)” and colored “Steel Blue” as per Figure 21. Finally, the third and deepest layer shown in Figure 22c, was labelled “Up to the Rafters (3 – 5 m)” and colored “Dark Blue” as per Figure 21. The layers’ nomenclature reflects the map’s user friendly approach. Figure 23 depicts the final map containing all 3 depth layers over the OSM basemap, thus displaying the full extent of the 1:200 year flood in this scenario.

When complete, the final map was provided to the ERA along with all associated raster data sets and shapefiles. The code for embedding the map was as follows:

```
<iframe width="100%" height="300px" frameBorder="0"
src="http://umap.openstreetmap.fr/en/map/1200yr-flood-
event_79627?scaleControl=false&miniMap=false&scrollWheelZoom=false&zoomContr
ol=true&allowEdit=false&moreControl=true&datalayersControl=true&onLoadPanel=un
defined&captionBar=false"></iframe><p><a
href="http://umap.openstreetmap.fr/en/map/1200yr-flood-event_79627">See full
screen</a></p>
```

Staff at the ERA may use the embedment code to display the interactive map on their webpage, using *NationBuilder* webpage development software, as a community

engagement tool. The use of OSM as a basemap for UMap provides an interface which is constantly updated and edited by the community. The ERA website should provide instructions as to how to contribute to the map, which can be accomplished through clicking on either of the two OpenStreetMap logos presented on the map. Instructions can be adapted from Appendix 1.

Results

The results from the youth workshop are shown below, in Figures 12a and 12b. Figure 12a shows the efforts of Group 3 with the main and secondary dykes in Annex Park displayed as white lines and labelled accordingly. Note how these dykes surround a wetland, this will be discussed further on. Figure 12b depicts the dykes as mapped by Groups 1 and 2, also white lines, on either side of the Elk River south of the West Fernie Bridge. The white, upside-down teardrop symbols mark areas of bank erosion, and storm water outfall culverts. Some labels are visible in these depictions, with remaining symbols having labels visible when the map is zoomed in to a smaller scale. The OSM basemap can be edited and updated by any user with an OSM user account; students were told they can continue to add to the basemap indefinitely.



Figure 12a: The result of Group 3's mapping including the main and secondary dykes in Annex Park (located in the center of this map, east of Elk River). The dykes are white lines with upside down tear drop shapes denoting storm water outfall culverts.

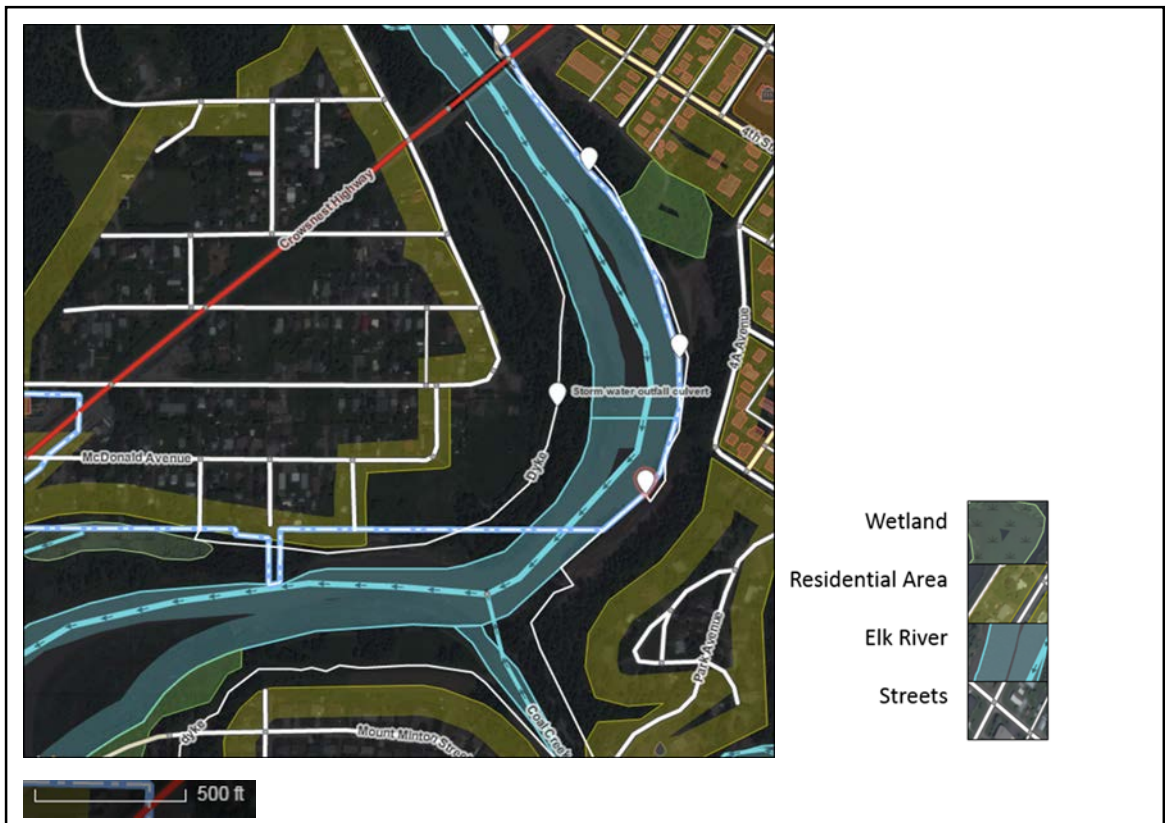


Figure 12b: The result of Groups 1 and 2’s mapping of dykes on either side of the Elk River south of the West Fernie Bridge. The dykes are white lines with upside down tear drop shapes denoting storm water outfall culverts. Note: view in in Edit Mode.

Figures 13a and 13b display the OSM basemaps of Fernie before and after the community mapathon, respectively. The polygons in Figure 13a are not finely classified, that is to say the polygons, or buildings, are not labelled as houses or commercial buildings. The large yellow polygons represent residential areas, there are clearly no houses represented by smaller polygons. There are very few buildings traced and of these they are not classified into building type. Figure 13b depicts many more polygons which are classified into building types. Classifications include house, commercial, hotel, etc. The houses and other buildings are smaller, red polygons, enclosed in the yellow residential polygons. The dykes, bank erosion, and storm water outfall culverts can also be seen in this view, which had been added by the youth hours before the community mapathon.



Figure 13a: Small area depicting OSM basemap before the community mapathon.

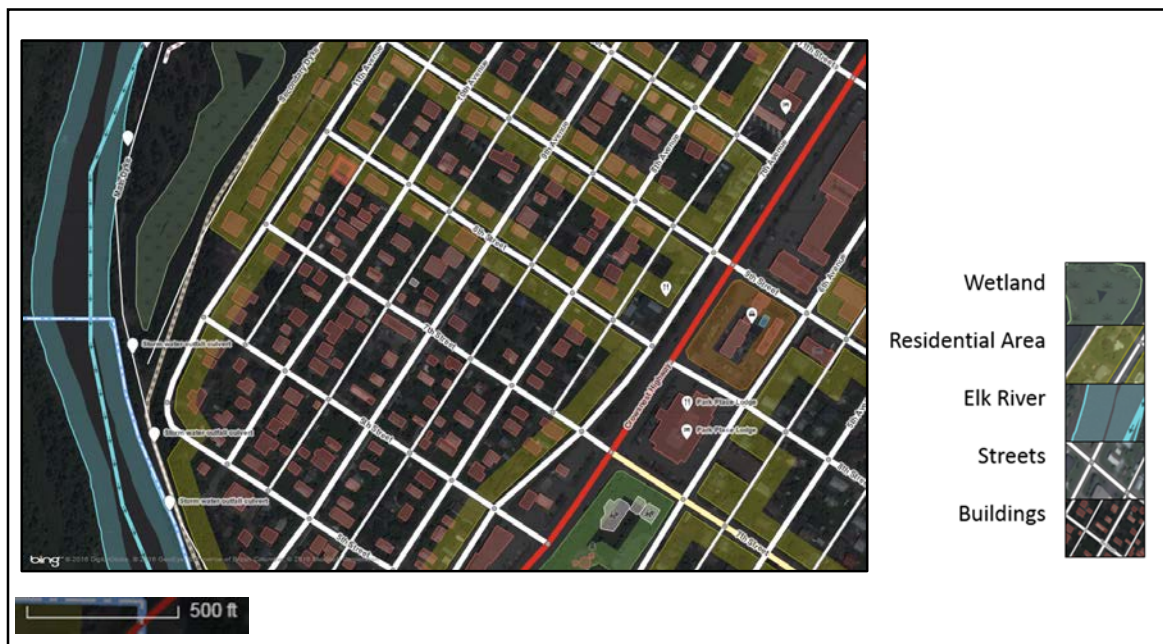


Figure 13b: Same small area as Figure 13a depicting OSM basemap after the community mapathon.

The entire OSM basemap of Fernie is shown in Figure 14, where hundreds of polygons were added by community members during the mapathon event. This is the

view that is displayed in UMap under the flood extent layers created for the Elk River Flood Solution Strategy to be used as an interactive community engagement tool. UMap is a front-end software for combining OSM with the flood extent files. The red box outlines the small section of the city enlarged in Figures 13a and 13b. This is the same map from Figures 12a and 12b, just with a different color scheme.

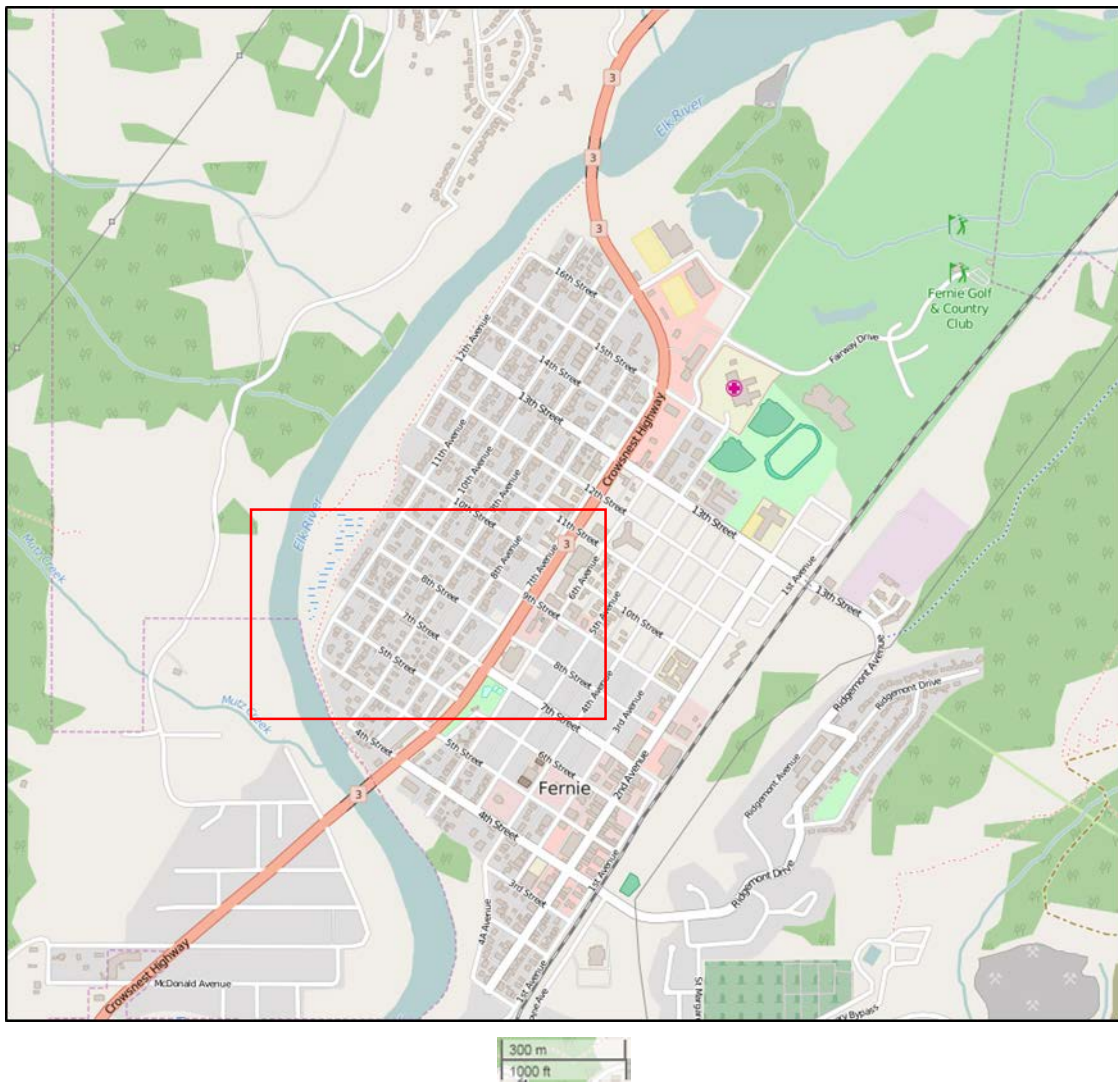


Figure 14: Entire extent of OSM basemap of Fernie after the community mapathon. Red box shows extent of Figures 13a and 13b.

The following figures (Figures 22a, 22b, 22c, and 23) are the results of the workshops and ArcGIS mapping outputs combined. The presence of the wetland is

clearly important in containing the flood waters between the main and secondary dyke. Under this flood scenario, the water is able to overflow the main dykes along the river, however where the wetland is located, the second dyke is able to prevent further flooding. This highlights the importance of healthy riparian and wetland areas in mitigating and adapting to flooding, which is discussed in the Discussion section. Of the portion of the city that is depicted as flooded, it appears that over fifty houses are impacted by flooding. Figure 23 displays the golf course's obvious flood risk, thankfully no people live there. As previously mentioned, however, recreation is of utmost concern to the people of Fernie so this may have an impact on their lifestyle.

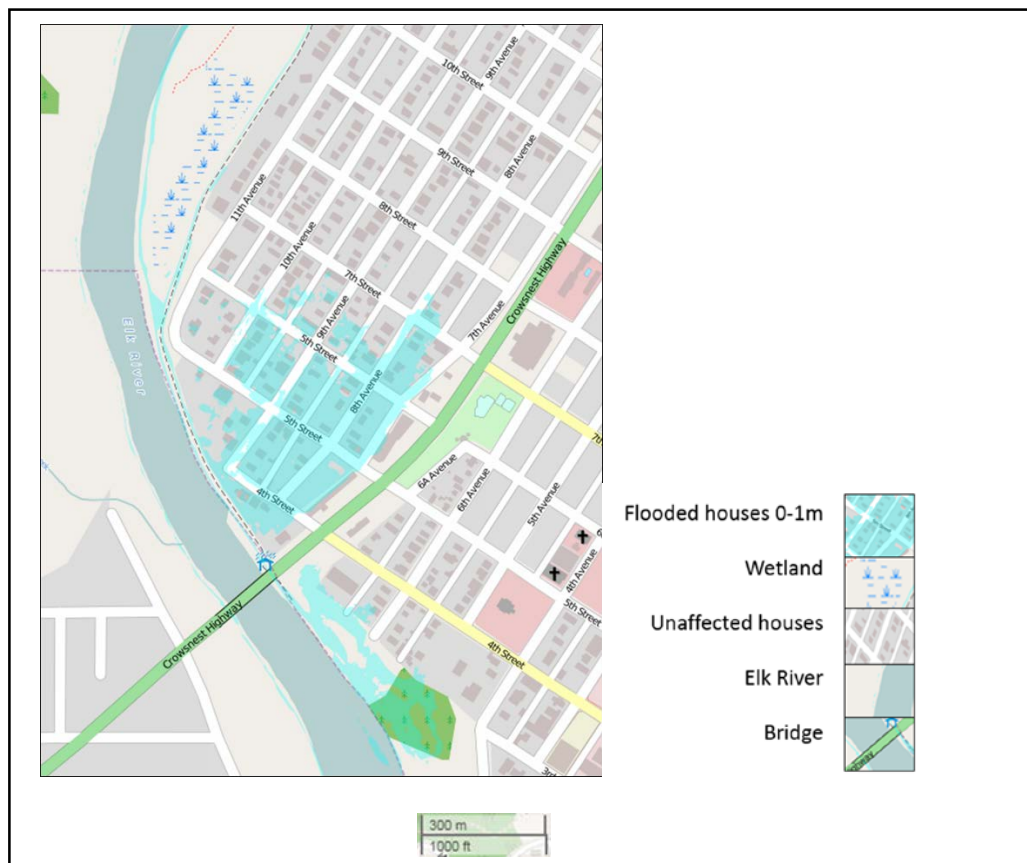


Figure 22a: Small area showing flooding in Fernie at a depth of 0 – 1 m.

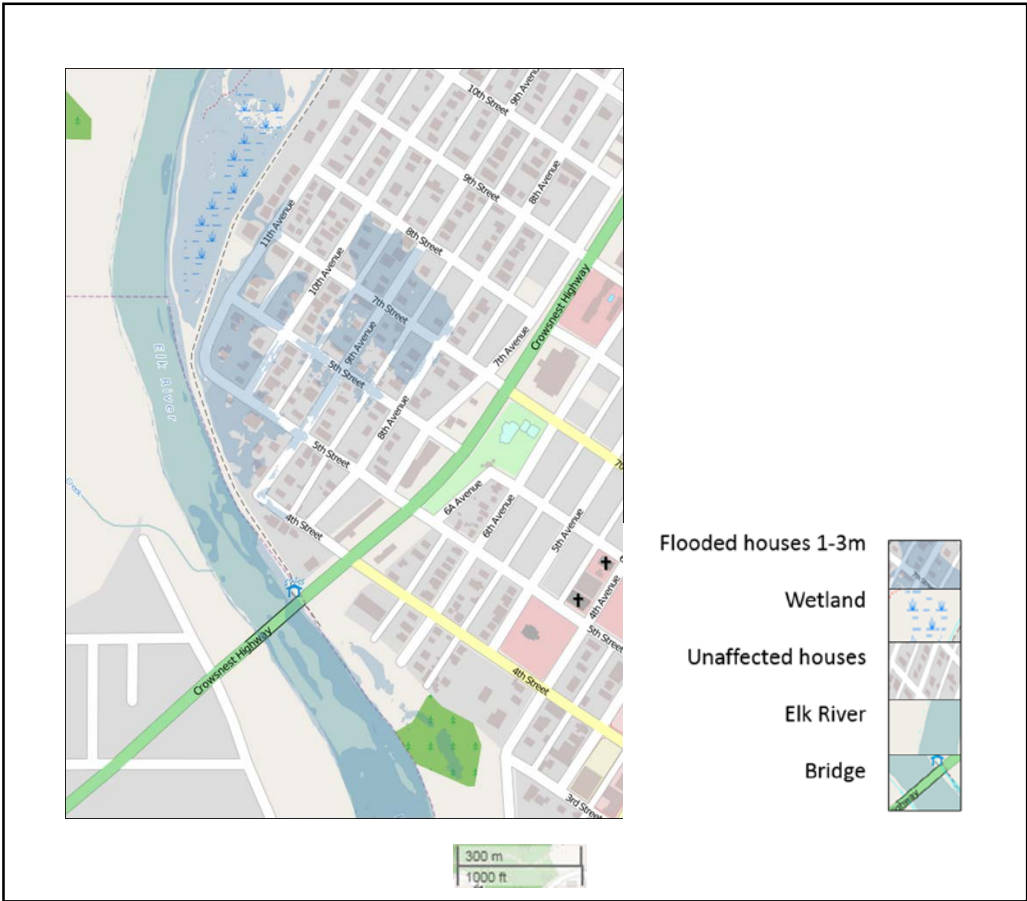


Figure 22b: Small area showing flooding in Fernie at a depth of 1 – 3 m.

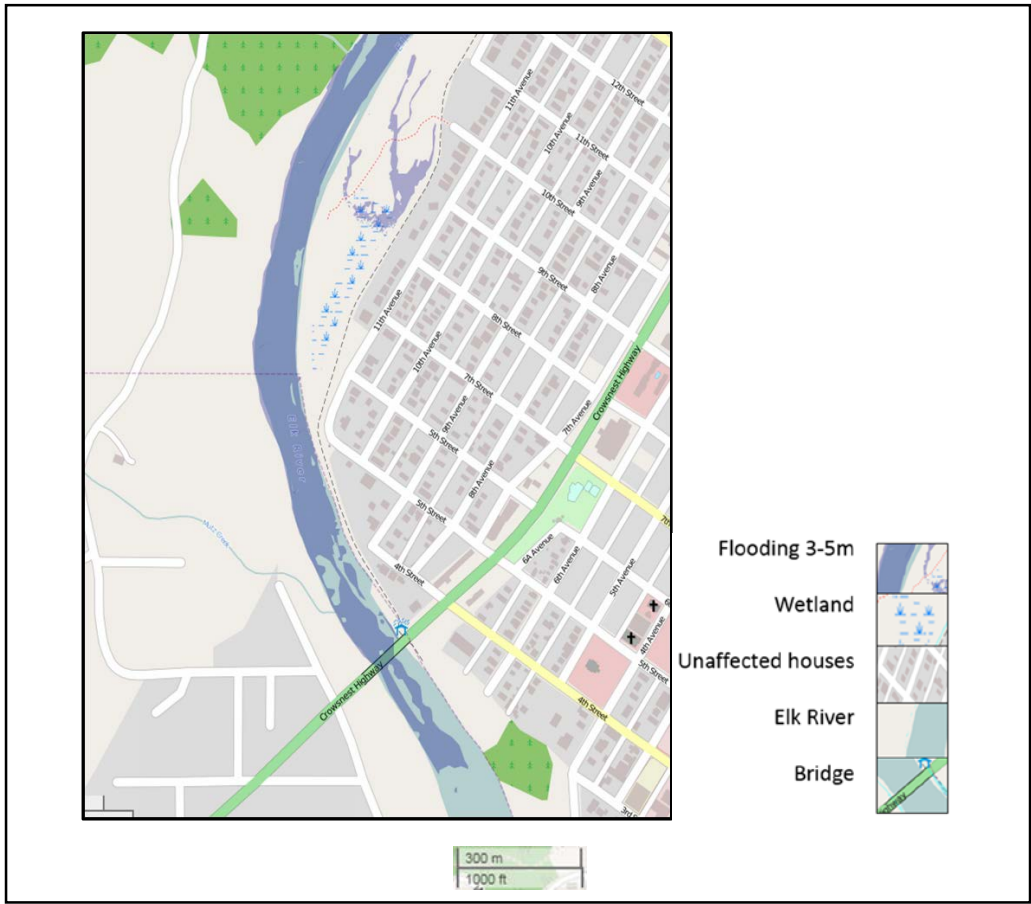


Figure 22c: Small area showing flooding in Fernie at a depth of 3 – 5 m.

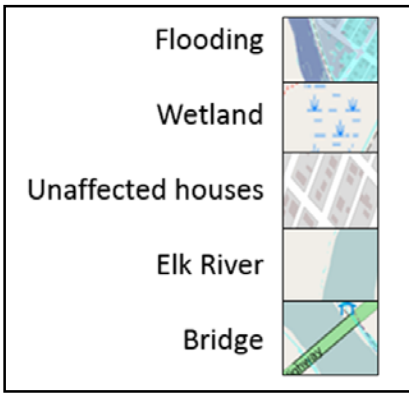
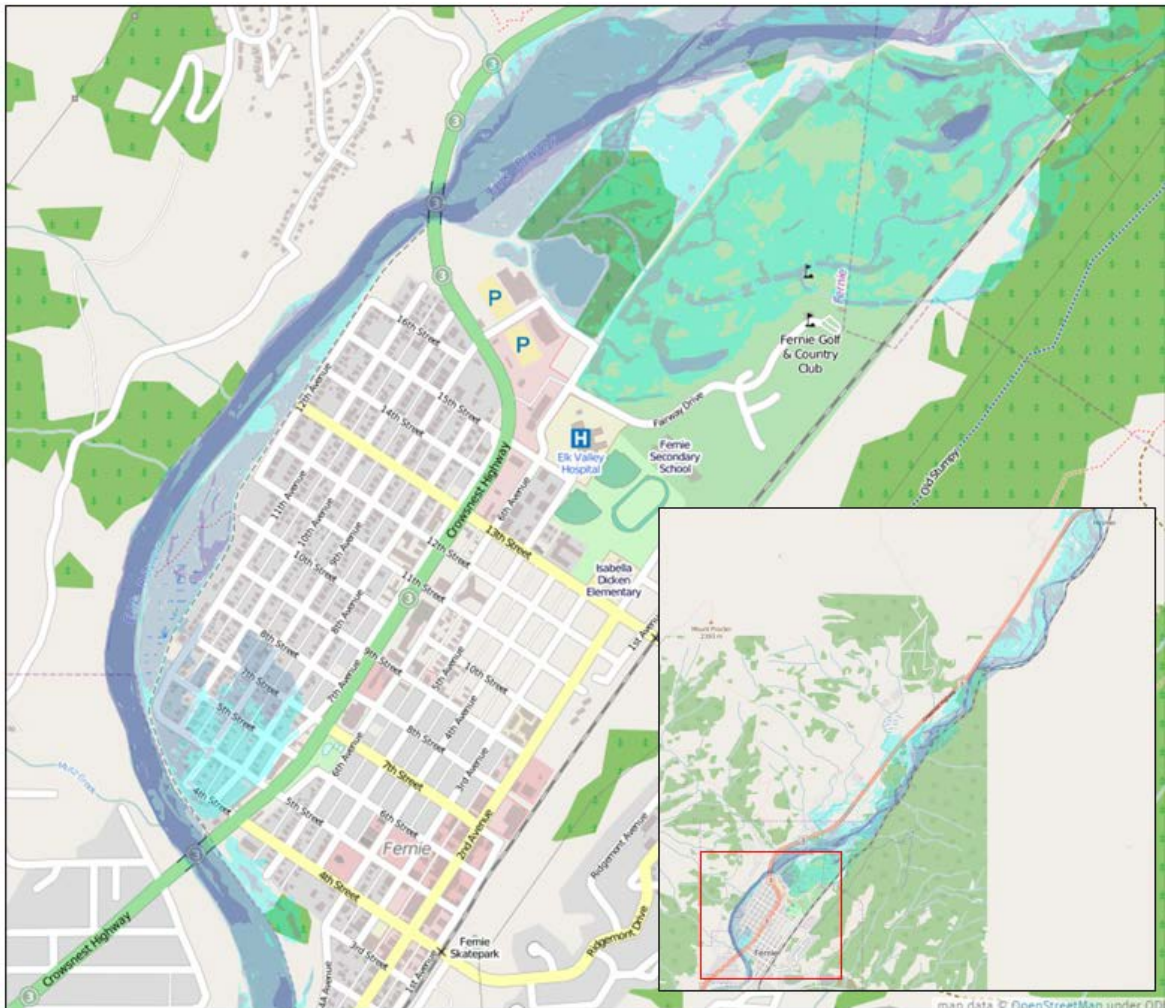


Figure 23: Flooding in Fernie showing all 3 depth layers in the final map using UMap.

Discussion

The Elk River that passes through the City of Fernie is prone to flooding, as history suggests, and due to the community's risk and exposure to this natural hazard, it is considered vulnerable by various standards. Populations that are vulnerable to hazards require measures of both mitigation and adaptation in order to become resilient to risk. While Fernie's population demographics suggest they may not seem vulnerable, they are certainly environmentally at risk and therefore inherently socially at risk as a result of their local economy's ties to the environment. The ERA commissioned a partnership with the University of Lethbridge through which they requested a hazard map that could be used as an interactive tool to educate the community on flooding.

The map was produced using scientific sources to provide flood information, as well as the participation of the local community as a resource for populating the city's features. It was not designed to replace detailed, professionally engineered site designs or hydraulic modeling maps, but to serve as a complement to this level of analysis for lay people to understand and make decisions accordingly. The map is a small part of a larger project and is not a comprehensive flood management plan; indeed it has several limitations. Flooding may occur outside of the areas shown on the map as there are several factors impacting flood water trajectory, i.e. log jams and/or ice jams. With the addition of new information, however, the map can be updated with current flood extents to reflect floodplain developments.

The involvement of the community in creating the map is what makes this approach unique. Although examples have been provided of the use of OSM basemaps in hazard maps and VGI in community planning projects, this thesis extends beyond these concepts. The resulting map is a product of intentional grassroots participation in building

the OSM basemap, as opposed to simply importing the OSM basemap that was incomplete for Fernie before the community workshops. This level of stakeholder engagement is much greater and more deliberate than, for example, holding meetings where locals can share their opinions that may or may not be counted towards a resulting community plan. This hazard mapping technique strengthens the facilitation of the Flood Solution Strategy by ensuring its credibility and acceptability through the involvement of locals in the creation of the map. When stakeholders are actively involved, studies have shown there is less discontent and thus they are more prone to implementing final decisions [78]. Furthermore, in having local community members populate the map with city features, they are able to validate their own remote mapping thus improving the quality of the map; and personal investment.

Enthusiastic and motivated participants contribute the most effectively [78]. During the community workshops, it was found that while all participants were motivated, community members were motivated by various reasons. The young participants of the youth workshop initially contributed because it was included in their school science class. The adult participants of the community workshop were volunteers who contributed for various reasons, including concern for the environment and entertainment. Curiously, the young participants who were told to participate were more enthusiastic to learn how to contribute to the map than the adult participants who had volunteered.

The purpose of the flood hazard map accompanied by community engagement was to enhance community resilience through identifying areas of vulnerability. With this information complementing collaborative action plans, coordination of adaptive and mitigative measures can be implemented on a multi-sectoral level. In highlighting

vulnerability and adaptation, citizen engagement is further enhanced [79]. Indeed, even the knowledge of possible consequences of flooding may facilitate resilience, with adaptation and mitigation undertakings of preparedness. The existence of a flood hazard map, such as the one provided to the ERA through the work done in this thesis, may facilitate preparedness through depicting where flooding may occur. Alcántara-Ayala et al. suggest that awareness fosters preparedness and can be regarded as “the essential and simplest non-structural measures to reduce exposure and vulnerability to hazards” [1]. Thus, given the perception of possible risk through the flood hazard map provided on the ERA website, the community’s behaviour may reflect preparedness even before adaptation and mitigation strategies become policy.

With flooding in particular, the vulnerable population along the Elk River may need to adapt to the impacts of climate change within their existing resources. An approach to floodplain adaptation has four cornerstones as outlined by the EPA [74]: 1) focus on the watershed; 2) integrate science into the decision-making process; 3) foster collaborative problem solving; 4) involve the public. The hazard map created for the ERA incorporated these cornerstones through the process of public engagement.

As part of the Flood Solution Strategy survey put forth to the community by the ERA, participants concluded that their most preferred method of flood mitigation was more riparian enhancement along the river, with municipal zoning coming in second [76]. This aligns with the results from this thesis, as it was clearly demonstrated that the wetland played a valuable role in holding back the flood waters from the secondary dyke. This is in line with adaptation strategies put forth by several organizations [74, 80]. In order to prepare for more severe and frequent floods as a result of climate change impacts, strategies involve restoring native plant species in riparian areas and controlling

invasive species [80]. Increasing riparian habitat connectivity and heterogeneity stores more water on the landscape which acts to maintain natural flow regimes and buffer against future flooding [80]. Part of restoring the natural function of the floodplain is to allow waterways to migrate and build roads and pathways in accordance with large buffer zones of riparian areas [80].

Along with the community's desire to enhance riparian areas, they also wanted municipal zoning laws to reflect flood risk. The resulting flood hazard map may also help policy makers to determine zoning laws, as the findings suggest that houses not be built alongside the river without the presence of dykes and wetlands. This involves the cooperation of districts across municipalities because the impacts of upstream adaptation strategies influence those downstream. For example, channelizing the river and diking upstream may increase flood velocity downstream. A portion of the youth workshop was to create waypoints on GPS units of culverts located on dykes, which is complementary to adaptation strategies that aim to maintain flood proofing structures.

Fernie has a very strong economic reliance on tourism, as portrayed previously through the use of the many forms of recreation in the valley, and through adaptation the community can actually enhance natural features as well as be protected from flooding. Public outreach both within the community and to visitors promotes the maintenance of healthy ecosystems and thus natural flood protection. Tourism may increase collaboration with volunteers and build a greater capacity for trail and park maintenance [80]. Furthermore, public engagement may lead to increased political support and funding to maintain access to the river.

Mitigation and adaptation strategies to natural hazards may be framed in different ways in order to influence public acceptance. They can be communicated as an economic

imperative, moral obligations, or even social acceptance and ideology with the vulnerable population making decisions based on socio-cultural experiences [81]. In the case of Fernie, it seems that the community acknowledges that it is intrinsically linked to the Elk River, with its major industries as well as their livelihoods impacted by flooding. The intention of the ERA's Flood Solution Strategy grassroots approach is to enhance the community's ability to make sense of their involvement and participate in a meaningful way. Studies have shown that efforts focused on enhancing people's capacity to become more involved, empower them to help themselves and recover faster [1]. This is accomplished through "mapping, understanding, and managing their own risks in various co-engaged processes including community based risk assessments"[1]. This work suggests that when coupled with the flood hazard map, the stakeholders in the Elk River watershed may enthusiastically accept adaptation measures based on the information they are provided with to make decisions for the community.

Challenges and Lessons

The greatest challenge in creating the flood hazard map was deciding which mapping software program to use with OSM as the basemap. The integration of GIS outputs into an online mapping software program took months of discovering the best course of action for this project. Initially, MapBox was chosen to host the OSM basemap with the flood extent features overlain, however it proved complicated for those not educated in computer programming. The idea of using OSM was to keep it simple for the ERA to utilize and update as more information came in when the collaborative project was complete. Thus, UMap was chosen due to its simplicity but it came with its own set of problems. For example, it is not possible for layers to be embedded under other layers,

therefore only one flooding event at a time could be displayed on the map with its associated extents. For this, MapBox would have been a better choice. For future work, it would be advisable for someone on the ERA to learn how to use MapBox in order to eliminate this particular limitation.

Another challenge was coordinating the efforts of all the collaborating partners. Unfortunately, the initial hydrological model that was to be used for the hydraulic model could not be completed in time for the project's end. For this reason, the developer of the hydraulic model that produced the GIS data for the flood hazard map, had to extend the amount of time it took to develop results. This extended the time it took to complete the flood hazard map, which had to be finished only days before the project's end. The solution to this problem is improved communication among collaborative partners.

Finally, the community workshops were at times challenging, particularly the adult mapathon. As previously mentioned, the adults had volunteered to map but their motivation seemed much less than that of their youthful counterparts. This may have stemmed from various valid reasons, however it seemed to inhibit their desire to learn a new skill. One readily identifiable solution is to have multiple mapathons with the same group of adults so that they can learn at a slower pace and not be constrained by time. Despite their struggle to achieve the OSM technique (Appendix 1), all adults reported that they had learned more about their city and its risk of flooding which was ultimately the goal of the workshop, alongside mapping. Furthermore, even though the adults did not participate in the workshop itself, they went home and proceeded to map the city. This was apparent in the addition of city features to the map from the same workshop participants, days after the event.

Chapter 4: Conclusions

The goal of this thesis was to demonstrate that OpenStreetMap, as a citizen science mapping software program, can communicate natural hazards as well as engage participants in disaster preparedness. This was accomplished through: the provision of a literature review, a detailed case study, and a functional application in a study area.

The literature review outlined the necessity for vulnerable populations to prepare for natural hazards and the benefits of facilitating citizen science in response. It also covered relevant works accomplished by others in the field. The review of the Nepal earthquakes in 2015 effectively established OSM's proficiency in immediate disaster response. While the case study was geared towards earthquakes and humanitarianism, it only strengthens the argument that OSM is diverse in its capacities in responding to natural hazards. The Elk River study produced a flood hazard map that can be used for both disaster preparedness (identifying vulnerable areas) and disaster response. In the event of a major flood, community members can instantly update their map to reflect any changes to city features, i.e. a damaged bridge or flooded road.

There is a potential for the flood hazard map produced for the ERA to evolve into a multi-hazard map, if time and resources were to permit. Just like with the flood extent layer files, any hazard extent manipulated into the appropriate format can be uploaded into the map. For example, damage extent from a forest fire can be mapped and thus potential campers will know where not to camp. Moreover, the extent could be mapped daily, showing where the fire is and where it may travel, warning vulnerable people in its path. This concept could apply to insect infestations, landslides, and other natural hazards.

If periodic risk assessments were to be carried out after this project, they could also utilize the OSM methodology introduced here. Assessments cover exposure and vulnerability to flooding, the capacities of predictive systems to distribute necessary information to policy makers, and methods for improved resiliency [1]. While the flood hazard map can be updated to reflect exposure and vulnerability, the website it is hosted on can be used to communicate information in a timely manner and host adaptive and mitigative methods for the improvement of community resilience. Furthermore, ongoing basemap updates by OSM users contributes to the enhancement of situational awareness during extreme events.

What is most clear in the findings of this thesis, and social policy as well, is the importance of a multi-inter-disciplinary approach, necessitating immediate and long term policies to sustain adaptations [79]. This is especially true for climate change adaptation in that it requires the efforts of almost all sectors. Multiple experts in various sciences, including engineering, were required to produce the information needed for the flooding extents used in the map.

The ERA, a grassroots environmental organization, had to partner with local and provincial government to collaborate on a multi-faceted strategy in approaching the hazard of flooding. This work integrates science into policy and planning through the involvement of municipal actors in the creation of the Flood Solution Strategy. Most importantly, the public was engaged using a proven citizen science method that not only connected them to the scientists and policy makers, but empowered them to make decisions in their community. Whether OpenStreetMap is used for communicating natural hazards in a humanitarian or community planning aspect, its capacity to engage citizens is clearly and demonstrably successful.

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Appendix 1: Instructions for editing in OpenStreetMap

Adapted from LearnOSM.org

Part 1: Sign Up for OpenStreetMap

1. Sign up for an account: <https://www.openstreetmap.org>
2. Click on link in the confirmation email and sign in to your account.
3. Read through the welcome page then hit “Start Mapping”.
4. Allow Google to use your location.
5. Get acquainted with the map but do not add any notes or edit any features just yet
 - a. On the right side of the screen there are several icons. Click on the layers icon and check the boxes that say Map Notes and Map Data.
 - b. In the Standard view, click on the Map Key icon to display a symbolic legend.

Part 2: Assign Yourself a Task

1. Go to <http://tasks.hotosm.org/> for a list of current projects. The task name is “Fernie Flood Hazard Basemap”
2. Log in to your OpenStreetMap account at the top right of the screen and click on “Grant Access”.
3. Once you select the task, you will be directed to a map showing a grid of Fernie.
4. Click on “Instructions” and read them carefully.
5. Once you’ve read all the way to the bottom click “Start Contributing”.
6. Click “Take a Task at Random”. You will be assigned an area to avoid much overlapping between participants. Alternatively you may click on any grid square you choose to work on.
7. Once you’ve unlocked the task, a grid square will appear in purple/blue. This is the area you will edit.
8. There are various editing tools that will allow you to contribute. We will be using OpenStreetMap iD editor. Click on the “Edit With” drop down box and select Edit with iD editor.
 - a. This will take you to a new window where your grid square will appear in pink over a satellite image of the area you are mapping. DO NOT close the OSM Tasking Manager page, you will need it for Part 3.

Part 3: Edit a Grid Square

Please wait for quick demonstration before proceeding.

1. Have the OSM Tasking Manager Instructions page open so you can refer to it while you make edits.
2. Zoom in and familiarize yourself with the grid square. Pick a feature (building, open area, road, etc.) that you can easily make out from the satellite image within your grid square.
3. Once you’ve zoomed in on a feature choose the appropriate editor tool.

- a. For roads and pathways, choose the “Line tool”. For buildings and open spaces, choose the “Area tool”.
4. Once you’ve created a feature you will be prompted to categorize it at the left side of the window.
 - a. For example if you edit a building, choose “Building”. You will then be prompted to categorize it further into house, apartment, or commercial etc. If you don’t know what it is, simply choose “Building”.
5. If you are satisfied with your feature, click “Save”.
 - a. You will have to click “Save” twice.
6. Repeat steps 3-5 to continue editing your grid square. Refer back to the instructions periodically in order to stay focused.

Appendix 2: Instructions for Youth Workshop

A. To turn on tracks:

1. In main menu, use toggle button to select “Track Manager”.
2. Select “Current Track”.
3. Scroll down to “Clear Current Track”, select yes (you are sure).
4. Select “Current Track” again... you are now making tracks!
5. Select “View Map”, then you should see a map without any tracks.
6. While viewing map, you can use up/down arrows on top left of GPS to zoom in/out.
7. After walking for a bit, make sure that you see tracks under “View Map”.
 - a. Note, even if you are not on the “View Map” page, your GPS will continue to make tracks!

B. To save tracks:

1. Once you have completed your section of the dyke, you will need to save your tracks.
2. In main menu, use toggle button to select “Track Manager”.
3. Select “Current Track”.
4. Select “Save Track”.
5. Enter a meaningful name for your track.

C. To make waypoints:

1. Use “back” button until you reach main menu
2. In main menu, use toggle button to select “Mark Waypoint”
3. Use toggle to name waypoint and make a note describing point

D. To upload GPS tracks and waypoints into laptop:

1. Connect USB cord to computer and plug into GPS.
2. While you wait for tracks to upload/save onto the computer, go to step 3.
3. Open “Open Street Map” by going to openstreetmap.org.
4. Select “Sign Up” in top right corner of browser and follow instructions to make an account.
5. In order for your GPS tracks to be seen by other public users, you must select “In addition to the above agreement, I consider my contributions to be in the Public Domain” before you click on “Agree”.
6. You will need to confirm your log in with your e-mail address. Check your e-mail and click the link to confirm your account. Click “Start Mapping”.
7. Select “Edit” at top of browser screen, then select “Edit Now” when prompted. Leave this open for now while you proceed to step 8.
8. Go to “My Computer”, select “Garmin eTrex”, open folder called “Garmin”, open “GPX” folder.

9. Select all files (tracks and waypoints) except “Current” and drag and drop them onto the map.
10. Go to Open Street Map and watch while your waypoints and tracks appear.

Appendix 3: Figures Referenced in Methodology

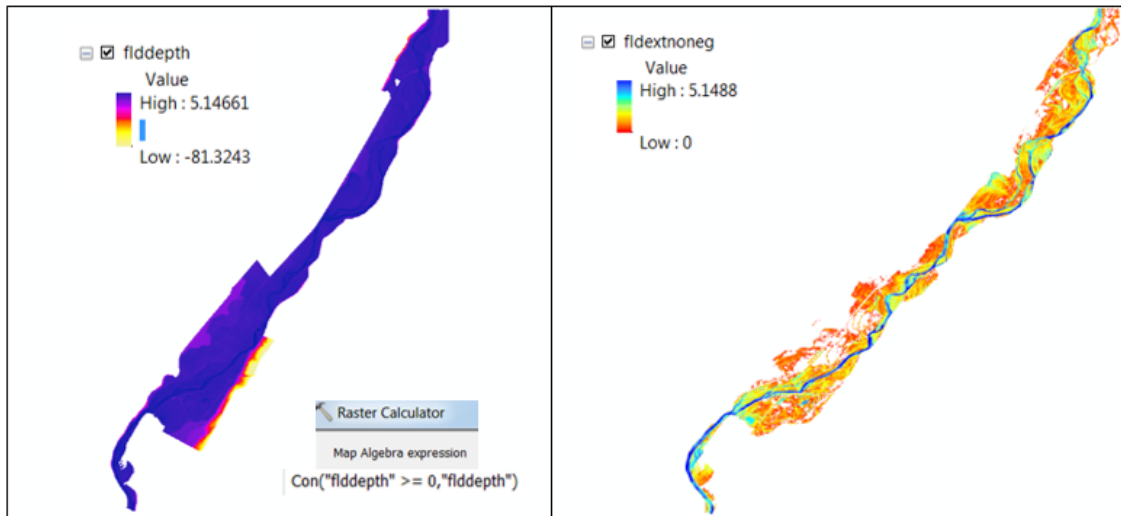


Figure 15: Original raster data set (left) and raster data set with no negative values (right).

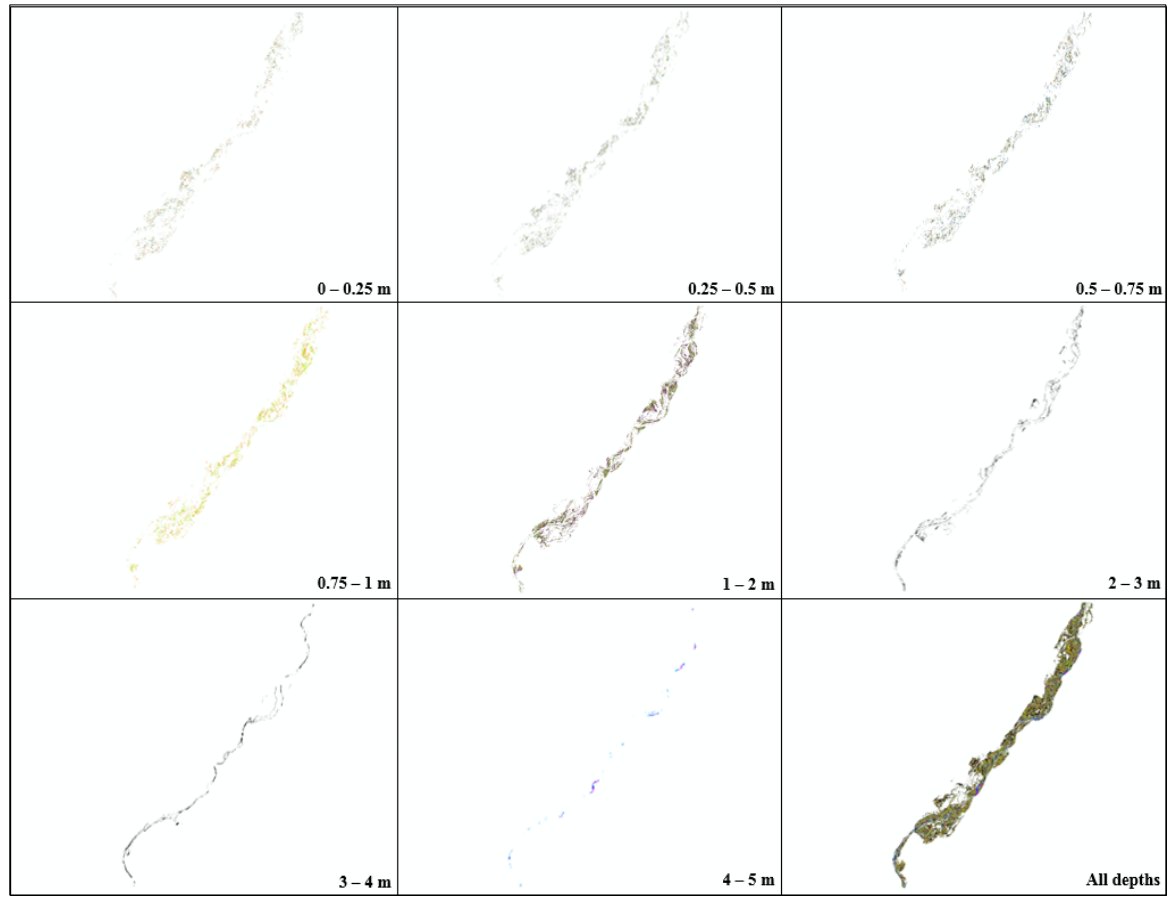


Figure 16a: Resulting raster data sets from Math Algebra expressions for 8 depths and all depths.

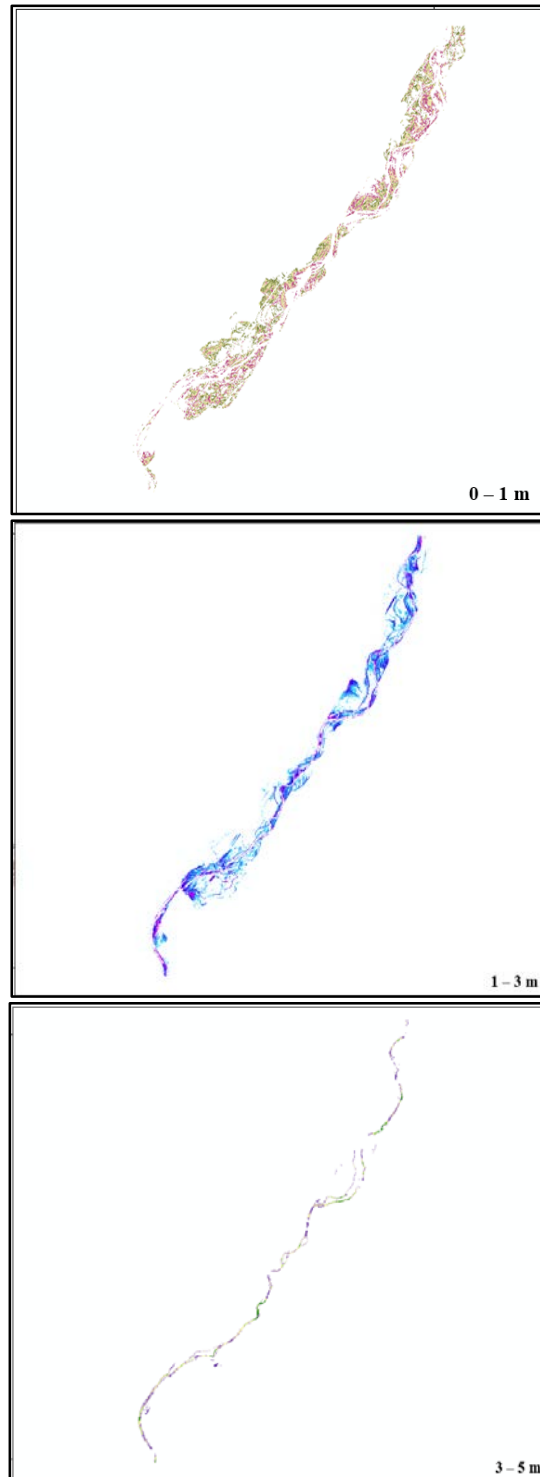


Figure 16b: Resulting raster data sets from Math Algebra expressions showing the 3 depths used in the final map.

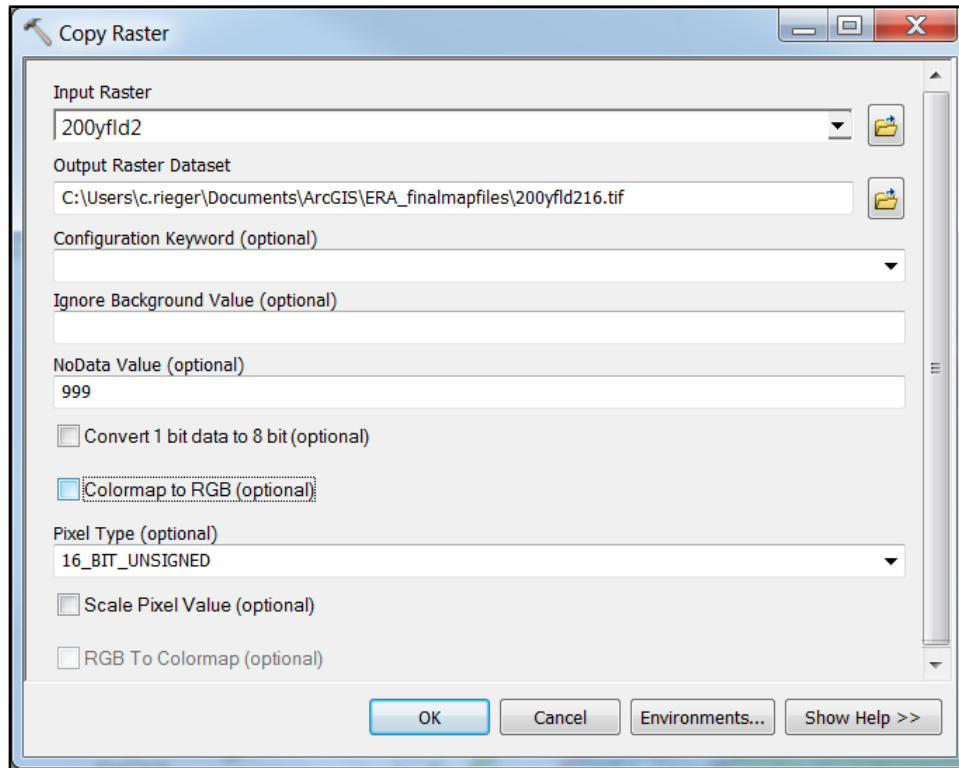


Figure 17: Copy Raster tool displaying an example for converting a 32 bit raster data set into a 16 bit raster data set.

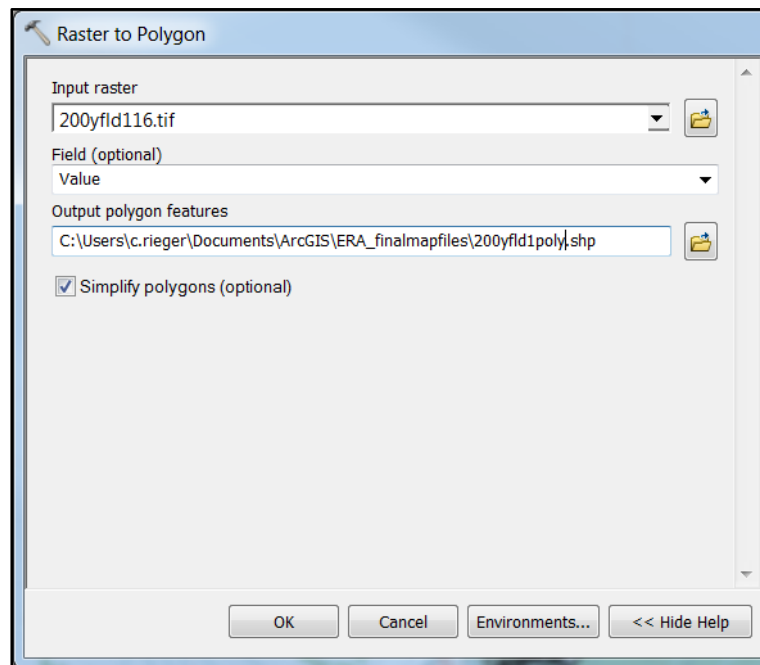


Figure 18: Example of Raster to Polygon tool converting a 16 bit raster to a polygon.

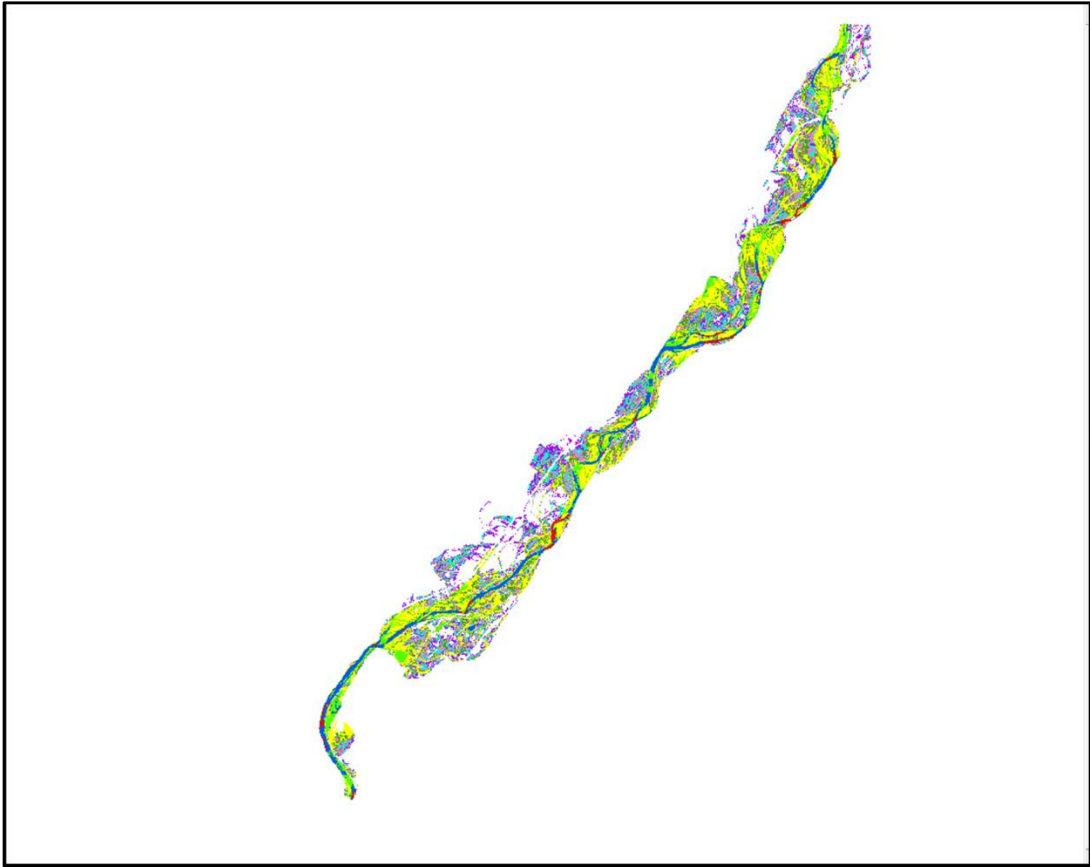


Figure 19a: 1:200 year flood extent shown in individual depth layers.

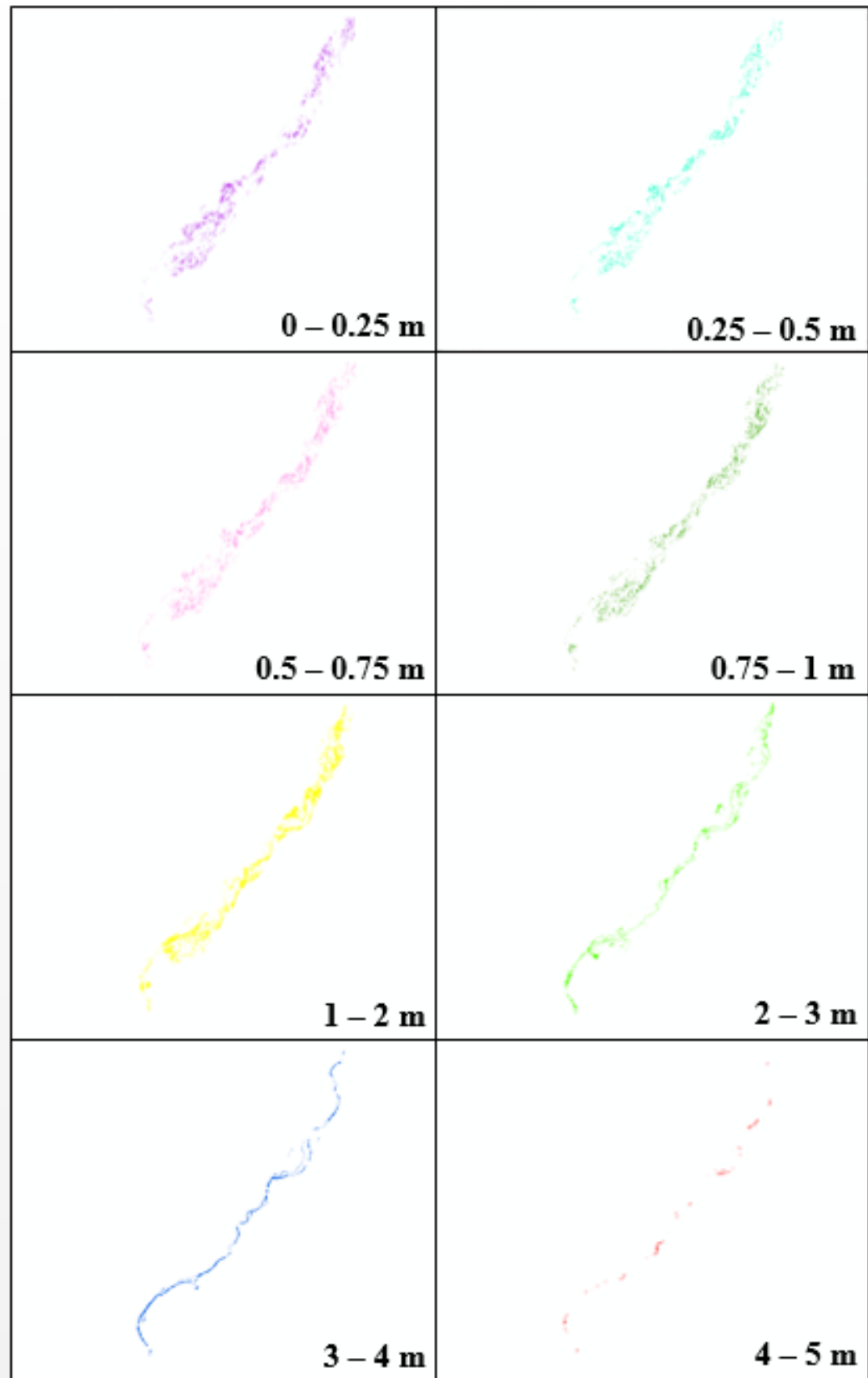


Figure 19b: 8 depth polygons displayed individually.

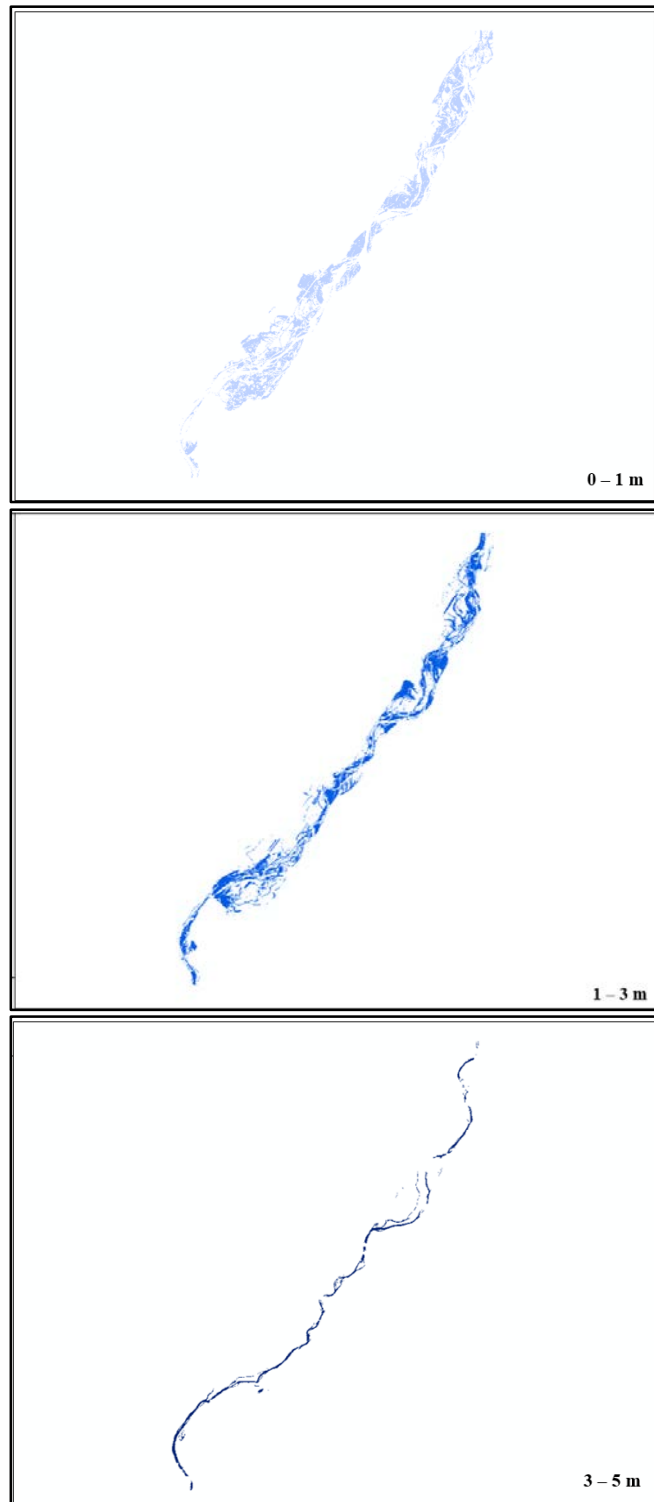


Figure 19c: 3 depth polygons used for the final map displayed individually.

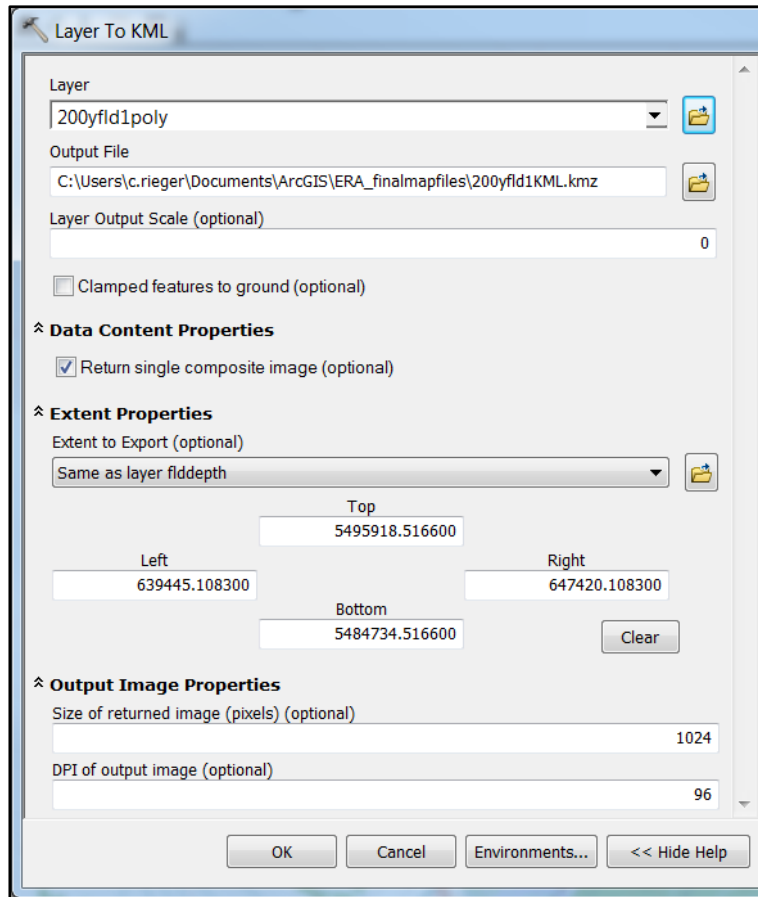


Figure 20: Example of Layer to KML tool converting a single polygon layer into a KMZ file.

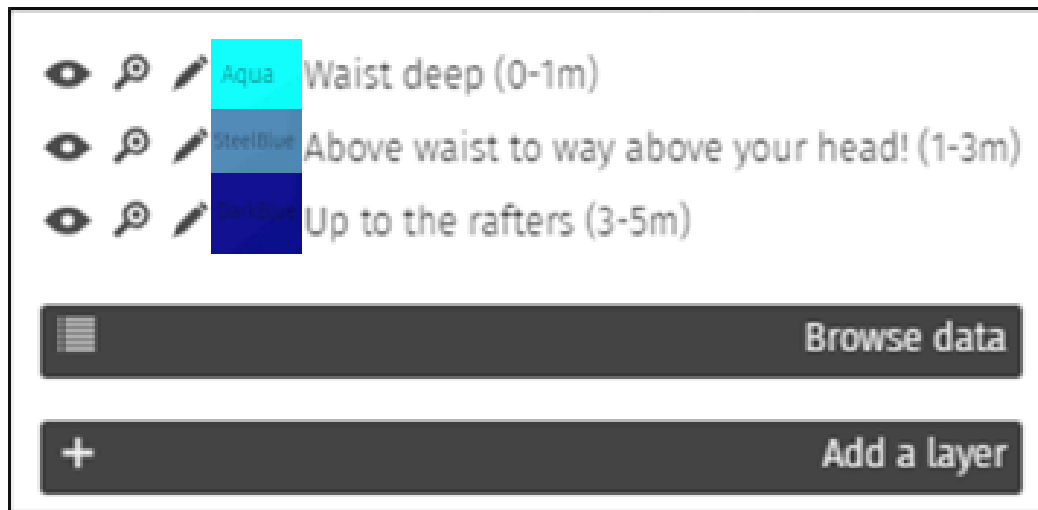


Figure 21: Labels for the 3 layers added to the final map in UMap.