RECLAMATION
Managing Water in the West

Appraisal-Level Investigation Summary of Findings

Verde River Fish Barrier

Central Arizona Project

U.S. Department of the Interior
Bureau of Reclamation
Phoenix Area Office
June 2010

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Appraisal-Level Investigation Summary of Findings

Verde River Fish Barrier

Central Arizona Project

Submitted to:
U.S. Fish and Wildlife Service
U.S. Forest Service
Arizona Game and Fish Department

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I. Introduction

The Verde River mainstem, tributary to Salt River in the Gila River drainage, historically was occupied by at least 12 native fishes: Colorado pikeminnow (*Ptychocheilus lucius*), razorback sucker (*Xyrauchen texanus*), Sonora sucker (*Catostomus insignis*), desert sucker (*Pantosteus clarki*), roundtail chub (*Gila robusta*), speckled dace (*Rhinichthys osculus*), longfin dace (*Agosia chrysogaster*), woundfin (*Plagopterus argentissimus*), spikedace (*Meda fulgida*), loach minnow (*Tiaroga cobitis*), Gila topminnow (*Poeciliopsis occidentalis*), and desert pupfish (*Cyprinodon macularius*)(Desert Fishes Team 2003, 2004). Although about half of those species are considered extirpated, the upper river retains a strong potential to reestablish several, provided nonnative fishes can be removed and the river secured against their reinvasion. Those actions could be accomplished by construction of a fish barrier followed by chemical renovation of the upstream river and its perennial tributaries.

Reclamation committed in a 2008 U.S. Fish and Wildlife Service (FWS) biological opinion to investigate the feasibility of constructing a fish barrier on the mainstem Verde River upstream of the town of Clarkdale. This action is one of a suite of conservation measures being implemented by Reclamation to compensate for transfers of nonnative aquatic organisms into the Gila River basin via the Central Arizona Project. Highest-priority streams under Reclamation's fish barrier construction program are those that can be secured to prevent extinction and stabilize rare stocks of native fishes, or that can be protected and renovated to replicate rare stocks of native fishes. A protected Verde River is intended to protect, augment, or re-establish the Verde River population of spikedace and many of the other native fishes listed above.

This appraisal investigation evaluates fish barrier options at several sites on the upper Verde River. We summarize site investigations and discuss biological, engineering, and construction considerations, including geology, hydrology, geomorphology, conceptual design, construction costs, and right-of-way. National Environmental Policy Act (NEPA), Endangered Species Act (ESA), and Clean Water Act (CWA) compliance needs are also addressed. This information is also intended to provide baseline information to the Arizona Game and Fish Department (AZGFD) relative to addressing fishery management conflicts (native fish vs. sport fish) on the upper Verde River. We originally concentrated our site investigation efforts on the Verde Rver to the reach between the town of Clarkdale and Sycamore Creek, as originally proposed in our March 16, 2001 addendum to the biological assessment that re-initiated consultation on CAP fish transfers to the Gila River basin. AZGFD and others requested we also examine sites further upstream, which are evaluated herein.

II. Study Area

The potential fish barrier sites considered in this report are located in northern Yavapai County between the towns of Clarkdale and Paulden, Arizona (Figures 1 and 2). All are located on U.S. Forest Service (USFS; Prescott or Coconino National Forests), AZGFD, or private lands. Elevations at the sites range from 3,369 ft. near Tapco to 4,197 ft. at the upstream site near the Prescott National Forest boundary (Figure 2). Based on U.S. Geological Survey (USGS) data from the gage station "Verde River near Clarkdale, Arizona" (no. 09504000, located 8.1 river miles upstream from our lowermost site), the Verde River watershed upstream of Clarkdale is approximately 3,500 mi^2. Major tributaries to the Verde River above site 1 include Big Chino Wash and Granite Creek, site 2 also receives drainage from Hell Canyon, and the lower sites also receive input from Sycamore Creek. Table 1 shows the length of perennial stream that would be protected above each barrier site.

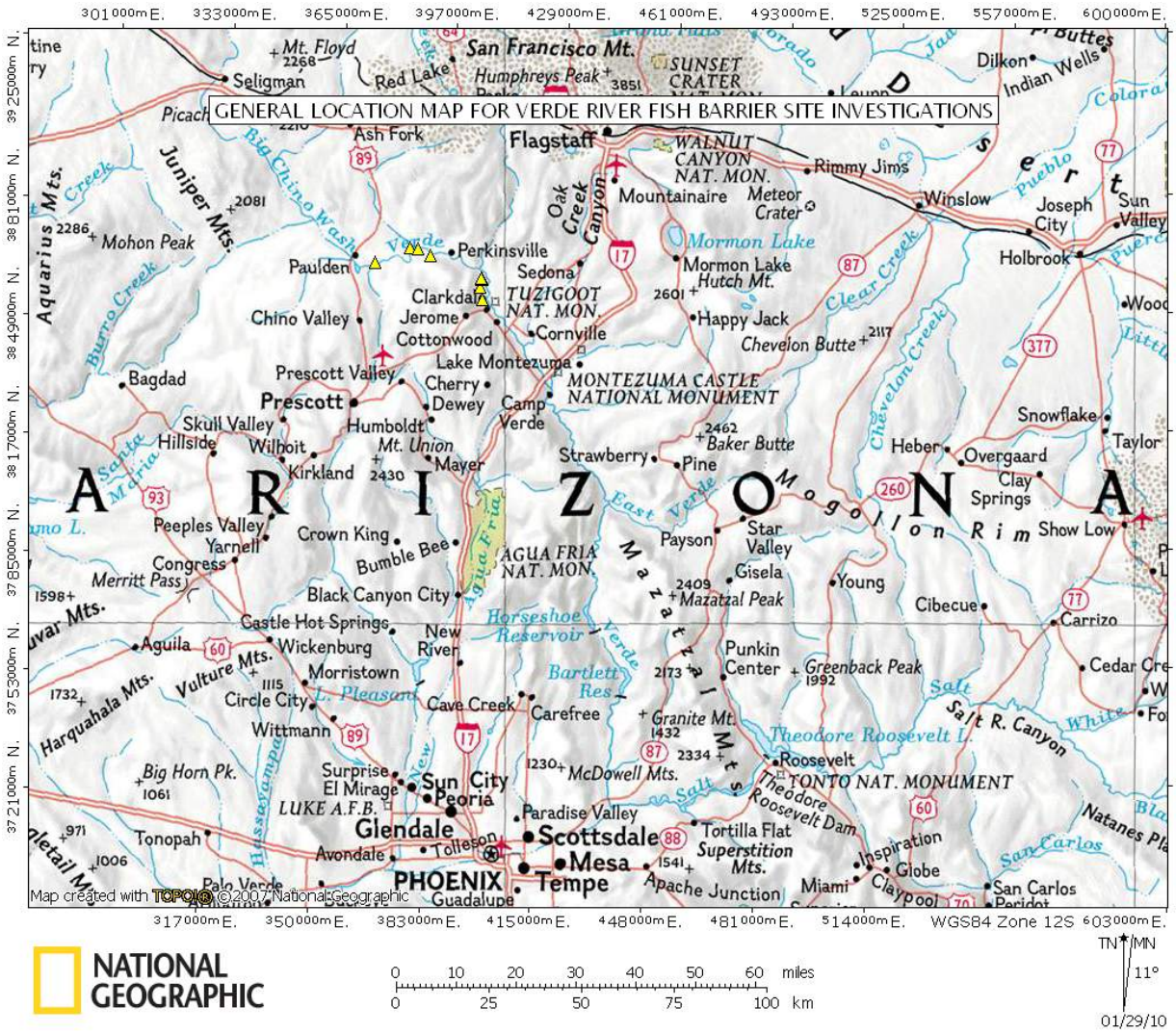

Figure 1. Map showing the general location of possible Verde River fish barrier sites (yellow triangles).

Table 1. Number of river miles of perennial water (starting 1.1 mi downstream from Sullivan Lake Dam) protected behind potential Verde River fish barrier sites. See Figure 2 for site locations.

Site Name	AZGFD	1	2	3	4	5	6	7	8	9
Length (mi)	4.5	16.7	18.7	22.8	38.7	38.9	39.2	41.5	45.9	34.7

Hydrology based on the USGS gage station near Clarkdale is summarized as follows: (http://az.water.usgs.gov/DataReports/DR04/Basins/VerdeBasin/stats/09504000.pdf): Maximum discharge of 53,200 cfs occurred on February 20, 1993, and minimum flow was 55 cfs on August 31-September 1, 1920. Mean annual precipitation in the watershed is 19.1 inches. Mean monthly discharges range from 77 cfs in June to 516 cfs in March. Magnitudes and probabilities of instantaneous peak flows for the Verde River gages near Clarkdale and Paulden are shown in Tables 2 and 3.

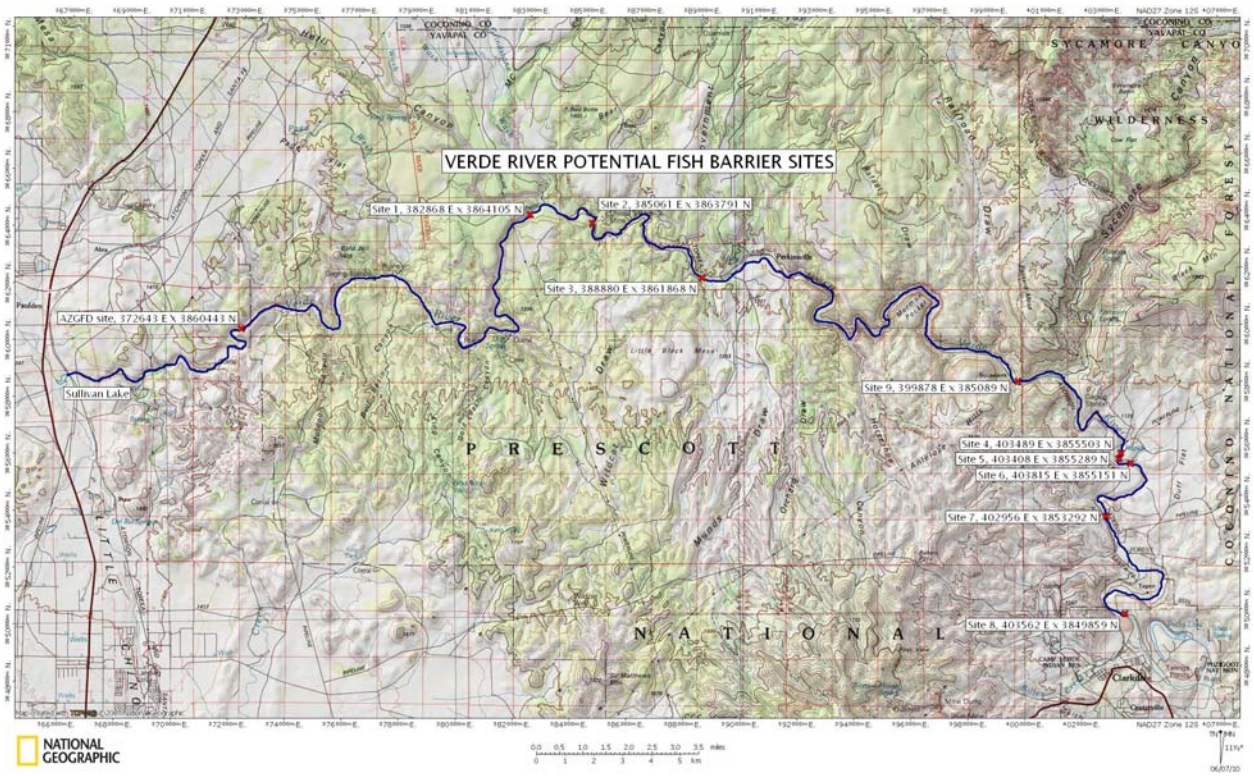

Figure 2. Map of the upper Verde River showing locations (UTM, NAD27) of fish barrier sites examined in this report.

Table 2. Discharge (cfs) for indicated recurrence interval (years) and exceedance probability (%) for the Verde River near Clarkdale (gage no. 09504000).

Recurrence interval (yrs)	2	5	10	25	50	100
Exceedance probability	50%	20%	10%	4%	2%	1%
Discharge	6,340	16,100	25,500	40,700	54,400	70,200

Table 3. Discharge (cfs) for indicated recurrence interval (years) and exceedance probability (%) for the Verde River near Paulden (gage no. 09503700).

Recurrence interval (yrs)	2	5	10	25	50	100
Exceedance probability	50%	20%	10%	4%	2%	1%
Discharge	1,380	4,550	8,540	16,700	25,900	38,400

The stream channel can be characterized as mostly canyon-bound with relatively narrow floodplains. Banks are mostly gravel/cobble or rarely bedrock when the river contacts canyon walls. Instream habitat mostly is long, shallow pools interrupted by relatively short riffle/rapid habitat types, with occasional long reaches of run. Riparian development is patchy, typical of most free-flowing rivers, but relatively dense where found, consisting of primarily cottonwood/willow.

III. Engineering and Design Considerations

A. General Information

Site investigations were performed at nine potential fish barrier locations as part of this study. The sites are described individually starting at the furthest upstream and moving downstream. Each site was evaluated for engineering and construction factors. Preliminary cost estimates are provided for each site.

All fish barrier sites investigated had alluvial-filled main channels that would require excavation to construct a barrier. All but one site had rock only at the canyon walls to anchor the structure to. As a result, the fish barrier must be engineered to withstand flood flows and associated scour while resting entirely on erodible materials, except at the ends.

The Verde River contains perennial flows at all potential fish barrier locations investigated. During construction, the surface flows will need to be diverted around the work. Dewatering of the foundation will be required during excavation to maintain stable trench slopes. Submersible pumps or above-ground pumps can be used for this purpose. Water pumped from the foundation would be discharged to the river downstream of the work. Dewatering is a critical element of the work, typically running about 25% of the total cost.

For barriers longer than 70 feet, the potential for sliding caused by hydraulic forces would likely be counteracted by an arch shape that transfers forces into the rock abutment. Shorter structures do not have contraction joints and can rely on end anchorage for sliding resistance.

The potential for scour to undercut the structure is mitigated by the use of concrete cutoff walls that extend below the anticipated scour depth. If bedrock is present, the cutoff walls can be tied directly to the bedrock. However, mid-channel bedrock at a reasonable depth is not expected. In general, it is not cost effective to remove alluvium in order to tie the structure to rock unless the

bedrock is within 25 feet of the surface. Cutoff walls need to be constructed to a depth of 20 to 25 feet below the stream surface to prevent the structure from being undercut.

Downstream scour of alluvial materials can be mitigated by the use of riprap. All fish barrier locations identified in this report have alluvial foundations, so riprap is assumed to be used at all sites.

Design Criteria:

- 4-foot vertical drop
- Sloping apron to keep fish from gathering at the base of the drop
- Design flood – 100-year instantaneous peak flow
- Concrete structure

B. Potential Fish Barrier Sites

1. AZGFD Site

a. General

The furthest upstream location investigated, this site is located on an Arizona Game and Fish Department parcel (Photo 1). A barrier at this site would protect approximately 4.5 miles of perennial river for native fishes. Existing roads provide well graded vehicular access to within ¾ mile of the potential site. Wide floodplain terraces would allow a road to be constructed to the site with minimal effort. The Verde River would need to be forded at least twice if a road to the fish barrier site were constructed.

There is no power to the area so generators would be required for all electrical needs.

Three potential fish barrier sites were identified within a 500-foot reach of the river near the downstream boundary of AZGFD land. This part of the river is the only portion of AZGFD property where the canyon walls narrow to less than 400 feet. Site A is located within 100 feet of the fence marking the boundary of the AZGFD property (Photo 2). The fish barrier would be about 370 feet across with rock at each end to tie to.

Site B is located about 400 feet upstream of the boundary fence. The canyon walls narrow to 330 feet, and provide rock at each abutment. Site B is the preferred location of the three AZGFD sites, and the cost estimate is based on this site.

Site C, located 190 feet upstream of the boundary fence, is actually the narrowest at 225 feet. The right end ties into rock at the right abutment. However, the left end of the structure at Site C would tie into a 250-foot long manmade rock and earthfill dike. The dike appears to have been placed to redirect a side drainage that comes in from the north. Although Site C is narrower than the others, the potential exists for the dike to fail by overtopping considering the higher water surface resulting from a fish barrier. Without analyses of the river hydraulics and the dike

materials, the uncertainties associated with Site C are too great to assume this site is a viable option.

The river elevation is about 4,200 feet. The mean annual flow at the Verde River near Paulden stream gage, located 5 river miles downstream with no major intervening tributaries, is 45 cfs.

b. Engineering and Geology

Although geologic investigations have not been performed, based on similar stream types it is unlikely that bedrock is within 50 feet of the surface except at the abutments. Excavation of alluvium up to 25 feet in depth to would be required to ensure the structure is constructed deep enough to not be undercut by river scour actions.

The site geology is made up of sedimentary materials, primarily sandstone, grading upward into shale, and overlain by limestone and dolomite on the mesas. The barrier would tie into a sandstone layer and be keyed into the abutment rock about 3 feet. Anchor bars would extend from the concrete into the rock for additional stability.

Stream diversion would be accomplished with channels and berms consisting of native materials. Surface flows would be routed to one side of the channel while half the barrier is constructed, then routed to the other side while the barrier is completed.

Dewatering will be required to prevent saturated excavated slopes from sloughing. Gradation analysis of the alluvial materials will determine the dewatering methods.

c. Construction Cost Estimate

The cost of construction for a fish barrier at Site B on the AZGFD property is estimated at $5,708,000 (see spreadsheet file VerdeFishBarrierCostEstimate6-3-10.xlsx for a detailed cost itemization).

Photo 1 – Aerial view of the three AZGFD sites. River flows from left to right. The furthest downstream alignment is Site A, the upper alignment is Site B, and the middle line depicts Site C.

Photo 2 – AZGFD Site A. Barrier would be located upstream (right) of the cattle control fencing. This view is from near the left canyon wall. The river is obscured by the cottonwood trees.

2. Site 1 (Hell Point)

a. General

Located 0.4 miles upstream of the confluence with Hell Canyon in Prescott National Forest, this site is about 185 feet wide, and offers a bedrock outcrop that extends halfway across the channel (Photos 3-5). A barrier at this site would protect approximately 16.7 miles of perennial river for native fishes. Existing dirt roads in moderate condition provide access to the top of the 350-foot deep canyon. Three jeep trails drop into the canyon at the confluence 0.4 miles from the fish barrier site. Two of the roads come from the north on each side of Hell Canyon. Another arrives from the south side of the Verde River.

Without improvement, these jeep trails would severely limit the type of construction equipment that could be driven to the site. Once vehicles reach the river bottom, a road from the confluence to the fish barrier site could easily be developed, but would require fording the river two or three times. An alternate construction access method would be to construct a cableway system from the top of the canyon to bring in materials, supplies, equipment, and personnel.

There is no power to the area so generators would be required for all electrical needs.

The bedrock intrusion slopes down from the right canyon wall and dives below the alluvium about halfway across the canyon. The remainder of the stream channel to the vertical rock face on the left abutment is alluvium.

The river elevation is about 3,950 feet. The mean annual flow at the Verde River near Paulden stream gage, located 8 river miles upstream with no major intervening tributaries, is 45 cfs.

b. Engineering and Geology

It is assumed that the bedrock intrusion does not stay close enough to the surface to tie the barrier to bedrock across the entire channel. So, excavation of alluvium up to 25 feet in depth would be required to ensure the structure is not undercut by scour actions. However, the bedrock intrusion offers a stable foundation for half of the total length of the structure. On bedrock, the barrier can essentially consist of a 2-foot thick, 4-foot tall wall, substantially reducing concrete quantities since an apron and scour walls are not necessary.

The structure would be keyed and anchored into canyon wall rock at the ends, and anchored along the bedrock intrusion with drilled and grouted anchor bars.

Stream diversion would be accomplished with channels and berms consisting of native materials. Surface flows would be routed to one side of the channel while half the barrier is constructed; then routed to the other side while the barrier is completed.

Dewatering will be required to prevent saturated excavated slopes on the alluvial side from sloughing. Gradation analysis of the alluvial materials will determine the dewatering methods.

c. Construction Cost Estimate

The cost of construction for a fish barrier at Hell Point is estimated at $2,910,000 (see spreadsheet file VerdeFishBarrierCostEstimate6-3-10.xlsx for a detailed cost itemization).

Photo 3 - Site 1 (Hell Point) looking upstream.

Photo 4 - Site 1 (Hell Point) looking across river toward left abutment.

Photo 5 - Site 1 (Hell Point) plan view. Hell Canyon joins the Verde River at the top of the photo. Three roads could be used to access the river bottom: one from the left, one from the top right, and one from the lower right.

3. Site 2 (U.S. Mine)

a. General

Also called Bear Siding, this site is 1.5 miles downstream of Hell Canyon in Prescott National Forest (Photos 6-8). A barrier at this site would protect approximately 18.7 miles of perennial river for native fishes. An abandoned mine along the road ¼ mile from the site is referred to as the United States Mine on topographic maps. Existing dirt roads in moderate condition allow vehicles to easily drive within 90 vertical feet of the river. From there, an existing jeep trail gains access to within 30 vertical feet of the river. A new road would need to be created for the final descent to the river. An alternative access method would be to lower materials, supplies, and equipment to the work site using a cableway system.

There are two viable locations for fish barriers, about 200 feet apart from each other. The upstream site is 181 feet across, and the downstream site is 165 feet across. Each has rock canyon walls to tie into, with alluvium foundation between.

There is no power to the area so generators would be required for all electrical needs.

The river elevation is about 3,910 feet. The mean annual flow at the Verde River near Paulden stream gage, located 9 river miles upstream, is 45 cfs. However, two major ephemeral tributaries join the Verde River just upstream of this site; Hell Canyon and MC Canyon.

b. Engineering and Geology

Although geologic investigations have not been performed, based on similar stream types it is unlikely that bedrock is within 50 feet of the surface except at the abutments. Excavation of alluvium up to 25 feet in depth to would be required to ensure the structure is constructed deep enough to not be undercut by river scour actions.

The site geology is made up of sedimentary materials, primarily sandstone at river level, grading upward into shale, and overlain by limestone and dolomite on the mesas. The barrier would tie into a sandstone layer and be keyed into the abutment rock about 3 feet. Anchor bars would extend from the concrete into the rock for additional stability.

Stream diversion would be accomplished with channels and berms consisting of native materials. Surface flows would be routed to one side of the channel while half the barrier is constructed; then routed to the other side while the barrier is completed.

Dewatering will be required to prevent saturated excavated slopes on the alluvial side from sloughing. Gradation analysis of the alluvial materials will determine the dewatering methods.

c. Construction Cost Estimate

The cost of construction for a fish barrier at the U.S. Mine site is estimated at $3,980,000 (see spreadsheet file VerdeFishBarrierCostEstimate6-3-10.xlsx for a detailed cost itemization).

Photo 6 – Site 2, U.S. Mine (Bear Siding) – Looking downstream from top of canyon at location of downstream site.

Photo 7 - Site 2, U.S. Mine (Bear Siding) – Looking upstream at location of upstream site.

Photo 8 - Site 2, U.S. Mine (Bear Siding) – Plan view of the two sites, river flowing down the page. Note the canyon-top road at right.

4. Site 3 (2 miles upstream of Perkinsville)

a. General

This site is located 0.6 miles upstream of the bridge across the Verde River at Perkinsville (Photos 9-10). A barrier at this site would protect approximately 22.8 miles of perennial river for native fishes. The Perkinsville Road (Forest Road 318) is an all-weather gravel road that provides good access to 0.3 miles of the site. A rough jeep trail gets within 500 feet, beyond which new roadwork would be necessary to get equipment and materials to the site.

The fish barrier site is located on a slow moving stretch of the river. Rock canyon walls are about 140 feet apart with a 20-foot wide terrace on the left abutment.

The town of Perkinsville, 1.6 miles away, has what appears to be singe phase power, although it is unlikely it would be economical to bring power from Perkinsville to the site. Unless this power source is utilized, generators would be required for all electrical needs.

The river elevation is about 3820. The mean annual flow at the Verde River near Paulden stream gage, located 13 river miles upstream, is 45 cfs. However, several major ephemeral tributaries join the Verde River upstream of this site.

b. Engineering and Geology

Although geologic investigations have not been performed, based on similar stream types it is unlikely that bedrock is within 50 feet of the surface except at the abutments. Excavation of alluvium up to 25 feet in depth to would be required to ensure the structure is constructed deep enough to not be undercut by river scour actions.

The site geology is made up of sedimentary materials, primarily sandstone. The barrier would tie into a sandstone layer and be keyed into the abutment rock about 3 feet. Anchor bars would extend from the concrete into the rock for additional stability. Except for the ends, the barrier would be founded on alluvium.

Stream diversion would be accomplished with channels and berms consisting of native materials. Surface flows would be routed to one side of the channel while half the barrier is constructed; then routed to the other side while the barrier is completed.

Dewatering will be required to prevent saturated excavated slopes from sloughing. Gradation analysis of the alluvial materials will determine the dewatering methods.

c. Construction Cost Estimate

The cost of construction for a fish barrier two miles upstream from Perkinsville is estimated at $3,379,000 (see spreadsheet file VerdeFishBarrierCostEstimate6-3-10.xlsx for a detailed cost itemization).

Photo 9 - Site 3, Perkinsville – Looking across river at right abutment rock.

Photo 10 - Site 3, Perkinsville – Plan view. Note access road crossing the train tracks.

5. Site 9 (1.1 miles upstream of Sycamore Creek)

a. General

This site was discovered during review of aerial images and has not undergone on-site evaluation (Photo 11). A barrier at this site would protect approximately 34.7 miles of perennial river for native fishes. There appears to be private holdings along the road, which runs from Sycamore Canyon along the river to the site. The road appears from aerial images to be passable, and provides access to within 500 feet of the barrier site at river level. The river would need to be forded twice to reach the site.

Since there may be private property associated with the actual barrier site and the access road, it could be difficult to work through the right-of-way issues associated with this site.

The Verde River Railroad is close to the river on the right abutment near the barrier tie-in point. A hydraulic analysis would appear necessary to ensure the barrier does not impact the railroad during flooding events and construction would not impact railroad operations.

The barrier would be about 120 feet across. It appears generators would be required for all electrical needs.

The river elevation is about 3,574 feet. The mean annual flow at the Verde River near Clarkdale stream gage, located about 3 miles downstream, is 197 cfs. However, the ungaged, perennial Sycamore Canyon joins the Verde River in the interim.

b. Engineering and Geology

Geology has not been evaluated at this site. The abutments may require some excavation to reach competent rock. Based on similar stream types it is unlikely that bedrock is within 50 feet of the surface except at the abutments. Excavation of alluvium up to 25 feet in depth to would be required to ensure the structure is constructed deep enough to not be undercut by river scour actions.

Stream diversion would be accomplished with channels and berms consisting of native materials. Surface flows would be routed to one side of the channel while half the barrier is constructed; then routed to the other side while the barrier is completed.

Dewatering will be required to prevent saturated excavated slopes from sloughing. Gradation analysis of the alluvial materials will determine the dewatering methods.

c. Construction Cost Estimate

A detailed cost estimate for this site is not appropriate without additional information. Assuming reasonable rights-of-way costs, good access, and the required length of the barrier, this site might be able to be developed for $3,800,000.

Photo 11 - Site 9, 1.1 miles upstream of Sycamore Canyon – Plan view, river flowing from left to right. The access road enters the photo from the right, above the river. The train tracks are at the bottom of the photo.

6. Site 4 (3.0 miles downstream of Sycamore Creek) – Elevation 3,477 ft

Site 5 (3.1 miles downstream of Sycamore Creek) – Elevation 3,476 ft

Site 6 (3.5 miles downstream of Sycamore Creek) – Elevation 3,468 ft

a. General

These three sites are being addressed together because they are in the same vicinity and have very similar physical characteristics (Photos 12-13). Barriers at these sites would protect approximately 38.7, 38.9, and 39.3 miles of perennial river for native fishes, respectively. The sites are located approximately 10 miles north of Clarkdale by gravel road. The last ½ mile is a good dirt road that accesses the top of the canyon walls, 120 feet above the river. The canyon walls are steep, making it difficult to pioneer a road down to the river. The least steep area has

slope of 1.6V : 1H over a 40-foot elevation section. An alternate construction access method would be to construct a cableway system from the top of the canyon to bring in materials, supplies, equipment, and possibly personnel. The distance between the rock canyon walls range from 125 feet at Site 5 to 160 at Site 6.

There is no power to the area so generators would be required for all electrical needs.

The mean annual flow at the Verde River near Clarkdale stream gage, located 1 river mile upstream, is 197 cfs, with no major intervening tributaries.

b. Engineering and Geology

Although geologic investigations have not been performed, based on similar stream types it is unlikely that bedrock is within 50 feet of the surface except at the abutments. Excavation of alluvium up to 25 feet in depth to would be required to ensure the structure is constructed deep enough to not be undercut by river scour actions.

The site geology is made up of sedimentary materials, primarily sandstone and conglomerate. There is significant talus at the base of the canyon wall that would need to be evaluated for suitability. The barrier would tie into a sandstone layer and be keyed into the abutment rock about 3 feet. Anchor bars would extend from the concrete into the rock for additional stability. Except for the ends, the barrier would be founded on alluvium.

Stream diversion would be accomplished with channels and berms consisting of native materials. Surface flows would be routed to one side of the channel while half the barrier is constructed; then routed to the other side while the barrier is completed.

Dewatering will be required to prevent saturated excavated slopes from sloughing. Gradation analysis of the alluvial materials will determine the dewatering methods.

c. Construction Cost Estimate –

The cost of construction for a fish barrier at Site 5, three miles downstream of Sycamore Creek, is estimated at $4,519,000 (see spreadsheet file VerdeFishBarrierCostEstimate6-3-10.xlsx for a detailed cost itemization).

Photo 12 – Site 6 – Looking downstream. Sites 4 and 5 similar.

Photo 13 – Sites 4, 5, and 6 – Plan view, river flowing down the page.

7. Site 7 (5.9 miles downstream of Sycamore Creek at Sob Canyon confluence)

a. General

This site has similar characteristics as Sites 4, 5, and 6 and is reached by driving approximately 7 miles north of Clarkdale (Photos 14-15). A barrier at this site would protect approximately 41.5 miles of perennial river for native fishes. This part of the river has good access via gravel road from Clarkdale The last mile to the top of the canyon is dirt, but in good condition. The canyon walls are 100 feet above the river. The canyon walls are extremely steep, making the possibility of pioneering a road down to the river virtually impossible. An alternate construction access method would be to construct a cableway system from the top of the canyon to bring in materials, supplies, equipment, and possibly personnel.

The distance between the rock canyon walls is about 200 feet at the narrowest point. The mean annual flow at the Verde River near Clarkdale stream gage, located 4 river miles upstream, is 197 cfs, with no major intervening tributaries. The river elevation is 3,430 feet.

b. Engineering and Geology

Although geologic investigations have not been performed, based on similar stream types it is unlikely that bedrock is within 50 feet of the surface except at the abutments. Excavation of alluvium up to 25 feet in depth to would be required to ensure the structure is constructed deep enough to not be undercut by river scour actions.

The site geology is made up of sedimentary materials, primarily sandstone and conglomerate. There is significant talus at the base of the canyon wall that would need to be evaluated for suitability. The barrier would tie into a sandstone layer and be keyed into the abutment rock about 3 feet. Anchor bars would extend from the concrete into the rock for additional stability. Except for the ends, the barrier would be founded on alluvium.

Stream diversion would be accomplished with channels and berms consisting of native materials. Surface flows would be routed to one side of the channel while half the barrier is constructed; then routed to the other side while the barrier is completed.

Dewatering will be required to prevent saturated excavated slopes from sloughing. Gradation analysis of the alluvial materials will determine the dewatering methods.

c. Construction Cost Estimate –

The cost of construction for a fish barrier at Site 7 is estimated at $6,018,000 (see spreadsheet file VerdeFishBarrierCostEstimate6-3-10.xlsx for a detailed cost itemization).

Photo 14 – Site 7 – Looking upstream from east side of canyon.

Photo 15 – Site 7 – Plan view. River is flowing down the page.

8. Site 8 (Mill Tailings at Clarkdale)

a. General

This site is at the edge of the town of Clarkdale (Photos 16-17). A barrier at this site would protect approximately 45.9 miles of perennial river for native fishes. The concept is to utilize a mill tailing pile for the right end of the barrier to tie into. The left end of the barrier will tie into natural rise on the other side of Sycamore Canyon Road. The road, which is in the floodplain, would have to be raised to go over the fish barrier. The site is 3 miles from downtown Clarkdale and has excellent access via the all-weather gravel road.

The barrier would be about 300 feet long. The portion of the barrier that the road would go over would have to rely on high velocities and shallow flows over the roadway surface to keep fish from moving upstream. Or a vertical drop through cattle guards could be constructed, similar to what was built at the Bonita Creek fish barrier.

The mean annual flow at the Verde River near Clarkdale stream gage, located 8 river miles upstream, is 197 cfs, with no major intervening tributaries. The river elevation is 3,360 feet.

b. Engineering and Geology

The riverside slope of the mill tailings pile is at or steeper than the angle of repose. Photo 16 shows that the slopes have slid in the past, probably due to river flows against the pile, leaving overhanging sections. This unstable condition would need to be dealt with during construction to mitigate safety concerns. The barrier would need to key well into the pile to ensure river flows do not erode around the end of the barrier. This could entail removal of a significant amount of tailings materials since the slope is steep and the pile is about 100 feet tall. It may be preferable to treat or plate the surface of the pile with concrete to protect the tailings from river erosion and provide a hard, non-erodible surface to tie to. Or a jack-and-bore method could be used to install a concrete filled pipe into the tailings for the barrier to tie into. The other end of the barrier would tie into sedimentary geology on the other side of the road.

The road would need to be raised about 4 feet to pass over the barrier and must be designed to ensure adequate traffic sight distance on the vertical curve.

Although geologic investigations have not been performed, based on similar stream types it is unlikely that bedrock is within 50 feet of the surface. Excavation of alluvium up to 25 feet in depth to would be required to ensure the structure is constructed deep enough to not be undercut by river scour actions.

The site geology is made up of sedimentary materials, primarily sandstone and conglomerate. Except for the ends, the barrier would be founded on alluvium.

Stream diversion would be accomplished with channels and berms consisting of native materials. Surface flows would be routed to one side of the channel while half the barrier is constructed; then routed to the other side while the barrier is completed.

Dewatering will be required to prevent saturated excavated slopes from sloughing. Gradation analysis of the alluvial materials will determine the dewatering methods.

c. Construction Cost Estimate

The cost of construction for a fish barrier at Site 8 (Mill Tailings) is estimated at $5,613,000 (see spreadsheet file VerdeFishBarrierCostEstimate6-3-10.xlsx for a detailed cost itemization).

Photo 16 – Site 8 – Looking southwest from road. Verde River is in center of photo. Tailings mound is about 100 feet in height.

Photo 17 – Site 8 – Plan view. Tailings mound is at the lower left. The river is flowing from left to right.

11. Other sites

If additional sites come to our attention, they can be evaluated and added to this report. For example, Site 9, 1.1 miles upstream of the Sycamore Creek confluence, appears to have some promise. However, a site visit would be necessary to confirm channel configuration, geology, and access conditions.

IV. Environmental Compliance

Consideration of a Verde River fish barrier beyond the appraisal stage must include provisions for compliance with National Environmental Policy Act (NEPA), Endangered Species Act (ESA), and Clean Water Act (CWA). The NEPA process entails writing draft and final Environmental Assessments of the preferred project and its considered alternatives, and potentially presenting the preferred and alternative projects at public meetings. The NEPA process normally can take 6-12 months to complete. As the reach of the Verde River considered herein has been designated as eligible for suitability under provisions of the Wild & Scenic River

Act, we assume that both a free-flow analysis and suitability study would be required. Addition of these compliance activities could easily extend the duration of the pre-project planning another year or two. If Reclamation were to undertake the NEPA compliance, our costs to perform this work is estimated at approximately $250,000, depending on the proposed action selected and the amount needed for USFS to conduct the Wild & Scenic suitability study. We assume that USFS would be a co-lead with Reclamation on NEPA compliance if the proposed action were to occur on USFS lands.

ESA compliance will involve writing a biological assessment that determines effects of the project to federally-listed species and designated critical habitat for species. FWS has previously determined in their 2008 biological opinion on CAP effects to native fishes in the Gila River basin that a fish barrier project on Verde River will not adversely affect designated critical habitat, but project impacts to listed species likely must undergo formal consultation. As the project is for the benefit of native fishes, consultation with FWS should proceed smoothly, as it did with Reclamation's Aravaipa Creek, Bonita Creek, and Fossil Creek fish barrier projects. Reclamation estimates that ESA compliance activities should not take more than 3-6 months, depending on the priority it receives from FWS. Estimated costs for Reclamation's ESA compliance is approximately $25,000.

A CWA 404 permit for the construction of 11 fish barriers (including the Verde River barrier) was issued to Reclamation on October 30, 2003. The permit includes values for "on-the-ground" impacts. Prior to construction of the Verde River barrier a final jurisdictional delineation must be submitted and approved by the Army Corps of Engineers. The construction impacts must be finalized and confirmed to be less than the estimated values specified in the permit. If the values are greater, Reclamation must request modification of the permit. The construction impacts include volume of fill for barrier, barrier footprint acreage, sedimentation zone acreage, construction impact acreage, and construction access acreage. Mitigation for impacts to "waters of the US" for this barrier has already been completed through Reclamation's acquisition of a Conservation Easement on riparian habitat along the San Pedro River. Processing time for CWA compliance is anticipated to be 3-6 months. Reclamation estimates that compliance costs associated with CWA regulations would be approximately $10,000.

The acquisition process for a 404 permit under requirements of CWA includes determining the impact footprint of the barriers (flooding, sedimentation, and construction zones), receiving a jurisdictional delineation from U.S. Army Corps of Engineers, and further processing of a 404 permit application. Identification of mitigation for impacts to "waters of the US" for this barrier has already been completed through Reclamation acquisition of stream/riparian habitat along the San Pedro River. Processing time for CWA compliance is anticipated to be 3-6 months. Reclamation estimates that compliance costs associated with CWA regulations would be approximately $10,000.

V. Discussion

A. Biological

The foremost issue in considering a fish exclusion barrier for native fishes on the Verde River is that AZGFD has not yet decided if the upper Verde is to be managed for native fishes, for sport fishes, or a combination. As we understand it, a process by which to make such a decision has been agreed upon within AZGFD, and the Verde River is to be the initial basin to be examined. However, we are not aware of a timeline for completion of the process. The other issue we assume the process will decide is the demarcation point(s) of any native fish management area, if such a management emphasis is made. The rest of this discussion is based on the assumption that at least a portion of the upper Verde River will be designated for native fish management. We anticipate that data analyses in our report can assist with the AZGFD decision-making process.

Because the Verde River fish barrier project is meant to mitigate biological effects of the CAP to native fishes (and especially threatened or endangered native fishes), biological considerations are foremost in weighing site-selection criteria. A fish barrier physically and reproductively isolates fishes upstream from those that reside downstream, and thus a barrier can further fragment what may be an already disjunct population. Spikedace has declined to the point where its remaining distribution is among the most fragmented of any native fish species that remains in the Gila River basin. Therefore, one of the primary considerations for a Verde River barrier location is to encompass as much of the potential population distribution as possible to minimize fragmentation of the existing population. Around the time of its federal listing in 1986, spikedace was found in virtually the entire reach of the Verde River shown in Figure 2, but the species has not been detected anywhere in the Verde River during the past decade. The March 21, 2007, final rule that designated critical habitat for spikedace in the Gila River basin (Federal Register 72(54):13356-13422) included the Verde River from Sullivan Dam to just upstream of Site 8 shown in Figure 2. This is one of only three stream "complexes" rangewide that are designated for critical habitat protection for spikedace.

The four upper sites will bisect spikedace critical habitat within the primary reach of the Verde River most recently inhabited (upstream from Sycamore Creek). Essentially, emplacement of a barrier at any of the four uppermost sites will focus Verde River spikedace recovery (and of other Verde River native fishes) on the uppermost 4.5-22.8 miles by leaving the remainder of the historically-occupied reach unprotected against nonnative fishes at this time. Although the 2008 biological opinion determined that a Verde River barrier would not adversely affect critical habitat, it is unknown if FWS will uphold that determination if a barrier was constructed significantly further upstream from Sycamore Creek, the upstream-most site considered in the biological opinion.

A contrary concern is that the upper Verde River might not be conformable to effective management against nonnative fishes. This may be due to its sport fishing popularity and the length of river susceptible to "bait-bucket transfers" of nonnative fish by anglers or others.

Given that the river reach upstream of any fish barrier location must be chemically renovated to remove nonnatives, if the reach is re-contaminated repeatedly with nonnatives, keeping the system nonnative-free becomes logistically difficult and costly. Some biologists believe such repeated bait-bucket introductions are likely, while others argue there are few data to support such a resigned view. However, if frequent nonnative invasions do become reality, it is inarguable that a shorter river reach is more easily managed against them.

Another aspect of this issue is the presence of several sport fish reservoirs in headwaters of the drainage (Watson Lake and Willow Lake in the Granite Creek watershed) that harbor nonnative fishes known to be problematic to persistence of native assemblages. Although both reservoirs are 25 miles upstream of the Verde River and most of the intervening reach is ephemeral, flood events that cause the reservoirs to spill have potential to contaminate the river with nonnatives. In other barrier/native fish restoration projects, we have attempted to eradicate all nonnatives from the drainage, including from stock-watering tanks.

Reclamation would support renovation of the sport fish reservoirs to remove problematic nonnatives, but such management decisions are beyond our purview. If such renovation cannot be undertaken, Reclamation would like to convene a group of expert biologists to discuss the subject and see if consensus can be achieved. Although Reclamation recognizes the invaluable biological significance the Verde River holds for spikedace and other native fishes, we wish to ensure that our native fish restoration projects are effective over the long term.

With these issues unresolved, a biological discussion of barrier placement defaults to consideration of the lowermost sites that would protect the greatest amount of stream for native fishes and impact the smallest portion of spikedace critical habitat. The lowermost site (mine tailings at Clarkdale, site 8), however, might be too exposed to human uses that could facilitate transfer of nonnative fishes above the barrier. The sites further upstream (but downstream of Sycamore Creek) are much less accessible to human access and therefore have advantages over the Clarkdale site. These sites, however, are also among the most expensive to construct.

B. Engineering

Generally, the proposed fish barrier structures become more expensive to build the further downstream they are located. The primary reasons for this trend are: higher base flows in the river; increases in canyon width; and poorer access to the river.

The increased cost needs to be weighed against the additional river miles protected by a barrier. Additional river miles can also make monitoring and maintenance of non-native fish status more difficult, as described in the *Biological* paragraphs directly above.

Site 1 (Hell Point) appears to be the least costly to construct, and has the advantage of bedrock running halfway across the channel. The bedrock provides a stable foundation, reduces concrete and earthwork quantities, simplifies dewatering efforts, and minimizes the portion of the barrier to be constructed over alluvium. The existing road down to the river at Hell Canyon requires work to be passable for construction traffic. Developing a road in the river bottom from Hell Canyon to the fish barrier appears uncomplicated.

Sites 2 (U.S. Mine) and 3 (Perkinsville) are also toward the lower end of the cost spectrum. These sites are relatively narrow and have decent access with some river bottom pioneering needed.
Except for Sites 1and 8, all fish barrier locations described in this report have similar foundation characteristics; that is alluvial foundations, anchoring into rock only at the ends of the structures. As a result, scour of the alluvial foundation during runoff events is the primary threat to the stability of the structure. Preventing the development of downstream scour holes caused by the structure is another challenge, to prevent gathering of non-native fish in close proximity to the structure.

The west end of Site 8 that connects to the tailings pile will require a unique approach. Because of the unstable materials and the amount of overburden, it is not reasonable to excavate deep into the pile to tie the structure in as would normally be done.

From a constructability standpoint, all the sites offer viable options. Access is common problem and will contribute significantly to the cost of construction. Work in the river would likely be interrupted by hydrologic events. The watershed is large, with several major tributaries and runoff could create havoc during construction. Contractors will mitigate this risk with higher bids.

VI. Cost Estimates

The cost estimates contained within this report should be considered appraisal level. Appraisal level costs estimates use existing data and information to develop costs. These estimates are conceptual and preliminary in nature, and should be used only to compare options with one another.

The cost estimates below are based on actual construction costs of fish barriers within the state of Arizona, then adjusted to January 2010 prices. The most recent large scale fish barrier built for Reclamation was a 160-foot structure in Bonita Creek near Safford, Arizona, completed in November 2008 for $2,915,000. Since 2008, construction costs trends for concrete structures have not changed significantly, and have in fact exhibited a slight decrease.

General Cost Estimate Assumptions:

a. Riprap hauled in, not produced on site
b. Concrete from commercial source

Please see the accompanying spreadsheet file VerdeFishBarrierCostEstimate6-3-10.xlsx for detailed cost itemizations for barrier sites examined herein.