Upper Verde River: Review of Stream-Riparian Monitoring Efforts Conducted by the U.S. Forest Service Rocky Mountain Research Station

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Summary

The Verde River, one of Arizona's major perennial rivers, is critical for local and regional biodiversity. It provides aquatic habitat for native fish and amphibian species, including several federally listed fish species, and riparian habitat for bird species (many Neotropical migrants) and a host of other vertebrates such as river otter, beaver, and herpetofauna. Much of the Verde River corridor is managed by the USDA Forest Service. Given its ecological value and increasingly high profile, the Forest Service must have full confidence in monitoring and research data collected on the Verde River, especially data that may be used to inform management decisions. Since 1994, Rocky Mountain Research Station (RMRS) personnel have collected monitoring data on the Upper Verde River, in collaboration with the Prescott National Forest. The overall goal of this monitoring was to describe and characterize temporal changes in riparian vegetation, physical channel features, and fish assemblages in the Upper Verde River.

During the week of April 7-11, 2008, a review of RMRS research and monitoring efforts on the Upper Verde River was conducted. The review consisted of presentations, followed by field tours to different sampling locations along the Upper Verde River including portions of the river accessible only by train. Published information and data were available principally for stream flow and fish-related work. During the review, few data were available to the review team, limiting our ability to assess what RMRS has contributed to current understanding of the Upper Verde River. Preliminary results and analyses addressing interactions between vegetation, geomorphology, and fish populations were discussed. Some portion of the monitoring results will be presented in a forthcoming General Technical Report (GTR).

We interpreted the observations from monitoring efforts by RMRS researchers and colleagues on the Prescott National Forest as hypotheses, responding to them as peer reviewers, while recognizing that the interpretations have not been formally stated or tested. In addition, we provided our professional perspective on the hypotheses/interpretations with ideas on how they may be more rigorously examined.

Presentations and field discussions of the monitoring data collected by RMRS personnel to date on the Upper Verde River led to concerns regarding limitations of monitoring efforts for interpreting riparian vegetation and geomorphic conditions. From an agency perspective, we believe that it is critical to emphasize that the limitations of the data must be clearly acknowledged, and that these monitoring data probably cannot be used to conclude cause-and-effect relationships or to justify management decisions. Indeed, RMRS personnel indicated that (due to lack of resources) the vegetation and geomorphic data were not collected to test hypotheses or to make cause-and-effect linkages. Until existing data are analyzed, peer-reviewed, and published, the statements and hypotheses regarding vegetative changes, trends, interactions with management activities, and linkages to fish habitat, physical characteristics and processes remain unsupported. Furthermore, lack of repeat sampling at fixed locations limits the power of the vegetation data for monitoring purposes and for evaluation of treatment effects, such as land use or natural disturbance. Despite these concerns, the collected data may be of considerable value. A recent report by The Nature Conservancy (Haney et al. 2008) notes the paucity of data available for the Upper Verde River. Following review and publication, the information derived from RMRS monitoring efforts could potentially contribute to discussions regarding future management directions by USFS and increased collaboration among the full range of Upper Verde River stakeholders.

1. Introduction

The Verde River, one of Arizona's major perennial rivers, is critical for local and regional biodiversity. The Verde River corridor provides aquatic habitat for native fish and amphibian species, including several federally listed fish species (Rinne 2005), and riparian habitat for bald eagles, southwestern willow flycatchers (federally listed as endangered), yellow-billed cuckoos (proposed for listing), other Neotropical migrant bird species, and a host of vertebrates including river otter, beaver, and various herpetofauna. Historical and current pressures on the Verde River, including recreation, roads, mining, invasive species, livestock grazing, and water extraction have likely contributed to the downward trends in rare species' populations. A recent proposal to pump and transfer water from the Big Chino aquifer — the subsurface headwaters of the Verde River — has focused attention on the both the value and vulnerability of the Verde River basin (Haney et al. 2008).

Much of the Verde River corridor is managed by the USDA Forest Service (Region 3); 40 miles of the Upper Verde River (UVR) are located within the Prescott National Forest (PNF), and portions of the Middle and Lower Verde River are within the Prescott, Tonto and Coconino National Forests. Given its ecological value and increasingly high profile, the Forest Service (especially Region 3, and the Prescott and Tonto National Forests) must have full confidence in monitoring and research data collected on the Verde River, especially data that may be used to inform management decisions. Since 1994, Rocky Mountain Research Station (RMRS) personnel have collected monitoring data on the UVR in collaboration with the PNF. The overall goal of this monitoring was to describe and characterize temporal changes in riparian vegetation, physical channel features, and fish assemblages in the UVR (Table 1). A list of observations derived from these efforts was summarized in a briefing report by Mike Leonard (Staff Officer for Planning, NEPA, Wildlife, Fish and Rare Plants, PNF) (Text Box 1).

During the week of April 7-11, 2008, a review of RMRS research and monitoring efforts on the UVR was conducted. The two objectives of the review were to: (1) assess the role of RMRS research in addressing stream-riparian management issues in the Upper Verde

River, particularly the status of ongoing RMRS monitoring and research in providing support for science-based management, and (2) provide input and recommendations for future research efforts. Our review focused on the following questions: What has been learned about the UVR from RMRS monitoring efforts? What is known about the Upper Verde River? What are major unknowns, particularly those that can potentially be addressed through additional research and monitoring efforts?

2. Description of the UVR Stream-Riparian Review

Members of the review team (with links to their individual Websites) and National Forest Systems (NFS) participants and their respective affiliations are listed in Attachments 1 and 2 to this report. Below is a brief summary of activities during the review:

1) Monday, April 7, 2008. 1:00 pm to 6:00 pm. RMRS Flagstaff Lab.

a) Presentations by Mike Leonard (PNF) and Linda Jackson (District Ranger, Chino Valley Ranger District, PNF).

i) Using a set of maps, Leonard provided background on the geology, hydrology, ongoing monitoring efforts on the UVR by the PNF, and land use of the Verde River basin (with emphasis on the UVR), noting the urban development patterns in Yavapai County. He also described a current proposal to pump and transport groundwater from the Big Chino aquifer to users in the towns of Prescott, Prescott Valley, and Chino Valley.

ii) Jackson described management issues and challenges faced by the PNF, and expressed the need for defensible information on the natural functioning of the river system to support management activities that are relevant and appropriate for the Verde River. She noted that aspects of current management are based on assumptions, and expressed frustration with application of some aspects of the 'trout model or paradigm', which was derived from work conducted in cold-water streams of the Rocky Mountains and Pacific Northwest, and does not reflect the natural processes of arid-land rivers.

b) Presentations by RMRS personnel.

i) Daniel Neary showed UVR hydrographs (Paulden gauge, 1963-2007) and discussed hydrologic connections between the Big Chino aquifer and Verde River surface flows; listed the types of data collected by RMRS staff on the UVR; and presented data on the soil erosion potential for uplands in the Verde River basin.

Alvin Medina showed historic photos of the UVR; photo pairs of stream reaches before and after the 1993 floods; diagrams to illustrate riparian and geomorphic sampling methods; photos to illustrate spatial and temporal changes in stream-riparian condition in specific reaches; text slides summarizing his interpretations of changing conditions and anticipated conclusions from the 1996-2007 sampling efforts. No data were presented to support interpretations and conclusions.

2) **Tuesday, April 8, 2008. Field visits to sites along the UVR.**

Stops were the Sullivan Dam, overlook near the confluence of Granite Creek and the UVR, Burnt Ranch (Arizona Game and Fish Dept. property), and the Verde Ranch (private in-holding on the PNF). From Burnt Ranch, we walked a portion of the river to a meadow on NFS land. During this field day, numerous topics were discussed, including: observed changes in riparian and geomorphic features prior to and following the 1993 floods; potential contributions to downward trends in native fish populations; existing information on historical conditions; natural range of variability in riparian condition and sediment dynamics; natural processes and functioning of the UVR system; management objectives, including the reinstatement of grazing on PNF riparian allotments.

3) **Wednesday, April 9, 2008. Verde River Canyon via Verde Canyon Railroad.**

The review participants rode via train to view inaccessible portions of the river through the Verde Canyon from Clarkdale to Perkinsville and back (http://www.verdecanyonrr.com.). This trip provided overlooks of approximately 24 miles the river, floodplain, and valley bottom, which stimulated discussions of riparian vegetation distribution, age class structure, and dynamics, tributary and upslope sediment sources, and formation and extent of geomorphic features, such as channel morphology, instream large wood, streambed materials and terraces.

4) **Thursday, April 10, 2008. RMRS Flagstaff Lab.**

John Rinne presented multi-year results from fish sampling efforts on both the Gila and Verde Rivers, including: occurrence of native fish species in canyon-bound vs. alluvial-valley reaches; habitat associations of native fishes, as suggested by occurrence (presence/absence) and numbers of native species in reaches dominated by gravel, pebble, or cobble-dominated substrates; temporal changes in occurrence and numbers of fish (native and non-native); and assessment of a 3-pass method for removal of non-natives over repeated sampling years. Some of these data have been published; however, Rinne noted that considerable fish data collected on the Gila and Verde Rivers have yet to be worked up and published (includes data collected by Rinne and colleague Dennis Miller, retired from Western New Mexico University). Following his presentation, the review team returned to the Burnt Ranch site and participated in the sampling of fish along several reaches of the UVR. Using electro shocking and seining techniques, Rinne demonstrated how he and his crews sample and measure fish for both routine monitoring and non-native removal research. Upon returning from the field, the review team summarized their interpretation of the hypotheses presented by Medina, Rinne, and Neary, as derived from Powerpoint^{TM} presentations and discussions in the field.

5) **Friday, April 11, 2008. 8:00 – 10:30 am. RMRS Flagstaff lab.**

The review team worked with Neary and Medina to clarify interpretations of observations, based on Monday’s presentations and discussions in the field.

Table 1. Summary of sampling efforts by RMRS researchers on the Upper Verde River.

Parameters Measured	Duration of Monitoring Effort	Status of Data
Hydrology (Neary) Flow records from USGS Paulden gauge	1963- present	U.S. Geological Survey Open File Report 2004-1411 Neary and Rinne 1997; 2001) Rinne and Miller (2006) GTR (unpublished)
Fish (Rinne) Species composition	Annual sampling along 7 reaches from 1994 -2007	Rinne et al. (1998), Rinne (2005) (see additional citations in Attachment 3); unpublished data to be included in GTR
Riparian Vegetation (Medina) Herbaceous species: composition, frequency, cover Woody species: composition, density, frequency	1997; sites 1-24 (PNF) 1998; sites 25-44 (PNF) 2000; sites on private lands 2001; sites 1-44 (PNF), sites on private lands 2002; sites on private lands 2005 – 2007; subset of sites each year	Unpublished; some portion to be included in GTR
Channel Features (PNF & Medina) Substrate (pebble counts), cross sections (some co-located with riparian sampling locations) slope, entrenchment, sinuosity, Rosgen channel type	1996-1998, 2000	Medina et al. (1997); unpublished data to be included in GTR
Water Quality (Medina) Temperature, conductivity, turbidity, suspended sediment concentration, dissolved O_2	April 2000 – January 2001	Unpublished data to be included in GTR
Macroinvertebrates (Medina) Benthic only	2000-2001; 4 seasons, 2 habitat types (pool, riffle), 1 reach	Unpublished data to be included in GTR
Historical Changes (Medina) River Change Study (aerial photography analysis) Site photos River Uplands	1937-2006 1920's-present 1930's-2005	Unpublished; some portion to be included in GTR

Text Box 1: Observations based on monitoring efforts on the Upper Verde River by Rocky Mountain Research Station and Prescott National Forest personnel (1994-present). The list was taken from the Upper Verde River Briefing Paper, prepared by Mike Leonard, Prescott National Forest (dated March 8, 2008; Attachment 4).

1. The UVR is a highly impacted riverine system.
2. The primary constituent elements for spikedace and loach minnow have trended downward.
3. Small bodied native fish fish species have all but disappeared, including species that are considered quite common statewide.
4. Invasive fish species, Asiatic clam, crayfish and bullfrogs dominate the aquatic system.
5. Flood events tend to favor native fish over non-native fish species. After large flood events in 1993 and 1995, native fish species, in particular small-bodied fish such as the native daces, responded positively for one to two years, then declined rapidly. Non-native species were temporarily reduced, but regained dominance over native species within 3-4 years. Flood events of lesser sale in 2004 and 2005 did not have similar results.
6. We have witnessed significant losses of sedge-dominated wetlands, important habitat for lowland leopard frogs, garter snakes and other wildlife.
7. Stream bank cover from sedges/rushes has decreased.
8. Woody species have increased.
9. Stream channel has become narrower and deeper.
10. There has been a reduction in sand and gravel substrates.
11. Water quality has deteriorated (in-channel erosion of terraces, organic loading).
12. Invasive plant species have increased.
13. Streambank instability has increased.

3. Management Objectives of the Prescott National Forest

Here, we briefly describe management objectives of the Prescott NF to provide background for the following sections (Sections 4 and 5) which present our perspective on how monitoring may be used to inform future management decisions. We realize that this a cursory overview of the many management challenges faced by resource specialists and line officers. During the review, PNF managers invited input on management approaches that "make sense for the Verde River". They identified the priority management objectives in their Land and Resource Management Plan (1986) and discussed the difficulties associated with meeting the forest's multiple uses and resolving issues of competing interests and conflicting objectives.

Elements of the plan germane to this review include:

- **Maintain or improve fish and wildlife habitats.**
  - Maintain and/or improve habitat for threatened or endangered species and work toward the eventual recovery and delisting of species through recovery plan implementation.
  - Manage for a diverse, well distributed pattern of habitats for wildlife populations and fish species in cooperation with states and other agencies.
  - Integrate wildlife habitat management activities into all resource practices through intensive coordination.

- **Restore and maintain riparian areas in satisfactory condition.**
  - Emphasize protection of soil, water, vegetation, wildlife and fish resources.
  - Give riparian-dependent resources preference over other resources.

- **Water Quality and Quantity, Watershed Condition, and Soil Productivity**
  - Protect and improve the soil resource.
  - Provide for long-term quality water flow needs through improved management technology.
  - Restore all lands to satisfactory watershed condition to improve quantity and quality of water produced and distribution of flow.

- **Range**
  - Meet threatened and endangered species requirements in all range or grazing activities.
  - Manage livestock grazing to achieve soil and water protection objectives.
  - Eliminate yearlong grazing prescriptions for riparian areas.
  - Implement of grazing systems that will advance ecological objectives for riparian-dependent resources with sufficient rest to meet physiological needs of vegetation.
  - Restrict allowable utilization of woody riparian species to ≤20%.

The Comprehensive Management Plan for the Verde Wild and Scenic River (2004), though covering a river segment downstream and, at this time, not inclusive of the Upper Verde, provides an example of multiple objectives for river management. The Verde Wild and Scenic River Plan emphasizes native fish species over nonnative fishes; the recovery, development, and maintenance of aquatic habitat with low substrate embeddedness, abundant aquatic food supply, and stable streambanks; and, additionally, the recovery, development, and maintenance of riparian vegetation characteristics (i.e. composition, density, and height) necessary for riparian-dependent species.

4. Observations and Hypotheses Derived from RMRS Monitoring Efforts

A summary of the monitoring data collected by RMRS personnel (Table 1) was derived from Powerpoint^{TM} presentations (April 7) and follow-up discussions. Content of the forthcoming GTR was generally discussed during the review; however, a draft copy was not provided because it was not yet ready for any level of distribution. The collection of certain data was collaborative between the PNF and RMRS, and it was unclear if the GTR will contain data collected by the PNF. Analyses of RMRS monitoring data are underway for the vegetation and geomorphic metrics. Our impression is that the UVR hydrographs and soil erosion information will also be included in the GTR. In addition, Medina has compiled an historical photographic record database to determine historical changes in the UVR. Currently, plans are to include some portion of the assessment of historical photographs in the GTR (please see Attachment 4).

During the review, the data available for discussion were essentially limited to the fish monitoring data provided by Rinne, some of which have been published (see Attachment 3 to this report). This limited our ability to address the first objective of the review: (*1) assess the role of RMRS research in addressing stream-riparian management issues in the Upper Verde River, particularly the status of ongoing RMRS monitoring and research in providing support for science-based management.* However, numerous observations — derived from monitoring efforts by RMRS scientists and PNF staff — on the ecological and physical processes of the UVR were presented on April 7 and discussed in the field. Therefore, the review team decided to organize this report around the observations themselves, considering them as working hypotheses about how the UVR functions. We recognize that some of these observations and interpretations may change as data are analyzed in more detail, and presented in the GTR and future publications. Since the observations and interpretations are being discussed among NFS and RMRS staff and other stakeholders, we focused on providing our ‘peer-review’ perspective to each hypothesis. Below, we comment on each hypothesis and the extent of supporting data or evidence to advance the discussion regarding the ecology and management of the UVR.

4.1 Riparian Vegetation Hypotheses

1. Woody vegetation establishment on the banks and floodplain causes channel narrowing and bed incision; incision causes lower water table and loss of wet meadows. Woody vegetation on floodplain causes scour through deflection and concentration of flow, leading to erosion and loss of meadows.

2. Herbaceous-dominated meadows are stable and resistant to loss during high flow events (20-30 yr. floods under current climatic conditions); UVR lost most wet meadows sometime between 1979 and 2007.

3. Increases in cover of woody species are associated with loss of wide, low gradient riffles (desirable native minnow habitat); the Verde River system did not “evolve with woody vegetation” (Medina, pers. comm.).

4. Variability in vegetation species composition/cover/density is high within and among sites over space and time, and is dependent on plant community type and position on the floodplain; variability is lower on grazed, sedge-dominated communities.

5. After high-flow events, grazed sites have lower cover of herbaceous invasives than ungrazed sites.

6. Woody vegetation could be linked to debris jams that could precipitate a catastrophic, dam-break flood.

7. Under current climatic regime (prior to 1890’s or recent settlement), woody vegetation could have been a significant component of the UVR ecosystem, but there is no evidence either way. Dating of buried wood in channel terraces may provide data.

***Response to Riparian Vegetation Hypotheses*:**

1. Woody vegetation establishment on the banks and floodplain causes channel narrowing and bed incision; incision causes lower water table and loss of wet meadows. Woody vegetation on floodplain causes scour through deflection and concentration of flow, leading to erosion and loss of meadows.

Channel narrowing and incision due to encroachment of vegetation is a well known process that can result from factors such as reduced stream flows, introduction of invasive species, or exclusion of ungulate grazing (McDowell and Magilligan 1997). This process was evident along the lower reaches of the UVR upstream from Clarkdale, where nearly continuous riparian vegetation confined the river and was associated with deep, narrow channels. The encroachment in this part of the river is a recent phenomenon (Webb et al. 2005). However, similar confinement by riparian vegetation and association with deep channels was not observed at other sites visited (Burnt Ranch, Verde Ranch). Consequently, further demonstration of this hypothesis is needed before it can be accepted as a general response along the UVR.

While it is plausible that incision causes lower water tables and loss of wet meadows, no supporting evidence was provided, nor is it clear that vegetation is the primary cause for incision. Other causes for incision at the field sites visited may include loss of beaver dams, downstream changes in base level, and periodic sedimentation at tributary junctions leading to cycles of channel aggradation and subsequent headcutting (upstream incision and knickpoint propagation). Beaver activity and tributary debris fans were observed during site visits.

Floodplain patches of woody vegetation create flow obstructions that can cause local scour upstream of the obstruction and complimentary deposition in the wake of the obstruction (e.g. Abbe and Montgomery 1996). However, the net effect of this process (scour vs. deposition) is not known, nor is it known whether the resultant scour around multiple woody obstructions would cause or contribute to the collapse of wet meadow systems.

Channel narrowing may be facilitated by vegetation establishing adjacent to and in the channel, although vegetation establishment may also occur in response to channel narrowing

(Hereford 1984). Cause and effect may be difficult to determine without field data on channel dimensions through time, establishment dates and ages of woody vegetation, and a detailed look at sediment stratigraphy. Reductions in peak flows, reduced frequency of high-flow events and reduced base flows may all result in channel narrowing, even in the absence of woody vegetation. Medina et al. (1997) discuss channel incision and its many possible causes, but present no strong evidence that incision has occurred or continues to occur. If channel incision is occurring, it is likely that shallow alluvial groundwater levels have declined and that wet meadows would transition to more mesic and xeric vegetation types. Vegetation and channel morphology data collected to date may suggest trends in feedbacks between vegetation and channel and floodplain form, but cannot be used to make cause-and-effect inferences. Additional, focused research on the UVR would be required to accept or reject these hypotheses.

2. Herbaceous-dominated meadows are stable and resistant to loss during high flow events (20-30 yr flood under current climatic conditions); UVR has lost most wet meadows sometime between 1979 and 2007.

Several studies demonstrate that grasses and non-woody shrubs can armor riverbanks and floodplains when this vegetation is pushed over during floods (Nepf 1999; Simon and Collison 2002). Furthermore, vegetative roots strengthen soils and make them more resistant to erosion. However, there is a threshold beyond which discharges and boundary shear stresses exceed the resisting strength of the vegetation, causing it to be eroded or uprooted. Consequently, the stability offered by grasses and shrubs has limits. The suggested value of a 20-30 year flood for this threshold is reasonable, but requires supporting documentation. Furthermore, as discussed above, it is unclear what has caused the observed loss of wet meadows in the UVR. Further consideration and analyses of competing or alternative hypotheses are needed.

Meadows dominated by perennial graminoids likely were historically transient features, as the Verde River hydrology is characterized by periodic flash-floods of large magnitude. Recent work on Sycamore Creek, AZ indicates that riverine wetlands are ‘alternative stable states’ and their persistence is largely driven by periodic flooding (Heffernan 2008). It is difficult to say whether wet meadows are more or less abundant today than they were historically and to assign reasons for changes. Photographs from the 1920s revealed a freshly scoured channel with little vegetation of any kind. RMRS personnel saw this as evidence that woody vegetation is a recent phenomenon and indicated that these interpretations were corroborated in repeat photographs in the "Ribbon of Green" (Webb et al. 2005). However, the pre-photos in all cases were from the late 19th and early 20th centuries, following European settlement. Settlement involved cutting wood for both fuel and building materials and the introduction of livestock, which undoubtedly influenced woody species (Leopold 1924). The late 19th and early 20th century was also a period of unusually frequent, extreme flood events in this region (Ely et al. 1993). These photos provide a snapshot in time, not necessarily a view of stable reference conditions. Furthermore, the lack of wet meadows in the photos presented by RMRS personnel provides little evidence of extensive wet meadows prior to woody vegetation establishment. It is likely that the upper Verde River corridor has been very dynamic (rather than a stable wet-meadow dominated system) and at any point in time contained marsh, meadow, woodland, and bare channel margin in some stage of recovery from the most recent flood.

It seems difficult to generalize that grazed wet meadows are more resistant to erosion than woodlands. It depends on proximity to the channel, the composition of the vegetation; stem density; the condition of the vegetation; root morphology; sediment/substrate texture; exposure to fluvial processes; and a range of other factors that vary spatially and through time. It is not difficult to imagine a wet meadow along a cut bank eroding on one side of the channel and being stable on the opposite side of the channel during a single flood event. Without data it is difficult to evaluate the claims about meadow stability and resistance to scour. Since riparian vegetation data were gathered in plots at different locations (non-permanent plots) it is even more difficult to assess change in vegetation through time or to relate observed differences between plots to relevant variables (grazing intensity, hydrology, other land uses).

Haney et al. (2008) estimate that only 12 out of 5587 acres of riparian area along the UVR are composed of 'wet meadow plant communities'. The estimate was based on a mapping effort by the Arizona Game and Fish Department (including private and public lands) and indicates that wet meadows currently occupy a very small proportion (i.e., 0.2%) of the UVR riparian area. The narrow valley bottom throughout much of the UVR likely limits the formation of meadows (even small ones), which requires deposition and accumulation of fine sediment and some degree of soil development. Soil development occurs during the intervals between large floods and may be accompanied by wet meadow formation. Furthermore, beaver likely had an important role historically in the formation and persistence of wet meadows in southwestern rivers like the UVR (Butler and Malanson 2005). The extent of meadow loss needs to be quantified and examined spatially within a watershed context, i.e. in terms of available sites as influenced by both physical and biological processes.

Evidence for both recent and historic changes in the extent of wet meadows may contribute to improved understanding about the processes that influence the location, extent, and persistence of wet meadows in the UVR system. However, no supporting information or data were available during the review. RMRS personnel also indicated that the maintenance of wet meadows was a priority management goal for private lands on the UVR to maximize forage production for livestock. On FS lands, additional management goals include habitat diversity, recreation, and maintenance of high quality, functioning, sustainable riparian areas, some of which are in direct conflict with management on private lands that tend towards a narrow range of habitats or a single habitat type (e.g., wet meadows).

3. Increases in cover of woody species are associated with loss of wide, low gradient riffles (desirable native minnow habitat); the Verde River system did not "evolve with woody vegetation" (Medina, pers. comm.).

Early expeditions in the Verde River watershed indicate that there were meadows, riparian forest and shrublands along the river in the 1850's (Leopold 1951; Shaw 2006). Riparian trees along the river included cottonwood, willow, ash, and walnut (Leopold 1951; Shaw 2006). These studies also indicate that "large trees were apparently harvested quickly after the Anglo arrival" (and prior to historical photographs; Shaw 2006). Hence, it is unclear whether the observed increases in riparian vegetation represent recovery to natural conditions following disturbance by settlers, or whether subsequent land use has allowed greater vegetation growth than was historically present prior to arrival by settlers (Leopold 1924).

If riparian vegetation is contributing to channel narrowing, it is possible that riffles and associated minnow habitat could be replaced by deeper channel morphologies (runs and pools). However, no supporting data were offered to support this hypothesis and no data-based association between the presence of woody vegetation and channel morphology was presented. During the review, RMRS personnel noted that some of the vegetation plots were co-located with permanently monumented channel cross sections. The review team suggested that the woody vegetation data, especially stem density and cover, could be analyzed in relation to the nearest permanent channel cross section to explore the above hypothesis. The method used to locate the vegetation plots, which were not permanently marked and may have changed each year depending on the stream/streambank location, may limit the types of spatial and trend analyses in vegetation that can be conducted. However, correlations between annual changes in the cross sections and woody vegetation characteristics could potentially be examined. If not part of current monitoring protocols, measurement of particle sizes in the vegetation plots is recommended to determine the substrate composition on which the woody species have established and to determine the order of events (tree establishment>sediment deposition>channel narrowing or sediment deposition>channel narrowing>tree establishment; Hereford 1984).

4. Variability in vegetation species composition/cover/density is high within and among sites over space and time, and is dependent on plant community type and position on floodplain; variability is lower on grazed sedge-dominated communities.

Riparian vegetation is known to be highly variable in both space and time (Bagstad et al. 2005; 2006; Lite et al. 2005). High interannual and intersite variability is typical of dynamic arid land riparian communities and leads to high plant diversity through time. Turnover of vegetation may be caused by natural disturbance processes such as flooding and the creation and destruction of new sites through scour and deposition (Bagstad et al. 2005; 2006; Lite et al. 2005). Turnover also occurs over the course of a single season as the availability of moisture changes from temporarily abundant during spring snowmelt and monsoon rain, to scarce during dry intervening periods (Stromberg et al. 2007). The exciting challenge for riparian plant ecologists is to explore the potential explanatory factors and determine which factors account for (or explain) some proportion of the variability, recognizing that considerable information may be contained in the variability itself. During the review, no vegetation data were presented, so the review team was not able to evaluate spatial or temporal variation in any of the vegetation data (composition, cover, richness, herbaceous vs. woody, exotic vs. native, etc.), although we would expect variability across plots, sites, and through time.

Considering the following questions in the data summary and analysis (in the forthcoming GTR) may assist in interpretation: how does within-site variability compare to the between-site variability both within years and across years? How much of the between-site variability (both within single years and across years) can be explained by site/reach characteristics such as valley bottom width, substrate composition, position on the floodplain, elevation, etc? How much of the between-year variability can be explained by hydrograph characteristics, precipitation, time since last flood, etc? What is the nature of the variability (i.e. species turnover, changes in cover, over what time frames)?

Limitations of the vegetation sampling methods and study design need to be acknowledged and may restrict the ability to address some of the questions presented above. First, by not permanently establishing vegetation transects or plots, the temporal variability may be more difficult to explain than if data were collected within the same plots (exact location) each year. Because the vegetation plots were located adjacent to the stream, plot locations changed at some sites from year to year (as indicated by RMRS personnel during site visits). So, although vegetation was sampled along the same reach or ‘sampling station’, the same area (plot location) may not have been sampled year-to-year. This may introduce a source of variation that might have been controlled or avoided. Given random sampling of the site and enough plots to characterize intra-site variability this might be an acceptable method, but given limited resources, permanent plots would have been advisable.

Second, because transects and plots were arranged directly adjacent to the active channel, a limited portion of the riparian area and floodplain were sampled. While these vegetation data may provide information about streamside conditions, particularly the dynamic and transient nature of the active channel, they probably do not incorporate the diversity of riparian vegetation and conditions along floodplain hydrologic gradients (i.e. the sampling approach may have consistently under-sampled the riparian area). It is difficult to predict how this sampling method may have influenced variability in the data, but it is important to clarify that, due to placement of transects and plots, the data represent only the portion of the riparian area directly adjacent to the stream. Finally, the monitoring protocol used for the UVR data collection was presented to the group, but the methods used by the PNF for collection of its early monitoring data differ from those currently employed by the RMRS. Comparison of these databases should be approached with caution. The influence of changes in sampling protocols needs to be considered.

One of the 'information needs' identified by Haney et al. (2008) for the Verde River was 'complete flora of the Verde River riparian corridor, ideally by river reach and for specialized habitats such as main stem spring sites' (page 45). The publication of the GTR may address this need; authors are encouraged to explicitly indicate sampling sites/stations with linked species lists for each site, so that readers can appreciate the extent of this floristic information.

5. After high-flow events, grazed sites have lower cover of herbaceous invasives than ungrazed sites.

Although a plausible hypothesis, no supporting data were provided during the review. Since herbivory is associated with removal of biomass, it is likely that most herbaceous species, native and invasive, would have lower cover at grazed sites.

If possible, we suggest that the data obtained from vegetation sampling be aimed at addressing fundamental questions that could potentially inform management: What are the herbaceous invasive species of concern and which are palatable to livestock and likely to be selected over natives? Over what time periods were relative cover differences at grazed vs. ungrazed sites observed? What are the levels or magnitudes of difference in cover (overall and by species) between grazed vs. ungrazed sites? How analogous ecologically are grazed vs. ungrazed sites (are they ecologically similar except for the grazing management)? How do grazed vs. ungrazed sites differ in overall composition of herbaceous species? What is the relative importance of grazing and hydrologic factors in determining the abundance of native and invasive plant species? Answers to the questions regarding the influence of grazing need to be supported by carefully designed studies, data analysis and objective interpretation. Evidence would come from carefully designed vegetation sampling along grazed and ungrazed reaches, replication, controlling for other factors that influence vegetation composition and cover, and statistical analysis of the data. For example, whereas the use of livestock to control weedy species is a common practice and can be used to facilitate native plant growth, overgrazing of natives can also open up space (bare or sparsely vegetated ground) providing opportunities for weedy species to invade.

6. Woody vegetation could be linked to debris jams that could precipitate a catastrophic, dam-break flood.

While possible, the probability and magnitude of such an event is unclear. Is there any historic evidence of dam-burst floods occurring in the UVR system, or in neighboring basins? What resources are at risk, and would the floodwave be dissipated by overbank flows?

7. Under current climatic regime (prior to 1890's or recent settlement), woody vegetation could have been a significant component of the UVR ecosystem, but there is no evidence either way. Dating of buried wood in channel terraces may provide data.

Woody vegetation has long been an important component of western arid-land riparian habitats. Woody vegetation growing along streams in the Verde River watershed (including the mainstem) were mentioned dozens of times in journals dating from the 1850's (Sitgreaves expedition in 1851 and Whipple in 1854, both referenced in Shaw 2006). Specifically cottonwood, willow, Arizona walnut, and Arizona ash are mentioned to have been growing along the banks of streams in this period prior to heavy grazing by livestock and prior to timber harvest by Anglo settlers. Wet meadows were also mentioned further suggesting that riparian areas were varied and (as we would expect) consisted of both woody and herbaceous vegetation. The relative abundance of woody vegetation likely fluctuates as a function of water availability and frequency and magnitude of fluvial disturbances, both of which are influenced by climate (cycles of snowpack- and monsoon-driven water delivery) and, water management (both surface and subsurface). The abundance of woody vegetation is also influenced by herbivory in the form of beavers, other native herbivores and livestock. *Populus* and *Salix* form a biologically important association that is often the focus of management in the southwest. The occurrence of water sources (springs, shallow groundwater) and occasional disturbance are conditions consistent with the presence of well-dispersed disturbance-adapted taxa such as *Populus, Salix, Baccharis,* and a suite of other native riparian species in the Colorado Plateau and Sonoran desert. In Webb et al. (2005, page 300), annual flood series are presented for 4 stream gauging locations on the Verde River, including the Paulden gage (established 1963). Downstream gages (established in 1890, 1915, and 1938) could potentially be used to extend the flood series for the upper part of the basin and assist in explaining recruitment patterns of woody vegetation.

The historic role of woody vegetation in the UVR is a critical question that deserves further investigation. Trenching or ground-penetrating RADAR might be used to document stratigraphy and to search for buried wood within river terraces. Carbon dating and dendrochronology of recovered wood could allow reconstruction beyond historical photos and written records.

4.2 Sediment and Channel Morphology Hypotheses

1. Sediment supply has been reduced by Sullivan Dam.

2. Ongoing channel incision of river terraces is a source of fine sediments; a secondary sediment source is from tributaries.
3. ("Hanging") tributaries are adjusting to downcutting in the main stem river and are contributing sediment via knickpoint propagation (upstream headcutting).

4. Cross sections have shown that some channel reaches have incised up to 1 m between 1996 and 2008 (data and photo-documentation (Black Bridge) will be in GTR); overall the entire UVR is incising.

5. Majority (80%) of UVR consists of B and C channels according to Rosgen classification (based on 1998-9 surveys); resurveys are needed to assess channel changes and trends.

***Response to Sediment and Channel Morphology Hypotheses*:**

1. Sediment supply has been reduced by Sullivan Dam.

Historically, sediment supply was likely reduced by the dam, but given the amount of sedimentation that has occurred upstream of the dam, it is unclear what the current trapping efficiency of the dam is, particularly for fine sediments. Furthermore, there are numerous sediment sources downstream from the dam (e.g. sparsely vegetated sideslopes, eroding terraces, tributary fans). The sites that were visited along the UVR had a broad range of particle sizes, depositional bedforms, and did not show obvious evidence of being sediment-limited. Analysis of channel characteristics collected by RMRS personnel over the sampling period may provide evidence of reduced sediment supply in terms of grain-size coarsening and/or channel incision. However, similar responses could also be caused by other processes (e.g. changes in downstream base level due to loss of beaver dams, wood jams and breaching of tributary fans, or relaxation following sediment inputs from historic floods (e.g. Madej and Ozaki 1996)). Consequently, there may be multiple, competing interpretations for observed changes in channel characteristics. Development of a sediment budget (Reid and Dunne 1996) and further quantification of the geomorphic effects of the dam (Grant et al. 2003) might resolve these issues. Finally, the consequences of reduced sediment supply on the physical and biological function of the river are unclear and deserve further explanation and quantification.

2. Ongoing channel incision of river terraces is a source of fine sediments; a secondary sediment source is from tributaries.

Eroding terraces were sediment sources at some of the sites visited, as were tributaries, which showed evidence of both recent and older sediment inputs (debris fans that in some cases may have temporarily blocked or diverted the river). However, the extent of these inputs, their characteristics (grain size, volume, and rate of supply), and their biological and physical consequences remain to be quantified. Development of a sediment budget, as discussed above, would partly address these issues.

> 3. ("Hanging") tributaries are adjusting to down cutting in the main stem river and are contributing sediment via knickpoint propagation (upstream headcutting).

These are plausible hypotheses, but require further evidence to be able to assess their validity. Repeated longitudinal surveys of the mainstem river and its tributaries would help to document the location, rate of movement, and concordance of knickpoints, while a sediment budget and/or bedload transport measurements would quantify the rate and size distribution of sediment inputs to the mainstem river. As discussed above, the relative physical and biological significance of these processes should be evaluated, ideally with some preliminary back-of-the-envelope calculations to assess potential significance before investing resources in further analyses of the issue.

> 4. Cross sections have shown that some channel reaches have incised up to 1 m between 1996 and 2008 (data and photo-documentation (Black Bridge) will be in GTR); overall the entire UVR is incising.

While plausible, this observation cannot be assessed at this time since the GTR and supporting data are not available. A subset of the data published by Medina et al. (1997) show channel incision, and the authors state that 14% of the channel length is unstable. However, further documentation of the spatial extent of such change along the length of the UVR, and within the context of geomorphic process domains (unconfined alluvial reaches vs. confined segments) (Montgomery 1999; Montgomery and Buffington 1997), is needed to assess the broadscale condition of the river. Moreover, study of the underlying causes for observed channel changes is needed. For example, some of the incision presented to the group during the field review was likely caused by tributary sediment inputs and consequent cycles of mainstem aggradation and subsequent headcutting (knickpoint incision) that from our limited field reconnaissance seems to be part of the natural, long-term geomorphic function of the UVR system. Placing observed channel changes within this larger geomorphic context is needed to understand both the cause and potential spatial extent of such changes.

5. Majority (80%) of UVR consists of B and C channels according to Rosgen classification (based on 1998-9 surveys); resurveys are needed to assess channel changes and trends.

Rosgen classification provides a basic description of channel morphology that may be a useful inventory and communication tool. However, it is unclear what, if any, interpretations will be made from these data. Using channel classification to infer stability/dynamics is cautioned. Furthermore, changes in state, both in terms of channel dimensions and overall morphology, may be part of the natural range of variability of some channels; hence, change should not be viewed as problematic until those changes are placed within the context of the natural range of system variability. Arid environments with flashy hydrographs are more likely to exhibit a broader range of channel conditions over time than snowmelt-dominated physiographies (Buffington and Parker 2005).

4.3 Fish Hypotheses:

1. Since 1994, there has been significant decline in native spp and increase in nonnative spp; relative abundances have changed from 80:20 native:nonnative to roughly the reverse. Since 1994, total number of all (native and nonnative) fishes sampled has declined as well.

2. Abundance and distribution of small native fishes are associated with and benefit from the availability of, wide, shallow, low gradient habitat types. These appear to be particularly important for the small minnows, but are also used by non-native red shiners.

3. Non-native fishes benefit from narrow, deep channels and associated habitat types (e.g. pools, high gradient riffles, deep runs, undercut banks).

4. Native and nonnative fish community structure interacts with valley form, hydrology, and other geomorphic process.

5. Predation by nonnative fishes is an important if not dominant constraint on native spp. recruitment.

6. Recruitment in native species is facilitated by large floods.

7. Restoration of wide shallow habitats (high width/depth ratio) would reduce non-natives and increase native spp abundance.

Response to Fish Hypotheses:

1. Since 1994, there has been significant decline in native spp and increase in nonnative spp; relative abundances have changed from 80:20 native:nonnative to roughly the reverse. Since 1994, total number of all (native and nonnative) fishes sampled has declined as well.

The data show substantial differences in relative number of native and non-native species with a general trend favoring non-native species since the 1993 flood. Spikedace have disappeared from samples. The sampling maintained by the Forest Service is limited in extent and by itself could be vulnerable to systematic bias or sampling error, but more continuous sampling conducted by other agencies confirms the general pattern. The trends in the data are striking and although sampling error is not addressed, the magnitude of change is large enough to overwhelm most anticipated sampling problems. Dramatic changes in community structure favoring non-native species and a substantial decline (if not extinction) in spikedace has undoubtedly occurred since 1994. There is no way to determine the variability in abundance in native species and spikedace before 1994. The monitoring data outlined above show a substantial decline in total number of fishes (native +non-native since 1994). There has been no discussion or speculation about this pattern, but it is consistent with a decline in small bodied and short-lived native minnows and an increase in large bodied, longer lived non-native forms. There is no information to consider changes in overall fish biomass or production.

2. Abundance and distribution of small native fishes are associated with and benefit from the availability of, wide, shallow, low gradient habitat types. These appear to be particularly important for the small minnows, but are also used by non-native red shiners.

Observations during routine sampling suggest that the presence of native fishes, particularly the small minnows (spikedace; longfin dace, speckled dace) is associated with shallow, low gradient habitat types. The primary evidence are general patterns of species occurrences which include relative abundances associated with geomorphological constraints (e.g. canyon bound vs. alluvial valleys) and relative abundance or capture rates among habitat types (e.g. high and low gradient riffles, glide runs, pools, etc). Fish are caught in greater abundance, or only, in these habitat types. A decline in abundance of small native minnows has also occurred concurrently with apparent channel narrowing and deepening. Channel measurements presented to date are limited to two sites and three dates in the Verde (e.g. Rinne in press, Table 4), but other data on channel cross sections may support the trend. The fish and channel measurement data presented so far (Rinne in press) are too limited for any statistical inference. Quantification of habitat selection or preference is not available. Although habitat utilization analyses would strengthen the contention that low gradient habitats are key, that analysis may not be possible without more detailed and extensive sampling. The hypothesis that native minnows may select or preferentially use these habitats is plausible particularly for summer low flow periods when sampling is conducted. It also seems consistent with the general biological understanding for these species. That does not exclude the potential importance of other habitats, however. For example other habitat types or channel elements could become important during extreme events (e.g., drought or flood refugia) or during other periods of the year when sampling has not been conducted. Utilization of alternative habitats as refugia during extreme events (e.g. Biro 1998) or in the face of expanding non-native predation (Olsen and Belk, 2005) could be an important mechanism for persistence of some native fishes.

3. Non-native fishes benefit from narrow, deep channels *and associated habitat types (e.g. pools, high gradient riffles, deep runs, undercut banks).*

The observations and evidence supporting this hypothesis are essentially the same as those outlined above. It also appears that the large bodied native species (suckers, roundtail chub) use these habitats as well. It is possible that the association between smaller bodied species and shallow habitat is a behavioral response to the presence of predators in the pools (not necessarily preferred habitat).

4. Native and nonnative spp community structure interacts with valley form, hydrology, and other geomorphic process.

The relative composition of the fish community appears to vary throughout the river. There is a general pattern favoring non-native species lower in the river and in canyon bound reaches that is consistent with a geomorphological control on the availability or abundance of different habitat types. Presumably patterns in channel form and constraint will affect patterns in habitat availability, species occurrences and abundance, and species interactions. This hypothesis is plausible and consistent with an expanding literature linking fish species distributions and habitat diversity with geomorphological process (e.g. Poff et al. 2001; Benda et al. 2004). An association of form and species composition at the reach scale in the Verde does not mean, however, that changes in channel form will lead directly to changes in species distribution and abundance. Other processes and conditions also change with valley constraint and the longitudinal gradient of the river; elevation (temperature and climate), flow volume, sediment supply, and hydrologic regime all could be correlated with valley form, but not necessarily linked through process. As a result primary environmental constraints and drivers on aquatic communities (e.g. carbon source, temperature, disturbance frequency, habitat size and complexity, substrate size) are changing moving along the longitudinal gradient of the system. It is impossible to resolve the specific effects without more work or summary of additional information. For example, it may be possible to demonstrate that specific habitat types (that can be associated with fishes) vary predictably in abundance, area, or local characteristics (e.g. depth, velocity, substrate size, area) among reach/geomorphic types or channel form. Habitat utilization or habitat preference information generated at the habitat unit scale, might then be used to support the idea that valley form does directly control the structure of the fish community and is not a spurious correlation linked to other environmental gradients.

5. Predation by non-native fishes is an important if not dominant constraint on native species.

Non-native predatory fishes including small mouth bass, green sunfish, channel catfish, and yellow bullhead occur in the UVR. Other predator species occur throughout the river. Multiple non-native species that may compete with native fishes are also now found throughout the system. Non-native species are numerically important in fish samples throughout the Verde River and as a group dominate the fish community. The hypothesis that non-native predation is a primary constraint on native fishes and a primary cause of their decline, is, however, limited to circumstantial evidence. Native species numbers have declined as non-native predators have increased in abundance or expanded in distribution. There is a negative association spatially among stream reaches as well. Some food habits research would probably confirm that non-native species prey extensively on native species, but those data are not available. Predation rates or demographic rates of prey potentially influenced by predation would also help, but cannot be estimated or approximated with existing data. Predator control efforts have produced no apparent benefit, but the effects of existing control on predator numbers, dynamics or distribution appear to be limited. There is detailed and extensive scientific information documenting the capacity of the native and introduced predatory species to influence the structure of fish communities in riverine and lake systems so the predation hypothesis is highly plausible. Predator-prey interactions, however, can be extremely complex and many efforts to manipulate or control the influence of predation have failed because of non-linear responses or interactions leading to limited or unanticipated responses in target or native species. There is even evidence that efforts to control predators can change, size, age, growth or recruitment and actually stimulate predation (e.g., Rieman and Beamesderfer 1990). Without more detailed information and some understanding of the critical dynamics it is impossible to conclude where or when predation has an important influence on abundance or persistence of native species. Non-native and native species may also interact through competition, physical alteration of key habitats, or alteration of predator prey dynamics. Red shiner and crayfish appear to be abundant through much of the upper Verde, for example, and could either directly compete with native minnows or buffer them from predation by nonnative forms. Those relationships would be expected to vary with habitat, and relative abundance of individual species.

6. Recruitment in native species is facilitated by large floods

Fish monitoring in the Verde River initiated after the large 1993 flood event, shows that relative abundance of juvenile native suckers and roundtail chub and total numbers of spikedace declined in years subsequent to the flood. The relative dominance of native and nonnative fishes strongly favored native fishes in 1994-1996, but reversed dramatically in 1997. Native fishes have remained at relatively low levels since that time; spikedace have disappeared from samples. Native populations did not appear to rebound following moderate flood events in 2004 and 2005. This may have been because the events were too small to provide the benefits attributed to flooding or because of other constraints on the populations. These data are too limited in themselves to lead to a conclusion or statistical support for the role of flooding and native species recruitment, but they are supported with observations in other systems (e.g. more frequent flooding and continued dominance of native fishes in the

Gila River). The flood benefit hypothesis is also supported through general life history theory (Olden et al. 2006) and other work (e.g. Minckley and Meffe 1987 cited in Rinne 2005); small minnows and suckers exhibit two distinct life history patterns reflecting adaptation to frequent disturbance rather than environmental stability. A general conclusion that flooding can benefit native species is highly plausible. One problem with any application, however is that the mechanism is not clear. Flooding may benefit native fishes by creation or rejuvenation of critical habitats for the fish or their forage that may in turn influence growth or survival, or by displacement or disruption of non-native predators and competitors, or by any combination of these. Any relationship between magnitude of flooding, native species response and the interaction of flooding with changing sediment supply and vegetation is also unknown.

7. Restoration of wide, shallow, habitats (high width/depth ratio) would reduce nonnatives and increase native spp abundance (see Attachment 4).

Based on the evidence associated with the observations and hypotheses outlined above, a key interpretation is that restoration of wide, shallow habitat types (presumably through the removal of wood and reintroduction of grazing) would facilitate the recovery of native fishes by expanding their habitats and simultaneously reducing the habitats for non-native predators. Assuming that the manipulation of channel morphology is possible, this is a plausible hypothesis. The data supporting this hypothesis, however, are far from conclusive and it is also seems plausible that such manipulations could have little value or be detrimental to native fishes. There are two key limitations to the general hypothesis:

- It is not clear whether the native: non-native community is controlled primarily by flood related mortality of non-natives, by flood stimulation of native recruitment, by channel morphology and habitat capacity regardless of flood history or by some combination of these. If flooding is fundamentally important through a mechanism other than alteration of channel morphology, expanding wide, shallow habitats may only change habitat capacities, but not the interaction of fishes in the habitats that remain. Changing hydrology (e.g. reduced magnitude or frequency of large floods) linked to climate and changing sediment supplies (e.g. Ely et al. 1993) could confound any process or relationship in the future.

- There is a fundamental problem of scaling. It seems unlikely that habitats could be manipulated throughout the system. How extensive would channel manipulation have to be to provide some benefit for native fishes? Can they persist and expand in reaches of a few km or do they require the interconnection of habitats at larger scales to persist and recolonize those habitats in the face of periodic disturbances (e.g. drought and flood)? Similarly can nonnative predators exploit areas beyond reaches that provide primary habitats and how far would that effect extend? Conceivably even small numbers of non-native predators might range widely with significant influence.

4.4. Hypotheses about Interactions:

1. After 1993 flood, beavers have created new instream habitats, e.g. ponding, slow water and marsh-like habitats. This raises the following questions the following questions: what is the role of beavers in the UVR? did the UVR evolve with beaver?

2. Grazing maintains wet meadows and prevents woody vegetation establishment.

3. Grazing maintains wide shallow stream habitats (habitat favoring native fishes); obligate wetland herbaceous vegetation stabilizes banks; once channels are widened, then herbaceous wetland vegetation stabilizes banks; however, channel form may change depending on subsequent flows.

4. Grazing reduces cover of invasive herbaceous plant species; grazing maintains native plant species.

5. Multiple factors, including knickpoints, woody vegetation, and debris dams, are causing channel incision along the UVR.

Response to Hypotheses about Interactions:

1. After 1993 flood, beavers have created new instream habitats, e.g. ponding, slow water and marsh-like habitats. This raises the following questions: what is the role of beavers in the UVR? did the UVR evolve with beaver?

As noted above, beaver likely had an important role historically in the Verde River basin and elsewhere in the southwest USA (Butler and Malanson 2005). Early accounts mention extensive beaver presence and activity in the UVR (Tellman et al. 1997). However, reconstructing past influences of beaver, as well as beaver removal, is challenging in watersheds throughout the West. Recent reentry of beaver into stream networks, especially those with pre-reentry data (such as the UVR), provides an intriguing opportunity to document their current role on stream and riparian habitat, as well as utilization of those habitats by fish and wildlife.

2. Grazing maintains wet meadows and prevents woody vegetation establishment.

It is unclear if grazing, either by livestock or native ungulates, maintains wet meadows. Most of the available literature suggests that meadows, particularly wet meadows (relative to mesic or drier-end meadows), are negatively impacted by grazing (Belsky et al. 1999; Kauffman et al. 2004). Although the supporting research has not been conducted in southwestern meadows (Rinne 1999; Clary and Kruse 2004), there is currently no published data to support this hypothesis for the southwest US or elsewhere in the western USA. Herbivory can have notable impacts on the growth of woody vegetation, particularly at early life stages. Heavy livestock grazing can dramatically hinder (even prevent) seedling establishment of woody riparian trees and shrubs.

3. Grazing maintains wide shallow stream habitats (habitat favoring native fishes); obligate wetland herbaceous vegetation stabilizes banks; once channels are widened, then herbaceous wetland vegetation stabilizes banks; however, channel form may change depending on subsequent flows.

Indeed, removal of vegetation and bank trampling associated with heavy grazing has been associated with changes in channel form (wider, shallower channels) (McDowell and Magilligan 1997). It is plausible that the banks of a wider shallower channel could become vegetated and that they might be more resistant to erosion than steeper banks along a narrower channel. It is questionable whether these wide shallower channels are riffles in the classic sense, and whether managing an entire river to maintain such “riffle” habitat is a reasonable management goal.

It is unclear if a wet meadow system would be less stable in the absence of livestock grazing. It is likely that wet meadows could remain productive and somewhat resistant to moderate flooding if moderately grazed; however, the statement that wet meadows are less stable when ungrazed is unsubstantiated.

Bank stability may not be an appropriate measure of stream health along the UVR. The UVR has historically been characterized by extreme events that remobilize the channel and floodplain. Whereas wet meadows form in deposits of fines upstream of tributary alluvial deposits, upstream of beaver dams, and along low floodplains, these features are transient.

4. Grazing reduces cover of invasive herbaceous plant species; grazing maintains native plant species.

Livestock grazing removes biomass, and generally results in reduction of both native and exotic herbaceous vegetation. Unless exotic species are preferred (no evidence for this was presented), grazing could lead to higher cover of aggressive exotic species. In areas with high cover of exotic species, grazing may be a valuable tool to remove cover and recover native species, but active seeding or planting of natives may be necessary to maintain cover of native species.

5. Multiple factors, including knickpoints, woody vegetation, and debris dams, are causing channel incision along the UVR.

While plausible, there was little compelling evidence from field visits and no data presented to suggest that the UVR is actively incising, nor which of these potential factors might cause incision in different locations of the river.

5. Review Summary

5.1 Upper Verde River: Status of Knowledge

A goal of the review was to address the following question regarding existing knowledge on the UVR: What are major unknowns, particularly those that can potentially be addressed through additional research and monitoring efforts? Below, we list the major unknowns that were identified during the review and provide input on possible data analyses, needed research, and cautions regarding potential limitations of data collected to date.

Vegetation

1. Until the GTR is published, RMRS information on riparian vegetation data from the UVR is unavailable, and thus unknown. Currently, vegetative attributes (cover,

diversity, composition), changes over time (invasives, valued natives, turnover rates), and interactions remain undocumented.

2. Distribution of riparian species, assemblages, and communities (especially valued meadow community types) throughout the UVR stream network in relation to valley form, geomorphologic surfaces, and channel features is unknown. This includes vegetation data from meadows, headwater springs, along tributaries and the mainstem. Information could potentially be gained by combining reach-scale vegetation sampling (i.e. data to be included in the GTR) with GIS analysis.

3. The distribution and characteristics of riparian vegetation relative to hydrological variables and management activities is unknown.

4. Estimates of changes in extent of wetlands (area – based) over time are unknown, and need to be examined in a spatially explicit watershed context. This could potentially be approached by combining reach-scale vegetation sampling, GIS analysis of aerial photos to quantify observations #6 and #8 (Text Box), and assist in addressing observation #6 and #8 (Text Box).

Geomorphology

5. Most of the geomorphic processes are unknown or undocumented at this point (until the GTR becomes available).

6. Hopefully the RMRS data collection will elucidate current channel conditions and recent trends, but these results should be placed in a broader context, i.e. are recent trends within the range of historic variability, or not?

7. Understanding of geomorphic processes within tributary basins and across upland hillslopes may be necessary for interpreting current conditions and developing defensible management strategies.

8. Larger-scale geomorphic analyses are encouraged. For example, what is the origin of the river terraces? Field observations made during site visits and examination of aerial photographs suggest that some terraces may be backwater deposits from tributary fans that blocked the mainstem river. These depositional environments may structure the long-term occurrence of low-gradient habitats for fish and beaver.

Fish and Aquatic Biota

9. Formal quantification of habitat selection or preference for native fishes could demonstrate the biological significance of distinct habitat types. Although suggestive data have been presented, additional research on habitat utilization, particularly during periods of stress or extreme flows could be useful as well. If this work is logistically infeasible in the Verde, work in other systems or a review of work in similar systems or with related species could provide a useful analog.

10. The distribution and extent of aquatic habitat types along the UVR has not been quantified. This work would be necessary to support any formal analysis of habitat selection, but could be useful in itself to understand the magnitude of change associated with flooding and management. Inventory and monitoring estimates of the total area in distinctly different types quantified with a statistically based sampling design would help understand habitat availability and change that occurs with disturbance and any intentional manipulation. Existing data might be used for an initial approximation of habitat availability and design for future work.

11. The potential mechanisms driving the assumed relationships between non-native species and native species are unclear. Research quantifying native species population dynamics (e.g., growth, mortality, and recruitment), native-nonnative food webs, and predation rates could help clarify the relative importance of the different alternatives.

12. Scaling of habitat utilization and species interactions is unknown. Assuming habitat conditions do influence or control the fish community structure, the extent of habitat alteration that might be needed to benefit native species is unknown. Studies to quantify the extent of foraging and life history movements for both native and non-native species might help clarify the scaling important to population responses. If direct measurements of the processes influencing population dynamics and structure are not possible genetic tools might be useful, but application with the species in these systems would require further work to determine feasibility.

13. The extent of intentional grazing and channel habitat manipulation possible within physical, ecological and political constraints is unknown. The detailed mechanistic studies outlined above are likely to be time consuming and expensive and may yield uncertain results. Management-research experiments rather than detailed mechanistic research may be the most effective way to resolve the uncertainties associated with grazing, native fishes, and introduced fishes but the logistical, scientific, and political constraints on such experiments will require thoughtful discussion and development. Experimental grazing and vegetation management might be attempted in select reaches. With a valid experimental design it may be possible to determine the extent of manipulation in channel/habitat response possible within existing physical, ecological and political constraints. The experimental manipulation of predator species could be continued, but research may need to be expanded to effectively quantify dynamics of the predator and prey populations and understand the magnitude of change required for any meaningful response.

<u>Interactions, processes, other:</u>

14. An understanding of the overall condition of the Verde River watershed is lacking. Existing watershed assessments could be expanded to include areas influenced by recreation, roads, upslope gravel mining; upland grazing; activities on private in holdings (TNC and ranchers); biotic inventories (in addition to plants and fish); distribution of aquatic and riparian habitat types; seasonal surface water chemistry and temperature at multiple, selected locations within the basin (including springs and

tributaries); and continued evaluation of biota relative to hydrologic variables, physical features, and both riparian and upland land use.

15. Influence of management activities, including grazing, and human impacts (e.g. unmanaged recreation) on riparian vegetation, fish species, aquatic-terrestrial habitat, and hillslope-channel physical features have not been quantified or documented beyond photo comparisons. In addition, the influence of management on natural processes and interactions among biota and physical features is unknown. Focused, well-designed experimental research is needed to address interactions and the influence of management in the UVR basin, as well as other Arizona rivers.

16. With the exception of the sampling efforts shown in Table 1, no data have been collected by RMRS on most groups of aquatic-riparian biota, including riparian and aquatic micro-and- macroinvertebrate assemblages, aquatic autotrophs (phytoplankton, periphyton, macrophytes), microbial organisms, invasive species of concern (Asiatic clam, crayfish, and bullfrogs), and valued species of concern (lowland leopard frogs, neotropical migrant bird species, bats). Some data were collected by other groups including university and agency scientists.

17. No information has been collected on basic stream-riparian ecological processes in the UVR, including seasonal nutrient cycling and organic matter dynamics, aquatic-terrestrial food webs, large wood dynamics, and species interactions (competitive, beneficial, other). Aspects of these processes, particularly in relation to management or human modification of the river, may be critical to understanding the disappearance and decline in native fish populations.

18. Interactions between and among riparian vegetation, channel features (substrates, dimensions, form), and distribution of aquatic-riparian vertebrate populations (fish, amphibians, birds) are unknown. Although work by RMRS scientists has increased understanding of habitat preferences for certain native fish species, considerably more information is needed. No interactions have been documented.

We recognize that exploring the listed ‘unknowns’ is beyond the current scope of research and monitoring capabilities of RMRS and the PNF and will require broader collaboration with other partners, including state agencies (Arizona Game and Fish Department), USGS researchers, local universities, and USFWS. Since so few data have been collected on the UVR, RMRS monitoring information may be an important contribution to current understanding of the river. It is important that existing data be fully utilized and analyzed and made available as soon as possible, so that efforts are not repeated or duplicated by others. Once published, we recommend that the GTR be given broad distribution and that RMRS become more actively engaged with the wide range of stakeholders who have been meeting to discuss the future of the Upper Verde River.

In addressing 'what is known about the UVR', two recent reports provide timely information on the status of knowledge. The first is USGS Open-File Report 2004-1411, entitled 'Geologic Framework of Aquifer Units and Ground-Water Flowpaths, Verde River Headwaters, North-Central Arizona (Wirt et al., 2004; http://pubs.usgs.gov/of/2004/1411) and focuses on the physical features of the Verde River basin, particularly the hydrology of the upper portion. The second is a report produced by The Nature Conservancy (TNC), entitled 'Ecological Implications of Verde River Flows' (Haney et al. 2008; http://www.biologicaldiversity.org; accessed March 2008). Collectively, these two reports (and citations within) provide a comprehensive summary of published work to date. However, both reports emphasize how little is really known about the Verde River.

5.2 Science Needs Assessment

This section is an extension of our responses to the hypotheses in Section 4, and further addresses discussions that occurred during the review. We do not mean to imply that these are priority management questions for the PNF, since they have already been identified. Nor do we intend that these comments identify high-priority research questions for the RMRS. Rather, they are intended as an assessment of the potential areas for integration of existing information and management of the UVR, RMRS monitoring efforts, and management questions posed by the PNF. The review illuminated the complex ecological issues related to potentially conflicting management objectives in a sometimes contentious socio-political climate. The staff of the PNF face difficult decisions to achieve the broader objectives of conservation of ecological diversity, and restoration and maintenance of ecosystem function while providing a sustainable delivery of goods and services demanded by their permittees and the general public.

As noted above, it is difficult to evaluate the riparian vegetation and geomorphological aspects of the work that has been conducted by RMRS personnel, because we were not presented with any summaries of the data, graphs, statistics or conclusions from data analyses. However, the conclusions that have been reached and were shared with the group implied that much is known about the riparian vegetation of the UVR and that the positive effects of grazing are fairly clear. Currently, these conclusions remain unsupported and valid objections to them could be raised. For example, the conclusion that livestock grazing along the UVR contributes to the maintenance of endangered fish habitat is questionable given the lack of data indicating patterns that would suggest such habitat is more abundant along reaches lacking woody vegetation. Many linkages in process are made with little data to support them (grazing >> riffles >> fish habitat). The desired state described by RMRS personnel for riparian areas along the UVR includes a stable, wide, shallow channel bordered by grazed meadow. It is unclear whether this will indeed provide abundant riffle habitat for native fishes along the UVR, but it seems unlikely to us that this scenario bears resemblance to historical conditions along the UVR.

The Verde River is unique in Arizona in that it is perennial along much of its length. However, it also experiences floods orders of magnitude larger than low flow. The system has a rich supply of sediment from surrounding hillslopes and tributaries and the channel and bed are comprised of alluvium along much of its length. The frequent large flood events likely restructure the channel regularly, facilitating the establishment of disturbance adapted species such as willow, cottonwood, seep willow, and suites of annual and short-lived species. Over time the river recovers between disturbances and less-disturbance adapted species can become established. Through time the UVR supports very diverse and dynamic riparian vegetation. Though wet meadows are components of this system, particularly during longer intervals between floods (Heffernan 2008), woody vegetation has likely always been an important component of this system. Early accounts from the 1850's suggest that there were abundant forests and riparian shrublands along the Verde River and its tributaries, and that there were marshes and wet meadows associated with beaver dams (Leopold 1951; Shaw 2006). RMRS personnel indicated that beaver were introduced and that they were undesirable because they facilitate channel incision through dam failure. Based on early accounts from the region, beaver trapping was common throughout the Gila and Verde Rivers in the 18th century and earlier (Leopold 1951; Blinn and Poff 2005).

Observations for the Upper Verde River by the PNF (Leonard's Briefing Paper) stated: "We have witnessed significant losses of sedge-dominated wetlands, important habitat for lowland leopard frogs, garter snakes and other wildlife." During the review, we were shown a low gradient reach with on-going beaver activity that, according to photos from the mid 1990's, had been an extensive 'sedge-dominated wetland'. We were informed that wet meadows, which this site once was, are important habitat and breeding sites for lowland leopard frogs (*Rana yavapaiensis*), garter snakes, and other wildlife on the Upper Verde. Leopard frogs had not been observed for some time, and the PNF associated the frog's disappearance, in part, with changes to its habitat. However, lowland leopard frogs utilize a variety of habitats and are not wetland or pond obligates. They inhabit permanent stream pools often overgrown with willows and cottonwoods, as well as side channels and stock tanks. They rely on debris piles, root wads, and undercut banks for cover (Sredl 2005). On Fossil Creek, tributary to the lower Verde River, Coconino NF biologists recorded frogs successfully breeding along stream channels amid overhanging cottonwoods and sycamores (Agyagos 2006).

We advocate that a full range of alternative hypotheses, in addition to the cessation of livestock grazing, be considered to explain changes in occurrence of native fauna and condition of riparian and aquatic habitat. Regarding the possible extirpation of lowland leopard frogs from the upper Verde River, a more likely cause than loss of suitable habitat may be the presence of nonnative aquatic species. The low frequency of lowland leopard frogs in mainstem rivers has been attributed to the presence of large populations of non-native organisms, including fishes, bullfrogs, and crayfish (Sredl *et al*. 1997). In a recent study, Witte *et al*. (2008) examined over a dozen environmental risk factors that may be associated with local disappearances of native ranid frogs, including lowland leopard frogs, in Arizona. The presence of introduced crayfish was one of the few factors significantly correlated with leopard frog disappearance, likely through predation and competition. The negative impact of invasive crayfish (abundant in the upper Verde River) on native fish and herpetofauna may be greater than shifts in riparian vegetation.

There are limitations to existing fish/habitat information; however, this is not a criticism of the work. Past efforts and existing data on fishes and their habitats were done on very limited funding and were not designed to answer questions or limitations like the ones posed above. Existing data provide critical information about the status of native species, important clues about the causes, and a foundation for hypothesis generation and the design of more detailed ecological studies. The current hypotheses are plausible and supported in theory and some observation from other systems. It is not possible, however, to predict with any confidence what, if any, habitat manipulations or management actions would lead to the restoration of native fishes. Addressing this hypothesis will require detailed ecological research or large scale management experiments, or both. There are important challenges to either approach, but management experiments designed through some collaboration of research, management, and other public-private interests could probably resolve critical uncertainties more quickly. Whether those experiments are even possible and the scale needed to gain meaningful information will require considerable discussion and debate.

The values implied by restoration ecology and conservation biology are often at odds (e.g. Noss et al. 2006). It is important for managers to recognize the difference and clearly articulate their goals and objectives in that context. It is implausible to us that the Verde River existed over evolutionary and important ecological time scales (100s to 1000s of years) without a substantial and dynamic flux of riparian vegetation including larger woody species. The period around the turn of the 19th century was unprecedented in the frequency of major floods in the region (Ely et al. 1993) that in combination with heavy grazing might well explain the apparent lack of riparian vegetation in the early 20th century. The flood record suggests anything but constancy and we would expect a system that varied through a broad range of geomorphic and ecological conditions driven by flood, drought, and vegetation succession through space and time. The native species complex evolved in that context and had the capacity to persist with it. Non-native species (fish and plant), loss of water, changing sediment supply, and other stresses have undoubtedly altered that. But, our sense is that the Verde still has the capacity to express some of the native diversity and dynamics.

Staff from the PNF expressed concern that the Pacific Northwest “trout model” still greatly influences perceptions of watershed condition and restoration in arid streams. Their point, that a management paradigm supporting attempts to create or maintain deep, narrow streams with high frequencies of pools may be inappropriate for flood-sediment driven desert streams, is well taken. There is a growing realization that natural disturbance and heterogeneity of habitats in time and space is the appropriate model in most systems. Current theory and a growing body of empirical evidence argues that maintenance of biological diversity and adaptive potential depends more on restoring or maintaining natural disturbance regimes and the integrity-connectivity of upland-riparian systems and stream networks that allow biological communities to vary and respond as they have over evolutionary/ecological time scales. It also recognizes that these systems are changing, potentially toward unprecedented conditions, in response to climate change, species invasions, and inescapable human disruption. Research that elucidates appropriate models for the processes that dominate southwestern arid river systems may help the PNF meet the broader goal of creating and maintaining systems that have the potential to function, adapt, and provide as many of the natural services and values as possible with limited human intervention, even if they do not maintain the strict ecological integrity implied by communities of purely native species (e.g. Calicott 1995; Calicott and Mumford 1997).

We do not expect that the forthcoming General Technical Report will completely resolve the many questions identified in this review. However, it may provide useful analyses and additional information that will provide the sound scientific basis for future management decisions.

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Attachments:

1. Review team with contact information and website links.

2. Review participants during visit, April 7-11, 2008.

3. Handout provided by John Rinne: Upper Verde River; Status of Information on Fishes, 1994-2006 (prepared Feb, 2007).

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Attachment 2. Review Participants

Name	Title	Affiliation	Participation
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David Merritt	Riparian Plant Ecologist	Stream Systems Technology Center	April 7-11, all activities
John Buffington	Research Geomorphologist	RMRS	April 7-11, all activities
Bruce Rieman	Research Fisheries Ecologist	RMRS, retired	April 7-11, all activities
Cynthia Tait	Regional Aquatic Ecologist	NFS, R4	April 7-11, all activities
Kerry Overton	Acting Program Manager Air, Water & Aquatic Environments Science Program	RMRS	April 7-11, all activities
Daniel Neary	Research Soil Scientist	RMRS	April 7-9, all activities; April 11, wrap-up meeting
Alvin Medina	Rangeland Specialist	RMRS	April 7-9, all activities; April 11, wrap-up meeting
John Rinne	Research Fisheries Ecologist	RMRS, retired	April 7, presentations April 10, presentation and field visit
Mike Leonard	Staff Officer for Planning, NEPA, Wildlife, Fish and Rare Plants	Prescott NF	April 7, presentations April 8, field visit
Linda Jackson	District Ranger, Chino Valley Ranger District	Prescott NF	April 7, presentations
Larry Bright	WFRP Team Leader	Prescott NF	April 7-9, all activities; April 11, wrap-up meeting
Janet Grove	Riparian Ecologist	Tonto NF	April 8-9, field visits
Jackson Leonard	Technician	RMRS	April 7, presentations April 8, 9, 10 field visits

Attachment 3. Handout provided by John Rinne: Upper Verde River; Status of Information on Fishes, 1994-2006 (prepared Feb, 2007).

UPPER VERDE RIVER
STATUS OF INFORMATION ON FISHES, 1994-2006

John N. Rinne
RMRS
February, 2007

RMRS has been monitoring and studying fish assemblages and factors potentially affecting these assemblages in the upper 60 km of the Verde River since 1994. Information has been published in numerous outlets (Appendix A). Activities have included monitoring fishes and their habitats since flooding in winter 1992-93, mechanical removal of predators 1999-2003 and summer 2006, and spikedace monitoring. In spring 2007, there will be 14 years of data at seven fixed monitoring sites over the upper 60 km reach.

Important relationships and changes in fish assemblages have been documented and unfavorable trends in native fishes have a high probability of repeating themselves. These are:

1. Native fishes were abundant and dominated fish assemblages only for a short term post-flooding in 1994-96 and 2006-?

2. Spikedace were abundant only from 1994-1996, at the extreme upper end of sampling reach. The species has not been collected since 1997.

3. Nonnative fishes became dominant during the extended low flow, drought period (1996-2003); three species of native fishes (including the threatened spikedace) became markedly reduced ((70%) and have virtually disappeared in samples.

4. Pilot mechanical removal activities from 1999-2003 failed to accrue any benefit to native species. A modified removal approach was initiated in 2006, however, funding is currently inadequate to continue this program.

5. Nonnative species are markedly, and steadily increasing once again based on monitoring at the seven long term sites.

6. Flooding and the nature of the upper Verde River hydrograph has been the primary, positive factor to sustain native fishes.

7. Base, drought flows and attendant livestock grazing removal appears to be the primary activities that enhance nonnative fishes in the upper Verde.

In summary, in absence of significant flooding, continued base flows and livestock exclusion, native fishes will once again decline and in some cases disappear from the upper Verde River. By contrast, nonnatives species will increase and dominate the fish assemblage in the upper Verde. Spikedace re-appearance will have an increasingly lower probability.

APPENDIX A

Upper Verde Published Information

1. Stefferud J. A.; **Rinne J. N**. 1995. Preliminary observations on the sustainability of fishes in a desert river: The roles of streamflow and introduced fishes. Hydrology and Water Resources in Arizona and the Southwest 22-25: 26-32.

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I. UPPER VERDE RIVER WATERSHED