APPENDIX C

APPENDIX C-1

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Report

In re Aravaipa Canyon Wilderness Area (W1-11-3342), in the General Adjudication of All Rights to Use Water in the Gila River System and Source, Ariz. Sup. Ct., Case Nos. W1-W4

Aravaipa Canyon Wilderness Area FRWR CLAIMS: Protection of Fish Resources

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Prepared for

Environment and Natural Resources Division, U.S. Department of Justice

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Summary

On request by the Environment and Natural Resources Division of the Department of Justice, in the adjudication of water rights in the case of *In re Aravaipa Canyon Wilderness Area* (W1-11-3342), in the *General Adjudication of All Rights to Use Water in the Gila River System and Source*, Ariz. Sup. Ct., Case Nos. W1-W4, we report hydrological requirements for native fish in Aravaipa Canyon, Arizona. The fisheries requirements were derived from existing literature, aided by the authors' experience studying fish communities in Arizona, Nevada, California, Eastern Washington, and Mexican deserts. We compiled numerous studies from peer-reviewed and "grey" (e.g., agency reports) literature to help determine habitat requirements for each native fish species in Aravaipa Creek throughout their ontology. Further, we analyzed existing literature to document effects of altered hydrographs on long term viability of fish communities. This information shows that fishes of the Aravaipa fish community use a variety of habitats in the creek and all parts of the natural hydrograph are important to various species and life stages. Unaltered flow conditions are especially important for desert fishes that have evolved under the natural hydrographs of desert streams. All native species require habitats and stream conditions that result from floods in early spring. These floods are key trigger events that 1) signal native species the start of their growing and reproductive seasons, 2) create habitat heterogeneity that favors the appearance of food resources and nesting habitats for these species, and 3) aid in providing the main channel with nutrients derived from inundated areas, that will be used by all components of the in-stream foodwebs, including native fishes. Maintenance of low flows during the dry season are key to the reproductive success of numerous native species, as most larval fish require 1) areas with low water velocities and fine sediments, 2) areas with warm temperatures relative to the rest of the channel in which to grow, 3) areas where algal growth provides them with food resources and coverage, and 4) cover from terrestrial and aquatic predators. The periodic flooding typical of desert streams during early spring and the monsoon season is important for displacing non-native fish predators and competitors and depressing their populations. Native fishes are adapted to flash flooding characteristic of desert streams. Those nonnative fishes typically stocked into Southwestern streams have been introduced from habitats outside the desert (e.g. lakes and backwaters of large river systems) that are characteristically more stable and do not experience the degree of flash flooding present in desert systems. Modifying the natural hydrograph will result in the disappearance of the flow conditions required by native species to survive in the long term. We conclude that long term viability of valuable native Aravaipa Creek fishes requires that the natural hydrograph is maintained unaltered.

Intact Riparian Areas are Critically Important for Arizona's Fish and Wildlife Populations and Economy

Riparian areas are critical for fish and wildlife of the desert Southwest. Only 0.4% of Arizona's total area consists of riparian areas (Zaimes 2007). However, 80% of vertebrates in Arizona spend some portion of their life cycle in riparian areas (Hubbard 1977), signifying their great importance to the state's fish and wildlife. Arizona's fish and wildlife are an important heritage of the state, their well-being contributes to the quality of life for the people of Arizona, and they are of considerable economic importance to the state as well. Annual expenditure in 2006 on wildlife watching, fishing and hunting in Arizona was estimated at $1.96 billion dollars (USFWS 2008). For comparison, this figure is greater than the revenue generated by all the state's livestock production in 2006 ($1.32 billion, USDA 2006), all the state's crop production in 2006 ($1.5 billion, USDA 2006), and 2007 Arizona spring baseball training ($0.3 billion, The Cactus League 2007).

Native desert fishes in Arizona are unique, most found nowhere else on the planet. Yet most of these fishes are highly imperiled. Of the 150 full species included in the fish fauna of the West (Lee et al. 1980, Lee et al. 1983), as of 1990, 122 taxa west of Rocky Mountains have disappeared, or were listed as threatened or endangered (Minckley and Douglas 1991). Although some of these taxa represent subspecies, not full species, the reduction in their numbers remains considerable.

The Native Fish Community of Aravaipa Creek is Recognized as Exceptional

Of few remaining riparian areas of Arizona, Aravaipa Creek and its fish community stands out as exceptional. Aravaipa Creek is one of the last remaining streams in the upper Sonoran Desert to sustain an intact diverse assemblage of native fishes (Eby et al. 2003, Turner and List 2007). The stream is often considered the best native fish habitat in Arizona (Bureau of Land Management 2013), and is extraordinarily popular with the public due to its distinct nature as an intact, preserved stream system. Because of its popularity, the Bureau of Land Management manages visitor use of the creek through a permit system. Because of the unique nature of the intact native fish community, the U.S. Bureau of Reclamation invested almost 2.7 million dollars on a fish barrier at the downstream end of the canyon, to protect the native fish community from intrusion from nonnative fishes (USBR 2001).

Natural Hydrology is Important for the Evolution and Maintenance of Desert Fish Communities

To sustain a natural desert fish community, such as that exists in Aravaipa Creek, maintenance of the natural hydrograph, to the extent possible, is critical. Native fish communities have evolved to live in the natural conditions present at a site. Specific species of desert spring fishes, such as pupfishes, topminnow and pool fishes have evolved to high temperature, low dissolved oxygen and often highly saline conditions in individual desert pools. Desert stream fish communities have evolved to hydrographs that contain adequate water base flows punctuated by flash floods. Fishes that live in desert rivers have evolved to live in warm turbid waters with high volumes, low visibility and huge flash floods. Below we discuss numerous studies showing specifically how maintaining natural conditions is important for the desert fishes of Aravaipa Canyon, and altering these conditions has had negative consequences for desert fish communities.

Peak flow, mean volume of flow, variability of flow, morphology of canyon-bound and broad alluvial reaches, dams, and introduced fishes are all either directly or indirectly related to the wellbeing of native fish assemblages in Southwestern rivers and streams (Rinne and Miller 2006, Propst et al. 2008, Gido et al. 2013). Habitat modification is known as a major factor threatening the majority of native species that can be found in Aravaipa Creek (Propst and Bestgen 1991, Rees et al. 2005, Arizona Game and Fish Department 2006, Turner and List 2007, Propst et al. 2008, Arizona Game and Fish Department 2002c). Habitat modification in rivers and streams is caused by water diversion, channelization, and degradation of riparian areas, among other factors (Rees et al. 2005, Turner and List 2007). Natural stream habitats are the result of a long hydrologic and geologic history. Fish assemblages have adapted to these habitats via long-duration evolutionary processes (Lytle and Poff 2004, Gido et al. 2013). Thus, the native fauna of a stream is adapted to, *and in need of*, the natural processes that allow their persistence. Any anthropogenic modification to the geology or hydrology of a stream and its basin will result in modifications to its native fish assemblage. Alterations to the chemical, physical or biological attributes of a river lead to changes in the structure, composition and behavior of biotic communities. These changes are reflected in a loss of biotic integrity in the river (Karr and Dudley 1981), and a loss of the "naturalness" of an ecosystem.

A natural hydrograph is key in maintaining a natural, unaltered, fish assemblage (Lytle and Poff 2004, Gido et al. 2013). A significant volume of literature has documented that non-native fishes take advantage of altered stream flows, hydrology, and temperature gradients to invade novel environments (Rees et al. 2005, Propst et al. 2008, Gido et al. 2013). Native species are more likely to benefit from free-flowing conditions, whereas human modified flows likely favor nonnative species (e.g., Minckley and Meffe 1987, Bunn and Arthington 2002, Schultz et al. 2003, Olden et al. 2006). For example, small-bodied nonnative species with opportunistic life-history strategies can benefit from unnaturally stable low flows during summer in the San Juan River, New Mexico and Utah, presumably because low flows are associated with stable spawning substrates and increased water temperature (Gido and Propst 2012). Reductions in hydrological variability (i.e., more consistent flows) favor non-native species (Eby et al. 2003, Schultz et al. 2003, Gido et al. 2013). Drought and long-term reductions in stream flow variability likely play critical roles in the persistence of nonnative fishes in systems with naturally variable flow regimes (Gido et al. 2013).

Natural and human-induced changes to flow regimes are major factors influencing abundance and recruitment of lotic organisms because they alter spawning habitat availability and quality, modify food resources, and constrain dispersal (Poff et al. 1997, Bunn and Arthington 2002, Gido and Propst 2012). Functional composition of stream communities is often influenced by flow attributes such as magnitude, predictability, and intermittency (Poff and Allan 1995, Bunn and Arthington 2002, Tedesco et al. 2008, Craven et al. 2010).

Intact Base Flows and Peak Flows are Both Important.

Both base flow, contributed chiefly by groundwater, and surface runoff, contributed by storm events and other factors, contributes to natural fluctuations in water levels essential for maintaining native desert stream fish communities. Natural regimes that include high peak flows are beneficial to fishes because they provide connectivity to floodplain habitats, clean spawning habitats of fine sediments, and stimulate ecosystem productivity (Junk et al. 1989, Poff et al. 1997, King et al. 2009, Gido et al. 2013). Large magnitude and long duration spring flows benefit recruitment of some native species adapted to naturally high discharge during spring (Gido et al. 2013). Many fishes native to the Southwest spawn on the ascending limb of the hydrograph in spring, when water temperature is relatively cool (Gido and Propst 1999, Brouder 2001, Kiernan et al. 2012). This allows larvae and juveniles access to off channel habitats, increased abundance of clean spawning substrates and backwaters, or decreased risk of predation (Gido et al. 2013).

Natural hydrological regimes in Southwestern streams include periods of low flows that are also key for native species. After spawning in the ascending limb of the hydrograph, larval and juvenile fish require habitats where they can feed (usually on algal materials and macroinvertebrates) and grow. These habitats are usually found in relatively shallow, low velocity, warm water areas where algal mats and associated microfauna can develop. Once they have attained a certain body size, native fish can move to mid-channel habitats where they can find suitable cover and larger-sized food items. Furthermore, the base flow is fundamentally important for governing the amount of fish that can live in a stream. The base flow and available food determine the stream's carrying capacity, or weight of fish that the water body can support. Lowering the base flow of a stream lowers the number of fish that a stream can support. Because fish populations naturally fluctuate, low base flows in a year a fish population is in a downward trend can result in the extirpation of the fish due to high temperature effects, low food availability, interspecies competition or some other factor.

As mid-summer monsoonal rains arrive, spates occur in the hydrograph. These low duration high-flow conditions are beneficial to native fishes as they allow the appearance of new food resources in their habitats, and allow movement and dispersal to other areas of the creek.

Each flow condition is thus important for the completion of a fish species' life cycle. The long term viability of the population of a given species in desert streams depends on the existence of natural flow conditions throughout several generations.

Aravaipa Creek has maintained relatively intact and unique native fish assemblage thanks to its natural hydrological regime and, among other conservation efforts, to the installation in 2001 of a fish barrier that impedes non-native fish movement upstream into Aravaipa Creek (Bureau of Reclamation 1998; http://www.usbr.gov/lc/phoenix/biology/azfish/aravaipacreek.html). The existence of seasonal floods that are too intense for non-native species to withstand have also helped conserve a natural fish community (Eby et al. 2003, Turner and List 2007). A main reason that nonnative fishes have failed to dominate the creek is their apparent lack of resistance to high velocities, sediment loads, and other features of flooding in the canyon-bound system. Floods exceeding base flow by 10 or more times displace nonnative species, but have little apparent effect over natives (Meffe 1982, Meffe and Minckley 1987). Reduced flow stability and increased frequency of spates (e.g., a sudden increase in river flood) have negative effects on nonnative fishes (Gido et al. 2013). This can be explained because their spawning periods can be disrupted by flooding, and because their food sources can be diminished after such events (Bestgen et al. 2006). Nonetheless, periodic invasions have occurred in upper areas of Aravaipa (Minckley 1981, Stefferud and Reinthal 2005), but nonnative species disappear after a few seasons or years.

The Variety of Fishes in Aravaipa Creek Use Different Parts of the Natural Hydrograph Throughout Their Life History

The fish community in Aravaipa Creek has been studied since 1943 (Stefferud and Reinthal 2005) and there is a wealth of information about its composition, conservation and economic importance, and management (e.g., Eby et al. 2003, Weber and Berrens 2006, Turner and List 2007). The fish community of Aravaipa Creek includes 7 native species and at least 5 established nonnative species (Table 1) (Stefferud and Reinthal 2005). Aravaipa Creek has a perennial length of 36 km, 100% of which is occupied by the full complement of native species (Turner and List 2007). Up to nine nonnative species have been collected for Aravaipa Creek, but not all have established populations, and have only been collected sporadically since 1943 (the first recorded sampling effort in the mainstem Aravaipa Creek) (Table 1). Nonnative species are restricted to the lowermost sections of Aravaipa Creek, preventing native species from facing well-documented negative interactions with nonnative species (Eby et al. 2003, Unmack and Fagan 2004). Five native species have probably been extirpated from the creek: Colorado pikeminnow *Ptychocheilus lucius*, razorback sucker *Xyrauchen texanus*, flannelmouth sucker *Catostomus latipinnis*, Gila topminnow *Poeciliopsis occidentalis*, and desert pupfish *Cyprinodon macularis* (Stefferud and Reinthal 2005).

Native fish in Aravaipa Creek each have specific habitat requirements. Each species has evolved to utilize different habitats in the stream, and different habitats are used differentially throughout a species' life history. Habitat selectivity arises from a species need to 1) locate food items necessary for their development, 2) locate areas that have adequate reproductive conditions, 3) evade predators or competitors, and 4) locate areas where water temperature and velocity for example, minimize their use of energy resources, among others. These needs are not mutually exclusive and all determine an individuals' location within a creek.

In Aravaipa Creek, *Rhinichthys cobitis* typically inhabit the fastest sections of the creek within riffles. *Rhinichthys osculus* and *Catostomus clarkii* also tend to inhabit relative fast flowing water, with the latter preferring deeper fast sections. *Meda fulgida* and *Agosia chrysogaster* are generally found in the tails of riffles, or in runs. Both *Gila robusta* and *Catostomus insignis* tend to predominately inhabit pools (P.J. Unmack, at www.peter.unmack.net, Accessed on June 11, 2013; Velasco 1997, Stefferud and Reinthal 2005). This general description of habitat use by native fishes sheds light on the diversity of habitats that exists in Aravaipa Creek (See Appendix 1 for details on the habitat attributes required by native species in Aravaipa Creek). This habitat diversity is the product of a combination of natural geological, biological and hydrological processes that continue to occur in the Aravaipa Creek basin. Any departure from these natural conditions will impose changes to the biotic communities that exist in the ecosystem.

Habitat preferences for fishes in Aravaipa are not static and change seasonally and throughout their ontology. Fishes in Aravaipa Creek exhibit a distinct pattern of seasonal movement (Siebert 1980). In this process fishes move into a canyon from broad valley reaches above and below and then return to valley reaches in winter. This pattern is probably the result of fishes moving in summer to avoid high water temperatures and possibly injurious intense solar radiation in broad, shallow valley reaches, and moving in winter to avoid the colder canyon reaches (Siebert 1980).

We provide specific habitat requirements by life stage for the fishes found in Aravaipa Canyon to show the importance of various parts of the hydrograph for different life stages and species in Appendix 1. This data emphasizes the variability in requirements of different species of the Aravaipa fish community.

Table 1. Fishes species of Aravaipa Creek, their origin (native to the creek or nonnative to the creek) and native species' designation under the U.S. Endangered Species Act (ESA status). Under ESA, "na" = not applicable for this report. Annotations for superscripts: [e] = species is established in Aravaipa Creek, [n] = species is not established in Aravaipa Creek, [?] = it is unknown if the species is established in Aravaipa Creek.

Scientific name	**Common name**	**Origin**	**ESA**
Agosia chrysogaster	longfin dace	Native	--
Catostomus clarkii	desert sucker	Native	--
Catostomus insignis	Sonora sucker	Native	--
Gila robusta	roundtail chub	Native	--
Meda fulgida	spikedace	Native	Threatened
Rhinichthys (= *Tiaroga*) *cobitis*	loach minnow	Native	Threatened
Rhinichthys osculus	speckled dace	Native	--
Cyprinella lutrensis[e]	red shiner	Nonnative	na
Ameiurus natalis[e]	yellow bullhead	Nonnative	na
Lepomis cyanellus[e]	green sunfish	Nonnative	na
Pimephales promelas[e]	fathead minnow	Nonnative	na
Gambusia affinis[e]	central mosquitofish	Nonnative	na
Micropterus salmoides[?]	largemouth bass	Nonnative	na
Ameiurus melas[n]	black bullhead	Nonnative	na
Cyprinus carpio[?]	common carp	Nonnative	na
Ictalurus punctatus[n]	channel catfish	Nonnative	na

Altering Natural Hydrology has Resulted in Severe Consequences to Other Native Desert Fish Communities

Southwestern rivers have a long history of man-made modification. As a consequence of human modifications, ranges of almost all native desert fishes have diminished, and many species have been locally extirpated. We discuss examples below of how fish communities occurring in the major desert streams and rivers in Arizona have been affected when their hydrology has been altered from its natural state. In the concluding paragraph we cite several more studies of fish communities in other regions that have been negatively impacted when hydrographs have been altered. To date, the natural hydrograph of Aravaipa Creek has been affected considerably less than the streams and rivers we discuss below. However, negative effects or local extirpation of native fish communities, similar to those we discuss, is a likely outcome if the Aravaipa hydrograph is altered.

Gila River Fish Community

The Upper Gila River (a sub-basin of the Colorado River Basin) historically supported relatively few fish species, but many of these were endemics, occurring nowhere else on earth. The fish community in this river includes roundtail chub, Gila chub, headwater chub, spikedace and loach minnow, among others. Spikedace, as well as other endemics have seen their range reduced as a consequence of habitat changes and negative interactions with non-native species (Rinne 1991, Douglas et al. 1994, Paroz and Propst 2007). The reasons for the decline of the spikedace are in part intimately related to land and water use practices in the region (Propst et al. 1986). Diversion of water for irrigation caused the desiccation of some reaches and reduction of flows in others. Ground-water pumping lowered water tables, and caused the dewatering of many streams and reductions of flow in others (Hendrickson and Minckley 1984, Propst et al. 1986). Streams were channelized to accelerate water transport and, ostensibly, to reduce the effects of floods. Dams inundated many lotic habitats and altered the amplitude and periodicity of natural fluvial regimes (Propst et al. 1986). All these effects contributed to increased siltation in the habitats used by spikedace and other native fish, stream fragmentation that inhibited population contact, invasion by predatory nonnative fishes, and elimination of the hydrographic characteristics required for spikedace and other native fish reproduction. These conditions were especially severe in the lower Gila River, where the system is now ephemeral and flows only in response to precipitation events or water releases from upstream dams (AZDWR 2005).

Colorado River Fish Community

The Colorado River had one of the most unique fish communities in the world. Seventy-five percent of those species were found nowhere else on the planet. Settlement of the lower basin brought dramatic changes to both the river and its native fish. Those changes began more than 120 years ago as settlers began stocking nonnative fishes. By 1930, nonnative fish had spread throughout the lower basin and replaced native communities. However, the ability of native species to persist at any level was further impacted with the construction of Hoover Dam in 1935 and other large water development projects (Mueller and Marsh 2002) that diverted water from the river, and led to the loss of its natural hydrograph. The Colorado River, once a warm, turbid river subject to huge flash floods -conditions which favored native fishes – was altered into a river containing a series of reservoirs that regulated flow and water temperatures. Water all along the river was strictly allocated and diverted to supply human populations. The combination of nonnative fish introduction, hydrograph alterations and physical habitat modifications led to the decline of native fishes such as the razorback sucker, bonytail, humpback chub, and the Colorado pikeminnow (Mueller and Marsh 2002, Osmundson et al. 2002).

Santa Cruz River Fish Community

The fish communities in the Santa Cruz river in southern Arizona have been affected by increasing water demands, altered streamflow regimes and the introduction of non-native species (Jackson Meyers 2010). While the river contains several stretches of natural and treated-effluent-supported river flow, many areas are desiccated. The Santa Cruz supports the endangered Gila topminnow and Gila chub, and also longfin dace, and desert and Sonora suckers. River fragmentation (due to groundwater pumping), introduced non-native species, and degraded water quality have led to declines for all native species (The Sonoran Institute 2010). Nonnative fish now dominate several areas of the Santa Cruz.

San Pedro River

The San Pedro River once contained a diverse native fish assemblage. Dewatering and other habitat alterations resulted in the demise of the spikedace, loachminnow, and most other native fishes (USFWS 1990a; 1990b)

Conclusion

Alterations to native freshwater fish communities or species due to hydrologic regime alterations are not exclusive to the Southwest. Numerous cases exist throughout the U.S. where damming, water extractions and deviations have negatively affected native fish and many times favored nonnative species. For example, hydrograph and habitat alterations have led to the decline of salmon runs and salmon populations in numerous California, Oregon, and Washington rivers (Raymond 1979, Quinn and Adams 1996, Kareiva et al. 2000), and declines in sturgeon populations in the midwestern U.S (Duke et al. 1999, Jacobson and Galat 2008). Any human derived departure from natural physical, chemical, and biological conditions in an aquatic ecosystem will have short and long term consequences to its native biota.

In summary, Aravaipa Creek is recognized as containing perhaps the best intact native fish community in Arizona. Fishes of Aravaipa Creek use all parts of the hydrograph for their varied life histories, including high spring flows, low base flows, and monsoon storm events. Flooding events in this canyon bound system are thought to have prevented dominance of nonnative fishes. Human alterations to natural hydrology have had severe consequences to most other native fish communities of Arizona. Protecting the health of the native fish community in Aravaipa Creek depends on preserving the natural hydrology of the system.

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Appendix 1. Habitat Requirements for Native Fish Species in Aravaipa Creek, Arizona

This section presents a species-specific account of habitat needs for native fishes in Aravaipa Creek. In creating this appendix we bring together existing literature on species habitat selectivity and requirements (peer reviewed and non-peer reviewed documents), field data, and literature on species' biology. In summary, loach minnow *Rhinichthys cobitis* typically inhabit the fastest sections of Aravaipa Creek within riffles. Speckled dace *Rhinichthys osculus* and desert sucker *Catostomus clarkii* also tend to inhabit relatively fast flowing water, with the latter preferring deeper fast sections. Spikedace *Meda fulgida* and longfin dace *Agosia chrysogaster* are generally found in the tails of riffles, or in runs. Both roundtail chub *Gila robusta* and Sonora sucker *Catostomus insignis* tend to predominately inhabit pools.

Agosia chrysogaster (longfin dace)

Longfin dace are considered habitat generalists and can be found over multiple depths, water velocities, and substrates, and have a relatively wide range of temperature tolerance (Bonar et al. 2010). Although longfin dace are known to prefer water of 20.0 cm in depth when spawning (Minckley and Barber 1971, Sublette et al. 1990), they are often found in deeper or shallower waters (Lewis 1978, Arizona Game and Fish Department 2006). Like other fishes, longfin dace may avoid deeper water when predators are present (Power 1987, Gelwick et al. 1997). In Aravaipa Creek, Arizona, Rinne (1992) found longfin dace occupying relatively shallow (12.0 – 22.0 cm) waters with water velocities of up to 40 $cm \cdot s^{-1}$ over pebble substrate. Longfin dace can swim against water velocities of up to 73.5 $cm \cdot s^{-1}$ (Ward et al. 2003). Minckley (1973) referred to longfin dace as the 'most successful, highly adaptable, cyprinid fish native to the deserts of the American Southwest'. However, their adaptability has not prevented their populations from declining throughout Arizona (Arizona Game and Fish Department 2006). In response to the onset of a flooding event, longfin dace will move directly into the margins of the current and move back into the channel as discharge declines: they are rarely caught in flood pools or backwaters (Minckley and Barber 1971, Rinne 1975). During low flows, they sometimes take refuge in moist detritus and algal mats until flow increases (Sublette et al. 1990). Longfin dace prefer gravel, sand, and pebble substrate, but can also be found among boulders (especially if finer substrates are found in the interstices of boulders (Barber and Minckley 1966, Lewis 1978, Meffee and Minckley 1987, Grimm 1988). Thus, suitable habitat for longfin dace includes water velocities between 0.0 - 30 $cm \cdot s^{-1}$, depths between 8.0 – 55.0 cm, and substrates from silt to cobble (Bonar et al. 2010). Longfin dace are generally found in water less than 24° C, but are tolerant of high temperatures and low dissolved oxygen (Arizona Game and Fish Department 2006).

Longfin dace spawn throughout the year but primarily in winter and spring from December to July, and perhaps until September or November, in low-desert habitats (Minckley and Barber 1971, Lewis 1978, Arizona Game and Fish Department 2006). During spawning, they excavate nests in shallow water 2-4 inches (5-20 cm) deep with a slight current and over sandy bottoms; eggs are buried by the spawning act (Arizona Game and Fish Department 2006). Larval longfin dace have a preference for areas with no-to-very low water velocities. Areas with abundant longfin dace larvae are usually encountered along streambanks, in shallow backwaters where dominant substrate is sand. They are especially abundant in areas where filamentous algal mats accumulate in the spring (Mercado-Silva et al., in preparation).

Species: *Agosia chrysogaster* (longfin dace)				
Life Stage:	Spawning	Larvae	Juvenile	Adult
Preferred Habitat	Shallow (5 -20 cm) areas in stream margins over sandy substrates, and low water velocities.	Sandy shorelines of streams in areas with no flow, but connected to the main stream. Commonly at depths < 13.5	Stream margins, in areas with sandy substrates, usually in shorelines, with very slow (0.0 – 15 cm/s) flow.	Areas with depth 8 – 55 cm, with low (0.0 to 30 cm/s) water velocities. Substrates: sand to pebbles. Can be found among boulders when fine sediments are found in the interstices.
Time of Year	Year round – but most common in December – July.	Early spring and throughout the summer, depending on timing of spawning.	Throughout the spring and summer, depending on time of spawning.	Year round
Water Velocity	Spawning will occur in areas where water velocities are slow.	Habitat for larvae in areas with very low water velocities	Areas with very slow (0.0 – 15 cm/s) flow.	0.0 – 30 cm/s

Catostomus clarkii (desert sucker)

In general, catostomids are benthic organisms, found in pools, slow runs or deep riffles of desert streams over gravel to boulder-sized substrate (Barber and Minckley 1966, Griffith and Tiersch 1989, Bonar et al. 2004). Both species of suckers reported for Aravaipa have similar habitat requirements. Adults desert sucker live in pools, moving at night to swift riffles and runs to feed (Arizona Game and Fish Department 2002a). Desert suckers occur at depths of 30 cm in water with a velocity of up to 25 $cm{\cdot}s^{-1}$ (Rinne 1992), but have been found in deeper pools with depths up to 45 (Bonar et al. 2010) and 65 cm (Fisher et al. 1981). Desert suckers can swim against water with velocities of up to 93.1 cm/s (Ward et al. 2003). They have been collected in waters with velocities of up to 38 cm/s, but most often 22-30 cm/s. Bonar et al. (2010) suggested a maximum suitable water velocity between 0.0 to 15.6 cm/s for desert suckers. Desert suckers feed by scraping stones using their cartilage-sheathed jaws. Some studies have indicated that desert suckers exhibit little seasonal movement and are resistant to downstream displacement despite floods (Arizona Game and Fish Department 2002a).

Desert suckers generally spawn in late winter and early spring where adults congregate in large numbers on riffles. Spawning usually occurs between March and May (Snyder and Muth 2004). Adhesive eggs are deposited in a shallow depression made in the gravel. Eggs hatch in a few days. Young tend to congregate along the banks in quiet water in tremendous numbers, then progressively move into the mainstream as they increase in size. Larval (12.8 – 20.1 mm TL) desert suckers have been collected in habitats 6.25 to 40 cm deep, predominantly in areas with sand to gravel, and water velocities between 0.0 to 13 cm/s (Mercado-Silva, in preparation). Juveniles are mature by their second year of life at a length of about 10.2-12.7 cm (TL) (Arizona Game and Fish Department 2002a). Juveniles occupy substrates with gravel to cobble in riffles, feeding primarily on chironomid larvae; however, adults are primarily herbivorous, scraping aufwuchs (diatoms and algae) from stones as well as ingesting plant detritus.

Desert suckers are thermally labile, but will usually select for temperatures between 13 and 22° C depending on the time of acclimation (Deacon et al. 1987). Bonar et al. (2010) found suitable temperatures for desert suckers between 14 and 19° C in Cherry Creek, Arizona.

Species: *Catostomus clarkii* (desert sucker)				
Life Stage:	Spawning	Larvae	Juvenile	Adult
Preferred Habitat	Adults congregate in riffle areas for spawning.	Larvae are found predominantly in areas with sand, but also occur in areas with boulders, cobble and gravel. At depths of up to 40 cm deep, but generally shallower than 15 cm.	They occupy riffles with gravel to cobble substrates.	They occur at depths of up to 65 cm, and water velocities of up to 38 cm/s, in areas with gravel to boulders. Can be found in pools adjacent to riffle areas.
Time of Year	Late Winter and early spring (March – May).	Late Spring to early summer.	Early summer – late summer	Year round, but congregate in riffles when spawning.
Water Velocity	Water velocities 20 – 30 cm/s	Usually in flows of 0.0 cm/s up to 13 cm/s.	Water velocity of up to 38 cm/s.	In flows 0.0 – 38 cm/s, but can resist flows of up to 93.1 cm/s.

Catostomus insignis (Sonora sucker)

Like desert suckers, Sonora suckers are benthic organisms and are commonly found in pools, slow runs or deep riffles of desert streams over gravel to boulder-sized substrate (Barber and Minckley 1966, Griffith and Tiersch 1989, Bonar et al. 2004). They have habitat requirements similar to those of desert suckers. Sonora suckers occur at depths of 30 cm in water with a velocity of up to 25 $cm{\cdot}s^{-1}$ (Rinne 1992). The highest water velocity they can swim against is 55.9 $cm{\cdot}s^{-1}$ (Ward et al. 2003). For Cherry Creek, Arizona, Bonar et al. (2010) suggested a maximum suitable water velocity of 50 $cm{\cdot}s^{-1}$ for Sonora suckers. Sonora suckers have an affinity for gravelly or rocky pools, or at least for relatively deep, quiet waters" (Minckley 1973). Adults tend to remain near cover in daylight, but move to runs and deeper riffles at night. Young live and utilize runs and quiet eddies (Minckley 1973). They are considered intolerant of lake conditions, although a few specimens were collected at Roosevelt Lake, Arizona, during netting and electrofishing surveys of the late 1980s (Arizona Game and Fish Department 2002c). The reason for this intolerance could be that sediments in lakes tend to be too fine (e.g., silt) and the species cannot find suitable food resources (e.g., crustaceans, ephemeropterans, protozoans, diatoms and algae (Minckley 1973, Clarkson and Minckley 1988).

The Sonora sucker is known to spawn in late winter through mid-summer (Sublette et al. 1990), generally in small streams or in riffles of larger streams (but see Minckley 1973). Eggs are deposited in riffles, fall into the interstices between gravels, and incubate (Reughard 1920 in Sublette et al. 1990). Importantly, Sonora suckers are a main component of the larval drift that occurs in the Gila River (Propst et al. 1987 cited in Sublette et al. 1990). Spawning does not appear to be correlated with any specific pattern of stream flow or temperature (Arizona Game and Fish Department 2002c). Young tend to congregate in great numbers along the margins of streams (Minckley 1973) and can also live and utilize runs and quit eddies (Arizona Game and Fish Department 2002c). Larval Sonora suckers (total length = 7 - 26 mm) have been found occupying shoreline areas with water velocity = 0.0 cm/s at depths < 13.75 cm (Mercado-Silva, in preparation).

Sonora suckers are tolerant of temperatures as low as 10°C, and up to 30°C for short periods (Rinne et al. 2001). Bonar et al. (2010) documented that Sonora suckers inhabit waters between 20 and 28° C, in Cherry Creek, AZ. Sonora suckers are tolerant of much higher temperatures than desert suckers found in that system.

Species: *Catostomus insignis* (Sonora sucker)				
Life Stage:	Spawning	Larvae	Juvenile	Adult
Preferred Habitat	Small streams or riffle areas in larger streams. Can also spawn in lentic habitats.	Found in sand to cobble substrates in shallow areas in the edge of streams	Pools, slow runs or deep riffles over sand to boulder size substrate.	Pools, slow runs or deep riffles over sand to boulder size substrate. Preferred habitats are in areas 13 – 60 cm deep, with water velocities 3.1 to 26.8 cm/s, but the species can occur in areas with slower/faster water velocities and in deeper pools.
Time of Year	Late winter through mid-summer.	Early spring to mid summer.	Early spring to mid/late summer.	Adults occupy these habitats year round.
Water Velocity	Water velocities from 0.0 cm/s to over 50 cm/s.	Found in areas with water velocity 0.0 – 13 cm/s	In areas with water velocities 0.0 - > 50 cm/s.	Maximum suitable water velocity of 50 cm/s, but usually found in slower areas and pools with no measureable flow.

Gila robusta (roundtail chub)

Roundtail chub are often found in stream reaches that have a complexity of pool and riffle habitats (Bezzerides and Bestgen 2002). Juveniles and adults are typically found in relatively deep, low-velocity habitats that are often associated with woody debris or other types of cover (Vanicek and Kramer 1969, McAda et al. 1980, Miller et al. 1995, Beyers et al. 2001, Bezzerides and Bestgen 2002). Sigler and Sigler (1996) reported that substrate in roundtail chub habitat may range from rock and gravel to silt and sand. Roundtail chub have been collected from depths from 20 to 200 cm over generally coarse substrates (e.g., cobble, pebbles, boulders), but occasionally over sand and gravel (Barber and Minckley 1966, Griffith and Tiersch 1989, Sublette et al. 1990, Rinne 1992, Barrett and Maughan 1995, Brouder et al. 2006). They select for relatively swift waters but also require calm deep pools, and have been collected at water velocities of 0.0 – 96 cm/s (Griffith and Tiersch 1989, Barrett and Maughan 1995). In Cherry Creek, AZ, Bonar et al. (2010) found them in pools adjacent to riffle or run areas and estimated their suitable velocity maximum at 30 cm/s. Beyers et al. (2001) documented a significant difference in localized diel movement patterns for roundtail chub with adults moving from shallow habitat at night to deeper habitat during the day (Rees et al. 2005). Temperature tolerance of roundtail chub has been reported up to 39°C (Deacon et al. 1987), but preferred temperature is between 22°C and 24°C (Weitzel 2002). However, Bonar et al. (2010) found them occupying sites with lower temperatures (14-22°C).

Roundtail chub in the Upper Colorado River Basin begin spawning when water temperatures reach about 18.3 °C (64.9 °C) (Vanicek and Kramer 1969, Joseph et al. 1977). In most Colorado River tributaries this increase in temperature coincides with a decrease in discharge after peak runoff (Bezzerides and Bestgen 2002). Spawning in the Yampa River at Dinosaur National Monument, CO, occurs between mid-May and early July. The time of spawning in other drainages and locations is probably similar and can go into the summer but is influenced by water temperature and the hydrograph (Kaeding et al. 1990, Moyle 2002, Rees et al. 2005, Carman 2006). Roundtail chub may or may not carry out upstream or downstream migrations close to the time for spawning; spawning related movement may depend on location and population, and may range from minimal localized movements to movement of more than 30 km (Rees et al. 2005). Eggs are potentially deposited near eddies or shallow pools with boulder or cobble substrate (Rees et al. 2005). Larvae have been reported in low velocity areas associated with backwater habitats (Haines and Tyus 1990, Ruppert et al. 1993); however, there has been no specific study to determine the importance or necessity of this habitat to larvae (Rees et al. 2005). Carter et al. (1986) suggested that roundtail chub actively drift during the mesolarval stage of development in the Upper Colorado River. Drifting occurs primarily after mid-July and appears to become more frequent as water temperatures initially increase. It was not determined whether the increase in drift was related to an increase in activity or an actual increase in larval abundance (Rees et al. 2005).

Species: *Gila robusta* (roundtail chub)				
Life Stage:	Spawning	Larvae	Juvenile	Adult
Preferred Habitat	At spawning, they prefer eddies or shallow pools with boulder or cobble substrate.	Low velocity areas associated with backwater habitats. Substrates in these areas are generally fine (e.g., sand)	They inhabit pool and riffle habitats that are often associated with woody debris or other types of cover. Depth between 20 to 200 cm.	They inhabit pool and riffle habitats that are often associated with woody debris or other types of cover. Depth between 20 to 200 cm.
Time of Year	Mid May to early July	June - August	Year Round	Year round
Water Velocity	0.0 to ~30 cm/s	Areas with low flow (0.0 cm/s), but can be drift downstream.	0.0-96 cm/s	0.0 – 96 cm/s

Meda fulgida (spikedace)

An endemic species to the Gila River Basin, spikedace is a fish that has seen its range severely reduced as a consequence of habitat changes and negative interactions with non-native species (Rinne 1991, Douglas et al. 1994). The preferred habitat of the spikedace is found in low-to-moderate gradient, intermediate sized streams, over sand, gravel or cobble substrates and where water velocities are slow to moderate (Rinne and Magaña 2002). They are known to attain greater abundance in streams with gradients between 0.4 – 0.6 %, which usually form low gradient runs to riffles (Neary et al. 1996). In Aravaipa Creek, such habitats are frequently associated with "shear zones" where two (or more) braids of streams converge (Rinne 1991). These areas and those along canyon walls or downstream of large boulders provide physical structure that produce eddying and sometimes pool formation (Rinne 1991). Investigations in Aravaipa Creek have shown that spikedace occupy deeper (24.9 ± 13 cm) and slower (29.8 ± 17 cm/s) waters over small sized (gravel and pebble) (3-64 mm diameter) substrates than are available (Rinne and Kroeger 1988, Rinne 1991). However, this habitat selectivity is not strong in other Gila Basin streams where the species occurs (Rinne 1991, Neary et al. 1996). Spikedace can be found in areas 15 - 30 cm deep, in areas where water velocity can vary between ~ 5 – 37 cm/s, and where substrate can be sand to bedrock (Rinne 1991). These quantitative descriptions support earlier qualitative descriptions by Miller and Hubbs (1960); Barber et al. (1970); and Minckley (1973) that described the species as inhabiting "deep (0.6-1.3 m), moving waters as those found in swift deep pools or the deeper parts of long pools, near riffle mouths over sandy or gravelly bottoms". Velocity is more important for habitat selectivity than depth (Neary et al. 1996). In the Verde River, spikedace were most common in velocities 55-85 cm/s (Neary et al. 1996) (but see Ward and Hilwig 2004).

Spikedace spawning is presumably cued by changes in discharge and temperature in spring-summer (Marsh 1996). During spawning females inhabit deeper pools and eddies, while males occupy riffles over sand or gravel beds (Barber et al. 1970), although it has been suggested that there is a preference for gravel over sand substrates (Neary et al. 1996). Young of the year have been observed in backwater areas over sand-silt bottoms, adjacent to pools. Rinne (1991) collected larval spikedace in slow currents in the immediate vicinity of riffles containing adults. Propst et al. (1988) reported that water depths and velocities occupied by larval spikedace in the upper Gila basin were significantly less (8.4 cm and 8.4 cm/s, respectively) than those occupied by either juveniles (16.8 cm and 16.1 cm/s, respectively) or adults (19.3 cm and 49.1 cm/s, respectively. Similarly, adults and juveniles occupy significantly different habitat than larvae in Aravaipa Creek (Rinne 1991). Spikedace are intolerant of high temperatures (>30° C)(Carveth et al. 2006, Carveth et al. 2007).

Species: *Meda fulgida* (spikedace)				
Life Stage:	Spawning	Larvae	Juvenile	Adult
Preferred Habitat	Slowly flowing waters less than 15 cm deep, over sand and gravel bottoms in water ~ 19 C. Females occupy deeper pools and eddies and males occupy riffles flowing over gravel and sand	Most occupy backwaters with sand-silt bottoms, adjacent to pools. But some occupy over gravel or cobble. Reported depths are around 8.4 cm	Young spikedace occur in backwater areas and shallow peripheral portion of streams that have slow currents along stream margins and sand or fine gravel substrates adjacent to swift pools. On average they are found at depths of 16.8 cm	They are most commonly found in shear zones where two riffle areas converge to form eddying currents. In larger rivers they occupy riffle areas of moderate velocities and gradient over grave - pebble substrates At depths of 19.3 cm on average.
Time of Year	March to May	March to May	April - June	Year round
Water Velocity		8.4 cm/s, or < 7 cm/s)	Usually found at water velocities of 16.1 cm/s	Reported in waters with velocities of 49.1 cm/s, but "preferred" flow are at >20 cm/s. Rinne (1991)reported them from water velocities 30.1 cm/sec. Neary et al. (1996) reported them in velocities 55 – 85 cm/s.

Rhinichthys cobitis (loach minnow)

Loach minnow are small benthic stream fish endemic to the Gila River basin in Arizona and New Mexico and the San Pedro River basin in Arizona and Sonora, Mexico (Minckley 1973, Propst et al. 1988). Loach minnow prefers turbulent, rocky riffles of mainstream rivers and tributaries up to about 2500m elevations. Most habitat occupied by loach minnow is relatively shallow, has moderate to swift current velocity and gravel-to-cobble substrate (Barber and Minckley 1966, Minckley 1973, Propst et al. 1988, Rinne 1989, Propst and Bestgen 1991). The species is rare or absent from habitats where fine sediments fill the interstitial spaces (small, narrow spaces between rocks or other substrate) (Propst and Bestgen 1991). On average, larvae, juvenile and adult loach minnow have been found in habitats with water velocities of 7.3 (± 9.1 SD), 33 (± 23.2) and 57. 3 (± 21.9) cm/s, respectively. Larval loach minnow have been found to occupy depths 16.4 ± 6.7 SD cm, while juveniles and adults occupy depths of 14.9 ±7.0 cm, and 18.3 ± 6.7 cm, respectively. Larvae are generally found in areas where sand is the dominant substrate, while juveniles occupy areas with gravel to cobble (Propst and Bestgen 1991).

Loach minnows occur in habitats with temperatures 9-12° C in winter to 21-24.5° C in summer (Propst and Bestgen 1991). Loach minnow have been observed dying in Aravaipa Creek at water temperatures of 30.58°C (Deacon and Minckley 1974) and 34.58°C (July 2002; observation by Widmer, Carveth, and Simms). These mortalities were attributed to thermal stress, although other biotic and abiotic factors cannot be discounted (Widmer et al. 2006).

Loach minnow reach sexual maturity at age one. Spawning occurs in late winter-early spring in Aravaipa Creek (Minckley 1973) and from late March into early June in New Mexico (Britt 1982; Propst *et al.* 1988). Spawning is in the same riffles occupied by adults. Adhesive eggs are deposited on the underside of flattened rocks; cavities usually are open on the side while the upstream portion of the rock is embedded in the substrate. As larvae emerge, they move to nursery areas with finer substrate particles, and lower velocities.

Species: *Rhinichthys cobitis* (loach minnow)				
Life Stage:	Spawning	Larvae	Juvenile	Adult
Preferred Habitat	Spawning is in the same riffles occupied by adults	Shallow (~ 16.4 cm) areas in areas with relatively slow flows (7.3 cm/s), and typically sand as substrate	Habitats are relatively shallow (~ 14.9 cm), have moderate to swift current velocity (~ 33 cm/s) and gravel-to-cobble substrate.	Habitats are relatively shallow (~ 18.3 cm), have moderate to swift current velocity (~ 57 cm/s) and gravel-to-cobble substrate
Time of Year	Late winter to early spring, but can extend into early June.	Mid spring to early summer	Year round	Year round
Water Velocity	Water velocities of approximately	Water velocities of approximately 7.3 ± 9.1 cm/s	Water velocities of approximately 33 ± 23.2 cm/s	Water velocities of approximately 57.3 ± 21.9 cm/s

Rhinichthys osculus (speckled dace)

Speckled dace usually live in clear, well-oxygenated water with abundant deep cover and moving water, most often occupying water less than 60 cm deep in riffles and runs (Valdez et al. 2001, Moyle 2002). Rinne (1992), Mullen and Burton (1995), Gido and Propst (1999), and Moyle and Baltz (1985) collected them from waters shallower than 32.0 cm and reported that water velocities preferred by speckled dace are relatively fast. Breeding adults prefer swift water (Arizona Game and Fish Department 2002b). Mullen and Burton (1995) found that speckled dace avoided velocities slower than 10 $cm \cdot s^{-1}$ and selected for velocities faster than 50 cm/s. Speckled dace cannot swim against water currents with velocities greater than 70.4 cm/s (Ward et al. 2003). Bonar et al. (2010) found that speckled dace had a maximum suitable velocity of 50 cm/s, and selected for depths between 9 and 30 cm, usually in areas with cobble to boulder substrates. They often congregate below riffles and eddies (Arizona Game and Fish Department 2002b). Speckled dace are often found among boulders and cobble, although they can also be occasionally found in soft substrates (Gido and Propst 1999). Speckled dace usually inhabit relatively cold waters in desert streams and have been collected at temperatures between 9 and 28°C (Deacon et al. 1987, Bonar et al. 2010).

Speckled dace are known to have two breeding periods, one in spring and the other in late summer. They spawn over coarse substrate using a broadcast spawning method. At the time of spawning speckled dace congregate in large groups and release many eggs in gravel areas (Arizona Game and Fish Department 2002b; Kaeding et al. 1990, Moyle 2002, Carman 2006). They are able to spawn in waters 18 – 29°C and can be induced to spawn by increasing water temperatures (Kaya 1991). During their larval stages speckled dace drift downstream along the shores of rivers, usually in areas with low water velocities, and often drift during night time (Robinson et al. 1998). Speckled dace larvae have been collected at water depths between 6 and 21 cm, in water velocities of 0.0 up to 11 cm/s, generally over sand or gravel substrates, although they can also occur in larger sediments (Mercado-Silva, in preparation).

Species: *Rhinichthys osculus* (speckled dace)				
Life Stage:	Spawning	Larvae	Juvenile	Adult
Preferred Habitat	Stream areas with swift currents, at depths < 30 cm, and gravel to cobble substrates.	Low velocity, shallow nearshore areas with gravel or sand substrates.	Habitats for juveniles are similar to those of adults. They inhabit relatively shallow (<30 cm) areas, in relatively fast water velocities between 10 and 30 cm/s, and are usually over cobble or pebbles, but can also live over fine substrates.	Habitats are relatively shallow (<30 cm), have relatively fast water velocities between 10 and 30 cm/s, and are usually over cobble or pebbles, but can also live over fine substrates.
Time of Year	Spring and summer	Late spring to early fall	Year round	Year round
Water Velocity	In areas with swift water currents (~30 cm/s).	Areas with no-flow to water velocities of up to 11 cm/s.	Water velocities of 10 – 30 cm/s.	Water velocities of 10 – 30 cm/s.

APPENDIX C-2

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ARAVAIPA CANYON RIPARIAN ASSESSMENT

in support of FEDERAL RESERVED WATER RIGHTS

LOWCLOUDS HYDROLOGY INC.

SEPTEMBER 2013

TABLE OF CONTENTS

Introduction

On request by the Environment and Natural Resources Division of the Department of Justice, in the adjudication of water rights in the case of *In re Aravaipa Canyon Wilderness Area* (W1-11-3342), in the *General Adjudication of All Rights to Use Water in the Gila River System and Source*, Ariz. Sup. Ct., Case Nos. W1-W4, this report describes the water needed to support the riparian ecology in Aravaipa Canyon, Arizona. In 1984 the United States Congress passed Public Law 98-406 creating the Aravaipa Canyon Wilderness. In so doing, Congress recognized that Aravaipa Canyon "is a primitive place of great natural beauty that, due to the rare presence of a perennial stream, supports an extraordinary abundance and diversity of native plant, fish, and wildlife, making it a resource of national significance" and deserving of permanent protection within the National Wilderness Preservation System. Congress established Aravaipa Canyon Wilderness for "the preservation and protection of this relatively undisturbed but fragile complex of desert, riparian, and aquatic ecosystems and the native plant, fish, and wildlife communities dependent on it ...." This report describes the riparian portion of this "relatively undisturbed and fragile complex," i.e., Aravaipa Canyon's riparian ecosystem and its flow-dependent plant communities.

The unique characteristics and functions of riparian ecosystems result from the ready supply of surface water and shallow groundwater and a more-or-less predictable pattern of seasonal and annual flow variations (Poff et al. 1997). The flow regime is the driving variable in these systems, strongly affecting other aspects of the riverine environment such as fluvial processes (e.g., flooding) and alluvial ground-water dynamics. The resulting composition and dynamics of riparian ecosystems thus reflect both direct and indirect effects of streamflow. Recognizing the dependence of Aravaipa's ecosystems on the "rare presence of a perennial stream," the 1984 Congressional designation of Aravaipa Canyon Wilderness implied a corollary reservation of federal water rights to fulfill the purposes of the wilderness designation; indeed, the implied reservation was made explicit in subsequent legislation (1990) which expanded Aravaipa Canyon Wilderness by more than 12,000 acres (P.L. 101-628). Thus, this report also describes the characteristics of the natural hydrograph that are inextricably linked to the riparian ecosystem of Aravaipa Canyon Wilderness.

Hydrology of Aravaipa Canyon

Aravaipa Creek is characterized by a relatively natural and wild flow regime that results in a more-or-less predictable annual pattern of wet and dry cycles. In a typical year, streamflow in Aravaipa Creek comprises two wet seasons of high flows and two dry seasons of lower flows, a pattern that is not unexpected given the bimodal nature of precipitation events within the Sonoran Desert. The resulting flow regime results from the interplay of three hydrologic processes that combine to produce the typical annual hydrograph for Aravaipa Creek: groundwater discharge from a regional aquifer system, evapotranspiration from the extant riparian plant community, and seasonal flooding from both convective, monsoonal thunderstorms and extended winter frontal rains. It is the imposition of the latter two processes (i.e., evapotranspiration and seasonal flooding) on the former process (i.e., discharge of basin groundwater) that results in the characteristic natural flow regime of Aravaipa Creek.

As is the case for most perennial streams in desert environments, base flows in Aravaipa Creek derive from discharge of basin groundwater. Two primary aquifers, a lower basin-fill aquifer and a younger, shallower alluvial aquifer, convey water from recharge areas along tributary channels and in the surrounding mountains to points of discharge near the upstream end of Aravaipa Canyon. Vertical movement of water from the deeper basin fill to the shallow floodplain alluvium is indicated; however, the shallow floodplain aquifer is by far the most transmissive unit in the basin. Thus, base flows in Aravaipa Creek result from regional ground-water discharge derived primarily from subflow in channel alluvium. Thinning of the channel alluvium due to uplift of basement rock in the Galiuro Mountains forces this subflow to the surface where it provides the base flows of Aravaipa Creek through the wilderness area.

Based on relatively stable water levels recorded from wells in the basin, the ground-water system of Aravaipa is believed to be in or very nearly in a steady state condition where annual recharge and discharge are balanced over time. Estimates of total recharge in the basin range from 7000 to 16,700 acre-feet per year (Ellingson 1980; Freethey and Anderson 1986; Adar 1984). Estimates of ground-water discharge as base flow range from 8500 to 9500 acre-feet per year (Ellingson 1980; Fuller 2000). Although influenced by annual and longer-term climatic cycles (i.e., droughts and wet periods), base flows derived from regional ground-water discharge are relatively stable throughout the year. The cycle of high and lower monthly flows characteristic of the annual hydrograph result from the influence of other phenomena on the base flows provided by groundwater.

The most predictable process affecting streamflow levels in Aravaipa Canyon is the imposition of a seasonal evapotranspiration draft on the shallow groundwater and base flows of Aravaipa Creek. In the high energy environment of Aravaipa Canyon, alluvial materials along the canyon bottom comprise sand, gravel, and coarser clasts that allow for direct and intimate connection of shallow groundwater in the alluvium with water levels in the channel. Following leaf-out of vegetation in late March and April, the evapotranspiration draft increases steadily through the growing season to a maximum value (usually in July), drawing down water levels in the alluvium and inducing losses of base flow from the channel. The result is declining levels of base flow starting in April and continuing until the onset of monsoon rains replenishes soil moisture, groundwater levels, and streamflows in the channel (discussed below). With leaf fall and the end of the growing season in late October and November, evapotranspiration declines to minimal levels and base flows return to normal over the winter months.

Two estimates of consumptive water use owing to evapotranspiration (ET) have been presented in the literature. Ellingson (1980) used several procedures to estimate both potential and actual evapotranspiration for riparian vegetation in the canyon bottom. Potential ET was estimated at 3677 acre-feet per year, while actual ET was estimated at 2466 acre-feet annually. In this estimate, maximum actual ET occurs in July (about 421 acre-feet) and represents approximately 6.85 cfs of consumptive use by riparian vegetation at the height of the growing season. A second estimate of actual water use by riparian vegetation is offered in the Fuller (2000) report. Using the difference between streamflow gains (about 7.1 cfs) in the canyon during the winter (December through March) and losses in the canyon (about 0.5 cfs) in the summer, Fuller estimates approximately 7.6 cfs is lost to ET at the height of the growing season. Using these numbers, Fuller (2000) estimates consumptive water use of 2300 acre-feet per year to ET in the Wilderness Area and an additional 1500 acre-feet per year to riparian areas upstream of the wilderness boundary. Considering the difference in methods used to estimate evapotranspiration in these two citations, the similarity in values for consumptive water use is impressive.

The processes of ground-water discharge and evapotranspiration are evident when Aravaipa flow records are evaluated with the effects of flood events removed. Figure 1 shows an annual hydrograph of median monthly flows (i.e., the flows that have been exceeded 50 percent of the time each month). The pattern of declining base flows in spring and early summer, interrupted by the monsoon weather patterns of July through September, and then recovering slowly through the winter months is evident in the plot. This figure depicts the base flow levels occurring in Aravaipa Canyon during the year and represents the non-flood annual hydrograph to which the species of Aravaipa have adapted over the centuries. Any water right to protect the aquatic and riparian ecosystems of Aravaipa Canyon Wilderness must mimic this pattern of streamflow to protect the integrity of these remarkable ecosystems.

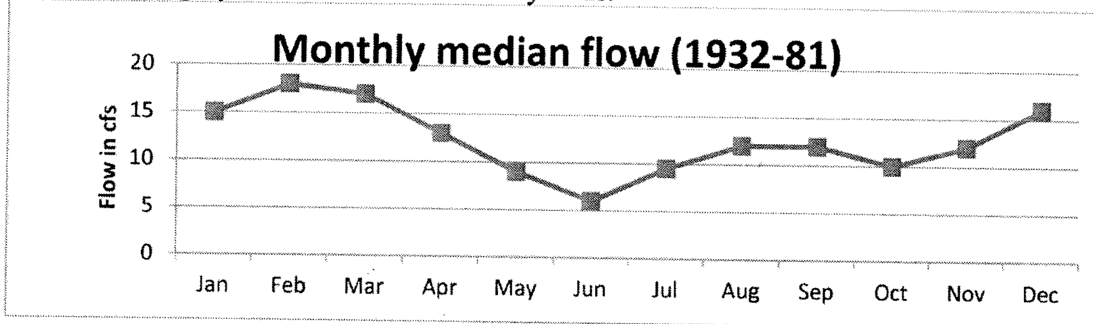

Figure 1. Monthly median flows for Aravaipa Creek through 1981.

Imposed on the base flow levels represented in Figure 1 above are the two seasons of precipitation and flooding that are common to this part of Arizona. Aravaipa Creek is dominated by winter (December-March) and monsoon (July-September) high flows separated by the base flow recessions of April through June and late September through early November. Runoff events during these two high-flow seasons produce roughly 60 to 70 percent of the total streamflow that passes through Aravaipa Canyon Wilderness. In the historical Aravaipa streamflow record, summer monsoon floods provide the highest instantaneous peak flow about twice as often as do winter floods (i.e., the monsoon season produces the highest peak flow of the year about 60 percent of the time compared to about 30 percent of the time for winter floods). About 10 percent of the annual floods (including the largest flood of record) occur in October when occluded cyclonic storms from the Gulfs of Mexico or California provide heavy rains for several hours.

Summer (monsoon) floods result from localized convective thunderstorms and tend to have high instantaneous peak flow rates but are generally of short duration. Compared to winter floods, monsoon floods tend to have lower mean daily discharge relative to their instantaneous peak flow, reflecting their tendency to be described as "flashy" (Stromberg 2002). Although winter floods are less frequent than monsoon events, they generally have a longer duration. Fuller (2000) found that winter periods experience an average of 4.9 storm events per year with an average duration of 5.5 days, while the monsoon season experiences an average of 6.8 storms per year with an average duration of only 2.1 days. When durations of one day or more are considered, winter storms provide the majority of the annual floods in the record.

Figures 2 and 3 depict the annual hydrograph of daily mean flows for two years of the systematic record. As indicated by these two figures, the occurrence of flood flows is random within the two storm seasons, with some years producing more water in the winter and other years producing higher flows in the summer. The stochastic nature of these storm events makes it impractical to specify a flood regime (other than the natural flood regime) for the wilderness; however, the importance of these seasonal floods to the ecology of the canyon cannot be overemphasized. The role of base flows and floods, as well as the natural recession from flood events, in maintaining the riparian ecology of Aravaipa Canyon is the subject of the following section.

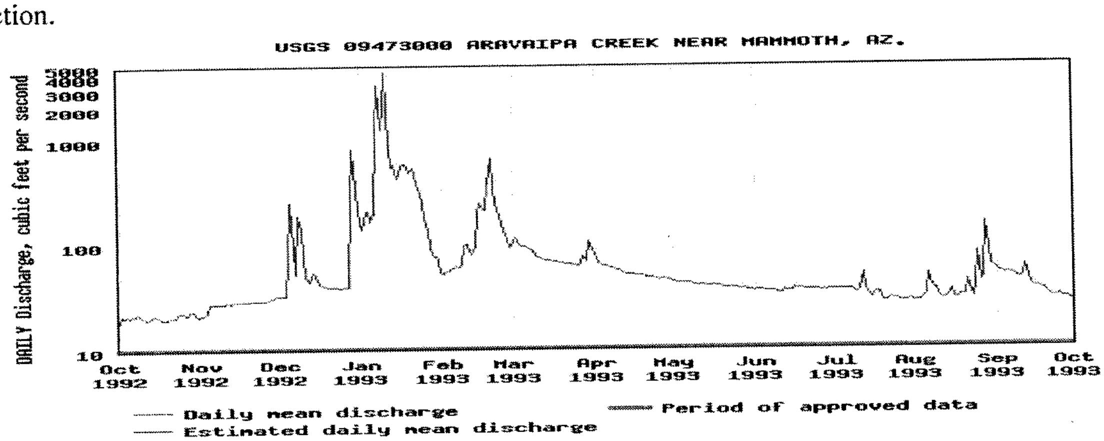

Figure 2. Daily mean discharge for water year 1993.

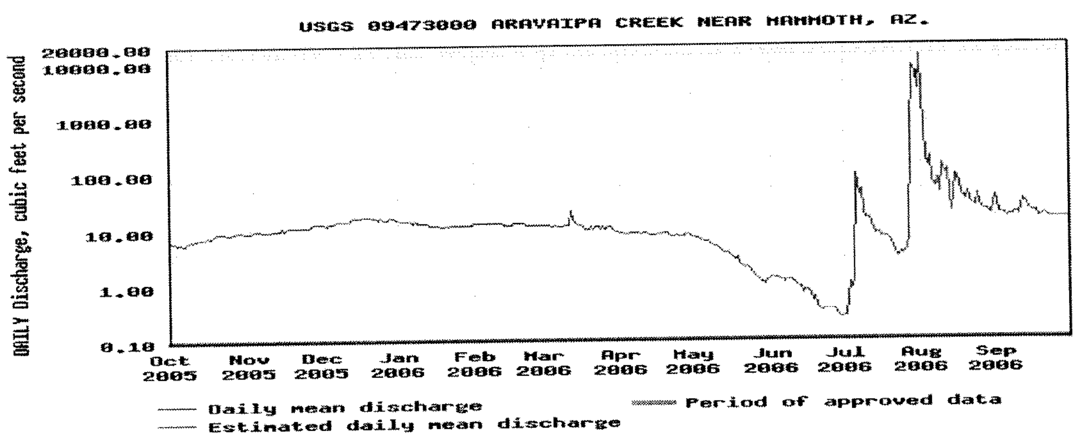

Figure 3. Daily mean discharge for water year 2006.

Flow Regime as the Master Variable

Riparian vegetation in arid and semi-arid environments is influenced by ground-water and surface-water discharge and both the base-flow and high-flow aspects of the flow regime. Biohydrology studies have examined relationships of riparian vegetation with many hydrologic parameters including total seasonal or annual streamflow, magnitude and variability of base flows, depth to ground water or saturated soil, and frequency, timing, and magnitude of flood pulses. Vegetation can be characterized in many ways, and studies have examined effects of surface- and ground-water flow regimes on vegetation abundance, plant species diversity, species composition, plant growth and vigor, and establishment and survival of tree species (Stromberg et al. 2005 and numerous op.cit. therein).

In a system like Aravaipa Canyon, the connection between surface water in the stream and shallow groundwater in the alluvium is intimate and nearly immediate. As mentioned above, high energy environments, such as Aravaipa Canyon, are characterized by floodplain and terrace deposits of sand, gravel, and coarser materials. The coarseness of these sediments results in a high degree of hydraulic conductivity between surface water and groundwater and tight coupling between stream stage and aquifer water levels (Stromberg et al. 2007). Thus, base flows occurring between storm seasons reflect ground-water levels supporting riparian vegetation in the canyon.

In the absence of seasonal evapotranspiration, Aravaipa Creek would be a gaining stream throughout most of its length in the wilderness area. But evapotranspiration during the growing season consumes substantial quantities of groundwater, and base flows recede as water moves from the channel into the adjacent alluvium. Depth to groundwater, seasonal and annual fluctuations in the water table, and rate of groundwater decline all respond to changes in base flow and serve to influence the abundance, age structure, and composition of riparian vegetation on floodplains and terraces (Stromberg et al. 2007 and numerous op.cit. therein). Indeed, the location of various riparian communities results directly from their topographic position relative to ground-water levels in the alluvium (more on this below). For example, numerous studies have documented the dependence of riparian herbaceous communities on perennial flows and shallow groundwater (<0.25 m deep) along the channel of desert streams (e.g., Stromberg et al. 2005; Leenhouts et al. 2006). And establishment and survival of many woody species have been linked to depth-to-water conditions as well (e.g., Stromberg 2001; Lite and Stromberg 2005).

In the absence of flooding, an annual pattern of high winter base flows (provided by ground-water discharge) followed by a long, continuous recession during the growing season (due to evapotranspiration), and recovery after leaf fall the following winter would yield a static and predictable riparian community that would deteriorate in quality over time. Pioneer species, such as cottonwood, willow, sycamore, and seepwillow, would be lost to the processes of ecological succession and replaced with mid-to-late seral species, such as velvet ash, Arizona walnut, and various species of mesquite. Avian and other wildlife habitat would suffer as diversity declined over time, and exotic species such as the invasive tamarisk would gain a competitive advantage over native species.

But the bimodal storm patterns of the Sonoran Desert ensure that no such long-term stability exists. High-intensity, short-duration summer thunderstorms and longer-duration moderate-intensity winter rains provide frequent floods of varying magnitude and duration that serve to reset ecological processes and maintain maximum diversity in the canyon. The effects of these floods are both hydrologic and geomorphic in nature and result in rejuvenation of aquatic habitats in the channel and creation of a variety of ecological sites in the riparian zone.

During the summer monsoon season, frequent thunderstorms and the resulting flash floods provide a source of water for riparian vegetation by increasing the water content of floodplain soils and recharging the alluvial aquifer. Base-flow recession is interrupted, and aquatic habitats are refreshed. In addition, summer floods can have a beneficial effect independent of water replenishment: storm runoff mobilizes nutrients that have accumulated in upland areas and deposits them on floodplain soils and in the shallow groundwater (Grimm and Fisher 1986). Summer floods can reduce levels of salinity in the soil, as well as stimulate microbial activity and organic matter decomposition (Molles et al. 1998). Summer floods also provide moisture needed for warm-season annuals to complete their life cycle, as well as opportunities for establishment of summer-germinating trees such as Arizona walnut and velvet mesquite (Stromberg et al 2005).

The effect of floods on canyon ecology is even more pronounced when winter floods are considered. The "flashy" nature of monsoon floods results in bedload transport of gravel and coarse materials in the channel and deposition of suspended load (i.e., sand) on floodplains and terraces (Malmon et al. 2005); however, the short duration of these events limits their ability to effect geomorphic change. To effectively modify the stream channel and adjacent fluvial surfaces (i.e., floodplains and terraces), the total volume and duration of the flood are more important than the absolute magnitude of the peak (Huckleberry 1994; Costa and O'Connor 1995). Thus the longer duration of winter floods causes stream channels to relocate and meander, creating abandoned channels and backwater depressions, and inducing channel widening and subsequent re-narrowing. Large, long, winter floods also scour and redistribute sediments, resulting in flood deposits that vary in depth, texture, and soil properties, and support different assemblages of plants (Stromberg 2001).

From a landscape perspective, floods create spatial heterogeneity and a shifting mosaic of patches, with each patch associated with a specific geomorphic surface and set of hydrologic conditions that support different types and/or age classes of vegetation (Stromberg et al. 2007). For example, a 1993 flood on the Hassayampa River eroded terraces that had developed adjacent to the stream channel and replaced them with a lower floodplain surface that was much closer to the water table. The lower surface responded with development of marshland vegetation (i.e., both herbaceous and pioneer woody species) which persisted until subsequent flooding deposited fresh sediment in the marsh. Subsequently, only pioneer woody species responded to the latter disturbance. The sequence of vegetation communities thus proceeded from mesquite bosque to marshland conditions to cottonwood-willow reproduction, which highlights the transitory nature of riparian marsh and other community types on the floodplains of arid-land rivers, and underscores the importance of maintaining floods of varying magnitude and duration to maintain patch diversity (Stromberg et al. 1997).

In Aravaipa Canyon, the effect of floods depends on both magnitude and duration of flooding. Fuller (2000) suggests that small floods have a controlling influence on channel morphology, which is not unexpected given the natural flow regime of the creek, i.e., the perennial nature of Aravaipa Creek allows channel morphology to adjust to frequent smaller floods. Fuller noted evidence that individual bed forms are quite mobile at instantaneous peak discharges approaching 4150 cfs and mean daily flows approaching 840 cfs; however, the overall channel morphology remained relatively stable at these flows. Anecdotal and photographic evidence from the 1983 and 1993 floods indicates that the largest floods (i.e., >15,000 cfs) can significantly modify the channel pattern and both channel and canyon-bottom geometry. These extreme high flows have the ability to do significant amounts of geomorphic work, reshaping the bed and banks of the creek and scouring adjacent flood surfaces. Thus, most of the riparian habitat, excluding only the highest terraces, is prone to reshaping by large floods. Even so, recovery of riparian vegetation is rapid, enhanced by the perennial flow regime within the wilderness (Figure 4).

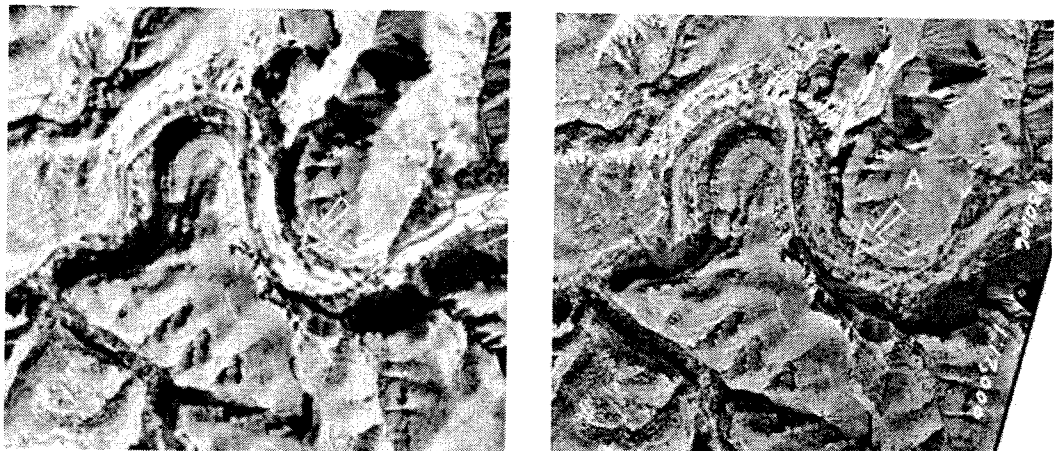

Figure 4. Comparison of 1984 (left) and 1993 (right) air photos of Aravaipa Canyon near Horse Camp Canyon. The 1984 photo was taken not long after the largest flood on record (30,000 cfs). The 1993 photo also was taken after a large flood (13,000 cfs), but note how much of the riparian vegetation, which established after the earlier flood, survived the 1993 event.

Base flows and flood flows are master variables controlling the nature of the riparian community in Aravaipa Canyon Wilderness, but there are additional hydrologic controls on the composition of the vegetation community. In the same way that hydric, herbaceous species require surface or near-surface water (i.e., consistent and reliable base flows) to proliferate, certain pioneer woody species (e.g., cottonwood and willow) require a specific sequence of flow conditions to successfully reproduce and survive to maturity. For these species, successful recruitment depends on high-energy winter floods to perform the "geomorphic work" necessary to create recruitment sites (i.e., seedbeds of fresh, moist sediment without competing vegetation) and to reinitiate community succession. Following germination of freshly deposited seeds in early spring, survival of the seedlings is only probable if the roots of the new seedlings can keep pace with a declining water table as flows recede through the remainder of the growing season. Thus, establishment of new cohorts of these pioneer species tends to occur with wet winters and springs, and a long, slow, natural recession from high-season flows to base flows (Stromberg 2001; Stromberg et al. 2007). From this example, it is clear that every component of the natural hydrograph impacts the community structure of the riparian ecosystem. The following section describes the resulting community structure and how certain components of the vegetation community are adapted to specific hydrologic conditions.

Riparian Plant Communities of Aravaipa Canyon

The riparian ecosystem of Aravaipa Canyon contains plant communities characteristic of two Natural Resources Conservation Service major land resource areas (MLRA): Arizona interior chaparral (Mogollon Transition MLRA 38), as well as the Upper Sonoran Desert (MLRA 40) (http://efotg.sc.egov.usda.gov/references/public/AZ/cramap.pdf). In contrast to the hot, arid upland environments typical of these MLRAs, Aravaipa Canyon and its natural flow regime provide a great diversity of aquatic and riparian habitats supporting a wide variety of native plant species. Indeed the riparian forest in the canyon and the native fauna it supports are part of the attraction for recreational users of the wilderness. Smaller but similar riparian ecosystems grow in several of the tributary canyons, forming ecological corridors through the more arid uplands. Although the riparian ecosystem of Aravaipa is influenced by many of the same factors that structure upland communities in the area, gradients of water availability and fluvial disturbance govern distribution of plant communities in the canyon. These two hydrologic factors influence the quality of riparian habitat along all arid-land streams.

The moisture gradient from aquatic to upland environments is a major factor controlling diversity of riparian communities. Individual plant species have unique needs or tolerances for depth to groundwater, soil saturation and nutrient levels, soil texture, drought, light availability, and competition from other plants, with the visible effect being species assemblages sorted by those influences (Stromberg et al. 1991). In general, the relative elevation of the ground surface increases with distance away from the stream, resulting in horizontal and vertical partitioning of community types such as rooted aquatic plants, streamside herbaceous vegetation, pioneer forest species (e.g., cottonwoods), and terrace shrublands and woodlands. Water availability also varies considerably along the length of the stream, as determined by the bedrock contours underlying the valley bottom. In areas where bedrock is shallow beneath channel and floodplain alluvium, such as downstream of Stowe Gulch in Aravaipa Canyon, the water table remains close to the surface and streamflows are perennial. Here vegetation is characterized by a variety of obligate and facultative wetland species. Areas underlain by deep alluvium, such as several miles downstream of the wilderness, experience surface flow only in response to significant runoff events and contain more mesic assemblages of plant communities. Throughout the area, depth to water sets the upper limit of riparian species' vertical position on the floodplain.

If depth to water sets the upper limit of species' vertical position on the floodplain, the ability to tolerate flood scour may be one factor setting the lower limit. The position of landforms relative to the channel creates a number of important environmental gradients in addition to depth-to-water: frequency and duration of inundation, exposure to shear forces, deposition and scour, and numerous characteristics of deposited sediment including texture and water-holding capacity (Merritt et al. 2009). In studies of seedling survival for young cohorts of pioneer woody species, removal of seedlings by flood scour was only slightly less common as a cause of mortality than desiccation from receding water levels (Karrenberg et al. 2002). Many of the pioneer species that colonize freshly scoured or deposited flood surfaces have physiological adaptations, such as highly flexible stems and branches, to enable them to survive in these high-disturbance environments. Other species have pre-formed breaking points on the stems and branches, and re-sprout vigorously from shoots and roots (Karrenberg et al. 2002). Along with the depth-to-water gradient, the disturbance gradient associated with Aravaipa Creek flooding is the primary determinant of riparian plant-community distribution.

Beginning within the low flow channel, Aravaipa Creek supports a large standing crop of watercress that covers extensive portions of the streambed each spring. Watercress is a perennial, herbaceous, semi-aquatic plant; thus, it is totally dependent on base flow in the stream. The hollow stems and floating leaves provide extensive mats of shelter and cover for invertebrates and larval fish in the river, and it can grow to lengths of a meter or more before dying back and yielding to flash floods in late summer. As in other locations throughout the San Pedro watershed, watercress is part of the extensive herbaceous community that is associated with perennial flow and near-surface groundwater in Aravaipa Canyon (Figure 1).

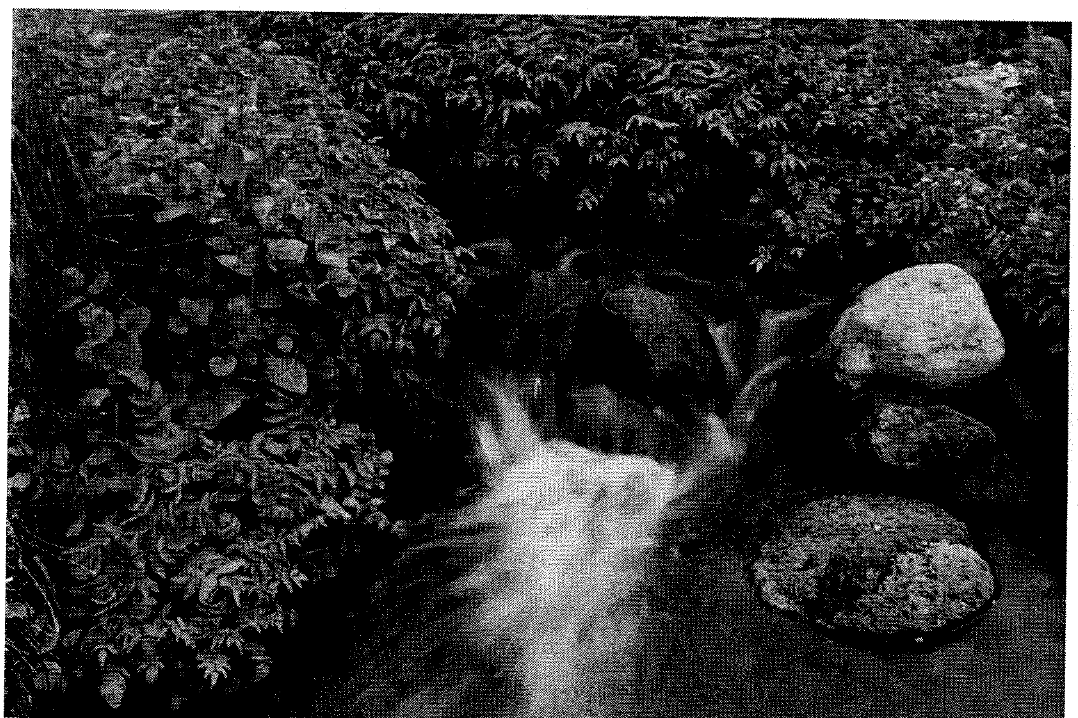

Figure 5. Hydric species like watercress, horsetail, and monkey flower grow together as part of the herbaceous community supported by base flows in Aravaipa Creek.

In addition to the widespread occurrence of watercress on the streambed of Aravaipa Creek, streambanks in the wilderness are lined with several species of sedge and rush below the elevation of the bankfull discharge. These obligate wetland plants form a riverine marshland community of variable width along the channel margin, where –in addition to being visually appealing—they serve to reduce bank erosion, enhance infiltration and storage of floodwaters, create well defined channels for fish and aquatic biota, and provide habitat for invertebrates and other terrestrial species (Figure 6). As obligate wetland species, these communities are intolerant of drought and typically grow on low fluvial surfaces where soils are saturated by streamflow or inflowing groundwater (Stromberg et al. 2005). Abundance of these species declines quickly at depths to groundwater greater than 0.25 m (Stromberg et al. 1996); thus, perennial flow appears essential for sustaining the riverine marshland community (Stromberg et al. 2005).

Figure 6. An herbaceous community of grasses, sedges, and rushes line much of the banks of Aravaipa Creek.

Situated above the communities of herbaceous vegetation lining the channel of Aravaipa Creek is the zone of recruitment for pioneer woody species, such as cottonwood, willow, sycamore, and seepwillow. As described above, reproduction of cottonwood and willow is linked to specific components of the annual hydrograph: flood flows that precede cottonwood/willow seed dispersal produce suitable germination sites; flow recessions following the winter/spring peaks expose germination sites and promote seedling root elongation; and base flows supply soil moisture to meet the seedlings' summer and winter water demand (Shafroth et al. 1998). The sequence required for successful recruitment of cottonwood and willow has been described quantitatively as a Recruitment Box Model (RBM) (Figure 7), where the box represents a window of opportunity for recruitment overlain on the annual hydrograph (Mahoney and Rood 1998). The vertical sides of the box are determined by the dates when viable seed is produced/present along the streambank; the horizontal top and bottom of the box correspond to elevations on the channel bank where seedlings can survive both declining water levels and future flooding; and the rate of streamflow recession within the box is such that elongation of seedling roots can keep pace with declining soil moisture (Figure 7).

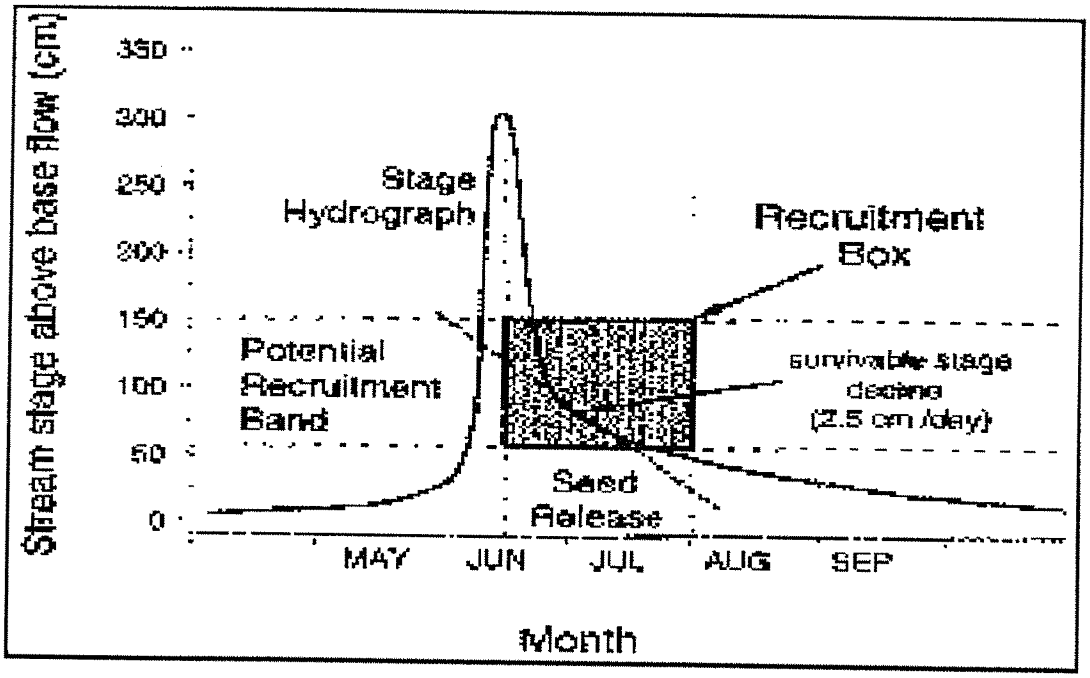

Figure 7. The Recruitment Box Model

The zone of recruitment for cottonwood and willow is a site-specific function of the stage-discharge relationship for the channel cross-section at the site of interest. If seedlings establish too high on the bank, desiccation that occurs during base-flow recession will lead to seedling mortality. If seedlings establish too low on the bank, they will be removed by subsequent flooding in the canyon. For the Bill Williams River in western Arizona, Shafroth et al. (1998) observed a successful cottonwood recruitment zone between 60 and 150 cm above the low-flow water surface. Goodding willow disperses seed somewhat later in the spring than Fremont cottonwood, and –as flood waters recede—establishes on sites that are slightly lower and closer to the low-flow channel (Stromberg et al. 2007). Young willow seedlings better survive subsequent inundation and scour due to the extreme flexibility of their stems and branches and an emphasis on lateral root development (Figure 8).

Figure 8. Note how young willow and cottonwood become established at a position just above and behind the herbaceous community lining the banks of Aravaipa Creek.

Other pioneer woody species found in the streamside zone include Arizona sycamore, Arizona alder, and seepwillow. Studies of the occurrence of Arizona sycamore have documented establishment patterns similar to those of cottonwood and willow. Similar recruitment episodes and intermingling of sycamore saplings with cottonwood and willow saplings indicate a high degree of similarity in regeneration niches among these species (Stromberg 2002). Arizona alder appears to be an obligate or facultative wetland species with depth-to-water requirements similar to pioneer woody species; however, alder is more shade tolerant and does not require the same level of disturbance for successful reproduction. Seepwillow is less restrictive in its water requirements and is highly adapted to disturbance with its highly flexible stem; thus, it occurs in a wide range of settings from within the channel to areas in and above the zone of pioneer species.

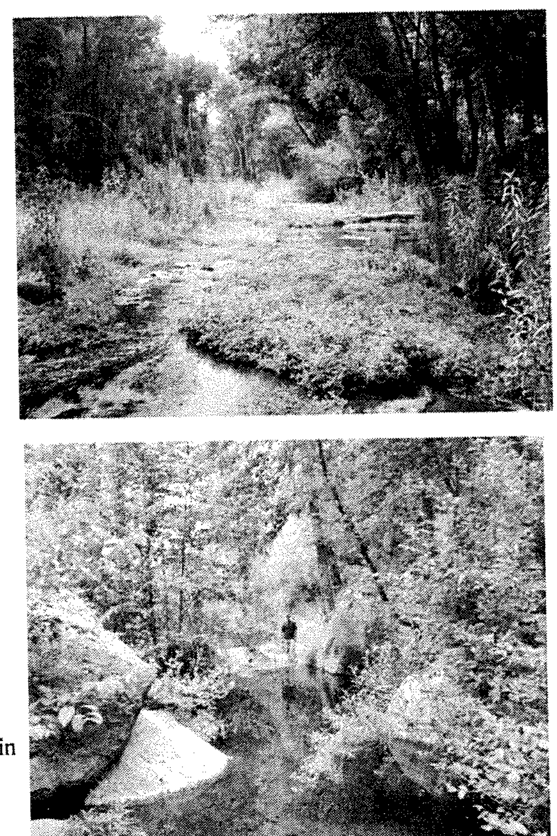

Figure 9. Seepwillow growing in the channel (top) and alder in a side canyon (bottom) in Aravaipa Canyon Wilderness.

Above the cottonwood -willow recruitment area, more mesic species coexist with mature stands of cottonwood and willow. Boxelder, velvet ash, and Arizona walnut are mid-seral species with intermediate requirements for water. They are more tolerant of shade and do not need disturbance for successful reproduction; thus, they are not usually found immediately adjacent to the active channel of Aravaipa Creek, but are typically located a short distance away with more mature vegetation. Root depth studies indicate these species can survive at locations up to 4 meters above the channel (Stromberg 2013). Of the three species, Arizona walnut was frequently observed as most distant from the stream.

On the highest streamside terraces are mesquite bosques and occasional Arizona walnut (Figure 10). These species are more shade tolerant and are capable of reaching deeper for groundwater. The invasive species *tamarix* (salt cedar) can also occur at higher levels above the channel, with large plants possessing very deep roots and capable of surviving on the highest terraces. Salt cedar possesses several character traits (e.g., it produces prolific numbers of seed throughout the growing season, is adapted to disturbance, and exudes salt from its leaves) that make it very competitive versus native species, and long periods of stability favor its spread.

Figure 10 . Arizona walnut and velvet mesquite growing together on a terrace above Aravaipa Creek.

Ecological Response to Hydrologic Alteration

The preceding description of the riparian ecosystem in Aravaipa Canyon Wilderness clearly illustrates the partitioning of plant communities along gradients of water availability (i.e., depth to groundwater) and disturbance from flooding. Indeed the riparian ecosystem of Aravaipa truly "is a primitive place of great natural beauty that, due to the rare presence of a perennial stream, supports an extraordinary abundance and diversity of native plant, fish, and wildlife." As such, Aravaipa is one of the few remaining, intact riparian ecosystems in the entire desert southwest. What makes Aravaipa Canyon such a "place of great natural beauty" is that this "fragile complex of desert, riparian, and aquatic ecosystems" is both "primitive" and "relatively undisturbed." And this description of Aravaipa Canyon's remarkable ecosystems applies to its natural flow regime as well. It is the maintenance of a relatively primitive and undisturbed natural flow regime that has produced the remarkable ecosystems of this wilderness canyon.

Throughout the American West there is a growing recognition of the important influence exerted by streamflows and fluvial processes on riparian-vegetation structure and composition (Stromberg 2001). Where natural flows have been altered, riparian values have changed (Merritt and Poff 2010), usually with a loss of habitat quality and impacts to native fauna. Changes in base flow have impacted water levels in riparian aquifers, producing shifts in the distribution of obligate and facultative wetland species composing herbaceous and woody plant communities. Changes in flood flows have eliminated the fluvial disturbance essential to recruitment of many pioneer woody species. The result has been the loss of most of the American Southwest's most productive habitats.

Loss of base flow and related declines in ground-water levels has produced significant changes in riparian communities throughout the region. Stromberg et al. (1996) noted a sharp reduction in abundance of obligate-wetland herbaceous species at ground-water depths below ≈0.25 m. And declines in riparian water tables associated with changes in base flow have produced a variety of responses in pioneer woody species, including physiological responses (e.g., reduced internal water potential, xylem cavitation, stomatal closure, reduced photosynthesis, etc.) and morphological responses (e.g., reduced leaf area, leaf senescence, branch sacrifice, crown die-back, etc.) (Rood et al. 2003; Smith et al.1991). These responses indicate stress to the plant community prior to mortality of the individual tree and demonstrate that this "fragile complex of ecosystems" is no longer "relatively undisturbed." Changes in depth-to-groundwater can also shift the competitive advantage from pioneer species like cottonwood and willow to invasive species like tamarisk, which is far more tolerant of deeper groundwater (Horton et al. 2001) and far less desirable for avian habitat. The impact of declining flows and water levels can be particularly severe along floodplains and terraces that are underlain by coarse substrate (Mahoney and Rood 1992). When water levels reach depths below those that existed at the time of plant establishment, plant mortality is likely to occur (Shafroth et al. 2000). Declining flows and water levels can also influence the mesquite bosques that occupy the highest terraces along the stream. For example, Stromberg et al. (1993) reported that depths to groundwater in excess of 6 m produced changes in tree size and stand structure at several mesquite sites in the Sonoran Desert of Arizona. As depth-to-groundwater increased, closed-canopy mesquite woodlands (bosques) gave way to shrublands more characteristic of upland areas, resulting in reductions in canopy height and lost avian habitat. Sublethal stress in mesquite along Tanque Verde Wash near Tucson was also noted as depth-to-groundwater increased from less than 5 m to more than 15 m (Stromberg et al. 1992). Declining groundwater levels that result from losses of base flow can thus shift the competitive advantage from native mesquite to invasive tamarisk on streamside terraces.

Other alterations to the natural flow regime, including alterations to the natural process of flooding, also have the potential to impact riparian functions and values. Poff and Zimmerman (2010) reviewed 165 papers related to altered flow regimes, and found that flow alteration can take the form of changes in magnitude, duration, frequency, timing, and rate of change for various flow phenomena (e.g., high or low flows). For example, Shafroth et al. (2002) investigated the construction of Alamo Dam on the Bill Williams River in western Arizona, which reduced the size of the 10-year flood by nearly an order of magnitude. In response, channel width of the river narrowed an average of 111 m (71%) downstream of the dam, with related changes in the composition of both riparian and aquatic habitat. Indeed, many of the changes in riparian ecology resulting from elimination/reduction of flooding are mediated through geomorphic processes, such as channel narrowing or coarsening of the substrate (Shafroth et al. 2010). In Aravaipa Canyon, reduced flooding would result in channel narrowing and associated loss of obligate wetland species (e.g.., watercress, sedges, rushes, etc.), as well as aquatic habitat. Overall, both disturbance and increased moisture conditions caused by floods contribute to increased species richness and cover of herbaceous plants in the riparian zone (Bagstad et al. 2005).

As described in an earlier section of this report, reproductive adaptations to the natural flood regime is a key component of the recruitment strategies of pioneer woody species in Aravaipa Canyon. Recruitment probability for cottonwood is highest under free-flowing conditions, and declines sharply under even slight flow modification, while recruitment probability for the invasive tamarisk remains high even under the most altered flow regimes (Merritt and Poff 2010). Thus, even slight deviations in flow away from the natural hydrograph could impact the riparian plant communities in an undesirable way. For example, changes in flood timing can simplify landscape patch structure in the riparian zone and shift community composition from pioneer species like cottonwood and willow to the more reproductively opportunistic tamarisk (Stromberg et al. 2007). Ultimately, loss of flooding altogether can result in loss of pioneer species and the upper canopy habitat they provide.

Summary

Aravaipa Canyon is characterized by a relatively wild and natural flow regime that supports an undisturbed and fragile riparian ecosystem. The annual flow regime in Aravaipa Creek comprises two wet seasons of high flows and two dry seasons of lower flows and results from the interplay of three hydrologic processes: regional groundwater discharge derived primarily from subflow in channel alluvium, seasonal evapotranspiration by the riparian ecosystem in the canyon, and seasonal flooding from convective late-summer thunderstorms (flash floods) and frontal winter rains (moderate intensities, but longer duration). The interplay of evapotranspiration and groundwater discharge produces the shape of the base flow portion of the annual hydrograph; summer and winter flood events are then superimposed on the base flow hydrograph. Both base flows and flood flows serve to support the riparian ecology.

The riparian ecosystem of Aravaipa Canyon results from the natural flow regime summarized above. In general, the relative elevation of the ground surface increases with distance away from the stream, resulting in horizontal and vertical partitioning of vegetation community types, such as rooted aquatic plants, streamside herbaceous vegetation, pioneer forest species (e.g., cottonwoods), and terrace shrublands and woodlands. This spatial partitioning results from two hydrologic gradients that are linked to the annual hydrograph: (1) Base flows and the associated groundwater determine depth-to-water beneath the channel, floodplain, and terraces along the stream. Virtually all obligate and facultative riparian species have depth-to-water requirements that determine their distribution and survival. (2) The disturbance regime related to annual flood events in the canyon has a direct deterministic impact on recruitment and survival of early-seral pioneer species along the channel. Since these pioneer species (i.e., willow, cottonwood, and sycamore) provide the upper canopy in the canyon, these communities play a major role in providing habitat for birds, mammals, and other organisms, and shade for recreational users.

Throughout the desert southwest, hydrologic modification (i.e., changes to the natural flow regime) has had deleterious effects on the riparian resources of the region. Changes in base flows have altered riparian groundwater levels, resulting in the loss of hydric herbaceous species along channels and shifts in overstory vegetation to more deep-rooted species (e.g., tamarisk). Loss of natural flood regimes (and their associated flow recessions) has eliminated regular recruitment of the very species that are most important for providing wildlife habitat (e.g., willow, cottonwood, and sycamore). Overall diversity has diminished, and native species have been put at risk.

In Aravaipa Canyon Wilderness, Congress has recognized and set in place an opportunity to protect one of the last remaining pristine ecosystems of its kind. The remarkable diversity of this primitive and undisturbed system, with its intact riparian and aquatic ecosystems and healthy assemblage of native species, warrants the level of special protection envisioned by Congress when it was incorporated into the National Wilderness Preservation System. This protection must include the natural flow regime, including a wild and natural flood regime, if this "undisturbed but fragile complex of ecosystems" is to be preserved for the enjoyment of future generations.

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APPENDIX C-3

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Aravaipa Canyon Wilderness:

Dependence of Recreational Values on Streamflows

Steven D. Moore, Ph.D.
Tucson, Arizona
July 2013

Purpose of this Report

The purpose of this report is to present findings relevant to the question of how recreational values depend on streamflows in Aravaipa Canyon Wilderness, Arizona. First, the wilderness area and Aravaipa Creek are described. Then, the federal mandates to provide recreational experiences for the public at Aravaipa Canyon Wilderness are reviewed. Then, two questions are posed and addressed with regard to the relationship between streamflows in Aravaipa Creek and recreational values in Aravaipa Canyon Wilderness. After these questions are discussed, a list of findings is offered that sums up the conclusions of this report. Following the list of findings is the *References Cited* section. In the *Appendix* are a statement of personal qualifications and a curriculum vita.

Aravaipa Creek, the Defining Feature Aravaipa Canyon Wilderness

As noted by Edward Abbey (1982), Aravaipa Creek is the defining feature of Aravaipa Canyon Wilderness:

> *Aravaipa is an Apache name (some say Pima, some say Papago) and the commonly accepted meaning is "laughing waters." The name fits.*

The creek flows through the center of, and largely determines the shape of, the 19,410 acre wilderness area overseen by the U.S. Bureau of Land Management (BLM). Aravaipa Creek has carved a sinuous path through volcanic and conglomerate rock, leaving towering red, orange, and gray walls as high as 1,000 feet (Figure 1). One of the last surviving perennial streams in southern Arizona, Aravaipa Creek supports a gentle and verdant riparian oasis in the midst of a scenic desert canyon. Seven native fish species—including two threatened species—inhabit the creek , seeking food and shelter among boulders and mats of watercress. Lining the banks of the creek are stands of cottonwood, Arizona walnut, alder, willow, mesquite, and box elder. On the slopes just above the creek are saguaro, barrel cactus, grasses, palo verde, prickly pear, and cholla. The trees, vegetation, and surrounding canyon walls provide habitat for more than 150 species of birds, 46 species of mammals, 46 reptilian species, and 8 amphibian species.

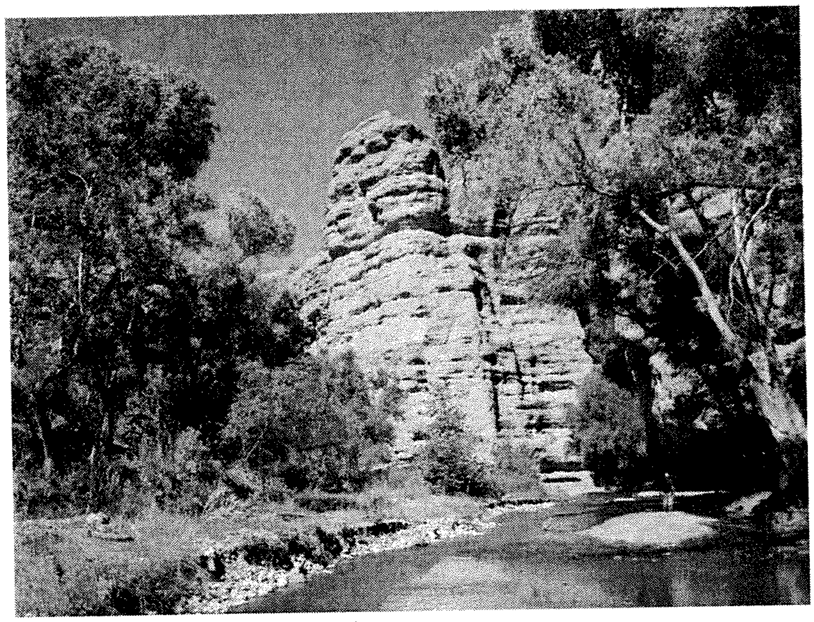

Figure 1. Aravaipa Creek in Aravaipa Canyon Wilderness.

Because of its rich biological features, perennial flows, and the uniqueness of a riparian oasis in the Sonoran Desert, Aravaipa Canyon Wilderness is a popular wilderness recreation attraction. During the period 1992 – 2012, 82,100 people visited the wilderness area, logging 147,423 recreational visitor days (RVDs)[1] (Figure 2) (Cooke 2013). Visitors come to Aravaipa Canyon Wilderness to hike, camp, enjoy solitude, view and photograph wildlife, and wade and swim in Aravaipa Creek. Because the canyon bottom is gently sloped, the wilderness area is particularly well suited for novice and casual backpackers, families, scouting groups, and day hikers willing to make the long drive to one of the canyon's two entrances. Visitation to Aravaipa Canyon Wilderness would probably even higher, except for the relative remoteness of the wilderness area from urban centers such as Tucson and Phoenix and a use limit administered by the BLM to protect the wilderness area's character.

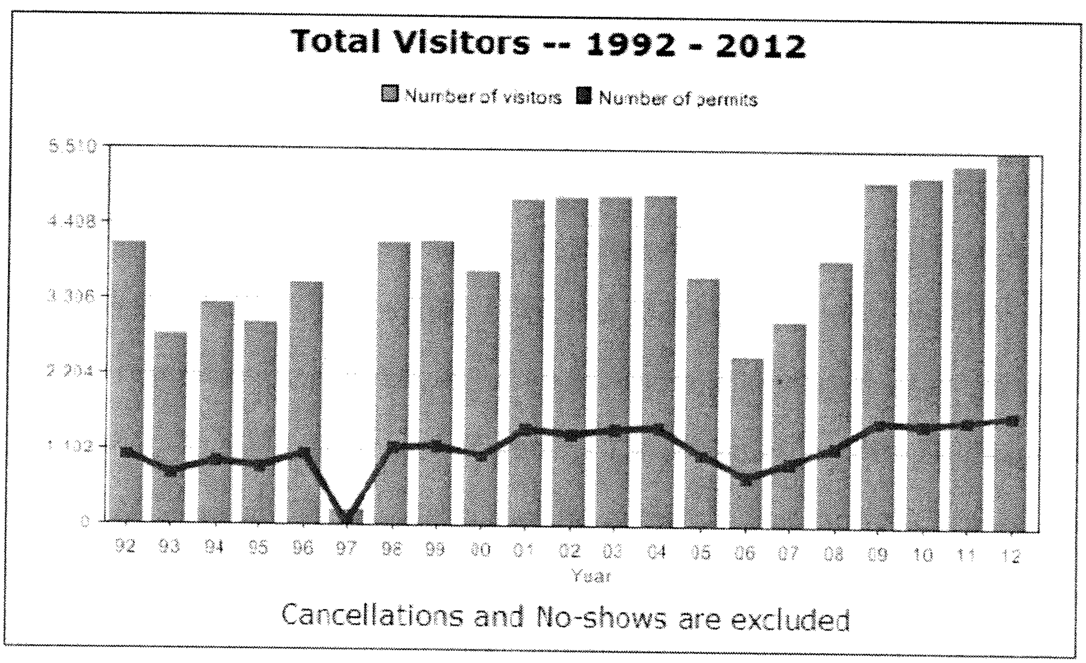

Figure 2. Aravaipa Canyon Wilderness Visitation, 1992-2012.[2]

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[1] A recreational visitor day is one visit by one person for 12 hours.

[2] For 1997, only visitation for January through March is displayed because the data table was damaged.

Federal Legislation and Agency Regulations Provide the Context for Protecting the Unique Recreational Features of Aravaipa Canyon Wilderness by Preserving Streamflows in Aravaipa Creek

The ultimate context for this report is provided by the purposes of federal wilderness designation as defined in the Wilderness Act of 1964 (P.L. 88-577; 16 U.S.C 1131):

> *...wilderness areas...shall be administered for the use and enjoyment of the American people in such manner as will leave them unimpaired for future use and enjoyment as wilderness, and so as to provide for the protection of these areas, the preservation of their wilderness character, and for the gathering and dissemination of information regarding their use and enjoyment as wilderness.*

Thus, the Wilderness Act clearly establishes that public use and enjoyment of (or recreation in) individual wilderness areas depends on preservation of key features that determine their wilderness character.

According to BLM wilderness management regulations (2012), the primary goal of wilderness management is to preserve wilderness character, which is defined as having four qualities: untrammeled by modern human control; natural conditions and processes; undeveloped land retaining its primeval character and influence; and opportunities for solitude and/or primitive and unconfined types of recreation. A fifth quality—unique, supplemental, or other features—must be figured into management actions when present. Aravaipa Creek, exactly the kind of unique feature envisioned in the BLM regulations, also contributes to the remaining four qualities targeted by the BLM for maintaining the character wilderness areas.

The significance of streamflows to the character of Aravaipa Canyon Wilderness is highlighted in its enabling legislation (Public Law 98-406), which provides specific references to Aravaipa Creek (emphasis added):

1. *The Aravaipa Canyon, situated in the Galiuro Mountains in the Sonoran desert region of southern Arizona,* ***is a primitive place of great natural beauty that, due to the rare presence of a perennial stream, supports an extraordinary abundance and diversity of native plant, fish, and wildlife, making it a resource of national significance.***
2. *the Aravaipa Canyon should, together with certain adjoining public lands, be incorporated within the National Wilderness Preservation System in order* ***to provide for the preservation and protection of this relatively undisturbed but fragile complex of desert, riparian, and aquatic ecosystems, and the native plant, fish, and wildlife communities dependent on it, as well as to protect and preserve the area's great scenic, geologic, and historical values,*** *to a greater degree than would be possible in the absence of wilderness designation.*

Important Recreational Values Supported by Streamflows in Aravaipa Creek

Although the enabling legislation does not specifically target recreation as an activity to be preserved in Aravaipa Canyon Wilderness, the legislation's references to resources of "great natural beauty;" the "abundance and diversity of native plant, fish, and wildlife;" and "great scenic, geologic, and historical values" imply the recreational values that are supported by Aravaipa Creek:

1. appreciation of scenic beauty;
2. observation of and interaction with abundant and diverse native plant, fish, and wildlife populations;
3. perception of the wilderness area as a place that retains its primeval character, is untrammeled by humans; and appears to be mainly influenced by natural conditions and processes; and
4. enjoyment of primitive and unconfined types of recreation.

The significance of these recreational values to visitors has been reported in research conducted about Aravaipa Canyon Wilderness and similar wildland areas.

Sociological Research Conducted at Aravaipa Canyon Wilderness Identifies Aravaipa Creek Streamflow as an Important Direct and Indirect Enhancer of Recreational Experiences

In 1987 and 1988, Moore, et al. (1989) conducted a mail questionnaire survey of visitors to Aravaipa Canyon Wilderness.[3] Funded by the BLM to evaluate the recreational carrying capacity limit established by the agency, the research examined sociological and environmental factors that influenced visitors' perceptions and enjoyment of the wilderness area.

In the questionnaire, Moore, et al., (1989) asked respondents to express how much they would like to (1) encounter 18 physical and biological attributes in Aravaipa Canyon Wilderness and (2) engage in 26 activities that are dependent on the physical and

[3] An 18-page questionnaire was mailed to approximately 800 people who obtained permits to visit Aravaipa Canyon Wilderness between 1 March 1987 and 28 February 1988. Specific numbers of permit holders were randomly selected each month of the study period. The sampling method was designed to allow each permit holder an equal probability of being mailed a questionnaire. Follow-up mailings sent to nonrespondents (as prescribed in Dillman [1978]) achieved an 83% response rate for the survey.

biological attributes of the wilderness area (Figure 3). All of the detractors and strong detractors were human impacts that contributed to a feeling of the wilderness area being trammeled (e.g., litter, overflights from airplanes, smoke from campfires, and graffiti). Four of the 19 enhancers and strong enhancers identified by respondents were activities that are directly dependent on streamflows in Aravaipa Creek: drinking water from the creek, observing and identifying fish (Figure 4), swimming in Aravaipa Creek, and walking in Aravaipa Creek (Figure 3). Six identified enhancers and strong enhancers were indirectly dependent on the ecosystem that is supported by adequate streamflows in the creek: identifying plants; photographing animals; observing and identifying birds; observing and identifying reptiles and amphibians; photographing the scenery; and observing and identifying mammals (Figures 3 and 4).

Figure 4. Observing fish and other wildlife is an important enhancer for visitors to Aravaipa Canyon Wilderness.

TABLE 1

Attributes of Aravaipa Canyon Wilderness that would detract from, enhance, or both detract from or enhance respondent's recreational experiences.

STRONG DETRACTORS[1]	STRONGLY DISLIKE	STRONGLY DISLIKE	NEUTRAL	LIKE	LIKE	N
Litter along travel routes	96.0%	2.5%	0.7%	0.0%	0.8%	658
Litter at campsites	95.9	2.8	0.6	0.0	0.7	658
Graffiti on rocks, trees, etc.	95.2	3.8	0.3	0.0	0.7	658
Human feces or toilet paper on the ground	89.3	8.3	1.5	0.0	0.9	656
Aircraft flying low overhead	68.7	19.7	10.6	0.6	0.5	657
DETRACTORS[2]						
Manure from livestock	53.2	22.4	22.7	0.9	0.8	655
Damaged trees or other vegetation	40.9	22.3	30.7	3.7	2.4	648
Campsites concentrated in camp areas	29.8	32.4	20.7	10.6	6.5	652
Charred logs and ash from camp fires	22.4	36.3	37.2	3.0	1.2	653
Light from other visitors' campfires	18.0	26.6	45.3	8.5	1.6	649
Smoke from campfires	12.9	20.8	50.4	12.2	3.7	654
DETRACTORS AND ENHANCERS[3]						
Toilet facilities at popular campsites	26.1	17.8	22.1	19.8	14.2	654
Rock fire rings at campsites	16.8	17.0	39.7	21.1	5.4	655
Maintained trails	13.5	19.2	23.4	29.5	14.5	657
Seeing a flood in ACW	28.3	15.3	25.2	18.8	12.3	653
Interpretive or directional signs at points of interest	14.7	14.6	18.2	32.7	19.8	657
ENHANCERS[4]						
Drinking water from Aravaipa Creek	9.7	13.5	22.7	27.4	26.6	657
Climbing rocks	1.3	7.2	32.4	29.6	29.4	654
Cattle fences at wilderness boundaries	3.5	5.1	28.9	26.9	35.7	655
Campsites dispersed throughout ACW	9.3	9.3	15.5	36.7	29.2	651
Observing and identifying fish	0.0	1.3	28.7	36.4	33.6	656
Sitting around a campfire	2.8	2.6	18.4	33.0	43.3	659
Swimming in Aravaipa Creek	1.2	1.9	18.6	31.5	46.7	655
Hiking to the canyon rim	0.6	1.9	17.5	35.7	44.2	654
Identifying plants	0.0	0.9	17.3	41.0	40.7	658
Photographing animals	0.5	0.4	15.5	27.4	56.2	658
Observing and identifying birds	0.3	0.5	15.4	35.5	48.4	657
Studying archeological artifacts	0.6	0.8	14.3	37.8	46.5	654
Examining the geology	0.1	0.6	13.3	39.7	46.2	657
Swimming in pools in side canyons	1.4	1.6	11.9	32.6	52.5	650
Observing and identifying reptiles and amphibians	0.0	1.1	11.6	41.0	46.3	656
STRONG ENHANCERS[5]						
Photographing the scenery	0.4	0.6	8.9	23.5	66.6	657
Walking in Aravaipa Creek	0.3	1.5	3.5	18.1	76.6	658
Observing and identifying mammals	0.0	0.1	3.2	30.4	66.3	657
Hiking in side canyons	0.1	0.6	2.5	20.4	76.4	657

[1] ≥ 85% of the respondents strongly disliked or disliked strong detractors.
[2] ≥ 40% but < 90% of the respondents disliked or strongly disliked and ≤ 20% liked or strongly liked detractors.
[3] ≥ 20% of the respondents disliked or strongly disliked and ≥ 20% liked or strongly liked attributes that were detractors and enhancers.
[4] ≥ 40% but < 90% of the respondents liked or strongly liked and ≤ 20% disliked or strongly disliked enhancers.
[5] ≥ 90% of the respondents liked or strongly liked strong enhancers.

Figure 3. Detractors and enhancers in Aravaipa Canyon Wilderness (From Moore, et al., 1989).

In Sociological Research, Recreational Visitors Ranked Water as the Most Important Attribute of Aravaipa Canyon

In another part of the questionnaire, Moore, et al., (1989) asked respondents to rank 13 attributes of three zones (main canyon, side canyons, and rim) in Aravaipa Canyon Wilderness (Figures 5). In the main canyon zone, which was visited by nearly all of the respondents, water was ranked as the most important attribute (Figure 6).

TABLE 2
Ranking of the most important elements of the main canyon, side canyon, and rimlands.

	MAIN CANYON		SIDE CANYON		RIMLANDS	
	%	RANK	%	RANK	%	RANK
Water	33.4	1	23.4	2	12.8	4
Peace and quiet	23.2	2	15.2	3	12.7	5
Solitude	16.4	3	23.8	1	19.4	1
Wildlife	8.7	4	8.8	6	15.8	3
Geology	6.9	5	11.3	4	8.3	6
Challenge	3.0	6	8.9	5	16.2	2
Vegetation	2.6	7	3.8	7	6.8	7
Ease of Hiking	2.3	8	2.3	8	1.5	10
Good campsites	1.6	9	0.0	13	2.3	9
Shade	1.4	10	1.9	9	2.8	8
Safety from natural hazards	0.4	11	0.0	13	0.0	13
Archeology	0.2	12	0.6	10	1.5	11
Meeting other visitors	0.0	13	0.0	13	0.0	13
	N = 545		N = 355		N = 65	

Figure 5. Ranking of important elements in three zones of Aravaipa Canyon Wilderness (From Moore, et al., 1989).

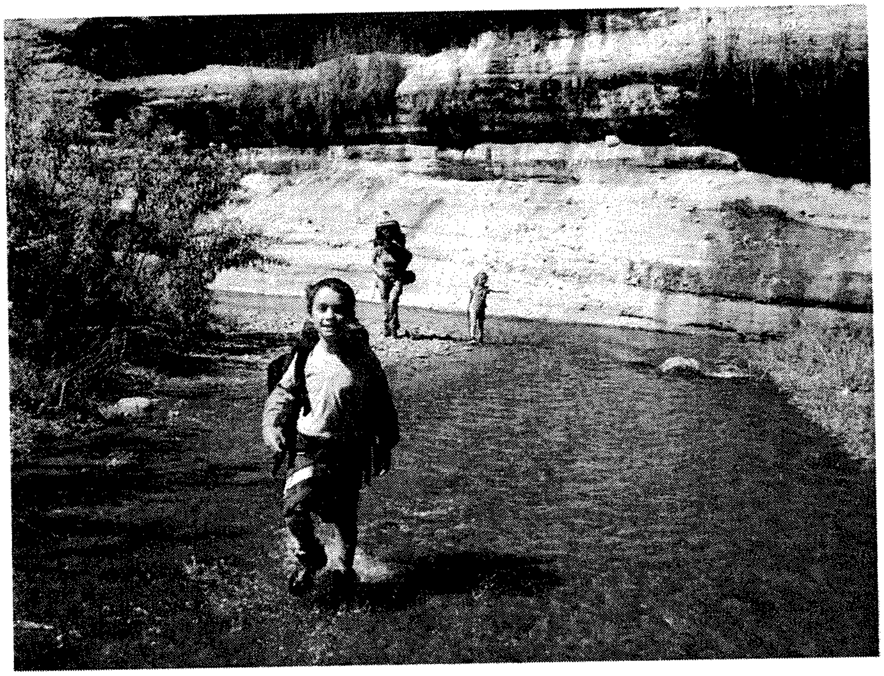

Figure 6. In Moore, et al., (1989), water was ranked by visitors as the most important attribute of Aravaipa Canyon.

Economic Valuation Research Indicates that Visitors Place a High Value on Recreation at Aravaipa Canyon Wilderness and Similar Wildland Areas

Weber and Berrens (2006) used Aravaipa Canyon Wilderness as a case study for valuing access to a Sonoran Desert canyon and its associated instream flow. To conduct their analysis, Weber and Berrens (2006) used available permit information and zip-code level census data to estimate a zonal travel cost model (ZTCM) of recreation trip demand. This analysis permitted the researchers to estimate non-market consumer surplus values[4] per recreational visitor day (RVD) spent at the wilderness. The estimates published by Weber and Berrens (2006) were $25.06/RVD for visitors entering the east portal of the wilderness area and $17.31/RVD for those entering the west portal.[5] Weber and Berrens (2006) also calculated a total net present value for the wilderness area in the range of $3.6 million to $4.7 million.

[4] Consumer surplus values in this case are the amounts visitors are willing to pay in excess of the explicit permit cost of $5 per visitor per day to experience Aravaipa Canyon Wilderness.

[5] The consumer surplus values are presented in 2003 dollars.

Weber and Berrens (2006) attributed their valuations to the importance of instream flows in a desert wilderness, although a "solitude surplus" was recognized for the east entrance of Aravaipa Canyon Wilderness.[6]

Using a variety of methods reviewed in Platt (2001), economic research on other water-based recreation areas has documented values similar to those calculated for Aravaipa Canyon Wilderness. For instance, Barrens, Ganderton, and Silva (1996) calculated an average annual household value of $28.73 for preserving flows in the Rio Grande River. A study by Crandall, Colby, and Rait (1992) estimated the value of birdwatching and hiking in the Hassayampa River Preserve in central Arizona at $520,000–$613,000 annually, depending on the valuation method.

Research and Commentary About Other Areas Underscores the Centrality of Water to Recreation in Wildland Settings

The centrality of water to recreation in wildland settings is a continuing theme of scientists, artists, and authors. For instance, Brown (2004) describes water as "...the lifeblood of riparian recreation areas." Running water conveys a sense of vitality (Brown 2004); is imbued with important cultural and symbolic values by people (Stokowski 2008); serves as an aesthetic backdrop or enhancer for non-water recreational activities (Field and Martinson 1986, Kakoyannis and Stankey 2002); and provides indirect benefits for wilderness recreation, such as maintaining habitat for birds and other wildlife (Brown 2004).

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[6] The east entrance to Aravaipa Canyon Wilderness is considerably more remote than the west entrance.

Two Guiding Questions About the Streamflows Needed to Sustain Direct and Indirect Recreational Values in Aravaipa Canyon Wilderness

Research conducted at Aravaipa Canyon Wilderness and other wildland areas thus reveals that water is central to the recreational experiences of visitors. Water provides direct benefits as a location and backdrop for recreational experiences. Water also affords indirect benefits by maintaining environmental conditions that support natural attributes that are important to visitors. Accordingly, when considering the streamflows needed to sustain recreational values in Aravaipa Canyon Wilderness, two guiding questions must be addressed that distinguish between the direct and indirect benefits of water for recreation:

1. ***What range of flows supports recreational values that are directly dependent on Aravaipa Creek (e.g., hiking and swimming in the creek; enjoying its sound and visual beauty; and perceiving the wilderness area as natural and untrammeled)?***

The relationship between streamflow and direct recreational value in river and stream systems has generally been found to be an an inverted U (Figure 7) (Shelby and Whitaker 1995, Brown 1991b, Brown 1991c, Brown, Taylor, and Shelby 1991). Direct recreational values are minimal at low or non-existent flows. As flows increase, direct recreational value for a site increases up to some peak streamflow. Beyond that peak, direct recreational value declines.

This relationship is due to a complex interplay among the physical environment, human perceptions of aesthetics, and real and imagined dangers posed by streamflows. Researchers have found that landscape aesthetics are optimized with intermediate

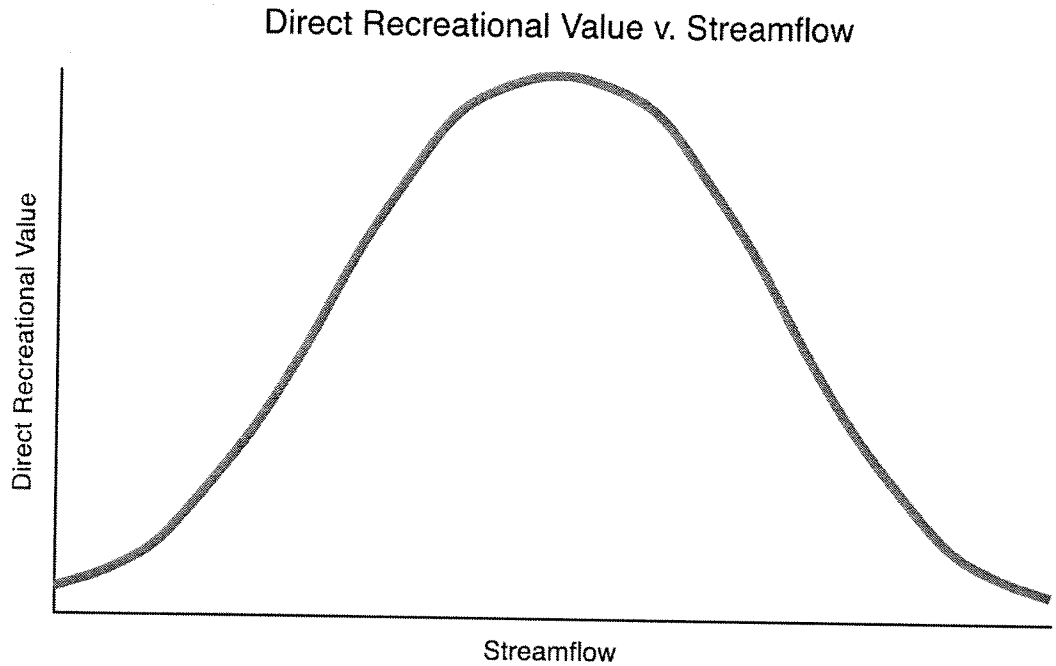

Figure 7. The generalized relationship between total recreational value and streamflow at a river or stream site.

streamflows (Zube, Pitt, and Anderson 1975, R. B. Litton 1984, Brown 1991a). Very high flows drown out contrasts between riffles and pools, may be turbid, and frighten people with real or imagined risks of being carried away. Low flows expose the material underlying a stream and eliminate the visual and auditory benefits of riffles and waterfalls (Figure 8).

Figure 8. At low flows, large expanses of the material underlying Aravaipa Creek are exposed, thus diminishing the aesthetic appeal of the wilderness area and the sense that it is untrammeled.

Moore, Wilkosz, and Brickler (1990) found that visitors to Aravaipa Canyon Wilderness were sensitive to decreases in streamflow below 23 cubic feet per second (CFS): at 18.4 CFS (the lowest monthly average flow reported for the study period) in comparison to 23 CFS, visitors were four times more likely to report that streamflows were less than they preferred. Moore, Wilkosz, and Brickler (1990) ascribed the empirical relationship to reduced perceptions of aesthetic value as declining streamflows exposed "bathtub rings," mats of drying algae, and clouds of insects attracted to shrinking pools of water. Supporting this conclusion is Moore, Wilkosz, and Brickler's (1990) finding that visitors who drank water from the creek were more likely to purify it at lower than mean streamflows.

Moore, Wilkosz, and Brickler (1990) also found that visitors who were present in the wilderness area at streamflows greater than 23 CFS were more likely to report experiencing more water than they preferred. Presumably, visitors who experienced such streamflows had difficulty hiking in Aravaipa Creek or possibly even feared flash flooding.

Using these results, a hypothetical plot of direct recreational value v. streamflow may be proposed for the period covered by Moore, Wilkosz, and Brickler's (1990) research (Figure 9).[7] This plot indicates that the direct recreational benefit of Aravaipa Creek would be nearly zero if streamflows were nonexistent. Direct benefits would increase with increasing streamflows until 23 CFS is reached. Beyond that flow, visitors would perceive less direct recreational benefit. In Figure 9, 23 CFS is used as the hypothetical peak because it was identified in Moore, Wilkosz, and Brickler (1990) as the inflection

[7] Note that the exact shape of the hypothetical curve is speculative and would need to be tested through additional research over a variety of flow regimes.

point where visitors were more likely to report experiencing "more water than I prefer" instead of "less water than I prefer."

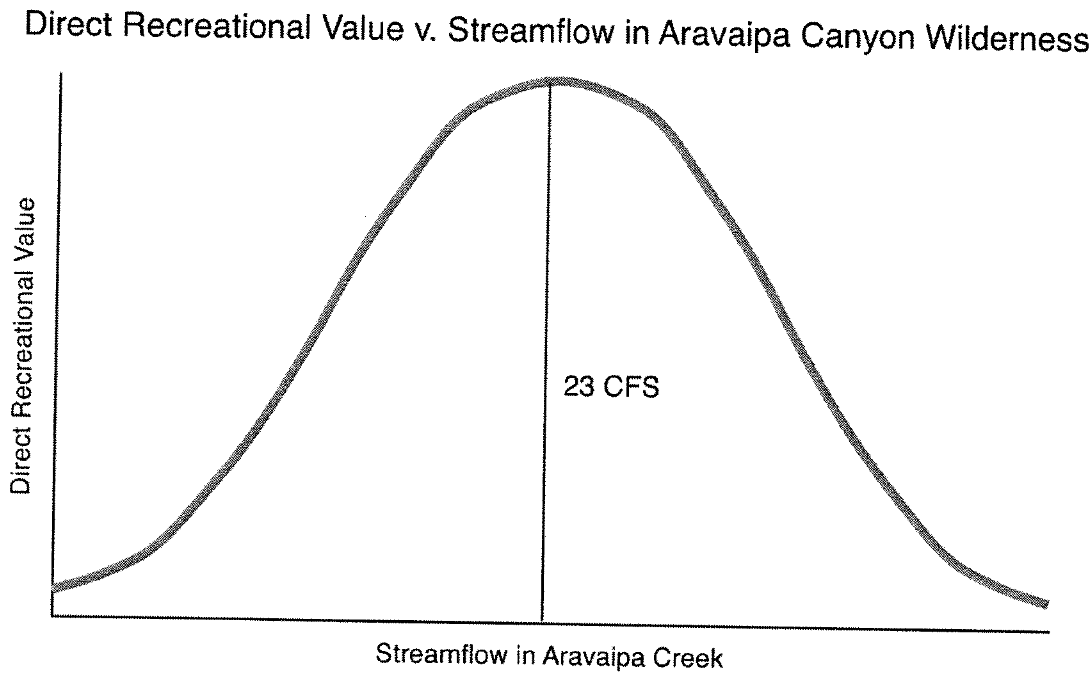

Figure 9. A hypothetical relationship between total recreational value and streamflow at Aravaipa Canyon Wilderness.

2. ***What flow regime is needed to support attributes of Aravaipa Canyon that are important for recreational visitors (e.g., habitat for fish in the creek and wildlife in the canyon; clear channels for hiking and beaches for camping; and lush riparian vegetation that affords natural beauty and shade)?***

Recreational activities such as birdwatching, watching fish and other wildlife, and camping on beaches and sand bars along the creek require sustained streamflows and even periodic flooding events (Brown 2004). Sustained flows are needed to support habitat for fish and wildlife that visitors like to view and photograph. Extreme flooding events are needed to clear brush from channels, reform beaches and clearings, and purge the canyon bottom of the artifacts of human use. Therefore, virgin flows in

Aravaipa Creek are likely to be needed to sustain attributes of Aravaipa Canyon Wilderness that were emphasized in the enabling legislation and are highly valued by recreational visitors.

CONCLUSIONS

The research and observations reviewed in this report support the following conclusions regarding how recreational values depend on streamflows in Aravaipa Canyon Wilderness:

1. Aravaipa Canyon Wilderness was designated to preserve ecological and recreational values that derive primarily from the unique existence of a perennial stream in a desert region.
2. Aravaipa Canyon Wilderness is a popular and highly valued recreational resource.
3. Aravaipa Creek is the primary recreational attraction of the wilderness area.
4. Streamflows in Aravaipa Creek support a verdant riparian zone that is foundational to recreational enjoyment of the wilderness area.
5. Direct recreational enjoyment of Aravaipa Canyon Wilderness (hiking and swimming in Aravaipa Creek; enjoying its sound and visual beauty; and perceiving the wilderness area as natural and untrammeled) has been documented to diminish as streamflows in Aravaipa Creek decline below and rise above 23 CFS.
6. Recreational activities indirectly served by Aravaipa Creek (e.g., birdwatching, wildlife viewing, and camping) depend on (1) streamflows needed to support the riparian zone and (2) extreme flooding events needed to clear and form the

stream channel. Thus, historical flows are probably the minimum needed to sustain indirect recreational values in the wilderness area.

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Appendix

Statement of Qualifications

My curriculum vita is included in the Appendix. I am currently the Director of Spatial Studies for the University of Redlands, California. In that position, I am responsible for helping to infuse spatial thinking throughout the undergraduate and graduate curriculum. Disciplinary areas touched by my work include environmental studies, government, history, literature, business, and religious studies. I am also chief executive officer (CEO) of Science Approach, a science education development business located in Tucson, Arizona. In that role and as executive director of the Center for Image Processing in Education, I have managed 18 federally and privately funded projects that introduced advanced technologies such as digital image analysis, remote sensing analysis, and geographic information systems to K-16 educators.

My doctorate is in renewable natural resource studies with a minor in sociology. As a graduate student and post-graduate scientist at the University of Arizona, I conducted research on the sociology of wilderness recreation and other forms of outdoor recreation. My dissertation research focused on determining the social contact norms for visitors to Aravaipa Canyon Wilderness during 1987 and 1988 (Moore 1989). The dissertation was an outgrowth of research conducted for the Bureau of Land Management to evaluate the recreational carrying capacity of Aravaipa Canyon Wilderness (Moore et al. 1989). This research also led to statistical analyses conducted to correlate perceptions of recreational value in Aravaipa Canyon Wilderness to streamflows in Aravaipa Creek (Moore, Wilkosz, and Brickler 1990, Moore et al. 1989).

Curriculum Vitae

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Professional Preparation:

1989 University of Arizona, Tucson. Ph.D. Renewable Natural Resources Studies and Sociology
1982 University of Illinois, Chicago. M.B.A. Human Resources Management and Accounting
1978 Southern Illinois University, Carbondale. B.A. Biology.

Appointments:

2013- Director of Spatial Studies, University of Redlands, Redlands, California.
2003- CEO. Science-Approach, LLC. Tucson, Arizona.
2000-2008 Executive Director. Center for Image Processing in Education (CIPE). Tucson, Arizona.
1999-2000 Associate Director. Center for Image Processing in Education (CIPE) Tucson, Arizona.
1995-1999 Director of Evaluation Services. Center for Image Processing in Education (CIPE), Tucson, Arizona.
1995-1998 Evaluator for NSF project: Family Math. New Frontiers, Tucson, Arizona.
1992-1996 Adjunct Faculty. Pima Community College, Tucson, Arizona.
1995-1996 Project Director, Peer Study Groups for Human Biology, Coalition to Increase Minority Degrees.
1993-1995 Senior Instructional Specialist. University of Arizona, Women's Studies Department, Tucson, Arizona.
1984-1993 Senior Research Specialist, Senior Instructional Specialist, and Research Associate, University of Arizona,
1992-1994 Project Director, Peer Study Groups for Native Americans. Coalition to Increase Minority Degrees.
1990 Assistant Professor (visiting), Environmental Studies Program, St. Lawrence University, Canton, New York.
1987-1988 Instructor, School of Renewable Natural Resources, University of Arizona, Tucson.

Currently Funded Projects (Principal Investigator [PI], Co-PI, or Evaluator)

VoxelDiscovery 5-8. NIH/NICHD. Phase I SBIR. $500,000. PI.

Completed Projects (PI)

Channel Mappers. NOAA California B-WET Program. $50,000. CIPE. PI.

CoastLines. NSF/DRL. $1,039,220. Science Approach. PI.

Exploring Data with GIS to Experience Sanctuaries. NOAA. $25,000. CIPE. Project Director (Contract).

Mapping an Ocean Sanctuary. NSF-Geoscience Education. $75,000. CIPE.

Mapping Ocean Sanctuaries. National Geographic Society. $45,000. CIPE. PI.

NeuroVisions. NIH/National Institute of Mental Health. Phase II SBIR. $750,000. PI.

NeuroVisions. NIH-National Institute of Mental Health. Phase I SBIR. $100,000. Science Approach.

NIH Biotechnologist. NIH/NLM. $100,000. Science Approach. PI.

Ocean Explorers. NSF-ITEST Comprehensive Project. $1.2 million. Center for Image Processing in Education (CIPE). PI.

Powers of Inquiry. NIH-National Institute of Environmental Health Sciences. Phase I SBIR. $750,000. Science Approach.

Powers of Inquiry. NIH-National Institute of Environmental Health Sciences. Phase II SBIR. $750,000. Science Approach. PI.

Satellite Observations for Science Education. NASA. $50,000. Evaluator.

Simplified Image Management and Processing Learning Environment for Science (SIMPLE Science). NSF NSDL. $400,000. CIPE. PI.

Visualizing Addiction. NIH-National Institute on Drug Abuse. $500,000. CIPE.

Visual Instruction Support for Inquiry-based Odysseys in the NASA Explorer Schools (VISIONES). NASA Explorer Schools Program. $300, 000. CIPE. PI.

Volumetric Imaging for Science Instruction of an Open Nature (VISION). NIH-National Institute of Child Health and Human Development (NICHD). Phase II STTR. $750,000. PI.

Volumetric Imaging for Science Instruction of an Open Nature (VISION). NIH-National Institute of Child Health and Human Development. Phase I STTR. $100,000. Science Approach. PI.

Publications:

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Brown, Wynne, and Steven Moore. In Revision. Exploring Neuron Form and Function: Using 3D Imaging of the Second Brain to Predict Neuronal Shape. Tucson, Arizona: Science Approach.

Synergistic Activities

Community Outreach

Upward Bound Instructor, Pima Community College, Tucson, Arizona

Participation in Professional Groups and Meetings:

Spatial Intelligence and Learning Center, Spatial Network
Tucson Business and Education Roundtable
Faculty for Undergraduate Neuroscience
American Association for the Advancement of Science
National Science Teachers Association
Greater Arizona e-Learning Association (Board Member and Secretary)

Review Panels:

Coalition to Increase Minority Degrees: 1992-1996.
Environmental Protection Agency Environmental Education Grants: 2003.
National Science Foundation: 16 panels during 2002-2012.
National Oceanic and Atmospheric Administration B-WET Program (2006).
National Institutes of Health (2009, 2011-2012).

Presentations at Professional, Scholarly, and Community Events

Moore, Steven D. and Paul Johnson. 1996. Image processing as an instructional tool for anatomy and physiology education at community colleges. Human Anatomy and Physiology Society Annual Meeting. Portland, Oregon. 1996.

Moore, Steven D. 1996. Image processing as a work place tool. Career Expo, Long Beach, California, 1996.

Moore, Steven D. 1996. Image processing as a tool for college science instruction. Society for College Science Teaching, Phoenix, Arizona, 1996.

Adams, Don, Paul Johnson, Sandy Zetlan, and Steven Moore. 1996. Image processing as a tool for allied health anatomy and physiology instruction. League for Innovation in the Community Colleges, Phoenix, Arizona, 1996.

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Johnson, Paul and Steven Moore. 1997. Using image processing in human anatomy and physiology instruction at community colleges. League for Innovation in the Community Colleges Annual Conference. Atlanta, Georgia. Moore,

Moore, Steven. 1998. Conversion of USGS 7. 5 Minute DEMs to a TIFF Image Format with Public Domain Software. National Imaging Technology in Education Conference. Mesa, Arizona.

Moore, Steven and Carla McCauliffe. 1998. Image processing, a tool for unlimited discovery. National Education Computing Conference. San Diego, CA.

Moore, Steven. 1998. Learning comes in bytes and megabytes: Evaluation of an Advanced Technological Education Project. League for Innovation in the Community College, Miami, Florida.

Moore, Steven. 1999. Image analysis and remote sensing for education. Conference on Remote Sensing Education. Boulder, Colorado.

Moore, Steven. 2000. Using Digital Raster Graphics in ArcView GIS. National Imaging Technology in Education Conference, Rochester Institute of Technology, New York.

Moore, Steven. 2000. What's up in Wayne s world? Image/J. National Imaging Technology in Education Conference, Rochester Institute of Technology, New York.

Moore, Steven and David Doty. 2000. Image analysis for anatomy and physiology, biology, and biotechnology education. Invitational workshop at the National Association of Biology Teachers annual meeting, Orlando, Florida.

Novak, Robert and Steven Moore. 2001. Booth presentation in showcase session of the Advanced Technological Education (ATE) program's Principal Investigators Conference, "Blueprint for Change."

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Moore, Steven. 2001. Why did the sheep cross the road? ESRI's Southwest User Group Conference (SWUG), Tucson. October 2001.

Moore, Steven. 2001. Discovering GIS Workshop. Visualization Technologies in Education Institute (VisTE). Tucson, Arizona. July 2001.

Moore, Steven. 2001. Workshops on Digital Image Processing, Digital Image Analysis, and Digital Image Capture. National Association of Biology Teachers annual conference. Montreal, Quebec. November 2001.

Moore, Steven and Don Adams. 2002. Image Analysis for Science Instruction. Partners In Science Annual Conference. San Diego, CA. 18 January 2002.

Moore, Steven, Francisco Guzman, and Kathi Pearlmutter. 2002. Imaging and Optical Discoveries for Science and Mathematics Education. Photonics West. San Jose, CA. 19 January.

Moore, Steven, Kris Rees, and Victor Shamas. 2002. *Visualizing Addiction*. Booth presentation at national meeting of the National Science Teachers Association. San Diego, CA: 26-30 March.

Moore, Steven, Kris Rees, and Victor Shamas. 2002. *Visualizing Addiction*. Booth presentation at National Educational Computing Conference. San Antonio, TX: 17-19 June.

Moore, Steven. 2002. Discovering GIS Workshop, Managing GIS Datasets Workshop, GIS Field Data Collection Workshop. Visualization Technologies in Education Institute, Tucson. July 16-20.

Moore, Steven and Rober Novak. 2002. Consortium for Optics and Imaging Education, Advanced Technological Education Conference, Assessing the Impact. American Association of Community Colleges. Washington DC. October 24-26.

Moore, Steven. 2002. Workshops on Digital Image Processing, Digital Image Analysis, and Digital Image Capture. National Association of Biology Teachers annual conference. Cincinnati, Ohio. November 1-2.

Moore, Steven, Kris Rees, and Victor Shamas. Visualizing Addiction. Booth presentation at international meeting of the Society for Neuroscience. Orlando, Florida: 2-6 November.

Moore, Steven. 2002. Digital Image Capture and Analysis. Exhibitor workshop at National Science Teacher's Association regional conference. Albuquerque, New Mexico. 4-6 December.

Moore, Steven, Kris Rees, and Victor Shamas. 2003. *Visualizing Addiction*. Workshops and booth presentation at National Educational Computing Conference. Seattle, Washington: 28 June-2 July.

Moore, Steven. 2003. *Imaging and the Brain Institute*. Digital image capture and analysis workshop for educators. Evergreen State College, Olympia, Washington: July 7-11.

Doty, David and Steven Moore. 2003. Digital Image Capture and Analysis Teacher Workshop. Syracuse Public Schools, New York. September 25-26.

Moore, Steven. 2003. Workshops on Digital Image Processing, Digital Image Analysis, and Digital Image Capture. National Association of Biology Teachers annual conference. Portland, Oregon. October 10-11.

Moore, Steven. 2003. Mapping An Ocean Sanctuary: Using Geographic Information Systems To Teach Ocean Science. California Islands Symposium, December 1-3.

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Moore, Steven. 2004. Workshops on Digital Image Processing, Digital Image Analysis, Digital Image Capture, and Geographic Information Systems. National Association of Biology Teachers annual conference. Chicago, Illinois. October 10-11.

Moore, Steven. 2004. Guiding Students to Light. Optical Society of America Annual Meeting Teacher's Day. Rochester, New York. 12 October.

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Edelson, Daniel, Elizabeth Youngman, and Steven Moore. 2006. Session on using GIS and NSF Long-Term Environmental Research (LTER) data for education. NSF LTER All Scientists Meeting. Estes Park, Colorado.

Moore, Steven and David Doty. 2006. Image capture and analysis for biology instruction. National Association of Biology Teachers. Albuquerque, New Mexico.

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Moore, Steven. 2008. How to Write a Winning Grant Proposal (Four Webinars). *CoastLines*. Tucson, Arizona: Science Approach.

Moore, Steven and Robert Kolvoord. 2008. How to Start, What is Important, and How to Assess Student Learning Webinar. *CoastLines*. Tucson, Arizona: Science Approach.

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Moore, S. (2009). *The Science Approach*. Paper presented at the Business Education Roundtable, Tucson Arizona.

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Moore, Steven. 2013. Modeling Modern Science for Middle School Students. Presentation to the Old Pueblo Rotary Club, Tucson, Arizona.

Moore, Steven and Mary Moore. 2013. Understanding Neurogenesis Through Digital Microscopy. Science in the City, Tucson Children's Museum, Arizona.

Moore, Steven. 2013. Making it Easy, Relevant, and Smart: Overcoming Barriers to the Use of Visualization in STEM Education. In Gordon Research Conference on Visualization in Science and Education. Bryant University, Smithfield, Rhode Island.

Collaborators & Other Affiliations

Collaborators and Co-Editors: William Beaver, Consultant, Tucson; Julie Bursek, Channel Islands National Marine Sanctuary (CINMS); Bruce Caron, Ph.D., New Media Research Institute; Sean Drummond, Ph.D., University of California, San Diego; Carsten Duch, Ph.D., Arizona State University; Daniel Edelson, Northwestern University; Laura Francis, CINMS; Elizabeth Gould, Ph.D., Princeton University; Donald Haviland, Ph.D., California State University, Long Beach; Judy Kelley, West Texas A&M University; Robert Kolvoord, Ph.D., James Madison University; Edythe London, UCLA Medical School; Will McClintock, UC Santa Barbara; Steven McGee, the Learning Partnership; Keith Mott, Ph.D., Utah State University; Eileen O'Toole, Ph.D., University of Colorado; B. Ramakrishna, Arizona State University; Richard Robb, Ph.D., Mayo Institute; David Smith, Northwestern University; Peg Steffen, NOAA; Susan Tapert, Ph.D., University of California, San Diego; William Tyler, Ph.D., Arizona State University; Allison Whitmer, Ph.D., Georgetown University; Carolyn Willard, GEMS Project, Lawrence Hall of Science, UC Berkeley; and Dawn Wright, Oregon State University.

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References

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APPENDIX C-4

Rec'd 3/11/13

U.S. Department of Justice

Environment and Natural Resources Division

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90-6-2-47C

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RECEIVED

MAR 11 2013

LEGAL
DEPT OF WATER RESOURCES

March 8, 2013

VIA First Class Mail

Re: *In re Aravaipa Canyon Wilderness Area,* Contested Case No. W1-11-3342

To Parties on the Court Approved Mailing list:

Enclosed please find the report of United States prepared by Steve Swanson of the Bureau of Land Management, entitled *Aravaipa Creek Arizona, Federal Reserve Water Right Claims.*

Sincerely,

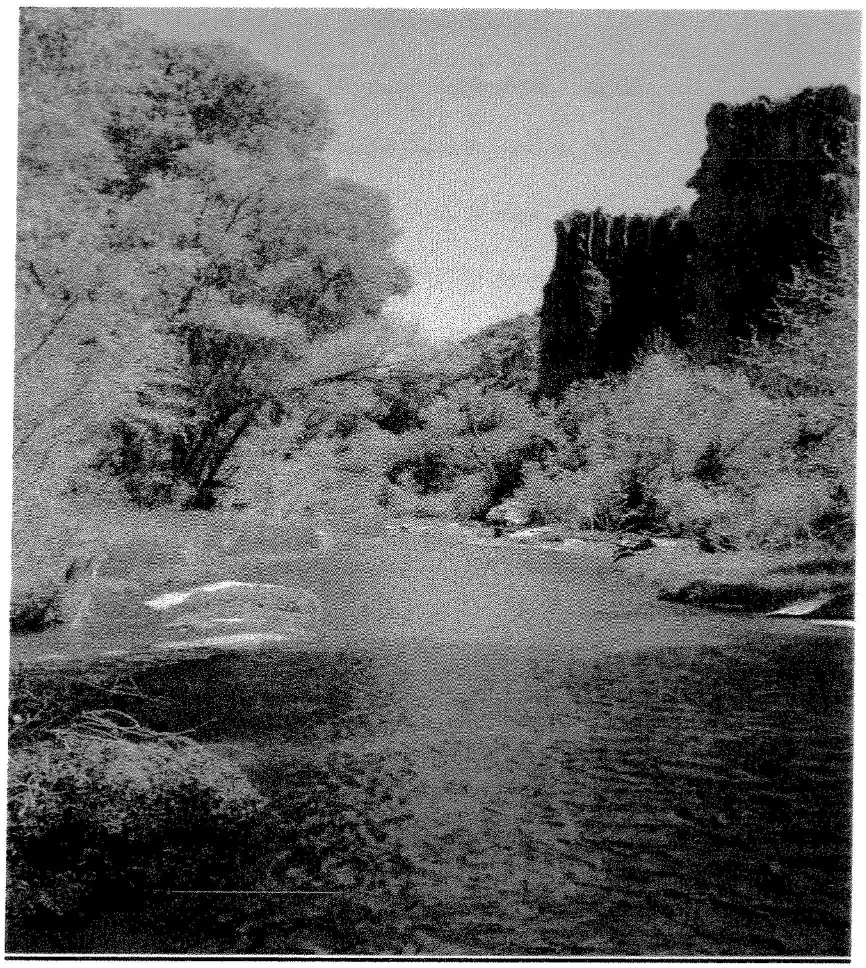
Susan Middagh
Susan Middagh
Paralegal Specialist

Encl.

Aravaipa Creek Arizona

Federal Reserve Water Right Claims

RECEIVED
MAR 11 2013
LEGAL
DEPT OF WATER RESOURCES



Bureau of Land Management

Department of Interior

2013

Steve Swanson

Surface Water Hydrology Specialist

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Introduction

In 1984 the United States Congress passed Public Law 98-406 recognizing that Aravaipa Canyon "is a primitive place of great natural beauty that, due to the rare presence of a perennial stream, supports an extraordinary abundance and diversity of native plant, fish, and wildlife, making it a resource of national significance;" and establishing the Aravaipa Canyon Wilderness "for the preservation and protection of this relatively undisturbed but fragile complex of desert, riparian, and aquatic ecosystems, and the native plant, fish, and wildlife communities dependent on it…" This Congressional reservation of Aravaipa's public lands into the National Wilderness Preservation System implied a corollary reservation of federal water rights to fulfill the purposes of the wilderness designation; indeed, the implied reservation was made explicit in subsequent legislation (1990) which expanded Aravaipa Canyon Wilderness by more than 12,000 acres (P.L. 101-628). In 2009 the Arizona Special master presiding over the Gila River adjudication initiated a contested case to address federal claims for reserved rights to waters in the Aravaipa Canyon Wilderness Area (ACWA). The following document presents the foundation for the federal claims to reserved rights for instream flow in the Aravaipa Canyon Wilderness.

Hydrologic Characterization

In Public Law 98-406, Congress identified the need to protect the entire complex of desert, riparian, and aquatic ecosystems and the native **communities dependent on it** [emphasis added]. The intent of the legislation is clear: to preserve the entire ecosystem rather than just addressing the needs of a few aquatic and riparian species. Since what is good for a few species is not necessarily what is good for the entire ecosystem [and vice versa] (Poff et al. 1997), characterization and quantification of this federal reserved water right must assess both the aquatic and riparian ecosystems and their dependence on the surface and ground waters of the area.

The integrity of stream corridors and their associated ecosystems results from the dynamic character of these environments (Richter et al. 1996, 1997). Dynamism is also central to the diversity of these systems, and flow is the master variable governing the distribution, abundance, and condition of the entire range of species (Poff et al. 1997). Flow regime is the primary determinant of environmental conditions that define channel and floodplain habitats (Arthington et al. 1991; Instream Flow Council 2002). Low flows define the basic stream character, including seasonality of water levels and extent of wet and dry stream reaches (Figure 1). Small floods provide environmental cues for flora and fauna, refresh ambient water quality, and trigger fish movements and riparian reproduction. Large floods perform the same functions as small floods and also reshape the stream channel through the scour and fill of bed sediments, creating new habitats and recharging floodplain alluvium (King et al. 2003). The natural variation in flow regime allows different species to flourish at different times (Instream Flow Council 2002), with some species flourishing in wet seasons or wet years and others flourishing in dry seasons or drought periods (Poff et al. 1997). Fluctuations in flow stimulate specific responses in aquatic and riparian plants and animals with life cycles timed to avoid or exploit flows of variable magnitude (Instream Flow Council 2002). Thus, the natural flow regime not only creates a mosaic of available habitats, but also influences the distribution of plants and animals throughout those habitats (Richter et al. 1997).

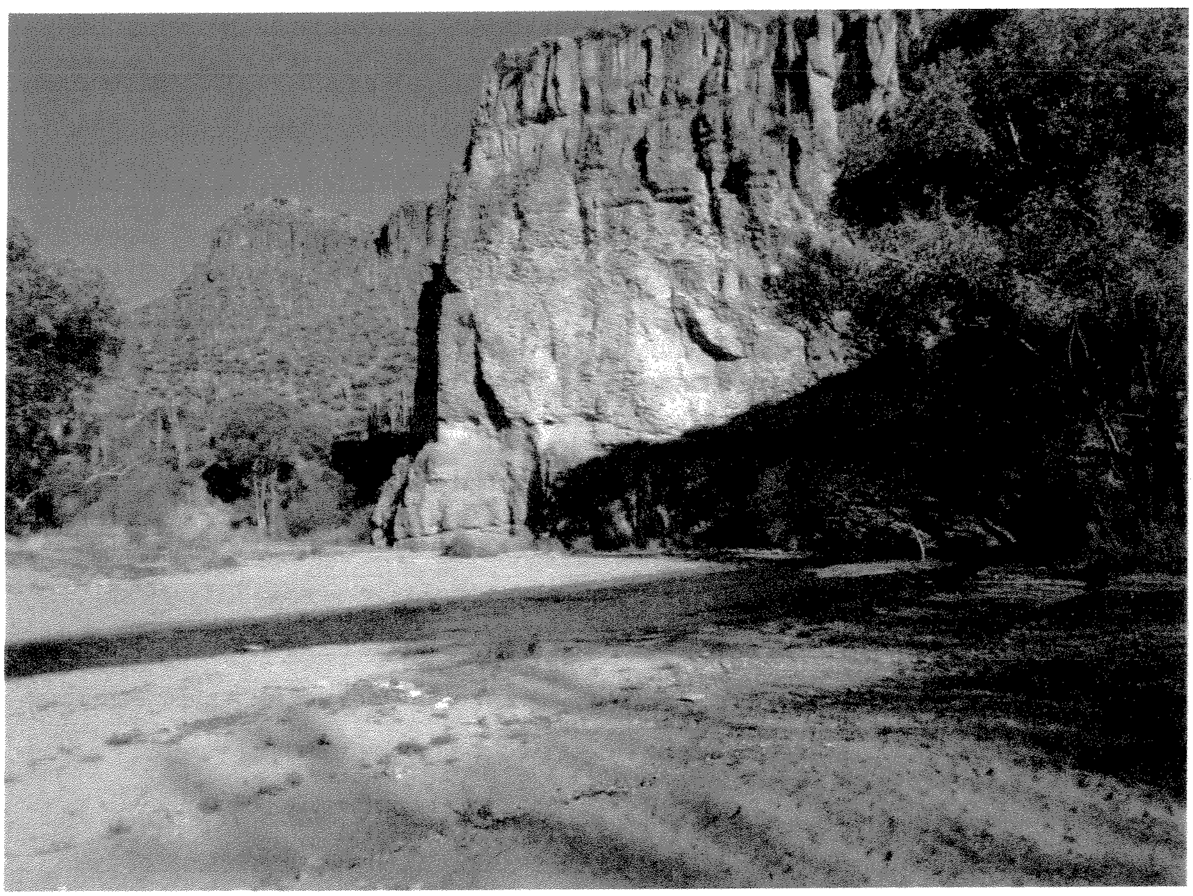


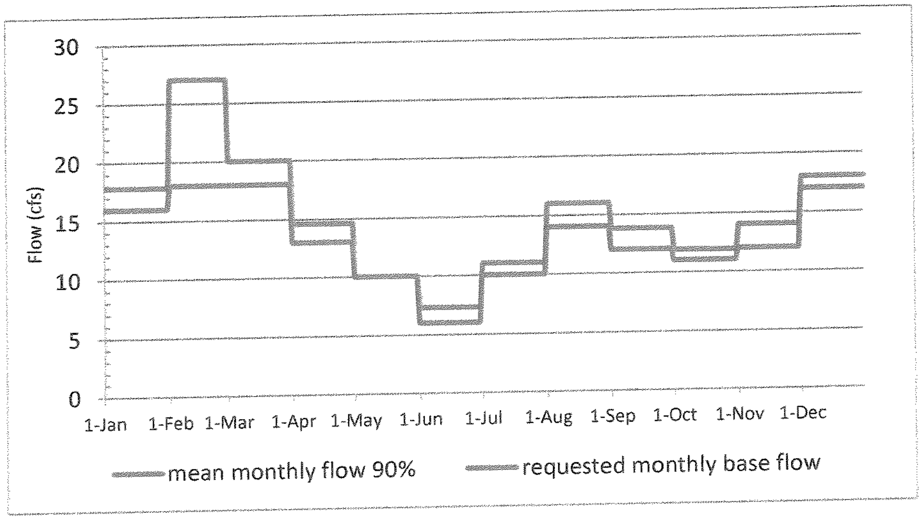
Figure 1. Low flows define seasonality of water levels and extent of wet and dry stream reaches.

Since different parts of the flow regime elicit different responses from the ecosystem (King et al. 2003), the natural flow regime must be the fundamental guide to maintaining ecosystem integrity. If essential features of the natural flow regime can be incorporated into the water right, the extant biota (flora and fauna) and functional integrity of the ecosystem should be maintained (Arthington et al. 1991). The water right must address seasonal variability in base flows and high flows, preferably recommending monthly flows to address variability of base flows and preserving as much of the natural flood regime as possible (King et al. 2003; Arthington et al. 1991). Therefore, the first approach for quantifying the water right is to characterize the natural, long-term flow regime. This characterization is best represented by an annual hydrograph that illustrates the typical flow fluctuations over a 12-month calendar year. However, the annual hydrograph should not be characterized by the conditions of flow from a single year. The flow regime is created by conditions established over a number of years. Because the reservation was established in 1984, conditions prior to this date should be evaluated to characterize the flow regime.

Stream flow claims for Aravaipa Creek are based on complete years of record between 1932 and 1984 at the USGS stream gage (# 09473000) located on Aravaipa Creek near Mammoth, AZ. Twenty-eight complete years of record are available in this period and include the following years: 1932-1940, 1942, 1967-1984. The beginning of the analysis was set at 1932 to coincide with the first available year of complete and reliable record. The end of the analysis was set at 1984 which coincides with the establishment of the Aravaipa Canyon Wilderness Area. Base flows claimed for each month represent the median of all daily means (Appendix 1) for the indicated month in the period of record.

Aravaipa Creek Monthly Claimed Base Flows		
	Base Flow (cubic feet per second)	Volume (acre-feet)
January	16	982
February	18	998
March	18	1105
April	13	772
May	10	614
June	6	356
July	10	614
August	14	859
September	12	713
October	11	675
November	12	713
December	17	1043
Total Annual Base Flow		9444

The hydrology of Aravaipa Canyon is predominantly driven by flood events. The top ten percent of the record, which encompasses all of the flood events, accounts for nearly two thirds all of the water moved through the system over 28 years of record. Ninety percent of the period of record accounts for only thirty six percent of the total volume. The plot below illustrates the mean monthly flow of the bottom ninety percent (top ten percent removed) for the period of record along with the requested monthly base flows listed above.



What the graph indicates is the similarity between the requested monthly base flows and the adjusted ninety percent monthly means. With the exception of February, all of the requested base flows are within approximately 10% of the means. The requested base flows represent most of the water the system has seen during ninety percent of the period of record.

The above analysis of monthly flows recognizes that approximately sixty-six percent of the water passing through the canyon is associated with random flood events that are critical to maintaining the wilderness character of the ecosystem (see Aravaipa Fisheries and Riparian reports). The table below summarizes the statistical characteristics of the historical flood regime over the period of record up to 1984.

	Return Period (years)						
Flow Type (cfs)	1.25	2	5	10	25	50	100
Instantaneous	2200	4540	10100	15900	26300	37000	50700
1-Day high	306	792	2265	4090	7935	12395	18741
3-Day High	165	439	1287	2348	4599	7220	10959
5-Day high	117	304	859	1527	2893	4434	6573
7-Day high	95	242	662	1153	2135	3218	4696

Based on the range of flood flows in the table above and the stochastic nature of these events, identifying a specific quantified flood regime (e.g., magnitude, duration, frequency) suitable for maintaining the wilderness ecosystem is not practical for the water right claim. As a surrogate for a specified flood regime, a mean annual volume of 24,600 ac-ft is claimed to protect the annual wilderness character of the hydrograph. This 24,600 ac-ft includes the 9,444 ac-ft identified above as monthly base flows. The additional 15,156 ac-ft is claimed as random and unmitigated flood flows distributed throughout the year. In addition to the annual hydrograph the capability to pass the periodic instantaneous flood events (e.g., 2, 5, 10, 25, 50, 100 yr) must be maintained.

Summary

Aravaipa Creek Annual Claimed Water Right		
	Base Flow (cubic feet per second)	Volume (acre-feet)
January	16	982
February	18	998
March	18	1105
April	13	772
May	10	614
June	6	356
July	10	614
August	14	859
September	12	713
October	11	675
November	12	713
December	17	1043
Total Annual Base Flow		9444
Unconstrained Flood Flows		15156
Total Annual Volume		24600
Unconstrained capability to pass up to the 100 year flood event of 50,700 cfs		

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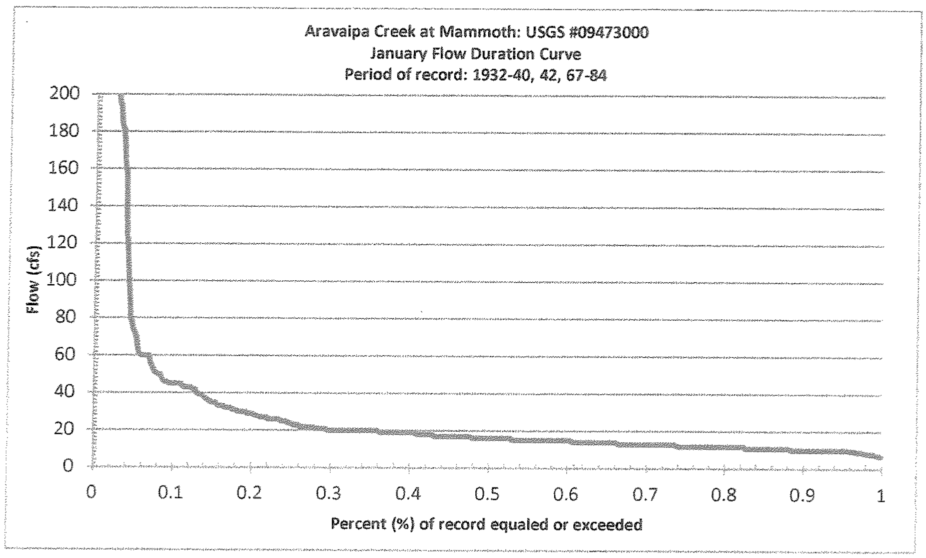
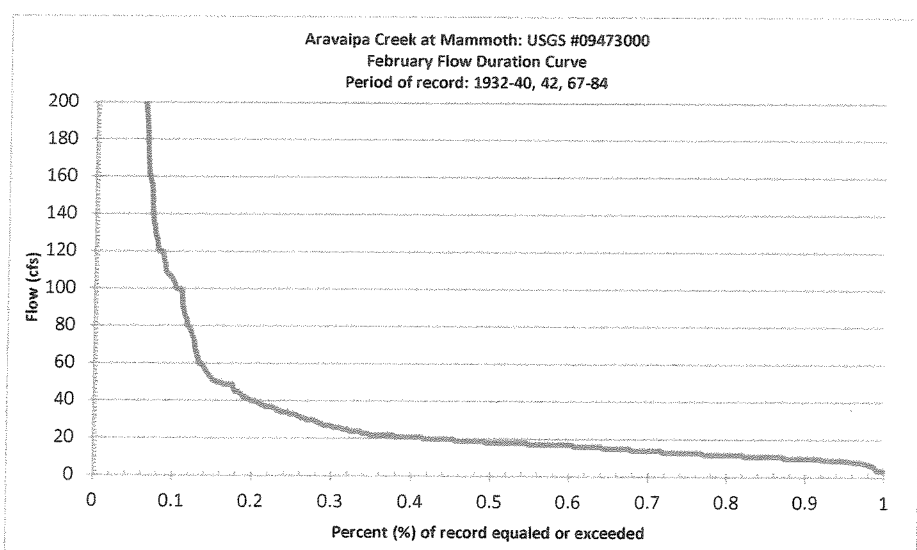
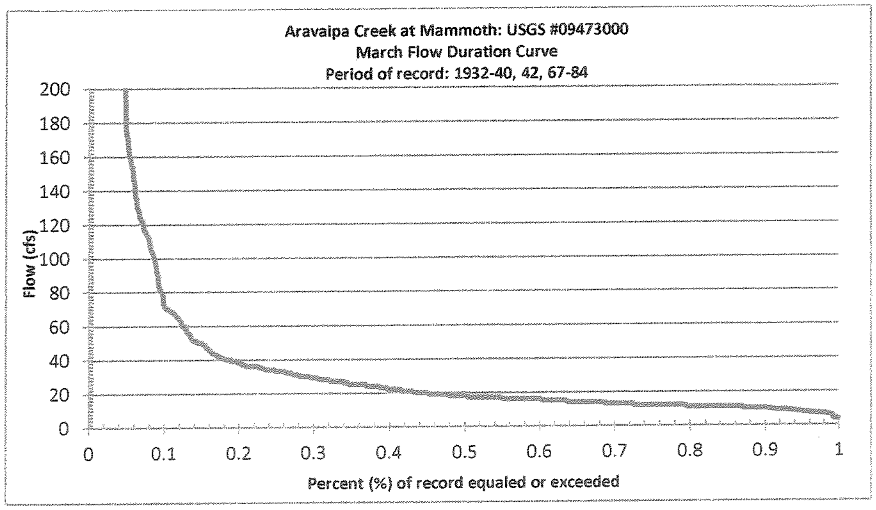
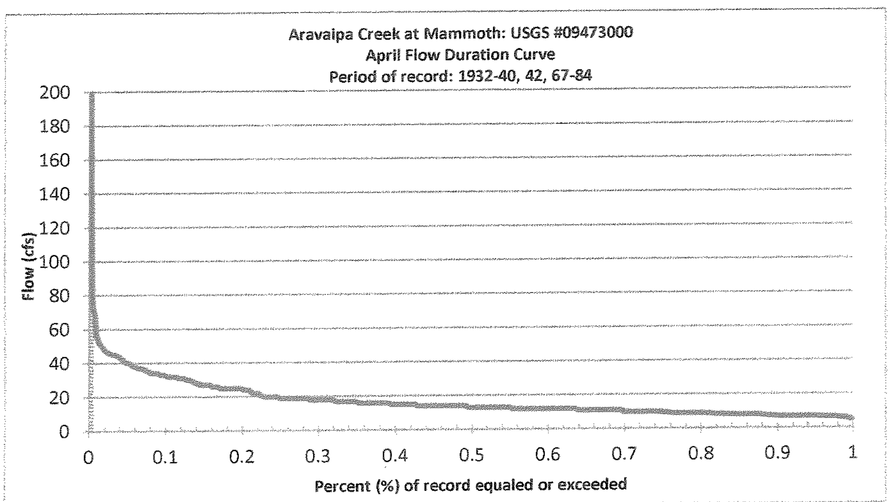
Appendix 1

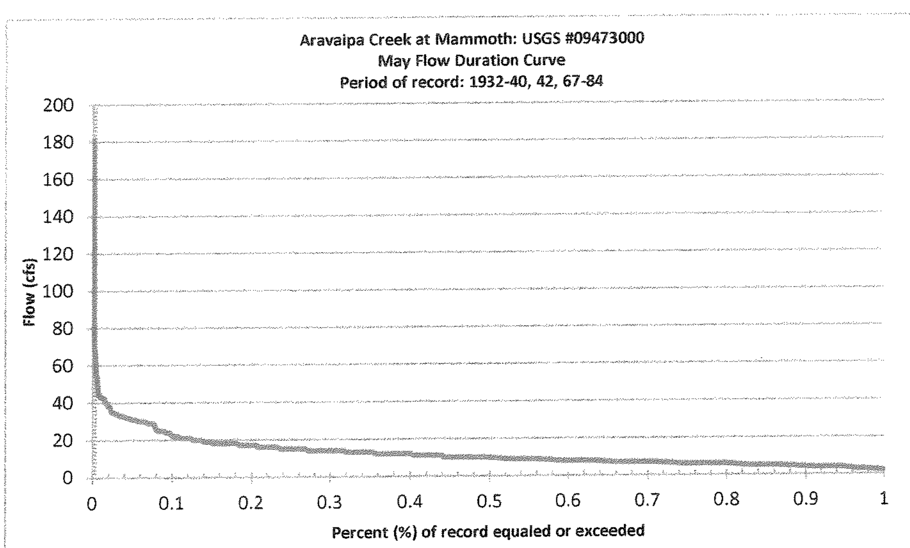
Flow-Duration Curves

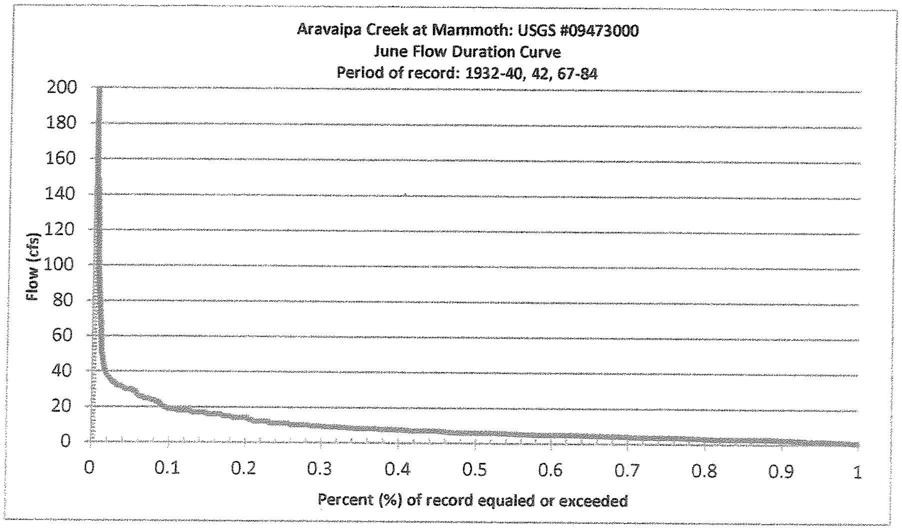


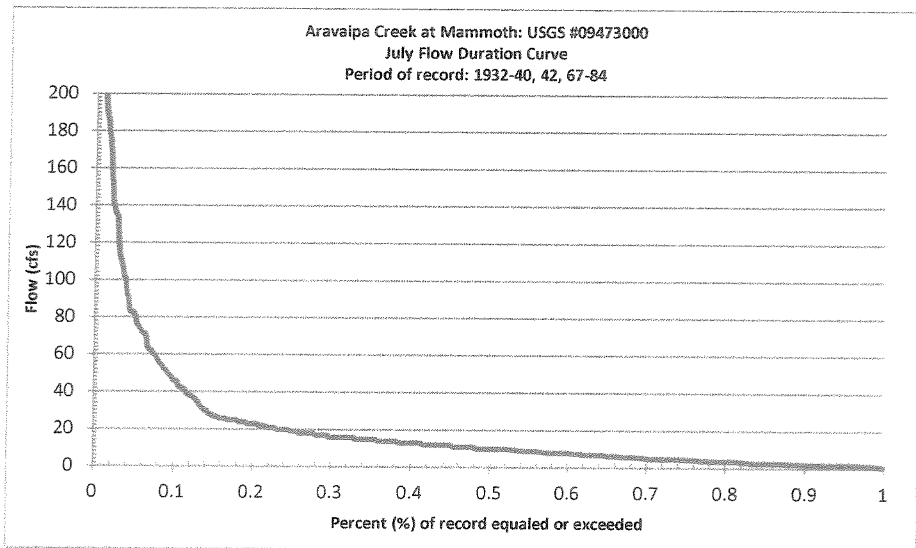


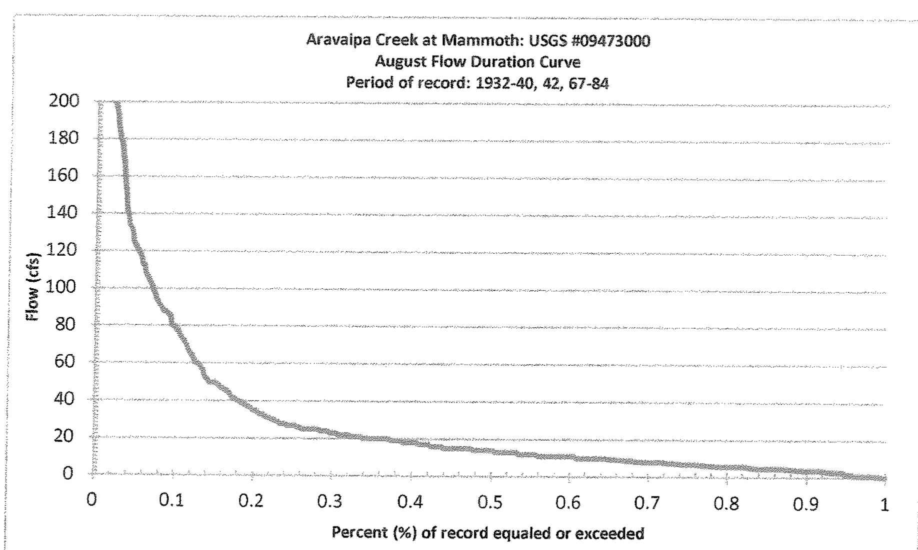

Aravaipa Creek at Mammoth: USGS #09473000
March Flow Duration Curve
Period of record: 1932-40, 42, 67-84
Flow (cfs)
200
180
160
140
120
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percent (%) of record equaled or exceeded

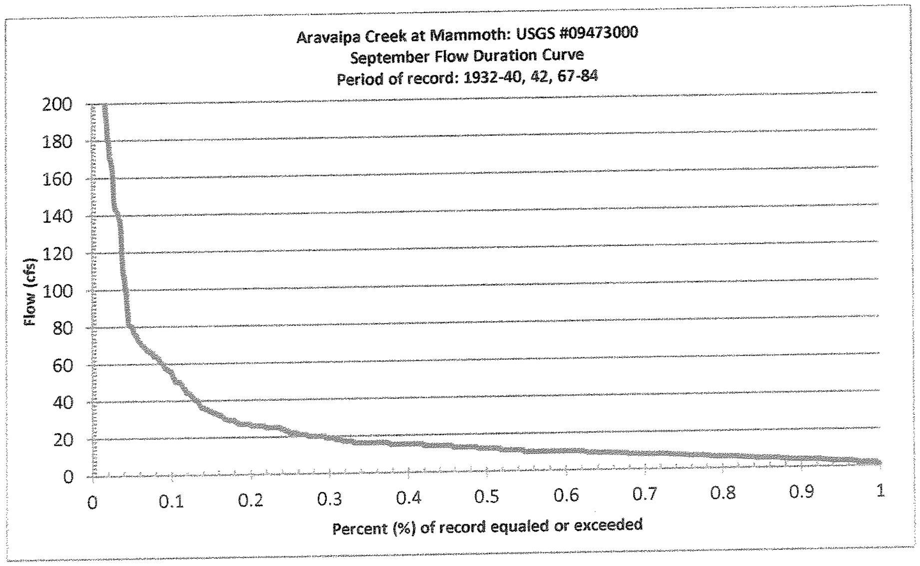

Aravaipa Creek at Mammoth: USGS #09473000
April Flow Duration Curve
Period of record: 1932-40, 42, 67-84
Flow (cfs)
200
180
160
140
120
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percent (%) of record equaled or exceeded

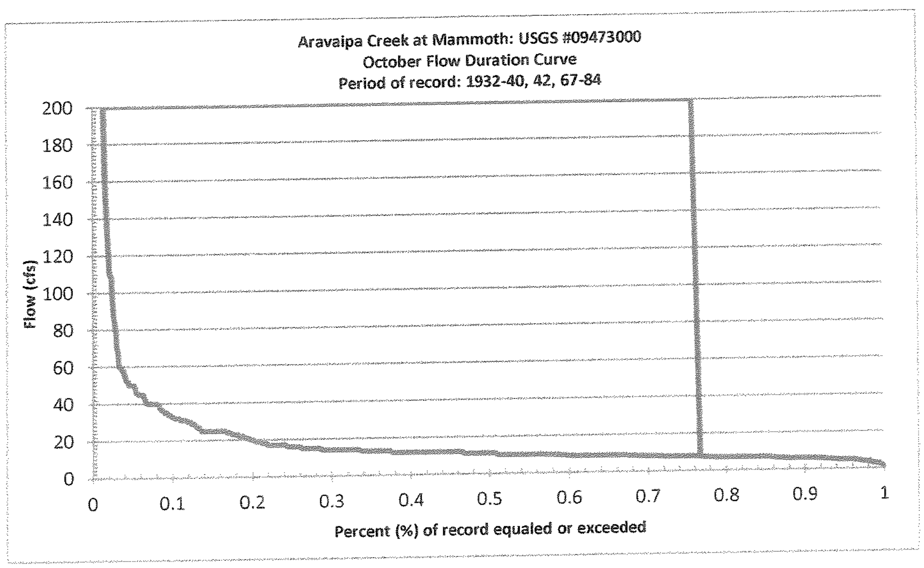

Aravaipa Creek at Mammoth: USGS #09473000
May Flow Duration Curve
Period of record: 1932-40, 42, 67-84
Flow (cfs)
200
180
160
140
120
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percent (%) of record equaled or exceeded

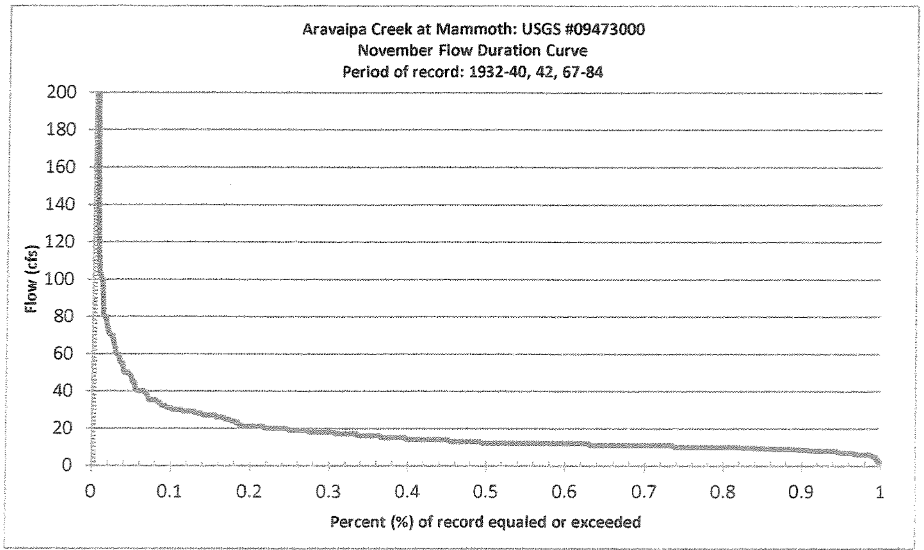

Aravaipa Creek at Mammoth: USGS #09473000
June Flow Duration Curve
Period of record: 1932-40, 42, 67-84
Flow (cfs)
0
20
40
60
80
100
120
140
160
180
200
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percent (%) of record equaled or exceeded

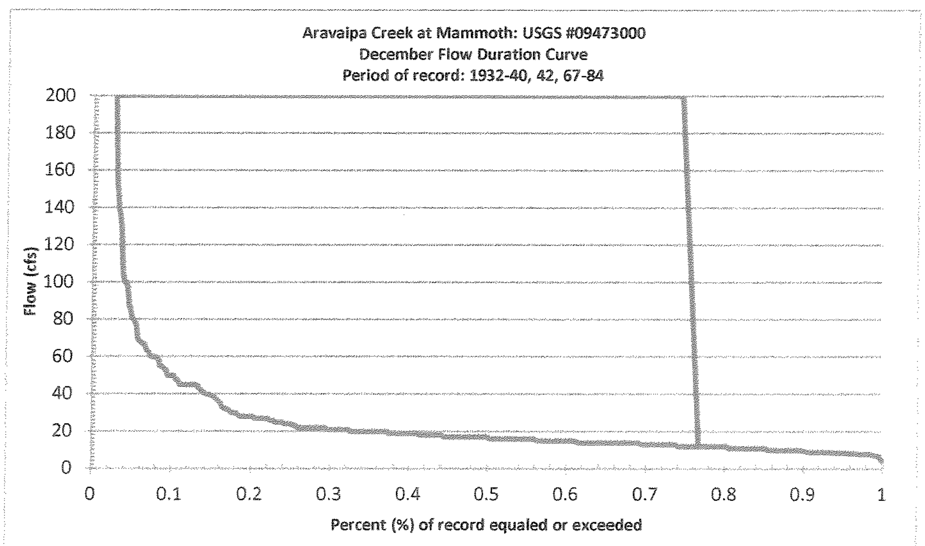

Aravaipa Creek at Mammoth: USGS #09473000
July Flow Duration Curve
Period of record: 1932-40, 42, 67-84
Flow (cfs)
0
20
40
60
80
100
120
140
160
180
200
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percent (%) of record equaled or exceeded


Aravaipa Creek at Mammoth: USGS #09473000
August Flow Duration Curve
Period of record: 1932-40, 42, 67-84
Flow (cfs)
0
20
40
60
80
100
120
140
160
180
200
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percent (%) of record equaled or exceeded


Aravaipa Creek at Mammoth: USGS #09473000
September Flow Duration Curve
Period of record: 1932-40, 42, 67-84
Flow (cfs)
200
180
160
140
120
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percent (%) of record equaled or exceeded


Aravaipa Creek at Mammoth: USGS #09473000
October Flow Duration Curve
Period of record: 1932-40, 42, 67-84
Flow (cfs)
200
180
160
140
120
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percent (%) of record equaled or exceeded

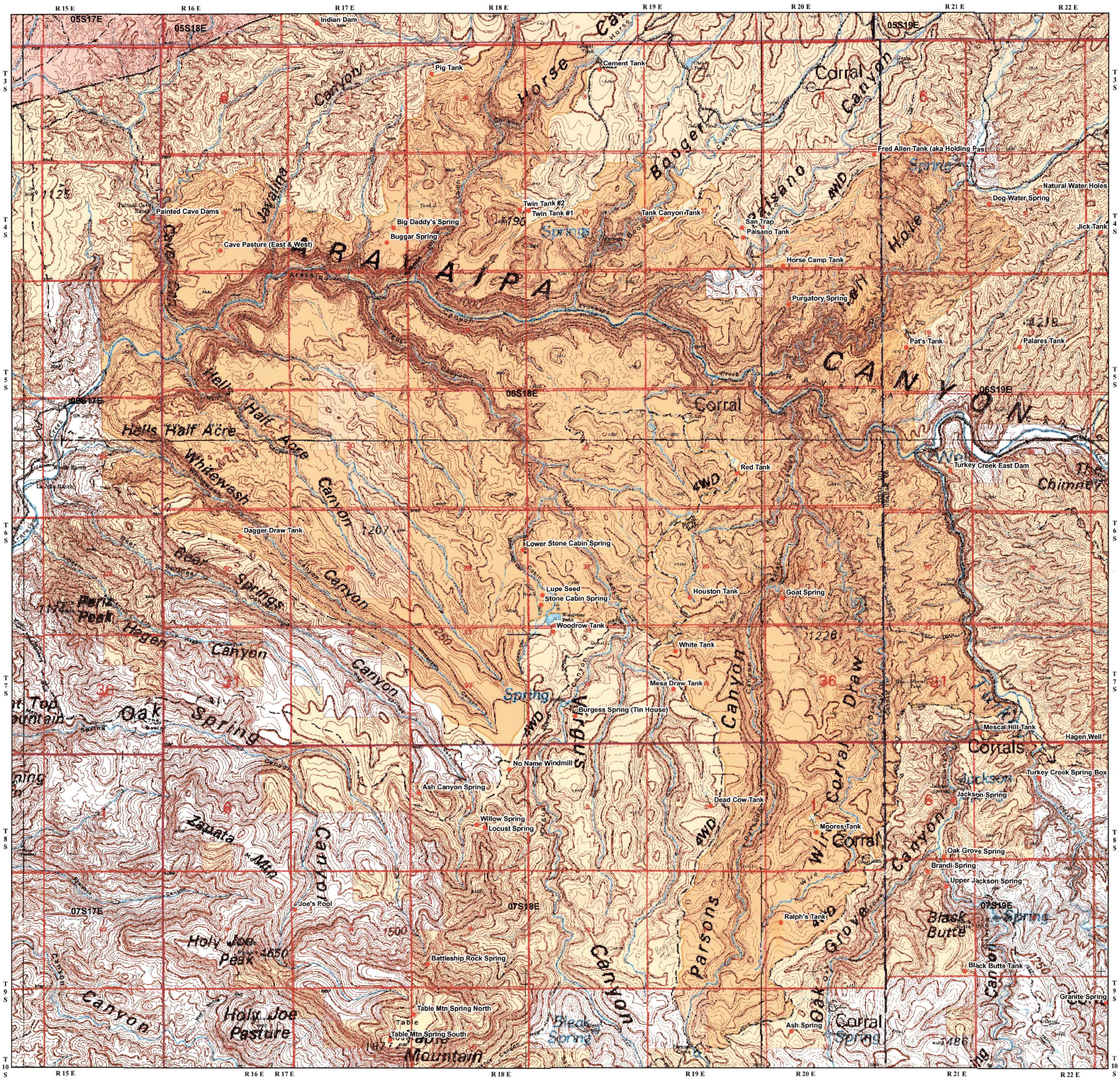

Aravaipa Creek at Mammoth: USGS #09473000
November Flow Duration Curve
Period of record: 1932-40, 42, 67-84
Flow (cfs)
200
180
160
140
120
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percent (%) of record equaled or exceeded

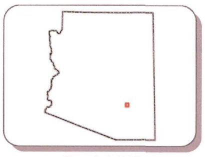

Aravaipa Creek at Mammoth: USGS #09473000
December Flow Duration Curve
Period of record: 1932-40, 42, 67-84
Flow (cfs)
200
180
160
140
120
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Percent (%) of record equaled or exceeded

APPENDIX C-5

State of Arizona

Surface Management Responsibility - Custom 1:100,000 Scale





Map created on Oct 05, 2010

LAND OWNERSHIP LEGEND

- Private Lands
- State Lands
- State Wildlife Area
- City, State, County Parks
- County Lands
- Indian Lands or Reservations
- Bureau of Land Management (BLM)
- National Forest Lands (USFS)
- National Park Service (NPS)
- USFW Service, National Wildlife Refuges
- BLM Wilderness Area
- Forest Service Wilderness Area
- NPS Wilderness Area
- USFW Service Wilderness Area
- BLM National Monument
- National Conservation Area
- Military Reservations/Corps of Engineers
- Bureau of Reclamation (BOR)

1:100,000

0.4 0.2 0 0.4 0.8 1.2 1.6 2 Miles

0.5 0.25 0 0.5 1 1.5 2 2.5 Kilometers

Surface Management Responsibility - Custom 1:100,000 Scale

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT
GILA DISTRICT OFFICE
SAFFORD FIELD OFFICE

Map produced by the BLM, Safford Field Office

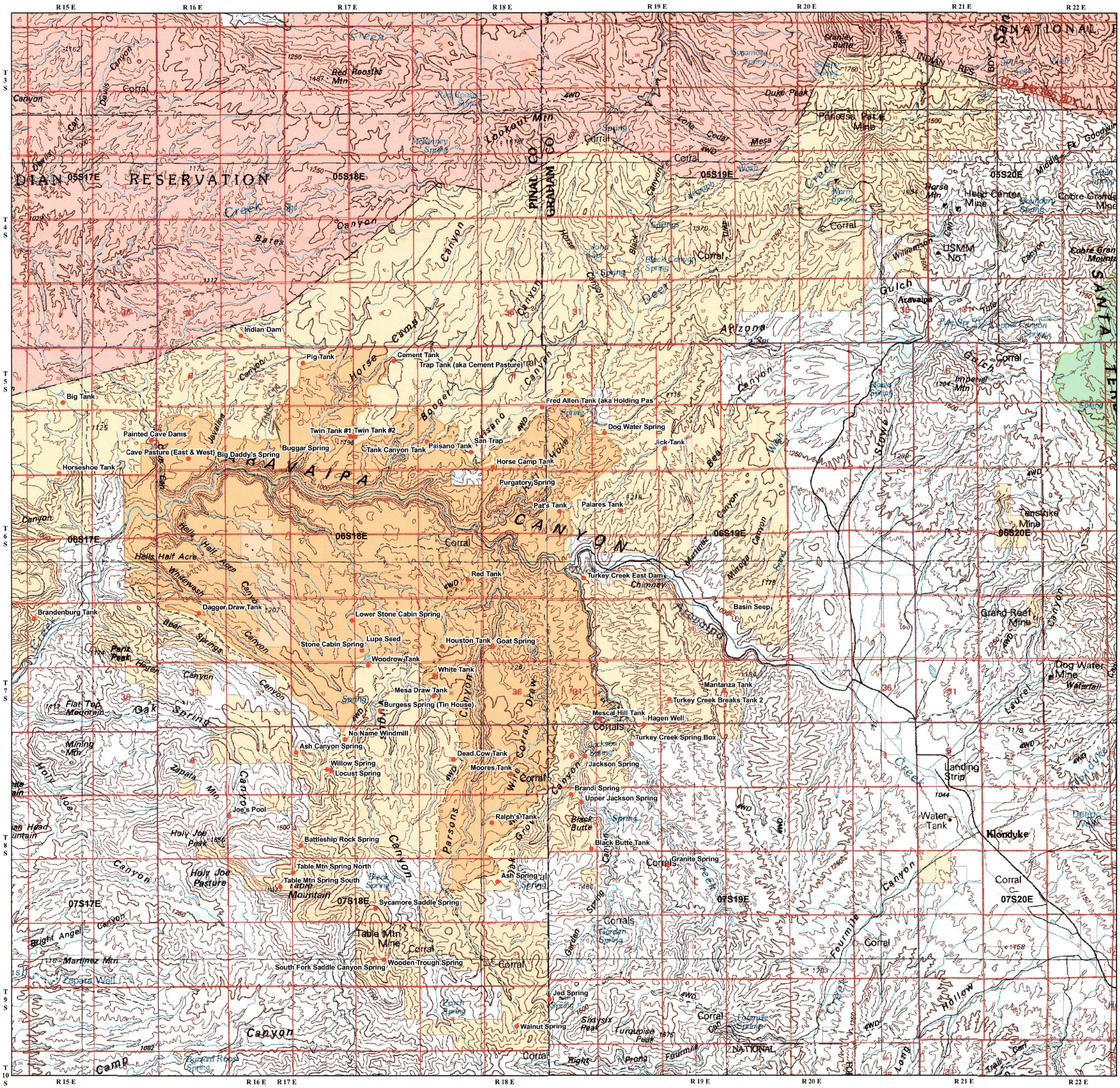
Land Status updated as of May 1, 2006

CAUTION:
Land ownership data is derived from less accurate data than the 1:24000 scale base map. Therefore, land ownership may not be shown for parcels smaller than 40 acres, and land ownership lines may have plotting errors due to source data.

No warranty is made by the Bureau of Land Management for the use of the data for purposes not intended by the BLM.

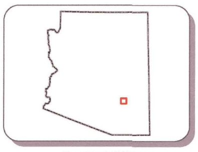
State of Arizona

Surface Management Responsibility - Custom 1:100,000 Scale



Private Lands	Indian Lands or Reservations	BLM Wilderness Area	BLM National Monument
State Lands	Bureau of Land Management (BLM)	Forest Service Wilderness Area	National Conservation Area
State Wildlife Area	National Forest Lands (USFS)	NPS Wilderness Area	Military Reservations/Corps of Engineers
City, State, County Parks	National Park Service (NPS)	USFW Service Wilderness Area	Bureau of Reclamation (BOR)
County Lands	USFW Service, National Wildlife Refuges		

LAND OWNERSHIP LEDGEND



Map created on Oct 05, 2010

1:100,000

0.8 0.4 0 0.8 1.6 2.4 3.2 4 Miles

1 0.5 0 1 2 3 4 5 Kilometers

Surface Management Responsibility - Custom 1:100,000 Scale

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT
GILA DISTRICT OFFICE
SAFFORD FIELD OFFICE

Map produced by the BLM, Safford Field Office

Land Status updated as of May 1, 2006

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