TECHNICAL MEMORANDUM

Arkansas River Corridor Projects

Concept Alternatives for Gates, Dam Spillway, Whitewater and Roughened Channel Fish Passage

TO: Tulsa County

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FROM: McLaughlin Whitewater Design Group

DATE: October 28, 2009 (Edits June 2, 2010)

I. INTRODUCTION

This technical memorandum provides concepts for three major design elements of the proposed dams and improvements on the Arkansas River. These elements are covered in the following three sections: Gates; Low-hazard Spillways (downstream side of dams); and Recreation and Fish Passage Improvements. The proposed projects at Sand Springs, Zink Dam, and South Tulsa/Jenks, all include these three elements. Locations and alignments of the dams have been set and are shown on sheets 4-6. Between these three dams, this project includes a total of approximately one mile of dam.

The scope of this effort is cursory and represents approximately five percent of the total effort of this first phase. Objectives include:

- Identifying and estimating the approximate size the major components.
- Outlining the types of the major elements types to be investigated in a future preliminary design phase.
- Identification of future design related efforts.
- Providing cursory-level budget cost information.

Without detailed analysis and preliminary design, estimates of costs are cursory and based upon experience and expert opinion for the type of proposed improvement. Reliable cost estimating would require a detailed preliminary design effort which is generally considered to be approximately 30 percent of the total design effort.

Background

Previous efforts that outline proposed improvements include the Arkansas River Corridor Master Plan, Phase I and II Master, and the Arkansas River Corridor Vision by the Tennessee Valley Authority (TVA). These documents are not the final decision documents, but rather were used as a starting point for this study. During this study, several technical memorandums were produced and form the starting point of the effort covered in this memorandum. These include:

Alternatives Workshop Meeting Summary (June 24&25, 2009); Fish Passage Data Review and Analysis (July 2, 2009); and the Hydrologic & Hydraulic Technical Memorandum (July 2009).

Related goals that have been modified or refined since the Master Planning studies or the TVA study include:

- Low-Hazard Spillways on all Dams
- Low-Hazard Sluice Gates on all Dams
- Flow Attenuation at the Sand Springs Dam
- Recreational Whitewater
- Roughened Channel Fish Passage

Low-hazard refers to the avoidance of the formation of "keeper" hydraulics that can occur downstream of conventional dams and gates. This type of hydraulic condition is often known as a "drowning machine" and formation of such hydraulics is not compatible with the recreational objectives of the proposed project.

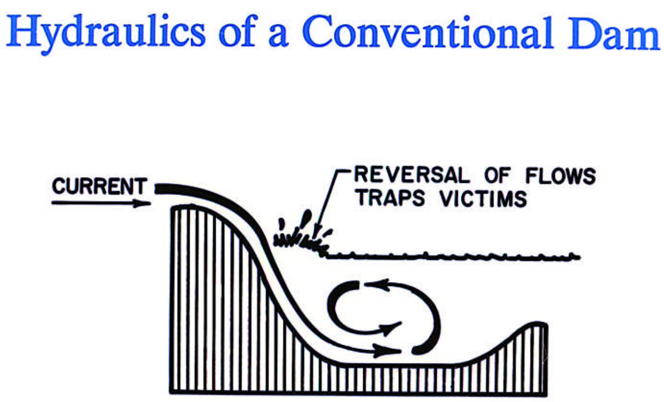


Diagram of "Keeper" Hydraulics
Commonly Known as a Drowning Machine

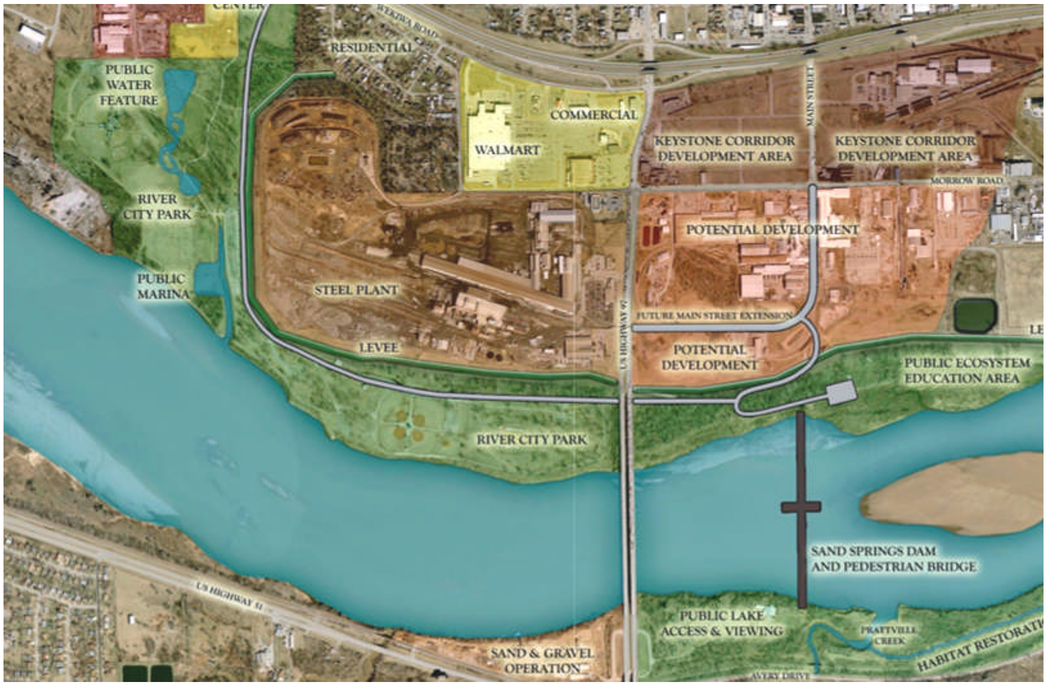
Recreational whitewater can include bypass channels around the dams to form waves and features found in rapids. These "whitewater river parks" have demonstrated significant positive economic impacts to communities. They provide quality-of-life improvements for local citizens and positive economic impacts by attracting users from the surrounding regions and increasing local property values.

Roughened Channel Fish Passages are also bypass channels around dams and provide for upstream and downstream passage of fish. These nature-like features mitigate impediments to fish migration that would occur with the construction of a new dam. These passages differ from conventional fish passages in that they are designed to mimic natural rapids rather than more structured fish passages structures. As such, they are typically larger and have are not as steep as a conventional fish passage structure, such as a fish ladder. Varying headwater elevations can be accommodated in these passages with specialized modulating gates as described below.

Recreational Whitewater Channel in Maryland

Project elements that remain the same as outlined in the previous studies include a large percentage of gates at each dam to pass sediment, mitigate floodplain impacts, and provide for upstream and downstream passage of migratory fish and downstream passage of fish eggs during the spring spawning months. Current estimates of the percentage of fixed crest dam/spillway to gates for the new dams average about 65 percent. This has been estimated based upon needed flood flow conveyance through the dams using HEC-RAS hydraulic modeling

The following site figures were developed as a part of this effort and show the locations of the dams. Locations for recreational and fish passage and dam cross-sections from the HEC-RAS modeling are also shown. Preferred alternatives were identified during the Alternatives Workshop. Various refinements have been made since and are included in the memorandum.



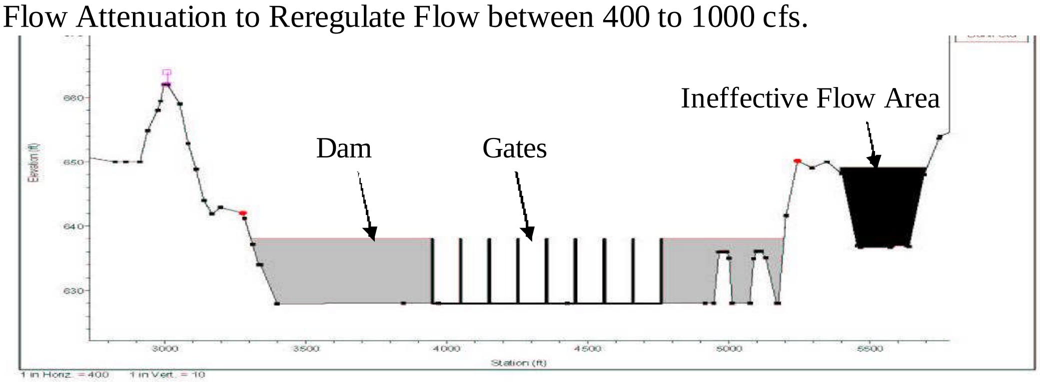
Dam at Sand Springs (Furthest Upstream)
Includes Flow Re-regulation for the Entire Reach, Low-Hazard Dam Spillway, Off-Channel Whitewater Course, and Low-Hazard Sluice Gates

Sand Springs:

Total Dam Length = 1890 feet
Spillway Crest = 638.0' ; Invert = 628.0'
Dam Height = 10 feet
Approximate Cross-Sectional Area of Gate Openings = 8,140 square feet (43% of entire structure)

Site Specific Features:

1. No Fish Passage
2. Whitewater Recreation Channel in Adjacent Park using a Separate Water Supply
3. Flow Attenuation to Reregulate Flow between 400 to 1000 cfs.



Modeled Cross-Section of the Proposed Dam at Sand Springs

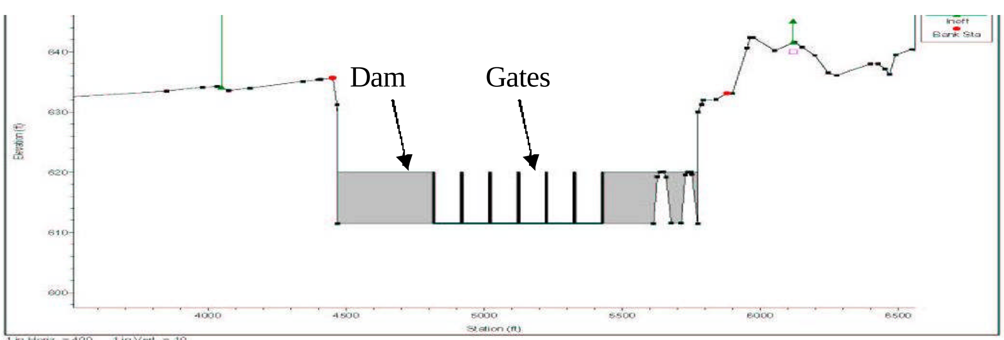
Zink Dam – Tulsa
Includes Low Hazard Dam Spillway Modification, Whitewater/Roughened Fish Passage Bypass Channel and Low Hazard Sluice Gates

Zink Dam (Existing):

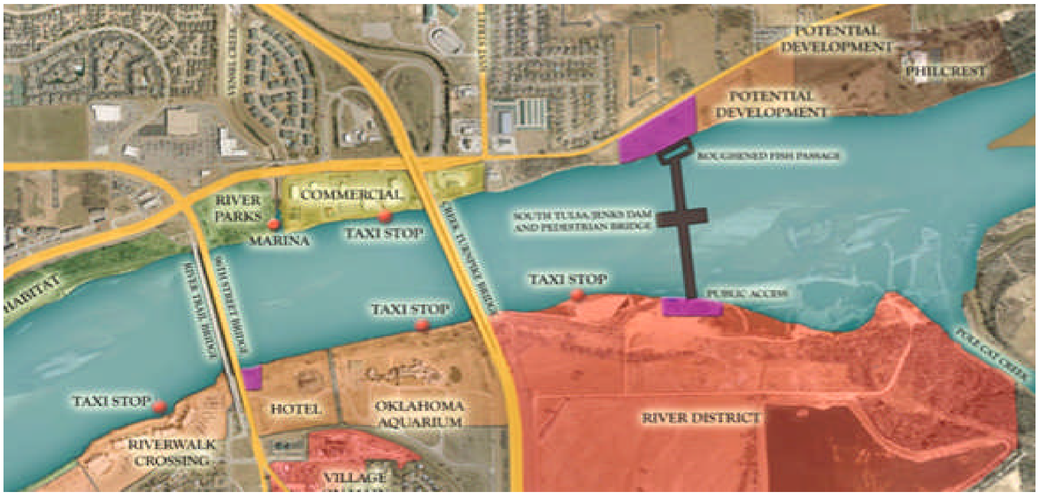
Total Dam Length = 1,305 feet
Spillway Crest = 620.0'; Invert = 611.5'
Dam Height = 8.5 feet (without proposed crest gates)
Approximate Cross-Sectional Area of Gate Openings = 5,910 square feet (New plus Existing) (53 % of entire structure)

Site Specific Features:

1. Potential Flow attenuation in upstream pool to augment re-regulation of flows
2. Proposed Three feet of Crest gate on remaining Dam Crest.
3. Whitewater Recreation By-Pass Channel along East Bank with Integrated Fish Passage
4. Whitewater feature along West Bank – "Tulsa Wave"



Modeled Cross-Section of the Proposed Zink Dam



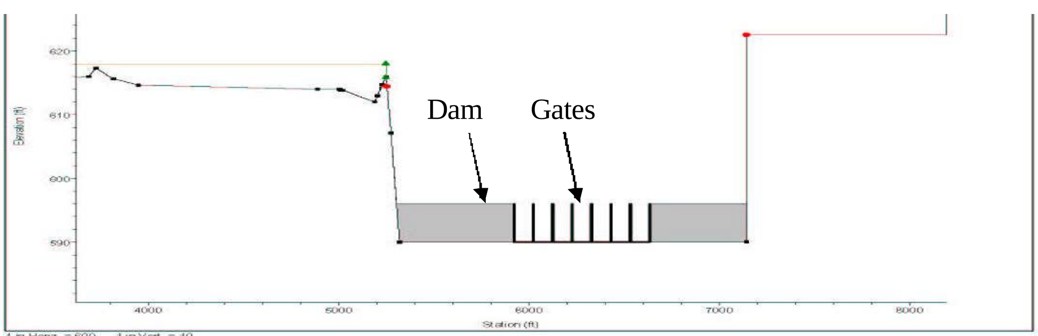
South Tulsa/Jenks Low Water Dam:
Includes Low Hazard Dam Spillway, Roughened Channel Fish Passage and Low-Hazard Sluice Gates

South Tulsa/Jenks Low Water Dam:

Total Dam Length = 1824 feet
Spillway Crest = 596.0’; Invert 590.0'
Height = 6 feet
Approximate Cross-Sectional Area of Gate Openings = 4,270 square feet (39% of entire structure)

Site Specific Features:

1. Roughened Channel Fish Passages – number & location to be determined.
2. No Whitewater Recreation Improvements
3. Seasonal Open-Gate Operation to Provide for Fish Passage.



Modeled Cross-Section of the Proposed Dam at South Tulsa/Jenks

Fish Passage

The primary migratory species of fish that were determined to be within this reach of the Arkansas River are the Striped Bass, Sauger, Paddlefish and Shovelnose Sturgeon. The shovelnose sturgeon appears to be the most restrictive species when determining fish passage requirements. A relevant fact that shovelnose sturgeon passage success dropped to 47% at 6 feet per second velocity in tests of fishway design (Table 3 from the Arkansas River Corridor Projects Fish Passage Data Review and Analysis prepared by CH2M Hill dated July 2, 2009) highlights the sensitivity to design velocities associated with the target species.

Lowering of the gates for fish and egg passage during the period between March through May has been proposed for the South Tulsa/Jenks Dam. Fish passage outside of this period would be accommodated via roughened channel fish passages at the South Tulsa/Jenks Dam and by a multipurpose recreational/fish passage channel at the Zink dam. As such, fish passage objectives will impact the design of the gates, roughened channel fish passages, multi-purpose whitewater recreation and fish passage channels, spillway, and river stabilization elements such as jetties or bendway weirs. Some criteria needed for planning is covered in the Fish Passage Data Review and Analysis Technical Memorandum and attached supplemental memorandum. For the purposes of this initial effort, the following criteria are used. It is noted however that future, more in-depth analysis and design should entail review and refinement of the following criteria.

- Maximum Passage Velocity — 4 to 6 feet/second
- Maximum Step Height — 0.25 feet
- Minimum Depth — 1.5 to 4 feet
- Pool Velocity — Less than 3 feet/second
- Minimum Attraction Velocity — 2 feet/second

Fish Passage Design Issues

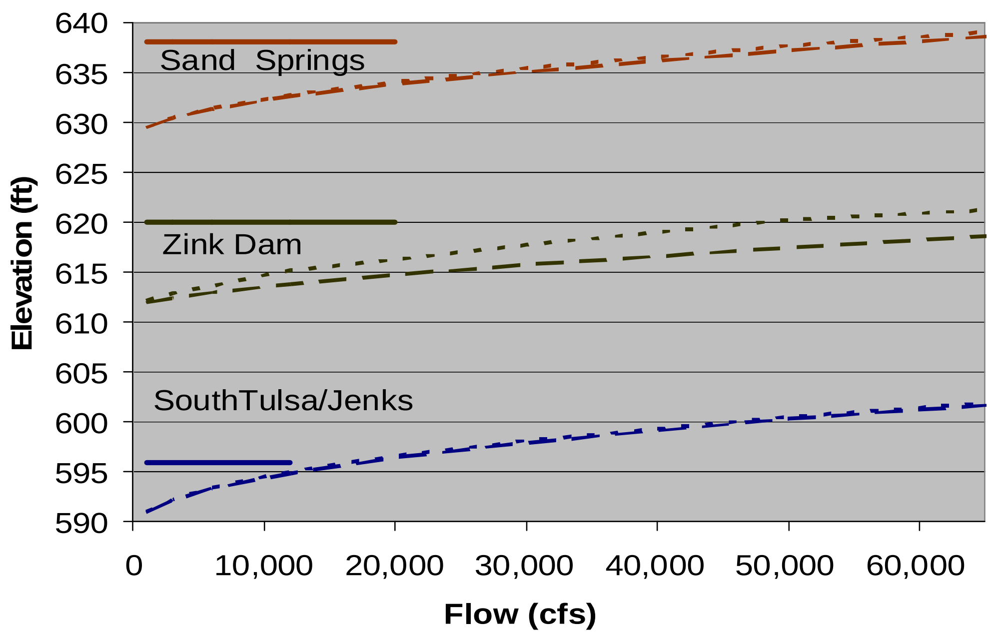
The distribution of velocity across the cross-section is important in the design of roughened channel fish passages and multi-purpose whitewater/fish passage channels. Velocities of concern are in the zones where fish passage will be occurring. This can be referred to as "fish-eye" velocity and is not the same as the average velocity in the cross-section. The primary zones of fish passage are generally along the banks and therefore these are the areas of concern for design purposes.

The creation of deeper flow paths and related fish passage along the river banks is appropriate given the substantial width of the river. Flow patterns can be created to guide fish from the middle of the river to the roughened channel fishway entrances on the side. This is particularly important because striped bass, sauger, and sturgeon tend to reside in the deepest part of the channel and not necessarily near the banks. The ability to adjust flows through the spillway gates and passages is important to produce the necessary flow patterns to lead fish toward the banks and roughened channels when they are the only means of upstream passage available (i.e., gates not lowered). Furthermore, creating flow paths that do not lead to the roughened channel passages ("dead ends") should be avoided.

Hydraulic Summary

The planning and design of the Gates, Low-Hazard Spillway, and Recreation and Fish Passage Improvements begins with basic hydraulic analysis. This analysis has been completed as outlined in the Hydrologic & Hydraulic Technical Memorandum and can be most succinctly summarized in headwater and tailwater curves. These curves are included below and show the predicted tailwater and headwater elevations at each dam. The predicted headwater curves with the gates lowered are shown as a short dashed line and are very close to the tailwater curves. The desired upstream pool water surface elevations are also shown on the curves.

Headwater and Tailwater Curves for the Three Dams



Curves Based Upon Hydraulics from July 2009 Technical Memorandum and Show:

- **Target Pool Water Elevation** **(solid line)**
- **Head Water Curve – Gates Lowered** **(short dashed line)**
- **Tailwater Curve** **(long dashed line)**

It can be observed that with the gates lowered all dams have relatively little impact on the water surface profile. In other words when the gates are lowered, the structures don't actually act much like "dams". This is due to the relatively large percentage of gates. It can also be observed that the tailwater approaches the crest elevation of the dams at flows between approximately 16,000 cfs at the South Tulsa/Jenks Low Water Dam to 61,000 at the Zink Dam.

The hydraulic analysis conducted as a part of this phase was limited to investigating gate areas and not options and designs of the total improvements. Future hydraulic analysis will be oriented toward the dam spillway, gates, and selected operational/hazard reduction approach (see below) options and designs. Future efforts will also include the rather significant whitewater and/or fish passage features downstream of the Zink and South Tulsa/Jenks Dams.

Flow Re-regulation

Flow re-regulation at the Sand Springs and Zink Dam is planned. Flow rates for re-regulation are reported to be 400 to 1,000 cfs or more. Further statistical study is needed to estimate durations in wet and dry periods to size gate openings and capacity ranges of the whitewater and roughened channel passages. Maintaining minimal flows to support fish habitat and providing reliable flow for weekend recreators are both important considerations that may have competing interests.

Topics of Particular Interest

Previous planning efforts did not focus on low-hazard gate design, in-river recreation channels, roughened channel fish passages, flow reregulation, crest gate and gate operations, and the integrated design of all these elements. There are several approaches to the design of a low-head dam with gates.

Low Hazard Design. One approach is to design the gates and the spillway to be low-hazard when overtopping occurs. This will be referred to as low-hazard spillways and low-hazard modulating gates. A low-hazard modulating gate is one that can be raised or lowered to control upstream flows and water surface elevations in a way to keep from creating a keeper hydraulic.

Avoidance of Overtopping. Another approach to avoid hazardous hydraulic conditions is to avoid overtopping of conventional spillways and gates. Flow that overtops raised or partially raised (non-boatable) gates or conventional spillways can create dangerous hydraulics. .
If overtopping is avoided until the tailwater submerges gates and spillways, retentive hydraulic jumps can be avoided. If this is not found to be practical, hazardous overtopping should be avoided within the normal recreational flow range. These approaches should be evaluated in the preliminary design phase.

the conventional spillways and gates It can also be avoided by raising the elevation of the crest of conventional gates to direct flows over low-hazard spillways and low-hazard modulating gates

Design Implications. Further design of conventional and low-hazard modulating gates will determine the location and size of the selected gates, the elevation of the gate inverts, and the elevation of the crest of the gates. The invert and location of the gates need to be set to form low-hazard hydraulic jumps and optimize sediment transport.

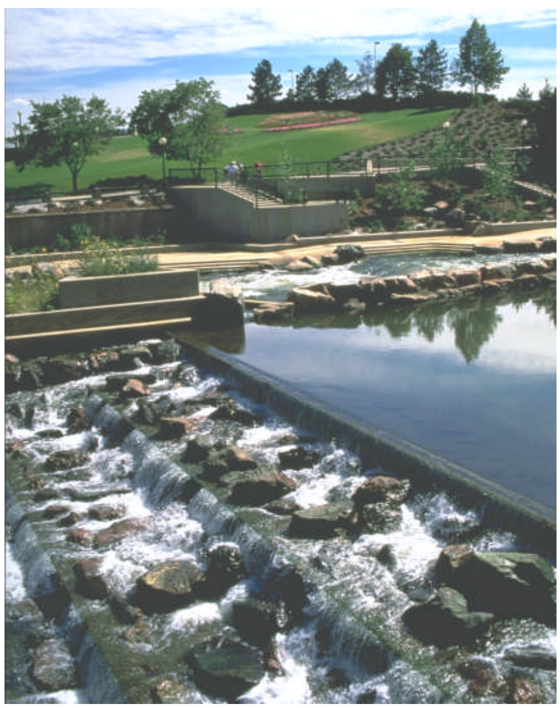
There are a number of design and operational options to avoid over-topping of conventional gates and spillways. One approach is to direct flows over low-hazard modulating gates. Another approach is to provide taller gates that direct flow over low-hazard spillways or gates. Long term monitoring, maintenance, and adjustment of the control system and gate operations are critical to operations. The selection of the gate type and gate operator will need to be considered due to frequent (several times a day) operation of non-boatable gates and modulation for low-hazard gates. Preliminary design needs to include evaluations with the owner/operator of each dam regarding future operational needs and maintenance costs associated with the various approaches.

In summary, a combination of low-hazard spillways, low-hazard modulating gates, crest gates, and conventional gates needs to be considered in the future preliminary design.

Future Preliminary Design Efforts

Design and analysis efforts to develop the total system of spillways, gates, recreation, and fish passage infrastructure at each dam are listed below. Efforts specific to each component are included in the following sections. These specific efforts need to support and be conducted simultaneously with the efforts listed below.

- Development of the general approaches to hazard mitigation
- Hydraulic, sediment transport, and cost evaluations.
- Further Development of fish passage criteria and design
- Development of operation and maintenance requirements - developed with dam owners.
- Gate option evaluations
- Selection of one of the general hazard mitigation approaches – with dam owners.
- Statistical evaluation of flow regulation based upon fish habitat and recreation/economic development objectives.



Low-Hazard Dam at Confluence Park in Denver, Colorado

II. GATES

Objective

The objective of this section is to describe different types of gates available for use in the Arkansas River to pass sediment, reduce hydraulic hazards to recreationalists, and enhance recreational opportunities throughout the greater Tulsa area. In addition, the gates selected need to accommodate fish passage during the spring months and control and direct flow to whitewater/fish passage bypass channels during other times of the year. This section is intended to provide initial ranges of costs and guidance in the future selection of of gates and configurations for all three proposed dam sites.

The approximate area of gates needed to convey flood flows has been estimated in the Hydrologic & Hydraulic Technical Memorandum and is shown in the previous section of this memorandum. In this effort, it was assumed that the gates would be founded at one selected invert elevation of the dam and have a height that would extend to the desired pool elevation or higher (as needed for controls/operations). The results of this evaluation were then used to estimate the needed cross-sectional area to avoid negative impacts on the regulatory floodplain. Future design efforts will be required to establish the actual height, width, and configuration of the gates to be used, as the sizing and configuration will depend on safety issues, sediment transport, cost, type of gates selected, maintenance, and aesthetic evaluations. However, it is reasonable to assume that the needed cross-sectional area developed in the Hydrologic & Hydraulic Technical Memorandum will remain roughly the same as it is determined in more refined analysis and design efforts. It is also recognized that the gate sizing may need to be altered based upon hydraulic requirements related to passage of fish during non-flooding periods.

To mitigate safety issues related to the formation of retentive hydraulic jump conditions downstream of the gates (a "keeper"), significant flow over the top of the raised or partially raised gates should be avoided. This will require a control system which would lower gates to avoid this condition. As an alternative or in conjunction with conventional gates, low-hazard modulating gates can be employed. These types of gates can be modulated to meet upstream headwater objectives while passing recreational whitewater craft. Controls for all gate systems described below can be designed and operated to automatically lower and raise gates (completely) and modulate low-hazard modulating gates based upon pressure transducers calibrated to headwater depths or coded with preset adjustments based on a range of flows.

Bascule and Pelican Gates

Bascule and Pelican gates as manufactured by Rodney Hunt Company and others are hinged crest gates operated by hydraulic or mechanical operators. The hinge is attached to the base of the structure or the invert of the river.

The Bascule gate is generally comprised of a flat plate reinforced with horizontal and vertical members. It has a single torque steel tube along the bottom, which is used as the hinge. A separate compartment is used directly adjacent to the Bascule gate to house the hydraulic cylinder. The hinge penetrates the wall of the separate box with a water-tight connection. Bascule gates are generally limited to a height of 10 feet and 100 feet long although lengths of 100 feet are not recommended (a more appropriate length consideration would be up to 50 feet long). The Bascule gate can be adjusted to any intermediate height between the river invert and the full height of the gate. Bascule gates, however, are not considered low-hazard modulating gates, but are good flow control structures. An approximate range of costs for Bascule gates are between $500 and $600 per square foot of gate, which was provided by Rodney Hunt. This cost does not include hydraulic operators or controls. The existing Bascule gates at Zink dam could be utilized as a part of the proposed design and coupled with new gates to provide higher levels of adjustability and an economical rehabilitation of the dam.

The Pelican gate is comprised of two curved plates with internal braces and vertical ribs forming a strong closed shell structure. Pelican gates have separate hinges as opposed to the Bascule gate which uses one steel tubular hinge. The Pelican gate can be operated a number of different ways, however, the most common are either using hydraulic cylinders on the downstream side of the gate to push the gate closed or by attaching hydraulic cylinders to the top of the gate that pull the gate closed. The multiple hinges and cylinders allow the Pelican gate to be lowered in sections rather than as a whole. An approximate range of costs for Pelican gates was provided by Rodney Hunt at $400 to $500 per square foot of gate – installed, but excluding hydraulic operators and controls.

Bascule and Pelican gates will require electrical and hydraulic controls used to operate/adjust the gates to adapt to different flow conditions. The hydraulic controls and housings are expected to cost approximately $80,000 per cylinder. It is expected that 4 cylinders will be required per 100 feet of gate. At a nominal 10 feet high, the cylinder cost is expected to be in the range of $320 per square foot of gate. A figure of $380 per square foot is suggested to include cylinders, controls, pumps, lines, etc.

Both of these gate types require periodic inspections of the hydraulic cylinders, gate seals, and painted coatings.

These types of gates can also be modified and utilized as low-hazard modulating gates with varying degrees of cost and sophistication. Bascule gates may be more expensive to modify due to the fact that a narrower low-hazard modulating opening is desired for modulation and would likely require one or more Bascule gate sections (including abutments, and operators). A Pelican gate is set up to operate with smaller independent sections without the need for additional abutments and related actuating infrastructure.

Fish passage for these types of gates, when operating in the fully down position during the spring, can be enhanced with the addition of roughness elements on the leading side of the gate panels. The author has included similar features on previous gate designs. These features however, can increase capital and maintenance costs.

Fusegates

Fusegates do not require electrical controls or hydraulic cylinders because they operate based on upstream water surface elevation and the associated head pressure. The gates are recoverable after tipping or folding by manual means. The advantage is that they may require less maintenance and do not require a constant pressure or power to be maintained in the raised position. The obvious disadvantage is that they require resetting once they are deployed. Fusegates would be implemented in combination with other types of actuated gates, thereby reducing the frequency of deployment and subsequent need for resetting.

Two types of fusegates that are commercially available (as manufactured by Hydro Plus) are folding fusegates and standard fusegates. Fusegates require periodic inspections to ensure the stand pipes are not plugged, the watertight seals are operating correctly and the gates are not structurally compromised.

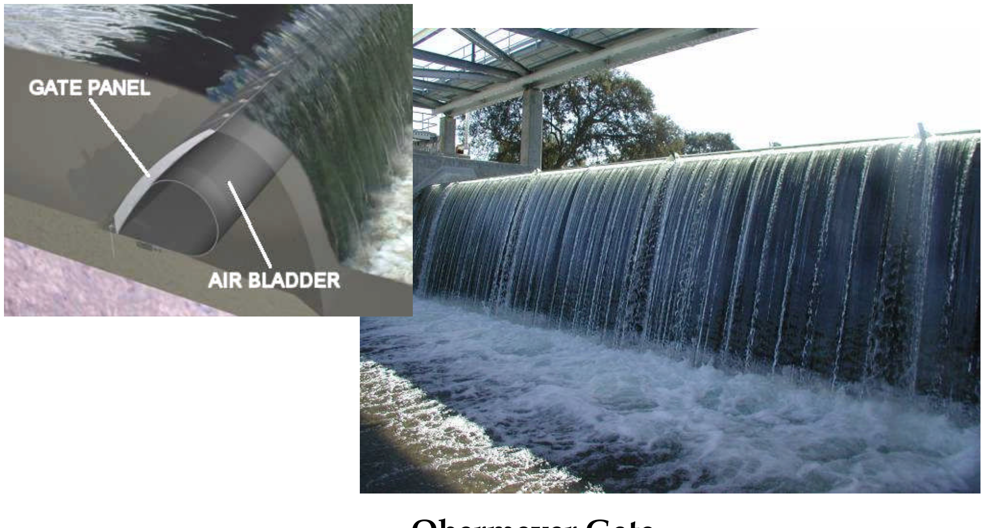
The folding fusegate is comprised of a flat plate extended upward to dam flow to a predetermined crest elevation. The folding fusegate has an upper leg and lower leg connected to the downstream side of the gate. A standpipe (inlet well) on the upstream side is connected to the downstream side of the gate. Once the headwater becomes high enough to flow into the standpipe, it will create an uplift pressure on a downstream plate that will, in turn, release the legs holding up the gate and the gate will collapse. Typically, inlet wells are installed at the edge of the dam and are connected to the folding mechanism at each gate by piping installed in the dam sill. The folding fusegate system is best utilized when gate overturning is more likely (i.e. 100 year flood events or more frequent). Hydro Plus folding fusegates can be manufactured in 18 feet to 27 feet widths and up to 9 feet high. These folding fusegates are reported by the manufacturer to cost approximately $400 - $500 per square foot installed. Generally, the folding system is more expensive than the standard fusegate system because the gate must be made of steel and is more complicated to fabricate. Piping of standpipe (inlet well) water to each gate also increases costs. As with other types of gates, the upstream faces of foldable fusegates can be modified with roughness elements to enhance fish passage when deployed. Currently, there are no known folding fusegate systems installed in the United States, which may present challenges for approval.

The standard fusegate has a leg extended along the invert in the upstream direction. The weight of the water above the invert holds the gate in place. The standard fusegate utilizes an individual standpipe set at a predetermined elevation. Once the headwater is high enough to flow into the standpipe, it creates uplift at the base of the gate which, in turn, tips the gate over. Elevations of the standpipe are selected such that overturning of the gate is not expected during the life of the structure; larger than 100 year flood events. Standard Fuse gates can be manufactured with widths of 3 feet to 70 feet and up to 35 feet high. Standard fusegates are typically more economical than folding fusegates. The cost is approximately $425 per square foot installed.

Obermeyer Gates

Obermeyer gates are basically hinged gates with patented rubber hinges with integral rubber bladders that actuate the gates. Like pelican gates, they consist of rows of independently actuated steel gate panels without the need for intermediate abutments between gate panels. The bladders are inflated with compressed air to raise the gate to varying crest elevations. The gates are attached to the structure foundation by anchor bolts. The inflatable bladders are then clamped over the anchor bolts and connected to air supply lines. The Obermeyer gates are manufactured in 5 foot or 10 foot widths. Standard air bladders are used for gates up to 6.5 feet high with various standard widths.

Obermeyer gates can be controlled as one continuous gate operated on a single air line or split into sections operated on separate air lines. When controlled on one air line the bladders are protected from deflating if one bladder is damage. Check valves are installed prior to each bladder to ensure this. Separate sections are advantageous for recreation and whitewater due to the requirement of holding a constant headwater elevation and maximizing the unit width flow



Obermeyer Gate

through the gates. As with the Bascule and Pelican gates, an Obermeyer gate set up for low-hazard modulating sections will require separate sets of controls to adjust the air pressure in the support bladders. Obermeyer gates will require periodic inspection to check the integrity of the air bladders and steel gates. The bladders are constructed of multiple plies of polyester and tire fabric which help protect them from tough environmental and vandal encounters. The estimated life of the rubber hinge and bladder is reported by the manufacturer to be about 35 years.

Obermeyer supplies the majority of gates for this type of application in the United States. They have been modified for use as low-hazard modulating gates in a several projects by the author. Variations have also been used to create high quality adjustable recreational features by the author.

The manufacturer has provided the unit cost information as a function of gate height. For gates between 2 feet and 4 feet high, the range in cost is $450 - $500 per square foot. For gates between 4 feet and 8 feet high, the range in cost is $550 - $650 per square foot. For gates between 8 feet and up, the range in cost is $850 - $950 per square foot. These costs include the gates, bladders and control equipment delivered to the site. However, recent bids have shown these figures to be 8 to 40 percent low.

Radial Gates

Radial gates, also called tainter gates, consist of a curved steel plate (disc) that radially pivot about a pin and bearing attached to concrete side walls adjacent to the gate passage. The face of the gate is connected to the pin and bearing by steel arms with cross bracing. A cable drum hoist or hydraulic actuation unit is utilized to lift the gate to allow water to pass under. Hoists can be manually operated with a handwheel and gearing or automated using electric motors or hydraulics. Water passing under a radial gate aids in lifting the gate. Radial gates are custom manufactured for specific project specifications. They can be used as bottom-opening gates to facilitate the transport of sediments. An approximate range of costs for radial gates are between $400 and $600 per square foot of gate installed.

Radial gates can be designed to enhance sediment transport by drawing off the bottom of the pool or can be adapted to accommodate fish and boat passage if designed as an over-shot application. Gate operation using mechanical units is simple and doesn't rely on more complicated hydraulic or compressed air systems. Fairly significant structural elements are required for mounting of the gate and lifting mechanism resulting in increased costs.

Low-hazard modulating Gates

A low-hazard modulating gate is a gate that can be modulated to control flow while allowing for boat and possibly fish passage. Several of the gates described above can be integrated into low-hazard modulating gates with the incorporation of plates connected with hinges and hydraulics.

Low-hazard Modulating Gate at
Adventure Sports Center, Maryland

MWDG has designed a system named the Waveshaper that integrates adjustable gates to accommodate varied flow conditions. There are two types of Waveshaper systems currently in use. The first type has an adjustable upstream crest and variable downstream edge or "lip". This gate provides modulating capabilities and adjustability for downstream tailwater elevations. The gates are actuated with hydraulic cylinders or air bladders. The second Waveshaper gate allows for downstream lip adjustability only.

Costs for low-hazard modulating gates have varied widely, but based upon two bids, the average unit cost is about $3,500 per square foot. Gate abutments/divider walls as shown above can cost on the order of $300,000.

Summary

Bascule gates, Pelican gates and Obermeyer gates are configured to easily adjust in sections, and can be modified to accommodate whitewater and navigation. Obermeyer gates require less complicated base structures due to the rubber gate hinges and bladders, but require long lengths of air line and air bladders. Pelican and Bascule gates require hydraulic cylinders. Bascule gates are more expensive based on the need for more gate abutments and hydraulic operating boxes.

The following table summarizes these cursory-level unit gate costs as well as advantages and disadvantages associated with each gate type. The costs include operators and controls, but do not account for costs associated with the foundation, abutments, and installation.

TABLE 1- Gate Summary

GATE TYPE	ADVANTANGES	DISADVANTAGES	CURSORY ESTIMATE OF SUPPLIED GATE COSTS
BASCULE GATE	Can be manufactured in long widths; decreases number of gates required to impound larger widths.	Requires more gates to accommodate variable flows, thereby increasing the cost of the system	$880 - $980/S.F.
PELICAN GATE	Provides a higher level of adjustability (gate opening width adjustability)	Can be manufactured in longer widths than a Bascule gate and require separate hydraulic cylinders per 100' of gate. Also requires a more complicated foundation.	$780 - $880/S.F.
FOLDING FUSEGATE	No mechanical or hydraulic requirement to be maintained in raised position; impounds flow up to a pre-determined headwater elevation, at which it collapses allowing additional river capacity. More recoverable than standard fuse gates after an overturning event.	Folding Fuse gates can not modulate flows and require extensive effort to be raised.. The most economical use for Folding Fuse gates is to set them in a manner in which they seldom collapse. More expensive than standard fuse gates.	$400 - $500/S.F.
STANDARD FUSEGATE	No mechanical or hydraulic requirements (as with the Folding Fuse gate); Has a lower capital costs than folding fuse gates.	Standard Fuse gates have the same disadvantages as Folding Fuse gates, but are harder to recover after overturning or need to be replaced after deployment.	$400 - $500/S.F.
OBERMEYER GATE	Provides high levels of adjustability and requires a cheaper structural foundation design. Is the "standard" of the industry in the U.S.	Gates manufactured in 5' or 10' widths; more gates required for larger opening widths. No failsafe mechanism to keep water impounded if a bladder fails.	4-8 FT $550-$650/S.F. 8FT+ $850-$950/S.F.
RADIAL GATE	Adjustability using individual gates and hoist mechanisms. Low operation and maintenance requirements.	Requires foundation walls (abutments/intermediate piers) to anchor gate. Can be hazardous to recreationalists.	$880 - $980/S.F
LOW-HAZARD MODULATING GATE	Multiple levels of adjustability to conform to varying flow conditions. Provides low-hazard hydraulics and can provide high-level recreational attractions.	Expensive, and requires more maintenance. Also requires more expensive foundation and abutments.	Varies – Recent Project cost of $3,500/S.F.

Gate Installation Costs

For this cursory level of effort, a percentage factor is often used for installation of equipment in civil projects. A recent project in Green River Wyoming involving the installation of Obermeyer gates included an installation factor of about 30 percent. Given the size of this project a factor of 20 percent seems reasonable for this cursory-level estimate.

Topics of Particular Interest

Folding Fuse Gates.

Fuse gates are intended to operate only at higher flood flows. These gates are the least expensive and could be a good option when used with other gates. They not require controls or power as they work on predetermined headwater elevations and are recoverable after collapsing during major flow events. Most importantly, they do not require mechanical force from an actuator to remain in the raised position. This has been reported by operation staff at the Zink Dam to be a major concern. Designs for fusegates that can right themselves without external lifting mechanisms have been contemplated by the author and should be considered in the preliminary design phase.

Given the combined length of over 2,200 linear feet of gates in this project, developing an optimal gate design and combination of gates is appropriate. Through additional evaluations and analysis of flood and recreational hydraulics, sediment management, fish passage, and capital and maintenance costs; a balance can be struck using cost effective gates with low-hazard gate systems to accommodate all flows through the Arkansas River.

Fish Passage and Sediment Transport

For these dams, the optimization of the gate design and selection to pass sediments is essential. The selection of appropriate gates for these purposes will require extensive hydraulic modeling and analysis to determine optimum gate configurations for each proposed dam site. Based on the information identified in this technical memorandum, it appears that the most cost efficient and hydraulic efficient option may be a combination of different types of gates. Design efforts and hydraulic modeling will identify gates that will be operated frequently as well as those that will seldom need to be lowered.

Along with hydraulic modeling to anticipate gate performance, additional analysis will also require careful consideration of roughened channel fish passage performance. The gate configuration should be analyzed and modeled to compliment fish passage and spillway configuration. This will require multi-dimensional hydraulic modeling to determine flow parameters for each fish passage route.

Future Preliminary Design Efforts

The following efforts are needed to further the design, selection, and cost estimating of the gates

- Refined fish passage criteria and design
- Detailed hydraulics of gates for fish passage and safety issues
- Determination of algorithms for normal and spring operations of the gates
- Further investigation and development of self-righting folding fuse gates
- Sediment transport analysis
- Detailed development of gate options – invert & crest elevation, types, operation frequency and hazard reduction approach
- Life cycle cost evaluation of the various gate options
- Preliminary design of spillway, and whitewater/fish passage channels

III. LOW-HAZARD SPILLWAYS

Public safety is an important consideration when designing in-river structures in recreational corridors. When analyzing the hydraulics of low head dams and gates, dangerous hydraulic conditions must be identified and avoided. The reverse roller occurs when a re-circulating flow pattern develops in a hydraulic jump. This traps and could potentially drown boaters, fisherman, or other recreationalists. Low-hazard spillways can minimize retentive hydraulic jumps downstream of dams.

Objectives

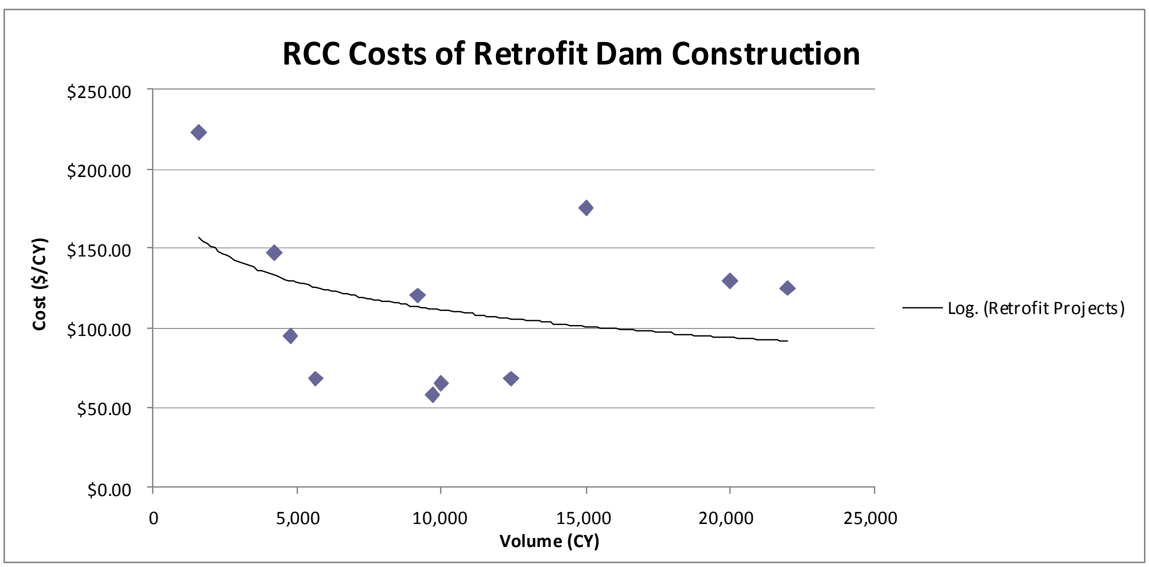
The primary design objectives related to safety at the proposed gates are as follows:

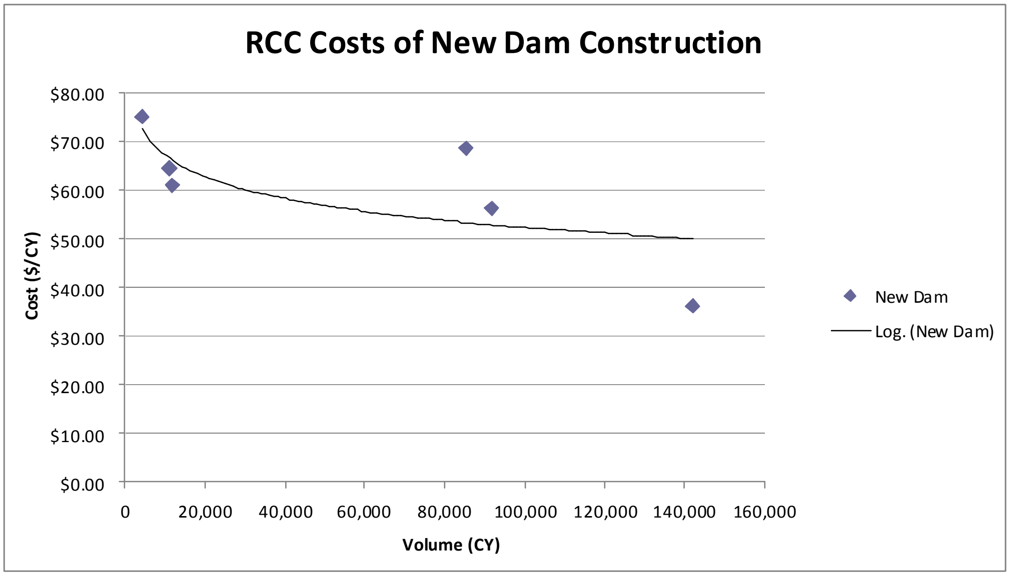
- Provide adequate river access for emergency responders.
- Provide portage access around dams and gates for in-river users.
- Provide in-river structures that minimize dangerous hydraulic conditions.

Construction Materials and Unit Costs

Construction of a low-hazard spillway can include grouted boulders, formed concrete, and Roller Compacted Concrete (RCC). The author has extensive experience in grouted boulder construction on a wide variety of river projects. If large tenacious boulders are readily available, a typical installed cost for grouted boulders is around $200 per cubic yard.

RCC is a much lower cost material and has become one of the primary construction materials in low-head dams. Furthermore, the range in cost does not vary as wildly as grouted boulders. The costs curves below were derived from data provided by the Roller Compacted Concrete Industry. The study was conducted on 2002 data, as such; the unit costs used to develop the figure below were increased by about 30% to adjust for inflation.





For this application it is thought that RCC would need to be surfaced for aesthetics and wear. Combinations of RCC and boulders could also be used to balance aesthetic, durability, and cost objectives. During preliminary design phase, an assessment of local materials, final spillway geometry selection, and input from stakeholders should be conducted or obtained prior to selecting the materials.

Costs for dewatering, abutments, foundations, access, gates, cut-off walls/seepage mitigation, armoring, divider walls and "islands" are not included in these costs.

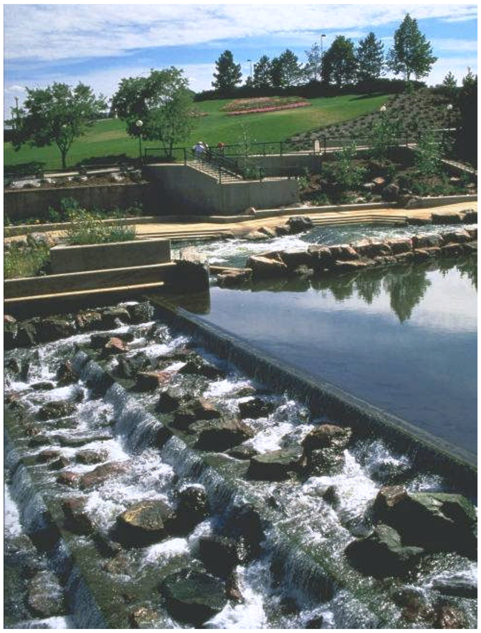
Types of Low-Hazard Spillways

There are a number of methods that have been used to mitigate retentive hydraulic jumps or "keepers" that occur downstream of low-head dams and spillways. The two used by the author include a stepped spillway and a sloped spillway.

Others include various modifications of ogee crest spillways and the porous weir as developed by TVA. Ogee crest modifications could be considered at the existing Zink Dam, but would not be appropriate at the new dams. TVA's porous spillway is outlined in their report and appears to be effective at breaking up the hydraulic jump. Aesthetic and maintenance issues with debris accumulating in the grates are concerns and should be evaluated in future design efforts.

Stepped Spillway

The most successful example of a low-hazard spillway integrated into an urban park environment is most likely at Confluence Park in Denver Colorado. The intent of the design was to avoid "keeper" hydraulics over a wide range of river flows. The structure has met this objective throughout its 15 year history. The spillway creates obvious abrasive conditions - telling even the novice user to stay away. The dam is often used in the background for local and national media events as it is aesthetically pleasing and creates desirable water "noise".

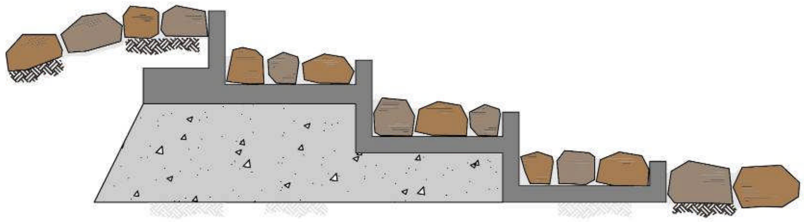


Stepped Dam at Confluence Park has Operated Successfully Since 1996

The table below provides actual construction costs from two constructed stepped dam projects. Unit costs are derived within the table. These dams are both built in alluvium, so foundation and seepage cut-off costs may be similar for this project. Note that unit costs provided in this memorandum only include the spillway and not the total costs of the dam which could easily be as great.

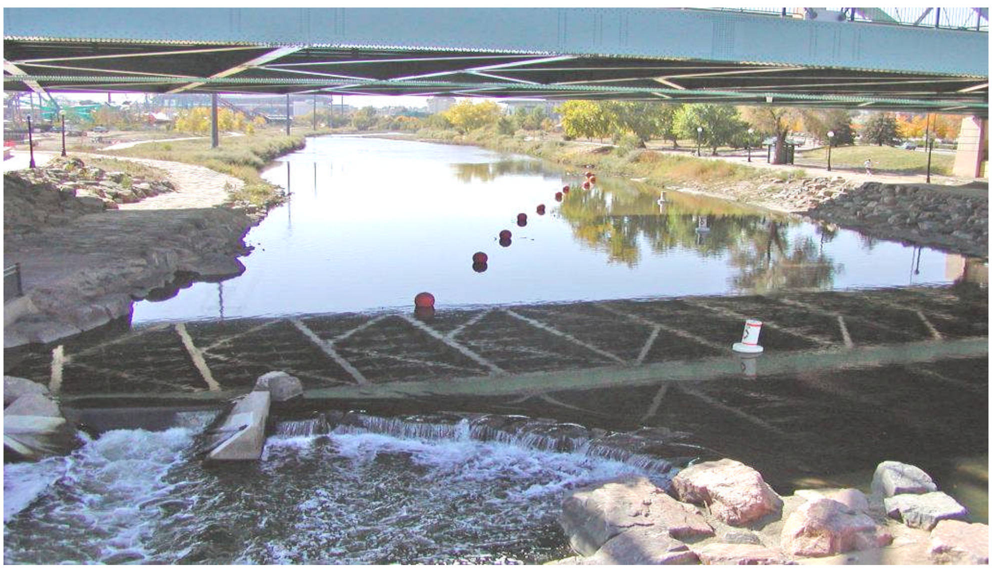
Project	Step Dam Description	Year	100-yr Flood Flow (cfs)	Total Cost (2009 Dollars)*	Total Cost/Square Foot of Dam Face (2009 Dollars)*
Yorkville Dam, Illinois	400 feet long (6' high)	2006	16,000	$2,772,545	1,160
Confluence Park, Colorado	75 feet long (7' high)	1994	19,400	$635,799	1,210
Average					1,190

A stepped downstream face can be constructed using roller compacted concrete, grouted boulders, or levels of sheet pile filled with rock. Design can lead to a wide variety of step heights and lengths.



Section of a Stepped Spillway Section Constructed of Cast-in-Place Concrete and Grouted Boulders. This is Similar to the Construction Method of the Stepped Spillway at Confluence Park (above).

In addition to the cost of the spillway, the cost of a stepped dam also must include: foundation, seepage cut-off, downstream scour protection, abutments, bank armoring, and fixed construction costs such as dewatering and water control, access, etc. Costs for these features are estimated elsewhere.



Buoy System and Portage Paths Upstream of Confluence Park

Efforts to Mitigate Recreationalists from Navigating a Stepped Dam and Non-Boatable Gates include Maintaining an Array of Buoys and Warning Signs, and Public Education

Sloped Spillway

A sloped downstream face can also be constructed with a sufficiently mild slope to minimize the dangerous roller effect. The surface can consist of grouted sloping boulders or RCC. The Bureau of Reclamation has used slopes of 5 percent on most of their recent low-hazard dams such as in the Hog Back project in New Mexico. However, the author believes that with proper design a dam with an average slope of about 10(h): 1(v) or 10 percent can produce low-hazard

Sloped Face Spillway at the "Hogback" in New Mexico (Bureau of Reclamation) Designed for Safety and Fish Passage

hydraulics for these applications. It is likely that a spillway with a simple and consistent 10 percent slope would not be used for these spillways. However, for cursory costing, we will assume the spillway volume would remain approximately the same. The actual spillway configuration would be developed during the preliminary design phase. Obviously due to the difference in effective slope, the unit cost for a sloped spillway is much higher. The advantage of a sloped spillway is that it does not entail abrasion and related impacts if navigated by inadvertent recreationalists. It would also not require avoidance systems such as the buoy systems shown above or a signage and public education program instructing users to avoid navigating the dam.

Topics of Particular Interest

Option for Roughened Channel in Spillway

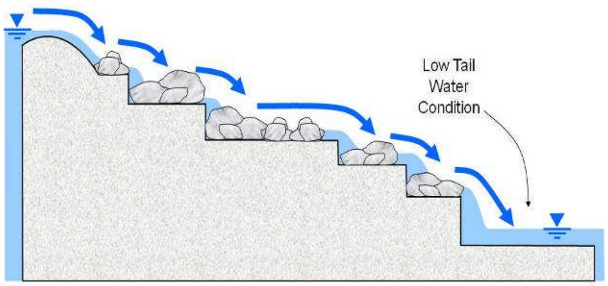
It may be practical to integrate a transversely-oriented roughened channel fish passage into the downstream face of the stepped or sloped spillways as described above. This integration would result in a cost savings for the merged applications. For instance, if an RCC spillway is used and configured in a way that roughened fish passage can be integrated into the slope, a reduction in the cost of the fish passage may be realized. This would require having sufficiently long spillway sections located near or adjacent to the shore and gates located closer to the center of the river. It would also require that flows overtopping these sections of the spillway occur only at flows where fish passage is not critical.

Emergency Access

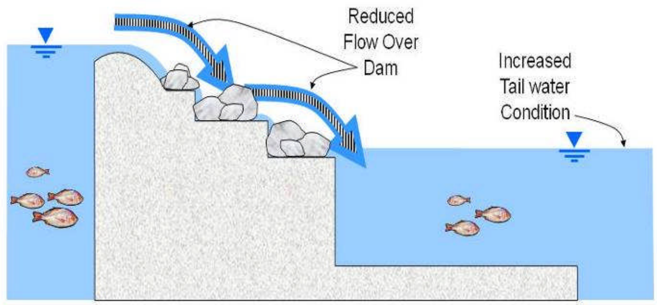
Access for emergency responders should also be taken into consideration when designing in-river structures. Periodic access points for emergency vehicles and personnel should be located in logical places to help facilitate river rescues.

Truncated Spillway Sections

Reduction in the size of a low-hazard spillway can be realized if significant flow is routed around the spillway until the river flow and corresponding tailwaters have risen. This may be accomplished by bypassing flows through the gates throughout the normal range of river flows. The following figure illustrates the impact of the elevated tailwater on the spillway design. Involved gate operations would also facilitate the transport of sediments and reduces the tendency for accumulation of sediments in the upstream pool.



Overtopping at Low Tailwater
Requires Longer Spillway



Overtopping at High Tailwater
Requires Shorter Spillway

Gate Operations May Allow Tailwater Elevations to Increase Prior to Overtopping of the Spillways – Thereby Reducing the Required Size of the Low-Hazard Spillway.

Future Preliminary Design Efforts

- Materials Investigation – Boulders, RCC, Concrete, etc.
- Spillway hydraulics
- Detailed evaluation of spillways options and related costs at each dam.
- Stakeholder and dam owner input on aesthetics, operations options, and safety.
- Selection of spillway type and related hazard reduction appurtenances.

IV. RECREATION AND FISH PASSAGE IMPROVEMENTS

Recreational Whitewater

Since 1975, whitewater river parks have been built in numerous communities throughout the United States. A whitewater river park includes creating man-made rapids which can be utilized to rafters, kayakers, and tubers.

Primary Users of River Whitewater Parks are Spectators, Families and Youths.

These parks provide quality-of-life improvements for local citizens and significant positive economic impacts to communities by attracting users from the surrounding regions and increasing local property values. One misconception is that these parks are primarily used by kayakers. Most of the in-river users of successful parks are the general public in rafts and various inflatable watercrafts. However, most of the people that use and enjoy whitewater river parks are spectators.

Venue Quality

One characteristic of a good venue is the access and setting of the venue. This is particularly true because most of the users and economic benefit of whitewater parks originates from viewing and land-based park users. All three sites offer excellent settings and access for development of successful recreational river venues.

A second characteristic of a good venue is the available flow rate and the reliability of the flow. A “re-regulated” river flow on the order of 400 to 1000 cfs is excellent for a whitewater venue. If this flow can be maintained during most of the time needed for recreation (reliability) then all three sites offer adequate flows to create high quality recreational venues.

A Recreational Whitewater Channel Flowing at just 350 cfs Provides a Regional Draw at this Park in Western Maryland.

The last ingredient to a great whitewater park is drop or gradient. The gradient at all dams with the river flows within the re-regulated flow seems adequate to create a regional or even national attraction. As with most sites, the drop diminishes as the flow increases and therefore reliability of the venues can be negatively impacted by excessively high flows. As an example, by review of the headwater and tailwater curves, it is obvious that the drop at the South Tulsa/Jenks site diminishes at normal hydropower release rates. To truly evaluate the recreational potential of each site, a flow and drop duration analysis needs to be conducted. This would support a cost benefit analysis to determine the optimal budget level for improvements as well as for determining the size, capacity and design of recreational improvements.

Future efforts need to evaluate the reliability of the flows and hydraulic drop during the spring and summer months at each site considered for recreational whitewater. Weekend flows should be a primary focus of this effort.

The extent and cost for the recreational whitewater courses will vary with the following design and site parameters:

- Design slope and resulting length
- Range and type of recreational users
- Ability to host competitive events
- Width
- Design flow

- Site Constraints – utilities, roads, access
- Aesthetic intent/goals
- Construction constraints

These will need to be evaluated with stakeholders and dam owners in the preliminary design phase.

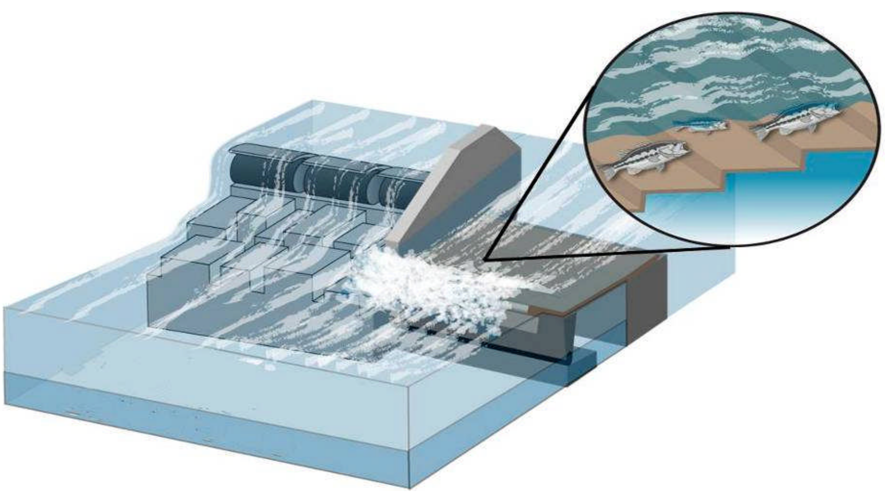
Fish Passage

There are two focuses of fish passage for this project. The first relates to passage during the spring for passage of migratory fish and downstream passage of fish eggs (striped bass). This passage will be accomplished by lowering of the gates. As discussed above, future design will include gate location, sizing, and design that promote passage. During the remainder of the year, the second type of passage - roughened channel, has been selected for providing fish passage as part of an adaptive management strategy. Roughened channel passage can be designed solely for passage of fish, or to pass fish and create recreational whitewater rapids. Proposed fish passage and recreational whitewater improvements at each site are listed above.

Fish Passage through the Gates

The main objectives in analyzing fish passage at the proposed gates are as follows:

- Determine hydraulic conditions throughout the range of flows upstream of the gates, at the gates, and downstream of each proposed gate.
- Compare target fish swimming performance criteria and recommend fish passage options that meet these criteria.
- Consider fish passage options that provide adequate depth for successfully passing fish.
- Analyze step heights within the fish passage that provide acceptable conditions for passing fish.



Gates can be Designed to Enhance Fish and Boat Passage

Roughened Channel Passages

A roughened channel is described as a manmade riverbed channel that mimics a natural river channel. These can be designed as separate in-river channels with their own invert slope as dictated by design criteria. Within the channel, water flows between, over, and around the many “roughness elements” such as rocks and boulders. The variation of interstitial flow allows for multiple routes and a variety of hydraulic conditions. The flow will be concentrated at the fish passage locations in an effort to provide adequate water depth velocities, and attraction flows to the passages.

Roughened Channel Fish Passages Designed Exclusively for Passage of Fish. These Designs may however impose Safety Hazards.

Roughened Channel Fish Passage is Integrated in these Multi-Purpose Recreational Projects.

Roughened channel fish passages can be constructed with large diameter boulders – perhaps 3 to 8 feet in diameter - that are partially grouted and separated far enough away from each other to provide adequate interstitial flow. These boulders can be configured downstream of the dam to provide a concentrated flow to attract fish while allowing fish to pass upstream along the banks and bed. Alternatively, roughened channel passages can be constructed of pneumatically applied concrete or “faux” rock like used in zoos.

Roughened channel fish passages and whitewater channels usually require a barrier or “divider wall” between the dam and the fish passage channel. This is needed to accommodate the differences in elevation and provide the adequate slope of the fish passage channel. As discussed above, another option may be to incorporate a fish passage channel along the face of the dam. This could be configured to provide a longer path and allow the fish to more gradually gain the elevation necessary to move upstream.

Size of Roughened Channel

The width of the fish passages and corresponding flow are difficult to ascertain at this conceptual level of planning. The design width will ultimately depend upon developing attraction velocities in the downstream pool, channel hydraulics related to meeting the minimum depth and maximum velocity – currently estimated at 2.5 feet and 4 ft/sec, respectively. In addition, the range of river flows where this criterion is to be met needs to be evaluated. As a result of the variation in these parameters, estimating capital costs at this level of study is approximate at best.

Fish Passage Sites Around the World					
Site	Type	Drop	Slope	Width	Flow
Trautmansdorf, Austria	Lowland Bypass Channel	6 ft	0.007	9 ft	0.7-18 CFS
Gutenstein, Austria	Step-pool Bypass Channel	5.5 ft	0.083	5 ft	1.5 CFS
Henfstadt, Thuringia, Germand	Pond Type Bypass Channel	24.42 ft	0	1.96-13.12 ft	1.8 - 3.5 CFS
Tessmer-Wehr, Austria	Riffle-pool Bypass Channel	5 ft	0.016	5-15 ft	3-150 CFS
Unzmakt, Austria	Step-pool Bypass Channel	28 ft	0.042	15 ft	6 CFS
Sinn, Germany	Pool Type Bypass Channel	9.186 ft	0.05	11.48 ft	12.35 CFS
Buchenhofen, Germany	Step-pool Bypass Channel	22.3 ft	0.042	3 ft	13.2 CFS
Beckinghausen, Germany	Pool Type Bypass Channel	9.84 ft	3.33%-2.8%	9.84-19.7 ft	17.6 - 35.3 CFS
Freudenau, Austria	Step-pool Bypass Channel	28.7 ft	0.01	33 ft	30-118 CFS
Umgehungsbach Raffelberg, Germany	Step-pool Bypass Channel	11.15 ft	0.053	8.2 - 9.84 ft	31.75 CFS
Bad Bodendorf, Germany	Rock Ramp Fishway	5.25 ft	0.04	82 ft	42.3-338.8 CFS
Buisdorf, Germany	Rock Ramp Fishway	8.7 ft	0.05	49.2 ft	52.9 CFS
St. Laurent des Eaux, France	0	6 ft	0.02	52.8 ft	63-835 CFS
Dattenfield,Germany	Rock Ramp Fishway	5.9 ft	0.05	32.8 ft	70.6 CFS
Muhlenhagen	Step-pool Bypass Channel	39.6 ft	0	0	98.8 CFS
Churchill, Canada	Rock Ramp Fishway	6.56 ft	0.0333	984 ft	150 CFS
Greifenstein, Austria	Step-pool Bypass Channel	4 ft	0.006	100 ft	175 CFS
Ruppoldingen, Switzerland	Mixed type Bypass Channel	21.4 ft	0.003	30-60 ft	175 CFS
Lichtenstein, Switzerland	Riffle-pool Bypass Channel	16.5 ft	0.01	33 ft	175 CFS

The above table is based upon data from *An Illustrative Handbook on Nature-Like Fishways-Summarized Version* by Wildman, Parasiewicz, Katopodis and Dumont, offers various parameters, including width from roughened channel passages around the world. Unfortunately it does relate width or capacity to that of the subject river or provide design criteria of the fish passage.

Two of the Bureau of Reclamation's more recent designs of roughened channel fishways, the Hogback in New Mexico and the Price Stubbs Dam in Colorado have relative width of fishways to dam in the range of 5 to 7.4 percent. This ratio is likely similar to the relative capacity of the dam and the roughened channel passage. It is reasonable that it is also related (as some level) to attraction velocities. In addition to the obvious factors; different species of fish, different hydrology, etc., these referenced sites are much less “sensitive” to capacity of the fish passages related to attraction velocities. This is because the dam spillways of the Bureau’s designs are full width rock ramps so that the outlet of the dam is close to the outlet of the fish passage. Additionally, the proposed dams on the Arkansas River will have gates opening on a regular basis, thereby further worsening attraction conditions to the entrance to the roughened channel passages.

Using a ratio of seven percent, a width of over 120 feet is found on the South Tulsa/Jenks Dam. Due to the width of the river it is assumed (for costing purposes) that a passage on each bank will be included. This yields two 60 foot wide roughened channel passages. Narrower widths may be possible if the entrance to the passages is controlled by gates (that promote fish passage). This would allow more flow into the roughened channels than would otherwise occur.

The length of the passage is also difficult to estimate at this conceptual level. This is due to the relationship between fish eye and average velocities, slope, and the design range of flows where the roughened channels are to meet the provided criteria. Based upon experience and the data presented above, a slope of 2 percent and a nominal width of 120 feet (in two channels) is proposed for use in cost estimating at this time. It is realized that this is a very approximate method and that this application of roughened channel passage in this region and for these fish species offers significant uncertainty in estimating costs.

Sand Springs Whitewater Course

During this evaluation, an option for an off-channel course was investigated. The location of the course is schematically shown on the site figure at the beginning of this memorandum. The course would not use water from the Arkansas River, but would use water from a former water supply for Sand Springs. Initial estimates of the available flow rate are much less than needed for even a modest “tubing” course. Recirculation pumps would likely be required to circulate flows needed to create a small river/creek experience. The pumps could be powered by conventional means or by recovering energy from the relatively high pressure supply pipelines that supply this flow and the flow to the water treatment plant. This innovative idea could provide this venue with a clean, reliable, and low operating cost source of water not commonly found in the region.

Future Preliminary Design Efforts

Schematic locations for the proposed features are shown on the site figures at the beginning of this technical memorandum. Design of the features is not part of this effort and will include the following preliminary design tasks:

- Further development of fish passage design criteria
- Determination of range of flows to be considered for fish passage
- Evaluation of the number and location of the roughened channels at the South Tulsa/Jenks Dam
- Hydraulic modeling and design related to attraction flows
- Determination of specific recreational goals
- Determination of gross dimensions of channels – length/slope and width
- Flow and hydraulic drop reliability evaluation
- Detailed hydraulics for normal and flood flows
- Recreational and/or economic evaluation
- Meetings with facility owners and stakeholders
- Refined physical modeling to meet fish passage and hazard reduction objectives at the Zink and Sand Springs Dams.

V. CONCEPTUAL-LEVEL BUDGET ESTIMATES

Cost estimating is limited by the lack of preliminary design and related supporting evaluations. Estimates are based upon research of various gates and constructed facilities, and design experience. Costs or budgets for the following improvements are not estimated herein:

- Foundation and seepage cut-offs
- Dam and gate abutments (Except for modulating gates)
- Divider structures between passages and modulating gates and the dams
- Existing structure or utility modifications
- Excavation or structural fill
- Construction dewatering and access
- Features related to mitigate flood impacts (if needed)
- Downstream armoring and stilling basin (if included)
- Pedestrian Bridge(s) and other access improvements
- Landscaping, land costs, and other site related items
- Environmental related costs (EIS, studies, etc.)
- Design, geotechnical and sediment transport investigations, computer and physical modeling.

Conceptual-Level Budget for Gates

Preliminary design of the project is needed to determine the type and/or combination of gates needed. Based upon the range of unit costs above it is suggested that an average unit cost of $1,000 per square foot for gates 8 feet and taller, and $700 per square foot for gates less than 8 feet in height be used for conceptual-level planning at this time. The unit cost for the gates at South Tulsa/Jenks is increased by 20% to account for inclusion of passage features during the spring months. These lumped unit costs assume some combination of movable and fuse gates and may appear to be lower than indicated in the above table - particularly due to the conceptual level of estimate. However it is believed that lower costs can be realized in more detailed preliminary design efforts. An average cost for low-hazard modulating gates of $4,200 is used. Unit costs for crest gates on the Zink Dam are the same as the gates up to 8 feet in height due to the retrofit nature of the installation.

The sole use of conventional full-height gates is not practical. To eliminate gate overtopping, inclusion of low-hazard modulating gates, gates higher than the normal pool elevation, or crest gates are needed. For this conceptual-level cost estimate, 2 feet of additional gate height is included. For aesthetic reasons this amount of additional height may not be selected, but inclusion in this manner allows budget for implantation of other more palpable options. Other approaches to reduce hydraulic hazards due to gate overtopping will be evaluated in preliminary design. These could include inclusion of crest gates on spillway crests, partially or fully modulating low-hazard gates, and various gate control schemes.

Conceptual-Level Budget for Spillways

The type, slope, and dimensions of the spillways will be determined in preliminary design. It is possible that different types of spillways will be used at different sites or at the same dam. Since the South Tulsa/Jenks and Sand Springs dams are not planned for in-river whitewater recreation, a stepped low-hazard dam is used for cost estimating purposes. A simplified average cross section with a crest width of 12 feet and an upstream slope of 0.5:1 and a downstream slope of 5:1 is assumed. A steeper back slope may ultimately be designed, but this would likely require forming or structural elements and not conventionally applied RCC or grouted boulders. For estimating purposes, the spillway section has an invert elevation three feet below the dam invert. The foundation estimates will include structure below this elevation. For this conceptual-level estimate, a value of $150/C.Y. will be used. This could represent surface RCC, or a combination of boulders, RCC, concrete grout, sheet pile, or cast-in-place concrete.

Conceptual-Level Budget for Roughened Channel Fish Passages

Conceptual-level cost estimates for a roughened channel fish passage can be expressed on a unit basis as dollars per square foot. This is because the cost is primarily in surface treatment or armoring. When using grouted boulders for fish passage, the associated costs can be estimated in cubic yards per square foot, etc. Grouted boulders that have provided adequate interstitial flow in other applications were generally a minimum of 3 feet in diameter. An approximate unit cost is about $40/ft^2 when including bedding, average thickness of the entire layer, and accounting for some increase in boulder costs compared with mountain regions. (As an alternate to large boulders, faux rock could be used.)

Conceptual-Level Budget for Whitewater Course

Costs for channels can vary widely based upon the above factors and resulting design and layout. The following table includes approximate construction costs for various whitewater channels constructed in different environments, conditions, and with different objectives.

Project	Whitewater Channel Description	Year	100-yr Flood Flow (cfs)	Total Cost (2009 Dollars)	Total Cost/Linear Foot of Bypass (2009 Dollars)
Yorkville Dam, Illinois	1000 feet long (6' drop)	2004	16,000	$2,705,000	$2,700
Confluence Park, Colorado	400 feet long (7' drop)	1994	19,400	$954,000	$1,000
Upper Batavia Dam	1010 feet long (9' drop)	2000	13,500	$3,806,000	$3,800
Horseshoe Bend	390 feet long (7.5' drop)	1994	31,500	$397,000	$400
Union Avenue	750 feet long (5.5' drop)	1992	16,400	$1,897,000	$1,900
Adventure Sports	1700 feet long	2005		$7,889,000	$7,900
Average				**$2,941,000**	**$3,000**

Some estimates of cost are based upon bid costs, while others are based upon detailed preliminary design efforts, or approximations of actual constructed costs. Costs have been brought to current dollars based upon the Construction Cost Index History as published in the Engineering News Report (ENR). These costs would not include the divider wall or island that separates the course from the dam and river, adjacent bank armoring and landscaping, construction dewatering and access. Given the conditions of these sites, including the alluvial bed and need for seepage cutoffs, flood control requirements, and confined nature of the banks, the author suggests a unit cost of about $3,000/l.f. at this conceptual level. This would include provisions for uplift and local piping – major issues in the design, but other armoring and structure is needed to protect the subgrade from adjacent erosion and scour.

Summary of Budgets for the Major Improvements

The following table extends the unit costs by the previously determined width and dam heights.

Site	Gross Dimensions Used for Cursory Estimating				Cursory-level Item Budget		
Item	Length (ft)	Height (ft)	Approximate Width of Foundation (ft)		Area Projected on upstream dam face or unit	Units	Lumped Unit Cost
Sand Springs Dam							
Low-Hazard Spillway	1,076	10.0	70	ft^2	10,800	ft^2.	$360
Gates	814	12.0		ft	9,800	ft^2	$1,000
Low Hazard Modulating Gate				NIC			
Whitewater/Fish Passage				NIC			
Zink Dam							
Low-Hazard Spillway	610	8.5	50	ft^2	5,200	ft^2.	$300
Gates	655	11.5		ft	7,500	ft^2	$1,000
Low Hazard Modulating Gate (2*20)	40	5.0		ft	200	ft^2	$4,200
Low Hazard Modulating Gate Abutments					2	lump	$500,000
Crest Gates	570	3.0		ft	1,700	ft^2	$700
Whitewater/Fish Passage	1,800				1,800	l.f.	$3,000
South Tulsa/Jenks Dam							
Low-Hazard Spillway	1,112	6.0	45	ft^2	6,700	ft^2.	$290
Gates	712	8.0		ft	5,700	ft^2	$1,200
Fish Passage Entrance Gates			tbd		250	ft^2	$1,500
Fish Passage Entrance Abutments					2	lump	$200,000
Fish Passage	300	120.0			36,000	ft^2	$40

References

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Tennessee Valley Authority (TVA) (Proctor et al., 2008), Arkansas River Corridor Vision, prepared for the US Army Corp of Engineers.

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Supplemental Fish Passage Information from Steve Layman, CH2MHILL

General

Period of Gate Lowering - March 1 through May 31 would cover peak spawning periods of migratory species of interest (p. 15 and Table 3 of TM); that is what we propose as a reasonable period of time for potential gate lowering or otherwise providing upstream and downstream passage for the migratory riverine species of interest, i.e., striped bass, sauger, paddlefish, and shovelnose sturgeon

Foraging fish Passage. Passage of foraging fish is an objective incidental to upstream and downstream passage of the target migratory species, and incidental to operation of a roughened channel in other seasons for whitewater recreation

Roughened Channels at South Tulsa/Jenks

"Fish Eye" Velocities Vs. Average Section Velocities. Velocities actually encountered at the position of the passing fish are more important than average section velocities; given strong enough attraction flow, upstream migrants tend to search for the best hydraulic conditions available for passage.

Cross-Section Of Interest For Passage. Passage along the river banks could be appropriate given the substantial width of the river if a flow pattern can be created to guide fish from the middle of the river to the fishway entrances on each side; striped bass, sauger, and sturgeon tend to occur in the deepest part of the channel, not necessarily near the banks; adjusting flows through the spillway gates could be important to producing the necessary flow pattern to lead fish toward the banks, especially if roughened channels are the only means of upstream passage available (i.e., gates not lowered); many of the small-bodied nongame species do tend to occur in shallow-water and stream-margin habitats along the shoreline.

Recommendations Regarding Passage Design Criteria.

1. ***From Technical Memorandum.*** Table 3 summarizes the swimming performance information found in the literature review for shovelnose sturgeon, paddlefish, striped bass, and sauger. Burst speed data were not readily available or comparable for adults of all of the species of interest. The data indicate the following likely descending order of sustained and burst swimming speed: striped bass; sauger; paddlefish; shovelnose sturgeon. Table 4 summarizes fishway design recommendations for shovelnose sturgeon, which might be considered the lowest common denominator among the 4 migratory species of interest.

2. ***Maximum Speed Recommendations.*** At the low end, the maximum passage speed recommended for shovelnose sturgeon is 3 to 4 ft/s (Table 4). Near the high end, the burst speed of walleye (surrogate for sauger) is 5.2 to 8.5 ft/s (Table 3). Given that sturgeon passage success declined to below 50% at 6 ft/s (Table 3), a maximum passage velocity of 6 ft/s would seem to be a reasonable criterion addressing the swimming capabilities of all the target species.

3. ***Attraction Flow - Velocity And Other Desired Flow Characteristics.*** Attraction flows of 2 to 4 ft/s for sturgeon (Table 4); not found in literature for the other species but presumably could be toward higher end of range because of other species' generally stronger swimming capabilities with possible exception of paddlefish.

4. ***Minimum Flow Depth.*** From Table 4 of the T.M, 0.7 to 4.5 ft (4 ft more desirable) for sturgeon; Minimum of 1.5 ft for striped bass (Table 3); so range of 1.5 to 4.5 ft seems appropriate.

5. ***Pool Velocity/ Cruising Speed.*** Shovelnose sturgeon cruised for 10 min at 3 to 4 ft/s; max sustained speed of walleye for 60 min was 1.0 to 2.4 ft/s and for 10 min was 1.4 to 3.7 ft/s (Table 3); pool velocity/cruising speed should probably be less than 3 ft/s depending on length of fishway and time needed to pass.

6. ***Maximum Passage Velocity /Burst Speed*** 4 to 6 ft/s as inferred above from range established by sturgeon and walleye.

7. ***Approximation Of Length Of Burst Speed*** *Not currently known*, but burst speeds are single effort, not sustainable for more than about 20 seconds.

8. ***Maximum Step Heigh*t** Defined (in part) by position in the water body and behavior; sturgeon tend to be bottom-dwelling and therefore less pre-disposed to ascending barriers near the surface; also defined in part by head loss between pools and corresponding velocities over a weir or through an orifice; a head loss of 0.5 ft corresponds with a velocity over a weir of about 5.8 ft/s (Clay, 1995, Design of Fishways and Other Fish Facilities); 5.8 ft/s is above the burst speed of sturgeon and near that of sauger. A head of loss of 0.25 ft corresponds with a velocity of 4 ft/s (Clay, 1995). Therefore, a max step height of 0.25 ft would be more desirable than 0.5 ft/s if technically feasible.

Passage During Lowered Gates:

Fields of Velocity. "Fish eye" velocities and not average section are the velocities of interest in design.

Passage Locations. From a biologist's perspective, location would seem to depend on the width of the gates used, minimization of head differential during operation for fish passage, volume and velocity of flow relative to flow passing the dam by other means, placement at the farthest upstream point at the dam, and downstream flow patterns for guiding fish toward the gates.

Maximum River Flow To Be Concerned With Passage This is not evident at this time, but perhaps the flow at which gates would require lowering to maintain pool levels within a normal operating band - Would that be the maximum hydraulic capacity of Keystone powerhouse?

Maximum Design Passage Velocity /Burst Speed Same as #6 above

Approximation Of Length Of Burst Speed See #7 above

Maximum Design Step Height Success will be highest when head differential the lowest; head differential should be eliminated to extent practical; depends in large part on velocities associated with head loss; see #8 above.