Final Report

TRAction Visioning Project

Prepared for

City of Reno

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Executive Summary

The City of Reno TRAction Visioning Project is an element of the Truckee River Flood Management Project's (TRFMP) master plan to provide improved safety along the Truckee River Corridor through the Truckee Meadows region in Washoe County. The reach of the river that runs through downtown Reno has unique land use and transportation needs and is experiencing a significant amount of redevelopment. The City of Reno has taken a leadership role in working with the TRFMP to determine the best solutions for improved flood protection in downtown Reno. This study is one step in defining the City's needs and opportunities and the constraints that exist for implementing any improvements.

Initial criteria from the outset of this study is that the downtown bridges serve as physical barriers during high river flow events and will need to be replaced with structures that pass significant high river flows and prevent flooding in downtown Reno.

The initial objective of this study was to determine the City's and community's vision for the "look and feel" of the replacement bridge structures along the reach of the Truckee River Corridor through downtown Reno, Nevada. In order to address what options the City would have for architectural and aesthetic treatments for the new bridges, the City and the Study Team agreed that some core design criteria would need to be determined in order to guide the "look and feel" of the bridges as they each become ready for replacement. The City directed the Study Team to create a technically accurate and updated hydraulic model of the downtown reach of the corridor in order to inform decisions on the best design criteria for flood protection. With updated survey and flood data from the 1997 and 2005 flood events, a revised model was built and used to determine the effects of various bridge and roadway designs and their impacts to the surrounding built environment and the viewsheds along the river corridor.

In support of the City's goal of developing criteria that would be reflective of the community's vision for the corridor, a public outreach effort designed to be inclusive of all interested parties within the City was developed as part of this study. This effort provided multiple avenues for community members to follow the study's progress and provide input on their vision for the corridor. The outreach effort included three public workshops as well as presentations for interested community groups and a project Web site. The primary focus of each of the Public Workshops is as follows:

- Workshop #1 provided an overview of the project objectives, parameters, and process. The workshop also included a "walking tour" slideshow of the corridor, a presentation discussing the goals and objectives of the TRFMP as they relate to the TRAction Visioning Project, and a presentation introducing potential bridge types and conceptual flood control options along with their potential aesthetic and structural impacts.
- Workshop #2 presented conceptual graphics and renderings depicting the limits of roadway reconstruction associated with the 50-year, 74-year, 100-year with 4-foot freeboard (U.S. Army Corps of Engineers [USACE] criteria), and 100-year with 2-foot freeboard flood protection design options. Flood impacts associated with the Virginia

Street Bridge were also illustrated to provide the public with a better understanding of the impacts the current bridge design has on flooding.

- Workshop #3 focused primarily on the 74-year and 100-year with 2-foot freeboard designs (feedback during previous workshops found the 50-year and 100-year USACE criteria to be generally unfavorable options) and the various bridge types to be considered in an effort to determine community preferences. Conceptual renderings were provided to give the public a sense of the aesthetic, roadway reconstruction, and structural impacts associated with the 74-year and 100-year design options. Conceptual renderings were also presented depicting below-supported, cable-stay, and tied-arch bridge types, providing a visual reference for the potential impacts each of these bridge types might have on the aesthetics and viewshed within the corridor. Attendees were provided with a survey form to gauge preferences between bridge types and level of flood protection.

Detailed workshop summaries including attendee rosters, public comment, presentation content, and Workshop #3 survey findings are located in Appendix H.

Negative community response to the more conservative criteria used by the USACE of 100-year flood protection with 4 feet of freeboard (clearance between the bottom of the bridge deck and the highest point of the water surface elevation) led the City to develop local design criteria. These locally preferred criteria better reflected the community values and were more acceptable based on the reduced physical impacts to the surrounding built environment and the reduced visual impacts along the river corridor. Lower elevations in roadway approaches and bridge decks create less impact to surrounding businesses, pedestrian and bicycle pathways, and viewsheds upstream and downstream along the river corridor.

Understanding the community appetite to maintain existing access to, from, and across the river along the downtown corridor, while still improving flood protection in downtown Reno, provided the direction required to develop the recommended design criteria.

Through the hydraulic analysis, roadway and bridge design, and community input, the Study Team arrived at the following conclusions and recommendations:

1. 100-year flood design, with 2 feet of freeboard, will provide for adequate protection through the downtown reach of the river corridor. This scenario meets the Federal Emergency Management Agency (FEMA) requirements for improved flood protection and allows a 100-year event to be maintained within the river channel.

2. A bridge structure that is supported by foundations beneath the bridge deck will provide a safe travel way, less expensive replacement costs, and an opportunity for pedestrian and bicycle pathways on the north and south sides of the river; will maintain existing viewsheds upstream and downstream of the river corridor; and will allow for architectural design and artistic influences to be reflected in each of the replaced structures. Bridge structures, which include foundations beneath the bridge deck, will require the development of a debris management plan to address potential debris accumulation around the piers at each bridge location during flood events.

3. Any other options, such as channel widening, dredging, or use of moveable bridge structures, are not low-risk, feasible options to maintain adequate flood protection in the long term and would be at risk of being higher cost solutions for the long term as well as the potential for causing or creating other reasons for flooding in the downtown during large flow events.
4. Community input on the "look and feel" of the structures can be accommodated under these design and replacement parameters.

While the conclusions presented in this study provide some baseline design criteria and assumptions, as each bridge is under consideration for replacement, unique challenges will need to be resolved. Each bridge location has a unique set of constraints and opportunities and will require individual considerations to make the implementation of these design criteria and assumptions acceptable to the community.

The body of this report presents the basis and justification for the Study Team's conclusions and recommendations. It also includes discussion of the various flood design year options and bridge types that were considered through the alterative analysis process.

Contents

Tables

Figures

Appendixes

Acronyms and Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
DTM	digital terrain model
FEMA	Federal Emergency Management Agency
ft^3/s	cubic feet per second
HEC-RAS	Hydrologic Engineering Center River Analysis System
LPP	Locally Preferred Plan
MCACES	Micro-Computer Aided Cost Engineering System
NDOT	Nevada Department of Transportation
NED	National Economic Development
TRFMP	Truckee River Flood Management Project
USACE	U.S. Army Corps of Engineers
WSEL	water surface elevation

1.0 Study Process and Methodology

The initial scope of work for this study was defined to identify the aesthetic and architectural themes and treatments for the four downtown bridges—Sierra, Virginia, Center, and Lake Street crossings—plus two upstream bridges at Arlington Avenue and Booth Streets.

The primary assumptions for this study were to consider the following design criteria for the bridge structure type:

- Clear-span bridges
- 100-year flood protection
- 4 feet of freeboard (following the U.S. Army Corps of Engineers [USACE] base criteria)

An early task in the study, not directly related to the contract scope of services, was direction by the City to prepare a USACE-formatted Micro-Computer Aided Cost Engineering System (MCACES) Cost Estimate for the replacement of the four downtown bridges. The purpose of this activity was to provide the USACE with a detailed cost analysis for the Environmental Impact Statement as part of the entire Truckee River Flood Management Project (TRFMP). As the Team completed this task, using the previously stated design assumptions, the main objectives of the study were initiated.

The Team first presented the concept to the City and the public to consider this reach of the Truckee River Corridor (from Booth Street downstream to Lake Street) as three distinct "zones" that would each lend themselves to different opportunities for aesthetic, architectural, and access features (see Figure 1-1). The concept of Zones A, B, and C were developed and defined as follows:

- **Zone A: Residential Zone.** This zone extends along Riverside Drive from Booth Street to west of Arlington Avenue and is primarily residential with pedestrian and bicycle use along the north side of the river corridor.

- **Zone B: Wingfield Park Zone.** This zone encompasses the area around Arlington Avenue and is primarily recreational with Whitewater Park and river access for recreational uses and bicycle and pedestrian use along the north side of the river.

- **Zone C: Downtown Zone.** This zone extends from Sierra Street to Lake Street. It has mixed land uses with residential, commercial, and recreational uses; pedestrian and bicycle use along the north and south sides of the river corridor; parking along Sierra, Virginia, and Lake Street Bridges; and downtown redevelopment activity with projects such as the Post Office Plaza, the 10 North Virginia Plaza, and the new ball park stadium, with commerce and mobility on surface streets the primary focus.

However, as the City received feedback from the community that the "zone" concept was an acceptable method for considering aesthetic and architectural features, a significant premise of the initial design assumptions was challenged and the design approach headed in a new direction, as discussed in Section 1.1. The focus for the balance of the study became the Downtown Zone. Further discussion on unique architectural and aesthetic treatments by zone will occur on a project-by-project basis.

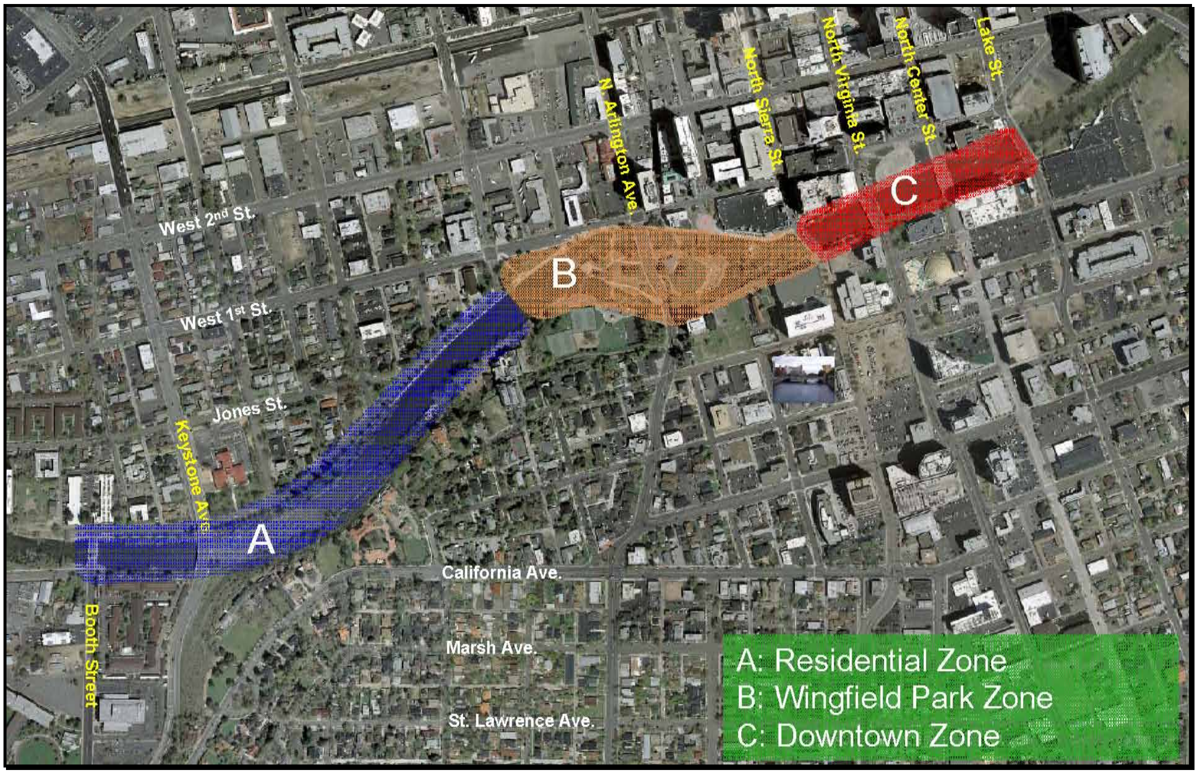

FIGURE 1-1
Truckee River Corridor "Zones" Concept

1.1 Redirecting Design Assumptions

Following the debut of the project at Workshop #1 in three different locations around Reno, the consensus of the public feedback was that the height of the bridge structures designed to meet the 100-year flood protection with 4 feet of freeboard resulted in unacceptable impacts, both physically and visually, particularly in the downtown reach of the river corridor. The significant increases in the roadway elevations and heights of the bridges over the river created major impacts to surrounding businesses, pedestrian facilities, and visual obstructions through the river corridor.

The City then directed the Study Team to consider other levels of flood protection and freeboard criteria that would improve flood protection along the river corridor and also reduce the physical and visual impacts of the bridge structures.

1.2 Study Process Steps Forward

The methodology discussed with the City for moving forward with the study followed this process:

- Conduct a topographic field survey to produce a more accurate and detailed hydraulic model of the downtown reach of the river corridor (east of Arlington Avenue to the Second Street and Kuenzli Bridges)
- Assume 2 feet of freeboard for design and modeling analyses to be consistent with the Nevada Department of Transportation's (NDOT) minimum freeboard requirements at bridges and to reflect community preferences
- Calibrate the new hydraulic model using existing flood data from the 1997 and 2005 events
- Determine flood protection scenarios that would be reasonable to develop conceptual-level designs for bridge replacements
- Provide conceptual-level roadway and structure designs for each of the flood protection scenarios
- Assume continuous pathways on both the north and south sides of the river between Sierra and Lake, with the exception of the south side access between Center and Lake Streets so as not to assume the Siena Property would be interested in an all-access pathway
- Develop design impact conceptual drawings for 50-year, 74-year, 100-year with 2-foot freeboard, and 100-year with 4-foot freeboard (USACE criteria) to be presented at Workshop #2
- Present conceptual designs and flood protection effects to public for Workshop #2; four different levels of flood protection and the resulting impacts of implementing those levels were shared with the community to understand the tradeoffs between improved flood protection and impact to the surrounding built environment
- Present inundation scenario to demonstrate flood impacts if the Virginia Street Bridge was maintained and Sierra, Center, and Lake Street Bridges were replaced.

Community response during Workshop #2 showed the strongest support for the 74-year and 100-year with 2-foot freeboard designs. Following the outcome and feedback of Workshop #2, the following methodology was defined along with the City staff to move the study toward a final recommendation:

- Present choices of bridge structure types
- Prepare and present planning-level cost estimates for bridge types and approach roadway reconstruction
- Prepare visual simulations comparing the 74-year (design year determined based on the water surface elevation of the 2005 flood event in Reno, Nevada) and 100-year designs
- Present to City Council the 74- and 100-year design scenarios for two different bridge types
- Prepare for Workshop #3 to have final public input opportunity on design year and structure type

- Reach agreement with the City that the aesthetic and architectural treatments for each bridge would be determined at the time of planning and design for each bridge project as it moved forward
- Reach agreement that this study would present the recommended design year and general structure type

Following the City Council Presentation on September 10, 2008, several questions arose regarding other methods of flood protection. The City asked for the Team to summarize previous studies and conduct some new analysis on the following flood protection scenarios:

- Upstream detention
- Deepening or widening the river channel
- Moveable/lift bridges

The intent for this step in the process was to evaluate these additional scenarios and provide enough justification to substantiate the need for conventional bridge replacement at the four downtown locations.

Workshop # 3 was then conducted to present physical and visual impacts of the 74- and 100-year flood design choices and the bridge types. The City asked the public for their preference of these choices and gave them a chance to learn more about the alternative methods of flood protection.

Finally, the City's direction was to provide a final report to document the study process, the analysis, and the public feedback and to present a recommendation to the City of the best and most feasible flood protection solutions for the river corridor.

This study process was dynamic and used the workshops as milestones to make decisions about how to proceed and where to focus the analysis, design, and simulation efforts. It was an incremental methodology, building consensus along the way with the City and the TRFMP in order to meet the final desired outcome of a flood protection design year and bridge type.

The rest of this report will summarize the details of each of these steps in the process and draw conclusions building on the results of each step.

2.0 History of Hydraulic Modeling in the Truckee River Downtown Reach

The Truckee River channel modeling work described in this report was built on previous hydraulic modeling efforts, which have been underway for nearly two decades. The known previous modeling conducted by several entities is briefly described in this section.

A physical, 1:30-scale model of the Truckee River was developed to determine the adequacy of the USACE's proposed channel improvements. The model reproduced approximately 3,200 feet of the Truckee River running through downtown Reno, Nevada. Tests conducted with these proposed channel improvements (assuming a design flow at 18,500 cubic feet per second [ft^3/s]) indicated areas within the modeled reach would need modifications to improve flow conditions (Stockstill, 1992). Documentation from this study was archived in the mid-1990s and later was lost (Forest, 2008).

An FLO-2D model was then constructed by Tetra-Tech. This model was used to replicate the January 1997 flood event and is discussed in the USACE report *Unsteady HEC-RAS Model of the Downtown Reach of the Truckee River* (USACE, 2005).

The USACE later determined that the FLO-2D model should be replaced with a Hydrologic Engineering Center River Analysis System (HEC-RAS) steady flow model. This model was calibrated to the 1997 flood event. This model begins at about 2 miles upstream of Mayberry Drive, west of downtown, and ends to the east at the US 395 crossing. Subsequently, the USACE created a calibrated, georeferenced, unsteady HEC-RAS model of the downtown reach, using the older steady-state model as much as possible. This study was documented in the previously mentioned 2005 USACE report. An important observation was made in this report relating to debris assumptions and simulation. The report stated that debris was simulated as 4-foot-thick floating debris associated with each pier at widths that extended 6 feet beyond the pier on both sides. If, however, the energy grade line reached the bridge soffit, the assumption was made that debris would accumulate along the entire low chord of the bridge at a thickness of 4 feet. A similar approach was taken in the current modeling effort discussed in this report (see Section 2.2, Modeling Approach and Methods).

2.1 Bridge Modeling of the Downtown Reach

As part of this study effort, a new steady-state hydraulic model of the Truckee River in downtown Reno has been developed using HEC-RAS version 4.0. The objective of this work was to create an updated hydraulic model for the Truckee River in the area between Arlington Avenue upstream and East 2nd Street downstream using updated field survey, geometry, and calibration data. This model includes simulations of water surface profiles resulting from 50-year, 74-year, and 100-year return period flood flows, under both existing conditions and proposed new bridge configurations. Geometry data for this model came from two sources including a topographic field survey and an existing electronic digital terrain model (DTM) file for the overbanks. The field survey provided river channel geometry and bridge geometry data. This model was calibrated using photos taken of the river during actual flood events where flow rates were known and recorded. This model is intended to supplement the USACE model that was developed through the earlier modeling efforts.

2.2 Modeling Approach and Methods

This section describes the approach and methods used to develop the existing conditions base model and future conditions models of the Truckee River downtown reach.

2.2.1 Model Input Data

The study team developed a contour file from a DTM to represent the topography of the overbank areas along the channel. The original DTM (with 1-foot contours) came from Washoe County. A topographic survey was conducted by the study team to accurately characterize the stream channel and bridges. These survey points were incorporated into the DTM to create a single geometric model of the channel, structures, and overbanks. Cross sections were cut for the channel and channel overbanks using this data and entered into HEC-RAS. The mapping information for this project is based on the 1988 vertical datum and the Nevada State Plane Grid horizontal datum. A map showing locations of the surveyed cross sections and a contour map are included in Appendix A of this report.

As-built drawings of the Arlington, Sierra, Virginia, Center, and Lake Street bridges were obtained and evaluated to ensure accuracy of bridge modeling. Information from these drawings (such as curvature of the bridge piers) was incorporated into the HEC-RAS model.

Photos taken during the 2005 flood event were obtained from various sources (mostly from the internet) and evaluated as part of the modeling effort to help link the 2005 flood flow rate to the water surface elevation (WSEL) at some of the bridges in the downtown reach. The 2005 photos used for this analysis (including photos from other flood events) are shown in Appendix B.

2.2.2 Model Calibration

An existing-conditions HEC-RAS model simulating the 2005 flood flow through the channel, bridges, and overbanks was developed using the input data previously described. The estimated peak flow rate through the downtown reach during this flood event as recorded at the Reno U.S. Geologic Survey gage was 16,400 ft^3/s. The existing conditions model was calibrated by adjusting Manning's *n* values and other loss factors used in HEC-RAS to adjust WSEL. These factors were adjusted until the WSEL at bridges matched to within relative accuracy of what the 2005 flood photos portrayed.

During the 2005 event, the City of Reno positioned a trackhoe on the Virginia Street Bridge that removed floating debris from the upstream face of the bridge. Removal of the debris from the model allowed for better calibration of the hydraulic model by better simulating the actual condition.

Figure 2-1 shows the comparison of the simulated water surface profile with the flood elevations as they appeared in the bridge photos taken during the 2005 flood. In this figure, the solid dots refer to calibration points (taken from photos), and the bold line refers to the simulated 2005 flood water surface profile.

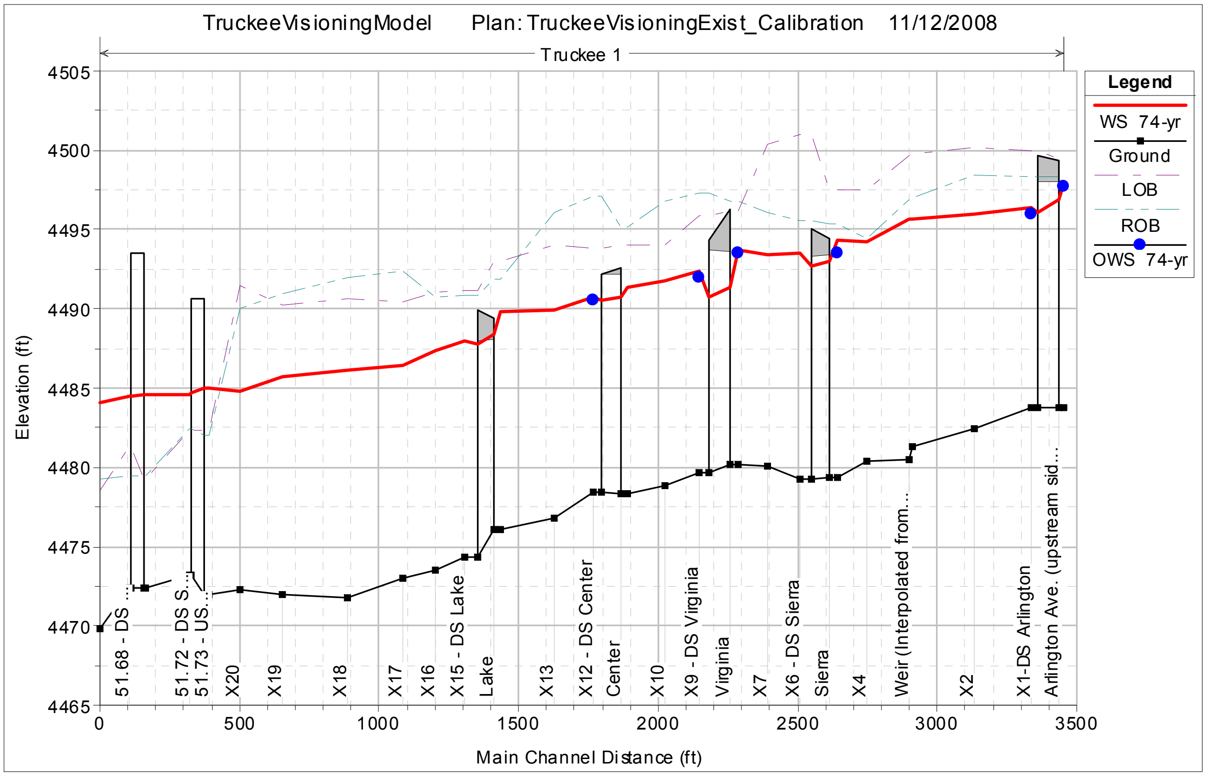

FIGURE 2-1
Hydraulic Profile Truckee River Downtown, 2005 Flood Event Calibration
*LOB = Left Overbank, ROB = Right Overbank, OWS = Observed Water Surface

Tables of the Manning's *n* values and other loss factors used for the model calibration are included in Appendix C of this report.

2.2.3 Flows Used in Modeling Existing and Proposed Bridge Structures

For the bridge modeling efforts, three different flood flows were analyzed. Table 2-1 summarizes the flows corresponding to the return period of the events. The analysis of the 2005 flood flow concludes that this event is approximately equivalent to a 74-year flood event.

TABLE 2-1
Flood Flows

Recurrence Interval	Flow Rate (ft^3/s)
50-year	13,684
74-year[(1)]	16,400
100-year	20,676

NOTE:
[(1)]The 2005 flood flow is assumed to be approximately equivalent to a 74-year flood event.

2.2.4 Methods for Modeling Bridges

The energy flow method is used to calculate WSEL at the bridges during low flow regimes. For high flow (flow over the bridge), the pressure and weir method is used with a submerged inlet and outlet coefficient of 0.8.

All proposed new bridges in the HEC-RAS model were assumed to have a single center pier. A sensitivity analysis conducted on the effect of the bridge pier found that the WSEL rises less than 0.2 foot with the pier. To be conservative, this modeling work assumes piers will be used even though the proposed bridges may not require this center pier. For all new bridges, debris on the piers was modeled by multiplying the bridge pier width by two.

Debris buildup on the low chords of the bridges was modeled and is considered a significant factor in flooding at the bridges in the downtown reach. Simulation of debris buildup is based on earlier work and studies by the USACE. Debris buildup consists of 4 feet of blocked flow just below the low chord of the bridge, which is modeled by dropping the low chord geometry by 4 feet in the HEC-RAS geometry editor. The low chord of the bridge is only dropped by 4 feet if it is determined that the WSEL without debris on the low chord exceeds an elevation that is 2 feet below the average low chord of the bridge. If the WSEL is found to be more than 2 feet below the average low chord of the bridge, then no debris blockage is used. It was typically found that once the debris blockage is used in the model, simulated flood waters back up behind the bridge and overtop the bridge deck.

Debris buildup on piers is simulated following methods used in the USACE modeling work. Debris is added to new piers by adding 6 feet to each side of the pier and to a depth of 4 feet below the water surface.

Debris buildup was not used in the 2005 calibration model because, during this flood event, the debris was removed by City workers and was not allowed to accumulate. It is assumed that this equipment may not be readily available during every major flood event; therefore, debris accumulation should be considered in assessing flood protection provided by the various scenarios.

2.2.5 Capacity of Existing Bridges

In order to compare proposed new bridge designs with the existing bridges, the capacity of existing bridges was estimated. To estimate capacity of the existing bridges in downtown Reno, some assumed freeboard criteria was incorporated in the model. The following assumptions were used:

1. For Sierra, Center, and Lake Street Bridges, assume freeboard requirement is 2 feet below the lowest point on the low chord of the bridge.
   - It is assumed this is consistent with the criteria for new bridges and is conservative.
2. For the Virginia Street Bridge, it is assumed that the freeboard requirement is 4 feet below the highest point on the low chord of the bridge.
   - The same assumption as the other bridges cannot be applied because the arches below this bridge extend to the bottom of the channel.

- This criteria provides an open space of about 230 square feet above the water surface that corresponds to this criteria. This is compared with the other three bridges, which have about 200 square feet of free space with 2 feet of freeboard.
- A judgment was made that Virginia needs a little more free space area than the other bridges due to the constricting sides of the arches and that 230 square feet is conservative.
- Other reasons for choosing 4 feet from the high point include that this is greater than 2-foot requirement, and it still provides 80 feet of total top-width of flow. 80 feet of top-width is about 50 percent of the total channel width. Anything less than this would seem too restrictive.

Using this freeboard criteria and the frequency curve supplied by the USACE, it was found that the capacity and approximate return period of the existing four bridges is as shown in Table 2-2.

TABLE 2-2
Summary of Flow Capacity

Bridge Location	Flow Rate (ft^3/s)	Approximate Return Period (years)
Sierra	8,840	17
Virginia	9,715	20
Center	9,580	19
Lake	5,330	4

When Lake Street was modeled in HEC-RAS, the water surface elevation calculated for 10,000 ft^3/s was right at the bottom of the bridge low chord arches. Based on the freeboard assumptions, the capacity of the bridge is defined as 2 feet lower than this level, for which we calculated a discharge of 5,330 ft^3/s.

Some inconsistencies in the USACE model downstream of the survey disproportionately impact the lower discharge flood profiles at the downstream reach of the model. Several different modeling methods were tried, including using the water surface from the unsteady USACE model and normal depth based on the river bottom profile, but the same reduced capacity was the result even though the cross-sectional area under the Lake Street Bridge is similar to the other bridges.

If the new Truckee River survey had continued much further downstream, this issue might have been resolved. Also, the freeboard assumptions previously discussed may be more conservative than is warranted for these reduced flows since they may not dislodge as much debris as a 100-year flood would. Debris loading was not increased from the originally assumed 4-foot pier width to the USACE assumption of 12 additional feet pier width because it is assumed there would be less debris with the smaller discharge.

Based on the analysis, historic date, and engineering judgment, it is assumed that the existing Lake Street bridge has a capacity of less than 10,000 ft^3/s but possibly not as low as

5,330 ft^3/s. It is probably in the 8,500 to 10,000 ft^3/s range of the other bridges, which refers to a recurrence interval of about 20 years.

2.3 Bridge Replacement Analysis and Results

Four scenarios were analyzed as part of the bridge replacement study and are described in the following paragraphs. Each scenario was developed in HEC-RAS starting with the calibration model of existing conditions as a foundation. All scenarios shown included changes only to bridges and not to the channel itself. The results of Scenarios #2 and #3 are represented as inundation flood maps showing the extents of flooding and areas where the flood flows are contained in the channel. Inundation maps for each of these scenarios are included in Appendix D of this report. Hydraulic profiles are also included in Appendix D.

Scenario #1: 50-year Flood Protection (13,684 ft^3/s). This scenario is known as a 50-year flood protection for downtown Reno because flows would be contained in the channel for flows up to the 50-year event. This design requires reconstruction of the Sierra, Virginia, and Lake Street Bridges. The existing Center Street Bridge remains in place. In this scenario, the low chords of bridges are at least 2 feet above the 50-year flood WSEL. The Sierra and Virginia Street bridges would be approximately 2 feet higher than existing conditions, while the Lake Street bridge would be approximately 4 feet higher than the existing bridge.

Scenario #2: 74-year Flood Protection (16,400 ft^3/s). This scenario is known as a 74-year flood protection for downtown Reno because flows would be contained in the channel for flows up to the 74-year event. This design requires reconstruction of the four bridges at Sierra, Virginia, Center, and Lake Streets. In this scenario, the low chords of bridges are at least 2 feet above the 74-year flood. The Sierra and Virginia Street bridges would be approximately 3.25 feet higher than the existing bridges, the Center Street bridge would be approximately 4.5 feet higher, and the Lake Street bridge would be approximately 6 feet higher.

Scenario #3: 100-year Flood Protection (20,676 ft^3/s). This scenario is known as a 100-year flood protection for downtown Reno because flows are contained in the channel for flows up to the 100-year event. This design requires reconstruction of the four bridges at Sierra, Virginia, Center, and Lake Streets. In this scenario, the bottoms of bridges are at least 2 feet above the 100-year flood. The WSEL along portions of the channel around Sierra Street are very near to overtopping the banks on both the north and south sides of the river. In this scenario, the Sierra and Virginia Street bridges would be approximately 4.75 feet higher than the existing bridges, the Center Street bridge would be approximately 6 feet higher, and the Lake Street bridge would be 6.75 feet higher.

Scenario #4: 100-year USACE Flood Protection. This scenario is a 100-year flood design corresponding to the highest level of flood protection and has a corresponding flow of 20,676 ft^3/s. All four downtown bridges require replacement to accommodate the 100-year flood design with 4 feet of freeboard (2 additional feet above Scenario #3), complying with USACE requirements. In this scenario, the Sierra and Virginia Street bridges would be approximately 6.5 feet higher than the existing bridges, the Center Street bridge would be approximately 7.75 feet higher, and the Lake Street bridge would be approximately 8.75 feet higher.

Virginia Street Bridge Impacts. The Study Team also summarized previous analysis to support replacement of the Virginia Street Bridge. These conclusions are supported by the analysis conducted as part of this study and were brought to the community as a reminder of previous decisions made by the City.

The justification for replacing the Virginia Street Bridge was included to demonstrate the reasoning behind the City's decision to replace this bridge. Replacing the Virginia Street bridge is necessary with any level of flood protection to avoid flooding in downtown Reno.

Tabular results of the hydraulic models from Scenarios #3 and #4 are included in Appendix E.

2.4 Dredging Analysis

During the course of the study, members of the community and City staff had questions regarding alternative channel dredging options in lieu of replacing bridges in the downtown reach of the Truckee River. The HEC-RAS model was modified to analyze the effects of dredging on the hydraulic profile. For a river that is currently in equilibrium, such as the Truckee River, dredging cannot be considered a long-term solution. The channel would need dredging on a regular basis. Dredging will alter the slope of the river and change the sediment transport at the bridges and along river channel walls. To determine potential effects of dredging, it would be useful to look at how dredging could affect the energy, slope, velocity, and stream power of the river. This analysis was not conducted as part of this study.

Scour resulting from the channel dredging could undermine the retaining walls lining the banks within the downtown reach and increase the scour at the bridges. The end of the Whitewater Park structure (where dredging would begin) may get undermined unless channel protection is installed. The dredging operation would have adverse environmental impacts. It could be difficult to get an environmental permit to operate an ongoing dredging program in this high profile and environmentally sensitive area of the Truckee River.

A sedimentation study was conducted by Wood Rodgers, Inc. earlier this year (Wood Rodgers, Inc., 2008) which complements some of the conclusions made from the HEC-RAS analysis. The results of that study are outlined in the following section.

2.4.1 Wingfield Whitewater Park Sedimentation Study

In May 2008, Wood Rodgers, Inc., conducted a reconnaissance level fluvial sediment study of the Truckee River in Reno to determine the approximate frequency and magnitude of sedimentation anticipated to occur within the Wingfield Whitewater Park. Sediment delivery in the stream channel is related to the flood hydrograph, channel geometry, sediment characteristics, and so on. To account for these factors, the FLUVIAL-12 model was used to simulate the hydraulics of stream flow, sediment transport, and stream channel changes, using three floods representative of major, moderate, and small events. The analysis provides general information on trends that are useful in evaluation of dredging options within the downtown reach of the Truckee River. The following conclusions are made in the Wood Rodgers, Inc., report:

1. Sediment deposition is likely to occur within the downtown reach during flood events on the order of 10-year and greater flows.
2. Deposition will occur during the highest flows. Therefore, an excavated channel may appear to have adequate capacity prior to a major event, with deposition occurring at the worst possible time during the peak of the flood resulting in loss of the anticipated flood protection benefits.
3. No analysis of "what-if" scenarios, such as the contemplated channel excavation, was included in the Wood Rodgers, Inc., analysis. However, based on basic fluvial principles, it is anticipated that depositional trends would be exacerbated by channel excavation in this reach. Sediment-transporting rivers tend toward fluvial processes, which result in a linear water surface profile (to the extent possible with consideration of hardened constraints). Thus, deposition within the deepened area would likely occur along with potential degradation upstream as the river strives to achieve a linear water surface profile.
4. Should a more rigorous analysis of the channel deepening concept be desired, the Wood Rodgers, Inc., model could be adjusted to include this feature.

The Wood Rodgers, Inc., study depicts the river channel geometry by the longitudinal profiles of the water surface and channel bed together with the cross-sectional profiles. Changes in river channel geometry were modeled using three floods. The modeled results indicate that the channel bed through Whitewater Park is subject to sediment deposition during major floods as well as small events. Since the channel banks are armored along the river reach, the channel bed through the park area tends to be built up by sediment deposition.

The amount of sediment deposition or erosion along the river channel reach through the park has been determined based on the spatial variations of sediment delivery along the river channel. The river channel reach through the Whitewater Park area is subject to sediment deposition during moderate and major floods. The amount of sediment deposition is in direct relation to the flood magnitude. Computed volumes of sediment deposition along the river reach in the park are as follows:

- Flood 1 (close to a 100-year flood): 11,100 cubic yards
- Flood 2 (close to a 25-year flood): 6,800 cubic yards
- Flood 3 (2,000 ft^3/s for 30 hours): 2,360 cubic yards

Joe Coudriet, of Flood and Drainage at Reno Public Works, recommends a fund of $29,000 per year for maintenance of the park to remove sediment. If the channel dredging were extended downstream for flood protection, the cost would likely increase substantially.

2.4.2 Dredging Analysis in HEC-RAS

Two different dredging scenarios were evaluated by the Study Team to determine how much the channel capacity could be increased. The first scenario evaluated dredging the channel an average of 5 feet through the downtown reach. The second scenario extends this dredging from downstream of the Whitewater Park (just downstream of Arlington Avenue) to Wells Avenue to the east.

2.4.2.1 Five-foot Dredging Scenario in the Downtown Area

In response to questions from the City, the Team evaluated a 5-foot-deep dredging scenario starting at 2nd Street and extending upstream to a point between Arlington and Sierra. This analysis was conducted while making broad assumptions to produce preliminary results in a timely manner. The HEC-RAS software allows the modeler to quickly sketch dredging scenarios by specifying a channel template and interpolating between two points. This method was used for this analysis. Note that this method could result in depths that vary from 5 feet of depth from the existing channel bottom. A conservative approach was taken by dredging slightly deeper than 5 feet in some areas.

Dredging the channel bottom by 5 feet will impact the geomorphology of the channel in ways that cannot be predicted without a full fluvial study. The dredged area will become a sediment trap during high flows in the future and will require frequent dredging. The bridge and channel retaining wall foundation designs in this area would need to be reviewed before finalizing this proposed dredge depth. Dredging at this depth could adversely impact the structural integrity of bridge or wall foundations in and adjacent to the river.

It was assumed that after dredging, the channel would be rectangular in shape and 140 feet wide. It was assumed that all the bridges would remain the same as they are today. The results of this analysis show that the water surface could be reduced slightly under the 100-year flood and more significantly under the 50-year flood. Figures 2-2, 2-3, and 2-4 show the resulting hydraulic profiles from the 5-foot dredging scenario for the 100-, 74-, and 50-year flood events, respectively. The pink line is the existing channel bottom, the black line is the channel bottom after dredging (~5 feet lower), the red line is the WSEL after dredging, and the blue line represents existing conditions.

Note that the transitions into the dredged area show an abrupt and relatively steep section representing a drop structure or short heavily armored drop. This drop could be incorporated into the future Whitewater Park extension. A 5-foot drop in the river will produce flow conditions that will require extensive protection against scour.

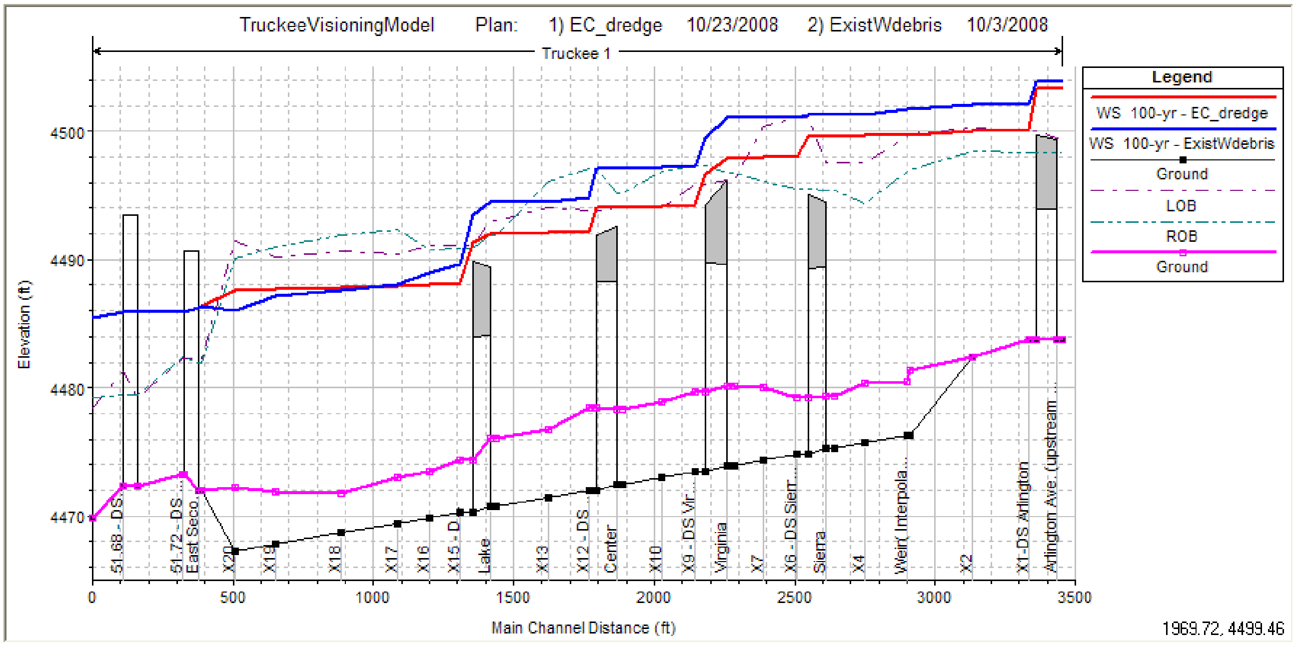

FIGURE 2-2
Dredging Scenario, 100-year Flood Event Hydraulic Profile
*WS = Water surface, EC = Existing Channel

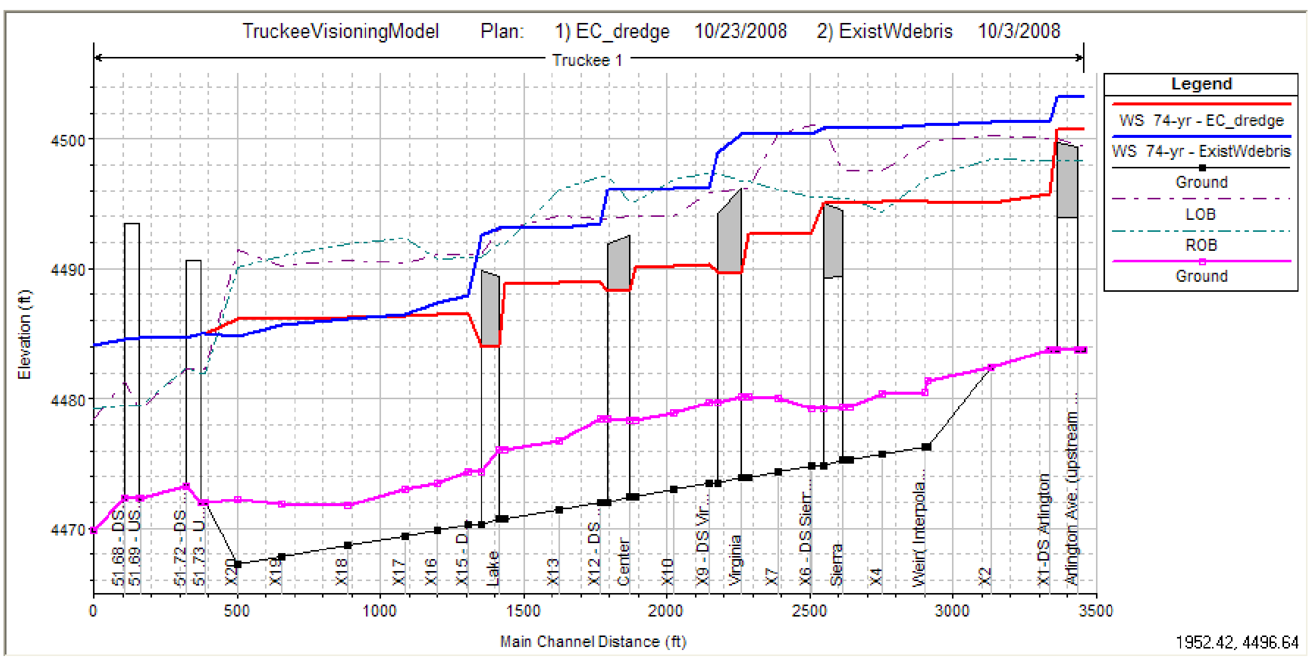

FIGURE 2-3
Dredging Scenario, 74-year Flood Event Hydraulic Profile

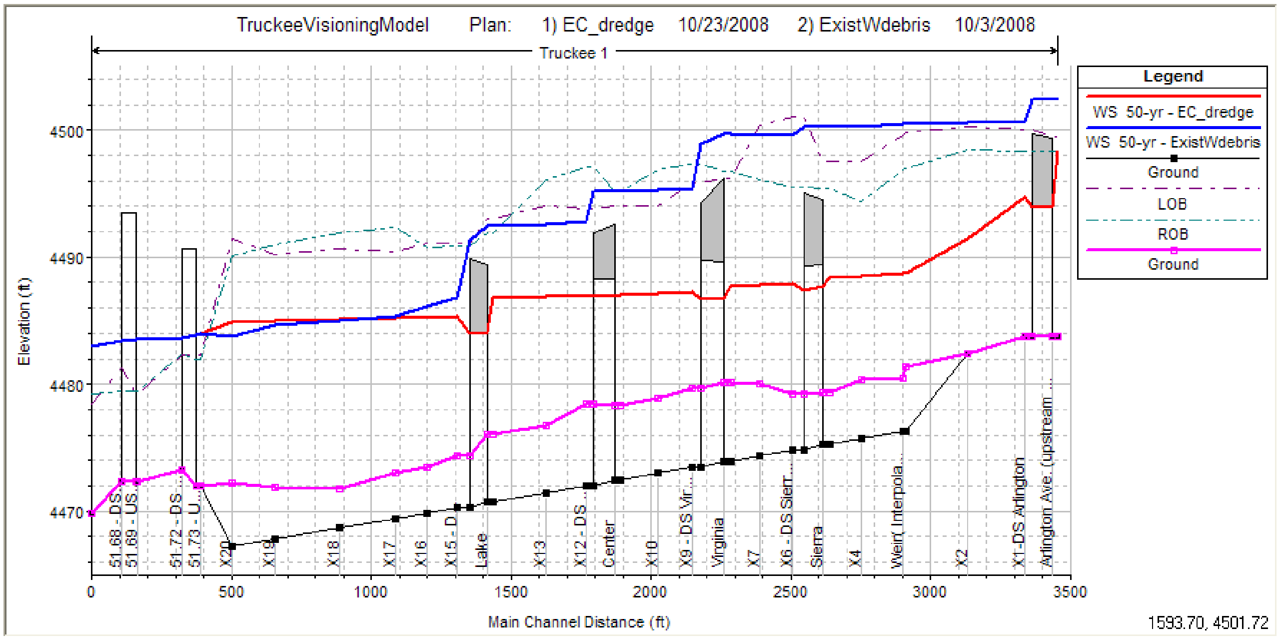

FIGURE 2-4
Dredging Scenario, 50-year Flood Event Hydraulic Profile

The hydraulic analyses indicate that the dredging would reduce flooding; however, the hydraulic analyses do not account for the sedimentation that would occur prior to the peak discharge, thereby nullifying most of the dredging benefit.

2.4.2.2 Extended Dredging Scenario

The rough hydraulic evaluation shows that extending the dredging at 5 feet of depth further downstream from 2nd Street would further reduce the modeled flood levels. This assumed dredging begins downstream of Wells Avenue and continues upstream to Whitewater Park between Arlington Avenue and Sierra Streets. This dredging scenario represents a major change to the river morphology and would likely have a significant impact on sediment transport. It is unknown whether this option is feasible due to possible negative impacts on structural foundations within the channel.

An attempt was made to simulate another dredging scenario for this reach using the original USACE HEC-RAS model that uses an unsteady flow regime. The transition from the existing channel to the dredged channel caused instabilities in the model, and reasonable results could not be obtained within a timely manner. An attempt was made to estimate an approximate order-of-magnitude benefit from dredging this reach by extrapolating a WSEL by hand and without doing any backwater or normal depth calculations. The drop in WSEL from the previous example was used as a basis for extrapolating the estimated benefit further downstream. It was assumed that where backwater from bridges does not affect the WSEL profile, normal depth slope would follow parallel to the channel bottom. Figure 2-5 shows an estimated representation of a possible WSEL profile under the 100-year flood event using engineering judgment and the assumptions that were stated previously.

Note that the existing-conditions geometry data used in this USACE model is different than the newly updated model being used for this TRAction Study analysis. Also note that the debris conditions were not removed from any of these dredging scenarios. Debris is simulated by artificially dropping the low chord of the bridge 4 feet if the WSEL comes within 2 feet of the actual low chord. As shown in Figure 3-5, this kind of dredging scenario could lower the WSEL profile during a 100-year flood event. However, as seen in the Figure 2-5, it is likely that the existing bridges could still have a significant impact on flooding in downtown.

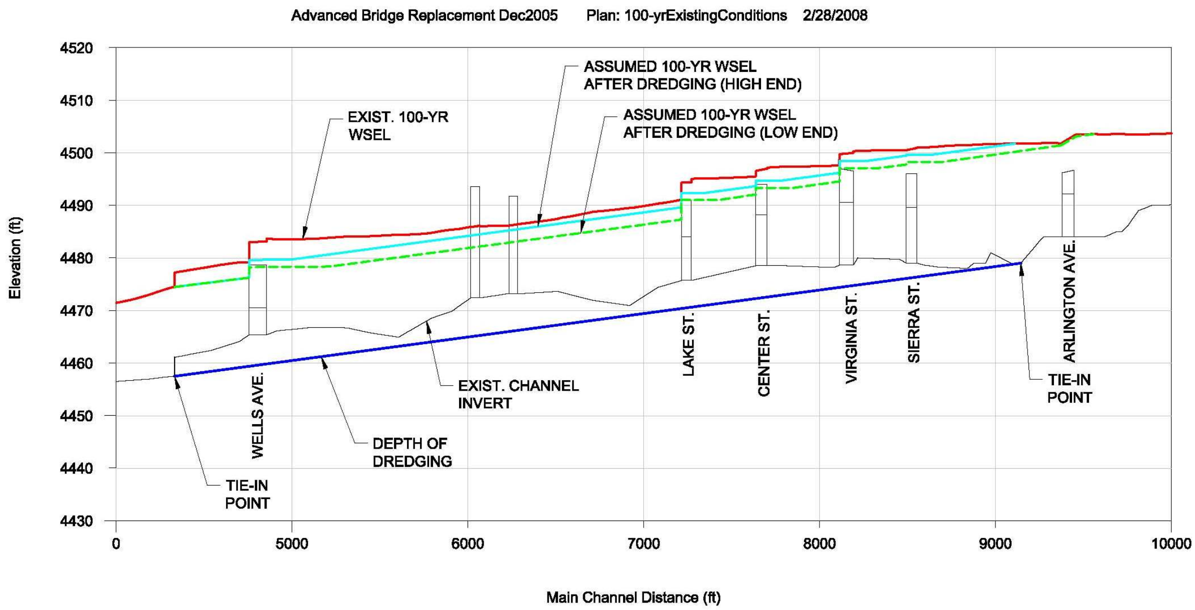

FIGURE 2-5
Extended Dredging Scenario, Assumed 100-year Hydraulic Profile

The potential reduction in flooding is purely hypothetical and based on this very limited analysis. Development of a more accurate accounting of the impacts and any potential benefits resulting from dredging of the Truckee River would require a detailed fluvial study. However, the result from the Wood Rodgers, Inc., analysis for Whitewater Park provides information that can be extrapolated to the dredging further downstream. This previous work indicates that dredging the channel may not be effective in reducing flooding due to sediment filling in the channel and would require periodic maintenance.

2.5 Widening Analysis

The Team evaluated widening the channel by 50 feet on each bank between Lake Street and 2nd Street to determine how widening may improve the conveyance capacity through the downtown reach based on a 50-year flood event. Results of this analysis show that widening this reach of the channel will not increase the hydraulic capacity for flood flows. Figure 2-6 is an example cross section showing what the channel will look like after widening. The pink line represents existing channel conditions.

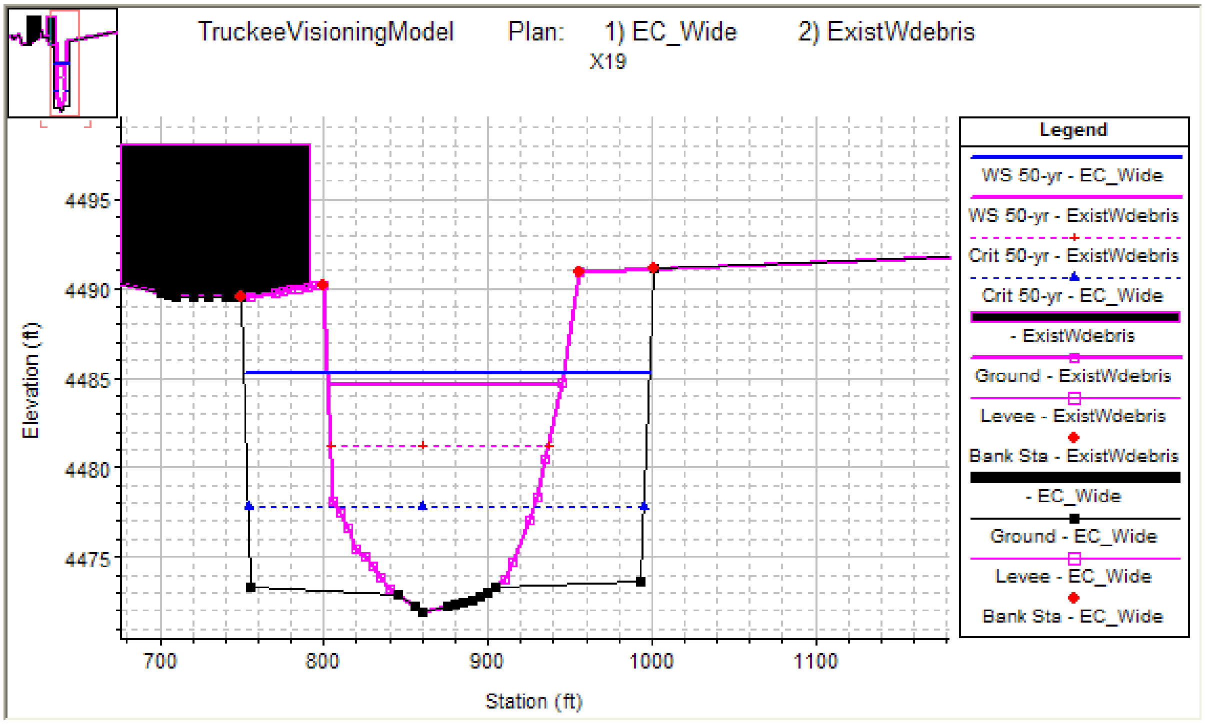

FIGURE 2-6
Widening Scenario, 50-year Flood Event—Cross Section
*Crit = Critical, Bank Sta = Bank Station

Figure 2-7 is a plot of the resulting hydraulic profile showing the effects of widening the channel by 50 feet on each side. The results from the 74-year and 100-year events are impacted in a similar fashion compared with the existing conditions.

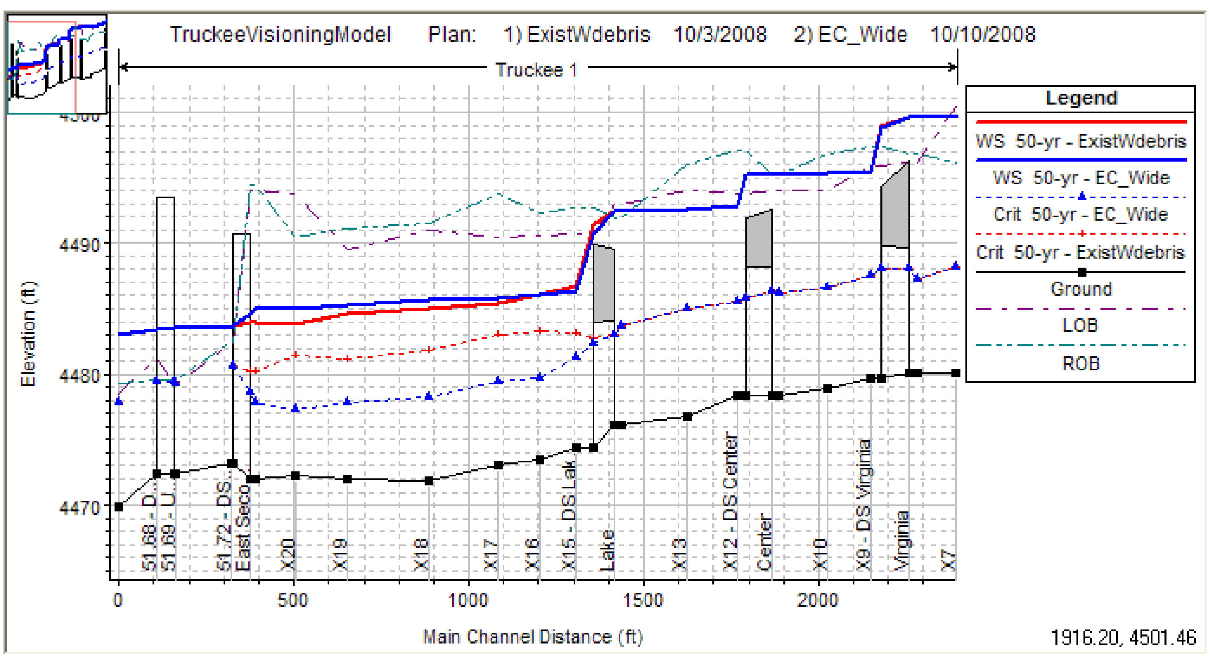

FIGURE 2-7
Widening Scenario, 50-year Flood Event—Hydraulic Profile

The blue line in Figure 2-7 represents the water surface during a 50-year flood with a widened channel, and the red line represents existing conditions. No appreciable drop in WSEL is seen under this channel-widening scenario. Widening the channel significantly slowed velocities in this reach and is the reason the water surface increased at 2nd Street. Decrease in velocity is the only benefit found from widening this reach. However, slower velocities in this reach may also result in sediment collecting, creating additional decrease in capacity. The important areas to focus on in the downtown section are the areas with significant head loss. The focus should be on those areas to reduce flooding, and those areas are the bridges. Notice the 6-foot drop at Lake Street compared with a 2.5-foot drop in the channel reach below Lake Street.

It is likely that widening the channel just downstream from 2nd Street would also have minimal benefit. Widening the channel for much longer distances downstream would probably help the downtown area but would likely be cost prohibitive. It is not known how much further downstream this would need to take place. The widening would need to be continuous because a narrowed section would cause backwater impacts that could be significant.

2.6 FEMA Requirements and Mapping

The City inquired of the Team if Federal Emergency Management Agency (FEMA) regulates the freeboard at bridges. We contacted Sarah Owen ([510] 627-7050) with FEMA Region 9 and she clarified that FEMA does not regulate bridges and does not have freeboard requirements for bridges.

For FEMA to give credit for flood reduction based on a levee, the levee requires 3 feet of freeboard. Based on the survey information we have, the buildings along the downtown reach of the Truckee River will not be in the future floodplain of the downtown reach if we proceed with the proposal to raise the bridges 2 feet over the 100-year flood level. Therefore, no levees will be required.

The regulatory FEMA floodplain can be drawn to where the WSEL calculated by the hydraulic model intersects the ground along the Truckee River. Under current conditions, buildings outside of this floodplain will not be in the floodplain of a 100-year flood design and will not be required to purchase flood insurance. Additional surveying will be required around some buildings to verify whether they are above the base (100-year) flood elevation.

The FEMA floodplain map indicates that during a 100-year flood event with the 100-year flood design, some small areas outside of the river channel may flood. This includes an area on the south bank along Island Avenue just upstream of Sierra Street and another area just upstream of Lake Street. The results of the model do not show flooding in these areas, but low spots along the roads are lower in elevation flood profile in the river.

2.7 Booth and Arlington Impacts

The original USACE model was used to answer the question of whether Arlington Avenue and Booth Street bridges would affect potential flooding. As no additional survey and geometry data were obtained upstream of Arlington Avenue under the current scope of work, the Study Team relied on previous analysis to provide a preliminary evaluation of these potential effects to the river system.

Figure 2-8 is a profile plot showing the WSEL from Booth Street down to Arlington Avenue under the 100-year flood condition. The water level at Arlington Avenue was manually set at the elevation calculated from the calibrated HEC-RAS model completed by the team. As seen in Figure 2-8, a fairly flat backwater curve continues upstream from Arlington Avenue for about 700 feet (refer to the red line labeled "PF 1"). This backwater is due to a constriction in flow at Arlington Avenue. Another scenario was analyzed where the water surface at Arlington Avenue was dropped by 6 feet (see the blue dashed line labeled "PF 2").

No matter where the water surface starts at Arlington Avenue, the WSEL is identical starting about 700 feet upstream of this point. The WSEL of either scenario matches at this point because the flow in the channel has returned to normal depth and the profile is no longer affected by the backwater from Arlington Avenue. While Arlington has a backwater impact of approximately 2 feet during a 100-year flood event, it does not show an impact to the Booth Street bridge.

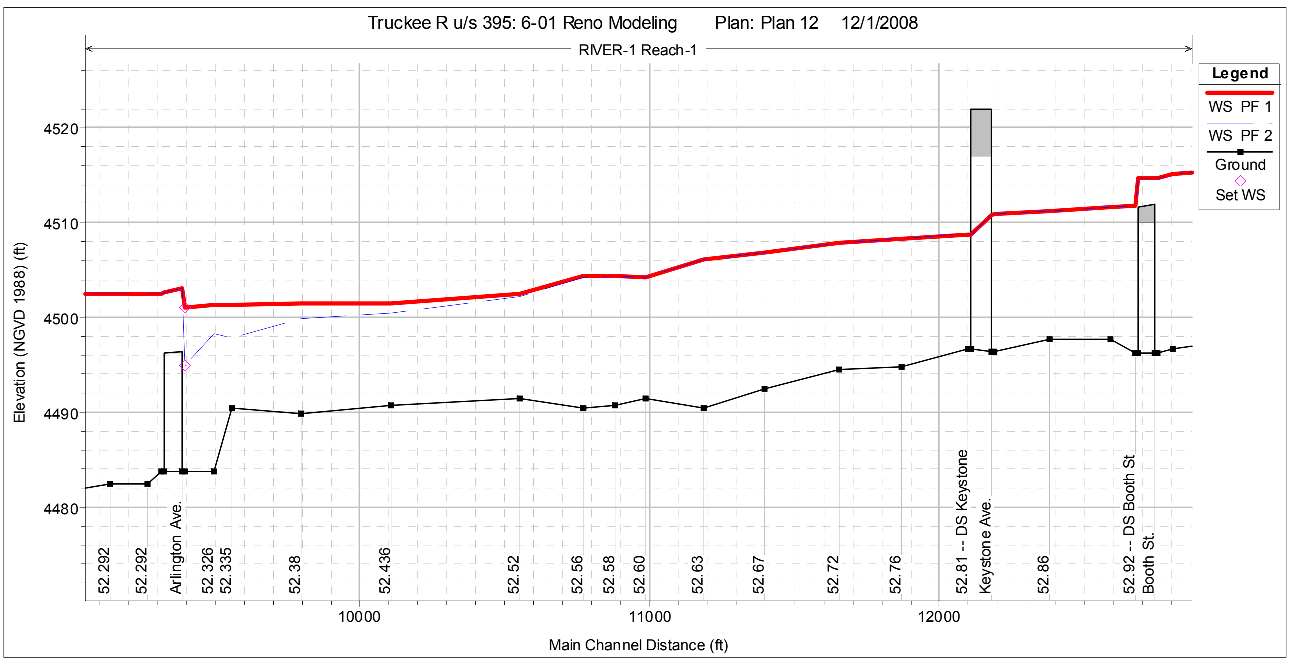

FIGURE 2-8
Effects of WSEL Changes at Arlington Ave. on WSEL at Booth Street

2.8 Conclusions

The following conclusions are based on the results from the hydraulic modeling, bridge analysis, dredging, and widening studies:

1. Raising bridges in the downtown reach would have the following impacts:
   - Increase the flow capacity of the channel

- Reduce the chance of debris collecting on the bridges
- Depending on the bridges that are replaced, provide up to a 100-year level of protection
- Reduce the need for raising floodwalls and assume only reconstructing the "sagging" locations along the existing floodwall facilities

2. Dredging just the downtown reach by 5 feet would likely have the following impacts:
   - Increase the amount of sediment deposited in the downtown reach and thus increase required maintenance
   - Provide up to a 50-year level of protection without changing the bridges, assuming the channel does not refill with sediment prior to the peak discharge
   - Result in flooding under 74-year event due to debris blockage at Lake Street
   - Reduce flooding under 100-year event if the channel remains free of sediment, but only slightly
3. Extended dredging by 5 feet from Wells Avenue to Arlington Avenue would likely have the following impacts:
   - Increase the amount of sediment deposited in the downtown reach and thus increase required maintenance—high flow events increase sediment deposits and can counter any benefits of dredging
   - Provide up to a 50-year level of protection without changing the bridges, assuming the channel does not refill with sediment prior to the peak discharge
   - Provide a 74-year level of protection with a lower WSEL at Lake Street, assuming the channel does not refill with sediment prior to the peak discharge
   - Under the 100-year event, flooding would be reduced, assuming the channel does not refill with sediment prior to the peak discharge
4. Widening the channel in the downtown reach would have the following impacts:
   - Increase the amount of sediment deposited in the downtown reach and thus increase required maintenance
   - Not increase flood capacity in the downtown area
   - Not prevent the Lake Street bridge from causing a 5-foot rise in WSEL and causing flooding upstream
5. Center bridge piers would have the following impacts:
   - Raising the bridge deck (of any structure type) would have a significant positive impact on WSEL.

Raising the bridges will provide a practical solution to minimize flooding in the downtown area without increasing required maintenance. Dredging the channel on a large scale could slightly increase the capacity of the channel if it does not refill with sediment, but there are many effects of dredging that are not currently understood, many of which are known to increase the cost of maintenance significantly. Even a very ambitious (and possibly risky) dredging project may not provide 100-year or 74-year flood protection if the bridges are not raised.

3.0 Roadway and Bridge Design

To develop an accurate analysis of physical and visual impacts to the downtown river corridor, and to understand the relative costs of mitigating these impacts, a conceptual-level design was prepared for replacing the four downtown bridges and adjacent roadway sections on the north and south sides of the river. Simulations are included in Appendix G depicting the visual impacts associated with the flood scenarios considered in this study. Following are the design criteria, assumptions, and results of this conceptual-level engineering effort.

3.1 Design Criteria

The horizontal alignment for the roadways is based on existing geometry. We assumed the future roadways will retain the path and width of existing roadways, although the existing horizontal curvature does not meet current standards based on the American Association of State Highway and Transportation Officials (AASHTO) *Policy on Geometric Design of Highways and Streets* (AASHTO, 2001). Roadway profiles are based on results from the hydraulic modeling analysis shown in Table 3-1. We used the water surface elevation for each flood event and added height for required freeboard (2 feet) and an estimated depth of bridge structure to calculate the minimum bridge surface elevation. Two feet of freeboard clearance was selected to be consistent with NDOT's minimum freeboard requirements at bridges. The depth of the bridge structure varies based on the type of structure, the width of the bridge, and the number of spans as discussed later in this section of the report.

TABLE 3-1
Water Surface Elevations from Hydraulic Models

Flood Event	Elevation at Sierra Street (feet)	Elevation at Virginia Street (feet)	Elevation at Center Street (feet)	Elevation at Lake Street (feet)
50-year	4,490.56	4,490.57	4,488.88	4,487.24
74-year	4,491.67	4,491.79	4,490.10	4,488.52
100-year	4,493.16	4,493.58	4,491.83	4,490.29

Roadway profiles were designed based on criteria from three sources: calculated minimum bridge surface elevations, AASHTO policy, and the desire for as little impact as possible. The impact of the design is measured both by visual impact and length of roadway approach reconstruction required. The criteria from the AASHTO policy are listed in Table 3-2. The drivers' sight distance is particularly important due to the amount of pedestrian traffic in the area.

TABLE 3-2
AASHTO Roadway Design Criteria

Criterion	Minimum Value	AASHTO Exhibit Referenced
Design Speed	30 mph	NA
Stopping Sight Distance	200 ft	3-1
K_{crest}	19	3-75
K_{sag}	37	3-78

NOTES:
ft = feet
mph = miles per hour
NA = not applicable
Source: AASHTO

3.2 Flood Designs and Approach Impacts

Reconstruction of the bridges in downtown Reno will require raising the approach roads to pass the 74-year and 100-year flood designs. The bridges will be set at an elevation high enough over the flood design to have a freeboard clearance and accommodate the depth of the bridge superstructure. Reconstructing the approach roads to match the new bridge elevations will impact the properties and public facilities adjacent to the roads.

Freeboard clearance is the distance between the flood design's water surface elevation and the bottom of bridge superstructure. The freeboard clearance allows debris to pass under the bridge without obstructing flows.

The depth of bridge is dependent on many factors. For this project, two bridge types were identified that provided the thinnest bridge section while minimizing the number of supports in the river. The bridge types are discussed in more detail in Section 3.3, Discussion of Bridge Types.

The capacity of the existing channel in downtown Reno is estimated to be between 10 and 50 years and is dependent on the amount of debris that accumulates on the bridge structures during a flood event. During the 2005 event, City forces were reportedly active in removing debris from the downtown bridges before it could accumulate. As such, the level of flooding observed downtown was much less than could be anticipated if debris accumulation had been more significant. The reliability of debris removal operations during flooding is dependent on many factors and is considered too questionable to be relied on when evaluating flood protection. Therefore, for the purposes of this study, debris was assumed to accumulate on in-river supports and, when the water surface elevation encroaches closer than 2 feet from the bottom of the bridge, along the bridge superstructure.

The Lake Street and Virginia Street Bridges have the biggest effect on limiting flow capacity in the channel. Except for Center Street in Scenario #1, all four bridges require replacement to increase capacity to the desired level of protection. The four bridges act together as a system. Appendix D shows an inundation map for the option of leaving the existing Virginia Street Bridge in place while replacing the Center and Lake Street Bridges. The level of inundation upstream of Virginia Street is essentially the same as the existing conditions inundation map with improvement downstream. No other options were evaluated where only one bridge was left in place with the others replaced, except for Scenario #1.

3.2.1 Flood Designs

The capacity of the existing Truckee River channel is restricted by the existing bridge crossings and is dependent on the amount of debris that accumulates on the structures. As flows increase and the water surface elevation begins to reach the bottom of the existing bridge decks, there is a tendency for debris to catch on the bridge decks and block the flow. With its low profile, the Lake Street Bridge is very susceptible to collecting debris and ultimately causes flow to back up throughout the downtown reach of the river. With debris assumed to partially block flows at Lake Street, the channel has a capacity of about 10,000 ft^3/s before the flow overtops the bank just upstream of the Lake Street Bridge. This flow volume represents a flood with a return period of between 10 and 50 years. The project evaluated four flood designs, all of which provide an increased flood protection for downtown Reno. Appendix D also shows inundation maps for each of the flood designs. The limits of inundation assume no flood wall replacements. In some instances, the flood waters are at or near the top of existing flood walls. The four flood designs are described as follows:

- **Scenario #1: 50-year flood design with 2 feet of freeboard.** The 50-year flood design is considered the lowest level of flood protection and has a corresponding flow of 13,684 ft^3/s. The area of flooding outside the Truckee River channel associated with the 50-year flood is shown in the inundation maps located in Appendix D. Three of the four downtown bridges require replacement to accommodate the 50-year flood design. The Center Street Bridge will not be replaced for this flood design. Scenario #1 and the USACE's National Economic Development (NED) design both provide a 50-year level of protection (NED assumes 4 feet of freeboard). Both designs may not provide a level of protection greater than a 50-year level because of the limited capacity of the Center Street Bridge. However, because the three new bridges being replaced are much higher under the NED design, the magnitude of flooding that may occur during a 74-year or 100-year flood would likely be less than that of Scenario #1.
- **Scenario #2: 74-year flood design with 2 feet of freeboard.** The 74-year flood design corresponds approximately to the historical flood event of 2005 and has a flow of 16,400 ft^3/s. As stated in Section 3.2, debris was removed from the bridges before and during the 2005 flood event because heavy equipment happened to be available. It is assumed that this debris removal activity greatly increased the capacity of the bridges. Having heavy equipment readily available just before and during any storm event is highly unlikely, so debris removal is not included in any scenario. The assumption to not include debris removal is considered a conservative assumption that more closely represents reality. This flood design is considered an intermediate level of flood protection. The area of flooding outside the Truckee River channel associated with the 74-year flood is shown in the inundation maps located in Appendix D. All four downtown bridges require replacement to accommodate the 74-year flood design.

- **Scenario #3: 100-year flood design with 2 feet of freeboard.** The 100-year flood design corresponds to the highest level of flood protection evaluated and has a corresponding flow of 20,676 ft^3/s. The area of flooding outside the Truckee River channel associated with the 100-year flood is shown in the inundation maps located in Appendix D. All four downtown bridges require replacement to accommodate the 100-year flood design. Some localized flooding occurs between the bridges at low points in the floodwalls.
- **Scenario #4: 100-year USACE flood design with 4 feet of freeboard.** The 100-year flood design corresponds to the highest level of flood protection evaluated and has a corresponding flow of 20,676 ft^3/s. The area of flooding outside the Truckee River channel associated with the 100-year flood is shown in the inundation maps located in Appendix D. All four downtown bridges require replacement to accommodate the 100-year flood design. A freeboard clearance of 4 feet complies with USACE risk and uncertainty requirements for bridges and may allow the USACE to certify the level of flood protection to FEMA. Some localized flooding occurs between the bridges at the low points in the flood walls; this may require their replacement to satisfy USACE requirements.

Table 3-3 is a summary of freeboard calculated for each bridge under the 74-year design scenario. In order to demonstrate that the designed bridges meet the freeboard criteria, the high and low points on the bridge chords are shown with resulting freeboard for each. The high freeboard is calculated by subtracting the high bridge chord elevation from the calculated WSEL. Average and low freeboard are calculated in a similar fashion, by subtracting the WSEL from the average and low points on the bridge chord, respectively. The table shows that the bridge designs provide at least 2 feet of freeboard for the average bridge chord.

TABLE 3-3
Water Surface Elevations from Hydraulic Models—74-year Design

Flood Event	Elevation at Sierra Street (feet)	Elevation at Virginia Street (feet)	Elevation at Center Street (feet)	Elevation at Lake Street (feet)
74-year WSEL	4,491.6	4,491.6	4,489.9	4,488.8
Bridge chord high point	4,495.2	4,495.8	4,494.4	4,492.6
Bridge chord average point	4,494.4	4,495.0	4,493.3	4,492.0
Bridge chord low point	4,493.7	4,494.3	4,492.1	4,491.3
74-year Freeboard—high	3.6	4.1	4.5	3.8
74-year Freeboard—average	2.8	3.4	3.3	3.1
74-year Freeboard—low	2.1	2.6	2.2	2.5

Table 3-4 is a summary of freeboard calculated for each bridge under the 100-year design scenario.

TABLE 3-4
Water Surface Elevations from Hydraulic Models—100-year Design

Flood Event	Elevation at Sierra Street (feet)	Elevation at Virginia Street (feet)	Elevation at Center Street (feet)	Elevation at Lake Street (feet)
100-year WSEL	4,493.3	4,493.6	4,492.1	4,490.8
Bridge chord high point	4,496.5	4,497.1	4,495.2	4,493.4
Bridge chord average point	4,495.7	4,496.5	4,494.4	4,492.8
Bridge chord low point	4,495.0	4,495.9	4,493.6	4,492.1
100-year Freeboard—high	3.2	3.5	3.2	2.6
100-year Freeboard—average	2.5	2.9	2.4	2.0
100-year Freeboard—low	1.7	2.4	1.6	1.3

3.2.2 Approach Impacts

The level of impact associated with the reconstruction of the approach roads is directly related to how high the bridges must be raised. The length of roadway approach reconstruction increases as the bridge elevation increases. Appendix F shows new road profiles for each roadway and associated flood design. The level of impacts to adjacent property and public facilities increases as the flood protection level increases. Appendix G presents the simulations that were developed to show the visual impacts associated with the flood scenarios considered in this study. The following subsections present a summary of the impacts.

3.2.2.1 Sierra Street

Table 3-5 shows the approximate amount of increase in the elevation of Sierra Street at the north and south sides of the river necessary to accommodate the various flood designs.

TABLE 3-5
Sierra Street Elevation Increases Required at Abutments to Accommodate Flood Designs

Flood Design	North Side of River	South Side of River
50-Year + 2 feet Freeboard	0.25 foot	1.0 foot
74-Year + 2 feet Freeboard	1.25 feet	2.75 feet
100-Year + 2 feet Freeboard	2.5 feet	4.0 feet
100-Year + 4 feet Freeboard (USACE)	4.5 feet	5.5 feet

NOTE:
Table presents approximate increases in street elevation needed to accommodate the flood designs. Table assumes above-supported bridges; below-supported bridges require 0.5 foot more on the north and south sides.

Northeast Corner

- Truckee River Lane runs along the north edge of the river from Sierra Street to the east. Each of the flood designs requires some reconstruction of Truckee River Lane. The 50-year flood design requires little reconstruction, while the 100-year plus 4 feet of freeboard flood design requires reconstruction from Sierra Street to about halfway to Virginia Street.
- The Palladio condominium complex is located along the north edge of Truckee River Lane and along the east side of Sierra Street from Truckee River Lane to First Street. The 50-year flood design has little to no impact on the Palladio. However, the 100-year plus 4 feet of freeboard flood design requires modification to many of the steps on the south side of the building along with construction of a retaining wall and modification to entrances along the west side of the building.

Northwest Corner

- Truckee River Lane runs along the north edge of the river from Sierra Street to the west. Each of the flood designs requires some reconstruction of Truckee River Lane. The 50-year flood design requires little reconstruction of Sierra Street while the 100-year plus 4 feet of freeboard flood design requires about 200 feet of reconstruction.
- The Century Theaters complex is located along the north edge of Truckee River Lane and along the west side of Sierra Street from Truckee River Lane to First Street. The 50-year flood design has little to no impact on the Century Theaters. However, the 100-year plus 4 feet of freeboard flood design requires modification to many of the steps on the south side of the building along with construction of a retaining wall and modification to entrances along the east side of the building.

Southeast Corner

- The Riverwalk runs along the south edge of the river from Sierra Street to the east. Each of the flood designs requires some reconstruction of the Riverwalk with the 50-year flood design requiring about 50 feet of reconstruction and the 100-year plus 4 feet of freeboard requiring reconstruction halfway to Virginia Street.
- A vacant lot sits south of the Riverwalk with the County Courthouse south of the vacant lot. Construction of a retaining wall between the Riverwalk and vacant lot is required for all flood designs except the 50-year flood design. There are two approaches along the east side of Sierra Street south of the bridge that will require some reconstruction for the 100-year flood design.

Southwest Corner

- The Riverwalk runs along the south edge of the river from Sierra Street to the west. Each of the flood designs requires some reconstruction of the Riverwalk with the 50-year flood design requiring approximately 50 feet of reconstruction and the 100-year plus 4 feet of freeboard requiring approximately 275 feet of reconstruction.
- Island Avenue Drive runs from Sierra Street to the west and is located between the Riverwalk and Reno City Municipal Court. Reconstruction of Island Avenue Drive is required for the 50-year and 74-year flood designs. The 100-year flood designs may

require closure of Island Avenue at Sierra Street. Access will be maintained to the entrance of the Reno City Municipal Court parking lot on Island Avenue.

- The Reno City Municipal Court is located along the south side of Island Avenue and the west side of Sierra Street. The 50-year flood design will have little to no impact on the Court. However, the 74-year and 100-year flood designs require construction of retaining walls along the edge of building on both Sierra Street and Island Avenue.

3.2.2.2 Virginia Street

Table 3-6 shows the approximate amount of increase required on Virginia Street at the north side and south side of the river to accommodate the flood design.

TABLE 3-6
Virginia Street Elevation Increases Required at Abutments to Accommodate Flood Designs

Flood Design	North Side of River	South Side of River
50-Year + 2 feet Freeboard	0 feet	0.75 foot
74-Year + 2 feet Freeboard	1.75 feet	2.25 feet
100-Year + 2 feet Freeboard	3.0 feet	2.75 feet
100-Year + 4 feet Freeboard (USACE)	5.0 feet	4.75 feet

NOTE:
Table presents approximate increases in street elevation needed to accommodate the flood designs. Table assumes above-supported bridges; below-supported bridges require 0.5 foot more on the north and south sides.

Northeast Corner

- The 10 North Virginia Street Plaza is located along the north edge of the river and along the east side of Virginia Street. The 50-year flood design has no effect on the 10 North Virginia Street Plaza. The 100-year plus 4 feet of freeboard flood design requires reconstruction of the walkway along the river for about 250 feet to the east from Virginia Street. Retaining walls are required along the existing planters up to the intersection of First Street.

Northwest Corner

- Truckee River Lane runs along the north edge of the river from Virginia Street to the west. The 50-year flood design requires no reconstruction of Truckee River Lane, while the 100-year plus 4 feet of freeboard flood design requires reconstruction halfway to Sierra Street.
- The Masonic Building is located along the north edge of Truckee River Lane and along the west side of Virginia Street from Truckee River Lane to First Street. The 50-year flood design has no impact on the Masonic Building. The 100-year plus 4 feet of freeboard flood design requires construction of retaining walls along the south edge of the building and in the sidewalk along Virginia Street to allow access into the Masonic Building.

Southeast Corner

- The Post Office parking lot runs along the south edge of river from Virginia Street to the east. Reconstruction of the parking lot is under consideration and would turn this area into a pedestrian plaza. The 50-year flood design will have little impact on the pedestrian plaza design. The 100-year plus 4 feet of freeboard flood design requires construction of taller retaining walls in the pedestrian plaza and increased ramp slopes within the Plaza.

Southwest Corner

- The Riverwalk runs along the south edge of the river from Virginia Street to the west. The 50-year flood design requires little reconstruction of the Riverwalk. The 100-year plus 4 feet for freeboard flood design requires reconstruction of the Riverwalk halfway to Sierra Street.
- The Riverside Artist Lofts are located along the south edge of the Riverwalk and west side of Virginia Street. The 50-year flood design has no impact on the Riverside. The 100-year plus 4 feet of freeboard clearance flood design requires construction of a retaining wall in the sidewalk and Riverwalk to allow access into the Riverside.

3.2.2.3 Center Street

Table 3-7 shows the approximate amount of increase required on Center Street at the north side and south side of the river for each flood design. The Center Street Bridge is not replaced for the 50-year flood design.

TABLE 3-7
Center Street Elevation Increases Required at Abutments to Accommodate Flood Designs

Flood Design	North Side of River	South Side of River
50-Year + 2 feet Freeboard	NA	NA
74-Year + 2 feet Freeboard	4.0 feet	1.0 foot
100-Year + 2 feet Freeboard	4.0 feet	2.5 feet
100-Year + 4 feet Freeboard (USACE)	5.75 feet	4.5 feet

NOTES:
NA = not applicable
Table presents approximate increases in street elevation needed to accommodate the flood designs. Table assumes above-supported bridges; below-supported bridges require 0.5 foot more on the north and south sides.

Northeast Corner

- A pedestrian path is located along the north edge of river and runs to the east. All flood designs require reconstruction of the sidewalk from the edge of bridge to the ATT building.
- A portion of the Plaza is located north of the sidewalk and east of Center Street. A retaining wall around the Plaza will be required for all flood designs.

Northwest Corner

- The 10 North Virginia Street Plaza is located along the north edge of the river and along the west side of Center Street. All flood designs require reconstruction of the walkway along the river for at least 200 feet to the west. Retaining walls are required along the edge of sidewalk to the intersection of First Street.

Southeast Corner

- The Siena Hotel is located along the south edge of river and along the east side of Center Street. The 74-year flood design will have little effect on the Siena Hotel. The 100-year flood designs will require reconstruction of the exit steps located at the edge of bridge. A retaining wall is required along the edge of sidewalk adjacent to the Siena. The 100-year plus 4 feet of freeboard flood design requires reconstruction of the entrance.

Southwest Corner

- The Post Office parking lot runs along the south edge of river from Center Street to the west. Reconstruction of the parking lot is under consideration and would turn this area into a pedestrian plaza. The 74-year flood design has only a slight effect on the new plaza design while the 100-year flood design requires construction of taller retaining walls and increased ramp slopes to access planned grades for the pedestrian plaza.

3.2.2.4 Lake Street

Table 3-8 shows the approximate amount of increase required on Lake Street at the north side and south side of the river for each flood design.

TABLE 3-8
Lake Street Elevation Increases Required at Abutments to Accommodate Flood Designs

Flood Design	North Side of River	South Side of River
50-Year + 2 feet Freeboard	2.25 feet	1.75 feet
74-Year + 2 feet Freeboard	4.5 feet	4.0 feet
100-Year + 2 feet Freeboard	5.25 feet	4.5 feet
100-Year + 4 feet Freeboard (USACE)	7.25 feet	6.5 feet

NOTE:
Table presents approximate increases in street elevation needed to accommodate the flood designs. Table assumes above-supported bridges; below-supported bridges require 0.5 foot more on the north and south sides.

Northeast Corner

- A vacant property exists along the north edge of river and runs along the east side of Lake Street. This property is planned for improvements in the future. All flood designs require a retaining wall between the sidewalk and vacant property, varying from 100 to 300 feet in length.

Northwest Corner

- A sidewalk runs along the north side of the river to the west. The 50-year flood design will have little effect on the sidewalk. The sidewalk will require reconstruction up to the ATT building for all other flood designs.
- The La Famiglia Restaurant is located north of the sidewalk and west of Lake Street. A retaining wall is required between the Lake Street sidewalk and the restaurant. The length of the retaining wall for the 50-year flood design will not adversely impact the restaurant. The length of retaining wall for the other flood designs must wrap around the First Street intersection and continue to the west. It is probable the restaurant will be adversely affected by these flood designs.

- First Street runs to the west just north of the La Famiglia Restaurant. All flood designs except for the 50-year flood design require reconstruction of a portion of First Street and its sidewalks.
- The ATT building is located on the north side of First Street and along the west side of Lake Street. Construction of a retaining wall adjacent to the building and modification to the building access is required for all flood designs except the 50-year flood design.

Southeast Corner

- A pedestrian path is located along the south side of the river and extends to the east. All flood designs require reconstruction of the pedestrian path. The extent of reconstruction varies from about 75 to 300 feet in length depending upon the flood design.
- The National Auto Museum is located south of the pedestrian path and east of Lake Street. An entrance with sidewalk is located near the end of bridge. Reconstruction of the sidewalk along with construction of retaining walls is required for all flood designs. An additional retaining wall is required between the Lake Street sidewalk and museum planter that extends up to the Mill Street intersection.

Southwest Corner

- The Siena Hotel is located along the south edge of river and along the west side of Lake Street. The hotel's main exit is located on the south end of the bridge. The exit requires moderate reconstruction for the 50-year flood design. The 74-year and 100-year plus 2 feet of freeboard flood designs require extensive reconstruction of the exit. The 100-year plus 4 feet of freeboard flood design may require the exit be closed. A retaining wall between the Lake Street sidewalk and hotel planter can extend as far as the Mill Street intersection.

3.2.3 Floodwalls and Levees

Based on data from the survey that was completed for this study, the buildings along the downtown reach of the Truckee River will not be in the future floodplain of the downtown reach if the bridges are raised 2 feet over the 100-year flood level. Therefore, no levees will be required.

The FEMA floodplain map indicates that during a 100-year flood event with the 100-year flood design, some small areas outside of the river channel may flood. This includes an area on the south bank along Island Avenue just upstream of Sierra Street and another area just upstream of Lake Street. The results of the model do not show flooding in these areas, but low spots along the roads are lower in elevation than the flood profile in the river. Low spots in the existing flood walls would require reconstruction in order to keep the 100-year flood event in the channel.

3.3 Discussion of Bridge Types

Improving flood capacity requires replacement of the bridges in downtown Reno. The bridges must be set at a higher elevation to allow the flood design to pass under the bridge without the accumulation of debris on the superstructure. The approach roads must be reconstructed to match the increased bridge elevation. The urban landscape is highly developed with the existing approach roads being fairly flat. To reduce impacts to adjacent properties, the increased bridge and roadway elevation must be minimized as much as possible.

Three factors influence how high the bridge elevation is set:

- **Flood design.** Four flood designs are being considered in this study, as previously mentioned. Each flood design has a different water surface elevation. The water surface elevation increases with level of flood protection.
- **Freeboard clearance.** The freeboard clearance is the distance from the top of flood design water surface to the bottom of the average point on the bridge superstructure. It provides a measure of safety for accumulation of debris. Values of 2 and 4 feet are used in this study depending upon the amount of flood protection desired.
- **Structure depth.** Structure depth or the thickness of the bridge is dependent on the type of bridge (girder, truss, arch), materials used (structural steel, prestressed concrete, reinforced concrete), and number of spans.

The structure depth must be minimized without affecting the flood capacity or structural performance. It is generally undesirable to place supports in the river. The supports can allow debris to accumulate reducing the area of opening under the bridge. Ideally, a clear span bridge with no supports eliminates debris accumulation.

3.3.1 Conventional Highway Bridges—Below-Supported Bridges

Conventional highway bridges include steel girders, precast prestressed concrete girders, and cast-in-place prestressed concrete. The supports to these structures are below the riding surface of the bridge. These types of bridges must have a structure depth of about 4 to 4.5 percent of their span length to ensure a cost-effective structural performance along with minimizing flexibility and vibration characteristics that can be uncomfortable for pedestrians.

A clear-span conventional highway bridge requires a structure depth of about 7 feet for the spans in this study. This is unacceptable due to the profile adjustment required and adverse impacts on adjacent properties. Placing one support in the river reduces the structure depth to about 4 feet, which reduces the profile adjustment to a more acceptable level. However, the river support will reduce the opening under the bridge due to debris accumulation and the bridge will not allow as much flood water to pass. To counter this, the south abutment of all four bridges was moved back to increase the total bridge length. This offsets the reduced area caused by the support and associated debris accumulation. A two-span conventional highway bridge having a structure depth of 4 feet is an acceptable alternative for the bridges in this study.

3.3.2 Signature Highway Bridges—Above-Supported Bridges

Signature bridges include arches, trusses, and cable-stay and suspension structures. They have the main supports above the riding surface of the bridge. The structure depth below the riding surface depends on the floor system and the span along the width of the bridge and not its length. For the road widths considered, the signature bridges in this study require a structure depth of about 3.5 feet. Signature bridges have a construction cost of

25 to 100 percent more than the conventional highway bridges and may have significantly higher maintenance costs depending on the bridge type. The advantage of the signature bridge is that it has no center pier, is thinner, and provides a unique architectural change to downtown Reno. A clear-span signature bridge with a structure depth of 3.5 feet is an acceptable alternative for the bridges in this study.

3.3.3 Redundancy

Redundancy in structural applications is the ability of a load to find an alternative path. This means a redundant bridge having multiple main support members will not collapse if there is a failure in one of the main support members. Redundancy has become especially important in recent years considering the collapse of the I-35W Bridge in Minneapolis and concerns nationwide on bridge security.

There is a distinct difference in redundancy between the above and below-supported bridge types. All below-supported bridges are redundant, having multiple main members. However, above-supported bridges are considered nonredundant and have the potential of collapse if there is a failure in one of the main members. Protection of the main members is necessary to reduce the potential failure.

3.3.4 Comparison of Maintenance Costs

The below-supported bridges in this study will have lower maintenance costs compared with the above-supported bridges, mainly because all above-supported bridges will be structural steel that have their members above the riding surface. The above-supported bridge members will be exposed to more of the elements compared with the below-supported bridges. In addition, the bridges having main cables such as the cable-stay and suspension bridges will have even higher maintenance costs.

The bridges with the lowest maintenance costs will be below-supported bridges constructed of prestressed concrete. Below-supported bridges constructed of structural steel will have a somewhat higher maintenance cost compared with prestressed concrete but will be lower than any of the above-supported bridges.

3.3.5 Moveable Bridges

3.3.5.1 General

Raising bridge elevations and reconstructing approach roads can have a significant impact on adjacent property and public facilities depending on the desired level of flood protection. An alternative to constructing a conventional fixed bridge with corresponding approach road reconstruction is to build a moveable bridge. A moveable bridge would not require significant approach road reconstruction. The approach road can remain at the existing elevation or require only a minimal increase.

Moveable bridges have a much higher construction and maintenance cost compared with the fixed bridges in this study. In addition, moveable bridges have an operational cost that fixed bridges do not.

3.3.5.2 Types of Moveable Bridges

Moveable bridges are used mainly where there is ship traffic, the vehicular traffic volume is relatively low, and construction of a fixed bridge with enough clearance under it is not economical.

There are three basic types of moveable bridges:

- Swing Bridge: A swing bridge pivots around a center pier to open the channel.
- Bascule Bridge: A bascule bridge is the conventional draw bridge. The bridge is split in into two pieces with a joint in the middle. The pieces pivot vertically at the abutments.
- Lift Bridge: A lift bridge spans over the river and lifts upward. Towers are located at each abutment to support the weight of the bridge during the lift.

The swing bridge is not viable for the Truckee River. A large center pier is required for the bridge to pivot on, and the bridge remains at the same elevation. The center pier creates an obstruction in the river during floods.

The bascule bridge is viable because it can accommodate the flood design by pivoting to the vertical position to ensure all of the deck is out of the river.

The lift span bridge is also viable. It can be raised to the elevation needed to accommodate the flood design. The amount of lift will be less than is typically needed for most lift spans but could be as much as 10 feet depending on the flood design selected for the project.

3.3.5.3 Depth of Moveable Bridge Superstructure

The bascule will cantilever from the abutment to midriver, while the lift span will span the entire river. Each will require a superstructure depth of about 7 feet. In comparison, the superstructure depth for a two-span fixed bridge is 3.5 to 4 feet.

If the approach roads to the moveable bridges do not change elevation, the flood capacity of the channel will be less than the existing bridges due to the greater structure depth. This will require operation of the bridge for lower level floods.

3.3.5.4 Planning-Level Construction Costs

A comparison of planning-level construction costs between the fixed (below and above) and moveable bridges is provided in Table 3-9. The costs for the below- and above-supported bridges are based on the Lake Street Bridge and the 100-year flood design with 2 feet of freeboard. Costs for the moveable bridges are derived from the Florida Department of Transportation's Bridge Costs for moveable bridges.

3.3.5.5 Mechanical and Electrical Equipment

Moveable bridges require mechanical and electrical equipment to operate the bridge. The mechanical equipment requires constant maintenance and has shown the need for periodic replacement of parts and major rehabilitation over time. The electrical equipment requires periodic maintenance and replacement. Proper maintenance is required for the bridge to operate when needed.

3.3.5.6 Operation and Training

Most moveable bridges have a full-time tender to open and close the bridge. A moveable bridge at one or all locations on the Truckee River will have a limited number of operations to allow flood flows to pass. Periodic inspection and operation will be required to ensure the bridge is operating correctly.

A full-time tender will not be required, but trained personnel will be needed for the operation. Trained personnel may need to be available on a 24-hour basis.

3.3.5.7 Maintenance Costs

The mechanical and electrical equipment must be maintained to ensure proper operation. Moveable bridges have a history of high maintenance costs. In addition to normal maintenance, full replacement of the mechanical and electrical equipment can be expected at least once during the life of the bridge.

3.3.5.8 Security

The mechanical and electrical equipment will require a secure facility to ensure their operation when needed.

3.3.5.9 Conclusion

Moveable bridges can accommodate the desired level of flood protection and minimize the effect on adjacent property. However, they are considered to have higher construction, maintenance, and operations costs when compared with fixed bridges. The additional costs associated with moveable bridges make them a less economical alternative.

TABLE 3-9
Comparison of Construction Costs for Fixed (Below and Above) Bridges and Moveable Bridges

Item	Below Bridges	Above Bridges	Moveable Bridges
Approach Costs	$3,150,000	$3,050,000	$150,000
Structure Costs	$9,650,000	$11,250,000	$31,150,000
Utilities and R/W	$2,200,000	$2,200,000	$200,000
Design Costs	$950,000	$1,300,000	$2,350,000
Construction Engineering	$1,250,000	$1,600,000	$2,800,000
Total	$17,200,000	$19,400,000	$36,650,000

3.4 Arlington Avenue and Booth Street Bridges

The Arlington Avenue and Booth Street Bridges were evaluated to improve their flood capacity as part of this study. These two bridges were considered in order to understand the flow and flooding scenarios to the entire downtown reach; however, they were not considered “priority replacements” and not studied to the same level of detail as the four downtown bridges. The cost estimates were not to the detail afforded the bridges in the downtown reach but were looked at from an order of magnitude basis. The estimates were based on conventional highway bridges for the 74-year flood design with 2 feet of freeboard and 100-year flood design plus 2 feet of freeboard.

3.4.1 Arlington Avenue Bridges

Arlington Avenue is located west of the Sierra Street Bridge and is considered just outside of the downtown reach of the Truckee River. Arlington Avenue crosses over the Truckee River on two bridges. The area between the bridges is Wingfield Park. First Street is located along the north bank of the river right at the edge of the north bridge, and Island Avenue is located along the south bank at the edge of the south bridge. Both First Street and Island Avenue will require reconstruction if the bridges require an increase in elevation to accommodate the flood design.

The study showed that even for the lowest flood design, 50-year flood design plus 2 feet of freeboard, water comes out of the channel and floods the area between the bridges. Reconstruction of Arlington Avenue is complicated by the high number of pedestrians within the park. The speed limit on Arlington Avenue is 15 miles per hour. Any reconstruction of the bridges and Arlington Avenue requires careful consideration of pedestrian access.

Two alternatives for Arlington Avenue were identified:

- Reconstruct the Arlington Avenue bridges at the same locations to the current level of flood protection. This is the least costly alternative in that only the two existing bridges are replaced with a minimal amount of approach road reconstruction. Both existing bridges are considered structurally deficient and eligible for replacement under the federal Highway Bridge Replacement and Rehabilitation (HBRR) Program. The bridges may require some increase in elevation to keep flood waters within the channel. The park area continues to flood for the all the flood designs.
- Reconstruct the Arlington Avenue bridges with one single bridge that extends between both banks. This results in a six-span bridge 450 feet long that spans over both existing river channels and the park. Pedestrians using the park would pass under the bridge. The bridge would be 82 feet wide and include four lanes of traffic with a sidewalk on each side.

Reconstructing the bridges at their current location and elevation does not meet any of the flood designs and as such is not considered an acceptable alternative. These planning-level cost estimates provided for the Arlington Avenue Bridge are based on replacing both bridges with one new bridge 450 feet long. The one long bridge is considered the acceptable alternative.

3.4.2 Booth Street Bridge

Booth Street is located about a half-mile upstream of Arlington Avenue. Booth Street, which runs north-south, terminates into Riverside Drive, which runs east-west, along the north side of the river. Idlewild Drive which runs east-west terminates into Booth Street at the southwest corner of the bridge. The existing Booth Street Bridge can accommodate the

50-year flood design with 2 feet of freeboard but requires replacement to meet higher levels of flood protection.

The planning-level cost estimates for the Booth Street Bridge are based on replacing the existing bridge with a new two-span bridge 128 feet long and 62 feet wide. It provides for two lanes of traffic, a center turn lane, shoulders, and sidewalks.

The bridge requires increasing its elevation to meet flood design requirements with an associated reconstruction of the approach roads. All approach roads require some level of reconstruction, with Riverside Drive being affected the most. Generally the total length of approach road reconstruction is about twice as much for the 100-year flood design compared with the 74-year flood design. Impacts from the approach road reconstruction include the following:

- **North Side of River.** There are a number of apartment complexes along the north side of Riverside Drive. The driveways accessing these complexes will be impacted by the need to raise Riverside Drive and construct retaining walls. Riverside Drive must be raised up to 5 feet to accommodate the 100-year flood design.
- **South Side of River.** The south side of the river is about 3 feet higher than the north side, and the impacts to adjacent properties will not be as high. There is an apartment complex on the southeast corner of the bridge. Its driveway access is near the south end of the bridge and will be impacted by the 100-year flood design event.

3.5 Conclusions

Increasing Truckee River flood capacity through downtown Reno requires reconstruction of the four bridges for all flood designs considered except for the Center Street Bridge under the 50-year flood design with 2 feet of freeboard. Each bridge must be set at an elevation high enough to clear the design flood with freeboard clearance to minimize the potential for collecting debris. Reconstructing the approach roads to match the new bridge elevations will impact adjacent properties and public facilities. Bridge types were identified that minimize the structure depth and approach road reconstruction.

The challenge is to maximize the level of flood protection while minimizing the effect on adjacent property and keeping costs down.

3.5.1 Recommended Flood Design

3.5.1.1 100-year Flood Design with 2 Feet of Freeboard

The 100-year flood design with 2 feet of freeboard appears to be the best flood design based on cost, level of flood protection, and effect on adjacent property due to approach road reconstruction when compared with the other flood designs. This design is consistent with the National Economic Development (NED) plan of 50-year flood design with 4 feet of freeboard and meets USACE criteria for a 50-year design.

The reconstruction costs for this flood design are about 5 percent higher for Sierra Street, Virginia Street, and Center Street compared with the 74-year flood design. The reconstruction costs for Lake Street are about 10 percent higher. There is also no significant difference between the effects on the approach road reconstructions between these two flood designs. Compared with the 74-year flood design, the 100-year flood design with 2 feet of freeboard provides a higher level of flood protection without a significant cost increase or effect on adjacent property.

3.5.2 Other Flood Designs

3.5.2.1 50-year Flood Design with 2 Feet of Freeboard

The 50-year flood design provides little increase in the current level of flood protection. This flood design has the lowest cost due to low approach costs and the Center Street Bridge remaining in place. This flood design does not appear to provide the increased level of protection needed for downtown Reno.

3.5.2.2 74-year Flood Design with 2 Feet of Freeboard

The 74-year flood design corresponds approximately to the historical flood event of 2005. This flood design is an intermediate level of protection between the 50- and 100-year flood designs. It requires replacement of all four bridges and reconstruction of approach roads. The total reconstruction costs for each bridge are not much lower than the 100-year flood design with 2 feet of freeboard. There is also no significant difference in the approach road reconstruction requirements between the two flood designs. The 74-year flood design provides a lower level of flood protection compared with the 100-year flood design with 2 feet of freeboard but without a significant decrease in cost or effect on approach reconstruction.

3.5.2.3 100-year Flood Design with 4 Feet of Freeboard (USACE)

The reconstruction costs associated with this flood design averages about 15 percent higher compared with the 100-year flood design with 2 feet of freeboard. The majority of the cost increase is due to approach road reconstruction. There is a significant change in the effect on adjacent property by increasing the bridge elevations by 2 feet. Two feet of freeboard provides an acceptable level of protection from debris accumulation and is standard for most highway bridge projects. The USACE's requirement of 4 feet includes an uncertainty in the flood design analysis and the risk of having a high-level flood. The 4-foot criteria may be acceptable for locations where an increased freeboard does not come with an adverse effect on adjacent property. This flood design does not appear appropriate for this project due to the effect on adjacent property.

3.5.3 Bridge Type

In addition to the above- and below-supported bridge types, moveable bridges were considered for the replacement bridges on this project. While an above-supported bridge type would be feasible in the identified locations, the below-supported bridge type or conventional highway bridges may be determined to be preferred due to their lower construction and maintenance costs and the higher level of structural redundancy they provide.

4.0 Cost Estimating

4.1 MCACES Estimates

The USACE is recommending a 50-year flood protection for the downtown reach of the Truckee River with bridges set to a 100-year level of flood protection (Scott Stonestreet/USACE, conference call with Truckee River Flood Management Project, Paul Urban, Jay Aldean and Kerri Lanza: January 8, 2009). The Locally Preferred Plan (LPP) at the time of the preparation of MCACES assumed a higher level of flood protection, which included a 100-year flood protection with 4 feet of freeboard clearance. Cost estimates were prepared for the LPP under a separate Reno TRAction Project. The cost estimates were prepared using the USACE MCACES requirements. The MCACES method of cost estimating was used to be consistent with the estimates prepared by the USACE for their 50-year flood protection recommendation.

The MCACES method for cost estimating uses the labor, materials, and equipment needed to construct a project. This requires a well-developed design to identify items of work and to be able to calculate fairly accurate quantities. The following assumptions were made on the design to develop it to a point where quantities could be calculated:

- New road profiles were developed to match the elevation increases in the bridges. The extent of approach road reconstruction was estimated to identify approach road reconstruction costs. New retaining walls at most adjacent properties were included to account for differences in elevations. New approach pavement, signals, sidewalks, and drainage were also included.
- A single-span tied-arch bridge type was considered for the bridge design parameters at the time of the preparation of the MCACES estimate and for determining impact as part of the USACE's Environmental Impact Statement documentation. This was consistent with the single-span bridge assumed by the USACE in their cost estimates. The tied-arch bridge provided the thinnest bridge superstructure to reduce the effect on adjacent property due to approach road reconstruction.
- Relocation of utilities, reconstruction of approaches, and modification of adjacent property were included in the estimate.

The MCACES estimate is provided in Appendix E.

4.2 Downtown Bridge Estimates—74-year and 100-year Flood Designs with 2 Feet of Freeboard

Planning-level cost estimates were prepared for the 74-year and 100-year flood designs. Both flood designs incorporate 2 feet of freeboard clearance. The cost estimates were prepared using the unit cost method. The unit cost method is used by most public agencies to develop cost estimates at all stages of project development. It requires quantities for the major work items and includes a contingency for the minor work items and project unknowns. The contingency at the early stages of project development is high and will be fine-tuned as the design is refined.

The following two bridge types were included in the cost estimates:

- Above-supported bridges, also called signature bridges, are single-spans that are supported by elements above the deck. They were selected originally for the MCACES estimate to provide a clear span of the river and minimize structure depth. These bridge types include a steel tied-arch, steel truss, cable-stay, and suspension. The cost estimates for above bridges are based on the tied-arch bridge. The tied arch has a much lower construction and maintenance cost compared with the cable-stay and suspension alternatives. The truss bridge has comparable costs to the tied arch but is considered to have inferior aesthetics.
- Below-supported bridges were added to the study to try and reduce bridge costs and provide a structure type that does not have its supports above the deck. A single-span below-supported bridge requires a structure depth that is too deep for this project. A center pier was added to reduce the superstructure depth to a depth comparable to the above-supported bridges. Hydraulic studies indicate a two-span bridge will not adversely affect water surface elevations for either of the flood designs. Structural steel girders, precast prestressed concrete box girders, and cast-in-place prestressed concrete box girders are viable structure types for below-supported bridges. The precast prestressed concrete box girder bridge was used for the cost estimates for the below-supported bridge alternatives. They have a lower cost compared with structural steel and provide faster onsite construction compared with the cast-in-place prestressed concrete box girder. Though the cost of the precast prestressed box girders is higher than the cast-in-place prestressed concrete box girder, there is risk involved in placing falsework in the river for an extended period of time while constructing the cast-in-place alternative.

The bridge lengths used in the cost estimates are longer than the existing bridges. The south abutments for all bridges have room to be moved further south. This provides a slight increase in hydraulic capacity and allows access under the bridges from the Riverwalk and future Post Office Plaza. The overall length of existing bridges and new bridges length used in the replacement cost estimates are shown in Table 4-1.

TABLE 4-1
Length of Existing and Replacement Bridges Used in 74-year and 100-year Flood Designs

Location	Existing	Replacement
Sierra Street	133 feet	153 feet
Virginia Street	138 feet	158 feet
Center Street	158 feet	168 feet
Lake Street	151 feet	161 feet

The bridge widths used in the cost estimates match the existing roadway widths and include at least a 10-foot-wide sidewalk on both sides of the street.

4.2.1 74-year Flood Design Estimate

The 74-year flood design cost estimates for the above- and below-supported bridges are shown in Table 4-2. The estimates include construction, design, construction engineering, utility, and right-of-way costs. A 20 percent contingency has been included and is considered appropriate for the conceptual level of detail that has been developed at this point in time.

TABLE 4-2
Downtown Bridge Reconstruction Cost Estimates for the 74-year Flood Design

Location	Above Bridge Type	Below Bridge Type
Sierra Street	$15,070,000	$13,080,000
Virginia Street	$15,370,000	$13,020,000
Center Street	$14,850,000	$12,510,000
Lake Street	$17,820,000	$15,640,000

NOTE:
Costs are based on 2008 dollars.

4.2.2 100-year Flood Design Estimate

The 100-year flood design cost estimates for the above and below bridges are shown in Table 4-3. The estimates include construction, design, construction engineering, utility, and right-of-way costs. A 20 percent contingency has been included and is considered appropriate for the conceptual level of detail that has been developed at this point in time.

TABLE 4-3
Downtown Bridge Reconstruction Cost Estimates for the 100-year Flood Design

Location	Above Bridge Type	Below Bridge Type
Sierra Street	$15,560,000	$13,660,000
Virginia Street	$16,000,000	$13,670,000
Center Street	$15,400,000	$13,210,000
Lake Street	$19,380,000	$17,240,000

NOTE:
Costs are based on 2008 dollars.

4.3 Arlington and Booth Estimates

Planning-level cost estimates for the replacement of the Arlington Avenue and Booth Street Bridges are provided only for the below-supported bridge type. The above-supported bridge type was not considered due to its higher cost.

The square foot area method was used to calculate the cost estimates for Arlington and Booth. This method can be used during the early stages of a project's development when quantities for the major items of work are not available and cannot be accurately identified. The square foot cost method relies solely on the accuracy of the square foot cost value assumed. Square-foot costs from other comparable projects are generally used. The cost estimates for Arlington Avenue and Booth Street estimates are based on the square foot cost values from the more detailed estimates developed for the downtown bridges.

Cost estimates were developed for the 74-year and 100-year flood designs to be consistent with the downtown bridges. Both flood designs have 2 feet of freeboard clearance. The cost estimates for the Arlington Avenue and Booth Street Bridges are shown in Table 4-4.

TABLE 4-4
Arlington Avenue and Booth Street Reconstruction Cost Estimates for the 74-year and 100-year Flood Designs

Location	74-year Flood Design	100-year Flood Design
Arlington Avenue	$19,000,000	$21,250,000
Booth Street	$ 6,580,000	$ 8,420,000

NOTES:
Estimates are for below-supported type bridges.
Costs are based on 2008 dollars.

5.0 Simulations and Architectural Renderings

Graphic simulations and architectural renderings were developed illustrating elevation and aesthetic impacts at the Sierra Street, Virginia Street, Center Street, and Lake Street crossings for both the 74-year and 100-year flood designs. These assumed below-supported bridges with a single center pier.

The simulations were presented during public workshops and presentations to City staff, providing visual perspective of the projected impacts to adjacent roadways, pedestrian access, and existing structures along with potential mitigation and design options.

Aerial simulations were also developed illustrating the corridor with either cable-stay or tied-arch bridge types at the aforementioned crossings to provide perspective on how these designs might affect viewsheds and the aesthetic character of the corridor.

Simulations and architectural renderings developed throughout the study can be referenced in Appendix G.

6.0 Public Involvement and Community Outreach

The public involvement aspects of the TRAction Visioning Project were designed to be inclusive of all interested parties within the City. These efforts were geared toward engaging the community during the evaluation of potential improvements and, as the project changed focus, to consider the flood design year and the bridge types as choices the City of Reno gets to make. Every effort was made to provide multiple avenues by which community members could take part in the process, have their questions answered, and voice their concerns and vision for the downtown Truckee River Corridor.

6.1 Public Workshops

A total of three public workshops were held to present information regarding the TRAction Visioning Project and solicit feedback from the community. Workshops were carefully planned with specific objectives to ensure productive and meaningful discussion and foster a spirit of collaboration between attendees and the Study Team. Various workshop formats were employed to encourage participation of individuals in attendance. Workshop formats included brainstorming sessions within various group sizes, formal presentations using PowerPoint presentations and large format displays, and open-house formats allowing one-on-one interaction with Study Team members.

Workshop attendees were encouraged to provide both verbal and formal written comments that were referenced during the project development and were summarized and provided to the City. Following is a brief synopsis of each of the public workshops. Detailed workshop summaries including, attendee rosters, public comment, and presentation content are located in Appendix H.

- Workshop #1 provided an overview of the project objectives, parameters, and process. The workshop also included a “walking tour” slideshow of the corridor; a presentation discussing the goals and objectives of the TRFMP as they relate to the TRAction Visioning Project; and a presentation introducing potential bridge types and conceptual flood control options, including channel widening and dredging options, along with their potential environmental, aesthetic, and structural impacts. Comments received generally supported artistic elements and structures that preserved the views and complemented the existing architectural themes within the corridor. Attendees also felt it was important to maintain and potentially expand recreational uses along the corridor including riverfront shops and promenades and expanded access for recreational activities directly tied to the river including fishing, swimming, kayaking, and so on. Pedestrian and bicycle safety and access were also recurrent themes. See Appendix H-1 for additional information on Workshop #1 including a public comment summary and presentation materials.

- Workshop #2 presented conceptual graphics and renderings depicting the limits of roadway reconstruction associated with the 50-year, 74-year, 100-year with 4 foot freeboard (USACE criteria), and 100-year with 2 foot freeboard flood protection design options. Flood impacts associated with the Virginia Street Bridge were also illustrated to provide the public with a better understanding of the impacts the bridge has on flooding as currently designed. Public feedback during this workshop tended to support the 74-year and 100-year with 2 foot freeboard design options. It was generally felt that the 50-year design did not sufficiently address the flooding problems experienced within the downtown corridor, while the potential aesthetic and structural impacts of the USACE 100-year with 4-foot of freeboard option were generally undesirable within the corridor and felt to be excessive when compared with the additional level of safety provided. With regard to the flood impacts of the Virginia Street Bridge, there was a general consensus that steps should be taken to mitigate these impacts, including possible replacement of the structure. See Appendix H-2 for additional information on Workshop #2 including a public comment summary and presentation materials.
- Workshop #3 focused primarily on the 74-year and 100-year with 2-foot freeboard designs (feedback during previous workshops showed the 50-year and 100-year USACE criteria to be generally unfavorable options) and the various bridge types to be considered in an effort to determine community preferences. Conceptual renderings were provided to give the public a sense of the aesthetic, roadway reconstruction, and structural impacts associated with the 74-year and 100-year design options. Conceptual renderings for below-supported, cable-stay, and tied-arch bridge types along with construction cost comparisons were provided. The option of using moveable/lift bridges was discussed including associated impacts and construction and maintenance costs. Attendees were provided with a survey form to gauge preferences between bridge types and level of flood protection. Survey results leaned strongly toward the 100-year flood protection design with below-supported structures preferred by a slim margin. The moveable/lift bridge option was found to be unfavorable by a strong majority. See the Workshop #3 summary in Appendix H-3 for additional discussion of survey findings and presentation materials.

Upstream detention and channel dredging and widening were also revisited during Workshop #3 to respond to questions raised regarding why these flood control options were found to be less favorable than bridge replacement. Potential habitat and environmental impacts were discussed in addition to the permitting, maintenance requirements, and structural impacts associated with dredging and widening of the channel to the extent required to provide significant flood protection benefits.

The presentation material shared at these three workshops can be found in Appendix H.

Table 6-1 summarizes workshop dates, locations, and notification methods.

6.2 Additional Presentations

In addition to the public workshops, various community groups and organizations were contacted and provided an opportunity to schedule presentations for their memberships. Presentation scheduling and materials were adapted to the extent possible to meet the needs of each organization that participated. Table 6-2 identifies those organizations and community groups that requested presentations and the dates these presentations were conducted.

TABLE 6-1
Workshop Details

	Location	Date/Time	Notification Methods
Workshop #1*	Reno City Hall 1 East First Street Northeast Community Center 1301 Valley Road McKinley Arts Center 925 Riverside Drive	October 4, 2007 5:00–7:30 P.M. October 9, 2007 5:00–7:30 P.M. October 11, 2007 5:00–7:30 P.M.	Reno Gazette Journal City of Reno Web site TRFMP Web site E-mail blasts Fliers distributed to riverfront businesses Mailing list
Workshop #2	McKinley Arts Center 925 Riverside Drive	February 19, 2008 5:30–7:30 P.M.	Reno Gazette Journal City of Reno Web site TRFMP Web site Telephone notifications E-mail blasts Fliers distributed to riverfront businesses Mailing list
Workshop #3	McKinley Arts Center 925 Riverside Drive	October 2, 2008 5:30–7:30 P.M.	Reno Gazette Journal City of Reno Web site TRFMP Web site E-mail blasts Fliers distributed to riverfront businesses Mailing list

NOTE:
*Workshop #1 was held on three separate dates and locations.

TABLE 6-2
Additional Presentations

Community Group/Organization	Presentation Date(s)
Palladio Homeowner's Association	October 2007 November 2007
Nevada Historic Society	December 2007
Reno Redevelopment Agency Citizen's Advisory Board	December 4, 2007 May 2008
Historic Reno Preservation Society	December 6, 2007
Downtown Improvement Association (DIA)	August 7, 2008 August 21, 2008 November 2007 January 2008
Historical Resource Commission	August 14, 2008 November 2007| January 2008
Reno City Council Presentation	September 2008 February 2009

6.2.1 Final City Council Presentation

On February 25, 2009, City staff presented the final conclusions of this study to the Reno City Council. A review of the flood year design, bridge types, and impacts to the local streets was presented. Staff presented two recommendations. The first was to proceed with a 100-year flood design with 2 feet of freeboard. The second recommendation was to proceed with an above-supported bridge type.

City Council supported the 100-year design recommendation and asked staff to continue considering the bridge type decision with further analysis and involvement of the local community.

A copy of the Staff Report and presentation given to City Council is provided in Appendix H.

6.3 Project Web Site

A project Web site was developed that included project background information, project objectives, and public workshop notifications. Workshop presentations, displays, handouts, comment forms, and meeting summaries were also made available via the Web site for those who were unable to attend the workshops.

Site visitors were encouraged to submit their questions and comments via contact links provided for designated City of Reno and TRFMP representatives.

7.0 References

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Florida Department of Transportation. 2008. *Transportation Costs Report: Bridge Costs.* http://www.dot.state.fl.us/planning/policy/costs. April.

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PLACES Consulting Services Inc. 2008.*Truckee River Topographic and Structures Survey of the Downtown Reach from Arlington to 2nd Street*. February.

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