February 8, 2013

SUMMARY OF MONITORING AND ASSESSMENTS RELATED TO ENVIRONMENTAL FLOWS IN USGS WATER SCIENCE CENTERS ACROSS THE U.S.

USGS scientists, in cooperation with local, State, Tribal, and other Federal partners, are pioneering new monitoring, assessment, research capabilities, and developing new methods and tools needed to address ecological flow issues in freshwaters in more than half of the 47 USGS Water Science Centers across the Nation.

Learn more:

Maintaining appropriate environmental flows in our Nation's rivers and streams is an evolving issue of concern across the Nation as flow alterations are a primary contributor to degraded river ecosystems and lead to the loss of native, threatened, and endangered fish and invertebrate species whose survival and reproduction are tightly linked to specific flow conditions. Altered flow conditions can also affect water quality, water temperature, water availability for agricultural, municipal, and industrial uses, recreational opportunities, and the maintenance of sport fish populations. For example, in streams with severely diminished flow, native trout, a popular sport fish that requires cool, fast-flowing streams with gravel bottoms, are replaced by less desirable species such as sunfish or non-natives such as carp.

National assessments addressing ecological flow needs are a major emphasis of the USGS. A recent national initiative implemented by Congress to support a broader understanding of ecological flow (or ecological water) needs and management-based ecological flow criteria and assessments across the US is through the USGS National Water Census Program (***Contact***: Eric Evenson, eevenson@usgs.gov, (609) 771-3904). In general, this national initiative has been designed to develop products, tools, and web-accessible architecture that help practitioners and other stakeholders to assess the water budget and possible impacts on aquatic health (including native and non-native species and habitat) and run management scenarios to optimize water resources that support both human and ecological needs. Specific efforts, for example, will allow users to estimate streamflows on a daily basis at the Hydrologic Unit Code (HUC) Level 12 for any watershed in the Nation, which will help identify stream reaches that may be vulnerable to low flows and degraded ecosystems, as well as to access a data portal which will serve biological and hydrological information to support the development of flow-ecology relations.

The National Water Census is engaged in three ongoing "Focus Area" studies in the Apalachicola-Chattahoochee-Flint (ACF), Colorado (CR), and Delaware River (DR) basins to develop and pilot models and decision support tools with a high degree of transferability to other basins. Specific activities have been added in each of the three areas to address priority water availability issues defined by the USGS and its stakeholders. For example, efforts are ongoing in the ACF basin to relate species occurrence and distribution to changes in streamflow patterns through fish occupancy models that relate daily water withdrawals to changes in the abundance of fluvial specialists. In the CR basin, models are being developed to test the availability of habitat needed to support different types of aquatic fauna under differing flow volumes and aquifer levels and determine how far the seasonal hydrology departs from the historic record. Ecological flow activities in the DR basin are designed to broaden capabilities for an integrated decision support system (known as DSS) that estimates effects of alternative water management scenarios on habitat availability for key native species such as trout and American shad, and endangered species such as the dwarf wedgemussel. Field and laboratory experiments are being conducted to develop habitat suitability criteria that model how these key aquatic species will physiologically respond to changes in temperature and hydrology. To accomplish this, modeled

estimates of habitat characteristics are also being developed for a large portion of the Delaware River mainstem across a range of discharge levels using advanced aerial technologies such as bathymetric LiDAR imagery.

The USGS National Water Quality Assessment (NAWQA) Program is another national program engaged in ecological flow science. Such science continues to be a major emphasis of Cycle III of the Program. A nationwide study released by NAWQA in 2010 showed that the amount of water flowing in streams and rivers across the Nation has been significantly altered in nearly 90 percent of waters that were assessed by a variety of land- and water-management activities, including reservoirs, diversions, subsurface tile drains, groundwater withdrawals, wastewater inputs, and impervious surfaces, such as parking lots, sidewalks and roads. (Press Release) (**Contact:** Daren Carlisle, dcarlisle@usgs.gov, (703) 648-6890). This study showed that annual and seasonal cycles of water flows — particularly the low and high flows — shape ecological processes in rivers and streams. An adequate minimum flow is important to maintain suitable water conditions and habitat for fish and other aquatic life. High flows are important because they replenish floodplains and flush out accumulated sediment that can degrade habitat. NAWQA findings also indicated that the severity and type of stream flow alteration varies among regions, due to natural landscape features, land practices, degree of development, and water demand. Differences are especially large between arid and wet climates. In wet climates, watershed management is often focused on flood control, which can result in lower maximum flows and higher minimum flows. Extremely low flows are the greatest concern in arid climates, in large part due to groundwater withdrawals and high water use for irrigation.

NAWQA Ecological Flow Publications:

- Eng, K., D.M. Carlisle, D.M. Wolock, J. Falcone. 2012. Predicting the likelihood of altered streamflows at ungauged rivers across the conterminous United States. River Research and Applications (Available online in advance of print, http://dx.doi.org/10.1002/rra.2565),
- Carlisle, D.M., Nelson, S.M., Eng, K., 2012, Macroinvertebrate community condition associated with the severity of streamflow alteration: River Research and Applications (Available online in advance of print, http://dx.doi.org/10.1002/rra.2626).
- Knight, R.R., and Cuffney, T.F., 2012, Invertebrate response to changes in streamflow hydraulics in two urban areas in the United States: U.S. Geological Survey Scientific Investigations Report 2012-5035, 19 p. (Also available at http://pubs.usgs.gov/sir/2012/5035/)
- Meador, M.R., and Carlisle, D.M., 2012, Relations between altered streamflow variability and fish assemblages in Eastern USA streams. River Research and Applications, v. 28 p. 1359–1368 (Also available at http://dx.doi.org/10.1002/rra.1534).
- Kennen, J.G., Murray, K.R., and Beaulieu, K.M., 2010, Determining hydrologic factors that influence stream macroinvertebrate assemblages in the northeastern U.S. Ecohydrology, v. 3, p. 88–106 (Also available at http://dx.doi.org/10.1002/eco.99).
- Carlisle, Daren M., Wolock, David M., and Meador, Michael R., 2010, Alteration of streamflow magnitudes and potential ecological consequences: a multiregional assessment. Frontiers in Ecology and the Environment, v. 9, p. 264–270 (Also available at http://dx.doi.org/10.1890/100053)
- Steuer, J.J. Stensvold, K.A., and Gregory, M.B., 2010, Determination of biologically significant hydrologic condition metrics in urbanizing watersheds: an empirical analysis over a range of environmental settings. Hydrobiologia, v. 654, no. 1, p. 27–55 (Also available at http://dx.doi.org/10.1007/s10750-010-0362-0).
- Carlisle, Daren M., Falcone, James, Wolock, David M., Meador, Michael R., and Norris, Richard H., 2010, Predicting the natural flow regime: Models for assessing hydrological alteration in streams: River Research and Applications, v. 26, p. 118–136 (Also available at http://dx.doi.org/10.1002/rra.1247)
- Falcone, J., D.M. Carlisle, D.M. Wolock, and M.R. Meador. 2010. GAGES: A streamgage database for evaluating natural and altered flow conditions in the conterminous United States. Ecology, 91:621 (Also available at http://esapubs.org/archive/ecol/E091/045/).

- Steuer, J.J., Bales, J.D., and Giddings, E.M.P., 2009, Relationship of stream ecological conditions to simulated hydraulic metrics across a gradient of basin urbanization. Journal North American Benthological Society, v. 28, no. 4, p. 955–976 (Also available at http://dx.doi.org/10.1899/08-157.1).
- 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, vol. 53, no. 10, p. 1983-1988 (Also available at http://dx.doi.org/10.1111/j.1365-2427.2008.02024.x).

Collaborative studies with local, State, and Tribal partners through the USGS Cooperative Water Program (CWP) and with other Federal agencies help to further enhance our national understanding of how alteration of streamflow characteristics and land-management activities affect the ecological health of rivers and streams in different geographic regions across the Nation. In general, cooperatively-planned efforts with partners in USGS Water Science Centers (WSCs) across the Nation are aimed at identifying critical streamflow characteristics; providing statistical tools and analytical approaches for predicting these characteristics; developing models that provide streamflow at ungaged locations, and understanding how changes in streamflow characteristics and hydrologic alteration may alter the structure and function of biological communities (fish, aquatic insects, and algae) in rivers and streams. The monitoring, assessments, and research help water managers develop effective strategies to ensure that water remains sufficiently clean and abundant to support aquatic communities and recreation opportunities, while simultaneously supporting economic development and ongoing human needs.

TENNESSEE

Tennessee (TN) ecological flow projects and research are supported in large part through the USGS CWP and the TN Wildlife Resources Agency, The Nature Conservancy (TNC), Tennessee Valley Authority, and the TN Department of Environmental Conservation. (***Contact*:** Rodney Knight, rrknight@usgs.gov, (615) 837-4731) (Studies available at: http://tn.water.usgs.gov/projects/EcologicalFlows/ .)

Selected key findings in Tennessee:

- **Streamflow influences fish health and abundance in Tennessee** - Analysis of streamflow and fish-community data across the Tennessee River Valley identified three aspects of streamflow essential to habitat suitability and food availability for insectivorous fish communities: (1) constancy (flow stability or temporal invariance), (2) frequency of moderate flooding (frequency of habitat disturbance), and (3) rate of streamflow recession. Watershed management decisions that minimize change in these aspects of streamflow have the potential to increase the health of the fish communities.

- **Climate and basin factors can be used to predict ecologically-relevant aspects of streamflow** - Throughout the US there are many more places were ecological sampling has occurred than where streamflow data are collected. Because of this disconnect, streamflow at places of ecological sampling must be estimated if any correlation between these two factors is to be determined. Streamflow is dictated by climate and basin influences, such as monthly mean precipitation, percent forest, and depth to bedrock. A statistical model was built to relate climate, land use, physical and regional basin factors to 19 ecologically-relevant aspects of streamflow (called streamflow characteristics). There were 231 sites in the Tennessee and Cumberland River basins available for model development. Some aspects of streamflow such as mean annual runoff, were highly predictable using statistical methods, other streamflow characteristics like annual maximum flow were less so.

- **Place is more important than land use for influencing streamflow** - When predicting ecological-relevant streamflow characteristics the most influential variables relate to where the site is located (regional physiology) versus what type of land cover (forest, agriculture, or urban) is present. Statistical models showed that regional physiology

was the most influential group of variables in predicting streamflow characteristics. This includes the percent of a watershed within either the Interior Plateau or Blue Ridge Level 3 ecoregions.

- **Altered streams have a different "hydrologic profile" than other streams** - Most streams in the United States have experienced some amount of alteration from natural conditions. Alteration can be a direct or indirect result of such processes as construction of a dam, water withdrawals from the stream, or conversion of forested land to urban land within a watershed. Streamflow characteristics for altered streams have a different "hydrologic profile" when compared to a pristine or minimally-altered stream. USGS studies considered the most forested sites within each ecoregion to be minimally-altered and the reference "hydrologic profile" to be the range of calculated values for each streamflow characteristic within this group.

- **Statistical ecologically relevant streamflow characteristics more reliable than a rainfall-runoff model** – In a comparison of a statistical model and rainfall-runoff model, statistical estimates of ecologically-relevant streamflow characteristics appear to be more reliable than estimates from a rainfall-runoff model. For the rainfall-runoff model, median departures (the median difference between predicted and observed values across six sites) for 13 of 19 streamflow characteristics were greater than 30 percent. Most of these median departures were between 30 percent and 50 percent, and a few were greater than 100 percent. In contrast, for the statistical model, median departures for only two characteristics were greater than 30 percent, and 12 characteristics had median departures that were less than 10 percent.

- **Only a few streamflow characteristics are needed to assess changes to fish community diversity in the Tennessee River basin**. The streamflow characteristics needed to understand potential shifts in fish community diversity to changes in streamflow were identified based on multivariate analysis of 10 fish community classes and measurements of streamflow departure from reference hydrologic conditions. Specifically, changes to fish community diversity by class were evaluated in the context of hydrologic departure from reference hydrology presented in Knight et al., 2012. Area-weighted maximum October streamflow was the only characteristic identified as critical to any class of the fish community diversity in the Blue Ridge ecoregion. Diversity of the fish community in the Ridge and Valley ecoregion appears to be more determined by changes to mean annual runoff, stability of flow, variability of low flow, and variability of high-pulse duration; fish communities in the Interior Plateau respond mostly to changes in area-weighted maximum October streamflow, rate of streamflow recession, stability of flow, frequency of moderate flooding, and the timing of the annual minimum flow. Not all streamflow characteristics were important for each class in the Interior Plateau or Ridge and Valley.

- **Reference hydrology defined by landscape characteristics has potential for describing optimal ecological conditions.** Reference hydrologic conditions defined by the most forested sites with observed streamflow are very similar to predicted reference conditions at sites with highest species counts for the Interior Plateau and the Ridge and Valley ecoregions. However, in the Blue Ridge ecoregion, reference hydrology defined by percent forest does not necessarily describe elevated species richness. This suggests reference hydrology, in the context of ecological richness, is inadequately or inappropriately defined by percent forest for this ecoregion and that reference hydrology should be defined at a smaller scale or using a more heterogeneous basin characteristic when selecting sites for reference definition.

- **Hydrologic characteristics may or may not be the most influential driver of fish community diversity.** Statistical tests showed little difference between hydrologic profiles developed from highest species counts and lowest species counts in the Blue Ridge and Interior Plateau, whereas in the Ridge and Valley about one third of the streamflow characteristics were distinct between profiles. This may mean that sites which have low fish diversity with otherwise reference quality hydrology in the Blue Ridge or Interior Plateau have other influences, such as water quality, water temperature, habitat disturbance, or other anthropogenic influences that are likely lowering fish counts. In all ecoregions, total nitrogen concentration and drainage area were significantly different between sites with the highest

and lowest species diversity. Population density (Blue Ridge and Ridge and Valley), and road density was also significantly different in the Blue Ridge.

- Flow outside of a reference condition (departure) may not necessarily be related to human alteration. In our study, streamflow characteristics were predicted by a regression model developed using streamflow characteristics that were calculated from 15 or more years of record. Sites that have hydrology outside of the reference range may describe natural variation in hydrologic conditions related to differences in landscape and climate characteristics across the Tennessee River Valley or may be due to alteration of hydrology related to human-induced activities such as increases in agricultural land or impervious surface area. The ultimate cause of hydrologic departure is often difficult to discern and likely involves aspects of human-induced hydrologic alteration and natural landscape and climatic variation.

Current Activities:

The National Park Service, Water Rights Division in Fort Collins, Colorado requested that the research and findings from the Tennessee Environmental Flow program be applied in two NPS units. These units, the Obed Wild and Scenic River and the Big South Fork National Recreation Area, face increasing pressure on hydrologic and ecological resources from surrounding communities through increased water supply and wastewater effluent requirements as well as shifting land use. As part of a funded agreement with NPS, the Tennessee WSC will be piloting an effort to incorporate findings from our research in combination with rainfall-runoff models to develop decision support systems for these park units. The resulting system will incorporate environmental flow science with the ability to evaluate changes in water supply requirements, wastewater needs, climate change, and shifting land use in the context of ecological goals and constraints established by the NPS. The system will provide a scientifically-based understanding of ecological consequences resulting from streamflow modification.

Publications and Technical Announcements:

- Knight, R.R., Murphy, J.C., and Wales, A.K., in DRAFT, Fish community response to altered ecological flow regimes: Departures from reference.
- Murphy, J.C., Knight, R.R., Wolfe, W.J., and Gain, W.S., 2012, Predicting ecological flow regime at ungaged sites: A comparison of methods: River Research and Applications, (Early view available at http://dx.doi.org/10.1002/rra.2570). (Technical announcement: April 19, 2012 -- Streamflow Models Evaluated for Reliability and Application to Predicting Fish Health http://www.usgs.gov/newsroom/article.asp?ID=3178).
- Knight, R.R., Gain, W.S., and Wolfe, W.J., 2011, Modelling ecological flow regime: An example from the Tennessee and Cumberland River basins: Ecohydrology, v. 5, p. 613-627 (Also available at http://dx.doi.org/10.1002/eco.246). (Technical announcement: January 25, 2012 -- USGS Identifies Streamflow Characteristics Critical to Tennessee River Basin Fishes http://www.usgs.gov/newsroom/article_pf.asp?ID=3084).
- Knight, R.R., Gregory, M.B., and Wales, A.K., 2008, Relating streamflow characteristics to specialized insectivores in the Tennessee River Valley: A regional approach: Ecohydrology, v. 1, no. 4, p. 394-397, (Also available at http://dx.doi.org/10.1002/eco.32).

VIRGINIA

The South Fork Shenandoah River and its counterpart, the North Fork Shenandoah River, join to form the Shenandoah River, which drains a large region that many in Virginia refer to as “the Valley” (located west of Shenandoah National Park). As population growth continues, agriculture continues to thrive, and new industries increase in the Valley, competition for clean water is a concern for policy makers, managers, planners, and citizens who recognize the need to protect streamflow as a resource for water supply, recreation, and ecological habitat for aquatic life. In 2005, the USGS, in cooperation with the Central Shenandoah Valley Planning District Commission, the Northern Shenandoah Valley Regional Commission, and Virginia

Commonwealth University, began an investigation to examine the instream flow needs of aquatic organisms of the South Fork as a companion study to an instream flow study on the North Fork. The two studies were similarly designed, and thereby provide consistent model output for Valley planners and water-resource managers. A range of scenarios are presented to provide managers and planners with information regarding current and future water resources in the basin, the availability of water for fish habitat, recreation, and the potential effects of withdrawals and conservation measures on fish populations. (***Contact***: Jen Krstolic, jkrstoli@usgs.gov, (804) 261-2635) (Studies available at: http://pubs.usgs.gov/sir/2012/5081 and http://pubs.usgs.gov/sir/2006/5025/.

Key finding from the recent USGS study in the South Fork:

- Findings suggest that for normal or wet years, increased water withdrawals are not likely to correspond with extensive habitat loss for game fish or nongame fish. During drought years, however, a 20- to 50-percent increase in water withdrawals may result in below normal habitat availability for game fish throughout the river and nongame fish in the upper and middle sections of the river. These simulations of rare historic drought conditions, such as those observed in the Valley in 2002 serve as a baseline for development of ecological flow thresholds for drought planning.

Related Publications:

- Krstolic, J.L., and Ramey, R.C., 2012, South Fork Shenandoah River habitat-flow modeling to determine ecological and recreational characteristics during low-flow periods: U.S. Geological Survey Scientific Investigations Report 2012–5081, 64 p. (Also available at http://pubs.usgs.gov/sir/2012/5081.)
- Krstolic, J.L., Hayes, D.C., and Ruhl, P.M., 2006, Physical Habitat Classification and Instream Flow Modeling to Determine Habitat Availability During Low-Flow Periods, North Fork Shenandoah River, Virginia: U.S. Geological Survey Scientific Investigations Report 2006–5025, 64 p. (Also available at http://pubs.usgs.gov/sir/2006/5025/.)

NEW YORK

USGS, in cooperation with The Nature Conservancy (TNC) and Pike County, Pennsylvania, is assessing local American eel populations, their life-history strategies, and factors that can affect local populations in tributaries to the Upper Delaware River in Pennsylvania, New Jersey, and New York. This work continues long-term collaborative investigations between the USGS and TNC over the past decade that have assessed effects of channel geomorphology and impoundments on the distribution of common and rare mussels in the Neversink River and have characterized fish assemblages in tributaries to the Upper Delaware River in New York, Pennsylvania, and New Jersey.

In the current study, a long-term eel monitoring program was initiated in three tributaries to the upper Delaware River during 2011. Specifically, data will be used to evaluate impacts of near-normal (historic) hydrologic regimes and altered water-release strategies on the physical habitat, water quality, local eel populations, and the biodiversity of native fish communities upstream and downstream from the Neversink reservoir. (***Contact*:** Barry Baldigo, bbaldigo@usgs.gov, (518) 285-5605) (Project description available at: http://ny.cf.er.usgs.gov/nyprojectsearch/projects/2457-EF700.html).

USGS, in cooperation with New York State Energy Research and Development Authority (NYSERDA) and TNC, is developing the New York Streamflow Estimation Tool (NYSET). This program will enable users to estimate daily-mean streamflow (statistics) at ungaged locations and evaluate hydrologic impacts of withdrawals for various water-uses. These data can be used to assist with permitting water withdrawals, implementing habitat protection, estimating contaminant loads, or determining the potential impact from chemical spills. This tool is the first step in understanding streamflow alteration, and contributes to the *Ecological Limits of Hydrologic Alteration (or ELOHA),* which is a scientifically robust and flexible framework for assessing and managing environmental flows across large regions when limited time and resources preclude evaluation of individual rivers. (***Contact***: Chris Gazoorian, cgazoori@usgs.gov, (518) 285-5615) (Project description available at: http://ny.cf.er.usgs.gov/nyprojectsearch/projects/LK00-A42.html).

USGS is also serving on the Technical Advisory Committee for the TNC sponsored effort to look at Sustainable Flows in the Great Lakes Basin in NY and PA and is an integral part of an effort looking at sustainable flows in the Delaware Basin as a part of the National Water Census.

MINNESOTA

Managing tens of thousands of miles of streams is an important activity in the State of Minnesota and yet it is not practical to measure stream flow at any given point and time for the vast number of streams. USGS, in cooperation with the Minnesota Pollution Control Agency, is applying USGS methodologies to estimate flows in ungaged watersheds – essential information that is used by the State agency to permit effluent discharge limits for industry and municipalities, allocate Minnesota's limited water resources, and evaluate the impacts of water appropriations on fish communities and endangered species. (***Contact***: Dave Lorenz, Lorenz@usgs.gov, (763) 783-3271).

USGS also cooperates with the Minnesota Pollution Control Agency to develop a reasonable statewide estimate of recharge (using a Soil-Water-Balance Model). Project findings will enhance environmental flow investigations as recharge and stream baseflow are critical components of flow needed for sustainability of aquatic organisms. (***Contacts***: Eric Smith easmith@usgs.gov, (763) 783-3100 and Mindy Erickson, merickso@usgs.gov , (763) 783-3231).

NEW JERSEY

New Jersey (NJ) ecological flow projects and research were developed through the USGS CWP in collaboration with NJ Department of Environmental Protection (NJDEP), New Jersey Geological Survey (NJGS), NJ Pinelands Commission (NJPC), and the NJ Highlands Council (NJHC) (***Contact:*** Jonathan Kennen, jgkennen@usgs.gov, (609) 771-3948).

USGS worked cooperatively with the NJGS, NJDEP and the USGS Biological Resources Discipline office, Fort Collins, Colorado on the Ecological Flow Goals project. The objective of this project was to develop new methods and tools to assess regional water availability which can be implemented by state water-use regulators to protect the ecological integrity of freshwater aquatic ecosystems. Through this effort the USGS developed the Hydroecological Integrity Assessment Process (HIP) for classifying river types according to their hydrologic characteristics and computing hydrologic alteration from baseline conditions. A series of software tools including the National Hydrologic Assessment Tool (NAHAT), New Jersey Hydrologic Assessment Tool (NJHAT), Hydrologic Indices Tool (HIT), and the New Jersey Stream Classification Tool (NJSCT) were developed. NAHAT and NJHAT are used to (1) establish a hydrologic baseline (reference time period), (2) establish environmental flow standards, and (3) evaluate past and proposed hydrologic modifications of streams nationally and in New Jersey, respectively. They accomplished this by using flow statistics, trend analysis, and a subset of ecologically relevant hydrologic indices (EHRI's) that address the five major components of the flow regime (magnitude, frequency, duration, timing, and rate of change). NJSCAT is a software product designed specifically for NJ to place streams not included in the original classification or simulated hydrographs developed at ungaged locations into one of the four NJ for stream types (***Contact:*** Jonathan Kennen, jgkennen@usgs.gov, (609) 771-3948)

Related Publications:

- Henriksen, J.A, Heasley, J., Kennen, J.G., and Nieswand, S., 2006, Users' manual for the Hydroecological Integrity Assessment Process software (including the New Jersey Assessment Tools). U.S. Geological Survey Open-File Report 2006-1093. 71p. (Also available at http://pubs.er.usgs.gov/usgspubs/ofr/ofr20061093.)Kennen, J.G., Henriksen, J.A., and Nieswand, S.P., 2007, Development of the Hydroecological Integrity Assessment Process for Determining

Environmental Flows for New Jersey Streams: U.S. Geological Survey Scientific Investigations Report 2007-5206, 55p. (Also available at http://pubs.usgs.gov/sir/2007/5206/pdf/sir2007-5206-508.pdf.)

- Kennen, J.G., Kauffman, L.J., Ayers, M.A., and Wolock, D.M., 2008, Use of an Integrated Flow Model to Estimate Ecologically Relevant Hydrologic Characteristics at Stream Biomonitoring Sites: Ecological Modelling v. 211, p. 57-76 (Also available at http://dx.doi.org/10.1016/j.ecolmodel.2007.08.014).

A spinoff project called the "Baseline Identification & Analysis for Ecological Flow Goals" was designed to identify the minimum period of record that could be used to conduct an ecoflow goals analysis for each of New Jersey's four stream types. The intention of this project was to help the NJDEP manage NJ streams by providing a method for evaluating potential impacts of a proposed water withdrawal by determining the change in streamflow characteristics. (***Contact:*** Ron Baker, rbaker@usgs.gov, (609) 771-3923).

Related Publication:

- Esralew, R.A. and Baker, R.J, 2008, Determination of Baseline Periods of Record for Selected Streamflow-Gaging Stations in New Jersey for Determining Ecologically Relevant Hydrologic Indices (ERHI) : U.S. Geological Survey Scientific Investigations Report 2008-5077, 72 p (Also available at http://pubs.er.usgs.gov/publication/sir20085077.)

The USGS in cooperation with the NJ Highlands Council (NJHC) is evaluating new methods to assess regional water availability that are protective of the ecological integrity of freshwater aquatic ecosystems. The USGS performed a pilot study using the ecological flow goals method as an alternative method of determining water availability and as a potential stream-class specific water availability tool for future iterations of the NJ Highlands Regional Master Plan. This initial study evaluated four gaged streams and determined the amount of water withdrawals by site that would result in exceedence of either the 25th-75th or 40th-60th percentile threshold range and these withdrawals to other measurements of water availability based on stream low flow statistics. (***Contact:*** Otto Zapecza, ozapecza@usgs.gov, (609) 771-3995) The Final Report is available at: (http://www.highlands.state.nj.us/njhighlands/master/releases/ecological_flow_goals_pilot_study.pdf)

At the request of the NJHC the USGS NJWSC is further applying the Hydroecological Integrity Assessment Process (HIP) to fifteen streams in the New Jersey Highlands (including the 4 pilot streams) with specific focus on comparing baseline (pre-development) and current flow regimes. These sites were chosen because they have long-term periods of continuous record, in basins with differing degrees of land use change, development, and stream flow characteristics. The objectives of this assessment are to 1) expand the information base for comparing the eco-flow goals process to other methods of calculating water availability, 2) provide a more comprehensive evaluation of the use of the ecological flow method including stream basins with varied land use and flow characteristics, and 3) provide a set of ecologically relevant hydrologic indices (EHRI's) that can be used as a basis for comparing pre- and post-watershed conditions or evaluating the effects of planned water-development projects. A comparison of the same recent ERHI to the same baseline ERHI is most relevant to current water management schemes. Preliminary findings show that when using this comparison for the 25th-75th percentile threshold, 14 of the 15 streams evaluated show that either a similar or substantially less amount of water can be withdrawn in the most recent 20 year period than during baseline flow conditions (***Contact:*** Otto Zapecza, ozapecza@usgs.gov, (609) 771-3995).

The USGS worked collaboratively with the NJPC, Rutgers University, U.S. Fish and Wildlife Service, and the NJDEP to examine the structure and function of the hydrologic system supporting Pinelands aquatic and wetland communities and the hydrologic and ecological response to groundwater-withdrawal stress. The study addresses two major research questions: 1) what are the probable hydrologic effects of groundwater diversions from the Kirkwood-Cohansey aquifer on stream flows and wetland water levels, and 2) what are the probable ecological effects of induced stream-flow and groundwater-level changes on aquatic and wetland communities? The study focused components of the hydrologic system that control groundwater and surface-water flow, depth to water in wetlands, and interactions between groundwater, wetlands, and surface waters, the development of models to quantify the response of the aquifer system in selected study areas to hydrologic stresses, understanding the

relations between changes water availability and aquatic communities and stream habitats; and data management. (Project description available at: http://nj.usgs.gov/projects/2454BDB/) (***Contact***: Robert Nicholson, rnichol@usgs.gov, (609) 771-3925).

Related Publications:

- Walker, R., Reilly, P. and Watson, K., 2008, Hydrogeologic framework in three drainage basins in the New Jersey Pinelands, 2004–06: U.S. Geological Survey Scientific Investigations Report 2008-5061 (Also available at http://pubs.er.usgs.gov/publication/sir20085061.)
- Kennen, J.G., and Riskin, M.L., 2010, Evaluating the effects of potential changes in stream flow regime on fish and aquatic invertebrate assemblages in the New Jersey Pinelands: U.S. Geological Survey Scientific Investigations Report 2010-5079 (Also available at http://pubs.usgs.gov/sir/2010/5079/pdf/sir2010-5079.pdf.)
- Walker, R., Nicholson, R., and Storck, D., 2011, Hydrologic assessment of three drainage basins in the Pinelands of southern New Jersey, 2004–06: U.S. Geological Survey Scientific Investigations Report 2011-5056 (Also available at http://pubs.er.usgs.gov/publication/sir20115056.)
- Sumner, D., Nicholson, R., and Clark, K., 2012, Measurement and simulation of evapotranspiration at a wetland site in the New Jersey Pinelands: U.S. Geological Survey Scientific Investigations Report 2012-5118 (Also available at http://pubs.er.usgs.gov/publication/sir20125118.)
- Charles, E., and Nicholson, R., 2012, Simulation of groundwater flow and hydrologic effects of groundwater withdrawals from the Kirkwood-Cohansey aquifer system in the Pinelands of southern New Jersey: U.S. Geological Survey Scientific Investigations Report 2012–5122 (Also available at http://pubs.er.usgs.gov/publication/sir20125122.)

Fourteen additional reports and publications by the cooperator and other collaborators are available at the bottom of the following web page: http://www.state.nj.us/pinelands/science/current/kc/index.html

Recently, the USGS worked cooperatively with the NJDEP, Division of Water Monitoring and Standards to relate a set of ecologically relevant flow parameters to known aquatic community impairment within a pre-defined hydrologic region in New Jersey. These attributes were used to 1) identify a series of critical flow parameters as surrogates for defining aquatic life impairment and 2) compare normalized flow duration statistics between streamflow impaired streams with non-impaired reference streams to develop hydrologic targets (percent deviation from reference) for rehabilitation of streams. The findings will help the NJDEP establish an applicable TMDL (Total Maximum Discharge Load) approach that addresses aquatic life impairments associated with hydrologic alteration for streams in New Jersey. The goal is to help improve river systems by reducing the impact of hydrologic stress such that beneficial uses of a stream may be restored. Hydrologic-based TMDLs (that is, a Hydro-TMDL) are developed by using established baseline hydrology and a streamflow model (that is, the Statewide Watershed Runoff Model) to predict aquatic community response along a gradient of stream degradation for a specific hydrologic region or stream type. Statistics based on flow duration processes (for example, 25- and 75-percent flow exceedences) and number of days during the period of record which exceed critical high and low flow values are directly compared and used to estimate acceptable streamflow targets that will be protective of instream and riparian habitat and meet aquatic life uses. (***Contact:*** Jonathan Kennen, jgkennen@usgs.gov, (609) 771-3948).

Related Publication:

- Kennen, J.G., Riskin, M.L., Reilly, P.A., and Colarullo, S.J., 2013. A Method to support total maximum daily load development using hydrologic alteration as a surrogate to address aquatic life impairment in New Jersey streams: U.S. Geological Survey Scientific Investigations Report 2013 (In Editorial Review).

The USGS NJWSC is also playing an integral role in developing flow-ecology response models in support of a Focus Area Study in the Delaware River Basin as a part of the National Water Census.

MARYLAND

The fractured rock region of Maryland, which includes land areas north and west of the Interstate 95 corridor, is the source of water supply for approximately 4.4 million Marylanders, or approximately 76 percent of the State's population. Whereas hundreds of thousands of residents rely on wells (both domestic and community), millions rely on surface-water sources. In this region, land use, geology, topography, water withdrawals, impoundments, and other factors affect water-flow characteristics. The unconfined groundwater systems are closely interconnected with rivers and streams, and are affected by seasonal and climatic variations. During droughts, groundwater levels drop and contribute to reduced streamflows, which in turn, can lead to reduced habitat for aquatic life. Increased demand, over-allocation, population growth, and climate change can affect the future sustainability of water supplies in the region of Maryland underlain by fractured rock.

In response to recommendations of the 2008 Advisory Committee on the Management and Protection of the State's Water Resources report, the Maryland (MD) Department of the Environment's Water Supply Program, the MD Geological Survey, the MD Department of Natural Resources, Monitoring and Non-Tidal Assessment (MANTA) Division, and the USGS developed a science plan to provide new scientific information, new data analysis, and new tools for the State to comprehensively assess and manage water resources in the fractured rock region of Maryland.

The science plan lays out five goals, one of which is to assess the role of streamflow and water withdrawals on the ecological integrity of streams. To date, USGS collaborates with ecologists from MD Department of Natural Resources to provide streamflow statistics and models of flow at ungaged streams and to evaluate aquatic biology data and water withdrawal impacts on ecosystem integrity. As part of the work, low-flow statistics were updated and provided in an USGS Open-File Report Additionally, StreamStats—USGS application software to estimate basin characteristics and stream flow at ungaged sites—was recently expanded to the whole state of Maryland, based on the low-flow work, and in collaboration with the MD State Highway. Basins were classified throughout Maryland to set the needed framework for hydrologic and ecological assessment. (Journal in review; details on the comprehensive plan are available at: http://pubs.usgs.gov/sir/2012/5160/). (***Contact***: Brandon Fleming, bjflemin@usgs.gov, (443) 498-5561)

Related Publication:

- Fleming, B.J., Hammond, P.A., Stranko, S.A., Duigon, M.T., and Kasraei, Saeid, 2012, A science plan for a comprehensive assessment of water supply in the region underlain by fractured rock in Maryland: U.S. Geological Survey Scientific Investigations Report 2012–5160, 29 p.
- Doheny, E.J., and Banks, W.S.L., 2010, Selected low-flow frequency statistics for continuous-record streamgage locations in Maryland, 2010: U.S. Geological Survey Open-File Report 2010–1310, 22 p (Also available at http://pubs.usgs.gov/of/2010/1310/.)

OREGON

USGS actively assesses environmental flows in streams throughout Oregon. Most of the tributaries, with the exception of the Clackamas River, to the Willamette River with dams operated by U.S. Army Corps of Engineers (USACE) have studies completed by either USGS or Oregon State University. USGS continues to work with the USACE, The Nature Conservancy, and the State of Oregon to develop future studies to address environmental flow issues. In addition, USGS served as a member of a technical advisory committee charged with developing a white paper on environmental flows (as described below). (***Contacts***: John Risley, jrisley@usgs.gov, 503-251-3279 and Terrence Conlon, tdconlon@usgs.gov, (503) 251-3232)

USGS activities currently focus in the Grande Ronde River basin, which drains to the Snake River, originating in the Blue Mountains ecological province of northeast Oregon (draining a total area of about 4,000 square miles and flowing 212 miles). Historically, the Upper Grande Ronde River supported large runs of spring Chinook salmon and summer steelhead, although

these stocks are now much reduced. Snake River spring Chinook salmon in the Snake River Basin, including the Grande Ronde, were listed as threatened in 2005 under the Endangered Species Act, and populations in the Grande Ronde River Basin are considered as high priority for recovery. Natural spawning of spring Chinook salmon occurs in the upper Grande Ronde River and its principle tributaries: the Wenaha River, the Wallowa River with its tributaries the Minan and Lostine Rivers, as well as in smaller streams in the upper basin. The ongoing USGS study, done in cooperation with the Columbia River Intertribal Treaty Fish Commission (CRITFC), focuses on development of tools to estimate baseflow in streams in the Upper Grande Ronde Basin in eastern Oregon needed to support aquatic ecosystems. Findings will help to statistically correlate landscape characteristics of small stream basins to baseflow during the dry summer months and to estimate baseflow in ungaged basins. The USGS work will characterize low-flow regime as a primary feature of habitat quality for salmon spawning and juvenile rearing areas throughout the year, as well as corridors and holding areas for adult migration during the summer and fall. A primary objective of this work is to develop the capacity for CRITFC personnel to characterize the low-flow regime as needed for specific stream reaches of interest. USGS will provide detailed analytical protocols for each step, and demonstrate their application for selected streams and reaches to be determined in collaboration with CRITFC. (***Contact***: Valerie Kelly, vjkelly@usgs.gov, 503-251-3240)

Two completed projects in the ORWSC on environmental flows responded to the needs of the Sustainable Rivers Project (SRP). SRP is a collaboration of The Nature Conservancy (TNC) and the U.S. Army Corps of Engineers (USACE) and its goals, in part, are to develop flow recommendations for operation of the flood control dams in the Willamette Basin in Oregon that are beneficial to aquatic ecosystems. USGS, working collaboratively with the U.S. Army Corps of Engineers (USACE), TNC, the Oregon Watershed Enhancement Board, and the Eugene Water and Electric Board, completed the McKenzie River and Santiam River environmental flow assessments. These studies helped to (1) compile and evaluate pre-dam streamflow, and simulated natural streamflow without dams and current regulated streamflow to understand the effect of dams on streamflow, and 2) collect and assess aerial photos, surveys, and geology of the drainages to understand channel migration, gravel bar development, and other fluvial processes. Flow recommendations were developed using the Regime Prescription Tool and published by TNC.

Related publications:

- Risley, John, Wallick, J.R., Waite, Ian, and Stonewall, Adam, 2010, Development of an environmental flow framework for the McKenzie River basin, Oregon: U.S. Geological Survey Scientific Investigations Report 2010-5016, 94 p. (http://pubs.usgs.gov/sir/2010/5016/)
- Risley, John, Bach, Leslie, Wallick, J. Rose, 2010, Summary Report: Environmental Flow Recommendations Workshop for the McKenzie River, Oregon: The Nature Conservancy, 34p. (http://or.water.usgs.gov/proj/McKenzie_flows/McKenzie_Workshop_report.pdf).
- Risley, J.C., Wallick, J.R., Mangano, J.F., and Jones, K.F., 2012, An environmental streamflow assessment for the Santiam River basin, Oregon: U.S. Geological Survey Open-File Report 2012-1133, 66 p. (http://pubs.usgs.gov/of/2012/1133/).
  Risley, John, Bach, Leslie, Wallick, in review, Summary Report: Environmental Flow Recommendations Workshop for the Santiam River, Oregon: The Nature Conservancy 2012 AGU presentation on McKenzie and Santiam Rivers environmental flows: http://fallmeeting.agu.org/2012/eposters/eposter/h13f-1414/

Other related URLs:

- USGS McKenzie River Environmental Flow project page: http://or.water.usgs.gov/proj/McKenzie_flows/
- USACE Regime Prescription Tool: http://www.hec.usace.army.mil/software/hec-rpt/
- Sustainable Rivers Program: http://www.nature.org/ourinitiatives/habitats/riverslakes/sustainable-rivers-project.xml
- Sustainable Rivers Program Factsheet: http://www.nature.org/ourinitiatives/habitats/riverslakes/sustainable-rivers-project-fact-sheetpdf.null

- The Nature Conservancy Willamette Flow management: http://www.nature.org/idc/groups/webcontent/@web/@oregon/documents/document/prd_022483.pdf

  ORWSC served on the Ecological Flows Technical Advisory Group to the Oregon Water Resources Department, which developed guidance on how ecological flows (similar to environmental flows) will be handled with implementation of legislation providing grants to developing water storage facilities in Oregon. (Ecological Flows Technical Advisory Committee, 2010, *Draft White Paper: Ecological Flows; a scientific framework for Implementing Oregon HB 3369: Oregon Water Resources Department, Salem, Oregon,* 37p.) (http://www1.wrd.state.or.us/pdfs/White_Paper_EFTAG_Draft_3.pdf)

WASHINGTON

USGS works collaboratively with a myriad of cooperators on a diverse array of projects related to environmental flows (***Contact***: Rick Dinicola, dinicola@usgs.gov, (253) 552-1603).

(1) USGS, in cooperation with the Northwest Indian Fisheries Commission and its member tribes performed low-flow surveys in small western Washington streams that are not currently part of a regional streamflow-monitoring network. Findings show that low summer streamflows during the driest years--particularly in streams without flow gages--can be estimated using relatively inexpensive methods and allow understanding of low flows even where and when we do not have the resources to measure them directly. Scientists are using this information to better understand low summer flows in specific streams, as well as to improve low-flow models for the region. Low flows in streams are essential for maintaining connectivity for fish migration and nutrient transport. (Press release) (***Contact***: Chris Curran, ccurran@usgs.gov, (253) 552-1614).

Related publication:

- Curran, C.A., Eng, Ken, and Konrad, C.P., 2012, Analysis of low flows and selected methods for estimating low-flow characteristics at partial-record and ungaged stream sites in western Washington: U.S. Geological Survey Scientific Investigations Report 2012-5078, 46 p (Also available at http://pubs.usgs.gov/sir/2012/5078/.)

(2) To help the City of Seattle manage high-flow releases during periods of heavy precipitation, the USGS is completing a geomorphic study of the Cedar River. In particular, the USGS is working with the Cedar River Instream Flow Commission (IFC) and the City of Seattle, through Seattle Public Utilities (SPU) to develop a conceptual model relating Cedar River geomorphology and aquatic ecology. The Cedar River watershed provides two-thirds of the water supply for the greater Seattle metropolitan region, in addition to being home to numerous federally listed salmon species. Seattle operates its water management facilities in the Cedar River to meet two primary objectives: delivery of high quality drinking water to its customers in the Seattle metropolitan area and protection of aquatic and riparian habitat in the mainstem Cedar River and Chester Morse Lake. Water management activities also strive to consider flood protection needs, water delivery to Lake Washington/Lake Washington Ship Canal, and hydropower production at the Seattle City Light Cedar Falls Hydroelectric Facility.

USGS scientists are determining the current geomorphic state of the Cedar River, measuring key geomorphic features and evaluating geomorphic benefits of resetting floods. A hydrodynamic numerical model of a representative reach of the river will be built to aid in the geomorphic assessment of the river, and research will also evaluate the amount of salmon-redd scour under different flood conditions. Particular attention will be paid to understanding the geomorphic response of the river under different magnitude/duration release scenarios for flood management. Finally, the USGS will identify the geomorphic/ riverine habitat metrics that are most important to monitor as part of a long-term monitoring program. (Project website: http://wa.water.usgs.gov/projects/cedarriverpeakflows/) C***ontact***: Chris Magirl, magirl@usgs.gov, (253) 552-1617).

Related publication:

- Magirl, C.S., Gendaszek, A.S., Czuba, C.R., Konrad, C.P., and Marineau, M.D., 2012, Geomorphic and hydrologic study of peak-flow management on the Cedar River, Washington: U.S. Geological Survey Open-File Report 2012-1240, 4 p., plus presentation (Also available at http://pubs.usgs.gov/of/2012/1240/.)

(3) USGS works in cooperation with King County will evaluate how current and potential future hydraulic conditions in a reach of the Lower White River will affect the potential for fish habitat and growth. The specific objectives are to: 1) estimate the abundance and distribution of potential juvenile spring Chinook habitat in the study reach for current and simulated post-setback levee conditions under low- and high-flow conditions; 2) estimate the abundance and distribution of energetically favorable locations under current and future conditions for low- and high-flow conditions using a nested 2-dimensional hydrologic, invertebrate-drift, and bioenergetics model; and 3) develop a publically available integrated hydraulic and fish habitat and energetic model. (Project website: http://wa.water.usgs.gov/projects/whiteriverbio/).

The White River Basin is located in western Washington and drains an area of about 500 square miles. Rivers in the White River Basin are fed by melt water from glaciers on Mt. Rainier, runoff from snowmelt and rain, and groundwater discharge. Beginning in the early to mid-twentieth century, the White River from river mile (RM) 9 to its confluence with the Puyallup River was extensively channelized with levees to prevent meandering and minimize flooding. These system changes affected fish habitat and growth potential. In recent years, setback levees have been built both to increase the carrying capacity of the rivers and help reduce flooding, and to potentially improve fish habitat and fish growth potential. Additional setback levees are being considered, however, prior to building any additional setbacks, management agencies are interested in getting estimates of potential changes in available fish habitat. Ideally, levee setbacks would be designed to reduce flooding and provide improved habitat for native fish like the federally listed Chinook salmon. Currently, insufficient information is available to quantify the impact of flood-mitigation strategies, like setback levees, on fish habitat and growth potential. (***Contact***: Bob Black, rwblack@usgs.gov, (253) 552-1687).

(4) USGS works cooperatively with Pierce County and King County to assess sediment dynamics, flood capacity, and river ecology in a major river Basin near Mount Rainier. The information is critical for management efforts related to flood reduction and improvements in aquatic habitat in the Lower Puyallup River Basin (Puyallup, Carbon, and White Rivers). USGS is measuring channel cross sections and analyzing changes in them over the past 25 years; sampling river bed materials for analysis; and building a computerized hydraulic model of the lower Puyallup River system that can be used to evaluate different management options. (Project website http://wa.water.usgs.gov/projects/puyallupseds/) (***Contact***: Chris Magirl, magirl@usgs.gov, (253) 552-1617).

Related publication:

- Czuba, J.A., Magirl, C.S., Czuba, C.R., Curran, C.A., Johnson, K.H., Olsen, T.D., Kimball, H.K., and Gish, C.C., 2012, Geomorphic analysis of the river response to sedimentation downstream of Mount Rainier, Washington: U.S. Geological Survey Open-File Report 2012-1242, 134 p (Also available at http://pubs.usgs.gov/of/2012/1242/.)

(5) USGS has just begun work with the Puget Sound Partnership, National Oceanic and Atmospheric Administration (NOAA), and Federal Emergency Management Agency (FEMA) to integrate flood risk reduction and ecosystem restoration information to ensure that floodplain management decisions support Puget Sound recovery and community goals such as public safety and recreation. (***Contact***: Chris Konrad, mailto:cpkonrad@usgs.gov, (253) 552-1634).

COLORADO

USGS works collaboratively with the Upper Colorado River Endangered Fish Recovery Program, Office of the Wyoming State Engineer, Argonne Labs, and Bureau of Reclamation to assess sediment and habitat in the Gunnison, Colorado, and Green

Rivers in Colorado and Utah. The primary objective of the sediment-monitoring project is to provide information to address key uncertainties in priority reaches of the Colorado, Gunnison and Green Rivers relevant to the role of flows and sediment transport on the formation and maintenance of backwater habitats and spawning bars. Findings are to be published in 2013. (***Contact***: Cory Williams, cawillia@usgs.gov, (970) 245-5257, ext 31).

USGS works collaboratively with the Colorado River Water Conservation District and the Colorado Water Conservation Board to relate streamflow to channel stability and habitat availability in a reach of the Lake Fork of the Gunnison River at Lake City, Colorado. The Lake Fork at Lake City study is designed to provide information to resource managers, planners, and designers on the effectiveness and durability of channel restoration techniques used for stream rehabilitation and flood protection. The study compliments and expands an ongoing USGS study on the geomorphic stability of restored or reconfigured channels at several sites in western Colorado. (***Contact***: Cory Williams, cawillia@usgs.gov, (970) 245-5257, ext 31).

USGS also works with the Colorado Water Conservation Board, National Park Service, and Bureau of Land Management to assess the effects of flow alteration in the Lower Yampa watershed through topographic surveying, sediment monitoring, and 2-dimensional streamflow and sediment models. The lower Yampa River in northwestern Colorado is the largest, relatively unregulated river system in the upper Colorado River basin. Water from the Yampa River basin continues to be sought for a number of municipal, industrial, and energy uses, and water-resource development in the Yampa River basin could alter the streamflow regime and, consequently, could lead to changes in the transport and storage of sediment in the Yampa River, changes to channel geometry, encroachment of riparian vegetation, and loss of aquatic habitat. (***Contact***: Cory Williams, cawillia@usgs.gov, (970) 245-5257, ext 31).

ARIZONA

The Verde River is one of a few remaining intact and relatively unaltered large rivers in Arizona. The Verde River watershed provides critical habitat for many of Arizona's threatened and endangered species, while supporting human communities, industry, and agriculture in a semiarid environment where water is scarce. The purpose of this USGS study, conducted by scientists in both Arizona and Utah, is to provide a rigorous scientific foundation that quantifies the association between hydrologic characteristics and ecological conditions in the Upper and Middle Verde watersheds. Cooperating agencies include The Nature Conservancy, Arizona Department of Water Resources, and Salt River Project (the main water utility in the Phoenix area). (***Contacts***: Steve Wiele, smwiele@usgs.gov, (520) 670-6671, ext 277 and Anne Brasher, abrasher@usgs.gov, (435) 259-3866). (Project description available at: http://az.water.usgs.gov/projects/E7000/index.html .)

The project is completing Phase One (December 2012) of a two-phase project. Existing data were compiled and analyzed in a report (USGS Scientific Investigations Report, currently in review), which helps to:

- assess biological status by sub-basin with an emphasis on the Verde Valley,
- evaluate hydrologic datasets and output from a USGS regional groundwater model for relevance to flow-ecology studies in the Verde Valley,
- develop monthly streamflow statistics for each sub-basin with additional detail for the Verde Valley, and
- develop an initial understanding of the relations between hydrological factors and biological responses.

Phase 2 is planned to look in more detail at the physical processes that link river flow and sediment to critical habitat characteristics in the semi-arid-southwestern stream system. This study has transferability and will provide information necessary to describe the ecological requirements and understand the effects of hydrologic alteration for sustainable management of water use in other semi-arid-region stream systems.

KANSAS

USGS in Kansas works collaboratively with several cooperators on a diverse array of projects related to environmental flows.

(1) In a cooperative study with the Johnson County Stormwater Management Program in Kansas, stream quality was described at about 20 sites on the basis of biological data (invertebrates and periphyton) and relations to environmental data including land use, water and streambed chemistry, habitat variables, and streamflow metrics. Results from data collected during 2003 through 2007 were published in a 2009 report available at http://pubs.usgs.gov/sir/2009/5235/. A follow-up report that includes data through 2010 is available at http://pubs.usgs.gov/sir/2012/5279/. The information provided by the project is being used to improve water-quality management programs, document changing conditions over time, and evaluate compliance with water-quality standards, Total Maximum Daily Loads (TMDLs), National Pollutant Discharge Elimination System (NPDES) permit conditions, and other established guidelines and goals. A description of the project and summary of results can be found at http://ks.water.usgs.gov/studies/qw/joco/jocostreamqual.html.

Streamflow metrics were calculated for sites that had streamflow gages (7 of the 20 sites). About 18 metrics that best describe flow characteristics in the study area were selected for correlation analysis with invertebrate and periphyton data. Several characteristics of streamflow, described by metrics such as base-flow index, minimum 7-day average flow, and coefficient of variability, were significantly correlated with stream health.

Biological conditions reflected a gradient in urban land use, with the less disturbed streams located in rural areas of Johnson County. Environmental variables that consistently were highly negatively correlated with biological conditions were percent impervious surface and percent urban land use. In addition, density of stormwater outfall points adjacent to streams was significantly negatively correlated with biological conditions. Specific conductance of water and sum of polycyclic aromatic hydrocarbon concentrations in streambed sediment also were significantly negatively correlated with biological conditions. Total nitrogen in water and total phosphorus in streambed sediment were correlated with most invertebrate variables. The most important habitat variables were sinuosity, length and continuity of natural buffers, riffle substrate embeddedness, and substrate cover diversity, each of which was correlated with all invertebrate metrics including a 10-metric combined score. Results indicated that although multiple factors are correlated with stream quality degradation, general urbanization consistently is determined to be the fundamental factor causing change in stream quality. Policies and management practices that may be most important in protecting the health of streams in Johnson County are those minimizing the effects of impervious surface, protecting stream corridors, and decreasing the loads of sediment, nutrients, and toxic chemicals that directly enter streams through stormwater runoff and discharges. (***Contact***: Teresa Rasmussen, rasmuss@usgs.gov, (785) 832-3576)

(2) USGS has conducted two studies, one completed and one ongoing, in cooperation with Johnson County Wastewater in Kansas to describe the effects of wastewater effluent discharge and treatment facility upgrades on streamflow and the environmental and biological conditions of receiving streams.

A study of the upper Blue River, which receives effluent from the Johnson County Blue River Main Wastewater Treatment Facility (WWTF), was conducted during April 2008 through March 2009. Three sites, one upstream and two downstream of the WWTF, along a 6.4 mile reach of the upper Blue River were sampled. Streamflow and water-quality were continuously monitored at an upstream and downstream site and discrete water-quality, stream-bed sediment, periphyton, and macroinvertebrate data were collected at all sites. Upgrades to the Blue River Main Wastewater Treatment Facility improved wastewater effluent quality, but wastewater effluent discharge still had negative effects on the water quality and biological conditions at the downstream sites. Wastewater effluent discharge into the upper Blue River likely contributed to changes in measures of ecosystem structure (streamflow, water chemistry, algal biomass, algal periphyton and macroinvertebrate community composition) and primary production, a measure of ecosystem function, along the upstream-downstream gradient. Because the Blue River Main Wastewater Treatment Facility is located in a rapidly urbanizing area, urbanization effects also may play a role in the decline in environmental and biological conditions along the upstream-downstream gradient. Despite

these differences in environmental and biological conditions, measures of ecosystem functional health indicated non-impairment downstream from the WWTF during most times of the year, indicating the declines in environmental and biological conditions along the upstream-downstream gradient were not substantial enough to cause persistent changes in ecosystem function. (Final report) (***Contact***: Jennifer Graham, jlgraham@usgs.gov, (785) 832-3511)

A study of Indian Creek, which receives effluent from the Johnson County Middle Basin and Tomahawk WWTFs is ongoing. Data are collected at five sites along a 9.5 mile reach of Indian Creek and one site on Tomahawk Creek, just upstream from the confluence with Indian Creek, from July 2011 through June 2013. Streamflow and water quality are continuously monitored at all sites. In addition, discrete water-quality, stream-bed sediment, algal biomass, and periphyton and macroinvertebrate community data are collected as part of this study. Additional information about the Indian Creek study is available online at: http://ks.water.usgs.gov/studies/qw/joco/IndianCreek.html. (***Contact***: Jennifer Graham, jlgraham@usgs.gov, (785) 832-3511)

(3) The city of Wichita, Kansas uses the *Equus* Beds aquifer, an important source of municipal water supply. To meet future water needs, plans for artificial recharge of the aquifer have been implemented in several phases. Phase I of the *Equus* Beds Aquifer Storage and Recovery (ASR) Program began with injection of water from the Little Arkansas River into the aquifer for storage and subsequent recovery in 2006. Construction of a river intake structure and surface-water treatment plant began as implementation of Phase II of the Equus Beds ASR Program in 2010. (More information about the city of Wichita's ASR program is available at: http://www.wichita.gov/CityOffices/WaterAndSewer/ProductionAndPumping/ASR/).

An important aspect of the ASR Program is the monitoring of water quality and the effects of recharge activities on stream conditions. This project monitors streamflow, water-quality, streambed-sediment, periphyton, macroinvertebrate, fish, and habitat data to quantify and characterize the effects of the return line of the ASR facility discharging into the Little Arkansas River. Data collected for this project will be used to establish baseline conditions before full implementation of aquifer recharge and to evaluate changes that may be related to the recharge program. In addition, data will be used to document stream quality, evaluate changing conditions, identify environmental factors affecting streams, provide science-based information for decision-making, and help meet regulatory monitoring requirements. (Protocols) (***Contact:*** Mandy Stone, mstone@usgs.gov, (785) 832-3578).

HAWAII

USGS, in cooperation with the State of Hawaii Department of Hawaiian Home Lands, assessed the availability and distribution of natural low flow in Anahola Stream in northeast Kaua'i, Hawai'i, which supports agricultural, domestic, and cultural uses within its drainage basin. Biological surveys were conducted as part of the study to determine the distribution of native and nonnative aquatic stream fauna. The report summarizes scenarios that describe (1) surface-water availability under regulated conditions of Anahola Stream if the upper and lower intakes are restored in the future; and (2) amount of flow available for agricultural use at the upper intake under a variety of potential instream-flow standards that may be established by the State of Hawaii for the protection of instream uses.

Related publication:

- Cheng, C.L., and Wolff, R.H., 2012, Availability and distribution of low flow in Anahola Stream, Kaua'i, Hawai'i: U.S. Geological Survey Scientific Investigations Report 2012-5264, 32 p (Also available at http://pubs.usgs.gov/sir/2012/5264/.)

USGS scientists completed two additional studies related to environmental flows on the island of Maui. These studies included an evaluation of the effects of surface-water diversions on habitat availability for native stream fauna (fish, shrimp, and snails). The first study, done in cooperation with the County of Maui and State of Hawaii, looked at effects of surface-water diversion on streamflow, recharge, physical habitat, and temperature. Information collected for this study includes discharge measurements under different streamflow conditions to characterize streamflow and seepage losses, hourly photographs of stream conditions from mounted cameras, snorkel surveys of stream fauna, measurements of microhabitat (depth, velocity, and substrate) under

different flow conditions, and measurements of water temperatures. Families of curves were developed to show the relations between surface-water diversion intake capacity (the maximum rate that an intake can divert) and (1) selected duration discharges for sites near the coast; (2) selected duration discharges for the diversions; (3) groundwater-recharge reduction; and (4) physical-habitat reduction for native stream fauna. These curves may be used by water managers to evaluate the effects of different diversion intake capacities on streamflow, water available for off-stream use, groundwater recharge, and habitat for native stream fauna.

Related publication:

- Oki, D.S., Wolff, R.H., and Perreault, J.A., 2010, Effects of surface-water diversion on streamflow, recharge, physical habitat, and temperature, Nā Wai ʻEhā, Maui, Hawaiʻi: U.S. Geological Survey Scientific Investigations Report 2010-5011, 154 p (Also available at http://pubs.usgs.gov/sir/2010/5011/)

The second study, done in cooperation with the State of Hawaii, used the Physical Habitat Simulation (PHABSIM) System, which incorporates hydrology, stream morphology and microhabitat preferences to explore relations between streamflow and habitat availability. The tool was used to simulate habitat/discharge relations for various species and life stages, and to provide quantitative habitat comparisons at different streamflows of interest. Hydrologic data, collected over a range of low-flow discharges, were used to calibrate hydraulic models of selected transects across the streams. The models were then used to predict water depth and velocity (expressed as a Froude number) over a range of discharges up to estimates of natural median streamflow. The biological importance of the stream hydraulic attributes was then assessed with the statistically derived suitability criteria for each native species and life stage that were developed as part of this study to produce a relation between discharge and habitat availability. The final output was expressed as a weighted habitat area of streambed for a representative stream reach. PHABSIM model results show the area of estimated usable bed habitat over a range of streamflows relative to natural conditions. In general, the models show a continuous decrease in habitat for all modeled species as streamflow is decreased from natural conditions. (Contact: Steve Anthony, santhony@usgs.gov, (808) 587-2406).

Related publication:

- Gingerich, S.B. and Wolff, R.H., 2005, Effects of surface-water diversions on habitat availability for native macrofauna, northeast Maui, Hawaii: U.S. Geological Survey Scientific Investigations Report 2005-5213, 93 p (Also available at http://pubs.usgs.gov/sir/2005/5213/.)

MICHIGAN

The State of Michigan ratified the Great Lakes-St. Lawrence River Basin Water Resources Compact on July 9, 2008, and, under the Compact, agreed to develop implementation legislation to prevent adverse resource impacts of water withdrawals on the ecosystems and watersheds within the Basin. Through cooperative science projects, USGS, in cooperation with the State of Michigan and Michigan State University, provides science to support to the state in the development of an innovative water-withdrawal assessment process and on-line screening tool for new or increased water withdrawals (On-line screening tool). This process combines ungaged-flow estimation, a statewide ecological flow classification of streams, estimation of streamflow depletion by wells, and ecological-response curves describing the potential impact of water withdrawals on characteristic fish populations within a legislative and management framework. USGS continues to provide science support in the administration of the assessment process and evaluation of its performance. In addition, new methods to estimate ungaged flows and to evaluate instantaneous flow measurements have been developed in response to needs identified in this work. Current efforts include work in the Great Lakes Basin to build on this approach and create a consistent hydro-spatial framework to support environmental flow science, restoration, and management. (***Contact***: Howard Reeves, hwreeves@usgs.gov, (517) 887-8914).

Related Publications:

- Hamilton, D.A., Sorrell, R.C., and Holtschlag, D.J., 2008, A regression model for computing index flows describing the median flow for the summer month of lowest flow in Michigan: U.S. Geological Survey Scientific Investigations Report 2008–5096, 43 p. (also available at http://pubs.usgs.gov/sir/2008/5096/).
- Hamilton, D.A. and Seelbach, P.W., 2011, Michigan's water withdrawal assessment process and internet screening tool: State of Michigan, Department of Natural Resources, Fisheries Division Special Report 55, 37 p.(also available at http://www.miwwat.org/wateruse/documents/Hamilton%20and%20Seelbach%20SR55.pdf).
- Holtschlag, D.J., 2009, Application guide for AFINCH (analysis of flows in networks of channels) described by NHDPlus: U.S. Geological Survey Scientific Investigations Report 2009-5188, 106 p. (also available at http://pubs.usgs.gov/sir/2009/5188/.)
- Holtschlag, D.J., 2011, Use of instantaneous streamflow measurements to improve regression estimates of index flow for the summer month of lowest streamflow in Michigan: U.S. Geological Survey Scientific Investigations Report 2010–5236, 86 p. (also available at http://pubs.usgs.gov/sir/2010/5236/.)
  Reeves, H.W., 2008, Documentation of the computer program STRMDEPL08— an extended version of STRMDEPL with additional analytical solutions to calculate streamflow depletion by nearby pumping wells: U.S. Geological Survey Open-File Report 2008-1166, 22 p. (also available at http://pubs.usgs.gov/of/2008/1166/.)
- Reeves, H.W., and Asher, A.J., 2010, Internet-based interface for STRMDEPL08: U.S. Geological Survey Open-File Report 2010–1247, 17 p (also available at http://pubs.usgs.gov/of/2010/1247/).
- Reeves, H.W., Hamilton, D.A., Seelbach, P.W., and Asher, Jeremiah, 2009, Ground-water-withdrawal component of the Michigan water-withdrawal screening tool: U.S. Geological Survey Scientific Investigations Report 2009-5003, 36 p. (also available at http://pubs.usgs.gov/sir/2009/5003/.)
- Reeves, H.W., Nicholas, J.R., Seelbach, P.W., and Hamilton, D.A., 2011, Management of surface water and groundwater withdrawals to maintain environmental stream flows in Michigan: Watershed Management Conference 2010— Innovations in Watershed Management under Land Use and Climate Change: Reston, Virginia, Environmental and Water Resources Institute of American Society of Civil Engineers, p. 409–420.
  Steinman, A.D., Nicholas, J.R., Seelbach, P.W., Allan, J.W., and Ruswick, Frank, 2011, Science as a fundamental framework for shaping policy discussions regarding the use of groundwater in the State of Michigan— a case study: Water Policy, v. 13, no. 1, p. 69-86 (also available at http://dx.doi.org/10.2166/wp.2010.047).
- Zorn, T. G., Seelbach, P. W., and Rutherford, E. S., 2012, A regional-scale habitat suitability model to assess the effects of flow reduction on fish assemblages in Michigan streams: Journal of the American Water Resources Association, v. 48, no. 5, p. 871-895 (also available at http://dx.doi.org/ 10.1111/j.1752-1688.2012.00656.x)

WISCONSIN

USGS has developed and maintains time-series processing code (TSPROC) that allows users to compute a full suite of environmental flow statistics as calibration targets (within the PEST suite of model calibration software). This enhancement reduces the uncertainty around model projections for these flow components. Code output is highly accessible and scriptable, and is therefore transferrable to applications across the Nation.

In addition, USGS works collaboratively with Wisconsin Focus on Energy, Wisconsin Department of Natural Resources (WIDNR), the US EPA, and the USGS Climate and Land Use Change Research Program on several research projects relating flows to selected species in lakes and streams. (***Contact***: John Walker, jfwalker@usgs.gov, (608) 821-3853).

For example, a collaborative project funded under the Great Lakes Restoration Initiative is using ecological flows to examine impacts of streamflow changes on ecological change. The Afinch model is used to generate daily streamflows and the resulting ecological flows, which are related to impacts on biological species, primarily fish. The overall goal of the study is to generate a consistent basin-wide data framework consisting of a unified stream classification system linking landscape, hydrologic, and biologic information to stream networks across the US Great Lakes basin. Specific objectives are as follows:

1. Develop estimates of gaged and ungaged streamflows for use in ecological classification.

2. Classify streams using landscape, ecological, and other hydrologic data.

3. Relate changes in environmental condition (i.e. flow, water withdrawal) to ecological change (i.e. ecological response of fish species occurrence and abundance in streams).

Recent collaboration with the WIDNR examined the potential effect of climate change on Loon Habitat in Northern Wisconsin. The work involved extremely detailed hydrologic modeling, limited lake modeling through a steady-state dissolved organic carbon (DOC) model, and basic loon nesting modeling through a logistic regression. Based on these limitations – provided the physical habitat characteristics of the lakeshore remain constant – there is no evidence that climate change will have an adverse impact on loons. In fact, clarity of the lake -- the main limnological characteristic for determining favorable habitat in the logistic regression -- is expected to improve based on IPCC projections of climate. However, there were numerous factors that were not considered, including more detailed nutrient and food web modeling of the lakes.

Publications in review:

- Hunt, R.J., Walker, J.F., Muffels, C.T., Selbig, W.R., Westenbroek, S.M., and Regan, R.S., in review, Simulating Coupled Groundwater/Surface-Water Flow using GSFLOW in the Trout Lake Watershed, Wisconsin: U.S. Geological Survey Scientific Investigations Report.
- Michael W. Meyer, Walker, J.F., Kenow, K.P., Rasmussen, P.S., Garrison, P.J., Hanson, P.C., and Hunt, R.J., in review, Potential effects of climate change on inland glacial lakes and implications for lake-dependent biota in Wisconsin, Final Report submitted to Wisconsin Focus on Energy, Research Grants: Environmental and Economic Research and Development Program Grant 08-06.

Released Publications:

- Walker, J.F., Hunt, R.J., Hay, L.E., and Markstrom, S.L., 2012, Watershed scale response to climate change—Trout Lake Basin, Wisconsin: U.S. Geological Survey Fact Sheet 2011–3119, 6 p. (also available at http://pubs.usgs.gov/fs/2011/3119/).
- Westenbroek, S.M., Doherty, J., Walker, J.F., Kelson, V.A., Hunt, R.J., and Cera, T.B., 2012, Approaches in highly parameterized inversion: TSPROC, a general time-series processor to assist in model calibration and result summarization: U.S. Geological Survey Techniques and Methods, book 7, chap. C7, 79 p., 3 apps. (also available at http://pubs.usgs.gov/tm/tm7c7/).

CONNECTICUT

USGS works with the Connecticut Department of Energy and Environmental Protection (CTDEEP) and other stakeholders to determine flow-duration statistics related to critical biological stages. Specifically, studies help to develop multiple linear regression equations for determining flow-duration statistics and estimates of flow exceedences (ranging from 25- and 99-percent) during six "bioperiods"—including (1) Salmonid Spawning (November), (2) Overwinter (December-February), (3) Habitat Forming (March-April), (4) Clupeid Spawning (May), (5) Resident Spawning (June), and (6) Rearing and Growth (July-October). The information is critical as State streamflow regulations recognize that in order to provide a healthy aquatic environment, streamflow needs to vary throughout the year. Regression equations also were developed to estimate flow exceedences without reference to a bioperiod. In total, 32 predictive equations were developed. Relations relating flow statistics to basin and climatic characteristics at monitored streams can be used to produce unbiased estimates of select flow exceedences statewide. (***Contact***: Liz Ahearn, eaahearn, (860) 291-6745).

Key finding from the recent USGS study:

- Significant explanatory variables were: drainage area, percentage of area with coarse-grained stratified deposits, percentage of area with wetlands, mean monthly precipitation (November), mean seasonal precipitation (December, January, and February), and mean basin elevation

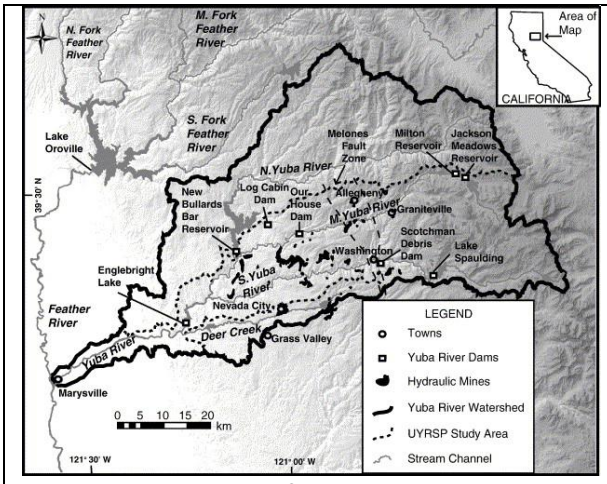
- Regression equations to estimate high and median flows (25- to 75-percent exceedances) are better predictors (smaller variability of the residual values around the regression line) than the equations to estimate low flows (less than 75-percent exceedance).
- Flow-duration statistics and the 32 regression equations for estimating flow-duration statistics in Connecticut are stored on the U.S. Geological Survey World Wide Web application "StreamStats" (http://water.usgs.gov/osw/streamstats/index.html).

Related Publication:

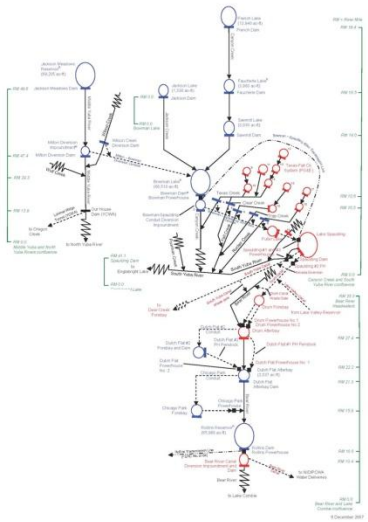
- Ahearn, E.A., 2010, Regional Regression Equations to Estimate Flow-Duration Statistics at Ungaged Stream Sites in Connecticut: U.S. Geological Survey Scientific Investigations Report 2010–5052, 45 p. (Also available at http://pubs.usgs.gov/sir/2010/5052/.)

CALIFORNIA

The key policy question in California is how to achieve water supply reliability while protecting ecosystem health. Environmental flow-related studies in the California Water Science Center provide the scientific information needed for resource managers to achieve these goals. These studies focus on the relationships and interconnections between precipitation and streamflow, physical and biological processes in rivers and estuaries driven by flow, and water operations and diversions. Virtually all of the watersheds in California are a complex combination of the natural watershed and man-made systems, and all of the major water facilities in the state are subject to operational restrictions based on environmental standards, many of them related to temperature conditions required by at-risk fish species. A core guiding principle for CAWSC environmental flow studies is that ecosystem health is determined by the maintenance of physical and ecological process, and that these are much more complex than the amount of water allowed to remain instream.



Yuba River watershed from Curtis et al., 2005, Conceptual model of sediment processes in the upper Yuba River watershed, Sierra Nevada, CA, Geomorphology, 68, 3-4, p. 149-166.



Yuba-Bear Hydroelectric Project Schematic, Nevada Irrigation District, 2007, FERC Project No. 2266.

Figure illustrates the difference between a conceptual model of the Yuba River watershed system based on natural features, and one based on water operations for the hydroelectric system. The complete water supply system is not represented.

USGS CAWSC Science Themes in Support of Environmental Flows

(1) USGS gaging stations provide critical information across the state for environmental flow studies and related management decisions. One example is the study of spawning habitat in the Yuba River between the foot of Englebright Dam and the Feather River confluence (USFWS Yuba River Spawning Report, August 2010).

(2) The effects of water diversions, barriers, and operable gates on flows in the Sacramento-San Joaquin Delta and the resulting effects on fish and the estuarine ecosystem have been the subject of conflict and billions of dollars of state and federal investments. Examples of ongoing CAWSC science directly related to this management question include research on fine-scale relationships between fish movement and flow during operational experiments (e.g. "Delta Cross Channel studies"), flow dynamics, sediment processes, and vegetation in relation to at-risk species habitat (e.g. work on sudden clearing of Estuary waters, turbidity influence on delta smelt spawning), and studies which combine field measurements and modeling to characterize the relationship between natural tidal flows, man-made channel geometry, and water quality (e.g. Franks Tract studies).

(3) Future climate conditions will likely cause water temperatures to rise throughout the Central Valley/ San Francisco Estuary system, changing the relationship between flows and stream habitat conditions. If it comes to pass, this would have significant ramifications for all of the water operation requirements designed to achieve downstream temperature ranges and unimpaired flows may not be cool enough to sustain at-risk fish species. (e.g. Brown and Bauer 2010, Cloern et al. 2011). The effects of climate change may also interact with other ongoing changes in the Delta to reduce habitat quality for at-risk species (Cloern et al. 2011, Brown et al. 2012).

(4) Estimating unimpaired flows, both historical and under future climate scenarios, is a key scientific need of agencies responsible for water rights management, water operations, and endangered species and ecosystem managers. The CAWSC has collaborated with CA Department of Water Resources, hydroelectric agencies, and the State Water Resources Control Board on several of these studies. Results include a temperature model for the Klamath River (Flint and Flint, 2008), the Feather River (Koczot, Markstrom, and Hay, 2011), the Yuba River (current project), and five southern Sierra basins (current project).

(5) Stressor-response models for benthic community assemblages in selected streams and rivers throughout the state have identified land use/ cover and large-scale climatic variables affecting flow, water quality and habitat quality as the principal factors affecting this segment of the ecosystem (Brown and May project description). One current project will specifically assess the relation of flow to benthic macroinvertabrate communities in southern California in cooperation with the Southern California Coastal Water Research Project (aka the "Southern California Flows project").

(6) Distinguishing the effects of water operations and infrastructure on flow from other stressors on native fish and ecosystem processes is an ongoing and core information need. One current project involves collaboration with the USFWS to develop a statistical life-history model for delta smelt, a listed species.

PENNSYLVANIA

The USGS has been involved in developing detailed water budgets for a number of watersheds over the past 10 years. This work has been done in cooperation with the Delaware River Basin Commission. Annual water budgets have been developed for the French Creek, East Branch Brandywine Creek, Wissahickon Creek, Pocono Creek, Greenwood Branch of the Rancocas Creek, and Cooper River watersheds. A regional ground-water-flow model (MODFLOW-96) was also developed for the French Creek Basin in Chester County, Pa. The model was used to assist water-resource managers by illustrating the interconnection between ground-water and surface-water systems. (***Contact:*** Ron Sloto, rasloto@usgs.gov, (610) 321-6072).

Related publications:

- Sloto, R.A., 2003, Geohydrology of the French Creek Basin and simulated effects of drought and ground-water withdrawals, Chester County, Pennsylvania: U.S. Geological Survey Water-Resources Investigations Report 03-4263, 82 p. (http://pubs.er.usgs.gov/publication/wri034263)
- Sloto, R.A., and Buxton, D.E., 2005, Water budgets for selected watersheds in the Delaware River Basin, Eastern Pennsylvania and western New Jersey: U.S. Geological Survey Scientific investigations Report 2005-5113, 37 p. (http://pubs.er.usgs.gov/publication/sir20055113)

The USGS, in cooperation with the U.S. Environmental Protection Agency (USEPA) and the Delaware River Basin Commission as part of the USEPA's Framework for Sustainable Watershed Management Initiative evaluated the effect of reduced recharge from land-use changes and additional ground-water withdrawals on stream base flow in the Pocono Creek watershed in Monroe County. Between 2000 and 2020, the population of Monroe County is expected to increase by 70 percent, which will result in substantial changes in land-use patterns. Two models were used. A Soil and Water Assessment Tool (SWAT) model developed by the USEPA provided areal recharge values for 2000 land use and projected full build-out land use. The USGS MODFLOW-2000 ground-water-flow model was used to estimate the effect of reduced recharge from changes in land use and additional ground-water withdrawals on stream base flow. A USGS report was published documenting the ground-water-flow-model simulations. (***Contact:*** Ron Sloto, rasloto@usgs.gov, (610) 321-6072).

The USGS was an active partner in the 2008 update of Pennsylvania's State Water Plan. The USGS, in cooperation with DEP, developed the Water-Analysis Screening Tool (WAST) to provide water managers with an assessment of water availability as related to aquatic-resource uses. The tool estimates water availability for current and projected water uses on the basis of low-flow stream statistics. This dynamic GIS-based Screening Tool allows users to quickly identify areas in the state where water use is approaching or exceeding availability using information from over 10,000 watersheds ranging in size from 10 to 2,000 square miles. (***Contact:*** Marla Stuckey, mstuckey@usgs.gov, (717) 730-6950).

Related Publications:

- Stuckey, M.H., and Kiesler, J.L., 2008, User's guide to the Water-Analysis Screening Tool (WAST) – A tool for assessing available water resources in relation to aquatic-resource uses: U.S. Geological Survey Open-File Report 2008-1242, 19p. http://pubs.usgs.gov/of/2008/1242/
- Stuckey, M.H., 2008, Development of the Water-Analysis Screening Tool used in the initial screening for the Pennsylvbania State Water Plan update of 2008: U.S. Geological Survey Open-File Report 2008-1106, 9p. http://pubs.usgs.gov/of/2008/1106/
- Stuckey, M.H., 2006, Low-flow, base-flow, and mean-flow regression equations for Pennsylvania streams: U.S. Geological Survey Scientific Investigations Report 2006-5130, 84p. http://pubs.usgs.gov/sir/2006/5130/

The USGS has worked with the Chester County Water Resources Agency in Chester County, Pennsylvania for more than 40 years to assess water quality using benthic-macroinvertebrates and water chemistry as indicators. IBIs have been produced based on the historical data collected under base-flow conditions (every Fall) during the long-term program. A USGS report, "A benthic-macroinvertebrate index of biotic integrity and assessment of conditions in selected streams in Chester County, Pennsylvania, 1998–2009," was published in September 2012 on conditions over the last decade. This study is integrated with other activities used to measure and describe water resources in the County, providing the County with information it needs for sound water-resources management. This includes, for example, monitoring streamflow at 17 stations in Chester County streams. (Access the Chester County/USGS Monitoring site). (***Contact***: Andrew Reif, agreif@usgs.gov, (610) 321-6069).

The USGS, in cooperation with the Pennsylvania Department of Environmetnal Protection, Susquehanna River Basin Commission, and The Nature Conservancy, has recently developed the **Ba**seline **S**treamflow **E**stimator (BaSE) to estimate baseline streamflow at a daily time scale for ungaged streams in Pennsylvania using data collected during water years 1960–2008 (report at http://pubs.usgs.gov/sir/2012/5142/). An in-depth evaluation of flow regimes to promote instream ecological health often requires streamflow information obtainable only from a time series hydrograph. Daily mean streamflow is estimated in BaSE using a methodology that equates streamflow as a percentile from a flow duration curve for a particular day at an ungaged location with streamflow as a percentile from the flow duration curve for the same day at a reference streamgage that is considered to be hydrologically similar to the ungaged location. As part of this work, new regression equations were developed to estimate 17 flow duration exceedances and new basin characteristics were added to StreamStats More information can be found at the project website. (***Contact:*** Marla Stuckey, mstuckey@usgs.gov, (717) 730-6950).

The USGS is also involved in the Water Census Delaware River Basin pilot study, implemented through the WaterSMART initiative (http://water.usgs.gov/wsi/). As part of this work, the USGS is developing a streamflow estimator tool similar to BaSE to generate daily mean flows for ungaged streams within the Delaware Basin. These daily mean flows will be used, along with compiled biological data (fish and invertebrate) to define flow and aquatic assemblage response for tributaries. (***Contact:*** Marla Stuckey, mstuckey@usgs.gov, (717) 730-6950).

TEXAS

USGS, in collaboration with the Northeast Texas Municipal Water District and the Texas Commission on Environmental Quality's Clean Rivers Program, is evaluating physical and biological characteristics at the meso-habitat scale in relation to environmental flow prescriptions for streams in the Cypress Basin in northeast Texas. The study is part of a broader Cypress/Caddo Lake Flows project, facilitated by the Nature Conservancy's Sustainable Waters Program and the Caddo Lake Institute, which seeks to assure adequate instream flows to sustain the ecological, recreational and economic values of Caddo Lake, its watershed, and the Cypress Basin. (***Contact***: Bruce Moring, jbmoring@usgs.gov, (512) 927-3585).

ARKANSAS

Proposed: The Arkansas WSC is pursuing possible projects in cooperation with the Arkansas Game and Fish Commission and the USGS Arkansas Cooperative Fish and Wildlife Research Unit. Proposed projects help to determine expected and observed flows at gaged and ungaged sites, and to produce a conceptual model that would describe flow periods important to various biological species or communities (such as, for example, adequate springtime flows for paddlefish and bottomland hardwoods, etc. and adequate summertime flows for darters). (***Contact***: Jim Petersen, petersen@usgs.gov, (501) 228-3620).

MISSISSIPPI

An issue identified by USGS and many of its partners in Mississippi is the need to establish effects of different flow regimes on biological communities and stream habitat. Through a myriad of projects, the Mississippi WSC has established a robust biological and habitat monitoring program in concert with several Cooperators, including the Band of Choctaw Indians and the Mississippi Department of Environmental Quality (MDEQ). For example, the USGS conducts macroinvertebrate and habitat assessments in streams in the Mississippi Delta and other selected sites throughout the State. At this time (2013), no projects directly assess the effects of flow alteration on the ecological health of Mississippi streams; however, USGS Mississippi Water Science Center and its partners have initiated projects including a statewide update of streamflow statistics and development of a GIS-based watershed boundary dataset that have laid a firm foundation for future environmental flow investigations (***Contact:*** Matt Hicks, mhicks@usgs.gov, (601) 933-2932).

Knowledge of the magnitude and frequency of low flows and flow- duration characteristics is important for the optimal development of surface-water resources in Mississippi and represents a strong foundation for the assessment of future ecological flow studies. The USGS in cooperation with the MDEQ is in the process of updating the low-flow statistics at continuous and partial record streamflow locations throughout the State. Updates may include up to 533 previously published locations and other locations where data have been collected since 1991. The updated low-flow statistics will also be used to prepare regional regression equations for predicting low-flow statistics for streams in ungaged basins and all statistics and regional equations will be accessible in the StreamStats database . (Project description: http://ms.water.usgs.gov/projects/LowFlow/) (***Contact:*** John Storm, jbstorm@usgs.gov, (601) 933-2951).

Additionally, the USGS, in cooperation with the MDEQ, U.S. Department of Agriculture-Natural Resources Conservation Service, Mississippi Department of Transportation, U.S. Department of Agriculture-Forest Service, and the Mississippi Automated Resource INformation System developed a 1:24,000-scale Watershed Boundary Dataset for Mississippi including watershed and sub-watershed boundaries, codes, names, and areas. The Watershed Boundary Dataset for Mississippi provides a standard geographical framework for water-resource assessments, ecological flow studies, and selected land-resources planning efforts. All of the data including watershed boundaries and drainage-area data are available for download. (Project description: http://ms.water.usgs.gov/projects/HUC/) (***Contact:*** Ken Van Wilson, kvwilson@usgs.gov, (601) 933-2922).

Related Publication:

- Wilson, K.V., Jr., Clair, M.G. II, Turnipseed, D.P., and Rebich, R.A., 2009, Development of a Watershed Boundary Dataset for Mississippi: U.S. Geological Survey Open-File Report 2008–1198, 8 p (Also available at http://pubs.usgs.gov/of/2008/1198/.)

UTAH

The USGS is collaborating with TNC, Arizona Department of Water Resources, and Salt River Project on an ecological flows study, which began in 2010, in the Upper Verde River basin. This study is designed to examine, in detail, the application of the Ecological Limits of Hydrologic Alteration (ELOHA) framework (a scientific framework that evaluates ecological water needs at multiple spatial scales) as a basis for understanding the relations between streamflow characteristics and aquatic species response. The assessment in the Upper Verde River includes evaluating the hydrologic record, how far the seasonal hydrology departs from the historic record, the amount of habitat needed to support different types of aquatic species under different flow volumes and aquifer levels, the status of native and nonnative species, and the water budget including groundwater that helps identify reaches vulnerable to drying. Hydrologic data collection is a major emphasis of this study because such data directly supports the development of habitat availability models across a range of water volumes and provides information on seasonal flow characteristics that may be limiting the abundance and distribution of aquatic fauna in the Upper Verde River (Project description available at: http://az.water.usgs.gov/projects/E7000/index.html .) (***Contact***: Anne Brasher, abrasher@usgs.gov, (435) 259-3866).

LOUISIANA

USGS Louisiana Water Science Center has worked with the State of Louisiana Department of Transportation and Development on studies related to environmental flow, in large part focused on low-flow characteristics and flood magnitude and frequency. Low-flow characteristics and flood magnitude and frequency study results have been documented for the entire state in several comprehensive reports (listed below) (**Contact**: John Lovelace, jlovelac@usgs.gov, (225) 298-5481 x3210). A study to update the period of record with the last 10-15 years of streamflow statistics for flood magnitude and frequency for the entire state is expected to be completed in 2014. (**Contact**: Scott Perrien, 225-298-5481 x3621).

Studies relating environmental flows to ecological communities have been documented for locations within southern Louisiana and include work completed through USGS and EPA cooperative efforts. For example, the USGS NAWQA Program looked at factors affecting temporal trends in ecological communities, including climate, water quality, and environmental flow conditions and habitat. Study results indicated some detectable trends for dissolved nitrogen concentrations and streamflow conditions up to 90 days prior to biological sample collection. A cooperative study with EPA documented effects of dissolved oxygen on macroinvertebrate and fish communities in extremely low flow streams and bayous in southern Louisiana prairie and large river alluvial ecoregions, and resulted in documented average thresholds for community metrics. (**Contact**: Scott Mize, svmize@usgs.gov, (225) 298-5481 x3600).

Related Publications:

- Justus, B.G., Mize, S.V., Wallace, J., and Kroes, D., 2013, Invertebrate and fish assemblage relations to dissolved oxygen minima in lowland streams of southwestern Louisiana. River Research and Applications (Also available at http://onlinelibrary.wiley.com/doi/10.1002/rra.2623/abstract/).
- Miller, M.P., Kennen, J.G., Mabe, J.A., and Mize, S.V. 2011. Temporal trends in algae, benthic invertebrate, and fish assemblages in streams and rivers of the south-central United States, 1993-2007. Hydrobiologia v. 684, p. 15–33. (Also available at http://dx.doi.org/10.1007/s10750-011-0950-7).

A continuing focus of USGS studies has been on flow releases, diversions, mainly from the Mississippi River, and the yearly operation of these control structures on receiving water bodies (other streams, lakes, and estuaries). The effects of increased streamflow and sedimentation from these diversions as well as changes in water quality associated with diversion releases can ultimately impact ecological communities living within these receiving waters. As part of the state of Louisiana's coastal restoration efforts http://lacoast.gov/new/default.aspx, the State intends to use river diversions to re-nourish sediment and nutrients and restore subsiding coastal wetlands. Long-term effects of diversion releases are relatively unknown and are in need of further investigation. In 2008, the Bonnet Carré floodway (diversion) was opened to allow Mississippi river water into Lake Pontchartrain briefly to relieve pressure upon levees along the river. Mississippi river water diverted into Lake Pontchartrain has shown some effects on water quality and phytoplankton communities within the lake. A follow up study of similar effects due to the 2011 Mississippi river flood event are almost complete and are expected to show effects of this massive diversion into the lake and extending into the surrounding Mississippi Sound. (**Contact**: Scott Mize, svmize@usgs.gov, 225-298-5481 x3600).

Related Publications:

- Mize, S.V., and Demcheck, D.K., 2009, Water quality and phytoplankton communities in Lake Pontchartrain during and after the Bonnet Carré Spillway opening, April to October 2008, in Louisiana, USA. Geo-Marine Letters v. 29, p. 431-440 (Also available at http://link.springer.com/article/10.1007%2Fs00367-009-0157-3).
- Ensminger, P.A., and Wright, L.S., 2003, Low-flow characteristics of Louisiana streams: Louisiana Department of Transportation and Development Water Resources Technical Report no. 70, 162 p (Also available at http://la.water.usgs.gov/publications/pdfs/TR70.pdf.)
- Wright, L.S., and Ensminger, P.A., 2004, Regionalized regression equations for estimating low-flow characteristics for selected Louisiana streams: Louisiana Department of Transportation and Development Water Resources Technical Report no. 75, 32 p (Also available at http://la.water.usgs.gov/publications/pdfs/TR75.pdf.)
- Ensminger, P.A., 1998, Floods in Louisiana, magnitude and frequency (5th ed.): Louisiana Department of Transportation and Development Water Resources Technical Report no. 60, 333 p.

MASSACHUSETTS

A large fraction of Massachusetts' 10,000 miles of perennial streams have been subjected to human alterations for hundreds of years, including water withdrawals, treated wastewater discharges, and dam construction, as well as forest clearing and urbanization in their associated watersheds. Such alterations have affected streamflow regimes, water quality, and habitat

integrity for fish and other aquatic biota. In recent years, the USGS, has completed a number of CWP studies with the Massachusetts Departments of Environmental Protection, Conservation and Recreation, and Fish and Game, to assess (1) natural streamflow regimes in the State; (2) character and extent of human alteration of these regimes; and (3) effects of altered environmental conditions and stream flows on native fish communities in Massachusetts streams. The results of this cooperative research program are described in a series of reports, grouped below by subject area.

(1) ***Natural streamflow regimes.*** Armstrong and others describe the natural streamflow regimes of southern New England, and the geographic and climatic factors that govern these regimes; see http://pubs.usgs.gov/sir/2007/5291/. Archfield and others document the Massachusetts Sustainable Yield Estimator (MA SYE), a new computer-modeling tool for estimating daily streamflows at ungaged sites in the State; see http://pubs.usgs.gov/sir/2009/5227/. The MA SYE served as a prototype for a regional tool (CRUISE) covering the Connecticut River Basin. See http://webdmamrl.er.usgs.gov/s1/sarch/ctrtool/index.html.

(2) ***Human alteration of flow regimes.*** The net effects of withdrawals and treated-wastewater discharges on streamflows were assessed by Weiskel and others at the outlets of 1,395 nested Massachusetts sub-basins, using the MA SYE tool. Impervious cover, dam storage, and degree of water-quality impairment were also described at the sub-basin scale; see http://pubs.usgs.gov/sir/2009/5272/.

(3) ***Effects on native fish communities.*** Armstrong and others analyzed fish abundance data from 669 stream sites previously sampled by the MA Dept. of Fish and Game, and related the abundance and richness of fluvial species at these sites to both physical basin factors and the anthropogenic factors described above. Percent impervious cover and the depletion of August median flows by withdrawals were significantly related to declines in fish abundance and species richness; see http://pubs.usgs.gov/sir/2011/5193/

The MA Executive Office of Environmental Affairs and its agencies are now implementing new environmental flow policies through the Sustainable Water Management Initiative based in part upon the results of these studies. New environmental flow CWP studies by USGS in Massachusetts includes the development of new methods of reservoir classification, and ground-water withdrawal impacts on regional stream flow in Southeastern Massachusetts. Contact: Peter Weiskel, pweiskel@usgs.gov (508-490-5026).

NEBRASKA **(to come)**