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National Water-Quality Assessment Program

Streamflow Characteristics and Benthic Invertebrate Assemblages in Streams Across the Western United States

Background

Hydrographic characteristics of streamflow (fig. 1), such as high-flow pulses, base flow (background discharge between floods), extreme low flows, and floods, significantly influence aquatic organisms. Streamflow can be described in terms of magnitude, timing, duration, frequency, and variation (hydrologic regime). These characteristics have broad effects on ecosystem productivity, habitat structure, and ultimately on resident fish, invertebrate, and algae communities. Increasing human use of limited water resources has modified hydrologic regimes worldwide. Identifying the most ecologically significant hydrographic characteristics would facilitate the development of water-management strategies. This fact sheet summarizes a recent publication in the journal Freshwater Biology: *Assessing streamflow characteristics as limiting factors on benthic invertebrate assemblages in streams across the western United States*, by Konrad and others (2008).

Benthic invertebrates include insects, mollusks (snails and clams), worms, and crustaceans (shrimp) that live on the streambed (fig. 2). Invertebrates play an important role in the food web, consuming other invertebrates and algae and being consumed by fish and birds. Hydrologic alteration associated with land and water use can change the natural hydrologic regime and may affect benthic invertebrate assemblage composition and structure through changes in density of invertebrates or taxa richness (number of different species).

This study examined associations between the hydrologic regime and characteristics of benthic invertebrate assemblages across the western United States and developed tools to identify streamflow characteristics that are likely to affect benthic invertebrate assemblages.

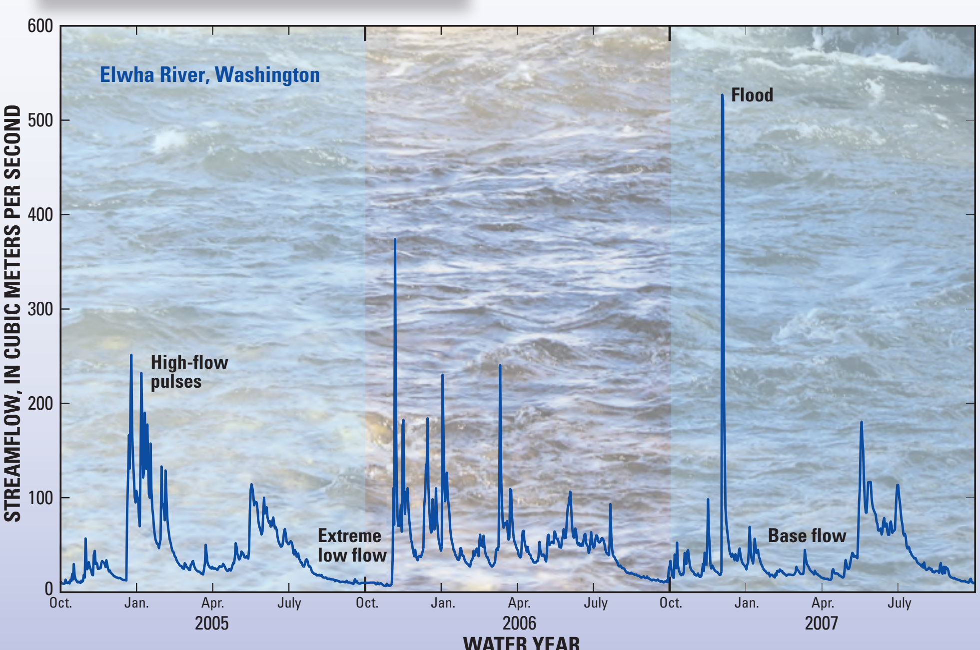

Figure 1. Different streamflow characteristics, including high-flow pulses, extreme low flows, floods, and base-flow conditions, that can influence aquatic organisms.

Figure 2. Benthic invertebrates include worms, insects, crustaceans, and mollusks. Some invertebrates spend their larval stage in the water and their adult stage as flying insects.

U.S. Department of the Interior
U.S. Geological Survey

Printed on recycled paper

Fact Sheet 2010–3110
December 2010

Study Design

Streamflow and invertebrate data collected at 111 sites in 11 western states (fig. 3) as part of the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) program were analyzed to identify associations between hydrographic streamflow characteristics (magnitude, frequency, duration, timing, and variation) and benthic invertebrate assemblages.

Streamflow characteristics were calculated using streamflow data from established USGS stream gages (fig. 4) that had recorded data for 5 to 15 years before the invertebrate samples were collected. This 10-year period was long enough to enable year-to-year variations in streamflow patterns to be characterized and short enough to minimize the effects of varying climate, land use, or water management on streamflow patterns.

An initial set of invertebrate metrics was generated with the USGS Invertebrate Data Analysis System (IDAS), available at http://nc.water.usgs.gov/reports/ofr03172/. A subset of these metrics was selected to use in the analysis. They characterize broad features of invertebrate assemblages, including abundance (number of individuals), richness (number of taxa), diversity (including evenness and dominance), traits (functional feeding groups and behavioral habits), and individual taxa.

Statistical Analyses

Quantitative samples of invertebrates were collected during base-flow conditions from the habitat at each site (typically riffles) that would support the highest density and taxa diversity of invertebrates (fig. 5). A statistical method called nonparametric screening procedure (NPSP) was developed to identify associations between pairs of streamflow characteristics and invertebrate metrics. Such associations typically have “ceilings” or “floors” (a limit on the minimum or maximum value of a metric). The NPSP plots data points to indicate ceilings and floors, both positive and negative, and calculates correlations between pairs of variables (fig. 6). We developed NPSP in Visual Basic for Applications® and implemented it as a macro in Microsoft Excel®.

Figure 5. Setting up to collect a quantitative macroinvertebrate sample.

After the strongest associations between streamflow characteristics and invertebrate metrics were identified using NPSP, selected ceilings and floors were quantified with a statistical method called quantile regression using the Quantreg package written by Roger Koenker (version 3.84 in the statistical program R, available at http://www.econ.uiuc.edu/~roger/research/rq/rq.html). Quantile regression is useful because biological condition is likely influenced by multiple factors; the more commonly used statistical method of ordinary regression is appropriate when the response is influenced only by one factor. In this study, ceilings were represented by the 90th quantile and the floors were represented by the 10th quantile.

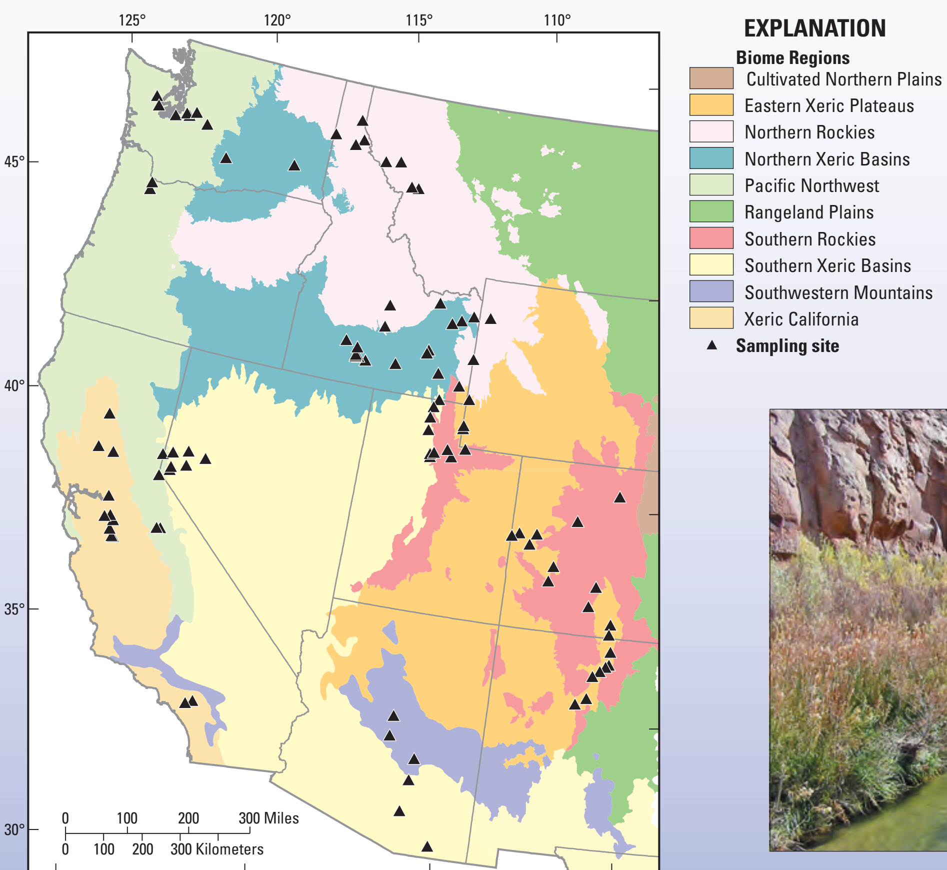

Figure 3. Sampling sites across the western United States.

Figure 4. Streamflow is recorded continuously at USGS gages across the country.

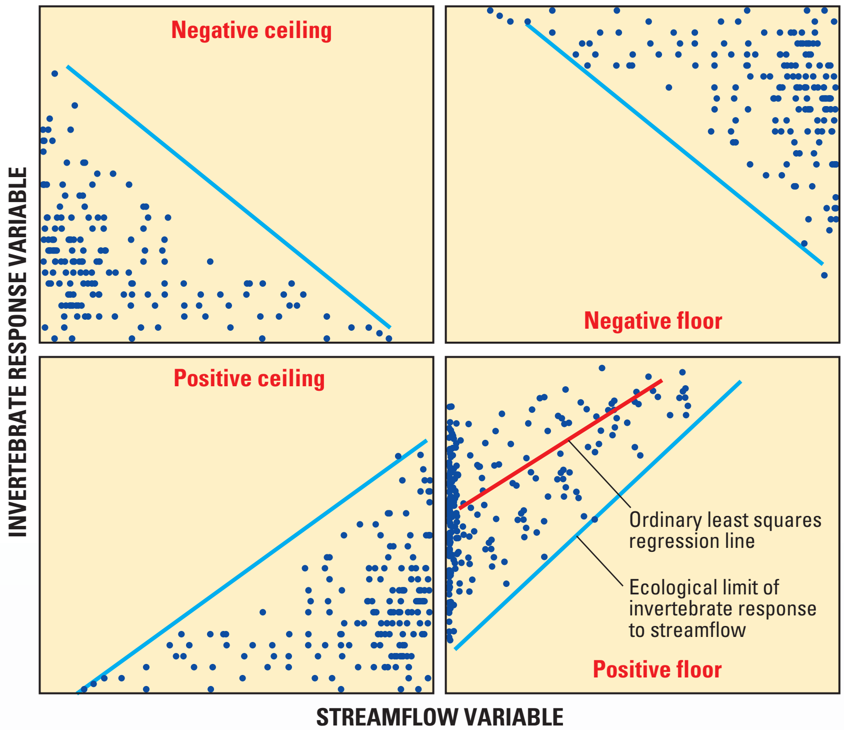

Figure 6. The nonparametric screening procedure plots data points to indicate ceilings and floors, both positive and negative. Positive floors and ceilings have a positive slope; negative floors and ceilings have a negative slope.

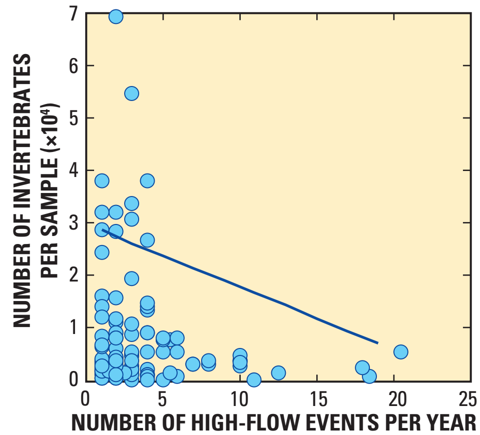

Figure 7. The density of invertebrates has a negative ceiling associated with the average number of high-flow events per year.

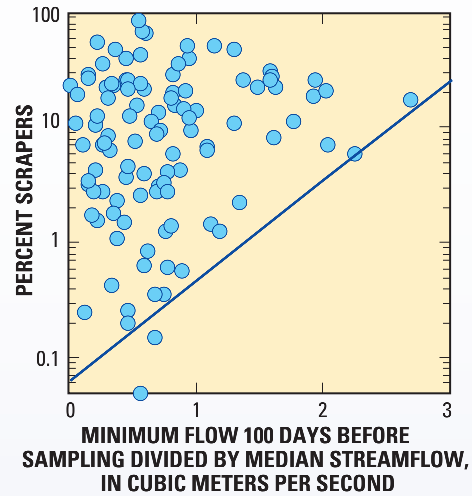

Figure 8. The percent abundance of invertebrates that scrape algae has a positive floor associated with the minimum streamflow.

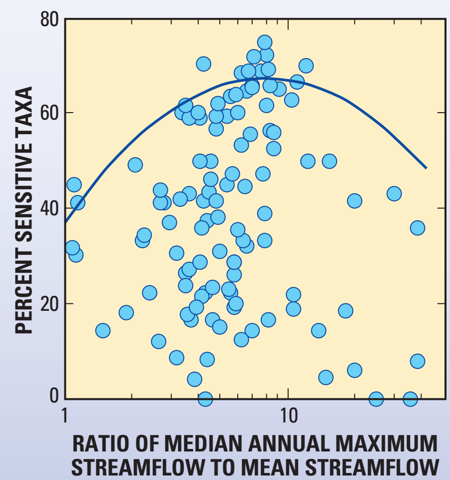

Figure 9. The percentage of water-quality sensitive taxa showed an intermediate response to maximum streamflow divided by mean streamflow; percentage of sensitive taxa was highest when maximum streamflow was about eight times the mean annual streamflow.

Results

Analyses using NPSP and quantile regression were used to compare multiple invertebrate metrics and hydrographic streamflow characteristics. Fourteen invertebrate metrics and 13 streamflow metrics were selected to represent key associations between invertebrates and streamflow. Of these, time to return to baseflow (following a high-flow event) was associated with seven of the selected invertebrate metrics, while daily and monthly variation in streamflow were each associated with six invertebrate metrics. High-flow duration and minimum daily streamflow were each associated with five invertebrate metrics.

Although streamflow characteristics 100 days before invertebrate sampling had more associations with invertebrate metrics than streamflow characteristics 30 days before invertebrate sampling, we cannot separate the 100-day and 30-day effects because of high correlation between flows at these time scales. A long-term flow regime represented by multiple year (5–15 years) streamflow statistics appears at least as important as recent flows (30 and 100 days) for structuring invertebrate assemblages.

Overall, every streamflow metric was associated with at least one invertebrate metric and every invertebrate metric was associated with at least one hydrologic metric. Three examples of these associations between streamflow characteristics and invertebrate assemblage structure are provided in this fact sheet. In figure 7, the density of invertebrates has a *negative ceiling* associated with the average number of high-flow events (flows that occur less than 10 percent of the time) per year, a streamflow frequency metric. This result shows invertebrate densities greater than 20,000 per square meter only at sites that had infrequent high flows (less than five events per year). In figure 8, the percent abundance of invertebrates that scrape algae has a *positive floor* associated with the minimum streamflow 100 days before invertebrate sampling divided by the median streamflow, a hydrographic variation metric. This indicates that scrapers are more abundant when streamflow is lower than average.

In addition to linear ceilings and floors, invertebrate metrics can show an intermediate maximum or minimum in response to a hydrographic characteristic. In figure 9, the percentage of taxa that were classified as intolerant to degraded water quality (water-quality sensitive taxa) was highest in streams where the mean annual maximum streamflow was about eight times the average streamflow, a streamflow variation metric. This hydrologic metric could be affected by human activities, such as flood control (reduced maximum streamflow) or urbanization (increased maximum streamflow from street runoff). Either type of change could limit the number of sensitive taxa as a percentage of all taxa. Additional examples and details are discussed in Konrad and others (2008).

Summary and Conclusions

Hydrographic streamflow characteristics appear to be ecologically significant as factors that limit invertebrate assemblage structure throughout the western United States. Applying statistical analyses (the nonparametric screening procedure in conjunction with quantile regression) identified and quantified limits on macroinvertebrate assemblages associated with streamflow. These associations can provide important information to managers who must balance human needs for water with conservation or restoration of biological resources. By comparing site conditions to these limits, resource managers can identify hydrographic streamflow characteristics that are likely to be important for maintaining or achieving a specific biological condition (for example, richness of invertebrate taxa).

Hydrologic metrics of streamflow variation at daily to interannual scales were among the most common characteristics associated with limits on invertebrate assemblage structure. Time to return to baseflow, daily variation, and monthly variation in streamflow were associated with the largest number of invertebrate metrics. Because changes in hydrologic regime are often caused by human activities, such as flood control or water diversions, these metrics may serve as useful benchmarks for managing streamflow.

Abundance (as a percentage of the whole sample) of Plecoptera (stoneflies), richness of non-insect taxa, and relative abundance of sensitive taxa (Ephemeroptera [mayflies], Plecoptera and Trichoptera [caddisflies]), were associated with multiple streamflow metrics. Metrics for sensitive taxa (fig. 10) generally had ceilings associated with streamflow metrics, whereas metrics of tolerant taxa, non-insects, dominant taxa, and chironomids (non-biting flies) generally had floors. Broader characteristics of invertebrate assemblages, such as abundance and richness, had fewer limits, but these limits were nonetheless associated with a range of streamflow characteristics.

Applying statistical limits rather than mean responses also demonstrates that biotic responses to streamflow may be conditional – they depend not just on flow conditions but on the other conditions also at a site. Streamflow should be recognized as only one of many factors influencing stream communities, and other factors may have a more influential role than streamflow at some sites. Nonetheless, our results indicate that a broad range of hydrographic streamflow characteristics appear to be important to biota in rivers and streams across the western United States.

The analyses presented here indicate that invertebrate responses could be generalized across a large region. However, to enhance the utility of these analyses for resource and water managers, further investigation of responses at smaller geographic scales is warranted.

High-flow pulse at Coyote Gulch, Utah.

Human uses of land and water resources modify many hydrographic characteristics of streamflow. New tools were developed to analyze the associations between streamflow characteristics and aquatic organisms.

More focused water-management strategies can be implemented with this scientifically-based knowledge that indicates which streamflow characteristics have the greatest influence on invertebrate assemblage structure.

By Anne M.D. Brasher, Christopher P. Konrad, Jason T. May, C. Scott Edmiston, and Rebecca N. Close

Additional details about the study can be found in

Konrad, C.P., Brasher, A.M.D., and May, J.T., 2008, Assessing streamflow characteristics as limiting factors on benthic invertebrate assemblages in streams across the western United States: Freshwater Biology, v. 53, p. 1983–1998.

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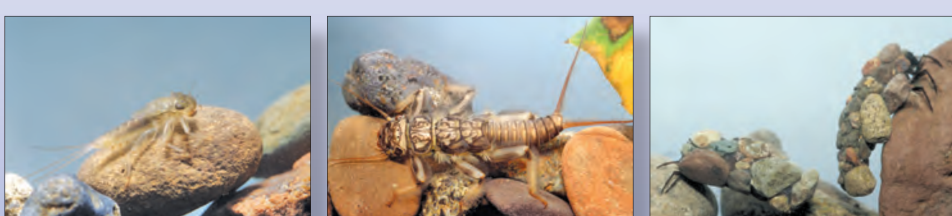

Figure 10. Water-quality sensitive taxa include mayflies, stoneflies, and caddisflies.