Critical Wildland Fire Research Gaps and Needs
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PNNL has identified a broad suite of critical research gaps and needs related to wildland fires, both guided by fundamental research conducted at PNNL and community-driven activities led by PNNL.

Critical Science Gaps and Needs Being Addressed by PNNL Research:

PNNL has active BER-focused research in two broad areas of wildfire research: 1) Impacts of wildfires on watershed function and nutrient cycling; and 2) Regional to global climate impacts of wildfires and associated feedbacks to climate. Critical gaps and needs associated with these two research areas, with relevant recent publications and points of contact, are described here.

Impacts of Wildfire Disturbances on Watershed Function and Nutrient Cycling: This research, currently primarily within the River Corridor SFA project, focuses on changes in organic matter composition and delivery to river systems and associated impacts on river corridor and watershed hydrobiogeochemistry. Points of Contact: Tim Scheibe (SFA PI) and Allison Myers-Pigg (Wildfire Research Campaign Lead). Critical research gaps include:

- Spatiotemporal drivers of river corridor response to wildland fires (e.g., influence of burn severity, land use, and time since fire) (Roebuck et al. 2022).
- Thresholds of hydrologic connectivity that control transport of pyrogenic organic matter from terrestrial to riverine environments.
- Chemical biomarkers of wildfires in organic matter, and understanding how those vary as a function of burn severity and combustion type, relevant to using them as tracers of fire activity in the environment (e.g. muffle furnaces vs. open burn tables vs. actual wildfires).
- Recovery and resilience of ecosystem structure and function to wildland fires (e.g., vegetation recovery, micro- and macro-fauna, and hydrobiogeochemical function).
- Impacts of other disturbances that compound the risks and impacts of wildfires, in particular extreme weather events such as atmospheric rivers, droughts, and/or heat waves.
- Incorporating impacts of wildfires (both hydrologic and biogeochemical) into river corridor and watershed models, and using those models to assess watershed-scale impacts of wildfires on watershed function and nutrient cycling.

Interactions between Wildfires and Regional to Global Climate: This research focuses on the effects of wildfires on regional and global climate, and feedbacks from climate conditions and perturbations to the occurrence and intensity of wildfires. It is conducted under a variety of projects funded by EESM and ASR programs. Critical research gaps and POCs include:

- Impacts of arctic warming on the frequency and intensity of wildfires in the western U.S. (POC: Hailong Wang; Zou et al. 2021).
- Composition and properties of wildfire smoke particles (aerosols) and their impacts on regional and global climate (POC: Jerome Fast (ICLASS SFA); Brege et al. 2021; Bian et al. 2021)
- Climatic and meteorological controls on wildfire risk and occurrence (POC: Ruby Leung; Wang et al. 2021; Dong et al. 2021)
- Interactions between water cycle, climate, and wildfires and their implications for forest and watershed management (POC: Mark Wigmosta; Povak et al. 2022)
- Role of wildfires in forest vegetation dynamics and demography under climate change disturbance (POC: Nate McDowell; McDowell et al. 2020)

Critical Science Gaps and Needs Identified in Recent Community Activities:

Two recent community activities led by PNNL scientists and others have focused on the identification of critical wildfire science gaps and needs. In May 2022, a breakout session was convened at the ESS PI Meeting entitled "Feedbacks between wildfires & ecosystem processes" by Allison Myers-Pigg (PNNL), Kevin Bladon (Oregon State University), Michelle Newcomer (LBNL), and Tim Scheibe (PNNL). Several invited flash talks were presented to set the stage for discussion, and then the participants broke into two groups to ideate around the question: "*What are the most important research topics related to feedbacks between wildfires and ecosystem processes?*" From the breakouts, 7 major themes emerged around wildfire impacts on ecosystem functions and processes, the interactions of those with human systems, and the need for development of predictive understanding of ecosystem structural and functional changes during ecosystem recovery. The River Corridor SFA also recently conducted an email survey of the scientific community to identify key research gaps and paths forward for this research community. A self-selected subset of the survey participants are currently working together to develop a crowdsourced journal article describing each of the identified themes in greater detail. We asked the question: "*What are the most pressing questions that need to be addressed to further our understanding of wildfire impacts on biogeochemical cycling in watersheds?*" We received almost 70 responses that were organized into six themes revolving around the impact of wildfires on ecosystem processes such as biogeochemical cycling (including pyrogenic organic matter), hydrology, terrestrial-aquatic linkages, and the recovery trajectories, traditional knowledge and management activities needed to understand wildland fire's role in ecosystem functions over varying spatial and temporal scales. Together, from these community-based activities, we highlight 4 major areas that contain essential knowledge gaps and represent major research needs in wildland fire impacts research. These are:

Gap 1: *Resilience and recovery trajectories of ecosystems to wildland fires*

Key Research Questions: How is system resilience to wildfire controlled by burn severity, return interval, and the compounded impacts of other disturbances? What are the key interactions between wildfires, return intervals, and landscape characteristics, and how do these relate to long-term shifts in system function?

Gap 2: *Effects of wildland fires on ecosystem structure and function*

Key Research Questions: How do wildfires affect terrestrial-aquatic fluxes of key nutrients (C, N, P) and their net ecosystem balances (e.g. ecosystem productivity and respiration)? What are the critical impacts of wildfires on the hydrologic cycle, including impacts on vegetative processes, groundwater and surface water processes, and hydrologic connectivity? What are the impacts of wildfires on microbial community composition and function, in particular utilization of pyrogenic organic matter?

Gap 3: *Feedbacks between wildland fires, anthropogenic systems (including management decisions) and biogeochemical cycling (including water quality)*

Key Research Questions: How do post-fire management choices (e.g. salvage logging, reseeding, natural recovery) affect hydrologic and biogeochemical function of watersheds? Are there best management practices (including indigenous knowledge) that would improve post-fire regeneration, optimize the ecosystem benefits of wildfires, and minimize risks of negative wildfire impacts on human systems?

Gap 4: *Predictive understanding of the role wildland fires play in ecosystem functions*

Key Research Questions: How can we best incorporate wildfire effects into hydrologic and biogeochemical process models? What are the critical linkages between land surface and atmospheric models in the context of wildfire? What are the appropriate roles of AI/ML or hybrid ML-process models in predicting short-term and long-term wildfire/ecosystem feedbacks?

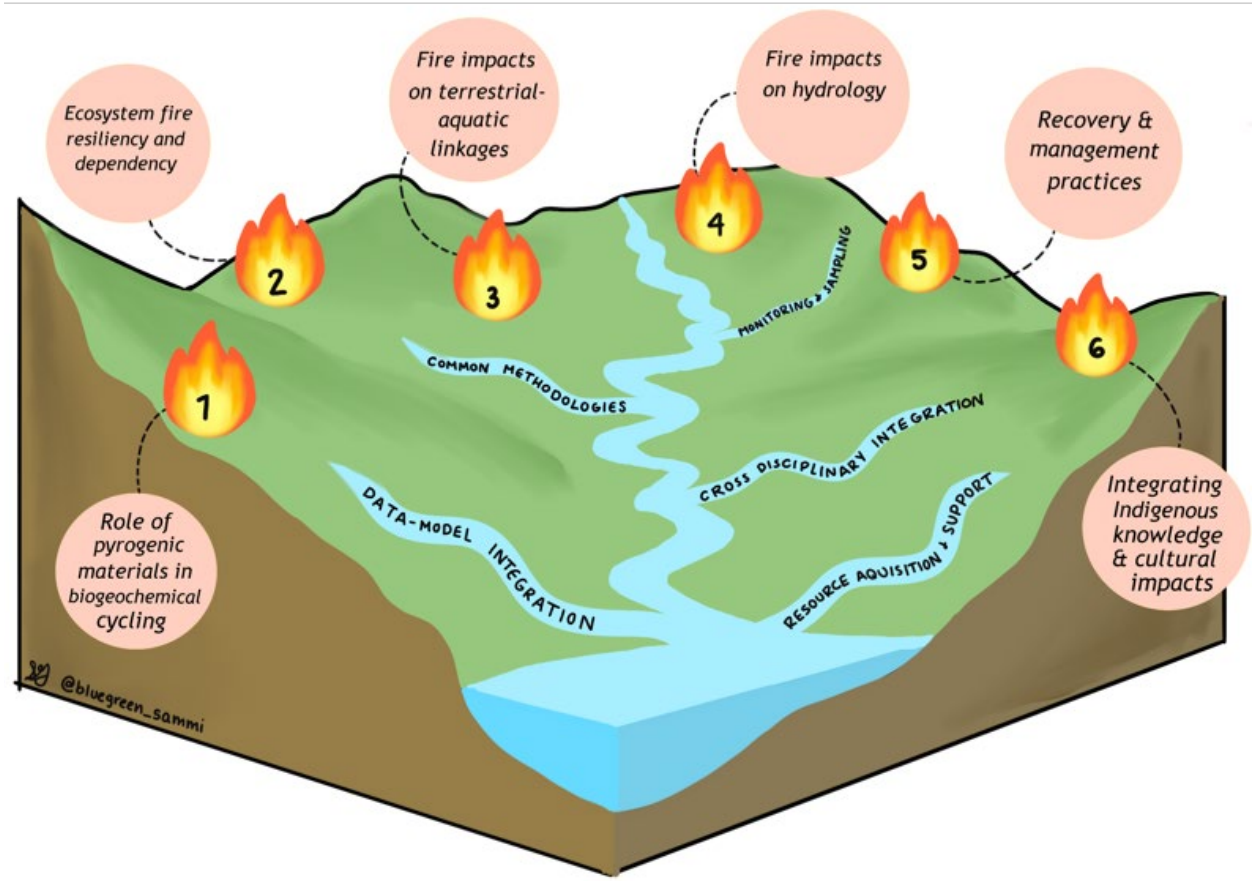
Appendix 1: Supplementary Information for Critical Science Gaps and Needs Identified in Recent Community Activities

Wildfire breakout session at 2022 ESS PI Meeting: In May 2022, a breakout session was convened at the ESS PI Meeting entitled "Feedbacks between wildfires & ecosystem processes." organized by Allison Myers-Pigg (PNNL), Kevin Bladon (Oregon State University), Michelle Newcomer (LBNL), and Tim Scheibe (PNNL). Several invited flash talks were presented to set the stage for discussion, and then the participants broke into two groups to ideate around the question: "*What are the most important research topics related to feedbacks between wildfires and ecosystem processes?*" Seven priority research needs were identified by the two breakout groups:

- Research Area 1: *Impacts of wildfires on microbial ecology:* What are the impacts of wildfires on microbial community composition and function, in particular utilization of pyrogenic organic matter? How do microbial community composition and function recovery over time following a wildfire event? How do shifts in microbial community and function impact plant health and vegetation demographics?
- Research Area 2: *Wildfire and aquatic ecology feedbacks:* How do wildfires impact biodiversity in riparian zones across successional stages? How will increasing frequency and severity of wildfires affect productivity of freshwater systems? What are the effects of wildfire on CO2 emission from inland waters?
- Research Area 3: *Feedbacks between wildfires and biogeochemical cycling:* What are the impacts of wildfire on long-term soil carbon storage and release? What are the critical processes involved in particulate organic matter generation, transport, and transformation? What are the effects of wildfires on soil and bedrock erosion and weathering rates?
- Research Area 4: *Wildfire feedbacks with anthropogenic systems:* What are the effects of land use changes and land management on wildfire severity and frequency? How do post-fire management choices (e.g. salvage logging, reseeding, natural recovery) affect hydrologic and biogeochemical function of watersheds? How does the urban-wildland fire interface impact recovery trajectories?
- Research Area 5: *Impacts of wildfires on water quality and quantity:* What are the long-term impacts of wildfires on water quality? What are the associated impacts on ecosystem health and function? What are the associated socio-economic impacts on human systems (e.g. drinking water treatment, loss of cultural or recreational resources)?
- Research Area 6: *Wildfire recurrence intervals, recovery trajectories, and ecosystem function:* How often do wildfires occur (what is the return interval) and how does this relate to the time required for system recovery? How is the recurrence interval changing as a function of climate change and extreme weather events? What are the effects of wildfire recurrence and recovery on system hydrology, biogeochemistry, and ecology?
- Research Area 7: *Develop a predictive understanding of wildfire/ecosystem feedbacks:* How can we best incorporate wildfire effects into hydrologic and biogeochemical process models? What are the critical linkages between land surface and atmospheric models in the context of wildfire? What are the appropriate roles of AI/ML or hybrid ML-process models in predicting short-term and long-term wildfire/ecosystem feedbacks?

Community Survey on Watershed Impacts of Wildfires: The River Corridor SFA recently conducted an email survey of the scientific community to identify key research gaps and paths forward for this research community. A self-selected subset of the survey participants are currently working together to

develop a crowdsourced journal article describing each of the below themes in greater detail. We asked "*What are the most pressing questions that need to be addressed to further our understanding of wildfire impacts on biogeochemical cycling in watersheds?*" We received almost 70 responses, that were organized into six themes summarized in the figure and text below:



- *Theme 1 - Pyrogenic organic matter (PyOM) and its roles in biogeochemical cycling:* What are the conditions (e.g. wildfire intensity, vegetation, watershed characteristics) that control the chemical character and amount of PyOM? What are the associated physicochemical properties of PyOM, and how do these control its transport and fate in watershed systems? What are the best analytical methods for characterizing PyOM?
- *Theme 2 – Wildfire impacts on hydrology:* What are the critical impacts of wildfires on the hydrologic cycle, including impacts on vegetative processes, groundwater and surface water processes, and hydrologic connectivity? How are these impacts modified by climate change and human interventions?
- *Theme 3 – Wildfire impacts on terrestrial-aquatic linkages and fluxes:* How do wildfires affect terrestrial-aquatic fluxes of key nutrients (C, N, P) and their net ecosystem balances (e.g. ecosystem productivity and respiration)? What are the key interactions between wildfires, return intervals, and landscape characteristics, and how do these relate to long-term shifts in system function?
- *Theme 4 – Ecosystem resilience to wildfire disturbances:* What are the impacts (and their spatial/temporal extent) of wildfires on water quality and treatability? How is system resilience

to wildfire controlled by burn severity, return interval, and the compounded impacts of other disturbances?

- *Theme 5 – Recovery and management:* How can ecosystem recovery best be predicted, and how can the negative impacts of wildfires be mitigated? Are there best management practices that would improve post-fire regeneration, optimize the ecosystem benefits of wildfires, and minimize risks of negative wildfire impacts on human systems?
- *Theme 6 – Cultural:* How can indigenous knowledge of ecosystem function be integrated with scientific understanding for wildfire management? How can risks and benefits associated with wildfires best be communicated to the public and other stakeholders?

A second survey question focused on identification of key roadblocks that inhibit holistic understanding of the spatiotemporal impacts of wildfires, and identification of potential pathways toward better integrating wildfire science across disciplines. The responses to this question were organized into five themes summarized here:

- *Theme 1 - Model integration:* What approaches and methodologies are needed for integrating models and experimental/observational data, especially across disciplines and scales?
- *Theme 2* – Monitoring/sampling approaches: How can we best obtain paired data before and after fires? What is the value of long-term monitoring and what should be measured/observed? How can we leverage existing infrastructure to improve empirical observations?
- *Theme 3 – Methods and dissemination:* What are novel or improved methods that could facilitate advances in wildfire science? Can we benefit from community adoption of standard methods and nomenclature? How can new advances best be communicated to the scientific community, ecosystem managers, and stakeholders?
- *Theme 4 – Cross-disciplinary integration:* What are best practices for integrative cross-disciplinary team science? Are there well-defined case studies that can serve as exemplars for future research teams?
- *Theme 5 – Funding*: What are the roadblocks to funding the cross-disciplinary teams with integrated modeling and empirical studies across scales necessary to address complex wildfire science challenges? How can these roadblocks best be overcome?

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