Dr. Winemiller's River Science Fact Sheet

Neches River, Hardin County

This fact sheet was prepared to provide a succinct and general overview of the main issues and state-of-the-art approaches involved in establishing environmental flow regimes. The emphasis of this fact sheet is on fishes, but it must be recognized that environmental flows support other biological components of river ecosystems, including riparian forests. For more detailed accounts and background information, the reader may consult reference materials listed at the end of this fact sheet.

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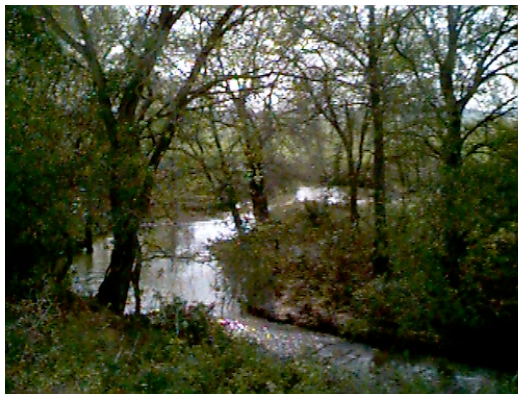
1. How much water does a fish need?

What is the minimum amount of water in a stream that will allow fish to survive? The answer, of course, depends on how long one would expect an individual fish or fish population to survive. An individual fish can survive in a bucket of river water for perhaps several hours to days, depending on the species. But sooner or later, the fish will use up all the dissolved oxygen, poison its environment with its own waste, or eventually starve. When flow in a river or stream is reduced to extremely low levels, populations of aquatic organisms are at first crowded together in remnant aquatic habitats. For example many fish species, large and small, will take refuge in the deepest places remaining in the channel. Small species that are only found in riffles, are forced to crowd together within any remaining channel areas that are shallow with flow. Fish that occupy floodplain habitats like side channels (sloughs) and oxbow lakes, will be crowded together at high densities, and sometimes these habitats dry up altogether.

Why is this a threat to population survival? Again, the answer depends on the severity of the crowding and the length of time the organisms are forced to endure this crowding. If the crowding were to occur for only one day during a year, then the impacts would be small. If the crowding were to occur for several weeks in succession, local populations of fishes and other aquatic organisms would be lost due to mortality from predation, disease, and in some cases degraded water quality.

How do river scientists figure out how much water is enough to prevent this sort of mortality that causes loss of species in streams and rivers? This is an age-old question in river management that scientists throughout the world have been trying to answer. Many different approaches have been investigated over the past several decades, and all of them lead to a solution that is the best approximation for limiting the negative impacts of crowding and habitat degradation. Basically, one must choose a flow value that maintains a certain amount of habitat to allow all the aquatic populations to survive, but the other critical issue is to limit the frequency and duration of the stressful and impactful conditions. Again, the answer to this basic question depends on how long the reduction in water must be endured by the organisms. Consequently, river scientists have arrived at a best approximation that the minimum flow is one that has a historical frequency of occurrence of no more than 5% of the time. They refer to this as a subsistence flow, the flow that is needed to maintain aquatic life during stressful periods of severe drought.

Why not choose a different number for this subsistence flow, perhaps a lower one? One could choose a lower value, but again, one must consider that the mortality rate of aquatic organisms crowded together will depend on the duration of such events and how often such events happen. If one could be confident that conditions in the river or stream and its watershed will remain just as they are, and never be changed in the future, managers could set this value at the 1% value (called the 1st percentile of low flows), because we know that this flow level happened at least once during some period in past. *If we expect conditions in the watersheds might change in the* *future,* for example some of the flow might be reduced compared to what they are now or were historically, then there would be a very high probability that populations of fishes and other aquatic organisms would be lost in the future. This is the reason why river scientists have established flows associated with an occurrence frequency of 5% as the benchmark for managing the risk of local species extinction in streams and rivers.



Walnut Creek, Robertson County

2. If fish can survive with this much water, why would they need any more?

Wouldn't a subsistence flow supply enough water for fish? Definitely not! Remember that subsistence conditions occur infrequently when there is severe drought. Fishes and other aquatic organisms cannot sustain populations if subsistence conditions occur too frequently or for long periods of time. In order to feed, grow and reproduce, fishes and other aquatic organisms need a certain amount of water that provides them with sufficient living space. Ecologists refer to this living space as *habitat*, and the amount of living space present at any given time for species is defined as its *habitat availability*.

How does one determine habitat availability? Many methods have been developed to determine habitat availability for fishes and other wildlife, but most rely on field research to determine patterns of space occupation followed by statistical analysis. The results of such studies are quantitative relationships (mathematical equations) that define where species occur on the landscape and which can be used to predict occurrence or abundance in different landscapes, or at a different time on the same landscape. To predict habitat availability for fish in streams and rivers, a common approach is the Physical Habitat Simulation – Instream Flow Incremental Methodology (PHabSIM-IFIM). These models are used to predict the amount of habitat that is available as living space (for feeding, growth, reproduction, and termed *weighted usable area*) under variable levels flow.

How is habitat availability affected by changes in flow? This is an important question that actually can be addressed by PHabSim-IFIM research. It turns out that increasing flow from a low level, for example the average base flow condition during a dry year to a higher level, such as would be experienced during a year with more rainfall, changes the amounts and relative proportions of habitats for fishes having different needs (different *niches* so to speak). This, of course, is the natural state of affairs, with some years having low base flows and others with significantly higher flows. Hydrologists can statistically estimate these different base flow conditions based on long-term records of flow at stream gages. Thus, river scientists and managers can use outputs from hydrological analysis and findings from PHabSim-IFIM research to estimate how the relative abundances of the various fish species should change as flow changes from dry to average to wet conditions. In every instance in which this has been done, both in Texas as well as other states and countries, it is the case that some species have more habitat under dry conditions, but these same species actually have less habitat under wet conditions. Other species show the reverse pattern, and some species actually have the most living space available to them during years with average rainfall.

Doesn't this assume that if there is more living space, the fish populations will be larger? Yes, this is the explicit assumption whenever the PHabSim-IFIM findings are applied for estimation of environmental flows. Basically, it is assumed that if base flows during dry, average or wet years are to some degree stable, then fishes can carry out their requisite activities for survival, growth and completion of their life cycles within available habitats. This should result in stable or positive population growth in the long term. Of course, flow pulses can and do come along, and these may interrupt normal activities. These periodic flow pulses also may cause physical disturbance to habitats, for example scouring the bed, suspending silt, moving fine sediments, and washing material (nutrients, leaves, woody debris) from the surrounding terrestrial landscape into the stream. *Some of these physical effects of high flows actually are critical for maintaining physical habitat structure in a patch mosaic and for supporting the productivity of the aquatic system.* The habitat patch mosaic is considered to be a very fundamental feature of stream and river habitats, and the disturbance regime caused by flow pulses appears to be critical for maintaining biodiversity. This has been termed the *patch dynamics model* of community ecology, and stream ecosystems provide some of the best "textbook examples" supporting this model. Essentially, the model predicts that species diversity will decline in the absence of environmental variation that causes periodic habitat disturbances. The species lost from the ecosystem initially would be those that normally colonize recently disturbed habitats where there is little competition for living space and resources. With time and the absence of subsequent disturbances, these colonizing species (certain algae, aquatic invertebrate and fish species) are outcompeted by other species that are superior competitors or eliminated by predators as the habitat matures (a community succession process at the patch scale). Because these colonizing species have naturally high rates of population growth, they often serve as very important food resources for other species in the ecosystem. Thus, the loss of colonizing species can have major ripple effects in the biological community.

3. Is there such a thing as too much water for fishes?

The answer to this question depends on how that water is delivered to the stream or river. If a great amount of water flows through the stream at the same level all the time, then this will surely cause the local extinction of many of the aquatic species. We can look at a reservoir as an extreme example. Reservoirs capture water that is delivered to a segment of a stream or river and hold it back, only allowing a reduced flow to escape below the dam. In effect, the amount of water for the segment above the dam is greatly increased and the rate of movement through that segment is greatly decreased. As a result, the fish populations undergo tremendous changes within the impounded segment. Certain species, such as largemouth bass and bluegill sunfish, find these conditions favorable and their populations flourish. Other fishes, usually the great majority of species, become extinct within the segment. Some of the fishes belonging to this latter group are called *fluvial specialist*, and examples of these flow-dependent fishes include species of the sucker family, most species of minnows and darters, and certain catfish and sunfish species. Obviously a reservoir presents an extreme case, but one can easily imagine that if great deal of additional water were delivered continuously to a river, its biological community would change. Here again, *the key concept is continuous flow vs. flow variation.*

What about floods – don't floods harm fish? Floods that pass a huge amount of water very fast have obvious harmful effects, not only for people and their structures, but they sometimes kill aquatic organisms and certainly cause disruption of the ecology of organisms that normally live within the main channel. Some fishes can withstand being displaced by the strong current by moving into flow refuges on the river bottom. Other fishes, in fact the majority of species in most rivers, move with the rising floodwaters into flow refuges along the flooded river margins. There are many more aquatic habitats available for fishes along the river margins (termed the *littoral zone* if associated with the channel, or *riparian area* if associated with the stream banks) that can serve as flow refuges during floods. If the flood is very large, fishes might be found great distances from the stream or river channel, and a few unfortunate ones might even be stranded there when the flood water eventually recede. But most aquatic organisms find their way back into the channel as floodwaters recede, and some may end up in productive *off-channel habitats* such as oxbow lakes or sloughs.

Are floods always bad for fish? Definitely not! In fact, river scientists have documented many essential functions of floods that allow fish populations to be maintained in streams and rivers. During small floods, ones that cause the river channel to swell but don't make it to the tops of the banks, fishes seize the opportunity to move into new aquatic habitats where they exploit abundant food resources, escape their predators, and, in some cases, spawn within areas having particular substrates, such as submerged grass, shrubs, sticks or leaf litter. River scientists have documented how certain fish species grow faster after a period of time spent feeding in expanded marginal aquatic habitats. Periods of high stream flow can be particularly important for fishes, including many minnow and sucker species, that spawn during or soon after increases in flow with limited duration (usually lasting for several days). These kinds of short-term increases in flow that fail to reach the tops of the streambanks are called *in-channel high flow pulses*.

What about bigger floods? During large floods, for example floods that top the riverbank in several places spilling water onto the floodplain, fishes will feed on terrestrial insects and other invertebrates and even terrestrial plant material, such as seeds and fruits lying on the ground. Some species of fish, like gars and carp, actually spawn in flooded plains. Spawning by fishes on floodplains during floods is commonly observed in tropical river systems, where large floods occur on an annual basis during the rainy season, but some temperate-zone fish species also do this. It is also very important to realize that large flow events, including *overbanking floods*, have other critical functions that fishes and other aquatic organisms are dependent upon when viewed over the long term. These functions include scouring and movement of bed materials, bank erosion and sedimentation, and connecting aquatic habitats that exist within-channel with those located along the margins or in the floodplain. *Fish habitat can only be maintained in the long term if flow pulses create a dynamic geomorphology– a constantly changing channel with pools, riffles, runs, backwaters, etc.*

Does it matter to the fish when these flow pulses or floods happen? Yes– if an in-channel high flow pulse occurs during a dry period or during a drought, the additional water expands the amount of habitat available for fishes and aquatic organisms for a short time. This short-term expansion of habitats reduces certain sources of mortality (termed *negative density-dependent factors*) and increases certain opportunities for feeding, growth and survival (termed *positive density-dependent factors*). These density-dependent factors are understood by ecologist to be the principal reason why populations have a degree of *stability*. For example, ecological models reveal that populations have much greater probability of exploding or crashing in the absence of density-dependent factors. In other words, they become less stable. This is one of the most fundamental issues in the field of ecology– *population regulation*. The study of population regulation has been extensive, and can involve very complicated mathematical models with intensive computation demands. By any modeling approach, one of the keys for predicting population dynamics is the relative influence of density-dependent factors. Any change in the per-unit-area density of organisms is likely to change the influence of density-dependent factors, including species interactions such as predation, parasitism, and competition, on population dynamics. The manner in which a given population of a species responds to various density-dependent factors depends on its *life history strategy*. A life history strategy is a set of attributes that determine the organism's reproduction, growth, and survival. The science of ecology has a long history of research on life history strategies, and fishes show a particularly great diversity of life history strategies.

Brazos River, Brazos County

4. With so many different life history strategies, wouldn't different fish species respond to conditions differently?

The various fish species wouldn't all show the same population dynamics would they? Correct! With such a diversity of life history strategies, we can predict that certain species will prosper under one set of environmental conditions (benefitting from positive density-dependent factors), but others might suffer from negative density-dependent factors. For example, when the flow in the stream channel gradually declines, piscivores (fish eaters) benefit from the intensified predation interactions that result from greater *per-unit-area densities* of fishes within the smaller amount of overall aquatic habitat. Small fishes that are prey for these piscivores suffer greater mortality from predation under this set of conditions. If we gradually expand the aquatic habitat with more flow, then the density-dependent influences reverse in a more-or-less graded manner. This is just one simple example, but ecologists examine the dynamics of the network of species interactions and resulting population dynamics within biological communities using *food web models*. Food web research using mathematical computer models has shown how easy it is to observe chaotic dynamics in the absence of controlling environmental factors. In rivers and streams, the principal controlling environmental factor exerting influence on density-dependent food web interactions is the hydrological regime. A *hydrological regime* is a description of the amount of water and distribution in time of how the amount is delivered to a stream segment.

5. How will we ever be able to determine which hydrological regime is sufficient to maintain all the species in a river or stream food web?

Isn't this too complicated? How can we understand the environmental needs of so many species and the dynamics of so many food web interactions? We probably can't predict dynamics for all of the species, at least for now; most communities contain too many species and too many interactions. Ecological research is continually improving our ability to predict food web dynamics through field experiments, and by combining field measurements with new approaches for computer modeling. This is a very active and important research topic for the field of ecology, and river scientists have produced some of the most influential food web studies to date.

Again, how can we determine a sufficient flow regime? River scientists currently use two complementary approaches to estimate the *environmental flow regime* (an environmental flow regime is the flow regime that best maintains the biodiversity and productivity of the river or stream). The first approach is to determine the flow requirements of a set of focal species. The set of focal species should provide examples of divergent life history strategies among the diversity contained in the biological community. Thus, even if river scientists can't predict food web and community dynamics with precision, they often can draw robust conclusions about how a given species population will respond to components of a flow regime. If the set of focal species is sufficiently diverse, then it is assumed that the regime that best satisfies their needs also will satisfy the needs of all the species within the system.

What is the second approach for estimating an environmental flow regime? The second approach is to estimate a flow regime that best approximates the natural flow regime. The natural flow regime is the historic pattern of flows that maintained the community of native species. This approach assumes that the risk of losing stream biodiversity or productivity is minimized when the environmental flow regime mirrors the various flow components of the natural flow regime. This assumption is supported by findings from numerous field studies and analyses conducted by river scientists and natural resource managers. For example, it has been shown that severe alteration of the flow regime is the most likely cause of rapid decline in several minnow species in North America. Several of these species, once abundant, are now listed as threatened or endangered.

Does the natural flow regime approach imply that all water must be protected to maintain biodiversity? No. In some cases, much water may be available for human appropriation even under implementation of an environmental flow regime that is based on the natural flow regime. What must be protected are the flow components that provide essential ecological functions, such as sediment movement (which maintains habitat among other things), nutrient dynamics, maintenance of water quality, cues and conditions for reproduction by fishes and aquatic invertebrates such as shrimp, crayfish and mussels, habitat patch dynamics and habitat availability for various life stages at appropriate times of the year and for feeding (food web interactions). The basic approach requires that the pattern of flow variation involving *flow components* (*subsistence flow, dry condition base flow, average-condition base flow, wet-condition base flow, in-channel high flow pulses, and overbanking flow pulses*) reflects the natural flow regime. The magnitudes of some of the flow components can, in certain cases, be adjusted, and because these components are often estimated as average frequencies of occurrence, there is no reason to expect that any given year would faithfully produce these average frequencies for components such as high flow pulses.

So how can one know if components have been adjusted too much? There are at least two ways to do this. First, the focal species analysis should be consulted to see if ecological risk is likely to increase. For example, reduction in the magnitude, frequency or duration of in-channel high flow pulses might eliminate important functions on which fluvial specialists depend. For example, many minnow species spawn on rising flow pulses, and altered flow regimes in several rivers in Texas and other regions of North America have greatly reduced several populations, with several species on the brink of extinction. High flow pulses may be required during spring or summer, for example, in order for certain species to spawn and for the young fish to have access to habitats that allow them to survive and grow.

The second method for assessing risk of adjustments to the natural flow regime has been termed *adaptive management*. The premise of adaptive management is that uncertainty in our predictions about the responses of complex systems (such as ecosystems) to input variables (such as flow) can be reduced if we manage the system as though we were conducting a long-term experiment. A given management action can be treated as a best approximation, and following a period of monitoring, the action can be changed and followed by continued monitoring, and so on. By evaluating responses to alternative management actions, uncertainty sometimes can be reduced. A third option for reducing uncertainty for risk management is to perform adaptive management on a computer by simulating alternative scenarios. This latter approach normally requires considerable investment in time and resources. For example, the massive ecological restoration effort for the Florida Everglades and Florida Bay is supported by a multi-million dollar ecological modeling effort.

Devils River, Val Verde County

6. Can environmental flows be determined for estuaries?

Are estuaries so different from rivers that these methods don't apply? Well, estuaries are different in many respects, but in general, the answer is no– the same strategy still applies. Estuaries are the places where the river flows into the sea. There are many different kinds of estuaries in terms of their size, shape, tidal influences and a host of other factors. Perhaps the greatest environmental difference between rivers and estuaries is that the latter are under strong influence of tides and wind. The dynamic and opposing forces of freshwater inflows and offshore wind pushing salty water out to sea, and tides and inshore wind pushing salty water into the estuary would make it difficult to apply, in a direct manner, the flow regime methods for streams and rivers to estuaries. However many of the same basic principles apply equally well to estuaries, for example the concepts of population regulation, habitat suitability, environmental variation and patch dynamics. Estuaries tend to be much broader than river segments, often with long water residence times, and of course the influence of salinity on the biological community cannot be ignored. Nonetheless, environmental flows can and have been estimated for many estuarine systems throughout the world using habitat availability modeling approaches.

It is important to keep in mind that a river is more than just the wetted channel, and the biological community of a river is more than just the aquatic organisms such as fishes, mussels and aquatic insects. Most aquatic organisms depend on periodic access to flooded riparian habitats, and most riparian plants, such as bald cypress trees, depend on periodic high flow pulses for seed dispersal, seedling establishment, and elimination of upland plants that can outcompete them on drier soils. The flow regime also influences nutrient dynamics, productivity and the types of food resources available to aquatic organisms. Many terrestrial wildlife species (mammals, birds, reptiles and amphibians) are dependent upon native aquatic and riparian habitats and food resources, and this is the reason why river corridors and river bottomlands are "hotspots" for wildlife diversity and abundance. This is true in all regions of the state, from the dry regions of west Texas to the relatively wetter regions of east Texas.

Learn More About River Science and Environmental Flow Regimes

Webpages:

Instream Flow Council–– http://www.instreamflowcouncil.org/

Texas Environmental Flows Programs––
http://www.tceq.com/permitting/water_supply/water_rights/eflows/resources.html

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