RESEARCH PROGRAM CHARTER Ref: FSM 4070 (4071.2)	**1. Number** 4354	**2. Station** RMRS
	3. Unit Location Fort Collins, Boise, Moscow, Flagstaff, & Missoula	

4. Research Work Unit Title:

Water and Watersheds (formerly Air, Water and Aquatic Environments)

5. Program Manager (Name and address)

Frank H. McCormick, Supervisory Biologist, 240 W Prospect Road, Fort Collins, CO 80526

6. Area of Research Applicability	**7. Estimated Duration**
local, regional, multiregional, national, or international	**10 years**

8. Mission

The mission of the **Water and Watersheds Research Program** is to conduct basic and applied research on the effects of natural processes and human activities on watershed resources, including interactions between aquatic and terrestrial ecosystems. The program develops core knowledge, methods, and technologies that enable effective watershed management in forests and grasslands, sustain biodiversity, and promote healthy watershed conditions. We emphasize integration across disciplines within and among RMRS science programs, across FS Research Stations, and with our science partners in USFS National Forest System and State & Private Forestry, other federal, state and Tribal agencies, universities and non-governmental organizations at local to international levels. We have the internal capacity for integration of physical and biological sciences that includes studies in the foundational disciplines of hydrology, biogeochemistry, forest engineering and soils, terrestrial and riparian plant ecology, conservation biology, aquatic ecology, and fisheries. We use high-quality, long-term data for evaluating local, regional and national environmental change and focused research that addresses specific resource management issues. We also provide managers with tools to evaluate environmental change and manage terrestrial and aquatic resources.

This charter describes a unified framework of watershed research that explores the complex relationships among the physical, chemical and biological properties of watersheds, the ecosystem processes that sustain biodiversity, and aquatic resource conservation and restoration. In this charter, we address priorities for a directed program of research that meets the science needs of natural resource managers and policy makers. RMRS adopted four key principals in developing this Charter:

1. This Charter is future-focused, describing the needed research to meet society's needs 10 years from now.
2. The multiplicity of scales and disciplines inherent to modern natural resource problems requires that our science is collaborative and interdisciplinary.
3. Co-Production of Science is a major paradigm we will use, working directly with partners and users to identify their needs, develop and deliver knowledge, and identify and conduct studies answering critical management questions.
4. Our applied science will provide feedback and support to our basic science activities.

Signature	Title	Date
Recommended: FRANCIS MCCORMICK Digitally signed by FRANCIS MCCORMICK Date: 2021.11.12 10:25:18 -07'00'	Research Program Manager	
Recommended: KENLI KIM Digitally signed by KENLI KIM Date: 2021.12.02 10:14:48 -05'00'	Staff Director	
Approved: MONICA LEAR Digitally signed by MONICA LEAR Date: 2021.12.08 06:40:24 -07'00'	Station Director	
Concurred: ALEXANDER FRIEND Digitally signed by ALEXANDER FRIEND Date: 2022.03.22 16:46:25 -04'00'	Deputy Chief for Research	

Because science delivery is an essential part of the research cycle, we respond to emerging issues by communicating science findings and enhancing their application. RMRS is committed to co-production of science, and we will use this paradigm in all phases of research from problem identification, research, and science delivery. We are committed to providing science-based applications and tools for sustainable natural resources management. We accomplish this by developing, evaluating, and deploying new methods for inventory and monitoring activities, predictive tools for watershed management and restoration, and decision support systems to improve land management. We devote time and resources to engaging with and educating the public, as well as land managers.

The Water and Watershed Research Program pursues knowledge discovery and development, modelling, and syntheses that inform management actions and policy decisions made by local, regional, national, and international clients and partners. Furthermore, our science, and the knowledge generated from it, informs scientific programs and studies worldwide. Our work directly supports the USDA Strategic Goals FY 2018-2022 to *Strengthen the Stewardship of Private Lands through Technology and Research* by enhancing the scientific basis of conservation planning and *Foster Productive and Sustainable Use of Our National Forest System Lands* by providing the science that helps ensure that public lands and watersheds are sustainable, healthy and productive.

Similarly, our work is aligned with the Forest Service Strategic Plan 2015-2020 Strategic and Management Objectives. Water and Watershed research contributes to the improvement of conditions that *Sustain Our Nation's Forests and Grasslands* so that they are resilient in the face of climate change. We *Deliver Benefits to the Public* by providing the scientific basis for management decisions to improve watershed condition on our Nation's forests and grasslands and ensure that they are functioning as intact ecosystems that provide abundant clean water and many other ecosystem services and benefits that contribute to human health, prosperity, and quality of life. Our science delivery and technology transfer efforts support the goal to *Apply Knowledge Globally* and reflects our core values of service to the public and improve global natural resource stewardship. The program's science supports the National Rise to the Future: National Fish and Aquatic Strategy goals to *Conserve Fish and Aquatic Resources; Strengthen Partnerships and Work Across Boundaries; and Deliver and Apply Scientific Research*. Watersheds integrate the strategic priorities and foundational research areas identified by Forest Service Research and Development. Our science spans the Water, Air and Soil; Wildlife and Fish; Fire and Fuels; Recreation; Forest Health; and Natural Resource Management disciplines. Finally, as identified in the Rocky Mountain Research Station Strategic Framework Research Priorities, Water and Watershed research is foundational to the RMRS mission.

9. Justification and Problem Selection

From its inception, the Forest Service has been charged with the protection of watersheds and water resources. Historically, this mission has focused on the management of vegetation (timber and fire), soil, water, wildlife, and fishery resources. With the requirements of the Clean Air Act, Clean Water Act, and Endangered Species Act, the Forest Service's mission has grown to include management of air quality, water pollution, recreation, and habitat conservation to protect these resources on federal lands.

Our research advances critical knowledge about complex physical and biological interactions in a wide variety of western ecosystems, seeks to understand how vegetation influences and responds to disturbance and management, and investigates watershed processes to determine their controls on spatial and temporal variation in water quality and quantity. We investigate how the region's biota have responded to past climate variation and thus have improved understanding of present changes and human engineering of the environment. In the fast-growing American West, agricultural, rural and urban economies are inextricably tied to water. Along with the increasing demand for water, a limited supply may be affected by projected changes in the regional climate, making it increasingly difficult to predict supply from year to year. Climate change is increasing variability in precipitation and resulting in warming temperatures in the West, leading to reduced snowpack; earlier snowmelt; larger, more severe wildfires; increased forest vulnerability to insects; altering sensitive high-elevation environments; and less dependable delivery of clean water. New knowledge gained from this research is essential to meet the complex and extensive challenges facing western water management.

In developing this charter, the Water and Watershed Program has committed to a coordinated effort with the National Forest System for shared responsibility for land management and providing the best available science for land management plans. This includes participation in RMRS-Regional Science Advisory Teams (Regions 1, 2, 3 and 4), the R4 Science Partners Program, the Rocky Mountain Restoration Initiative, responses to national program-level requests (e.g., Burned Area Emergency Response and Legacy Road programs and drought and climate assessments), regional and forest-level climate vulnerability assessments and countless peer-to-peer consultations that form the majority of our support for resource managers.

It is through these interactions that program scientists have developed and maintained long-term relationships with USFS colleagues that help us align our research with existing and emerging management needs. As active participants in Shared Stewardship Initiatives in Colorado and New Mexico, program scientists provide science leadership focused on desired outcomes derived from public listening sessions. We have developed and maintained partnerships with other federal, tribal, and state agencies, local governments and public utilities, and non-government organizations that depend on the science we produce.

The research described in the charter will aid watershed managers to make decisions now that will ensure availability of water to meet societal demands for water. Three problem areas will define the work of the Program.

First, an improved understanding of the water balance will lead directly to improved management of water supplies. Improved forecasting tools will allow greater flexibility and improved results from reservoir operations, protecting more people from floods while making more water available for water users and conservation of fish. Improved understanding of geomorphic processes will help protect fish habitat, water quality, and human life by identifying areas where erosion, mass wasting, and sediment transport are most likely to affect these values. Biogeochemical research will provide managers the information needed to inform sound decisions aimed at protecting water quality and at sustaining soil and forest productivity. Our watershed studies will help managers and decision makers evaluate the influence climate change on the delivery of clean water from western watersheds.

Second, improved science information on the effects of natural and anthropogenic disturbances on aquatic, riparian, and terrestrial species and habitats will help managers better understand 1) the complexity of wild populations of aquatic, riparian, and terrestrial species; 2) how this complexity is related to the diversity of riverscapes and landscapes; 3) how natural or anthropogenic disturbance interacts with wild populations; and 4) how invasions of non-native species can alter the responses of native species to riverscape and landscape patterns and processes. This understanding will result in more informed land management decisions, forewarn managers about likely changes in habitats and populations from disturbance or invasion, and enable strategic management intervention in the highest priority landscapes.

Third, the Water and Watershed Research Program scientists work in formal and informal teams across the agency and in partnership with our other stakeholders to jointly develop research questions and science-based strategies to improve watershed management.

Within the broad framework of watershed research, our contribution to this shared effort falls principally within the scope of the following three Research Problem Areas:

- **Core watershed research quantifies the dynamics of hydrologic, geomorphic, and biogeochemical processes in forests and rangelands at multiple scales.**
- **Core watershed research quantifies the biological processes and patterns that affect the distribution, resilience, and persistence of native and non-native aquatic and riparian species.**
- **Integrated, interdisciplinary research explores the interactions of physical and biological ecosystem processes that contribute to watershed condition in a changing environment.**

10. Approach to problem solution.

Natural resource management challenges in the 21st century are increasingly complex, requiring managers to balance different social, political, ecological and economic objectives and stakeholder concerns. The Water and Watershed Science Program addresses natural resource problems in the immediate and long term to discover and develop scientific knowledge and guide the translation of research results into viable products that meet the needs of natural resource managers. We produce the science to guide watershed restoration and create resilient landscapes that provide watershed-based ecosystem services.

Our research addresses needs in both basic and applied science and management for advancing our understanding of watershed conditions, while focusing on the synergy between physical and biological components. Fundamental studies are needed to elucidate biological and ecological patterns, while applied research will incorporate findings into real-world applications to evaluate effects of natural disturbance, human activities, and management practices on selected response variables. Applied work will be relevant to new challenges faced by managers, as well as evaluating past actions to address best management practices.

Our core science implements long-term research studies across local to national spatial extents. This research involves experimental manipulations to quantify process-level mechanisms, broader landscape-scale assessments and regional modelling. The outcomes of our core research are relevant to managers today and will help assess future conditions and concerns regarding changing climate, disturbance regimes, and land-use. Long-term data collected within experimental forests has helped elucidate the immediate and persistent consequences of forest management, the climatic factors and forest conditions influencing current insect outbreaks, and the response of western watersheds to climate change. We have investigated how the region's biota have responded to past climate variations and thus have an improved understanding of present changes.

The three problem areas present opportunities for integration across the eight RMRS Science Programs. We anticipate that scientists will pursue traditional programs of research, and that teams within and across the programs will be organized around specific Problem Areas as new critical research needs emerge. Our research teams will comprise physical and biological scientists working across the West and will embrace collaborative, interdisciplinary, and integrative approaches to address science questions. Scientists in the Water and Watersheds Science Program collaborate with scientists in the National Genomics Center for Wildlife and Fish Conservation to apply genomic and environmental DNA (eDNA) approaches to describe western aquatic biodiversity and explore the status and distribution of aquatic species of conservation concern in the West.

Our network of experimental forest and research natural areas gives RMRS watershed researchers the unique opportunity to evaluate the response of physical and biologic factors to management, periodic disturbance and climate change. Deterministic approaches to process-level studies and model development provide great potential for real solutions in a changing climate. Long-term data collected at experimental forests in Colorado (Fraser Experimental Forest), Wyoming (Glacier Lakes Ecosystem Experimental Site) and Arizona (Sierra Ancha), as well as Research Natural Areas and other sites suited to long-term monitoring has helped elucidate the immediate and persistent consequences of forest management, the climatic factors and forest conditions influencing current insect outbreaks, and the response of western watersheds to climate change.

Shifting human demographics will continue to alter the values that people hold for ecosystem services. Whereas well-established methods exist to estimate monetary value of market and non-market goods and services, such as the cost of drinking water infrastructure and treatment facilities, more research is needed to assess and account for the cultural, educational, and spiritual values of clean air, clean water, healthy watersheds, and sustainable fish and wildlife. It will be essential for the long-term sustainability of western ecosystems for our physical and biological scientists to include social scientists in their research to translate ecosystem processes into ecosystem services and assessments of the socio-economic value associated with their proper management and conservation. As new threats to fragile environments emerge, we will integrate social scientists into our research teams to identify key research questions and perspectives.

Science delivery and applications will be accomplished initially through peer-reviewed publications in scientific journals. Published results will be disseminated to managers, the general public, and interest groups to ensure effective technical transfer and application of research results. Field trips, workshops, brochures, general technical reports, and one-page handouts will be used as appropriate to translate results into user-friendly formats readily digestible by managers and other interested parties. We will also develop synthesis documents to summarize the state-of-knowledge on key air, water and aquatic management issues. These products, along with the original peer-reviewed publications, will be available on the RMRS website. We will work to identify ways to simplify the application of research results to make them more useful to lay people and make research results more available over the internet. The above strategy will accomplish both while ensuring the relevance of the research described herein. Where appropriate will propose to advance our ongoing efforts of technology transfer of our research products through a Research, Development, and Applications Program.

The Water and Watershed Research Program works in the following three problem areas:

Problem Area 1 – Core watershed research to discover and develop knowledge that quantifies the dynamics of hydrologic, geomorphic and biogeochemical processes in forests and rangelands at multiple scales.

Watershed research on physical processes and functions provides cause-and-effect knowledge that underlies and validates management decisions, resulting in productive and diverse forests, grasslands, and aquatic ecosystems. Our research quantifies and models the hydrologic, geomorphic and biogeochemical processes influencing water yield and water quality. It examines responses of terrestrial, riparian and aquatic systems to changes in vegetation, disturbance regimes, management activities, and climate. Current and future research will measure the delivery, transport, and storage of water, nutrients, sediment, and large wood, and will model these fluxes across a range of temporal and spatial scales, evaluating how disturbance and management practices influence watershed properties and processes. Our research will guide management responses to natural and anthropogenic disturbances and improve understanding of the consequences of unprecedented climate variability and change.

Current and future research efforts are broadly categorized in the following Elements:

1a. Provide better understanding of the water cycle from the accumulation process to runoff, including interception, sublimation, evapotranspiration, infiltration, groundwater and other hydrological processes. This research focuses on improving water supply forecasting. Current forecasts of runoff volume and timing are limited by a high degree of uncertainty from most basins of operational size, with consequences to at-risk aquatic species, downstream municipalities, industry, commerce and agriculture. The basic water balance of snowmelt-driven hydrologic systems is uncertain because we cannot adequately represent the interception, sublimation, evaporation, and melting of the snowpack beyond the plot scale. Furthermore, evaporation and transpiration represent a large portion of the forest water budget, yet direct measurements of evapotranspiration and the contribution of vegetation to site water balance are rare. The uncertainty increases further at the basin scale where it is complicated by inadequate knowledge of the factors that regulate net radiation, air temperature, forest structure, and leaf area. Understanding of the hydrologic links between high-elevation snowpack and the lower elevation water availability and demand remain rudimentary. Integrating field studies with remotely sensed data and models will increase our knowledge of these interacting processes and reduce uncertainty in runoff forecasts.

A basic problem still facing hydrologists is determining the seasonal accumulation patterns of the snowpack in complex terrain and how topography and vegetation cover affects subsequent snowmelt. Improved understanding of controls on snow distribution at the process level is needed, including interception, sublimation, redistribution, evaporation and melt. We need better models for predicting spatial and temporal variation in snow distribution, which will ultimately improve water yield forecasting. Efforts to expand hydrologic processes from point measurements to landscape, basin, and regional scales remain preliminary.

Incorporation of new tools and techniques, such as remote sensing using visible and microwave frequencies, are critical to successfully moving from process-level understanding to broader-scale applications.

The hydrologic and carbon cycles are intimately linked and largely controlled through the processes of transpiration and photosynthesis. Terrestrial vegetation fixes millions of tons of carbon per year and as a consequence, approximately 2/3 of the annual global precipitation falling on terrestrial ecosystems is returned to the atmosphere via evapotranspiration. Improved understanding of the biophysical controls and linkages between these two processes at multiple scales will be critical to balancing the delivery of water and carbon ecosystem services from public lands.

Outcomes:

- Improve understanding of the contribution of vegetation to site water balance by quantifying the effects of forest type and structure on the hydrological processes that drive the water cycle.
- Improve snow transport and distribution models in complex terrain by quantifying the difference in sublimation of snowfall interception at different elevations and determine the contribution of large snow drift deposits in alpine basins to the subalpine water balance.
- Refine estimates of the difference in the water balance between disturbed and undisturbed slopes.
- Develop hydrologic forecasting models to assist with flood risk estimation and water supply.
- Assess the effects of different types of catchment disturbance on melt and runoff generation processes.
- Evaluate the consequences of land management alternatives for dealing with bark-beetle and other native and non-native insect outbreaks on water yield, water quantity and carbon storage.

1b. The movement of sediment and wood from hillslopes and through stream channels is affected by natural and human disturbances. Natural and anthropogenic disturbances can greatly increase the erosion potential of forest and rangeland soils. Soil erosion and mass wasting patterns and rates are a result of complex interactions between the local climate, geology, soil, and topography. Soil properties (such as hydraulic conductivity and erodibility) and vegetation (including above ground biomass, surface residue cover, and root strength) are altered by these driving factors and may further modify erosion processes. These processes are highly variable in both time and space, further complicating our ability to predict sediment and large wood loads associated with chronic vs. pulsed disturbances. Chronic fine sediment is a significant pollutant of streams, making them less able to meet a myriad of uses, such as those outlined in the Clean Water Act; fine sediment is also commonly associated with other pollutants, such as nutrients, pathogens, and heavy metals. When sediment reaches streams, managers need to know how fast and how far it will be carried downstream, how long it will be stored in a given stream reach, and how long it will take to move through the channel network. To meet federal and state standards for beneficial uses of wildland streams, and to maintain forest and rangeland sustainability, natural resource managers need new knowledge and tools to improve their ability to predict and mitigate onsite erosion and offsite water quality impairment caused by forest disturbances.

Acute inputs from less frequent, episodic disturbances (i.e., pulsed events), such as landslides, debris flows, and avalanches are often temporarily destructive, but valuable for long-term habitat formation, in part because of the delivery of wood, organic matter, and nutrients to streams. The role of large wood in streams and riparian areas has become increasingly recognized as beneficial over the last several decades. Large wood affects geomorphic, hydrologic, and ecological processes in streams and rivers, and its numerous roles link aquatic, riparian, and upland portions of watersheds. Large wood strongly influences channel form in small streams, creating pools and waterfalls, and altering channel width and depth. In addition, the presence of large wood in streams affects erosion, transport, and deposition of sediment, the creation and expansion of gravel bars, and channel and floodplain sediment retention. Furthermore, large wood alters channel hydraulics, hyporheic exchange, thermal structure, and residence time of solutes and particulate matter (including pollutants), thereby structuring the diversity and quality of stream habitats and influencing ecosystem metabolism. Variation in instream wood abundance is tied to forest succession and disturbance, but in ways that are currently difficult to predict. Large wood is delivered to streams by a number of processes, ranging from steady inputs of riparian and hillslope trees to large, episodic inputs resulting from natural disturbances.

Although several models have shown that large-scale forest disturbance (such as fire and insect-caused tree mortality) can result in pulsed delivery of large wood and sediment to streams, these predictions have not been validated by empirical studies. Our research contributes to the development of recommendations for managers who are challenged with maintenance of instream wood loading and channel stability in areas affected by fire, insect infestation, and harvest activities (including fuels reduction).

Outcomes:

- Understand how geomorphic history and bedrock geology influence sediment regime and affect system sensitivity to changes in flow and sedimentation.
- Improve estimates of sediment transport as a function of sediment supply, streamflow regime, and stream channel characteristics.
- Improve existing hydrology and erosion risk models (GRAIP and GRAIP_Lite; WEPP and ERMiT) by quantifying onsite and offsite erosion effects of transportation network design, management and recreational use; wildfire and fuel management; and other human and natural disturbances.
- Predict effects of climate change on sediment and wood yield, their routing through the channel network, and associated changes in channel morphology and riverine habitats.
- Quantify controls on landslide, avalanche, or debris-flow location, size, runout path; downstream routing of sediment and wood through river networks; and associated hazards to infrastructure along river corridors (e.g., roads, bridges, dams/diversions, campgrounds, and municipalities).
- Identify and quantify the watershed effects of wildfire, fuel management, salvage logging and other hillslope disturbances.
- Evaluate temporal changes in riparian and in-channel wood loading, stream channel adjustment and large wood dynamics in response to insect-caused canopy mortality, fuel reduction and harvest activities.
- Evaluate the effectiveness of wildfire rehabilitation activities including the utilization of excess biomass for erosion control and other beneficial uses.
- Quantify the effects of severe wildfire and prescribed burns on soils and improving remote sensing approaches to assessing soil burn severity.

1c. Biogeochemical processes link deposition, uptake, storage and export of water, carbon, nutrients and pollutants in western watersheds. Multi-scale research of the biogeochemical linkages between terrestrial, riparian, and aquatic environments will increase basic understanding of watershed processes and help evaluate the effects of disturbance and land management. Stream chemistry and water quality are influenced at various locations within the catchment by interacting hydrological and biogeochemical processes. Analysis of the spatial and temporal variation in long-term, high-elevation, lake and stream water chemistry will help guide future surface-water monitoring efforts aimed at detecting changes in water quality. Improved monitoring approaches will help determine the response of high-elevation terrestrial and aquatic ecosystems to critical loads and provide support to the National Air Program's monitoring of atmospheric deposition and its effects.

Outcomes:

- Quantify the nutrient and carbon dynamics of alpine, subalpine, and riparian ecosystems.
- Refine approaches for monitoring and assessment of critical loads of nutrients in forest ecosystems.
- Characterize the hydrologic and biogeochemical linkages between terrestrial, riparian, and aquatic environments.
- Characterize stream and lake thermal regimes related to natural disturbances, riparian vegetation and water quality dynamics.
- Characterize the effects of disturbance, restoration and harvest practices on soil and aquatic biogeochemistry and water budgets.
- Determine the impact of extensive insect outbreak and associated management on sustained soil and forest productivity and the delivery of clean water.
- Examine the relationships among forest regeneration, soil moisture and nutrients, and water availability in forested watersheds recovering from insect outbreaks and wildfire.

- Evaluate the effectiveness of current and new watershed conservation Best Management Practices for protecting surface water quality and other watershed resources.
- Evaluate the biogeochemical responses of terrestrial, riparian, and aquatic ecosystems to atmospheric deposition and air-borne pollutants.
- Develop assessment approaches and sampling methodologies to assist aquatic resource managers with the mitigation of acid mine drainage and contamination by heavy metals in surface waters.

Problem Area 2 – Core watershed research that quantifies the biological processes and patterns that affect the distribution, resilience, and persistence of native and non-native aquatic and riparian species.

Research in this problem area defines the biological processes and patterns that affect the distribution, resilience, and persistence of native aquatic, riparian and terrestrial species. Research results are applicable to restoring watersheds impacted by human activities such as timber harvest and recreation, evaluating watershed conservation and best management practices, forecasting water supplies to municipalities and irrigators, and reducing impacts from land management activities and infrastructure to aquatic organisms. Studies will examine historical and current cycles of drought, insects, and fire-affected vegetation characteristics and other resource values over time and how fundamental, yet complex processes can be modeled to predict the effects of future natural disturbances and climate variability. Research will evaluate the watershed impacts of air pollution and atmospheric deposition and quantify how land management alters soil and water quality.

In aquatic ecosystems, our focus will continue to be with aquatic vertebrates in general, and fishes in particular. Although that does not mean we will ignore the trophic and ecological processes that require an understanding of other species and aquatic ecosystem components, fishes will represent an important currency for communication of our work. Fishes are often the dominant and most widely distributed vertebrates found in many of the mountain streams of the region. Fishes play an important role in structuring aquatic ecosystems at levels ranging from top-level predators to prey to sources of nutrient transport. Pacific salmon are considered keystone species because the marine-derived nutrients they supply disproportionately influence riparian and even upland plant and animal communities. Non-anadromous migratory forms in interior systems may play a similar, though less visible role. Invasive non-native fishes can potentially replace or displace native species with cascading effects on the functions and organization of aquatic communities.

An essential aspect of ecological research is the study of interactions between organisms and the environment, including dependence on physical factors and interactions with other biota. Adaptations permit species to inhabit particular environmental niches, for example thermal tolerance, branch architecture, and phenology. The interactions between individuals of the same species are important for both formation of habitat and reproduction in many species. The continuity of species representation on the landscape may be important for resilience to major disturbances and changing climates. Interactions with other species can be competitive or benign and play an important role in the spatial distribution and representation of species. As changes such as new species introductions, an altered climate, or human activities impair habitats, the relationships may shift and invasions or factors that affect habitat quality may pose critical threats to native species.

A growing body of theory and empirical evidence suggests that localized persistence and resilience of species, populations, and communities can be understood only across a series of spatial and temporal scales and contexts. A better understanding of the dominant processes influencing the distribution, connection, and dynamics of species and populations through time and space requires work at multiple scales, especially at scales larger than typical of past research. It will require the adaptation of theory and analytical tools developed in other disciplines.

Physical and ecophysiological factors control the distribution of riparian plant species and communities as well as their response to management and disturbance, particularly harvesting, flow alteration and fire and insect outbreak. Changes in fire and flow regimes and invasion by non-native species are changing riparian environments.

Current and future research efforts are broadly categorized in the following Elements:

2a. Addressing the fundamental components of freshwater ecology: defining species and understanding their distributions. Effective conservation and management of freshwater biota during an era of rapid climate change, non-native species invasions, and habitat loss, as well as widespread efforts to maintain, restore, and expand the distributions of at-risk species, requires accurate information about species distributions across broad areas to guide decision-making. The complexity of aquatic ecosystems can at times be overwhelming and attempting to prioritize which aspects of aquatic ecosystems will become critical. Therefore, the goal of this element is to focus on the two properties fundamental to understanding freshwater ecosystems, regardless of the research question or management issue: what species are present, and where are they. Despite the fiscal and intellectual investments devoted managing, monitoring, investigating and restoring to aquatic species and their habitats, the lack of critical information has contributed either to misdirected conservation or a failure to act when conservation would have been effective. Our goal is to identify species and describe their distribution, to apply those data to understand the present status and forecast the future distribution of focal species, and to share those data with our stakeholders to meet their present management needs and to position the Forest Service and society to address unforeseen or emerging scientific and management issues.

Of equal importance to species conservation is a refined understanding of life-history diversity, population and evolutionary structure, and dynamics for fish species of concern. Two concepts dominate current theory of how populations persist in spatially and temporally varying environments: (1) spatial structure and metapopulation dynamics, and (2) life-history or phenotypic diversity. Metapopulation theory suggests that the geometry and connectivity of suitable habitats (or habitat patches) will constrain the dynamics of populations associated with those habitats. We have demonstrated that connectivity among habitats is critical to the persistence of fish populations of concern. However, to objectively weigh the benefits and risks associated with past and future management, mesoscale disturbances (such as fire), and climate change on the geometry and condition of available habitats, it will be necessary to better understand the underlying processes (e.g., extinction/colonization, dispersal/gene flow) that structure fish populations and influence their dynamics.

Life-history variation within fish species may play an important role for the resilience or productivity of individual populations. Species diversity of fishes in the Intermountain West is relatively low, but phenotypic diversity is remarkably high. The array of migratory patterns, trophic types, and life-histories appear to be adaptations to the dynamic and varied nature of the streams, rivers, and lakes that exist in this region. Previous work has generally reinforced the notion that management to conserve or re-establish opportunities for the full expression of diverse life histories is important. Knowledge of how that diversity is distributed across landscapes or the conditions that influence its expression are necessary to guide conservation management. Such information can be key to evaluating management actions and prioritizing conservation and restoration efforts. Even for well-studied species such as salmonid fishes, existing information is incomplete. Few life stages of a relatively small number of species are well understood.

Outcomes:

- Apply phylogenetic tools describe new species, to identify units of conservation, or assess the validity of accepted species, whether by targeting traditional approaches at poorly studied groups or by adopting next-generation genetic tools to address taxonomic problems. This lays the foundation of a robust taxonomy on which to base conservation management and scientific inquiry.
- Conduct broad-scale phylogeographic investigations to delimit the ranges of existing, proposed, or unrecognized taxa. This establishes the range limits of these taxa and builds a multi-agency community of support by developing a consortium of interested biologists to defray costs by making in-kind contributions and to broaden the sampling area that can be characterized.
- Devise genetic markers for aquatic species throughout streams in the West that will characterize genetic diversity, quantify population connectivity, detect hybridization, explain phylogenetic relationships and identify and delimit distinct population segments to inform strategic species and population management (salvage, broodstock development, protection or assisted migration of core conservation populations).

- Enhance the ability of eDNA sampling to embrace more species across a greater range of habitats and more efficiently characterize community composition, and to refine its use for estimating animal abundance and detecting patterns of movement. This extends high-precision estimates of habitat occupancy to more species and allows biologists to address more refined questions about populations.
- Apply eDNA sampling as a monitoring tool to provide rapid status assessments of aquatic species at scales ranging from local to range-wide scales, to generate the baseline biological data necessary for species distribution models (SDMs). As the eDNA data delimit the occupied range, models can suggest why those habitats are occupied, and together they are used to forecast how that range might change under a variety of scenarios and to inform prioritization of conservation actions and areas.
- Enhance the eDNAtlas as a tool to provide data to stakeholders in an open-access, flexible format, enabling them to tailor those data for their own uses; as a general repository for eDNA-based data obtained by other practitioners, further enhancing the value and visibility of the database; and as a means to foster collaborative and robust species monitoring by initiating eDNA sampling projects for species of interest. By engaging biologists throughout the agency, their peers at other federal, state, and tribal agencies, NGOs, and academic institutions, as well as citizen scientists, the eDNAtlas fosters communication among stakeholders, leverages hundreds of individual contributions into a robust, definitive assessment of species distributions, and emphasizes Forest Service leadership in the stewardship of the nation's aquatic resources.
- Describe the distribution and variation in fish life-history patterns at multiple scales and the characteristics of habitats occupied by the different life stages (e.g., spawning, juvenile rearing), and model associations between environmental variables (e.g., stream size, cover, temperature, connectivity) and aquatic species or life-stage distributions.
- Develop remote sensing and geospatial data sources to relate aquatic habitat attributes and spatial structure of populations and their roles in persistence of aquatic species.
- Improve understanding and predictive abilities regarding the thermal ecology of aquatic ecosystems given the importance of temperature to stream metabolism and communities of ectothermic organisms.
- Develop and deliver spatially explicit decision support tools that integrate information sources affecting aquatic species of management concern. These tools may take the form of Bayesian belief networks, high-resolution maps, and supporting databases.
- Describe spatial structure, straying and dispersal, distribution and variation in life-history patterns and regional dynamics of native salmonid populations by the application or extension of patch-based models, molecular genetic markers, otolith microchemistry, and demographic analysis.
- Model associations between environmental variables (e.g., stream size, cover, temperature, connectivity) and aquatic species or life-stage distributions. Examine the generality or transferability of these models and their utility for predicting the distribution of potentially suitable habitats and resident species.

2b. Examine the physical and biological factors that regulate the distribution of wetland and riparian species, populations and communities and their response to flow alteration, fire, insect outbreak, invasion by non-native species, management practices and climate change. Although riparian areas occupy only 0.5 to 2.0% of the landscape in the region, they provide numerous ecological functions, most of which are tied to riparian vegetation. Riparian vegetation supplies habitat and forage to an array of terrestrial and aquatic species, furnishes shade, large wood, and allochthonous organic inputs to streams, and increases hydraulic roughness and stability of stream banks and floodplains. In addition, riparian plant communities frequently constitute the most floristically and structurally diverse vegetation in a region. Distinctive characteristics of riparian vegetation — species composition, population dynamics, community structure and distribution — are driven by the hydrologic regime, geomorphological setting, and related gradients in soil moisture, and are strongly influenced by vegetative legacies and life history strategies. Although we have emphasized the importance of thinking at multiple scales, much remains to be learned about the fine-scale distribution and habitat use of native and non-native aquatic, riparian, and terrestrial species. In addition to extending our knowledge of the fine scale distribution and habitat use of species, an important element of this work will be integration of information developed at larger scales. Since the fundamental processes and patterns influencing species distributions may change with the scale of analysis, models developed at smaller scales may provide a different (though complementary) understanding than that developed at larger scales.

An essential aspect of ecological research is the study of interactions between organisms and the environment, including dependence on physical factors and interactions with other biota. There are some adaptations that permit particular species to inhabit particular environmental niches, for example thermal tolerance, branch architecture, and phenology. The interactions between individuals of the same species are important for both formation of habitat and reproduction in many species. The continuity of species representation may be important for resilience to major disturbances and changing climates. Interactions with other species can be competitive or benign and play an important role in the spatial distribution and representation of species. As new species are introduced or as the climate changes, the relationships may shift, and invasions may pose critical threats.

Headwater wetlands are critical hydrologic source areas and points of high local and regional biodiversity. Recent debate on the jurisdictional protection of headwaters under the Clean Water Act highlights the need for informed science regarding the ecology and contribution of high elevation wetlands relative to downstream waters. In the Rocky Mountain region, the distribution and biota of headwater wetlands have resulted from patterns of glaciation and past climatic events, and the condition and persistence of these systems may be particularly vulnerable to management, disturbance, and climate change. Our research on alpine and subalpine wetlands, seeps and springs examines hydrologic connectivity within watersheds, describes the characteristic plant communities, and establishes a baseline for monitoring the short-and-long-term impacts of disturbance and climate change.

In many watersheds in the Western US, natural flow regimes have been altered by regulation of streams and rivers (diversions, groundwater pumping, and dams) and other management practices. Although the impacts of regulated flows below dams have been examined for some riparian plant communities, the short and long-term influences of stream flow diversion on structural and functional characteristics of riparian and aquatic ecosystems are poorly understood. To determine the stream flows needed to sustain riparian vegetation and function, we need a better understanding of the influence of natural and regulated flows on the distribution and maintenance of riparian plant communities over a range of stream types. Water use is an inevitable consequence of plant growth and the ability of plants to move water from soil to leaf while acquiring CO_2 for photosynthesis sets a fundamental constraint on their ability to survive in a particular habitat. Knowledge of how the ecophysiological constraints to plant water and carbon uptake control the response of riparian vegetation to altered flow regimes will contribute to mechanistic explanations of the minimum flows required to sustain key riparian species.

Non-native species invasions, their impacts and potentials are critical in riparian and terrestrial plant communities as well. Management and restoration require understanding factors that lead to invasions, identifying circumstances where non-native species are likely to invade, and identifying management priorities and tools for monitoring, inventory, evaluation, and control of invasions.

Outcomes:

- Determine the effect of disturbance and management on headwater and riparian wetland condition. Identify the hydrologic, geomorphic, and ecophysiological variables that determine the distribution of wetland and riparian plant communities at local, regional, and watershed scales.
- Quantify the effects of hydrological alterations on the ecophysiological characteristics of key riparian plant species and identify measurable attributes of riparian vegetation that are most sensitive to changes in hydrologic regimes.
- Determine the spatial and temporal scales over which selected vegetation and physical variables should be measured along riparian corridors to assess impacts of altered hydrologic regimes.
- Evaluate the effects of climate change on the distribution of aquatic and riparian species, populations, and communities.
- Evaluate the consequences of bark-beetle caused canopy mortality on wetland, riparian, and forest understory plant communities.

- Examine the role of fire on the dynamics and persistence of key riparian plant species and communities and the susceptibility of burned riparian areas to invasion by non-native species.
- Characterize the effects of disturbance and management on the vulnerability of headwater wetland and riparian environments to invasion by non-native species.
- To improve predictions of future invasion potential by non-native species, determine the influence of physical and land use variables on the distribution of invasive non-native plant species along riparian corridors.

2c. Examine the impacts of non-indigenous aquatic species on native fish species. Non-indigenous species are becoming increasingly widespread in aquatic, riparian, and terrestrial ecosystems throughout the region. In some cases, non-indigenous aquatic species have been intentionally introduced for purposes ranging from pest control to supporting recreational fisheries. Problem resolution requires understanding factors that lead to invasions, identifying circumstances where non-native species are likely to invade, and identifying management priorities and tools for monitoring, inventory, evaluation, and control of invasions.

Outcomes:

- Understand the environmental and ecological factors influencing the interaction between and coexistence of native and non-native species and the ultimate risk of hybridization, replacement, or displacement of native species once non-natives are established.
- Develop methods based on collecting environmental DNA to assess the presence or absence of at-risk native fish and non-native fish species in streams in the western U.S. to permit rapid, reliable, and noninvasive monitoring that avoids the expense and mortality associated with traditional sampling. eDNAtlas interagency database.
- Develop species distribution models to estimate the probability that isolated populations of native fishes will persist and to predict future invasion potential by established non-native species.
- Understand the environmental and ecological factors influencing the interaction between and coexistence of native and non-native species and the ultimate risk of replacement, displacement, or hybridization with native species once non-natives are established. Understand future invasion potential by non-native species, including those that are already established.

Problem Area 3 – Integrated, interdisciplinary research explores the interactions of physical and biological ecosystem processes that contribute to watershed condition during a period of rapid environmental change. Changing landscape and climate conditions affect water availability and how freshwater systems process nutrients, store carbon, and provide critical habitat for vulnerable species. Uncertainty about the consequences of climate change presents one of the greatest challenges currently facing water and land managers in the West. Managers and decision makers require estimates of how increased variability in precipitation and warming temperatures will influence local and regional snowpacks, the timing and amount of runoff and changes in the chemical composition of stream water. The larger, more severe wildfires and increased vulnerability of western forests to insects and disease associated with changing climatic conditions are also expected to present greater obstacles to the delivery of clean water for national forest lands. Our current process-level knowledge is inadequate to predict how the complex, interrelated physical and biological factors will respond to climate change at useful spatial scales.

Natural and anthropogenic disturbances alter physical conditions on the landscape that, in turn, affect habitat availability, quality, and ecological processes over space and time. Conversely, plants and animals can passively or actively modulate rates and styles of physical processes, with changes in species distribution and composition altering physical process domains and watershed condition. Here, we conduct a broad range of studies examining these two-way biophysical interactions and their significance for land management and conserving/restoring natural resources in the face of a changing climate and land use.

Current and future research efforts are broadly categorized in the following Elements:

3a. Water availability and quality will be affected by changes in precipitation and temperature regimes or patterns. Changes in precipitation and temperature will have significant potential effects on the distribution and abundance of upland and riparian plants and animals. To provide viable options for managers to address climate change, we will need to predict likely natural resource shifts and educate and inform the public on current and future states of water supply and provide viable options to address water supply issues through proper management of headwater forests. Large scale forest disturbances from insect outbreaks and wildfire are reshaping the West. Forest regeneration following these disturbances will do so under pressure from climate change. Climate warming has caused fundamental shifts in distributions of forest types in many parts of the world over the past five decades and the latest "reset" of forest conditions in bark beetle-affected and large burned areas will likely catalyze and accelerate type conversions. Mean annual temperature, atmospheric CO_2 concentration and frequency and severity of drought are all expected to increase during the next century over the West. Certain tree species will thrive and expand, and others may decline under future environmental conditions, yet there are significant gaps in our ability to predict the species composition and growth response of Western forests to changing climate.

Outcomes:

- Quantify the effects of changing forest structure on the rates and amounts of snow sublimation in forested watersheds within the Rocky Mountain region of northern Colorado and southern Wyoming.
- Relate long-term changes in precipitation (water and snow amounts, duration, timing, and frequency) and rising temperatures to forest, riparian and wetland vegetation and responses to disturbance.
- Quantify long-term relationships between historical climate change and observed environmental responses (e.g., stream flow dynamics; stream water quality).
- Quantify ecosystem fluxes of water, nutrients and CO_2 in watersheds as an indicator of watershed condition and relate those fluxes to climate variability. Incorporate this knowledge into ecosystem level models to forecast potential changes in ecosystem water and carbon cycles.
- Document changes in nutrient (carbon and nitrogen) and water budgets in a small watershed as a result of forest succession, harvest, insect outbreaks and regeneration. Establish a collaborative program with other RMRS research work units to establish planting trials aimed at assessing the mechanisms of survival and long-term growth of forest species and which elevational provenances are the most likely to expand or contract their range in disturbed areas. Trials will be established across the RMRS Experimental Forest and Range network for long term monitoring and protection of these critical research assets.

3b. Assess the biophysical ecology of high elevation groundwater dependent ecosystems. Groundwater dependent ecosystems (GDEs) are among the most productive of high mountain ecosystems, are critical ecological components of headwater systems, and provide essential ecosystem services and resources. Climate change has the potential to dramatically alter hydrology and all related ecosystem components, making GDEs particularly vulnerable to climate change. GDEs also have the potential to serve as refugia (at least for a while) in otherwise dramatically changing areas. This research will investigate the critical components of GDEs and their interrelationships, including surface and subsurface hydrology, sediment regime, vegetation patterns and their response to changing hydrology, resource utilization by aquatic and terrestrial animals, assessment of probable climate change effects, assessment of limits of water diversion to avert environmental degradation, and recreational use and importance.

Outcomes:

- Investigate how changes in the amount, duration, frequency, and timing of precipitation, as well as shifts in temperature regimes resulting in warmer nights, earlier snow melt, and warmer, drier summers interact at multiple spatial and temporal scales to affect ecosystem carbon and water cycles.
- Quantify the biological and physical factors regulating soil and vegetation responses to changing climate and adjacent land management. Develop Best Management Practices for managing riparian vegetation in high elevation GDEs.

3c. Examine the effects of climate change on watershed processes, biophysical interactions, and shifts in species distribution and resilience. Uncertainty about the consequences of climate change presents one of the greatest challenges currently facing water and land managers in the West. Managers and decision makers require estimates of how increased variability in precipitation and warming temperatures will influence local and regional snowpack, the timing and amount of runoff, and changes in water quality (stream temperature, chemical composition, and sediment and nutrient loads), potentially endangering reliable delivery of clean water to national forest lands and downstream municipalities. Altered streamflow and changes in hydroclimate also have direct consequences for channel hydraulics, river morphology, sediment transport, hyporheic exchange, and riparian function. Furthermore, the larger, more severe wildfires and increased vulnerability of western forests to insects and disease associated with changing climatic conditions are expected to alter rates and magnitudes of hillslope erosion, wood inputs, and basin sediment yields. Collectively, climate-driven changes in hydrology, geomorphic processes, and thermal regimes of air, soil, and water are expected to cause shifts in the distribution and composition of terrestrial, riparian, and aquatic species that, in turn, may have complex feedbacks with physical watershed processes. Our current process-level knowledge is inadequate to predict how the complex, interrelated physical and biological factors will respond to climate change at useful spatial scales. Future watershed research will integrate detailed studies of point processes into landscape and regional-scale assessments of the likely change in climatic drivers, disturbance regimes, vegetation distributions, physical and biological processes, and ecosystem function. The long-term data records maintained by the USFS Experimental Forest and Range network combined with geographically extensive crowd-sourced databases developed with our partners provide RMRS scientists with unique opportunities to contribute to the characterization of climatic variability and evaluations of how such change alters biophysical interactions and conditions of western watersheds.

Outcomes:

- Quantify the integrated effects of climate change and climate variability on hydrologic, geomorphic, and biogeochemical processes in terrestrial, riparian, and aquatic ecosystems using field observations and development of predictive models.
- Quantify the biological and physical factors regulating soil and vegetation responses to interacting bark beetle and fire disturbances.
- Determine how anticipated climate change will alter the timing and magnitude of floods, channel morphology, sediment transport regimes, and risk of critical scour to affect incubating salmonid embryos and other life stages in different hydroclimates throughout western North America and Europe.
- Characterize the effects of climate variability on aquatic and terrestrial ecosystems by examining salmon spawning distributions and the influence of climate and landscape characteristics. Use crowd-sourced databases (stream temperature, genetics, and species occurrence) and geostatistical models to understand and predict how species distributions, available habitats, and risk of non-native invasion will shift over time in the face of climate change and where long-term climate refuge habitats may continue to support native populations later this century.
- Use a long-term database of salmonid spawning sites in the Middle Fork Salmon River and basin-scale models of physical conditions to understand how hydrology, geomorphology, stream temperature, and wildfire structure the distribution and quality of spawning sites under current conditions and those anticipated under a warming climate.
- Understand how atmospheric, hydrologic, and geomorphic processes influence patterns of aquatic biodiversity, ecological traits, and species dynamics and persistence.
- Predict and monitor long-term changes in bed load transport, channel morphology, and salmonid habitat following post-fire debris flows in mountain basins of central Idaho to assess risk to aquatic resources and river-corridor infrastructure and to inform managers of the potential consequences of climate-driven increases in wildfire and debris flows.
- Describe effects of habitat fragmentation and recent isolation on the genetic diversity and persistence of native salmonids.

- Model associations between environmental variables (e.g., stream size, cover, temperature, connectivity) and aquatic species or life-stage distributions. Examine the generality or transferability of these models and their utility for predicting the distribution of potentially suitable habitats and fishes.

3d. Watershed restoration and conservation of threatened and endangered species. Results of our research program are applicable to restoring watersheds affected by human activities (such as timber harvest and recreation), evaluating watershed conservation and best management practices, forecasting water supplies to municipalities and irrigators, and reducing impacts from land management activities and infrastructure to aquatic and riparian organisms. Studies will examine historical and current cycles of drought, insects, and fire-affected vegetation characteristics and other resource values over time and how fundamental, yet complex processes can be modeled to predict the effects of natural and anthropogenic disturbances and future climate variability. In terms of riverine ecosystems, the effects of fire and fuels management have focused on the persistence and condition of native fish populations and riparian plant communities. The vulnerability of fish to fire depends on the quality and distribution of affected habitats and the habitat specificity of the fish species of concern. Currently, the most challenging questions are how the changing nature of fire in the landscape interacts with land, fuel, and fire management, and how these are being influenced by a changing climate.

Outcomes:
- Document changes in channel morphology, riparian condition, and salmonid habitat resulting from post-fire inputs of sediment and wood and develop models to predict downstream movement of these inputs, associated risks to river corridor infrastructure, and ecosystem recovery.
- Develop guidelines for stream restoration plans for rivers impacted by flow diversion and channel straightening in Idaho by combining high-resolution topographic measurements, monitoring and modelling of hyporheic exchange, morphodynamic modeling, and habitat modeling for threatened and endangered salmonids.
- Determine the minimum habitat sizes and qualities that are required by species to persist, and where these potential habitats currently exist or will exist under future climate change.
- Assess the role of fire on the dynamics and persistence of native and non-native fish populations.

11. Program Cooperators and Partners

RMRS Station Science Programs
Forest and Woodland Ecosystems; Fire, Fuels and Smoke; Human Dimensions; Managing Resilient Dryland Ecosystems; Wildlife and Terrestrial Ecosystems.

Other Forest Service Research Stations
Pacific Southwest Research Station, Pacific Northwest Research Station, Southern Research Station

National Forest System
Cooperative relationships exist with the Regional Offices of the Northern (Region 1), Rocky Mountain (R2), Southwestern (R3), Intermountain (R4), Pacific Northwest (R6) and Pacific Southwest (R5) regions and more than 25 National Forests in those regions. RMRS research and National Forest System scientists co-produce and apply research findings. Scientists from the Water and Watershed science program serve on the regional Science Advisory Teams for Regions 1-4. The Water and Watershed science program works closely with the Washington Office staff of the National Forest System's National BAER Program, Biological and Physical Resources staff and the National Stream and Aquatic Ecology Center.

Federal Agencies
Department of Agriculture: Agricultural Research Service; National Resources Conservation Service.
Department of Defense: U.S. Army Corps of Engineers; Strategic Environmental Research & Development Program.
Department of Energy: Bonneville Power Administration

Federal Agencies (continued)

Department of Interior: Bureau of Land Management: U.S. Fish and Wildlife Service; U.S. Geological Survey; U.S. Bureau of Reclamation.

Jet Propulsion Laboratory

National Aeronautics and Space Administration

National Oceanographic and Atmospheric Administration: NOAA Fisheries; National Weather Service

U.S Environmental Protection Agency: Office of Research and Development; Office of Water

Interagency Monitoring Programs

The Water and Watershed Research Program consults with or participates in the National Atmospheric Deposition Program, AmeriFlux, SNOTEL, CASTNet, Pacific Northwest Aquatic Monitoring Program, PacFish/InFish Biological Opinion Monitoring Program, and the Pacific States Marine Fisheries Commission.

Tribes

Burns Paiute Tribe
Columbia River Inter-Tribal Fish Commission
Confederated Salish and Kootenai Tribes
Confederated Tribes of the Colville Reservation
Confederated Tribes of Umatilla Indian Reservation
The Confederated Tribes of Warm Springs
Hoh Tribe
Kalispel Tribe of Indians
Kootenai Tribe of Idaho
Muckleshoot Indian Tribe
Nooksack Indian Tribe
Port Gamble S'Klallam Tribe
Quileute Nation
Quinault Indian Nation
Sauk-Suiattle Indian Tribe
Shoshone Bannock Tribes
Squaxin Island Tribe
Stillaguamish Tribe of Indians
Suquamish Tribe
Yakama Nation

State Agencies

Arizona: Department of Environmental Quality; Game & Fish Department

California: Department of Fish and Wildlife; Department of Water Resources; Environmental Protection Agency; State Water Resources Control Board

Colorado: Department of Public Health & Environment; Department of Wildlife and Parks; Colorado State Forest Service; Colorado Natural Heritage Program

Idaho: Department of Environmental Quality; Department of Fish and Game; Department of Water Resources

Montana: Department of Environmental Quality; Department of Natural Resources and Conservation; Department of Fish, Wildlife and Parks

Nevada: Department of Conservation and Natural Resources; Department of Wildlife

New Mexico: Environment Department; Department of Game and Fish; New Mexico State Forest Service

Oregon: Department of Environmental Quality; Department of Fish and Wildlife

South Dakota: Department of Game, Fish and Parks

Utah: Division of Wildlife Resources

Washington: Department of Fish and Wildlife; Department of Ecology; Department of Environmental Quality

Wyoming: Department of Environmental Quality; Game and Fish Department; Wyoming Natural Heritage Program

Local Government Agencies and Public Utilities

Humboldt County RCD, CA
King County, WA
Mendocino County RCD, CA
Central Klickitat Conservation District, WA
Colorado River District
Denver Water
Eagle River Water and Sanitation District
Foster Creek Conservation District
Northern Water
Pierce County, WA
Skagit County, WA
Snohomish County, WA
Salmon Drift Creek Watershed Council
Salt River (AZ) Partnership
Seattle City Light
Wasco County Soil and Water Conservation District
Underwood Conservation District
United Water Conservation District

University Partnerships

Boise State University
College of Idaho
Coconino Community College
Colorado State University
Idaho State University
Michigan Technical Research Institute
Montana State University
Northern Arizona University
Salish Kootenai College
South Dakota State University
Southern Illinois University, Edwardsville
Tulane University
University of California, Berkeley
University of California, Santa Barbara
University of Idaho
University of Montana
University of New Mexico
University of Washington
University of Wyoming
Utah State University
Washington State University

Non-government organizations

Bear Creek Watershed Association
California Trout
Clark Fork Coalition
Coalition for the Cache La Poudre Watershed
Columbia Riverkeeper
Crooked River Watershed Council
Eel River Recovery Project
Escondido Creek Conservancy
Friends of the Teton River
Grand County Water Information Network
Henry's Fork Foundation
Hood River Watershed Group
Idaho Power
Insight Consultants (Yoncalla, WA)
Mattole Salmon Group
Methow Restoration Council
The Nature Conservancy
North Fork John Day Watershed Council
PacifiCorp
Partnership for the Umpqua River
Riverbend Sciences
Rogue Riverkeeper
Skagit River System Cooperative
South Yuba River Citizens League
Trout Unlimited
Upper Deschutes Watershed Council, WA
Walla Walla Basin Watershed Council
Wildlife Conservation Society

12. **Scientific Workforce and Staffing Plan:** Scientific workforce available for accomplishing the planned work described in the Charter (based on current staff and anticipated changes. **Science delivery and technology transfer activities are factored into scientists' time devoted to the respective problem areas.**

Name	Title	Core Watershed Research (PA#1)	Aquatic Resources Research (PA#2)	Integrated Watershed Research (PA#3)
Frank McCormick	Program Manager			
John Buffington	Geomorphologist	75		25
Kate Dwire	Riparian Ecologist	40	25	35
Kelly Elder	Hydrologist	75		25
Robert Hubbard	Ecologist	20	50	30
Daniel Isaak	Fish Biologist	15	55	30
Charles Luce	Hydrologist	60	20	20
Daniel Neary	Soil Scientist	50	10	40
Charles Rhoades	Biogeochemist	60	10	30
Peter Robichaud	Engineer	75	5	20
Sandra Ryan	Geomorphologist	75		25
Russ Thurow	Fish Biologist	10	70	20
Michael Young	Fish Biologist	10	60	30
Vacant	Ecologist	40	40	20
Vacant	Ecologist	50	20	30
Vacant	Engineer	70		30

During the charter period of the Air, Water, and Aquatic Environments Science Program (2009– 2021), six research scientist positions and eight professional scientist positions became vacant, affecting all research Problem Areas of the program. Imminent retirements (CY21) in three critical disciplines will further directly impact the proposed problem areas of the Water and Watershed Program. Two additional retirements anticipated by CY22 will further degrade research capacity unless positions can be refilled. The program has developed a strategic workforce plan that addresses the science needs to address the research plan in this charter.

13. **Costs**.

The Water and Watershed program anticipates the need to invest between $790,000 and $1,165,000 annually exclusive of salary. Travel allocations under the FRSE budget line are not adequate to meet our research commitments. This cost estimate accounts for base salary adjusted for inflation and cost of living allowances, within grade increases and promotions, and retirements with recruitment of early career personnel. It also includes operating expenditures that will be needed to replace, and ideally upgrade, laboratory equipment that would enhance our analytical capabilities in support of post-fire water quality research and monitoring, the National Air and Wild and Scenic Rivers Program, and the Air Monitoring Program in the Rocky Mountain Region (R2). It includes investments in maintaining or improving the research infrastructure associated with the operations at our three experimental forests. The estimates also include targeted investments in emerging research areas. The program anticipates receiving funding from other agencies and research partners to complement and enhance the research portfolio. The total cost estimate over the 10-year research plan in the charter is approximately $64 million.

Costs (in thousands) distributed among the three problem areas.

Fiscal Year	Problem 1	Problem 2	Problem 3
2022	$ 2,672	$ 1,442	$ 1,561
2023	$ 2,697	$ 1,456	$ 1,575
2024	$ 2,747	$ 1,483	$ 1,604
2025	$ 2,797	$ 1,510	$ 1,634
2026	$ 2,849	$ 1,538	$ 1,664
2027	$ 2,661	$ 1,436	$ 1,554
2028	$ 2,665	$ 1,439	$ 1,557
2029	$ 2,747	$ 1,483	$ 1,604
2030	$ 2,815	$ 1,519	$ 1,644
2031	$ 2,815	$ 1,520	$ 1,644
2032	$ 2,841	$ 1,534	$ 1,660