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ORIGINAL PAPER

Municipal flood hazard mapping: the case of British Columbia, Canada

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Abstract Historical responses to flood hazards have stimulated development in hazardous areas. Scholars recommend an alternative approach to reducing flood losses that combines flood hazard mapping with land use planning to identify and direct development away from flood-prone areas. Creating flood hazard maps to inform municipal land use planning is an expensive and complex process that can require resources not always available at the municipal government level. Senior levels of government in some countries have addressed deficiencies in municipal capacity by assuming an active role in producing municipal flood hazard maps. In other countries, however, senior governments do not contribute to municipal flood hazard mapping. Despite a large body of research on the importance of municipal land use planning for addressing flood hazards, little is known about the extent of flood hazard information that is available to municipalities that do not receive outside assistance from senior governments for flood hazard mapping. We assess the status of flood hazard maps in British Columbia, where municipalities do not receive outside assistance in creating the maps. Our analysis shows that these maps are generally outdated and/or lacking a variety of features that are critical for supporting effective land use planning. We recommend that senior levels of government play an active role in providing municipalities with (1) detailed and current information regarding flood hazards in their jurisdiction and (2) compelling incentives to utilize this information.

Keywords Flood hazard map · Flood risk map · Land use planning · British Columbia · Canada · Content analysis

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1 Introduction

Floods are the most frequently occurring natural hazard on earth (Jha et al. 2012). Societal responses to floods have historically relied on efforts to limit flood hazards (e.g., through structural protections such as dams and dikes), limit the susceptibility of buildings to damage (e.g., through construction, design, and elevation standards), and limit the exposure of individuals and communities to financial losses (e.g., through insurance and disaster financial assistance). However well intentioned these responses have been, they have nevertheless served to stimulate development in hazardous areas, to increase the potential exposure of people and property to floods, and to reduce the ability of the natural landscape to control floodwaters (Burby and Dalton 1994).

Scholars increasingly promote an alternative approach to reducing flood losses that relies on the municipal government land use planning function. Previous research suggests that well-constructed land use plans implemented at the municipal level can be effective in helping to reduce losses from natural hazards in part by directing new development to locations that are relatively safe from hazards (Nelson and French 2002; Burby 2006; Brody et al. 2007, 2008). In order to be effective, however, such plans must first be informed by an accurate identification and analysis of local hazard threats (Deyle et al. 1998). Maps of local flood hazards are the “cornerstone” of land use restrictions employed at the municipal level for flood mitigation purposes, and they provide critical information to planners and the general public when making day-to-day decisions that involve protecting people and property from flood damages (Watt and Paine 1992, p. 129).

The production of flood hazard maps that can inform municipal land use planning is an expensive and complex process that can require resources that are not always available at the municipal government level. In some countries, municipalities receive outside assistance (e.g., from senior levels of government) in developing flood hazard maps; in other countries, municipalities do not receive such assistance. While there is now a large body of research on the importance of the municipal government land use planning function for addressing flood hazards, less is known about the extent of flood mapping information that is available to municipalities to support land use planning, particularly in municipalities that do not receive outside assistance in developing flood hazard maps.

The purpose of this paper was to assess the status of flood hazard maps in a jurisdiction where municipalities do not receive outside assistance for flood hazard mapping. We focus on municipalities in the Canadian province of British Columbia (BC), which contain a large number of residents in areas that are generally considered to be flood-prone. As of this writing, municipalities in BC do not receive outside assistance from senior levels of government in developing a detailed understanding and identification of local flood hazards through the creation of flood hazard maps. These municipalities thus represent a useful case for examining (1) whether and to what extent municipalities possess sufficiently accurate information regarding the location and magnitude of likely flood events to facilitate the effective use of land use planning for reducing potential flood losses, when (2) the production of such information must be funded by municipal governments alone with no outside assistance.

The remainder of this paper is organized as follows. First, we discuss the relationship between flood maps and land use planning and describe the efforts of particular senior governments to promote flood hazard mapping as a means of informing municipal land use planning efforts to reduce flood hazards. Second, we discuss flood hazards in BC and the current status of flood hazard management in the province. Third, we discuss our research questions and expectations. Fourth, we describe our data collection methods, variables used, and analytical techniques employed. Fifth, we present and discuss our findings, and then conclude with recommendations for various levels of government to promote the creation and use of flood hazard maps to inform land use planning.

2 Municipal flood mapping

2.1 Municipal flood maps and land use planning

Flooding is a natural phenomenon that becomes a "natural hazard" when humans choose to occupy lands that are subject to flooding. Human occupation of flood-prone areas not only locates people and property in harm's way, but also increases the actual incidence and severity of flood events. Development activities in flood-prone areas commonly involve: grading and filling floodplains, including their associated wetlands; dredging/channelizing rivers; constructing buildings and infrastructure; and replacing natural landscapes with impervious surfaces, all of which combine to reduce the ability of the natural landscape to store floodwaters and attenuate flows, thereby increasing the speed and force with which precipitation flows across the land and into streams and rivers. In essence, "all land use decisions have some potential impact on flooding" (Faber 1996, p. 1).

"Planning" has been defined as using knowledge to guide action (Friedmann 1987). Within the context of land use planning, knowledge regarding the interface between human settlements and natural systems is required to make appropriate decisions regarding the type, location, timing, and scope of new development. Land use planning that is employed for the purpose of reducing flood losses requires knowledge regarding local flood threats, including the location of flood-prone areas, the probabilities of particular flood events, and the associated flood elevation levels for specified events (Excimap 2007).

The process of identifying hazards is the "essential foundation for managing land use in hazardous areas" and is a prerequisite for "sustainable land use" (Deyle et al. 1998, p. 120). Hazard identification data can be reported in maps and technical reports that provide information to educate the public and to build commitment among elected officials for addressing natural hazards (Deyle et al. 1998). Hazard maps and their associated reports are also invaluable for planners, who can use them to identify and illustrate hazard-prone areas to which specific land use policies can be applied, ranging from design standards that can help to reduce risk to restrictions on development/redevelopment. The identification of hazards is taking on increased importance with population growth and the expected impacts of climate change (Ahmad and Simonovic 2013).

There are two basic types of flood maps: a flood *hazard* map and a flood *risk* map. Flood hazard maps display *hazard* parameters including the probabilities of flood events in particular locations (usually expressed as a 1 in X chance of occurring in a given year), flood depths, and flow velocities. Flood risk maps display *risk* parameters including assets at risk, vulnerable populations, probable damage, and losses. While both types of maps can provide valuable information to decision makers, flood hazard maps are particularly useful for land use planners because the maps indicate the locations within a community where flood events are most likely to occur, thus providing critical insight into the suitability of land for development versus preservation (Excimap 2007). Subsequent to the identification of hazardous lands, municipalities can choose to utilize land use planning tools such as zoning, subdivision regulations, siting provisions, and design standards to achieve desirable land use patterns and to mitigate natural hazards (Godschalk et al. 1998).

2.2 Municipal flood mapping in the United States under the National Flood Insurance Program

While flood hazard maps are critical for informing effective land use planning efforts at the municipal level, the process of creating the maps requires resources and expertise that are likely to be lacking within municipal governments, particularly those that serve small populations. As a result, widespread flood hazard mapping at the municipal level is unlikely to occur unless outside assistance is provided (e.g., by senior levels of government). The USA serves as an illustrative example of a country in which the federal government plays a major role in providing municipalities with detailed flood hazard information. The National Flood Insurance Program (NFIP) was established in 1968 in the USA and is administered by the Federal Emergency Management Agency (FEMA). The NFIP provides federally backed, reasonably affordable flood insurance to community residents and businesses and promotes hazard identification and floodplain management at the municipal level. The hazard identification process involves the production of flood hazard maps (officially called “flood insurance rate maps,” or “FIRMs”) for nearly 25,000 communities that participate in the NFIP (FEMA 2013). FIRMs contain a standardized set of information for all communities, including floodplain and floodway delineations and flood elevations. The maps also display stream cross sections that can be cross-referenced in tables and profiles of the companion Flood Insurance Study (FIS) that contains more detailed information about flooding characteristics at each cross section, along with additional flood hazard information pertaining to the community and information pertaining to the FIS itself. FIRMs are periodically updated by FEMA—or by municipal/state governments in conformance with FEMA standards—to account for changes over time in geography, construction and mitigation activities, and meteorological events, subject to urgency and available funding (FEMA 2014).

FEMA provides NFIP communities with an FIS (including FIRMs), which is available to the public, insurance companies, lenders, real estate agents, and so on. In exchange, federal law requires that lenders that finance federally backed mortgages for structures that are located in the floodplain must ensure that mortgagees purchase NFIP flood insurance coverage for the structures. Since flooding can still occur outside of the Special Flood Hazard Area (SFHA) that is shown on the FIRMs, NFIP flood insurance is also available at a reduced rate for residents who voluntarily choose to purchase coverage for structures that are not located in the SFHA. Communities that participate in the NFIP are also required to adopt floodplain management standards that include regulations for development in floodplain areas that meet or exceed minimum standards specified by the NFIP. These standards include elevation, siting, and construction standards, prohibitions on development in the floodway, and standards for grading and filling, among others. Research on the effectiveness of the standards that municipalities implement under the NFIP suggests that the standards help to reduce flood losses (Highfield and Brody 2013).

2.3 Municipal flood mapping in Canada under the 1975 Flood Damage Reduction Program

Prior to 1975, the Canadian federal government’s role in addressing flood hazards had primarily been limited to funding the installation of structural protections in the various provinces. A variety of factors converged in 1975 to convince the Canadian government that a different approach to addressing flood hazards was warranted, including a growing recognition that it was becoming less feasible to continue funding the construction of large-scale remedial projects and to continue making disaster assistance payouts in the aftermath of major flood events (Environment Canada 2014). The Flood Damage Reduction Program (FDRP) was launched in 1975 and represented a significant philosophical shift in the national approach to flood risk management in Canada, from a reliance on structural protections and disaster assistance to a more proactive, non-structural approach that could potentially reduce flood losses and the need for post-disaster financial assistance. The primary objective of the FDRP was to discourage development in flood-prone areas, by identifying such areas through flood mapping and then encouraging relevant zoning authorities to place zoning restrictions on new development in those areas (Environment Canada 2014).

To facilitate the flood hazard mapping process, the FDRP encouraged each province to sign a general agreement with the federal government to provide for cost sharing on a 50–50 basis (Bruce 1976; Watt 1995). The general agreements identified basic approaches to reducing flood damages and specified the policies that were agreed upon by the two levels of government (Environment Canada 2014). The general agreements could also be supplemented by subsidiary agreements to delineate and designate flood hazard areas, as well as to arrange for floodplain regulation, flood forecasting, and structural adjustments. Once areas were designated as being subject (at a minimum) to a 100-year recurrence flood, the following FDRP policies applied to those areas: (1) federal/provincial governments would not build, approve, or finance flood-prone development; (2) the governments would not provide flood disaster assistance for any development built after an area was designated (unless in the flood fringe and adequately flood proofed); and (3) provinces would encourage local authorities to zone on the basis of flood risk (Environment Canada 2014).

Among other things, the FDRP represented a concerted effort to standardize the flood hazard mapping process and specifications at a national level across Canada (Thomson 1984). The detailed hydrologic and cartographic specifications included in the maps produced under the program helped to implement uniform high standards across the country, while nevertheless recognizing special needs in each region. The mapping agreements signed under the FDRP established the 1 in 100-year flood as the federal minimum criterion for the definition of flood risk, with more stringent criteria being adopted in some jurisdictions (Environment Canada 2014).

British Columbia was one of the last provinces to join the FDRP, when "An agreement respecting floodplain mapping in the province of British Columbia" (Mapping Agreement) was signed between the provincial and federal governments in 1987. The Mapping Agreement established the framework for a cost-sharing program to develop official maps of selected areas in the province, which would be affected by a 1 in 200-year flood, with the maps then being disseminated to zoning authorities and other government departments. Upon designation of a floodplain area, it was agreed that (1) neither Canada nor BC would engage in or provide financial assistance to third parties for further undertakings in designated areas unless such undertakings were floodproofed or were in areas protected by dikes; (2) both Canada and BC would encourage appropriate zoning authorities and other appropriate entities under their respective jurisdictions to impose land use restrictions that would prohibit further undertakings in designated areas or would render such undertakings subject to requirements for adequate floodproofing; (3) neither Canada nor BC would provide disaster assistance for costs or losses incurred as a result of a flood in designated areas, unless damaged construction had been adequately floodproofed or was in an area protected by dikes (BC Ministry of Forests, Lands and Natural Resource Operations 2014).

The federal government terminated the FDRP in the late 1990s, in part because some senior officials considered the focus of the program to be too narrow and not sufficiently aligned with ecosystem-based planning (de Loë and Wojtanowski 2001). In BC, the Mapping Agreement theoretically provided support for a systematic approach to identifying and mapping flood-prone areas across the province and to encouraging that the identified areas be subject to land use restrictions aimed at reducing flood risks. However, little funding was actually allocated for mapping in the Mapping Agreement (Day 1999). The primary focus of BC's participation in the FDRP was instead centered on expanding and enhancing the diking system in the province. The lower Fraser diking program was the most capital-intensive project supported under the FDRP (Day 1999), with some $75 million being invested in the project (Booth and Quinn 1995). Thus, while the FDRP was considered to have been quite successful in identifying urban risk areas in other parts of Canada and in helping to direct development away from such areas (Watt 1995), the decision to commit such a large portion of available funding to building dikes in BC prevented the province from capitalizing on detailed flood mapping opportunities and on the additional damage prevention potential afforded by the land use planning policies promoted by the program (Day 1999).

2.4 Flood insurance rates maps in the USA as a comparative case for evaluating municipal flood hazard maps in British Columbia

While the purpose of this paper was to examine municipal flood hazard maps in a country (i.e., Canada) where municipalities do not receive outside assistance in producing the maps, we have provided details on the FIRMs created under the NFIP in the USA because they serve as a useful starting point for evaluating municipal flood hazard maps in BC, for at least two reasons. First, the NFIP represents an example of what can happen when a federal government decides to play a major role in helping to reduce flood losses by funding the creation of municipal flood hazard maps and by requiring the municipal recipients of the maps to adopt floodplain management standards. Roughly 25,000 municipalities in the USA have been provided with detailed flood hazard maps under the NFIP that inform municipal land use planning and that are periodically updated over time to reflect changes in relevant information contained within the maps. Second, legal scholars have observed that American environmental law and policy has historically influenced Canadian environmental law and policy, with Canadian legislators often enacting comparable legislation to that enacted in the USA (albeit multiple decades later, in some cases) (Boyd 2003). As a result, features of the NFIP and its approach to municipal flood hazard mapping might reasonably be expected to help guide Canadian policy makers should they choose to craft a similar program in Canada.

3 Addressing flood hazards in British Columbia

Flooding poses a major threat to persons and property in Canada. A flood event in the summer of 2010 caused nearly $1 billion in damages in the Alberta and Saskatchewan provinces, and major spring and summer flooding in the Prairies region in 2011 that caused more than $1 billion in damages was dubbed the "flood of the millennium" by a federal government climatologist (Nguyen 2011). More recently, flooding in southern Alberta in June 2013 caused at least $1.7 billion in insured property damages alone, making it the costliest natural disaster in Canada's history (Toneguzzi 2013). While these flood events occurred outside BC, researchers consider the Greater Vancouver Regional District (GVRD) in southern BC to be at greater risk of future flood damages than any other location in all of Canada (National Round table on the Environment and the Economy (Canada) 2011). High population densities and expansive flood-prone areas in the GVRD combine to produce exceptionally hazardous conditions.

Flooding in BC can occur throughout the entire year. Some communities are more vulnerable to fall flooding due to heavy rains or rain-on-snow events, and other communities are more vulnerable to spring freshet flooding from rapid snow melt. Coastal communities are subject to potential sea level rise, while communities across the province are generally susceptible to flooding from intense precipitation which may occur at any time of the year. In addition, ice jams, reservoir releases, and mechanical failure of flood protection works may also cause flooding anywhere in the province (BC Ministry of Public Safety 2007). Climate change will likely exacerbate flood risks in BC. Although there is an extensive system of dikes in the GVRD and throughout much of the province, the diking system was not designed with climate change in mind and may thus be insufficient to protect BC communities from increased flooding and sea level rise expected to accompany global climate change. In the absence of additional action aimed at reducing flood risks, annual flood damages to dwellings in BC by the 2050s are projected to range from $2.2 billion at the baseline level to $7.6 billion under a "high climate change" scenario, with annual per capita costs that range from $565 to $2,146 dwarfing the national projections of $108 to $364 (National Round table on the Environment and the Economy (Canada) 2011). These alarming figures point to the urgent need for proactive planning in BC to reduce existing and future flood risks.

As of 2014, the provincial government of BC operates a three-pronged "Integrated Flood Hazard Management" program that consists of emergency management, dike safety, and land use management. The land use management function is limited to providing flood hazard management guidance to local governments through publications such as the "Flood Hazard Area Land Use Management Guidelines" (hereinafter referred to as "the Guidelines"). The Guidelines document recommends (but does not require) that municipalities develop "flood plain maps" that show (1) areas that can be expected to flood once every 200 years on average, (2) the location of the normal channel of watercourses, (3) surrounding features or development, (4) ground elevation contours, and (5) flood levels for the 200-year flood.

The Integrated Flood Hazard Management program in BC does not include provisions for offering flood insurance to municipalities or homeowners, and as a result, municipal flood hazard maps in BC will theoretically be used primarily for land use planning purposes rather than for guiding decisions around insurance. Whereas flood insurance is made available by the federal government to municipalities in the USA that choose to participate in the NFIP, the federal government has never offered flood insurance in Canada (Canadian Broadcasting Corporation 2013). In addition, Canada is the only G8 country in which flood insurance is not available in the private sector (Beeby 2013). In general, the federal government does not consider the provision of flood insurance to be part of its role, and the private insurance companies indicate that flood insurance is too expensive for them to provide or for homeowners to purchase (CTV News 2013). In addition, insurance executives consider existing flood maps in Canada to be inaccurate and outdated, thus making them inadequate for informing potential flood insurance decisions. Unless and until there are new flood hazard maps that are not only up-to-date but that also consider the potential impacts of climate change on future flooding, private insurance companies are unlikely to offer comprehensive flood insurance in Canada (Beeby 2013).

4 Research questions and expectations

In jurisdictions such as the USA where the federal government plays a strong role in facilitating municipal flood hazard mapping, most municipalities are provided with detailed flood hazard maps that can serve as the foundation for informed decision making regarding local land use and development, as well as for decision making in relation to federally backed flood insurance and mortgages. In other jurisdictions such as BC where municipalities do not receive outside assistance in developing flood hazard maps, municipalities may not possess the necessary capacity (or commitment) to create the maps on their own. There are thus reasons to be concerned that municipalities in jurisdictions like BC may not possess flood hazard maps that can usefully inform land use decision making.

To provide insight into the status of flood hazard mapping in a location where municipalities do not receive outside assistance in creating the maps, we collected and evaluated all municipal flood hazard maps in BC, and addressed three general research questions: (1) How many of BC's 159 municipalities possess a flood hazard map? (2) What is the content of municipal flood hazard maps in BC? and (3) Does the content of maps created under the Mapping Agreement vary from that of maps not created under the Mapping Agreement?

Our first set of analyses focuses on whether municipalities in BC possess a flood hazard map. Preparing a usable flood hazard map requires significant financial resources and technical expertise. Given that municipalities in BC do not receive outside assistance for flood hazard mapping, we expect that many of BC's municipalities will not possess a flood hazard map for their community.

Our second set of analyses relates to the content of the existing municipal flood hazard maps in BC and the extent to which the maps incorporate the features included in our protocol. Unlike FIRMs in the USA that contain a standardized set of features, we expect to find substantial variation in the content of flood hazard maps in BC. A recent study of municipal flood bylaws in BC showed that there was much room for improvement in the bylaws (Stevens and Hanschka 2014), which leads us to expect that municipal flood hazard maps will be of similar quality. In other words, we generally expect the maps to generate relatively low scores on the variables we describe below.

We anticipated that at least some of the maps under study would have been developed under the Mapping Agreement, such that the entire set of maps could be meaningfully split into two groups: one group of maps that were developed under the Mapping Agreement (that we refer to as "Mapping Agreement maps" or "MA maps") and one group of maps that were not (that we refer to as "Non-Mapping Agreement maps" or "NMA maps"). We expect to find that MA maps will be of higher quality than NMA maps, and thus that MA maps will contain more of the features that we are looking for than will NMA maps.

5 Data collection, variables, and analytical techniques

5.1 Data collection

We utilized the methodology of content analysis to evaluate municipal flood hazard maps in BC. Content analysis has been used in previous studies to examine various substantive foci in land use plans and related documents, including the study of municipal flood bylaws in BC (Stevens and Hanschka 2014) as well as studies of sustainable development, Smart

Growth, coastal management, affordable housing, and climate change, among other issues (Stevens et al. 2014).

We sought to obtain and evaluate all extant municipal flood hazard maps in BC as of the summer of 2010. To identify the maps, we contacted each municipality to ascertain whether they possessed a flood hazard map for their jurisdiction and to obtain copies of those maps that were available. In most cases, we were able to obtain electronic copies of flood hazard maps, though in a few cases, we obtained hard copies instead. Once we obtained copies of all extant flood hazard maps, we developed a draft evaluation protocol comprised of items that were informed by the following three sources:

1. *FIRMs produced by FEMA*: The FIRMs produced by FEMA served as a useful template for designing our protocol in part because of their dual purpose that involves informing land use decisions as well as decisions relating to flood insurance and mortgages. The FIRMs are specifically designed to provide sufficiently detailed information to enable various users to make informed decisions that relate to protecting people and property from future flood damages, and to ensure that at-risk properties are identified so that appropriate risk reduction measures can be employed. FIRMs contain a standardized set of features that are displayed for every community, including generic map features (e.g., legends and north arrows) as well as flood-hazard-specific information (e.g., floodplain boundaries and flood elevations in most cases). We examined a subset of FIRMs and compiled an inventory of features contained in the maps, and then created individual protocol items for each relevant feature.
2. *The Guidelines and related documents published by the provincial government of* BC: We created individual items for features that are recommended in the Guidelines and related documents. While the provincial government does not require municipalities to adopt a flood hazard map or to include particular material in the map if a municipality chooses to adopt one voluntarily, it does provide municipalities with some degree of guidance should a municipality decide to create its own flood hazard map. The Guidelines document, for example, recommends that the floodplain boundary shown in a map be the boundary that corresponds to the 200-year flood and that 200-year flood elevations be displayed on the map. We thus created protocol items to measure each of the features that were recommended by provincial guidelines.
3. *The authors' judgment:* After creating items that were informed by the first two sources, we then performed a careful review and evaluation of the set of items to determine whether the items measured all of the features that we believed should be present in a municipal flood hazard map in order to maximize its informative value and usability. Based on this evaluation, we added supplementary items to our protocol to measure the following: the year the map was produced; floodplain boundaries and flood elevations for the 500-year flood; floodplain boundaries and flood elevations for a flood with an expected frequency other than 200 or 500 year; parcel boundaries; and impacts that infrastructure within a stream channel has on floodwaters. If present in a flood hazard map, these additional items can provide planners and decision makers with more detailed information about flood events of varying intervals and a better understanding of the threat that floods pose to individual properties.

Our protocol initially contained 36 items, each of which utilizes a binary scoring system with a score of 1 indicating that the item was found to be present in a flood hazard map and a score of 0 indicating that the item was not found to be present. This is a common practice, in that researchers that employ content analysis routinely utilize one of two scoring schemes: a binary scheme that measures whether items are absent or present, or an ordinal scheme that also measures absence but makes an additional distinction between content that is present but that is lacking in some way (e.g., it is vague and/or non-mandatory) and content that is present and not lacking (e.g., it is clearly worded and/or mandatory). Ordinal scoring schemes can sometimes provide researchers with more information, but also serve to complicate the coding process by requiring coders to make fine-grained distinctions that can lead to disagreements across coders and the production of less reliable data. Our decision to employ a binary scoring scheme was driven in large part by the substantive focus of the items in our evaluation protocol. Our items generally relate to content that is best conceived of as either being present or absent, with little to no room for making distinctions such as "present but vague" and "present and clear." In the case of floodplain boundaries, for example, flood hazard maps either do or do not display the boundary.

We began by pre-testing a draft of our protocol on two flood hazard maps from Canadian municipalities outside of BC, making revisions to the protocol after independently coding and discussing each of the two pre-test maps. Once the content and format of the protocol were finalized, we independently administered the protocol to each map, communicating frequently to resolve disagreements on scores assigned to items and to develop a reconciled dataset.

After we independently coded each of the maps, we calculated Krippendorff's alpha (α) for each of the 36 items as a measure of intercoder reliability (Krippendorff 2013). We calculated α scores through the use of the web-based tool developed by Freelon (2010). We also calculated a percent agreement score for each item to measure the percentage of maps for which the two coders agreed on the map score. Following the procedures recommended by (Stevens et al. 2014), we chose to exclude from our analysis those items that displayed a combination of low α scores and relatively low levels of agreement on item scores across coders. Based on our review of the respective α score for each of the 36 items, we chose to exclude four items from our analysis, and our analysis is thus based on 32 items.

As described in more detail below, we grouped the 32 items into the following four categories, based on the substantive content of each item: Administration, Floodplain Delineation, Landscape Features, and Companion Documents. Table 1 shows each of the 32 items in our protocol, along with the α score, percent agreement score, and source for each item.

5.2 Variables

Our analyses in this paper focus on categories of item subsets from the protocol as well as on scores for selected individual items. To create variables comprised of item subsets, we first assigned each of the 32 items in our protocol to one of the four categories shown in Table 1. This process yielded an Administration variable (five items), a Floodplain Delineation variable (20 items), a Landscape Features variable (four items), and a Companion Documents variable (three items). We then regrouped the same 32 items into three additional variables that relate to the three sources we drew upon in creating the items. This process yielded a FEMA variable (comprised of items derived from the standard FIRM format), a Guidelines variable (comprised of items derived from the Guidelines and related documents published by the BC provincial government), and a Supplementary variable (comprised of the supplementary items we added to the protocol). The FEMA variable is comprised of 11 items; the Guidelines variable consists of 14 items; and the Supplementary variable consists of 7 items. Table 2 shows the variables created from item subsets that are used in this study.

Table 1 Items in evaluation protocol

Item name	Alpha	Agreement[b]	Source
Category: Administration			
Legend that identifies/explains the various elements of the map Legend	1.00	1.00	FEMA
Scale that relates measurements on the map (e.g., inches) to measurements on the ground (e.g., feet) Scale	1.00	1.00	FEMA
North arrow or some other means of indicating direction Arrow	0.70	0.93	FEMA
Year that the map was produced Year	0.69	0.87	Authors
Vertical datum used (e.g., Canadian Geodetic Vertical Datum of 1928) Datum	0.88	0.96	FEMA
Category: Floodplain delineation			
Area that is subject to flooding Floodplain	(0.02)	0.96	FEMA
Area that can be expected to flood, on average, once every 200 years 200 years	0.94	0.97	Province
Area that can be expected to flood, on average, once every 500 years 500 years	0.66	0.99	Authors
Area that can be expected to flood, on average, once every some other number of years Other years	0.84	0.97	Authors
Delineate the floodway boundary Floodway	0.49	0.97	FEMA
Location of the normal channel of all watercourses, with symbology in the legend Watercourses legend	0.96	0.99	Province
Location of the normal channel of all watercourses, without symbology in the legend Watercourses no legend	0.67	0.84	Province
At least one flood elevation Elevation	0.87	0.94	FEMA
At least one flood elevation for the 200-year flood (i.e., the estimated elevation of the 200-year flood along a stream) Elevation 200 years	0.87	0.94	Province
At least one flood elevation for the 500-year flood (i.e., the estimated elevation of the 500-year flood along a stream) Elevation 500 years	Undefined[a]	1.00	Authors
At least one flood elevation for some other specified flood Elevation other years	1.00	1.00	Authors
Flood construction levels for 2010 FCL 2010	Undefined[a]	1.00	Province
Flood construction levels for 2100 FCL 2100	Undefined[a]	1.00	Province
Flood construction levels for 2200 FCL 2200	Undefined[a]	1.00	Province

Table 1 continued

Item name	Alpha	Agreement[b]	Source
Floodplain limits for 2010 FCL 2010	Undefined[a]	1.00	Province
Floodplain limits for 2100 FCL 2100	Undefined[a]	1.00	Province
Floodplain limits for 2200 FCL 2200	Undefined[a]	1.00	Province
Sea level rise planning areas for 2100 SLR 2100	Undefined[a]	1.00	Province
Sea level rise planning areas for 2200 SLR 2200	Undefined[a]	1.00	Province
Tsunami evacuation planning area Tsunami	Undefined[a]	1.00	Province
Category: Landscape features			
Boundaries of at least some individual parcels Parcels	1.00	1.00	Authors
Impacts that infrastructure within the stream channel has on floodwaters Infrastructure impacts	Undefined[a]	1.00	Authors
Overlaid on top of an aerial photograph Photograph	1.00	1.00	FEMA
Ground elevation contours Contours	0.95	0.99	Province
Category: Companion documents			
Reference an accompanying technical study Study	0.00	0.99	FEMA
Include at least one cross section for a stream Cross section	0.84	0.94	FEMA
If includes at least one cross section for a stream, can cross section be cross-referenced in an accompanying technical study Cross-reference	0.97	−0.01	FEMA

[a] The value of Krippendorff's alpha is undefined when an item is independently determined by two or more coders to be present in every plan, or absent from every plan. In these situations, the formula for calculating Krippendorff's alpha involves dividing by zero

[b] Agreement refers to the proportion of scores for an item on which the two coders agreed. For example, an agreement score of 0.95 indicates that the two coders agreed on 95 % of the scores for that item

In addition to reporting scores for the variables described in Table 2, we also report the scores for certain individual items. Due to space constraints that prohibit direct discussion of each of the 32 items in the protocol, we focus on a small number of individual items that we consider to be particularly worthy of attention, either because their frequency of inclusion in the maps under study is relatively high (or low) or because we consider them to be relatively important for assessing the maps under study.

5.3 Analytical techniques

We utilize descriptive statistics and means comparison tests to evaluate the flood hazard maps under study. The descriptive statistics provide insights into the mean values of

Table 2 Variables

Variable name	Description	Number of items
Substantive content of items		
Administration	Items relate to administrative aspects of the maps	5
Floodplain delineation	Items relate to delineating floodplains and other flood-related information	20
Landscape features	Items relate to features of the landscape within the map's geographic coverage	4
Companion documents	Items relate to companion documents that provide supplementary technical information	3
Source of items		
FEMA	Items are derived from the FIRMs produced by FEMA	11
Guidelines	Items are derived from the Guidelines and related documents	14
Supplementary	Items are derived from the authors' judgment	7

variables, and the means comparison tests enable us to evaluate differences between MA maps and NMA maps. Given that MA maps were produced under the same program according to a particular set of standards, whereas NMA maps were produced under varying circumstances, it is not reasonable to assume that the two sets of maps will display equal variances with respect to the inclusion of the items in our protocol. As such, we assume unequal variances in our means comparison tests.

6 Findings

6.1 Variable scores

Just 68 (or 43 %) of the 159 municipalities in BC were able to provide us with a flood hazard map. Six municipalities directed us to an online mapping system for their municipality that included a flood hazard layer, and the remaining 85 municipalities had not adopted a flood hazard map as of the time we contacted them. Our analysis is based on the 68 flood hazard maps that we collected and evaluated.[1]

Findings from our analysis of the substantive content of the flood maps are presented in Table 3. Overall, the maps under study were fairly strong in the area of Administration, containing 3.5 out of five items on average for a mean score of 0.70. Nearly two-thirds of the maps contained four or more items, with 31 maps containing four items and 11 containing all five items. An additional 16 maps contained three items. Eight maps contained just one item, and none contained <1. Sixty-three of the maps contained a legend, 58 contained a north arrow, 55 contained a scale, and 48 indicated the year of production. Just 15 maps indicated the vertical datum used to calculate flood elevations.

The maps performed very poorly on the Floodplain Delineation variable, containing just 3.1 (or roughly one-sixth) of the 20 items on average. Only one map contained as many as

[1] We chose not to include the online mapping tools in our evaluation because they represent a separate flood hazard map format.

Table 3 Summary statistics for the administration, floodplain delineation, landscape features, and companion documents variables

Variable name	Mean no. of items	Mean score	Min score	Max score	SD
Administration	3.5/5	0.70	0.20	1.00	0.23
Floodplain delineation	3.1/20	0.16	0.05	0.40	0.08
Landscape features	0.9/4	0.22	0.00	0.50	0.14
Companion documents	0.3/3	0.09	0.00	0.33	0.15

eight items, and only 17 contained four or more items. Nearly 70 % of the maps contained either two or three items, and four maps contained just one item.

The only Floodplain Delineation feature under study that was present in all 68 maps was the depiction of the area that was subject to flooding. The only other feature to be present in more than one-half (i.e., 44) of the maps was the depiction of watercourses on the map, without a symbol for the watercourses in the legend. Eighteen of the maps depicted watercourses with a symbol in the legend. Twenty-six of the maps showed at least one flood elevation, and 25 showed the area that could be expected to flood once every 200 years on average. Just one map showed the area that could be expected to flood once every 500 years on average, and just one map depicted the boundary of the floodway. Ten items were absent from all 68 of the maps, including flood construction levels, floodplain limits, and sea level rise planning areas for 2010, 2100, and 2200, among others.

The maps were also weak with respect to showing landscape features. The mean score for the Landscape Features variable was 0.22, with the maps containing an average of 0.90 of the four items. Six of the maps contained two items, 47 maps contained one item, and 15 maps contained zero items. Among the individual items that make up the Landscape Features variable, the most common was the depiction of parcel boundaries, which was present in 42 of the maps. Just 12 maps showed ground elevation contours, and only five maps overlaid flood hazard information on top of an aerial photograph. None of the maps indicated the impacts of infrastructure within the stream channel on the displacement or rise of floodwaters.

The maps contained very few references to companion documents or features that could be cross-referenced for more detailed information in companion documents. On average, the maps contained just 0.3 of the three features in the Companion Documents variable, with 18 maps containing one feature and all remaining 50 maps containing zero features. The only feature present in the 18 maps was at least one cross section for a watercourse. None of the maps indicated that the cross sections could be cross-referenced for more details in an accompanying technical study, and none of the maps made reference to accompanying technical studies.

We now present findings for the variables that relate to the source of the items, as shown in Table 4. Scores were highest for the FEMA variable, with the maps containing 4.5 of the 11 items on average. Three maps contained as many as eight items, and one map contained as low as one item. Forty of the maps contained four or fewer items. Scores were much worse for the Guidelines variable. Maps contained just 1.7 out of 14 Guidelines items on average, and nine maps contained the maximum observed score of four items. Thirty-four maps contained just one item, and six maps contained zero items. Scores were also poor for the Supplementary variable, as the maps contained just 1.5 out of seven items. One map contained as many as four items, with 58 of the maps containing one or two items and five maps containing zero items.

Table 4 Summary statistics for the FEMA, guidelines, and supplementary variables

Variable name	Mean no. of items	Mean score	Min score	Max score	SD
FEMA	4.5/11	0.41	0.09	0.73	0.15
Guidelines	1.7/14	0.12	0.00	0.29	0.08
Supplementary	1.5/7	0.22	0.00	0.57	0.11

6.2 Means comparisons

We now examine whether the scores for the variables under study vary across MA and NMA maps. During the process of evaluating the maps, we observed that while some (i.e., five) of the maps were in fact created under the Mapping Agreement, four maps were created by the provincial government of BC in the early 1980s just prior to the time the Mapping Agreement was signed. The five maps created under the Mapping Agreement are very similar in content and format to the four created just prior to the Mapping Agreement, and for analytical purposes, we include all nine of these maps under our "MA" designation.[2] Table 5 shows the results of independent samples t-tests to test for mean differences on the variables for all of the maps under study. As shown in the table, the nine MA maps have higher mean scores than the 59 NMA maps on every variable that we created. The differences are particularly notable on the Floodplain Delineation, Companion Documents, FEMA, and Guidelines variables, where the scores for the MA maps are all at least twice as high as those for the NMA maps.

Table 6 shows the frequency at which each of the 32 items in our protocol was included in the flood hazard maps under study. The fourth column in the table indicates the statistical significance of differences in these frequencies across MA and NMA maps. Within the Administration category, MA maps were more likely to include a north arrow and to indicate the vertical datum that was used. Within the Floodplain Delineation category, MA maps were more likely to indicate the boundary of the one in 200-year flood and to indicate a boundary for a flood other than the 200- or 500-year flood. Whereas all maps under study indicated a floodplain boundary, 89 % of MA maps indicated a boundary for the 200-year flood versus only 29 % of NMA maps. All MA maps included at least one flood elevation, whereas only 29 % of NMA maps did so. MA maps were also much more likely to display flood elevations for the 200-year flood, and for some flood other than the 200 or 500 year. The only Floodplain Delineation item that NMA were more likely to include was the display of watercourses with a symbol in the legend. All of the MA maps indicated the location of watercourses, but none of them included a symbol for watercourses in the legend. In the Landscape Features category, NMA maps were much more likely than MA maps to display parcel boundaries, whereas MA maps were much more likely to display ground elevation contours. Lastly, all MA maps contained at least one cross section for a stream, compared to just 15 % of NMA maps.

[2] It is worth noting that the flood hazard data that are represented in the NMA maps under study may have been produced by the provincial and/or federal governments, either under the Mapping Agreement or as a separate venture by the provincial government. However, the NMA maps under study are not currently in the standard format that was utilized by the province prior to the Mapping Agreement or that was used when maps were produced under the Mapping Agreement.

Table 5 Mean comparisons

	MA maps (n = 9)	NMA maps (n = 58)	Difference in mean scores	*p* value for mean difference
Administration (max = 5)	4.4 (88.9 % of max)	3.4 (67.5 % of max)	1.1	0.05
Floodplain delineation (max = 20)	6.1 (30.6 % of max)	2.6 (13.2 % of max)	3.5	0.00
Landscape features (max = 4)	1.4 (36.1 % of max)	0.8 (19.5 % of max)	0.7	0.01
Companion documents (max = 3)	1.0 (33.3 % of max)	0.2 (5.1 % of max)	0.9	0.00
FEMA (max = 11)	7.0 (63.6 % of max)	4.2 (37.9 % of max)	2.8	0.00
Guidelines (max = 14)	3.8 (27.0 % of max)	1.4 (9.7 % of max)	2.4	0.00
Supplementary (max = 7)	2.2 (31.7 % of max)	1.4 (20.3 % of max)	0.8	0.06

6.3 Qualitative comparisons

We conclude our findings with visual examples of flood hazard maps from the USA and from BC that highlight variation in the content and quality of the maps. We begin by examining portions of a FIRM from Clackamas County, Oregon (Map number 41005C0064D). As shown in Fig. 1, the FIRM uses blue and black dotted patterns with line boundaries to indicate the respective locations of the 100- and 500-year floodplains, as well as diagonal hatching to indicate the location of the floodway. The floodplain area shown in the figure is for a segment of the Clackamas River. The wavy dark lines are Base Flood Elevation lines that stretch from one side of the floodplain to the other; the numbers listed on the middle of the lines are numerical listings of the flood elevations for the 1 percent Annual Chance Flood (100-year flood) rounded to the whole foot. The straight lines that are alphabetically labeled at each end (e.g., "BA," BB, "BC") are surveyed cross sections (cross-section lines) that can be further referenced in tables and profiles of the companion FIS, where the tables and profiles contain more detailed information about flooding characteristics at, as well as between, each cross section, such as: precise flood elevations of the 10-year (10 %), 50-year (2 %), 100-year (1 %), and 500-year (0.2 %) flood events; water velocities and volumes; width of the cross section; and distance from stream mouth. The flood hazard data are overlaid on top of an aerial photograph, which helps to inform the map user with respect to the features of the landscape and the density of development that is exposed to flooding. Each FIRM also contains an identification panel like the one shown on the lower right section of Fig. 1, which, among other things, indicates the date that the map went into effect. In addition, each FIRM contains a detailed legend panel that describes the map's symbology and includes a north arrow, a scale, and a description of each of the eleven flood zones that can appear on a FIRM.

As we noted earlier, MA maps contain more of the features that FIRMs contain than do NMA maps. To help illustrate this point, we examine the MA map created for the City of Parksville, BC, that contained more of the items in our protocol (i.e., 15) than any other map under study. Figure 2 shows a segment of the Parksville map. Fig. 3 shows the legend for the map. The legend indicates that the curvy dark black line in the map corresponds to

Table 6 Individual item frequencies in flood hazard maps

Item name	% of all maps	% of MA maps	% of NMA maps	Difference[a]
Category: Administration				
Legend	93	89	93	
Scale	81	89	80	
Arrow	85	100	83	MA***
Year	71	78	69	
Datum	22	89	12	MA***
Category: Floodplain delineation				
Floodplain	100	100	100	
200 years	37	89	29	MA***
500 years	2	11	0	
Other years	9	56	2	MA**
Floodway	2	0	2	
Watercourses legend	27	0	31	NMA***
Watercourses no legend	65	100	59	MA***
Elevation	38	100	29	MA***
Elevation 200 years	22	89	12	MA***
Elevation 500 years	0	0	0	
Elevation other years	10	67	2	MA***
FCL 2010	0	0	0	
FCL 2100	0	0	0	
FCL 2200	0	0	0	
FCL 2010	0	0	0	
FCL 2100	0	0	0	
FCL 2200	0	0	0	
SLR 2100	0	0	0	
SLR 2200	0	0	0	
Tsunami	0	0	0	
Category: Landscape features				
Parcels	62	11	69	NMA***
Infrastructure impacts	0	0	0	
Photo	7	33	3	
Contours	18	100	5	MA***
Category: Companion documents				
Study	0	0	0	
Cross section	27	100	15	MA***
Cross-reference	0	0	0	

[a] MA indicates that the item was more frequent in Mapping Agreement maps; NMA indicates that the item was more frequent in non-Mapping Agreement maps

* $p < .10$; ** $p < .05$; *** $p < .01$

the "Designated floodplain limit" for the 200-year flood. The straighter black lines that move diagonally from the bottom left to the upper right are stream cross sections, and the legend indicates that the set of numbers on each cross section refer to flood elevations for

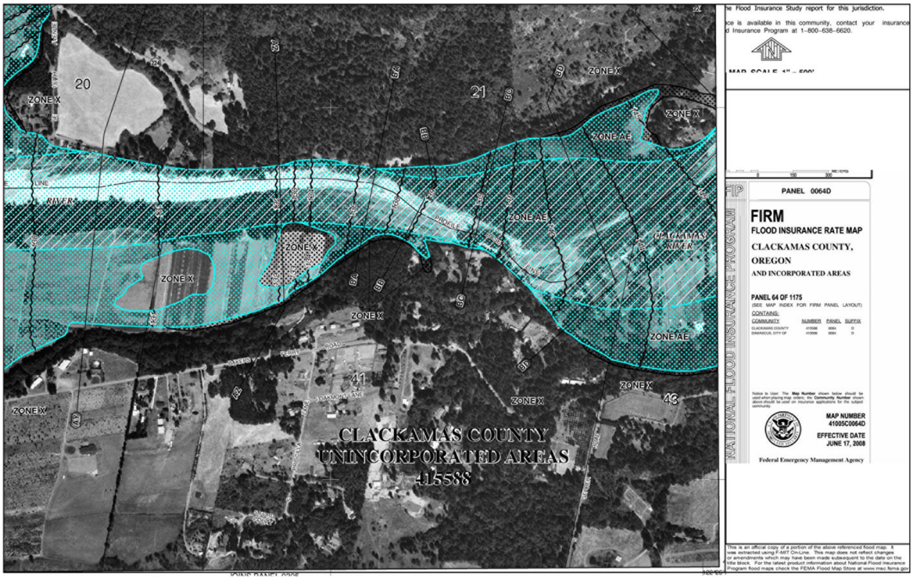

Fig. 1 FIRM from Clackamas County, Oregon

the 200-year flood and the 20-year flood. The map segment also displays ground elevation contours and indicates the location of buildings. The Parksville map is one of six of the nine MAs that do not include an aerial photo base. Like all MA maps, however, the Parksville map does include a panel with more information regarding map contents and an identification panel that includes an "Issue of mapping date," among other things.

We now provide examples of NMA maps from BC that serve as examples of flood hazard maps that do not provide a strong foundation for effective land use planning. The first map is from the City of New Westminster, which contained just four of our protocol items and is shown in its entirety in Fig. 4. This map uses a light-colored shading to indicate the location of areas subject to flooding, but provides no additional details regarding the likely occurrence of flooding or flood elevations. There are no cross sections that can be referenced for additional information, and the scale of the map does not enable the user to determine whether particular parcels of land or particular buildings are located inside the floodplain boundary.

The second map is from the Town of Golden, shown in Fig. 5. This map also contained just four protocol items, and while the map does enable the user to determine the location of particular parcels of land relative to the "Special policy area" that is subject to flooding, the map does not provide any additional flood hazard information and does not contain a legend or the features that are commonly present in a legend that contribute to the map's usability. The special policy area boundary is also hand-drawn, which raises concerns regarding its precision and accuracy.

7 Discussion

Our analyses and findings address our previously stated research questions by (1) determining how many municipalities in BC have a flood hazard map, (2) assessing the content

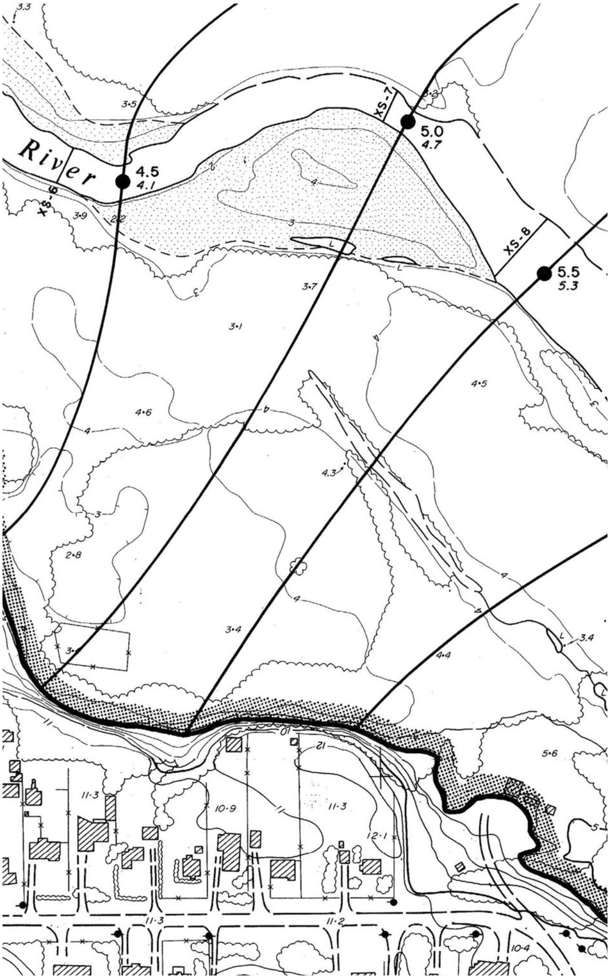

Fig. 2 Segment from City of Parksville flood hazard map

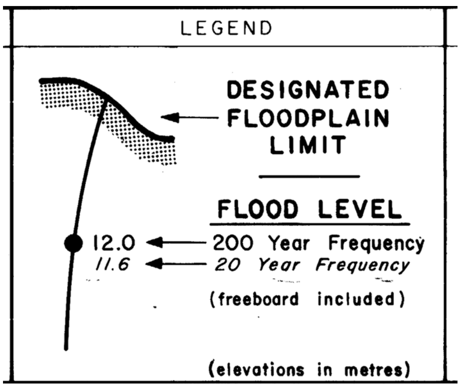

Fig. 3 Legend from City of Parksville flood hazard map

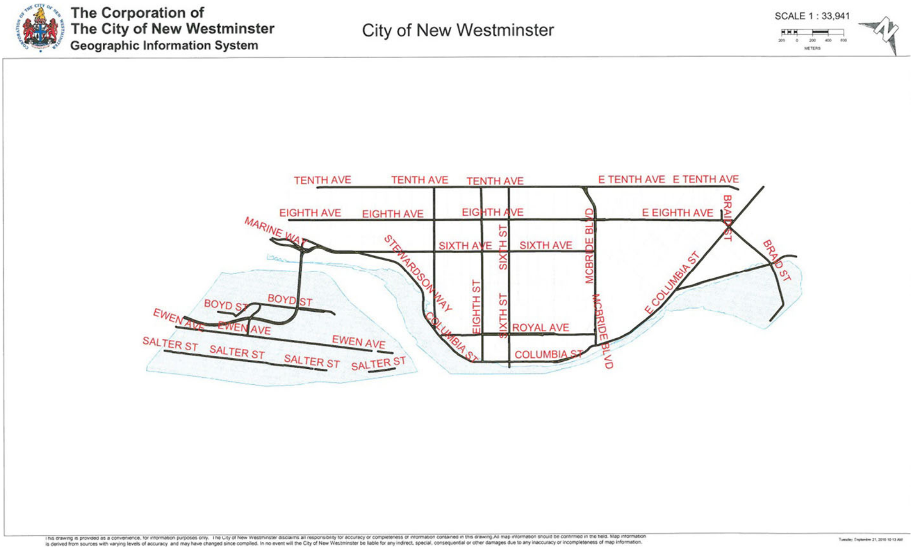

Fig. 4 City of New Westminster flood hazard map

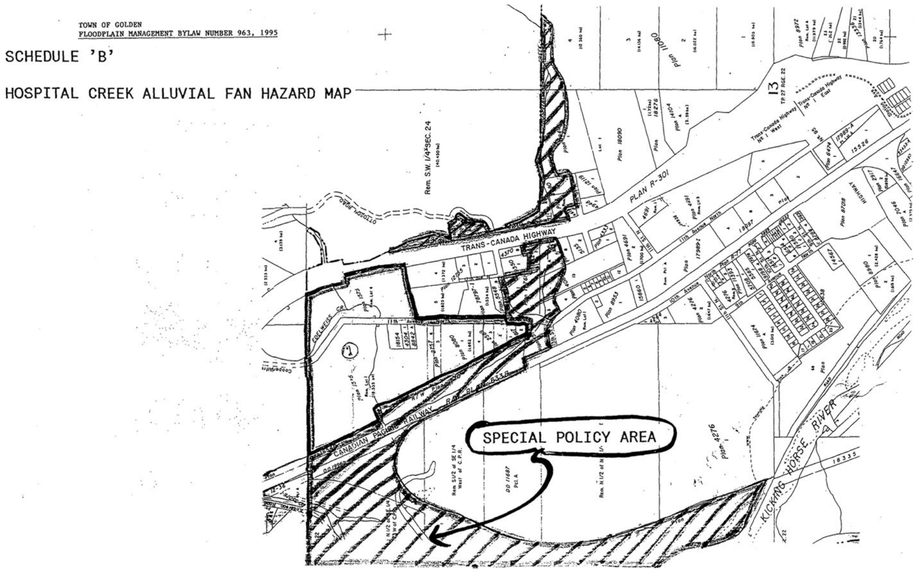

Fig. 5 Town of Golden flood hazard map

of those maps, and (3) comparing maps created under the Mapping Agreement to maps not created under the Mapping Agreement. We found that 85 municipalities in BC did not possess a flood hazard map or an online mapping tool with flood hazard information. This finding is cause for concern, given that effective land use planning for reducing flood losses requires detailed knowledge regarding the location and likelihood of local flood threats. To the extent that planning constitutes acting on knowledge, a lack of knowledge serves as a major barrier to pursuing appropriate action.

Yet our findings also suggest that the mere existence of a flood hazard map may not be sufficient to thoroughly inform municipal land use planning efforts. We found the maps in BC to be lacking many of the items in our protocol, with no map containing more than 15 of our 32 protocol items. The maps were relatively strong in relation to our Administration variable, though it is worth noting that some of the maps lacked features such as legends, north arrows, and/or scales that should arguably be included in every map. These features contribute to any map's usability, and it is not expensive or technically challenging to include them. It is particularly important to indicate the vertical datum that was used to develop the flood elevations shown in the map. Flood elevations on flood hazard maps are referenced to a unique set of vertical datum, which is a specific set of reference points on the earth's surface from which ground and building elevations can be determined by survey. Given that different sets of vertical datum can vary from one another by several feet, accurate survey elevation work for determining the relationship of the elevation of a building site, along with the elevation of a building's components (e.g., crawlspace floor, first habitable space, adjacent grades), relative to flood elevations shown on a flood hazard map requires that the surveyed elevations are either developed using the same vertical datum as that referenced on the flood hazard map or converted to the vertical datum to which the flood hazard map is referenced.

The maps were very weak in an area (i.e., floodplain delineation) in which they should theoretically be strongest, given that flood hazard maps exist specifically to identify and provide details regarding local flood threats. While every map under study did depict the areas within the local jurisdiction that were subject to flooding, most of the maps failed to indicate the occurrence level for the magnitude of flood event that was indicated and failed to include flood elevations for the indicated flood. These are critical pieces of information for land use planners and decision makers because they speak to how likely a flood event is to occur on an annual basis and provide information with respect to "safe" building elevations for a specified flood event. The maps also failed to contain all of the items relating to future flood construction levels and sea level rise, which is not surprising given that the provincial documents that call for such information were published relatively recently. In addition, only a subset of the municipalities under study is located in coastal areas where sea level rise is relevant.

The majority of the maps (62 %) show parcel boundaries, which is a useful feature for planners and property owners alike, in that this feature enables a determination to be made with respect to the location of particular parcels in relation to the floodplain boundary. This is one feature that was more common in NMA maps than in MA maps, and it is worth noting that the FIRMs created by FEMA do not show parcel boundaries. One possible explanation for this is that parcel boundary data are likely to be stored at the municipal (or regional) level, such that federal/state/provincial governments involved in creating flood hazard maps may not have direct access to those data. The FIRMs do, however, contain an aerial photo base, which was present in only five of the maps under study. Aerial photographs are useful for both planners and other users of flood hazard maps (e.g., members of the general public), in that they help users to appreciate the exposure of community assets to flooding in a way that is not as clear in the absence of a photograph.

Only a small portion (18) of the maps showed cross sections for streams, and no maps indicated that the cross sections could be cross-referenced in technical studies. This highlights another advantage of the FIRMs. Cross sections on FIRMs can be further referenced in tables and profiles of the companion FIS to obtain more detailed information about flooding characteristics at, and between, each cross section. This additional information constitutes additional knowledge that land use planners can utilize to guide action for reducing potential flood losses.

Our final research question and set of analyses involved comparing the content of MAs with that of NMAs. We found that MAs had higher scores than NMAs on all of the variables we created, which serves to reinforce the importance of senior government involvement in flood hazard mapping. Maps that were created under the Mapping Agreement between the federal government of Canada and the provincial government of BC were produced according to a standardized procedure that ensured that each map contained particular information that is valuable to land use planners, a procedure that is similar to that used by FEMA to produce FIRMs. The content of maps that were not created under the Mapping Agreement was much less consistent and much less comprehensive on average. To the extent that municipalities are expected to create flood hazard maps on their own, it would appear that they lack either the capacity or the commitment to do so in a manner that is as thorough as that employed by senior levels of government.

While MA maps were generally stronger than NMA maps, all of the maps were relatively weak in comparison with our evaluation protocol. None of the maps under study contained as many as one-half of our 32 protocol items, and none contained more than 73 % of the items associated with any of the three variables we created based on item sources. The maps fared particularly poorly in relation to the items we created based on the Guidelines and related provincial documents, which is perhaps not surprising but nevertheless cause for concern. The Guidelines and related documents were published within the past decade and reflect contemporary knowledge regarding how to reduce flood losses through land use planning. Given that these documents were published relatively recently, it is likely to be the case that most (if not all) of the maps under study were created before these documents were published. If this true, this would help to explain why the maps are generally lacking the features promoted in the documents. However, the fact that the maps are lacking such features highlights a need for updating the maps in order to not only ensure that flood hazard data are updated and accurate, but also to ensure that the maps are designed in such a way as to maximize their value for municipalities wishing to use them as the foundation for effective land use planning.

We now make one final observation regarding the age of the maps under study. Whereas the standard FIRM format includes an indication as to the date that the map went into effect, the maps under study did not generally contain this information. As a result, it is difficult to say for certain whether the flood hazard data contained in the maps are up-to-date. However, seven of the nine MA maps indicated a "Date of mapping issue," with these dates ranging from 1982 to 1995. Thus, even the newest MA map is (as of this writing) nearly 20 years old. It is possible that at least some of the NMA maps were produced more recently, but even if that were true, it would seemingly be the case that the most informative maps (i.e., the MA maps) would be the most outdated, with the most up-to-date maps (i.e., the NMA maps) being the least informative. In either case, neither set of maps provides a current and comprehensive foundation for converting flood hazard knowledge into action aimed at reducing flood losses.

8 Recommendations

Flood hazard maps provide a critical foundation for moving from knowledge to action and for utilizing land use planning to help reduce flood losses. Our findings give reason to believe that municipalities in BC currently lack sufficient knowledge to pursue effective action with respect to reducing flood losses. The majority of municipalities apparently do not possess a flood hazard map, and those that do apparently possess maps that are outdated and/or not very informative.

These findings are generally consistent with our expectations. As we stated earlier, the primary purpose of this paper was to assess the status of flood hazard maps in a jurisdiction where municipalities hold the primary responsibility for addressing local flood hazards and do not receive outside assistance in developing flood hazard maps. In general, the current status of municipal flood hazard maps in BC suggests that when responsibility for flood mapping is allocated to municipal governments with no contribution from senior levels of government, municipalities are likely to lack the capacity and/or commitment to produce any kind of flood hazard map, much less a high-quality map that can adequately inform local decision making.

With this in mind, we now specify particular recommendations for various levels of government that can be followed in Canada and elsewhere to promote the creation and use of flood hazard maps and land use planning. First, we recommend that senior levels of government (e.g., federal and provincial/state) play an active role in making certain that municipalities have access to detailed and current information regarding flood risks in their jurisdiction. Our findings suggest that it is not feasible to expect that every municipality will develop a flood hazard map on its own and that assistance from higher levels of government is therefore critical. Senior levels of government can draw upon the experiences of the NFIP in the USA and the (defunct) FDRP in Canada to design and implement a program for mapping flood hazards in municipalities and for encouraging municipalities to use the maps to guide their land use planning efforts. These programs have involved partnerships between federal and sub-federal levels of government that have been successful in mapping hazardous areas while simultaneously requiring municipalities to engage in floodplain management activities that take advantage of the information provided in the maps.

Governments that conduct flood hazard mapping programs should endeavor to provide maps to all municipalities, or at a minimum those that are known to be at immediate risk from flooding (e.g., because they are near water bodies and/or because they have experienced flooding in the past). The maps should contain all of the information that municipalities need to make informed land use and development decisions, including the features contained in our evaluation protocol. The maps created by FEMA under the NFIP provide a good template, though they could be enhanced by including additional features such as parcel boundaries that can be examined in relation to floodplain boundaries and ground elevation contours that can be compared with flood elevations. The Guidelines and related provincial documents in BC also recommend that creators of flood hazard maps take into consideration the potential impacts of climate change on future flood events, including changes in floodplain boundaries and flood elevations. Flood hazard maps can account for uncertainty in projections of climate change impacts by erring on the side of caution when determining the location of floodplain boundaries, either by incorporating a buffer around the boundaries or by calculating and depicting the boundaries for less frequent (but higher magnitude) flood events, such as the 500-year or 1,000-year floods.

To be certain, the process of developing flood hazard maps for multiple municipalities will require a significant financial investment. There are reasons to believe, however, that such investments are likely to pay off. A recent study found that each dollar that FEMA invested in flood mitigation project grants saved roughly $5 in expenses that would have been necessary to address the impacts of flooding that would have been expected to have occurred in the absence of the mitigation projects undertaken (Multihazard Mitigation Council 2005). In a very meaningful sense, then, it might very well be cheaper to be safe than sorry.

Federal/provincial governments can further improve the expected payoff from investing in flood hazard mitigation through flood hazard mapping by requiring municipalities to enforce floodplain management regulations as a condition of receiving flood hazard maps and by conditioning eligibility for post-disaster financial assistance on adequate enforcement of the regulations. The two federal programs we reviewed earlier in the paper provide useful guidance in this respect. Under NFIP in the USA, municipalities that receive FIRMs (as well as federally backed flood insurance and disaster financial assistance) are required to enforce floodplain management regulations as a condition of participation in the program; under the FDRP in Canada, areas that were designated as floodplain were subject to particular policies that limited public investment in new development in those areas and limited public disaster financial assistance to residents of such areas. By requiring municipalities to engage in floodplain management practices, potential flood losses and federal expenditures on structural protections and disaster assistance can both be reduced. Furthermore, by requiring that municipal floodplain management practices be grounded in the flood hazard information contained in flood hazard maps, senior governments can increase the extent to which the maps are actually used by municipalities to support local land use planning.

9 Directions for future research

Our analysis focused on whether municipalities in BC possess a flood hazard map, and whether municipal flood hazard maps that do exist contain certain features that contribute to their informative value and usability. While we found that the majority of municipalities do not possess a flood hazard map and that existing maps tend to lack many important features that contribute to their usefulness, the extent to which this is problematic will depend in part upon how flood risks vary across the province. Future research can make a contribution to our understanding of flood risks in BC and the importance of senior government involvement in municipal flood hazard mapping by determining whether there is any association between flood risks (or flood history) at the municipal level and the presence of flood hazard maps. In other words, are municipalities that are most at risk from flooding more likely to possess a flood hazard map, or is the likelihood that a given municipality will possess a flood hazard map determined by other factors besides local flood risk levels? In addition, it would be useful to know whether the content and quality of flood hazard maps that municipalities possess tends to improve with local flood risk levels. It seems reasonable to hypothesize that municipalities that are more at risk from flooding would be more likely to possess either a flood hazard map that was produced by a senior government or that was produced by the municipal government itself, though additional research would be necessary to test this hypothesis.

10 Conclusion

It has been said that "Without knowledge action is useless, and knowledge without action is futile."[3] Within the context of societal responses to flood hazards, action in the form of land use planning requires knowledge in the form of flood hazard mapping in order to be useful and effective for reducing potential flood losses. It stands to reason that the geographic distribution of such knowledge will depend in large part upon the extent to which senior governments contribute to the production of municipal flood hazard maps. In jurisdictions where senior governments make no contribution to municipal flood hazard mapping, widespread flood hazard mapping across municipalities is unlikely to occur because many municipalities will lack the capacity and/or commitment necessary to pursue flood hazard mapping on their own; in jurisdictions where senior governments make a major contribution to municipal flood hazard mapping, municipalities can be provided with detailed flood hazard maps that can usefully inform action aimed at addressing local flood hazards.

Our evaluation of municipal flood hazard maps centered on the Canadian province of BC, where municipalities do not receive outside assistance in flood hazard mapping. The findings we presented highlight the potential costs associated with the decision on the part of senior governments to make no contribution to municipal flood mapping, in that the majority of municipalities in BC do not possess a flood hazard map of any kind, and the remainder possess flood hazard maps that are outdated and/or lacking in features that contribute to their usability. Whereas scholars promote the use of land use planning to help reduce potential flood losses, municipalities cannot appropriately employ land use planning for such purposes if they lack detailed, up-to-date information regarding the location and expected frequency of potential flood hazards. Our findings suggest that municipalities might lack the capacity and/or commitment to produce local flood hazard information on their own, which points to the critical role that senior governments can play in helping to reduce flood losses at the municipal level. By implementing flood hazard mapping programs similar to those currently operated in the USA or to the FRDP that was previously operated by the federal government of Canada, senior governments can provide municipal governments with both the knowledge they need to plan effectively for reducing flood risks and the incentive to act on that knowledge.

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[3] Attributed to Abu Bakr, father-in-law of the Islamic prophet Muhammad.

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