FOSSIL CREEK: RESTORING A UNIQUE ECOSYSTEM

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Relicensing of the Childs/Irving Hydroelectric Project (Childs/Irving) provided an opportunity for restoration of a unique travertine ecosystem in central Arizona. Childs/Irving, located on Fossil Creek in Gila and Yavapai counties, has generated electricity since the early part of this century. The original hydropower license for Childs/Irving was issued on January 1, 1945 by the Federal Power Commission for a 50-year period. In 1994, Arizona Public Service Company (APS) applied to the Federal Energy Regulatory Commission (FERC) to relicense the project. The relicensing and associated environmental assessment process provided a rare opportunity to restore a unique, but degraded travertine ecosystem by restoring streamflow to a mostly dewatered creek. This paper describes many of the unique features of the ecosystem and some of the issues that surfaced during the environmental assessment process.

The Project

From its origin in the incised canyons of the Mogollon Rim country just north of Strawberry, Arizona, Fossil Creek flows in a southwesterly direction for 17 miles before entering the Verde River below Childs. It flows on lands entirely under the jurisdiction of the National Forest Service, and forms the boundary between the Coconino and Tonto national forests for much of its length. Fossil Creek is an intermittent stream from its headwaters until it reaches Fossil Springs, which are located approximately one third of the way down the mainstream of the creek. The springs emerge over a 1,000 foot reach of the creek, at a constant discharge of 43 cubic feet per second (cfs) and a constant temperature of 72°F.

In the early 1900s the flow from these springs was diverted from the creek and used to generate hydroelectric power for the mines near Prescott, Jerome, and Crown King. Water is diverted at Irving Dam, 0.2 miles downstream from the springs, and is transported 10.4 miles by a series of open flumes, syphons and penstocks to power plants at Irving and Childs. The diverted water is eventually discharged to the Verde River at Childs, 4 miles above its confluence with Fossil Creek. A small reservoir (Stehr Lake) located between the power plants at Irving and Childs provides a 3-day supply of water to Childs when the diversion system in the upper watershed is shut down.

The power plants at Irving and Childs have a combined generating capacity of 4.2 megawatts and produce 37,000 mwhrs per year, enough power to sustain about 4,000 homes. The Irving plant, constructed in 1915, is located next to Fossil Creek and 4 miles downstream of the diversion dam. It produces one third of the power generated by the two plants. The Childs plant, constructed in 1908–1909, was one of the first hydroelectric power plants built in the West. It is located on the banks of the Verde River and generates the remaining two thirds of the power. Total generating capacity of these plants is less than 0.1 percent of the total power production capacity of APS. The Childs/Irving project was designated as a National Historic Mechanical Engineering Landmark in 1976 and was entered into the National Register of Historic Places in 1991.

Generation of the power produced by the Childs/Irving plants requires diversion of all of the natural discharge of Fossil Springs. Save for leakage of 0.2 cfs at the diversion dam and discharge of an additional 2 cfs at the Irving plant, the entire baseflow of the creek is contained within the water delivery system of the power project. Only flood flows and runoff in excess of the capacity of the diversion system (48 cfs) are allowed to flow down the natural channel.

Childs/Irving was issued a license for a period of 50 years on January 1, 1945 by the Federal Power Commission. In 1994, APS applied to the Federal Energy Regulatory Commission (FERC)

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for a new permit. Since 1990, the Forest Service, Arizona Game and Fish Department, and U.S. Fish and Wildlife Service have worked closely as an interagency team with APS to prepare the relicensing application. The team's sole function was to advise the applicant on affected resources. The application developed by APS does not consider alternatives for operation of the power plants and diversion works or for maintaining various flow scenarios in the creek. The Coconino and Tonto national forests are now conducting a joint environmental analysis with FERC that does consider alternative streamflow scenarios.

The entire relicensing process takes about 5 years and is triggered by the Federal Power Act that requires water power operators to be periodically reevaluated so that, if warranted, the operation may be either discontinued or modified, to reflect changing societal values, operational advancements, or other factors.

The Ecosystem

Vegetation on the upland watershed consists of ponderosa pine forest in the headwaters, followed by several plant communities including chaparral brushlands, pinyon–juniper woodlands and semi-desert grasslands as the creek descends. Elevations range from 7260 feet near the headwaters to 2550 feet at the Verde River confluence. Average annual precipitation is 18.1 inches at Childs and 19.9 inches at Irving.

The constant discharge of 43 cfs from Fossil Springs represents slightly more than 70 percent of the average annual water yield of the basin above the springs. A diverse aquatic and riparian community has developed downstream of the springs as a result of this reliable and sustained flow. The riparian community is diverse in both species composition and age structure. Woody riparian species include Arizona walnut, Arizona sycamore, velvet ash, Arizona alder, Fremont cottonwood, and willow species. The riparian community most closely resembles that of the Arizona sycamore–velvet ash type and appears to be typical of flood-dominated riparian systems in the southwestern United States. Seedlings are by far the most common age class and are concentrated in a narrow band along the fringe of the streams' free water surface. Older age classes are more prevalent on terraces further removed from the active channel of the stream. The proximity of seedlings to the stream results in high seedling mortality due to scouring from flood flows. Reduction in baseflow to 0.2 cfs below the diversion dam and to 2 cfs below the Irving plant restricts seedlings to a narrower band within the active channel than probably occurred historically when baseflow was 43 cfs.

The aquatic community consists of populations of predominantly native fish species. Above Irving Dam, roundtail chub, desert and Sonora suckers, and speckled dace are naturally present, and razorback suckers were stocked in 1988. Below Irving Dam, the first three species are still present, but in greatly reduced numbers due to reduction in flow. Longfin dace are also found in isolated reaches. Non-native species found below the diversion include green sunfish; smallmouth bass and yellow bullhead occur only in the lower 3 to 4 miles of the creek and probably originate from the Verde River. The razorback sucker is an endangered species, and the remaining native fish species have category 2 status (listing as threatened or endangered may be appropriate, but data substantiating the listing are not available). Razorback suckers are not native to Fossil Creek although they are native to Arizona. It is not known whether this population will become self-sustaining. The roundtail chub is the species of greatest concern in Fossil Creek because of its status under the Endangered Species Act and with both the Forest Service and Arizona Game and Fish Department. The Sonoran and desert suckers are also of concern because of declining populations throughout their range.

The large and sustained baseflow, the presence of a nearly intact native fish community, and a diverse riparian community all contribute to the remarkable resource values of Fossil Creek. But the factor that makes Fossil Creek unique is that the water discharged from the springs is laden with calcium carbonate that precipitates to form travertine deposits when exposed to atmospheric conditions. Travertine deposits are rare in Arizona and are considered to be outstanding natural resources where they occur (e.g. Havasu Creek, Tonto Natural Bridge, and the Little Colorado River).

The waters of Fossil Springs emerge from limestone, which provides a geologic environment conducive to the formation of travertine. Travertine is calcium carbonate deposited from solution in ground and surface waters. Chemically, travertine is identical to the mineral calcite. Water discharged from the springs has high concentrations of calcium carbonate and dissolved carbon dioxide. As this water travels downstream and is exposed to the atmosphere, carbon dioxide gas is released. Release of carbon dioxide raises the pH of the water, causing the water to become supersaturated with calcium carbonate. When a critical level of supersaturation is reached, travertine precipitates from solution and deposits on the bed and banks of the channel. When the concentration of calcium carbonate falls below the critical level of supersaturation, formation of new travertine ceases.

Travertine deposition is influenced by external environmental factors as well as the chemical composition of the water. Most travertine deposition occurs at and below areas of turbulence, where the greatest amount of carbon dioxide is released. Algae also plays a major role in travertine deposition. Although not fully understood, two mechanisms are thought to be responsible. First, algae consumes carbon dioxide through photosynthesis, thereby acting as a type of outgassing mechanism. Secondly, algae filters suspended particles of calcite and provides a matrix for calcite nucleation and precipitation. Whatever the mechanism, the contribution of algae to travertine formation is significant.

In free-flowing streams, travertine precipitates on rocks, leaves, and other objects in the channel. Encrustation of these features by travertine, forming "fossils," accounts for the origin of the creek's name. Typically, dams are formed that can build up to several feet in height and create deep pools. A sequence of several pools often form in a stairstep pattern down the stream channel. It is not uncommon for travertine formations to accrete several inches per year in areas of stream turbulence.

Historic accounts predating the construction of Childs/Irving report large travertine structures in Fossil Creek. In 1891, Charles F. Lummis described waters "so impregnated with mineral that they are constantly building great round basins for themselves, and for a long distance flow down bowl after bowl." In 1904, F.W. Chamberlain, naturalist aboard the U.S.S. Albatross, reported dams "from several inches to a few feet in height, the highest is said to be 10 feet." He went on to describe the pools: "The largest pools seen were 50 to 60 yards long, 20 to 30 feet wide, and approximately 20 feet or more deep." According to Chamberlain's account, travertine formations were present along a 2-mile reach of the creek, beginning about a half mile below Fossil Springs. Today, relic travertine structures can be found at least 1 mile below Irving. Near Fossil Springs, massive travertine deposits 100 to 200 feet above the current stream channel are evidence that travertine must have formed in Fossil Creek for many thousands of years prior to construction of the power plants.

Management Issues

Both Forests view the relicensing and environmental analysis process as an opportunity to restore a unique ecosystem to Fossil Creek. From the Forest Service perspective, travertine and its importance to the ecosystem, particularly in terms of fish habitat and riparian resources, is the main issue driving the environmental analysis and derivation of alternatives.

Operation of the power plants reduces baseflow from 43 cfs to 0.2 cfs in the reach from the diversion dam to the Irving plant and from 43 to 2 cfs in the reach below Irving. Over the 85-year diversion period, travertine deposits that historically existed in the channel above the Irving plant have been eroded, primarily from flood flows. Formation of new travertine structures and growth of existing structures has ceased due to diversion of spring flows.

In the existing Fossil Creek system, travertine precipitates on the flume and tailraces of the hydroelectric facilities. However, even under the current operating system some formation of shallow travertine dams and structures is occurring below Irving where a minimum flow of about 2 cfs is maintained.

Construction and operation of the power plants changed the travertine balance of the system. Prior to construction of the power plant facilities, water flowed in the natural channel, and for about the first half mile downstream of the springs it had the appearance of a typical southwestern mountain stream with a moderate to steep gradient, confined channel and flood plain, and a gravel, cobble, boulder and bedrock streambed that generated significant turbulence and release of carbon dioxide. Beyond the first half mile below the springs, calcium carbonate reached supersaturation and travertine deposition occurred. Based on historic accounts, most if not all of the travertine was deposited in about a 2-mile reach below the diversion and above Irving. In the current system, water is diverted by the diversion dam just downstream of the springs into a relatively smooth-surfaced flume that generates little turbulence and provides little opportunity for outgassing of carbon dioxide. Release of carbon dioxide does not begin in earnest under the current system until water is forcefully discharged from the tailrace at the Irving plant. As a result, most travertine deposition in the channel occurs below Irving and at rates much reduced from natural conditions. Significant deposition also occurs below the tailrace of the Childs power plant.

During the relicensing process the resource agencies and APS have been discussing the streamflow quantities necessary to maintain and enhance the natural resources associated with Fossil Creek. APS agreed that diversion of all flows from the creek to the power plants was not in the best interests of downstream resources. As a result, APS's application proposed to leave 10 cfs in the natural channel between the Irving Dam and Irving, and 5 cfs below Irving. Although this would be an improvement over existing conditions, Forest Service personnel did not believe that this flow regime would meet the objective of restoring this unique ecosystem. Accordingly, the Forest Service recommended to FERC that a range of alternative flow regimes, including full retirement of the project, be developed. Consequently Forest Service personnel are working with FERC to evaluate alternative flow regimes in the environmental analysis process. One flow regime being considered calls for restoring the entire natural flow of the creek between Irving Dam and Irving, the reach of Fossil Creek that historically had the greatest travertine deposition. This alternative would allow the travertine system to restore itself in the quickest manner possible, although it is not known how long this would take. Flows downstream of Irving would be increased to 5 cfs, an amount believed sufficient to allow the natural ecosystem to function, while still allowing power production to continue at Childs.

One of the major issues that developed during the environmental analysis process is whether travertine would reform in the stream channel under the reduced diversion alternatives. Discussions centered around the effects of watershed conditions on peak flows and the scouring effect of peak flows on travertine formations. One line of thought was that widespread overgrazing around the turn of the century so degraded watershed conditions that peak flows from storm events are much greater today than prior to the introduction of livestock. The increase in peak flows is thought capable of producing scouring floods that would destroy any potential new travertine formations.

It is well documented that large herds of cattle moved into southern and central Arizona in the late 1800s. These herds together with periods of drought resulted in the loss of much of the herbaceous and shrubby vegetation that for centuries provided protection for the soil. The net result was increased runoff and accelerated erosion. Eyewitness accounts of accelerated erosion during this period are well documented. One such account of Fossil Creek in 1904 (Chamberlain) states that "close pasturing" of ranges in the watershed probably resulted in the "unusual wash of mud that has made it more or less unfit for fish life." Since establishment of the Forests at the turn of the century, livestock numbers have been substantially reduced, and management practices improved. Soil conditions within the watershed have been mapped as a component of the Terrestrial Ecosystem Survey (TES) (Coconino National Forest 1994). The survey indicates that soil conditions are generally satisfactory, with current soil loss rates mostly within tolerable levels. Productivity of these soils is being maintained or improved due to acceptable vegetative ground cover that minimizes on-site soil loss.

Due to improvements in watershed conditions, the severity of runoff events is probably less today than at the turn of the century. Modeling of the Fossil Creek watershed, to evaluate peak flows under alternative ground cover conditions, suggests that peak flows under the most degraded watershed conditions were from 10 to 20 percent greater than under pre-livestock grazing conditions (Loomis 1994).

Even under natural conditions travertine systems are subject to regular cycles of deposition and erosion. During periods of heavy runoff, travertine formations can be destroyed by mechanical erosion due to abrasion by bedload materials and debris transported by flood flows. However, there is also evidence that travertine formations rebuild rapidly after such events. Havasu Creek below the rim of the Grand Canyon, approximately 150 miles north-northeast of Fossil Creek, is an example. It contains several miles of travertine-dominated dams and pools that are subject to periodic flooding. Recent severe flooding has impacted and removed sections of the travertine dams and deposits. However, the travertine quickly rebuilt and reestablished a system of dams and pools.

Historic observations of Fossil Creek also support the concept that travertine formations can withstand the increased severity of flood events attributable to degraded watershed conditions or will rebuild rapidly following such events. The presence of large travertine formations was reported by Lummis in 1891, and again by F.W. Chamberlain in 1904, long after heavy grazing had impacted the watershed but prior to diversions for Childs/Irving.

If we accept the idea that travertine formations will rebuild with maintenance of greater baseflows despite somewhat greater magnitude flood events, then based on the historical accounts of Lummis and Chamberlain, it is likely that with restoration of increased baseflows there would be a major change in the channel morphology of Fossil Creek above the Irving Plant. First, travertine appears to fill the interstitial spaces of the gravel and cobble deposits and acts as an adhesive to hold these deposits together. These "conglomerates" would have greater ballast than the individual particles and would be more resistant to movement during high flows. This stability is important for providing protection to looser deposits and rooting substrates. Secondly, travertine influences channel morphology through formation of the dams or bowls described in the Lummis and Chamberlain accounts. The presence of these dams results in a channel with a stepped profile, or as Lummis described it, "constantly building great round basins for themselves, and for a long distance flow down bowl after bowl." Formation of these structures would probably increase the stream's width and raise the water surface above the scoured bedrock channel that exists today. This in turn could increase bank moisture and possibly create a more lush riparian community than we see today. The steep sideslopes adjacent to the channel would probably prevent much increase in width of the riparian zone.

Travertine basins would also probably act as areas of deposition that would retain organic and inorganic materials in the system for a greater length of time for the biological community to utilize. Depositional sites are typically more productive than areas scoured to bedrock. In terms of fish habitat, formation of travertine dams in the low-flow channel would probably result in more habitat complexity than we see today. It is likely that a number of microhabitats would form in and around the dams, resulting in a range of water depths, velocities, and hiding cover. Today the habitat is in fairly large units of long boulder riffles and long bedrock-controlled pools with limited hiding cover and complexity. The complexity provided by travertine may also be important for providing areas of refuge during high flow events. Increased streamflow in other reaches of the creek would also benefit the predominantly native fishery simply by increasing the available habitat.

Travertine dams may also play an important role in flood plain function. By widening the channel and creating areas of flatter slope they help to dissipate flood flow energies. By creating depositional sites for riparian plants they create additional roughness elements that can also aid dissipation of flood energy. In today's system, many of the roughness elements resisting flood flows and holding the flood plain together are remnant travertine structures. Removal of the travertine formation process means that these remnant structures will slowly degrade over time through weathering and erosion. It is likely that the riparian community that has developed on flood plains supported by travertine structures will also degrade over time.

Riparian vegetation in stream reaches not affected by travertine deposition would also benefit from an increase in streamflows. Increased baseflow would move the area of seedling germination and growth farther from the low-flow channel than occurs under existing conditions. Exposure to scouring flood flows should be reduced and the rate of survival increased.

Ecosystem Management Considerations

The Forest Service mission is evolving under Chief Jack Ward Thomas to place greater emphasis on ecosystem management than has traditionally occurred within the agency. He believes the National Forest's traditional focus on commodity outputs should change "from sustained yields of products from ecosystems to the sustenance of ecosystems themselves" (Thomas 1994). He continues to support "the active use of ecosystems for the benefits they provide so long as that use does not unduly risk sustainability of those ecosystems." Application of the increased emphasis on ecosystem management to the Fossil Creek system would require restoration of increased baseflows to the natural channel. Restoration of this unique ecosystem would meet the intent of at least three of the criteria listed in the Strategic Agenda in the Chief's Forest Service Agenda for the Future (Thomas 1994). These include:

1. Enhanced protection of ecosystems. This criterion emphasizes special care for ecosystems that are fragile or rare.
2. Restoration of deteriorated ecosystems. This criterion emphasizes repair or improvement of damaged ecosystems and management to improve the likelihood that diversity, long-term sustainability and future options are maintained.
3. Implementation of ecosystem management. This criterion emphasizes research and monitoring to help maintain the long-term health and productivity of ecosystems.

Throughout the relicensing and environmental assessment process (which is not yet complete), a major challenge has been working with other agencies and groups that have different missions, goals, and modes of operation. For example, the very rigid and strictly codified relicensing process of FERC limits adaptive management, and to a certain extent, interdisciplinary exchange. The process is focused on producing a license, and not necessarily a functioning ecosystem. On the other hand, the traditional multiple-use policy of the Forest Service encourages a "something for everyone" product, and again not necessarily a functioning ecosystem.

Agency cultures also played a large role in limiting discussions. For example the Forest Service has been primarily a rural-based, resource exploitation agency used to dealing with large-scale terrestrial resources in a pragmatic way, whereas FERC is primarily an urban-based, engineering-dominated agency used to processing (and approving) applications for hydropower development. APS clearly is in the business of producing and selling power, although their actions indicated a commitment to achieving a "greener" image. Other agencies, including the Arizona Game and Fish Department, U.S. Fish and Wildlife Service, Arizona Department of Environmental Quality, and APS's contractor also had different cultural and individual biases.

Dealing with these cultural biases and agency differences was always a challenge. Open recognition and discussion of differences was helpful, though not completely effective in breaking down barriers. Communicating a vision of a restored ecosystem was also a challenge. There was also substantial debate regarding the accuracy of technical information and the appropriateness of applying particular models to the ecosystems under study. Much of the modeling and analysis evaluated only the effects of changes in streamflow on the channel as it exists today and not as it could be in the future with the restoration of a travertine system.

Future analyses involving complex ecological relationships, interagency teams, or controversial issues could benefit from the experience gained during this process. To help visualize ecosystem potential, as opposed to current conditions, it is not only important to familiarize people with the area in question, but also with more pristine ecosystems having similar characteristics. Obtaining and communicating accurate technical information early in the process is critical. Once the initial information was gathered and analyses completed, these were accepted as "gospel" and were relied on throughout the assessment process despite criticism that revealed inadequacies and presentation of better information that became available later. It is also important to use models in the analysis that are appropriate for the area being studied, and to apply those models properly. Most importantly, it is vital to recognize that ecosystems and human societies are dynamic; a land use that was appropriate and needed at the turn of the century may be an anachronism in today's society.

Although the scientific and ecological relationships of the system are the focus of the current analysis, the final decision will be subjective and value based, with the human element playing a large role. The final outcome is still uncertain, but it is likely that base flows will be at least partially restored in Fossil Creek. Monitoring the changes in the ecosystem and the changes in human use of the watershed must be accomplished, and should be fascinating.

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