Fossil Creek Gaging Alternatives Evaluation And Recommendations

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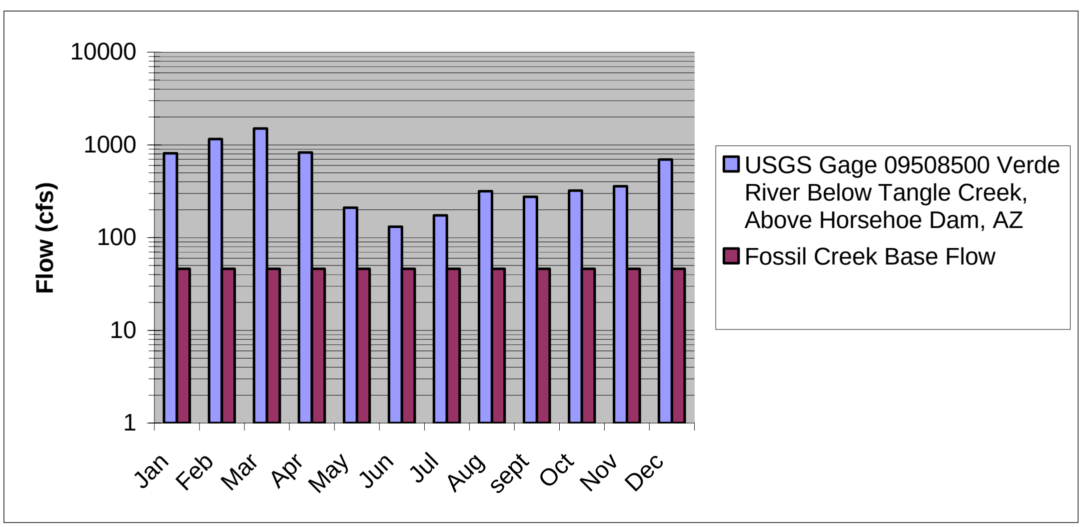
NOTE: MOST FIGURES IN THIS REPORT WERE PREPARED AND PRODUCED IN COLOR. BLACK AND WHITE REPRODUCTIONS OF THESE FIGURES MAY NOT CLEARLY SHOW FEATURES THAT ARE EASILY VISIBLE IN COLOR.

Fossil Creek Gaging Station Alternatives Evaluation and Recommendations

Introduction

In 2005, Arizona Public Service (APS) began decommissioning the historic Childs-Irving hydroelectric power facilities in the Fossil Creek area. The ultimate success of the June 18, 2005, flow restoration at Fossil Creek, the 2004-2005 native fish restoration action by a consortium of state and federal agencies, renewed travertine development in the reach between the Fossil Springs Diversion Dam and Irving, and creek-side recreation are critically dependent on the continuity of Fossil Creek base flow, as provided by the Fossil Springs.

The 46-*cfs* base flow (assumed based on limited flow data) of Fossil Creek originates primarily from Fossil Springs. This flow represents a significant portion (nearly 30 to 40%) of the Verde River base flow during the low flow month of June, as established from stream flow gaging at the U.S. Geological Survey (USGS) Tangle Creek gaging station, which is below the confluence of Fossil Creek with the Verde River but above Horseshoe Dam. The histogram below illustrates monthly median Verde River flow between 9/1945 and 9/2003, as well as the mean 46-cfs Fossil Creek base flow as established through measurements between the Fossil Springs and the Fossil Springs Diversion Dam. As can also been seen in the histogram, during other months of the year, Fossil Creek's base flow constitutes a considerably smaller portion of Verde River's median monthly flow.



USGS Tangle Creek gaging station Verde River median monthly flow (9/1945 – 9/2003) at the USGS Tangle Creek gaging station, in comparison to the 46 cfs Fossil Creek base flow.

With the hydrologic, ecosystem-sustaining and recreational roles of Fossil Creek in mind, monitoring of the Fossil Springs flow and quantification of the flow variability, also known as stream-flow gaging, are sought by a wide variety of researchers and agencies. Some of the benefits that would be realized from gaging Fossil Creek are as follows:

- Gaging would provide baseline data on Fossil Springs flow for Naco/Redwall aquifer groundwater studies;
- In recent years, Salt River Project (SRP, 1999), working with others, such as the U.S. Bureau of Reclamation (USBR), has installed low-flow gaging stations on the Verde River at Campbell Ranch (Arizona Game and Fish Department property) near Paulden, at Black Bridge in Camp Verde, upstream of the confluence of the Verde River and Beaver Creek, and at the Verde Falls, below Beasley Flat. A low-flow gaging station on Fossil Creek would improve the low flow monitoring "network" in the Verde watershed;
- The nearby communities of Strawberry and Pine have an interest in obtaining Naco/Redwall aquifer ground water, which could potentially impact the Fossil Springs flow, and thus impact the Fossil Creek and Verde River base flows. Since APS will no longer be utilizing this baseflow, it will not be monitored. Gaging Fossil Creek would thus serve to protect Fossil Creek flows by detecting any reduction in flow that might occur from such groundwater development.
- Gaging data for Fossil Creek would be beneficial to numerous individuals, research projects and organizations that are interested the flows that occur in this region of the greater Verde River watershed.
- Since stream flow is the fundamental driver for the very existence of a riparian environment, gaging Fossil Creek during the gradual decommissioning of the Childs-Irving hydroelectric facilities will aid in quantitatively evaluating the impacts of removal of flow diversion on a river or stream and would consequently aid in improving our river and stream restoration techniques.

Research Objectives

Assess constraints and opportunities for gaging

The proposed long-term gaging on Fossil Creek must address the regulations and constraints of the U.S. Forest Service (USFS). The USFS is responsible for land and natural resource management on the Tonto and Coconino National Forests, which abut Fossil Creek to the south and north. In addition, APS remains responsible for certain elements related to the Childs-Irving hydroelectric facilities and will be decommissioning these facilities for several years before handing their sites over to the Forest Service. SRP plays a prominent role in low-flow gaging in the Verde watershed and has an interest in low-flow gaging on Fossil Creek. The U.S. Bureau of Reclamation (USBR) and Central Arizona Project (CAP) are involved in construction and operation of a new (constructed Fall, 2004) fish barrier on lower Fossil Creek. Typically, the U.S. Army Corps of Engineers (USACE), through the Clean Water Act Section 404 Nation-Wide Permit program or through Individual 404 permits, is involved in permitting construction of stream gaging operations. Finally, the U.S. Geological Survey, (USGS), which has long been involved in stream flow gaging, and up until recently operated a gage on the Childs-Irving flume, may elect to become involved in the future.

As part of this effort, we assessed the regulatory and political landscape that is shaped by the interests of these agencies and private sector entities, and identified the regulatory and agency constraints and permits necessary for implementing a stream flow gage on Fossil Creek.

Identify suitable existing technology

We provide here a literature review of available and emerging technology for stream flow gaging and recommend specific technologies for implementation of gaging in Fossil Creek.

Evaluate the entire stream reach for suitable gaging locations

As a part of other ongoing Fossil Creek research, monitoring and outreach, NAU faculty and graduate students in Civil & Environmental Engineering have been classifying and characterizing Fossil Creek, from a point several miles above Fossil Springs to the confluence with the Verde River. Many of the reaches in Fossil Creek are bedrock-controlled and provide optimum locations for stream flow gaging.

Complementary to the above efforts, as part of this project, we evaluated the entire stream reach for suitable gaging locations. Our evaluation included field reconnaissance, HEC-RAS modeling of low flow at promising locations, and compilation and interpretation of photographic and other documentation.

Coming into the project, it was a given (assumed) that a gage location as close to the Fossil Springs complex as possible is desired, in order to minimize variable evapotranspiration and infiltration losses. However, the stream reach between the Fossil Springs Diversion Dam and Irving is anticipated to host considerable travertine pool and dam development following the June 18, 2005, flow restoration. Additionally, the lowering of the Fossil Springs Diversion Dam, presently set to commence in late 2007 or early 2008, will release considerable sediment to the system. Once the lowering commences, there is the potential for considerable channel adjustments between the Diversion Dam and the Fossil Springs. With these considerations in mind, we felt that it was necessary to consider all of Fossil Creek, from the Diversion Dam to the confluence with the Verde River, as part of our research.

Issue recommendations for gaging on Fossil Creek

Upon concluding the above actions, we created a decision matrix in order to rank the suitability of the selected sites based on factors that include: ease of installation; interference with gaging from sediment and/or travertine deposition; long-term site stability; hydraulic characteristics; accessibility; control; recreational exposure; anticipated cost; distance from springs; permitting certainty; and applicable technologies.

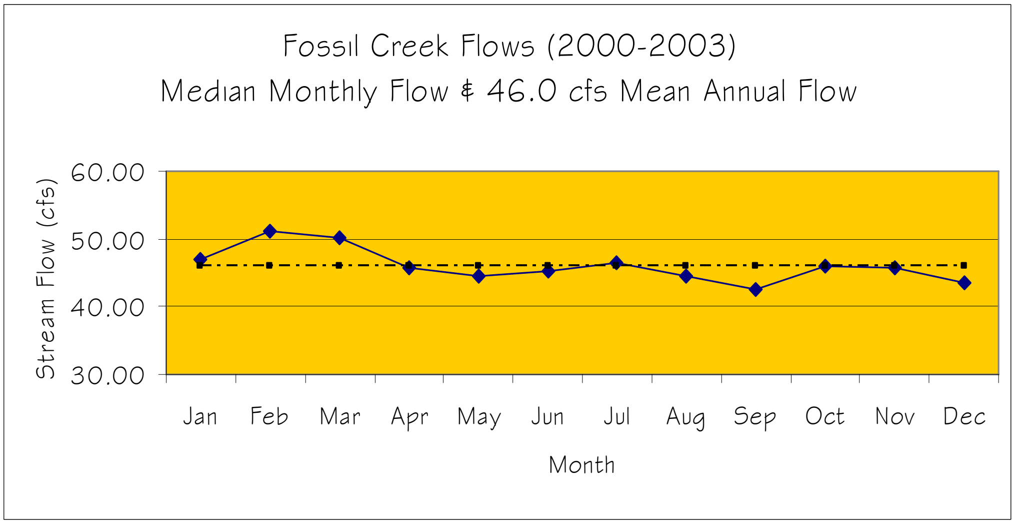
We then prepared this written report for distribution to USFS, SRP, USBR, USGS and others. The report identifies a preferred alternative (consisting of a location and technology) for gaging, and includes a cost estimate, both for the initial installation and for annual operation and maintenance expenses, including publication and distribution of the gaging data – presumably using a suitable web site. This report:

- will be posted on Northern Arizona University's Watershed Research & Education Program website: watershed.nau.edu;

- summarizes the findings of research that was conducted principally by Ed Monin, as part of his M.S. project work at Northern Arizona University.

History of Gaging on Fossil Creek

For a number of years, the USGS gaged flow on the Childs-Irving diversion in Fossil Creek, but not in the Fossil Creek channel. *In other words, this stream has never been gaged with permanent instrumentation!* Permanent gaging on Fossil Creek has been proposed and discussed by many, but no actions have been taken to date. In support of developing an in-stream flow right application, Tonto National Forest hydrologists Grant Loomis and Kathy Nelson measured Fossil Creek stream flow below Fossil Springs by means of monthly measurements with field-portable equipment during 1999-2003. These measurements required considerable effort and expense on the part of the Tonto National Forest and the program could not be sustained over the long term. However, the data obtained, which are presented below, quantify the magnitude and variation of the near-constant base flow that is sustained by the Fossil Springs.



Point measurements of cumulative discharge of all springs discharging from Fossil Springs complex from 2000-2003 made by Tonto National Forest researchers. Measurements made above the Fossil Springs Diversion Dam and below the Fossil Springs.

Gaging Methods

Stream flow gaging requires instrumentation or structures to measure one or both of water surface/depth and water velocity at a given location. For an engineered flume or weir structure, the water surface observation alone provides a measure of discharge through the structure, using an empirical equation valid for the structure. Otherwise, water surface elevation and velocity data are together used to develop a rating curve of discharge versus stage (water surface elevation) at that location. Then, observations of water surface provide a measure of discharge at that cross-section. If the channel changes over time, the rating curves must be periodically updated.

Increasingly, both water surface/depth and velocity are simultaneously monitored and with the cross-section known, and possibly periodically re-assessed, discharge can be determined.

An extensive summary of gaging technology is available at:

http://wwwrcamnl.wr.usgs.gov/sws/fieldmethods/StageMeasurement/index.htm

All of the structures and instrumentation identified and reviewed here may be configured with data logging or telemetry – which are not addressed as part of this report.

Specific structures use for modifying stream flow in a manner that allows gaging based on water surface elevation observations alone are:

- weir;
- flume.

When gaging, the water surface elevation can be monitored using a:

- graduated staff;
- weight on wire;
- submerged pressure transducer;
- submerged ultrasonic transducer;
- unsubmerged ultrasonic transducer;
- unsubmerged radar transducer;
- buoyant float that rides on the water surface;
- bubble manometer; and,
- other less common devices.

Velocity measurements can be established using:

- mechanical current meter (propeller device);
- ultrasonic transducer;
- unsubmerged optical transducer;
- unsubmerged microwave transducer; and,
- other less common devices.

The current meters have been traditionally used for discrete, infrequent, non-continuous observations, whereas the ultrasonic transducers, relatively new on the scene, can be used for continuous monitoring applications.

Hybrid systems are now available that combine ultrasonic velocity and depth transducers to allow simultaneous continuous monitoring of both water surface elevation and velocity.

The above-described structures, instruments and transducers along with their principal features, advantages, and limitations are illustrated below:

Weir

- High resolution gaging of low flow – when appropriately sized;
- Rugged;
- Can be used in combination with rugged float-in-still gage;
- May silt in and may then no longer function as a weir – requires silt removal to restore proper function;
- Extensive infrastructure construction; and,
- Significant maintenance may be required.

Weir at Campbell Ranch, near Paulden, on the Verde River

Flume

- Can be designed for self-cleaning functioning;
- High gaging resolution of low flow – when appropriately sized;
- Rugged;
- Subject to blocking by debris; requires maintenance;
- Can be used in combination with float-in-still type of gage;
- Extensive infrastructure construction; and,
- Significant maintenance may be required.

Flume in Beaver Creek watershed near Stoneman Lake

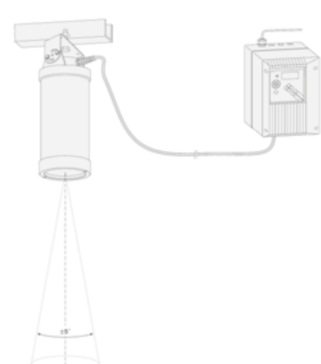
Four-foot short Parshall flume, discharging 62 cfs under free-flow conditions; scour protection is needed for this much drop. Photo from: USBR Water Measurement Manual – Chapter 8.

Ultrasonic Water Level Sensor

- Non-contact measurement of water surface elevation;
- Suitable for long-term installation and operation;
- Sensitive to human or natural disturbance if unprotected.

Radar Level Sensor

- Non-contact measurement of water surface measurement;
- Suitable for long-term installation and operation;
- Sensitive to human or natural disturbance if unprotected.

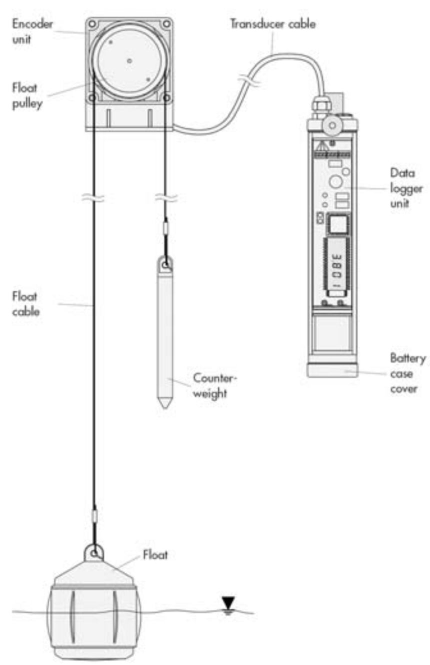


Pressure Transducer

- Submerged installation;
- Battery-operated data logging with no cable is an option for certain of these transducers;
- Suitable for long-term installation and operation;
- Sensitive to human or natural disturbance if unprotected.

Float in Still

- robust infrastructure;
- still provides for damping of time-varying signal, e.g., due to turbulence.
- time-tested reliability.

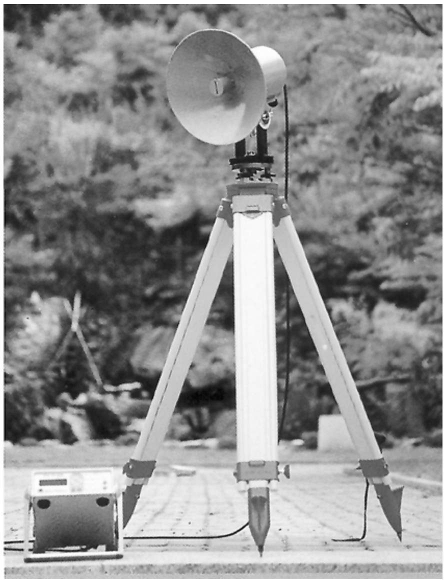


Optical Water Surface Velocity

- Useful for water surface velocity measurements during high-stage floods;
- Suitable for long-term installation.

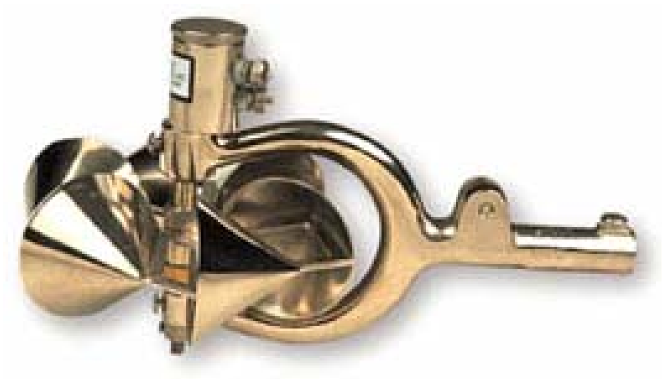
Microwave Water Surface Velocity

- Useful for water surface velocity measurements during high-stage floods



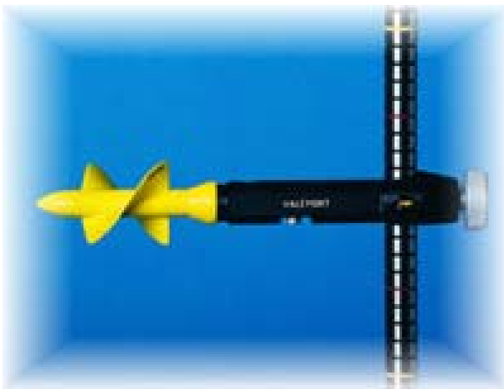
Mechanical Current meter – Vertical Axis

- Attaches to top-setting wading rods;
- Used for infrequent non-continuous velocity measurements;
- High accuracy.



Mechanical Current meter – Horizontal Axis

- Attaches to top-setting wading rods.
- Low thresh-hold velocity;
- Used for infrequent non-continuous velocity measurements;
- High accuracy.



Current meter – acoustic doppler velocity meter

- Attaches to top-setting wading rods;
- Compatible with traditional approaches using propeller type instruments;
- Used for infrequent non-continuous water velocity measurements;
- High accuracy.

Current meter – Electromagnetic

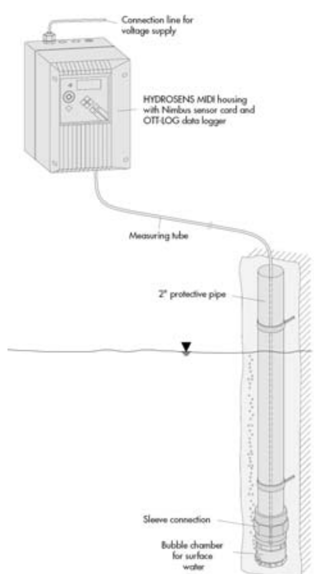
- Attaches to top-setting wading rods;
- Compatible with traditional approaches using propeller type instruments;
- Moderate accuracy;
- Advantageous in channels where fouling of mechanical sensors is problematic.

Current Meter – Ultrasonic Velocity with Water Level Transducer

- For monitoring flows in small channels from 1 ft (0.3 m) to 16 ft (5 m) deep;
- Doppler technology;
- Typically mounted on the channel bottom;
- Measures water surface elevation and vertically-integrated velocity;
- Sensitive to human or natural disturbance if installed in unprotected area.

Bubble Manometer

- Does not require the installation of a stilling well (offers considerable savings in installation cost and setup time);
- The manometer shelter can be located distant from the water's edge in an obscure location and the orifice may be easily moved to follow a stream channel that shifts location or changes through sediment aggradation;
- Gas bubbles tend to keep the orifice from being covered with sediment (good for locations with high sediment aggradation);
- Sensitive to human or natural disturbance if installed in unprotected area.



Field Methods

General

The entire length of Fossil Creek from Fossil Springs to the confluence with the Verde River was investigated in order to determine reaches along the creek that would provide optimal locations for gaging sites. Although the gage sites were identified with both high and low flow gaging in mind, it is the selection of good low flow gaging sites that proved to be most challenging due to the following considerations:

- The *natural* streambed and channel characteristics must provide adequate geomorphological and hydraulic conditions for good gaging resolution at low flow.

- To discourage vandalism, cut down on gaging technology costs, provide for ease of installation, and to minimize interference with the natural beauty of Fossil Creek, most of the sites were chosen based on the presence of geomorphological and hydraulic characteristics that were appropriate for the installation of gaging technologies that can operate with a minimal installation of gaging infrastructure.

- Because of the irregular nature of Fossil Creek streambed morphology there were no set 'rules' (based on research on low-flow gaging practices and protocol) as to what characteristics a proposed site should possess in order to provide optimal resolution. For this reason, the potential gage sites were selected based on knowledge of river and stream hydrology and the hydraulics of man-made structures designed for good gaging resolution (flumes and weirs). A starting point for the approach that was taken in gage site selection was to find stream reaches that naturally mimicked a flume or a weir.

- Manning's roughness coefficients were determined for each reach of interest based on a visual inspection of the reaches and comparison with values from Rosgen (1996).

The following information is germane to our field methods and field work.

- The field personnel consisted of Edwin N. Monin and a field assistant. The field investigations required a combined time of approximately 15 days in the field. Field work was completed in the late spring and summer of 2005.

- The field equipment consisted of a light-weight surveying level and rod, total station and prism, hand held GPS, range finder, compass, digital camera and basic field geology investigative equipment.

- The stream reaches above and below the potential gage location were surveyed using a total station, rod, and prism in order to obtain cross sections, slopes in between cross sections, and water surface elevations. GPS coordinates of the site were obtained using a Thales hand-held Mobile Mapper GPS unit. Digital photographs were taken of the potential gage location(s), left bank, right bank, and upstream and downstream along the reach.

Site Characteristics

Once a site that had reasonable potential for gaging was identified, the following characteristics of the site were considered before the site was chosen as a finalist for a more in-depth analysis. It should be noted that no site was strong in all these characteristics.

Control

Control is a measure of the resistance of the stream reach to change. Poor control is typically associated with a moveable channel bed or moveable channel walls. This is a fundamental consideration, because if a channel changes often then the stage of the stream at a given discharge will change often and the gaging data will be inaccurate until calibrated. Good control in a stream reach was the first thing that hinted of a good potential site. A reach with ideal control would have durable bedrock cliffs on both sides that were tall enough so that the highest flows of interest would not spill over the cliff tops. A bedrock thalwag is equally desirable.

Frequent visits to the field to collect water surface elevation and velocity data for a range of discharges, for gage re-calibration, would be required for a gage site with poor control.

Optimal Hydraulic Characteristics

The sites were evaluated for optimal hydraulic characteristics. A narrow channel was desired in order to achieve a steep discharge vs. stage curve which allows for good gaging resolution. A hydraulic jump below the gage site was also sought as this eliminates any effects on the stage of the stream from changes in downstream hydraulics. Finally, the site needed to have a stream reach at the potential location of the gage with a relatively smooth and near-steady-state water surface. Along with a smooth surface, it was preferable for the water in the reach to have some velocity in order to minimize the effects of stream bed aggradation due to sediment deposition. This last consideration becomes even more important with the anticipated lowering of the upstream Fossil Springs Diversion Dam, as it is expected that a large quantity of sediment that was previously trapped behind the dam will be episodically transported downstream during high-magnitude storm or snow-melt events.

Permitting Considerations

Permitting is an important consideration. A gage can only be placed in locations that the Forest Service is willing to permit. As discussed below, after presenting the proposed gauging site locations to the Forest Service representatives, they stated that gages at some of the proposed sites would be difficult or impossible to permit. Obviously, the inability to obtain a permit for a site is a major problem and can greatly affect the ranking of potential gage sites.

Long-Term Stability

Potential gage sites in Fossil Creek ideally should be in a location that would not be affected by bed aggradation or degradation, due to fluvial processes, bank failures, slope failures, etc.

As mentioned above, the anticipated episodic release of sediment presently stored behind the Fossil Springs Diversion Dam is an additional consideration. This release of sediment is impossible to forecast definitively. We anticipate that the episodic release will occur in part as a *wave* or *pulse* of sediment gradually moving downstream toward the Verde River. As time goes by, this wave will be attenuated, and *dispersion* will occur, with the fines moving out ahead and the coarse fraction moving more slowly.

In addition, the Fossil Springs emanate from the Naco/Redwall formations. Historically, these waters formed extensive travertine deposits in the 2-3 mile reach below the site of the Fossil Springs Diversion Dam. Since the flow was diverted by the dam for nearly a century to the Irving power plant 4 miles downstream, there was little travertine formation in Fossil Creek, excepting limited deposition below Irving, due to Irving plant operations. The June 18, 2005, restoration of flow will lead to restoration of significant travertine deposition in the 2-3 mile reach below the diversion dam. This renewed travertine deposition will lead to the formation of 'travertine steps', which are dams and pools, and deposition of travertine on the streambed, and this would have a serious negative effect on any gage site in that reach. With this consideration in mind, potential gage sites that were located within the 2-3-mile reach below the Fossil Springs Diversion Dam, i.e., the reach with abundant historic distribution of travertine dams and pools, had to be eliminated from general consideration, though we did consider one site, the "Big Waterfall, discussed below, in the 2-3 mile reach.

Ease of Installation

Ease of installation was also a consideration when choosing sites, as minimal infrastructure was desired. For example a high cliff on the stream bank can serve as a flood-safe location for installing an ultrasonic or radar transducer that can shoot directly onto the water surface. This eliminates the need for a larger more invasive structure to house gaging equipment. Alternatively, submerged ultrasonic or pressure transducers have potential application for sites where no steep bedrock channel walls exist. At the other end of the spectrum, sites where flumes or weirs were considered ranked low for this characteristic as installation of these structures require that considerable infrastructure be set in place, operated and maintained.

Distance from Fossil Springs

Another criterion for consideration is the distance from Fossil Springs. The greater the distance, the more time there is for the flow to be affected by evaporation, evapo-transpiration, etc. This decreases the accuracy of the measurement of the actual discharge from the Fossil Springs.

Cost

Cost is a necessary consideration for any installation. Sites that could be gaged with a minimal amount of equipment and construction offered the added benefit of minimal cost. Of course, capital cost must be weighed in conjunction with operations and maintenance (O & M) costs. For example a minimally-invasive low-capital-cost gage that was washed out every couple of years by floods would have high maintenance costs.

For the purposes of this report, capital cost estimates were necessarily preliminary. The estimates were developed from actual costs for low-flow gages recently constructed by SRP (Curt Kennedy, SRP, personal communication) for similar gaging sites that have been installed on the Verde River in the past 6 years. Costs so obtained were adjusted for inflation in order to prepare our cost estimates. Cost estimates do not include data recording or telemetry equipment.

Recreational Exposure (Vandalism)

The entire base flow of Fossil Creek has now been restored below the Fossil Springs Diversion Dam, and already more people are visiting the creek at many locations below the Fossil Springs. Furthermore, most of the gage sites are located in areas with a lot of bedrock exposure and it is these areas have the biggest waterfalls, cliffs, and pools on the creek and consequently offer the best recreational opportunities. There is thus an unavoidable conflict between recreation and gaging. We hope that minimally invasive gaging infrastructure will prove beneficial as the relative obscurity of the structures, instruments and related infrastructure will mitigate the risk of vandalism. An alternative perspective holds that the concrete infrastructure inherent to a flume or weir is unlikely to suffer from vandalism.

Accessibility

Accessibility is a ‘double edged sword’ as it offers the benefit of easier access to sites for installation and maintenance, but it also leads to greater exposure to recreationists and vandals. An optimal site would have reasonable access for operation and maintenance, but be somewhat inaccessible so as to mitigate exposure to the general public.

Applicable Gaging Methods

The gaging methods that could be set in place at a given site were also considered, because it is advantageous to have the option of choosing from a variety of methods for any given site and, it is important to know in advance that at least one of the methods would work well.

Data Compilation

The field data were compiled, analyzed and interpreted in four phases:

(1) Geo-referenced raster data with USGS topographic quadrangle maps were downloaded into ArcGIS software and the Fossil Creek area was clipped from each quadrangle map. GPS locational data for each potential site were imported into ArcGIS software and the potential site locations were mapped.

The following three phases of activity apply only to finalist sites selected from the list of potential sites.

(2) The surveying data were place in an Excel spreadsheet to facilitate organizing and formatting of the data for subsequent phases.

(3) The Excel spreadsheet data were exported and used to build an input file for HEC-RAS (U.S. Army Corps of Engineers, 2002) simulations of stream channel hydraulics. The necessary data included: the contour of each cross section in order for the program to compute cross sectional area and hydraulic radius at various flows, slopes in between cross sections, the water elevation at the flow that was present during the survey was entered so the program had a boundary condition for steady flow analysis at the existing flow, and a Manning's roughness coefficient was entered for the right bank, left bank, and channel. These roughness coefficients were estimated based on values determined for reaches that approximate bedrock by Rosgen (1996). The program was then run at various low flows (discharges) and the stage at the potential location of the gage was recorded for each discharge simulated.

(4) The stage versus discharge values were entered into an Excel spreadsheet and a low-flow stage versus discharge rating curve was created for the site.

Potential Gaging Sites

The locations of gaging sites identified by our field survey were plotted on 7.5-minute quadrangle base maps, which are excerpted from USGS 7.5-minute quadrangles Strawberry, Hackberry and Verde Hot Springs. Presented in sequential order below are a series of four maps of Fossil Creek, going from the Fossil Springs Diversion Dam down to the confluence with the Verde River.

During the course of the field reconnaissance, the difficulty of gaging an irregular stream channel while achieving high resolution at low flow became abundantly clear. Additionally, a site suitable for low-flow gaging may not be optimal for high-flow gaging, and vise-versa. The added constraint of finding sites that would require minimal gaging infrastructure presented an added challenge. The following considerations were found to be important in selecting an appropriate site with good *potential* for high-resolution of gaging low flows on Fossil Creek:

1) Good control was the first consideration. The stream channel had to have banks and bed resistant to change during high flow events.

2) A narrow and relatively shallow channel was desired in order to achieve a steep discharge vs. stage curve which allows for good resolution.

3) A hydraulic jump below the gage site was sought as this mitigates, at least for low flows, effects on stream stage due to downstream changes in hydraulics.

4) The site needed to have a stream reach at the potential location of the gage with a relatively smooth and turbulence-free water surface at low flow. It should be remembered that signal averaging and filtering can be applied to mitigate or eliminate noise in the stage data due to channel turbulence. A still type of stage monitoring system provides a similar function.

5) Ideally, the flow in this reach would have the necessary velocity to mitigate streambed aggradation in the reach.

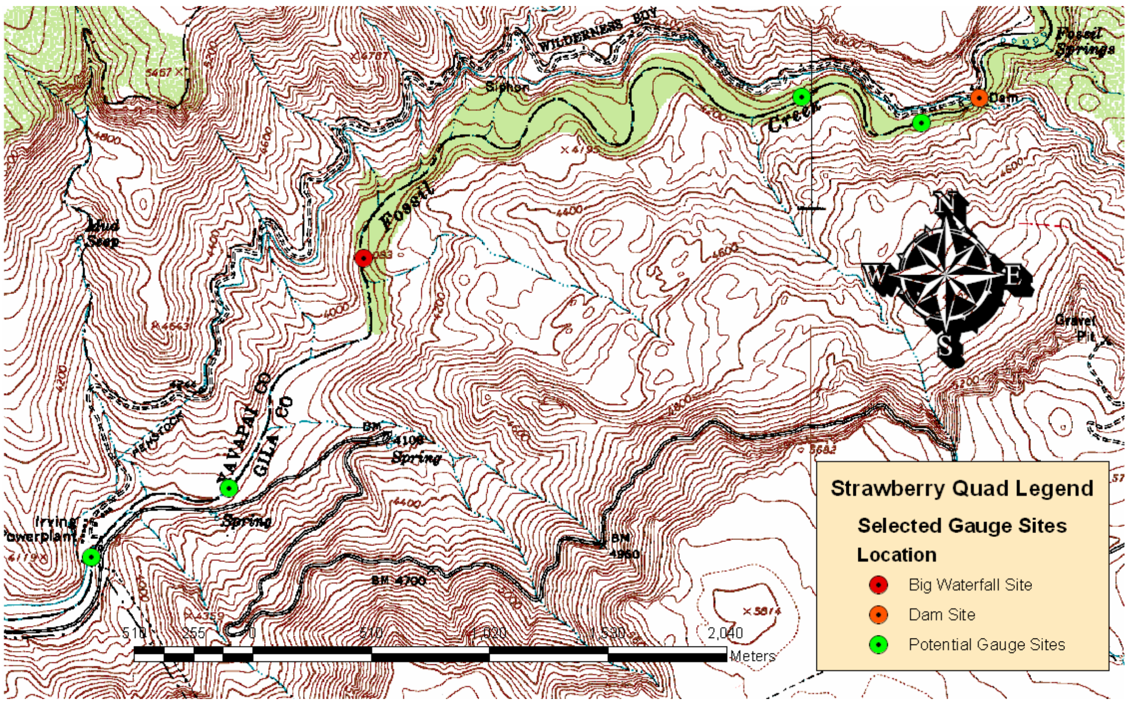
6) For sites where an ultrasonic or radar gage was to be placed to shoot down on the water surface, it was desirable to have a high overhanging cliff on one of the banks in order to minimize the amount of infrastructure required to mount a gage.

7) Other considerations such as long-term stability, access, distance from the Fossil Springs, and exposure to recreational impacts also had to be considered.

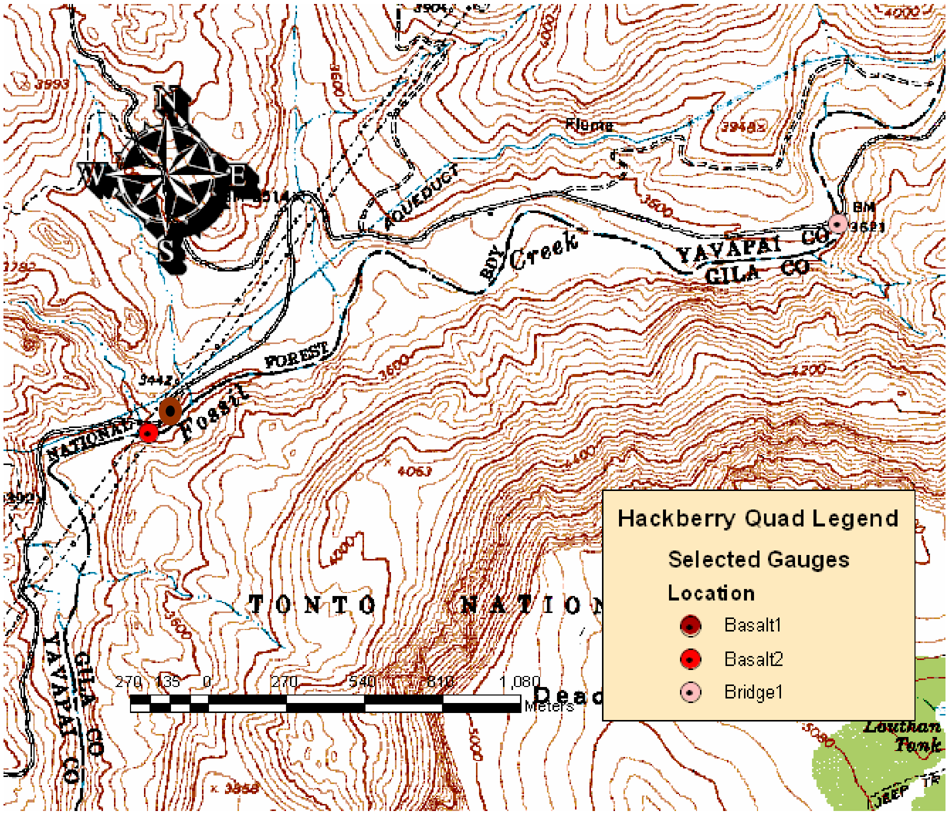
All of the potential gage sites that were identified were selected by attempting to optimize compliance to the above mentioned considerations. Sixteen sites were identified as having potential for a gaging station. As no ‘perfect site’ was found after a detailed investigation of the 14-mile stretch of Fossil Creek from the Fossil Springs Diversion Dam to the confluence with the Verde, and sixteen sites presented a number too great for detailed evaluation of each, the list was pared to seven sites, again taking into consideration the above traits. These seven investigated sites were collectively evaluated for their adherence to the desired characteristics.

With reference to the maps below, the seven sites that were evaluated in detail are:

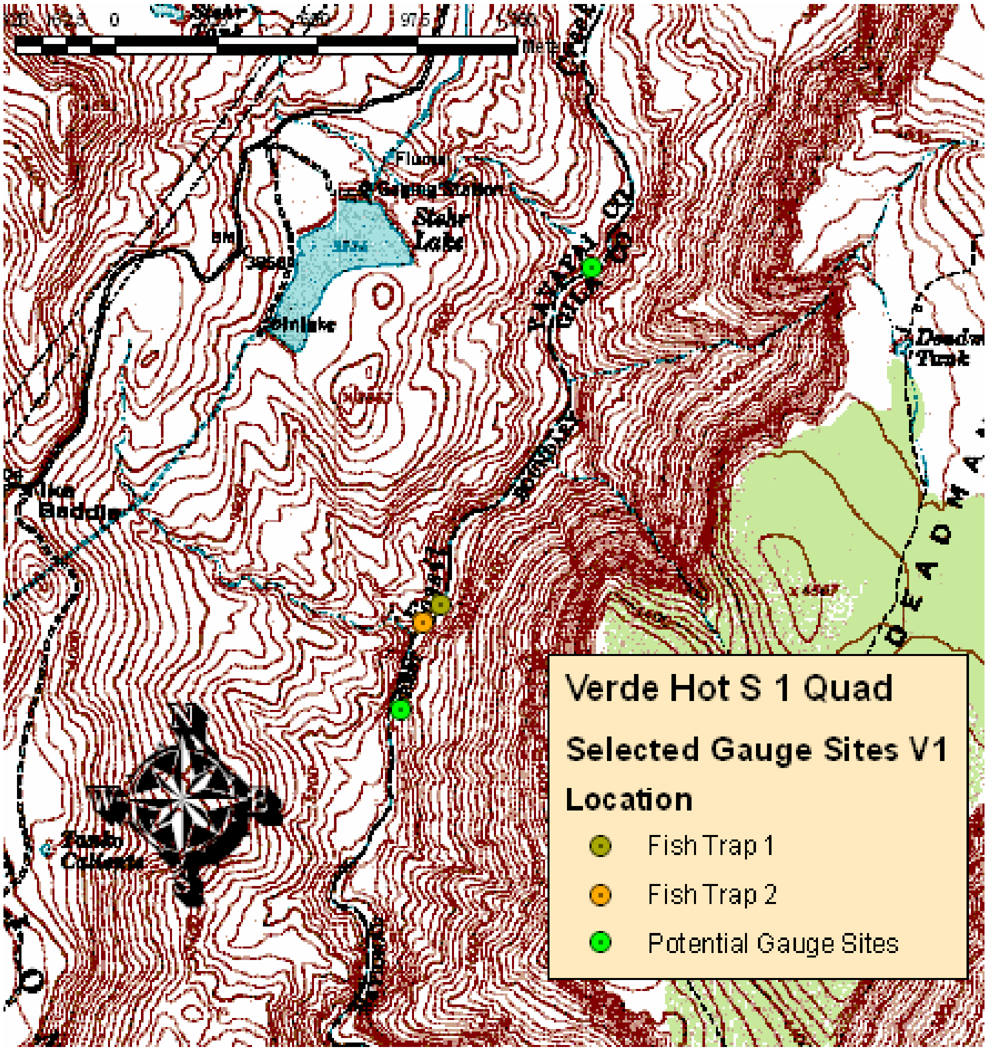
- Fossil Springs Diversion Dam;
- Big Waterfall;
- Bridge 1;
- Basalt 1;
- Basalt 2;
- Fish Trap 1;
- Fish Trap 2.



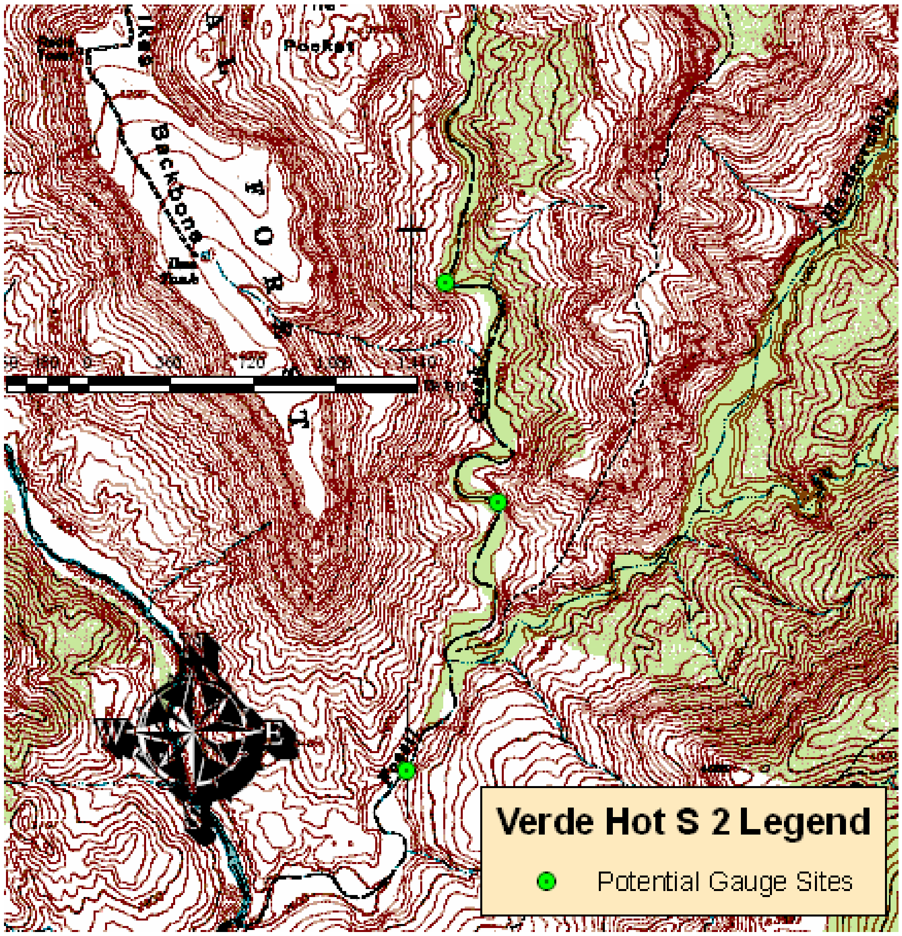
Map 1: Fossil Creek between the Fossil Springs Diversion Dam and the Irving Power Plant. The Big Waterfall and (Diversion) Dam gage sites were selected for detailed evaluation. Other potential gage sites are shown in green.



Map 2: Fossil Creek below Irving and above Stehr Lake. The Basalt 1, Basalt 2, & Bridge 1 gage sites were selected for detailed evaluation.



Map 3: Fossil Creek near Stehr Lake. The Fish Trap 1 and Fish Trap 2 gage sites were selected for detailed evaluation. Other potential gage sites are illustrated as well.



Map 4: Fossil Creek above the confluence with the Verde River. Potential gage sites are illustrated.

Gaging Site Finalists

Site #1: Fossil Springs Diversion Dam

Location The Fossil Springs Diversion Dam gage site (see Map 1, above) is located approximately 0.1-0.2 miles downstream of the Fossil Springs. The approximate UTM NAD 27 Zone 12 coordinates are: 447,119 m E, 3,808,793 m N.

Fossil Springs Diversion Dam gage site.

Suggested Gage Curt Kennedy, a water measurement expert at SRP, suggested a weir for this site. The weir could be created by cutting a notch in the dam as part of lowering to its final height. A pressure transducer could be installed in the floor or sidewall of the notch.

Long-Term Stability This notch would serve as a control of pre-determined and well-defined dimensions that would provide for high-resolution gaging. The notch could be armored, e.g. with steel plating, in order to mitigate dimensional changes caused by erosion**.** Major concerns with this option include clogging of the notch or the upstream channel by sediment releases following lowering of the diversion dam, or by vegetation, dead trees, etc. To some extent this concern holds for other potential gaging locations downstream because the Fossil Creek channel will undergo change through cycles of sediment aggradation and erosion. Travertine deposition should not be a factor at this location because sufficient degassing of carbon dioxide, necessary for precipitation of travertine from the Fossil Springs waters, does not occur until further downstream.

Proposed location of weir structure for flow gaging at the Fossil Springs Diversion Dam.

Geology The diversion dam was constructed in a limestone bedrock reach which has limestone cliffs on both banks. There is a deep pool below the dam and the limestone cliffs surrounding it form a fairly deep canyon through this section. In addition, a hole in the left bank bedrock, below the dam, has been created by erosional fluting.

Control The diversion dam itself, and the limestone cliffs provide the general control in this section. However, if the suggested gage was constructed at this site the main control at low flow would be provided by the armored rectangular-notch weir.

Hydraulic Characteristics At the present time, this section functions as an overflow weir that is heavily silted-in on its upstream side, with a vegetated surface subject to rearrangement by large flood events. The section offers the potential for double duty as a low-flow and high-flow gage due to the relatively narrow and confined canyon with a dam and waterfall.

Ease of Installation This site offers a setting that is very conducive to the initial installation of gaging equipment. Since the dam is already in place, a good portion of a weir structure is already present. Constructing a notch in the dam as it is lowered would most likely present minimal challenge. If other gaging technologies are chosen for this site the cliffs surrounding the section would provide a good foundation for placing equipment with a minimum amount of infrastructure and are high enough to protect the equipment from flood flows.

Recreational Exposure This area has traditionally been a very popular location for cliff jumping and rope swings, so recreational exposure is high. The risk of vandalism to gaging equipment is high.

Access Access to this site is afforded via the 4-mile APS flume road. The site is located at the end of this road and is readily accessed when the road is passable. However, we understand that the flume road is to be abandoned once APS completes its decommissioning operations – anticipated to occur around 2009-2010.

Cost It is difficult to develop a cost estimate for this site because of the anticipated installation as part of dam lowering, and no costs could be obtained for analogous installations. We estimate that, if the gage were installed at the time of lowering the diversion dam, the cost would be approximately $20,000.

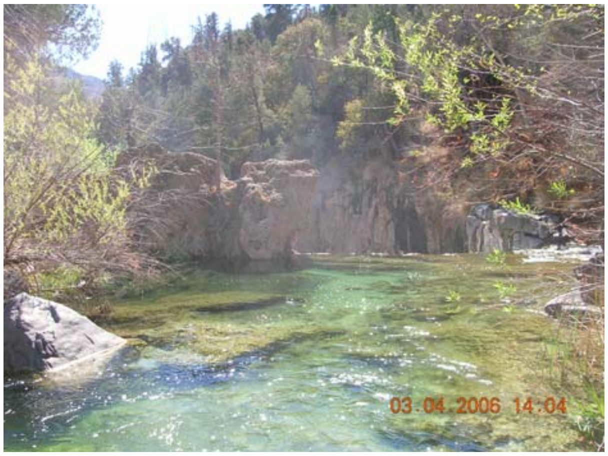
Site #2: Big Waterfall

Location The Big Waterfall gage site (see Map 1, above) is located immediately above Fossil Creek's largest naturally-formed waterfall, approximately 3 miles downstream of the Fossil Springs or 1 mile upstream from the trailhead, above Irving, to Fossil Springs. The approximate UTM NAD 27 Zone 12 coordinates are: 444,430 m E 3,808,112 m N.

Left bank

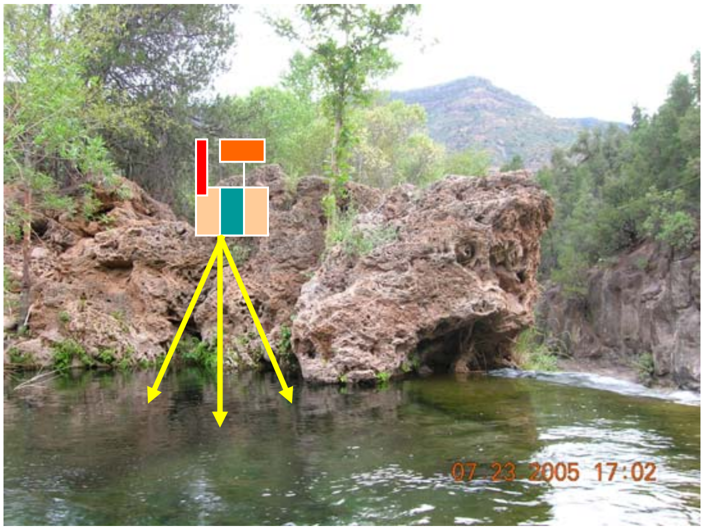
Right Bank

Upstream



Downstream

Suggested Gage An ultrasonic or radar water level sensor could be mounted on the left bank travertine cliff. Alternatively, in order to reduce the exposure of the gaging equipment, a pressure transducer could be located on the cliff wall, below the water surface. Or, a bubble manometer could be installed at this location. The manometer's bubbling action may mitigate the effects of sediment accumulation or travertine buildup from interfering with the streambed sensor operation.



Proposed gage site at the Big Waterfall Site.

Long-Term Stability Sedimentation, travertine accumulation and recreation/vandalism are major concerns at this location. Light travertine deposition is currently present at this location and is expected to increase with flow restored. The expected sediment release from the Fossil Springs dam lowering will allow for sediment deposition in the pool above the waterfall. This aggradation and presumed eventual degradation will affect the rating curve for this location. High-flow floods have the potential to impact the pool similarly. Light travertine deposition is currently present at this location and is expected to increase with the restored flow below the dam which will also alter the streambed at this location. A gage at this location will likely need frequent recalibration.

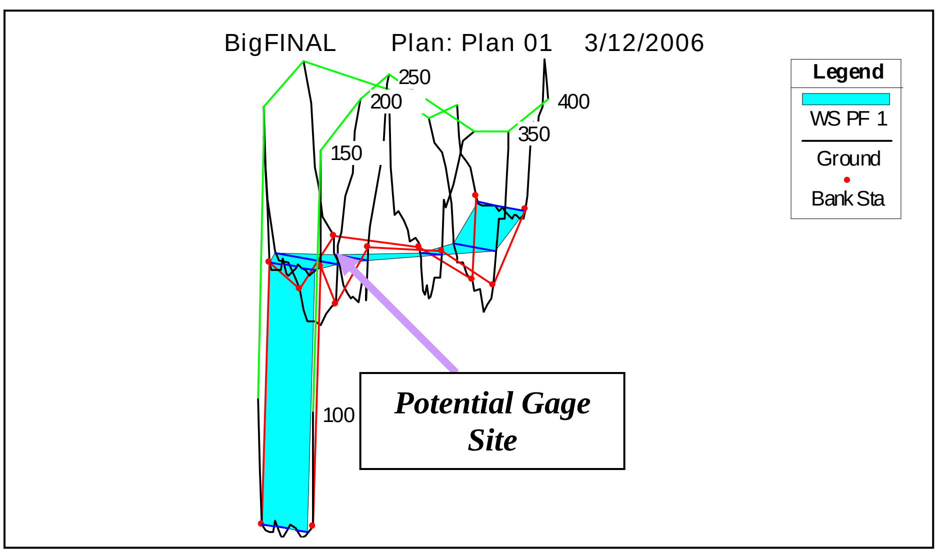
Geology The streambed at this site is dominated by basalt bedrock. The right bank is predominantly a basalt cliff and the left bank consists of a boulder-covered slope with intermittent travertine cliffs.

Control Control in this reach is provided by basalt bedrock on the right bank and boulders and travertine cliffs on the left bank. This channel should not be significantly altered by large flow events.

Stream Dimensions at Gage Location At the suggested gage location, the width of the stream channel is approximately 54 feet with a maximum depth of approximately 5 feet at a 46 cfs flow. The maximum depth occurs in a pool near the left bank; nearly half of the cross section at this location is 3 feet or less in depth.

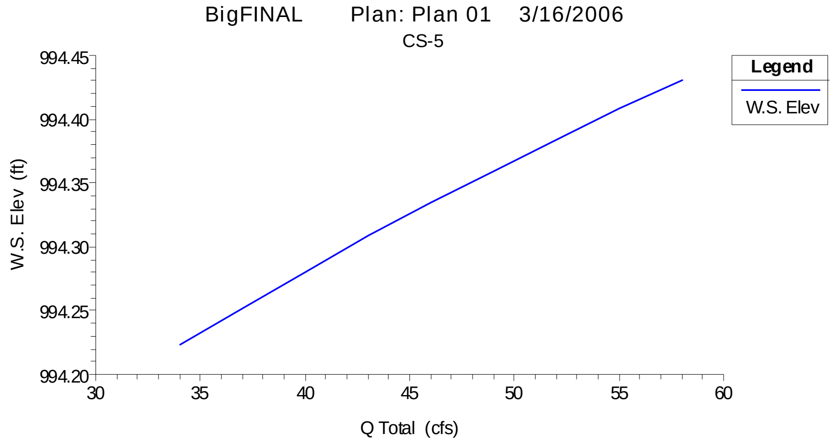
Hydraulic Characteristics This gage site has fair hydraulic characteristics for gaging. The channel is fairly broad with good control on one bank and a stable ledge at the overflow. The reach contains a hydraulic jump upstream of a pool and a downstream waterfall. The pool provides a relatively smooth, turbulence-free, water surface which aids in achieving optimal high resolution gage performance. The downstream waterfall prevents changes on the gaged reach if the hydraulic characteristics of the downstream change for any reason. The pool presumably experiences cycles of sediment deposition and erosion in response to high-flow events.

HEC-RAS Methodology and Results To better quantify the required gage resolution at this site, field survey data were gathered and applied in a HEC-RAS hydraulic simulation of low flow through this. Manning's roughness coefficients (*n* values) were obtained from Rosgen (1996; Figure 8-2). An overbank *n* value of .028 was used; *n* of .03 was used for the stream channel thalweg. The HEC-RAS program numerically solves a differential equation and boundary conditions are required; in this case we used the mixed condition option, given the upstream (tranquil) and downstream (supercritical) boundaries. Simulations were run for low flows between about 35 to nearly 60 cfs, both above and below the known Fossil Creek base flow of 46 cfs, in order to obtain a stage/discharge curve for the site that allowed us to assess whether this potential gage location would provide good resolution of base flow. (*A similar procedure was followed for the other sites*.)



HEC-RAS 3-D illustration of reach and cross sections at Big Waterfall site for simulated 46 cfs flow.

Stage/Discharge Rating Curve The following stage/discharge curve was obtained for the cross section (CS-5) located at the potential gage location for flows ranging from 34 to 58 cfs:



Simulated water surface elevation versus low flow discharge at Big Waterfall site.

Interpretation Based on this plot, the water surface elevation should rise from approximately 994.23 ft to 994.43 ft for flows between 34 and 59 cfs. This means a rise of 0.0082 feet will be realized for each 1 cfs increase in flow. Resolving changes of 1-2 cfs will be difficult at this location.

Ease of Installation This site has a travertine cliff on the left bank which would provide an adequate location for the installation of ultrasonic or radar gages with minimal gaging infrastructure. A subsurface pressure transducer or bubble manometer could also be installed at this location.

Recreational Exposure This site is located just above the largest waterfall and one of the deepest pools on Fossil Creek and cliff jumpers and recreationists frequent this location. The site is also fairly easy to access. The recreational exposure will be high.

Cost Cost estimate for an ultrasonic or radar water level sensor mounted on the left bank travertine cliff: $20,000

Access Access to this site is easy, via a trail on the left bank of the stream that originates just upstream from the Irving trailhead to Fossil Springs.

Site #3: Bridge 1

Location The Bridge 1 Gage Site (see Map 2, above) is located approximately 0.75 miles southwest of Irving on the Fossil Creek road, where it crosses the creek.

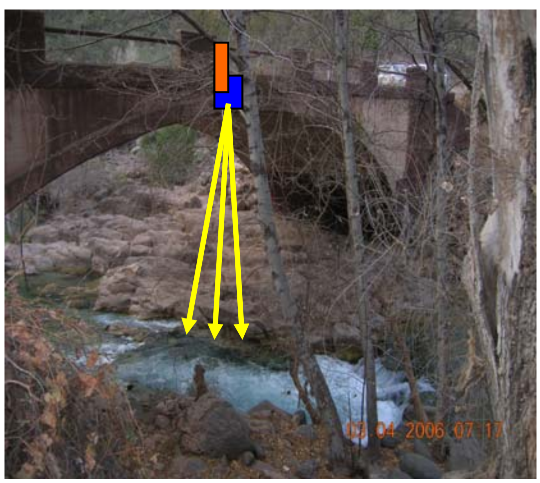
Left Bank

Right Bank

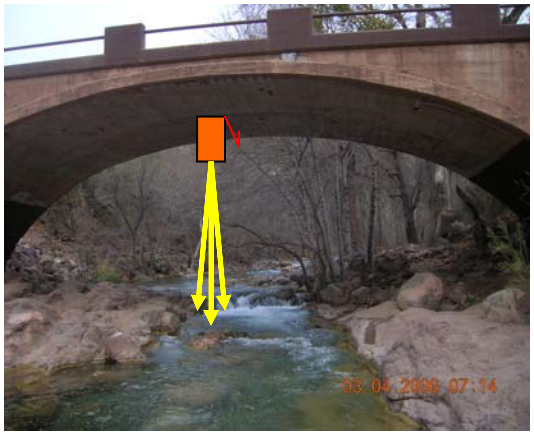
Upstream

Downstream

Suggested Gage An ultrasonic or radar water level sensor mounted on the Fossil Creek road bridge is suggested. This transducer could be mounted on the north or south side or center of the bridge, though the north edge or center of the bridge are recommended because the hydraulic conditions below are more favorable at low flow due to a hydraulic jump that separates the gaging surface from a downstream pool. Possibly, a velocity sensing transducer could be used in conjunction with a water level sensing transducer. Alternatively, a low-flow flume could be constructed and flow could be monitored with a bridge-mounted water surface sensor.



Suggested north side gage mount.



Alternative center gage mount.

Long-Term Stability Given that this is a bedrock site and that new post-flow-restoration travertine is expected to form only considerably upstream; this site should have good long-term stability. Additionally, the site is well scoured and sediment accumulation should not be an issue here.

The expected sediment release from the Fossil Springs dam lowering will eventually make its way to this location as well, though the sediment wave will be greatly attenuated and spread out along the stream by the time it reaches this location.

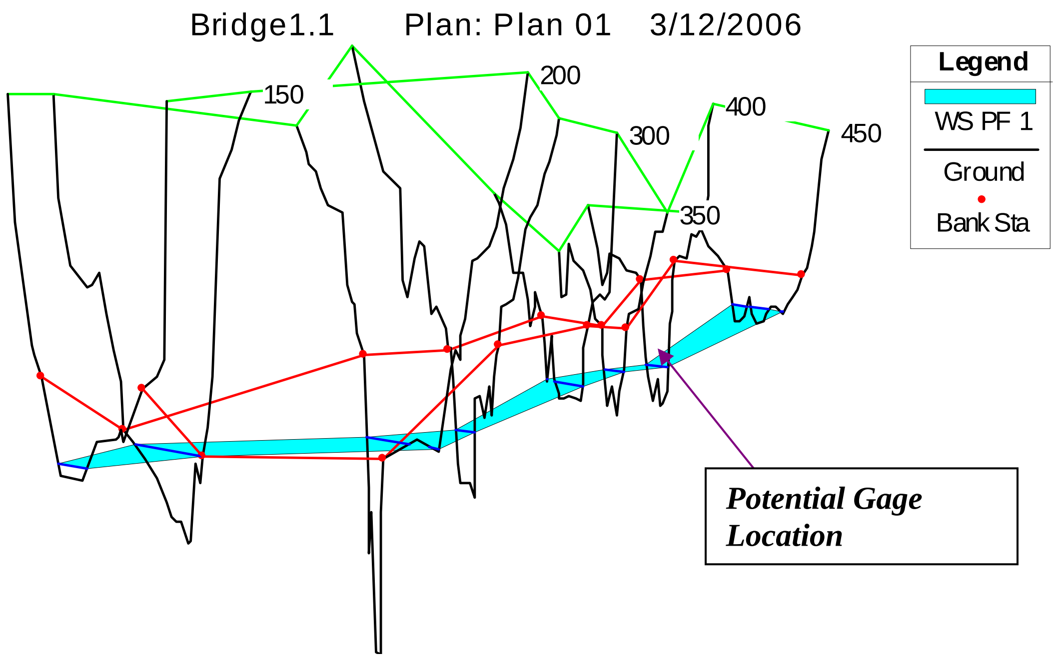
Geology The streambed at this site is dominantly volcanic bedrock. The right and left banks are basalt cliffs near the streambed with boulder slopes and intermittent basalt cliffs higher up.

Control Control in this reach is provided by stable basalt bedrock with boulder cover higher up. Additional control is provided by the bridge abutments. This reach should not be significantly impacted by high flow events.

Stream Dimensions at Suggested Gage Location At the suggested gage location on the north side of the bridge, the width of the stream channel is approximately 11 feet with a max depth of approximately 2 feet at 46 cfs flow.

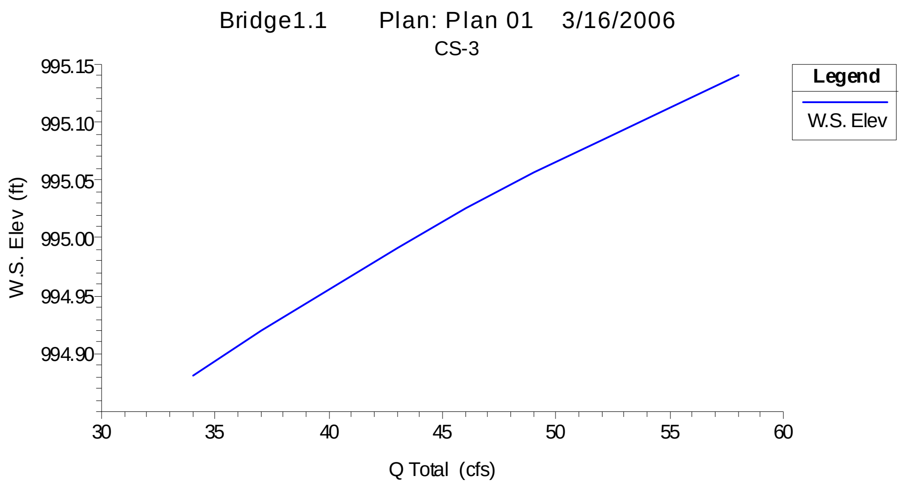
Hydraulic Characteristics This gage site has moderately good hydraulic characteristics for gaging. The channel is narrow with good control on both banks. The suggested location has hydraulic jumps both upstream and downstream of a pool. The pool provides a relatively smooth water surface which aids in achieving optimal high resolution gage performance. However, there is some turbulence, which could have a small effect on gage resolution. The stream appears to maintain velocity through the pooled area sufficient to hold sediment in transport.

HEC-RAS Methodology and Results Following the methodology described under the Site #2 (Big Waterfall) description, above, HEC-RAS software was applied to estimate the sensitivity of this site as a stream flow gage. Manning's roughness coefficients (*n* values) were obtained from Rosgen (1996; Figure 8-2). An *n* value of .028 was used for the overbank areas and a value of .03 was used for the stream channel thalweg. The HEC-RAS simulations for this site followed the protocol described above for the Site #2 (Big Waterfall) site.



HEC-RAS 3-D illustration of stream reach and cross sections at Bridge 1 site for 46 cfs flow condition.

Stage/Discharge Rating Curve The following stage/discharge curve was obtained for the cross section (CS-3) located at the potential gage location for flows ranging from 34 to 58 cfs.



Simulated water surface elevation versus low flow discharge at Bridge 1 site.

Interpretation Based on this plot, the water surface elevation should rise from approximately 994.88 ft to 995.14 ft between flows of 34 and 58 cfs. This means a rise of 0.011 feet will be realized for each 1 cfs increase in flow. This is an improvement over the Big Waterfall site, but still challenging.

Ease of Installation Gage installation at this site could be accomplished with relative ease. The roadway provides easy access, and the bridge offers a sound platform for transducer mounting.

Recreational Exposure There is a large pool visible from the road at this site. This site is frequented for rope swinging and swimming, however, there is not a place to jump from the bridge into the nearby pools. Based on the above considerations, it is expected that recreational exposure would have only a moderate impact on this gage.

Cost
Our cost estimate for an ultrasonic or radar water level sensor mounted on the bridge is approximately $20,000; a flume constructed and instrumented at this location could cost upwards of $75,000 or more.

Access This site is located at the bridge on Fossil Creek Road so the access is trivial.

Other Applicable or Recommended Technologies A bubble manometer, submerged ultrasonic transducer, a pressure transducer, or float-in-still gage could also be placed at this site, but the installation of these options could be more involved and the associated costs could be greater than for bridge-mounted transducers.

Site #4: Basalt 1

Location The Basalt 1 gage site (see Map 3, above) is located approximately 0.75 miles southwest of the intersection of the Fossil Creek Road and the Childs Road. The site is close to where APS power lines cross Fossil Creek.

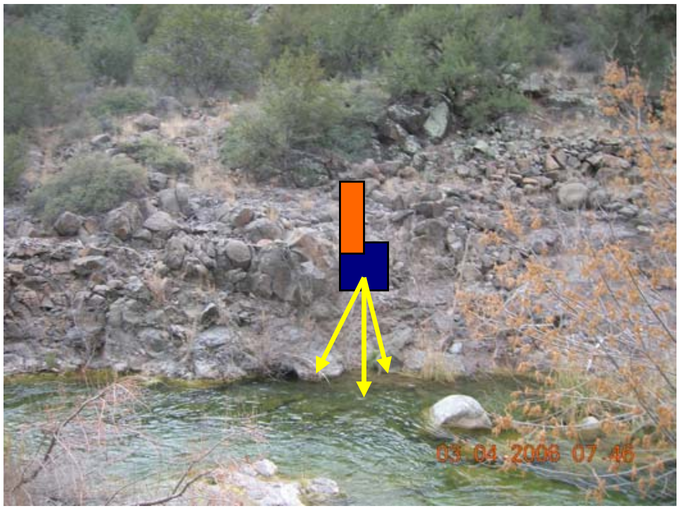
View of left bank.

View of right bank.

View downstream.

View upstream.

Suggested Gage An ultrasonic or radar water level sensor could possibly be mounted on the left bank basalt cliff, depending on sensor geometry requirements. To reduce the exposure of gaging equipment, a pressure transducer or bubble manometer could be located below the water surface on this wall. A submerged ultrasonic transducer is another option. A flume could possibly be located here, as the reach naturally mimics a flume somewhat and the bedrock would provide a solid foundation. On the river right bank there is an overflow bank approximately 5 m wide that could possibly provide an area for the diversion of flow during construction although this would most likely be a difficult procedure given the restraints in this channel due to the natural bedrock control on each bank. In addition, construction of a flume would probably be unacceptable in this natural reach.



Potential gage location at Basalt 1 site.

Long-Term Stability This is a bedrock site and new post-flow-restoration travertine is expected to form only considerably upstream. This site should have good long-term stability. There is some potential for time-varying sediment aggradation and degradation at this location.

The finer fraction of sediment released from the Fossil Springs dam lowering will eventually make its way to this location, though the sediment wave should be greatly attenuated and spread out along the stream by the time it reaches this location.

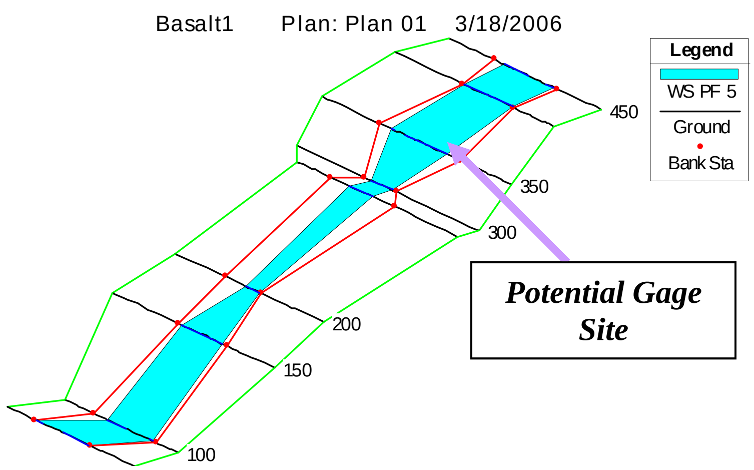
Geology The streambed at this site is predominantly volcanic bedrock. The right and left banks are predominantly basalt cliffs adjacent to the streambed with boulder slopes and intermittent basalt cliffs higher up.

Control Control in this reach is provided by stable basalt bedrock and boulders on the right and left banks and in the thalweg. This channel should not be significantly impacted by high flow runoff events.

Stream Dimensions at Suggested Gage Location At the suggested gage location, the width of the stream channel is approximately 22 feet with a max depth of approximately 2.5 feet at a 46 cfs flow.

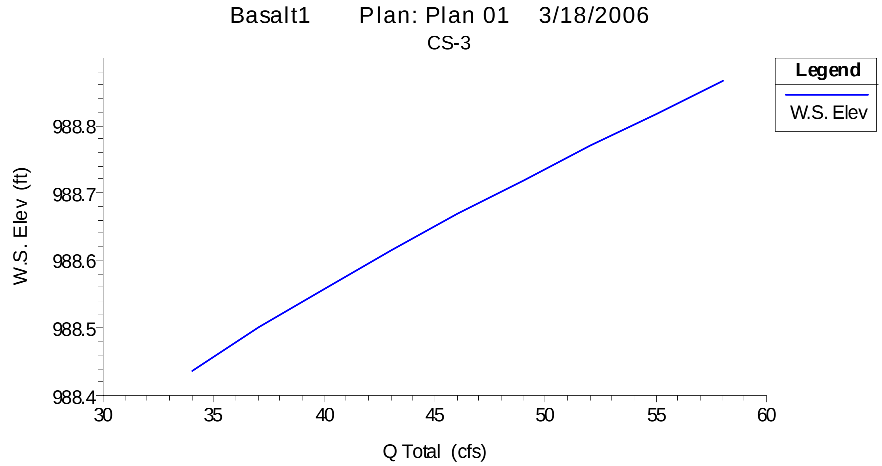
Hydraulic Characteristics This gage site has moderately good hydraulic characteristics for high resolution gaging. The channel is narrow with good control on both banks. The reach contains hydraulic jumps upstream and downstream of a pool. The pool provides a relatively smooth water surface which would aid in achieving optimal high resolution gage performance. The downstream hydraulic jump prevents hydraulic changes on the proposed gaged reach in event of hydraulic changes below it. The stream maintains a good flow velocity through the reach which holds sediment in transport and consequently mitigates some of the effects that sediment aggradation would otherwise have on this reach.

HEC-RAS Methodology and Results In order to investigate the potential for this stream reach to provide good gage resolution, a field survey was conducted on this site and the data were used with HEC-RAS software to obtain hydraulic simulations of the reach. Manning's roughness coefficients (*n* values) were obtained from Rosgen (1996; Figure 8-2). An *n* value of .028 was used for the overbank areas and .03 was used for the stream channel thalweg. The HEC-RAS simulations for this site followed the protocol described above for Site #2 (Big Waterfall).



HEC-RAS 3-D illustration of stream reach and cross sections for Basalt 1 gage site for 46 cfs flow simulation.

Stage/Discharge Rating Curve The following stage/discharge curve was obtained for the cross section (CS-3) located at the potential gage location (illustrated above) for flows ranging from 34 to 58 cfs.



Simulated water surface elevation versus low flow discharge at Basalt 1 Site.

Interpretation Based on this plot, the water surface elevation should rise from approximately 988.43 ft to 988.86 ft for flows between 34 and 58 cfs. This means a rise of 0.018 feet will be realized for each 1 cfs increase in flow. Of all sites considered, this location offers the greatest sensitivity for gaging in its natural condition.

Long-Term Stability Given that this is a bedrock site and that new post-flow-restoration travertine is expected to form only considerably upstream; this site should have good long-term stability. Additionally, the site is well scoured and sediment accumulation should not be an issue here.

The expected sediment release from the Fossil Springs dam lowering will eventually make its way to this location as well, though the sediment wave will be greatly attenuated and spread out along the stream by the time it reaches this location.

Ease of Installation This site has a basalt cliff on the left bank, which would provide an adequate location for the installation of ultrasonic or radar gages. Some additional gaging infrastructure would be required because the cliff does not extend out over the flow and does not have sufficient height to avoid high flows. A subsurface pressure transducer or bubble manometer could also be installed with relative ease at this location.

Recreational Exposure In comparison to other nearby sites, this stream reach does not have large pools or good spots for recreational jumping. Consequently, it is not a preferred site from a recreationist's standpoint. Based on the above considerations, we expect that recreational exposure would not have a significant impact on this gage.

Access Access to this site is very easy via existing dirt roads, though the continued existence of those roads cannot be assured.

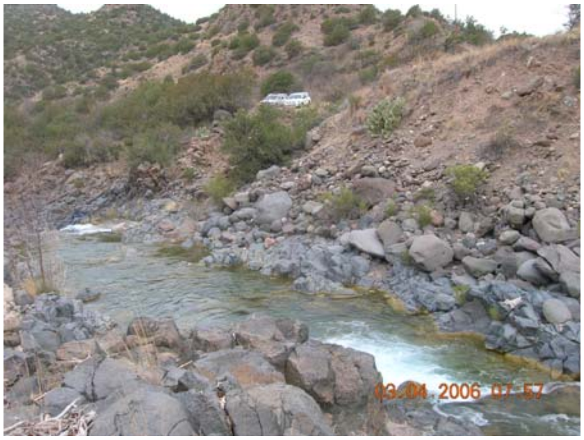
Cost
A water level sensor mounted on the left bank basalt cliff would cost approximately $25,000.

Other Applicable or Recommended Technologies A weir is not recommended at this location as the natural channel does not provide a good site for a weir and a great deal of disturbance would be required. For the same reason, flume construction would probably not be feasible at this location.

Site #5: Basalt 2

Location The Basalt 2 Gage Site (see Map 3, above) is located immediately downstream, roughly 100 feet, from the Basalt 1 site.

Left bank.



Right Bank.

Downstream view.

Upstream view.

Suggested Gage An ultrasonic or radar water level sensor could possibly be mounted on the left bank basalt cliff, depending on sensor geometry requirements. That is, the cliff at this location does not overhang the water and the sensor would probably need to be offset considerably from the cliff face. To reduce the exposure of gaging equipment, a pressure transducer or bubble manometer could be located below the water surface on this wall. A submerged ultrasonic transducer is another option. A flume could possibly be located here, as the reach naturally mimics a flume somewhat and the bedrock would provide a solid foundation. However, there is very minimal space on the bank overflow so flow divergence during construction of the flume would be difficult and costly.

Suggested gage location on left bank.

Long-Term Stability This is a bedrock site and new post-flow-restoration travertine is expected to form only considerably upstream. This site should have good long-term stability. There is some potential for time-varying sediment aggradation and degradation at this location.

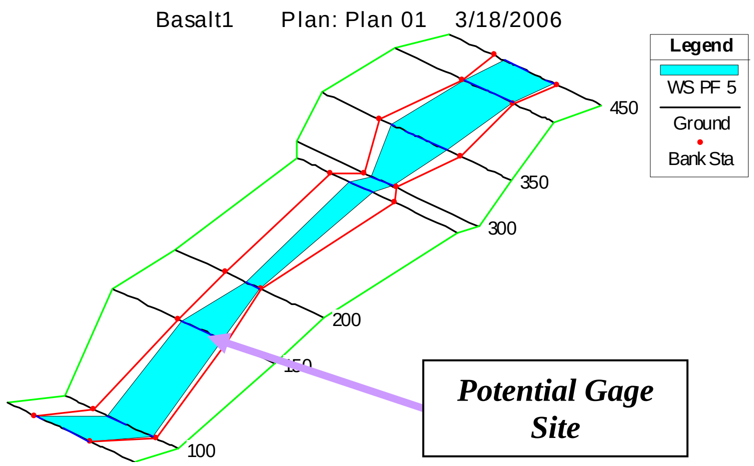
The finer fraction of sediment released from the Fossil Springs dam lowering will eventually make its way to this location, though the sediment wave will be greatly attenuated and spread out along the stream by the time it reaches this location.

Geology The streambed at this site is predominantly volcanic bedrock. The right and left banks are predominantly basalt cliffs at and near the stream bed with boulder slopes and intermittent basalt cliffs higher up.

Control Control in this reach is provided by very stable basalt bedrock and boulders on the right and left banks. This channel will not be significantly altered by large flow events.

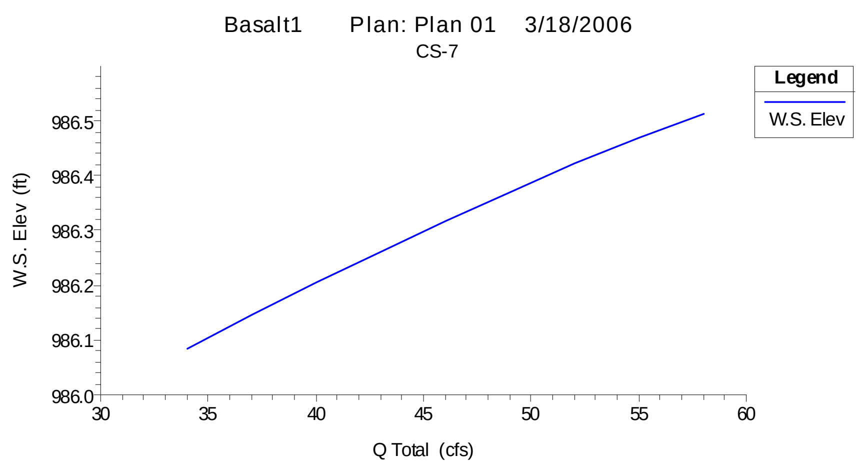
Stream Dimensions at Suggested Gage Location At the suggested gage location, the width of the stream channel is approximately 15 feet with a max depth of approximately 3.5 feet at a 46 cfs flow.

Hydraulic Characteristics and HEC-RAS Simulations (See Basalt 1 Gage Site description for hydraulic characteristics and for HEC-RAS protocols).



HEC-RAS 3-D illustration of stream reach and cross sections for Basalt 2 Site.

Stage/Discharge Rating Curve The following stage/discharge curve was obtained for the cross section (CS-7) located at the potential gage location (illustrated above) for flows ranging from 34 to 58 cfs:



Graph of Water Surface Elevation versus (low) flow at Basalt 2 Site

Interpretation Based on this plot, the water surface elevation should rise from approximately 986.08 ft to 986.52 ft for flows between 34 and 58 cfs. This means a rise of 0.018 feet will be realized for each 1 cfs increase in flow. This is very similar to the Basalt 1 site, and this location similarly offers greater sensitivity for gaging in its natural condition.

Long-Term Stability (See Basalt 1 Site summary)

Ease of Installation (See Basalt 1 Site summary)

Recreational Exposure (See Basalt 1 Site summary)

Cost
An ultrasonic or radar water level to be mounted on the left bank basalt cliff would cost approximately $25,000-$30,000 (due to need for substantial mounting infrastructure)

Access (See Basalt 1 Site summary)

Other Applicable or Recommended Technologies No other technologies are recommended for this site.

Site #6: Fish Trap 1

Location The Fish Trap (*Barrier*) 1 Gage Site is located approx. 150 yds upstream of the recently constructed U.S. Bureau of Reclamation fish barrier on Fossil Creek. The approximate UTM NAD 27 Zone 12 coordinates are: 438,752 m E 3,801,727 m N.

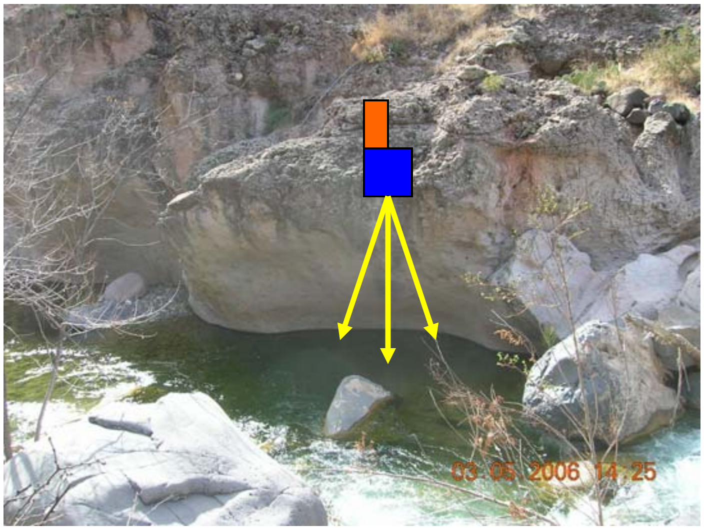
View of left bank.

View of right bank.

View upstream.

View downstream.

Suggested Gage An ultrasonic or radar water-level sensor mounted on the right bank conglomeratic tuff cliff.



Right bank mount of potential gage.

Long-Term Stability This is a bedrock site and new post-flow-restoration travertine is expected to form only considerably upstream. This site should have good long-term stability. There is some potential for time-varying sediment aggradation and degradation at this location.

The finer fraction of sediment released from the Fossil Springs dam lowering will eventually make its way to this location, though the sediment wave will be greatly attenuated and spread out along the stream by the time it reaches this location.

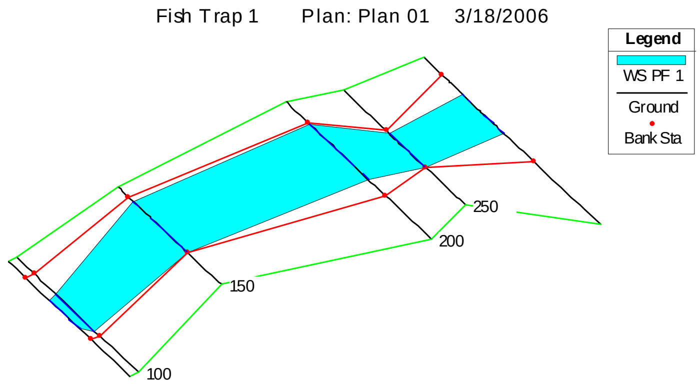
Geology The streambed at this site is dominated by volcanic bedrock. The right bank is a conglomerate tuff cliff and the left bank is predominantly basalt boulders with intermittent cliff-forming conglomeratic tuff.

Control Control in this reach is provided by stable tuff bedrock cliffs on the right bank and basalt boulders with intermittent tuff cliffs on the left bank. This channel should be stable in response to high-flow runoff events.

Stream Dimensions at Suggested Gage Location At the suggested gage location, the width of the stream channel is approximately 31 feet with a maximum depth of approximately 2 feet at a 46 cfs flow.

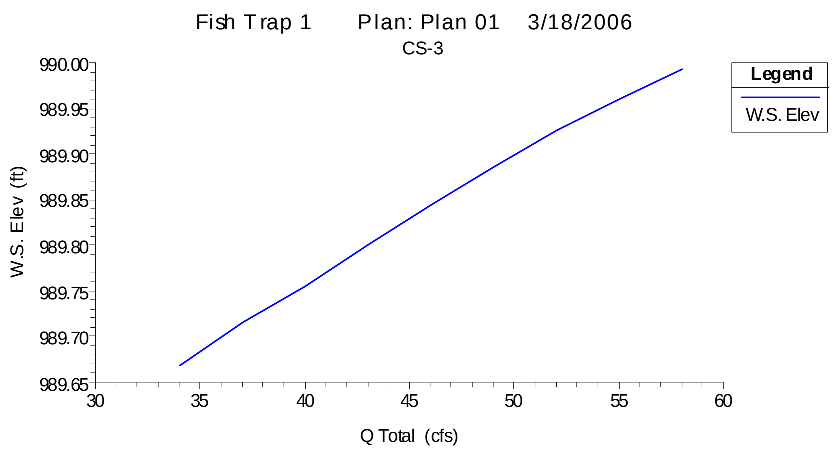
Hydraulic Characteristics This gage site has good hydraulic characteristics for gaging. The channel is narrow with good control on both banks. The reach contains hydraulic jumps upstream and downstream of a pool. The pool provides a relatively smooth water surface which aids in achieving optimal gage performance. For the low flow condition, the downstream hydraulic jump prevents hydraulic changes on the gaged reach if the hydraulic characteristics of the stream change downstream. Given the pool, there is some potential for sediment aggradation and degradation over time.

HECRAS Methodology and Results (See Basalt 1 for Manning's *n* values, HEC-RAS methodology).



HEC-RAS 3-D illustration of stream reach and cross sections at Fish Trap 1 site for 46 cfs flow simulation.

Stage/Discharge Rating Curve The following stage/discharge curve was obtained for the cross section (CS-3) located at the potential gage location (illustrated above) for flows ranging from 34 to 58 cfs:



HEC-RAS simulation of water surface elevation versus low flow discharge at Fish Trap 1 site.

Interpretation Based on this plot, the water surface elevation should rise from approximately 989.665 ft to 990.00 ft for flows between 34 and 58 cfs. This means a rise of 0.014 feet should be realized for each 1 cfs increase in flow.

Ease of Installation This site has a conglomerate tuff cliff on the right bank which overhangs the suggested gaging pool and has sufficient height to avoid high flows. This cliff provides a good mounting surface, making gage installation relatively straightforward.

Recreational Exposure This site is located just above the fish trap on Fossil Creek and access, discussed below, is difficult. Because of this, it is expected that recreational impacts on this site will be minimal.

Cost An ultrasonic or radar water-level sensor mounted on the right bank of the conglomeratic tuff cliff would cost approximately $20,000.

Access Access to this site by foot is difficult, requiring a 2 to 3 mile river hike. There are no known trails leading to this site.

Other Applicable or Recommended Technologies No other technologies are recommended for this site.

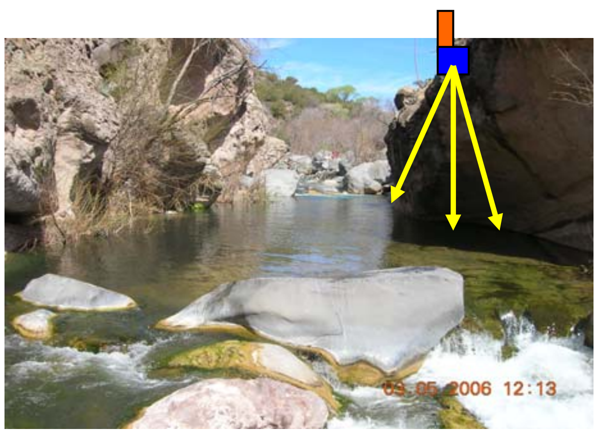
Site #7: Fish Trap 2

Location The Fish Trap (barrier) 2 Gage Site is located approx. 125 yds upstream of the U.S Bureau of Reclamation fish trap structure on Fossil Creek. This site is immediately downstream of the Fish Trap 1 Site. The approximate UTM NAD 27 Zone 12 coordinates are: 438,752 m E and 3,801,727 m N.

View downstream.

View upstream.

Suggested Gage An ultrasonic or radar water level sensor could be mounted on the conglomeratic tuff cliffs present on both river left and river right.



Suggested gage placement, in this case, on river left (view is toward upstream).

Long-Term Stability This is a bedrock site and new post-flow-restoration travertine is expected to form only considerably upstream. This site should have good long-term stability. There is some potential for time-varying sediment aggradation and degradation at this location.

The finer fraction of sediment released from the Fossil Springs dam lowering will eventually make its way to this location, though the sediment wave will be greatly attenuated and spread out along the stream by the time it reaches this location.

Geology The streambed at this site is dominated by volcanic bedrock. The right bank and left banks are conglomerate tuff cliffs.

Control Control in this reach is provided by stable tuff bedrock cliffs on both the right and left banks. The reach is a bedrock slot, which provides excellent control. This channel should be stable under high-magnitude flood flows.

Hydraulic Characteristics See Fish Trap 1 site summary.

HEC-RAS Methodology and Results This site was too difficult to survey with the available equipment. No hydraulic analysis was performed on this site. However, based on a visual inspection of this site, it is expected that it would possess acceptable hydraulic characteristics for high-resolution gaging.

Ease of Installation See Fish Trap 1 site summary.

Recreational Exposure See Fish Trap 1 site summary.

Costs An ultrasonic or radar water-level sensor mounted on the right or left bank of the conglomeratic tuff cliff would cost approximately $20,000.

Access See Fish Trap 1 site summary.

Other Applicable or Recommended Technologies See Fish Trap 1 site summary.

Permitting

An important issue for permitting a gaging station in Fossil Creek is jurisdiction. From the Fossil Springs (actually, beginning a short distance above the Fossil Springs) to the confluence of Fossil Creek with the Verde River, Fossil Creek is the boundary between the Tonto and the Coconino National Forests. Above that point, the Coconino National Forest manages both sides of the creek. For the sites considered in this report, we understand a permit application will have to be submitted to the Coconino National Forest.

In the event that a structure spanning the creek is selected for the gage, such as would be the case for the Bridge 1 Site, one of the Forests would be designated as the lead and a special use permit for the structure would have to be obtained that would apply to both Forests. Permit approvals for any structures in the wilderness require approval from as high up as the regional forester, which is a step above the Forest Supervisor.

Assuming that the gage would be installed for long-term operation, the installation would be regulated under Forest Service Handbook 1909.15, Chapter 31.2.3, which requires a Categorical Exclusion, with documentation and a decision memo from the Forest Service line officer responsible for approving or disapproving the Special Use Permit that goes with the Categorical Exclusion. The Categorical Exclusion is the simplest analysis necessary to comply with the National Environmental Policy Act (NEPA). The analysis would include scoping and a Biological Assessment & Evaluation that looks at effects on Threatened and Endangered species (this goes to the US Fish and Wildlife Service).

Additionally, depending on the magnitude of the disturbance, e.g., for construction of a new flume/weir structure, a Clean Water Act Section 404 permit may be required. The available Section 404 Nation-Wide Permit No. 5, *Scientific Measurement Devices*, as described in NWP Final Notice, 67 FR 2078, paragraph 5), provides for:

> "devices, whose purpose is to measure and record scientific data such as staff gages, tide gages, water recording devices, water quality testing and improvement devices and similar structures. Small weirs and flumes constructed primarily to record water quantity and velocity are also authorized provided the discharge is limited to 25 cubic yards and further for discharges of 10 to 25 cubic yards provided the permittee notifies the District Engineer..." [*in this paragraph, discharge refers to earthen or other fill placed in the watercourse*]

Additional issues to consider are the pending application for designation of Fossil Creek as a Wild & Scenic River, and the potential location of a gage in a Wilderness area. For example, NWP No. 5, discussed above, stipulates that:

> "No activity may occur in a component of the National Wild and Scenic River System; or in a river officially designated by Congress as a ‘‘study river’’ for possible inclusion in the system, while the river is in an official study status; unless the appropriate Federal agency, with direct management responsibility for such river, has determined in writing that the proposed activity will not adversely affect the Wild and Scenic River designation, or study status."

Based on the above mentioned stipulations, prior to installation of a gage, a study on the impacts of installing a gage on any Wild and Scenic characteristics of Fossil Creek would have to be performed. As an example, an extensive analysis of the effects of a fish barrier on the free-flowing characteristics of the Wild and Scenic reach of Fossil Creek was conducted as part of the Environmental Assessment of the fish barrier recently constructed. Forest Service guidance for administration of proposed Wild and Scenic rivers allows construction of flow measurement devices when necessary for protection, conservation, rehabilitation, or enhancement of river area resources. They must be compatible with the classification of the river area and harmonize with the surrounding environment. They must not pose a direct and adverse impact on the river values (Forest Service Manual 2354 WO amendment 2300-94-4).

It can be reasonably concluded that permitting a gage that minimizes physical disturbance to the channel would be the easiest route. For this reason, from a permitting perspective, it is concluded that the construction of a flume or a weir should only be considered if all other options prove inadequate for the desired gaging operation.

Finally, it should be noted that the Red Rock Ranger District of the Coconino National Forest conducted a review of a draft of this report in mid-spring of 2006. As part of their review, they considered the suitability of gages at the final seven proposed sites discussed herein. The Forest Service decided that the dam and the two fish barrier sites would not, in all likelihood, be permitted for gage installation. In addition, the waterfall location was not recommended by the Forest Service. The Forest Service did, however, recommend the Bridge 1 site and the two sites at the Sally May confluence (Basalt 1 and 2) for further evaluation and possible permitting.

Decision Matrix & Recommendations

In order to provide the best recommendation on the most suitable of these seven sites, the following decision matrix was created to rank each site based on the following eleven considerations:

- control;
- hydraulic characteristics;
- HEC-RAS results (steepness of stage/discharge curve at potential gage location);
- long-term stability;
- ease of installation;
- cost/infrastructure;
- recreational exposure;
- permitting likelihood;
- distance from Fossil Springs;
- access, and;
- number of gaging methods (technologies) that likely can be readily implemented at the site.

Scores of 1 to 5, with 5 being the top score, were given for each of the seven sites considered. The ranking for the applicable gaging methods was scored higher if a larger suite of methods could be used at a site, because having options was considered to be beneficial. The cost ranking was scored lower for sites that would require the installation of a greater amount of gaging infrastructure. Access is ranked as ease of accessibility for gage maintenance. Some characteristics were given larger weights, as these characteristics, at least in our minds, have a greater relative importance when selecting a site.

Decision Matrix

Site	Relative Weight	Site #1 Diversion Dam	Site #2 Big Waterfall	Site #3 Bridge 1	Site #4 Basalt 1	Site #5 Basalt 2	Site #6 Fish Trap 1	Site #7 Fish Trap 2
Control	2	5	4	4	4	4	4	5
Hydraulic Characteristics	2	5	4	3	3	4	4	5
HEC-RAS Discharge Curve	2	5	3	4	5	5	4	5
Long-Term Stability	1.5	3	3	4	5	5	5	5
Cost/Infrastructure	1.5	3	4	5	3	4	5	5
Installation	1	4	4	5	4	4	4	4
Recreational Exposure	1	2	1	4	4	4	5	5
Access	1	5	4	5	5	5	3	3
Applicable Technologies	0.75	3	4	4	5	4	5	4
Permitting Certainty	1.5	0	0	5	4	4	0	0
Distance from Fossil Springs	1	5	4	3	2	2	1	1
Weighted Average		**5.2**	**4.4**	**5.7**	**5.5**	**5.8**	**5.1**	**5.5**

Based on the decision matrix, Sites #3 (Bridge 1) and #5 (Basalt 2) offer the best overall characteristics, given the selection criteria. These sites are considered the best candidates on Fossil Creek for a gage if only one site is to be gaged. Sites #4 (Basalt 1) and #7 (Fish Trap #2) also ranked high, but Site #7 is not recommended due to the potential for permitting difficulties. Specifically, we anticipate that the National Forest Service would not be inclined to grant a permit for gaging at site #7 because this stretch of river will likely gain a “Wild and Scenic” designation in the future.

If a small gaging station network is considered, a recommended option would be to install one gage at Site #1 (Diversion Dam), which is located just below the Fossil Springs, and another at Site #3 (Bridge 1), which is roughly halfway between the start of Fossil Creek and its confluence with the Verde River. Such a gaging network would be advantageous for several reasons. First, it would allow stream flow loss detection over a fairly long stretch of the creek. In addition, both gages would be located at existing structures on stretches of creek that are less likely to receive a “Wild and Scenic” designation. This would increase the likelihood of success with regard to permitting by the Forest Service.

If a flume is desired, the recommended solution would be a low-flow flume constructed at the Bridge 1 site. The Bridge 1 site offers an ideal bedrock foundation for the installation of a flume and it would also be suitable for gaging higher-magnitude storm flows that occur on Fossil Creek. Advantages of a flume at this location include durability, ease of gaging with overhead sensors, and good stability for long-term monitoring.

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References

Blakey, R.C., 1990, Stratigraphy and geologic history of Pennsylvanian and Permian rocks, Mogollon Rim region, central Arizona and vicinity: Geological Society of America Bulletin, v. 102, p. 1189-1217.

Buchanan, T.J. and Somers, W.P., 1968, Discharge Measurements at Gaging Stations. USGS Training Manual, Book 3, Applications of Hydraulics.

Carter, R.W., and Davidian, J., 1968, General Procedure for Gaging Streams, U.S. Geological Survey, Techniques for Water-Resources Investigations, Book 3, Chapter A6.

Montgomery, David R. and Buffington, J. M., 1997, Channel – reach morphology in mountain drainage basins. GSA Bulletin, May 1997.

Montgomery, David R. and Buffington, John M., 1998, *Channel Processes, Classification, and Response*, Springer-Verlag, New York.

Morrison Maierle, 2003, Investigation of Groundwater Availability for Pine/Strawberry Water Improvement District, prepared for the Pine/Strawberry Water Improvement District.

Nelson, K., 2003, Fossil Creek Instream Flow Assessment (Application Number 33-96622), Coconino and Tonto National Forests, 23 p., plus appendices.

Pierce, H. W., 1987. An Ancestral Colorado Plateau Edge: Fossil Creek Canyon, Arizona. In Geological Society of America Centennial Field Guide – Cordilleran Section [ed. M.L. Hill]. Boulder: Geological Society of America.

Rantz, S.E., et al., 1968, Measurement and Computation of Streamflow, U.S. Geological Survey, Water Supply Paper 2175

Reconnaissance Evaluation of Potential Low-Flow Gaging Sites Main-stem Verde River, SRP, December, 1999.

Rosgen, D., 1996, Applied River Morphology, Second Edition, Wildland Hydrology, Pagosa Springs, Colorado.

SRP, 1999, Verde River Low Flow Monitoring Study, prepared by SRP under Federal Grant No. 99-FG-32-0110.

Twenter, F.R., 1962, The significance of the volcanic rocks in the Fossil Creek Area, Arizona. In Guidebook of the Mogollon Rim region, east-central Arizona. [13th Field Conference.], New Mexico Geological Society, Socorro, N.M.

US Army Corps of Engineers, 2002, HEC-RAS River Analysis System User’s Manual, Version 3.1.

US Bureau of Reclamation, 2001, Water Measurement Manual, revised reprint, Washington, D.C.

Wahl, K.L., 1984, Evolution of the use of channel cross-section properties for estimating streamflow characteristics, in Meyer, E.L., ed., Selected papers in the hydrologic sciences: U.S. Geological Survey Water-Supply Paper 2262, p. 53-66.

Wohl, E.E., Merritt, D.M., 2001, Bedrock Channel Morphology, GSA Bulletin, v. 113, No. 9, 1205-1212.