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STREAM NOTES

To Aid in Securing Favorable Conditions of Water Flows

Rocky Mountain Research Station

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Assessment of Threats to Riparian Ecosystems in the Western U.S.

by David M. Theobold, David M. Merritt, John B. Norman, III

Rivers and riparian ecosystems are recognized as important areas for conservation as they provide a range of services to society, provide unique and productive habitat for wildlife, and serve as corridors for connecting otherwise disconnected landscapes through exchanges of water, sediment, nutrients, pollutants, and organic materials. Although riparian ecosystems and wetlands only occupy 0.8 to 2% of the landscape in the arid western U.S. (NRC 2002; Naiman et al. 2005), they provide habitat, water, and other resources to greater than half the wildlife species in the region and harbor the highest plant, bird, insect, reptile-amphibian, and mammal biodiversity of any terrestrial ecosystem. Riparian areas are also utilized by society for a range of ecosystem services such as recreation, water supply, agriculture, grazing, etc. The human demand on resources associated with rivers and riparian areas in the western U.S. is rapidly increasing, putting these areas at greater risk of reduced and compromised ecosystem function.

The threats to riparian ecosystems include invasive species, herbivory (both domestic livestock and wild ungulates), wildfire and fuels treatments, ecosystem fragmentation, drought, climate change, disease and insects, legacy impacts, urban development, mineral extraction, changes in hydrology, and geomorphic change (table 1). In addition, rivers and riparian areas are particularly vulnerable to alteration of hydrologic regimes by dams, diversions, and groundwater pumping (e.g., Graf 1999; Allan 2004). The overall objective of the report, ***Assessment of Threats to Riparian Ecosystems in the Western U.S.*** (Theobold et al. 2010), was to provide an initial, coarse-scale assessment of historical, current, and future threats to streams and riparian areas in the western U.S. (fig. 1). This effort is intended to support the development of a comprehensive strategy for the management of riparian areas and their watersheds while recognizing the need to balance sometimes conflicting interests and demands for ecosystem services. Here we summarize the results and recommendations discussed in Theobold et al. (2010).

Methods

We utilized existing geospatial datasets and climate change

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Table 1. Threats to riparian ecosystems.

Threat	Examples of causes	Examples of effects
*Changes in flow regime† and dewatering	Surface water: dams, diversions, changes in land-use, climate change; Groundwater: pumping, land use change, climate change	Water stress of vegetation, shifts in plant species composition, homogenization of riparian zone, simplification of biota, isolation of floodplain from stream, changes in stream-riparian organic matter exchange and trophic dynamics, alteration of floodplain biogeochemistry terrestrialization, secondary effects (fragmentation, channel change)
*Channelization	Bank hardening, levee construction, structural changes in channel (deepening, berm development, meander cutoff)	Isolation of floodplain from stream, changes in fluvial processes, changes in hydraulics (aquatic habitat and channel forms), alteration of floodplain biogeochemistry
Invasive species	Introduction, altered processes in system that facilitate establishment & spread (e.g., herbivory, changes in flow regime)	Displacement of native species, formation of monoculture, changes in site characteristics (e.g., biogeochemistry, soil characteristics, changes in water balance), shifts in community composition, changes in habitat structure
Changes in sediment delivery to channel	ORV use, roads (drainage, gravel application), livestock/herbivore trampling, changes in vegetative cover in watershed and/or along channel, direct mechanical impacts to channel, dams, and diversions	Shifts in channel and floodplain form (through increased or decreased sediment delivery to channel), changes in channel processes, incision/aggradation
Herbivory	Domestic grazing, wild herbivores (predator control)	Bank trampling, compaction, vegetation changes (cover, composition), stream capture, nutrient inputs
Wildfire and fuels	Fuel buildup from invasive species, fire suppression, decadent vegetation, flood suppression, lack of flooding-slower decomposition of organic materials	Increases in frequency and intensity of fires, loss of fire intolerant taxa, changes in the structure of riparian vegetation and habitat quality and distribution, subsequent shifts in biota

*equally significant; all others loosely ranked; †Magnitude, frequency, timing, duration, rate of change, and inter-annual variability in stream flow.

scenarios available at broad spatial scales to model the primary processes of three factors at smaller spatial scales that influence water and sediment yield along stream corridors: 1) longitudinal flow regime connectivity and fragmentation; 2) upland processes and sediment production; and 3) lateral connectivity and land-use modifications in the riparian zone. We estimated changes in longitudinal flow regime connectivity and fragmentation by measuring the ratio of the normal storage volume of a dam to the natural mean annual discharge (assuming no dams or other human modifications). We used the Revised Universal Soil Loss Equation to estimate sediment production from uplands. To estimate the direct loss of riparian zone areas, as well as the loss of lateral connectivity, we measured the proportion of human-dominated land uses to natural cover types within the valley bottom. Our assumption is that quantifying the factors which govern these processes, provides the best available information to assess existing and potential riparian conditions relative to historic conditions, detect patterns and trends across the western U.S, and project likely future changes tied to human and natural changes conditioned by land use and climate.

We used the U.S. Geological Survey National Hydrography Dataset (NHD; 1:100,000 scale) to identify stream reaches, and 30 m resolution elevation and other data where available. We grouped streams from the NHD that were represented by the same unique reach from a coarser dataset, the U.S. EPA's Reach File 1.2 (Hall et al. 2000). This resulted in reach catchments that are roughly comparable to the 12-digit and 14-digit hydrologic unit codes (HUC) or HUC 6 level and HUC 7 level watersheds, respectively.

We developed three scenarios to characterize conditions in the past (1900-1940), present (1940-2000), and future (2000-2030). We selected our time period to break at 1940 to be consistent with other studies that have shown that atmospheric CO_2 began to increase rapidly around 1940. The 1940 break is also roughly consistent with the rapid expansion of urban areas and the construction of the interstate highway system. By modeling the

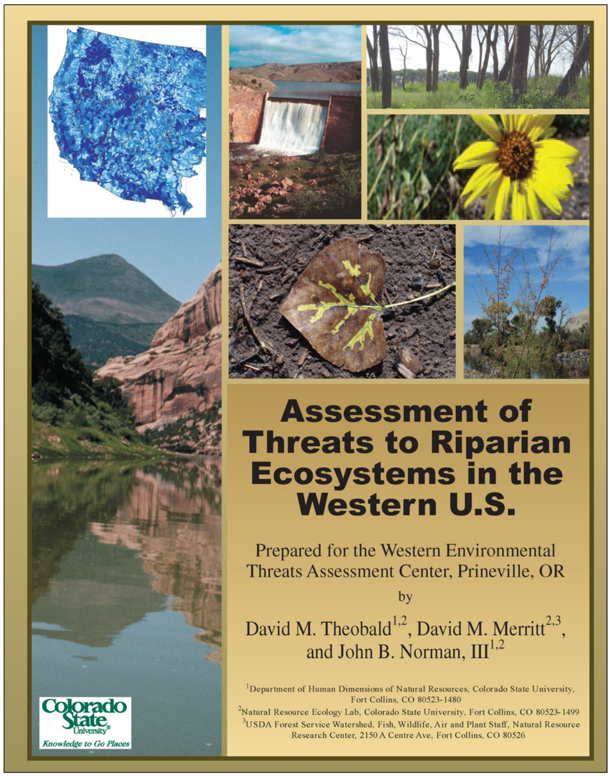

Figure 1. Cover page of the publication, ***Assessment of Threats to Riparian Ecosystems in the Western United States***.

processes of the three factors (longitudinal connectivity/fragmentation, upland sediment production, lateral connectivity/land-use modification) for these three time periods, we were able to evaluate the current status of streams relative to unaltered reference conditions and identify those riparian areas most at risk of future change under various future scenarios of climate change and human-caused land cover change.

We standardized each of the three individual factors considered and then summed their values to calculate a single, integrative index referred to as the "riparian threats score". This score provides a relative index of threats to riparian systems.

Riparian Threats Score

Threats in the past to future scenarios indicate that the highest threats to riparian areas in the western U.S. occur largely in western Washington, southern Idaho, northern Utah, southern Arizona, and southern New Mexico (fig. 2). The least threatened areas include parts of the Cascade Mountains, the Sierra Nevada Mountains, eastern and southern Utah, and western Colorado.

Our measure of longitudinal flow connectivity/fragmentation indicates that reservoirs can store between 16 and 200+% of the annual stream discharge with lower modification from the past to current scenarios for the Pacific Northwest (~18%) and the upper Missouri River basin (~47%), and higher modification in the Rio Grande River basin (~272%), the Great Basin region (~225%), and the Colorado River basin (~220%). However, flow modification is highly variable spatially with about 10% of the watersheds having at least 100% modification, 16% of the watersheds having 50% modification, and 23% of the watershed having at least 20% modification. About 55% of the watersheds had no flow modification, indicating that no major reservoirs were located within that watershed. Potential future changes in longitudinal connectivity/fragmentation due to climate change assumed that the number of dams and their storage volumes did not change during this period. Climate change projections indicate flow modification in the future will likely increase substantially for Colorado, California, and to a lesser extent the Great Basin region because of decreased discharge. Climate change projections indicate flow modification in the future will likely decrease for the Arkansas River basin and Rio Grande River basin because of increased discharge. Climate change projections indicate flow modification in the future is likely to be minimal for headwater watersheds in the Pacific Northwest and a few watersheds in Arizona and New Mexico.

Changes in sedimentation from the past to current scenarios show small decreases in urban areas such as the Front Range of Colorado and Puget Sound in Washington as well as other localized watersheds throughout the western U.S. Most of the changes, however, include large increases (>100%) in sediment produced from some watersheds. This occurs mostly in eastern Washington, the Great Basin region, the central valley of California, and southern New Mexico. There are fairly subtle changes likely in the future in terms of sediment yield averaged by the HUC 4 level watershed. Some areas are likely to have a decrease in sedimentation due to land use changes that are dominated by urbanization. Changes in sediment yields estimated by our model are based only upon land use changes; changes in sedimentation due to future climate change are not modeled explicitly.

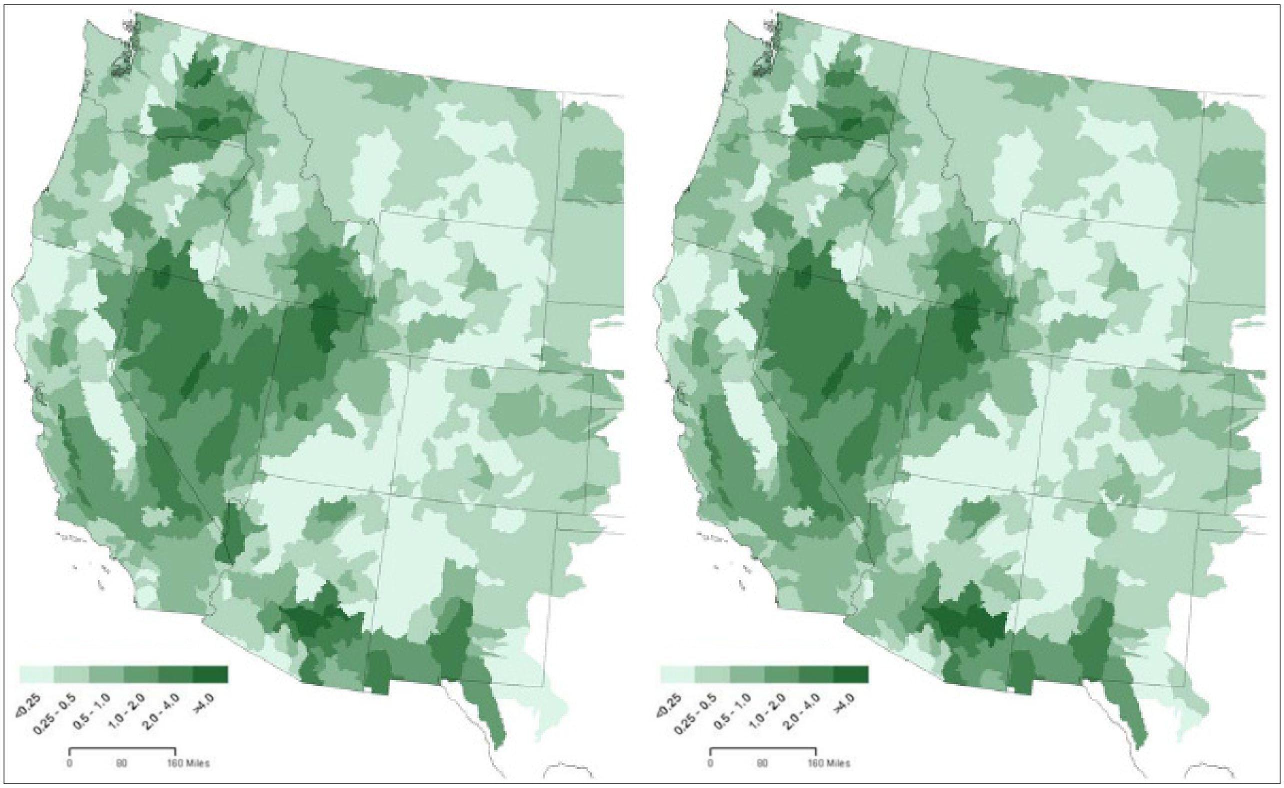

Figure 2. The raw values of riparian threats score for past to current scenarios (left) and current to future scenarios (right). Score values were calculated by standardizing the flow fragmentation, sediment production, and lateral connectivity values and then summing those values to score areas with the greatest riparian threat level (dark green shading) through the lowest riparian threat level (light green shading).

Overall, we found that 15% of the West's potential riparian areas are modified by roads, development, or agriculture (cropland/pastureland, excludes grazing). The watersheds with riparian zones that have been most heavily modified include the Central Valley basin and Los Angeles basin in California, the Willamette Valley in Oregon, eastern Washington, and northern Montana. Watersheds in the southern Sierra Nevada Mountains, the northern Rocky Mountains in Idaho, the Colorado plateau, and eastern Wyoming are in the best condition. Modifications of riparian areas will likely increase to 16% by 2030 due to land use encroachment associated with housing development. This projected modification of riparian values is a conservative number because it does not include changes to the transportation infrastructure.

Summary

Climate change, increased human demands for water, continued water development and their combined and interactive effects pose significant threats to native riparian habitats throughout the western U.S. (Baron et al. 2002; Wohl 2005). Expansion and continued operation of hydropower facilities will continue to regulate the flow of rivers as human demands for clean sources of energy intensify (EPA 2005). It is important to recognize that along with continued human demands for water, timber, recreational opportunities, development, and agricultural opportunities along rivers, floodplains, and across valley bottoms come many opportunities to improve management of riparian areas. By recognizing the regional to local hierarchy of threats to riparian ecosystems, we are better equipped to sustain and enhance the ecosystem services provided by these systems now and into the future.

Environmental flow management is one tool that has the potential to restore processes and functioning of riparian ecosystems by strategically managing flows at appropriate times and quantities to optimize yield on the investment (Arthington et al. 2006). By strategically managing the timing, frequency, magnitude, duration, and interannual variability of flows to accommodate desired processes along rivers, human water needs can be met while supporting river functions (Merritt et al. 2010; Poff et al. 2010). Proper management of vegetation cover and soil stability for various land-use activities (e.g., livestock, agriculture, urbanization, recreation, roads, fire, mining, timber extraction, etc.) throughout the watershed is increasingly important for riparian ecosystems that may already be stressed due to water extraction or flow alteration. However, management of riparian areas themselves is paramount as healthy riparian ecosystems serve as a buffer between upland activities and aquatic ecosystems and healthy riparian ecosystems are more resistant and resilient to perturbations and external stressors or environmental threats.

There are no comprehensive datasets readily available that provide field-based riparian condition estimates, making it difficult in general to provide a rigorous validation of our riparian threats score. Findings from our analyses, however, should serve as a red flag for identifying riparian areas in the western U.S. that have the potential to change most dramatically in the future due to human activities and projected climate change. Areas with a high riparian threats score in our analyses are those that warrant further and more detailed analyses at a finer spatial scale.

Additional Information

For a more in-depth discussion and complete list of references on this topic, please refer to the report by Theobald et al. (2010). An electronic copy of the report can be downloaded at http://www.fs.fed.us/wwetac/projects/theobald.html. Also available at this website is a web-based bibliography of riparian threats.

Acknowledgements

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The Western U.S. Stream Flow Metric Dataset

by Seth Wenger, Charlie Luce, Daniel Isaak, Helen Neville, Alan Hamlet, Marketa McGuire Elsner

Hydrologic regimes are of fundamental importance in determining the physical and ecological characteristics of rivers and streams. Climate change is predicted to alter flow regimes in the western U.S., potentially causing earlier runoff and shifting some streams that are currently snowmelt-dominated to ones that receive both rain and snow in the winter. This could have significant impacts on aquatic communities. To study these changes, we developed a dataset of flow metrics for streams in the western U.S. under historical conditions and for different future climate change scenarios. The dataset is both broad in coverage and fine in resolution.

Figure 1. Coverage of the dataset. Files are divided geographically into six regions based on the National Hydrography Dataset. Rivers with drainage areas exceeding 250 km^2 are not covered.

Dataset Development

The University of Washington Climate Impacts Group, Trout Unlimited, and the U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station used the Variable Infiltration Capacity macroscale hydrologic model to estimate stream flows at a daily timestep under historical and forecasted future climate conditions across major river basins of the western U.S. (fig. 1). Forecasts were for the A1B emissions scenario for the 2040s and 2080s, using (1) an ensemble of 10 global climate models (2) MICROC3.2, a model that predicts a large amount of warming in the region, and (3) PCM1, a model that predicts a low amount of warming. The individual models (MIROC and PCM) were used to bracket the range of uncertainty in warming, while the ensemble represented a best-guess model consensus. For the historical scenario and each of the six forecasts, we estimated a hydrograph for every individual stream segment in the 1:100,000 scale National Hydrography Dataset (NHD; http://www.horizon-systems.com/nhdplus/), excluding large rivers (drainage area > 250 km^2). We then calculated a set of summary hydrologic indices (flow metrics) to describe key attributes of the flow regime for each segment. These include mean annual flow, the mean timing of runoff, and the frequency of high flows in the winter, among others (table 1).

We validated the historical flow predictions using observed data from U.S. Geological Survey gaging stations (fig. 2) (Wenger et al. 2010). The modeled raw daily and monthly hydrographs showed scattered performance, with reasonable matches to the observed flows in some places and poor correspondence in others. Differences were greatest in areas with high groundwater connectivity. Some aggregated, biologically relevant metrics, such as mean flows and high flow timing, were reasonably well modeled across all stations. Other metrics, particularly related to summer extremes (high or low) performed poorly. Annual flow timing showed systematic biases.

The flow metrics are available as table attributes that can be readily linked to NHD stream segments to facilitate visualization and analysis at various scales. The full projected hydrographs are not available for download at this time. For more details on the dataset and links to download the data from the different regions please refer to the website: http://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml.

Applications

The development of the dataset was motivated by an interest in how shifting flow regimes might

Table 1. Flow metrics included in the dataset

Flow Metric	Description
Daily Mean	The mean daily flow, averaged over a year.
Winter2yr	The probability of a 2-year flow event occurring in the winter.
Winter 1 5yr	The probability of a 1 5-year flow event occurring in the winter.
Winter99	The number of days in the winter in which flows are among the highest 1% for the year.
Winter 95	The number of days in the winter in which flows are among the highest 5% for the year.
Channelflow	The 1 5-year flow, sometimes considered the channel-forming flow.
CtrFlowMass	Timing of the center of the mass or center of timing of flow. The day of the water year at which 50% of the year's flow has passed. This metric can indicate snow- vs. rain-dominated systems.
Summer95*	The number of days in the summer in which flows are among the highest 5% for the year.
Summer20*	The number of days in the summer in which flows are 20% of the daily mean.
MeanSummer	The mean flow during the summer.
Highlow*	The ratio of high flow magnitude to low flow magnitude.
Flow7q10	The 7-day low flow with a 10-year return interval.

*Note: Based on our validations, metrics indicated with an asterisk are not reliable and are not recommended for use.

affect the distribution of stream fishes such as trout. We are using the dataset to model trout response to certain flow metrics under current conditions, and then predict how distributions may change as these flow metrics change in the future (Wenger et al. in press, Wenger et al. in review). Other scientists at the Rocky Mountain Research Station are using the data to investigate physical phenomena, such as potential winter sediment scour depths. The data have also been used in a pilot project to assess the vulnerability of infrastructure and fish populations to climate change in the Sawtooth National Forest.

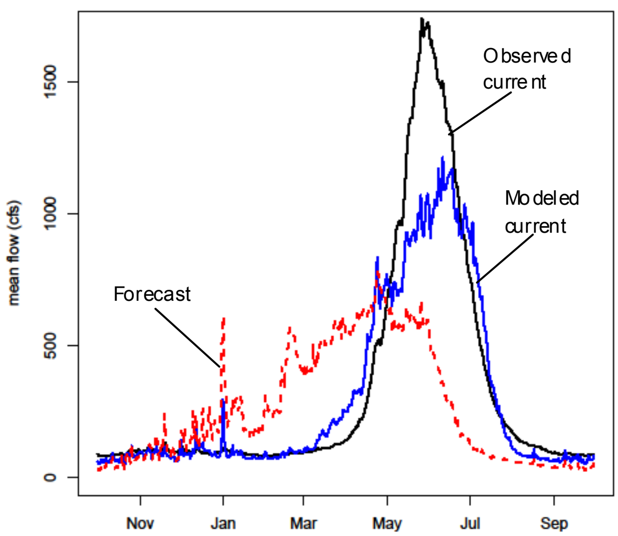

Figure 2. Mean annual hydrographs for Johnson Creek, Idaho for historical gaging station data (black line) modeled historical conditions (blue line), and forecast conditions under the 2080s A1B climate scenario using the composite of 10 models (dashed red line). Each hydrograph represents a 20-year average. Note the projected shift to earlier runoff and higher winter flows.

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