DESIGN AND INSTALLATION OF A FLUME TO MONITOR SPRING DISCHARGE AT THE HEADWATERS OF THE VERDE RIVER

Curt Kennedy[1]

ABSTRACT

Many rivers in the Southwestern US are under threat of declining base flows caused by groundwater withdrawal and poor forest/watershed management. This paper describes the design and installation of a Critical Depth Flume (Flume) to accurately monitor base flows on the upper Verde River, located in North Central Arizona. Although Flumes are very common and accurate flow measurement structures, there application in native channels has been limited. Some of the problems associated with using a Flume in native channels are: maintenance, cost, flood damage, sedimentation, shifting channels, unstable substrate, and limitations due to the Endangered Species Act and 404 permit. This paper illustrates how these issues were addressed at one location in North Central Arizona.

BACKGROUND

At its origin the upper Verde River emerges from a series of springs. Within about a quarter mile, the flow transitions from zero too 20 cfs. The Big Chino Aquifer is the primarily source of this spring water. The river and aquifer are connected through a geologically complex area at the headwaters.

Record population growth in this region has resulted in increased pumping that threatens to lower the water table within the Big Chino Aquifer. Currently the water table in the Big Chino Aquifer is approximately 25 feet above the water surface elevation of the Verde River; as the water table is lowered, flows in the river will be reduced. If the water table is lowered more than 25 feet, flow in the upper reach of river could stop or become intermittent. The Cities of Prescott and Prescott Valley have committed to mitigate any impacts from pumping. The flume is designed to access any base flow impact.

FLUME DESIGN

Flume design at this location was aided by an almost constant discharge associated with the springs. An emphasis was placed on resolution where small changes in discharge would result in measurable changes in water surface elevation within the flume. This was accomplished with side contractions to narrow the throat of the Flume. Other design considerations included:

---

[1] Senior Analyst, Salt River Project, Mail Station PAB112, P.O. Box 52025, Phoenix AZ. 85072-2025, cgkenned@srpnet.com

- Avoiding interference with the natural sediment transport.
- Maintaining the drop in water surface that occurs in the ambient pool-drop channel conditions.
- Surviving large floods associated with the 1,500 square mile watershed upstream of the flume (flows of 25,000 cfs have occurred at this location).
- Avoiding installation of a hazard to kayakers, rafters or other river enthusiasts. (This too often is not considered when designing features in natural channels.)
- Maintaining safe flow conditions for the public and recreation.
- Developing a design that would allow flow to return to the channel where the flow is located after flood events.
- Maintaining the natural energy slope associate with the channel to avoid submerging the flume.
- Avoiding obstructions/structures that would result in scour during high flow events that could compromise the flume's structure and stability.
- Creating a low maintenance measurement flume – one that would not retain silt or aquatic weeds that would require machine cleaning.
- Minimizing cost – the budget for design and construction was $75,000.
- Developing permits (404, section 7 ESA) that would allow maintenance and refurbishment of the flume without re-permitting.

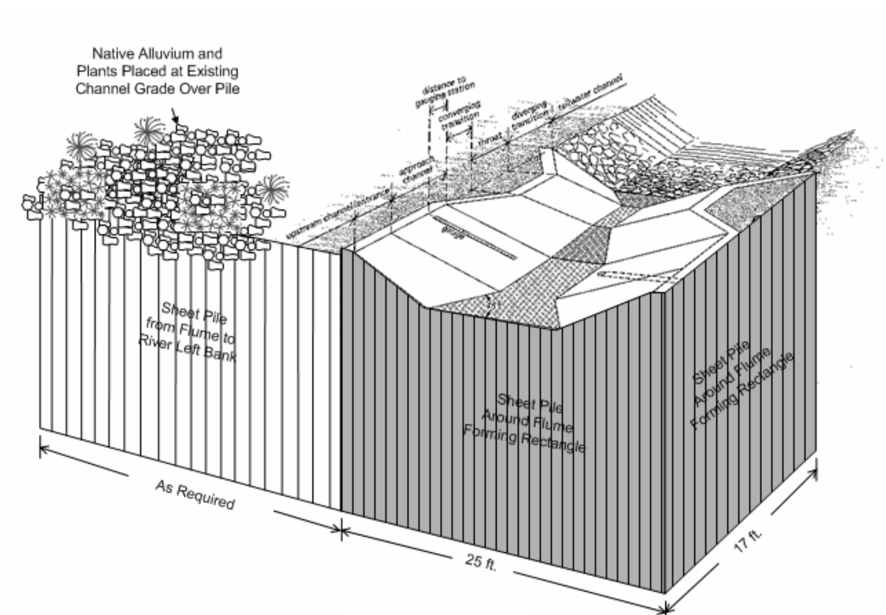

Figure 1.

WinFlume [add reference] and HEC-RAS [add reference] were used to design the flume in addition to standard manual analyses for specific channel characteristics. Because this flume would be located in a native channel, virtually every decision required evaluation from an overall system perspective. This requires an interdisciplinary understanding of the systems. For example, too much change in water surface will result in pooling upstream and scour downstream. To maintain equilibrium conditions of the channel, the flume should be designed to guard against submergence by increasing the change in water surface occurring through the flume.

To obtain resolution within the range of known spring discharges, the flume was designed with side contractions. Side contractions have the benefit of not impeding sediment transport and allowing precise control of the Froude number within the flume's approach channel. To accommodate higher flows, the side contracted section was incorporated into a complex trapezoidal design (Figure 2). This allows reasonable accurate measurement up to 100 ft^3/sec. with precise measurement in the range of 10 ft^3/sec. - 25 ft^3/sec, flow rates greater then 100 ft^/sec are not measured. The drawback to complex trapezoidal design is they can be hard to build in the field. To overcome this, each transitional section (like the one shown in Figure 2) was precisely fabricated in a steel shop prior to installation in the field.

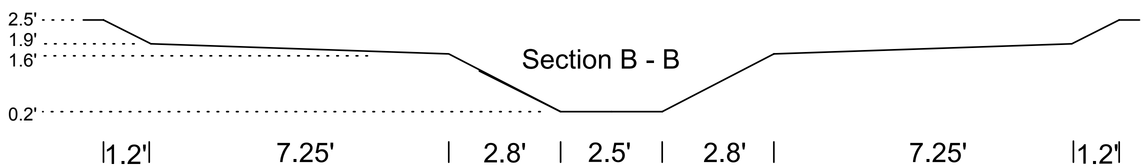

Figure 2

To provide an easy-to-use find reference point for the instrumentation and field gauges, a small Sill (0.20') was incorporated into the design. Making the end points of each section terminate at the same elevation made installation easy.

Once a satisfactory flume design was obtained, the channel and flume were modeled in HEC-RAS. This allows the designer make assessments regarding the river's response to different flood flows.

It is critical that the placement of a small flume within the larger stream channel not disrupt the system equilibrium. This is a balancing act. Streams are dynamic by nature, and you must constrain certain processes to assure viable operation of the flume. The items evaluated during the design of this flume were:

- Channel material and alluvial particle size distribution.
- Recurrent interval of floods

- Channel constraints (mountains, rock outcrops)
- Distribution of riparian growth
- Channel slope
- Distance between riffles and average fall at riffles
- Depth of unconsolidated channel alluvium

The channel in the area of the flume was formed by relatively frequent high energy floods. The average particle size is medium to coarse gravel with some infrequent large boulders; there is little or no sand, slit or clay. To minimize the exposure of this flume to the destructive erosional forces in this region; the flume was located in a reach of river that opened to a large, wide alluvial terrace. This choice has the benefit of exposing the flume to lower flow velocities during flood flows. The negative aspects of this choice are that the flume will be constructed on unconsolidated alluvium, and that the channel slope could be quite variable through time due to the absence of stable structure.

Photo 1.

Effectively addressing the issues of constructing on an unconsolidated alluvial material and channel slope variability are critical to the longevity and accuracy of this flume. At this site we chose to use sheet piles to control these variables. Photo 1 shows the initial installation of sheet piles to develop a dry working area and define the perimeter of the flume. Latter in construction sheet piles would be used to form sub-surface walls to control scour, return the channel to the flume after floods, and stabilize the channel’s slope. Photo 2 shows the outline of the concrete flume prior to restoring flow. The workers are cutting sheet piles to the finish contour of the concrete.


Photo 2.


Photo 3.

Photo 3 shows the site after a 25,000 cfs flood flow with the scour walls exposed. These walls serve two minimize scour and return the base flow channel to the flume. Note that the walls are angled downstream, and are sloped up from the base flow channel to the high flow channel banks. This forces the channel to return to the flume; as the flood flows recede, water moving downstream is forced to change direction back toward the low flow channel as it brakes over the pile wall. This process continues as the flood flows recede.

Determination of how deep to construct the scour walls was done with a scour depth analysis. Because the scour process is quite variable, two different methodologies were used to predict scour depth and then compared. The primary factors controlling scour depth are flood size and particle size and distribution. At this site scour depths were predicted to reach 3 meters, this 3 meter value was used as the depth of the subsurface wall.

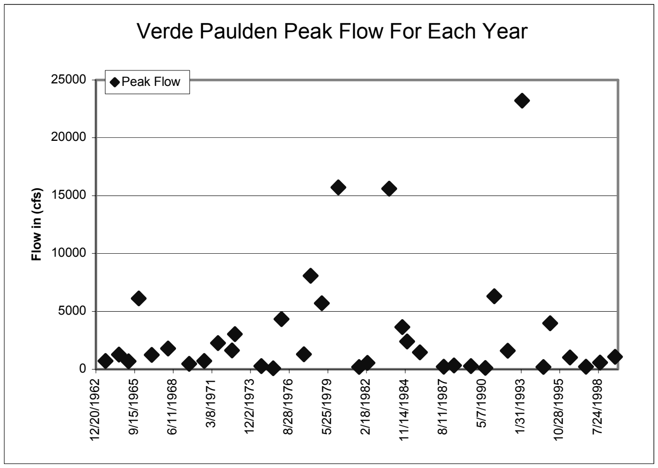

Figure 3.

Another function of the scour walls is to control channel slope, which is critical in preventing submergence of the flume. At this location the channel cross-section was elevated 0.3 foot to guard against submergence and increase the downstream fluid velocity to prevent deposition of sediments. To maintain channel stability, par ticular care was taken to match the natural distance between riffles and the fall at each riffle. For this reason this flume was constructed at the natural location of a riffle.

PERFORMANCE

This flume has been in service and monitoring base flow since June of 2004.

Under normal base flow conditions the spring's discharge as measured through the flume has shown the diurnal patterns associated with plant evapotranspiration. One notable exception occurred consistently on Sunday afternoons where a 0.5 cfs – 1 cfs drop in flow would occur. It turns out that marijuana growers were pumping water from the Verde River upstream of the flume, this stopped when the field was discovered by law enforcement.

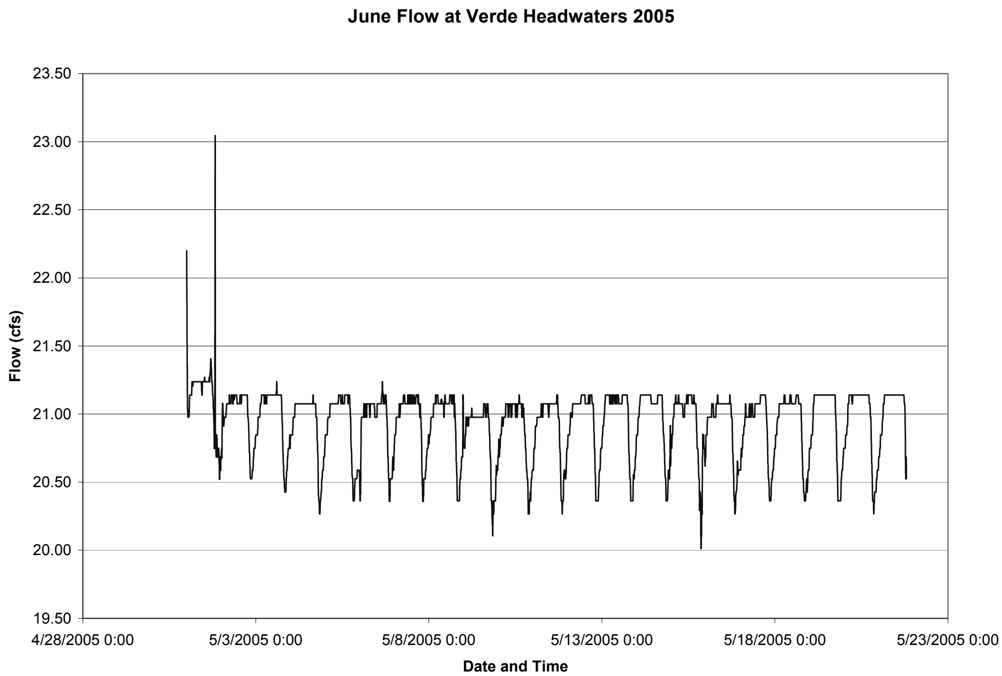

Figure 4.

The flume's first winter/spring runoff season was notable in that three major flood flows occurred; the highest flow being approximately 25k cfs. Photo 4 was taken approximately five miles upstream of the flume by a local resident at Sullivan Dam. These floods exposed the tops of the sheet pile walls and shorted the satellite communicator. The sheet piling was covered with native alluvium by a backhoe in approximately ½ day, the satellite communicator was replaced. The flume and instrument package were unharmed.

Photo 4.

This site has produced a high quality record of base flow data for this reach of river. This information will provide water resource managers the data needed to protect and manage this springs that provide flow to this river for year to come.