RESEARCH WORK UNIT DESCRIPTION Ref: FSM 4070	**1. Number:** RMRS-4353	**2. Station:** Rocky Mountain Research Station
	3. Unit Location: Boise, ID	

4. Research Work Unit Title:

Integrated Research on Watershed Processes and Aquatic Ecology to Guide Management of Aquatic Ecosystems and Water and Soil Resources

5. Project Leader (Name and address):

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6. Area of Research Applicability:	**7. Estimated Duration:**
Western United States	5 years

8. Mission:

Develop knowledge of the biophysical conditions and processes that influence water quality and quantity, aquatic habitat quality, and the distribution, diversity, and persistence of fish and other aquatic species. Apply this knowledge to develop guidance for water resource management and the conservation and restoration of fish populations and other aquatic species at scales that define functional aquatic ecosystems.

9. Justification and Problem Selection

Conservation of aquatic biological diversity, water quality and quantity, and maintenance of the physical and ecological processes that influence those resources are central to the mission of public land managers. Conservation of freshwater ecosystems represents a significant challenge. Freshwater ecosystems and their associated species are imperiled throughout the world. In the Intermountain West, the status of freshwater systems varies widely, but dramatic species' declines and the growing number of listings under the Endangered Species Act and other designations of concern signal only limited success in this effort. In many regions, habitat loss and invasions of non-native species have all but eliminated the potential for conservation or restoration of native species. Many of the most important remnants of native species distributions and aquatic ecosystem integrity are now associated with Federal lands or small private reserves.

Past attempts to manage or conserve aquatic resources have commonly focused on direct manipulation of watersheds, habitats, or their associated species. This work has included: 1) the creation of reserves of pristine habitats, in some cases intentionally isolating those from potentially invasive non-native species; 2) restoration or restructuring of habitats through physical manipulation of stream channels; 3) attempts to minimize changes in existing habitats by establishment of thresholds of allowable disturbance; and 4) artificial propagation of fish to supplement recruitment in unproductive habitats or populations. Research and theory developed largely in the last 10 to 15 years suggest important limitations to these general approaches. One of the most important concepts emerging from landscape ecology and ecosystem theory acknowledges the dynamic and complex nature of most natural systems and their linkages across scales of space and time.

The dynamics of physical process in aquatic ecosystems can be manifested in the form of major events that substantially affect physical environments and associated species. Often, such events are described as

10. Approach to Problem Solution (Start at conclusion of item 9.)

Signature	Title	Date
Recommended: /s/ Jack B. Waide	**Assistant Director for Research**	10/29/2004
	Assistant to Staff Director	
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"disturbances." Whereas some forms of "disturbance" may be viewed as potential threats to species and ecosystem ecosystem function (e.g., forest roads and associated effects), other forms may indeed be essential to natural ecosystem function. For example, large disturbances such as fire and associated hydrologic events have been obvious forces structuring these systems in recent time, but also in deeper geomorphic and evolutionary history. Disturbances will undoubtedly continue to be important in the future and may even become more pronounced. Predicting the effects of different natural and human related disturbances to freshwater ecosystems and ensuring the resilience of these systems to those disturbances represent central problems in natural resource management. Management that ignores the fundamental physical and ecological processes structuring and maintaining natural systems, their inherent variability, and their history seems destined to fail.

The complex nature of dynamic and disturbance-driven ecosystems requires a new perspective for management and regulatory frameworks that have developed from applied aquatic research and experience of the past. The body of applied work in stream systems has focused on links between individuals or small groups of individuals and the micro-habitats or stream reaches they were observed in over a period of a few days to a few years. In other words, the focus was largely on the biological processes that explained the abundance and distribution of aquatic organisms such as salmonid fishes among habitats or reaches of stream at any moment in time or within a limited area. This research has been extremely valuable in understanding how fishes use distinct habitats, the capacity of those habitats, and even the relative productivity of different streams. It has proven less useful as a foundation for management of entire, dynamic ecosystems or large networks of streams. The history of the research-management-regulatory process has been focused largely on the creation and maintenance of optimal (and often static) habitat conditions, project by project, reach by reach, across any basin or watershed of interest.

The discussion in applied science relevant to the management of dynamic landscapes and aquatic ecosystems now argues for a broader perspective. Our own work and that of others suggests, for example, that the resilience and persistence of many species in any stream depends not just on the immediate conditions of habitat in that stream, but also on the context of that habitat in a larger basin and on interconnections with other habitats and populations. Maintenance of diverse communities and populations that will be productive and resilient in the future depends on conserving or restoring watershed and landscape-level processes that create networks of complex habitats. It also depends on conserving or restoring the biological and ecological processes that allow populations to persist, prosper, and evolve in the face of the dramatic spatial and temporal variability that exists in the environments available to them.

These concepts lead to new questions in applied aquatic ecological research. How can managers effectively think about, measure, and manipulate whole networks of populations? How can they prioritize the work that inevitably must still occur on a local or project scale? To help answer these questions, we believe it will be necessary to define key ecological processes, patterns, and appropriate scales necessary to understand the distribution, resilience, and persistence of native aquatic species and to conserve aquatic ecological diversity and integrity (Problem 1).

The network of habitat available for aquatic species is controlled by hydrologic and geomorphic processes that govern the flow of water, sediment, energy, and organic matter through watersheds and streams. Recognizing that these fluxes vary tremendously in time and space, one of the primary challenges facing biologists and managers is to understand how resultant habitats are distributed in space and time. This question automatically shifts the focus from reaches or habitat units to an ensemble of habitat units and larger spatial scales than have been traditionally considered. Several linked questions emerge from this seemingly simple query: what are the most important processes controlling the spatial and temporal variation of streamflow, stream temperature, substrate, wood, and channel complexity; what is the nature of dynamics within a stream network and what are the relevant spatial and temporal scales that we should use to evaluate these dynamics; what are the constraints on potential flows, temperatures, or channel conditions; and, are variations in physical conditions primarily determined by topography, geology, climate, or other aspects of the physical setting, or are they more strongly a function of history of channel or vegetation disturbances? After some initial perturbation, some systems tend toward a single stable state determined by innate characteristics of a watershed, whereas other systems may exhibit path-dependent dynamics that can reach different states depending on the history of changes and disturbances. There is some indication that stream habitats exhibit both kinds of dynamics, but it is not clear what the controls are or which type of dynamic to expect in any particular stream. Although we see dynamic conditions of streamflow, temperature, substrate, wood, and channel complexity in individual streams, the behavior of an ensemble or network of streams may be more stable, but in the aggregate, rather than in any single habitat or stream reach within the network. Is there some scale at which this is true, or is there a huge range of temporal variability at all spatial scales? Does the disturbance frequency depend on spatial extent? Disturbance plays a role in driving habitat dynamics, and the historical approach of examining frequency-magnitude relationships must be modified to consider spatial context and linkage if it is to be relevant to ecological questions. We can view land management as a perturbation to natural disturbance and dynamic processes, yielding a need to understand how management can add spatially and temporally to the dynamic behavior and how it can interrupt or amplify history-dependent dynamic behaviors. We must scale up in our view of aquatic ecosystems to approach any of these questions. As a consequence, it is necessary to understand the dynamics of large-scale hydrologic and geomorphic processes in forests and rangelands (Problem 2). This work is important in its own right as we attempt to improve our knowledge of the physical structure and function of watersheds and stream networks. It is also a critical component of our efforts to investigate the connections of physical processes to the conservation and function of aquatic species and ecosystem processes.

Ecological diversity in aquatic ecosystems is inextricably linked to the physical diversity, dynamics, and history of landscapes, watersheds, and streams. Gradients imposed by climate, hydrology, and geomorphology fundamentally structure the nature and distribution of habitats used by aquatic species. Those habitats will in turn control the productivity, dynamics, resilience, and persistence of the species that inhabit them. Disturbance and the processes that shape landscapes and their streams ultimately shape ecological patterns and the evolution of aquatic species. We are unlikely to effectively understand and manage biological diversity if we don't understand the physical processes that constrain and shape it. We are unlikely to effectively manage human disturbance of watersheds and stream networks without understanding natural disturbance and the ways ecological systems, habitats, species, populations, and individuals persist and even flourish in the face of it.

Whereas generalized linkages between physical and biological systems are well known, research among these respective disciplines is seldom integrated. Integration is not simply the process of citing literature from different fields. It involves active collaboration in conceiving research questions, scientific knowledge discovery, and application to management problems. Integration is essential because the degree of complexity and specialization required to effectively study aquatic ecosystems is far beyond the reach of most, if not all, individual scientists. Accordingly, products from a genuinely integrated effort can represent more than the sum of collective expertise of participating collaborators. For example, understanding linkages between environmental conditions and biological responses (e.g., species population persistence) is greatly enriched if there is an understanding of long-term physical processes that create key environmental conditions. In turn, biological responses can provide important insights into physical processes. An example would be the evolution of stream networks as revealed by genetic relationships among fish populations and fish assemblage composition. Finally, active integration can help to identify key problems and focus research more effectively. In other words, biologists can provide key perspectives on "what ecosystems or species need," and physical scientists can provide key perspectives on "what physical processes can deliver." A third major focus of our proposed work then is to develop the knowledge required to link physical and biological research to develop a better understanding of how hydrologic and geomorphic processes influence aquatic ecological diversity, and the dynamics and persistence of populations (Problem 3).

There is continuing need for research programs to provide science and technology to assist land managers in their efforts to assess, prioritize, and design conservation and restoration efforts that are transparent and scientifically defensible. The Forest Service is faced with increased public scrutiny, competing and contentious resource demands, reduced funding and technical staffs, and a lack of consistent and scientifically defensible data and understanding across field units. It is, therefore, critical to develop sampling tools, predictive models, and decision frameworks that can produce useful data syntheses and analyses. To ensure the relevance of the research conducted by the Boise Aquatic Sciences Laboratory to the needs of land and resource managers, it will be necessary to enhance collaboration between researchers, technical developers, and resource managers to produce more informed management and research decisions, and to develop cost-effective routes for science delivery (Problem 4).

10. Approach to Problem Solution:

Problem 1 - Define key ecological processes, patterns, and appropriate scales necessary to understand the distribution, resilience, and persistence of native aquatic species and to conserve aquatic ecological diversity and integrity.

A growing body of theory and empirical evidence suggests that localized persistence and resilience of species in aquatic ecosystems will be understood only within a broader spatial and temporal context. A better understanding of the dominant processes influencing the distribution, interconnection, and dynamics of populations through time and space requires work at multiple scales, especially at larger scales than typical of past research. It will require the adaptation of theory and analytical tools developed in other disciplines. It will require new sampling approaches.

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, and in particular salmonids, are culturally and economically important and represent defining elements of the aquatic ecosystems in the Intermountain West. 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 structuring entire aquatic ecosystems. Pacific salmon are considered keystone species known to strongly influence riparian and even upland plant and animal communities; conceivably, 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 whole systems.

We propose four primary elements to the continuation of our work under this problem: 1) life-history diversity, population structure, and dynamics; 2) distribution and habitat utilization; 3) sampling tools; and 4) non-native species invasions.

1. *Life-history diversity, population structure, and dynamics* - Two concepts dominate current theory of how populations persist in and exploit spatially and temporally varying environments: spatial structure and metapopulation dynamics; and life-history or phenotypic diversity.

   Metapopulation theory suggests that the geometry and interconnection of suitable habitats (or habitat patches) will constrain the dynamics of the individuals and populations associated with those habitats. We have demonstrated patterns in species occurrence and persistence that are consistent with metapopulation theory. This work reinforces the notion that interconnection of habitats is critical to the persistence of populations. To objectively weigh the benefits and risks associated with past and future management, climate change, and other effects on the geometry and condition of available habitats, however, it will be necessary to better understand the underlying processes (e.g., extinction/colonization, dispersal/gene flow) that structure populations and influence their dynamics.

   In addition to metapopulation structure, life-history variation within 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. Highly varied and distinct migratory patterns, trophic types, and life-history schedules appear to be adaptations to the dynamic and varied nature of the streams, rivers, and lakes that exist in this region. Our previous work and that of others generally reinforces 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 will be necessary to guide management to conserve it.

   We propose studies to:

- 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), and ultimately link patterns to underlying habitat and landscape constraints. Output: An understanding of where and how intraspecific diversity is distributed in native salmonids.

- Describe effects of habitat fragmentation and recent isolation on the genetic diversity and persistence of native salmonids. Output: New models allowing managers to evaluate the risks associated with isolation and fragmentation of habitats based on the size, time of isolation, and other characteristics of remnant habitats.

- 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. Output: An improved understanding of relevant scales and the influence of habitat geometry and interconnection on the persistence of native salmonids and other species.

2. *Distribution and habitat utilization* - 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 species. 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. There is literature describing the spawning habits of cutthroat trout, for example, but few studies provide other than general descriptions of spawning sites. Data are almost completely lacking for some life stages that are difficult to study. Winter habitat use of juvenile salmonids, for example, is little studied and poorly understood. In addition to extending our knowledge of the fine scale distribution and habitat use of fishes, an important element of this work will be to integrate with information developed at larger scales (see element 1). 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. Our goal is to develop approaches for arraying the expected distributions of species, life stages, and assemblages at habitat, reach, or stream segment scales.

We propose studies to:

- Describe characteristics of habitats utilized by different life stages of key aquatic species (e.g., spawning, juvenile rearing). Output: Empirical description of key habitats.

- Model associations between environmental variables (e.g., stream size, cover, temperature, connectivity) and fish 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. Output: Models for predicting suitable habitats, species, life stages, and assemblages at multiple scales.

3. *Sampling tools* - There is widespread need among biologists and managers for reliable methods to assess the status and distribution of fishes, to monitor populations, and to measure their responses to natural disturbance, management, and changing habitat conditions. Although a large body of literature describes techniques for sampling fish populations, few guidelines are published for assessing sampling bias and precision. Our own work indicates that traditional sampling methods can be highly biased, and that bias may be linked to the environmental conditions biologists hope to associate with the distribution and abundance of the species they sample. Furthermore, we find that common methods used to validate the use of current sampling methods may themselves be biased. The need to work at larger scales is also problematic. It is apparent that sampling efforts used to describe individual reaches or segments of streams cannot simply be extended to entire basins without an unrealistic expansion of funding, personnel, and equipment. The ability to detect trends and important differences in fish numbers and distributions at large scales will depend on obtaining reliable estimates of occurrence and abundance more efficiently.

We propose studies to:

- Measure bias, precision, and inter-observer error of aerial and ground-based salmon redd counts. Output: Models of redd sightability and standardized approaches to reduce redd count errors.

- Measure efficiencies of various methods (e.g., electrofishing, snorkeling) for sampling presence/absence and abundance of stream fishes. Output: Models for predicting detection probabilities of select species and life stages and guidelines for sampling stream fishes.

- Evaluate select methods and sampling intensities for assessing salmonid spawning habitat conditions. Output: Development of guidelines for monitoring salmonid spawning habitats.

4. *Non-native species invasions* – Non-native species are becoming increasingly widespread in aquatic ecosystems throughout the region. In some cases, non-native aquatic species have been intentionally introduced for a variety of purposes ranging from pest control to supporting recreational fisheries. The positive values of non-native species introductions are countered by concerns over their potential effects on native species and ecosystems. Concerns with non-native species are often widespread, uncertain, and sometimes create conflicts with other management objectives such as restoration of passage for aquatic organisms, habitat management, and recreational fisheries. Problem resolution requires understanding factors that lead to invasions, identifying cases where non-native species are undesirable once they do invade (i.e., “Where is displacement or replacement of native species likely to occur?”), and ultimately identifying effective management priorities and tools for monitoring, inventory, and evaluation of invasions. As the list of invading aquatic species grows and established species invade further, managers will be faced with a host of new challenges for conserving native species and ecosystems.

We propose studies to:

- Understand future invasion potential by established non-native species. Output: New predictive models for classifying streams or stream segments that are likely to be invaded by non-native species (such as non-native brook trout and rainbow) across landscapes, watersheds, or entire river basins.

- 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. Output: New predictive models for classifying streams or stream segments where species invasion is likely to result in the loss or substantial reduction of native species populations.

<u>Problem 1 - Anticipated Outcomes</u>: Ultimately, the knowledge generated from this research will help managers become more strategic . The general implication is that space and the distribution and interconnection of aquatic populations and

their habitats matter. But, how much habitat and how many populations are enough, and where should they be? If we are to conserve or restore functional habitat networks and the diversity and resilience of aquatic biota, deciding where to focus management and conservation will become essential. This research will provide the foundation for managers who must consider the relative risks and benefits of actions that will influence the distribution and interconnection of habitats for sensitive species. It will provide the context for understanding watersheds, populations, or habitats that may be particularly important to the function of a larger network or the conservation of biological diversity. Such context is critical for understanding the implications of specific project level actions (e.g., fish passage restoration, burned area emergency rehabilitation) and alternatives to Forest Plan objectives, recovery of threatened and endangered species, and water quality. A better understanding of context will allow managers to more effectively consider tradeoffs in land allocations and prioritize the limited resources available for management of aquatic systems. This work will also provide the foundation for the decision support tools outlined in Problem 4.

Problem 2 - Understand the dynamics of large-scale hydrologic and geomorphic processes in forests and rangelands.

Although we recognize that aquatic ecosystems are biologically and physically dynamic, land management still struggles with application of this view. Progress in managing dynamic systems will require a shift from managing for the state of a particular habitat element within a stream network, to managing for some distribution of states over time within a larger network. In essence, the spatial scale of the management problem increases dramatically beyond the scale of most existing science. Most watershed process studies have been conducted on hillslopes, small watersheds, and stream reaches. Extending the science to landscapes, large watersheds, and networks of stream channels is more complex than a simple aggregation problem; the fundamental character of the issues can change with an increase in scale, and there is a general lack of understanding about large-scale hydrologic and geomorphic processes.

Advances in this area require new model designs, measurement approaches, and data. One of the most difficult issues is how to reframe problems in a manner relevant to larger spatio/temporal scales. For example, while precipitation intensity alone is adequate information for a plot or small watershed study, the spatial distribution of precipitation becomes important in larger systems. Long time scales pose particularly difficult measurement problems because they often exceed our capacity for direct observation. Large spatial scales also require different sampling design and measurement technologies. Thus, a common thread in the elements of this research is a need to recharacterize the issues for larger spatial and temporal scales, and especially to define the processes that are relevant at the larger scales and the means to quantify them at those scales. For some issues, simple aggregation from small scales is appropriate; for others, more complex solutions are necessary.

To address the overall unit mission of aquatic ecosystem conservation, we will focus primarily on physical processes involving water flow and temperature, and sediment/soil movement. Geochemistry and nutrient issues will be used if they are useful as tracers or measurement tools.

We propose work in four interrelated elements: 1) scaling fluxes of water and energy; 2) dynamics and scaling of sediment flux; 3) the role of natural and anthropogenic disturbance agents in driving hydrologic and geomorphic processes; and 4) evaluate and develop monitoring technologies, techniques, and strategies.

1. *Scaling fluxes of water and energy* – The hydrologic system is the fundamental driver of ecosystem processes in forest, grassland, and aquatic ecosystems. The movement of water forced by solar radiation and gravity drives biological and physical processes across the landscape. Spatio-temporal patterns of water availability and its quality are fundamental descriptors in both terrestrial and aquatic systems. Movement of energy is no less important and is coupled intimately with the movement of water. While a tiny proportion of incoming solar energy is converted photosynthetically into biomass, the majority of energy goes into heating and evaporation. Heating and evaporation are, in turn, strong controls on the availability of water in relationship to snowmelt, seasonal low flows, and the timing of runoff and the temperature of water. Flow and temperature are fundamental characteristics of aquatic habitat that express strong controls on fish occurrence. Rapid snowmelt and severe precipitation events (thunderstorms) create major fluxes of water into the soil that express strong controls on geomorphic processes such as gullies, landslides, and debris flows.

We propose studies to:

- Model the scaling of snowmelt processes. Snowmelt modeling for a single small plot has advanced to a high degree, but models of large areas are hampered by assumptions of uniform snow conditions.
  Output: Physically based snowmelt models for large areas.

- Model basin-scale controls on stream temperature. Spatial patterns in stream temperature are one of the strongest controls for some fish species. These patterns are derived from basin characteristics controlling low flows in streams and solar radiation inputs to streams. Output: Physically based and empirical models of stream temperature applicable to stream networks.

- Describe basin-scale controls on low flows. Low stream flows control use of habitats by fish and their migration and exert an influence on stream temperature. Unfortunately, there is only rudimentary understanding of how summer low stream flows are distributed on the landscape and the relative influence of basin characteristics and vegetation state. Output: Approaches for predicting low stream flow probabilities as a function of basin characteristics and vegetation status.

2. *Dynamics and scaling of sediment flux* – The spatio-temporal aspects of sediment flux are primary physical components of watershed systems that must be understood before land use planning can incorporate ecosystem dynamics. Many erosion/sedimentation studies have tended to be either local in scale or of short duration. The dynamics of a sediment system and its response to forcing by extrinsic or intrinsic variables is rarely evaluated, with the recent exception of a few numerical models. Assessment of these model predictions has been almost exclusively on the basis of resulting landscape surface morphology, a measure that may not allow us to uniquely identify the cumulative result of surface processes. Direct observations of sediment system dynamics are also predominately done at the single event scale.

We propose studies to:

- Characterize the scaling of major channel reorganizing events. It has become clear that the channel reach is an inappropriate unit of measure for management or regulation of stream ecosystems. What then do we replace it with? The concepts of "minimum dynamic area" or "representative elementary area" suggest that there may exist spatial scales over which some sort of average or statistically repeatable behavior can be expected. Do these exist in the context of severe disturbances? What are they? What processes determine them? Output: Development of practical approaches to apply theories about dynamic aquatic ecosystems to land use planning by defining appropriate extents to planning and monitoring units.
- Measure spatially averaged and spatially explicit long-term erosion rates. There are few data that allow us to consider modern erosion rates and the effects of land management in the context of “natural” or "background" conditions over longer timeframes. In the Idaho Batholith, various tracer technologies may allow for measurements of denudation at longer time scales, on the order of ≤10,000 years ago, the period since the last major glaciation. Output: a) Understanding of present day erosion rates in the context of long-term erosion rates; b) understanding of the spatial and temporal components of system dynamics, e.g., do some areas of a landscape experience higher or more variable rates of erosion in response to short-term events.
- Define controls on channel changes induced by major events. The impacts of punctuated hillslope and small basin erosion on receiving channel conditions depend on the materials those events bring into the channels, and these materials in turn depend strongly on the geomorphic history of the hillslopes and small basins and the character of the bedrock (mechanical properties, weathering, and erodibility). Output: Methods to qualitatively predict how major events from particular tributary basins affect main-stem geomorphology.
- Quantify controls on landslide/debris flow location and size. Current mechanistic models of landslides and debris flows are two-dimensional and do not properly incorporate the strength contribution of vegetation roots. They also normally include an assumption of steady state precipitation conditions and simplified groundwater hydrology. Output: Three-dimensional models of shallow slope stability that more accurately predict the location and size of debris flow risks.

3. *The role of natural and anthropogenic disturbance agents in driving hydrologic and geomorphic processes* – Watershed processes governing the movement of water, sediment, and energy through hillslopes and streams are governed primarily by climatic, edaphic (soil), and biotic (vegetation) conditions. Climatic influences are probably the most dynamic but probably least controllable component. Soil and vegetation conditions are dynamic within time scales influenced by human management so that we have some control over how disturbance affects these components of the hydro-geomorphic system. Primary external disturbance mechanisms for vegetation are fire, harvest, grazing, and disease, while the primary external disturbance mechanisms for soils are road building and fire. As we increase the scale of consideration for hydrologic and geomorphic processes, we also need to expand our understanding of effects of disturbance agents to larger scales.

We propose studies and analyses on the following practices and disturbances:

- Forest roads – Although forest roads affect only a small fraction of the landscape, their influence on hydrologic and geomorphic processes is well out of proportion because of their linear nature. They can influence movement of water from large areas of forest by interception and rerouting, and they can be a persistent source of fine sediments. Science has primarily focused on road plots to date, and scaling our understanding to both road segments and networks is an important challenge. Key questions about forest roads are:
    - What are the hydrologic effects of road segments and networks? What are the geomorphic implications?
    - How much fine sediment is generated from road segments and networks, and how might it be most efficiently modeled?
    - How do we prioritize portions of the network for decommissioning, and which decommissioning practices are effective?

- Harvest, grazing, and disease – The loss of vegetation cover with forest harvest, grazing, and disease alter energy fluxes controlling snowmelt, stream temperature, and groundwater conditions. The accompanying losses in root strength are an important control on landslide susceptibility. Outputs: Quantification of the effects of vegetation loss on energy fluxes and spatial distributions of root strength.

- Fire effects – After wildfire or prescribed fire in forests and rangelands, changes to vegetation canopy and soil characteristics alter runoff generation processes. One of the more dramatic changes is in the formation of water repellent soil layers. Science to date has focused on local, point-scale descriptions of the strength and origin of water repellency, but the spatial distribution of water repellency and its temporal variation are the key pieces of information relative to runoff generation. Outputs: Tools to evaluate post-fire changes in runoff, gully formation, and channel network extension and effectiveness of proposed treatments.

4. *Evaluate and develop monitoring technologies, techniques, and strategies* – Measurement of changes to hillslopes and stream channels is important for rational management of aquatic ecosystems. As we come to understand the importance of scaling our understanding of watershed processes, the need for broad-scale monitoring becomes more apparent. This suggests the use of tools that measure areal distributions directly, such as remote sensing, or tools that are inexpensive and efficient at local scales, allowing broad application.

Anticipated developments for monitoring and measurement include:

- Evaluate the use of LIDAR, a remote sensing tool used to measure land surface topography with high resolution to characterize the spatial distribution of root strength, improve landslide risk assessment, and monitor channel/floodplain change over time.

- Develop methods for remote sensing of shade. Shading from vegetation is a key variable affecting stream temperature. To estimate stream temperature distributions around a basin, ground-based measurements are inadequate, and there is need to estimate it from reflectance information.

- Develop efficient methods for channel condition and change monitoring. Unfortunately, such monitoring is often slow and expensive. Development of methods that are faster, relevant to management goals, and statistically sound is important if landscape-level monitoring of channels is to be undertaken.

- Develop methods for tracing sediment sources in streams. When monitoring networks of roads interacting with networks of streams, it would be valuable to measure the proportion of sediment derived from roads compared to other sources. Tracer technologies can be useful in partitioning sediment sources, and we are developing methods that can help with attribution of sediment source based on mineral content and color.

Problem 2 - Anticipated Outcomes: The knowledge gained from this research will be used to: 1) inform managers about how their decisions affect water resource availability and quality; 2) inform managers about how their decisions will affect aquatic habitat conditions and dynamics; and 3) provide more efficient and more informative methods to measure conditions and track changes in aquatic ecosystems. The increased understanding of the physical nature of severe disturbances in streams is a key piece of understanding necessary to incorporate uncertainty about major events into the planning process in explicit and rational ways. For example, reactionary decisions to fight a fire or to apply extensive post-fire mitigation measures to protect watershed resources can be considered in a more reasoned manner if we have a clear understanding of the range of potential effects from ensuing severe weather events. An improved quantitative understanding of snowmelt, streamflow, and stream temperature effects will become increasingly important as competing demands for scarce water resources increase. Simple 'increase' or 'decrease' determinations will be less satisfactory as these quantities have substantial values attributed to them by downstream users. Finally, we expect to see increased use of this information in prioritizing and allocating scarce restoration resources to work on streams, roads, and terrestrial vegetation. Knowing the spatial distribution of habitat and water quality conditions is critical in making choices about which efforts would produce the greatest payoff within any given context of regulations and fish distributions.

Problem 3 - Link physical and ecological research to develop a better understanding of how hydrologic and geomorphic processes influence aquatic ecological diversity, and the dynamics and persistence of populations.

Although meaningful integration of our physical and biological research is the most difficult problem we face, it represents a vital opportunity to advance science and management. Realization of the inextricable link between physical and biological systems has focused the attention of science and management on maintenance of natural variation, disturbance, and the processes critical to biological resilience. Two concepts have dominated the emerging discussion of potential management solutions to these problems: 1) a need to conserve and restore a diverse network of habitats representing the critical elements of biological diversity; and 2) a need to implement more natural management that is consistent with the patterns and processes of disturbance necessary to create and maintain productive and diverse habitats. Our intent is to contribute to the broader perspective necessary to move forward with these ideas. We propose two primary elements in future work: 1) associations between physical constraints, physical processes, and biological diversity; and 2) disturbance, habitat, and population dynamics.

1. *Associations between physical constraints, physical processes, and biological diversity* - Under Problem 1, we propose to develop more effective tools for the inventory and description of important elements of intra-specific diversity, the distribution of species, and key life stages. In Problem 2, we propose to better define the physical processes that may structure habitats through time and space. It will rarely be possible for managers and biologists to complete the extensive inventories necessary to fully describe important elements of diversity in many systems. If physical patterns and processes constrain the distribution of species, life stages, and life histories, we should be able to apply an integrated understanding of these linkages to predict the distribution of biological diversity. The concept of "process domains," for example, proposes an explanation of species distributions in systems dominated by a particular physical regime. How well does this concept work in practice among different climatic and hydrologic regions? Can similar concepts be used to explain the expression of distinctive life histories within species? Can we predict the distribution and extent of critical or distinctive habitats for species or key life stages from our understanding of physical processes ultimately shaping those habitats? We propose to integrate the tools and results emerging from work under Problems 1 and 2 to evaluate landscape features, including hydrologic, geologic, and geomorphic characteristics, and disturbance history (or regimes) as predictors of species, life stages, distinctive life histories, and the diversity of those elements in watersheds and river basins of the Intermountain Region.

We propose studies to:

- Link geology, geomorphology, and process domains or regimes to species diversity, life history expression, and intra-specific diversity. Theoretical and limited empirical work suggests that gradients of productivity, substrate composition, hydrologic regime, and disturbance history will be associated with life history. We can begin to test these ideas in the river basins of central Idaho that support distinctive physical gradients and common species pools. Potential studies include substrate, disturbance history, and rainbow trout in the Boise basin, and productivity and cutthroat trout in the Coeur d'Alene basin. Similar work may also be possible with Chinook salmon in the Salmon River basin. Output: Results from this work should provide an improved understanding of the primary gradients in physical characteristics associated with intra-specific diversity within regional populations of key species and moderate sized river basins.

- Understand the influences of geomorphic history on bio-geography and population structure of aquatic species. Historical patterns of colonization and gene flow constrain the distribution of species and the distinctiveness of potential conservation units. Physical descriptions showing where barriers to dispersal are or were will be required to understand contemporary population structure. Output: An understanding of the relative significance of short- (e.g.,10^1 year) and long-term (e.g., $>10^3$ year) physical processes contributing to patterns of habitat connectivity, and maintenance of genetic diversity and distribution of unique conservation units.

- Link hydrology, geomorphology, and sediment and energy fluxes to the distribution and extent of habitats for key life stages. To understand the dynamics of the distribution, extent, and quality of Chinook salmon spawning habitats, for example, it will be necessary to extend and link existing models of shear stress, sediment supply, hyporheic exchange, and geomorphic controls, and then validate those models based on the distribution and spawning success/productivity of actual populations. To predict the distribution, extent, and quality of bull trout spawning and rearing habitats, it will be necessary to describe the physical controls on water temperature, including geomorphic history, and then validate those models from direct observations of fish distribution and persistence. Output: Landscape models of habitat distribution and geometry that can be linked to biological interpretations of population structure and ultimately the distribution of critical habitat networks. This work will also provide the foundation for extending our understanding of disturbance and environmental changes that will challenge management in the future (see element 2 below).

2. *Disturbance, habitat, and population dynamics* - Disturbance can be a product of both human and natural influences and has emerged as a major theme in the study and management of aquatic ecosystems. Increasingly, it is becoming clear that natural disturbance is an important part of ecosystem function, whereas many forms of human-caused disturbance may threaten species or impair aquatic ecosystem services (e.g., clean water). The view of disturbance as a creative or destructive force often depends on the spatial and temporal scale of events and biological responses in question. Management objectives are often linked to protecting and restoring key elements of aquatic ecosystems (e.g., threatened and endangered or management indicator species) that are resilient in the face of disturbance.

   We are beginning to understand the role of spatial structure and life history diversity in resilience to disturbance, but we do not understand what the ultimate limits of that resilience might be or the implications of changing patterns of disturbance and habitat availability. Changing fire regimes, climate, and future management might all lead to fundamentally different patterns of disturbance and available habitat than have been observed in the past. We propose to extend the dynamic view of landscapes to assess the role of large disturbances associated with fires and climatic events in the distribution, dynamics, and persistence of species at watershed and river basin scales.

We propose studies to:

- Extend the results of current studies to describe the distribution, extent, and duration of change in available habitat following recent fires in the Boise River basin. Severe wildfire has burned over more than 60 percent of the Middle Fork Boise River basin in the last 15 years, triggering debris flows and floods, altering the function of riparian areas, killing fish directly, and altering the structure and characteristics of habitat available to remaining populations. Output: An understanding of long-term dynamics in suitable habitat, key drivers (e.g., fire, climate), and fish population dynamics.

- Develop linked dynamic physical and biological models. Our existing work suggests that habitat patch sizes for species like bull trout have been adequate to absorb patterns of disturbance over the measurable past. We propose to link dynamic models of fire, vegetation, and watershed processes to predict the distribution and dynamics of key habitats for select species. Our intent is to explore the implications for populations facing disturbances under future alternative climate, fire, and management scenarios. Output: Tools to visualize potential future landscape conditions and influences of management and natural processes on species distributions and persistence. The goal would be to develop realizations of the potential effects of anticipated climate change, fuels management, fire, and other disturbances across entire river basins.

- Describe the responses of native salmonid populations to catastrophic disturbance. Output: An improved understanding of the responses of native salmonids to catastrophic disturbances (natural and human-caused). New work should include facets of disturbance that may enhance or threaten populations, depending on the nature and extent of individual events and the context within which they occur.

- Examine the response of streams and aquatic ecology to restoration activities in a watershed. This study is envisaged as an adaptive management experiment applying large scale restoration efforts to the vegetation communities and roads in a watershed, and measuring responses to physical watershed processes and stream ecosystem functioning including trophic processes, non-native invasion mitigation, and native fish population responses.

Problem 3 - Anticipated Outcomes: We believe this research will support a more efficient classification of terrestrial-aquatic systems and advance the development of models that will place management actions, natural disturbances, and environmental change in a biophysical context. It will rarely be possible for managers to conduct complete or detailed inventories of the aquatic species and inter- or intra-specific diversity characterizing entire river basins. Still, they must manage with some understanding of where sensitive species and critical habitats or hotspots of biological diversity are, or have the potential to be. By understanding the fundamental linkages between the physical environment and biological diversity, it should be possible to characterize or classify ecologically distinct watersheds, streams, or habitats based on physical characteristics. That knowledge can be used in representation and prioritization of land allocations and stratification of monitoring and adaptive management.

To understand the relative importance of management actions, human and natural disturbances, and changing climate to aquatic ecosystems, it will be necessary to build models that characterize the dynamics of forests, watersheds, habitats **and** populations over much larger temporal and spatial scales than have typically been considered in the past. The first generation of physical process models necessary to characterize the spatial and temporal patterns of disturbance and channel evolution are now being built, but they are not linked very well to ecological drivers (e.g., forest vegetation and fire) or responses (e.g., salmonid population dynamics and persistence). The development of linked conceptual models will provide the foundation for more complete mathematical models and help guide future research and the coordination of research groups working toward a common goal. Results will also help managers visualize the relative significance of short- and long-term perspectives in their work and will identify critical uncertainties for management experiments and a research-management collaboration.

Problem 4 - Enhance collaboration between researchers, technical developers and resource managers to produce more informed management and research decisions, and to develop cost-effective routes for science delivery.

The primary goal of the R1/R4/RMRS Aquatic Technology Transfer program is to provide the bridge between the biological and physical scientists at the Boise Aquatic Sciences Lab, and resource specialists and land managers engaged in making aquatic land management decisions. Our census of National Forest aquatic practitioners and land managers in association with National and Regional direction indicates that primary issues over the next 5–10 years will be the application of new science; strategies for prioritization of limited resources and conservation of biological diversity; objective evaluation of the effects of grazing, dispersed recreation, ORV use, roads, invasive species, watershed and stream-riparian restoration, forest health and fire projects; maintenance of water quality; and the development of more efficient and effective inventory and monitoring tools. To address these issues, the R1/R4/RMRS Aquatic Technology Transfer (TT) Group will focus their resources on delivering timely, relevant aquatic and watershed research publications, issue-driven synthesis documents (TT Shorts), and technical procedures and tools through the Boise Lab's www Web site, Regional meetings, workshops, and field unit consultations. The Boise Lab's biological and physical scientists are continuously involved in delivery and application of their science through the R1/R4/RMRS Technology Transfer program and through individual efforts.
We anticipate five elements to this work: 1) continue to assess aquatic specialists' needs for technical information and better tools; 2) develop new tools; 3) continue to develop and refine pathways for science delivery; 4) multi-scale assessments, land use effects analysis, and planning; and 5) multi-scale monitoring and inventory procedures.

1. *Continue to assess aquatic specialists' needs for technical information and better tools* – Specialists' needs are assessed in various ways through questionnaires; participation in Regional and Forest program manager and annual biologist meetings; an established e-mail network; annual work plan development and review by Regional Fisheries Program Managers and Fish and Wildlife Directors; participation in issue-driven field reviews and project consultations; and staying current with national and regional National Forest policy, directives, and guidance. Since the integration of the biological and physical scientists at the Boise Lab, we are exploring ways to increase our linkage to Regional, Forest, and field unit physical scientists.

2. *Develop new tools* - The Technology Transfer Specialist is part of the Boise Lab's leadership team for representing National Forest aquatic issues and needs in the discussions and design of scientific research and tool development. The TT Group is attempting to harness the Boise Lab's scientific expertise, publications, and technical tools into decision support frameworks, and issue specific synthesis documents to help keep aquatic resource specialists up to date with available aquatic technical information. The TT Group is engaged in specific Region 4 projects to assist in application of the latest science, tools, and procedures to Regional, Forest, and District programs.

We propose specific projects along the following lines:

- Develop a new interface and expanded parameter space for BayVAM, a viability assessment module for native fish populations.

- Develop a user interface and supporting documentation for PVANC, a population viability assessment module for time series data such as salmonid redd counts.

- Develop a decision support framework articulating the critical dependencies and interactions relevant to the management of barriers and non-native species invasions.

- Develop road inventory protocols and analysis methods to efficiently assess road effects on watersheds**.**

- Develop a Fire Enhanced Runoff and Gully Initiation Model (FERGI) that estimates the probability of runoff generation amounts and gully initiation positions on hillslopes after fire and fire mitigations.

3. *Continue to develop and refine pathways for science delivery* - The TT Group will focus their resources on delivering timely, relevant aquatic and watershed research information to managers and resource specialists through the following methods:

- Expand user friendly delivery of biological and physical scientist publications and tools through the Boise Lab's Web site.

- Provide issue-driven synthesis reports, "TT Shorts," that summarize the latest research findings, tools, procedures, and background literature.

- Define, organize, and host issue-driven workshops to communicate understanding of the latest information, theory, tools, and procedures on a specific National Forest issue.

- Participate in Regional and Forest meetings to define research needs and transfer the latest Boise Lab research.

- Participate in field unit consultations and reviews to transfer the latest science, technical tools, procedures, and expertise upon National Forest request.

4. *Multi-scale assessments, land use effects analysis, and planning* - Aquatic practitioners spend most of their time conducting assessments and planning to support natural resource decisions at the Regional, Forest, and project level. National Forest managers must address aquatic species extinction risks; land management threats to at-risk species, their habitats, and watersheds; and local and regional scale population viability. National Forest managers are responsible for defining management actions to protect, maintain, and restore threatened, endangered, and sensitive aquatic species to ensure that healthy populations are well distributed across federal lands that historically supported them. Approaches to assist in assessments, land use effects analysis, and conservation and restoration prioritization are needed. These approaches will be relevant for developing, revising, or updating Forest plans, sub-basin assessments, watershed analysis, and project NEPA and ESA consultation.

We propose studies to:

- Help facilitate the development and application of technical tools for predicting and tracking the likely outcome of proposed management actions and alternatives on the aquatic environment.

- Help facilitate the understanding of the characteristics of populations that make them more or less likely to persist.

- Assist in the development of decision support frameworks to make transparent the components and pathways relevant to multi-scale assessments and management decisions.

- Assist in data acquisition and analysis to support the Forests' Analysis Matrix of Pathways and Indicators for soil, water, riparian, and aquatic resources.

5. *Multi-scale monitoring and inventory procedures* - Monitoring and inventory procedures provide the basic information that assists in making science based decisions or adjustments in management. We anticipate continued emphasis in these general areas:

- Assist in the development of methods for monitoring broad scale to fine scale land management decisions.

- Assist in the development of cost-effective physical and biological sampling methods to address management indicator species (MIS) and/or at-risk species distributions, population status and trends, watershed and channel conditions, and natural and anthropogenic disturbances.

- Help Forests formulate strategic monitoring and inventory programs to track hypothesized relationships and management objectives.

- Continue to provide support to field units utilizing the R1/R4 Fish & Fish Habitat Inventory Procedures, and assist in the transition of data archives from this format to that supported by the Natural Resource Information System (NRIS).

- Improve and reduce the cost of precision precipitation and evaporation measurements in remote mountain settings using improvements in electronics and robotics to design new gaging equipment.

- Apply and train personnel in road inventory techniques that directly address current scientific understanding of the erosion, mass wasting, and hydrologic effects of forest roads in an automated GIS-based analysis tool.

- Apply and refine inexpensive methods to monitor runoff and erosion from forest road segments and short hillslope plots to allow for local calibration of erosion estimation tools and improve monitoring of management practices.

11. Staffing

The Research Work Unit (RWU) is staffed with three physical scientists, three biological scientists, and a technology transfer specialist. Each of these positions has a professional hydrologist or biologist working in direct support. A GIS analyst supports the entire work unit. The technology transfer specialist is funded equally by Forest Service Regions 1 and 4 and the RWU. The support staff for the technology transfer specialist is supported entirely by Region 4. The RWU uses seasonal, term, and post doctoral postitions as funding allows. Currently, we support four post doctoral scientists in collaboration with the University of Idaho, Boise State University, and University of Nevada Reno.

Physical Scientists	Professional Support Staff
C. Luce, Hydrologist, (team leader)	T. Black, Hydrologist
J. McKean, Geomorphologist	C. Bohn, Hydrologist
John Buffington, Geomorphologist	K. Seyedbagheri, Hydrologist
Barbara Gutierrez, Physical Scienctist, (post doc.)	
Mic Lewicki, Geomorphologist, (post doc.)	

Biological Scientists	Professional Support Staff
B. Rieman, Fish Biologist (Project Leader)	D. Horan, Fish Biologist
	D. Nagel, GIS analyst
J. Dunham, Fish Biologist	G. Chandler, Fish Biologist
R. Thurow, Fish Biologist	J. Guzevich, Fish Biologist
K. Overton, Tech. Tran. Specialist	S. Wollrab, Fish Biologist
D. Isaak, Fish Biologist, (post doc.)	
A.Rosenberger, Fish Biologist, (post doc.)	
H. Neville, Ecologist, (post doc.)	

Cooperators

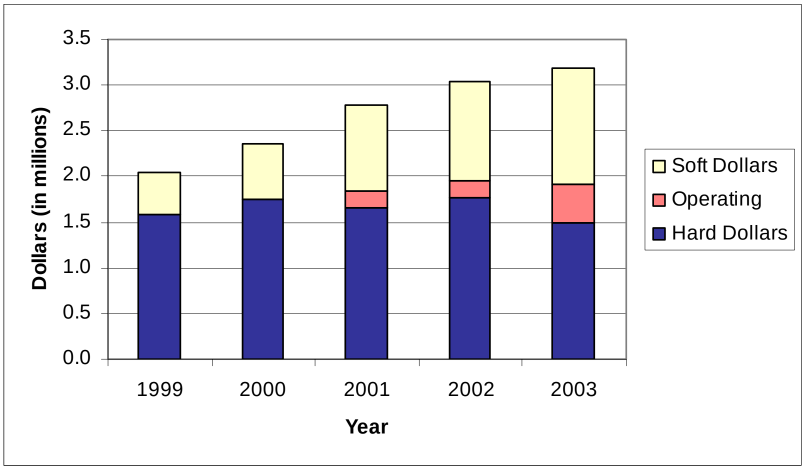
The RWU cooperates with State and Federal agencies, laboratories, tribes, and universities through funding and collaborative research. The project has chosen to focus its staff within the core disciplines of fish biology, hydrology, and geomorphology in order to better facilitate idea exchange and expertise in these areas. Progress on the stated research program, particularly in Problem 3, will require expertise in such disciplines as terrestrial ecology, riparian ecology, and fire behavior. While many cooperators have specialized expertise within our core disciplines, a number of other cooperators provide expertise in important related fields. Current cooperators include:

Agricultural Research Service, Boise Lab
Boise National Forest
Boise State University
Bonneville Power Administration
Idaho Department of Fish and Game
Idaho State Department of Health and Welfare-Division of Environmental Quality
Lincoln University, New Zealand
Massachusetts Institute of Technology, Department of Civil and Environmental Engineering
Nevada Division of Wildlife
Nez Perce Tribe
NOAA Fisheries, Northwest Fisheries Science Center
Oregon Department of Fish and Wildlife

Oregon State University, Department of Forest Engineering
Pacific Northwest Research Station, Wenatchee Lab
Payette National Forest
Region 1 - U.S. Forest Service
Region 4 - U.S. Forest Service
Rocky Mountain Research Station, RWU-4352
Salmon-Challis National Forest
Shoshone-Bannock Tribe
U.S. Bureau of Reclamation, Boise
USDI Bureau of Land Management, Oregon State Office
U.S. Fish and Wildlife Service
University of California, Berkeley, Department of Earth and Planetary Science
University of Colorado, Department of Civil, Environmental, and Architectural Engineering
University of Georgia/USGS Cooperative Fish and Wildlife Research Unit
University of Idaho Ecohydraulics Research Group, College of Engineering
University of Idaho Fish and Wildlife Dept., College of Natural Resources
University of Oregon, Department of Geological Sciences
University of Montana, Wild Trout and Salmon Genetics Laboratory
University of Nevada Reno, Biological Resources Research Center
University of Washington, College of Forest Resources
Utah State University, College of Engineering
Washington Department of Fisheries and Wildlife

Funding

Funding for the RWU is primarily from Forest Service Research, with additional soft funding generated through some of the cooperators listed above. Hard funding is allocated approximately equally among the six scientists in the work unit. Total hard dollar funding from Forest Service Research and other soft dollar funding sources over the last 5 years is shown below. “Operating” is the discretionary funding available from total hard dollars after salaries, Station overhead, and support costs are removed. Operating could not be separated before 2001 because it was split with elements of the work unit that have since been transferred. Hard funding through Forest Service Research is anticipated to remain roughly stable over the next 5 years. That level of funding should be adequate to maintain the planned facilities and the salaries of the current permanent staff. The discretionary funding or “operating” will likely decline in the future. Our expectation is that near the end of the 5 year period, virtually all proposed research will depend on “soft” dollars. The research outlined in this plan is ambitious and probably exceeds our capabilities to complete in its entirety without substantial new sources of hard dollars. For that reason, elements of the program that move ahead most quickly will depend on our success to continue existing and develop new outside funding.



Other Considerations
The work outlined in Problems 1 and 2 represents a logical extension of research already underway in the Boise Aquatic Sciences Laboratory. The foundation for this work is well developed in the Laboratory and our staff, or the facilities and staff of our cooperators. The skills and background of our research scientists, professional support staff, and established colleagues and collaborators are adequate to move forward quickly with the application of existing methodologies or the

extension of techniques from closely related fields. The work outlined in Problem 3 will be more challenging. Integrated research requires a commitment to collaboration among disciplines that has often proven difficult to maintain. The current staffing of the project and the interests of the science staff provide a unique opportunity to move forward. The mix of physical and biological disciplines and the experience with larger scale applications in our group provide a good foundation for integrated research in montane aquatic systems. We do not have the full range of disciplines and skills, however, to move forward on all phases of the work we propose in the second element of Problem 3. Fire and the ecology and dynamics of forests and riparian plant communities represent primary controls on disturbance and the processes influencing energy fluxes and channel structure. Climate change and the dynamics of precipitation are important drivers of hydrologic regimes and large erosional events. To begin to build a more dynamic view of aquatic ecosystems, it will be necessary to engage scientists working in these areas. The development of more complete conceptual models will be a critical first step in the outreach to other scientists. If we can successfully engage the range of perspectives necessary to move forward there, the potential for generating the funding and participation from scientists needed to fully support the development of new quantitative models will be greatly enhanced. The work outlined in Problem 4 acknowledges the growing role of effective science delivery in natural resource management by elevating what has been a supporting element of the research program to the status of a full problem. The Technology Transfer program is well established with a long history of collaboration and support from the National Forest System. The established ties to Forest biologists and managers in the Intermountain and Northern Regions promise an effective link in the future. It will be important, however, to reach out to other emerging programs that promise new skills and technologies in the growing focus on science delivery throughout the region and nation.