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Flathead Basin, Montana, ecosystem case study

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Abstract

The Flathead Basin project began as a river-basin EIS, guided by a citizen-based steering committee which eventually evolved into the Flathead Basin Commission, a State-legislated body. Water quality has dominated the Commission's agenda, and has been the basis for assessing ecosystem change. Science has played a central role in providing information, driving adaptive management, developing an understanding of ecosystem structure and function, and informing the public. The ecosystem approach involved defining the system as the Flathead Lake catchment basin, synthesizing available information on the system with models, considering alternative management strategies, and making initial management decisions.

Flathead Lake is one of the 300 largest lakes in the world and among the top five in water quality. A 1983 algal bloom and declining summer O_2 levels in the late 80's signalled onset of nutrient loading. In vitro experiments showed phosphorus to be the major cause. In response, the Montana Water Quality Bureau, with state legislative concurrence, banned local sale of phosphorus detergents and facilitated upgrading of sewage treatment plants. Point-source release was reduced 15% with reduction in algal productivity. Non-point sources are still a problem and being explored.

A dam on the South Fork of the Flathead River, which altered the downstream temperature environment, was retrofitted to normalize tailwater temperatures. Based on project research, Federal Energy Regulatory Commission is considering changes in operations of Kerr Dam, located at Flathead Lake outlet, to reduce bank erosion from wave action. Based on discovery of a complex aquatic community of organisms in the Flathead River flow through the subsurface, geologic strata, the Montana governor and Secretary of Interior signed a Federal water-rights compact protecting surface and interstitial waters, and protecting clean-water flows into Flathead Lake.

Water quality of the lake in terms of the native food web has been permanently altered by human introduction of a non-native crustacean, Mysis, *which eliminated the native zooplankton; and by introduction of Kokanee salmon which eliminated the native westslope cutthroat trout, and the non-native lake trout which are suppressing the native bull trout, a candidate for threatened or endangered listing.*

In total, the Flathead Lake ecosystem research has placed science and management in proper human context through public education and debate, making possible adaptive changes in management actions.

INTRODUCTION

I am here to tell you about a long-term project to provide a scientific basis for conserving the natural attributes of the Flathead River - Lake Ecosystem in northwestern Montana, USA, and southwestern British Columbia, Canada. I intend to emphasize the role of science, but the project always has been very interactive with the human communities in the ecosystem. The work is rather unique, I think, because it has involved high-profile ecological science in grassroots decision processes.

The project is based at the Flathead Lake Biological Station, which was created in 1896, and is the second oldest biological field station in the United States. Since its creation, the Biological Station has been a point of reference for the scientific information needed to resolve conflicts over uses and abuses of environmental goods and services.

The main theme of this presentation is that credible science can provide information about how an ecosystem functions and thereby drive an adaptive- management process that in the long term will sustain the attributes of the ecosystem that the public values highly. I will show important ecosystem processes and responses and describe how that science was used as the basis for ecosystem management. Hopefully, this case history will illuminate the applicability of ecosystem principals in management of regional natural resources.

HISTORY AND EMPHASES OF THE PROJECT

The study got its main start in 1976 as a river-basin EIS. Funding was stimulated by a proposal for a large coal strip-mine in the British Columbia part of the basin; people were very concerned about potential damage to environmental attributes of Glacier National Park and Flathead Lake (International Joint Commission 1988). A citizen-based steering committee determined how EIS money provided by the Environmental Protection Agency would be spent and what scientific questions posed by me and others would be emphasized in the initial studies.

In the mid-1980's, this steering committee evolved into the Flathead Basin Commission, which is a State-legislated body comprised of management agency heads in the basin plus an equal number of citizens. I am not a member of that commission. My role has been to provide the ecological information based on our scientific studies to the commission; whereas, the Commission sponsors forums and discussions of the science and policy implications, thereby allowing the public to be interactive on environmental matters.

I want to couch most of what I have to say in terms of water quality because water quality in this basin reflects not only the environmental variability of the system, but in many respects water-quality considerations integrate what many people perceive as quality of life. In every local survey in which people are asked why they like to live in Flathead country, they always comment on the high-quality waters, especially in Flathead Lake. Water quality has dominated the agenda of the Flathead Basin Commission and served as the primary variable for assessing ecosystem change. The role of scientists like me has been to demonstrate trends in water-quality indicators as accurately as ecological science allows.

For example, an important indicator of high-quality water is the native bull trout (*Salvelinus confluentus*). This fish is found only in clean, cold waters of the Pacific Northwest, such as Flathead Lake and its tributaries. I have a strong suspicion that this fish will be on the minds of a lot of people at this conference in the near future. It is likely to be listed under the Federal Endangered Species Act, or at least recommended for listing, by the Fish and Wildlife Service. It is an inhabitant of almost all of the streams and rivers in the upper Columbia River Basin where water quality remains near the pristine baseline. Throughout its native range, populations of bull trout are increasingly fragmented owing to habitat degradation by pollution, dams and negative interactions with introduced exotic fishes and other biota. The bull trout is declining in the Flathead catchment as a consequence of changes in water quality caused by human activities which I describe in detail below. Hence, the bull trout is a keystone species that serves as a barometer of the condition of water quality in the Flathead and elsewhere.

OUR ECOSYSTEM APPROACH

The primary scientific objective of our work at the outset in the early 1970's was to understand the distribution and abundance of animals, including bull trout, in an ecosystem perspective, and to conserve, if possible, the processes and responses that maintained ecosystem integrity (sensu Angermeier and Karr 1994). A key hypothesis has been that the critical ecosystem attributes are dynamic, constantly changing within a range of natural variation. Human activities always add additional environmental change. Indeed, in contrast to many talks at this conference, I have always thought that sustainability of any particular ecosystem state is probably mythical. Few natural resources worldwide have been sustained for any long period of time since the industrial revolution; environmental change is a given. The challenge is to manage renewable resources so that environmental change does not substantially degrade the quality of human life.

I will review our approach to long term documentation of environmental change in the Flathead in a series of steps that summarize what we've done over the years. And, when I say "we" or "our," I am referring to a long list of scientists, managers, politicians, and citizens that participated over the years in the research and ensuing debate of the implications of the results for public policy.

The first thing we did was define the ecosystem as the catchment basin of Flathead Lake. These boundaries were established in part because our keystone species, the bull trout, lives in the lake but spawns, broods, and smolts in the tributaries. Moreover, it was apparent at the outset that the high quality of water in Flathead Lake resulted from the fact that the land-use activities in the catchment basin had not significantly degraded the lake's tributaries. The lake is, in many respects, simply a wide spot in the river. Later, we acknowledged the "open" nature of the ecosystem and included the airshed and outlet river as key components of the ecosystem.

In retrospect, I think we implicitly embraced a unifying general definition of "ecosystem": the totality of ecological, social, and economic processes (function) that interconnect organisms (structure), including humans, with their environment within the Flathead River Basin and during a given period of time (ca. 1975 to date). We intentionally started large in scope, and worked down in scale to solve problems.

The second thing we did at the outset was to synthesize what we knew about ecosystem structure and function, and formally published it in the peer-reviewed literature. Periodic synthesis of existing knowledge is essential in regional ecosystem analyses. Often mathematical models are used to synthesize processes and responses that are important to managers. We have used mathematical and statistical models extensively to understand biophysical controls on Flathead water quality; we used models to formalize what we knew and to examine uncertainties, not to predict the future.

Next, we proposed various alternative management strategies and assessed uncertainties about them. In doing so, we were concerned about law, ecological theory, and whether a management hierarchy existed that could implement a management recommendation. Keep in mind that this was an interactive process that involved scientists, like me, national forest and park administrators, Native American and other community leaders, and informed citizens. We always had a great deal of concern about the degree of understanding of the science on the part of the general public, and believe me, after years of dialog about water quality and associated variables, a large share of the public can indeed converse accurately about the limnological phenomena in Flathead Lake.

We soon realized that some decisions had to be made and actions initiated even though our empirical knowledge of ecological processes and responses too often was incomplete.

So, we took some chances early on and said, "Well, here's what we know and there are a number of uncertainties in the science, but let's get out there and do what appears to be the right thing and determine empirically what happens." I'll show you some examples pertaining to water quality below. In some cases, clearly the management actions were misguided. But, in several cases the actions were smashing successes based on the data collected to date. Most importantly, since our water-quality data have been systematically and accurately collected over a 20-year period (coupled with less complete information back to the inception of the Station in early 1900's), actions could be evaluated along the way and adaptively changed as indicated by the data. I can't overemphasize the power of such long-term databases.

Throughout the years, the public made us scientists be accountable for the accuracy of our data and recommendations. This was especially true when we recommended that we ought to have a regional ban on the sale of phosphorus-containing detergents to protect water quality. The detergent industry, which of course was opposed to local controls on the sale of their products, came into the Flathead and said these local scientists don't know what they are talking about. Contentious public debate ensued. But, we were able to clearly demonstrate that water quality in Flathead Lake in fact was deteriorating as a consequence of input of phosphorus and nitrogen from urban sewage-treatment plants in the basin. The most expedient and cost effective way to reduce the nutrient load was to limit phosphorus-containing detergent use, while sewage-treatment plant technology in the basin was upgraded. In the end, the public endorsed the recommendation over the howls of industry and today the phosphorus load from sewage-treatment plants has declined by 15 percent and algal productivity in Flathead Lake has declined to near baseline conditions (Stanford et al. 1994a). Without question this would not have happened without a sound science rationale for the recommendation coupled with resounding public endorsement of the implications of the science. That endorsement was possible because of the interactive nature of the research and management process as mediated by the Flathead Basin Commission.

THE FLATHEAD RIVER-LAKE ECOSYSTEM AND ITS EXCEPTIONAL WATER QUALITY

Flathead Lake is one of the 300 largest lakes in the world. Of those 300 that occur in temperate regions of the globe, Flathead Lake is among the top five in terms of water quality. It is slightly larger than Lake Tahoe, but not nearly as deep. Flathead Lake now has better water quality than Tahoe, largely because so many more people live in the Tahoe basin (Naiman et al. 1995). Flathead Lake is so clear that in the fall you can lower a dinner plate, which we call a secchi disk, into the water column and see it 15 meters below the surface of the water. Many shoreline residents drink the lake water without treatment. Flathead Lake is indeed a very special resource for Montana, the United States, and the world.

But, three interactive problems threaten the high quality of water in Flathead Lake. One is nutrient pollution, phosphorus particularly, as noted above. Secondly, a dam on the outlet of the Flathead Lake and a hydropower reservoir (Hungry Horse) on the South Fork of the Flathead River partially determine the way in which water moves through the ecosystem and thereby influence flux of nutrients and other materials through the ecosystem. And third, we have suffered the consequences of food-web change caused by introductions of exotic biota.

These three interactive processes are the centerpieces of land- and water-use management in the Flathead and illustrate the utility of basic research as a focal point for citizen input to management processes at a regional scale.

FIRST SIGNS OF NUTRIENT ENRICHMENT

As noted above, in 1983 we had a lake-wide bloom of a pollution alga called *Anabaena flos aqua*. This alga is very distinctive and is not mentioned in any of the Biological Station analyses dating back to 1900. So, we were quite sure that it was a new wrinkle in the lake, very likely related to accelerated nutrient loading. Moreover, since 1977 we have continuously monitored species composition and production of algae in Flathead Lake. The long-term trend has been increasing production, apparently in relation to accelerating inputs of nutrients from human sources. In the late 1980's, one of the bays in the lake began to experience a decline in oxygen near the bottom in late summer, a classic indication of chronic change associated with too much algal growth in the water column. The overall implication of the science was that the lake was approaching a threshold of change that would considerably alter quality of life.

So, here were scientific data that early on showed us we probably had a problem. What did we do about it? First of all, we shared the information with the community through the Basin Commission forums and other public activities.

At the same time, we wanted to reduce uncertainty surrounding what we knew about the problem. The first thing was to determine whether nitrogen or phosphorus was causing the algae to grow excessively. So we initiated a set of experiments and found that we got a growth response from phosphorus during most of the year and from both phosphorus and nitrogen in the late summer. We also showed that grazing of algae by zooplankton was much less influential on total algal production than limits imposed by lack of phosphorus.

But this conclusion was based on experiments in bottles. Did it also hold for the real-world environment of the lake? Our detailed, long-term field data showed that phosphorus coming into the lake was largely contained in the Flathead River, which is the predominant tributary of the lake. However, we also were able to show that most of the urban sewage and non-point nutrient loads enter the river upstream of the lake. In summary, we were able to separate natural and human sources of variation in the nutrient supply from the catchment to the lake via the Flathead River. In terms of relative flux, phosphorus input was likely to cause a greater algal growth response than nitrogen, corroborating the *in vitro* studies.

We also showed that a large amount of phosphorus enters the lake annually from the airshed, mostly from wood smoke. Shoreline inputs of nutrients from septic systems also was demonstrated but the volume was minuscule in relation to river and airshed sources.

Based on these data, the Montana Water Quality Bureau recommended actions be taken to reduce the amount of phosphorus and nitrogen loading that was occurring in the system (Water Quality Bureau 1984). Owing in large part to the public education forums by the Flathead Basin Commission, the recommendations were endorsed by the Montana legislature in the form of a local-option ban on sale of phosphorus-containing detergents. And a sequenced upgrading of all sewage-treatment plants (STP's) in the basin to include nutrient removal was facilitated by the Montana Water Quality Bureau and the US Environmental Protection Agency.

Today we have reduced the point-source problem by about 15 percent. Prior to this action, the phosphorus load from the plants was about 20 percent of the annual load coming into the lake. Algal productivity declined dramatically in apparent relation to these management actions (Stanford et al. 1994b). However, concern exists about these improvements being offset by non-point or diffuse sources of nutrients related to forest harvest, agriculture, and air pollution. We are in the process of allocating loads to those activities, so that alternative management practices can be implemented to reduce non-point sources.

EFFECTS OF DAMS

I want to shift now to the second water-quality threat. The natural flow and temperature dynamics were vastly changed by construction and operation of the big hydropower dam on the South Fork of the Flathead River upstream from Flathead Lake. In the summer, cold water from the bottom of the reservoir caused a 17 degree celsius temperature change almost instantaneously in the tailwaters as the generators turned on. Our studies showed that this was harmful to fish and invertebrates in the river (Stanford 1990) and even may have changed the heat budget of Flathead Lake downstream. These studies lead to recent retrofit of the dam for temperature management. Temperatures now are close to natural in the dam tailwaters and downstream. So again, management action has been taken as a consequence of the scientific information about the ecosystem-level ramifications of the problem.

Another problem related to dam operations concerns shoreline erosion. The flux of water through Flathead Lake was changed in 1938 by construction of a hydropower dam (Kerr) at the outlet. Spring floodwaters are held in the lake during the summer and fall to facilitate power production. Prior to the dam, the lake shoreline flooded briefly and then declined to minimum pool elevation. Since 1938, owing to storage for hydropower operations, the lake has been held at full pool allowing wave action to erode the top of the shoreline (backshore). The Flathead River delta has changed from a depositional to erosional zone and extensive shoreline reconfiguration has occurred (Lorang et al. 1993a). Moreover, suspension of eroded sediments in the lake reduces water clarity and is a nutrient source for algal growth. Through studying how these waves impact the shoreline and how sediment is moved around (Lorang and Stanford 1993), we've determined that by simply lowering the elevation of the lake one foot we could reduce the power of the waves striking the shoreline at full pull by about 60 percent (Lorang et al. 1993b). Fisheries and riparian problems caused by many years of extreme flow fluctuations in the river downstream from the dam also were documented (Stanford and Hauer 1992).

In relicensing proceedings for Kerr Dam, the Federal Energy Regulatory Commission (FERC) used our studies as rationale for changing dam operations to ameliorate erosion on the Flathead Lake shoreline as well as reduce the impacts of hydropower fluctuations in the river downstream from the dam. Again, a reregulation plan would not have eventuated without public interactions, because early on the dam operators, State, and Tribal authorities, had privately agreed to a mitigation package that largely ignored the science. Citizens objected and FERC produced an alternative plan that included detailed consideration of the management implications of the many years of research, including lowering the full-pool elevation of the lake to ameliorate shoreline erosion. The FERC plan also was subject to extensive public debate and many shoreline residents objected to the lowering of the full-pool elevation for fear of dewatering docks. Final decisions have not been made, but I can say at this time that the science and public concerns were thoroughly aired and appear to be decisively influencing the process.

FLOODPLAIN ECOLOGY AND INSTREAM FLOWS

Now I want to briefly show you how rivers are ecologically connected to flood plains, creating mosaics of riparian habitats, which influence water quality. A lot has been said in the preceding talks at this conference about ecosystem approaches to protection of small-stream riparian zones. These zones are substantially larger and more important in large gravel-bed rivers like the Flathead.

In the unregulated tributaries of the Flathead River, we recently demonstrated the importance of interstitial flow of river water through the gravel and cobble substratum of the expansive flood plains. Water penetrates the porous substratum at the upstream ends of the flood plains and flows through the lattice-like structure of the substrata. Interstitial flow of river water creates an underground aquatic environment that contains a complex food web, including many species of insects and crustaceans that are new to science (Stanford and Ward 1988). Microbial metabolism in these underground food webs elevates nitrogen and phosphorus concentrations as river-water fluxes through the groundwater flow pathways (Stanford et al. 1994b). At the downstream end of the flood plain, nutrient-rich ground water is forced back to the surface by natural bedrock constrictions of the underground flow pathways creating complex mosaics of riparian wetlands. Hence, the flood plains of gravel-bed rivers often are hydrologically and ecologically interconnected with the river channel by hypogean flow pathways. In the Flathead River and other gravel-bed rivers, these flood plains often exist from valley wall to valley wall and are arrayed like beads on a string from headwaters to piedmont and coastal valley bottoms (Stanford and Ward 1993).

We used this interstitial-flow concept with the Department of Justice and National Park Service to help resolve Federal reserve water rights for Glacier National Park, which is bounded by the North and Middle Forks of the Flathead River. In contrast to the usual instream flow argument to protect Park resources, we showed that river water and river food webs extend laterally far beyond what would normally be considered a 100-year flood plain and that protection of Park resources was dependent on reservation of the virgin flow of the river as the Federal reserve water right. Based on our studies the National Park Service argued that future developments of surface or interstitial waters of the river would be harmful to Park resources, such as bull trout that spawn and rear in the riparian wetlands. A spin-off is the protection of clean-water flows into Flathead Lake. The Montana legislature agreed with the rationale, and the Governor and the Secretary of Interior recently signed an unprecedented Federal water-rights compact that reserves the virgin flow of the rivers for posterity.

CHANGES IN THE FOOD WEB OF FLATHEAD LAKE

Clearly the lake is connected to its upstream catchment. During spring runoff, sediments naturally eroded from floodplain terraces in the unregulated portions of the basin are carried into the lake and provide a natural nutrient pulse. The lake is so big that the Coreolis effect of the earth's rotation circulates the spring sediment plume down the west shore and drives it back well up along the east shore. The ecosystem is "open," continually subject to natural and human-mediated external influences.

I now want to present a quick tour of the food web of Flathead Lake and show you a legacy of management failure resulting from ignorance of ecosystem function. The tour starts at less than ten microns in size with bacteria that interact with a photosynthetic alga in upper layers of the lake water. This is what scientists call a microbial loop because the bacteria are using exudates from the algae as nutrients, and cycling them very rapidly. The algae-bacteria complexes are food for a cladoceran zooplankton. The cladocera (water fleas) are fed on by all sorts of fishes, one of which is the westslope cutthroat trout (*Onchorynchus clarkii clarkii*). Historically, this fish was the preferred food of the top carnivore in the lake, the bull trout.

The cutthroat trout were largely replaced many years ago by introduction of Kokanee salmon, which were more efficient foragers for water fleas. Kokanee salmon became very abundant and a very popular fishery. In the fall, adult salmon migrated in large numbers to various places in the basin to spawn. The spawning salmon attracted large numbers of bald eagles which fed on them (Spencer et al. 1991). The eagles attracted large numbers of tourists and a micro-economy developed around this ecological phenomenon.

However, the eagle attraction did not last long because *Mysis relicta*, a large crustacean zooplankter, was introduced into Flathead Lake by fisheries managers in an attempt to enhance the Kokanee so that people could catch even more and bigger salmon. This was a big mistake because the end result was opposite to what was hoped for. *Mysis* feed at night on the small water fleas (cladocera) that were the food source for the Kokanee. Unfortunately for.the Kokanee, *Mysis* live on the bottom of the lake in the daytime. They are nighttime ramblers. Kokanee feed only in the daytime when they can see the water fleas. Well, to make a long, sad story short, the *Mysis* ate all of the water fleas and didn't provide expected food for the Kokanee. In Flathead Lake there are now very few cladocera zooplankton and in 1988 the salmon fishery collapsed and has not recovered in spite of extensive restocking efforts. The eagles and tourists have gone elsewhere (Spencer et al. 1991).

Mysis also have now declined because other fish in the lake have increased population size by feeding on the abundant shrimp. The one that is the most successful is the one that evolved with the shrimp in the big lakes of the Canadian Shield area, namely the lake trout (*Salvelinus namycusch*), a non-native species that was introduced many years ago along with the Kokanee. We now have wall-to-wall lake trout in Flathead Lake. Probably in direct relation to the increase in highly predatory lake trout, the bull trout population appears to be declining rapidly. Lake trout are in-lake spawners whereas bull trout spawn in the tributaries. The new *Mysis* food source has allowed small lake trout to explode in numbers. As the fish have increased, they have depleted their food supply, forcing them to out-migrate. They are going everywhere. They're going downstream. They're going upstream. They're invading lakes in Glacier National Park and the consequence is they're probably preying heavily on the young bull trout in the tributary brood areas as well as in the Flathead Lake.

In this case too little information was available to justify introduction of *Mysis* and the consequences were too severe to allow an adaptive change in course when new information was available. Water quality in Flathead Lake, at least in terms of the native food web, was changed forever. It is important to note that this change was already well underway as a consequence of fish introductions early in the century.

CONCLUSIONS

Now to sum up. I've shown you the major ecological processes and responses in this regional ecosystem. The river and lake clearly are functionally interconnected in ecosystem terms. We have identified both natural and human-caused sources of environmental variation and the ecosystem is constantly changing.

I argue that we have been practicing ecosystem management from the very beginning in the Flathead. At the outset in the early 1970's, we defined our ecosystem as the entire catchment and we determined very early on the strong interactors that were most important to ecosystem structure and function. We made attributes of water quality that were important to people the primary indicator of ecosystem change. We defined ecosystem goods and services that were at risk and in several clear cases ameliorated the effects of human-mediated environmental change by adaptive implementation of management actions. And, we continually focused on them in terms of what was important for law, theory, and a public-management hierarchy. We monitored the system response and documented successes and, in the case of *Mysis* introductions, also demonstrated management failure. We continually attempted to reduce scientific uncertainty through basic research and recognized that new information allows re-evaluation of the ecosystem processes and responses. When science and management actions are placed in proper human context through public education and debate, adaptive changes in management actions can effectively occur.

I recommend this experience as a potential model for ecosystem management elsewhere. The model is more formally presented in (Stanford and Ward 1992). Good luck.

LITERATURE CITED

Angermeier, P. L., and J. R. Karr. 1994. Biological integrity versus biological diversity as policy directives. BioScience 44(10):690-697.

International Joint Commission. 1988. Impacts of a proposed coal mine in the Flathead River Basin. International Joint Commission, 26 pp.

Lorang, M. S., P. D. Komar, and J. A. Stanford. 1993b. Lake level regulation and shoreline erosion in Flathead Lake, Montana: A response to the redistribution of annual wave energy. Journal of Coastal Research 9(2):494-508.

Lorang, M. S., and J. A. Stanford. 1993. Variability of shoreline erosion and accretion within a beach compartment of Flathead Lake, Montana. Limnology and Oceanography 38(8):1783-1795.

Lorang, M. S., J. A. Stanford, F. R. Hauer, and J. H. Jourdonnais. 1993a. Dissipative and reflective beaches in a large lake and the physical effects of lake level regulation. Ocean and Coastal Management 19:263-287.

Naiman, R. J., J. J. Magnuson, D. M. McKnight, and J. A. Stanford, eds. 1995. Freshwater imperative: A research agenda. (1st ed.). Island Press, Washington, D.C. 165 pp.

Spencer, C. N., B. R. McClelland, and J. A. Stanford. 1991. Shrimp stocking, salmon collapse, and eagle displacement: Cascading interactions in the food web of a large aquatic ecosystem. BioScience 41(1):14-21.

Stanford, J. A. 1990. Mitigating the impacts of stream and lake regulation in the Flathead River Basin, Montana: an ecosystem perspective. Open File Report 113-90. Flathead Lake Biological Station, The University of Montana, Polson, MT. 71 pp.

Stanford, J. A., B. K. Ellis, D. G. Carr, G. C. Poole, J. A. Craft, and D. W. Chess. 1994a. Diagnostic analysis of annual phosphorus loading and pelagic primary production in Flathead Lake, Montana. Flathead Lake Clean Lakes Project, Phase One. FLBS Open File Report 132-94. The University of Montana, Polson, MT. 54 pp. + appendices.

Stanford, J. A., and F. R. Hauer. 1992. Mitigating the impacts of stream and lake regulation in the Flathead River Catchment, Montana, USA: an ecosystem perspective. Aquatic Conservation 2:35-63.

Stanford, J. A., and J. V. Ward. 1988. The hyporheic habitat of river ecosystems. Nature 335(6185):64-66.

Stanford, J. A., and J. V. Ward. 1992. Management of aquatic resources in large catchments: recognizing interactions between ecosystem connectivity and environmental disturbance. Pages 91-124 in Naiman, R. J., ed., Watershed management. Springer-Verlag, New York, NY. 542 pp.

Stanford, J. A., and J. V. Ward. 1993. An ecosystem perspective of alluvial rivers: connectivity and the hyporheic corridor. Journal of the North American Benthological Society 12(1):48-60.

Stanford, J. A., J. V. Ward, and B. K. Ellis. 1994b. Ecology of the alluvial aquifers of the Flathead River, Montana. Pages 367-390 in Gibert, J., D. L. Danielopol, J. A. Stanford, eds., Groundwater ecology. Academic Press, Inc., San Diego, CA. 571 pp.

Water Quality Bureau. 1984. Strategy for limiting phosphorus in Flathead Lake. Department of Health and Environmental Sciences, Mt. 20 pp.