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Linking hydrological change and ecological response in streams and rivers of the eastern United States

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Abstracts

SESSION 1: ISSUES AND INFORMATION NEEDS OF FEDERAL AGENCIES

INSTREAM FLOW ISSUES AND INFORMATION NEEDS IN THE APALACHICOLA-CHATTAHOOCHEE-FLINT RIVER BASIN OF ALABAMA, FLORIDA, AND GEORGIA

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The large and biologically diverse ACF Basin of Alabama, Florida, and Georgia, has become a battleground for instream flow issues in the southeast U.S. A large number of existing and proposed dams, a rapidly growing human population, concomitant growth in consumptive water use, and an increasing reliance upon irrigation in agriculture, are all contributing to hydrologic and other habitat alterations in the basin that threaten its aquatic biodiversity. In 1997, Congress passed the ACF Basin Interstate Water Compact, which created the ACF Basin Commission. The ACF Commission was charged with negotiating an equitable apportionment of the surface waters of the basin between the three states. The subsequent negotiations focused mostly on the operations of the existing federally owned mainstem dams and reservoirs, but not on allocating water for consumptive uses in each state. Failing to reach an agreement within the time allotted, the Compact terminated in 2003, dissolving the Commission. All three states are now parties to law suits naming the Corps of Engineers as defendant, and most recently, Alabama and Florida have given notice of their intent also to sue the Corps for alleged violations of the Endangered Species Act (ESA). I discuss some of what is known and still unknown about the flow-related habitat needs of the ESA-listed species in the basin. The overarching need in the Basin is for an instream flow prescription that managers and regulators would apply adaptively to decisions affecting the water resource. The prescription should represent an informed societal choice about the desired balance between human uses of the Basin's waters and the ecological integrity of those waters. However, many questions about how to achieve that balance are not yet answered, and the daily needs of water management decisions cannot wait until they are answered. I suggest that the water management community of the basin collaborate in developing: 1) an instream flow prescription that is based upon the best available science; and 2) a hydro-biological monitoring/research program that is designed to improve upon the prescription and adapt it to changing circumstances over time.

EVOLUTION, ECOSYSTEM PATHWAYS, RIVERS, ETERNITY, AND THE SEA …ARE DIADROMOUS SPECIES A FORGOTTEN VITAL LINK?

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Diadromous fishes form a vital, and perhaps often overlooked, link among riverine, estuarine, and marine ecosystems. For perspective, this presentation explores the global roles of river systems as critical pathways for evolution of vertebrate species, biogeochemical processes, and important links between land and sea throughout geological time. Since the Silurian period over 400 million years ago the diadromous species have moved along the evolutionary pathway of the vertebrates, the major river basins of the world. We briefly examine the hypothetical ecological role of diadromous fishes using the example of the American shad, to demonstrate river connections with large marine ecosystems and federally managed fisheries. Research needs are identified.

HYDROLOGIC ISSUES AND INFORMATION NEEDS OF THE NATIONAL PARK SERVICE

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Many challenges face the National Park Service (NPS) today as growth, development and drought pressures increase in the eastern United States. The NPS manages 388 units nationwide, with roughly 250 of those units occurring east of the 100th meridian. The NPS is charged by Congress "to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them ***unimpaired*** for the enjoyment of future generations" (16 USC 1). Park ecosystems are increasingly impacted by development pressures and decisions made within legal and administrative boundaries that seldom, if ever, coincide with park and watershed boundaries. As a result, water and water-related resource attributes are being threatened by reservoir construction and operation, new surface water diversions, groundwater pumping, requests to the NPS to sell or lease water, channel alteration, floodplain development and/or encroachment, and water pollution. The greatest challenge facing the NPS is how do we assess "impairment" and develop the necessary scientific tools to determine our management objectives for desired future resource conditions.

Current NPS issues in the eastern United States include: potential flow and resource effects of a proposed tributary dam on Bear Creek at Buffalo National River in Arkansas; cumulative reservoir impacts on wild and scenic river values at Obed Wild and Scenic River; resource impacts caused by bank stabilization and the construction of artificial island complexes for threatened and endangered species on the Missouri River in the Missouri River National Recreation area; impacts of expanded groundwater

development on wetlands at Cape Cod National Seashore; and the identification of instream flow needs for use in interstate stream compacts and water allocation negotiations at the Chattahoochee River and Delaware Water Gap National Recreation Areas.

The NPS strives to develop sound science and data for use in water allocation issues and water right negotiations and must develop management tools, including predictive models, to help us assess the current and future impacts of water resource use and development. Current issues of interest to the NPS include the development of baseline inventories and habitat simulation models for native fish, insects and mussels; development of methods to predict impacts of flow and ground water alterations on wetland and riparian communities; development of methods to assess the cumulative impact of reservoir construction and ground water pumping on surface water flow and regional aquifers; development of methods to assess impacts of flow changes on recreational, aesthetic, historic and cultural values; and finally, the development of economic models to assess the importance of resource protection in complex water allocations.

RESEARCH NEEDS FOR THE EFFECTIVE USE OF HYDROLOGICAL AND ECOLOGICAL INDICATORS OF ECOSYSTEM INTEGRITY FOR ENHANCED STAKEHOLDER COLLABORATION

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The Corps of Engineers has developed a Civil Works Strategic Plan and Environmental Operating Principles, based on ecological principles of environmental sustainability, in order to better balance water resource management objectives. Fundamental to implementation of this plan and attendant principles is true stakeholder collaboration and sound scientific support for acceptable and defensible decision-making. Stakeholder collaboration is a process involving policy, practice, and outcomes. Recognition and inclusion of societal needs as goals and objectives are developed is a critical early step in sustainable water resource management. Scientific support is provided through the development of assessment techniques, indicators and metrics, predictive capabilities, and decision support technologies. Effective use of indicators is based on accepted ecosystem attributes and drivers that can be readily measured to describe changes in environmental conditions over time and space. The concepts of adaptive management and performance measures provide a framework for the effective use of hydrologic and ecologic indicators but require scientific evaluation in the context of temporal and spatial considerations. Traditionally, existing indicators (e.g., flow, water quality constituents, biotic indices) have been used in a more "site" specific evaluation and often for a brief period in time. As larger, system-level assessment, restoration, and management activities (e.g., Everglades, Upper Mississippi River, Columbia River, Coastal Louisiana, etc.) develop, issues of scale and effective indicator selection will require additional scientific support. Emerging technologies (e.g., LIDAR, hyperstpectral imagery, and other remotely sensed signals) offer an opportunity to measure and monitor over larger scales, and provide novel approaches to indicator use in evaluating ecosystem integrity.

HYDROLOGICAL AND ECOLOGICAL CONNECTIVITY UNDER THE CLEAN WATER ACT: SCIENCE GAPS AND RESEARCH NEEDS

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The U.S. Supreme Court held in *Solid Waste Agency of Northern Cook County* (*SWANCC*) that the Clean Water Act (CWA) is not intended to protect isolated, intrastate waters based solely on their use by migratory birds (January 2001). While the Court's decision did not create a brightline test for what Congress intended to regulate under the CWA, the Court's reasoning implies that the CWA intended some "connection" to navigability and that isolated waters need a "significant nexus" to navigable waters to be jurisdictional. Subsequent to *SWANCC* there have been many lawsuits challenging CWA jurisdiction over tributaries; much of the post-*SWANCC* debate addresses headwaters and intermittent and ephemeral streams. The issue of hydrologic connectivity is particularly significant. The degree of hydrologic connectivity that would be required for a water to be regarded as jurisdictional is ultimately a policy issue–however, there are a great many areas where science can inform that decision-making. This presentation will briefly discuss the *SWANCC* decision, current issues regarding its impact on CWA jurisdiction over isolated waters, and specific science gaps and research needs.

SESSION 2: ISSUES AND INFORMATION NEEDS OF STATE REGULATORY AGENCIES

THE EVOLUTION OF AN INSTREAM FLOW POLICY IN GEORGIA

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WHAT DO YOU MEAN I DO NOT HAVE ENOUGH INFORMATION ON INSTREAM FLOW REQUIREMENTS TO SUPPORT OUR POSITION – KEY SCIENCE GAPS FROM THE PERSPECTIVE OF A STATE RESOURCE AGENCY

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State resource agency staffs are required to protect and conserve the natural resources of their states as the public trustee of these resources. This frequently places them in either legal or quasi-legal proceedings concerning water issues that range from simple instream construction permitting issues to water adjudications of entire watersheds or states. All of these proceedings require significant evidence to support agency positions and are usually challenged by project owners or developers and their agents. Failures in these proceedings can be traced to the some key gaps in our understanding of how river systems and their inhabitants function along with the value of these resources.

A good deal is understood about how river systems function. There are fundamental understandings of flow dynamics, water chemistry, sediment transport, and aquatic community functioning. Examples in the Midwest include: development of improved synthetic hydrographs; models that link temperature to discharge; and improved relationships between fish communities and temperature. However, many of these relationships are not yet at a fine enough detail to support state resource agencies in legal water proceedings. While we understand many of the larger scale variables, we do not have the necessary relationships between many stream processes such as channel formation and maintenance, and sediment and woody debris transport along with their associated macro- and microhabitat characteristics and discharge that are required to provide the needed accuracy and precision to estimating the effects of water use changes on aquatic communities. The existing relationships usually only provide crude estimates of population changes. Essential information on the timing, duration and magnitude of discharge events to support stream processes, thus habitat, are missing and needed at this time**.** There is also little information on the long-term effects of already prescribed instream flows regimes at various physical and biological scales so we have not been able to learn how stream processes change from these new regimes over time.

At the biological scale, additional work is needed to understand the inherit variability of biological communities from both the temporal and spatial aspects. Little is known about how biological communities function on either short- or long term timeframes within the discharge and habitat constraints placed upon them. The incorporation of population dynamics into instream flow analysis needs much more work to be a usable tool for state agency staff. There is also a poor understanding of how aquatic communities use and move through watersheds and work is needed here to improve instream flow recommendations. Finally it is essential that new methods be developed that can accurately determine the economic value of the resource and changes to it. Without this final piece of the puzzle, state resource agency staff and the aquatic resources of this county will continue to be at a distinct disadvantage in many water proceedings.

MANAGING WATER RESOURCES IN NEW JERSEY: AN OVERVIEW FROM A REGULATORY PERSPECTIVE

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It is an increasingly complex challenge to ensure adequate water supply and quality for present and future generations and protect the State's natural resources. Requests for new or increased diversions consider an expanding list of factors, including: intended water use, anticipated impacts of the proposed diversion on stream flow, groundwater levels, saltwater intrusion, wetlands, threatened and endangered species habitats and movement of ground water contamination. Water supply planning and regulatory programs work to promote water conservation, use of alternative sources for non-potable purposes and the most efficient use of existing supplies. Regional studies are funded to assess the status of areas of water supply concern, assist in determining suitable locations for new sources of supply and potential impacts associated with increased withdrawals. As water demands climb and environmental protection measures improve, it is important to continue to develop practical, scientifically defensible assessment tools and operating practices that most efficiently utilize existing supplies in order to achieve our water resource management objectives.

THE CHALLENGE OF INTERSTATE FLOW MANAGEMENT: THE DELAWARE BASIN'S EFFORTS TOWARDS ECOLOGICALLY SUSTAINABLE USE AND WATER SUPPLY

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Flow management in the Delaware River Basin has been an issue of contention since the 1700s, long before the U.S. Supreme Court defined the basic water management rules for the basin in 1954. Over a half-century after the Supreme Court Decree, a collaborative effort between New York City, state, interstate, and federal government agencies, as well as the non-profit and academic sectors, is seeking to facilitate sustainable management of Delaware Basin waters into the future. There are a range of unique challenges involved in interstate water management and the scientific uncertainty associated with defining ecological flow needs in the Delaware Basin only enhances these challenges.

Studies on defining ecological flow needs are initially focused on the heavily regulated Upper Delaware, using a blend of techniques in an attempt to address the needs of target species and the ecosystem as whole. A 2-dimension hydrodynamic model is being developed for representative reaches in the Upper Delaware and will be coupled with habitat preference data for a range of species and species guilds. To enhance this approach, we will integrate Indicators of Hydrologic Alteration analysis and targeted research and plan to undertake a set of expert workshops to translate available information into flow recommendations that incorporate inter- and intra-annual variability.

The basin decision-makers have agreed to take these scientific findings into account when assessing policy decisions on water allocation and instream flows. Yet defining ecological flow recommendations without empirical stressor-response relationships between flow alteration and ecological integrity is a challenge. One of the advantages in the Delaware Basin is having the forum established to keep communications open between the parties leading the scientific studies and the water policy-makers. Upper Delaware studies should be valuable basin-wide, as the basin states begin to examine instream flow protection policies for regulated and unregulated streams. The experience of the interstate flow management process in the Delaware Basin provides guidance on research needs that should be applicable to basin-wide flow management throughout the country.

MESSAGE IN A BOTTLE: THE FLORIDA "MINIMUM FLOW" DILEMMA

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An eight-fold increase in surface water and groundwater withdrawals during the last 50 years has resulted in declining flows in a growing number of Florida streams. To regulate consumptive water use and provide for the protection of aquatic ecosystems, the Florida Legislature enacted the Florida Water Resources Act in 1973. Contained in the legislation was a mandate for establishment of "minimum flows and levels" (MFLs) in streams and lakes. The Act defined MFLs as "the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area," but provided no specification that MFLs must be reflective of the levels, timing, duration, and frequency characteristic of natural stream flow patterns. The Act also created Florida's five water management districts and charged them with setting MFLs within their respective boundaries using the "best available information". Florida's state fish and wildlife agency, the Florida Fish and Wildlife Conservation Commission (FWC), was given no statutory authority in the legislation and has acted in an advisory capacity in the MFL process. To date the process used to implement most MFLs has not taken into consideration the long-term maintenance of biological integrity in the subject stream systems. An example case is Madison Blue Spring in the Suwannee River basin of north Florida. Blue Spring is a first magnitude spring (annual median flow > 100cfs) located within a state park; at times the spring supplies up to one-quarter of the flow for the nearby Withlacoochee River. The spring is located less than one mile from, and shares the same water source as, a newly constructed bottled water plant. The consulting firm hired to formulate and recommend a minimum flow for the spring recommended a minimum flow that was over 40 percent below the historic average flow. The recommendation included an analysis of impacts on only one habitat type (shoals) and gave no consideration to the fact that the Withlacoochee River in the area of Madison Blue Spring is designated by the U.S. Fish and Wildlife Service as critical habitat for the threatened gulf sturgeon (*Acipenser oxyrinchus desotoi*). In an effort to improve the MFL process and ensure protection of aquatic ecosystems, FWC established two research teams dedicated to developing the scientific tools necessary for identifying and establishing flow regimes that are consistent with the natural stream flow patterns. These teams are currently in the process of identifying indicator fish and aquatic invertebrate species and metrics, developing habitat selectivity models for these organisms and metrics, and selecting simulation models appropriate for making minimum flow recommendations that are habitat based and protective of natural ecosystem processes.

SESSION 3: TRADITIONAL AND INNOVATIVE APPROACHES TO CHARACTERIZING HYDROLOGIC ALTERATION AND ASSESSING CHANGES IN STREAM BIOTA

CHARACTERIZING HYDROLOGIC VARIABILITY USING THE NEW "INDICATORS OF HYDROLOGIC ALTERATION" SOFTWARE

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The "Indicators of Hydrologic Alteration" (IHA) method and accompanying software was originally developed in 1996. This statistical hydrology tool is now used by hundreds of ecology and hydrology researchers around the world. It has become the most commonly-used method for characterizing hydrologic variability or change in ecological or environmental flow studies. The IHA method has been cited in more than 100 journal papers or books to date. Many scientists have used the IHA method simply for the purpose of characterizing changes or trends in ecologically-relevant hydrologic parameters, but it has also been used extensively in developing environmental flow targets for rivers. The software is available free-of-charge by downloading from our website at: www.freshwaters.org

The original IHA method included computation of the central tendency and dispersion characteristics (both parametric and non-parametric) for 33 different hydrologic parameters. Version 7 of the IHA software, publicly-released on February 1st (2005), includes computation of 34 new parameters that are called "environmental flow components" or EFCs. The design of these new parameters has been strongly influenced by the work of river scientists working on environmental flow prescriptions in Australia and South Africa. The EFCs are calculated by first dissecting a hydrologic time series (i.e., multi-year hydrograph) into easily recognizable events or patterns that recur on either intra- or inter-annual time scales. These patterns include extreme low flows, low flows, high-flow pulses, small floods, and large floods. The IHA software computes statistical characteristics of these patterns, describing their magnitude, timing, duration, frequency, and rates of change.

We believe that this new suite of EFC parameters will provide ecological researchers with an even more powerful characterization of hydrologic variability and change that will be particularly useful in flow-ecology studies and environmental flow assessments. As with earlier versions of the software, version 7 includes many options for calculating differences between "pre-impact" and "post-impact" time periods, or estimating trends in any of the 67 hydrologic parameters. The new version also includes much-improved graphical capabilities.

PUTTING FLOW ALTERATION INTO A LANDSCAPE CONTEXT

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Predicting ecological responses to flow alteration is complex for non-trivial reasons. First, the "scale" of flow characterization (and potential effect) varies from the local, habitat-driven (ecohydraulic perspective) to the whole watershed, climatically-driven (hydroecological perspective). Second, the "regime" of flow is multi-dimensional, and the relative importance of various components in driving ecological change is often unclear. Third, "other environmental drivers" often independently or interactively (with flow) influence ecological organization and condition. Thus, a major scientific challenge is forging a better understanding of how ecological systems respond to multiple, interacting drivers, and of how the consequences of flow alteration *per se* at some particular scale can be quantified and predicted.

In this presentation, I will argue that advancing our understanding of the ecological consequences of flow alteration requires that we consider the multi-scaled, hierarchical nature of stream ecosystems and that we adopt more mechanistically-based, "functional" approaches that directly relate ecological responses (indicators) to particular environmental drivers (including flow). I will present some results from a collaborative research project in which we explain variation in benthic macroinvertebrate "functional" composition in >300 streams across the western United States. Our success in doing this reflects 1) a clear definition of specific ecological responses (indicators) that can be mechanistically related to specific environmental drivers (including flow), 2) detailed characterization of the "mechanistic" drivers at multiple scales, and 3) adequate biological data sets.

Using these results, I will discuss the opportunities this approach provides for generalizable characterization of ecological responses to flow alteration, and suggest how hydrogeomorphic classification approaches might provide a useful framework for defining stream response potential to flow alteration across the multivariate landscape.

STATE OF THE SCIENCE OF INSTREAM FLOW

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The science that has developed to address the complex issues crucial to protecting instream flows (i.e. water flowing in streams) is an amalgam of ecology, fisheries biology, geomorphology, hydraulics, hydrology, limnology, and social science. This review addresses the current activities in developing and testing key hypotheses in the science of instream flow. The time frame which we have had as scientists for developing and testing has been adequate to provide valid scientific methods to support the administrative programs that protect and restore instream flows. Key advances in understanding hydraulic modeling, habitat selection by fishes, appropriate spatial scales, flow variability, flood-plain vegetation assemblages, channel evolution, and ecosystem processing of nutrients will be highlighted. However, the limitations of science and the need to adopt a realistic philosophy of change will be discussed. Realistic expectation of the role of science and scientists in this ongoing debate must be fostered.

APPLYING CONCEPTS OF LANDSCAPE ECOLOGY TO RIVERS
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Instream flow issues, and the methods to address them, have undergone a continuous evolution from the mid-1970s until the present time. During the period 1975 – 1985, complete dewatering of streams was a serious problem in the western U.S. To address the problem, a multitude of methodologies were developed to identify a minimum flow to be protected as a minimum reservoir release or a state-issued instream flow water right. From 1980 until 1995, reservoir operations and re-licensing of hydro-electric dams by the Federal Energy Regulatory Commission (FERC) became high priority issues. Resolution of instream flow releases below storage facilities invariably involved negotiations between reservoir managers, power producers, and natural resource managers. This type of problem instigated the development of incremental methodologies that allowed the assessment of alternative water management options. The Instream Flow Incremental Methodology (IFIM, Bovee 1982; Bovee et al. 1998) was originally developed for this purpose. The key features of IFIM included the formulation of management alternatives through water allocation, reservoir releases, water quality treatments, temperature modification, channel modifications, or combinations thereof. The adequacy of alternatives was evaluated on the basis of physical feasibility and effectiveness in meeting management objectives, and included risk analysis and contingency planning to address circumstances when the alternative would fail.

During the 1990s, several paradigm shifts encouraged a revised view of instream flow issues. The concept of Habitat Use Guilds (Bain and Boltz 1989) provided the impetus to analyze habitat at the community level, rather than species-by species. Concepts associated with the Flood Pulse Advantage (Junk et al. 1989), Ecological Connectivity (Ward and Stanford 1995), and the Natural Flow Paradigm (Poff et al. 1997) expanded the term “instream” to include the floodplain and off-channel habitats. Seasonality, periodicity, and variability of flows were now considered as important as flow magnitude during negotiations with water managers. These changes in perspective have largely been responsible for an evolution of instream flow issues from species-oriented habitat management to community habitat and ecosystem restoration or rehabilitation.

Concurrent advancements in technological capability enabled improvements in quantification and analysis of river habitats. The development of high-speed personal computers and computer networks has been foremost among the changes. High-precision GPS and remote sensing technology have allowed rapid and large-scale collection of detailed bathymetric and topographic data needed for spatially explicit descriptions of river habitats. Enhancements in two-dimensional hydraulic simulation models and GIS capabilities have provided the means to apply many of the concepts of landscape ecology to rivers. An example of such an application is the use of habitat patch dynamics (Bowen et al. 2003) to describe a template for restoration of ecological functions in highly modified river systems.

The concepts of landscape ecology applied to restoration are parsimonious with IFIM, but will require re-definition of reference conditions. Future research should examine methods and procedures by which these reference conditions are defined, expansion of the habitat-use guild concept for community-level habitat analysis, inclusion of floodplain and riparian processes (including the large woody debris cycle), and applications to inhibit invasive species.

FLOW, FORM, AND FISH RESPONSES IN AN INTENSIVELY ENGINEERED RIVER SYSTEM: THE LOWER MISSOURI RIVER
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Contrary to the self-formed alluvial river paradigm, morphology of highly engineered rivers can be practically independent of flow regime. The Lower Missouri River (LMOR, Sioux City, Iowa to St. Louis, Missouri) is a good example: it owes its morphology to the Corps of Engineers, not to equilibrium between flow and sediment regimes. On such rivers, rehabilitation and management can address flow or form separately, or combinations of the two, to achieve desired habitat availability. On the LMOR, management debate has centered on the combination of flow and form restoration needed to recover threatened and endangered species. Recently, the same debate has arisen for management of aggressive exotic species.

Multidimensional hydraulic models provide essential and powerful tools for inventorying combinations of depth and velocity in time and space. In the LMOR, multidimensional models have been used to address the tradeoff between flow and form, and as basic tools to understand habitat availability. One prominent limitation of such models is difficulty in defining ecologically meaningful habitats. We address this limitation by using point and patch samples of habitats used by radio- and acoustic-tagged fish. Habitats used by the endangered pallid sturgeon (*Scaphirhynchus albus*) and invasive asian carp (Bighead Carp, *Hypophthalmichthys nobilis;* and Silver Carp, *Hypophthalmichthys molitrix*) are very different and require different methods of analyzing model output. The carp use patches of slow, deep water that can be defined with Froude number criteria whereas the adult sturgeon use zones with high gradients of velocity and depth. Usage of these habitats is compared to modeled availability to estimate selection, and thereby to provide guidance for optimizing the tradeoff between flow and form manipulations in LMOR management.

LINKING BIOLOGICAL PRODUCTION WITH HYDROLOGY AND HYDRAULICS IN LARGE RIVERS

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Large rivers are among the worlds most productive ecosystems. Most large rivers have been altered substantially and are managed for multiple, and sometimes conflicting, uses. Ongoing restoration efforts seek to enhance or recover ecological services in highly altered large rivers. Biological production is the core of most ecological services and therefore provides a useful basis for both prediction and assessment of responses to river restoration efforts. However, our ability to provide reliable predictions of likely responses to hydrological alterations is remedial and often limited to conceptual principles.

Research on production of river fishes underscores the need for integration of biology, hydrology, hydraulics and geomorphology to discover new options for improved management of large rivers. Biological production responds to hydrology at multiple spatial scales from basin-wide flooding through local hydraulic features. Although large rivers tend to be heterotrophic ecosystems, recent research suggests that production of fishes is supported by algal primary production which is, in turn, strongly influenced by hydrology and hydraulics. Large-scale flooding also seems to influence secondary production by fishes. Over smaller spatial scales, fishes respond to hydraulic features and disturbances. Our challenge is to provide useful predictions of responses of biological production at multiple trophic levels resulting from hydrologic change and hydraulic modification at multiple spatial scales. That task will require closer collaboration between the biological and hydrological sciences.

USING A HUMAN DISTURBANCE GRADIENT TO IMPROVE STATE WATER QUALITY PROGRAMS

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Key elements of disturbance are human activities that alter the landscape, such as urbanization, agriculture, and mining. These disturbances cause stress on the aquatic ecosystem in six general categories (Habitat Structure, Flow Regime, Water Quality, Toxics and bioengineered chemicals, Energy Sources, and Biotic Interactions). Oftentimes, the ecological community is exposed to multiple stressors. This results in cumulative effects and presents added challenges to adequately characterizing the human disturbance gradient (HDG), but it also provides a means of quantifying the HDG for different regions of the country. The human disturbance axis helps to explain how several key human activities influence aquatic environments and, in turn, biological conditions. It is important to understand the distinction between disturbance and stressor. ***Disturbance*** describes human activity and can occur on the land and at the landscape scale, but a ***stressor*** is any environmental factor (i.e., physical, chemical and biological) that adversely affects aquatic organisms, typically at a site or reach scale. Developing an HDG that accounts for these perturbations enables states to proactively interpret and translate ecological data.

SESSION 4: CASE STUDIES LINKING HYDROLOGY AND ECOLOGY IN LOTIC SYSTEMS

STREAMFLOW REQUIREMENTS FOR PROTECTION OF FISH AND HABITAT IN THE IPSWICH RIVER

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Relations among stream habitat, fish communities, and hydrologic conditions were investigated in 23 relatively natural-flowing rivers in Southern New England and in the Ipswich River, a highly flow-stressed river in northeastern Massachusetts. A naturalized flow regime for the Ipswich River was determined using streamflows simulated by an HSPF rainfall-runoff model under no withdrawals and 1991 land use conditions (Zarriello and Ries, 2000). Streamflow variability in the Ipswich River and at the 23 rivers in Southern New England was determined using the Range of Variability Approach (RVA). Stream flow regimes at the relatively natural-flowing rivers were further characterized by use of monthly flow durations and by classifying stations into four regional groups for the November to May period, and into two groups, on the basis of percentage of sand and gravel in the contributing area, for the June to October period.

Fish communities were evaluated by comparison to a target fish community developed for New England streams (Bain and Mexler, 2000). Fish communities in the mainstem Ipswich River contained few fluvial-dependent or fluvial-specialist species (requiring flow), and were dominated by macrohabitat generalists (tolerant of low-flow, warmwater, and ponded conditions). Fish communities sampled in relatively natural flowing rivers in Massachusetts had percentages of fluvial fish that were similar to those of the target fish community.

Aquatic habitat in the Ipswich River was predominantly provided by stream margin habitat such as overhanging brush, undercut banks, and woody debris. These habitats decrease as streamflow declines, and generally become unavailable after streamflows drop to the point where the edge of water recedes from the streambank. Riffles were also identified to be critical habitats because they are among the first habitats to exhibit fish-passage problems because of drying during low flows. Flows that maintain habitat at riffle sites keep rivers from segmenting during low flows, and also provide sufficient depth to provide stream-margin habitat in nearby reaches.

Streamflow requirements for habitat protection were determined for the Ipswich River and for the relatively natural-flowing rivers by use of three methods based on hydrologic records – the Tennant method, the New England Aquatic-Base-Flow (ABF) method, and the Range of Variability (RVA) approach, and by use of two field methods based on hydraulic ratings in riffles– the Wetted-Perimeter and R2Cross methods. Streamflow requirements and statistics determined from these studies together with evaluations of management alternatives for balancing ecologic and water-supply needs (Zarriello, 2001, 2002, 2004) are being used by state agencies to guide the development of instream flow policies for Massachusetts.

LINKING STREAM FISH ASSEMBLAGES TO HYDROLOGIC ALTERATION ALONG A GRADIENT OF URBANIZATION

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Landscape urbanization and associated increases in impervious surface cover have resulted in widespread hydrologic alteration of streams. Fishes may be impacted by increased erosional stormflows and reduced baseflows in urbanized streams either directly (e.g., via physical washout) or indirectly (e.g, via reduced habitat quality, water quality, or habitat availability). We investigated what aspects of the hydrograph are particularly important in driving fish assemblage structure and what fishes are most affected by these hydrologic alterations in small streams. We measured hydrologic patterns and sampled fish assemblages in 30 small streams (basin area 8-20 km^2) in the Etowah River basin (Georgia, USA) that were stratified by percent impervious cover (<10%, 10-20%, >20%) and the estimated degree of hydrologic alteration (based on synoptic measurements of baseflow yield). Continuous stream stage monitoring at each study site for 1 y (January 2003-2004) was used to used to derive hydrologic variables. Relations between hydrology and fishes were tested at the times of year when fishes are expected to be most vulnerable to hydrologic alteration: in late spring and summer (May-August) during spawning, and in autumn (August-November) during low flow periods.

Increased % impervious cover was positively correlated with the frequency of storm events and rates of the rising and falling limb of the hydrograph (i.e., storm "flashiness") during most seasons. Increased duration of low flows associated with impervious cover only occurred during the autumn low-flow period, and this measure of low-flow conditions corresponded to increased richness of habitat generalist species (i.e., tolerant of lentic conditions). The lack of hydrologic relations with other fishes, however, suggests that reduced baseflows during the study year (a year with higher than average precipitation) was not a dominant mechanism of fish assemblage alteration. Altered stormflows in summer and autumn were related to decreased richness of endemic (locally distributed), cosmopolitan (widespread), and sensitive fish species, and decreased abundance of lentic tolerant species. Species predicted to be sensitive to urbanization based on life history and other attributes were also related to stormflow variables and % fine bed sediment in riffles. Overall, hydrologic variables explained 22 to 66% of the variation in fish assemblage richness and abundance.

The linkages between hydrologic alteration and stream fishes were potentially complicated by contrasting effects of elevated flows on sediment delivery and scour, and mediating effects of stream gradient. Nonetheless, % variance in fish assemblages explained by hydrologic variables was 2-36% higher than that explained by impervious surface cover alone. Stormwater management practices that promote natural hydrologic patterns are likely to reduce the negative effects of impervious cover on stream fish assemblages.

FISH ASSEMBLAGE RESPONSES TO WATER WITHDRAWALS AND WATER SUPPLY RESERVOIRS IN THE GEORGIA PIEDMONT

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Understanding effects of flow alteration on stream biota is essential to developing ecologically sustainable water supply strategies. To improve our understanding of the biological effects of water withdrawals, I collaborated with the Georgia Department of Natural Resources (GDNR) in a State Partnership Program study of relations between fish assemblage characteristics and water extraction in wadeable streams in the Piedmont region of Georgia. The Piedmont is an area of rapid growth in human populations and water demand. We sampled fishes downstream from water supply withdrawals, where withdrawals were either taken directly from the stream ("stream-intake sites", total n=14) or from an instream impoundment ("reservoir sites", total n=14) with the sampled reach occurring immediately downstream of the intake or dam. Permitted average monthly withdrawal amounts ranged from < 0.05 to > 13 times the stream's 7Q10 flow, providing a broad gradient of potential flow alteration. Sites varied in drainage area from about 14 to 1010 km^2; reservoir sites tended to occur on smaller streams and have larger relative withdrawals. We sampled during two years (2000 and 2001) of regional drought and a third year (2003) with above-average rainfall and stream flow.

Sample ordination (using non-metric multidimensional scaling of fish catch data) and evaluation of alternative linear regression models predicting estimated species richness provided evidence that increasing permitted withdrawal amount and use of an instream reservoir altered downstream fish assemblages. Samples of fish assemblages downstream from reservoirs had lower abundances of a variety of fluvial specialist species compared to sites downstream from stream-intakes. Stream intake sites displayed greater assemblage similarity to samples from regional reference sites (sampled in 2000 and 2001 by the GDNR). Additionally, among alternative regression models predicting species richness of fluvial specialists as functions of drainage area, percent urban land use upstream from the withdrawal, average bed sediment size, and water withdrawal variables, the most strongly supported models consistently included drainage area and either withdrawal type (2001) or an index of permitted withdrawal size (in 2000 and 2003). Species loss was estimated to be about three to five fish species at sites downstream from reservoirs compared to stream-intakes, and about six species as permitted water withdrawal amount increased from 0 to 12 times 7Q10. Wide confidence intervals indicated substantial variability in responses, especially during the above-average flow year (2003) when 90% confidence intervals for both effects included 0. I expect that predictions of biological responses to water withdrawal and flow alteration will always entail considerable uncertainty given the additional, unmeasured effects of other influences (such as stream fragmentation and pollutant input) as well as sampling variability. However, estimates of species loss such as those provided by this study could be used in landscape models to support adaptive water supply planning intended to meet societal needs while conserving biological resources.

THE EFFECTS OF EXTENDED LOW-FLOWS ON FRESHWATER MUSSELS IN THE LOWER FLINT RIVER BASIN, GEORGIA: A CASE STUDY

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Freshwater mussel assemblages in the Flint River Basin (FRB) of southwestern Georgia are among the most diverse in the southeastern Coastal Plain of North America. Historically, 29 species, including 7, endemics occurred in the FRB. A drought during the summer of 2000 caused extended low flows and many perennial streams dried or became intermittent. Pre-drought surveys conducted in 1999 allowed an assessment of the impact of the drought on mussel assemblages. During extreme drought conditions (June-October 2000), mussel survivorship and habitat conditions (water depth, water temperature, dissolved oxygen and flow velocity) were monitored weekly at nine locations representing a gradient in stream size. Cumulative unionid mortality ranged from 13 - 93% per site, and was associated with low flow velocity (below 0.01 m/s) and dissolved oxygen concentrations below 5 mg/L. During 2001, 21 stream reaches that had abundant or diverse mussel assemblages in 1999 were resurveyed. Study sites were classified as flowing or non-flowing during the drought based on data from stream gauging stations or visual observation of study reaches. Mussels were classified by conservation status, either stable, special concern, or federally endangered. Greater than 90% of the mussels observed in the lower FRB were species with stable conservation status. Special-concern species represented 5 to 6% and endangered species represented 1% of mussel abundance. Sites that ceased flowing during the drought had significant declines in the abundance of stable species and in taxa richness. Endangered species also showed evidence of a decline in non-flowing sites. Sites that maintained flow had increases in stable species and no change in special concern, endangered species, or species richness through the drought. Sites that showed declines in mussel abundance had a significantly lower frequency of wood debris than other sites. Field observations suggested that shallow depressions beneath wood debris may act as a refuge for freshwater mussels during stream drying. Greatest declines in mussel abundance usually occurred in the mid-reaches of the major tributaries of the lower Flint River. These reaches depend on the Upper Floridian aquifer, which is heavily used for irrigation, to maintain base flows. Declines in mussel populations appear to be associated with unusual climatic conditions and increasing demand on the area streams and the regional aquifer system for irrigation water supply.

DEVELOPING ENVIRONMENTAL FLOW REQUIREMENTS: SAVANNAH RIVER CASE STUDY

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Many river restoration projects are focusing on restoring environmental flow regimes to improve ecosystem health in rivers that have been developed for water supply, hydropower generation, flood control, navigation, and other purposes. In efforts to prevent future ecological damage, water supply planners in some parts of the world are beginning to address the water needs of river ecosystems proactively by reserving some portion of river flows for ecosystem support. These restorative and protective actions require development of scientifically-credible estimates of environmental flow needs. This presentation outlines an adaptive, inter-disciplinary, science-based process for developing environmental flow recommendations. It has been designed for use in a variety of water management activities, including flow restoration projects, and can be tailored according to available time and resources for determining environmental flow needs. The five-step process includes: (1) an orientation meeting (2) a literature review and summary of existing knowledge about flow-dependent biota and ecological processes of concern; (3) a workshop to develop ecological objectives and initial flow recommendations, and identify key information gaps; (4) implementation of the flow recommendations on a trial basis to test hypotheses and reduce uncertainties; and (5) monitoring system response and conducting further research as warranted. A range of recommended flows are developed for the low flows in each month, high flow pulses throughout the year, and floods with targeted inter-annual frequencies. An application of this process is described for the Savannah River (GA/SC), in which the resultant flow recommendations are being incorporated into a comprehensive river basin planning process conducted by the U.S. Army Corps of Engineers, and used to initiate the adaptive management of Thurmond Dam. Under the Sustainable Rivers Project – the national collaboration between The Nature Conservancy and the Corps of Engineers – this process of applying adaptive management to restore and protect ecosystems downstream of dams is being applied in nine river systems across the U.S.

PHYSICAL AND CHEMICAL EFFECTS OF MOUNTAINTOP REMOVAL AND VALLEY FILL MINING ON STREAM BIOTA

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Over a thousand miles of central and southern Appalachian stream have been buried as a result of mountaintop removal and valley fill mining for coal in the states of WV, KY, TN, and VA. In south-central WV alone it is estimated that 15 percent of mountaintops have been removed and permits have been issued for >500 square miles of West Virginia to be surface mined. Hundreds of thousands acres of productive hardwood forest have been lost and topsoil removed. Forests have been replaced with grasslands and herbaceous plants communities. Streams in the formally adjacent valleys (including first, second, and some third-order) have been buried to a depth of 450 feet with the overburden (fill) from the mountaintop removal operations.

What constitutes headwater streams and their relationships to downstream areas remain a point of contention among stakeholders in the region. In addition to the direct and obvious impact of burial, valley fills impact many physical, chemical, and biological aspects of downstream reaches. These include altered downstream parameters such as: hydrology and flow regime; temperature, chemistry, sedimentation, with concomitant effects on downstream biota. The popular press and claims of laymen in the region generally contend that valley fills increase the probability of downstream flooding; whereas, mining interests have attributed extreme floods to local differences in rainfall between catchments. Scientific studies, while limited to only a few basins in the study region, suggest more complex issues including geological differences among basins, present and past land use practices, rainfall detention in different regions, antecedent conditions and various other factors are involved in differences among catchments. Much more intensive instrumentation of a large number of basins may be required to solve the problem of addressing regional propensity for flooding. There is strong and irrefutable evidence that the presence of valley fills increases flow duration from a given basin and probably total discharge per unit precipitation.

While some view increased flow as a positive factor, there are a number of negative aspects on downstream biota when increased loading of undesirable chemicals (including selenium, increased conductivity, and various other ions) resulting from extensive earthmoving activities are considered. Biotic indices also show distinct impairment downstream of valley fills. Furthermore, the long-term consequences of elevated loading of chemicals on water quality and biota in downstream reaches and reservoirs of the region have not been considered.

GEOMORPHIC AND ECOLOGIC CONSEQUENCES OF HYDROLOGIC CHANGES IN URBAN STREAMS - EXAMPLES FROM THE PACIFIC NORTHWEST

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Around the world, urban development has had profound consequences on hydrologic processes and streamflow patterns. Modified streamflow patterns, in turn, represent an anthropogenic stressor that affects the biological conditions of urban streams. Although restoration of streamflow patterns is not a feasible short-term goal in many urban areas, management actions may be able to target those aspects of modified streamflow patterns with the most severe biological responses. Targeted management actions require the development of streamflow statistics that are ecologically significant; such statistics may be quite different from those traditionally used to describe the hydrologic effects of urban development. Ecological theory suggests that changes in the frequency and area of streambed disturbance during high flows could be a biologically significant consequence of urban streamflow patterns. Three statistics that may indicate the disturbance regime of a stream include: the fraction of time that streamflow exceeds mean streamflow, the fraction of time that streamflow exceeds the ½-year flood, and the frequency of peaks greater than the 10th percentile streamflow.

The statistics are used in a hydro-geomorphic analysis of streams in the Pacific Northwest to show how streamflow patterns influence the disturbance regime of streambeds and how urban development is likely to result in streamflow patterns that produce frequent and extensive disturbance. Variation in the biological conditions of streams appears to be associated with variation in these statistics, however, the link between streamflow changes characteristic of urban development and a biological response awaits more definitive proof.

ECOSYSTEM RESPONSES TO EXPERIMENTAL HYDRAULIC VARIATION: A TOOL FOR DEVELOPING AND VALIDATING INSTREAM FLOW MODELS

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One of the central challenges encountered during many stakeholder deliberations about flow allocation is the high level of uncertainty associated with the models used to predict ecosystem responses to specific changes in flow. For example, the natural flow regime concept has produced important advances in quantifying a river's degree of hydrologic alteration, but this approach is less well suited to generating numerical predictions of ecological responses to a specific change in hydrology. On the other hand, models designed to generate quantitative predictions of ecological responses to changes in hydraulic habitat are not easy to develop for some critical ecosystem components. For instance, the benthic biota that fuel many river food webs inhabit hydraulic environments that can be very difficult to characterize using available models and measurement systems. Moreover, even when statistical correlations can be established between biotic abundances and physical habitat using this method, such relationships may generate erroneous predictions about the response of abundance to a specific flow change. Collectively, these potential limitations suggest the need for additional tools that can be used to develop more accurate instream flow models.

We describe an array of experimental methods that can help improve the accuracy of predictions about ecosystem responses to flow changes, and we evaluate the potential strengths and limitations of these methods for different applications. These methods range from small-scale laboratory and field experiments that examine responses of key benthic biota to local changes in near-bed velocity, to whole-river experiments that quantify community responses to flow changes associated with dam reoperation. For example, we present results from studies examining responses of nuisance algal growths to experimental hydraulic variations in both the Jackson River, Virginia and the Waipara River, New Zealand. We also describe result s from one of the world's largest multi-river management experiments – an examination of ecological responses to dam reoperation below nine dams in the Tennessee Valley.

The biggest strength of experimental approaches is that they can provide direct, quantitative evidence demonstrating how particular ecosystem characteristics respond to specific flow changes. One potential limitation of these methods is that it can be difficult to "scale-up" from short-term, local-scale experiments focused on particular ecological components to predicted responses at larger spatial, temporal, and organizational scales. Experimental methods may be particularly useful when there are critical ecosystem components (e.g., endangered freshwater mussels) or highly contentious deliberations for which the uncertainty associated with predicted responses to flow changes must be kept very low. If used judiciously, we believe that experimental methods can significantly augment the set of tools available for defining the flows required to protect or restore the health of river ecosystems.

SESSION 5: MODELING TO SUPPORT WATER SUPPLY PLANNING AND DECISION-MAKING

DECISION SUPPORT MODELING FOR ECOSYSTEM MANAGEMENT IN THE GEORGIA COASTAL PLAIN AFFECTED BY IRRIGATION PUMPING

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Streamflow regulation is one of the most important issues facing natural resource managers and planners in the southeastern U.S. In recent years, the rapidly growing human population has led to increased water demands from agriculture, industry, and municipalities. The increased water demands have had presumably, unintended negative effects on the aquatic resources in the region. These effects can be minimized if natural resource managers are informed as to the nature and extent of potential impacts. This requires tools for assessing the potential impacts of river regulation and water development on stream habitats and aquatic communities.

Identifying and quantifying the effects of river regulation and water development on aquatic communities is crucial for developing effective conservation strategies. These effects, however, occur in systems with high natural variability over time and space that is further complicated by cumulative effects. Thus, natural resource managers are faced with difficult decisions fraught with the complexity and uncertainty associated with ecological systems and multiple management objectives (e.g., water development, species conservation) that are further complicated by the lack of comprehensive information. To aid the decision-making process, managers need tools that formalize these complexities into a common framework consisting of relationships among management actions, sources of uncertainty, and outcomes. Because existing knowledge is imperfect, such an approach also should be able to incorporate future data so managers can learn through time as data are collected. In such instances, decision modeling is synonymous with adaptive management, an approach that incorporates uncertainty inherent in natural systems and knowledge gained through scientific process to prescribe flexible scenarios for conservation and management of water resources. Thus, the most useful tools should provide the means to quantify potential risks to aquatic communities so that, (1) the effects of different management actions can be examined *a priori*, (2) the relative influence of various sources of uncertainty can be examined, and (3) the value of collecting additional data (e.g., monitoring) can be estimated.

Here I describe an adaptive management framework for managing water resources in the Flint River Basin, in southwest Georgia. The basin contains a diverse aquatic community and includes at least four endangered species. Streamflows in the coastal plain portion of the basin are affected by irrigation pumping from the underlying Floridian aquifer. The irrigation decision model contains water use, streamflow, habitat availability, dissolved oxygen, temperature, and fish community response components. Spatially-explicit USGS groundwater-surface water models are used to estimate flow regime under varying irrigation scenarios. These estimates then are used to inform the remaining model components for estimating fish community response. Uncertainty is incorporated as conditional dependencies (probabilities) and via alternative models of fish community response. The framework also provides for the integration of monitoring data so that models of aquatic community response can be improved as data are collected.

A NEW HYDROECOLOGICAL ASSESSMENT PROCESS TO EVALUATE THE EFFECTS OF WATER MANAGEMENT ON HYDROLOGIC VARIABILITY IN STREAMS

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The natural flow regime paradigm and parallel stream ecological theories have established the importance of protecting or restoring the range of natural hydrologic variation for maintaining natural physiochemical processes, biodiversity, and the evolutionary potential of aquatic and riparian communities. A synthesis of recent research advances in hydroecology has been coupled with a newly developed stream classification tool to produce a hydroecological assessment process with national and international applicability. This process can be used to classify streams into hydrologic types and identify a set of non-redundant, ecologically relevant hydrologic indices for 10 critical components of flow.

Three programs have been developed for implementing the hydroecological assessment process: (1) the Hydrologic Indices Tool (HIT), which calculates 171 ecologically relevant hydrological indices using daily flow and peak flow gage data; (2) a New Jersey Hydrologic Assessment Tool (NJHAT), which establishes a hydrologic baseline time period and baseline environmental flow standards, and can be used to compare the effect of past and proposed streamflow alterations; and (3) a Stream Classification Tool (SCT) for the State of New Jersey designed for assigning unclassified streams to pre-defined stream types. A National HAT has also been developed. Biological response models, including principal component, cluster, and discriminant function analyses were used in the development and implementation of HAT and SCT for New Jersey.

The U.S. Geological Survey, in cooperation with the N.J. Department of Environmental Protection, has undertaken a pilot effort to use the hydroecological assessment process to evaluate the effects of past and proposed surface-water withdrawals, ground-water extraction, and land-use change on stream ecosystems with the ultimate goal of integrating the assessment process into ongoing regulatory programs. Once implemented, this scientifically defensible process will improve the understanding of the effects of anthropogenic changes on hydrologic variability and help planners and resource managers balance current and future water requirements with needs of the biotic community.

VEGETATION MODELS TO INFORM STREAMFLOW ALTERATION DECISIONS

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Decisions about streamflow alteration often consider the response of vegetation in riparian or bottomland areas, where plant communities are distinct from surrounding uplands because of their proximity to a watercourse. Valued attributes of these areas include aesthetic characteristics; the presence of rare plant species; periodic expansion of aquatic habitat during inundation; aquatic food chain support and other material exchanges; and wildlife habitat provided by features that are often rare in the surrounding uplands. Variation in riparian vegetation is not only a component of ecological response to hydrologic change, but is also increasingly viewed as an important input to physical models of the riverine environment – as a hydraulic roughness element, as an influence on water supply through transpiration from the alluvial aquifer, and as a determinant of the erosivity of banks and floodplain surfaces.

The development and use of streamflow-vegetation models have not emphasized articulating a general procedure or protocol. Three general vegetation modeling approaches have been used to inform streamflow decisions. State-transition models iteratively apply rules for change to simulate vegetation over time as a function of streamflow. These include individual-based, forest stand models representing trees on small plots; compartmental models representing cover types or communities; matrices of transition probabilities; and sets of if-then rules governing specific transitions.

Static vegetation models describe quasi-equilibrium relations between vegetation and temporally aggregated site conditions. In an application to the Fremont River, UT, the transverse distribution of individual plants was used to fit Gaussian occurrence probabilities on a direct gradient of hydroperiod, or inundation duration. A linkage of hydrologic flow duration curves to stage-discharge relations (from a hydraulic model), to species occurrences (from their hydroperiod distributions) can be used to predict the repositioning of species in the bottomland as a function of altered flow regime. Although this approach has been used most often with inundation gradients, it has also been employed with gradients of depth to groundwater near rivers in more arid landscapes.

Finally, an intermediate class of models scores hydrographs or flow regimes according to how well, or frequently, certain conditions are met relative to the life history requirements or tolerances of different plants. This approach has been most extensively applied to the regeneration niche of trees, especially with disturbance-dependent species such as cottonwood.

Advances in both measurement capabilities and concepts promise improvements in predictive relations between streamflow and riparian vegetation. However, the most significant, easily obtainable, improvements are in the realm of scoping and problem definition within a larger water management decision – what aspects of vegetation should be related to what kinds of possible alterations, how should uncertainty be represented in the analysis, and the appropriate spatial and temporal scales of analysis.

TOOLS TO ASSESS ENVIRONMENTAL FLOWS IN DAM OPERATIONS

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There are constant challenges to integrating scientific understanding with policy development. Certainly one of these impediments in the arena of managed rivers is the difficulty of integrating detailed ecological knowledge (and associated uncertainty) with the structured and established realm of water management operations. One of the early successes of the Sustainable Rivers Project (SRP) – the national collaboration between the U.S. Army Corps of Engineers (Corps) and The Nature Conservancy (Conservancy) to re-operate dams to restore and protect ecosystems – has been an effective blending of ecological and engineering knowledge and tools. This presentation will introduce some tools being used to help define and assess environmental flow recommendations. One tool – currently under development and referred to as the "Pulsinator" – is designed to facilitate definition of environmental flow recommendations by diverse groups of scientists, engineers, and water managers. This is the first joint software development effort undertaken by the Corps and the Conservancy. Other tools that will be discussed include the Conservancy's Indicators of Hydrologic Alteration (IHA) software, and the Corps' Ecosystems Functions Model (HEC-EFM), Reservoir Evaluation System – Simulation model (HEC-ResSim), and River Analysis System (HEC-RAS), all of which are products of the Corps' Hydrologic Engineering Center. Some of the ways these tools help bridge the ecological-engineering gap will be illustrated with examples from the SRP sites.

POSTER SESSION

STREAMFLOW AND THE REGENERATION NICHE OF COTTONWOOD ALONG THE WILD AND SCENIC REACH OF THE MISSOURI RIVER

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Riparian cottonwoods provide important habitat and aesthetic values in the western US where surrounding uplands are often too dry to support trees. Much of the evaluation of the effects of flow alteration has focused on the regeneration niche of the structurally dominant, native cottonwood. Cottonwood is a pioneer, disturbance-dependent species that best establishes from seed on surfaces that are bare and moist during a relatively brief period following seed dispersal. Recruitment of these seedlings to trees depends on the site being relatively safe from future disturbance. The life history requirements for recruitment are best satisfied on fluvial disturbance patches and are thus dependent on the flows and fluvial geomorphic processes that create these sites. In unconstrained geomorphic settings, cottonwood recruitment is most associated with channel narrowing and meandering.

Plains cottonwood (*Populus deltoides* Marsh. subsp. *monilifera* (Ait.) Eckenw.) stands along the Wild and Scenic reach of the Missouri River in Montana are sparse and discontinuous. Historical accounts, including Lewis and Clark journals, suggest that cottonwood stands in this geologically constrained reach were also spatially restricted prior to European settlement of the region – in contrast to sections of the Missouri River in wider valleys where historically extensive meandering produced broad cottonwood forests. Because the recreational and wildlife values of these stands are high, concerns about how flow alteration and cattle grazing may be limiting reproduction are expressed in multiple decision arenas including licensing by the Federal Energy Regulatory Commission; operation of Bureau of Reclamation facilities; management of Bureau of Land Management grazing allotments; management of river recreation; and evaluation of flow alternatives that might be proposed to protect endangered river fish occurring in the reach.

In a retrospective study using tree excavation and dendrochronology we established that current trees were disproportionately established in flood years. A long-term monitoring study has been measuring cottonwood seedling establishment and mortality on hydraulic transects at a set of eight sites along the Missouri River to verify the mechanisms producing this flood dependency. Results from this ongoing study suggest that (a) in most years large numbers of new seeds germinate in the bare, moist zone between the flow lines of the spring peak and fall minimum; (b) seedling mortality in subsequent years is extremely high because of grazing, flood damage, and winter ice scour; and (c) successful recruitment is most likely when infrequent high flows have positioned seedlings high on the bank, where local channel movement occurs, and where grazing intensity is low. This is a clear example of how the relation between streamflow and a valued environmental response (a) is mediated by geomorphic processes and (b) is dependent on a multi-year pattern of streamflow variation rather than any absolute flow magnitude.

DEVELOPING REFERENCE CONDITIONS AND BIOLOGICAL INDICATORS FOR URBAN STREAMS

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There are two objectives of this project. The first is to determine the most appropriate technique for establishing reference conditions for urban watersheds, and the second is to develop biological indicators that are responsive to the multiple types of stressors common to urban systems. Reference conditions used in stream and watershed biological assessment frameworks represent ecological characteristics that are acceptable, thus, the challenge for urban systems is defining what is acceptable as a benchmark. Our dataset was assembled from multiple, routine biological monitoring programs throughout the Mid-Atlantic region, representing data from approximately 2000 stream sites. Increased sensitivity and responsiveness of biological indicators in urban systems can be attained only with more detailed description of stressor conditions to which they are related. Landscape measures such as "percent urban" or "percent imperviousness" are likely inadequate because they summarize stressor sources, and are at least one step removed from the actual stressors to which biota are exposed. We suggest that the dominant class of stressors in urban systems is strongly related to hydrologic changes, and should be used as principal input to the urban stressor gradient. Thus, we have developed an ArcView/Excel-driven hydrologic model that produces site-specific daily flow data used in calculations of hydrologic indicator values (e. g., flood frequency, flashiness). Initially, the urban gradient will be described using a suite of potential stressor sources (land cover characteristics, percent imperviousness) and potential stressors (selected water chemistry variables, hydrology, visual-based physical habitat quality, and indicators of hydrologic alteration). We attained relatively solid correlations between percent urban and modeled indicators (e. g., variance of daily flow [r2=0.31], flood frequency [r2=0.36], and flashiness [r2=0.37]). Since undisturbed streams don't exist, sites are being selected along the urban source/stressor gradient that represents "best attainable" conditions. We are currently testing the responsiveness/sensitivity of biological indicators to those variables using taxa presence-absence or assemblage level data, individual metrics, or broader biological indices. This approach will allow the best sites to be selected representing various levels of urbanization, and will be appropriate for adaptation to the tiered aquatic life use framework. It is also being tested with datasets from the Cleveland, Ohio, and San Francisco, California metropolitan areas.

IMPROVED ESTIMATES OF LOW FLOW CHARACTERISTICS OF UNGAGED BASINS USING VARIABLES FROM A SIMPLE GROUNDWATER MODEL

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Obtaining good estimates of low flow at ungaged basins is important to streamflow ecology. Traditional methods examine simple basin attributes, such as drainage area and slope, to estimate low flow characteristics with very large errors. These errors are primarily due to not incorporating relevant variables related to the low flow generation process. Inclusion of variables directly related to the low flows is key in reducing the error on estimates for ungaged basins.

Low-flow characteristics were estimated at 109 ungaged basins in six States located in the southeast United States using daily streamflow data collected by the USGS. These characteristics were computed from a regression model using physically derived variables from a Boussinesq groundwater model and drainage area, *DA*. Several regression models were analyzed using different combinations of these lumped parameters and *DA*, and a metric of the root mean square error, *RMSE*, based on the prediction error sum of squares method was used to evaluate model performance. The lumped parameters were the short-term, a_3, and long-term, a_1, recession behavior of an aquifer system, and were derived solely from the daily discharge record for a gaged basin. The way that the RMSE is computed is that it treats a gaged basin as an ungaged one. For a real ungaged basin, streamflow is not available and as a result an estimate needs to be determined. To overcome this problem of obtaining a_1 and a_3 for ungaged basins, two locally weighted regressions (LOESS) among a_1 , latitude, and longitude was performed in a delete-one jackknife simulation, and similarly for a_3. The parameter values for the regression models were determined from the a_1 and a_3 from the gaged basins. The LOESS estimated values of a_1 and a_3 were then placed into these regression equations to obtain an estimate of the low flow characteristic. The LOESS a_3 values were found to result in a large increase in *RMSE*; on the other hand, a_1 values introduced much less error. The a_3 values were found to be strongly correlated to *DA*, but the a_1 values were not. These results indicate that the *DA* variable has relevant information about the short-term response of an aquifer, while missing the long-term response. This behavior explains why the *DA* is often used a predictor variable in low flow regression studies, so the *DA* acts as a good surrogate variable for the short-term response of an aquifer. The optimal model producing the lowest RMSE was a regression model using a_1 and *DA* as predictor variables.

NE AMPHIBIAN RESEARCH AND MONITORING INITIATIVE

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Stream salamanders are sensitive to acid-mine drainage and may be sensitive to low acid-neutralizing capacity (ANC) of stream water and soils in watersheds. Many streams in Shenandoah National Park (SNP), Virginia, experience episodic acidification from acidic precipitation inputs, and studies have indicated effects on stream biological communities. We surveyed for salamanders in 25-m by 2-m transects located on stream banks adjacent to water channels in SNP using a stratified random sampling design. The sampling design was based on elevation, aspect, and bedrock geology and was focused on four species: Eurycea bislineata, Desmognathus fuscus, D. monticola, and Gyrinophilus porphyriticus. We investigated the relations among salamander metrics (number of individuals, number of species, count of E. bislineata, summed count of D. fuscus and D. monticola, total body length, snout-vent length) and habitat (elevation, aspect, number of crayfish, number of overturned objects) and water-quality variables (temperature, pH, ANC, specific conductance).

We found no overwhelming evidence indicating that stream salamanders are affected by the acid-base status of streams in SNP. D. fuscus and D. monticola abundances were greater both in streams that had higher ANC and in higher elevation (>700 m) streams. Neither counts of E. bislineata nor the number of species were related to any of the habitat variables. Our sampling methodology preferentially detected the adult age class of all study species and did not allow us to estimate population sizes.

Because population size and counts of individuals likely do not exhibit a 1:1 relationship, more study is needed to directly test potential effects of watershed acidification on stream salamander populations in SNP.

LINKING GROUND-WATER AND SURFACE-WATER HYDROLOGY AND CHEMISTRY TO AQUATIC COMMUNITY STRUCTURE AT THE WESTERN LAKE ERIE SHORELINE

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The relation between ground water flows and chemistry and Great Lakes nearshore habitat and water quality has been little studied. In southeastern Monroe County, Mich., near Erie State Game Area (ESGA), the potentiometric surface of regional ground water in the Silurian/Devonian carbonate aquifer results in natural discharge to rivers, springs, and to western Lake Erie. In northeastern Monroe County, near Pointe Mouillee State Game Area (PMSGA), quarry dewatering has drawn down regional ground-water levels as much as 45 m below lake level. Regional ground-water chemistry of the Silurian/Devonian aquifer reflects the dominance of $CaCO_3$, $CaMg(CO_3)_2$ and $CaSO_4 \cdot 2H_20$ in bedrock of Monroe County, and differs substantially from Lake Erie chemistry in dissolved solids, Ca, SO_4, and Si composition. Nearshore springs may influence coastal geomorphology (tufa mounds) and sediment chemistry, indicating important roles for geologic processes in Great Lakes nearshore ecosystems. Consistent with regional observations, we demonstrated that seepage potential in the nearshore at ESGA is upward, or toward Lake Erie and that shallow nearshore ground-water chemistry reflected regional ground-water composition modified by travel through anoxic lake and wetland sediments. In contrast, seepage potential at PMSGA is downward, or away from Lake Erie. At Pointe Mouille regional ground water is directly discharged to a Lake Erie embayment, where it mixes with lake water and seeps downward into nearshore sediments, producing a different lake and ground-water chemistry than at ESGA. Invertebrate and young fish community structure, abundance and type of emergent vegetation, and abundance of an invasive species (Zebra mussels) all differed between the two sites, suggesting important roles for ground-water/surface-water interactions in development of the economically-important Lake Erie recreational and commercial fishery, and in the success of native and invasive nearshore biota. Nearshore ground-water/surface-water interactions exhibit features of “submarine ground-water discharge,” recently a subject of interest in marine research but never previously considered for the Great Lakes. Processes similar to those we studied may occur throughout the Great Lakes

QUANTIFYING THE EFFECTS OF STREAMFLOW REGULATION ON AQUATIC HABITAT IN THE UPPER OSAGE RIVER BASIN, WEST-CENTRAL MISSOURI

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The rivers of the upper Osage Basin support important aquatic and riparian resources within Missouri. Currently (2005) 35, 2, and 15 percent of the Marais des Cygnes, Little Osage, and Marmaton River Basins, which comprise the upper Osage Basin, are regulated by impoundments upstream from the Missouri-Kansas state line. Plans to construct an additional 283 flood-control impoundments in Kansas eventually would increase basin control to 45, 2, and 59 percent, respectively, of the Marais des Cygnes, Little Osage, and Marmaton Basins. Demands on streamflows for industrial, recreation, municipal, and irrigation uses continue to increase in the basin. The combined effects of the impoundments and increases in stream depletion may alter the quantity and timing of streamflow, which may have adverse ecological effects on downstream aquatic and riparian communities.

The Missouri Department of Conservation strives to protect and restore flow regimes that help sustain biological integrity, water quality, stream-system functions, and public benefits (e.g. recreation). Streamflows that mimic the timing, frequency, rate of change, magnitude, and duration of natural flows are essential for maintaining streams, rivers, wetlands, bottomland hardwoods, bottomland lakes, and wet prairies. To maintain habitat and community diversity with time, streamflow regimes must include flows that maintain the aquatic community and riparian habitats. Such regimes should vary seasonally and annually to mimic natural flow variability.

More information is needed to better understand the specific effects of flow alterations on riverine habitats and to determine appropriate flow regimes for the upper Osage Basin. Therefore, concurrent studies are being conducted by the U.S. Geological Survey, in cooperation with the Missouri Department of Conservation, to quantify the effects of multiple impoundments on low-flows and flood frequency, and to quantify relations between discharge and habitat area distribution for select fish species.

The effects of regulation and point-source withdrawals on streamflows are being determined using HSPF/BASINS. The relation between discharges and habitat areas are being determined using two-dimensional hydraulic simulations (River2D) of incremental flows, substrate mapping, and empirically determined selection categories for select fishes that use shallow-water habitats. Comparisons will be made between aquatic habitat availability under pre-impoundment, current, and proposed-regulation flow conditions in the upper Osage River Basin.

MEASURING HYDROLOGICAL CHANGE DURING EXURBAN DEVELOPMENT: COLLABORATIVE HYDROLOGIC RESEARCH IN THE CLARKSBURG SPECIAL PROTECTION AREA

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This research project is focused on the Clarksburg Special Protection Area (CSPA) in Montgomery County, Maryland. The CSPA subwatersheds are on the outer edge of the exurban development shockwave expanding outward from the Washington DC metropolitan area. The CSPA is an area of rapid development that we expect will be built out within the next five to ten years. The Montgomery County Department of Environmental Protection (DEP) has been monitoring stream biology and chemistry in the area streams and the CSPA involves special best management practices (BMPs) that are designed to limit the impact of development on water resources.

This research is an example of a Federal-Local technology-transfer partnership where innovative technologies are researched at the Federal level and the results made available at a local level for neighborhood solutions. This research is a collaborative effort where local stakeholders are involved setting research goals and Federal agencies are involved offering expertise and capabilities not available at the local level.

The objective of the USEPA research is to correlate the impacts of ongoing development and the mitigating effect of local best management practices (BMPs) on the hydrological, biological, and chemical parameters of the CSPA water resources using a Before-After, Control-Impact (BACI) study design. The BACI design employs both positive and negative controls (stream gauges and monitoring in areas without development and areas developed without the CSPA BMPs) as well as pre- and post development data from areas gauged prior to development within the CSPA. The USEPA is focused on determining the effectiveness of BMP mitigation on streamflow disturbance, channel erosion and stream sedimentation due to impervious surfaces, sub-surface storm sewers and altered landform due to urbanization.

Our primary research activities are to map the development as it occurs; both the anthropogenic surface structures such as roads, buildings, parking lots, and changes in surface topography associated with urbanization and the subsurface storm sewer network; and to monitor the physical, chemical, and biological aspects of the associated water resources as that development happens. Changes in streamflow and biological and chemical parameters of the CSPA water resources (or the lack thereof) will be correlated with development patterns, anthropogenic alterations of the environment, and the BMPs designed to mitigate the impacts of development. The USEPA has funded the placement of five research-grade streamflow gauges and have obtained two LIDAR overflights of the study area (2002 and 2004) that greatly increases the spatial resolution of the topographical analyses possible in the CSPA. These and future LIDAR collections will be used to determine if this technology can be used to map changes in stream morphology associated with development as well as to assist in the hydrological modeling and surface mapping of that development.

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INCORPORATING HUMAN WATER USE INTO ANALYSIS OF STREAMFLOW DISTURBANCE REGIMES

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Patterns of streamflow disturbance are likely to be a major organizing feature of the habitat template for stream biota. The streamflow disturbance regime in streams is frequently characterized by variability in both annual floods and prolonged low-flow periods. The intensity, frequency, and predictability of timing for these extreme events provide important context for understanding the response of aquatic organisms to physical habitat conditions. Many of these kinds of ecologically-relevant streamflow metrics can be derived from flood- and low-flow frequency distributions, although the necessary data are not universally available. Regional frequency analysis is a useful way to estimate the frequency distributions for ungaged sites based on pooled data from a number of gages within a homogeneous region. The standard USGS regional frequency analysis assumes spatially contiguous regions that are subject to minimal human impact, however, which greatly limits the application of this approach because of the pervasive extent of human water use. This analysis describes an alternative methodology for developing streamflow metrics from flood- and low-flow frequency distributions for ungaged streams impacted by human activity.

Regionalization is based upon canonical correlation analysis, a multivariate approach that defines appropriate groups of gaged sites that may not be spatially contiguous. Because of the extent of human activity, data quantifying the extent and type of land and water use are included to improve the identification of appropriate regions. Results are presented for tributary streams to the upper Missouri River, as defined by sites sampled as part of the USEPA's Environmental Monitoring and Assessment Program (EMAP). A comparison of extreme flow estimates based upon the two contrasting regionalization methods indicates that the alternative method results in greater regional homogeneity and more accurate extreme flow estimates.

NORTH FORK SHENANDOAH RIVER INSTREAM-FLOW STUDY

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Instream Flow Incremental Methodology (IFIM) techniques were used for an investigation in the North Fork Shenandoah River Basin in Virginia. Objectives were to relate water availability to physical habitat needs of fish, and to provide science-based information for water-resources conservation planning for low-flow conditions. Detailed mapping of physical habitat (100 river mi) provided an accurate representation of river conditions for habitat-flow modeling. The abundance and distribution of mesohabitat types from upstream to downstream were examined through downstream accumulation of mesohabitat length. Water-quality data were collected during a July 1999 low-flow period to investigate dissolved-oxygen concentrations and their potential impacts on the aquatic community. Float trips and fishing are important recreational activities on the river, so the fish community was selected for the development of habitat-suitability criteria. Dr. Donald Orth and students at Virginia Polytechnic Institute and State University (VPI) grouped fish species into four *guilds* on the basis of depth, velocity, substrate, and cover preferences, and produced habitat-suitability curves used in habitat-simulation modeling. Field data collection was completed by the U.S. Geological Survey (USGS) and VPI for 6 reaches and 36 transects to represent hydraulic properties of the river in the predominant habitat types throughout the North Fork Shenandoah River drainage (1,033 mi^2). Each reach was visited at least three times during hydraulic-data collection to measure water-surface elevations, water depths, water velocities, transect discharges, and a best-estimate reach discharge during low-, medium-, and high-flow conditions. Physical habitat simulation was completed for each reach; results and management implications were reported for three sections of river: upper, middle, and lower. Time-series analysis and calculation of habitat exceedance values show an increased susceptibility to habitat degradation in the upper and middle reaches of the North Fork Shenandoah River during low-flow periods. With an increase in water withdrawals, habitat loss or degradation would be most prominent in the first 60 miles of river. The final report for the North Fork Shenandoah River Instream-Flow Study is underway, and a similar study of the South Fork Shenandoah River has been initiated.

ARKANSAS' LOWER WHITE RIVER – A SYSTEMS PERSPECTIVE TOWARD AN ECOLOGICALLY SUSTAINABLE RIVER MANAGEMENT APPROACH

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The White River, Arkansas, has been extensively manipulated for flood control, navigation, municipal and infrastructure development, and as a water source for irrigation. Numerous geomorphic changes along the lower White River including excessive bank erosion, rapid channel migration , headcuts, and floodplain dissection have been observed in recent years. These result from the channel, flow, and sediment regime changes associated with these manipulations. Dam operation has altered the frequency and duration of bankfull and flood flows as well as compressed the hydrograph. Channel maintenance removes snags and riffles, thus altering channel hydraulics. Dams trap coarse bed materials altering the nature of the substrate while land clearing and channelization increases the input of fine sediment to the system.

No one entity is specifically charged with managing this dynamic resource; projects are planned, authorized, and constructed in the absence of any cohesive or coherent plan for assessing the river's response to the cumulative effect of these actions. Natural resource managers along the river deal first hand with the results of hydrologic and geomorphic change, i.e., the direct loss of terrestrial and aquatic habitat including dewatering of floodplain lake complexes, collapse and retreat of riverbanks with associated loss of bottomland hardwood forest, and degradation of in-channel habitats. Similarly, infrastructure managers have been confronted by threats to transportation, flood control structures and public utility infrastructure. Problems caused by this geomorphic instability are being treated individually on a case by case basis.

The natural resource and infrastructure manager's primary responsibility is the protection of the resources under their charge. Their first instinct is often to implement the most immediate and obvious "fix" to the problem. Such "fixes", however, focus on the immediate problem, are localized, and are not put into larger system-wide context. Both are faced with the dilemma of confronting these problems knowing that their actions are not advancing system stability. Rather than advance long-term solutions, the fix will "win the battle but lose the war."

The long-term use of natural resources in an ecologically sustainable manner requires sophisticated approaches to resources management, protection, and regulation. Future river management actions must be accomplished within a framework that provides a comprehensive understanding of system-wide processes and controlling factors, including a diagnosis of alterations and associated impacts. A systems approach to managing the White River is needed if the ecological functions of the system are to be protected. Two such approaches to achieving geomorphic stability are being promoted within the lower White River: TNC's Ecologically Sustainable Water Management (ESWM) and a comprehensive study of the lower portions of the White and Arkansas rivers at their respective confluences with the Mississippi River.

EFFECTS OF BASE FLOW AUGMENTATION ON A WARMWATER STREAM: PERCEPTIONS GAINED THROUGH LONG-TERM MONITORING OF MULTIPLE ECOLOGICAL CRITERIA-UPDATE

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Note: This is a poster adaptation and update of a presentation at an Instream Flow Symposium in 2001 held in Saratoga Springs, New York, at the 2001 Northeast Fish and Wildlife Conference.

Understanding effects of altered flow regimes on aquatic systems requires studies of multiple ecological criteria over a range of spatial and temporal scales. Long-term comparisons of ecological variability in relation to natural and altered flow regimes are especially important because various system responses to altered flows can occur immediately, gradually, or abruptly after varying periods of time. Because perceptions of ecological variability are scale-dependent, comparisons within and between systems that are needed to generalize effects of altered flow regimes also need to address issues of scale, context, and the specific nature of flow modification in terms of the magnitude, timing, frequency, duration, and rate of change in flow conditions. To illustrate such concepts, I use observations from three decades of ecological sampling on East Branch Perkiomen Creek, a Piedmont warmwater stream in southeast Pennsylvania. Base flow in the East Branch has been substantially augmented since 1989 by a power-plant cooling water transfer system. Specific examples to be presented include 1) a characterization of flow regime modification in relation to natural patterns of hydrologic variation, 2) a generalization of habitat modification in relation to spatial and temporal scales of observation, and 3) comparisons of biotic variability within and between pre- and postaugmentation survey periods. For the latter, multiple criteria were observed along a longitudinal gradient of increasing stream size. Criteria for ecological description include estimates of spatial and temporal variation in: riffle benthic macroinvertebrates, growth and condition of selected fish species, species abundance and distribution, variability in year-class strength and population size, and fish assemblage composition along the gradient before and after flow augmentation. Various special projects required by regulatory agencies provided opportunity to assess concurrence between observed patterns of ecological change in the East Branch and predictions made before project start-up, several of which were based on microhabitat analysis using the PHABSIM component of the Instream Flow Incremental Methodology.

Attendant watershed development over the life of the project has further modified the "natural" hydrograph, leading to substantial geomorphic change in some areas and a pronounced change in broad-scale context for the system. Currently, monitoring data have been collected through fall 2004, although some recent scope reductions have occurred. Project developers are investigating the possibility of decommissioning the higher operational phases of the diversion (while maintaining a low-level "conservation release"), which would produce a management intervention of considerable ecological interest.

NORTHEAST INSTREAM HABITAT PROGRAM

Piotr Parasiewicz, Sean Werle, Lori Johnson, Joe Rogers and Brett Longworth.

Increasing demands for water to meet human needs while protecting aquatic ecosystems and the lack of adequate planning tools for management of running waters has been identified as an urgent problem facing the Northeastern United States. The Northeast Instream Habitat Program (NEIHP) is a multidisciplinary research and outreach initiative that aims to improve the scientific and methodological foundation for the ecologically sound, sustainable management of running waters.

The NEIHP employs a mesohabitat-scale approach to river management assessment using the habitat modeling system MesoHABSIM. Mesohabitats are described by their hydromorphological units, geomorphology, cover and other hydraulic characteristics. When applying the MesoHABSIM survey approach, mesohabitats are mapped at different flows within sections of a river to determine habitat for reference fish and mussels community. The result of the model is a seasonal description of magnitude, frequency and duration of critical habitat events as well as a quantitatively evaluated selection of restoration scenarios (e.g. channel improvements, flow augmentation) to maintain protective habitat patterns. The NEIHP was founded as a partnership among the University of Massachusetts Amherst, US Geological Survey, US Fish and Wildlife Service, and

Environmental Protection Agency. It addresses the needs of resource conservationists and stewards, receiving feedback from advisory committees of state and federal agencies and NGO's.

The NEIHP is part of the New England Regional Water Quality Program and is funded by USDA §406 Water Quality funds, UMass Extension, state and federal natural resource agencies and NGO's. NEIHP is an integrated research, teaching and extension program with a strong commitment to research and development, sustained outreach, training and technical assistance, and development of expanded graduate and undergraduate education. NEIHP tools have been applied at multiple projects in the Northeast region (CT, MA, NH and NY). The techniques have become part of legislative recommendations for development of state-wide instream flow standards in Connecticut, Massachusetts and New Hampshire.

AQUATIC INSECT RESPONSES TO STREAM RESTORATION. HOW DO WE DEFINE SUCCESS?

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Geomorphic monitoring of streams following restoration is a widely used form of monitoring to determine project success. However, little is know about the ecological functions of restored stream reaches since monitoring protocols infrequently use biological indicators. A national review program found that only 14-20% of all projects had any post-construction monitoring.

Benthic maroinvertebrate larvae (aquatic insects) were collected as part of an EPA funded project with the North Carolina Division of Water Quality and continued as part of a grant at North Carolina State University. Data were collected prior to and post-construction at 12 stream restoration projects and these data were used to prepare preliminary success criteria for biological communities. Success criteria are proposed and include an analysis of Dominant-In-Common (DIC) taxa between upstream reference reaches (if available) and the restored reach, and the presence of indicator taxa or habitat specialists. At this point all of these restoration projects have less than 5 years of post-construction information; however, based on these data restored stream reaches have not met the proposed success criteria (DIC of 75%). These data suggest that a minimum of five years of post-construction information need to be collected, but also that the use of success criteria using biological communities will need to be further tested.

HYDROLOGIC CONTROL OF NITRATE LOADING AND TRANSFORMATION IN BACKWATER LAKES OF THE UPPER MISSISSIPPI RIVER

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Floodplain backwater lakes (BWL) are biogeochemically active and potentially able to remove significant portions of transported nitrate (NO3-) from the Upper Mississippi River ecosystem. We explored nitrate transformations in BWL receiving high nitrate water under natural flooding and controlled inflow conditions to determine: 1) patterns of NO3- loss; 2) biogeochemical processes affecting NO3- transformation; and 3) effect of loading rate on removal capacity. In a large (300 ha) BWL, floodwater NO3- concentrations dropped from 6.5 to < 0.5 mg-N· l-1 in 12 d, with a total loss of >18 tons-N. Under controlled inflow another BWL (Third Lake, 15 ha) exhibited high rates denitrification (22 µg-N · cm-2 · d-1), limited by NO3- loading and tightly coupled with nitrification. Nitrate retention was linear to load (r2=0.95), with greatest retention occurring in late June. Mass balance suggested an average of 48 kg · d NO3- was removed from Third Lake (~ 43 % of the total load), ~ 60 % via denitrification.

These results show backwater lakes of the Upper Mississippi River have tremendous potential for NO3- removal, a potential that is directly related to river-flood plain connectivity. Managed reconnection of backwaters to main channels could reduce downstream flux of NO3- while also restoring other ecologic functions and meeting multiple management goals.

ECOLOGICALLY SUSTAINABLE WATER MANAGEMENT: CASE STUDIES, TOOLS AND COLLABORATION

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Human demands for freshwater have more than doubled during the past half century and continue to increase as the human population swells globally. With the corresponding intensive management of rivers, hydrologic alteration – changes in the natural patterns of river flows – has become a leading cause of the precipitous decline in freshwater ecosystems. For example, in the United States – which is a global hotspot for freshwater biodiversity – 37% of freshwater fish and 69% of freshwater mussels are imperiled. However, rapid scientific advancements in river ecology during the past few decades have provided the understanding necessary to support river management that both sustains ecological integrity and meets human needs. Through its efforts to improve river flow conditions for the benefit of freshwater biodiversity, The Nature Conservancy has worked with river scientists, water managers, and conservationists around the world to develop a framework for ecologically sustainable water management. This poster summarizes the ecologically sustainable water management framework, presents an example tool – referred to as the Indicators of Hydrologic Alteration – that is used to help guide water management, and highlights a national collaboration between the Corps and TNC on ecologically sustainable water management.

HYDROLOGY, HABITAT USE, MOVEMENT AND POPULATION STRUCTURING OF A NATIVE BROOK TROUT AND INTRODUCED ATLANTIC SALMON POPULATION

Jason Coombs [1], Ben Letcher [2], and Keith Nislow [3]
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Native brook trout, *Salvelinus fontinalis*, and introduced Atlantic salmon, *Salmo salar*, populations are being studied in a small Massachusetts watershed, tributary to the Connecticut River to determine the influence of hydrology and habitat on movement and population structure. The section of the watershed being intensively analyzed consists of three distinct tributaries characterized by a) an open channel to the mainstem, b) a perched culvert at the confluence, and c) a natural waterfall at the confluence. The upper mainstem is blocked to upstream migration by an impassable dam impounding a water supply reservoir. Individuals are captured and tagged with uniquely coded PIT (passive integrated transponder) tags that are subsequently detected by both section defining stationary antenna and portable wand antennae used to scan stream reaches during scheduled sample periods. Hydrologic data, individual fish biological data, and habitat data are recorded. Non-lethal fish tissue samples are used to genetically characterize the populations using microsatellite DNA. The study design will provide data to correlate movement with environmental variables such as discharge, temperature, and photoperiod, and physical variables such as size, age, and sex; and determine the interactions between density, movement, and growth; determine population structuring through molecular differentiation among tributary and main stem populations. These data will provide resource managers with new insights on the resource management benefits of proposed dam removals and reduced habitat fragmentation by improved road crossings and culvert designs.

TESTING MITIGATION OF URBAN STREAM HYDROLOGY AND ECOLOGY BY DISCONNECTING IMPERVIOUS AREAS: A PILOT STUDY

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Extensive impervious surfaces in urban and suburban areas have resulted in widespread hydrologic and ecological alteration of receiving streams. Decentralized stormwater management (e.g., infiltrating runoff at sources and disconnecting stormwater pipes) may improve stream ecosystems by reducing erosional stormflows, increasing stream baseflows, and reducing delivery of pollutants into streams. In a small, residential watershed in Cincinnati, OH, where a majority of the total impervious area (TIA) in sub-watersheds are in rooftops and driveways (50-71% of TIA), we will distribute parcel-level Best Management Practices (BMPs), in the form of rain gardens and rain barrels, for stormwater mitigation. Due to the legal and socioeconomic challenges associated with retrofitting stormwater management, we opted to use a voluntary economic auction to assess landowners' willingness-to-accept compensation for installing BMPs on their property. Thus, we will be testing whether the auction will result in enough BMP installation to observe improved hydrological and ecological conditions in downstream sites. We have established six monitoring stations throughout the watershed, at which several years of baseline data will be collected prior to the installation of the rain gardens and barrels. A BACI (Before-After Control-Impact) design will be used to test the "impact" of parcel-level BMP installation. Preliminary data shows that these headwater urban stream reaches are characterized by low macroinvertebrate EPT (Ephemeroptera, Plecoptera, and Trichoptera) richness (1.6 to 3.8 species), low proportional abundance of diatoms (9.6 to 24.6%), high conductivity (580 to 1240 $\mu s\ cm^{-1}$) and high concentrations of *E. coli* (1413 to 5113 CFU per 100 ml) and fecal coliform bacteria (3199 to 5298 CFU per 100 ml). We expect that the most upstream sites (vs. control areas not receiving BMPs and sites farthest downstream) will demonstrate the greatest improvement of stream hydrological and ecological condition after retrofit stormwater mitigation. If ecological responses do not track hydrologic improvements, protection of streams in urban areas may be more feasible than restoration.

HABITAT ASSESSMENT OF THE POTOMAC RIVER FROM LITTLE FALLS TO SENECA POOL

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A current multi-agency agreement establishes a Potomac River minimum low-flow requirement (100 million gallons per day or mgd) or flow-by at Little Falls and a recommended operational guideline of 300 mgd at Great Falls. The Maryland Department of Natural Resources initiated a re-evaluation of the low-flow requirements for protecting the lower Potomac River aquatic ecosystem near Washington, D.C. A habitat assessment was conducted during record low flow conditions in summer 2002. The assessment included development of a habitat map, a field survey of habitat types, and measurements of hydraulic and water quality conditions.

The low flows in 2002 enabled the habitat assessment team to make successful assessments over several months during rare low flow conditions. Results of water level recordings showed the greatest change in stage with changes in flow at Lock 8 and Old Angler's Inn, and smaller changes at Carderock and Little Falls Dam. A reduction in flow from 500 mgd (770 cfs) to 300 mgd (465 cfs) resulted in relatively small reductions in water level: 2.2 inches at Carderock, 3.6 inches at Old Angler's Inn, 3.9 inches at Lock 8, and 1.6 inches at Little Falls Dam.

Results of measurements show that very high temperatures occurred at flows well above the current recommended minimum flow-by level and were probably more related to air temperature and solar radiation than to any particular flow level below about 970 mgd (1500 cfs). Measurements of dissolved oxygen showed lowest levels occurring in two of the largest pool areas of the river (Little Falls Dam and Seneca Pool) which were at or slightly below the Maryland state standard of 5 mg/l. Dissolved oxygen values in two other pool areas (Aqueduct Dam and Old Angler's Inn) were never lower than 7 mg/l during the measurement period.

Results of macrohabitat surveys confirmed the very diverse nature of habitats in the study reach. There is a predominance of Pool habitat (37%), followed by Shallow Run (24%), and Deep Run (19%) habitats. Results of microhabitat surveys indicate some very deep areas in the study reach. The pool beneath the American Legion Bridge is quite deep, averaging over 20 feet overall, 40 feet in the main channel, and reaching 94 feet at its maximum depth. Mather Gorge and Old Angler's Inn Pool are both also relatively deep, with average main channel depths 23 and 22 feet, respectively, and with maximum depths of 45 and 36 feet, respectively. The remaining large pool areas (above Little Falls Dam, above Aqueduct Dam and Seneca Pool) are relatively shallow, with maximum depths less than 15 feet and average depths less than 8 feet.

In April 2003, a workshop was convened with a special panel of nationally recognized experts on habitat assessment to investigate and develop methods to evaluate flow-by requirements. The panel collectively considered and debated the various methodologies applicable to the Potomac River to address study objectives. The final product of the workshop is a set of recommendations for 1) the best method or approach, given current financial resource limitations, to address study objectives, and 2) an alternative long-term method or approach which could better accomplish those objectives, yet might exceed current resources or available data.

DATABASE OF TRACER STUDIES IN U.S. CHANNELS AND APPLICATION TO PREDICITING VELOCITY IN STREAMS AND RIVERS OF THE UNITED STATES Schwarz, G.[1], Harvey, J.[2], Asfaw, E.[3], and Qiu, Y.[4]

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Time of travel (TOT) studies are among a select set of fundamental stream measurements collected by the USGS. These studies use dye and salt tracer injections to acquire information on stream velocity and longitudinal dispersion of solutes. Thousands of measurements have been recorded over the years and stored away in USGS reports. Unfortunately, in their current form, these data have little scientific value. The purpose of this project is to improve access to these data by compiling these data into a single, consistent, electronic database. A second purpose is to assemble a complementary dataset of stream and watershed attributes, and to perform statistical analysis to develop a predictive model of stream velocity for any U.S. channel.

There is an increasing need for improved estimates of stream velocity in the U.S. as state and regional water managers are called upon to provide information and make decisions on topics such as the protection of drinking water quality and regulation of streamflow and velocity to preserve habitat value for wildlife. TOT estimates are also important for water quality models, affecting the attenuation of contaminants in streams. The compilation of a large TOT database provides necessary information to develop predictive equations that estimate TOT for any reach under varying flow conditions.

The TOT database builds on previous work by Harvey Jobson of the USGS, consisting of a compilation of over 900 TOT measurements in 90 rivers collected from 25 USGS reports. The current database has compiled information from more than 100 additional reports, leading to an additional 2,500 measurements from over 220 rivers. Additionally, each measurement from the combined database has been spatially referenced to a specific reach location on the Reach File 1 (RF1) reach network. All measurements conform as closely as possible to the reporting conventions adopted by Jobson. Many observations include measurements of both peak velocity and velocity of the leading and trailing edge.

Future plans call for spatially referencing all observations to the National Hydrography Dataset (NHD) reach network. This referencing will permit the TOT data to be linked to additional NHD stream characteristics currently being developed, including drainage area, mean annual streamflow, stream sinuosity, and reach slope. A statistical analysis will then be undertaken to relate velocity measurements to contemporaneous streamflow, the stream characteristics described above, and other GIS information that describes the "friction" streamflow encounters within streams. The predictive equations obtained from this analysis will permit extrapolation of velocity estimates to non-monitored streams and alternative flow conditions. The data compiled from the study will be made accessible through the Internet and a report documenting sources and methods will be written.

STREAMFLOW MANAGEMENT: A POWERFUL TOOL FOR SUSTAINABLE TAMARISK CONTROL

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Throughout arid and semi-arid regions of the western U.S., the decline of native riparian forests has often been attributed to water development and the human-caused modifications in streamflow and the fluvial processes to which many native species are adapted. Over this same period of time, tamarisk (*Tamarix* spp.) invasion has occurred and is thought to be facilitated by streamflow regulation. Evidence suggests that tamarisk is more frequent and abundant on more heavily regulated streams compared to streams that maintain a more natural flow regime. Long-term control of tamarisk requires either sustainable replacement with other vegetation or frequent re-treatment.

A common goal associated with tamarisk control is the restoration of native forest. Restoring the natural processes to which native species are adapted can be a powerful, and sometimes essential, tool for achieving sustainable revegetation. Streamflow management can be used to create conditions that are more favorable for native species and less favorable for tamarisk. For example, on some rivers high flows can be timed to coincide with periods when seed dispersal of native cottonwood and tamarisk do not overlap. Reoperations of Alamo Dam on the Bill Williams River, AZ are largely focused on promoting cottonwood willow forest ecosystems while inhibiting tamarisk. Experimental releases during years of high runoff (1993 and 1995) were largely successful. Similar prescribed releases have been successful in fostering cottonwood recruitment along the Truckee River in NV, the Rio Grande River in NM, the Oldman River in Alberta, and other rivers in the western U.S.A strategic, regional plan for tamarisk control should include identification of areas where there is potential for streamflow management to favor the establishment of native taxa in place of tamarisk.

SPECIAL SESSION: EXPLORING EXPANDED COLLABORATIONS WITH THE NATURE CONSERVANCY

PUTTING SCIENCE INTO CONSERVATION PRACTICE: EXAMPLES FROM GLOBAL TO LOCAL SCALES

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The Nature Conservancy uses a science-based approach for conserving biodiversity. The purpose of this talk is to provide an overview of the process that the Conservancy uses for setting priorities, developing strategies and assessing results. In its first few decades, the Conservancy implemented its work largely by reacting to opportunities. Since that time, the Conservancy has developed numerous planning tools, which are used within an adaptive management framework, to provide a better science foundation for its work.

For the last decade, the Conservancy has used a process for identifying significant conservation areas within ecoregions and basins. Strategies for conserving these areas are developed using a process that identifies conservation targets, assesses their current status, and describes a set of actions to restore their ecological integrity or abate critical threats. To complement these existing efforts, the Conservancy is developing a process for setting a 10-year goal for conserving the world's biodiversity and a process for measuring progress. A major challenge is the integration of these various activities across different spatial scales, so that global assessments guide local actions, and local actions accelerate our understanding of how to achieve the larger goals. Examples from freshwater ecosystems illustrate the methodology of several planning tools.

THE FUTURE OF ENVIRONMENTAL FLOW SCIENCE AND MANAGEMENT

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Many new scientific approaches and analytical tools have been developed in recent years for assessing the environmental flow needs of rivers. Many of these approaches and tools require considerable financial expenditure and time, however, making them impractical for application to hundreds or thousands of rivers within each state. Water managers need a more rapid, less expensive and scientifically-credible means to determine environmental flow needs on many of the rivers and streams under their jurisdiction. One means for addressing these needs would be to develop regionalized standards for hydrologic protection that could be applied when developing regional water supply plans or making regulatory decisions on specific rivers. The Nature Conservancy is developing a "Limits of Hydrologic Alteration Method" that will suggest limits on hydrologic alteration that are linked to the targeted level of ecological health for each river. This presentation will provide an overview of this new "desktop" method and the flow-ecology research that will be needed to develop it in each region.