Carson City Board of Supervisors
Agenda Report

Date Submitted: January 20, 2012

Agenda Date Requested: February 2, 2012
Time Requested: 15 minutes

To: Mayor and Supervisors

From: Carson Water Subconservancy District

Subject Title: For Possible Action: To adopt the Hydraulic Modeling and Floodplain Mapping Guidelines, dated October 2011 for the Carson River only. This document provides a set of guidelines or best practices for engineers, developers, hydrologists, regulators, municipalities, and/or other stakeholders who will be modeling or reviewing hydraulic models for the Carson River. Also a short presentation will be given to the Board of flood plain mapping efforts of the Carson River in Carson City. *(Ed James)*

Staff Summary: The Hydraulic Modeling and Floodplain Mapping Guidelines, dated October 2011 for the Carson River provides a set of guidelines or best practices for engineers, developers, hydrologists, regulators, municipalities, and/or other stakeholders who will be modeling or reviewing hydraulic models. This request will be followed by a short presentation to the Board of the flood plain mapping efforts for the Carson River through Carson City.

Type of Action Requested: (check one)

(____) Resolution (___) Ordinance
(X) Formal Action/Motion (____) Other (Specify)

Does This Action Require A Business Impact Statement: (___) Yes (X) No

Recommended Board Action: I move to adopt the Hydraulic Modeling and Floodplain Mapping Guidelines, dated October 2011 for the Carson River.

Explanation for Recommended Board Action: In September of 2010, through a grant from NDEP, Carson Water Subconservancy District (CWSD) entered into an agreement with HDR Engineering, Inc. (HDR) to produce a guidance document for hydraulic modeling and floodplain mapping for the upper and middle Carson River. The goal of the document is to provide a set of guidelines or best practices for engineers, developers, hydrologists, regulators, municipalities, and/or other stakeholders who will be modeling or reviewing hydraulic models for the Carson River.

Applicable Statute, Code, Policy, Rule or Regulation:

Fiscal Impact: none

Explanation of Impact: N/A

Funding Source: N/A

Alternatives: Not to adopt the guidelines.

Supporting Material: Hydraulic Modeling and Floodplain Mapping Guidelines, dated October 2011 document

Prepared by: Robert D. Fellows, Carson City Floodplain Administrator

Reviewed By: ______________________ Date: 1/24/12
(Public Works Director)

______________________ Date: 1/24/12
(City Manager)

______________________ Date: 1/24/12
(District Attorney)

______________________ Date: 1/24/12
(Finance Director)

Board Action Taken:

		Aye/Nay
Motion: ______________	1) ______________	________
	2) ______________	________
	3) ______________	________
	4) ______________	________
	5) ______________	________

____
(Vote Recorded By)

Hydraulic Modeling and Floodplain Mapping Guidelines

In 2008, all the counties in the Carson River Watershed adopted the Carson River Watershed Regional Floodplain Management Plan (Plan). This Plan summarized the issues, concerns, and opportunities communities face along the Carson River. The Plan also recognized the value and critical functions provided by the floodplains for public safety and reduction of flood damage. From the Plan several suggested actions were proposed. One of these suggested actions was to update the FEMA floodplain mapping using the most recent topographical data and state of the art hydraulic modeling. This suggested action is currently being pursued along the Carson River upstream of Lahontan Reservoir to Alpine County and should be completed in 2015. To enhance the use of these new floodplain maps the various county floodplain administrators, representatives from the state, and various other water professionals suggested the development of a guidance document and protocol for modeling and flood mapping for the Carson River.

In September of 2010, through a grant from NDEP, Carson Water Subconservancy District (CWSD) entered into an agreement with HDR Engineering, Inc. (HDR) to produce a guidance document for hydraulic modeling and floodplain mapping for the upper and middle Carson River. The goal of the document is to provide a set of guidelines or best practices for engineers, developers, hydrologists, regulators, municipalities, and/or other stakeholders who will be modeling or reviewing hydraulic models for the Carson River.

The guideline is divided into two parts, a conceptual framework and technical guidance. The conceptual framework explains a basic summary of key concepts of hydrology, USGS streamflow data, hydraulic modeling, GIS mapping, and historic flooding information. The technical guidance section is for practitioners and gives detailed criteria and standards for any person, agency, or firm conducting floodplain modeling or mapping for the Carson River upstream of Lahontan Reservoir.

Although the hydraulic modeling and floodplain mapping for the Carson River upstream of Lahontan Reservoir will not be completed until 2015, CWSD is asking the four counties that will be involved with the new floodplain mapping, Alpine, Douglas, Carson, and Lyon, to adopt the guidelines. This will allow county staff, developers, FEMA, and other interested parties to begin applying a uniform process which will consider floodplain management on a watershed wide basis. thinking about floodplain mapping on a regional basis. The guideline is a living document and can be modified in the future.

Hydraulic Modeling and Floodplain Mapping Guidelines

Carson River, NV & CA

Date: October 2011

Prepared for:

Carson Water Subconservancy District

Funding Provided by:

Nevada Division of Environmental Protection

Project number: 137049

List of Acronyms

1-D	One-dimensional
2-D	Two-dimensional
ASPRS	American Society for Photogrammetry and Remote Sensing
CFR	Code of Federal Regulations
cfs	Cubic feet per second
CRC	Carson River Coalition
CTP	Cooperating Technical Partners
CWSD	Carson Water Subconservancy District
DEM	Digital Elevation Model
DFIRM	Digital Flood Insurance Rate Map
DTM	Digital Terrain Model
ESRI	Environmental Systems Research Institute
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
GIS	Geographic Information Systems
GPS	Global Positioning System
GUIDE	Guidelines and Specifications for Flood Hazard Mapping Partners
HEC-RAS	Hydrologic Engineering Centers River Analysis System
IMU	Inertial Measurement Unit
LiDAR	Light Detection and Ranging
LN	Break line format
Mr. SID	Multi-resolution seamless image database
NAD83	North American Datum of 1983
NAVD88	North American Vertical Datum of 1988
NDEP	Nevada Division of Environmental Protection
NFIP	National Flood Insurance Program
n	Manning's Roughness Coefficient
PT	Point line format
RMSE	Root mean square error
SA	Suggested Action
TIN	Triangulated Irregular Network
TSDN	Technical Support Data Notebook
USACE	U.S. Army Corps of Engineers
USGS	United States Geological Survey
WSELs	Water-surface elevations
WSP	Water Supply Paper

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1 INTRODUCTION

"Flooding in the Carson River Watershed is a natural process that occurs on a regular basis. It is also one of the most devastating and costly natural events that our communities face. The Carson River is unique in that we have no flood control structures and have extremely limited upstream storage capability. However, we have the best flood control mechanisms available – open floodplain lands.

The actions of one community have the potential to impact downstream communities, making flooding a watershed-wide challenge."

-Carson River Watershed Regional Floodplain Management Plan

These excerpts from the *Carson River Watershed Regional Floodplain Management Plan* (Plan) summarize the issues, concerns, and opportunities communities face along the Carson River. The Plan is a living document providing suggested actions and strategies for floodplain management within the Carson River watershed. All communities along the river have adopted this Plan to encourage the realization of the value and critical functions provided by floodplains for public safety and reduction of flood damage. Actions were developed to address the need for accurate data, reduction of negative impacts from existing infrastructure, and outreach and education.

In an effort to provide guidance for future floodplain mapping efforts along the Carson River, the Carson River Coalition (CRC), hosted by the Carson Water Subconservancy District (CWSD), organized a Hydraulics and Hydrology Committee in May 2010. This committee, made up of stakeholders and experts, met to provide guidance on modeling and flood mapping protocol for the Carson River. The committee discussed specific models and methodologies and chose a preferred set of models, procedures, specifications, and guidelines. Funded by the Nevada Division of Environmental Protection (NDEP), a modeling and mapping guide was chosen as a mechanism to summarize these preferences and provide a manual for the Carson River watershed.

This guide covers required modeling and mapping procedures for the Main Carson River and both East and West forks. The downstream extent shall be Lahontan Reservoir in Lyon County, Nevada. For the West Fork, the approximate upstream extent shall be Hope Valley, and for the East fork, Monitor Pass, both in Alpine County, California (Figure 1). This guide, and subsequent modeling/mapping, addresses several suggested actions (SAs) from the Plan:

- **SA-14:** Secure funding for and conduct watershed-wide unsteady-state state modeling to identify flood water storage requirements and to look at the cumulative effects of watershed development.
- **SA-15:** Support Federal Emergency Management Agency's (FEMA) Map Modernization Program and encourage FEMA to update Flood Insurance Rate Maps (FIRMs) with current and future conditions. Significant verification of topography and other variables should be conducted prior to release of draft FIRMs.
- **SA-16:** CWSD continue to participate in FEMA's Cooperating Technical Partner Program.
- **SA-17:** Strive for up-to-date and consistent data collection and maintenance to include updating of flood studies where necessary and conduct studies for significant water courses and alluvial fan areas that have not been analyzed. This data should be used to update FEMA maps and fill data gaps. Complete delineation of the floodway throughout river system and incorporate into FIRMs.
- **SA-18:** Flood studies and maps should be updated after significant flooding events.

The ultimate goal of this guide and modeling/mapping effort in the Carson River Watershed is to provide a consistent and complete tool to assess cumulative impacts of land use changes within the 0.2-percent chance (500-year) floodplain. There is also a strong desire among local stakeholders to use the modeling/mapping as a means for mitigating flood hazards to downstream communities, loss of riparian habitat and floodplain function, and degradation of water quality. Any proposed land use changes can be introduced to the model to evaluate cumulative impacts to floodplain extents, peak flow, peak flow timing, and flood volumes.

The CWSD, NDEP and participating communities require the procedures outlined in this guide, to the greatest extent practicable, accompanied by sound engineering judgment, for future floodplain modeling and/or mapping within the 0.2-percent (500- yr) floodplain extents along the Main Stem and East and West forks of the Carson River in the study areas outlined in Figure 1. This guide will also serve as a basis for any model/map revisions.

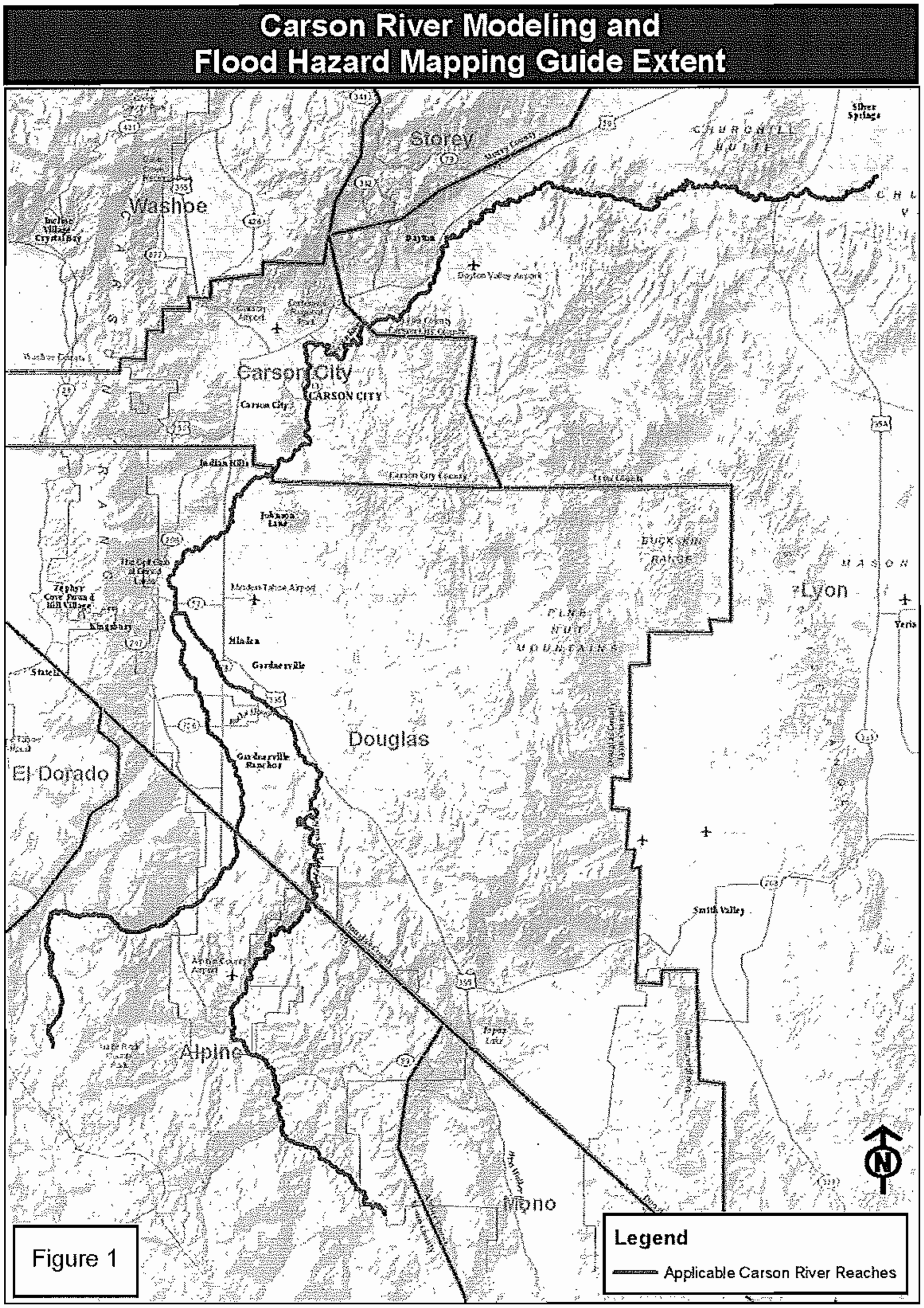

Figure 1: Study area map

2 PURPOSE AND SCOPE

The purpose of the Carson River *Hydraulic Modeling and Floodplain Mapping Guide* (Guide) is to provide criteria, standards, and modeling guidance for future hydrologic analysis, hydraulic modeling and flood hazard mapping studies on the Carson River within Lyon, Carson City, Douglas and Alpine counties. It provides a convenient source of technical information that is specifically tailored to the unique hydrologic and hydraulic characteristics of the Carson River watershed. Practitioners' use of the consistent set of criteria in this guide will result in uniform modeling practices throughout the watershed, across jurisdictional boundaries, and potentially reduce conflict between regulatory agencies and the land development community. It should be noted that this Guide only applies to the floodplains and floodways associated with main stem and the East and West forks of the Carson River. It is not intended to provide modeling direction for tributaries or alluvial fans associated with the Carson River. Topics not included in this Guide are to be conducted using best engineering judgment and local, state, and federal standards.

The Guide is not intended to replace or supersede federal regulations set forth in 23 Code of Federal Regulations (CFR) Part 650, 44 CFR Part 60, or 44 CFR Part 65. The Guide covers types of models to be used, acceptable software, data requirements, data collection, terrain development, and surveying standards, specific direction on hydrologic and hydraulic modeling parameter selection, and prescribes floodplain delineation techniques. This guide does not cover rainfall-runoff simulation.

3 CONCEPTUAL FRAMEWORK

The following section summarizes a variety of pertinent concepts relating to the technical portions of the Guide. A broad overview of hydrology, hydraulic modeling, and Geographic Information Systems (GIS) is presented to familiarize the reader with these concepts.

3.1 Hydrology

An accurate and useful hydraulic model is predicated on a sound hydrologic analysis for the study reach of interest. Generally, two different approaches can be used to represent the flow of water in a hydraulic model. These are known as steady-state flow and unsteady-state flow.

Steady-state flow assumes that depth, velocity, and discharge at a given location do not vary with time. A single flow value is assumed along the entire study reach. A common application of a steady-state flow evaluation is the use of peak discharges associated with flood events.

Unsteady-state flow assumes that discharge, as well as depth and velocity, can change over a given time period at a single location and throughout the study reach. This change in flow over time is often represented graphically by a hydrograph, with time on the x axis and discharge or flow on the y axis (Figure 2). Hydrographs for both the 1997 and 2006 floods on the Carson River at the United States Geological Survey (USGS) stream gage near Carson City are shown in Figure 2. It should be noted that although the length and magnitude of the two events shown in Figure 2 are quite different, the overall shape of the hydrograph curves is quite similar.

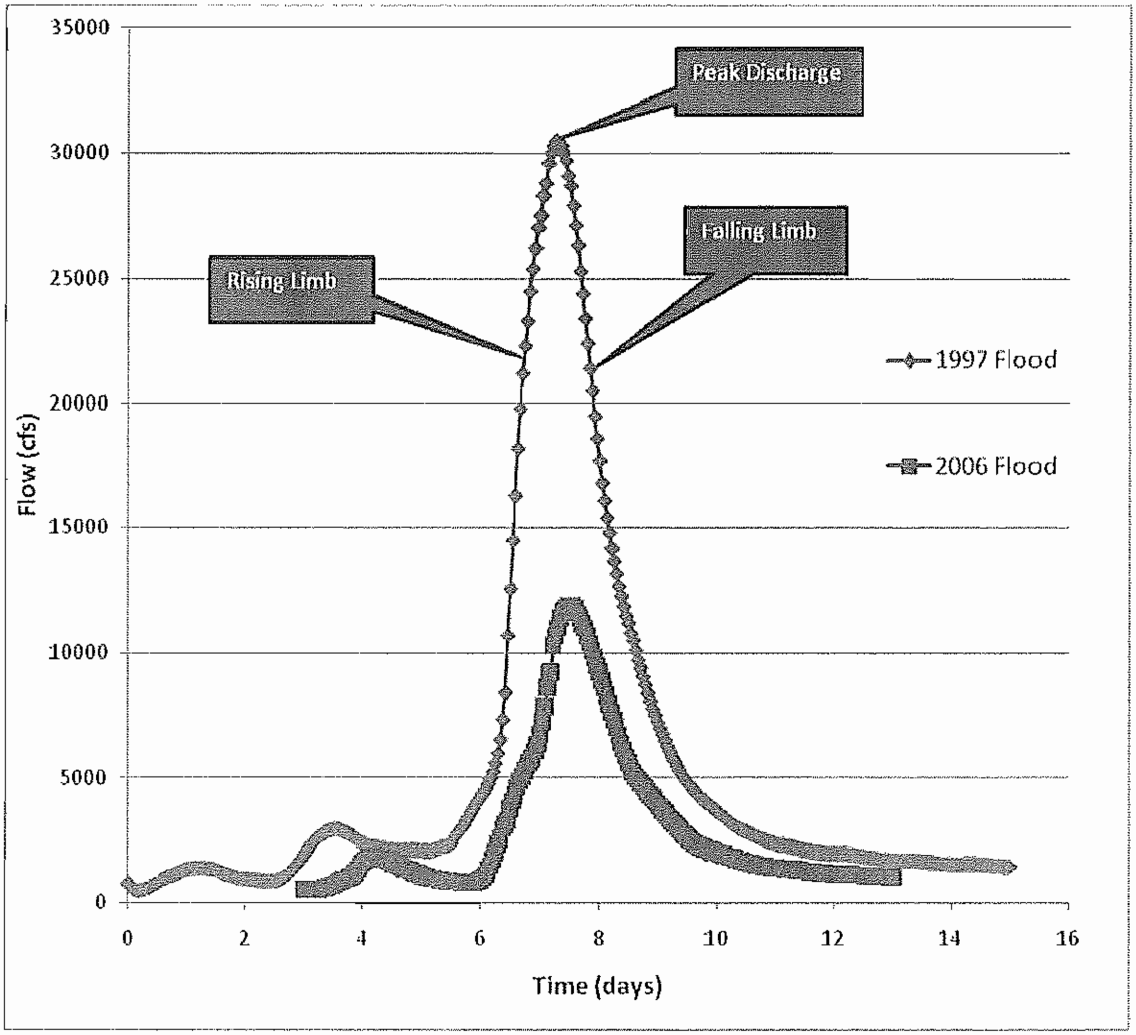

Figure 2: Example hydrographs from the *Carson River Near Carson City* USGS stream gage

The time period chosen often represents a specific storm event, extending from the time flow increases above normal baseflow until the storm peak has passed and flow returns to normal levels. The portion of the hydrograph with increasing discharge is known as the rising limb, while the section of decreasing discharge is called the falling limb. The highest point on the hydrograph curve indicates the peak discharge for the storm. The way that the watershed responds to precipitation determines the shape of the hydrograph. If runoff rapidly makes its way into the stream channel after the start of the storm, the rising limb will be quite steep, whereas a flatter sloping rising limb indicates that precipitation takes longer to arrive in the channel from the overbank regions. This explains why the two curves shown in Figure 2 have a similar shape, but different magnitudes. The area under the curve represents the volume of water associated with the storm event in question.

Both steady- and unsteady-state models have benefits, drawbacks and appropriate applications. Steady-state hydraulic models have the benefit of relative ease of setup and stability during analysis. However, they are not able to model the range of flows that occur during a storm event. Unsteady-state flow models are able to more accurately simulate the timing and volume of the flood event being modeled. In addition, an unsteady-state model is able to represent flow attenuation caused by storage of flood water in the channel and overbank areas. It is the desire of member agencies within the Carson Water

Subconservancy District to simulate the attenuation that occurs in the reaches where significant overbank storage exists. It is the desire of the member agencies to exercise a floodplain management strategy that considers both the hydrologic and hydraulic impacts of encroachments or modifications to the Carson River floodplain that would change these storage dynamics and result in downstream changes to the hydrograph.

3.2 USGS Streamflow Data

USGS operates and maintains streamgaging stations on rivers and streams throughout the world. These stream gages collect stage data, generally recording one stage value every 15 minutes. Stage is the height of the water-surface above a given stream gage datum. These data are available from USGS in numerous formats.

The raw 15-minute data, referred to as instantaneous data, are available through the USGS website (*http://waterdata.usgs.gov/nv/nwis/rt*). Specific data requests may be required to obtain instantaneous data prior to roughly 1990.

Mean daily flow data are also provided by USGS. These values represent an average of the recordings for a given 24-hour period. This averaging process tends to impact the instantaneous peak flow values that are reported, reducing the usefulness of this data set for statistical analyses in support of flood flow determinations.

Peak streamflow data represents the maximum instantaneous flow value that occurs during each water year. These data are not subject to averaging; therefore, they provide a better base for flood flow estimates. It should be noted that there may be gaps in peak flow measurements due to errors in measurement or damage to stream gages during extreme events. A minimum of 20 data points (water years) are recommended when performing statistical analyses on peak flow data.

As mentioned above, the automated stream gage digitally records stage, rather than directly recording discharge. Stage data are converted into discharge based on a stage-discharge rating curve, which is developed by taking direct discharge measurements in the river at various stage elevations over a period of many years. These discharge values are plotted against the related stage elevations to develop and approximate the rating curve for that stream gage location (Figure 3). During large flow events, care must be taken when attempting to extrapolate the rating curve beyond measured data points. It should also be noted that measurements of flow rate are performed with a variety of methods. Direct measurements have been performed using a flow meter or more recently with newer Doppler sounders. These types of measurements can be very accurate for the lower range of stages. At higher depths and velocities, these measurements can be more complex and less accurate. The data collected for these estimates includes the cross section at the location of the measurement (which is typically the same location over a period of time), velocity distribution, cross section area and estimated discharge. All of these data can be useful for model calibration.

Some of the methods used to estimate peak flow are based on indirect measurements. These measurements use the slope-area method after the event has occurred. This is done with cross section and high water mark surveys. The accuracy of these estimation techniques are highly dependent on the quality of the high water marks, which can often be difficult to accurately determine for a number of reasons, and upon estimation of roughness parameters for the reach in which the estimate is performed. If the indirect estimate is inaccurate, it can influence the rating curve fit to the data points and result in an inaccurate estimation of an event's peak, hydrograph shape and volume. Therefore, these data need to be reviewed for reasonableness when attempting to calibrate an unsteady flow model using gage data.

It is also important to understand data collection history. The location of the gage or the location for direct measurements may have changed over the history of the gaging station. This is also important to consider when using these data.

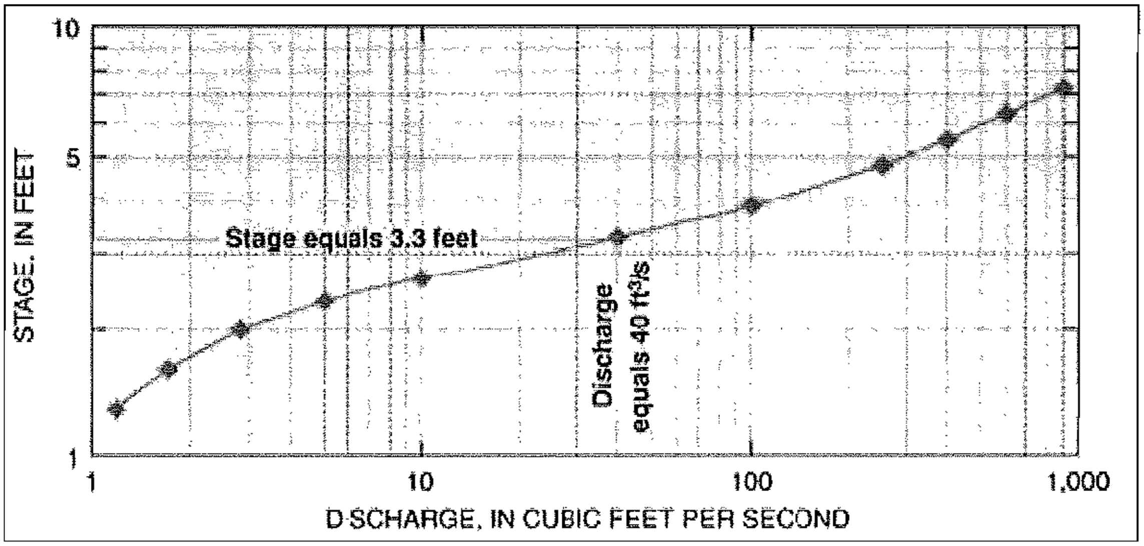

Figure 3: Example rating curve, after USGS, 2011

3.3 Hydraulic Modeling

Hydraulic models are used in many different settings to estimate water-surface elevations, flooding inundation limits, flow velocities, flow rates, and other hydraulic parameters. Models can be used to simulate irrigation systems and pipe networks as well as open channels and natural river systems. Numerous software programs have been developed for this purpose. Each software package has an appropriate use, depending on conditions and the type of data output desired. River systems, such as the Carson River, are generally evaluated using two types of models: one-dimensional (1-D) steady and unsteady flow models and/or two-dimensional (2-D) unsteady flow models.

3.3.1 One-dimensional Modeling

One-dimensional models use a simplifying assumption that hydraulic parameters, such as water-surface elevations, are represented by an average value across an entire cross section when estimating stage, velocity distribution and energy losses between cross sections (Figure 4). This assumption is essentially correct for river systems where flowpaths in the channel and the overbanks are well-defined, and overbank flooding is at the same water surface elevation as the main channel. Often, these models can simulate bifurcated flow using lateral structures and interconnected stream reaches or storage areas (unsteady models). One-dimensional models can be run in steady- or unsteady-state, depending on the physical setting and the purpose of the modeling effort.

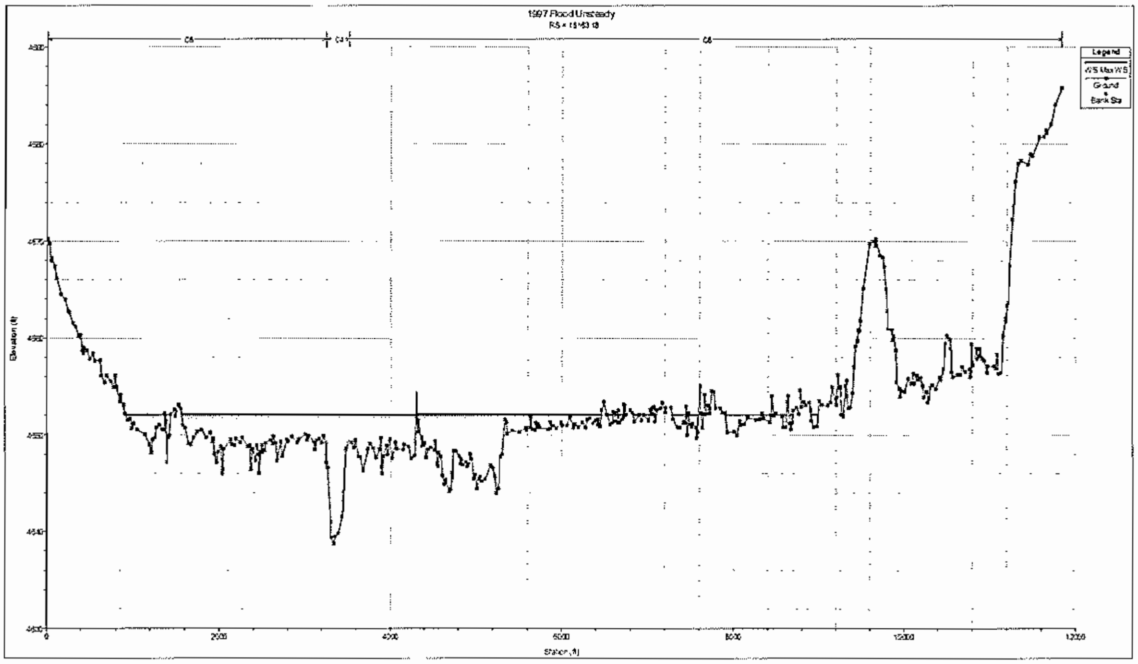

Figure 4: One-dimensional model cross section showing constant water-surface elevation

Unsteady–state flow 1-D models use a hydrograph as flow input. The full dynamic wave solution takes into account both conservation of mass and conservation of momentum. This unsteady-state analysis allows the model to account for both temporal and spatial changes in flow conditions within the system. The advantages to this system are that changes in flood wave timing, volume, and peak flows can be evaluated along a study reach. This makes 1-D unsteady-state modeling a valuable tool to evaluate downstream impacts of changes in the Carson River floodplain.

3.3.2 Two-dimensional Modeling

In generalized terms, 2-D models operate on a grid- or mesh-based routing scheme with a single water-surface elevation applied to each gridded section. Hydraulic parameters are calculated for each cell and compared to adjacent cells to route water through the grid network. Two-dimensional models are typically run with a hydrograph as input and are computationally more complex than 1-D models.

A common 2-D application is for analysis over complex topography (e.g., alluvial fans) where flow frequently bifurcates or converges while traversing through a watershed. Volume conservation is an important part of 2-D modeling. Like most 1-D models, most 2-D models also employ a rigid boundary assumption.

An example of 2-D modeling for an alluvial fan in the arid southwest is depicted in Figure 5. Using this tool, a visual impact analysis can be prepared for depths, velocities, and inundation limits within the study area. It should be noted, that this is simply an example of a 2-D application. Application of a rigid boundary assumption to an active alluvial fan is not a valid solution for this type of flooding hazard since it would not account for changes in geometry due to deposition, erosion or channel avulsions.

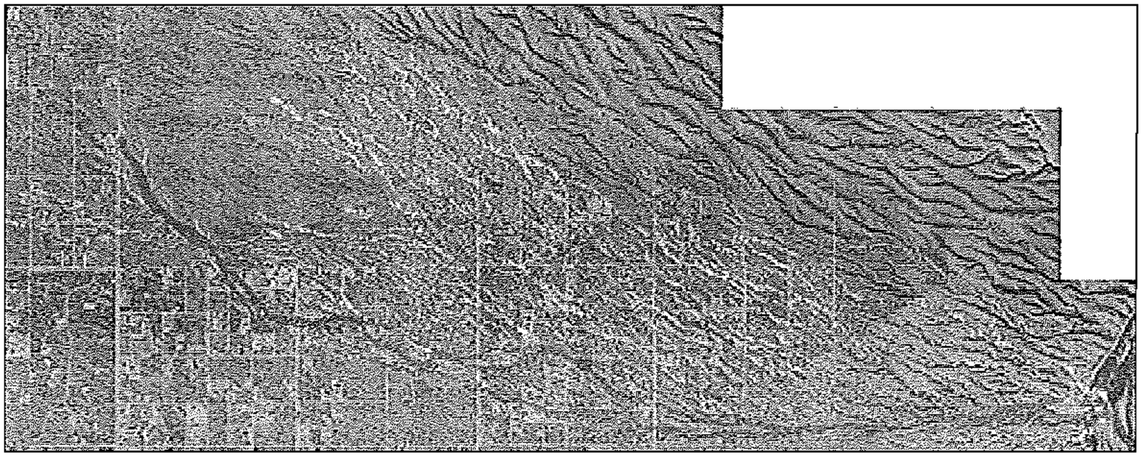

Figure 5: Example: Two-dimensional modeling for alluvial fan

3.4 Geographic Information Systems (GIS)

GIS is a multi-faceted tool that promotes use and development of spatially referenced data, data storage, and visual representation of the data across many disciplines. Distinct advantages of using the GIS platform for model development are the ability to reduce the effort and increase the accuracy associated with pre- and post-processing the results from hydraulic models. Many forms of spatial data can be used in the data processing allowing a more efficient and verifiable means of representing spatially variable data (land use, roughness, topography, flow patterns, etc.). For water resource professionals, GIS has become an integral tool in the day-to-day operations for investigating and solving problems. GIS aids in the development of graphical products for visual review with corresponding tabular attribute tables that containing the source data. An example of cross sectional data displayed in GIS with the source attribute data are shown in Figure 6.

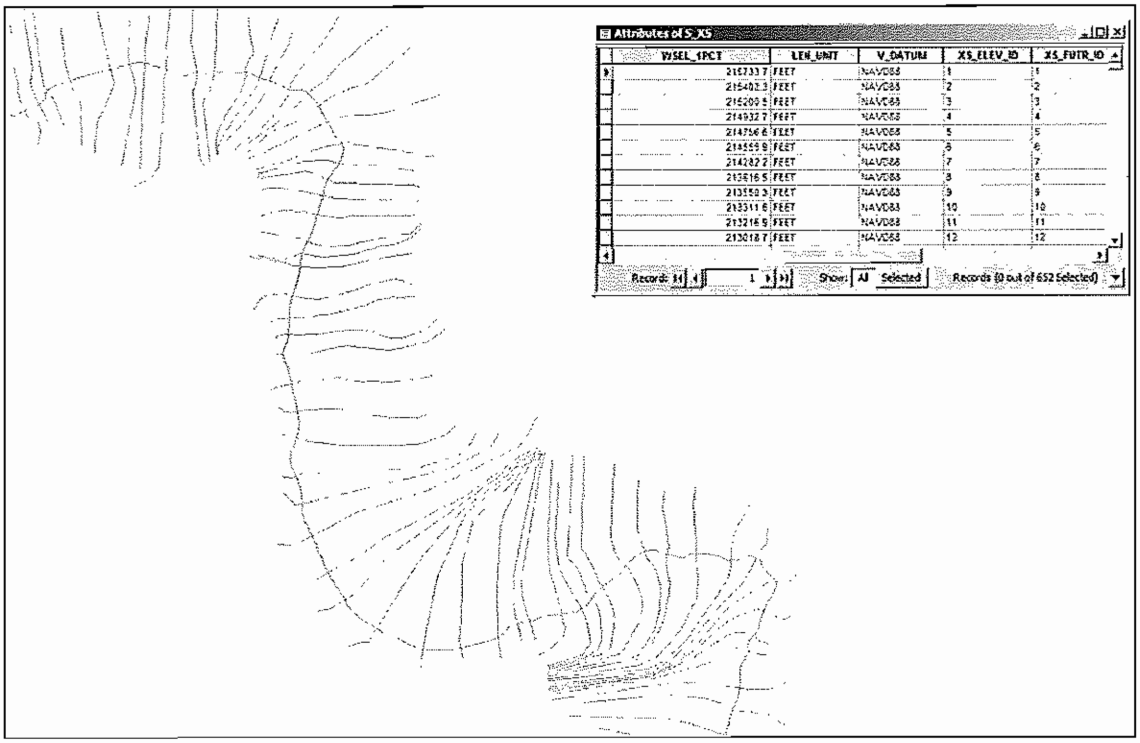

Figure 6: Example GIS visual and tabular product

Within the GIS software platform, various extensions and tools are available to aid in the collection and extraction data for hydraulic and hydrologic analysis. Examples are the HEC-GeoHMS and HEC-GeoRAS tools developed by Environmental Systems Research Institute (ESRI) for the U.S. Army Corps of Engineers (USACE). Through the use of GIS, floodplain boundaries can be developed and displayed from water-surface elevations (WSELs) from a hydraulic model. GIS also has the capability to develop terrain/surface models from raw topographic data to support the extraction of geo-referenced hydraulic model geometry. Figure 7 is an example of a digital floodplain modeling output overlaid on a digital terrain.

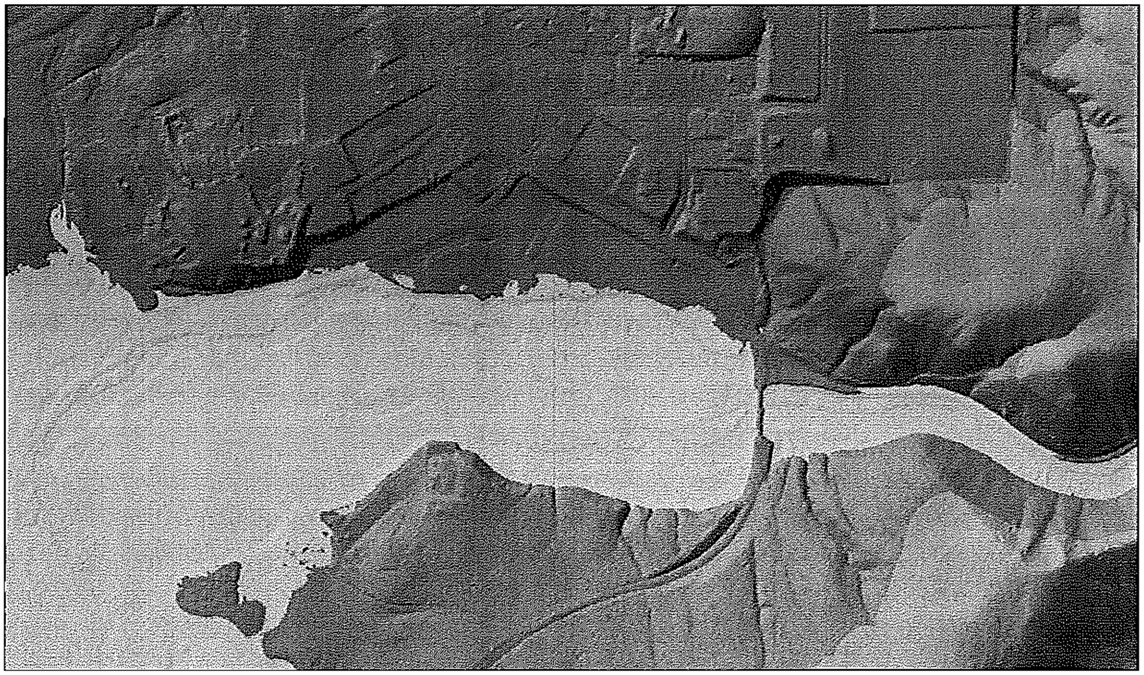

Figure 7: Example GIS digital floodplain on terrain surface

GIS has the capability to provide aesthetically pleasing and technically sound map products that support data development, alternative analysis, stakeholder reviews, FEMA deliverables, and public involvement. An example of work maps developed in GIS to display the results of a floodplain re-delineation study for FEMA is shown in Figure 8.

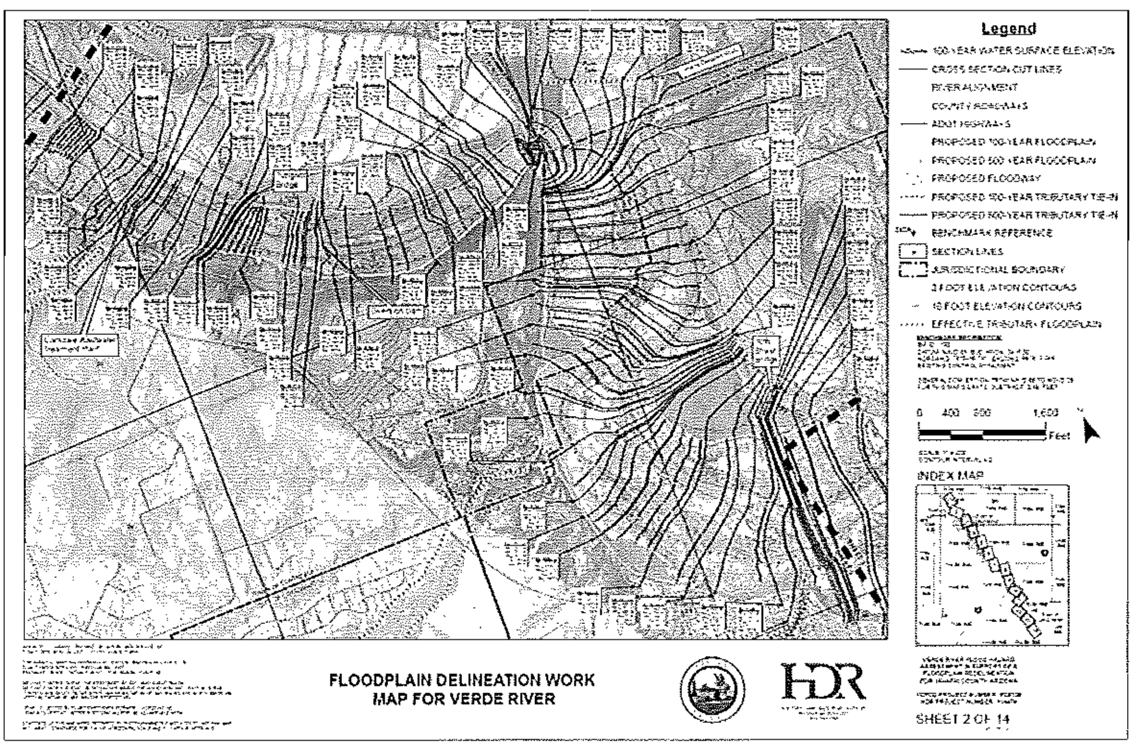

Figure 8: Example GIS floodplain re-delineation work map

3.5 Historic Flooding

The Carson River system periodically experiences flood events. Typically, these events occur during the winter season involving rain-on-snow. Three large floods have occurred since 1986. On February 19, 1986, a warm rainstorm resulted in a peak flow at the Carson River near Carson City stream gage of 13,200 cubic feet per second (cfs), while the Carson River Fort Churchill stream gage recorded a peak flow of 16,600 cfs. From December 30, 1996 to January 2, 1997, a series of warm rain storms produced rain on an unusually heavy snowpack, resulting in the largest flood on record. The Carson City stream gage peaked at 30,500 cfs, and the peak flow at the Fort Churchill stream gage was 22,300 cfs. Another warm storm occurring over December 30 and 31, 2005, resulted in a maximum flow of 11,900 cfs at the Carson City stream gage and a flood flow of 9,800 cfs at the Fort Churchill stream gage. The estimated recurrence intervals for these events are given in Table 1.

Table 1: Historic Floods on the Carson River

Date	Stream Gage Location	USGS Estimated Peak Flow (cfs)
February 1986	Carson River near Carson City	13,200
	Carson River near Fort Churchill	16,600
January 1997	Carson River near Carson City	30,500
	Carson River near Fort Churchill	22,800
January 2006	Carson River near Carson City	11,900
	Carson River near Fort Churchill	9,800

These events can be used as the basis of flow hydrographs for modeling efforts, as well as to calibrate models. As seen in Table 2, the recurrence interval of these flood events varies, depending on the location of the stream gage in question. Although the peak discharge of a certain event may not correspond to the statistically determined 1-percent chance (100-year) or 0.2-percent chance (500-year) flood flow, the shape of the flood hydrograph is very important for modeling the Carson River. The hydrograph shape represents the response of the watershed upstream of that point to a given storm.

It should be noted, that the reported estimates are determined with various methods with differing levels of confidence. Direct measurements are the most accurate form of measurement typically made by USGS. Direct measurements are performed using velocity meter or acoustic sounder. Unless unusual conditions exist at the time of measurement, USGS will typically rate these estimates as "good." Another approach to making an estimate of peak flow is with the use of an indirect measurement. An indirect measurement is made days or weeks after the peak flow has receded. High water marks are field-identified and cross section surveys are performed for a series of cross sections in the vicinity of the high water marks. A slope area method calculation is performed to make the estimate. This slope-area calculation may be verified with a step-backwater analysis in some cases.

The accuracy of this type of estimate is dependant on many factors, such as:

- High Water Mark Data Quality – Obtaining reliable high water mark data is often difficult. Wave action, floating debris influences, superelevation on channel bends, degradation of high water marks from precipitation, presence of secondary high water marks that provide a false impression, etc., can make identification of accurate high water mark data difficult.
- Assignment of Accurate Roughness Values – Assignment of accurate roughness values may be a significant factor in some settings.
- Channel Changes – The cross section surveys are performed after the flooding event has receded. Channel bank erosion, channel bed erosion, channel bed aggradation and vegetation loss at the time of the survey may, or may not, be representative of the conditions that existed at the time of peak flow.

Anomalies in the Carson River estimates for the 1997 event have been noted and will require additional investigation to determine effective use of these data for calibrating the model.

4 TECHNICAL GUIDANCE

The following sections cover the technical guidance for floodplain modeling and mapping for the Carson River within the Study Reach defined in this guide (Figure 1). The use of the term "practitioner" referrers to any persons, agency or firm conducting floodplain modeling or mapping or updating floodplain models or maps for the Study Reach.

4.1 Hydrologic Analysis

For unsteady-state flow modeling, the practitioner shall use flow or stage hydrographs for model input and boundary conditions. Historic hydrographs extracted from the data listed in Table 2 shall be used for calibration efforts. Synthetic hydrographs for the flood recurrence interval of interest (i.e., 1- percent chance, 0.2-percent chance) shall be developed using a balanced hydrograph method described below.

It should be noted that CWSD has developed regional hydrographs for the Carson River System within the study area covered by this guide. The practitioner shall use these data to the extents practicable.

4.1.1 Hydrologic Data

USGS has installed numerous stream gages along the Carson River. A selection of those stream gages which provide useful flow data are listed in Table 2, along with the period of record of the instantaneous flow data, annual peak flow, and direct measurement data available for each stream gage. Other stream gage sites along the river have limited periods of record or do not collect stage and discharge information and are not included in this table.

4.1.1.1 Mixed Population Data

For the Carson River Watershed, floods typically occur in response to rain-on- snow events in the Sierra Nevada Mountain Range. These floods generally occur in the winter months (historical occurrence has been between November and March) and can differ from spring melt (April to June) or summer rainstorm events. The practitioner shall investigate the historic gage records to determine if a mixed flood population exists and whether analysis warrants separating winter and spring/summer events.

Table 2: Carson River USGS Stream Gages

Stream Gage ID #	Description	Instantaneous Flow Period of Record	Number of Records	Peak Stream Flow Period of Record	Number of Records	Field Measurements Period of Record	Number of Records
10309000	East Fork Carson River Near Gardnerville	10/1/1990 - 9/30/2009	551360	5/28/1890 - 5/20/2009	90	11/6/1938 - 12/30/2010	888
10309100	East Fork Carson River at Minden	3/12/1994 - 9/30/1998	140321	6/2/1975 - 3/24/1998	15	4/1/1974 - 2/22/1999	175
10310000	West Fork Carson River at Woodfords	10/1/1993 - 9/30/2009	545656	6/9/1890 - 5/3/2009	94	10/21/1938 - 12/27/2010	887
10310358	West Fork Carson River at Muller Lane near Minden	3/18/1994 - 9/30/1998	152195	3/11-1995 - 6/7/1998	4	3/14/1994 - 10/7/1998	45
10310407	Carson River near Genoa	10/1/2001 - 9/30/2009	258915	4/14/2002 - 5/4/2009	8	9/28/2001 - 12/27/2010	100
10311000	Carson River near Carson City	10/1/1989 - 9/30/2009	513242	5/12/1939 - 5/4/2009	71	8/21/1938 - 12/27/2010	916
10311400	Carson River at Deer Run Rd Near Carson City	10/1/1990 - 9/30/2009	513298	1/15/1980 - 5/4/2009	25	3/15/1979 - 1/26/2011	347
10311700	Carson River at Dayton	4/12/1994 - 9/30/2009	323517	5/12/1994 - 5/19/2008	10	4/11/1994 - 1/14/2011	168
10312000	Carson River Near Fort Churchill	4/2/1987 - 9/30/2009	517792	6/20/1911 - 5/5/2009	99	9/27/1957 - 1/19/2011	712

4.1.2 Hydrograph Development

For all hydraulic analysis conducted in the study area (Figure 1), a balanced hydrograph shall be developed using USGS stream gage data and the procedures outlined below. It is anticipated, however that balanced hydrographs will be developed by early 2012 at all stream gages for the study area and will be available from CWSD for use in hydraulic modeling.

4.1.2.1 Annual Maxima Flood Frequency Analysis

The practitioner shall develop an annual maxima flood frequency curve for the study reach of interest. For this analysis, only stream gages with 20 years of data (not necessarily continuous) or more shall be used. Instantaneous annual maxima stream flow values shall be collected for the specific reach of interest. These data shall be used to perform a Log Pearson Type III distribution using the statistical approach outlined in Water Resources Council Bulletin 17b. In general, station skew shall be used where practical. Any deviations from this shall be based on sound engineering judgment.

4.1.2.2 Flow Duration Frequency Analysis

The practitioner shall evaluate mean daily flow data to develop flow-duration-frequency relationships for the balanced hydrograph. Average daily stream flow values for the annual peak shall be used for the 1-day, 3-day, 5-day, 7-day, and if necessary, the 10-day averages to develop frequency curves for each duration. Water Resources Council Bulletin 17b shall be used for these analyses. These values shall be used in conjunction with an historic "pattern" hydrograph to develop a synthetic balanced hydrograph for the reach.

4.1.2.3 Balanced Hydrograph

Once evaluation of annual maxima and mean daily flow data is complete, the practitioner shall use these data points along with an historic "pattern" flood hydrograph, to construct a balanced hydrograph. The instantaneous peak flow estimate shall be straddled by the 1-day, 3-day, 5-day, 7-day, and 10-day peak values and to create a preliminary balanced hydrograph. Adjustments to the preliminary hydrograph shall be made to preserve volume and capture the shape, to the greatest extent possible, of the pattern hydrograph.

4.2 Data Collection and Data Development

The following section summarizes the types, form, and specifications for data collection and development to support hydraulic modeling and mapping.

4.2.1 Aerial Photography

Aerial photography provides significant value by providing the visual element of the study reach and its surrounding environment. The use of aerial photography is particularly important when preparing a product that displays spatially referenced information to an audience who may have limited knowledge of the site conditions.

To support project evaluations, the practitioner shall collect ortho-rectified aerial photography for the study reach as available. If aerial photography is to be collected specifically for a project, the following procedures shall be used:

- The mapping collection for perennial rivers shall, to the extent practicable, be coordinated to occur during the low flow periods with the least amount of shadow coverages, thus providing the largest amount of exposed ground.
- Aerial photography collection for detailed projects shall, at a minimum, use 1"=600' photo scale based on post-processed airborne Global Positioning System (GPS) and Inertial Measurement Unit (IMU) coordinates for the center of the photos.
- The aerial photography collected shall be completed in cooperation with the topographic mapping collection, to ensure that both products reflect a single collection reference point in time.
- The contents of the mapping shall be performed to support the National Map Accuracy Standards for 1" = 100' horizontal scale and 2' contour intervals for both flat terrain and detailed studies used to supersede existing delineation data.
- The photographs collected shall be provided in a tiled format, with an index grid, and sequential naming using either alpha or alpha-numeric combinations from left to right and upstream to downstream.
- Documentation prepared by the aerial collection company shall include a collection report that maps the flight patterns, indicates the date and time of collections, provides a digitally reference supported grid (preferred GIS format).
- The practitioner shall prepare the delivery request of aerial photography using the Mr. SID (multi-resolution seamless image database) format with a description of the software packages utilized to produce them. This format is preferred due to the losses wavelet compression capability which yields high compression ratios and significant reduction in file sizes without compromising the quality of the raster image.

If the aerial photography collection is being conducted in support of a FEMA-level quality deliverable, the *Guidelines and Specifications for Flood Hazard Mapping Partners* [April 2003] (GUIDE) shall be followed with respect to Appendix A: Guidance for Aerial Mapping and Surveying.

The following three examples are critical excerpts that shall be followed from the GUIDE:

1. Aerial photography shall be flown under the following conditions:
   - While the sun angle is above 30 degrees;
   - When there is no snow cover;
   - When the flooding sources are in the main channels; and
   - When leaves are off the trees.

2. The assigned practitioner shall perform aerial surveys under the direct supervision of a registered land surveyor or American Society for Photogrammetry and Remote Sensing (ASPRS)-certified photogrammetrist, consistent with state regulations.

3. The practitioner shall abide by the requirements set forth with the GUIDE for vertical root mean square error (RMSE) standards in section A.8.6.1. Additionally, the practitioner shall abide by the requirements set forth with the GUIDE for pre-project and post-project deliverables in sections A.8.7.1 and A.8.7.2 respectively.

Figure 9 is an example of a gridded aerial photography deliverable within a geodatabase format to support a project coverage area.

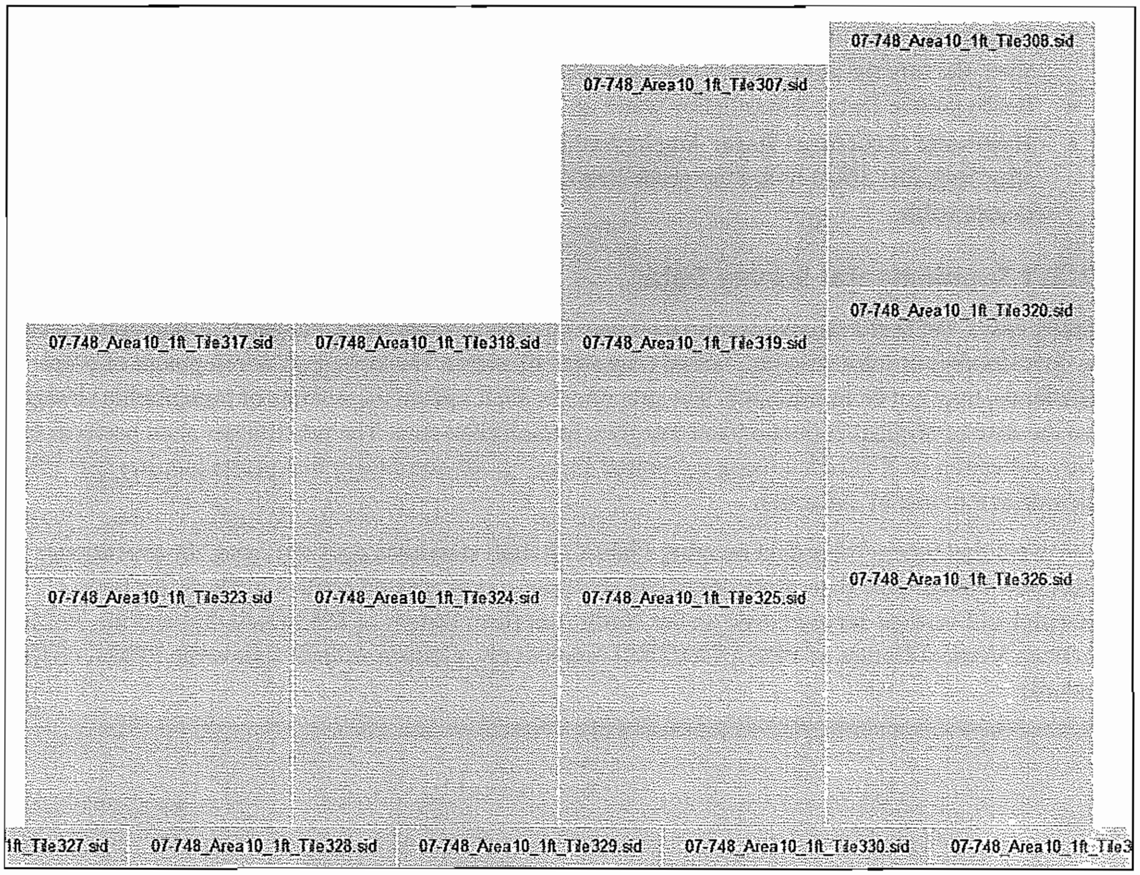

Figure 9: Example of a gridded aerial photography database deliverable

4.2.2 Terrain Data

Topographic data may be readily available for a study reach. In the event that a project is located in a remote area that does not have detailed topographic mapping, coarser data may be available from USGS for reference and use within the GIS platform.

The practitioner shall conduct an evaluation to determine sources of topographic coverage and coverage extents for the study reach. The practitioner shall use the most current topographic data meeting FEMA's GUIDE, Appendix A. The data collected shall be in either point (PT) and break line (LN) format or Dense Light Detection and Ranging (LiDAR) (LAS or ASCII XYZ). Both products have unique variables for resolution, accuracy, and point spacing which affect the net size of the product produced.

A Digital Elevation Model (DEM), Digital Terrain Model (DTM), or Triangulated Irregular Network (TIN) may be used if supporting documentation or source files accompany them and the surface meets National Map Accuracy Standards.

The product of a terrain survey after post processing by the practitioner often represents the "bare earth" equivalent which omits certain elements that are necessary to support the definition of a detailed study. The practitioner is required to collect survey data for missing terrain data. Typical survey data to be collected, described in more detail below, include the following:

- **Supplemental Survey Data:** Areas within the study limits where the topography has changed since the original aerial/terrestrial data collection.
- **Bathymetric Data:** Areas below water on the date that aerial survey was collected.
- **Hydraulic Structures Data:** Any hydraulic structures such as bridges, culverts and inline structures that affect hydraulic grade line for which as built information is absent or questionable.

4.2.2.1 Supplemental Survey Data

In many cases, the best available terrain data may be several years old. Changes in topography, such as new development or infrastructure, lateral migration of stream channels, and development of point bars/islands, may not be represented. The practitioner shall update these areas of topographic change since the date of original collection and integrate into original data. The practitioner shall perform the survey collection of XYZ data, using calibrated survey grade equipment that meets industry and FEMA standards at the time of collection.

In the event that topographic data meeting FEMA GUIDE standards does not exist, the practitioner shall collect new topographic data. Data collection shall use survey ground control methods for both horizontal and vertical survey based on the North American Datum of 1983 (NAD83) and the North American Vertical Datum of 1988 (NAVD88) respectively. Collection shall follow the FEMA GUIDE standards.

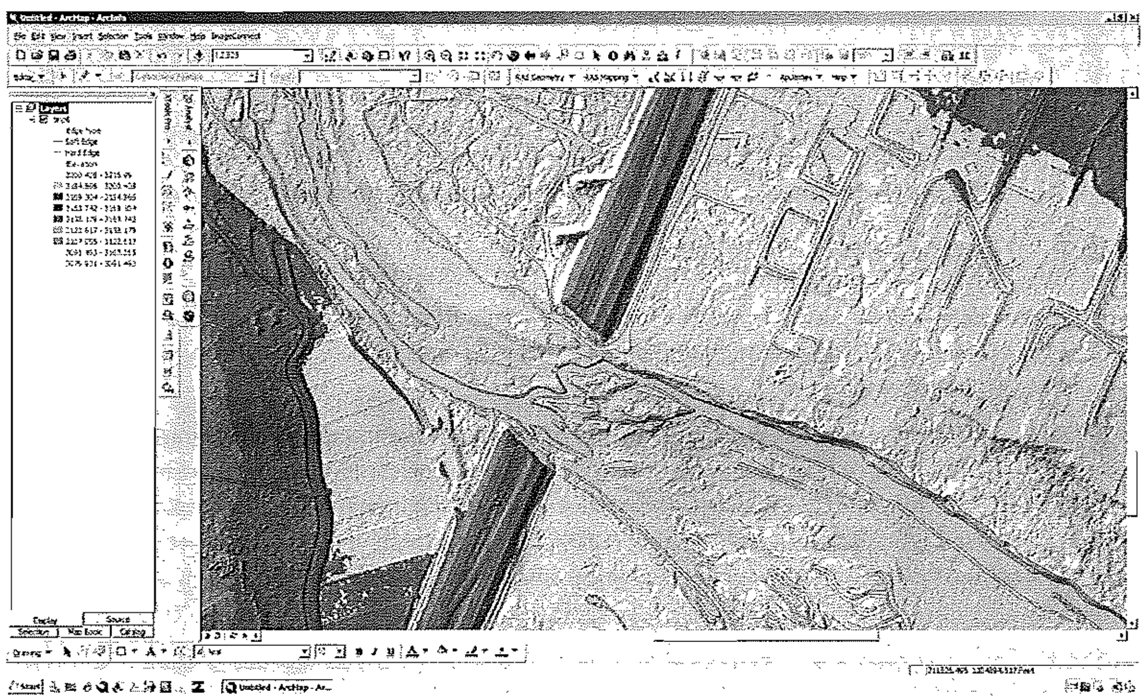

Figure 10: Example bare earth surface terrain missing bridge data

4.2.2.2 Bathymetric Data

In most instances, additional survey may be necessary to collect underwater channel geometry or "bathymetric" information. The practitioner shall collect information in support of the project need(s) as directed by a qualified water resource specialist, whom shall identify the location and frequency of cross sections. These collections are also subject to industry standards and those set forth by FEMA's GUIDE. In general, cross sections shall be collected to capture changes in channel grade, such as pools and riffles. Additionally, cross sections shall be collected at areas of channel expansion and contraction.

4.2.2.3 Hydraulic Structures Data

Hydraulic structures, such as bridges, culverts or inline dams, are often removed from LiDAR collection for the development of the equivalent "bare earth" or ground coverage file. Depending on the availability, as-built data for hydraulic structures may be available from local municipalities or transportation authorities. As-built plans have the potential to provide a cost effective mechanism for obtaining data for modeling structures such as bridges, culverts, weirs, diversion structures, or dams.

In the event that adequate information from as-built documents is not available or conflicts with survey references, additional structure surveys will be necessary. Practitioners shall perform this survey collection of XYZ data, using calibrated survey grade equipment and methods that meet industry and FEMA standards at the time of collection to accurately capture the geometry of all hydraulic structures that may effect water-surface elevations for the study reach. For bridges, this may include high chord, low chord, guard rails, deck profiles, pier information, and/or abutments. For culverts, this may include inverts, crowns, culvert size and shape, wingwalls, sediment depths, and/ or deck profile. For inline dams, this typically includes a profile along the top of the structure.

4.2.2.4 Additional Data

Additional data that may be collected to support hydraulic modeling and flood hazard mapping includes but is not limited to the following:

- Land use
- Vegetation cover
- Roads, Highways, Interstates
- At-grade-crossings, culverts, bridges
- Dams, Levees, Lateral Weirs, Irrigation Diversion Structures
- Siphons, Pump Stations
- Emergency Spillways
- Storm Water Retention/Detention Facilities
- Structures Identification (Habitable and Ancillary)
- Assessors Parcel Data

4.3 Manning's Roughness Values

Developing an assessment of Manning's roughness values is an important part of any hydraulic modeling analysis. The Manning's n value assigns a roughness parameter that simulates resistance to flow within a hydraulic model. Best practices for determining the n values consist of aerial photo interpretation, field reconnaissance, review of effective studies, and review of agency literature or published requirements, and model calibrations (not discussed in this section). The practitioner shall review the best available data and identify local requirements which may govern the selection of roughness coefficients.

4.3.1 One Percent and Greater Flood Frequencies

Depending on the return frequency the practitioner is modeling and the type of hydraulic system being modeled, a combination of aerial and/or field reconnaissance methodologies can be employed to estimate Manning's roughness values. For the purposes of this guide and as outlined in FEMA's GUIDE, Manning's n values may be estimated using aerial photography with appropriate calculation methods (outlined below) for flood frequencies equal to or exceeding the 1-percent chance (100-year) flood. Although not required, an attempt must be made to incorporate field photos of channel and overbanks for use in Manning's n estimations.

4.3.2 Less Than One Percent Flood Frequencies

For all flood frequencies less than the 1-percent chance (100-year) flood, the practitioner shall conduct a physical field reconnaissance of the study reach or wash where access and conditions permit. During this investigation, digital photography shall be collected and documented for unique site characteristics affecting the Manning's roughness values. Locations of field photos shall be recorded on aerial maps.

The n value assessment of ephemeral washes versus perennial streams will greatly differ, due to the visibility of bed material. Visual inspections of perennial streams are limited to sand bars, areas of outcropping, or under water cross section investigations due to visual restrictions from the conveyance of water. Ephemeral washes are open, limited only by isolated discharge periods, and field reconnaissance in the form of walking the wash bottom can be performed.

Photographic documentation (described above) for an ephemeral washes is standard practice, however the use of a reference grid is highly recommended to provide a sense of relative size for the comparison of bed/channel form materials depicted. An example of an ephemeral wash n value inspection tool is depicted in Figure 11, using a 1foot by 1 foot PVC pipe grid, which internally holds a string grid of 1 inch by 1 inch grid:

Figure 11: Field reconnaissance inspection tool

Photographic documentation for a perennial stream is more complex and is most often conducted from the banks of the wash or river. Although the stream bottom cannot be seen in the photography, the embankments and overbank vegetation are captured to support the development of the corresponding roughness values.

The practitioner shall develop a presentation map or series of presentation maps depicting the field reconnaissance conducted. These maps shall include the location of photographic collection points as described above with project reference information.

The practitioner shall develop a photographic documentation log, which displays the photography collected, identifies the site or photo number and the date of collection. An example of a photograph log template documenting field investigation is shown in Figure 12 for a single point.

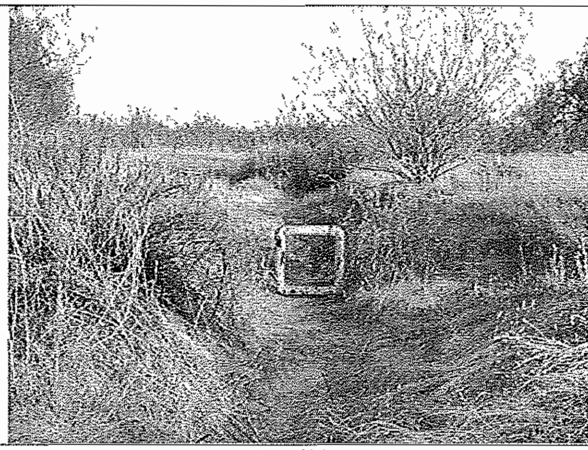

PHOTO 01
Looking Upstream. ~1' Bottom Width. No Difference in Soil Composition From Surrounding Area. No Destruction of Terrestrial Vegetation. Partially Incised. Not Jurisdictional

Figure 12: Example of field reconnaissance photo log at a single point

Using the photography log and the presentation maps for the field reconnaissance, the practitioner shall prepare calculations to compute the corresponding Manning's roughness coefficient, n value, based on the individual factors observed in the field.

Many textbooks and manuals have been written that describe the Manning's n value and the factors involved in the selection. Three publications often referenced for such guidance are Barnes (1967), Chow (1959), and Ree (1954). These publications may be used as appropriate to support Manning's n determinations.

The step-by-step procedures for developing the Manning's n value are detailed in USGS's Water-Supply Paper 2339 (WSP 2339), *Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Floodplains.* A simplified and brief description of the process is provided below. It should be noted that developing roughness values for floodplain can be quite different than the values used for channels. Additionally, seasonal variability for roughness coefficients may need to be considered, but is not detailed here-in.

Cowan (1956) developed a procedure for estimating the individual efforts of five factors that commonly occur to guide in the estimation of the n value for a channel. Cowan's equation for developing the n values indicates the following computation:

$$n = (n_b + n_1 + n_2 + n_3 + n_4) * m$$

Where:

n_b = a base value of n for a straight, uniform, smooth channel in natural materials
n_1 = a correction factor for the effect of surface irregularities
n_2 = a value of variations in shape and size of the channel cross section
n_3 = a value for obstructions
n_4 = a value for vegetation and flow conditions
m = a correction factor for meandering of the channel

The selection of a base n value for channel sections is based on the classification of a stable or sand channel. Stable channels remain relatively unchanged throughout most ranges of flow, while sand channels are assumed to have unlimited supply of sand with bed materials moving with relative ease to take on new bed form configurations. The roughness coefficients applied to a longitudinal reach, channel or floodplain are often located at sections of regular geometric shape or irregular shape for many naturally occurring channels.

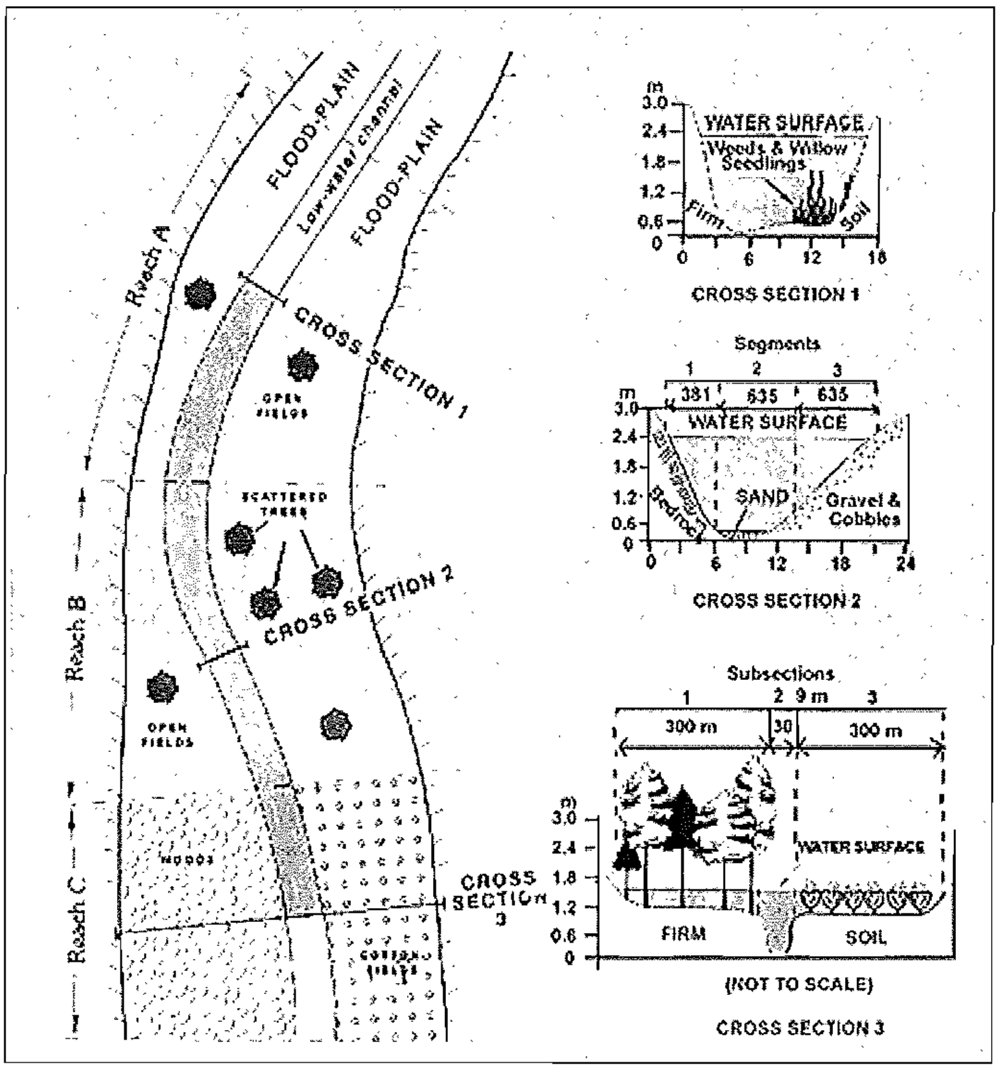

Figure 13: Graphic of floodplain subsections for Manning's n calculations (from WSP 2339)

Refer to Appendix A for suggested base Manning's n values dependant on channel bed materials.

Adjustment factors for the channel n values add increments of roughness to the base n value n_b for each condition which impacts the roughness. The following summarizes the adjustment factors for channel n values:

- Irregularity (n_1): A correction factor which accounts for the ratio of width to depth in eroded and scalloped banks. In some cases large adjustments are necessary if irregular banks contain project points into the stream.
- Variation in Channel Cross Section (n_2): A correction factor which accounts for the alternating of large and small cross sections, sharp bends, constrictions, and lateral shifts in the low-water channel bed.
- Obstruction (n3): A correction factor which accounts for both naturally occurring and man made obstructions within the channel and floodplain, assigned four levels of obstruction: negligible, minor, appreciable, and severe.
- Vegetation (n4): A correction factor which accounts for the affects of vegetation dependant on the depth of flow, percentage of wetted perimeter covered by vegetation, density, degree of vegetation flattening by high water, and vegetation alignment.
- Meandering (m): A correction factor dependant on the ratio of the total length of meandering in a channel to the straight length of a channel. Meandering is separated into three categories of minor, appreciable, and severe. This correction should only be considered when the flow is confined to the channel.

Table 1 in the WSP 2339 gives base n values, while Table 2 provides recommendations for the corresponding correction factors (n value adjustments) for n1 through n4 and m for channels. These values are separated by levels of impact and provide guidance with respect to the ranges of correction that may be applied.

The n value computed for channel roughness is determined by following the series of decision-based adjustments based on user review and application of corrections to the based n value. Similarly the n value computed for floodplains are subject to a base value which is adjusted to compensate for vegetation density in the floodplain through respective subsections.

A flow chart for procedures for assigning n values was developed within WSP 2339, which is referred to as Figure 21 in that document, providing guidance for the order of operations for both channel and floodplain roughness computations.

There are several references, guides, and technical white papers that a user can refer to for Manning's n values for typical channels. An extensive compilation of n values for channels (streams) and floodplains can be found in Chow's *Open-Channel Hydraulics* handbook (Chow, 1959). Excerpts to the most common channel values from this book have been included within the Hydrologic Engineering Centers River Analysis System (HEC-RAS) user's hydraulic reference manual to support the engineering community. In general, the bed value shall be in a range of 0.020 to 0.05 for an alluvial system in the silt to cobble range. Overbanks shall range from 0.030 to 0.20 depending on the naturally occurring vegetation and coverage materials, assuming no significant obstructions. Blocked obstructions and man made features may have an influence on the resulting overbank roughness coefficients.

An example of Manning's n value ranges and respective values within Table 3 is provided for reference:

Table 3: Example Manning's n Values for Floodplains and Channels

Type of Channel and Description	Minimum	Normal	Maximum
A. *Natural Streams*			
1. **Main Channels**			
a. Clean, straight, full, no rifts or deep pools	0.025	0.030	0.033
b. Same as above, but more stones and weeds	0.030	0.035	0.040
c. Clean, winding, some pools and shoals	0.033	0.040	0.045
d. Same as above, but some weeds and stones	0.035	0.045	0.050
e. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
f. Same as "d" but more stones	0.045	0.050	0.060
g. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
h. Very weedy reaches, deep pools, or floodways with heavy stands of timber and brush	0.070	0.100	0.150

4.4 Terrain Development

As an underlying support to the hydrologic and hydraulic modeling software packages, various types of digital terrain surfaces are used to extract model geometries. These surfaces shall be prepared from aerial survey data comprised of either digital point and break line files or mass points, such as Airborne LiDAR. Both of these data sets are commonly used. For the purposes of this Guide, the practitioner shall evaluate the opportunities for both products and their utility for the development of a single or multiple surfaces to support hydraulic modeling for the study area.

There are many software packages currently available for developing TIN or DTM from raw survey products. Both the TIN and/or DTM shall be developed from mass point files or point and break line data. Alternatively, raster or DEM data may be used for a terrain surface, however the resolution shall be small (1/2 foot square grid cell resolution) to prevent degradation and loss of quality from the source data.

The float file format is used within HEC-RAS Mapper to support post processing of HEC-RAS hydraulic model results. The float file format may be used with Mapper to support flood hazard delineation within the HEC-RAS system.

Surface models used for 2-D modeling differ based on software requirements. Data used to develop the surface model shall be in the form of "bare earth" LiDAR data (.LAS) or 3D ASCII data files (.TXT) or equivalent.

National Map Accuracy Standards for surface development and use with hydraulic modeling have been established by FEMA. The requirements for a standard TIN differ from that of a LiDAR product. The practitioner shall follow the FEMA GUIDE for mapping partners and the specific requirements of each products development and submittal criteria. Copies of all developmental information are to be provided in both electronic and hard copy for approval within a study.

Traditional photogrammetric surveys are subject to the requirements set forth by the FEMA GUIDE, specifically Appendix A, Section A.7. LiDAR surveys are subject to the requirements set forth by the FEMA GUIDE, specifically Appendix A, Section A.8 and the recent procedural memorandum No. 61 from FEMA, which addresses revised requirements for the topographic data prepared for use within a new flood hazard analysis for the Nation Flood Insurance Program (NFIP). As part of the best practices for developing terrain data, it is essential to collect copies of the survey control data, flight report, and final sign and sealed survey report that clearly declares the contents of the submittal meet the FEMA standards discussed above. The resulting Root Mean Square Error (RMSE), both vertical and horizontal accuracies, scale, and resolutions must be declared for reference and comparison to the standards. The practitioner shall prepare finalized products with a licensed surveyor's certification, stating that products prepared comply with the FEMA GUIDE, Appendix A requirements.

In the event a single TIN surface file size is too large for utilization within the hydraulic or GIS software applications, the practitioner shall prepare mosaic TINs. Due to the potential for interpolation errors, an overlapping buffer is necessary to prevent errors during the data extraction process. A buffer zone equal to five percent of the tile size shall be incorporated around the adjoining tiles. Refer to FEMA GUIDE, Appendix A, Section A.4.4 for additional information related to the requirements for mosaic TINs.

The practitioner shall record the process used to develop the mosaicked TINs and provide the process results and a copy of the reference map in both electronic and hard copy. This documentation shall be maintained for use in the preparation of the final technical document delivery for FEMA.

4.5 Hydraulic Modeling

This section of this Guide covers hydraulic model selection and best practices for developing models. It addresses both 1-D and 2-D modeling. In general, the practitioner shall use both 1-D and 2-D models, as appropriate and unsteady-state flow inputs. Unsteady-state flow development is covered in Section 4.1 Hydrologic Analysis.

4.5.1 Model Selection

The selection of either 1-D or 2-D modeling shall be governed by the type of stream or overbank floodplain environment to be modeled.

4.5.1.1 One-dimensional

A 1-D model shall be used in areas where both the channel and overbank flow paths are either clearly defined or easily discernable from aerial photography and topographic data. Additionally, a 1-D model shall be used in situations where hydraulic structures, such as bridges, culverts and weirs need to be evaluated for their effects on hydraulic grade lines.

While there are numerous versions of hydraulic models available, HEC-RAS shall be used due to its accessibility as public domain software, computational framework, validation, forward compatibility with previous version of the software, continued support, unsteady-state modeling features, and the ability to interface successfully with supporting platforms such as AutoCAD and GIS.

The most current version of the software shall be used for modeling and can be downloaded directly from the USACE at the following website:

http://www.hec.usace.army.mil/software/hec-ras/hecras-download.html

4.5.1.2 Two-dimensional

A 2-D hydraulic model shall be used for complex unsteady-state flow environments with shallow dispersive flow which commonly bifurcates between channels, rills, or sections of undefined flow paths. As a general rule of thumb, the 2-D application is best suited when shallow flow paths traverse through the study area in a relatively random, dynamic matter, exchanging flow across multiple channels. Shallow overbanks floodplain areas and alluvial fans typically experience this type of flow behavior.

4.5.2 One-dimensional Hydraulic Model Development

The following section covers the best practices and specifications for developing a 1-D HEC-RAS model for the Carson River.

4.5.2.1 Cross Sections

Cross sections shall be oriented perpendicular to flow within the stream channels and overbank regions. This often results in section lines with one or more bends, to account for changes in flow direction across the channel and overbanks, as seen in Figure 14.

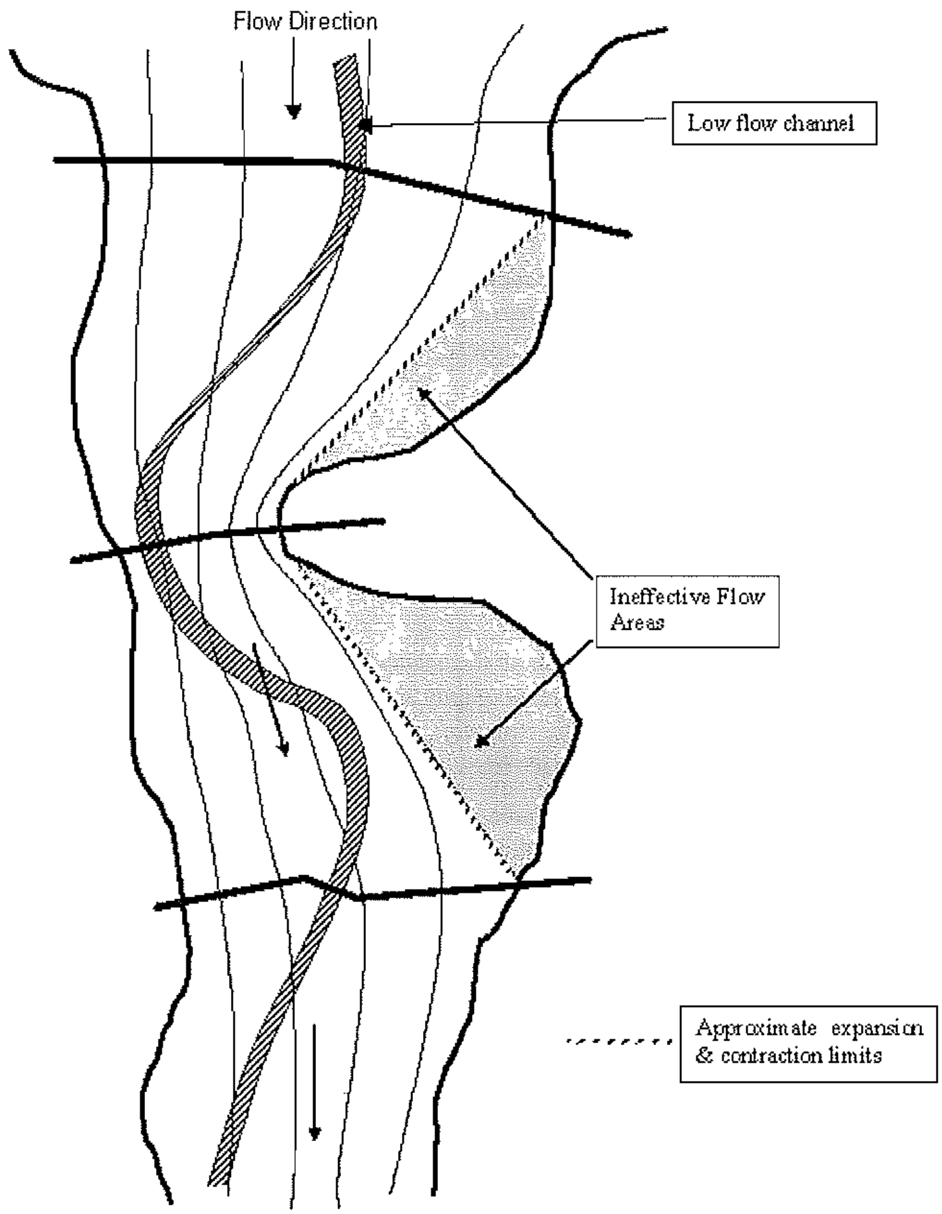

Figure 14: Cross section layout (after Arizona DWR, 2002)

Each section should be long enough to extend past the anticipated floodplain boundary of the event being modeled. The model assumes that cross section geometry remains roughly the same up and downstream for one half the distance to the next section. Therefore, sections need to be placed closely enough to represent large changes in the river system. Unsteady-state flow modeling requires sections be spaced more tightly, due to the model's sensitivity to changes in hydraulic parameters. Factors to be considered when determining cross section spacing include: significant flow contractions and expansions, pool/riffle sequences, changes in channel and floodplain roughness, and flow change locations. Sections should be placed as near as possible to surveyed cross sections to minimize usage of interpolated elevations.

4.5.2.2 Ineffective Flow

Portions of the river system which do not actively convey flow shall be accurately represented in the model. These are known as ineffective flow areas. Examples include eddies and slackwater areas behind large obstructions, as well as those areas above or below hydraulic structures where water is not being conveyed downstream. The ineffective flow areas option in HEC-RAS shall be used to render flow in these areas ineffective. Practitioners shall follow guidance outlined in the HEC-RAS Users Manual and Hydraulic Reference Guide.

Determination of ineffective flow areas in the vicinity of bridges and/or culverts depends on flow expansion (ER) and contraction (CR) ratios (Figure 15). This ratio represents the extent of ineffective flow along the channel per unit of length of ineffective flow across the channel. These factors are used to determine the distance above and below the structure that a portion of the flow is rendered ineffective. The practitioner shall follow guidance found in the USACE *HEC-RAS Hydraulic Reference Manual*. Examination of the specific structure and its placement in relation to the channel and floodplain, along with engineering judgment is also required when establishing ineffective flow areas. In many cases a 1:1 CR and 2:1 ER are used.

4.5.2.3 Hydraulic Structures

When modeling bridges and culverts, a minimum of four cross sections are required to represent the hydraulic performance of the structure and impact to water-surface elevations. Figure 15 is a schematic of the required sections from chapter 5 of the USACE *HEC-RAS Hydraulic Reference Manual*.

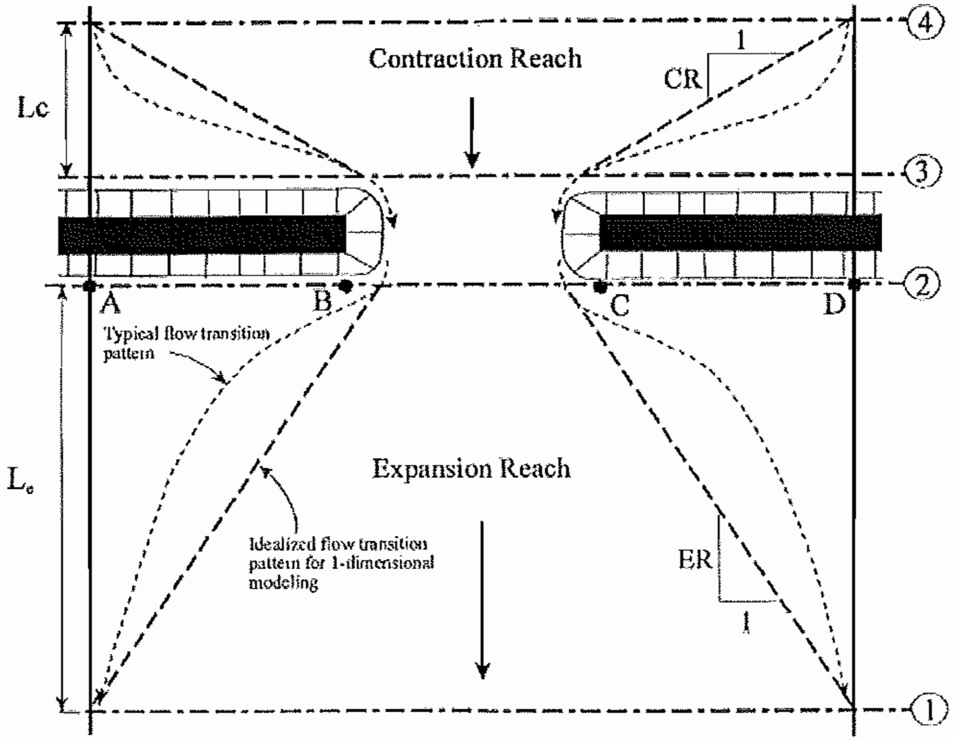

Figure 15: Cross section layout for modeling bridges (after USACE, 2010)

Cross sections 1 and 4 should be placed far enough up and downstream of the structure to be outside of the extent any flow expansion or contraction, as well as ineffective flow, caused by the structure. Cross sections 2 and 3 should be placed near the upstream and downstream faces of the structure, usually at the toe of the associated roadway embankment.

The shape, location, and dimensions of bridge piers must also be included in the model. For those bridges and culverts built on a skew, the skew angle must be calculated and entered into HEC-RAS to reduce the open area available for flow. The bridge high and low chord data must be determined and entered into the model. Survey data or as-built drawings should be used to determine the overtopping elevation of the bridge deck. If guard rails or fencing exists on the bridge, it may be appropriate to use the top of these features as the high chord elevation, depending on their ability to trap debris and/or impede flow. Any bridge abutments that block the open area of the bridge must be coded into the model as well.

When modeling culverts, entrance loss coefficients need to be selected that are appropriate to the structure in question. Table 6.3 of the USACE *HEC-RAS Hydraulic Reference Manual* provides guidance on values for various culvert configurations. The exit loss coefficient is commonly assumed to be 1.0.

At least one cross section is required to correctly model an inline weir placed in the channel. This section shall be placed upstream of the structure to allow the model to correctly calculate the impact of the weir on water-surface elevations.

4.5.2.4 Split Flow

In many stream systems bifurcated or split flow occurs when multiple channels with unique channel inverts and water-surface profiles form within a larger floodplain. In this situation, it is necessary to use a split flow approach to more accurately estimate independent hydraulic conditions in each channel. The modeler shall use a defined junction and separate stream reaches to represent the situation if conditions warrant. See Figure 16 for an example of a split flow situation, including an example cross section layout. The model performs an iterative calculation process to determine the magnitude of flow in each channel.

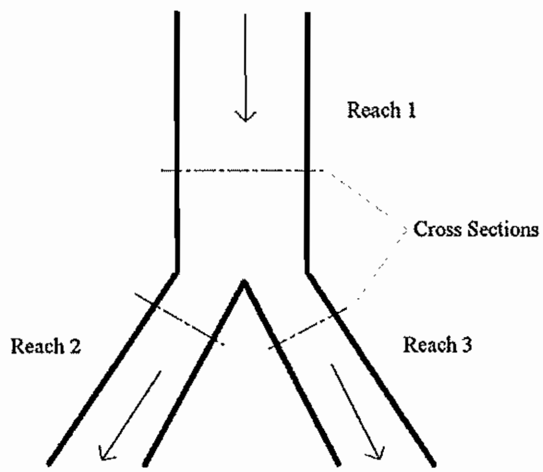

Figure 16: Split flow configuration

Another flow split situation occurs when water leaves the main channel along an extended length and enters another channel, a storage area or travels as overbank flow. In this situation, a lateral weir shall be used adjacent to the channel to more accurately represent this type of split. In this case, the lateral weir should be laid out along the high points of the anticipated overtopping section. It should be noted that in many cases flow will not only leave but reenter the main channel along this split reach. The modeler shall associate lateral weirs with the appropriate "losing" stream for a steady-state model. For unsteady-state flow models such as the Carson River the model can assess flow in both directions over the weir.

4.5.2.5 Weir Flow

Flow over lateral weirs and hydraulic structures is sensitive to the weir coefficient used. This coefficient represents both the form (broad-crested, rectangular, etc.) of the weir as well as the resistance to flow created by the roughness of the weir surface. Hence, a concrete floodwall would tend to have a higher weir coefficient, resulting in higher discharge, than a vegetated earthen levee. Appropriate weir coefficient values can be found in the USACE *HEC-RAS Hydraulic Reference Manual.* Lateral weirs shall be used at any point along the river where water "breaks out," or intermittently leaves and re-enters the channel.

4.5.2.6 Storage Areas

Storage areas shall be used to represent the overbank region in areas where velocities are low to zero and water-surface elevation is better approximated by volumetric calculations. Examples include offline ponds and detention basins. These areas should be connected to the main channel and/or adjacent storage areas using lateral weirs placed the high points of the channel bank, and an elevation/storage curve or other representative function to represent the storage area.

4.5.3 Boundary Conditions

For 1-D, unsteady-state flow modeling on the Carson River, there are several boundary conditions that may be used at the modeler's discretion. The following discussion is a summary of the principal types of boundary conditions anticipated for the Carson River. In general, however the modeler shall use regional hydrology developed by CWSD for the purposes of modeling the Carson River. Updates may be available and the practitioner shall contact CWSD to obtain the most current hydrology for input to the model. For specific guidance on entering data and boundary conditions not covered in this Guide, refer to chapter 8 in the latest version of the *HEC-RAS River Analysis System Users Manual.*

4.5.3.1 Flow Hydrograph

As described in Section 5, a series of flow hydrographs have been developed at USGS stream gage locations for the Carson River within the area covered by this Guide. Hydraulic models shall use these hydrographs, where applicable as upstream or downstream boundary conditions. The most common use will be for upstream boundary conditions. In the event that the study reach begins or ends at a location not coincident with USGS stream gage locations, output hydrograph from adjacent models shall be used for boundary conditions.

4.5.3.2 Stage Hydrograph

Stage hydrographs are similar to flow hydrographs and may also be used as upstream or downstream boundary conditions. These data follow the same direction described above for flow hydrographs.

4.5.3.3 Internal Boundary Stage/Flow Hydrographs

It is possible to introduce an internal boundary condition in the model to force a stage or flow hydrograph at an area where values are known, such as a USGS stream gage. Modelers shall follow procedures outlined in the flow and stage hydrograph sections above.

4.5.3.4 Rating Curves

Rating curves are available through USGS, as described in Section 3.2, and may be used as a downstream boundary condition where appropriate. The primary application for the Carson River would be for calibration of known flood events. Rating curves may also be used for modeling theoretical events, where appropriate. For low gradient water-surface profiles the modeler shall use a rating curve only if it is far enough downstream from the study reach to prevent errors introduced by that rating curve.

4.5.3.5 Downstream Boundary Condition

Normal depth boundary conditions can be used as a downstream boundary condition. Friction slope shall be entered as the water-surface slope in the downstream vicinity of the reach. The boundary condition shall also be applied far enough downstream of the study reach to prevent errors introduced by the normal depth calculations. If a normal depth boundary condition is used as a downstream boundary condition, calibration efforts must be made to ensure that the computed rating matches observed measurements at gage locations, if available for the downstream reach of the model.

4.5.4 Model Calibration

To the extent practicable, HEC-RAS models for the Carson River shall be calibrated to known historic flood events using available high water marks, direct and indirect measurement data, historic event hydrographs and photographs showing flooding extents. Stage data shall be used at downstream and internal model boundaries. The flowing steps, taken from the *HEC-RAS Users Manual Version 4.1*, shall be generally followed for calibration:

1. Run a range of steady-state flow discharges and adjust Manning's n values so that model calibrates to rating curves at USGS stream gages and any known high water marks.
2. Review historic 15 minute flow data and select several flood events to use for unsteady-state calibration. These events shall encompass a wide range of flows (low to high and back to low). Table 1 provides a list of potential calibration events.
3. Adjust storage areas and lateral weirs to produce matches in flow hydrographs.
4. Adjust Manning's n values to produce matches in stage hydrographs.
5. Fine tune Manning's n values using vertical variation capabilities for low to high stages.
6. Verify calibration by running events not used in calibration.

For a complete discussion on calibration see chapter 8 in *HEC-RAS Users Manual Version 4.1*. Modeler shall also follow FEMA Guidelines and Specifications for Flood Hazard Mapping Partners Appendix C, Section C.3.3.4.

4.5.5 Floodway Development

When necessary, regulatory floodways shall be developed following standard modeling procedures outlined in chapter 10 of *HEC-RAS Users Manual Version 4.1* and Appendix C, section C.4 in FEMA's GUIDE.

Because modeling is being performed in unsteady-state flow for the Carson River, mapping partners must receive approval from the FEMA regional project officer and agreement from the communities involved before performing a floodway analysis. Practitioners shall also verify the allowable water-surface elevation rise due to floodway encroachment for all local municipalities covering the project reach. If no standard exists, the NFIP regulation of 1-foot maximum shall be used.

For unsteady-state 1-D modeling, floodways can only be determined using Method 1 as described in the *HEC-RAS Users Manual Version 4.1*. Modelers shall follow the recommended procedure from chapter 10 in *HEC-RAS User's Manual Version 4.1* as follows:

1. Begin with a 1-percent chance flood, calibrated unsteady-state flow plan.
2. Create a steady-state flow plan using the peak flows from the unsteady-state plan results.
3. Perform a steady-state flow encroachment, beginning with Method 4 equal conveyance.
4. Copy the 1-percent chance plan and rename to represent "new" encroached plan.
5. Adjust downstream boundary condition (i.e., hydrograph, rating curve) to reflect target water-surface elevation rise at all stages/flows.
6. Import steady-state flow plan encroachment stations into "new" unsteady-state encroached plan developed in step 4.
7. Run the unsteady-state model and check results against base 1-percent chance model described in step 1.
8. Adjust encroachments as necessary to achieve target water-surface elevation rise throughout the study reach.

4.5.6 *Two-dimensional Hydraulic Model Development*

The practitioner shall use FEMA-approved 2-D hydraulic models. Two-dimensional modeling guidelines and procedures shall be covered in future versions of this guide.

4.6 Floodplain and Floodway Mapping

Upon completion of the hydraulic modeling, the resulting water-surface elevations and water-surface extents can be exported to the AutoCAD and/or GIS software environment. Alternately, the hydraulic results can be used directly with HEC-RAS Mapper. Tools included within both software packages conduct an intersection between water-surface elevations extracted from HEC-RAS and the terrain surface, yielding a third representing flooding limits. The process is conducted for each return event, producing a group of floodplain and floodway limits. The practitioner shall select either method described above, document the process, and provide copies in support of the Technical Support Data Notebook (TSDN) deliverable.

The inundation limits reflected by the floodplain and floodway polygons produced by either method described above shall be reviewed by the practitioner. The results generated frequently contain small "pocket islands" that reflect an elevated feature which exists above the modeled water-surface elevation, but does not meet FEMA's requirements to be maintained as an island of zone X. In addition, the practitioner shall review the data for triangulated dangles on the perimeter of the data set, these appear in the form of triangular sections either dangling to the interior or exterior of the data set as a result of the interpolation between the surfaces. These dangles shall be removed and documented using the best engineering judgment for the study area.

In the event that multiple elevation surface files (mosaicked tiles) are used to support the post processing, the practitioner shall inspect the areas subject to overlap and manually refine the resulting floodplain and floodway line work with respect to the topographic data, reported water-surface elevations, and existing features. This process shall be documented and performed using the best engineering judgment in the areas of occurrence.

The final floodplain and floodway line work shall be compared by the practitioner against project contours to validate the resulting boundary. This entails a comparison of the hydraulic WSEL, floodplain line work location, and governing contours. The practitioner shall document the review process.

4.6.1 *FEMA Standards*

The floodplain and floodway products prepared from successful floodplain delineation and cleanup, shall be packaged for delivery by the practitioner, according to the FEMA GUIDE, Appendix L. Digital Flood Insurance Rate Maps (DFIRM) are digital versions of flood maps formatted following FEMA guidelines and specifications. DFIRMs allow communities to view flood insurance rate maps with digital media or through the internet.

Key features of the DFIRM data set that the practitioner shall address are coordination, standards, horizontal and vertical accuracies with controls, data structure, quality control, deliverable format, and metadata. Per FEMA, the DFIRM database specifications contain the following additional defined spatial and non-spatial data items and tables:

- Subbasins with links to discharges, storm data, and regression equations;
- Gages, including rain gages, stream gages, and coastal gages;
- Nodes with links to node discharge data and zipped hydrologic models;
- Profile base lines;
- Overbank flow paths;
- Additional cross section data, including links to a frequency (rating) table and the zipped hydraulic models;
- Additional coastal transect data, including links to the zipped coastal models;
- Primary frontal dunes;
- Modeled coastal shorelines;
- Outline of the studied area(s) with links to FEMA case information;
- Photographs, sketches, and similar documents linked to spatial features;
- Documentation for variable data that may be developed for the flood study/mapping project (e.g., topographic data, land use, soils, roughness);
- Zipped files containing general information on methodology (e.g., Technical Support Data Notebook defined in Appendix M of the GUIDE); and
- Zipped Flood Insurance Study (FIS) report components (e.g., FIS text, flood profiles, floodway data tables).

The practitioner shall comply with the DFIRM standards listed above and use the FEMA DFIRM database prototype to support the product development for the Carson River. The practitioner shall refer to the FEMA website directly to inquiry for changes or updates to requirements.

http://www.fema.gov/plan/prevent/fhm/dfm_dfhm.shtm

A copy of the DFIRM database prototype can be downloaded directly from FEMA at the following location:

http://www.fema.gov/library/viewRecord.do?id=3175

The practitioner shall prepare the digital DFIRM database using metadata per FEMA requirements listed in the GUIDE, Appendix L, Section L.6 and or L.8. The metadata examples for draft digital data identify the requirement of the following key components of product identification and information:

- Citation Information
- Project Description with Abstract and Purpose
- Time Period of Content
- Status
- Spatial Domain
- Keywords
- Place
- Access Constraints
- Use Constraints
- Point of Contact
- Native Data Set Environment
- Cross Reference
- Data Quality Information
- Spatial Data Organization Information
- Spatial Reference Information
- Entity and Attribute Information

- Distribution Information
- Metadata Reference Information

4.6.2 Work Map Components

The practitioner shall prepare topographic and aerial photographic work maps in support of the TSDN for submittal to FEMA. The practitioner shall develop an index map depicting the study area. The index map shall include project full name or title, agency project reference number, practitioner project number, study limit explanation, description of authority for study, communities/town/cities/or tribes participating within the study area, elevation reference mark or benchmark elevation control data, project title, north arrow, scale bar, survey and aerial photography collection methods and standards utilized. The date of production shall be included upon the final products (including the cover sheet).

The work maps shall be prepared in full size format (24"x36") in portrait or landscape format and index, key legend, project full name or title, agency project reference number, practitioner project number, north arrow, scale bar, and a index map depicting the relative location for the panels focus with the study area.

The work maps shall be prepared using a standard engineering scale, selected using best engineering judgment for the display of data prepared in support of the study area. Examples of standard engineer scale are 1"=200' for 1"=400' for the viewport map scale. Additional FEMA requirements for mapping related products can be found in the GUIDE, Appendix M, Section M.2.1 through M.2.3.

The resulting work maps shall be signed by a registered professional engineer (within the state of study analysis) in support of the TSDN deliverable to FEMA. The practitioner shall prepare both electronic and hard copies for both the coversheet and work maps products.

5 MODEL STORAGE AND MANAGEMENT

CWSD is currently participating in the FEMA Cooperating Technical Partners (CTP) program. The goal of this program is for local communities, participating in NFIP, to take an active role in maintaining up-to-date flood hazard maps for their respective jurisdictions. CWSD shall act as the clearing house for any up-to-date hydraulic models for the Carson River intended to update flood hazard mapping through FEMA. CWSD will store and manage models to make certain that land use changes have been incorporated and impacts have been reviewed by stakeholders and respective interested municipalities. Copies of completed models will be distributed by CWSD to any parties interested in making land use changes. This Guide will serve as the basis for any changes to these models. Once changes have been made a new proposed condition version shall be delivered back to CWSD for updates to the database. Additionally, any updates to hydrologic data along the study areas covered in this Guide shall be submitted to CWSD for review and incorporation into the database.

Modeling additions or changes for the project area shall be documented based on FEMA's *Guidelines and Specifications for Flood Hazard Mapping Partners Appendix M: Guidance for Preparing and Maintaining Technical and Administrative Support Data.* Updates/additions to the model and associated reporting shall be archived at both the CWSD and FEMA as study reaches are completed.

6 REFERENCES

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Chow, V.T., 1959. *Open-channel Hydraulics*: New York, McGraw-Hill Book Co., p. 680.

Ree, W.O., and Crow, F.R., 1977, *Friction factors for vegetated waterways of small slope:* Agricultural Research Service, U.S. Department of Agriculture, ARS-S-151, p. 56.

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U.S. Army Corps of Engineers, 2010, *HEC-RAS River Analysis System Users Manual Version 4.1,* Hydrologic Engineering Center, CPD-68.

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U.S. Geological Survey, 1982, *Guidelines for Determining Flood Flow Frequency*, Bulletin #17B of the Hydrology Subcommittee.

APPENDIX A: Manning's Roughness Tables from HEC-RAS Users Manual

Table 3.1
Manning's 'n' Values

Type of Channel and Description	Minimum	Normal	Maximum
A. *Natural Streams*			
1. Main Channels			
a. Clean, straight, full, no rifts or deep pools	0.025	0.030	0.033
b. Same as above, but more stones and weeds	0.030	0.035	0.040
c. Clean, winding, some pools and shoals	0.033	0.040	0.045
d. Same as above, but some weeds and stones	0.035	0.045	0.050
e. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
f. Same as "d" but more stones	0.045	0.050	0.060
g. Sluggish reaches, weedy. deep pools	0.050	0.070	0.080
h. Very weedy reaches, deep pools, or floodways with heavy stands of timber and brush	0.070	0.100	0.150
2. Flood Plains			
a. Pasture no brush			
1. Short grass	0.025	0.030	0.035
2. High grass	0.030	0.035	0.050
b. Cultivated areas			
1. No crop	0.020	0.030	0.040
2. Mature row crops	0.025	0.035	0.045
3. Mature field crops	0.030	0.040	0.050
c. Brush			
1. Scattered brush, heavy weeds	0.035	0.050	0.070
2. Light brush and trees, in winter	0.035	0.050	0.060
3. Light brush and trees, in summer	0.040	0.060	0.080
4. Medium to dense brush, in winter	0.045	0.070	0.110
5. Medium to dense brush, in summer	0.070	0.100	0.160
d. Trees			
1. Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
2. Same as above, but heavy sprouts	0.050	0.060	0.080
3. Heavy stand of timber, few down trees, little undergrowth, flow below branches	0.080	0.100	0.120
4. Same as above, but with flow into branches	0.100	0.120	0.160
5. Dense willows, summer, straight	0.110	0.150	0.200
3. Mountain Streams, no vegetation in channel, banks usually steep, with trees and brush on banks submerged			
a. Bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
b. Bottom: cobbles with large boulders	0.040	0.050	0.070

Table 3.1 (Continued)
Manning's 'n' Values

Type of Channel and Description	Minimum	Normal	Maximum
B. *Lined or Built-Up Channels*			
1. **Concrete**			
a. Trowel finish	0.011	0.013	0.015
b. Float Finish	0.013	0.015	0.016
c. Finished, with gravel bottom	0.015	0.017	0.020
d. Unfinished	0.014	0.017	0.020
e. Gunite, good section	0.016	0.019	0.023
f. Gunite, wavy section	0.018	0.022	0.025
g. On good excavated rock	0.017	0.020	
h. On irregular excavated rock	0.022	0.027	
2. **Concrete bottom float finished with sides of:**			
a. Dressed stone in mortar	0.015	0.017	0.020
b. Random stone in mortar	0.017	0.020	0.024
c. Cement rubble masonry, plastered	0.016	0.020	0.024
d. Cement rubble masonry	0.020	0.025	0.030
e. Dry rubble on riprap	0.020	0.030	0.035
3. **Gravel bottom with sides of:**			
a. Formed concrete	0.017	0.020	0.025
b. Random stone in mortar	0.020	0.023	0.026
c. Dry rubble or riprap	0.023	0.033	0.036
4. **Brick**			
a. Glazed	0.011	0.013	0.015
b. In cement mortar	0.012	0.015	0.018
5. **Metal**			
a. Smooth steel surfaces	0.011	0.012	0.014
b. Corrugated metal	0.021	0.025	0.030
6. **Asphalt**			
a. Smooth	0.013	0.013	
b. Rough	0.016	0.016	
7. **Vegetal lining**	0.030		0.500

Table 3.1 (Continued)
Manning's 'n' Values

Type of Channel and Description	Minimum	Normal	Maximum
C. *Excavated or Dredged Channels*			
1. **Earth, straight and uniform**			
a. Clean, recently completed	0.016	0.018	0.020
b. Clean, after weathering	0.018	0.022	0.025
c. Gravel, uniform section, clean	0.022	0.025	0.030
d. With short grass, few weeds	0.022	0.027	0.033
2. **Earth, winding and sluggish**			
a. No vegetation	0.023	0.025	0.030
b. Grass, some weeds	0.025	0.030	0.033
c. Dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
d. Earth bottom and rubble side	0.028	0.030	0.035
e. Stony bottom and weedy banks	0.025	0.035	0.040
f. Cobble bottom and clean sides	0.030	0.040	0.050
3. **Dragline-excavated or dredged**			
a. No vegetation	0.025	0.028	0.033
b. Light brush on banks	0.035	0.050	0.060
4. **Rock cuts**			
a. Smooth and uniform	0.025	0.035	0.040
b. Jagged and irregular	0.035	0.040	0.050
5. **Channels not maintained, weeds and brush**			
a. Clean bottom, brush on sides	0.040	0.050	0.080
b. Same as above, highest stage of flow	0.045	0.070	0.110
c. Dense weeds, high as flow depth	0.050	0.080	0.120
d. Dense brush, high stage	0.080	0.100	0.140