

**Critical Zone Processes in a Post-Fire Mountain Landscape:
A Proposed Research Station in Waterton Lakes
National Park**

Proposed Critical Zone Research Station:

*Waterton Lakes National Park
Cameron Creek - Blakiston Valley*



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Abstract

Waterton Lakes National Park, located in the southern Canadian Rockies, it provides a unique setting for studying how the Critical Zone functions in a post-fire mountain landscape. The Critical Zone helps us understand how water, energy, and nutrients move through landscapes (Brooks et al., 2015).

The park's strong environmental gradients, steep valleys, and the impacts of the 2017 Kenow Wildfire create natural contrasts in snowpack, soil moisture, vegetation recovery, and disturbance. This project proposes the establishment of a long-term Critical Zone Research Station based in Blakiston Valley and Cameron Creek Valley. The research program focuses on three major themes: (1) how snowmelt, rainfall, and rain-on-snow events shape streamflow timing and water chemistry; (2) how slope aspect and soil moisture–temperature regimes influence soil respiration and post-fire vegetation recovery; and (3) how human disturbance affects soil compaction, infiltration, and downstream water quality.

A multidisciplinary team specializing in hydrology, soil science, vegetation ecology, geomatics, and modelling will support all field and analytical components. Data from the three projects will be integrated into the Waterton Integrated Process Model (WIP-Model), a simple process-based framework designed to test how climate change, wildfire severity, and recreation pressure influence long-term watershed function.

The research station will provide Parks Canada and local communities with insights into runoff behaviour, soil recovery, erosion risk, and vegetation resilience. The project also supports several global “Grand Challenges” in Earth system science, including long-term observing, improved forecasting, and informed response to environmental change. Overall, the station strengthens Canada's capacity for Critical Zone research while supporting ecological recovery and sustainable management in a nationally significant landscape.

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1. Introduction and Background

1.1 The Critical Zone

The Critical Zone (CZ) is the Earth's delicate outer layer, where rock, soil, water, air, and living organisms come together. It stretches from the top of plants and trees down through the soil and weathered rock to the solid bedrock beneath. This zone is vital for numerous ecological and hydrological processes, including nutrient cycling, soil formation, plant growth, and water movement. Because it connects biological, chemical, and physical systems, changes such as climate shifts, disturbances, or land-use alterations can significantly affect how the CZ functions. Studying the Critical Zone helps us understand how landscapes function as interconnected systems and how they might respond to future environmental changes.

1.2 The Critical Zone in Mountain Environments

Mountain landscapes hold special significance for CZ research because many river systems originate in high-elevation headwaters. These areas provide essential water resources to downstream communities, ecosystems, and agriculture. With their steep slopes, deep snowpacks, complex microclimates, and sharp elevation changes, they exhibit rapid variations in soil moisture, temperature, vegetation, and runoff over short distances. Usually, snowmelt drives streamflow but rising temperatures and changing precipitation patterns are altering snowpack behaviour, melt timings, and rainfall intensity (Moore et al., 2020). Wildfires, recreational activities, and extreme weather events add additional stress to mountain soils and plants. Recent trends in hydrology already show shifts in snowpack and runoff timing (Whitfield & Cannon, 2000). All these factors make mountain catchments particularly valuable for understanding how the Critical Zone responds to both natural and human influences.

1.3 Why Waterton Lakes National Park?

Waterton Lakes National Park, located in the southern Canadian Rockies of Alberta and adjacent to Montana's Glacier National Park, offers an ideal setting for a Critical Zone Research Station. The park's landscape undergoes rapid changes, transitioning from open prairie grasslands to steep alpine valleys, resulting in noticeable shifts in climate and ecology. The 2017 Kenow Wildfire, which burned about 35,000 hectares and created distinct burn severity patterns (Parks Canada, 2021), significantly shaped the current landscape. Some slopes are still healing, while others remain exposed. These differences provide researchers with the opportunity to study the recovery of soil, plants, and water systems after significant disturbances.

This project focuses on two valleys: Blakiston Valley in the northwest and Cameron Creek Valley in the southeast. They differ in slope direction, elevation, snow retention, and microclimate. Their accessibility and environmental contrasts make them ideal for long-term Critical Zone research.

1.4 Research Motivation

Changes in climate, wildfire frequency, and precipitation patterns influence how the mountain landscape functions. Earlier snowmelt, more rain-on-snow events, and severe wildfires affect soil stability, runoff, nutrient cycling, and vegetation recovery. Waterton provides a unique chance to study these processes within a single system. This research project aims to understand how snowmelt, soil moisture, temperature conditions, vegetation recovery, and human activities shape the Critical Zone in a post-fire mountain environment. The research station relies on a team with expertise in hydrology, soils, vegetation, and geospatial analysis. Hydrology specialists monitor streamflow and water quality; soils and ecology experts study soil microclimate and vegetation recovery; GIS and modelling professionals integrate these data to better understand interactions among the components of the environment.

1.5 Major Research Project Themes

The Waterton Critical Zone Research Station is structured around three major research project themes, each addressing a different part of the system. Together, these themes capture the core components of the Critical Zone: hydrology, soils, vegetation, and disturbance.

1.5.1 Project Theme 1 Summary: Snowmelt and Rainfall Impacts

This project examines the impact of snowmelt, rainfall, and rain-on-snow events on streamflow and water chemistry in the headwaters of Blakiston and Cameron Creeks. The hydrology team will compare event responses to understand how different water inputs affect runoff timing, dilution, and solute export.

1.5.2 Project Theme 2 Summary: Soil Moisture–Temperature Regimes and Forest Recovery

Slope aspect influences soil moisture, temperature, and vegetation recovery following a wildfire. This project examines how microclimate differences affect soil respiration, post-fire regrowth, and nutrient cycling. Measurements will be taken across burned and regenerating slopes of different aspects and severities.

1.5.3 Project Theme 3 Summary: Human Impacts on Critical Zone Processes

This project compares disturbed areas near roads and trails with undisturbed forest and grassland to assess the impact of human activities on soil structure, water infiltration, surface runoff, and vegetation.

1.6 Integration Through the Waterton Integrated Process Model (WIP-Model)

The three projects are linked through the Waterton Integrated Process Model (WIP-Model). The modelling team will integrate field measurements, sensor data, and GIS-derived terrain information to understand how the Critical Zone reacts under different scenarios, such as warmer winters, increased rainfall, or changes in vegetation cover. The model integrates hydrology, soils, and vegetation to provide a more comprehensive understanding of how multiple CZ components interact across the Waterton landscape.

2. Proposed CZ Research Station Location

2.1 Region & Specific Site

The proposed Critical Zone Research Station will be situated in Waterton Lakes National Park in the southern Canadian Rockies of Alberta, directly bordering Glacier National Park in Montana. This region is renowned for its distinct transition from open prairie to steep alpine terrain, resulting in strong environmental gradients over relatively short distances.

The research station focuses on two central valleys within the park:

- Blakiston Valley (northwest part of the park)
- Cameron Creek Valley (southeast part of the park)

These valleys drain into the Waterton watershed but differ in elevation, slope aspect, vegetation, and fire history. Blakiston Valley has cooler, north-facing slopes that retain snow longer, while Cameron Creek features warmer, south-facing slopes with earlier melt and drier conditions. The topographic contrast, post-fire landscape, and road access make this area an ideal location for long-term Critical Zone research.

2.2 Site Context & Relevance

2.2.1 Climate & Hydrology

Waterton Lakes National Park has a cool mountain climate shaped by both Pacific and continental weather systems. Average annual precipitation ranges from about 800 to 1,400 mm, and most of the streamflow is driven by spring snowmelt (Parks Canada, 2024). Winters are influenced by frequent chinook winds, which can rapidly warm the air and cause sudden melt events or shifts in snowpack conditions.

This mix of deep seasonal snow and sudden warm periods creates an ideal setting for studying how snowmelt, rainfall, and rain-on-snow events influence streamflow, water temperature, and solute movement. The steep, narrow valleys of Blakiston and Cameron respond quickly to weather changes, allowing the hydrology team to capture clear differences between event types.

2.2.2 Vegetation & Disturbance (Kenow Fire 2017)

The park features a strong gradient in vegetation, ranging from prairie grasslands and open forests at lower elevations to denser subalpine forests and alpine meadows at higher elevations. In September 2017, the Kenow Wildfire burned across much of the park, including large sections of both Blakiston Valley and the lower Cameron Creek corridor.

The fire created a mosaic of burn severities, leaving some areas scorched and exposed while others retained partial canopy cover. Recovery has been uneven, with north-facing slopes showing faster vegetation regrowth and south-facing slopes remaining more open.

These post-fire conditions produce natural contrasts in soil structure, moisture retention, organic matter, and erosion potential. They also enable the soils, hydrology, and vegetation components of the CZ team to compare how different burn severities influence long-term landscape processes.

2.2.3 Topography & Geomorphology

Waterton's landscape was shaped by repeated cycles of alpine glaciation, which carved out steep U-shaped valleys, cirque basins, and morainal terraces (Osborn & Gerloff, 1997). Elevation ranges from approximately 1,300 m in the valley bottoms to over 2,800 m along ridge tops. The substantial elevation and aspect gradients create distinct differences in snow accumulation, soil moisture, and vegetation cover. North-facing slopes remain cooler and wetter, while south-facing slopes warm earlier and tend to be drier during the summer. These patterns form a slope sequence—a classic catena described by Schaetzl & Anderson (2013), where soils and water movement change predictably from upper slopes to valley bottoms. This geomorphic structure provides an ideal setting for studying soil development, microclimate variation, and the movement of snowmelt and rainfall through a mountain catchment.

2.2.4 Soils & Regolith

Soils in the study area vary significantly in terms of slope position and parent material. The soils of Waterton Lakes National Park survey (Coen & Holland, 1976) identify several distinct soil orders across the valleys:

- Upper slopes:
Shallow Brunisols and Regosols developed from coarse colluvium and glacial till
Low water-holding capacity and rapid drainage
- Mid-slopes:
Slightly deeper Podzolic soils under recovering conifer vegetation
More organic matter and moderate moisture retention
- Valley bottoms:
Wetter Luvisols and Gleysols formed in fine glacial and alluvial material
Higher nutrient and water storage

These soil differences impact infiltration rates, soil respiration, vegetation recovery, and nutrient cycling across the post-fire landscape. The variation between burned and unburned areas also offers opportunities to measure how soil properties change after disturbance.

2.3 Accessibility

Both Blakiston Valley and Cameron Creek Valley are accessible via maintained roads, making them suitable for consistent fieldwork throughout the year. Red Rock Parkway provides access to Blakiston Valley, with several pullouts near canyon viewpoints and trailheads. Cameron Lake Road leads directly through Cameron Creek Valley, offering access to lower, mid-slope, and upper valley sites. These routes enable field teams to transport equipment, revisit sampling plots during snowmelt or rainfall, and regularly download sensor data. Winter access may be limited during major storms, but chinook events and ongoing road maintenance allow for periodic snow surveys and sensor checks.

2.4

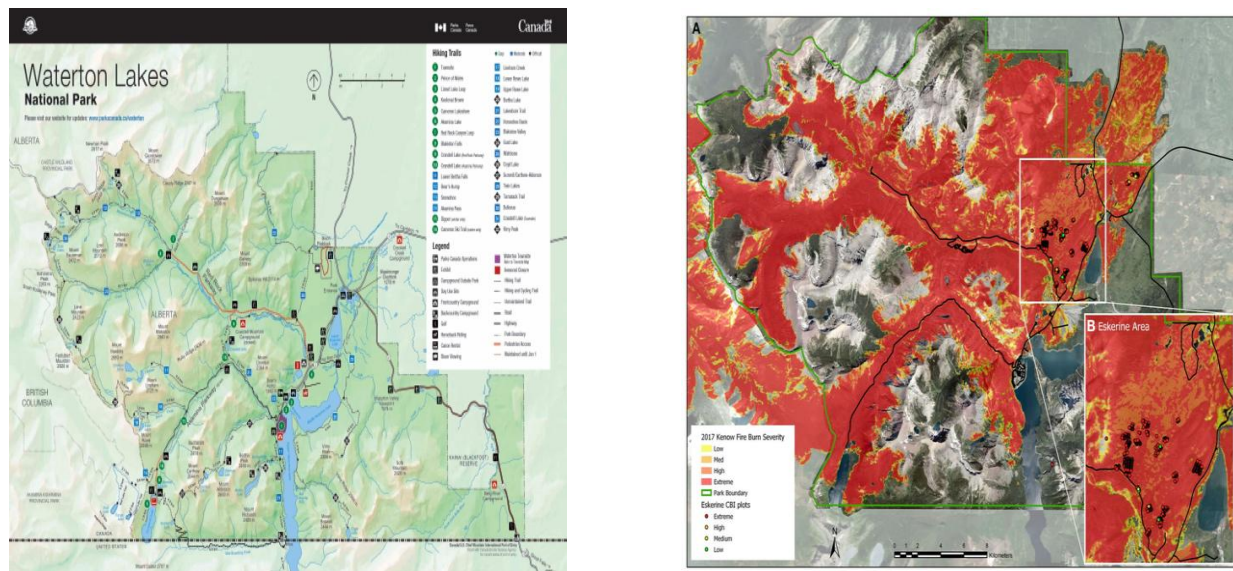


Figure 1. Regional map of Waterton Lakes National Park and burn-severity patterns from the 2017 Kenow Wildfire. Adapted from Parks Canada (2022) and Buunk (2021).

3. Proposed Research Project Themes

This section outlines the three main research project themes at the Waterton Lakes Critical Zone Research Station. Each project theme focuses on a distinct aspect of the mountain Critical Zone, examining hydrology, soils, vegetation, and human disturbance. The research team includes specialists in hydrology, soil science, vegetation ecology, geomatics, and modelling, ensuring each project theme benefits from relevant expertise. All project themes are connected through shared field sites and data integration within the Waterton Integrated Process Model (WIP-Model).

3.1 Project Theme 1: Snowmelt and Rainfall Impacts on Streamflow and Water Chemistry

3.1.1 Background

Mountain headwaters react quickly to weather changes. Snowmelt produces steady, cool flows, while rain causes sharper, more variable stream responses. Warmer temperatures increase rain-on-snow events, significantly boosting runoff and carrying nutrients and sediments downstream (Pomeroy et al., 2007; Fang et al., 2013). Blakiston and Cameron Creek offer a comparison: Blakiston retains snow longer on north-facing slopes, while Cameron warms earlier with mixed melt and rain. Studying both helps understand how snowmelt and rain influence streamflow after a fire.

3.1.2 Research Questions

1. How do snowmelt and rainfall events differ in their effects on streamflow timing and magnitude?
2. How do changes in stream temperature and electrical conductivity help identify whether an event is driven by snowmelt, rainfall, or a mix of both?
3. How do rain-on-snow events compare to pure snowmelt or rainfall events in these steep headwater systems?

3.1.3 Study Sites

Monitoring sites will be located along:

- Upper Blakiston Creek, where colder microclimates and deeper snowpacks result in slower melt.
- Lower Cameron Creek, where south-facing slopes cause earlier melt and more combined melt-and-rain flows.

These contrasting aspects will enable clear testing of hydrological differences.

3.1.4 Methods

To measure the impact of different types of events on streamflow, pressure transducer stage loggers will be installed at key locations in both Blakiston Creek and Cameron Creek to record continuous changes in stream height. Electrical conductivity (EC) loggers will be deployed at the same sites to capture dilution and flushing signals during snowmelt and rainfall. Discharge will be calibrated using a salt-dilution gauging method. Water samples will be collected during four key periods: early snowmelt, peak melt, summer rainfall events, and rain-on-snow (ROS) events. These samples will be analyzed for dissolved organic carbon (DOC), nitrate, phosphate, and turbidity to assess changes in water chemistry. Satellite imagery from Sentinel-2 and MODIS will be used to monitor snow cover and the timing of snowmelt across the valleys. At the same time, precipitation and air temperature data will be obtained from nearby weather stations to aid in the interpretation of the event.

3.1.5 Equipment

Pressure transducers, EC loggers, turbidity meters, handheld GPS units, water sampling bottles, field thermometers, and access to Sentinel-2/MODIS imagery.

3.1.6 Expected Outcomes

Snowmelt is expected to produce steady, gradual hydrographs with lower electrical conductivity (EC) due to dilution and cooler water temperatures. Rainfall events should create sharper peaks with higher EC and more intense nutrient flushing. Rain-on-snow (ROS) events will likely exhibit a combination of both signals, characterized by rapid runoff and colder water. Together, these patterns will help the hydrology and modelling teams understand how Waterton's headwaters respond to different types of events under changing climate conditions.

3.1.7

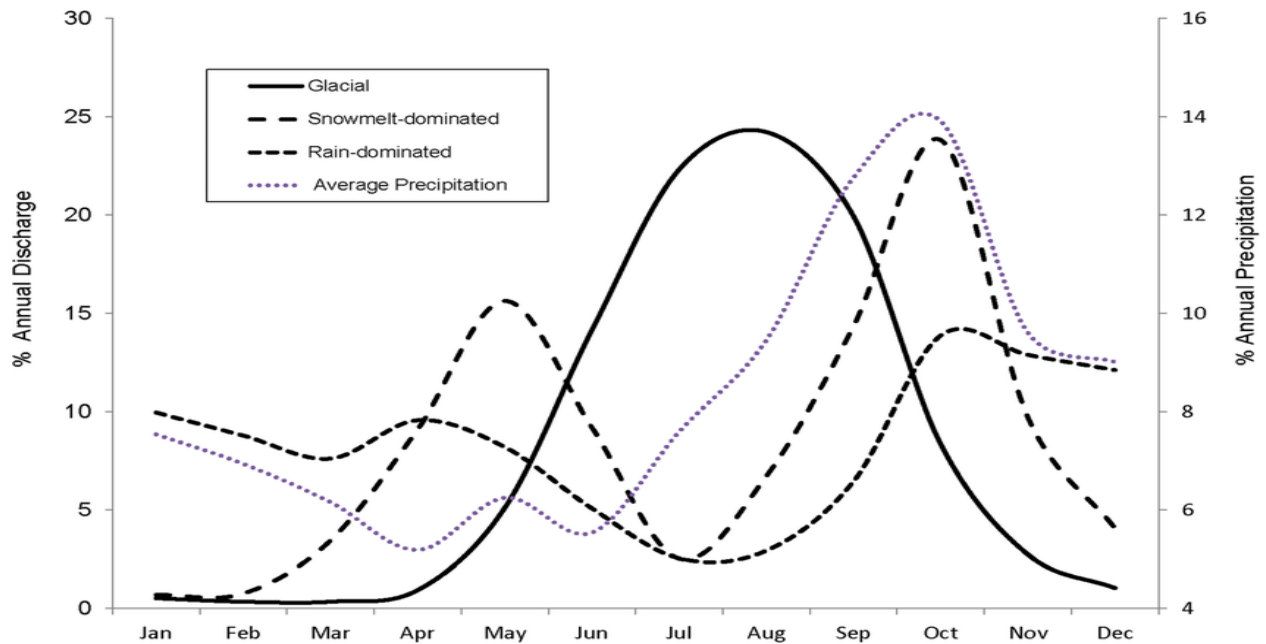


Figure 2. Example hydrograph comparing snowmelt-dominated and rainfall-dominated streamflow. Snowmelt shows a gradual rise, while rainfall produces a sharp peak. Adapted from Shanley et al. (2015).

3.2 Project 2: Soil Moisture–Temperature Regimes & Forest Recovery

3.2.1 Background

Slope aspect significantly influences mountain microclimates: north-facing slopes retain snow longer and stay cooler and wetter, while south-facing slopes warm earlier and dry out faster. Post-wildfire, these variations affect soil respiration, nutrient cycling, and regrowth. It is vital to note that; soil respiration is strongly controlled by both temperature and moisture (Lloyd & Taylor, 1994; Reichstein et al., 2003; Hursh et al., 2017). Waterton’s landscape, with its natural gradient in burn severity, soil exposure, and vegetation recovery, is ideal for studying how soil microclimate impacts early forest regrowth in burned valleys.

3.2.2 Research Questions

1. How do soil moisture and temperature differ by slope aspect and burn severity?
2. How do these conditions influence soil respiration?
3. What patterns of vegetation recovery emerge across different microclimates?

3.2.3 Study Sites

Paired slope-aspect plots will be established in:

- Blakiston Valley - cooler north-facing slopes, varied burn severity.
- Cameron Creek Valley - warmer south-facing slopes with faster drying.

Plots will represent unburned, low-severity, moderate-severity, and high-severity burn areas.

3.2.4 Methods

Soil moisture and temperature will be measured using TDR probes and thermistors. Soil respiration will be measured with a portable IRGA chamber. Vegetation surveys (including DBH, sapling counts, canopy photos, and ground cover) will be conducted in each plot. Basic micro-topographic data (shade, slope position) will support interpretation.

3.2.5 Equipment

- TDR moisture probes, Thermistors, IRGA chamber, DBH tape, Field camera, GPS

3.2.6 Expected Outcomes

North-facing slopes tend to retain more soil moisture and warm up more gradually during the season, often supporting quicker early-stage regrowth and more stable soil microclimate conditions after fire. Conversely, south-facing slopes receive more direct sunlight, dry out sooner, and typically show slower vegetation recovery as seedlings and soil organisms face greater moisture stress. High severity burn plots on either aspect are likely to have less organic

matter, weaker soil structure, and lower respiration rates early on due to the loss of surface litter and decreased microbial activity.

3.2.7

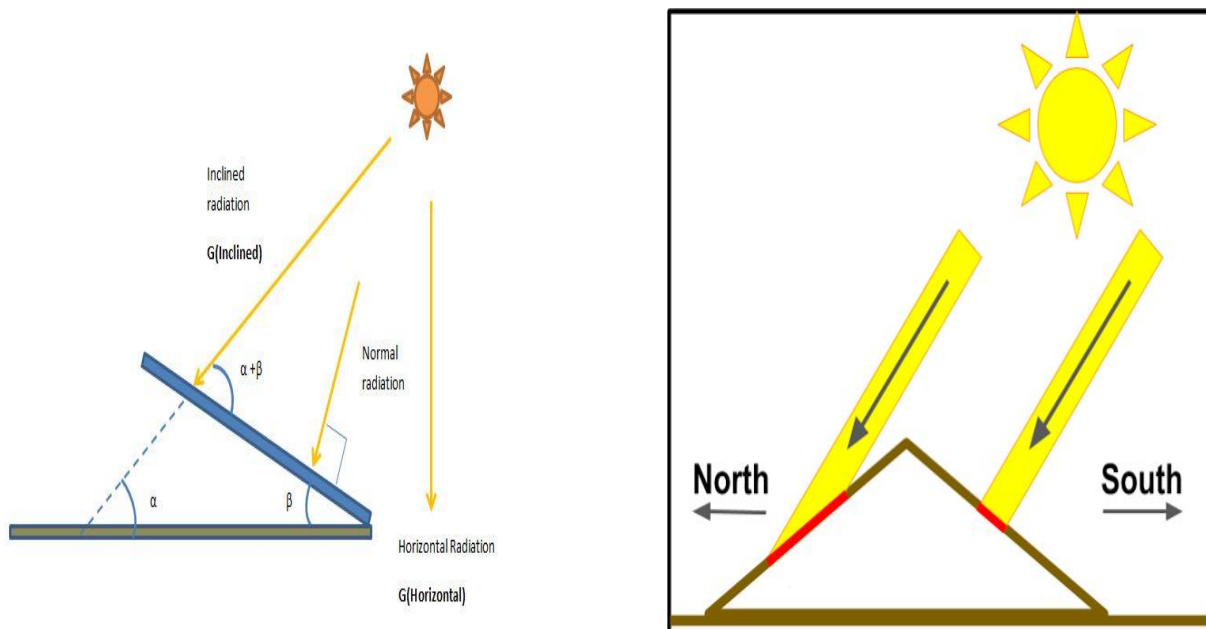


Figure 3. Conceptual diagrams illustrating how slope aspect influences incoming solar radiation. South-facing slopes receive more direct sunlight and warm more quickly, while north-facing slopes receive lower-angle radiation and retain moisture longer. (Source: UBC, Synergy Files, 2015.)

3.3 Project 3: Human Impacts on Critical Zone Processes

3.3.1 Background

Human disturbance, including recreation, trail use, and roads, has measurable impacts on soil structure and runoff pathways. Compaction reduces infiltration and increases surface flow, affecting erosion risk and water quality (Ziemer, 1981). In Waterton's recovering post-fire system, disturbed soils may erode more easily, especially during rainfall events.

3.3.2 Research Questions

1. How does soil compaction vary between disturbed and undisturbed plots?
2. How do roadside culverts influence downstream turbidity and conductivity?
3. How is vegetation cover affected by recreation pressure?

3.3.3 Study Sites

Disturbed and undisturbed paired plots will be established along Red Rock Parkway and Cameron Lake Road.

3.3.4 Methods

Bulk density will be measured using soil cores, and infiltration will be tested with a double-ring infiltrometer. Stream water upstream and downstream of culverts will be sampled for conductivity and turbidity. Vegetation cover will be measured along transects. UAV imagery will map the extent of disturbance.

3.3.5 Equipment

- Soil core kit, double ring infiltrometer, EC meter, turbidity tube, UAV, and measuring tapes.

3.3.6 Expected Outcomes

Disturbed soils are expected to be more compacted, with lower infiltration rates, while culvert sites are expected to exhibit higher turbidity after storms. Vegetation cover is likely to be sparser in areas that are frequently used.

3.4 Integration: Waterton Integrated Process Model (WIP-Model)

The WIP-Model brings together the key findings from all three research projects to understand how hydrology, soils, vegetation, and disturbance interact across the Waterton landscape. The modelling team will integrate stage–EC relationships from Project Theme 1, soil moisture–temperature data and respiration measurements from Project Theme 2, and disturbance parameters such as infiltration reduction and vegetation cover from Project Theme 3. Event separation using tracers, such as EC, follows common hydrograph separation approaches (Klaus & McDonnell, 2013). GIS-derived slope, aspect, and burn-severity layers will provide the spatial framework for the model.

The modelling team will implement the WIP-Model in R or Python, using simple linked modules rather than a full hydrologic simulator to keep the approach realistic and feasible for a long-term field-based research station. Hydrologic responses will be simulated using conductivity-based event separation, while soil moisture and respiration will be incorporated into the microclimate and recovery modules. Disturbance coefficients will adjust infiltration and sediment pathways based on field measurements.

The overall purpose of the WIP-Model is to evaluate how the Critical Zone may respond under different scenarios, such as warmer winters, changes in snowmelt timing, increased rainfall intensity, or greater recreation pressure. This integrated approach enables the research team to link processes measured at the plot scale to broader catchment-level patterns, thereby supporting long-term monitoring and informed decision-making for Waterton Lakes National Park.

4. Scientific Summary and Significance

4.1 Key Findings from the Three Research Projects

Together, the three research project themes build a connected picture of how the Critical Zone functions in Waterton's post-fire landscape.

Project Theme 1 reveals that snowmelt yields steady, colder flows with dilution effects, whereas rainfall generates sharper peaks and stronger solute flushing. Rain-on-snow events combine both signals, which is essential under warming conditions.

Project Theme 2 highlights how slope aspect and burn severity shape soil moisture–temperature regimes, soil respiration, and vegetation recovery. North-facing slopes remain cooler and wetter, while south-facing slopes dry earlier and show slower regrowth.

Project Theme 3 demonstrates that human disturbance increases soil compaction, lowers infiltration, and raises downstream turbidity near culverts. These changes influence how water and sediments move through the basin.

Combined, these findings provide a clear understanding of how water, soils, vegetation, and disturbance reorganize following a wildfire.

4.2 Contribution to Critical Zone Science

This station expands integrated CZ research into the southern Canadian Rockies, a region characterized by strong environmental gradients and recent significant disturbances. By connecting hydrology, soil processes, vegetation recovery, and human impacts, the research aligns with contemporary CZ science, which focuses on cross-disciplinary measurement and modelling. The WIP-Model enhances this effort by linking plot-scale measurements with catchment-scale predictions.

4.3 National & International Relevance

Mountain headwaters are crucial for maintaining a downstream water supply and mitigating hazards. Understanding how snowpack, runoff, and soil moisture respond to warming and wildfires is vital across Canada and worldwide. The proximity to Glacier National Park also enables effective comparisons with U.S. mountain systems, situating the station within a broader CZ research framework.

4.4 Relevance for Climate Change, Post-Fire Recovery & Water Management

Projected earlier melt, increased winter rainfall, and more rain-on-snow events will affect soil moisture, erosion potential, and streamflow timing. The post-Kenow landscape provides a rare opportunity to track long-term recovery across varying burn severities. Findings will help identify erosion-prone slopes, runoff risks near disturbed surfaces, and areas where vegetation may recover slowly.

4.5 Importance for Protected Areas and Mountain Landscapes

National parks like Waterton are popular landscapes where ecological protection and recreation need to be balanced. The findings from this CZ station will help land managers understand how recreation impacts soil and water processes, especially in areas recovering from fire. Beyond Waterton, the results provide a framework for monitoring and managing other protected mountain landscapes that face similar pressures, including wildfire, climate change, and human activity. Overall, this project enhances Canada's role in global Critical Zone research while supporting the long-term resilience of a nationally significant ecosystem.

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Appendix 1. Research Personnel & Expertise

Principal Researcher Expertise

The CZ Research Station is supported by principal researchers with expertise in hydrology, soil science, vegetation ecology, geomatics, and environmental modelling to complement the CZ Research Station.

The *Hydrologist* specializes in snowmelt hydrology, rainfall–runoff processes, and stream chemistry.

The *Soil Scientist* focuses on soil moisture–temperature regimes, soil respiration, and post-fire soil structure.

The *Vegetation Ecologist* studies post-fire regrowth, canopy structure and species recovery across slope aspects.

The *Geomatics & GIS Specialist* provides expertise in DEM processing, UAV mapping, remote-sensing analysis, and spatial data integration.

The *Environmental Modeller* leads development of the Waterton Integrated Process Model (WIP-Model), integrating hydrologic, soil, vegetation, and disturbance datasets.

Role of Postdoctoral Fellows and Graduate Students

Postdoctoral fellows support advanced data analysis, modelling development, and coordination across research themes.

PhD students contribute to long-term monitoring, lead specialty measurements (e.g., soil respiration or hydrochemical sampling), and assist with remote-sensing analysis.

Master's students help maintain sensors, conduct seasonal field campaigns, process samples, and support data management. Both PhD and MSc students contribute directly to model calibration and scenario testing.

Role of Undergraduate Students

Undergraduate researchers assist with field logistics, equipment transport, GPS positioning, soil and vegetation surveys, UAV flights, sample organization, data entry and other administrative duties. Their support ensures continuous sampling during peak seasons, helping to maintain long-term datasets.

Role of Research Technicians

Research Technicians provide essential support by installing and maintaining sensors, assisting with field safety, and conducting routine site visits. Laboratory Technicians process DOC and nutrient samples, maintain calibration standards, and ensure high-quality chemical analyses.

Appendix 2. Broader Impacts & Grand Challenges

Benefits to Society and the Public

The proposed Waterton Lakes CZ Research Station supports long-term understanding of how wildfire, climate change, and recreation affect soils, water, and vegetation in mountain environments. This information benefits Parks Canada and the public by improving decisions related to erosion control, trail placement, flood risk, and watershed protection. Communities also gain a clearer understanding of post-fire recovery and how headwater systems supply reliable freshwater under changing climate conditions.

Grand Challenges Addressed

The station addresses several Grand Challenges identified by Reid et al. (2010). It contributes to observation by establishing a sustained monitoring system that measures hydrology, soil microclimate, vegetation recovery, and disturbance patterns. It supports forecasting through the WIP-Model, which utilizes field measurements to predict how the Critical Zone may respond to future warming, altered snowmelt timing, and increased rainfall intensity. It also aids response by offering science-based recommendations for managing erosion risks, disturbed soils, and recreation impacts in a post-fire national/provincial park.

Outreach and Educational Activities

The station provides opportunities for student field courses, senior projects, and community-based learning. Educational outreach may include public talks, interpretive materials, and collaborations with Parks Canada, such as trail signage and online updates. Digital outreach tools (e.g., story maps, short videos, and visualization dashboards) can help visitors understand watershed processes while also highlighting post-fire recovery.