



Millstream Watershed Visualization Project

*Identifying watershed issues, values and strategies
using participatory modelling & participatory mapping*



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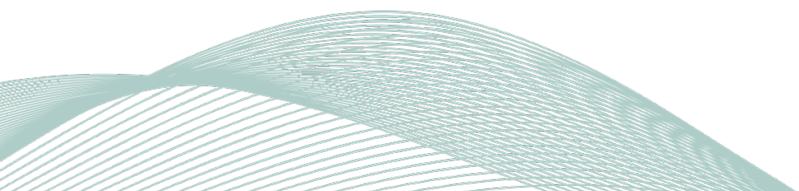
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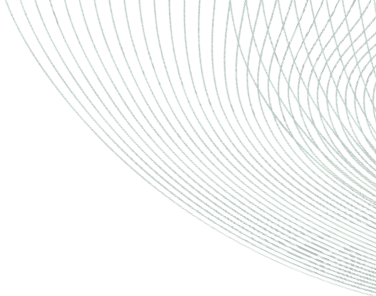
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We respectfully acknowledge that the Millstream Watershed is part of the unceded Lands of the Coast Salish Peoples. We specifically honour the Xwsepsum (Esquimalt), Lekwungen (Songhees), Sc'ianew (Beecher Bay) and W̱SÁNEĆ Peoples, represented by the Tsartlip, Pauquachin, Tsawout, Tseycum and Malahat Nations.

For countless generations, these communities have nurtured a deep cultural, spiritual, and ancestral connection to this Land. They have been their stewards, protectors, and knowledge-keepers of this ecologically rich, vibrant, and biodiverse region. We are deeply grateful for the privilege of living, working, and learning in these traditional territories.

Hay'sxw'qa si 'em (hy-sh-kwa sea-em) - Thank you, honourable ones.

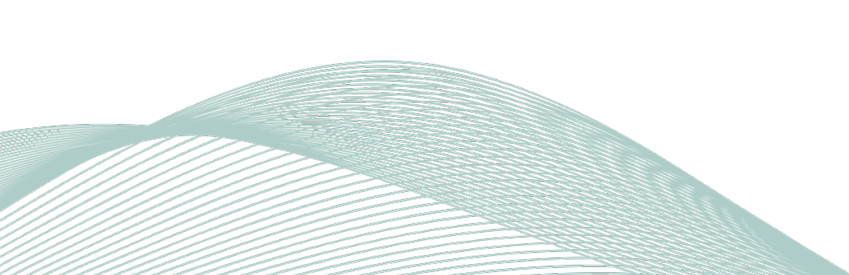


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1. Introduction

Watersheds, as a geographical unit, capture the ecological services, interactions, and functions that are critical to the health and wellbeing of local flora and fauna and the resources needed for human livelihoods and development (Castro et al., 2016; Yoneda et al., 2018). The health of watersheds face numerous risks that endanger their ecological integrity and the services they provide, and thus, it is critical to implement effective watershed management strategies, such as those that relate to flood protection and safeguarding of water resources (Lubis, 2022). In particular, climate change presents a number of risks to watersheds, as it alters and disrupts hydrological processes due to changes in precipitation and temperature (Tsvetkova & Randhir, 2019; Marshall & Randhir, 2008). Climate change exerts impacts on streamflow, sediment loading, and water nutrient levels, affecting water quality, aquatic habitat, and the overall health of watersheds (Marshall & Randhir, 2008).

Other major risks to watersheds include urbanization. Urban development can lead to the degradation of watersheds through pollution and alteration of natural water flow patterns (Sharma et al., 2020; Aboelnour et al., 2020). Human activities and development in watersheds typically result in severe adverse effects to the ecosystems and ecosystem services in these watersheds (Peters & Meybeck, 2000), presenting a need for planning and management strategies that contribute to watershed resilience and local sustainability (Gamble & Hogan, 2019). These strategies must be informed by considerations around the trade-offs between conservation efforts and developmental imperatives, while incorporating a range of environmental, social, cultural and economic factors (Sadeghi et al., 2023). Accordingly, holistic and integrated approaches to watershed planning and management are needed to prioritize long-term ecological health while addressing the diverse needs of society.

Integrated watershed management involves a recognition of the range of and interactions among social, economic, environmental, and cultural considerations surrounding the protection of water resources and (broadly) the health and wellbeing of the ecosystems and communities within the watershed (Tang & Adesina, 2022; Ikhlas & Ramadan, 2024). Integrated approaches to planning and management involve not only strategies and policies that target water systems within a watershed, but also the associated built and natural environments surrounding these systems (Wang et al., 2016; Wani et al., 2008). In addition, integrated watershed planning and management require stakeholder engagement and participatory practices that empower local community members by involving them in decision-making processes and fostering ownership of conservation efforts (Kolavalli & Kerr, 2002; Chandrakar et al., 2016). Such engagement can include a range of different people and groups, such as local residents, Indigenous communities, government agencies, non-governmental organizations, and others.

The Systems-based Visualization Tools for Integrated Watershed Management project is a research effort that develops an experimental interactive visualization tool for supporting integrated watershed management planning and stakeholder engagement in the Millstream Creek Watershed (British Columbia, Canada). The project uses a community-based participatory approach, and it involves engaging local and regional governments, non-governmental organizations (NGOs), researchers, and other stakeholders to develop the tool and to identify watershed strategies and issues to be examined using the tool. The research project consists of three phases:

- **Phase 1** uses workshop methods to engage stakeholders in identifying issues and potential strategies in the Millstream Creek Watershed and to co-design the visualization tool.
- **Phase 2** develops the visualization tool, which consists of a virtual environment that users experience from the first-person perspective to see and learn about the implications of different watershed management options.
- **Phase 3** tests the visualization tool in another stakeholder workshop, where participants try the tool and provide feedback on its usefulness in terms of enhancing understanding of issues and possible strategies for addressing these issues in the Millstream Creek Watershed.

This report details the methods and outcomes of the first phase of the project. For more information on the full research project, visit the project webpage:

www.triaslab.ca/watershed

2. Millstream Creek Watershed

2.1. Location and Physical Characteristics

The Millstream Watershed (Fig. 1) is located on southern Vancouver Island, British Columbia. The watershed encompasses an area of 26 km², with a diverse and complex landscape consisting of natural and urban areas. Extending from the Gowlland Range to Esquimalt Harbour, the watershed falls primarily within the Districts of Highlands and Langford, with portions in Colwood and View Royal (Fig. 2).

Figure 1. Millstream Watershed map

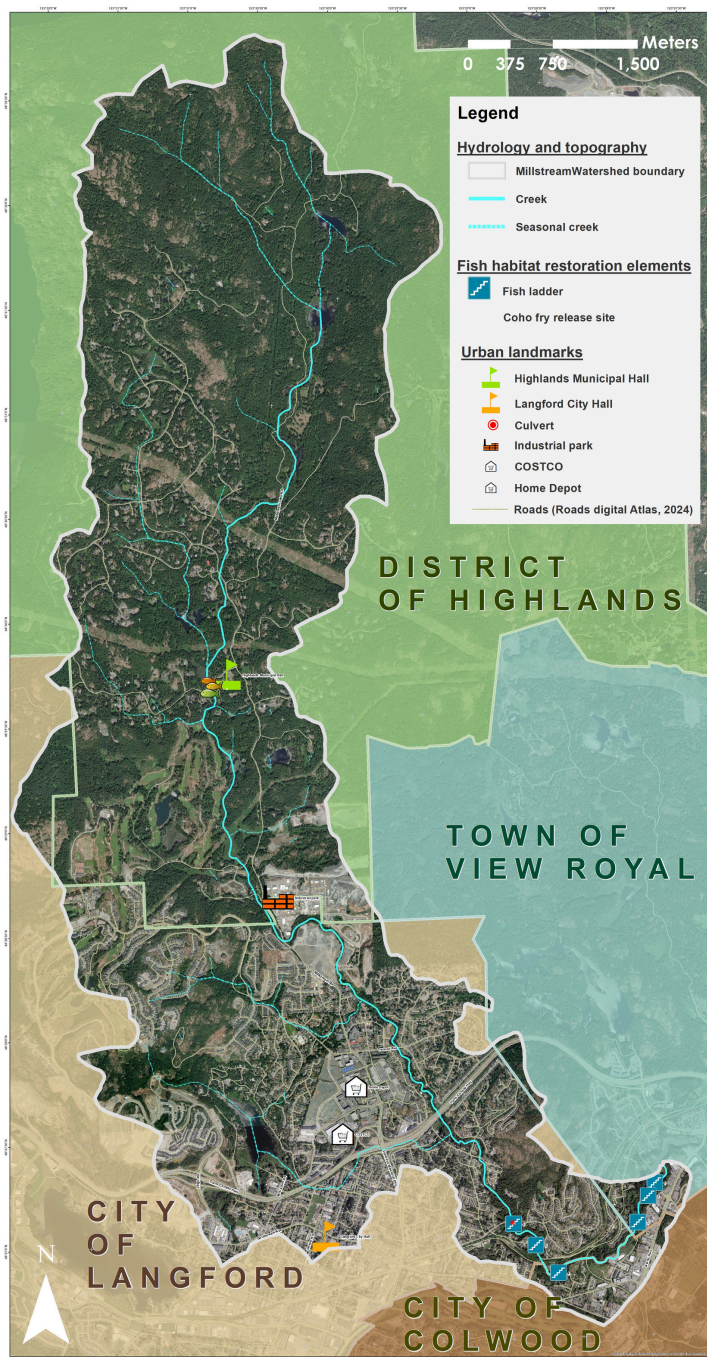
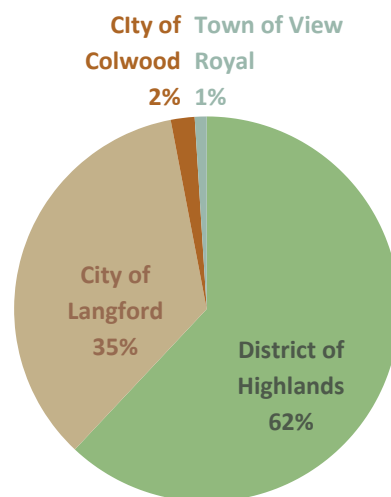


Figure 2. Millstream Watershed's surface area by each municipality



The area's topography was shaped by glacial retreat around 12,000 years ago, resulting in a diverse landscape of rocky outcrops, hills, lowland lakes, and wetlands (Weston and Stirling, 1986; Millstream Watershed Management Forum, 1999). The underlying geology is mainly comprised of bedrock formations and glacial deposits (SHIP Environmental Consultants Ltd., 1996). Millstream Creek serves as the primary waterway, nourished by multiple tributaries such as Earsman Creek. The watershed also includes over 15 ponds and 7 lakes (some of which have been altered by dams and weirs), as well as canyons, cascades, waterfalls, and other landscape features (SHIP Environmental Consultants Ltd., 1996).

2.2. Biodiversity and Ecosystems

The Millstream Watershed supports diverse ecosystems, ranging from cedar-sword fern and skunk cabbage communities in wetter areas to Garry oak and arbutus-covered rocky outcrops in drier areas (Millstream Watershed Management Forum, 1999). This diversity of habitats provides refuge for a wide array of wildlife species, including:

- Birds: Bald eagles, turkey vultures, great blue herons, and various songbirds.
- Fish: Cutthroat trout, coho salmon, smallmouth bass, rainbow trout (introduced), and stickleback.
- Mammals: Black bears, black-tailed deer, cougars, otters, and raccoons.

2.3. Land Use and Human Activities

Land use varies significantly across the watershed. According to the Millstream Watershed Prototype Study (SHIP Environmental Consultants Ltd., 1996), the upper, northern region is predominantly rural, with scattered houses, home businesses, and hobby farms. The lower, southern region is urbanized, with residential, institutional, commercial, and light industrial uses. Major transportation routes, including the Trans Canada Highway, Highway 14A, and the Esquimalt and Nanaimo Railway, traverse the lower watershed. Human activities have significantly impacted the watershed. Land clearing and paving for development have led to increased runoff, erosion, and flooding. Contaminated runoff from urban areas, farms, and failing septic systems has also degraded water quality (Ministry of Environment British Columbia, 2011). The construction of dams and weirs has altered natural flow patterns in Millstream Creek and its tributaries (SHIP Environmental Consultants Ltd., 1996).

2.4. Environmental Concerns and Management

Water quality in the watershed faces increasing threats from runoff, erosion, and pollution caused by human activities. While strategies such as improved stormwater management, riparian vegetation restoration, septic system upgrades, and community education have long been identified as important for the watershed (Millstream Watershed Management Forum, 1999), their implementation has not been comprehensive. The construction of dams and weirs has fragmented the fish habitat in Millstream Creek and its tributaries. Additionally, the former Westshore Motorsports Park within the watershed raises concerns about potential soil and sediment contamination with heavy metals from past motorsports activities (Dheenshaw, 2022). Further investigation and remediation may be necessary to address potential human and environmental health risks.

The Millstream Watershed faces significant challenges arising from urbanization, alterations in land use, and contamination. Effective management strategies and continual restoration efforts are imperative to ensure its long-term health and sustainability. Emphasizing the conservation of riparian zones (i.e., the transitional areas between water and land) is of paramount importance for maintaining watershed health (Naiman, Decamps, & McClellan, 2010). These zones play a critical role in filtering nutrients, stabilizing banks, providing habitat, and regulating water temperature (Naiman & Decamps, 1997). Continuous monitoring, scientific inquiry, and cooperative management are essential for addressing persisting challenges and safeguarding this vital natural resource for posterity. Efforts have been made toward local ecosystems, such as the Millstream Fishway which is a major restoration project completed in 2020 by the Peninsula Streams Society (2021) that aims to improve fish passage and restore connectivity for coho salmon and cutthroat trout. However, more efforts are needed to effectively protect and enhance the social and ecological values and health of the watershed.

3. Methods

The study uses workshop methods to engage local government and stakeholders in the research and the development of an experimental tool for supporting integrated watershed management and planning. The workshops were offered three times in March 2024, and each workshop ran for 2.5 hours. The workshop began with a presentation on the research project and its objectives, the concept and purpose of the visualization tool, and the reasons for requiring stakeholder input in the tool. Then, the workshop attendees were given letters of informed consent to participate in the research for them to sign (and were given opportunities to ask any questions before signing and participating in the study).

Following the presentation, participants engaged in a series of activities that were organized into two parts of the workshop: (1) participatory modelling and (2) participatory mapping. The participatory modelling activities involved participants identifying and systems mapping relationships among key watershed issues, values, and potential management strategies (e.g., Gray et al., 2015). The participatory spatial mapping activities involved participants identifying locations of value, challenges, and suitable targets for management strategies on a map of the Millstream Creek Watershed (e.g., Burdon et al., 2022). This part of the workshop also included an exercise where participants identified (in written form) the visual and acoustic features of one of the locations on the map as it would appear/sound if watershed management strategies were implemented and effective.

3.1. Participants

Participants were recruited through online searches and snowball sampling techniques. Potential participants were invited to participate in one of the offerings of the workshop. In total, 17 participants attended the workshop, representing a variety of stakeholder groups with interests and involvement in the Millstream Creek Watershed. These participants included people from environmental organizations (n=10), local government (n=4), academia (n=2), and the private sector (n=1).

3.2. Participatory Modelling

Participatory modelling involves facilitated exercises where stakeholders create systems maps of the interactions and relationships surrounding an issue, and these systems maps can then be used in analytical and modelling efforts (Barbrook-Johnson & Penn, 2021). In this workshop, participants were organized into groups of 2 to 3 individuals, and each group worked on developing a system map. First, participants identified the values associated with the health and wellbeing of the Millstream Creek Watershed and its communities. Next, participants identified the key challenges facing the watershed and threatening to adversely affect the values. Participants then drew connections between the challenges and values these challenges threaten/affect, thereby identifying relationships in the system.

After examining the connections among values and challenges in the watershed, the participants brainstormed and identified the systems relationships of strategies aimed at addressing the challenges and protecting/enhancing the values. The participants then rated on a scale of 1 (low) and 10 (high) their level of confidence in a relationship with respect to whether it occurs in the Millstream Creek Watershed and how strong it is. Finally, a plenary discussion was held, where the different groups briefly described their systems maps and provided overviews of the relationships among values, challenges, and strategies in the watershed. The systems maps were aggregated, and the full system was analyzed using network analysis techniques. This analysis involved examining the relationships formed with the different system elements, or nodes, using centrality, in-degree, and out-degree metrics. These metrics respectively refer to the number of connections associated with a node, the number of connections where the node is the target of the interaction, and the number of connections where the node is the source of the interaction.

A scenario modelling exercise was conducted following the network analysis. This exercise involved a “what-if” analysis of the impacts of various strategies on the system, meaning that simulations were done that illustrate the effects that implementing different strategies would have on the watershed values and challenges. Using the Mental Modeler software, the scenario modelling and simulations were done by “activating” certain nodes (i.e., increasing their strength and impact on the system) to highlight the effects of these nodes on the system. The results of the scenario analysis revealed the potential effects and outcomes of different interventions applied in watershed management efforts.

3.3 Participatory Mapping

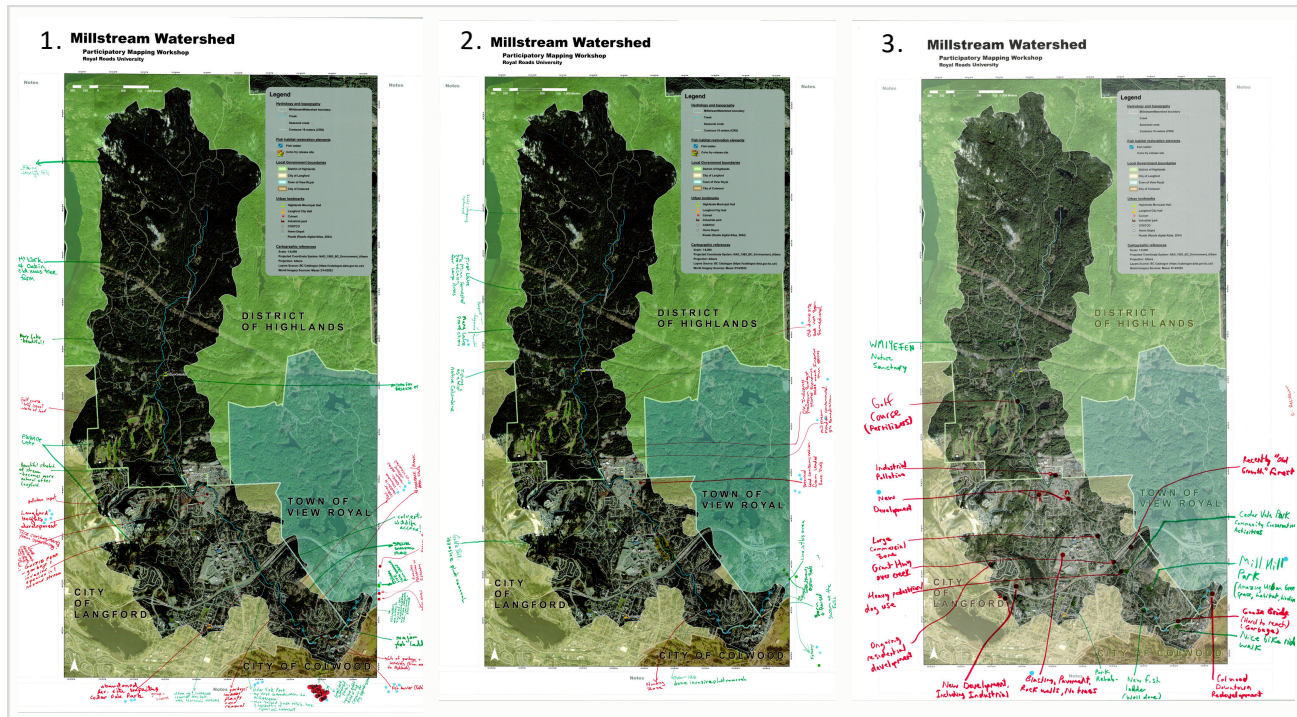
Participatory mapping is a useful technique for capturing and communicating local values and knowledge in a spatial format among stakeholders during workshops and among community members, organizations, and government agencies while catalyzing social change through bridging information gaps and encouraging collaborative decision-making (Cochrane & Corbett, 2020). The technique enables collaborative examinations of issues and the co-creation of spatial knowledge and understanding of challenges, resulting in a rich representation of an area's social and cultural complexities (Burdon et al., 2019). This workshop engaged stakeholders in a participatory mapping exercise that involved identifying "special places," high-value locations, and areas of concern and issues in the Millstream Creek Watershed. The mapping activities were followed by an exploration of potential management strategies and an activity that involved mentally visualizing a desirable future state for the watershed.

The participatory mapping was done using a large (30x60 inches) printed map at a 1:9,000 scale, which workshop participants used to identify locations within the Millstream Creek Watershed. This map used the North American Datum of 1983 (NAD83) and the BC Environment Albers projection system, and it displayed the watershed boundary, streams, 10-metre contour intervals, municipal boundaries, landmarks (e.g., Highlands Municipal Hall, City Hall of Langford), and environmental features relevant to the watershed health, such as fish ladders and fry release points. In addition, major roads were displayed on the map to provide a reference for the participants as they identified different locations in the watershed. Data for the map layers were sourced primarily from the BC Data Catalogue. The base layer used a high-resolution (31 cm ground resolution per pixel) WorldView-3 satellite image captured by Maxar on February 14, 2023. Other data sources included Roads Digital Atlas (2024), which was used to identify major roads on the map.

The participatory mapping exercise began by inviting participants to think about and discuss their "special places" (Schroeder, 2002), meaning locations in the Millstream Creek Watershed that have personal aesthetic and emotional value. This prompted participants to share stories about their experiences with these places, revealing their sense of place tied to their memories.

Participants used green stickers to mark the special places on the printed map. Following the special places exercise, participants used red stickers to identify locations experiencing severe environmental challenges or concerns. While marking these places, participants explained the significance and nature of the issues in the locations on the map via a group discussion. Each participant then received three blue stickers to "vote" on which they felt were the most significant and noteworthy places of value and/or pressing concerns, which resulted in the identification of areas of shared value and concern.

Figure 3. Outputs from each workshop session (1, 2, 3).



Following the participatory mapping exercise, participants were asked to develop/identify strategies for managing the watershed, namely strategies that could be targeted at the areas marked with blue dots. The participants had a chance to revisit the system maps data through a gallery walk, which allowed them to engage in peer-to-peer discussions and exchange ideas in an informal setting. They also brainstormed using their personal knowledge, experiences, and concerns. To organize the participants' ideas and discussion points, the potential strategies were classified into themes that align with the climate-biodiversity-health nexus framework developed by Newell (2023) to support integrated planning efforts. Specifically, the strategies were classified in terms of whether they contributed to climate action, biodiversity conservation, community health, or something else.

The final activity of the workshop was a visualization exercise, where participants envisioned an ideal future state for the Millstream Creek Watershed. The exercise involved participants imagining themselves in the watershed if the strategies identified in the previous stage were implemented and effective and then writing about what they see and hear in these imaginings. The study used a mixed methods approach, collecting spatial, quantitative, and qualitative data to understand stakeholder perspectives within the Millstream Creek Watershed comprehensively. Stakeholder-generated maps were digitized using ArcGIS. Kernel density estimation analysis (using a bandwidth of 2.5 standard deviations) was then employed to identify statistically significant clusters of values and challenges in the watershed. These clusters represent hotspots of place-based interests and concerns.

Qualitative data was collected from various sources in the workshop, including notes written on the maps by stakeholders, transcripts of audio recordings of workshop discussions, strategies written on sticky notes during the climate-biodiversity-health classification exercises, written visualization exercises, and the researchers' observational notes. The analysis was done using NVivo (v. 14), and it involved an inductive coding approach to identify emergent ideas and themes in stakeholder workshop data. This approach resulted in a codebook, as data were iteratively reviewed and examined, and a total of 56 codes were identified. Then, axial coding was employed to systematically categorize coded data and produce a series of coherent themes from the workshop ideas and outcomes. These themes captured key issues, potential areas for improvement within Millstream Creek Watershed, and ideas for developing the visualization watershed planning and management tool.

Following the axial coding, the data on the strategies organized via the climate-biodiversity-health (and "other") framework was analyzed to explore relationships between these strategies/categories and the emergent themes. The potential interconnections among climate-biodiversity-health categories were explored by counting the frequency of assigned strategies to each. Ultimately, the goal was to generate a comprehensive approach that addressed stakeholder needs and fostered a deeper understanding of the interconnected nature of effective watershed management.

4. Results

4.1. Systems Mapping and Modelling

4.1.1. Systems components

As seen in Figure 5, a range of values surrounding the Millstream Creek Watershed emerged from the workshop activities, reflecting a wide variety of concerns and aspirations for protecting and enhancing the watershed. Some values are inherently ecologically-focused, such as biodiversity, stream resilience, and water quality and volume. Others capture the emotional and cultural dimensions of place, such as aesthetic appreciation, sense of place, nostalgia, and Indigenous rights. Values relating to social wellbeing were also identified, such as mental and physical health, inclusion, caring, and trust. Other noted values, such as sustainable coexistence, respect, reconciliation, and trust, represent the importance of fostering relationships, both within communities and among humans and ecosystems.

Challenges identified in the system capture a range of environmental and social issues. Accessibility was noted by multiple participants, specifically in terms of how a lack of accessibility for certain groups and park users limits the opportunities for recreation and nature appreciation. Another major challenge identified by the participants is "weak governance. Weak governance includes issues such as insufficient efforts toward conservation and limited community involvement in decision-making.

Value **Challenge** **Strategy**

Positive connection **Negative connection**

4.1.2 Network analysis

The analysis of the systems map shows that biodiversity has a high level of centrality (Table 1), meaning that it is important in terms of the dynamics and interactions of the system. The education and awareness node closely follows the biodiversity node with respect to centrality, illustrating the role that information sharing and increased awareness about watershed issues and strategies have on the system. Following education and awareness, community outreach and greenspace also exhibited high degrees of centrality.

Although not as high as other nodes in terms of centrality, regulation and enforcement had a relatively high proportion of out-degree connections, which indicates that it has a significant role in influencing other nodes (particularly in terms of implementing strategies and interventions). Similarly, climate change, and the municipal task force have proportionately high numbers of out-degree connections, illustrating that their role in the system relates to the influence they exert on other nodes. In other cases, nodes such as pollution and respect exhibited a bidirectional influence in the system, and these nodes were found to have similar numbers of in-degree and out-degree connections.

Table 1. Types, centrality, and connectivity metrics

Node	Type	Centrality*	Indegree**	Outdegree***
Biodiversity	Value	16	14	10
Education & awareness	Strategy	15	10	9
Community outreach	Strategy	14	7	11
Greenspace	Strategy	11	8	9
Pollution	Challenge	9	9	7
Regulation & enforcement	Strategy	9	3	8
Respect	Value	9	5	4
Water quality & volume	Strategy	8	8	2
Development	Challenge	7	6	7
Invasive species	Challenge	6	6	3
Weak governance	Challenge	6	3	4
Accessibility	Challenge	5	5	3
Climate change	Challenge	5	3	4
Municipal task force	Strategy	5	1	5
* Total number of connections ** Total number of incoming connections *** Total number of outgoing connections				

The nodes with lower centrality values (i.e., than those discussed above) include rehabilitation, storytelling, physical health, resource availability, governance (which in this case refers to clarity of policy), monitoring, sustainable coexistence, and water quality and quantity. In terms of challenges, development, invasive species, weak governance, and accessibility were all found to have relatively low centrality values. These lower values indicate that the nodes have fewer direct effects on other systems elements and dynamics; however, their indirect effects can have a strong influence on the system, particularly if these affect nodes with high centrality values.

4.1.3. Scenario analysis

The strategy-related nodes associated with involvement of organizations, municipal task force, co-management opportunities, funding, storytelling, community outreach initiatives, water management, and education and awareness, and signage were identified as leverage points in the system in terms of their impact and influence on other nodes. This identification was done using sensitivity analysis, which involves examining how changes in a certain node affect the outcomes or state of other nodes in a system.

Table 3 displays the outputs of this analysis, showing the number of other nodes impacted when a particular node is "activated." Activating a node involves setting its value to +1, which increases the influence or activity level of strategy-related nodes using Mental Modeler software. This process helps to observe and analyze the effects on the system, providing insights into how changes in one part of the system can impact others.

Table 2. Impact on the system upon activation*

Nodes	Sensitivity	Nodes	Sensitivity
Co-management opportunities	28	Story telling	24
Municipal task force	28	Respect	19
Involvement of organizations	27	Nostalgia	18
Funding	26	Regulation & enforcement	13
Leadership	26	Vision	13
Resource availability	25	Development	12
Monitoring	25	Weak governance	12
Community outreach	24	Climate change	10
Education & awareness	24	Inclusion	10
Signage	24	Rehabilitation	8
*Activation of node occurs when the input value of node in the system is placed at 1 and rest at 0.			

The involvement of organizations node produced an increase in reconciliation between the landscape and local communities, trust in governance measures, and community outreach efforts for conservation and awareness creation. It also resulted in an increase in a sense of caring towards the watershed, which can bolster rehabilitation efforts, greenspace augmentation, and water management practices. The municipal task force node exhibited a positive impact on watershed regulation and enforcement, indicating that forming such an entity could potentially lead to better regulation of industrial activities and a reduction in adverse environmental impacts. Furthermore, it reduces the existing reliance on professionals and bolster stream resilience, promoting sustainable coexistence within the watershed area.

The co-management had a positive/enhancing influence on storytelling and cross-jurisdictional communication. In addition, these collaborative efforts hold potential for addressing issues around competing interests, while also fostering a deeper understanding of watershed issues among stakeholders. Funding also demonstrated to be a key leverage point, having an enhancing effect on education, awareness, community outreach, and climate change mitigation efforts in the watershed.

The water management node led to an increase in rehabilitation, greenspace augmentation, education awareness, ecosystem services, and climate change mitigation outcomes. As demonstrated by the scenario analysis, watershed management practices and interventions hold the potential to improve (along with environmental factors) community well-being and resilience against environmental challenges. Relatedly, the education awareness and signage nodes produced increases in water management effectiveness, water quality improvement, climate change mitigation efforts, and community outreach initiatives.

The storytelling strategy had an enhancing effect on climate change mitigation efforts, community outreach, and ecosystem services. Storytelling also formed positive relationships with multiple values for the watershed, such as caring, respect, sense of place, and sustainable coexistence among stakeholders within the watershed. Similarly, community outreach positively influenced various components of the system, indicating effective engagement and awareness-raising activities may result in community members becoming more actively involved in conservation efforts that lead to improvements in watershed health. These results suggest that, through these interventions, communities in the Millstream Creek Watershed could build its capacity to address complex environmental issues effectively.

Figure 6. System response to activated nodes
(co-management opportunities, involvement of organizations, municipal task force, funding)

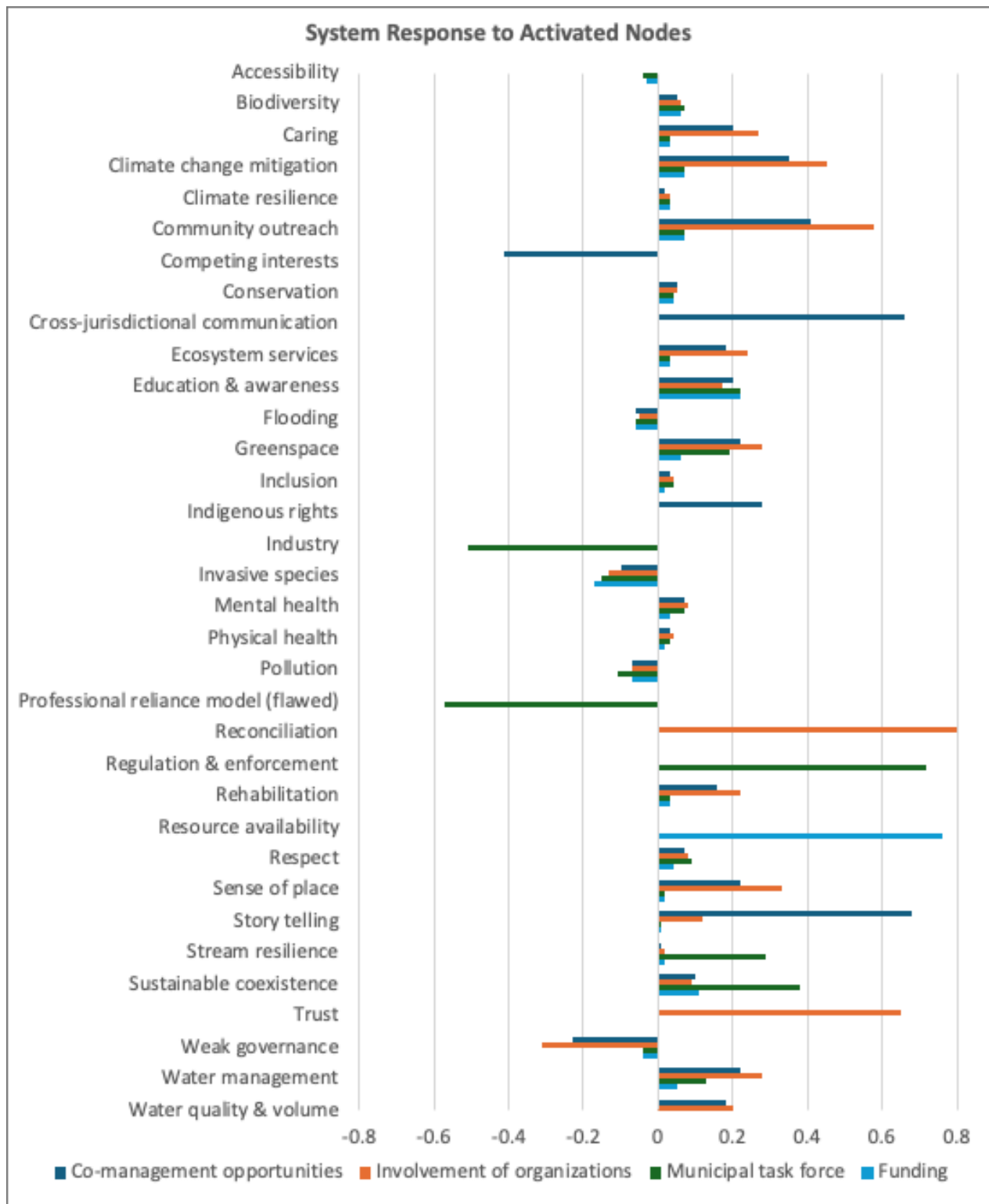
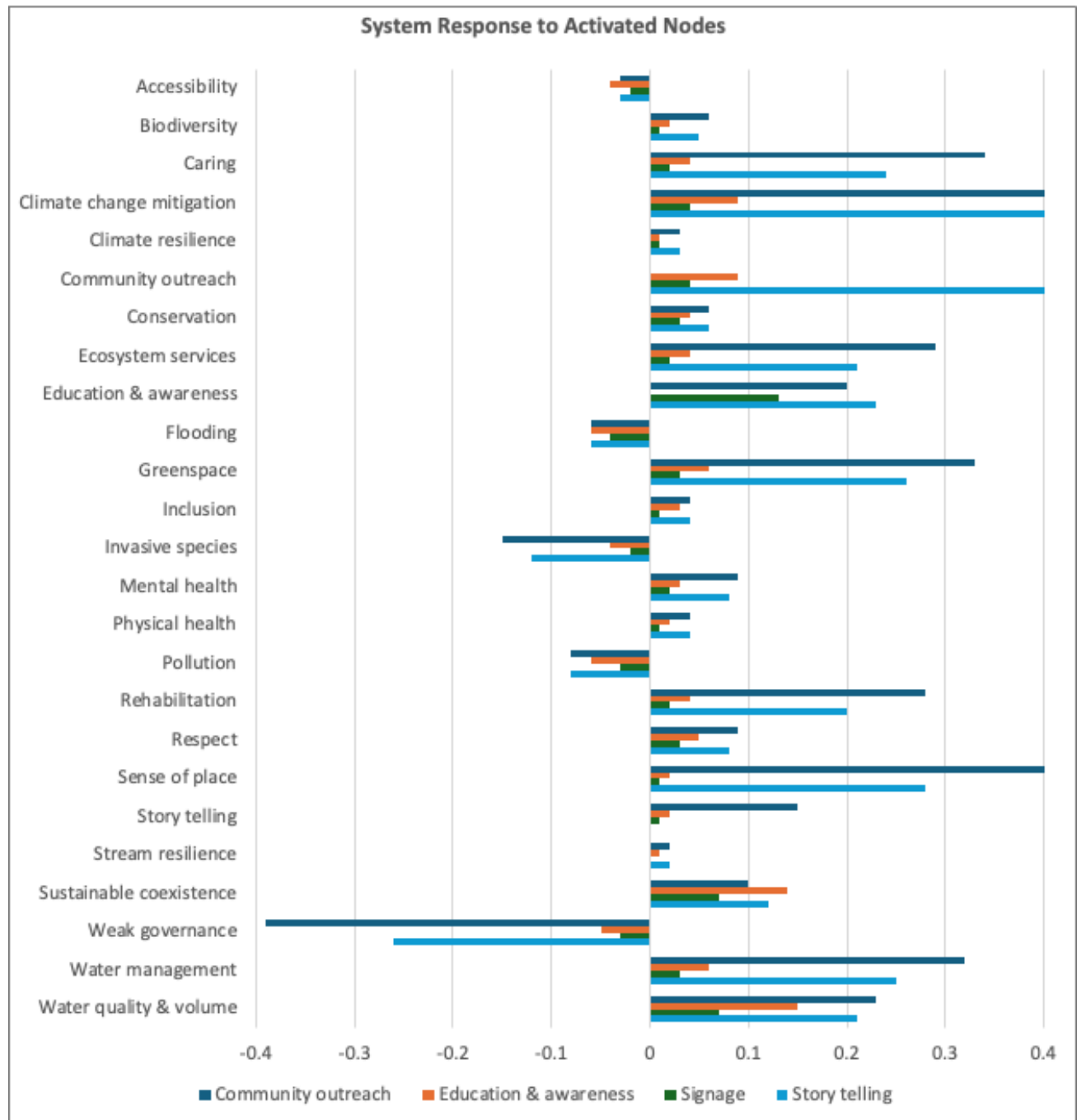


Figure 7. System response to activated nodes
(community outreach, education & awareness, signage, storytelling)



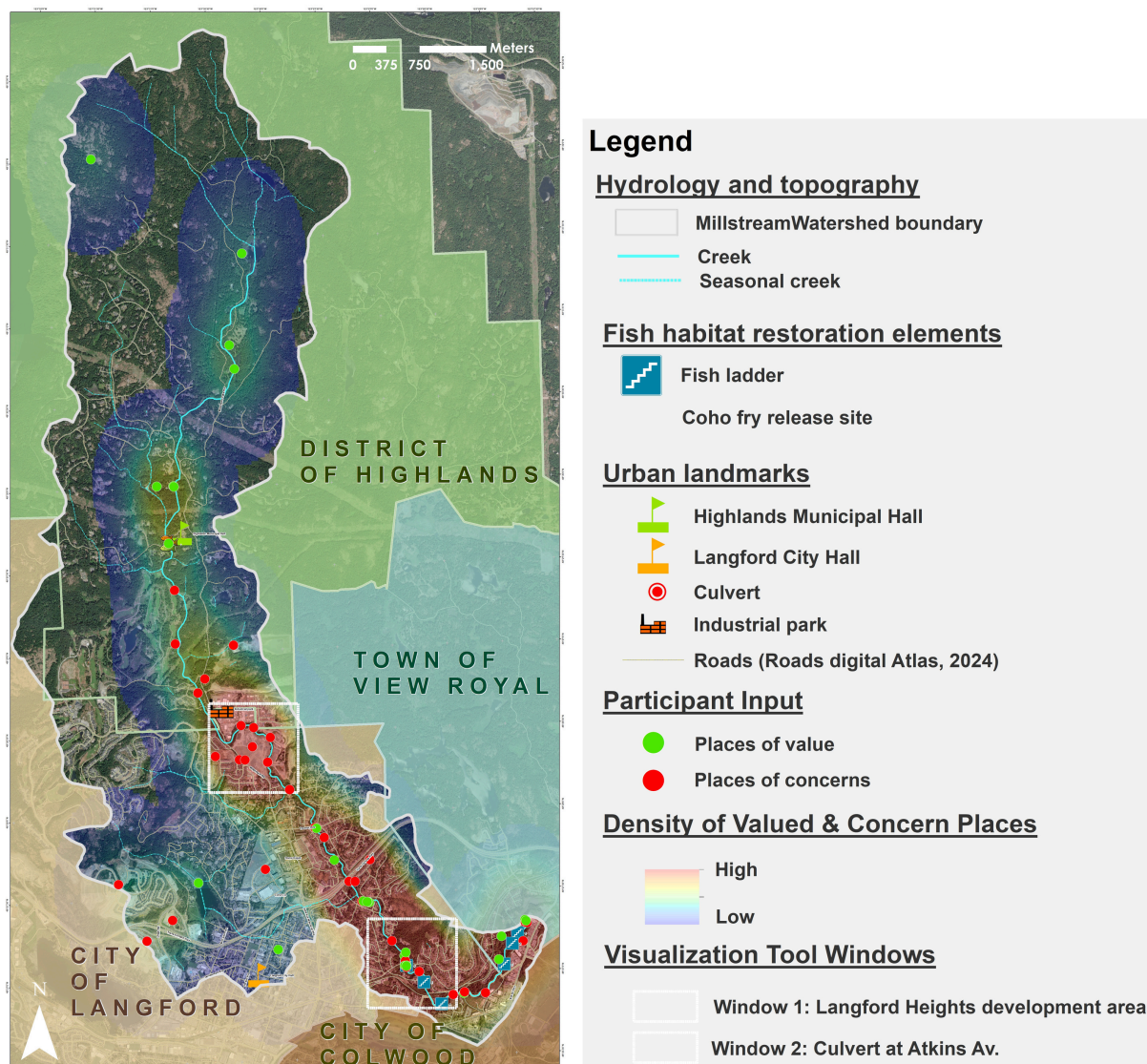
4.2 Spatial analysis and visualization

4.2.1 Heatmap

Figure 8 shows a “heatmap” that was produced through the Kernel density estimation analysis. The heatmap displays areas of clustering, these being higher densities of places of value and concern that were marked by the participants in the participatory mapping exercise. These maps demonstrate that the values and concerns locations are not evenly distributed throughout the Millstream Creek Watershed, as they show distinct spatial clustering.

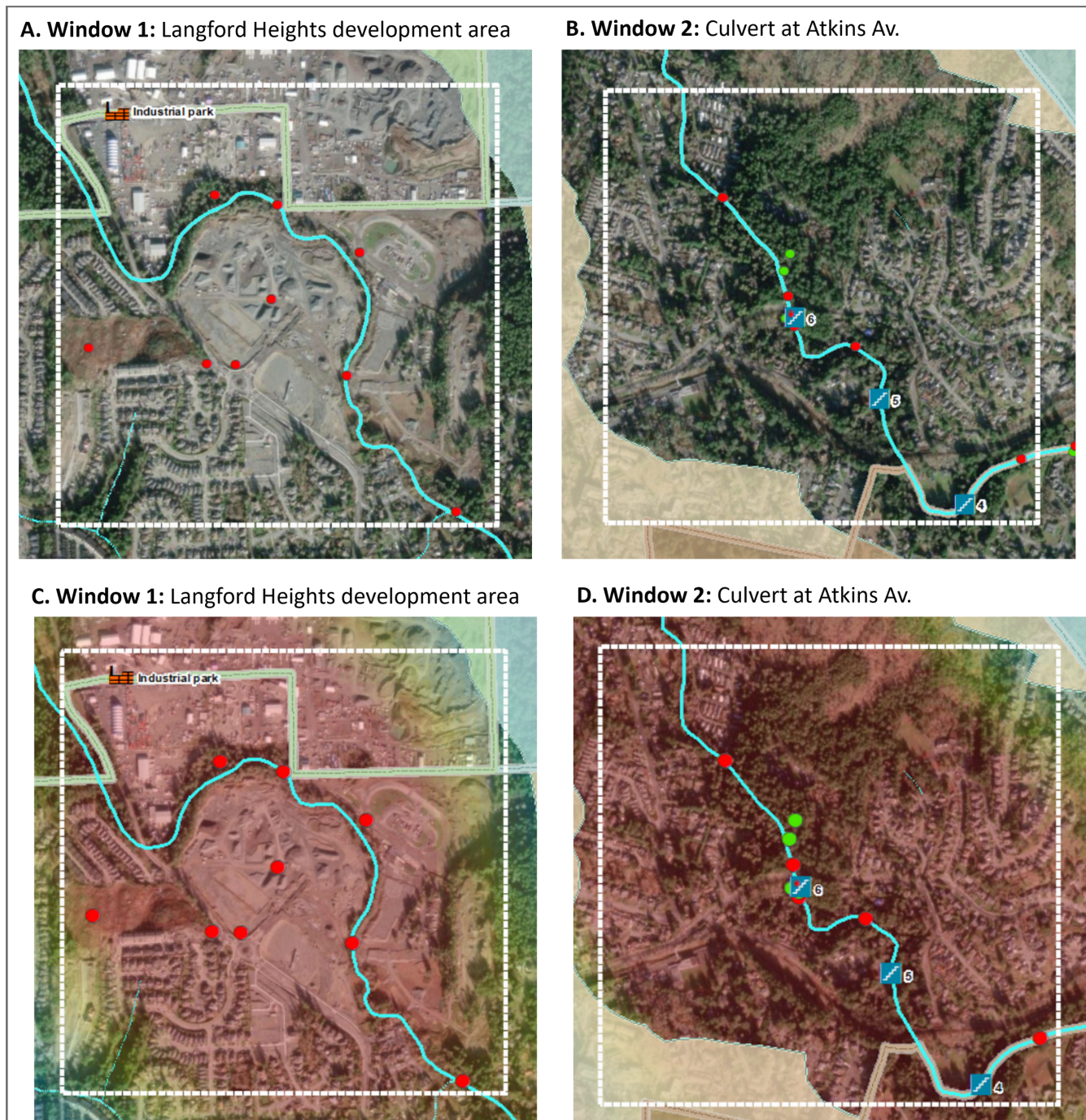
The areas of concern are clustered in places such as the Langford Heights development area. The places of value (i.e., “special places”) data points clustered in locations such as the WMIYETEN Nature Sanctuary (formerly Mary Lake), and areas where these are clustered with little to no clustering of environmental concerns represent places of high ecological value.

Figure 8. Heat map density of valued and concerned places
(Red represents hotspots of environmental concerns. The spectrum of colours from red to yellow to blue represents decreases in point densities.)



Areas that serve as the focus of the visualization tool are marked with white squares. Figure 9 shows zoomed-in views of two locations that are areas of particularly high environmental concern. These zoomed-in views, or “windows,” have been demarcated to support the design of the visualization tool, meaning that these will be areas the visualization users will be able to visit and experience from a first-person perspective. The windows are centred on the major hotspots of environmental issues identified through Kernel density estimation analysis. These views will facilitate the representation of data through real-world objects and images, offering stakeholders the opportunity to discern prevailing issues and potential enhancements.

Figure 9. Maxar satellite imagery (A, B) and corresponding heatmap visualizations (C, D) for 1 km² windows.



4.2.2 Thematic Analysis

The analysis of the data collected through the participatory mapping and strategy identification activities revealed a series of themes. When analyzing the participatory mapping data, the themes capture major categories/types of values held by participants, as well as the key areas of concern with respect to watershed issues and impacts to watershed health. The analysis of the strategies data identified common strategic priorities and types of interventions. Table 3 lists these themes and the respective codes used in the analysis. The themes are described in detail below.

Table 3. Emergent themes from workshop data and associated codes

Category	Themes	Codes (n = references)	Total
Places of Value	Significance And Identity	Belonging (n=x), Childhood Memories, Homescape, Indigenous Heritage-Nature Sanctuary	n=18
	Nature and Biodiversity	Appreciating nature's intrinsic value, Preserved habitat, Riparian habitat relict	
	Environmental Stewardship	Habitat protection, Environmental stewardship, Volunteering	
	Recreation	Beautiful walk, Birdwatching, Cycling, Hiking, Swimming	
Places with Issues	Unsustainable Development	Competing land uses, Land-Use challenge	n=15
	Habitat Fragmentation and Loss	Habitat loss, Habitat barriers, Invasive species	
	Water Quality Issues	Water pollution (industrial, tires, fertilizers, etc.)	
	Waste And Environmental Degradation	Excessive woody debris, Garbage, Gravel, Lacking oxygenation	
Strategies	Governance	Intermunicipal collaboration, Land use policies, Multi-level Governance collaboration, Municipal environmental management initiatives, Ownership	n=23
	Public Engagement and Environmental Education	Collaboration, Advocacy and engagement	
	Riparian Corridors Restoration	Removing invasive species, Species reintroduction, Stream restoration	
	Environmental Management	Fish ladder, Flood management, Rain gardens, Trash removal, Water quality monitoring	
	Accessibility	Public access, Shared-use paths	

Places of value themes include significance and identity, nature and biodiversity, environmental stewardship, and recreation. The significance and identity theme relates to locations that hold deep place meanings for individuals and communities and shape their sense of belonging and attachment to the watershed. Memories are often tied to these places, such as childhood experiences, family homes, or ancestral lands (e.g., "Born and raised, swam at the falls," "My backyard," "Mary Lake protection: respect, Indigenous, peaceful"). The nature and biodiversity theme is associated with areas that are appreciated for their natural state and opportunities for wildlife sightings (e.g., "Estuary life, coho schooling, pinnipeds," "Really tiny but it's a unique riparian zone," "Amazing urban green space, habitat, biodiversity," "Wildlife access!").

The environmental stewardship theme was coded to data about places where communities actively protect and restore their surroundings in recognition of the benefits these efforts have for both humans and wildlife (e.g., "Cedar Vale, done invasive plant removal," "My first introduction to Millstream, helped build the riffle, replanting of riparian habitat," "Community conservation activities," "Major fish ladder"). The recreation theme captures spaces designated for public enjoyment and use, such as parks, trails, and natural areas. These locations offer activities that promote physical and mental wellbeing, such as walking, biking, and hiking (e.g., "Hiking Jocelyn Hill," "Special walking place," "Nice bike ride/walk").

Places of concern themes include unsustainable development, habitat fragmentation and loss, water quality issues, and waste and environmental degradation. The unsustainable development theme captures areas experiencing rapid development leading to negative consequences, including environmental degradation, social uncertainty, and aesthetically unpleasing built environments (e.g., "Dense development: many people and dogs; need recreation access, but overuse?" "Langford heights development," "Abandoned development site impacting Cedar Vale Park"). The habitat fragmentation and loss theme is associated with areas where participants have identified significant land cover changes and/or barriers for native species to thrive (e.g., "Giant Highway over the creek," "Professional biologist stated economic value more important than species," "Recently old growth forest removal," "Poor habitat complexity: structure, gravel, woody debris, lacking oxygenation").

The water quality issues relate to pollution from various sources that negatively affect the health of water bodies (e.g., "Golf course: water quality issue," "Industrial pollution input," "Tire contaminants," "Storm drains from highway"). The waste and environmental degradation theme was coded to comments about significant waste accumulation and environmental damage in these areas (e.g., "Heavy pedestrian and dog use," "Lots of garbage and invasives," "Old dump site has not been remediated").

Strategies themes included clarity in policy, public engagement and environmental education, riparian corridor restoration, environmental management, and accessibility. The governance theme focused on coordinated watershed management achieved through collaborative efforts among diverse stakeholders and across multiple levels of government. Data coded with this theme includes comments about establishing effective governance structures, such as a cross-municipal watershed management board or organization.

Such entities would be designed to address issues related to land-use practices, ownership rights, and environmental considerations within the watershed, while also building a sense of shared responsibility and accountability among all the communities in the watershed. Other strategy themes include public engagement and environmental education, which capture stakeholder collaboration, advocacy, and active public participation in improving watershed management. The theme includes data/comments that emphasize the value of environmental education in shaping the future stewards of the watershed, particularly children, by educating them about the importance of the watershed and encouraging them to appreciate and interact with nature. The strategy theme of riparian corridor restoration relates to efforts toward restoring and enhancing the health of riparian and aquatic ecosystems by removing invasive species, planting native vegetation, and enforcing a minimum setback of 30 metres.

The environmental management theme captures practices such as water quality monitoring, constructing and maintaining fish ladders, employing flood management techniques (e.g., rain gardens), and conducting regular trash removal. Finally, the accessibility theme focuses on improving public access to the watershed by developing a network of shared-use paths. These paths would be open to the public and designed to accommodate a variety of users, including pedestrians, cyclists, and potentially individuals with mobility limitations. Following the thematic analysis of the strategies data, this study analyzed the climate-biodiversity-health (and other) classifications of interventions identified by the stakeholders (Figs. 10 and 11). This analysis aimed to identify the connections between the climate-biodiversity-health groupings and the emergent themes discussed above. This analytical approach resulted in a rich understanding of the relationships between different types of watershed management strategies and the critical sustainability priorities of climate, biodiversity, and health.

Figure 10. Strategies by Theme

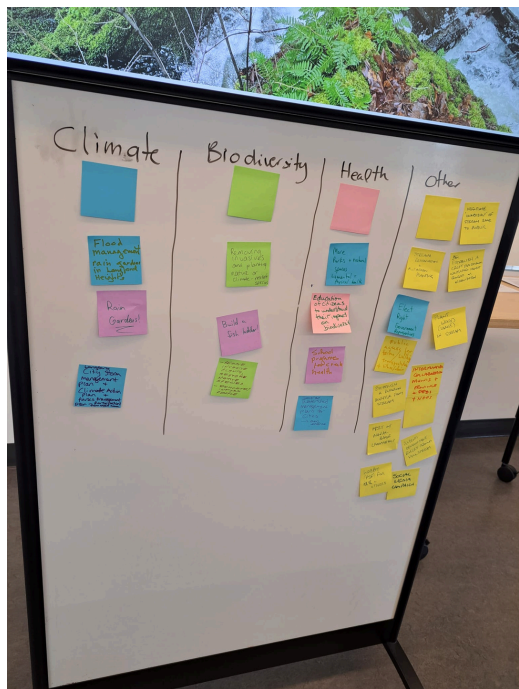
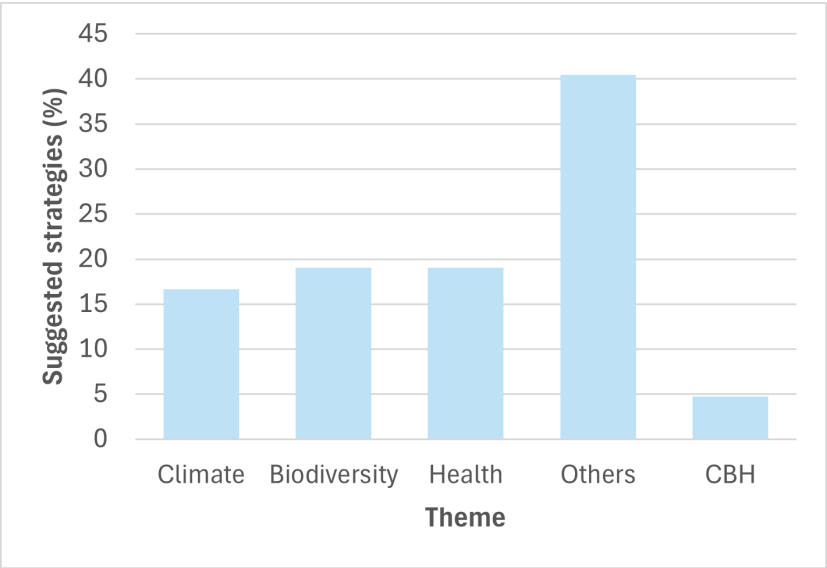


Figure 11. Distribution of Suggested Strategies by Theme



4.2.3 Visualization exercise

The workshop's culminating activity consisted of an individual visualization exercise, wherein participants were encouraged to envision the watershed, or a specific location within it, in its optimal ecological state. This exercise served a dual purpose: 1) to provide the research team with valuable insights into the community's desired conditions for the watershed, and 2) to foster collaborative co-creation of the visual and auditory components of the visualization tool. Participants were asked to form mental images of the watershed, considering the implementation of the strategies identified in the previous workshop activities. The thematic analysis, presented in Table 4, offers a detailed overview of the key visual and auditory characteristics that were identified as part of this desirable state. This analysis is a valuable tool for understanding the elements that contribute to a healthy ecosystem and a positive human experience in the watershed.

The thematic analysis of visualization data revealed a number of different visual and auditory features; however, the most highly-coded themes were visual in nature. This includes riparian corridor restoration (26 references), with a number of the comments relating to improving the health and stability of riparian areas (e.g., “a continuous corridor of green extending 30 meters back from the stream, replacing the bare ground rubble and storm flows entering,” “native plantings would be put in to protect the creek bed and biosphere”). A second frequently coded theme related to environmental management strategies (18 references), which involved the implementation of green and wildlife infrastructure and ecological protection and enhancement efforts (e.g., “rain gardens slowing erosion,” “ladders working together”). Finally, the biodiversity and human health enhancement theme appeared frequently in the data (16 references), which captured the interconnectedness between human and ecological wellbeing (e.g., “a healthy engaging space to enjoy nature and that nature can enjoy,” “the stream connects the community to place, is a refuge for humans and biota alike”).

The combination of the visualizations can be summarized in terms of acoustic and visual elements. The revitalized stream corridor showcases a thriving riparian ecosystem, characterized by a diverse array of native flora and fauna. A substantial 30-metre buffer zone safeguards this ecosystem, while the presence of cedar and fir trees ensures both ecological vitality and user comfort through the provision of shade. The healthy fish population in the stream serves as a testament to the high water quality, which is essential for a flourishing ecosystem. Complemented by rain gardens and stabilized banks, these elements signify the success of the restoration efforts. Inclusivity is a top priority, which includes an accessible trail network catering to both walkers and wheelchair users, as well as a separate bike path, promoting community connection and inclusiveness. The low housing density surrounding the stream fosters an abundance of vegetation, creating a verdant corridor and minimizing environmental impact.

Purposefully positioned viewpoints and entry access points offer ample opportunities for residents and visitors to engage with the natural surroundings. Educational signage, offering insights into the historical, ecological, geographical, and Indigenous perspectives, further enriches the visitor experience, fostering a heightened appreciation for the area. The auditory environment is predominantly tranquil, characterized by the peaceful sounds of the babbling brook, the rustling of the wind through the trees, and the joyful voices of children enjoying nature. The absence of disruptive noises such as construction and traffic only serves to enhance the serene ambiance. Furthermore, a diverse repertoire of bird calls, frog croaks, and insect chirps enriches the auditory landscape, facilitating a deeper connection with the local wildlife.

Table 4. Visualization of emerging codes and frequency.

Category	Codes	Frequency of mention
Landscape (things to watch)	Riparian corridor restoration	26
	Environmental management strategies	18
	Biodiversity and Human Health Enhancement Correlation	16
	Controlled accessibility	8
	Path details	8
	Educational signage	7
	A place to cool down and contemplate	2
	Appreciating nature's intrinsic value	1
	Shared-use paths	1
Soundscape (things to hear)	Absence of human noise	7
	Birds	6
	Water	6
	Community awareness and Stewardship	3
	Joyful voices	2
	Nature sounds	2
	Frogs	1
	Insects	1
	Trees swishing	1

5. Conclusions

The study highlights the interconnectedness of different values, challenges, and interventions in the Millstream Creek Watershed, illustrating how improvements in one area, such as water management or education and public awareness initiatives, can have indirect effects on other aspects of watershed management and community resilience. In addition, in the complex social-ecological system in the Millstream Creek Watershed, such strategies can also be connected with watershed issues and challenges. For example, the Millstream Creek Watershed faces environmental threats related to how water bodies and ecosystems can be accessed and entered at numerous points in the watershed. This presents a challenge of attempting to balance objectives related to public access and environmental protection. While accessibility can lead to increased environmental appreciation and sense of place, excessive use of natural areas in the watershed exacerbates ecological degradation.

A number of the issues were found to have cascading and compounding effects. For example, pollution emerges from other watershed challenges, such as development, weak governance, and development pressure. Pollution has adverse effects on the environment and also human wellbeing, impacting mental and physical health. Issues such as invasive species compound the ecological impacts, and such issues can go unchecked in the event of ineffective (environmentally speaking) governance.

Other cascading effects include the water quality issues resulting from increased development, and these issues affect the ecological resilience in streams and greenspaces in the watershed. To address these challenges, participants recommend stringent regulations (and enforcement of these regulations) that involve safeguarding the watershed's freshwater systems. Regulations should also target invasive species and pollution to improve ecological resilience in the stream. Additionally, regulations that aim to bolster water quality and quality are key for maintaining environmental and social wellbeing.

Community outreach was identified as an important strategy for improving conditions in the watershed and producing social benefits, as it directly (and negatively) influences weak governance and indirectly improves accessibility. Community outreach efforts that include education, awareness, and rehabilitation can lead to the creation of more green spaces and better water management. In addition, storytelling initiatives such as social media posts, and articles can engage different community members of a variety of ages and demographics, while communicating the importance of values like respect, caring, and a sense of place. Education and public awareness initiatives also demonstrated to be key strategies for improving the watershed health, and these initiatives can indirectly support efforts toward addressing issues related to accessibility, pollution, and flooding. Education and awareness are also instrumental in enhancing conservation efforts and nurturing respect for the environment.

Some strategies and values had stimulating and enhancing effects on other strategies. For instance, leadership and vision positively influence (respectively) community outreach and clarity in policy. In other cases, multiple different strategies exerted positive effects on particular values. For instance, regulation- and education-related strategies improve sustainable coexistence, which was expressed as a key watershed value by the participants. In addition, governance-based strategies, such as organizational involvement, cross-jurisdictional communication, and co-management opportunities, enhance the effectiveness and resilience of local watershed conservation efforts.

The relationships among certain strategies and values demonstrate the complexity of the social-ecological systems in the Millstream Creek Watershed. For instance, community stewardship formed relationships with Indigenous rights and mental health in the systems map produced through this research, which relates to how Indigenous knowledge and community-driven initiatives play an important role in environmental stewardship. As another example, the systems connections between ecosystem services and climate change mitigation capture the bidirectional relationship between environmental preservation and climate action.

This research illustrates the complexity and interconnectedness of concerns, values, and strategies in the Millstream Creek Watershed. Translating this complexity into an interactive visualization is a challenge; however, the mental visualization exercise (which built upon the systems mapping and spatial mapping work) resulted in a strong direction for developing the tool. As identified by the participants, a visualization of the watershed in a desirable state involves a healthy ecosystem and accessible spaces for recreation, education, and nature appreciation. The specific visual and auditory characteristics identified through this research serve as valuable building blocks for a visualization tool in that they define elements and features to include a scenario where a series of strategies have been implemented and have been effective in improving the ecological and social health and wellbeing in the Millstream Creek Watershed.



Figure 12. Photograph of an old-growth riparian corridor segment along Millstream Creek

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