DESIGN OF A LOW FLOW CHANNEL FOR SALT RIVER RESTORATION

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Abstract: The U.S. Army Corps of Engineers, the City of Phoenix, and the Flood Control District of Maricopa County have been partnering in the planning, design, and construction of a habitat restoration project along the Salt River in Phoenix, Arizona. The project, known as the Phoenix Rio Salado Habitat Restoration Project, encompasses a 5.5 mile reach of the Salt River and is located approximately 1-mile south of downtown Phoenix. The initial design feature was the design of a low flow channel to convey a design discharge of 12,200 cfs without significant scour or deposition. The low flow channel was designed to maintain the flood carrying capacity of the Salt River throughout the project reach by balancing the loss of capacity from the introduction of plants and trees within the river, with additional capacity created by channel excavation.

The low flow channel design consisted of initially establishing the channel slope, channel geometry, and proposed grade-control structures locations by utilizing stable channel analysis. The stable channel slope was estimated using several analysis methods, and the initial channel cross-section geometry was determined using velocity constraints and normal depth methods. Sediment transport modeling was then performed to refine the channel geometry and determine the optimum location for grade control. The low flow channel analysis also included the design of guide dike structures to help maintain the low flow channel alignment and minimize formation of channels in the overbank areas.

Construction of the low flow channel and the associated hydraulic structures was completed in early 2001. Flows within the Rio Salado exceeded the 12,200 cfs low flow channel design discharge for extended periods in early 2005. This paper will present the approach utilized in the design of the low flow channel and discuss the performance of the low flow channel and associated features.

INTRODUCTION

The U.S. Army Corps of Engineers, the City of Phoenix, and the Flood Control District of Maricopa County have been partnering in the planning, design, and construction of a habitat restoration project along the Salt River in Phoenix, Arizona. The project, known as the Phoenix Rio Salado Habitat Restoration Project, encompasses a 5.5 mile reach of the Salt River which extends from Interstate 10 (I-10) to 19th Avenue. The project is located within the banks of the Salt River plus a 50-foot wide area at the top of each bank. **Figure 1** shows the Phoenix Rio Salado Habitat Restoration Project reach.

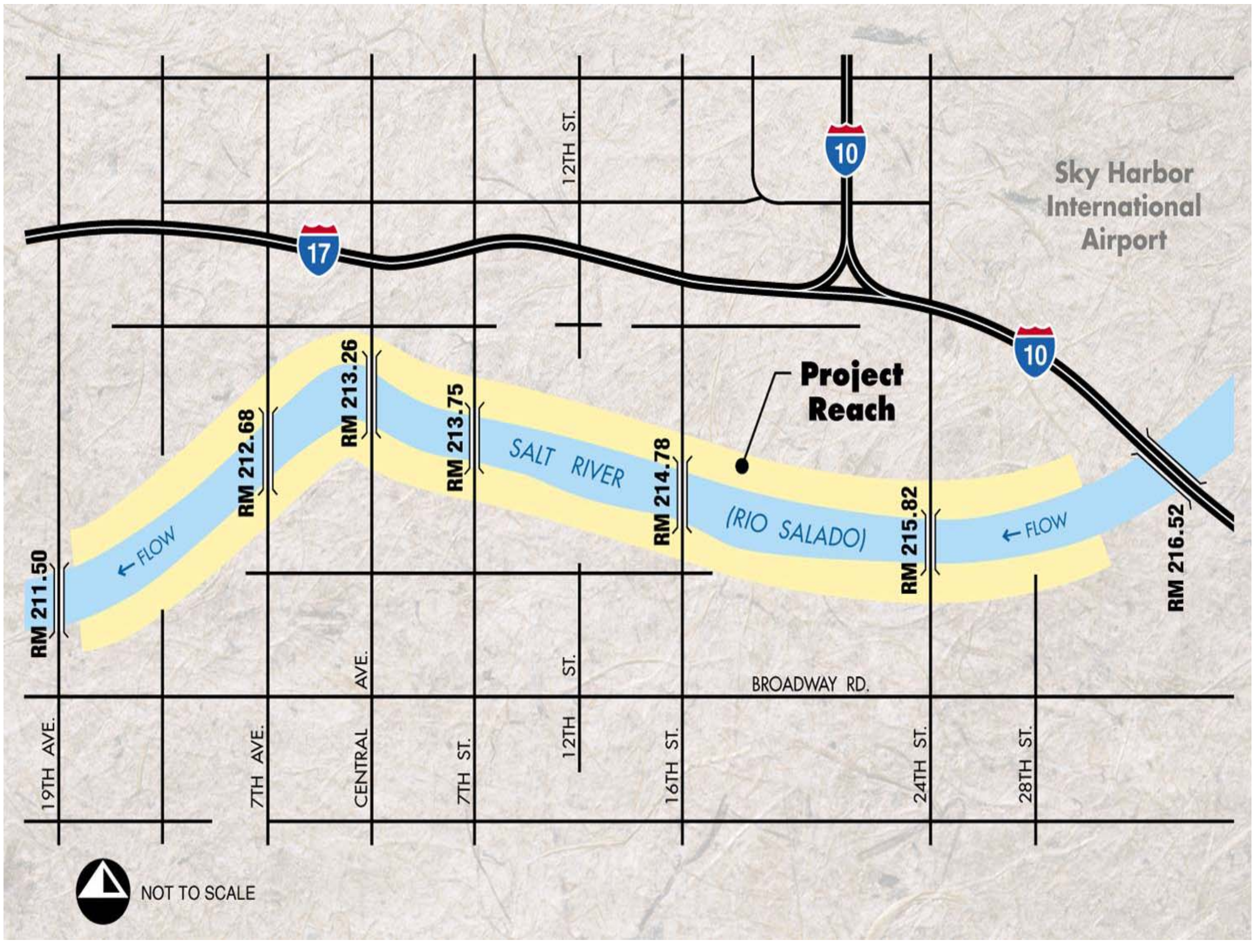

Figure 1 Phoenix Rio Salado habitat restoration project reach.

Key features of this restoration project include:

- A low flow channel constructed in the bottom of the present river, designed to pass the more frequent storm release;
- Wells and a water delivery system to bring water to the trees and other vegetation, wetlands, ponds, and the stream;
- Habitat elements such as riparian tree species, volunteer riparian grasses and shrubs, open water ponds, and a small flowing stream;
- A park located in the overbanks of the low flow channel; and
- A recreational and interpretive trail system.

LOW FLOW CHANNEL DESIGN PROCEDURE

The low flow channel is intended to replicate the low flow channel in a native river. It adds to the flood carrying capacity of the river through the project as well as balances the loss of capacity resulting from the introduction of plants and trees into the channel. There were many constraints on the design of the low flow channel. Because this was a habitat restoration project, the low flow channel was required to have "soft" sides and bottom. This means that the channel should be earthen instead of being constructed out of concrete or soil cement. To maximize the area available for the park in the overbanks and the trail system, the footprint of the low flow channel was minimized. However, the low flow channel was still large enough to convey a design discharge of 12,200 cfs without significant scour or deposition. The low flow channel was sized to carry all long-term releases from Roosevelt Dam lasting over 30 days, thus preventing drowning of the habitat. Grade control structures were located throughout the low flow channel to minimize scour. In addition, guide dikes were proposed to help preserve the alignment of the low flow channel during flood events that exceeded the capacity of the channel. The construction of the low flow channel was completed in 2001. The invert of the low flow channel is 8 to 12 feet below the pre-project channel invert and the bottom width ranges from 160 feet to 205 feet (WEST 2000). **Figure 2** shows the low flow channel approximately one year after construction was completed.

Figure 2 Low flow channel looking upstream from 7th Avenue.

<u>Design Approach</u>: The low flow channel was initially designed using channel stability methods. First, the channel slope of the existing low flow channel was determined. Then, several slope stability methods were used to determine a range of stable design slopes and a design stable slope selected for design of the low flow channel. An initial estimate of the geometry of the low flow channel was determined using the normal depth method and the estimate of the stable slope. The U.S. Army Corps of Engineers' HEC-RAS v. 2.2 (1998) was used to confirm the channel capacity of the initial design. This initial design of the low flow channel was then refined using sediment transport modeling techniques. The sediment transport modeling was performed using HEC-6T v. 5.13.05 (Mobile Boundary Hydraulics 1999), which is an enhanced version of the U.S. Army Corps of Engineers' scour and deposition in rivers and reservoirs computer program HEC-6 v. 4.1 (1993).

Stable Channel Analysis: Several methods were used to establish an appropriate stable slope for the low flow channel. The existing channel slope was examined first, and then several slope stability methods were used to bracket an appropriate design slope for the low flow channel. The existing overall channel slope within the project reach was 0.0027. If a channel is in a quasi-equilibrium state, then the existing channel geometry is a good indication of the stable channel conditions. However, there were many factors in the Rio Salado project that suggested that the existing low flow channel was not in a quasi-equilibrium state. These factors include:

- Levee work and channelization both upstream and downstream of the project reach,
- A history of sand and gravel mining throughout the reach, and
- A reduced peak discharge as a result of the recent raising of Roosevelt Dam.

Three different stable slope methods were used: the U.S. Army Corps of Engineers' Engineering Manual (EM) No. 1110-2-1418 (USACE 1994), the Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA) *Sediment and Erosion Design Guide* (Resource Consultants 1994), and U.S. Army Corps of Engineers' Hydraulic Design Package for Channels, or SAM (Thomas et al. 1995). Stable slopes resulting from the various methods are shown in **Table 1**.

Table 1 Results from stable slope analysis.

Stable Slope Method	Stable Slope
Existing Conditions	0.0027
EM-1418	0.0010
AMAFCA	0.0033
SAM	0.0087

Initial Channel Design: A design slope of 0.0025 was selected for the low flow channel. In order to determine the initial geometry of the low flow channel, the normal depth method was used subject to velocity constraints and the capacity of the channel was verified using HEC-RAS v. 2.2 (1998). In order to maintain the stable design slope, several grade control structures were proposed. The elevation drop at each grade control structure was limited to 3 feet in order to prevent the formation of dangerous hydraulic rollers.

The low flow channel was broken into two portions: an upstream reach and a downstream reach. The initial design for the upstream portion of the low flow channel had a channel bottom of 165 feet, a depth of at least 8 feet, side slopes of 3H:1V, and a channel slope of 0.0025. The initial design for the downstream portion of the low flow channel had a channel bottom of 205 feet, a depth of at least 8 feet, side slopes of 3H:1V, and a channel slope of 0.00125. The channel slope was reduced in the downstream reach of the low flow channel to complete the transition to the existing channel near 19th Avenue. The alignment of the low flow channel closely followed the existing channel thalweg. In addition, the proposed low flow channel maintained a similar sinuosity to the existing low flow channel. Total sinuosity for the existing low flow channel was 1.06 while the total sinuosity for the proposed low flow channel was 1.07.

Sediment Transport Modeling: Twenty-two long-term sediment transport simulations were completed using HEC-6T v. 5.13.05 (Mobile Boundary Hydraulics 1999) to refine the initial low flow channel design. The simulation results were also used to evaluate the grade control locations, determine over-excavation depths, determine annual maintenance requirements, and estimate the effects of the 25-year, 50-year, and 100-year discharge events.

FINAL LOW FLOW CHANNEL DESIGN

Channel Configuration: The final design of the low flow channel was very similar to the initial design. The appropriate geometric parameters of the proposed low flow channel are shown in Table 2.

Table 2 Final geometric parameters for low flow channel design.

Reach	Channel Slope	Bottom Width (ft)	Side Slopes	Channel Depth (ft)
Upstream Reach	0.0025	160	3H:1V to 4H:1V	> 8
Downstream Reach	0.0015	205	3H:1V to 4H:1V	> 8

Grade Control Structures: In order to maintain the stable design slope, grade control structures were needed along the low flow channel. The sediment transport simulations were used to determine the optimal number of grade control structures. The analysis suggests that four grade control structures were needed in addition to the grade control structure upstream of the project reach (downstream of I-10) and immediately downstream of the project reach (downstream of 19th Avenue). The grade control structures were designed for the 100-year flood event of 166,000 cfs and were located:

- At the upstream limit of the Rio Salado project,
- Immediately downstream of the 24th Street Bridge,
- Downstream of the 16th Street Bridge, and
- Immediately downstream of the Central Avenue Bridge.

The grade control structures located near bridges also provide scour protection for the bridges. The toe down depth for the grade-control structures is 27 feet. To help prevent the formation of hydraulic rollers, RCC aprons with steps 3 feet in height were constructed. The grade control structure at the 24th Street Bridge can be seen in **Figure 3**.

Guide Dike Structures: Guide dikes were incorporated into the project to help maintain the alignment of the low flow channel, protect the main channel banks from erosion, and reduce damage in the overbank areas. The dikes also help to prevent the development of secondary low flow channels in the overbanks. This was accomplished by directing flow toward the low flow channel during the period of receding flood flows, which help preserve the location of the original meander geometry and location of the low flow channel. Like the grade control structures, the guide dikes were designed to withstand a 100-year flood event (166,000 cfs).

There are 36 guide dike structures along the 5.5 mile Rio Salado project reach. The guide dikes extend from the banks of the low flow channel to the banks of the main Salt River channel. The guide dikes were constructed entirely of RCC.

Figure 3 Grade control structure at the 24th Street Bridge.

<u>Bridge Scour Countermeasures</u>: Of the five major bridges that cross the Salt River within the Rio Salado project reach, two of these bridges (the 24th Street Bridge and the Central Avenue Bridge) were found to be scour vulnerable with the construction of the low flow channel. Various hydraulic and structural scour countermeasures were evaluated for these two bridges. The selected scour countermeasure for both bridges was to construct an RCC apron within and immediately adjacent to the low flow channel. The RCC aprons protect the piers located within the low flow channel plus one pier on each overbank area. The RCC apron for the 24th Street Bridge can be seen in **Figure 3**.

PERFORMANCE DURING THE 2005 FLOOD EVENT

The winter of 2004/2005 was unusually wet in Arizona. The Granite Reef Diversion Dam released water into the Salt River and the first flows of the season at Priest Drive were recorded on December 31, 2004. Within the next few days, discharges as high as 20,000 cfs were recorded at the gage. Except for brief pauses, the river flowed continuously until early March. For a six day period from February 12 to February 18, 2005, the discharge exceeded the design discharge of 12,200 cfs. The highest recorded flows were on February 13, 2005, when the flow did not go below 20,000 cfs and a peak flow of 28,034 cfs was reached. **Figure 4** shows the maximum recorded daily flows from January 2005 through March 2005 at the Priest Road gage. **Figure 5** illustrates flow in the low flow channel during the February 2005 flow event. The low flow channel performed very well with minor erosion of the "soft" banks occurring at a few locations, but no major failure of the banks.

Following the event, there was no noticeable scour of the channel bed with the exception of local scour immediately downstream of the grade-control structures. The guide dikes performed exceptionally well in maintaining the alignment of the low flow channel. In a few locations, erosion of the low flow channel bank exposed the end of the guide dike, but lateral movement of the low flow channel was minimized. **Figure 6** shows the exposed guide dike following the February 2005 event. In summary, the Rio Salado low flow channel effectively conveyed flow releases in excess of the flow releases for which the channel was designed.

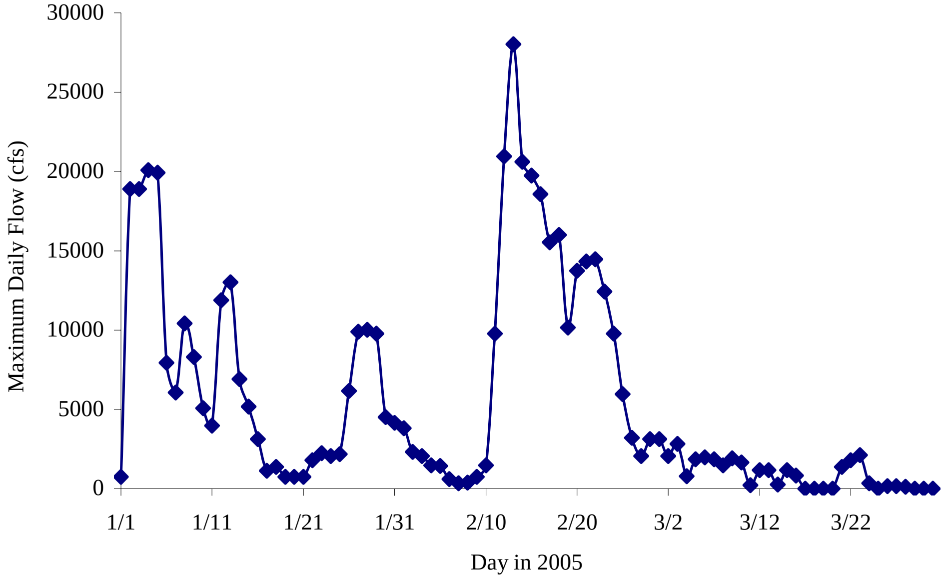

Figure 4 Maximum daily flows at the Priest Road gage.

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Figure 5 February 2005 flow at a grade control structure.

Figure 6 Exposed guide dike following the February 2005 event.