RESEARCH PROGRAM CHARTER Ref: FSM 4070	**1. Number** RMRS-4354	**2. Station** RMRS
	3. Unit Locations Albuquerque, NM; Boise, ID; Flagstaff, AZ; Fort Collins, CO; Missoula, MT; Moscow, ID	

4. Research Program Title
Air, Water and Aquatic Environments Science Program

5. Program Manager (Name and address)
Frank H. McCormick (Acting). Boise Aquatic Sciences Laboratory, Idaho Water Center, Suite 401, 322 East Front Street, Boise, Idaho 83702

6. Area of Research Applicability	**7. Estimated Duration**
Regional, National, and International	10 years

8. Mission

The mission of the Air, Water, and Aquatic Environments (AWAE) 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 goal of this program is to develop core knowledge, methods, and technologies that enable effective watershed management in forests and grasslands, sustain biodiversity, and maintain healthy watershed conditions. We emphasize integration across disciplines and across RMRS science programs, across FS Research Stations, and with our science partners. We have the internal capacity for integration of physical and biological sciences that includes studies in the disciplines of atmospheric sciences, soils, forest engineering, biogeochemistry, hydrology, terrestrial and riparian plant physiology and aquatic ecology and limnology, conservation biology and fisheries. We use high-quality, long-term data for evaluating local, regional and national environmental change. 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 resource conservation and restoration. In this charter, we address priorities for a directed program of research that meets the science needs of resource managers and natural resource policy. Because science delivery is an essential part of the research cycle, AWAE Program scientists respond to emerging issues by communicating science findings and enhancing their application.

8b. <u>Response to National and Station Priorities</u>: AWAE research supports the mission of the U.S. Forest Service and is integrated with the USFS Research and Development Strategic Plan and the Rocky Mountain Research Station's Strategic Framework. Our research is positioned to support four of the strategic goals of Forest Service Research and Development and five of the FS R&D Strategic Program Areas (SPAs), and have expertise and have made significant contributions to core research in the USFS Research and Development "Growth Platforms". Further, this research is important to all 6 focus areas in the Station's strategic framework (Changing Ecosystems, Conflicting Values, Wildland Fire, Healthy Environments, Wildlife and Fish; and, Communicating With our Stakeholders).

The primary focus of our research to provide the core knowledge that helps **restore, sustain, and enhance the Nation's forests and grasslands (Goal 1).** We achieve this goal by increasing foundational knowledge in soil, water, and atmospheric research and the responses of terrestrial and aquatic species to natural and human disturbances including the introduction of invasive species, and landscape and climate change. By quantifying these relationships and their underlying processes, we

will contribute vital knowledge to the development of successful management strategies for sustaining healthy ecosystems.

We support **Goal 2 (Provide, Sustain, and Enhance Benefits to the American People) through our research in** ecosystem structure, function, processes, and their interactions in dynamic, rapidly-changing landscapes. This research benefits management strategies that help detect, quantify and mitigate threats to ecosystem services by disturbances (fire, air and water pollution, invasive species).

Our research cycle fully incorporates science delivery to resource managers and the public. We are committed to **provide science-based applications and tools for sustainable natural resources management (Goal 7).** 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 communicating with and educating the public. Conservation education under Goal 7 provides indirect support for **Goal 3 (Conserve Open Space)** and **Goal 6 (Engage Urban America with Forest Service Programs).**

We make significant research contributions that are central to the strategic initiatives of the Forest Service. Water availability and changing climate have recently been identified by the Chief of the Forest Service as two of the priorities now facing the agency. Our research meets Forest Service R&D strategic objectives in the Water, Air, and Soils; Wildlife and Fish; Invasive Species; Wildland Fire and Fuels; and Resource Management and Use SPAs. Our research in Watersheds, Climate Change and Experimental Forests and Rangelands represents foundational research on which collaborative approaches may be built. Population in the region is also rapidly expanding; the Urban Natural Resource Stewardship Growth Platform, linked with our existing work in Conservation Education, represents an additional opportunity for us to expand our outreach efforts to relate the conservation of water resources and aquatic species. Similarly, by linking our Experimental Forests and Rangelands, some of which provide drinking water for major metropolitan areas in the West, with prospective Urban Long-Term Research Areas in the Denver Metro and the Front Range growth corridor, Boise, Phoenix, Albuquerque, Salt Lake City, and Las Vegas.

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9. Justification and Problem Selection

Water has shaped the American West, where desert playas and forests exist only a few miles apart. Gradients in water availability, often modified through human engineering, constrain the distribution and abundance of biota in dramatic ways and frame land use, tying most cities and agriculture in the region to major rivers and groundwater reservoirs. Along with the increasing demand for water in the West, there is a limited supply that may be affected by projected changes in the regional climate, making it increasingly difficult to predict supply from year to year. Similar problems confront the public and natural resource managers throughout the U.S. New knowledge gained from research will be essential to meet the complex and extensive challenges facing western water management.

Despite the arid climate and variability in water supply, the West is the fastest growing region in the nation, with several major urban centers. We have made huge economic investments to stabilize water supply (e.g., in dams, canals, and wells), but we are only now beginning to consider the ecological consequences of altering the flow of rivers, streams, and springs on aquatic, riparian, and terrestrial resources. The growing human population and increasing energy development are increasing the deposition of atmospheric pollutants and altering sensitive high-elevation environments. Moreover, climate change is increasing variability in precipitation and warming temperatures in the West, leading to reduced snowpacks; earlier snowmelt; larger, more severe wildfires; increased forest vulnerability to insects; and less dependable delivery of clean water.

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, how vegetation influences and responds to disturbance and management, and how watershed processes determine the spatial and temporal variation in water quality and quantity. 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 improved understanding of present changes.

Under the framework of watershed research, we will focus on two key program areas:

- **Core watershed research quantifies the dynamics of hydrologic, geomorphic and biogeochemical processes in forests and rangelands at multiple scales and defines the biological processes and patterns that affect the distribution, resilience, and persistence of native aquatic, riparian and terrestrial species.**

- **Integrated, interdisciplinary research explores effects of climate variability and change on forest, grassland and aquatic ecosystems.**

10. Approach to Problem Solutions

Our research address needs in both basic science and management to advance understanding of watershed and biological 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 both relevant to the needs of managers and well coordinated via the empirical evaluation of actual management actions.

Our core research implements both long-term research and short-term studies. Both involve 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. 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 improved understanding of present changes.

The two problem areas also represent an opportunity for integration across the eight RMRS Science Programs. We anticipate that scientists will pursue traditional programs of research, but also that teams within the Program will be organized around specific focus areas as new critical problems 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. Our network of experimental forest and research natural areas give 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.

Problem 1 – Core watershed research quantifies the dynamics of hydrologic, geomorphic and biogeochemical processes in forests and rangelands at multiple scales and defines the biological processes and patterns that affect the distribution, resilience, and persistence of native aquatic, riparian and terrestrial species.

Element 1.1. *Ecosystem research on ecological processes and functions provides cause-and-effect knowledge that underlies and validates the management decisions and results in productive and diverse forests, grassland, and aquatic ecosystems.* We will quantify and model the hydrologic, geomorphic and biogeochemical processes influencing water yield and water quality and nutrient, sediment and large wood production, delivery, transport and storage. Current and future research will measure and model these fluxes across a range of temporal and spatial scales and will evaluate how disturbance and management practices influence watershed properties, processes and outcomes. Our research will guide management responses to disturbance and improve understanding of the consequences of unprecedented climate variability and change.

Current and future research:
1. Provide better understanding of the water cycle from the accumulation process to runoff, including interception, sublimation, evapotranspiration, infiltration, and other hydrological processes. Current ability to provide useful runoff forecasts is limited by the large amount of uncertainty in forecasted volume and timing of runoff from most basins of operational size, with consequences to threatened fishes, downstream municipalities, industry, commerce and agriculture. That uncertainty is greatly increased by climate change and associated changes to forest vegetation, such as fire, drought mortality, and insect kill. 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 represents 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 demands 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.

One of the basic problems still facing hydrologists is determining the seasonal accumulation patterns of the snowpack in complex terrain and how that affects subsequent snowmelt. Improved understanding of controls on snow distribution at the process level is needed, including interception, sublimation, redistribution, evaporation and melt. We are in need of 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.

Outputs:

- Quantify the difference in sublimation of snowfall interception at different elevations.
- Improve snow transport and distribution models in complex terrain.
- Improve our understanding of the contribution of vegetation to site water balance.
- Quantify the contribution of large snow drift deposits in alpine basins to the subalpine water balance.
- Quantify the effects of forest type, and structure on the water cycle from accumulation process to runoff, including interception, sublimation, evapotranspiration, infiltration, subsurface flows, and other hydrological processes.
- Refine estimates of the difference in the water balance between disturbed and undisturbed slopes.
- Assess the effects of fire, insect-kill and vegetation management on melt and runoff generation processes.
- Evaluate the consequences of land management alternatives for dealing with the current bark-beetle outbreak on water yield, water quantity and carbon storage.
- Develop hydrologic forecasting models to assist with flood risk estimation and water supply.

2. The movement of sediment and wood from hillslopes and through channels is affected by natural and human disturbances. Under undisturbed conditions, forest and rangeland soil erosion rates are low; however, both anthropogenic and natural disturbances can greatly increase the erosion potential. These include roads, mining, timber harvest, grazing, recreation and prescribed fire or wildfire. Recent trends in forest management require greater access for thinning, removal of unhealthy trees, post-disturbance salvage logging, and post-harvest operations. Increased access will lead to greater erosion risks. Disturbances may be triggered by climatic events and sequences such as heavy rains or rapid snow melt, or extended droughts followed by fire and moderate storms. Soil erosion and mass wasting patterns and rates are a result of a complex interactive process driven by the local climate and influenced by geology, soils, and topography. Soil properties, such as hydraulic conductivity and erodiblity, and vegetation, including above ground biomass, surface residue cover, and root strength are altered by these driving factors and many 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 and pulse 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; it 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 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, hydrological, 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. The 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 the pulse 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 fuel reduction harvest activities.

Outputs:

- Define controls on channel changes induced by hillslope disturbance events.
- Quantify controls on landslide/debris flow location and size.
- Improve estimates of sediment transport as a function of sediment supply, streamflow regime, and stream channel characteristics.
- Understand how geomorphic history and bedrock geology influence sediment regime and affect system sensitivity to changes in flow and sedimentation.
- Measure onsite and offsite erosion impacts of recreation, road removal, and road network design.
- Evaluate the effectiveness of current and new wildfire rehabilitation activities and the impacts of salvage logging after wildfire.
- Determine the watershed impacts of fuel reduction from increased forest access and increased hillslope disturbances; and evaluate the utilization of excess biomass for erosion control and other beneficial uses.
- Develop models of hydrology and erosion responses to wildfire, alternative fuel management, and other human and natural disturbances.
- Evaluate temporal changes in riparian and in-channel wood loading in response to insect-caused canopy mortality, and fuel reduction harvest activities.
- Quantify stream channel adjustment and large wood dynamics following wildfire.
- Assess the role of avalanches in delivery of large wood to headwater streams.

3. 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. At the watershed scale, net nutrient and carbon export occurs when the products of atmospheric inputs, parent material weathering, soil erosion, and soil nutrient transformations and decomposition exceed summed plant, soil or microbial uptake and gaseous losses. Various alpine, forest, riparian and range ecosystem types

encompass a broad array of biological and physical conditions, where nutrients, carbon and water cycles are linked in unique ways. The distinct nutrient demand and above and belowground litterfall quantity and composition of different vegetation types influence how soil nutrients and carbon are stored, transformed and released from various ecosystems. Locally, biogeochemical processes may be concentrated at sites, such as riparian zones, where hydrologic pathways and nutrient substrates converge. In such biogeochemical hotspots, plant uptake and microbial denitrification within riparian zones help buffer stream water from nutrient inputs; hyporheic and in-stream uptake and transient storage contribute to additional nutrient retention.

Knowledge about the spatial connectivity between hillslope, riparian and surface water biogeochemical processes in snow-dominated hydrologic systems of the mountain west remains inadequate. More importantly, the degree to which riparian soils and vegetation attenuate carbon and nutrient release to streamwater following extensive canopy mortality and associated salvage logging or other management operations is poorly understood. Biogeochemical research will help managers evaluate the effectiveness of watershed conservation Best Management Practices and will quantify influence of various management operations on soil disturbance, forest and soil productivity and watershed conditions.

Growing concern that increasing industrial and mobile emissions and subsequent atmospheric deposition may degrade water quality and ecosystem productivity and health has motivated regulatory changes. Throughout the West, there is a recognized need to develop a comprehensive understanding of how atmospheric inputs and air pollutants influence terrestrial and aquatic ecosystems. The amount of nitrogen deposited on western watersheds has increased significantly in recent years and in some cases may exceed the retention capacity of terrestrial ecosystems. Water and land managers require research that identifies critical load thresholds for nitrogen and other atmospheric inputs beyond which impaired soil and water quality are expected. Analysis of the spatial and temporal variation in long-term high-elevation lake and streamwater chemistry will help guide future surface water monitoring efforts aimed at detecting changes in water quality.

Outputs:

- Quantify the nutrient and carbon dynamics of alpine, subalpine and riparian ecosystems.
- Characterize the hydrologic and biogeochemical linkages between terrestrial, riparian and aquatic environments.
- Determine the impact of extensive insect outbreak and associated management on sustained soil and forest productivity and the delivery of clean water.
- 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.

4. Surface waters and aquatic ecosystems are the most sensitive component of high elevation ecosystems to atmospheric depostion, and thresholds are low for critical loads of deposition of pollutants in these sensitive ecosystems. Growing concern that increasing industrial and mobile emissions and subsequent atmospheric deposition may degrade air and water quality and ecosystem productivity and health has motivated regulatory changes. Increased energy development in the West leads to increased deposition of air-borne pollutants such as nitrogen and heavy metals as well as sediment from land disturbance. These impacts can lead to degradation of terrestrial and aquatic ecosystems. Throughout the West, there is a recognized need to develop a comprehensive understanding of how atmospheric inputs and air pollutants

influence terrestrial and aquatic ecosystems. The amount of nitrogen deposited on western watersheds has increased significantly in recent years and in some cases may exceed the retention capacity of terrestrial ecosystems. Water and land managers require research that identifies critical load thresholds for nitrogen and other atmospheric inputs beyond which impaired soil and water quality are expected. Analysis of the spatial and temporal variation in long-term high-elevation lake and streamwater chemistry will help guide future surface water monitoring efforts aimed at detecting changes in water quality.

Outputs:

- Determine the impact of energy development on terrestrial, riparian, and aquatic ecosystems.
- Determine critical loads for nitrogen and sulfur in natural ecosystems.
- Develop and evaluate protocols for monitoring atmospheric deposition and Air Quality Related Values in wilderness ecosystems.

Element 1.2. *Watershed restoration and conservation research addresess the key science needs to support watershed restoration and the conservation and restoration of threatened and endangered 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 will quantify how land management alters soil and water quality.

Current and future research:
1. Examine the physical and biological factors that regulate the distribution of wetland and riparian species, populations and communities and their response to disturbance, management and climate change. For wetland and riparian plant species, our goal is to identify the hydrologic, geomorphic, and physiological variables that determine their distribution and persistence at regional, watershed and stream segment scales.

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 Mountian 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.

2. 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. 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 given 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.

3. Changes in fire and flow regimes and invasion by non-native species are changing riparian environments.

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 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.

The effects of fire and fuels management on stream-riparian ecosystems and biota 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.

Outputs:

- Identify the hydrologic, geomorphic, and ecophysiological variables that determine the distribution of wetland and riparian communities and plant species at local, regional, and watershed scales.
- Determine the spatial and temporal scales over which selected vegetation and physical

variables should be measured along stream-riparian corridors to assess impacts of altered hydrologic regimes.

- Determine the influence of physical and land use variables on the distribution of invasive non-native plant species along riparian corridors.
- Understand future invasion potential by established non-native species.
- Determine the effect of disturbance and management on headwater and riparian wetland condition
- Identify measurable attributes of riparian vegetation that are most sensitive to changes in hydrologic regimes.
- Quantify the effects of hydrological alterations on the ecophysiological characteristics of key riparian plant species.
- 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.
- Evaluate the impact of climate change on the distribution of aquatic and riparian species, populations, and communities.
- Determine the influence of physical and land use variables on the distribution of invasive non-native plant species along riparian corridors.

Element 1.3. *Define key biological processes and patterns to understand the distribution, resilience, and persistence of native aquatic, riparian, and terrestrial populations, species, communities and habitats.* 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.

A growing body of theory and empirical evidence suggests that localized persistence and resilience of species, populations, and communities will be understood only within a broader spatial and temporal context. 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.

In aquatic ecosystems, our focus will continue to be with aquatic vertebrates in general, and fishes in particular. That does not mean we will ignore the trophic and ecological processes that require an understanding of other species and aquatic ecosystem components, but it does mean that fishes represent an important currency for communication of our work. Fishes are often dominant and sometimes the only vertebrates found in many of the mountain streams of the region; they can play an important role in structuring aquatic ecosystems. Pacific salmon are considered keystone species known to 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.

Current and future research:
1. Increase understanding of the life-history diversity, population structure, and dynamics for fish species of concern. Two concepts dominate current theory of how populations persist in spatially and temporally varying environments: spatial structure and metapopulation dynamics; and 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, small-scale disturbance (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 reestablish 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. Only a few life stages of a relatively small number of species are well understood.

Outputs:

- Describe characteristics of habitats utilized by different life stages of key aquatic species (e.g., spawning, juvenile rearing).
- 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.
- Understand how atmospheric, hydrologic, and geomorphic processes influence aquatic ecological diversity, and species dynamics and persistence.
- Quantify the distribution and variation in fish life-history patterns at multiple scales (e.g., within and among streams or among basins and distinct biophysical regions).
- Describe effects of habitat fragmentation and recent isolation on the genetic diversity and persistence of native salmonids.
- Describe spatial structure, straying and dispersal, and regional dynamics of native salmonid populations by the application or extension of patch-based models, molecular genetic markers, otolith microchemistry, and demographic analysis.
- Extend application of existing tools including radio telemetry, otolith microchemistry, fine-scale ecological data, and age structure analysis to quantify the distribution and variation in life-history patterns at multiple scales (e.g., within and among streams or among basins and distinct biophysical regions).
- Information on the timing, extent, and magnitude of movement of cutthroat trout in streams to mitigate the effects of habitat fragmentation.

2. *Examine the impacts of non-native fish invasions on native fish species.* Non-native species are becoming increasingly widespread in aquatic, riparian, and terrestrial ecosystems throughout

the region. In some cases, non-native aquatic species have been intentionally introduced for purposes ranging from pest control to supporting recreational fisheries. Positive values of non-native introductions are countered by potential harm to native species and ecosystems. 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.

Outputs:

- Devise alternative approaches for the management and control of invasive species.
- Efficacy of pheromone-based approaches to selectively remove nonnative brook trout.
- The role of fire on the dynamics and persistence of native and nonnative fish populations.
- Models that estimate the probability that isolated populations of native fishes will persist or that nonnative fishes will invade.
- Understand future invasion potential by established non-native species.
- Understand future invasion potential by 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 or displacement of native species once non-natives are established.

Problem 2 – Integrated, interdisciplinary research explores effects of a changing environment (including climate variability and change) on forest, grassland and aquatic ecosystems.

Element 2.1. *Water availability and quality will be affected by changes in precipitation and temperature regimes or patterns.* This 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.

1. Examine the effects of climate change on watershed processes. 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. 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, biological processes and vegetation distributions. The long term data records maintained by the USFS Experimental Forest network provide RMRS scientists unique and important opportunities to contribute to the characterization of climatic variability and evaluations of how such change alters the quantity and quality of water provided by western watersheds.

Outputs:

- Develop techniques to assess the integrated consequences of anticipated climate change and variability to physical, biological, and socio-economic systems at the regional scale and selected local sites in West.

- Quantify the impact of climate change and climate variability on hydrologic, geomorphic and biogeochemical processes in terrestrial, riparian and aquatic ecosystems.

Element 2.2. *Climate change will be accompanied by changes in atmospheric deposition that will affect critical loads of nutrients and atmospheric pollutants in forest ecosystems.* Atmospheric deposition to high elevation terrestrial and aquatic ecosystems is a complex process where air pollutant chemicals, including nitrogen, sulfur, ozone, and heavy metals such as mercury, are deposited to surface waters, terrestrial ecosystems, and soils as gases and particulates or in rain or snow. Of particular concern in the mountain West is deposition of nitrogen, sulfur, ozone, and heavy metals from energy development and their effects on air and water quality in high elevation ecosystems. The Clean Air Act specifically protects Class I wilderness from air pollutants. The critical loads and levels of pollutants that these ecosystems can tolerate is important in managing ecosystems sensitive to atmospheric deposition.
The focus of this element is to quantify loads of atmospheric pollutants and determine the response of terrestrial and aquatic ecosystems to atmospheric deposition.

Outputs:

- Determine the response of high-elevation terrestrial and aquatic ecosystems to atmospheric deposition including nitrogen, sulfur, ozone, and heavy metals to address potential deterioration of wilderness ecosystems.
- Determine the critical loads of nitrogen and sulfur and critical levels of ozone for high elevation mountain ecosystems.
- Understand how atmospheric, hydrologic, and geomorphic processes influence air and water quality, aquatic ecological diversity, and species dynamics and persistence.
- Use the extensive wilderness, experimental forests, research natural areas, and national park lands in the West for long-term monitoring of physical and biological change to provide representative areas for differentiation of anthropogenic and climate effects.
- Develop and communicate decision support frameworks for understanding the cause-effect pathways, available science and science needs to help managers deal with atmospheric deposition.

The consequences of industrial and mobile emissions for atmospheric deposition on air and water quality and forest ecosystems have motivated regulatory changes. The National Research Council Report on Air Quality Management identified a need for additional research and long-term monitoring to develop a comprehensive understanding of multiple air pollutants on ecosystems, including the ecological consequences of soil cation depletion and enrichment of nitrogen (N) and sulfur (S) in soil.

A research challenge is to quantify the processes and pathways by which atmospheric deposition moves within the ecosystem and its ecosystem effects. This research requires an integration of physical and biological sciences from atmospheric to terrestrial to aquatic systems. Atmospheric deposition of pollutants moves through these ecosystem components and exits watersheds in surface waters. The AWA program with its air, water, and aquatic sciences disciplines is uniquely positioned to conducted integrated research on the impacts and threats from energy development on atmospheric deposition in western ecosystems. Long-term monitoring of atmospheric deposition and its effects on aqautic and terrestrial ecosystems is necessary to examine change to sensitive ecosystems from energy develoment and climate change.

A large percentage of the source of fresh water supply for the western U.S. is in headwaters on National Forest land. Increased energy development in mountain and intermountain areas of the

Western U.S. impacts atmospheric deposition, and its subsequent affect on both air and water quality in the headwater ecosystems. Monitoring atmospheric deposition in these remote regions is challenging and requires new techniques. Increased interaction across RMRS research programs will enhance understanding of the impact of atmospheric deposition on mountain ecosystems. For example, the Rocky Mountain Center, a RMRS FFS Program fire-weather prediction tool (http://fireweather.info), already has the capacity to model and predict hourly atmospheric deposition of ozone in Western landscapes. Further development of this tool for deposition of nitrogen and sulfur would be useful to federal land managers.

Outputs:

- Determine the impacts of oil, gas, wind, and solar energy development on terrestrial and aquatic ecosystems.
- Test methods for monitoring atmospheric deposition and its effects.
- Quantify the impact of climate change and climate variability on aquatic and terrestrial ecosystems.
- Examine the spatial and temporal patterns of atmospheric nitrogen deposition on alpine and subalpine aquatic ecosystems using long-term wilderness lake chemistry datasets with the objective of developing a protocol to address the temporal and spatial sampling needs of aquatic systems.
- Examine how changes in lake water nitrogen and acid neutralizing capacity are related to changes in phytoplankton populations of aquatic ecosystems.

Benefits from Research. 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 need 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.

Improved science information on the effects of natural and anthropogenic disturbances on aquatic, riparian, and terrestrial species 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 nonnative 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. Beneficiaries include resource managers and others interested in the effects of natural and anthropogenic disturbance on aquatic and terrestrial resources, and we hope, the resources themselves.

Science Delivery – Science delivery and applications will be accomplished primarily 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 made available via development and maintenance of a user-friendly 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. We will propose to advance our ongoing efforts of technology transfer of our research products through a Research, Development, and Applications Program.

Conservation Education – Conservation education will be an integral part of our efforts. Human population growth coupled with a rapidly changing climate is handing future generations major issues and crises with air, water and aquatic resources. Development and promotion of an aggressive conservation education program is an agency priority to introduce children, their teachers and parents to knowledge and experts to help understand ecological processes and the role of science in helping future generations make wise choices on managing natural resources. We will engage in numerous activities aimed at reaching peoples from all sectors of the American public. These include classroom visits, open houses, public presentations, development of educational tools (e.g., kids-in-the-creek; trout-in-the-classroom; science for kids, their teachers and parents; science matters), providing laboratory tours, conducting field trips and publications and presentations in the popular media.

Future opportunities – 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 and application is needed to assess and account for cultural, educational, and spiritual values of clean air, clean water, healthy watersheds, and fish and wildlife. It will be essential for the long-term sustainability of western ecosystems for our physical and biological scientists to reach out to social scientists 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.

11. **Program Cooperators and Partners**

RMRS Station Programs: Grasslands, Shrublands, and Desert Ecosystems; Wildlife and Terrestrial Ecosystems; Forest and Woodland Ecosystems; Fire, Fuels and Smoke; Human Dimensions.

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), and Pacific Northwest (R6) Regions and many National Forests.

National Forests: Arapahoe-Roosevelt, Apache-Sitgreaves, Bitterroot, Boise, Coconino, Coronado, Gila, Kaibab, Lolo, Medicine Bow-Routt, Nez Perce, Payette, Pike-San Isabel, Prescott, Sawtooth, Salmon-Challis, and Tonto.

National Forest System: National Forest System Fish and Aquatic Ecology Unit Natural Resource Information System Missoula Technology and Development Center San Dimas Technology and Development Center WO Stream Team WO Watershed, Fish, Wildlife, Air & Rare Plant staff **Interagency Monitoring Programs:** Aquatic Riparian Effectiveness Monitoring Program National Atmospheric Deposition Program Pacific Northwest Aquatic Monitoring Program, Portland OR PacFish InFish Biological Opinion Monitoring Program **Federal Agencies** Agricultural Research Service Bonneville Power Administration Bureau of Land Management Joint Fire Sciences Program National Aeronautics and Space Administration National Resources Conservation Service NOAA Fisheries, Northwest Fisheries Science Center NOAA, National Weather Service U.S Army Corps of Engineers U.S Environmental Protection Agency Region 10 U.S Environmental Protection Agency, Office of Research and Development, Corvallis, OR U.S Fish and Wildlife Service	U.S Geological Survey, Forest & Rangeland Ecosystem Science Center U.S Geological Survey, Water Resources Division U.S. Bureau of Reclamation **State Agencies** Arizona Game & Fish Department California Fish and Game Colorado Department of Public Health and Environment Colorado State Forest Service Idaho Department of Environmental Quality Idaho Department of Fish and Game Montana Department of Fish, Wildlife and Parks Nevada Division of Wildlife Oregon Department of Environmental Quality Oregon Department of Fish and Wildlife Washington Department of Ecology Washington Department of Fisheries and Wildlife **Tribes** Confederated Tribes of the Warm Springs Reservation Shoshone-Bannock Tribe Nez Perce Tribe Northwest Indian Fisheries Commission, Olympia WA

Academic Partners	**Non-Government Organizations**
Boise State University	Denver Water
Colorado State University	Ecoresults Inc.
Kyoto University, Japan	ESSA Technologies, Ltd., Vancouver, BC
Lincoln University, New Zealand	Forest Concepts Ltd
Massachusetts Institute of Technology	Friends of Mount Evans and Lost Creek Wildernesses
Montana State University	Geoengineers
Northern Arizona University	International Energy Agency Bioenergy Tasks 30 and 31
Oregon State University	Phelps Dodge Corporation
University of Aberdeen, Scotland	Spatial Dynamics
University of Alaska, Fairbanks	Soil & Water Conservation Society
University of Arizona	Stillwater Sciences, Berkeley CA
University of Buffalo, New York	Terraqua Inc.
University of California, Berkeley	The Macaulay Institute, Scotland
University of Canterbury, New Zealand	The Nature Conservancy
University of Colorado	Trout Unlimited
University of Florida	Watershed Sciences Inc.
University of Georgia/USGS Cooperative Fish and Wildlife Research Unit	
University of Idaho	
University of Minnesota	
University of Montana	
University of Nevada, Reno	
University of Oregon	
University of Sao Paolo, Brazil	
University of Wales Aberystwyth	
University of Washington	
University of Western Australia, Australia	
University of Wyoming	
Utah State University	
Washington State University	
Western New Mexico University	

12. Scientific Workforce: Scientific workforce available for accomplishing the planned work described in the Charter (based on current staff and known changes. **Estimated fraction of time in each Research Problem Area (total of 1.0 for each scientist).**

Name	**Title**	**Integrated Research**	**Technology Transfer**	**Watershed Sciences**	**Biological Sciences**
Frank McCormick	Acting Program Manager				
John Buffington	Fluvial Geomorphologist	0.30	0.20	0.40	0.10
Kate Dwire	Riparian Ecologist	0.30	0.10	0.10	0.50
Kelly Elder	Hydrologist	0.40	0.10	0.40	0.10
William Elliot	Engineer	0.20	0.30	0.40	0.10
Randy Foltz	Engineer	0.20	0.10	0.70	0.00
Robert Hubbard	Ecologist	0.40	0.10	0.25	0.25
Daniel Isaak	Fisheries Biologist	0.30	0.10	0.10	0.50
Charles Luce	Hydrologist	0.40	0.20	0.30	0.10
Hugo Magana	Fisheries Biologist	0.10	0.05	0.0	0.35
Jim McKean	Geomorphologist	0.20	0.20	0.50	0.10
Robert Musselman	Plant Physiologist	0.65	0.25	0.0	0.10
Daniel Neary	Soil Scientist	0.20	0.20	0.50	0.10
Kerry Overton	Fisheries Technology Transf Specialist	0.40	0.20	0.20	0.20
Charles Rhoades	Biogeochemist	0.30	0.10	0.50	0.10
Peter Robichaud	Engineer	0.20	0.30	0.40	0.10
Sandra Ryan	Geomorphologist	0.20	0.10	0.60	0.10
Russ Thurow	Fisheries Biologist	0.20	0.20	0	0.60
Michael Young	Fisheries Biologist	0.10	0.15	0.10	0.65
Bruce Rieman	Emeritus Fisheries Biologist	0.10	0.15	0.0	0.05
John Rinne	Emeritus Fisheries Biologist	0.10	0.15	0.0	0.05

Signature	Title	Date
Recommended:	Program Manager	
	Deputy Station Director, Internal	
	Assistant to Staff Director	
	Staff Director	
Approved:	Station Director	
Concurred:	Deputy Chief for Research	