# TECHNICAL MEMORANDUM

**To:** Chris Kabala, P.E., City of Tempe

**From:** Dean B. Durkee, Ph.D., P.E. and Frances Ackerman, R.G, P.E., Gannett Fleming, Inc.

**Date:** September 14, 2011

**Subject:** TTL Dam Replacement Project – Alternatives Evaluation Status Update

## INTRODUCTION

The purpose of this Technical Memorandum 1 is to update the City of Tempe on the progress of the Tempe Town Lake Dam Replacement Project Alternatives Evaluation. The information presented below summarizes the project background, the existing conditions, the requirements and criteria for a dam replacement system, descriptions of potential alternatives, the alternatives evaluation process and the short list of alternatives still under consideration at this time. Additional information regarding the alternatives evaluation process, Failure Modes and Effects Analysis, and final alternative selection will be presented in the final project report.

## PROJECT BACKGROUND

Tempe Town Lake is an urban lake located in the Salt River, in the City of Tempe, Arizona. Groundbreaking for the lake was August 8, 1997, and Tempe Town Lake was officially opened to the public in November 1999. The lake is formed by two Bridgestone inflatable rubber dams constructed across the Salt River bed at the upstream and downstream ends of the lake. The City of Tempe (City) owns the dams. The original downstream dam consisted of four 16-foot high air-inflated rubber bladders, each approximately 200 feet long anchored to a concrete foundation slab. The foundation slab was constructed of roller-compacted concrete overlain by a reinforced concrete slab at the riverbed level to allow the passage of water when the rubber dam is deflated.

In the past, dam inspection activities indicated that the rubber bladders which were used to construct the dam were deteriorating more quickly than anticipated, probably as a result of exposure to the extreme heat and high ultraviolet radiation conditions in the Arizona desert. Based on this, Bridgestone recommended replacing the bladders after 10 years of service, or in 2009 or 2010 (URS, 2008). The bladder replacement was scheduled to occur in early 2010, but was delayed until July 2010 when winter storms increased the flow of water over the dam. On July 20, 2010 one of the four downstream Tempe Town Lake rubber bladders (bladder #2) failed and the lake was completely drained. The failure did not result in any personal injuries.

A forensic investigation was performed by SEA, Ltd. to determine the cause of the bladder failure. The investigation indicated that the failure was the result of the age of the dam and the environmental conditions, notably temperature, to which the dam was subjected. These conditions caused delamination or separation of the layers that make up the rubber dam. This separation is characteristic of Intra Carcass Pressurization (ICP). The bladder carcass breach occurred near where the bladder made contact with the concrete apron, where the bladder curvature deviates from its "cylindrical" profile and flattens out on the foundation. The bladder flexes where there is such a change in curvature. This flexure causes a constant back and forth motion resulting from the movement of the bladder in response to the force of the water against the dam. The back and forth movement within the bladder carcass can cause small internal tears which then become the accumulation location for any air that penetrates the reinforced rubber carcass.

The penetration of air into the reinforced bladder rubber depends on both the carcass temperature and time, but the carcass temperature is the dominant factor. As the air penetrates the bladder rubber and accumulates at the internal tears, it builds up pressure, i.e., ICP. Over time, this accumulated pressure causes the separation or delamination of the layers of rubber that make up the bladder wall. The delaminated area no longer has the strength and structure of the other areas of the bladder and acts as a preferential site for failure. Once the accumulated air caused a large enough area of delamination of the layers, the stress became larger than remaining strength of the bladder and failure occurred.

After the failure, the scheduled bladder replacement was performed and all four downstream rubber bladders were replaced by the end of 2010. The replacement bladders were provided by Bridgestone under a five-year lease agreement to the City, although Bridgestone had, by that time, discontinued sales of their rubber dams. The replacement bladders are scheduled to be removed at the end of the lease period.

## □R□□EC□ □□R□□SE A□D SC□□E

The purpose of the Project is to select, design and construct the “best-value” solution for replacement of Town Lake downstream dam, based on the viable technologies available, location, environmental and social considerations, and cost, including upfront cost as well as life cycle costs. The Project will be performed in phases, with Phase 1 consisting of validating the concept and selecting appropriate dam technology for the replacement. Phases 2 and 3 will include final design and construction, respectively, of the Project.

## I□F□RMA□I□□ S□□RCES

The following reference documents were reviewed for development of alternatives and overall understanding of the project:

- Rio Salado Town Lake Feasibility Study, April 1992.
- Geotechnical/Hydrological Data Report, December 1994.
- Rio Salado Town Lake Design Report, March 1995.

- Geotechnical/Hydrological Data Report, February 1996.
- Geotechnical/Hydrological Data Report Addendum No. 1, February 1996.
- Hydraulic Analyses for the Rio Salado Town Lake Dams, March 1996.
- As Builts - Rio Salado Dam Facilities, November 1998.
- Proposal for Operational and Maintenance of Town Lake, from SRP, February 24, 1998.
- Tempe Town Lake Downstream Dam Alternatives Study Final Report for Tempe, May 27, 2008.
- Tempe Town Lake Dams Annual Report, June 10, 2009.
- Salt River Hydraulic Master Plan for FCDMC, June 30, 2010.
- Design Plans for Town Lake Pedestrian Bridge, Project No. 6501541, January 2009.
- Tempe Town Lake Downstream Dam Bladder Replacement Project, Final Engineering Report, January 2011.
- Schedule C, Schedule for Design, Permitting, Contracting, Construction and Installation of New Dam, January, 2011.
- As Builts - Salt River Channelization Project, April 1989.
- Addendum to Design Reports, November 1996
- Section 7 Study for Modified Roosevelt Dam, Arizona by USACE, March 1996
- Gila River and Tributaries Hydrology by USACE, May 1982

**S□MMAR□ □F E□IS□I□□ C□□DI□I□□S**

The Salt and Verde Rivers upstream from Town Lake drain a watershed of approximately 13,000 square miles. Flow along these rivers is controlled by four upstream storage dams on the Salt River which form a continuous chain of lakes almost 60 miles long, and by two storage dams on the Verde River (Figures 1 and 2). The Granite Reef Diversion Dam is located approximately 40 miles downstream of the confluence of the Salt and Verde Rivers and 22 miles east (upstream) of Town Lake Dam.

The design discharge for the Salt River at Town Lake that is to be used for the alternatives evaluation process is based on the capacity of the river channel at this location. In this regard the design discharge of 210,000 cubic feet per second (cfs) was selected based on hydraulic analyses. At flows of 210,000 cfs or greater there is potential for a flow breakout along the south bank (just upstream of the dam) which will ultimately drain into the Rio Salado Parkway and then further south and west. The selected design discharge is consistent with Flood Control District of Maricopa County (FCD) guidelines for development within the Salt River. The FCD is currently recommending the design discharge within Salt River to be based on the 200-year frequency storm event. At the Town Lake downstream dam the 200-year peak flow is 207,000 cfs which is just slightly lower than the selected design flow of 210,000 cfs.

The Town Lake downstream dam is located approximately 3,400 feet east of Priest Drive, at the downstream end of Tempe Town Lake (Figure 3). The original location of the dam was approximately 300 feet downstream of the final location. However, as a result of a Value Engineering (VE) study performed for the design, the dam location was moved upstream approximately 300 feet to the coincide with Grade Control Structure No. 4, (GCS No. 4) which

was constructed as a part of the Salt River Channelization Project in 1989. The modification was intended to reduce cost for the foundation by constructing it upon the existing GCS and to reduce the effects of the lake on an existing landfill. According to as-built plans for the Salt River Channelization Project, GCS No. 4 spans the entire width of the channel and consists of cement-stabilized alluvium (CSA) with a shear key into bedrock at elevation 1101 (approximately 30 feet bgs).

The original four Bridgestone rubber bladders were 16-feet in diameter. The replacement rubber bladders, installed in 2010, are 15-foot diameter Bridgestone bladders. The existing dam is shown in Photograph 1 below. The two outer spans are 193' 6", center-to-center, and two inner spans are 228'0", center to center. The rubber bladders are bolted to the foundation slab, piers and abutments with a single anchor line, shown in Photograph 2. Air supply lines embedded in the foundation slab connect the bladders to blowers located in the operations building at the north abutment.

The reinforced concrete piers have sloping sides and are 38'6" long (upstream-downstream) at the top and 60'2" long at the base. The piers are 5'6" wide at the top and 27'4" wide at the base. The piers include fabricated metal bulkhead channels approximately 6 feet upstream from the rubber dam anchor line for temporary cofferdam construction. The piers provide anchorage for the rubber bladders and support for the new pedestrian bridge above the dam.

**□hotogra□h 1. Existing □o□n □a□e dam**

As shown on Figure 4, the reinforced concrete foundation slab was founded on a new roller-compacted concrete (RCC) section that was constructed upon GCS No. 4. A 2-foot thick layer of drain rock was placed against the slope of GCS No. 4 and along the prepared base for the RCC section before RCC placement. The RCC section was tied into GCS No. 4 with two rows of grouted #11 steel anchors on 10-foot centers along the entire length of the dam. The 3-foot thick reinforced concrete foundation slab was constructed on the RCC/GCS No. 4 substructure. The as-built plans indicate that GCS No. 4 was to be removed to an elevation of 1126 feet and the upstream projection of GCS No. 4 was to be removed as necessary to construct the upstream cutoff wall.

The anchor line for the rubber dam was constructed 9 feet from the downstream from the back face of the foundation slab (Photograph 2). The foundation slab was thickened to approximately 6 feet behind the anchorages and a row of 18" square pile sockets were embedded 5 feet into the thickened slab section approximately 6 feet upstream from the rubber dam anchor line to be used for temporary cofferdam construction.

**Photograph 2. Rubber dam anchor line**

A 3-foot thick soil cement-bentonite cutoff wall was constructed approximately 13.5 feet upstream from the upstream face of the foundation slab. The soil cement-bentonite cutoff wall tied into the upstream apron to reduce seepage and assist with construction dewatering. The cutoff wall was connected to the slurry walls along the north and south lake shorelines which are part of the lake infiltration management system. The soil cement-bentonite cutoff wall varies in depth between approximately 20 feet bgs and 45 feet bgs along the dam alignment. It is deepest at the south end of the dam and becomes increasingly shallower to the north. The wall is embedded in a low permeability clayey gravel unit.

The reinforced concrete downstream apron and stilling basin with chute blocks at the upstream end and a dentated endsill (dragons teeth) is approximately 30 feet wide (Photograph 3). The apron is underlain by a 2-foot layer of drain rock which is continuous with the drainage layer beneath the RCC substructure. 4-inch diameter schedule 80 slotted PVC pipes on 20-foot centers are included in this section of the drainage layer. Approximately 4 feet of compacted granular fill was placed below the drainage layer and the downstream apron.

**□hotogra□h 3. Do□nstream a□ron and stilling basin**

The downstream apron is tied into a 4-foot thick reinforced concrete downstream cutoff wall. The downstream cutoff wall was constructed using the alternate panel method. The downstream cutoff wall generally extends to approximately 25 feet bgs (design elevation 1105), but extends only to approximately 20 feet bgs for short segments at each end. A note on the as-built plans states “Locations where the bottom of the wall profile is less than the design elevation, indicates interface with bedrock.” However, review of the borings logs indicate that, except at the north end, the wall is embedded in the clayey gravel unit.

**S□MMAR□ □F E□A□□A□I□□ CRI□ERIA**

During the Alternatives Evaluation Workshop held on August 1, 2011, the project team discussed the project criteria that were used during the original dam design (1992) and during the alternatives study performed in 2008, and the criteria included in the RFQ for the current project. Based on these criteria the project team established the final project criteria as follows:

- Shall (Must Have)
- Should (Should Have)

Objectives that shall be met were considered essential to the acceptable performance of the project, while objectives that should be met represent important desired characteristics and every effort possible should be made to meet them. The final project objectives are summarized in Table 1.

During the alternatives evaluation, all alternatives proposed for the Town Lake dam were revisited to verify the results and confirm that all potential alternatives had been considered. The alternatives developed in 1992 and 2008, and additional alternatives considered for this evaluation, were assessed relative to their ability to meet these project criteria.

**Table 1. Summary of Original Project criteria**

| **Must Have Project Criteria** |
|---|
| Safety |
| Maintain or improve current level of flood protection (200-yr). |
| Minimize the reduction in flood passage capacity. |
| Minimize the increase in flood impacts to surrounding areas. |
| Ability to capture the tail end of a flood event to maintain the full lake condition during higher frequency events. |
| Maintain structural integrity of the dam under maximum design discharge. |
| Reliably lowered when needed. |
| Design must be compatible with pedestrian bridge and immediate surrounding area. |
| Meet the December 28, 2015 Bridgestone contractual requirement for replacement. |
| High degree of reliability. |
| Meets regulatory requirements. |
| Maximize value (cost/benefit). |
| Demonstrated performance in this climatic environment. |
| **Should Have Project Criteria** |
| Ability to capture the tail end of a flood event to maintain the full lake condition during design flood. |
| Minimize operations and maintenance costs. |
| Simplicity of operation. |
| Proven technology. |
| Design that allows the lake to be maintained during construction. |
| Maintain current lake bottom grade. |
| Minimize downstream scour. |
| Vandalism prevention. |
| Maintain original design lake level. |
| Minimize environmental impacts. |
| Aesthetically compatible. |
| Maintain the existing pier configuration and minimize structural modifications as much as possible. |

## DESCRI□□I□□ □F A□□ER□A□I□ES

Table 2 includes a summary of the alternatives that were originally considered for the Tempe Town Lake downstream dam and alternatives that were evaluated during the 2008 alternatives study. All alternatives are described in the following sections, including additional alternatives developed since the 2008 study.

**able 2. Summar o ro ect alternatives**

| Stud Date | Alternative | Re orted Fatal Fla |
|---|---|---|
| 1992 | Tainter gates | Do not meet flood control criteria |
| | Bascule or bottom-hinged gates | |
| | Inflatable dams (water-filled) | Safety and operational constraints (fill time too long to catch end of flood) |
| | Inflatable dams (air-filled) | Selected previously |
| | Ogee crest weirs | |
| | Labyrinth weirs | Hydraulic and sediment transport constraints |
| | Fuse plugs of various configurations | |
| 2008 | Pneumatically operated hinged crest gates (Obermeyer) | |
| | Hydraulically operated hinged crest gates | |
| | Bridgestone dual body rubber dams | No longer available |
| | Dyrhoff rubber dams (Sumitomo) | |
| | Radial gates (tainter gates) | |
| | Vertical lift gates | |
| | Swing gates | Did not meet Must Have criteria |
| | Bascule gates | Did not meet Must Have criteria |
| | Fusegates (Hydroplus) | Did not meet Must Have criteria |

## □AI□□ER □A□ES

Radial gates, also referred to as tainter gates, consist of cylindrical steel segments mounted on radial arms that rotate on trunnions anchored to the piers. The cylindrical plate structure is concentric to the trunnion which causes the resultant of the hydrostatic force to pass through the trunnion, thus, there is no moment resulting from this force to be overcome by the gate hoist. Spillway flow is regulated by raising or lowering the gate by means of cables or drum hoists to adjust the discharge under the gate.

Tainter gates are considered to be the most economical, and usually the most suitable, type of gate for controlled spillways due to simplicity, light weight, and low hoist-capacity requirements.

The radial gate alternative ranked number 6 during the 2008 Phase 1 alternative screening and was not retained for Phase 2 alternatives comparison and ranking.

**□hotogra□h 4. □ainter gates**

## □ASC□□E □A□ES

A bascule gate is a type of hinged crest gate in which the gate structure incorporates an actuator (torque tube) along the bottom edge which transfers the water load through to the actuator. The actuator is normally a hydraulic cylinder. The torque tube allows operation from one side, however, use of bascule gates is limited to short spans due to gate deflection and other structural considerations.

Gate sizes are generally limited due to the required torque tube size needed to raise the gate under unbalanced hydraulic loading conditions. The torque tube will deteriorate quickly and will bind under sediment loads. For these reasons, Bascule gates were not considered a viable alternative and were not included in the 2008 alternatives ranking procedure.

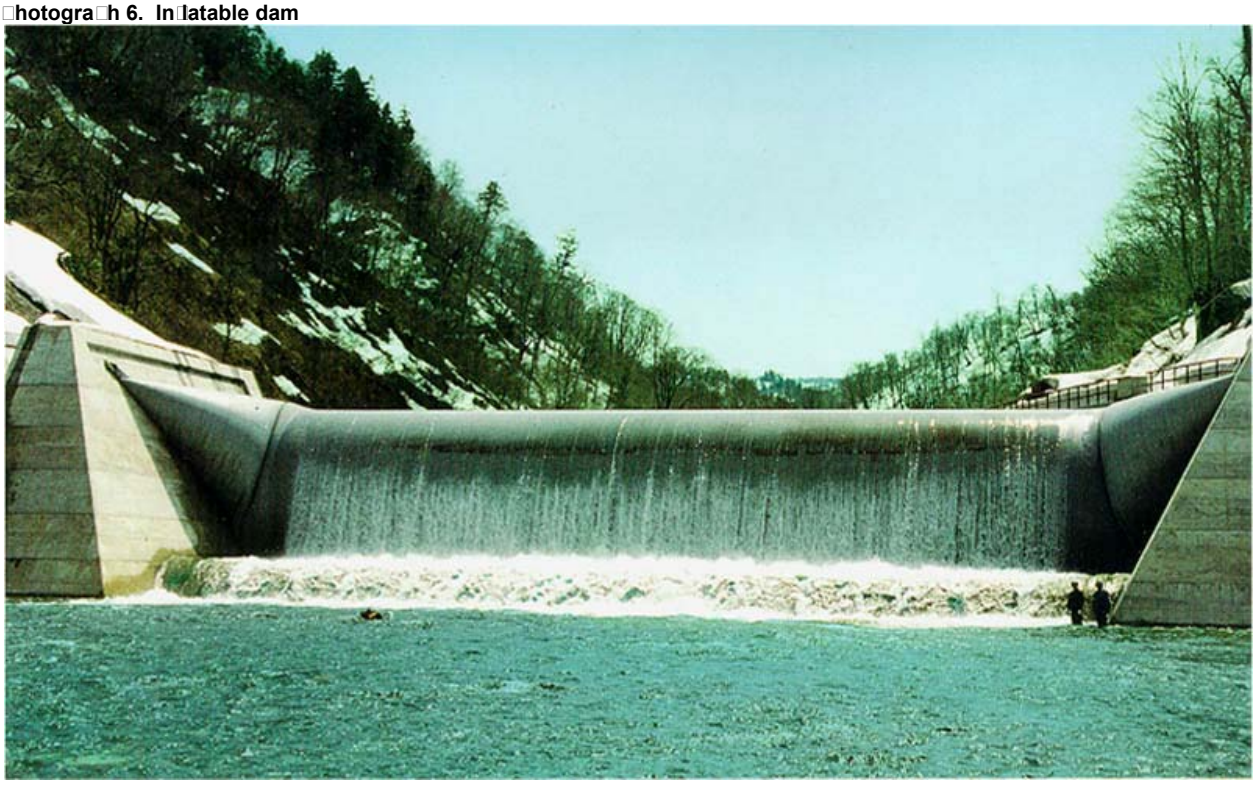
**□hotogra□h 5. □ascule gates**

## I□F□A□A□□E R□□□ER DAMS □WA□ER□A□D AIR□FI□□ED□

Inflatable rubber dams are installed across channels or streams as water control structures. The dam consists of a sheet of rubber-coated fabric (rubber body or bladder) which is fixed to a reinforced concrete foundation using clamp plates and anchor bolts. The dam is inflated by pumping air or water into the rubber body until the design height is reached. It is deflated by allowing the air or water inside the rubber body to escape. Air-filled bladders can be deflated or inflated more rapidly, and they are little affected by freezing conditions.

The Dyrhoff rubber dam (formerly Sumitomo) is an inflatable structure with different construction than the Bridgestone dam. The Dyrhoff rubber dam consists of layers of nylon fabric coated with synthetic rubber. Individual layers of rubber-coated fabric are bonded together to form a bladder which is fixed to the reinforced concrete foundation using clamp plates and anchor bolts. The Dyrhoff rubber dam (Sumitomo) dam ranked as the number 3 alternative in 2008 when cost was included as a consideration. When cost was not a consideration, the Dyrhoff rubber dam was the highest ranked alternative.

**□hotogra□h 6. In□latable dam**



## □□EE CRES□ WEIRS

An ogee crest is an overflow weir having an S-shaped cross section that is used to create an uncontrolled overflow spillway. The weir creates a permanent barrier across the river. When the water surface exceeds the elevation of the weir crest, flow occurs. Ogee crest weirs were mentioned as a potential alternative in a report from the original Town Lake Dam feasibility study. Because it is an uncontrolled structure that does not retract or lower during flood events. During flood events it would create considerable backwater and raise water levels upstream, and was therefore not considered further during this alternatives evaluation.

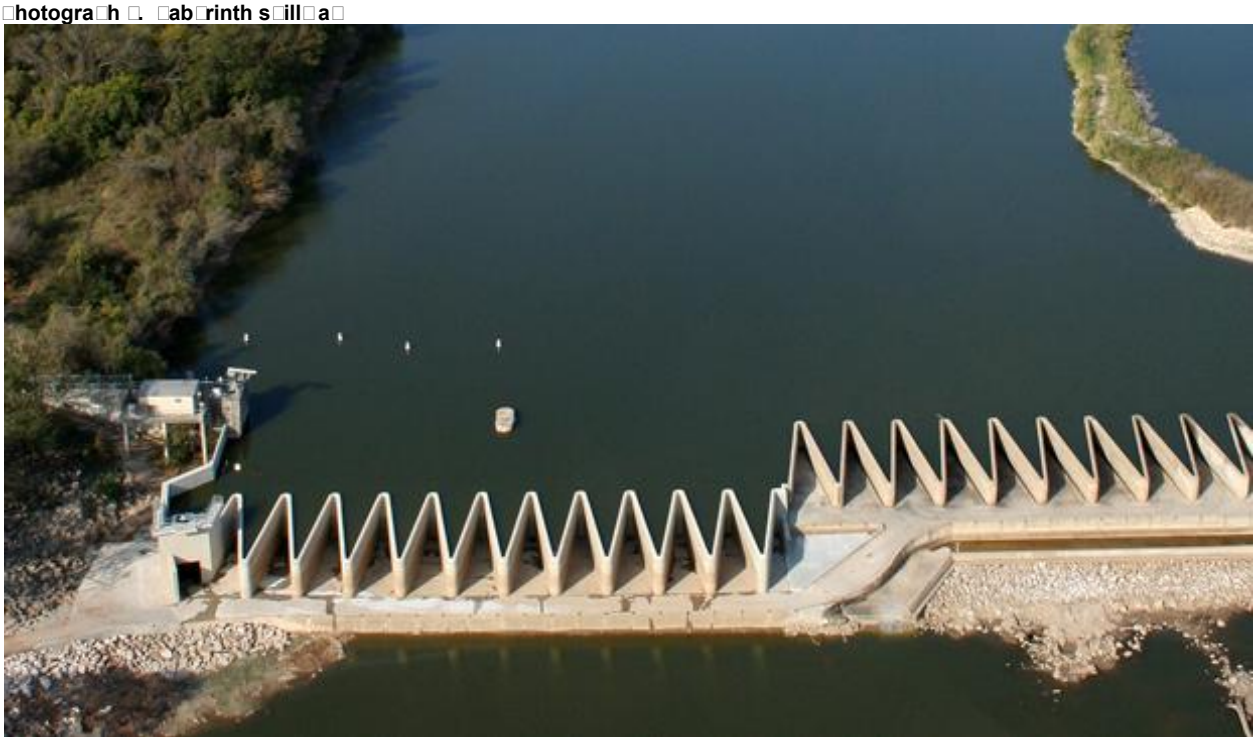
**□hotogra□h □. □gee crest □eir**

## □A□□RI□□H S□I□□WA□

A labyrinth spillway provides added crest length for a given total spillway width, so that less head is required to pass a given discharge. The additional spillway crest length is obtained by constructing a series of trapezoidal or triangular walls within the total spillway width. These walls are thin and cantilevered, vertical on the upstream face and steeply sloping (1:10 or 1:16) on the downstream face. They are supported with a concrete base slab or are tied into the foundation.

A labyrinth design is particularly beneficial when the spillway width is fixed, upstream water surface elevations are restricted, and large discharges must be passed with relatively little overflow depth. Labyrinths are particularly suitable for use at a reservoir site, either as a service spillway or an auxiliary spillway. Storage capacity can also be increased because the labyrinth crest can be set at a higher elevation than a straight crest while still passing the required discharge. Like ogee spillways, a labyrinth spillway is an uncontrolled structure that does not retract or lower during flood events. During flood events it would create considerable backwater and raise water levels upstream, and was therefore not considered further during this alternatives evaluation.

**□hotogra□h □. □ab□rinth s□ill□a□**



## F□SE □□□□S

A fuseplug, or fusegate, is a non-mechanical structure consisting of three main components; a bucket, a base, and an intake well connected to a chamber in the base. Fusegates are designed to breach and wash out when overtopped, and can often be used as a low cost substitute for some or all gates in a spillway control structure. Under normal operating conditions, the fusegate functions like an aerated labyrinth weir for discharges up to the design discharge. For discharges greater than the design flow, flow enters the chamber at the base of the gate through the intake wells. As flow increases, increased pressure in the bottom chamber exerts an uplift force on the gate, causing it to become unstable and tilt by rotating about its downstream edge and be washed out.

In addition to lower capital costs, fusegates have the advantage that breaching is designed to be automatic whenever overtopping occurs and they do not require electrical or mechanical controls to function. Fusegates can be designed to breach sequentially so that only as many fuse gates are activated as needed to pass the required flow.

Fusegates cannot be replaced during flooding, making re-establishment of the Lake by capturing the tail end of the flow impossible. For this reason, fusegates were not considered a viable alternative during the 2008 alternatives study. However, the project team reconsidered this criterion and made capturing the tail end of the flow a “should have” criterion rather than a “must have” criterion, if cost advantages were significant and other criteria could be met. Therefore, fusegates were considered during this alternatives evaluation, particularly as a part of a combined alternative that incorporates fusegate in one or more spans and another structure type in the remaining spans.

**□hotogra□hs □ and 1□. Fusegates**

## □□E□MA□ICA□□□ □□ERA□ED HI□□ED CRES□ □A□ES □□ □ERME□ER□

Obermeyer spillway gates are patented bottom-hinged crest gates produced by Obermeyer Hydro, Inc. Obermeyer gates consist of a row of steel gate panels supported on their downstream side by inflatable air bladders. The upstream water surface elevation is maintained by controlling the pressure in the bladders and thus the height of the bladders. Obermeyer gates can be operated continuously over a broad range of gate positions, flow rates, and water surface elevations. In addition, groups of gates can be operated independently to allow various discharges. The Obermeyer gate system can be installed with or without downstream panels to protect the rubber bladders from vandalism and weathering and to enhance aesthetics.

During the 2008 alternatives study, Obermeyer crest gates had the highest overall ranking of any project alternative when cost was included as a consideration. When cost was not included as a consideration, this alternative ranked second to the Dyrhoff (Sumitomo) rubber dam alternative.

**□hotogra□h 11. □berme□er gate**

## H□DRA□□ICA□□□ □□ERA□ED HI□□ED CRES□ □A□ES

Hinged crest gates are bottom-hinged steel panel gates operated by means of hydraulic cylinders attached at each end of the gate panels. The gate panels and hydraulic cylinders could be attached to the existing concrete piers to which the rubber dams are mounted.

The length of the gates is limited due to gate deflection and other structural considerations. This width limitation would necessitate construction of additional intermediate piers to support the hydraulic cylinders and form side seals for the gates. The cylinders raise the gates, which lower under their own weight plus the force of the water acting on the gate.

During the 2008 alternatives study, hydraulically-operated hinged crest gates were ranked as the number 2 alternative when cost was included as a consideration. When cost was not a consideration, this alternative ranked below both the Obermeyer crest gate and the Dyrhoff rubber dam alternatives.

**□hotogra□h 12. Hinged crest gate**

## □RID□ES□□ □E D□A□ □□D□ R□□□ER DAMS

The 2008 alternatives study included evaluation of a dual body rubber dam under development by Bridgestone. At that time, the Bridgestone dual body rubber dam ranked 4 overall during the Phase 1 alternative screening and was recommended for further development and Phase 2 analysis. However, Bridgestone discontinued sale of rubber dams during the 2008 alternatives analysis process and so this alternative was not carried through Phase 2.

## □ER□ICA□ □IF□ □A□ES

Vertical lift gates are rectangular in shape and consist of a structural framework to which a steel skin plate is attached, normally on the upstream side. The hydrostatic load on the gate is transferred to the concrete structure through surfaces located in slots formed into the sides of the piers. The gate moves vertically within these slots in its own plane on a type of sliding bearing which characterizes the gate as a slide gate, wheel gate, tractor gate, etc.

Lift gates are operated by hoists to allow water to pass beneath. The gates would need to be constructed downstream of the proposed bridge to prevent interference between the pedestrian bridge and the superstructure required to operate the gates. The superstructure would extend to a height greater than twice the height of the gates to allow operation of the gates.

During the 2008 alternatives study, vertical lift gates ranked number 5 during the Phase 1 alternative screening and was not retained for Phase 2 alternatives comparison and ranking.

**□hotogra□h 13. □ertical li□t gate**

## SWI□□ □A□ES

Swing gates are often used to regulate flow on navigable rivers and as a barrier against tides and wave action. The gates consist of a structural framework and steel skin. They are operated by either torsion of the gate at the piers, or through a cable system from a pier that extends upstream. The gates would span the existing piers, maintaining the existing effective flow area. The existing piers would require additional reinforcement and the addition of concrete to form vertical faces for sealing. Either extension of the piers or additional equipment within the existing piers would be required for operating the gate. There is no known instance where swing gates have been used for dam operations in an active river channel and they have not been proven for this situation. During the 2008 alternatives study, swing gates were not considered a viable alternative and were not included in the alternatives ranking procedure.

**□hotogra□h 14. S□ing gate**

## F□□DA□□E □R C□□□A□SA□□E F□SE□A□ES □H□DR□ □□□S□

A relatively new fusegate system, known as a “foldable” fusegate and developed by Hydroplus, was also evaluated during the 2008 alternatives study. The foldable fusegate does not overturn like the usual fuse gate and wash away downstream. The foldable action is similar to a hinged crest gate, where a series of struts on the downstream side of the gate fold over under flood loading, thus lowering the gate. After the flood has passed, the fusegates are raised back into position using a crane and the struts are reset. During the 2008 alternatives study, folding fusegates were not considered a viable alternative due to their inability to capture the tail end of the flood to reestablish the Lake, and were not included in the alternative ranking procedure. However, the project team reconsidered this criterion and made capturing the tail end of the flow a “should have” criterion rather than a “must have” criterion. Therefore, fusegates were considered during this alternatives evaluation, particularly as a part of a combined alternative that incorporates fusegate in one or more spans and another structure type in the remaining spans.

**□hotogra□h 15. H□dro□lus □olding □usegates**

## EAR□H EM□A□□ME□□□F□SE □□□□

Fuseplug embankments are typically located within an auxiliary spillway channel. They function in an analogous manner to a traditional or folding fusegates: they are designed to breach and wash out when overtopped. The embankment is designed to wash out in a predictable and controlled manner when additional spillway capacity is required, producing a deeper channel for higher operating heads on the auxiliary spillway crest or grade sill. Similarly to other auxiliary-type spillways, fuseplug embankments are generally designed to operate for floods having return periods of 100 years or more. When a wide spillway is required, the fuseplug can be divided into smaller sections using concrete walls, with each section constructed to a different elevation for operation at successively higher water surfaces. The entire fuseplug would therefore not wash out unless the full capacity of the spillway was required.

A fuseplug embankment is designed as a zoned earth and rockfill embankment with a sloping impervious core. The core is inclined so that as the downstream materials wash away, pieces of the core will break off under gravity loads and be carried away with the flow. A sand filter should be provided around the core to prevent piping of the finer silt or clay materials from cracks which may develop within the core. The compacted sand and gravel zones are designed to be noncohesive and easily erodible once the washout process begins. A pilot channel is typically provided within the embankment, having a crest 3 feet lower than the fuseplug crest. The outer zones for the pilot channel section are composed of slightly larger rockfill and fewer sand sizes to ensure a rapid break.

**□hotogra□h 16. Earth emban□ment□use □lug**

## C□M□I□ED A□□ER□A□I□ES

The existing Town Lake dam consists of four air-inflated rubber bladders, each approximately 200 feet long, anchored at the north and south abutments and at the three intermediate piers. One of the project objectives is to maintain the existing pier configuration and minimize structural modifications as much as possible. Significant modifications to the existing pier configuration that result in obstructions to flow would decrease the discharge capacity and have negative cost implications relative to alternatives that retain the existing pier configuration.

Because the existing pier configuration results in four spans, it would be possible to construct dam replacement alternatives using different types of dam(s) and/or spillway control structures in the different spans. For example, constructing a gravity dam in one or more of the spans in combination with a gate system in the remaining span(s) might reduce life-cycle costs associated with using gate structures exclusively. Several alternatives incorporating different dams and/or gate structures in the different spans between the existing piers have been suggested as possible dam replacement alternatives. Because the feasibility of such combined alternatives to meet the project objectives is largely a function of the hydraulic capacity of the alternatives, three mixed-type alternatives were evaluated. The configurations for the alternatives evaluated reduced the effective flow area by 50% and were selected to provide an understanding of the potential feasibility of a broad range of mixed-type alternatives.

Combined alternatives evaluated included the following:

1) Roller compacted concrete dams in the outer two spans and gate structures in the inner two spans.
2) Gate structures constructed on half-height roller compacted concrete dam in all spans.
3) Labyrinth weir in the outer two spans and gate structures in the inner two spans.

These alternatives were selected to assess whether reducing the effective area of the spillway by one-half would be feasible. These configurations would still allow capturing the tail end of the flood to maintain the water surface elevation in the lake. If it were feasible to reduce the effective area of the spillway by a significant amount, a number of alternatives could be envisioned that would meet the project objectives.

## E□A□□A□I□ □F A□□ER□A□I□ES

A one day Alternatives Evaluation Workshop was conducted on August 1, 2011 by the Project team, the City of Tempe, and selected stakeholders. The Workshop included a review of the project history, objectives, goals, and alternatives described above. The Project team reviewed and refined the project criteria developed for previous studies to develop the final, categorized list of project criteria against which to compare potential alternatives (see Table 1). The Project team also reviewed hydrologic and hydraulic modeling that has been performed on the Salt River to establish the hydraulic capacity of the Salt River at the Town Lake downstream dam (210,000 cfs) and the project design criteria as the 200-year storm event (207,000 cfs). The results of preliminary modeling of the 200-yr storm event performed to establish a range of backwater elevations that could be anticipated upstream from Town Lake Dam for the alternatives under consideration were presented.

The alternatives were discussed by the project team to assess their ability to meet the project criteria. When alternatives were determined to not meet the project criteria, they were considered

fatally flawed and were not considered further. Alternatives for which fatal flaws were not identified were retained for further analysis. The results of the workshop are discussed below and summarized in Table 3.

Radial gates, bascule gates, and the combined alternatives were all determined to be fatally flawed because each of these alternatives would require reduction in the effective area of the spillway during the design flood. Radial gates and bascule gates would require additional intermediate piers and the mixed-type alternatives, such as concrete dams in the outer spans and gates in the inner spans, include closed spans or portions of spans. These reductions in flow area result in increased water surface elevations behind the dam and increased upstream flooding. Examples of upstream flooding associated with reducing the flow area are shown in Figures 5, 6 and 7. The cost of vertical lift gates was deemed to be a fatal flaw because these gates would require an extensive superstructure and would have to be installed downstream from the existing dam location to avoid conflict with the pedestrian bridge. These requirements would necessitate extensive modifications to the existing structure. The structural integrity of swing gates could be compromised during the design flood and they would not be capable of capturing the tail end of the flood to maintain the lake level. Earth embankment fusepugs were fatally flawed due to their potential poor reliability. An earth embankment that retains water to maintain the lake level for some period of time may not quickly and predictably fail and wash out when conditions require. Upstream flooding would result if the embankment did not fail during the design flood.

The following four alternatives did not include fatal flaws and were retained for further analysis:

- Obermeyer Gate
- Hinged Crest Gate with Hydraulic or Electric Cable Operators
- Inflatable Rubber Dam
- Hydroplus Fuse Gate

Two of these alternatives, hinged crest gates and fusegates, include potential fatal flaws. However, the project team believed that design of these systems may be able to include sufficient mitigation measure such that they were still considered potentially viable alternatives at this stage.

Gannett Fleming
Your Trusted Advisor Since 1915

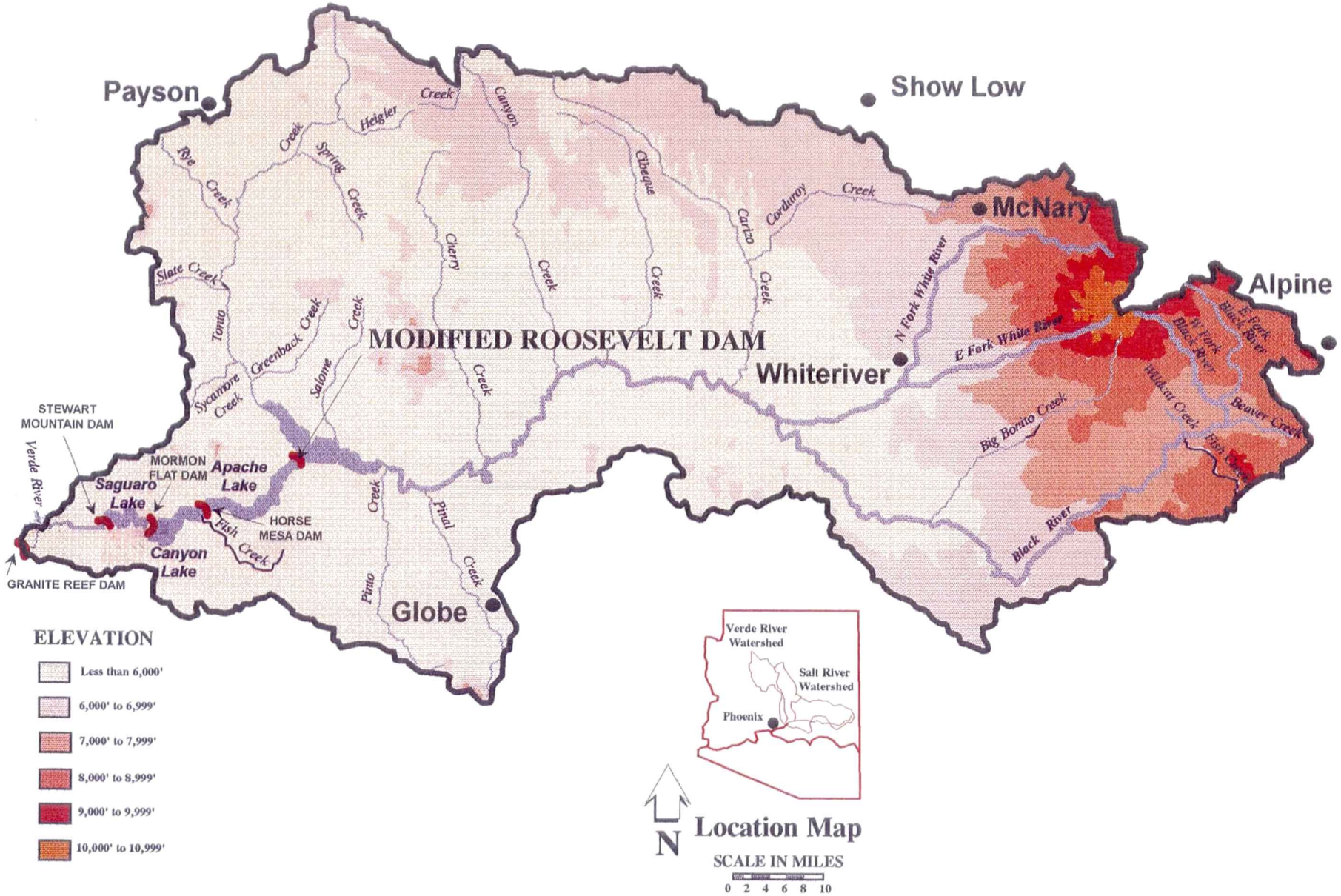
**□able 3. Summar□ o□Alternatives Evaluation Wor□sho□**

| □rimar□ □ro□ect ob□ectives | Categor□ | H□draulicall□Cable o□erated hinged crest gates | D□rho□□ rubber dams □Sumitomo□ | Radial gates □tainter gates□ | □ertical li□t gates | S□ing gates | □ascule gates | Fusegates □H□dro□lus□ | Earth emban□ment□use□lug | Combined: gate or rubber dam ato□ hal□□ height concrete dam | Combined: concrete dam in outer s□ans□gate or rubber dam in inner s□ans | Combined: lab□rinth □eir in outer s□ans□gate structure in inner s□ans | □neumaticall□ o□erated hinged crest gates □□berme□er□ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Safety | 1 | Yes | Yes | | | | | Yes | | | | | Yes |
| Maintain or improve current level of flood protection. | 1 | PFF (Area Limits) | Yes | FF | | | FF | Yes | PFF | FF | FF | FF | Yes |
| Minimize the reduction of flood passage capacity. | 1 | PFF (Area Limits) | Yes | FF | | | FF | Yes | PFF | FF | FF | FF | Yes |
| Minimize the increase in flood impacts to surrounding areas. | 1 | PFF (Area Limits) | Yes | FF | | | FF | Yes | PFF | FF | FF | FF | Yes |
| Ability to capture the tail end of a flood event to maintain the full lake condition during higher frequency events. | 1 | Yes | Yes | | | FF | | Yes | | | | | Yes |
| Maintain structural integrity of the dam under maximum design discharge. | 1 | Yes | Yes | Yes | | FF | | Yes | | | | | Yes |
| Reliably lowered when needed. | 1 | Yes | Yes | | | | | Yes | | | | | Yes |
| Design must be compatible with pedestrian bridge and immediate surrounding area. | 1 | Difficult | Yes | | | | | Yes | | | | | Yes |
| Meet the December 28, 2015 Bridgestone contractual requirement for replacement. | 1 | Yes | Yes | | | | | Yes | | | | | Yes |
| High degree of reliability. | 1 | Yes | Questionable | | | | | Yes | FF | | | | Yes |
| Meets regulatory requirements. | 1 | Yes | Yes | | | | | PFF | | | | | Yes |
| Is cost a fatal flaw? | 1 | No | No | | Yes | | | PFF | | | | | No |
| Demonstrated performance in this climatic environment. | 1 | Yes | PFF | | | | | ? | | | | | Verify |
| Ability to capture the tail end of a flood event to maintain the full lake condition during design flood. | 2 | Yes | Yes | | | | | No | | | | | Yes |
| Minimize operations and maintenance costs. | 2 | Issues | Yes | | | | | Yes | | | | | Yes |
| Simplicity of operation. | 2 | Yes | Yes | | | | | Yes | | | | | Yes |
| Proven technology. | 2 | Yes | Questionable | | | | | Yes | | | | | Yes |
| Design that allows the lake to be maintained during construction. | 2 | Need cofferdam | Need cofferdam | | | | | Yes | | | | | Yes |
| Maintain current lake bottom grade. | 2 | Yes | Yes | | | | | Yes | | | | | Yes |
| Minimize downstream scour. | 2 | Yes | Yes | | | | | Yes | | | | | Yes |
| Vandalism prevention. | 2 | Good | PFF | | | | | Yes | | | | | Yes |
| Maintain original design lake level. | 2 | Yes | Yes | | | | | Yes | | | | | Yes |
| Minimize environmental impacts. | 2 | Yes | Yes | | | | | Yes | | | | | Yes |
| Aesthetically compatible. | 2 | Yes | Yes | | | | | Yes | | | | | Yes |
| Maintain the existing pier configuration and minimize structural modifications as much as possible. | 2 | No | Yes | No | | | | Yes | | FF | FF | FF | Yes |
| Alternative Carried Forward? | | Yes | Yes | No | No | No | No | Yes | No | No | No | No | Yes |

PPF = Potential Fatal Flaw - A feature or characteristic of an alternative that may render it unable to meet “must have” project criteria.

FF = Fatal Flaw – A feature or characteristic of an alternative that renders it unable to meet “must have” project criteria.

# FIGURES

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# Roosevelt Dam Watershed

Figure: 1

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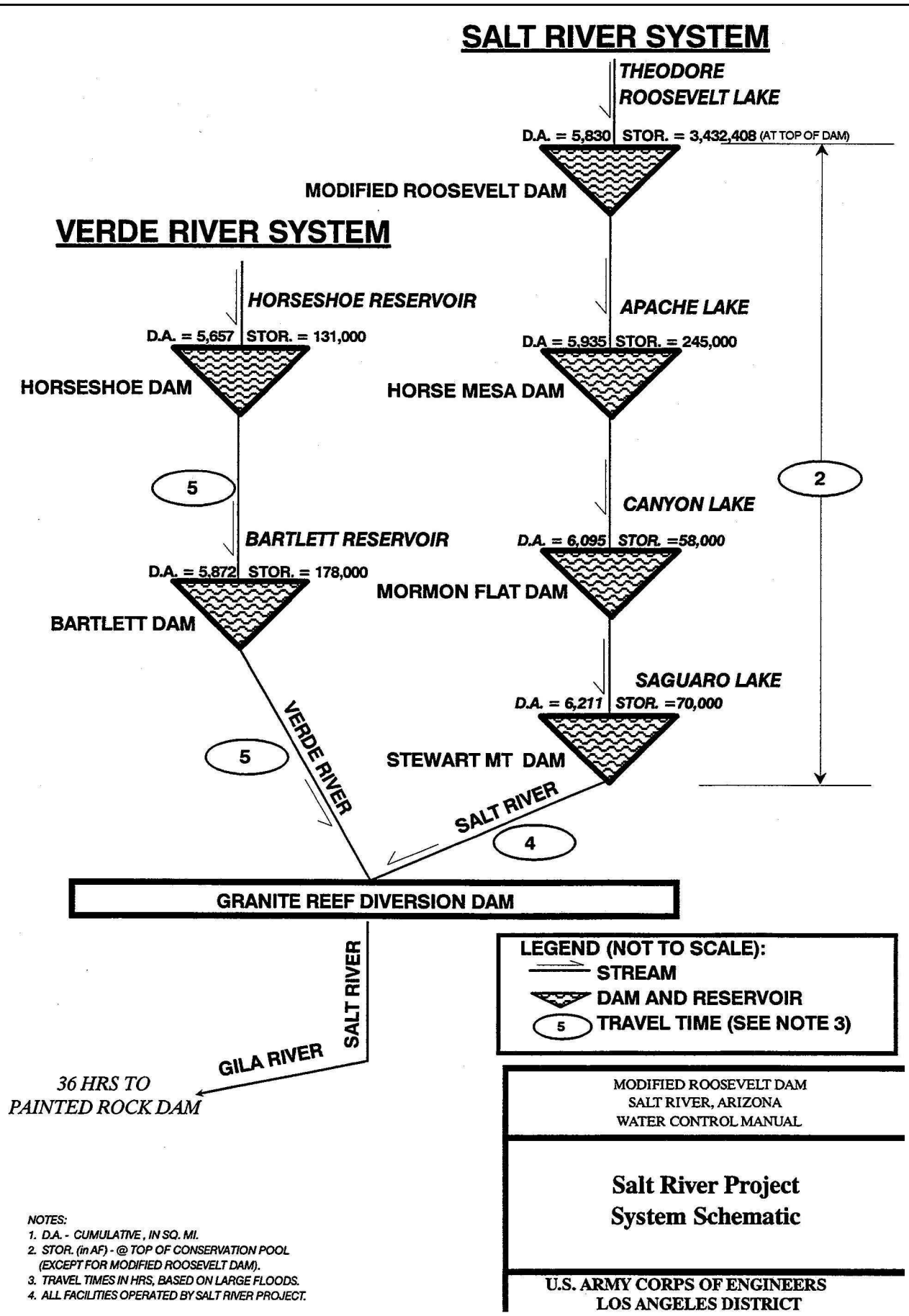


NOTES:
1. D.A. - CUMULATIVE, IN SQ. MI.
2. STOR. (in AF) - @ TOP OF CONSERVATION POOL (EXCEPT FOR MODIFIED ROOSEVELT DAM).
3. TRAVEL TIMES IN HRS, BASED ON LARGE FLOODS.
4. ALL FACILITIES OPERATED BY SALT RIVER PROJECT.

MODIFIED ROOSEVELT DAM
SALT RIVER, ARIZONA
WATER CONTROL MANUAL

**Salt River Project System Schematic**

U.S. ARMY CORPS OF ENGINEERS
LOS ANGELES DISTRICT

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# Salt River Watershed Schematic

Figure: 2

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# Aerial Image

Figure: 3

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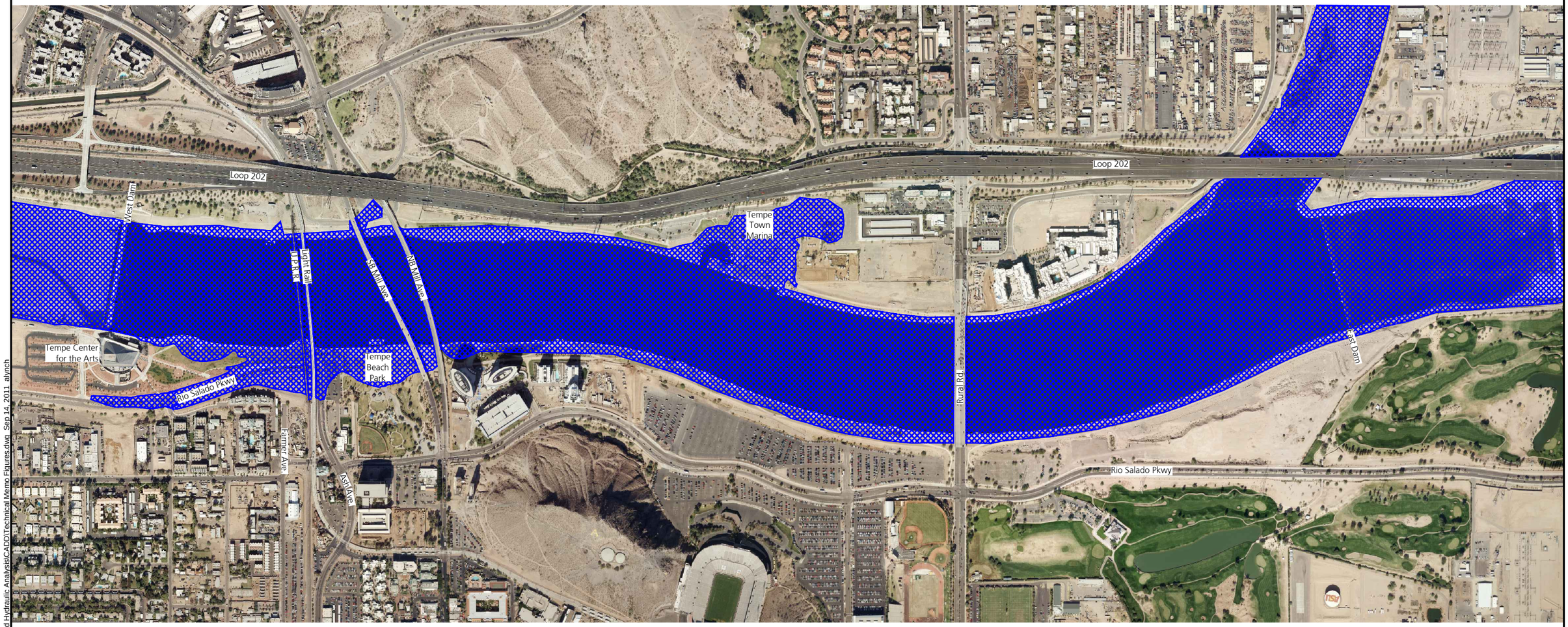


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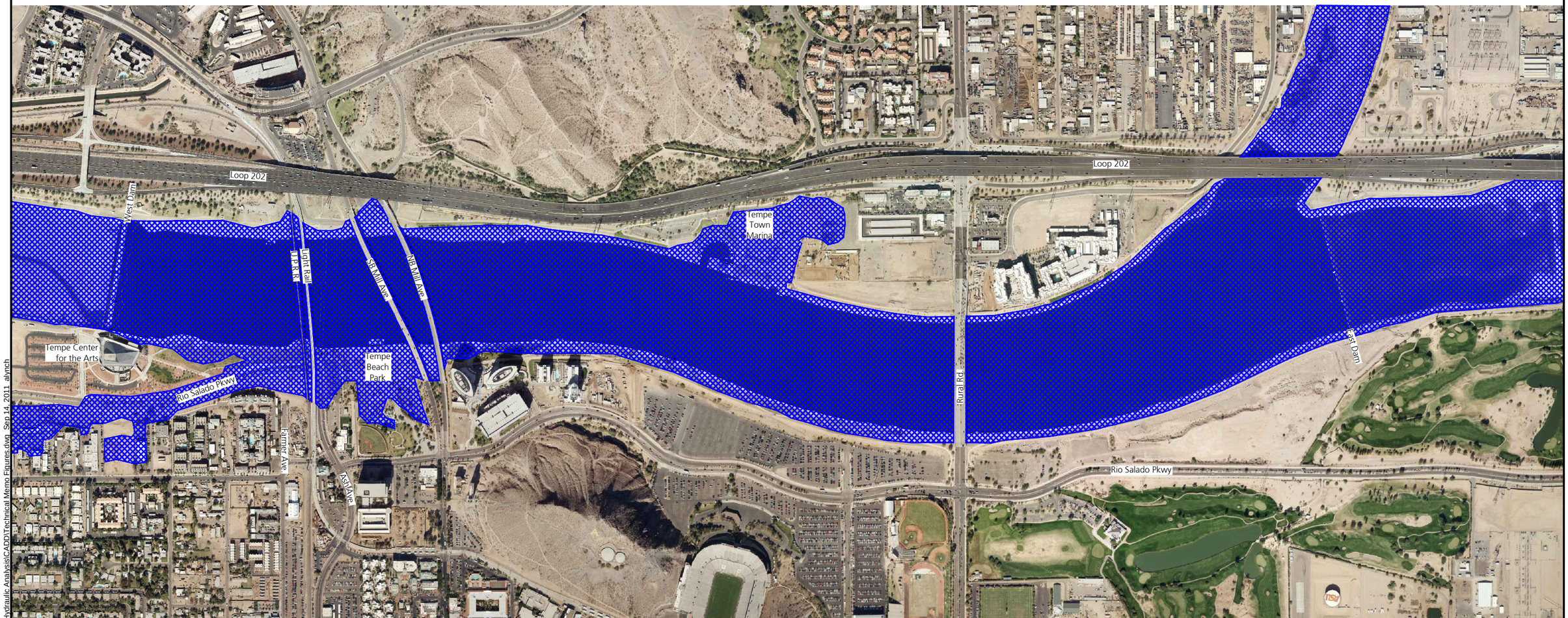
# Existing Conditions Flooding Area

Figure: 4

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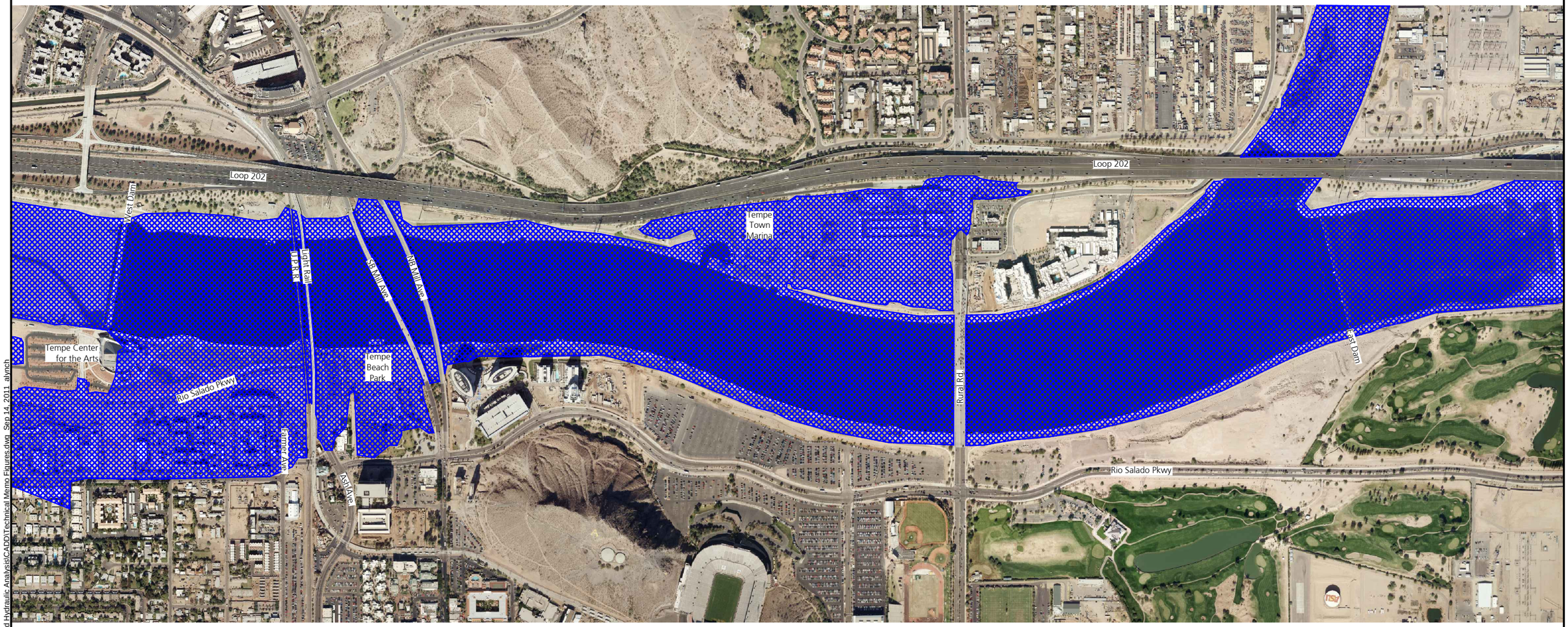
# Hinged Crest Alt. Flooding Area

Figure: 5

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# Combination Alt. Flooding Area

Figure: 6