ECOSYSTEM RESOURCE CONSIDERATIONS IN RESERVOIR MANAGEMENT

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INTRODUCTION

In the early days of water development, natural aquatic and riparian ecosystems were poorly understood, social and environmental objectives were not quantified, and the listing of threatened and endangered species did not even exist. In general, differences between natural ecosystems and newly created reservoir aquatic and riparian ecosystems were not considered when planning water development projects. This paper describes the evolution of a maturing process in water management from project development for a single economic objective to the current environmentally minded ecosystem era. A perspective is presented on the role of ecology, with several terms defined, which demonstrates the importance the broader scientific community has on influencing federal resource management agencies to view water operations more holistically. This section is then followed by an overview of federal policies that evolved into today's strategy for management of water resources with a perspective for maintaining a healthy and sustainable physical, chemical, and biological ecosystem. Several references are made to water development projects and federal actions specific to the Colorado River Basin which are used as vivid examples of public sentiment and federal policy at that particular historical time. Three river basins, each that contain a variety of possibly conflicting resource objectives, in which the author has had extensive involvement, are then briefly described, the resource issues identified, and some insights into quantifying these ecosystem resource considerations are provided. The three reservoir controlled basins include the Colorado River Basin in seven southwestern states; the Klamath River Basin flowing out of southern Oregon, to the Pacific Ocean through northern California,; and the Rainy River, a portion of Lake of the Woods drainage, along the Minnesota-Canadian international border that encompasses Voyageurs National Park.

Water policy in the United States evolved starting from the early 1900's based upon single purpose water development projects that satisfied a well defined economic objective. This is particularly true in the seventeen western states with federal projects primarily funded by the Bureau of Reclamation (BOR). The evolution of water policy is still active and remains strongly influenced by changing political, economic and social values. With this evolution is a maturing in water use and accompanying terminology from single purpose rivers, to multi-purpose basins, to today's reference to ecosystem management. This concept of ecosystems management includes protection of natural, cultural, recreational, fish and wildlife, and environmental resources, as well as endangered species for the enjoyment and use by future generations. Many engineers, water managers, scientists, biologists, fishermen, native Americans, and federal government employees have applied themselves in a most conscientious and professional manner to manage and preserve our nation's natural resources for a long time. As a growing awareness of environmental issues plays out in the media and we are bombarded by holistic terminology like ecosystems management or sustainability, are these individuals really going to conduct their business any differently ? The answer for some I am sure is "no", but for many I believe we will find as a popular folk song says, "the times they are a changing".

Reservoirs Alter River Ecology

Untamed rivers that are regulated by the construction of large dams suffer major ecosystem shifts. Reservoirs replace river ecosystem environments. Man made lakes are unnatural resources that create new physical and biological conditions that management agencies are charged with protecting and preserving. These created systems change rapidly over short time periods and are difficult to sustain. Reservoirs trap river sediments, generally create deltas at the mouth of inflowing rivers, alter water temperature and water quality, create habitat for non-native fish species, which often thrive in the new habitat, present an obstacle to native fish migration, and may create wetlands or new riparian resources. For recreational users, reservoirs provide lake resources that include beaches, boat access, swimming, and good sport fishing; however, the reservoir may have displaced scenic vistas, canyons, and archeological, historical or cultural sites.

Downstream from large dams the effects on natural rivers are well documented (Vanoni, 1975). Typically, rivers downstream from large dams experience fewer and smaller floods. Immediately below dams the sediment starved water releases cause net erosional effects that degrade the stream bed, remove or erode alluvial bars, and degrade or cut into vegetated stream banks. The channel morphology downstream changes and sediment deposition is possible, when tributary inflows contribute substantial amounts of sediment that cannot be transported by the decreased regulated main channel flows. This sediment imbalance can create fine grained river substrates, increased width-to-depth ratios, formation of channel bars, and increased lateral instability.

The characteristic quality and temperature of water released from stratified reservoirs is critical to aquatic species. Clear water releases increase light penetration and therefore alters primary production, fish habitat and the ability to hide from predators. Macro invertebrate species also respond to these changes in water, substrate, and vegetation. Dams operated for peaking power fluctuate releases on a daily or even hourly basis, following a diurnal power demand pattern. Although regulated flow releases can provide increased benefits and a longer and safer season for boating, white water rafting, and kayaking, extreme fluctuations can be detrimental to recreational water use and small fish. These more predictable flow release cycles also favor non-native vegetation species that may proliferate and out compete native species that have evolved and adapted to natural flow cycles and stream dynamics.

ECOSYSTEM JARGON

What follows is a review water management operations and some of the 1990's terminology that is thrown around to encompass some resource values. The terminology presented stems from the field of ecology and is required because of this modern holistic view of the world as ecosystems. Although the exact meaning of many terms can be debated, I have attempted to provide meaningful definitions that relate to water resources. A good overview and scientific basis for ecosystems management is given by Christensen et al. (1996), which also provides some history and discussion for many related definitions.

Let's start with **biodiversity**, a shortened form for the two words biological and diversity. One definition from a 1993 workshop to create The Freshwater Imperative: A Research Agenda for Limnology is as follows: "the totality of life on earth, in all its variety of molecular, cellular, specific, ecological, and landscape patterns". This translates simply into all living things and the physical environment they occupy. This terminology really says it all and includes all life on earth! The definition of biological alone is meant to include all forms of living matter and all items that pertain to, impact or affect living organisms. By the addition of the term diversity, one implies and adds emphasis that there needs to be a mix of different life organisms. Within the fields of biology and ecology scientists often refer to levels of diversity (e.g., high or low) in combination with population numbers for specific species to make determinations about the "health" of a system. I believe it is this emphasis that is important to the modern day use of biodiversity and is relevant to water resources. It is this concept of diversity and a mix of species that steers a return to natural and healthy systems and calls for man made projects (e.g., reservoirs) to be managed for a variety of species; not necessarily for a single, and possibly only one, endangered species.

Another important term that has received ever increasing exploitation in recent times is **ecosystem(s)**. As with biodiversity, ecosystems is a combined form of **ecological systems**. From a water resources perspective an ecosystem can describe anything from a drop of water to the entire global hydrologic cycle. However, a landscape or land area is generally associated with a defined ecosystem. Included in the Great Lakes Commission Ecosystem Charter (HYDATA, 1994) is a statement that ecosystems are "the interacting components of air, land, water and living organisms, including humans". I believe that the current wide spread usage of ecosystem is meant to emphasize a more holistic view of all resource values contained within an appropriately defined area. This terminology correctly recognizes that, in addition to water, animals, and the atmosphere are transport mechanisms that extend across and beyond our traditional drainage basin boundary (i.e., a watershed). Other noteworthy references are made that "ecosystems are used for the benefit of humankind without destroying the ecological balance, that is, utilization of the ecosystem on an economically sound basis" (Mitsch and Jorgensen, 1989). The delineation of landscape boundaries to define a given ecosystem is highly influenced by the particular objective and resource(s) for which the ecosystem is being studied, managed, or inventoried. Of particular importance in these definitions is the reference to using ecosystems for human and, therefore, economic benefit within limits.

A further expansion of this dialogue leads quite naturally to the phrase **sustainable ecological systems**. Just as ecosystems are currently poorly defined, a research agenda,"The Sustainable Biosphere Initiative: An Ecological Research Agenda" proposed by the Ecological Society of America (Lubchenco et al., 1991) has identified the sustainability of ecological systems as one of the greatest challenges facing human society, yet it is one that has received little attention to date. That research agenda defined sustainable ecological systems research priorities "including the definition and detection of stress in natural and managed ecological systems; the restoration of damaged systems; the management of sustainable ecological systems; the role of pests, pathogens, and disease; and the interface between ecological processes and human social systems". Also noteworthy in this referenced ecological research agenda was the admission that, "research programs exist to develop specific (i.e., single) sustainable natural resources. However, current research efforts are inadequate for dealing with sustainable systems that involve multiple resources, multiple ecosystems, and large spatial scales". Additional suggestions highlighted the absence of research focused on natural ecosystems and resources that lack market value, as opposed to commodity based managed systems (e.g., agriculture). This has serious implications for multi-purpose water management because it is a true statement as applied to existing water resource projects and research activities.

This mention of commodities and market value, as well as the reference of ecosystems used for human and economic benefit, leads into the need to define the terms **sustainable development** and **sustainability**. According to a member of the World Wildlife Fund, sustainable development is that which "meets the needs and aspirations of the present without compromising the ability to meet those of the future" (Wright, 1994). According to Turner (1988), "the term sustainability implies management practices that will not degrade the exploited systems or any adjacent systems". These last two definitions do not specifically mention utilization by humans or economic benefit.

Several fairly recent developments within the federal government will set the stage for the United States' outlook on **sustainable development** for years to come. Within the US Department of Interior a new agency, the National Biological Survey (NBS), was created in November 1993; and although this agency was short lived, surviving for two years, the agency's mission was preserved and merged into the existing US Geological Survey as the Biological Resources Division. The mission for this agency was concisely stated by Bruce Babbitt, Secretary of Interior, "to provide the scientific knowledge America needs to balance the compatible goals of ecosystem protection and economic progress". Further details of that reorganization are described in a report entitled "A Biological Survey for the Nation" by the National Academy of Science-National Research Council, (1993). A summary document about the formation of the NBS stated that projects should target areas that are either changing rapidly because of human activity; or that have important ecological characteristics such as high levels of biodiversity. These two areas of research are critical to the ecosystems management strategies of the federal government (Raven, 1993). There are numerous references in the Department of Interior and in President Clinton's administration to biodiversity, ecosystems, and to balancing ecosystem protection with economic progress. This recognizes that an economic analysis must also incorporate all elements of the biological and human social system.

The concept of **ecological integrity** is another pair of terms that I will attempt to define. This phrase is often used in combination with, or to imply, sustainability (i.e., a maximum level of ecosystem development), or to indicate the need for ecosystem protection and restoration. Integrity is defined in most popular dictionaries as "an unimpaired condition; soundness, wholeness or completeness; unity and even purity; and the quality or state of being complete or whole". An extension of this definition to ecological integrity implies keeping the ecosystem "whole" or "pure"; that is, in a natural undisturbed and healthy state. Therefore, maintaining ecological integrity of an ecosystem will allow the system to continue to provide the same "benefits" to society into future generations; a sustainable ecological system. Implied within this definition is the maintenance of a balance between the integral geologic, atmospheric, and biologic resource system components. A recommendation in a workshop report on "America's Waters: A New Era of Sustainability" (Natural Resources Law Center, 1992) calls for resource management agencies to establish quantifiable measures of ecological integrity, which should then be incorporated into agency goals, objectives and performance evaluation criteria. At present there is a total lack of any measure for ecological integrity, and this may in fact be a nebulous term.

ECOSYSTEMS IN WATER RESOURCES

Engineers, hydrologists and water resource scientists have used the phrase **safe yield** since at least 1923; whereas, the earliest use of "ecosystem" was first made by an ecologist in 1935 (Tansley, 1935). Safe yield was defined by a member of the US Geological Survey as "the rate at which water can be withdrawn for human use without depleting the supply to such an extent that withdrawal at this rate is no longer economically feasible" (Meinzer, 1923). Later on, some classical references in the field of hydrology (Kazmann, 1956; and Linsley, Kohler & Paulhus, 1958) restated this definition of safe yield as "a quantity of water subject to change as a result of changing economic and physical conditions; this concept can be applied only to a complete groundwater unit". This term, safe yield, has been referred to as sustainable yield, a phrase that is most similar to sustainable development. A phrase "ground water mining" is used by hydrologists to indicate water withdrawal at a rate greater than the average annual replenishment to an aquifer. Just maybe, hydrologists have been practicing safe development all these years. Of particular interest in these definitions of safe yield are the references to "changing economic conditions" or "economically feasible"; and that "this concept applies only to a complete groundwater unit". A complete unit is easily equated with an ecosystem, which was defined above as also including components for human and economic benefits.

As a refresher, definitions for sustainable development imply using resources to meet human social needs and managing development on a sound economic basis. Unfortunately, very little, if any, methods or data exist to quantify the economic value of most natural resources. According to the Ecological Society of America (Lubchenco et al., 1991), most current research focuses on commodity based managed ecosystems with little attention to sustainability of natural ecosystems whose goods lack a market value. The true cost or value of ecosystem resources that include ecological integrity and diversity remain unknown. Many water projects have been developed over time to provide human and economic benefits, but without accounting for the impacts and losses in water quality, biodiversity, wetlands, riparian, and habitat area, to name a few resources that lack true market value. "America's Waters: A New Era of Sustainability" (Natural Resources Law Center, 1992) states that "ecological protection assumes a priority beyond the measure of economic analysis". This statement is made because of the recognition that most ecosystem resources were not appropriately accounted for in past economic analyses. Some recommendations in the above cited report include: "Federal hydropower pricing should reflect the full economic and environmental cost of producing power, and revenues should be used to assist in financing water conservation and ecosystem protection and restoration"; and that "Federal Energy Regulatory Commission (FERC) licensing and relicensing should treat the ecological and nonpower values of rivers as co-equal with power generation ...". Several other references, in the water resources literature, suggest that water and power projects have not in the past accounted for all the true resource costs and benefits to the environment or in the ecosystem.

So what should be used to define an ecosystem boundary? This is a most difficult question whose answer certainly depends upon the resources or issues of concern. River basins, watersheds, hydrologic units or drainages are a good basic unit or building block for constructing ecosystem boundaries. However, transbasin diversions of water, air, and other resources further complicates and enlarges the required boundaries. A general principle stated by the Natural Resources Law Center (1992) is "watersheds should form the basic unit of analysis and activity in order to protect and sustain aquatic biological diversity, including instream, wetland, riparian, and related upland resources". Additional reference is made to the importance of the watershed resources as components of larger regional, interstate, or even international ecosystems. Burt (1993), then representing the Soil Conservation Service (SCS), US Department of Agriculture, identified the need for a common point of reference to coordinate environmental issues and programs within the agency; he noted that water is one of the major driving forces in the ecosystem. The SCS had settled on the watershed as a convenient boundary for environmental and resource management planning that includes land resource protection and pollution abatement. The Environmental Protection Agency (Wayland, 1993) defines a **watershed approach** as "comprehensive watershed management that entails (1) recognizing that all resources within natural (hydrologically-defined) watershed boundaries are part of interconnected systems and are dependent upon the health of the ecosystem as a whole, ... (3) building partnerships and programs within the watershed, (4) ...

implement selected solutions, thereby achieving greater efficiency and effectiveness through management on a watershed basis". The US Geological Survey (USGS, 1979) has developed a hydrologic unit map of the United States that is largely based on river basin drainages. This mapping has provided the basic unit of identification for atmospheric, hydrologic, and hydraulic water data measurements. In addition to being used for water resources management, these ecosystem units have also been widely used for numerous geographic and biologic studies.

A triad of ecological, social, and economic factors is often used to describe the critical elements of ecosystem management. The largest federal land management agencies have embraced the concept of ecosystem management although, as Wood (1994) with the Bureau of Land Management points out, acceptance of ecosystem management dictates limits on social and economic uses. A similar triad is described for the US Department of Agriculture's Forest Service by Kaufmann, et al. (1994) in describing ecosystem sustainability. An active role by government in management of these resources is justified by the fact that they are by far the largest landowner and manager of water and land resources. Public lands at the federal level are managed by Department of Interior agencies that include the National Park Service, Fish and Wildlife Service, Bureaus of Indian Affairs, Land Management, and Reclamation, and also includes the National Forest Service within the Department of Agriculture. Other active management agencies at the state and local level include variations of state fish and game, wildlife, or park departments, as well as municipalities or water districts or boards. More recent, but no less influential, participants in the management of water and land resources are captured in the "non-governmental-oragnizations" or NGO's. These groups generally represent non-profit citizen based special interests with particular emphasis on the environmental, recreational, or fish and wildlife spectrum of important values worth preserving. A NGO may represent a very special interest such as a sport fishing or kayaking interest only, or alternatively consist of a general environmental based constituency (e.g., the Nature Conservancy). Another most important participant not adequately represented by the Bureau of Indian Affairs are individual Native American tribes that may either reside within a river basin or merely have other vested interest in preserving "traditional cultural property", defined by Parker (1993) as a place rooted in the history of a community and important to maintaining that community's traditional beliefs and practices.

EVOLUTION FROM SINGLE PURPOSE TO ECOSYSTEM MANAGEMENT

A brief history of water resources development in the United States, with particular focus on environmental issues, is provided by the American Society of Civil Engineers in a report prepared by their Committee on Social and Environmental Objectives (Lyon, 1984). From the end of the nineteenth century until the 1920's, dams were built across rivers based solely on the justified needs for one single purpose. During that time human interests were focused on creating economic opportunity for settlement of new territories. The single water purposes included navigation, which was then followed by irrigation. President Theodore Roosevelt prioritized this desire to encourage settlement of the arid lands in the western United States. Under his presidential leadership the US Congress passed the Reclamation Act of 1902 which created the Reclamation Service, later called the Bureau of Reclamation (BOR). This agency set out to develop and build projects that provide irrigation water, delivery systems, and storage. Although this era focused on single purpose projects and river development schemes with economic objectives, President Roosevelt recognized the need to protect our natural resources from wasteful development.

Citizens of the United States were not ignorant of environmental values or oblivious to natural beauty at the beginning of the twentieth century. The original Organic Act (USC 1916) creating the National Park Service states its mission as "... to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment ... as will leave them unimpaired for the enjoyment of future generations" (Mantell, 1990). In the Colorado River Basin, Grand Canyon National Park was established in 1919, but originally proclaimed as a Forest Reserve in 1893; and Dinosaur National Monument became a monument in 1915, later followed by designation for other national treasures. Although the early twentieth century included many actions to set aside parks and forests, any environmental components of water development were overshadowed by the primary and economically motivated project purposes.

In the 1920's the concept of multiple use surfaced and concurrently Congress passed the Federal Power Act to encourage private hydropower developments. Soon there after federal projects included hydropower components as a way to finance or subsidize the costs of larger water projects. Coincidentally, other interstate water allocation struggles on the Colorado River forced a division into Upper and Lower Basins under terms of the 1922 Colorado River Compact. As a part of the Lower Basin development plan, the Boulder Canyon Project Act of 1928 was authorized. This BOR project included the construction of hydroelectric powerplants, Hoover Dam forming Lake Mead, and the All American Canal for delivery of irrigation and domestic water supplies to southern California. Ever since then the Colorado has been further developed and managed as a basin with multi-purpose water development projects. The 1928 Act specified the purposes of the dam and reservoir as first for river regulation, navigation improvement and flood control; second, for irrigation and domestic uses and satisfaction of perfected water rights; and third, for power. Of particular note at this time is the absence of any specific references to environmental, natural or recreational resource concerns.

By the 1950's interest in flood control had taken hold, allowing the Corps of Engineers to build dams with no requirements for repayment. Thus, the federal government was fully funding and providing flood control without reimbursement costs. The BOR received the Colorado River Storage Project Act of 1956, which authorized construction of Glen Canyon Dam forming Lake Powell and three other major storage units all within the Upper Colorado River Basin. Glen Canyon Dam is at the division between the Upper and Lower Basins and includes significant hydroelectric power. These projects and the passage of the 1956 Act had to overcome substantial opposition and political forces formed by a coalition of conservation groups concerned with locating a dam within a national park or monument. As a consequence of the deliberations surrounding this act, the Secretary of Interior was charged with responsibilities related to these projects that provide for public recreation; that conserve the scenery, natural, historic and archaeologic objects, and the wildlife on project lands; and to mitigate losses and improve conditions for the propagation of fish and wildlife.

Many people refer to the 1960's as the onset of the environmental era, but it also brought attention to the need for a national water policy. As Born (1989) briefly describes, a call for a national water policy surfaced several times earlier during this century. A 1961 report by the Senate Select Committee set the stage for the 1965 Water Resources Planning Act, establishing the US Water Resources Council and river basin commissions. In 1968 the Wild and Scenic River Act was passed which exemplifies the national interest in preserving and protecting non-market values of the nation's rivers and waterways. The National Environmental Policy Act (NEPA) of 1969 was a major piece of legislation that impacted the types of in-depth studies and alternatives that were required in project planning. Most noteworthy in NEPA was the requirement that Environmental Impact Statements (EIS) be prepared, which involved evaluating project alternatives for economic, social, and environmental consequences.

The progressive period of the 1960's for multi-purpose water projects, was followed by the passage of the 1972 Clean Water Act, PL 92-500. This act not only stressed the health related impacts of water consumption and the need to clean up and set standards for water discharges, but also protected America's waterways for recreation and water-body contact activities (e.g., swimming). This act thereby elevated water quality considerations to a level policy field with traditional water resources development. The Endangered Species Act of 1973 and Amendments provides the Fish and Wildlife Service (FWS) with the responsibility for management of native fish species. The FWS has identified critical habitat for threatened fish species along a substantial portion of the Colorado River and in numerous other rivers. The authority given the FWS under Section 7 Consultations maintains their active involvement in the reservoir operation planning process, resulting in their request for alternative monthly flow releases and maintenance of minimum instream flow levels. In 1973 the US Water Resources Council is successful and put in place the "Principles and Standards for Planning Water and Related Land Resources". These Principles and Standards represent a multi-objective approach to water resources planning and gave maximum emphasis to environmental quality objectives. The often referenced secondary benefits of social well-being and environmental protection were elevated to an important, if not equal, level in water resources decision making. Therefore, the 1970's appears to be a decade in which the concepts of an ecosystem approach to water resources planning and management had truly come into being.

In many respects the 1980's were a setback for ecosystems management of water and other resources. Part of this period reflects the changing hardships brought about by economic difficulties felt nationally and around the world. This decade brought about a dismantling of the US Water Resources Council and a repeal of the Principles and Standards with substitution of a diluted Principles and Guidelines. A major federal effort was placed on cost recovery, which in many respects refocused water development toward strictly single purpose market values such as power, municipal or agricultural water supply purposes. The federal government policy mandated an emphasis on cost-sharing of projects with state governments or among other publicly interested parties, and the forming of partnerships for water development. On a positive note several water quality laws were enacted during this decade and several efforts to study environmental and ecosystem issues in a multitude of river basins were undertaken. Noteworthy of mention are major multi-million dollar research efforts: the Glen Canyon Environmental Studies (National Research Council, 1987) and the creation of the Klamath River Basin Fisheries Task Force.

The rules and laws governing water management were rapidly changing during the last quarter of the twentieth century. A good review of water resources planning and how social and environmental objectives were expected to be a part of this process in the United States is provided by Hobbs et al. (1989). Several conferences and proceedings during this period (Viessman and Schilling, 1986; and Baumann and Haimes, 1987) addressed methods and concerns related to these objectives in water resources planning. These conferences and their associated reports attempted to educate engineers in how to integrate social and environmental objectives into the rigorous multi-objective planning process. Unfortunately very few water resources plans or management studies have successfully utilized objective and quantitative information for many resource objectives. Some research efforts have attempted to measure dollar values for resource objectives, however this remains a difficult, if not impossible, task for the natural, cultural, and endangered species resources, where oftentimes a qualitative assessment of the resource response to significant changes in water flows is all that is available. Conflicts over water regulation and reservoir operations still exist because water resources systems are optimized for traditional benefits (e.g., hydropower, flood control), which were historically and continue to be quantified in economic terms. This is particularly true within the western United States where Department of Interior resources are involved and include water issues related to instream and riparian resources. Most often, social and environmental objectives, if indeed they are specifically identified, are not quantified in any units of measure that relate to flow characteristics typical to river and reservoir simulation analysis. At best these resource objectives are qualitatively assessed and, in general, a demand is made for more time to study impacts upon these resources. Public concern for these issues typically creates an outcry after flow alternatives are analyzed and a water management plan that does not fully consider or satisfy these social and environmental objectives is recommended. The establishment of an open and two-way communication process which provides the opportunity to exchange information, ideas, and viewpoints between and among technical experts, water managers, or decision makers and with other stakeholders or even the general public can result in greater public acceptance of management decisions (Chechile and Carlisle, 1991).

Recent 1990's Actions to Protect Ecosystem Resources

With the onset of the 1990's the federal government increased support of resource protection for a variety of societal values and increased the role for greater partnerships with state, local, and public participation in water management decision making. Numerous water management issues were referred to federally established or supported task forces, steering committees, or other forms of public and representative involvement groups that were formed to help study and resolve conflicts over water. The federal government passed the rather extensive Reclamation Projects Authorization and Adjustment Act of 1992 which contains forty different Titles primarily addressing water authority in the western states. One Title included in that act was the Grand Canyon Protection Act which requires the Secretary of Interior to operate Glen Canyon Dam to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established, including natural and cultural resources and visitor use. The 1992 Act affords protection of these ecosystem resources by emphasizing that these are considered as primary purposes of the original Colorado River Storage Project Act of 1956. Several ongoing studies started by these federally supported committees continue to provide information and data for the Colorado River Basin (National Research Council, 1996), the Klamath River Basin, and in support of water operations on Lake of the Woods drainage impacting Voyageurs National Park. The new information learned about ecosystems and changing societal values that are presently favoring protection of valuable and unique resources will alter the management and operations of reservoirs into the future. In several basins a temporary "quick fix" operating scheme was implemented under a strategy which identifies "adaptive management" as the long-term solution to protecting and restoring endangered species or for improving downstream water quality. In the final analysis, non-traditional and typically non-market value resources will gain position and stature in a multi-purpose ecosystem water management study and alter river and reservoir operations into the future.

The most recent focus on Glen Canyon Dam in the spring of 1996, with the experimental high flow "flood" release or "spike" flow release, captured the national media's attention and international interest with the federal government's research plan and hope that the man-made flood would help heal and rebuild natural habitat in the downstream Grand Canyon. The almost immediate and initial measurements did in fact indicate that the controlled reservoir releases rebuilt or restored sand beaches and backwater habitats. Some supporters of this flood flow release see the time that water management and reservoir operations will be used to restore or save endangered species and their habitat at a sacrifice to more traditional power generation. More recently in the summer of 1997, a noteworthy NGO had mustered enough influence to call for the draining of Lake Powell, and return the river flow to an uncontrolled natural run of river condition. This concept played out extensively in popular magazines, newspapers, radio, television, and even in front of a federal committee of the Congress. Some of the logic used to support the draining of this reservoir made reference to earlier management decisions and environmental compromises made at the time of ongoing and emotional national and Congressional debates prior to the authorization of the Colorado River Storage Project Act of 1956.

Elsewhere in the United States, other serious efforts are also mounting to drain reservoirs and remove two dams on the Elwha River in northwest Washington state, which drains into the Olympic Peninsula. The Department of Interior has over the past few years investigated and evaluated proposals for the Elwha River that have to date produced two EIS's for the purposes of fully restoring the ecosystem, eliminating the unlicensed hydropower generation that was installed at the turn of the century, and returning river access to six species of salmon that are denied passage through the dams. Most recently (November 1997), the federal government's FERC denied a license renewal for a hydroelectric dam across Maine's Kennebec River, first built in 1837 to power a textile mill and upgraded in 1920 to generate electricity. That decision to deny a license reflects a balanced view based on environmental as well as social and economic considerations. Additionally, this decision ordered that the structure be ripped out so that sturgeon, bass, salmon, and smelt can reach seventeen miles of their spawning grounds. These investigations to remove reservoirs or to severely alter operations are also supported by other parallel and ongoing federal government activities to purchase and retire farm land, and restore the parcels to native vegetation, while at the same time re-plumbing water management structures that control water storage and releases to the Everglades, in Florida. This effort is supported both financially and politically by a broad mix of federal, state and local governments, as well as a spectrum of special interest and political groups. All of these efforts at dismantling existing water storage structures are an attempt to restore the "natural flows and conditions" with the hope that these actions will bring back the native biologic mix of plants and animals.

ECOSYSTEM CONSIDERATIONS IN THREE RIVER BASINS

This section provides a description of numerous ecosystem resource considerations that exist in three river basins within the United States. These three rivers continue to face re-regulation and changed reservoir operations due to changing social and environmental priorities. Each sub-section begins with a brief description of the river basin. One viable and more manageable means of identifying the extensive resource considerations is to group similar impact variables into categories often referred to as criteria. This approach is used in the sub-sections that follow, which identify criteria and then several more specific resource considerations (i.e., attributes) of interest in the particular river basin. In most instances the identified criteria are often overlooked by traditional water management operations. More specifically, the individual attributes are finer detail resource issues than most engineers, hydrologists, or water managers are accustomed to thinking about, particularly in terms of reservoir operations. The quantification for many of these resource considerations as a function of alternative reservoir operations is generally lacking. Most often other scientists can provide a qualitative statement about the impact a change in reservoir water level, downstream river water level, and/or reservoir discharge is expected to have on the resource consideration (i.e., attribute). In addition, seasonal, diurnal, and time varying changes in levels and discharges can be the most important or sensitive reservoir operational decisions. Fluctuating flows, typically associated with a peaking hydropower operation, for example, may have the most damaging impact on physical habitat, biologic nesting or reproduction, and erosion of archeologic features.

Qualitative statements for each attribute as a response to a changed or alternative reservoir operation can be converted to quantitative dimensionless units of impact. This technique can be accomplished by comparing the relative degree of impact to either a "no action" or the status quo alternative, or by using some other base for comparison such as the maximum achievable level for a given attribute. In this scenario one could compare qualitative statements such as significantly improved, above average, average, adequate, poor, severely reduced, etc., to create a relative numeric value. Alternatively, each attribute can be compared based on a variety of physical measurements such as: acres or square feet of habitat available; number of days flows are adequate for white water boating; number of days water temperature is appropriate for fish to migrate in the river; number of days nesting shorebirds or other shoreline mammals are protected from flooding during the nesting season; or number of days of adequate reservoir water depths for recreational boat navigation or for access to floating boat docks. For example, compute the maximum spawning habitat provided under optimum reservoir operations; then compare available habitat from other simulations to the computed maximum habitat to provide a relative value. These techniques have been used in some river basin studies and at least provide an approach to measuring resource considerations that escape accurate valuation in monetary terms.

Colorado River Basin Ecosystem

Within the Colorado River Basin the potential for conflict due to over appropriation of available water and changing water use priorities certainly exists. Eight large dams and related water diversions have earned the Colorado River the title of the most regulated river in the United States (Gray, 1991). More than six times the mean annual flow can be stored in the basin's reservoirs. The Colorado ecosystem includes an array of biological diversity while still supporting human economic and social values on an international scale, supplying water to the seven western states of Wyoming, Colorado, Utah, Arizona, New Mexico, Nevada, and California, and to Mexico. Originally, diversions from the Colorado River were for a single purpose, providing water for irrigation, domestic use, or mining claims. As development and regulation increased, a variety of other beneficial purposes were added that included hydroelectric power, flood control, supply and storage for domestic and industrial users, lake and river based recreation, and fish and wildlife protection. Regulation has also greatly altered the natural aquatic and riparian habitats formerly associated with the unregulated river. A more detailed discussion for many of the resource considerations are described in the Final Environmental Impact Statement prepared for Glen Canyon Dam (US Bureau of Reclamation, 1995). Other resource issues, with particular emphasis on impacts in the eight National Park Service areas located along the Colorado River, are given by Flug and Jackson (1993a and 1993b).

Reservoir operations and water management of the highly regulated waters of the Colorado River include numerous constraints with respect to water rights allocations, state apportionments, and other issues of water transfer. In addition, traditional objectives of water management and reservoir operations have been programmed into computer models for simulation of the Colorado River system since the 1970's. However, an identification of resource criteria or ecosystem considerations remains an important, but difficult, exercise for water management. What follows is only a sampling of resource considerations that have been identified on the Colorado River. Many other considerations and attributes are variations of what is presented below, but are modified for the site specific characteristics associated with the respective reservoir or river reach.

Cultural resources are an important criteria for protection of archeological sites, that include submerged vessels and fossils; and because several Native American tribes reside within and historically used portions of the river corridor and adjacent riparian areas. Traditional cultural properties and use areas include sacred sites, places for religious worship, natural springs, willow gathering areas, and geologic features that provide specific minerals, pigments, or other substances for use in traditional ceremonies. Many such features and attributes are well documented within the Grand Canyon and along other side canyons tributary to the mainstem Colorado River.

Recreation has become a growing industry within the Colorado River Basin and directly impacts the tourism industry that so much of the basin's economy depends upon. The demand for flat water boating in reservoirs and a variety of white-water boating experiences below controlled reservoir releases has exploded along portions of the Colorado River. These attributes depend upon scheduled flow releases and are severely impacted by fluctuations in flow that can make river rapids unsafe, impassable, detract from the adventure, and at times create downstream water level changes that isolate beach shoreline areas high-and-dry from the river channel flow. Within the reservoirs, minimum water levels at specific dates that mark the beginning of boating season are required on Lakes Mead and Powell to provide navigation access to and from boat docks and for access to scenic side canyons. Other attributes that contribute to the recreation resource criteria include angler fishing safety; availability of camping beaches due to fluctuating reservoir discharges and due to sediment transport further downstream; wilderness values which relate to natural conditions and preservation on native vegetation; and fishing conditions that can include access to shoreline beaches and fish feeding areas. In several instances economic calculations have been made to measure attributes within the recreation criteria. Sport fishing can be identified separate from recreation because several river reaches represent blue ribbon or gold medal fisheries; and because many of these non native species were introduced into the Colorado River.

Endangered and Special Status Species include several species of fish attributes such as the humpback chub; razorback sucker; flannelmouth sucker; Colorado squawfish; and also bald eagle; peregrine falcon; southwestern willow flycatcher; and Kanab ambersnail. These species, which may exist in very small numbers, utilize some very limited and specific habitats that include site specific gravel bars which are needed for spawning at specific time periods and may be triggered by sensed changes in water temperature. The development of water with altered flow and temperature patterns has severely impacted native species in parts of the basin. Additional requirements for many of these species is the need to re-establish backwater areas and riparian wetlands for use by these species at various life stages. Although these are difficult attributes to quantify, the FWS can and has influenced reservoir operations under their authority to protect some of these endangered species.

A Northern Minnesota River Drainage Basin

Voyageurs National Park resides in northern Minnesota and includes extensive low lying areas and numerous small land locked lakes that eventually flow into the Winnipeg River. However, more significantly from a water management perspective, two large lakes extend across the international border with Canada. The larger Rainy Reservoir includes several hydropower generation units that are privately owned and operated on both sides of the international border. These units at International Falls, MN, the cold spot of the US, were initially constructed after the turn of the century, but continue to support pulp and paper mill activities. The smaller upstream Namakan Lake is actually formed by two separate stop log controlled dams, one dam on each side of the international border. This Rainy River drainage system was initially a fur traders route known as the Voyageurs Highway. Although these dams are privately owned and operated to generate power for the pulp and paper mills, the history of their water management is influenced and partly regulated by an international lake control board which operates under authority of the International Joint Commission (IJC), a creation from the Boundary Waters Treaty in 1909 between the United States and Canada. At various times the lake board of control has modified reservoir rule curves, usually in response to a significant flood event. A brief description of the history of reservoir operations is given by Flug and Kallemeyn (1993).

At the present time an International Joint Steering Committee, established a few years ago by the IJC, is still operating to further evaluate modified reservoir operations and to foster an agreement on improved rules for reservoir operations, which satisfies the needs of all concerned interests. As of late 1997 the steering committee has asked for an analysis of inflow forecasting in an attempt to reduce rule curve violations. The National Park Service has been an active participant in activities to re-regulate these reservoirs and has supported and/or been involved in numerous research studies to better understand biological needs from the hydrologic system (Kallemeyn, 1987). An analysis of historical regulated flows and seasonal reservoir water level changes as compared to natural occurrences of lake levels was conducted by Cole (1982), which indicated that small changes in the timing of water level drawdowns could enhance habitat conditions for several native species. Noteworthy of mention is an effort and report by Kallemeyn and Cole (1988), which analyzed data from several research field studies and from the literature to assess the consequences of reservoir flow levels on several attributes. They then proceeded to develop criteria and a numeric rating scheme to further evaluate alternative reservoir operations for these resource considerations. A description of a weighted average multi-criteria procedure to quantify and evaluate the resource attributes using their rating criteria is given by Flug and Ahmed (1990). An identification of some of these biologic and recreation resource considerations is given in the paragraphs that follow.

Recreational navigation was and remains important on Namakan Reservoir and Rainy Lake because these waters are a haven for fishing and canoeing enthusiasts, and tourism is now the largest industry in the area. Small changes in the timing and water levels in the spring, summer, and fall can have large impacts upon the accessibility of small water craft to numerous small land locked lakes. Additionally, the commercial fishing resorts request an extended season to navigate houseboats into and out of their properties. These requested changes are on the order of only three feet and a few weeks change in time.

Biologic conservation criteria in Voyageurs National Park are important because of the park status that requires resource management to preserve and protect for future generations. Native Americans are present in this area and they have areas and protected rights to harvest wild rice that propagates and grows within these reservoirs. Critical water level changes that influence wild rice production include very gradual increases in water depth during the growing season from May to July, so that the submerged plants can grow at a rate equal to the water level rise. Other biologic attributes include habitat for otter, beaver, muskrat, and shoreline nesting birds. Reservoir operations that fluctuate the over-winter drawdown levels negatively impact lodges and burrows for beaver, muskrat, and otters, who are best left with their homes undisturbed during the winter, preferring stable water levels during this time period. For nesting shoreline and marsh birds, small water level rises of less than two feet during June can flood bird nest and limit reproductive success.

Klamath River Basin

The Klamath River Basin Fisheries Task Force (Task Force) was established by an act of Congress in 1982 to coordinate activities of Federal, state, county, Tribes, and anadromous fishery resource user groups in the Klamath River Basin. The Task Force has been directed by Congress to work with the Secretary of the Interior to restore Klamath River Basin anadromous fisheries to optimum levels by 2006. This river drains upland areas in southern Oregon that under natural pre-development conditions contained extensive wetlands and wildlife areas that supported the western hemisphere's largest population of and migration route for numerous bird species. The BOR manages the upper basin agricultural project, and is presently upgrading their Klamath Project Operations Plan, a water resources accounting model that will describe the features of the federal Klamath Project from Upper Klamath Lake to Iron Gate Dam. Since 1994, the US Geological Survey-Biological Resources Division (USGS-BRD) has interacted with the Task Force, primarily through its Technical Work Group (TWG), to restore this western riverine ecosystem. The TWG identified as a high priority the need to develop a water quantity model for the Klamath River Basin, including the major tributaries (Shasta, Scott, Salmon, and Trinity Rivers). The USGS-BRD has undertaken this project to provide a water quantity model, a network simulation model, capable of evaluating various historic and simulated river flow scenarios at selected points along the Klamath River. Additional support for this effort was also provided by PacifiCorp (who own and operate the hydropower operations) and the BOR; these two groups manage reservoirs in this system. The network model will provide information on flows at locations of expected fish habitat. This identification, enumeration, and quantification of flows, system constraints, and operating rules will provide good information about locations and reservoir system operating policies that are bottlenecks with respect to providing instream flow needs to restore the anadromous fisheries.

The overriding objective in the development and implementation of the water quantity model is to define feasible river flow quantities and seasonal patterns under various management alternatives, which enhance habitat for threatened and endangered species. A part of this model development project required extensive coordination and cooperation with BOR, PacifiCorp, and other research study efforts to ensure the integration of compatible water quality and habitat models at a time step appropriate to analyze the relationship between flow and anadromous fish habitat in the Klamath River. Unfortunately, at this date the water quality and habitat studies are at an earlier stage in project development than the network flow model. These other resource studies are still identifying river locations, collecting field data, and have not as yet established data outputs and results. Field work and data collection are still needed to support the biologic models that include fish growth, population, and migration. The data needs include hydraulic measurements to provide channel depth, velocity, and substrate characteristics at known locations used by several species of salmon, trout, and suckers during different life stages. Additionally, based on a preliminary analysis, water temperature appears to be a critical limiting factor in the migration and spawning of these fish species. Planned field work also includes, and the fish population model requires, information to develop habitat suitability indices (HSI's) or curves that essentially describe the preference of specific fish species at different life stages for specific combinations of water depth, velocity, substrate, and possibly water temperature. The understanding of results from these scientific research efforts and integration into a water operations plan will lead to more acceptable management decisions.

CONCLUSIONS

This paper describes ecosystem management as a maturing process in the evolution of river development from single purpose projects to multi-purpose water management. Several examples taken from large scale water development projects of the Colorado River System and elsewhere are provided to document this premise. In parallel, a brief description of the limited national water policy that evolved in the twentieth century is also provided. Individuals express a greater want for non-market value goods (e.g., natural resource protection or recreation) during periods of economic growth. These are times when they can afford the luxury of leisure and are not dependent on expending all or most of their resources on day to day living. Just as economic conditions are cyclical, so too are the forces pushing for full consideration of multi-purpose objectives, environmental concerns, non-market values, and ecosystem protection. As presented earlier in this paper, the definitions for sustainable development include language that suggests balancing economic factors with other social and ecological factors; that is, a balancing act between preservation and economic development. Many of America's forefathers were environmentally conscious individuals and very caring about the ecosystem in which they lived, but may have been somewhat limited by the lack of knowledge about ecosystem components and interactions that still exists today. Certainly many water resource managers, civil engineers, hydrologists, ecologists and many others attempted to treat water development on a holistic basis. Many of these visionary water developers truly looked at rivers as a system and attempted to satisfy a growing and thirsty population, while providing water storage, reservoirs, and recreational lakes. In general, they tried to make better use of natural resources for the good of mankind. Good water resources professionals have preceded my generation and as I look back at their projects I believe they felt they too were promoting sustainable development, biodiversity, and ecological integrity. As we approach the twenty-first century, numerous dams, reservoirs, and hydroelectric power installations are scheduled for review, evaluation, and relicensing by FERC. Additionally, several other rivers will be presented with required changes in operation to preserve and protect threatened and endangered species under authority of the Endangered Species Act. Other projects and operations will come under scrutiny by federal and public agencies, and in some instances, an environmental impact statement or review under NEPA will be required due to planned significant changes in reservoir operation as compared to past practices. All of these projects will then have to withstand participation and scrutiny from the public and NGO's, and then accommodate increased protection for ecosystem values for several social and environmental objectives.

Note: All opinions expressed are those of the author and do not necessarily represent the policy of the US Geological Survey or Department of Interior.

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