# EL RÉGIMEN NATURAL DE LOS RÍOS UN PARADIGMA PARA SU CONSERVACIÓN Y RESTAURACIÓN

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***We must manage rivers to maintain as much of their natural variability as possible, because the functioning of the river ecosystem depends upon its natural, dynamic character.***

## 1 THE WATER CYCLE AND RIVER FLOW

The hydrologic cycle describes the continuous flux of water from the atmosphere to earth and oceans, and back again to the atmosphere (Allan 1995, Figure 1). Precipitation in the form of rain and snow may enter rivers and lakes directly as surface runoff, but most infiltrates into the ground, and much of this groundwater enters river channels more gradually, as shallow sub-surface flow. Depending upon soil structure,

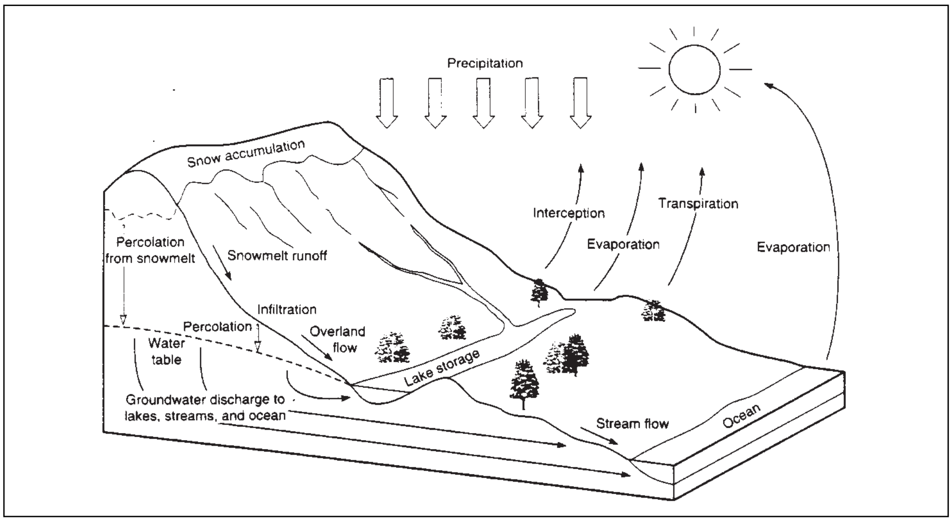


*Figure 1. Schematic drawing of the water cycle (From Allan 1995, redrawn from Dunne and Leopold 1978).*

some groundwater penetrates to deeper layers, or moves more slowly, in its downslope travel to river channels and, eventually, the sea.

As all of us have observed, a river can be a raging torrent during periods of heavy rain, flow normally even during periods when little rain has occurred, and may come perilously close to drying during prolonged droughts. This is because water from precipitation enters stream channels at different rates, depending upon the pathway traveled. Surface runoff is rapid, and accounts for the rapid swelling of a river into its flood peak. Shallow sub-surface flow is slower, and maintains the river in flood for some days after rain ceases. Deeper groundwater at the level of the water table provides stable baseflow to a river, maintaining its flow despite long periods without rain. However, should this rainless period continue into a drought, the water table may fall, and the riverbed may become dry.

A hydrograph describes the changing flow of a river. It is a graph of the volume of water flowing past a point, referred to as discharge, and usually is measured in m3/s. One might wish to examine the hydrograph over a period of days, in response to a particular storm, or over a year, as in this example (Figure 2). As we examine the annual hydrograph of this river, we see that discharge varies from week to week, and that a few large floods dominate the annual export of water. In addition, we immediately face the question: do we expect the hydrograph to be the same from year to year? Will the same number of large floods occur, at approximately the same time of the year? What is the probability of a much larger flood?

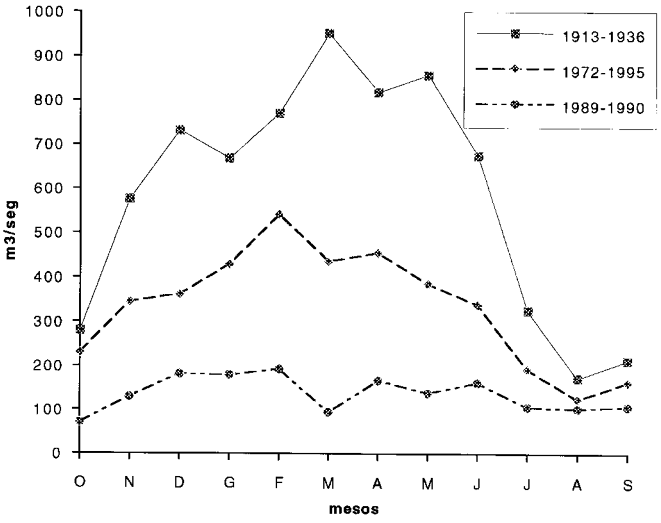


***Figure 2. An annual hydrograph from a Spanish river.***

Hydrologists and water engineers have many methods to quantify the statistical pattern of floods. This knowledge is critical to the construction of bridges and dams, and to the management of reservoirs. It represents the explicit recognition by engineers and planners that river flow is highly variable, on time scales of days, weeks, years, decades, and centuries.

From the ecological perspective, it is important to understand that dynamically changing flow affects all aspects of the functioning of the river ecosystem. Before discussing how a river ecosystem depends upon flow and flow variation, I wish first to establish that every river has a natural flow regime.

## 2 THE NATURAL FLOW REGIME

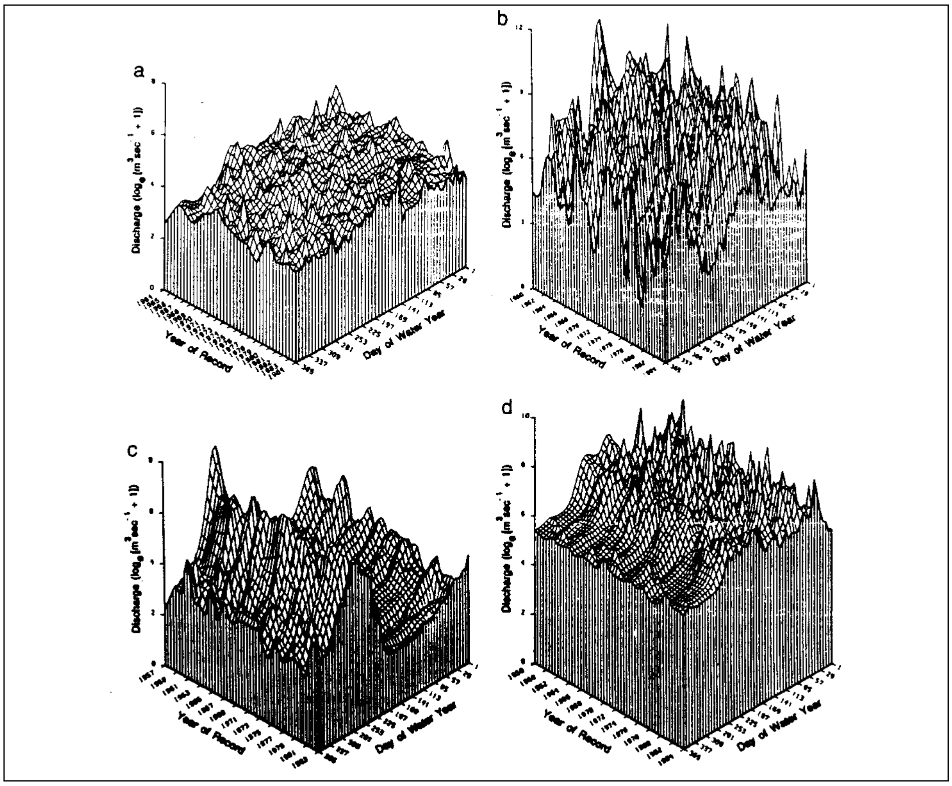
The concept of a river's flow regime is best illustrated by comparing the pattern of river flow among many rivers over a large area, as my colleague LeRoy Poff has done in the USA (Poff 1996). It can be seen that rivers of a particular region have similar hydrographs. For example, rivers of the Rocky Mountains of the USA, and in other mountainous areas of the temperate zone**,** receive most of their precipitation as snow during winter months, and experience a predictable (in timing, at least) spring peak in runoff. We build dams near the base of those mountains to capture runoff and generate electricity. We know that water will be abundant during the spring, and scarce during the summer.

Poff's analysis documented that rivers could be roughly grouped according to timing and magnitude of discharge (Figure 3). Moreover, the geographic variation in flow regime is understandable, and is the result of regional differences in climate, geology, topography, and vegetation. Just as we can recognize that each region has a characteristic climate, we should recognize that rivers in that region tend to have a characteristic flow regime. Today's river flow may be unpredictable, but today's weather also is unpredictable.

Once we recognize that river flow is variable, but with some predictable regional pattern, we begin to think in terms of a natural flow regime. In order to characterize aspects of flow that may be ecologically important, we quantify five components of the flow regime: magnitude, frequency, duration, timing, and rate of change (Richter et al. 1996).

The *magnitude* of discharge is the amount of water moving past a point, per unit time. The flood crest and peak discharge are measures of magnitude, but so is the annual minimum or other drought flow.

The *frequency* of discharge refers to how often a flow of a specified magnitude occurs over a specified time interval. By analyzing many years of river discharge, one can estimate how often a flood or drought of a given magnitude occurs. For example, it improves our understanding of Figure 2 to know whether the peak flow in that year is of a magnitude that occurs at least once a year, or much less frequently. Often we specify the frequency to be relatively rare (1 in 10 years, or even 1 in 100 years), and then find the magnitude of this relatively rare event.



*These histories show within- and between-year variation for (a) Augusta Creek, Michigan, a relatively stable, groundwater-fed stream; (b) the Satilla River, Georgia, in a region where intense rains may occur in any month; (c) the ipper Colorado River, Colorado, where snowmelt in May-June results in predicable spring run-off; (d) South Fork of the Mckenzie River, Oregon, where rain occurs episodically throughout the winter.*

***Figure 3. Flow histories based on long-term, daily mean discharge records. From Poff et al. 1997, BioScience 47(11):769-784, used with permission of BioScience).***

The *duration* is the time period associated with the specified flow condition. For example, one may wish to know the number of days that a floodplain is inundated, or the cumulative number of days in a year that flow is less than some specified minimum value, which might be critical for dilution of municipal wastewater.

The *timing* or *predictability* of flows is a measure of the regularity with which they occur. Annual peak flows may occur within a relatively narrow window of time, as in snowmelt-driven rivers, or be highly irregular, as in many arid-land rivers.

The *rate of change,* or *flashiness,* of flow refers to how quickly flow changes. “Flashy” streams have rapid changes in flow, whereas flow changes slowly in ‘stable” streams. Hikers in the canyon streams of the arid southwestern USA are sometimes killed by flash floods.

Together, these five measures give us the tools to characterize the flow regime of a river, and begin to identify regional or geographic patterns in river flow. Before we examine more specifically how human activity modifies the natural flow regime of rivers, we should consider the many ways that the physical and biological condition of a river depends upon flow variability.

## 3 PHYSICAL AND BIOLOGICAL RIVER PROCESSES DEPEND UPON FLOW VARIATION

The physical habitat is of great importance to the biota, so much so that the types and variety of habitat are considered to be the primary determinant of the types and variety of species found in the ecosystem. Habitat includes many, diverse elements: the sediments, gravels and other rock types that make up the bed of the stream; stream channel elements such as pools, riffles, and meanders; other channel features such as gravel and sand bars, and side-channels; whether stream banks are undercut, which can be good fish habitat, or sandy and gently sloping, which can be good nesting locations for turtles, and much more. Flow, and flow variation, help to create and maintain these habitat features (Poff et al. 1997).

One also should take a spatially broad view that reaches beyond the riverbank and into the riparian zone and the flood plain. These habitats are connected to the river channel at times of high flow, and this can be important in the life cycle of some organisms. Sediments, nutrients, and organic matter can be transferred from the channel into the valley, and vice-versa.

Sediment transport and channel maintenance are two physical processes of rivers that depend very directly upon flow variability. Occasional floods erode, transport, and deposit sediments in a cycle referred to as “scour-and-fill”. In a large flood some channel substrate is carried away, but as the flood subsides, deposited material replaces what was removed, so that the shape of the streambed is largely unchanged. Most sediment transport is done by floods of intermediate magnitude, because they have the force to erode sediments, and occur not too infrequently. Very large floods may have long-term effects on channel structure, but occur too infrequently to play a dominant role in sediment transport. Floods of sufficient magnitude to overflow the banks occur with roughly a 1.5-year recurrence frequency, and are critical in maintaining the river’s connectivity to its floodplain.

In some types of rivers, the trunks of fallen trees and other woody debris play a critical role as habitat and in creating habitat. In floodplain rivers of the Southeastern USA, most biological production and most fish are associated with fallen trees. In many salmon-producing rivers of the Pacific Northwest, tree trunks create pools, which are important nursery habitat for young fish. Floods help to move wood into river channels, where the force of river flow over, under, and around the log scours out pools and other biologically useful habitat.

The biological communities of flowing water depend in many ways on habitat conditions that can only occur when flow is variable (Poff et al. 1997). Fishes benefit from occasional high flows that remove fine sediments from the stream bottom, maintaining gravel habitat with adequate interstitial space where organic matter and invertebrates can be abundant. As mentioned, floods bring woody debris into stream channels, creating habitat. Floods also maintain floodplain wetlands, which can be important nursery grounds for some fish species. Many aspects of the life cycle of fishes, including timing of spawning, rearing, and migration can be cued to the flooding cycle.

Riparian plants usually are characteristic of their streamside environment, adapted to periodic flooding and a high level of soil moisture. Without periodic inundation, and if soils become drier, riparian species are likely to be competitively displaced by plants more characteristic of drier, upland regions. For example, cottonwoods (*Populus* spp) are disturbance-adapted species that benefit from the opening of new habitat by periodic flooding. Their seeds are water-dispersed, and new plants are established when floodwaters slowly recede, producing the right conditions for germination by depositing seeds along stream margins in wet soil, with a gradually receding water table.

Figure 4 illustrates how flows of various magnitudes and timing are needed to maintain a diversity of riparian plant species and aquatic habitat (Sparks 1995, Poff et al. 1997). Inflowing groundwater (A), replenished when flooding recharges the water table, provides baseflow to the stream channel and sustains riparian vegetation very near the water's edge. Frequent, small floods (B) transport fine sediments, maintaining "clean" gravels that provide habitat and food supply for invertebrates, and spawning and rearing conditions for fish. Floods of intermediate size (C) inundate low-lying flood plains and deposit sediments and possibly plant seeds, thereby facilitating the colonization of disturbance-adapted plant species. These floods also import organic matter from the riparian zone into the stream channel, transport the bulk of the river's sediment load, and help maintain the characteristic form of the active river channel. Larger floods occurring on the time scale of decades (D) inundate the aggraded floodplain terraces, where later successional plant species are found. Infrequent, large floods (E) can effect significant change in channel form, and uproot mature riparian trees, depositing them in the stream channel where they can create high-quality habitat for many aquatic species and last for decades to centuries.

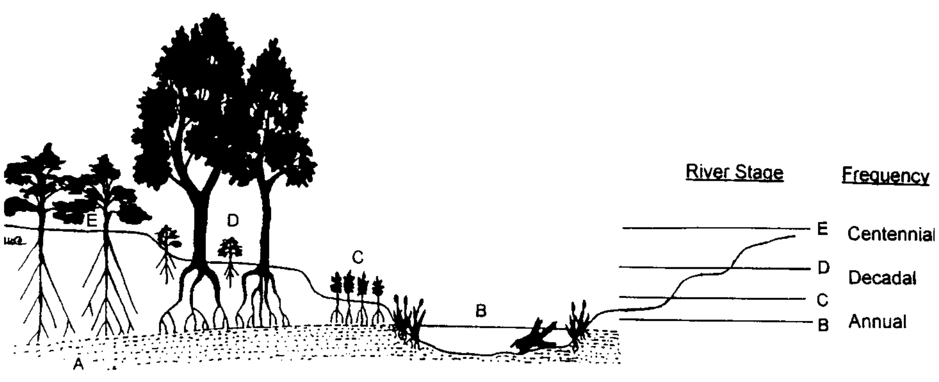


***Figure 4. Geomorphic and ecological functions provided by different levels of flow. .***

*From Poff et al. 1997, BioScience 47(11):769-784, used with permission of BioScience).*

## 4 HUMAN ALTERATION OF THE FLOW REGIME

Human activities alter a river's natural flow regime in many ways (Allan 1995, Poff et al. 1997). I will emphasize two main classes of alterations: direct changes brought about by dams, channelization, and other engineered change to the river channel; and indirect changes, usually the result of land-use practices, which alter how water moves into river channels.

Dams and reservoirs are the most obvious direct modifiers of river flow, capturing both low and high flows to serve human needs. Within the USA it is estimated that >85% of inland waterways are artificially controlled for a variety of purposes, including flood control, generation of electrical power, irrigation, municipal water needs, navigation, and for recreational enjoyment of reservoirs. Water use in the USA is amongst the world's highest in per capita terms. Approximately 13% of this water use is classified as municipal, 45% is industrial, and 42% is agricultural. The USA west of the 100th Meridian, traditionally considered too dry for non-irrigated agriculture, has experienced the most intense activity directed at dams, canals, and diversions. Water supply issues are especially acute in the Southwest, which has 6% of the USA water supply, but accounts for 31% of its use.

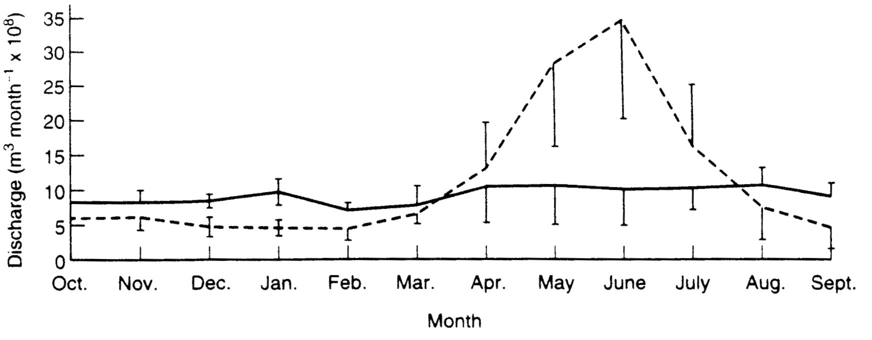
Dams differ widely in size, purpose, design, and operation. Large dams usually are inventoried, but smaller dams may not be, and so the true number is difficult to ascertain. Nontheless, the pace of dam-building throughout this century has been remarkable. Indeed, it can be calculated that the earth's spin has increased, albeit by an infinitesimal amount, by the storage of so much water in reservoirs at mid to high latitudes, just as a skater spins more rapidly when she holds her arms close to her body (Chao 1995).

Although dams often serve more than one purpose, consider the difference between a storage and a flood-control structure. The former type of dam captures high flows, to dispense at times of scarcity; the latter stays as empty as possible, captures stormflow to prevent downstream damage, and then empties as soon as it can to serve once again as a flood-control structure. Hydroelectric facilities adjust their releases to conform to the time period of peak electrical demand, which might be the working hours of the day, or the months when air conditioning demand is greatest.

Water stored behind a dam stratifies into warmer, surface waters and cooler, deep waters. Sometimes the deep water becomes de-oxygenated, due to decomposition of biological production that occurs in surface waters but sinks to the bottom. Thus water released from the bottom of the dam likely is cooler, and may be de-oxygenated, compared to water spilled over the top of a dam, which is likely to be much warmer (Allan 1995).

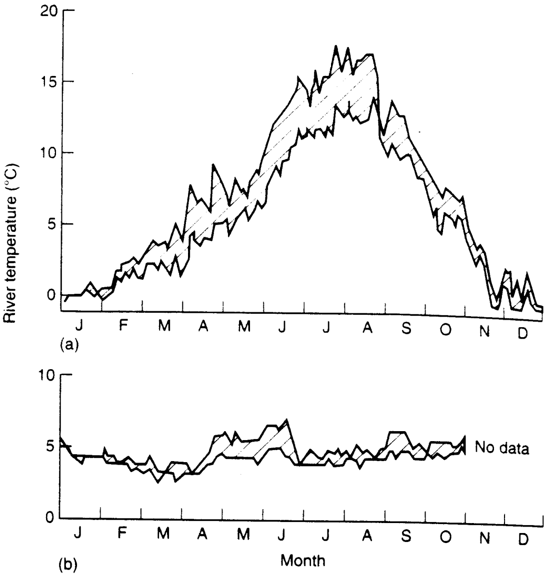
Figure 5 shows the average annual hydrograph of the Colorado River before and after closing of the Glen Canyon Dam. Virtually all seasonality in discharge is eliminated. Figure 6 shows the annual temperature range of river water in a dammed versus an unregulated river in Montana. Virtually all seasonality in temperature is eliminated.

Sediment transport is dramatically altered as sediments are trapped in reservoirs above dams. The river below the dam is described as sediment-starved, and often the river will down-cut its bed, or the sediments will become armored, meaning they are so compacted they are unlikely to shift as sediments normally do. Yet another problem emerges if the river is so tamed below the dam that it lacks the flushing flows that periodically flush out fine sediments. These fine sediments will accumulate and fill the pore



*Before (1942-62, dotted line) and after (1963-77, solid line) impoundment of Lake Powell.*

***Figure 5. Monthly means and ranges of discharge in the Colorado River at Lees ferry from Allan 1995, after Paulson and Baker 1981).***



*(a) unregulated Middle Fork and (b) regulated South Fork of the Flathead River, Montana, during 1977.*

***Figure 6. Thermal regimes. From Allan 1995, after Ward and Stanford 1979b).***

spaces between stones, making the substrate less suitable for bottom-dwelling organisms.

Even in the absence of dams and channel modifications, the flow regime of rivers can be altered by human actions, particularly by land-use activities, including timber-harvest, agriculture, and urbanization (Poff et al. 1997). Compare the hydrologic pathways and rates of surface and sub-surface flow in an unaltered (Figure 7) vs. altered river catchments. The four components of runoff are shown in Fig 7a . Overland flow (1) occurs when precipitation exceeds the infiltration capacity of the soil. Shallow subsurface stormflow (2) is due to water that infiltrates the soil but is routed relatively quickly to the stream channel. Saturated overland flow (3) occurs when the water table is near the ground surface, such as near the stream channel, upstream of first-order tributaries, and in soils saturated by previous precipitation. All of these pathways are relatively fast compared to groundwater (4), which recharges the water table and provides water into the stream channel even during periods of little or no precipitation. Together, overland and shallow subsurface flow pathways create the hydrograph peaks that are the river's response to a precipitation event, and groundwater provides the river's baseflow.

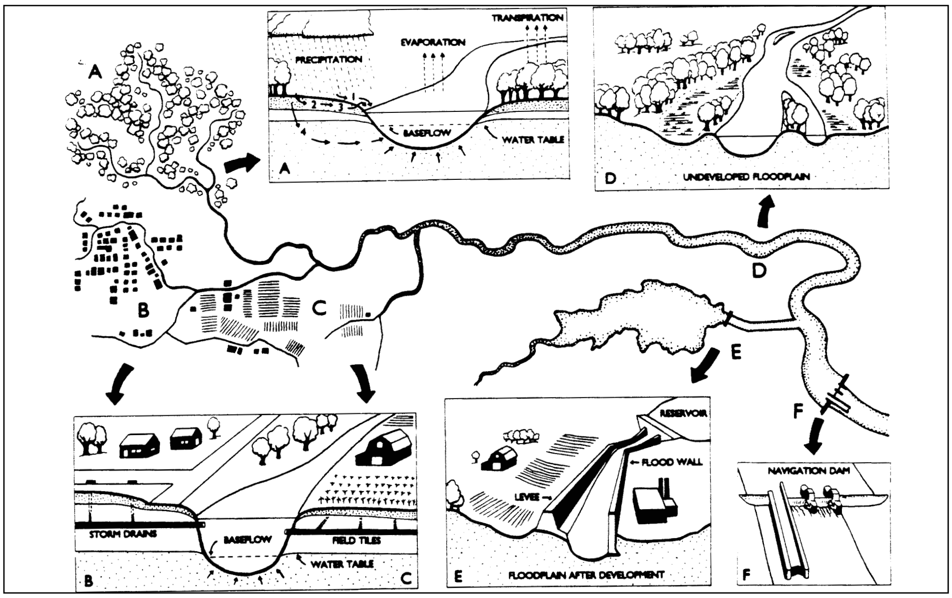


***Figure 7. Stream valley cross-sections at various locations in a watershed illustrate basic principles about natural pathways of water moving downhill and human influences on hydrology.***

*From Poff et al. 1997, BioScience 47(11):769-784, used with permission of BioScience).*

Diagrams of an urban (Fig 7B) and an agricultural (Fig. 7C) landscape illustrate how changes in land use bring about changes in flow regime. In the urban system, the greater extent of impervious surface, primarily rooftops and paved areas, causes an increase in overland flow relative to infiltration and sub-surface flow. Below-ground drains, built to accommodate this surface flow, quickly routs stormwater into streams. The consequences are many. The magnitude of the peak flow is likely to increase, the flashiness will increase greatly and, since less water will infiltrate to the water table, base flow likely will decline. Agriculture may have similar consequences, particularly if the ground is bare of vegetation when it rains, and if drainage ditches and below-ground tiles are used to increase surface and sub-surface run-off.

The increased flashiness of urban and many agricultural catchments causes erosion of sediments from river banks and channel, and channel habitat often becomes degraded and more uniform. If river channels are straightened to speed run-off, and levees or berms constructed to prevent the river from over-topping its banks, then instream habitat is further degraded, and river linkages to the riparian zone and flood plain may be severed.

Many adverse consequences of an altered flow regime can be explained from changes to the physical attributes of the river ecosystem, as discussed above. The biota are also affected more directly, in diverse ways. In the absence of flushing flows, the accumulation of fine sediments among river gravels can impede water circulation. Reduction in oxygen and food supply can make the bottom habitat less suitable for many invertebrates, as well as the eggs and juveniles of some fishes. In the absence of floods that over-top river banks, floodplain wetlands can not serve as nursery grounds for fish. Riverbanks cannot receive rich sediments and the recharge of groundwater that nourish riparian plant communities, and riparian areas cannot return organic matter to the river food web. The timing of reproduction in some fishes, and the dispersal and establishment of seeds in some riparian trees, depends on floods that occur with some predictability. Flow stabilization is an important cause of the dominance by the exotic plant salt cedar (*Tamarix* sp) in the riparian areas of many rivers of the southwestern USA. At the other extreme, the frequent and large variations in flow that are required by power plants operated to meet peak energy demands can flush out vulnerable species, and strand others in de-watered reaches.

## 5 RESTORING NATURAL FLOWS

A variety of approaches are available to restore natural flows to a river. Dam removal is one option, and is increasingly being considered in the USA, especially for old, small dams whose economic value is questionable. More frequently, however, we see a growing awareness of the opportunities to modify dam operations so as to reduce ecological costs, and a growing partnership between economic and ecological interests, aimed at finding creative compromises that benefit all parties.

In the USA, the Federal Energy Regulatory Commissions (FERC), part of the Department of Energy, licenses private and public dams built for hydropower generation. Licenses typically last 30-50 years, and stipulate how the dam is operated. Relicensing of dams provides the opportunity to re-examine dam operating principles and the economic rationale for maintaining the dam. With new recognition of negative ecological effects, changes in dam operation often can be negotiated relatively easily. Where the economic cost/benefit relationships of a particular dam have become less favorable, dam removal is increasingly an option accepted by all parties. In these circumstances, the costs of dam removal, and potential adverse effects such as release of sediments accumulated behind dams, are problems that must be solved before a dam can be removed. In a landmark case settled in 1998, environmental interests prevailed over economic interests in defeating the re-licensing of a small dam on a salmon river in Maine.

Motivated by an improved understanding of the ecological consequences of highly altered flow regimes, a number of experiments are underway in the USA (Poff et al. 1997). In order to re-juvenate gravel habitats in the stream bed, provide migrations routes for juvenile salmon, and assist establishment of riparian plants, dam releases in the Trinity River, California, are being manipulated to mimic the timing and magnitude of peak flows. In order to restore riparian trees, particularly cottonwoods, dam releases in the Truckee River, California/Nevada, mimic the timing, magnitude, and duration of peak flow, and the rate of flow recession to base flow.

An enormous, long-term restoration project is underway in Florida, aimed at restoring the linkages between the Kissimmee River, Lake Okeechobee, and the Everglades, with consequences for coastal marine waters as well. The Kissimmee was channelized as part of a flood control plan, completed by the US Army Corps of Engineers in 1971. The river, which originally meandered 166 km from Lake Kissimmee to Lake Okeechobee, had a floodplain 1.5-3 km wide, and comprised a rich mosaic of river and wetland habitat supporting great biological diversity. The channelized river, reduced to 90 km in length and deepened to reduce flooding, was largely cut off from its associated floodplain, causing enormous ecological damage. Calls for restoration were heard even before the project was completed. Recently begun, this effort is expected to cost in excess of US$1 billion dollars.

A controlled flood in the Grand Canyon, conducted in March 1996, is perhaps the most dramatic example of the challenges and opportunities that await us in learning to manage dams to benefit ecosystems as well as for their economic purposes (Collier et al. 1997, Poff et al. 1997). Since the Glen Canyon dam first began to store water in 1963, creating Lake Powell, annual floods have been virtually eliminated from some 430 km of the Colorado River, including Grand Canyon National Park. Prior to this dam, melting snow in the upper basin produced an average peak discharge driven by snowmelt in the upper basin exceeding 2,400 $m^3/s$; after the dam river flow was generally maintained at less than 500 $m^3/s$. This roughly five- to seven-fold reduction dramatically changed the Colorado's flow regime, altering the dynamic nature of this sediment-laden river. Most of the sediment moving down the Colorado River was thereafter trapped in Lake Powell.

Deprived of both its sediment load and spring flood peak, the River's habitat began to change downstream of the dam. The annual cycle of scour and fill had maintained large sandbars along the river, prevented encroachment of vegetation onto these bars, and limited cobble and boulder deposits at the mouths of tributaries from constricting the river at the mouths of tributaries. Under its new regime of low and constant flows, the river accumulated sand in the channel rather than in bars farther up the river banks, with resultant loss in low-velocity habitat for juvenile fishes, and campsites for river runners.

Flow regulation favored increased cover of wetland and riparian vegetation, allowing it to expand into sites that were regularly scoured by floods in the constrained, fluvial canyon of the Colorado River. Much of the woody vegetation that has established post-dam is composed of the exotic salt cedar. Restoration of flood flows clearly would help restore the riverine and riparian ecosystem toward its former state, but scientists could not say precisely how the system would respond to an artificial flood.

In a fine example of adaptive management (a planned experiment to guide further actions), a controlled, 7-day flood of approximately 1300 $m^3$/s was released in late March 1996. This volume, less than half of the pre-dam average for a spring flood, was the maximum that could be obtained through power turbines aided by four bypass pipes, and resulted in lost hydropower revenues of about US$ 2 million dollars.

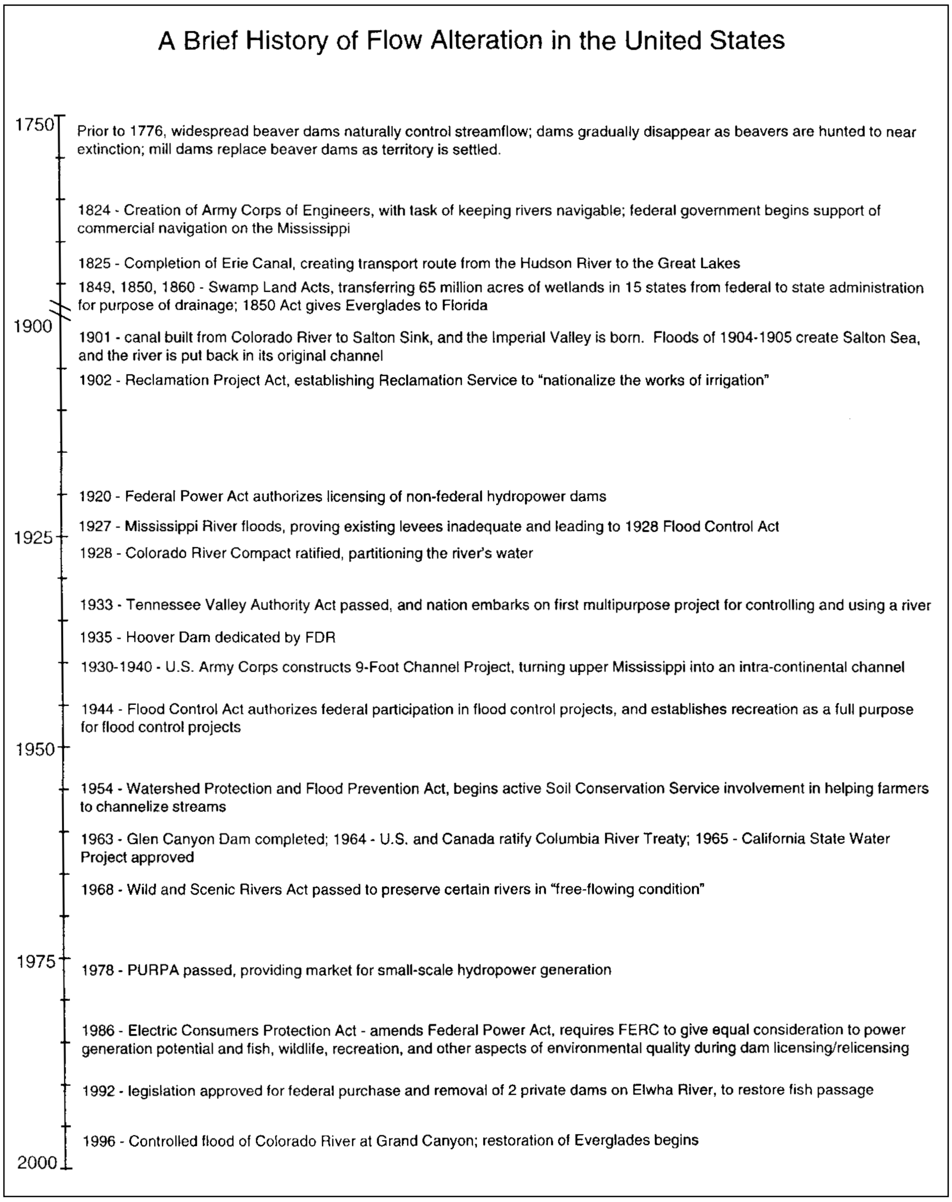
The immediate result was significant beach building: over 53% of the beaches increased in size compared to 10% that decreased, and over 55 new camping beaches were created. Restoration was rapid, with most of the change occurring in the first 1-2 days. Full documentation of the effects will continue, by measurement of channel cross sections and studies of riparian vegetation and fish populations. However, recent reports indicate that bars are eroding, and further artificial floods likely will be needed to sustain the benefits.

## 6 CONCLUSION: VALUES OF RIVERS

Rivers are a renewable resource, providing great benefits to humankind for municipal, industrial, and agricultural use, in power generation, and for navigation. Rivers also are ecosystems, harbouring commercially valuable fishes and their own rich biodiversity (Allan and Flecker 1993, Abramovitz 1996). Rivers provide recreational enjoyment and spiritual renewal to many. Gradually, and in many parts of the world, we are learning to manage our rivers so as to reduce the conflicts between their unquestioned economic value, and the need to sustain healthy, productive ecosystems over the long term.

A brief history of human actions affecting rivers in the USA (Figure 8) illustrates that flow alteration has a long history. However, over the past decade or so, the pendulum has begun to swing back toward preservation and restoration. Operators of hydropower facilities must give more weight to wildlife and fisheries. The Kissimmee River is being restored to a meandering channel permitting river-floodplain linkages. Following the devastating 1993 Mississippi flood, human settlements are not being re-established in some parts of the Mississippi floodplain. Dams are being managed to produce flows, including artificial floods, which help maintain natural river functions.

In conclusion, we should visualize flow regime as a “master variable” that maintains the ecological integrity of river ecosystems (Figure 9). The five components of the flow regime – magnitude, frequency, duration, timing, and flashiness – have many direct and indirect effects on other factors influencing ecological integrity (Poff et al. 1997). Managers of water resources should strive to maintain the flow regime of rivers in as natural a state as possible, to sustain the ecological integrity of these important ecosystems.



A Brief History of Flow Alteration in the United States

Prior to 1776, widespread beaver dams naturally control streamflow; dams gradually disappear as beavers are hunted to near extinction; mill dams replace beaver dams as territory is settled.

1824 - Creation of Army Corps of Engineers, with task of keeping rivers navigable; federal government begins support of commercial navigation on the Mississippi

1825 - Completion of Erie Canal, creating transport route from the Hudson River to the Great Lakes

1849, 1850, 1860 - Swamp Land Acts, transferring 65 million acres of wetlands in 15 states from federal to state administration for purpose of drainage; 1850 Act gives Everglades to Florida

1901 - canal built from Colorado River to Salton Sink, and the Imperial Valley is born. Floods of 1904-1905 create Salton Sea, and the river is put back in its original channel

1902 - Reclamation Project Act, establishing Reclamation Service to "nationalize the works of irrigation"

1920 - Federal Power Act authorizes licensing of non-federal hydropower dams

1927 - Mississippi River floods, proving existing levees inadequate and leading to 1928 Flood Control Act

1928 - Colorado River Compact ratified, partitioning the river's water

1933 - Tennessee Valley Authority Act passed, and nation embarks on first multipurpose project for controlling and using a river

1935 - Hoover Dam dedicated by FDR

1930-1940 - U.S. Army Corps constructs 9-Foot Channel Project, turning upper Mississippi into an intra-continental channel

1944 - Flood Control Act authorizes federal participation in flood control projects, and establishes recreation as a full purpose for flood control projects

1954 - Watershed Protection and Flood Prevention Act, begins active Soil Conservation Service involvement in helping farmers to channelize streams

1963 - Glen Canyon Dam completed; 1964 - U.S. and Canada ratify Columbia River Treaty; 1965 - California State Water Project approved

1968 - Wild and Scenic Rivers Act passed to preserve certain rivers in "free-flowing condition"

1978 - PURPA passed, providing market for small-scale hydropower generation

1986 - Electric Consumers Protection Act - amends Federal Power Act, requires FERC to give equal consideration to power generation potential and fish, wildlife, recreation, and other aspects of environmental quality during dam licensing/relicensing

1992 - legislation approved for federal purchase and removal of 2 private dams on Elwha River, to restore fish passage

1996 - Controlled flood of Colorado River at Grand Canyon; restoration of Everglades begins

***Figure 8. A brief history of flow alteration in the United States.***

*From Poff et al. 1997, BioScience 47(11):769-784, used with permission of BioScience).*

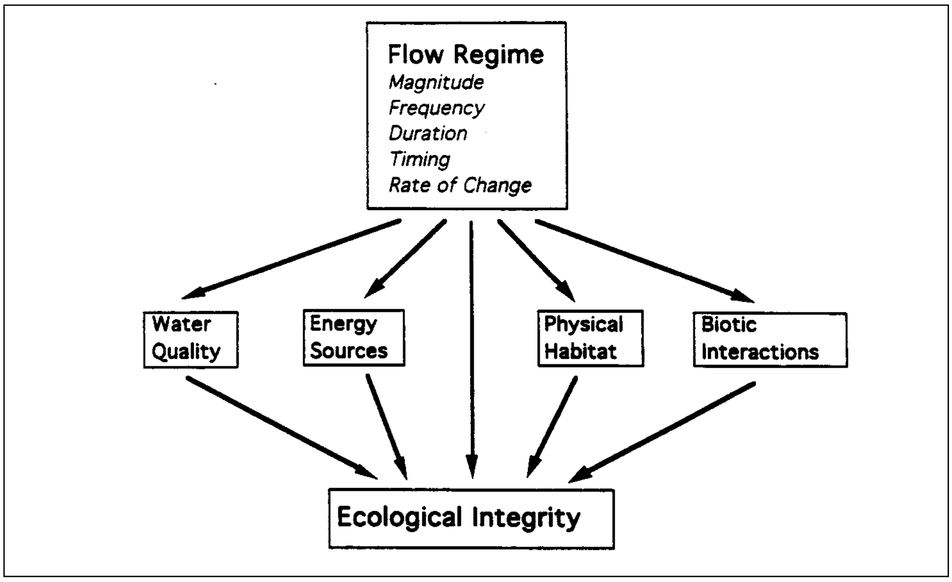


***Figure 9. Flow regime is of central importance in sustaining the ecological integrity of river ecosystems.*** *From Poff et al. 1997, BioScience 47(11):769-784, used with permission of BioScience).*

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