Broadscale Analysis of Climate Change Impacts on Coldwater Fish in the Western, United States

Summary of Methods

Scientists from U.S. Geological Survey's Northern Rocky Mountain Science Center, U.S. Forest Service's Boise Forest Sciences Laboratory and Trout Unlimited are engaged in a collaborative effort to assess climate change impacts on interior species of native salmonids. The first phase of this effort is a broadscale assessment conducted in a GIS environment making use of best available information on a west-wide basis. The analysis is conducted as a spatially distributed model at 800 meter spatial resolution. Final results of this project will be available by fall 2009. The methodology used in the analysis is described below.

Project Scope

Our broadscale assessment analyzes four potential impacts from climate change to populations of native trout in the interior West: increased summer temperature, increased winter flooding, increased wildfire risk, and long-term persistent drought. We recognize that all four of these factors have historically shaped both the biotic and abiotic components of western ecosystems. Our interest is in changes to the magnitude, spatial distribution and timing of these events. It is the increasingly uncharacteristic nature of extreme heat, winter floods, wildfire, and drought in conjunction with degraded and fragmented habitats that poses a threat to the native species that evolved with these forces. Figure 1 shows the project's geographic extent and the ranges of the native trout included in our analysis.

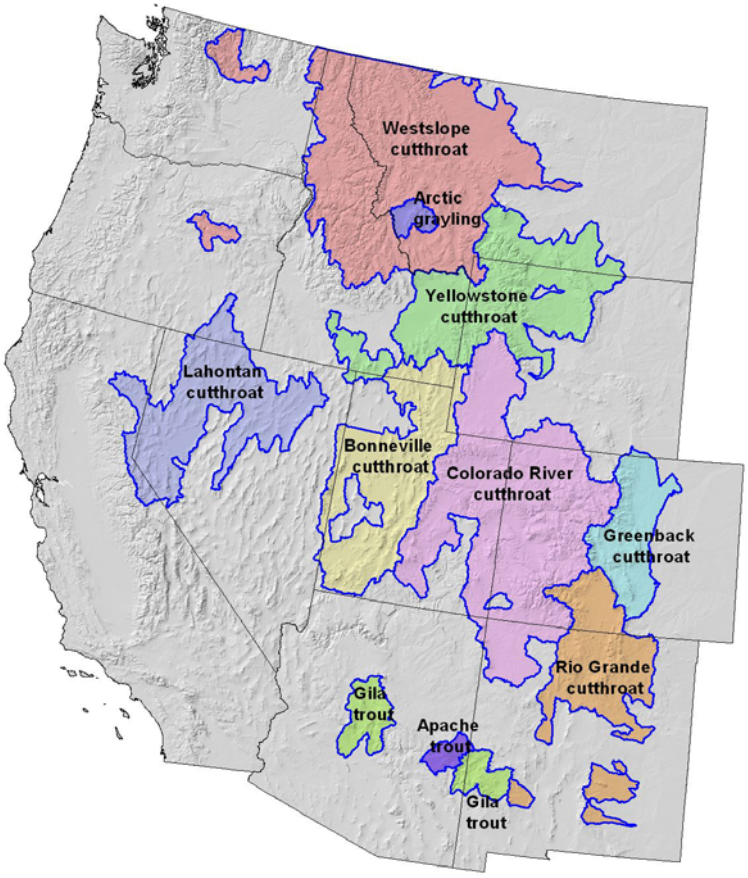

Figure 1. Geographic scope of project and ranges of native trout evaluated in broadscale assessment.

We assumed a 3°C temperature increase which is consistent with global circulation model projections for the Western United States by 2050 (Climate Impacts Group 2004). The results of our analyses for each factor were summarized by subwatershed (6th Hydrologic Unit Code). This allowed us to analyze the interaction of potential global warming induced environmental change with data on population and habitat conditions for native trout.

Summer Temperature

Coldwater fish are highly sensitive to water temperature. The paucity of data at a regional scale on water temperature and the strong correlation between air and water temperature, make air temperature a reasonable surrogate for analyzing thermal changes in aquatic environments across large geographic areas. Our analysis applies the methods of Frank Rahel and others (1996) who used changes in mean July air temperature, often the hottest month of the year in the Rocky Mountains, to model habitat loss due to global warming for a coldwater guild of brown, rainbow, brook and cutthroat trout in the Rocky Mountains.

We used national data on average July temperature from 1970-2000 (800 meter spatial resolution) published by the PRISM Group at Oregon State University to establish a baseline from which to model change (figure 2). The average July temperature was used to characterize the thermal limits for each species or subspecies based on the relationship between the historical distribution and air temperature, assuming that this relationship would reflect species-specific adaptations and preferences. By using historic rather than current distributions to define thermal limits we hoped to minimize anthropogenic effects on species distribution and emphasize fish responses to natural habitat suitability. Kilometers of historic habitat were calculated for 1°C temperature intervals for each fish. The resulting graphs for most fish were a bell curve with the majority of the habitat found in a narrow thermal range.

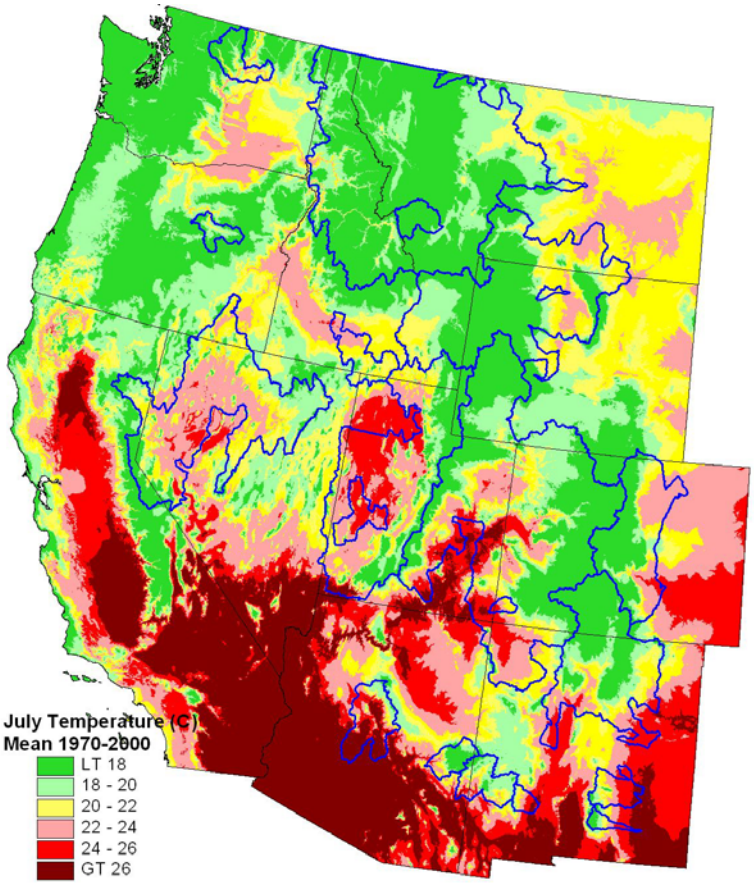

Figure 2. Average July temperatures from 1970 – 2000 (PRISM Group). Native trout ranges (blue lines) show the variability in thermal tolerances between the southwest and northern subspecies.

Three thermal classes were defined for each fish taxon based on breakpoints in the curve. An effort was made to maintain similar percentages between species of historic habitat in each class. The majority of the bell curve, including the lowest temperature limits, contained 85-90% of the historic habitat and was classified as thermally suitable. The upper temperature limits, beyond the bell curve, were considered unsuitable and contained less than 5% of the historic habitat. The remaining habitat at the lower end of the bell curve was classified as thermally marginal where

local conditions (eg riparian shading, channel depth, and flow) could make the difference between suitable and unsuitable conditions.

Our assessment of global warming impacts applied a 3° C temperature increase to the 1970-2000 mean July air temperatures. The area-weighted average temperature under the global warming scenario was calculated for each subwatershed within the historic range of each species and subspecies analyzed. Using the species-specific 'suitable', 'marginal' and 'unsuitable' temperature breakpoints previously defined, we scored each subwatershed for the level of risk to the local populations from increased summer air temperatures: 1 (suitable, low risk), 2 (marginal, moderate risk), or 3 (unsuitable, high risk).

Winter Flooding

Our intent in this analysis was to identify those subwatersheds at increased risk of uncharacteristic winter flooding as a direct result of warmer winter temperatures due to climate change. We have drawn on the findings of Hamlet and Lettenmaier (2007) who analyzed uncharacteristic winter flood events for the western U.S. as a result of global warming. They used mid-winter temperature to define three types of basins: rain dominant, snow dominant, and transient between rain and snow. Winter flooding in rain dominant basins is a function of the individual storm event and the size and runoff characteristics of the catchment. Flood events in these basins will not change due to rising temperatures without a corresponding increase in precipitation. Snow dominant basins do not typically flood in mid-winter but rather flooding occurs later as spring run-off. Low- to mid-elevation snow dominant basins currently near the freezing line, however, may experience a change in run-off timing and characteristics with warmer winter temperatures. Transient basins, where both rain and snowstorms occur in the winter months, are currently the primary location of significant flooding events for much of the western U.S. (Hamlet and Lettenmaier 2007). The magnitude of the flood event depends on the intensity and duration of the rainstorm and the antecedent snow pack.

Because our focus was on the risk of channel altering winter flood events and we are not attempting to analyze changes in storm intensities, we initially relied on cumulative winter precipitation to identify low risk areas. We assumed that watersheds receiving less winter precipitation were less susceptible to large flood events than watersheds with a wetter winter precipitation regime. To make this distinction, we used PRISM average monthly precipitation data from 1970 – 2000 for the snow accumulation period of November through March (figure 3). Total precipitation amounts were calculated for this five-month period and then reclassified into 10 groups using the 'natural breaks' methodology. This formula identifies groupings of data values that minimizes variance within groups and maximizes variance between groups. Precipitation amounts for the driest classification were less than 11.2 cm (4.4 inches) and were considered to be at low risk for winter flooding.

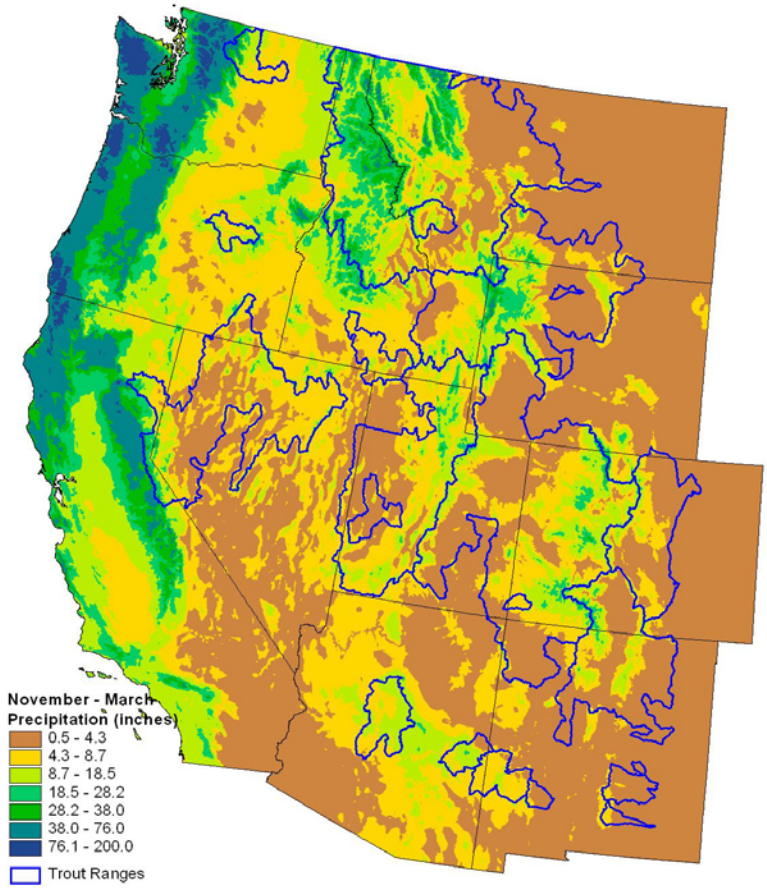

Figure 3. 30-year (1970-2000) average cumulative precipitation from November 1 to March 30. The dark brown areas were considered low risk for winter flooding due to limited winter precipitation.

Areas receiving more than 11.2 cm of winter precipitation were classified by basin type according to average late winter temperatures. We used late winter temperatures (January – March) rather than mid-winter (December – February) since this is a warmer and potentially more vulnerable period for rain on snow events and there is more snowpack in place in the mountainous regions. We used the PRISM data for monthly average temperatures from 1970-2000 for the January to March timeframe. Temperatures for the three month period were averaged and then reclassified. Areas with a mean winter temperature less than -1° C were classified as snow dominant while those with a mean winter temperature greater than +1° C were rain dominant and everything between -1° C and +1° C was considered transient.

Increased risk of winter flooding from global warming was based on the change in winter precipitation type. A 3° C temperature increase was added to the current winter mean temperature and the landscape was reclassified. The greatest risk was assigned to areas that change from snow dominant to transient or rain dominant. Places that change from transient to rain dominant were assigned a moderate risk score because they would be likely to experience more flood events in the near term, as they continue to receive some snow along with an increasing frequency of warm mid-winter storm events, until they ultimately become rain dominant. Once this occurs, the winter flood risk may actually decline because there will no longer be an antecedent snow pack to contribute to high run-off. The cold, high elevation mountains that are likely to remain snow dominant as well as the valley bottoms that are currently rain dominant were classified as low risk. We recognize that these downstream reaches may experience greater winter flows due to upstream events, but the complexity of dams and reservoir management makes it difficult to analyze downstream flood effects accurately. Figure 4 shows the results of our flood analysis.

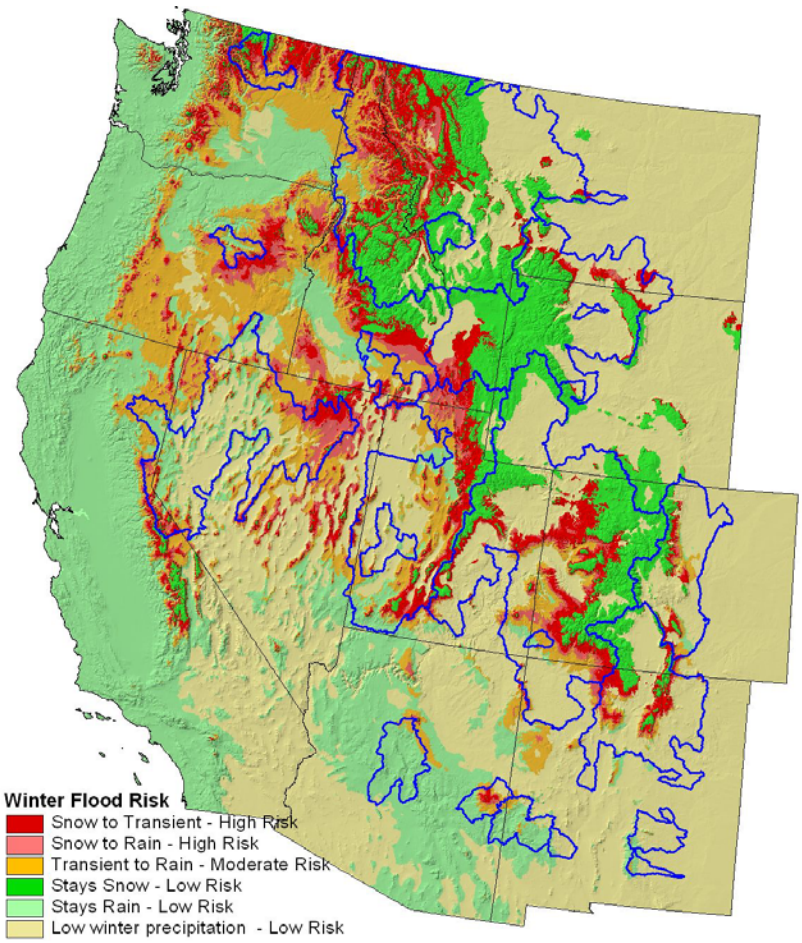

Figure 4. Results of winter flooding analysis. Areas in brown receive very little winter precipitation and are considered low risk. The mid-elevations show the highest risk due to increases in rain-on-snow events.

Wildfire

Our analysis of increased wildfire risk does not incorporate a fixed temperature increase because wildfire does not have a temperature threshold like thermal limits for fish or the difference between rain and snow events. Rather, we assume that wildfire is a function of climate, fuels, and ignition and that changing climatic conditions for the West will continue to increase the likelihood of uncharacteristic wildfires assuming the presence of fuels and an ignition source.

In order to define the spatial characteristics of increased wildfire risk we applied the findings of Westerling and others (2006) who found that fire frequency and duration and, therefore the total area burned, in the forested regions of the Rocky Mountains were closely associated with timing of snowmelt. Areas where snowmelt occurred earlier had more fires and a longer fire season because the forests had more time to dry. They found that the topographic zone of 1680 – 2690 m had the most pronounced earlier snowmelt and also more and larger wildfires. Figure 5 shows the extent of the topographic zone defined by Westerling and others. We classified everything above and below this zone as low risk for wildfire while the area within the zone (pink area on map) was subject to further analysis.

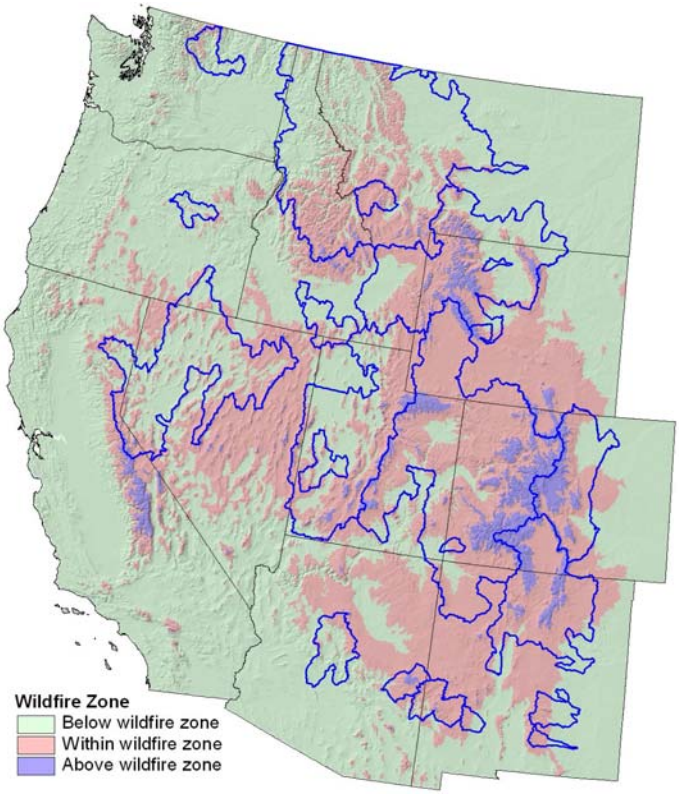

Figure 5. The area in pink shows the topographic zone defined by Westerling experiencing the greatest increase in area burned.

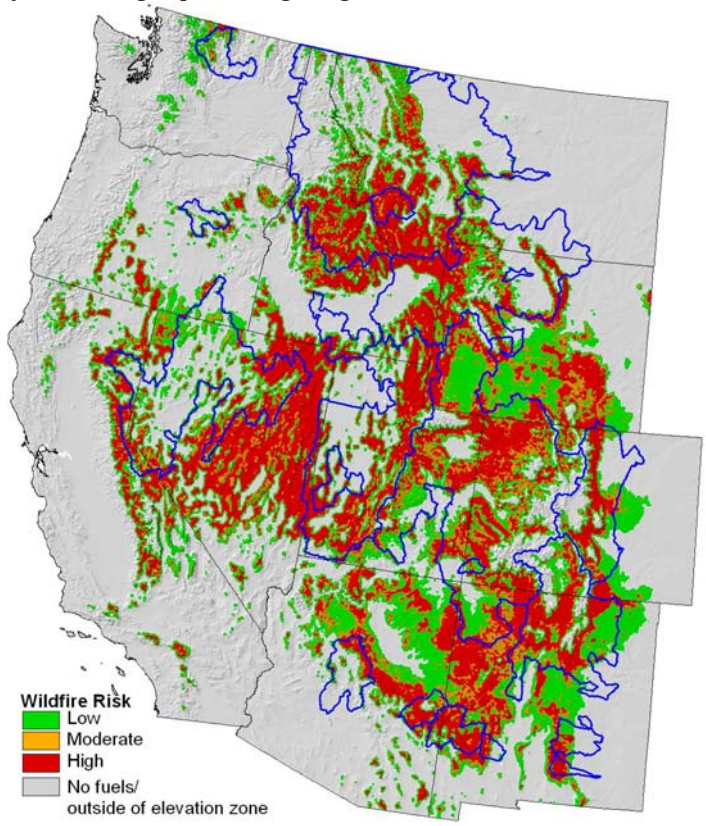

Figure 6. Results of wildfire analysis. Red areas are high risk.

To further classify risk within the focal elevational zone, we relied on the Anderson Fire Behavior Fuel Model (Anderson 1982) as updated by the U.S. Forest Service and Department of the Interior's LANDFIRE program (e.g., www.landfire.gov). This spatial data set identifies 13 different fuel types based on satellite imagery collected between 1999 and 2003 with a spatial resolution of 30 meters. Using the description of fire behavior associated with each of the fuel types, we assigned the grassland and mesic shrubland classes a low risk (score of 1) and the others a high risk (score of 3). Converted lands and non-fuel categories such as urban areas, agricultural lands, and barren ground were classified as having no fire risk and were given a score of zero. We then used a 5 km² moving window to calculate an average score for fire risk that reflects not only the fuels within a particular grid cell but also the risk associated with adjacent grid cells. The final results of our wildfire analysis are shown in figure 6.

Drought

Our analysis of increased drought risk due to climate change is based on research by Martin Hoerling and others at NOAA Earth System Research Laboratory (Hoerling and Eischeid 2007). They used the Palmer Drought Severity Index (PDSI) to model drought risk across the western U.S. for the period 2035-2060. They found that heat related moisture loss will overwhelm potential increases in precipitation due to global warming and result in an unprecedented near perpetual state of drought across much of the interior West. In an effort to downscale their findings, which are reported by climate division (60,000 ha to 12 million ha in size), we integrated mean annual precipitation (1970-2000) and elevation with their Palmer Drought Severity Index (PDSI) year 2060 forecast.

The PDSI is reported by climate divisions developed by the National Climatic Data Center (NCDC) to represent areas of similar climate although political boundaries are also used.

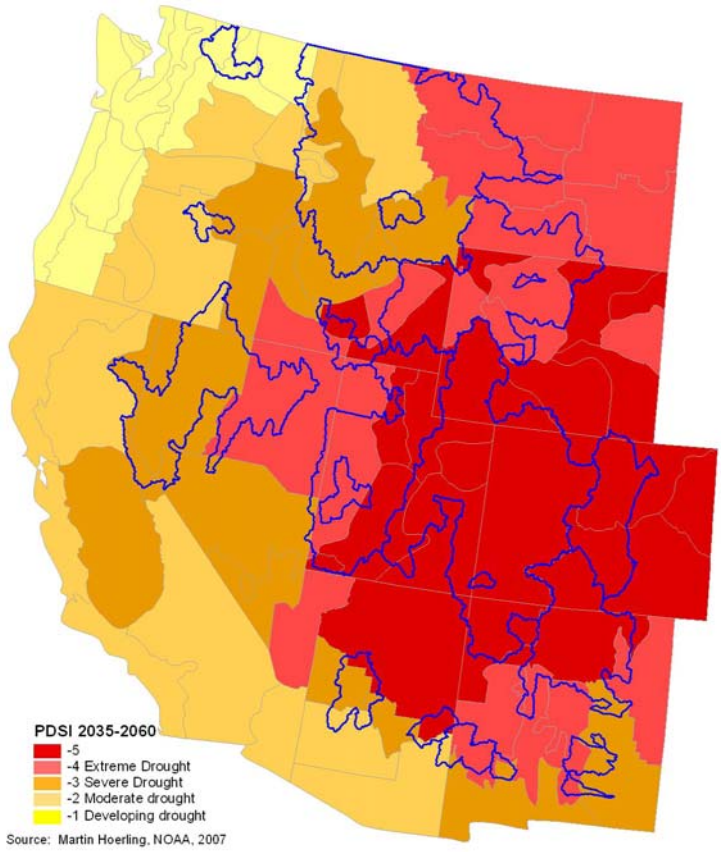

Figure 7. Projection of Palmer Drought Severity Index by climate division for the period 2035-2060 by Hoerling and Eischeid (2007).

Figure 7 shows the PDSI developed for 2060 by Hoerling and Eischeid by climate division. In order to reduce the artificial effects of political boundaries we modified the climate divisions to conform to sub-basin (4th Hydrologic Unit Code) delineations. In situations where a sub-basin was split by a climate division, we assigned the entire sub-basin to the division containing the largest portion of the sub-basin. Hoerling and Eischeid's PDSI scores were assigned to our modified climate divisions and reclassified into three risk categories as follows:

- -1 Developing drought: low risk
- -2 Moderate drought: moderate risk
- -3 Severe drought: moderate risk
- -4 Extreme drought: high risk
- -5 Extreme drought: high risk

One of the major criticisms of the PDSI is that it was originally developed for use in the plains states where there is uniform topography and it does not capture the regional microclimates associated with mountainous terrain in the West. Therefore, we included elevation as a mitigating factor for Hoerling's drought forecast using the findings of Westerling and others (2006) related to snowmelt and described above in the wildfire discussion. We assumed that elevations above 2690 meters were less prone to prolonged drought because the snowpack remains well into the spring, thus providing higher base streamflows during the critical summer

months. In order to extend the timeframe of Westerling's findings from current conditions to 2060, we applied our 3°C temperature increase to the upper limits of the current snowmelt zone (2690 meters) assuming a normal lapse rate of 6.5°C/1000 meters. We defined areas between 2690-3190 meters elevation as moderate risk to future drought while areas above 3190 meters were considered low risk. Elevations below Westerling's 2690 meter threshold for changes in the timing of snowmelt, defaulted to the drought risk associated with the PDSI forecast. To summarize, we classified the mitigating effects of elevation as follows:

- Greater than 3190 meters – low risk;
- 2690-3190 meters – moderate risk;
- Less than 2690 meters – no mitigating effects.

In addition to the mitigating effect of snowpack retention in high elevations, we also incorporated mean annual precipitation as a local factor that might alleviate regional drought conditions. Our objective was to identify anomalies within the climate divisions where the effects of heat related moisture loss on streamflows are reduced due to significantly greater precipitation amounts than the surrounding region.

The mean annual precipitation from 1970-2000, produced by the PRISM Group (2007), was used for this portion of the analysis. The standard deviation was calculated for the interior West where the average precipitation was found to be 16 inches with one standard deviation at 25 inches and a second standard deviation at 35 inches. We reclassified mean annual precipitation into the following three drought risk categories:

- Greater than 2 standard deviations (> 35 inches) – low risk;
- 1-2 standard deviations (25 – 35 inches) – moderate risk;
- Less than 25 inches – no mitigating effects.

After classifying each of the three variables (PDSI, elevation, and precipitation) into risk categories, drought risk was determined using the lowest risk from each of the three variables. For example, a PDSI of high risk for a low elevation that receives 40 inches of rain would be given a low risk score due to the mitigating effects of the wet climate. The PDSI was considered to represent the worst-case scenario so no area received a higher risk than the PDSI score regardless of precipitation or elevation. Figure 8 shows the results of our analysis.

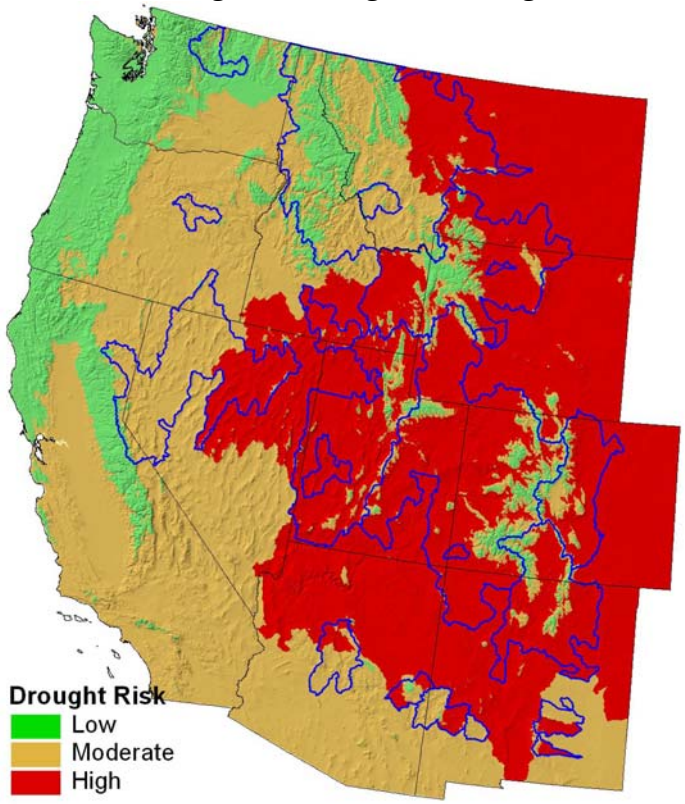

Figure 8. Drought risk using Hoerling and Eischeid's PDSI 2060 forecast as the foundation.

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