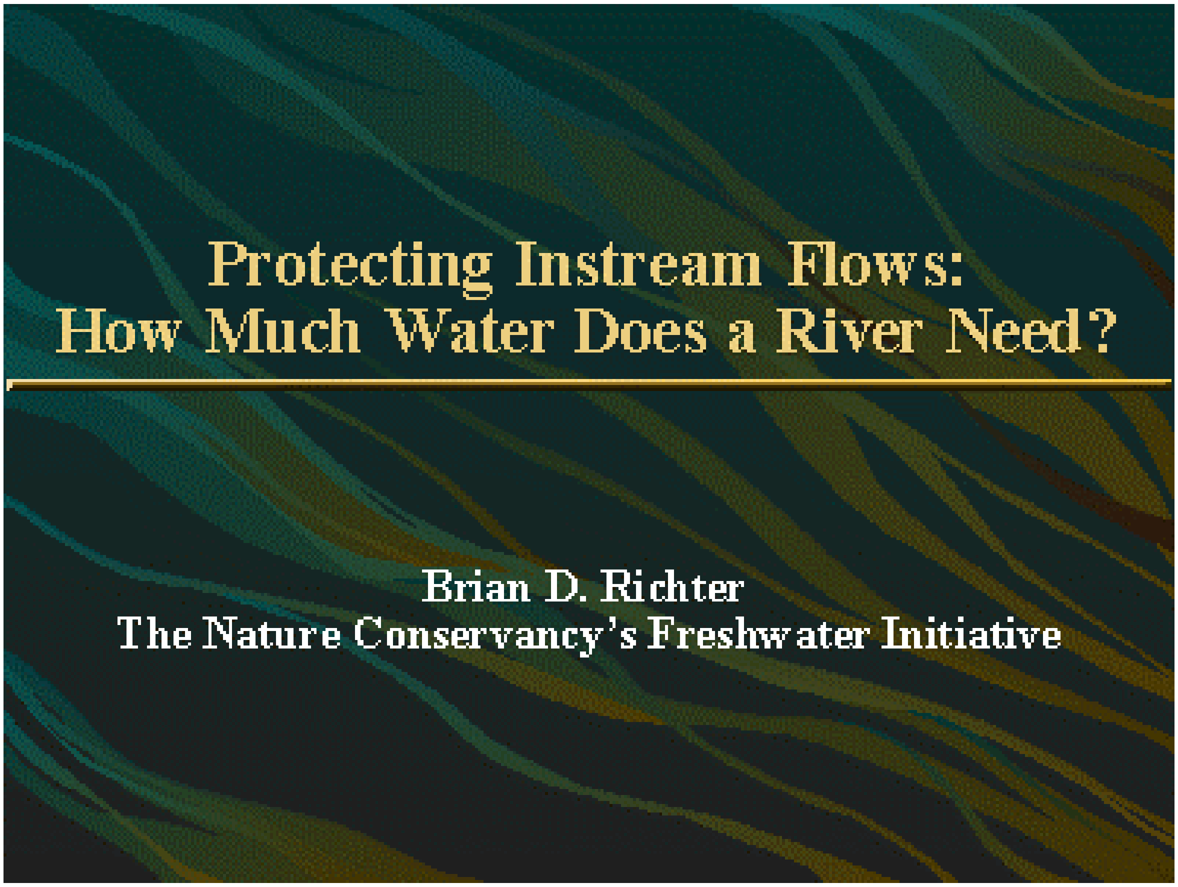
Protecting Instream Flows:
How Much Water Does a River Need?
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The Nature Conservancy's Freshwater Initiative

Introduction:

This module discusses an approach for defining and restoring the streamflow conditions that sustain the biological diversity -- native riverine species, aquatic and riparian communities, and natural ecosystem functions -- of rivers. This approach is applicable when working with dam operators or water managers to change the way water is being stored, released, or diverted for human use. It is also useful in watershed restoration projects wherein various best management practices or other measures are being used to restore natural watershed functions, including hydrologic regimes.

Figure 1. Dam operation can and should consider effects on the river downstream from storage and release patterns.

Watershed management focuses mostly on **water quality** issues, but **water quantity** is extremely important in its own right (Figure 1). Writing for the U.S. Supreme Court in the case *Jefferson City Public Utility District v. Ecology Dept. of Washington*, Justice Sandra Day O'Connor said that the separation of water quality from water quantity (or flow) was an artificial distinction that had no place in a law intended to give broad protection to the physical and biological integrity of water. Further, she claimed that reducing water quantity or flow was capable of destroying all designated uses for a given body of water, and that the Clean Water Act's definition of pollution was broad enough to encompass the effects of reduced water flow. This Supreme Court decision upheld the State of Washington's right to require a minimum water flow necessary to protect salmon and steelhead and to disapprove a hydroelectric plant application that would have diminished the existing flow.

The amount of flow in rivers affects many issues of water quality and quantity together – for example (Figure 2, next page), pollutant concentration, water temperature, aquatic habitat, and recreational uses – all of which prompts us to ask the crucial management question, **"How much water does a river need?"**

Pollutant Concentration Higher flow is important for dilution of pollutants; in fact, many rivers and streams that violate water quality standards for common pollutants do so when flows are abnormally low.	**Aquatic Habitat** Pools, runs and secondary channels are deeper, more varied and more abundant when flow is higher, and this allows a river or stream to support more abundant and diverse aquatic life.
Water Temperature The amount of water in a stream or river affects its resistance to becoming too warm, because more water takes longer to heat. Higher flows protect sensitive, coldwater species like trout and salmon from harmful or even lethal water temperatures.	**Recreational Uses** Sports such as whitewater rafting and canoeing depend on certain levels of flow for the number of days per year that outfitters can make a living. Flow also significantly affects other sports such as fishing.

Figure 2. Four major issues concerning water quality and quantity relationships

A good way to address this key watershed management question is through the "Range of Variability Approach" (RVA), which is based upon two overarching principles:

1. River ecosystems and the native species dependent upon them can best be conserved by protecting as much as possible of the natural variability in flow – a concept that has been called the "natural flow paradigm" (Figure 3).

2. Because we will not perfectly understand how much alteration of natural flow regimes is ecologically tolerable in any particular river, the definition of an adequate or preferred flow regime should be determined in an adaptive fashion – a concept that has been called "adaptive management" (Figure 4, next page).

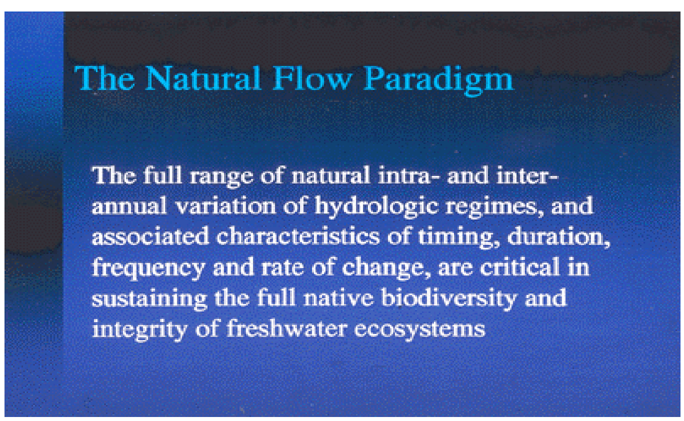

Figure 3. The natural flow paradigm

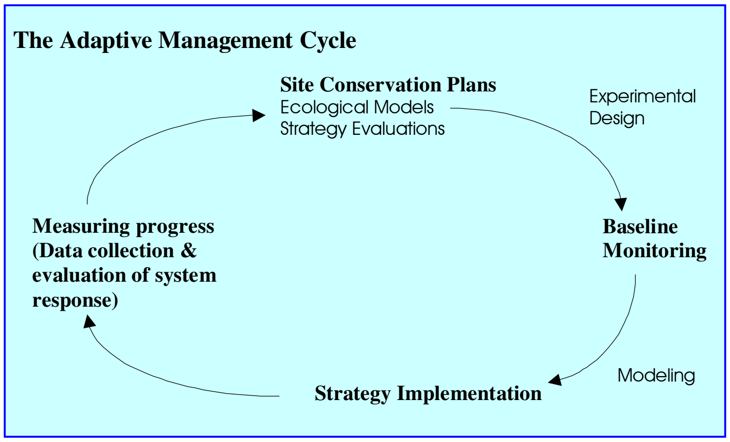

Figure 4. Adaptive management

Steps in the Range of Variability Approach (RVA)

STEP 1. Characterize range of flow using 22 hydrologic parameters.

STEP 2. Select flow management targets based on these parameters.

STEP 3. Design a management system that will attain these targets.

STEP 4. Implement the management system and monitor its effects.

STEP 5. Repeat characterization yearly and compare new values to the management targets.

STEP 6. Incorporate new monitoring information and revise either the management system or the RVA targets as necessary.

Ecological Significance of Natural Flow Regimes

The natural flow paradigm springs from an understanding that aquatic and riparian organisms depend upon, or can tolerate, a range of flow conditions specific to each species. For example, certain fish species will move into floodplain areas during flood events to spawn, feed, or escape predation from other species occupying the main channel. If flooding occurs at the right time of the year, and lasts for the right amount of time, these fish populations will benefit from the flood event (Figure 5).

Figure 5. Flooding is a regular seasonal event for some types of rivers, and their aquatic communities depend on it.

On the other hand, other species may be adversely affected by the same flood. For example, benthic (bottom-dwelling) macroinvertebrates may be scoured from the streambed (Figure 6, next page) or riparian trees may become stressed or die from prolonged flooding and associated oxygen deprivation (Figure 7). Also important is the rate at which flow levels change. If the river level rises too fast, it can trap animals such as amphibians and reptiles on the floodplain. Conversely, young plants such as cottonwoods taking root on the floodplain can die from moisture stress if their growing root systems cannot keep up with the dropping water table linked to falling river levels (Figure 8).

Figure 6. Mayfly nymph

Figure 7. Trees killed by prolonged flooding

Figure 8. Low water levels can lead to stress and mortality of floodplain plants

Natural low-flow conditions can be equally important. Prolonged natural droughts might help certain plants such as baldcypress trees become established on the floodplain, before river levels again rise up around their growing trunks (Figure 9). In the river channel, low flows will concentrate fish and other aquatic organisms, benefiting predators such as larger fish or wading birds (Figure 10, next page). If low flows are too severe, or last for too long due to human influences, large numbers of individuals may perish and jeopardize the local populations of certain species.

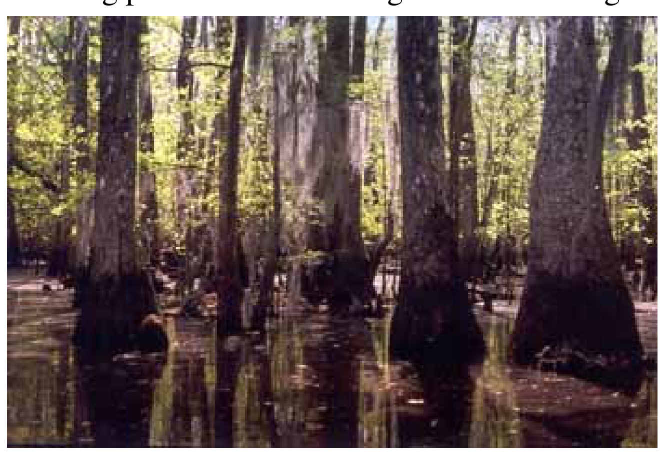

Figure 9. Seasonally-flooded cypress swamp

Figure 10. Common egret

Thus, rather than trying to prescribe a flow regime that benefits some species all of the time, a better approach is to restore or sustain a flow regime that benefits each species some of the time (Figure 11). The species that are found in each river have endured many trials of adverse flow conditions, exploited many occasions of favorable flow, and have managed to persist in their native rivers over long periods of time. Until very recently in evolutionary time, the variation in river flows has been dictated largely by natural climatic and environmental conditions. These natural river flows have influenced the development of behavioral (e.g., floodplain spawning), physiological (e.g., tolerance for oxygen deprivation), and morphological (e.g., body shape) traits in riverine species. Thus, perpetuation of the natural flow regime is the best approach for conserving the full richness of a river's biological diversity.

Flow regimes exert a strong influence on other ecosystem conditions as well (Figure 12). Water chemistry, temperature, nutrient cycling, oxygen availability, and the geomorphic processes that shape river channels and floodplains are often tightly coupled to streamflow variation. Natural flow regimes are therefore intimately linked to many different aspects of ecological integrity.

Figure 11. Kern River

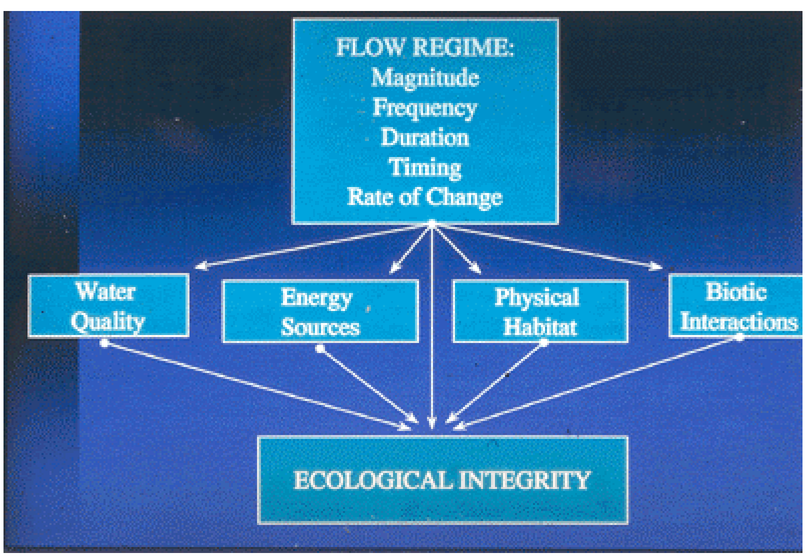

Figure 12. Characteristics of flow are crucial to a river's ecological integrity

Human Alterations to Natural Flows

Human activities and uses of water have substantially altered river flow regimes in the U.S. Today, less than two percent of U.S. rivers remain relatively free-flowing and undeveloped. One of the more obvious forms of flow alteration results from the construction of dams and reservoirs. The operation of dams for flood control, water supply, barge navigation, hydroelectric power generation, or recreation affects the timing and amount of water releases from a dam. More than 5,500 large dams and 100,000 small dams have been built in the U.S.

Less obvious is the degree to which land uses for various human activities, such as agriculture, timber harvest, urbanization, or grazing have affected aspects of natural flow regimes in rivers that drain human-altered landscapes (Figure 13). Hydrologic systems can be quite sensitive to changes in soil infiltration capacity and evapotranspiration rates, which explains why some intensive land uses can change flood peaks and low flow conditions by orders of magnitude.

Figure 13. The U.S. has over 5,500 large dams

Quantifying Changes in Flow Regimes

The Nature Conservancy has developed a statistical method and software, called the "Indicators of Hydrologic Alteration" (IHA), for assessing the degree to which human activities have changed flow regimes (Figure 14). The IHA method is based upon the concept that hydrologic regimes can be characterized by five ecologically-relevant attributes:

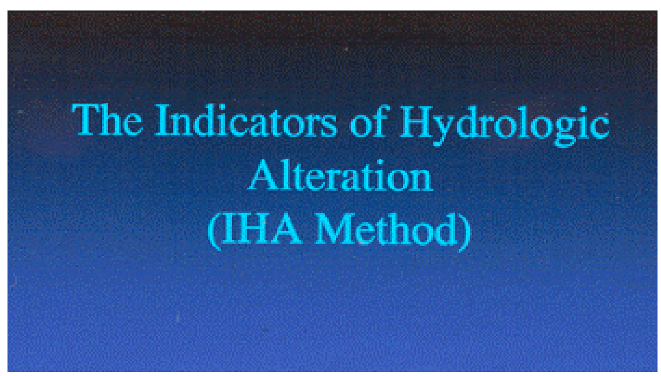

Figure 14. The IHA method

- ***Magnitude*** of flow is simply the amount of water passing a fixed point in the river at a specific point in time (Figure 15).

- ***Frequency*** describes how often a particular condition, such as a large flood, has occurred (Figure 16).

- ***Duration*** refers to the length of time that a specific flow condition lasts, such as the duration of extremely low flow conditions (Figure 17).

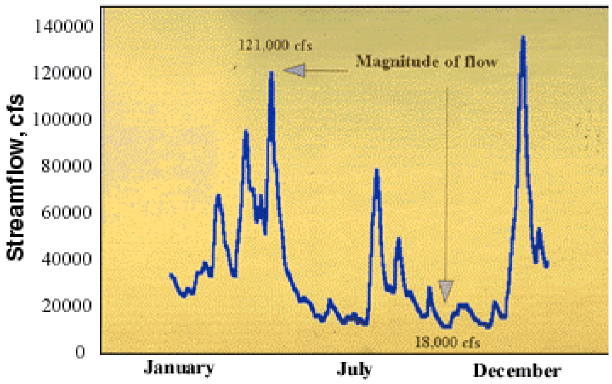

Figure 15. Magnitude of flow can vary immensely

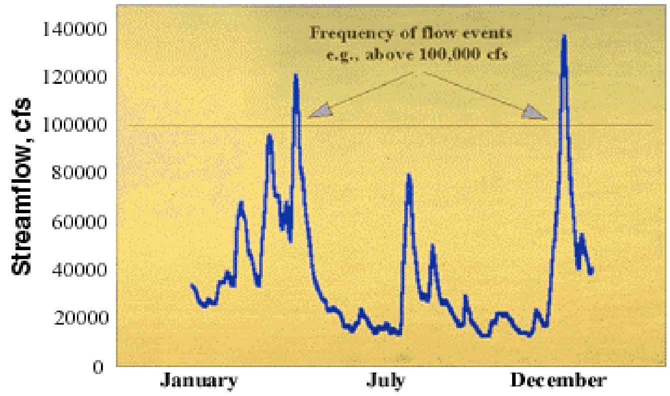

Figure 16. Frequency of high flow events is an important measure of a river's natural behavior

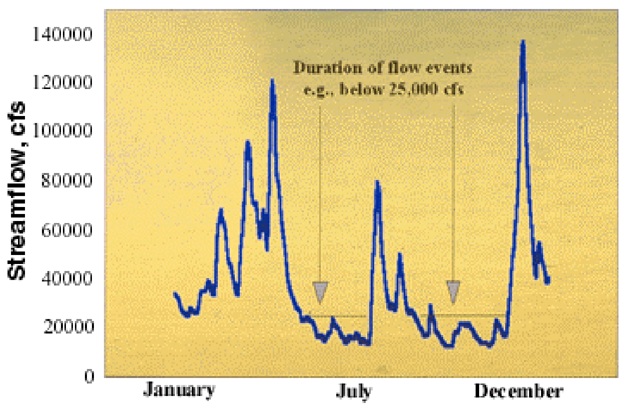

Figure 17. Duration must be considered as well as flow levels

- ***Timing*** describes the time of year at which particular flow events occur, such as the timing of floods or low flow extremes (Figure 18, overleaf).
- The ***rate of change*** indicates how quickly the flow changes, as flows rise or fall from day-to-day. (Figure 19, overleaf).

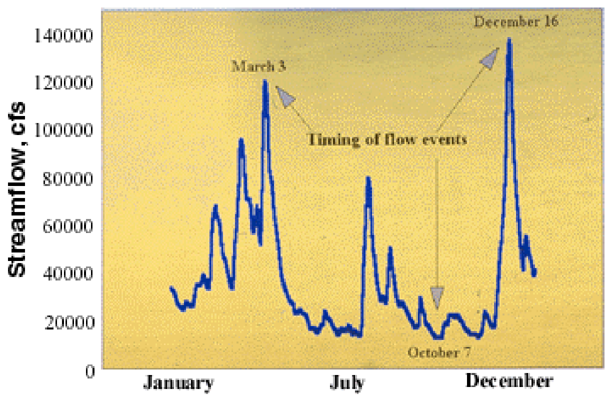

Figure 18. Some flow events are timed regularly with the seasons

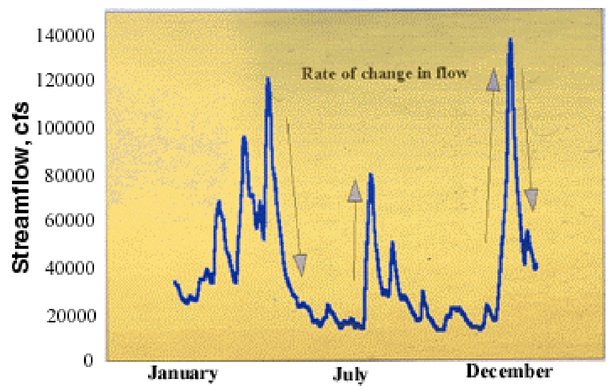

Figure 19. Rapid changes in flow characterize 'flashy' systems

Collaborating with river ecologists around the world, The Nature Conservancy compiled a list of 22 hydrologic parameters that can be used to assess changes in a river's flow regime over time (see Table 1 at the end of this document). These parameters provide a means for quantifying the five attributes listed above, and have proven to be sensitive indicators of various forms of human-induced flow alteration, such as by damming, diversions, ground water pumping, and conversion of a watershed to agricultural uses or urbanization (Figure 20). The IHA software utilizes daily streamflow information as input. More information about the IHA method and software can be found on the IHA page at http://www.freshwaters.org/ccwp/iha.html and in the following journal article: Richter B.D., Baumgartner J.V., Powell J. & Braun D.P. (1996) A method for assessing hydrologic alteration within ecosystems. *Conservation Biology*, 10:1163-1174.

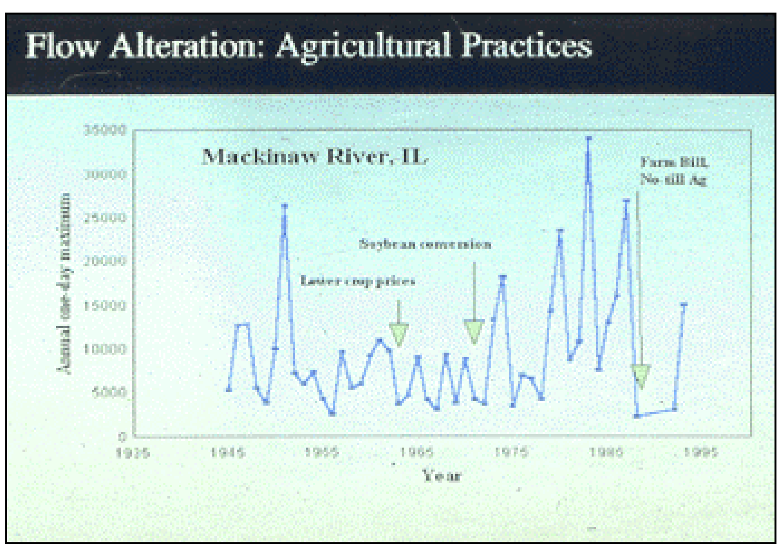

Figure 20. Major events in agriculture are reflected in Mackinaw River flow over the years

Adaptively Managing Instream Flows

When attempting to manage or restore a river's flow regime for the benefit of native species and natural ecosystem functions, quantification or estimation of natural flow regime characteristics can provide a benchmark standard or "compass direction" (Figure 21). While full restoration or protection of natural flow regimes will not likely be possible in most cases, the natural regime characteristics provide a target to shoot for, or a pathway upon which to proceed. Numerous flow restoration experiments now underway around the world are illustrating that many native species can benefit greatly from incremental restoration of natural flow conditions (see Table 2 at the end of this document for a list of these projects).

Figure 21. River monitoring helps inform decisions on dam releases and natural flow patterns to imitate

Figure 22. Unmanned monitoring devices can gather river data over long periods

Fortunately, within the U.S. and other developed nations, daily streamflow data have been collected at thousands of river sites (Figure 22). In many cases, these data collection efforts began prior to the onset of major flow alterations, such as before construction of large dams and large diversion works. By quantifying hydrologic conditions during a period of more natural watershed and river conditions, river scientists can develop some initial flow restoration targets.

Rather than determining one single average or static target level for a particular hydrologic variable, such as the annual peak flood flow, a natural range of variability can be identified as the management or restoration target. For example, using the Range of Variability Approach (Figure 23), the river would be managed in such a way that the annual values of each IHA parameter fall within or outside a selected range of natural variation for that parameter at the same frequency of occurrence as during the natural flow period.

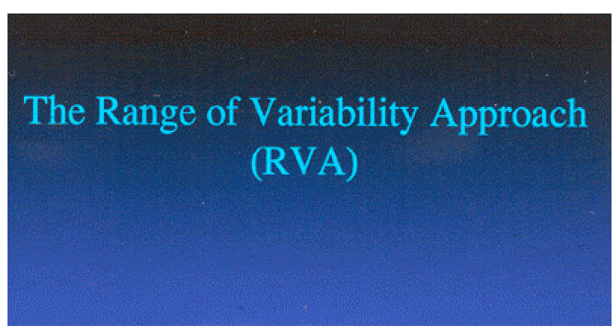

Figure 23. The RVA

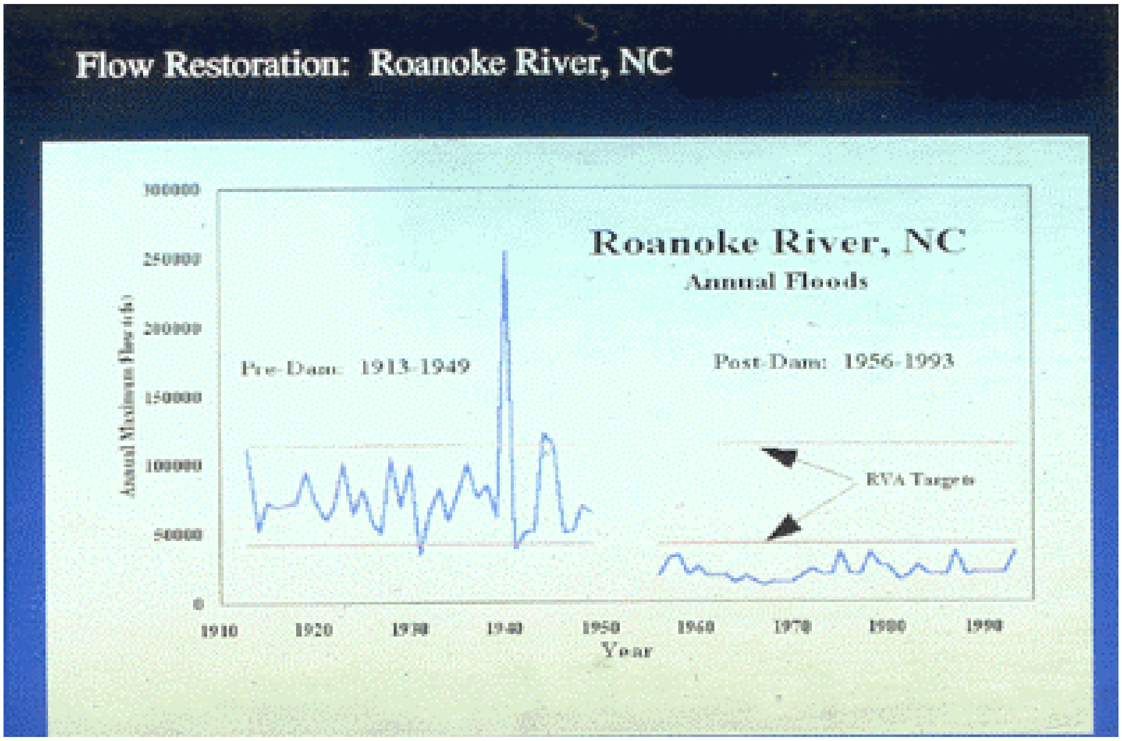

Figure 24. Pre- and post-dam flow in the Roanoke River, VA

The RVA can be illustrated by referring to a graph of annual flood peaks in the Roanoke River, North Carolina (Figure 24). Dams were constructed on the Roanoke in the 1950's, resulting in a substantial reduction in flood magnitudes. The "RVA Targets" shown in this graph represent the 25th and 75th percentiles of the pre-dam, or more natural, period. Using the RVA, river managers would strive to restore flood levels that would fall below, within, and possibly above the RVA target window in 25%, 50%, and 25% of all years, respectively.

Again, it should be recognized that full restoration of certain hydrologic conditions like extreme floods will be socially or economically undesirable in many river systems (Figure 25).

Figure 25. Extreme floods remain social undesirable in developed river corridors

River managers might be further constrained by existing water rights, water quality regulations, and other factors. However, incremental or partial restoration of key hydrologic conditions such as the natural range in annual floods, or their timing or duration, as well as natural low-flow conditions can yield substantial ecological benefits. In most river systems, some degree of flow restoration can be attained without severely compromising existing or historic uses, economic benefits, or endangering lives and structures. These actions can be pursued while working to reduce or eliminate constraints that currently limit further restoration.

The question that remains is, "How much restoration of a particular flow condition is enough?" (e.g., to produce measurable or significant ecological benefits) (Figure 26). The best way to answer this question is to create an adaptive management program adequate to test hypotheses about the likely benefits to expect from varying degrees of flow restoration.

In the Range of Variability Approach, there are six essential elements of such a program. The steps are described in Figures 27-32.

Figure 26. The answers to the question "How much flow is enough?" are river-specific, but can be identified through the RVA.

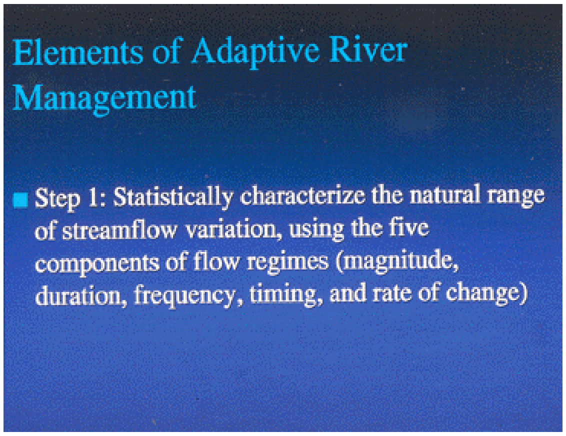

Figure 27

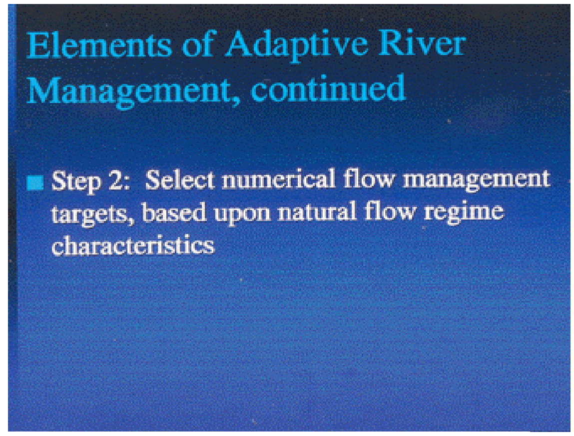

Figure 28

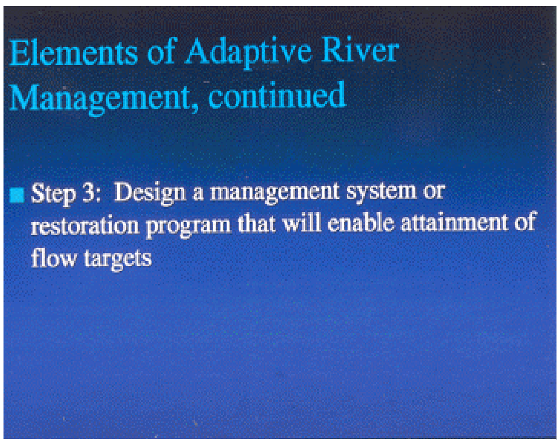

Figure 29

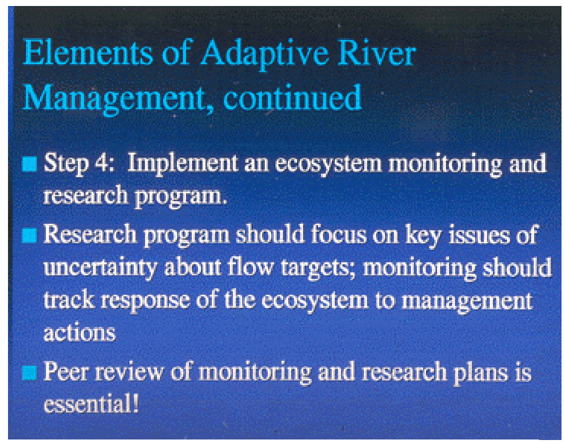

Figure 30

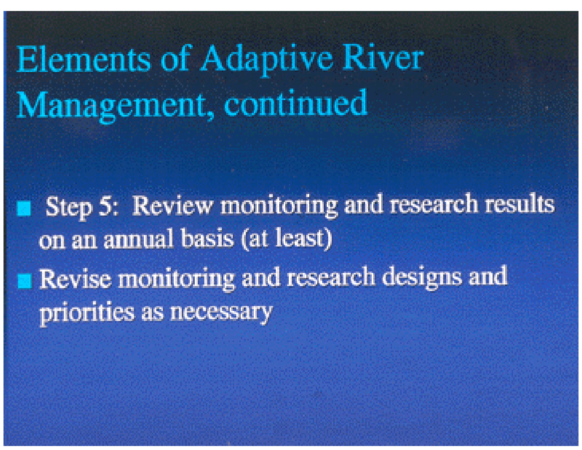

Figure 31

Figure 32

More information about the Range of Variability Approach can be found at http://www.freshwaters.org

or, in:

Richter BD, Baumgartner JV, Wigington R, Braun DP. 1997. How much water does a river need? *Freshwater Biology* 37: 231-249.

Now that you have successfully completed the module, you can evaluate your understanding by taking the test on page 19.

Table 1. Summary of hydrologic parameters used in the IHA and RVA, and their characteristics			
General Group	*Regime Characteristics*	*Streamflow Parameters Used in the RVA*	*Examples of Ecosystem Influences*
1. Magnitude of Monthly Discharge Conditions	Magnitude Timing	1. Mean discharge for each calendar month	* Habitat availability for aquatic organisms * Soil moisture availability for plants * Availability of water for terrestrial animals * Availability of food/cover for fur-bearing mammals * Reliability of water supplies for terrestrial animals * Access by predators to nesting sites * Influences water temperature, oxygen levels, photosynthesis in water column
2. Magnitude and Duration of Annual Extreme Discharge Conditions	Magnitude Duration	1. Annual maxima one-day means 2. Annual minima one-day means 3. Annual minima 3-day means 4. Annual maxima 3-day means 5. Annual minima 7-day means 6. Annual maxima 7-day means 7. Annual minima 30-day means 8. Annual maxima 30-day means 9. Annual minima 90-day means 10. Annual maxima 90-day means 11. Number of zero-flow days 12. 7-day minimum flow divided by mean flow for year (Abase flow @)	* Balance of competitive, ruderal, and stress-tolerant organisms * Creation of sites for plant colonization * Structuring of aquatic ecosystems by abiotic vs. biotic factors * Structuring of river channel morphology and physical habitat conditions * Soil moisture stress in plants * Dehydration in animals * Anaerobic stress in plants * Volume of nutrient exchanges between rivers and floodplains * Duration of stressful conditions such as low oxygen and concentrated chemicals in aquatic environments * Distribution of plant communities in lakes, ponds, floodplains * Duration of high flows for waste disposal, aeration of spawning beds in channel sediments
3. Timing of Annual Extreme Discharge Conditions	Timing	1. Julian date of each annual one-day maximum discharge 2. Julian date of each annual one-day minimum discharge	* Compatibility with life cycles of organisms * Predictability/avoidability of stress for organisms * Access to special habitats during reproduction or to avoid predation * Spawning cues for migratory fish * Evolution of life history strategies, behavioral mechanisms

Table 1. Summary of hydrologic parameters used in the IHA and RVA, and their characteristics, continued			
General Group	*Regime Characteristics*	*Streamflow Parameters Used in the RVA*	*Examples of Ecosystem Influences*
4. Frequency and Duration of High/Low Flow Pulses	Magnitude Frequency Duration	1. # of high pulses each year 2. # of low pulses each year 3. mean duration of high pulses within each year 4. mean duration of low pulses within each year	* Frequency and magnitude of soil moisture stress for plants * Frequency and duration of anaerobic stress for plants * Availability of floodplain habitats for aquatic organisms * Nutrient and organic matter exchanges between river and floodplain * Soil mineral availability * Access for waterbirds to feeding, resting, reproduction sites * Influences bedload transport, channel sediment textures, and duration of substrate disturbance (high pulses)
5. Rate/Frequency of Hydrograph Changes	Frequency Rate of change	1. means of all positive differences between consecutive daily values 2. means of all negative differences between consecutive daily values 3. # of flow reversals	* Drought stress on plants (falling levels) * Entrapment of organisms on islands, floodplains (rising levels) * Desiccation stress on low-mobility streamedge (varial zone) organisms

Table 2: Summary of recent projects where flow regimes have been "naturalized" (from Poff et al.: *The natural flow regime: a paradigm for river conservation and restoration;* BioScience 1998)			
Location	Flow Components Mimicked	Ecological Purpose	Reference
Trinity River, CA	timing and magnitude of peak flow	rejuvenate gravel habitats, provide flows for outmigrating salmonid smolts	Barinaga 1996, Trinity River Report 1997
Truckee River, CA	timing, magnitude, duration of peak flow, rate of change during recession	restore riparian trees	Christensen 1996
Owens River, CA	increase base flows, partially restore overbank flows	restore riparian vegetation and habitat for brown trout and native fish	Hill and Platts 1997
Rush Creek, CA and other tributaries to Mono Lake	increase minimum flows	restore riparian vegetation and habitat for waterfowl and non-native fish	Los Angeles DWP
Oldman River and tributaries, southern Alberta	increase summer flows, reduce rates of post-flood stage decline	restore riparian vegetation (cottonwoods) and cold water fisheries (trout)	Rood et al. 1995
Green River, CO	timing and duration of peak flow; duration and timing of non-peak flows; reduce rapid baseflow fluctuations from hydropower generation	recovery of endangered fish species; enhance other native fishes	Stanford 1994
Gunnison River, CO	timing and duration of peak flow; duration and timing of non-peak flows; reduce rapid baseflow fluctuations from hydropower generation	recovery of endangered fish species	Pfeiffer et al. 1996
Rio Grande, NM	timing, duration of floodplain inundation	ecosystem processes (e.g., nitrogen flux, microbial activity, litter decomposition)	Molles et al. 1995
Pecos River, NM	magnitude, frequency, timing	spawning signal for endangered fish	Hoagstrom et al. 1994
Bill Williams River, AZ (proposed)	mimic natural flood peak timing and duration	promote establishment of native trees	US Army Corps of Engineers 1996
Pemigewasset River, NH	do not exceed natural frequency of high flows during summer low flow season; reduced rate of change during hydropower generation	enhance native Atlantic Salmon recovery	Federal Energy Regulatory Commission 1995
Location	Flow Components Mimicked	Ecological Purpose	Reference

Table 2: Summary of recent projects where flow regimes have been "naturalized" (from Poff et al.: *The natural flow regime: a paradigm for river conservation and restoration;* BioScience 1998)			
Roanoke River, VA	restore more natural patterning of monthly flows in spring; reduce rate of hydrograph rise/fall	increased reproduction of striped bass	Rulifson and Manooch 1993
Kissimmee River, FL	magnitude, duration, rate of change	restore floodplain inundation to recover wetland functions and native species	Toth 1995

Self Test for Protecting Instream Flows Module

After you've completed the quiz, check your answers with the ones provided on page 22 of this document. A passing grade is 7 of 10 correct, or 70%.

1. River ecosystems can best be conserved by getting rid of the natural variability in flow.

☐ A. True

☐ B. False

2. Different species in the same river may be beneficially or adversely affected by the same natural flood.

☐ A. True

☐ B. False

3. The US Supreme Court recently ruled that water quantity was closely linked to water pollution, but not to water quality.

☐ A. True

☐ B. False

4. Adaptive management of river flow involves helping native and non-native species become adapted to managed flow regimes.

☐ A. True

☐ B. False

5. Full restoration of certain hydrologic conditions like extreme floods will often be socially or economically undesirable, but restoring annual flooding levels is often feasible and desirable.

☐ A. True

☐ B. False

6. Water chemistry, temperature, nutrient cycling, oxygen availability, and the geomorphic processes that shape river channels and floodplains are often tightly coupled to streamflow variation.

☐ A. True

☐ B. False

7. Once uncertainty about flow regimes has been resolved, there is no need to continue monitoring.

☐ A. True

☐ B. False

8. Which of the following is significantly influenced by both water quality and water quantity?

☐ A. water pollution

☐ B. recreational uses

☐ C. water temperature

☐ D. aquatic habitat

☐ E. all of the above

☐ F. none of the above

9. Determining an adequate flow regime requires measuring and considering approximately ______ hydrologic parameters.

☐ A. 5

☐ B. 17

☐ C. 22

☐ D. 33

10. The IHA method characterizes flow regime by quantifying which of the following attributes?

- ☐ A. magnitude of flow, frequency of given flow levels
- ☐ B. velocity of flow, duration and timing of given flow levels
- ☐ C. timing, duration and rate of change of a given flow level
- ☐ D. B and C
- ☐ E. A and B
- ☐ F. A and C
- ☐ G. none of the above

Answers for Protecting Instream Flows Module Self Test

Q1: B Q2: A Q3: B Q4: B Q5: A Q6: A Q7: B Q8: E
Q9: C Q10: F