How do mountain watersheds respond to changes in forest disturbances caused by climate change?

Watershed responses to climate change-driven disturbances in temperate montane ecosystems of the Western United States

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Will mountain forest disturbances and thus watershed characteristics be impacted by climate change and can we use stream hydrology and chemistry to identify these impacts? Watershed hydrology and vegetation dynamics will be impacted by changes in climate, which will likely cause decreased snowpack, earlier snowmelt, earlier peak streamflow, and increased evaporation, as well as increased frequency of large-scale disturbances. Stream waters are indicators of upstream conditions over multiple spatial and temporal scales. The authors present a conceptual framework combining hydrography and chemography to study watersheds and their reactions to 4 disturbances: precipitation snow to rain transition, vegetation shifts, wildfire, and insect outbreaks.

How does the hydrochemograph integrate watershed processes and change?

- Biogeochemical changes in streams and surrounding areas can be detected with long-term, high-frequency stream point sampling of the hydrograph and chemograph.
- Hydrochemography of mountain streams can provide insight into how climate change may impact water quality and quantity, dry and runoff periods, and weathering, which all influence downstream water movement and chemistry.

How can we categorize water flow and source in the Mountain West? Are there differences in hydrochemistry among sources?

- Snowpack is an important source of water in the Mountain West. It accumulates beginning in October to December and melts off in May to June. Snowmelt runoff dominates stream flow during spring and early summer.
- Groundwater is an important source of baseflow during the post-runoff period and through late summer. Local geomorphic and geologic features store water, such as talus slopes, moraines, alluvium, and fine-grained deposits all act as slow-release reservoirs. Groundwater flow through bedrock can also be important.
- The hydrochemograph may be most useful in detecting climate-induced change when the groundwater contribution is small because hydrochemistry differs among bedrock types and solute concentrations increase with water residence time.

How will climate change alter the hydrograph? Will this impact nutrient export?

- Climate warming will result in reduced snowpack, earlier snowmelt with later pulses, and possible flooding from rain on snow events.
- Nitrate export into the stream will be higher early in the season from melting snowpack and rainfall. The same amount of nitrate may enter the system in a year, but the concentration during peak flow will be lower.

How will vegetation shifts be reflected in the hydrograph? Is the chemograph impacted similarly?

- With warmer and drier conditions, models suggest that Mountain West forests will be replaced by non-forest vegetation. Because forest vegetation regulates water flow and quality, shifts in vegetation may lead to increased flow and nutrient export. Increased nutrient export can result in eutrophication.

How does wildfire disturbance affect streamflow? How is nutrient export affected?

- Streamflow generally increases after a wildfire but the magnitude of increase depends on burn severity, precipitation, and position in the stream network. In many streams, discharge returns to pre-fire levels within 5-10 years post-fire.
- After wildfire, export of nitrate, total phosphorus, and ammonium showed large increases while phosphate, dissolved organic carbon, and total suspended solids changed little. Depending on the context of the fire, some streamwater nutrient levels may remain elevated for years.

What are the impacts of insect outbreaks? How do they impact the hydrograph and chemograph?

- Bark beetles cyclically impact forests, causing tree mortality. Because of climate change their range is larger and frequency and severity of their disturbances have increased. Tree death occurs in three phases, with different signals in the hydrograph and chemograph.
- During the green phase trees die; the hydrograph is not impacted. During the red phase needles redden and fall, leading to decreased snow reflectance and earlier peak discharge. In the gray phase, dead needleless trees remain standing allowing increased snow accumulation and radiation, resulting in earlier snowmelt and higher discharge.
- Beetle outbreaks cause increased organic matter and nutrient concentrations in streams. This is partially caused by increased vegetative productivity and litter breakdown. Systems with high nitrogen deposition have increased nitrogen export. Old-growth stands tend to export more nitrogen than mixed-age or managed stands.

Overall, how are changes in the disturbance regime likely to impact mountainous watersheds?

- Changes in mountain forest disturbances, such as differences in their severity, frequency, magnitude, and timing could potentially restructure ecosystems in the Mountain West. Periods of drought and flood will occur more frequently and result in changes to nutrient processing as well and in biotic communities.

Research Approach/Methods

- The authors combined evidence from a review of published literature and case studies to develop their conceptual framework for how climate-driven changes impact the hydrographs and chemographs of watersheds.
- The hydrochemograph couples water movement with the solute and nutrient signatures and can be used to investigate ecological processing, pulse or press disturbances, nutrient imbalances, changes in source water, vegetation shifts, and local-scale nutrient availability.

Keywords hydrograph, chemograph, hydro-chemograph, hydrology, biogeochemistry, climate change, disturbance, vegetation change, wildfire, insect outbreak

Images

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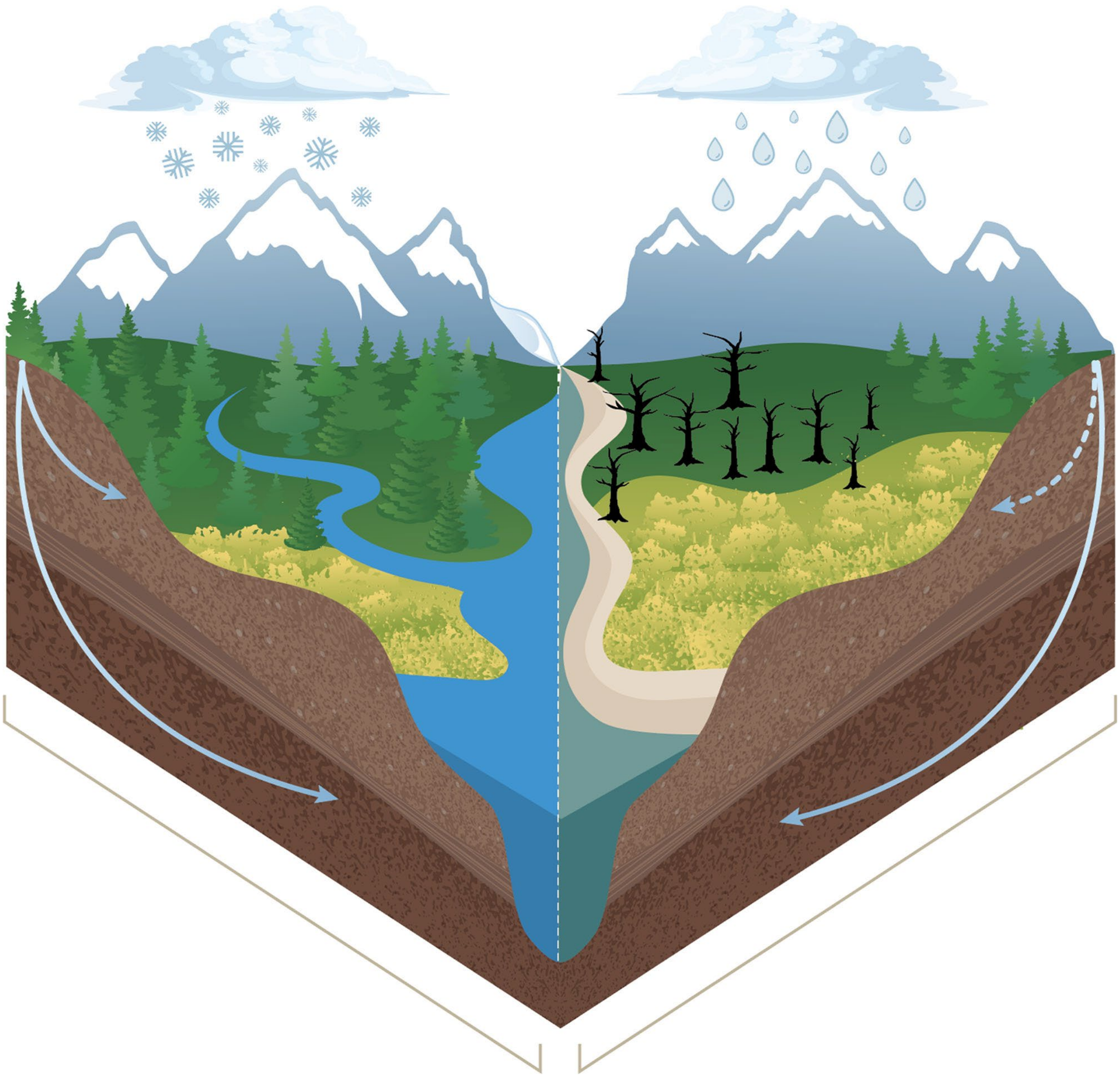

Figure 1 in Rock et al. 2024. Historic (left) and future (right) conditions in Mountain West ecosystems. Warmer temperatures are altering hydrological processes by decreasing snowpack in high-elevation locations (Gergel and others 2017), inducing earlier melt of snowpack (Barnhart and others 2016; Musselman and others 2017), and shifting dominant precipitation inputs from snow to rain which increases flood-inducing rain-on-snow events (Musselman and others 2018). Shifts in vegetation are represented by forest migration to higher elevations, conversion of forest to non-forest vegetation at lower elevation, and conversion of high-alpine meadow to young forests creating patchy old growth stands mixed with younger new growth (Rust and Minckley 2020). Predicted increases in fire and insect outbreaks will lead to increased rates of forest conversion to non-forest vegetation (Rhoades and others 2017; Rust and Minckley 2020; Higuera and Abatzoglou 2021).

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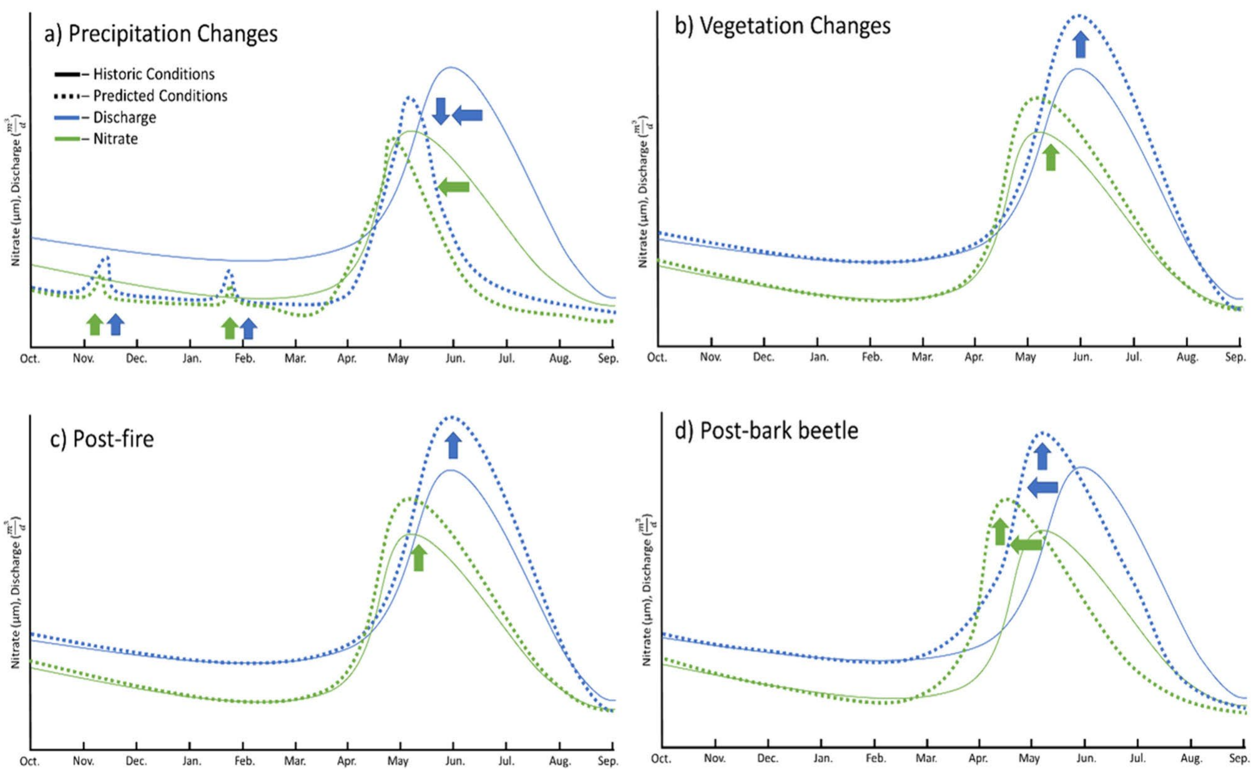

Figure 2 in Rock et al. 2024. Hypothetical hydrochemographs representing A rain-on-snow events, B changing from a forested system to a meadow, C post-fire, D post-bark beetle. Arrows indicate direction of shift following the observed disturbance.