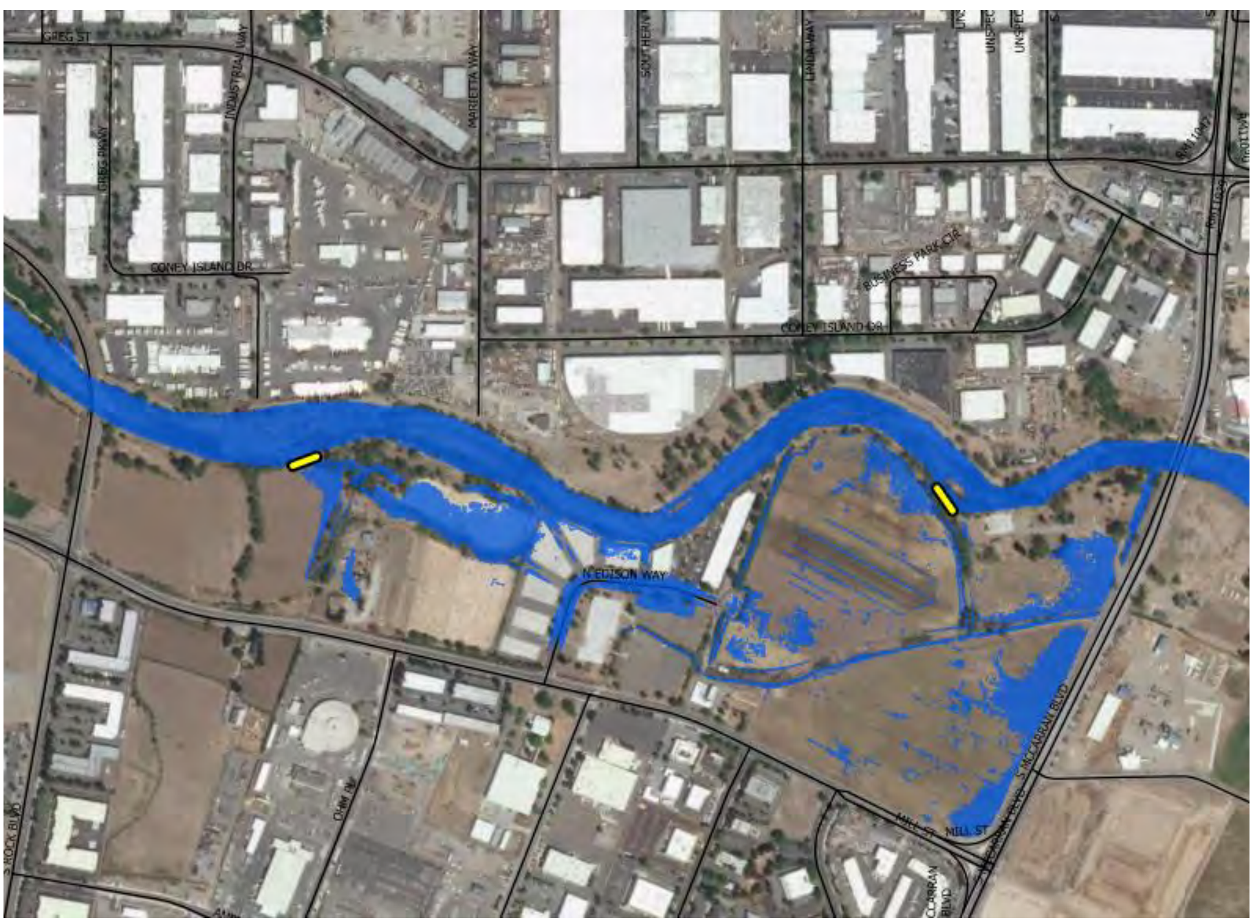
Appendix I

Truckee Basin Water Management Options Pilot Study—Channel Capacity Analysis

BUREAU OF RECLAMATION

Truckee Basin Water Management Options Pilot Study—Channel Capacity Analysis

Truckee Basin Water Management Options Pilot Study, Nevada and California



U.S. Department of the Interior December 1, 2022

Mission Statements

The U.S. Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated Island Communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Truckee Basin Water Management Options Pilot Study—Channel Capacity Analysis

Truckee Basin Water Management Options Pilot Study, Nevada and California

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Cover Graphic: Truckee River Truckee Meadows Reach - 6,000 CFS Peak Flow Inundation Boundary for Channel Capacity Analysis

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Abbreviations & Acronyms

1985 WCM	1985 *Truckee River Basin Reservoirs, Truckee River, Nevada and California: Water Control Manual*
1D	one-dimensional
2D	two-dimensional
cfs	cubic feet per second
DAS	Digital Aerial Solutions, LLC
FEMA	Federal Emergency Management Agency
FIRO	Forecast-Informed Reservoir Operations
Flood Project	Truckee River Flood Control Project
ft	feet
GNSS	Global Navigation Satellite Systems
GRR	Truckee Meadows General Reevaluation Report
IR	infrared
HEC	USACE Hydrologic Engineering Center
HEC-DSS	Hydrologic Engineering Center Data Storage System
HEC-RAS	Hydrologic Engineering Center River Analysis System
LiDAR	Light Detection and Ranging
LBAO	Bureau of Reclamation – Lahontan Basin Area Office
LVC	Long Valley Creek
NAIP	National Aerial Imagery Program
NAD83	North American Datum of 1983
NAVD88	North American Vertical Datum of 1988
NGVD29	National Geodetic Vertical Datum of 1929
NSE	Nash-Sutcliffe Efficiency
NTD	North Truckee Drain
PMR	Physical Map Revision
Quantum	Quantum Geospatial
Reclamation	Bureau of Reclamation
RR	railroad
RM	Reference Mark
RTC	Northern Nevada Regional Transportation Commission
SEC	Southeast Connector
TIN	Triangulated Irregular Network representation of the terrain surface
TMWRF	Truckee Meadows Water Reclamation Facility
TRFMA	Truckee River Flood Management Authority
Truckee Basin	Truckee River Basin
UNR	University of Nevada, Reno
USACE	US Army Corps of Engineers
USDA	US Department of Agriculture
USGS	US Geological Survey
WSE	water surface elevation
WMOP	Truckee Basin Water Management Options Pilot Study
XS	Cross Section

Introduction

The Truckee River Basin (Truckee Basin) covers approximately 3,060 square miles in California and Nevada, with flows originating in the Sierra Nevada mountains at elevations exceeding 10,000 feet (ft). The Truckee River flows approximately 121 miles from the Lake Tahoe outlet to its terminus at Pyramid Lake. While 90 percent of the flow and virtually all the basin's water storage originates in California, the water demands are primarily in Nevada.

There are three Bureau of Reclamation (Reclamation) projects within the Truckee Basin:

- The Washoe Project (Stampede and Prosser Dams and Reservoirs, and Marble Bluff Dam)
- Portions of the Newlands Project (Lake Tahoe Dam, Derby Dam, and the Truckee Canal)
- The Truckee Storage Project (Boca Dam and Reservoir)

There are three other dams in the Truckee Basin owned and operated by other agencies:

- Donner and Independence Lake Dams (owned and operated by Truckee Meadows Water Authority)
- Martis Creek Dam (owned and operated by US Army Corps of Engineers (USACE))

Reservoir operations for flood control in the basin are currently governed by the 1985 *Truckee River Basin Reservoirs, Truckee River, Nevada and California: Water Control Manual* (1985 WCM), issued by the USACE. However, the WCM no longer reflects current conditions due to changes in climate, infrastructure, and policies.

The Truckee Basin has historically experienced droughts and large flood events. The current operating rules, which prioritize the reduction of flood risk, make it difficult for water managers to adapt to climate change and basin changes and to plan for dry-season water supplies. Even in large runoff years, the 1985 WCM flood-control diagrams (or reservoir rule curves) and snowmelt parameters often prevent filling of the reservoirs into the flood storage volume until too late in the season. During years with significant snowpack, by the time filling is finally allowed into flood storage pools (based on high snowmelt parameters), runoff has receded to a level such that some reservoirs cannot be filled to capacity.

To address these challenges, the Truckee Basin Water Management Options Pilot (WMOP) study aims to develop flexible flood-risk reduction criteria without increasing downstream flood risk by evaluating Forecast-Informed Reservoir Operations (FIRO), flexible rule curves, and changes to downstream regulation goals. The WMOP study will then be documented in a Viability Assessment document and provided to the USACE for their review and a subsequent update to the 1985 WCM on their approval.

To support the Truckee Basin WMOP study, the capacity of the Truckee River channel from upstream of Reno, NV through the Truckee Meadows and on downstream to the community of Wadsworth, NV has been analyzed based upon HEC-RAS hydraulic simulations. That analysis is the subject of this report.

Background

The Truckee River Basin drains approximately 3,060 square miles and terminates in Pyramid Lake, NV. Basin elevations range from about 3,790 feet at Pyramid Lake to over 10,000 feet in the Sierra Nevada mountains. The Truckee River originates at the northwestern shore of Lake Tahoe, where an outlet structure regulates flow out of the lake and into the river. From Lake Tahoe, the river flows about 15 miles in a northerly direction, then flows eastward through the city of Truckee, California. The river flows north and east for about 40 miles to the city of Reno, NV, then continues north and east to Pyramid Lake. The major Truckee River tributaries between Lake Tahoe and Reno are the Little Truckee River, Prosser Creek, Donner Creek, Martis Creek, Hunter Creek, Alum Creek, and Dog Creek. Additional significant tributaries that join the Truckee River downstream of Reno include Steamboat Creek, Dry Creek, the North Truckee Drain (NTD), and Long Valley Creek. In addition to the flow regulation provided by Lake Tahoe, flows originating above Reno are also partially regulated by the Donner Lake, Martis Creek, Prosser Creek, Stampede, and Boca dams. The drainage area of the Truckee River at Reno is approximately 1,067 square miles, with 506 square miles partially regulated by Lake Tahoe.

The current USACE Water Control Manual regulations mandate a target (control) maximum flow rate of 6,000 cubic feet per second (cfs) at the US Geological Survey (USGS) stream gage at Reno. The WMOP study channel capacity analysis is intended to determine whether the channel capacity in the study reach from Reno downstream to Wadsworth is actually greater than 6,000 cfs. If so, this could allow for greater flexibility in operation of the upstream reservoirs.

Hydraulic models representing the Truckee River and associated tributaries in the Truckee Meadows reach, which extends from upstream of Reno to downstream of Vista, and in the Lower Reach, which extends from below Vista downstream to Wadsworth, have been developed in support of a Federal Emergency Management Agency (FEMA) Physical Map Revision (PMR) with the 1% annual chance exceedance flow as the focus. This PMR will provide updated floodplain mapping for both the Truckee Meadows reach and the Lower Reach. The hydraulic models are based on the USACE Hydrologic Engineering Center River Analysis System (HEC-RAS) software. The Truckee Meadows model is a fully two-dimensional (2D) model with unsteady state flow conditions. The Lower Reach model is a one-dimensional (1D) model that was developed using steady state flow conditions and was converted to unsteady state flow with updated hydrology for this study. All topographic data, hydraulic models, and water surface elevations used or reported are based upon the North American Vertical Datum of 1988 (NAVD88) unless otherwise noted.

Project Tasks

The channel capacity analysis portion of the Truckee River WMOP Study consisted of several discrete tasks, each of which is summarized in this report. These tasks were:

- Streamgage Flow and Gage Height Data Set Development
- Hydraulic Model Calibration
- Hydraulic Model Validation

- Synthetic Incremental Flow Hydrograph Development
- Channel Capacity Identification and Inundation Mapping
- Channel Capacity Analysis Documentation (Final Report)

Hydraulic Models

The underlying data sources and general model development processes involved in creating the HEC-RAS hydraulic models that serve as the basis of the channel capacity analysis are described in the following sections.

Truckee Meadows Reach Model

To assess hydrodynamic behavior of the Truckee River within the Truckee Meadows to support a FEMA PMR, HDR Engineering chose to develop a fully 2D hydrodynamic model of the study area using the US Army Corps of Engineers' HEC-RAS Version 6.2 software package. This model has the capability to simulate flow in two dimensions using a depth averaged velocity. This capability allows for a more robust evaluation of overbank hydrodynamics and, potentially, more accurate mapping. This version of HEC-RAS can simulate pressure flow bridges as 2D components, which was not possible in prior versions of HEC-RAS.

The basis for this hydraulic model was the previously developed Truckee Meadows Regional Model. The model domain extends along the Truckee River from White Fir St., upstream of Reno, eastward to downstream of Vista. In the north-south direction, the model extends from Vintage Hills Parkway, in northern Sparks, down to near South Meadows Parkway, in southern Reno. The model was updated with as-built information and field survey data collected for the PMR effort. All 1D features were eliminated and are now represented using the HEC-RAS 2D capabilities. A model base grid cell sizing of 150 ft was chosen to allow for sufficient detail to capture flood wave dynamics and balance runtimes. Model "breaklines" were added at hydraulically significant high features in the modeling domain to eliminate "leaky cells." Hydraulic structures were added to the model geometry based on field surveys and as-built information.

The primary focus of the PMR HEC-RAS model was the simulation and mapping of the 1% annual chance exceedance event, which has a Truckee River peak flow of 20,700 cfs at the Reno gage. Geometric changes such as grid cell refinement to capture smaller overbank events were not part of the scope of this study and therefore model geometry was not refined for this purpose. Small obstructions to flow such as Jersey barriers and earthen berms are not represented by the model geometry at many locations. The overall HEC-RAS geometry is shown in Figure 1.

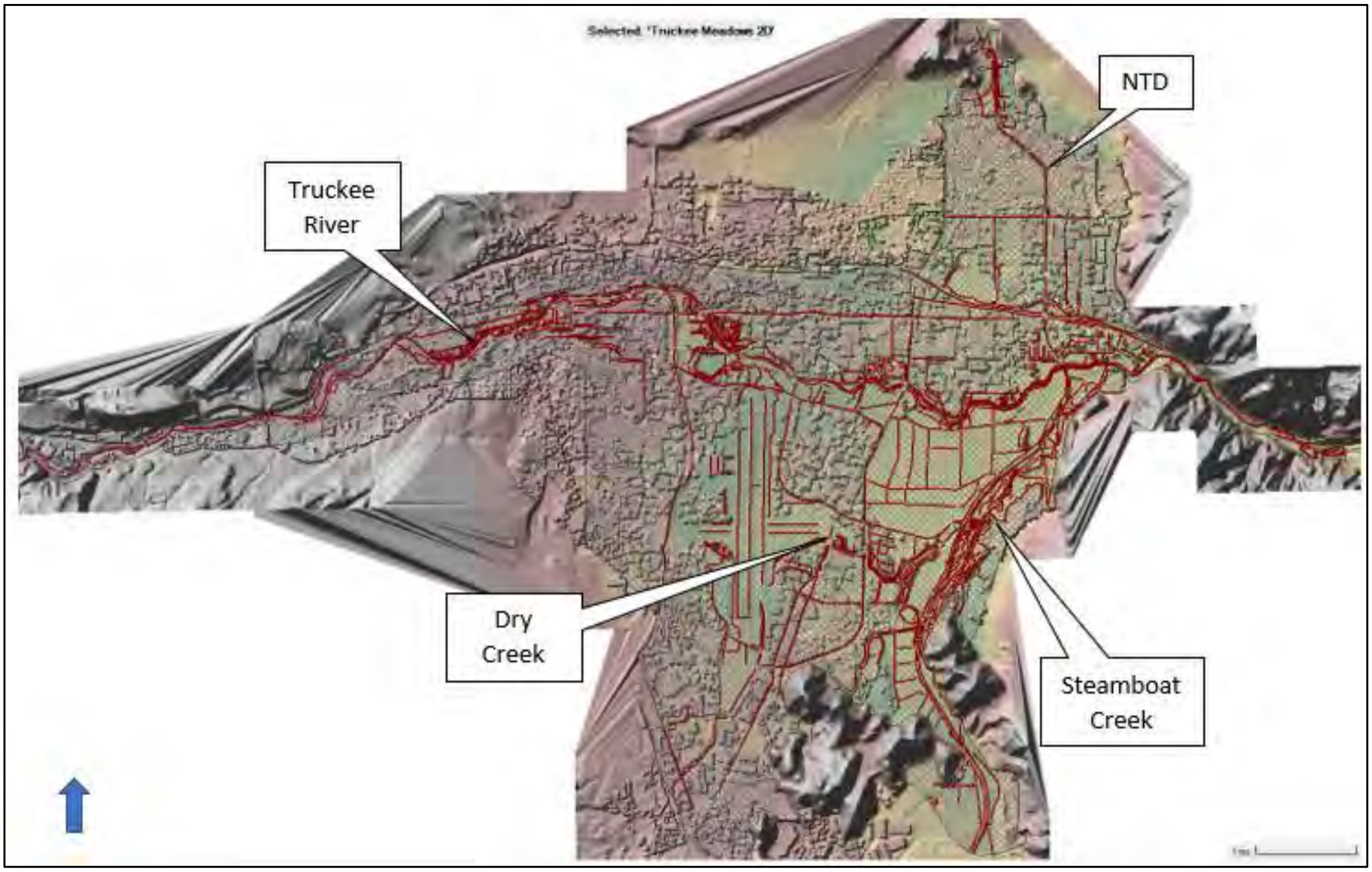

Figure 1. Truckee Meadows HEC-RAS Model Configuration

To simulate the hydrodynamics of the Truckee River and its tributaries in the Truckee Meadows area, a composite terrain of the Truckee River, Steamboat Creek, Dry Creek/Boynton Slough, NTD, and associated overbank areas was compiled from multiple data sources. All topographic data used are based upon NAVD88.

The primary source of topographic data for the overbank regions of the model domain is represented by conventional infrared (IR) Light Detection and Ranging (LiDAR) data collected by the USGS in September and October of 2017. These data were provided to HDR by the Washoe County GIS department in the form of LAS point files. The LiDAR data were collected for the USGS by Digital Aerial Solutions, LLC (DAS) between September 19, 2017 and October 27, 2017. The supporting documents provided by DAS state that all the LiDAR data produced meet at least QL2 accuracy standards, with the majority of the Reno and Sparks urban areas meeting the higher QL1 data standard. The GeoCue Group Inc. LP360 software package was used to create 1 ft resolution floating point grid or "float files" (*.FLT) based on the LAS points classified as 'bare earth" by DAS.

The Veterans Parkway, also referred to as the Southeast Connector (SEC), is an arterial roadway paralleling Steamboat Creek from South Meadows Parkway in the south and extending downstream to the Truckee River. The road is elevated above the surrounding floodplain in many locations, and results in a major change to prior overbank flow patterns. This roadway was constructed relatively recently, with construction still taking place during the 2017 collection period of the USGS IR LiDAR. Due to the unavailability of conventionally collected topographic data, the SEC and associated topographic features are represented based upon a Triangular Irregular Network (TIN) terrain model provided to HDR by the Northern Nevada Regional Transportation Commission (RTC), which contracted for and oversaw the construction of the SEC. Comparison of the SEC TIN surface with as-built plans for the roadway indicate that the surface represents the roadway and its associated grading and volume mitigation features quite well.

Buildings are represented within the terrain using elevated features to prevent overbank flow from moving through the building areas. The outlines of these features are based upon a building footprints shapefile provided to HDR by the Washoe County GIS department.

A limitation to the traditional LiDAR data is the inability of IR LiDAR to penetrate water, resulting in missing data in the stream channel where water is present on the collection day. To remedy this gap in the 2017 IR LiDAR data, several sources of bathymetric topography were added to supplement the overall 2017 terrain. Bathymetry for this project included "green" and IR LiDAR collected during drought conditions, sonar data collected by HDR, and channel data from previous hydraulic models.

In 2014, the Truckee River Flood Management Authority (TRFMA) contracted with Quantum Geospatial (Quantum) to collect LiDAR data for the Truckee River and near overbank regions from the Nevada/California state line downstream to Wadsworth, NV (Quantum, 2015). The LiDAR missions utilized both conventional infrared LiDAR and green LiDAR sensors. The green LiDAR sensor can penetrate water to approximately one Secchi depth below the water surface, which is a measure of the transparency of a body of water. The missions were conducted during October 2014, which coincided with a very low flow period on the Truckee. This enabled the collection of good quality bathymetric data along much of the study reach. However, areas of the river which were deep or had high turbidity prevented the acquisition of bathymetric data. The technical data report provided by Quantum to accompany the LiDAR data deliverables does not state the accuracy of the data in terms of QL standards, but the reported aggregate nominal pulse spacing and absolute accuracy meet or exceed the QL2 minimum criteria provided in USGS TM 11 B-4, LiDAR Base Specifications. Immediately following delivery of the LiDAR data by Quantum, HDR performed an independent data quality inspection. The results of this report confirm the data meets or exceeds the QL2 accuracy criteria.

To improve the quality of the channel representation in the Truckee River reach between the NTD and Lockwood, HDR performed a sonar survey of the channel bottom in June 2018, collecting elevation data during two survey missions. GPS survey data representing important hydraulic features and a USGS benchmark point on the Truckee Meadows Water Reclamation Facility (TMWRF) property were collected during this field effort. The hydraulic features surveyed included the tops of large boulders in the river near the USGS Vista gage, and a portion of the rock weir immediately upstream of the lower railroad (RR) bridge.

After bathymetric sonar data were processed, a raster (a rectilinear matrix of elevation data) surface representing the channel bottom was developed using the final GPS, sonar, and LiDAR elevations. This was accomplished using the HEC-GeoRAS software package with cross sections laid out along the sonar transects. For the in-channel boulders and the rock weir, some rock features were inaccessible for survey due to high flow depths. The elevations of these features were estimated by assigning elevations from comparable nearby features that were surveyed. The station-elevation data were imported into HEC-RAS, and HEC-RAS Mapper was used to produce an interpolation surface for the channel region.

Small, manually created interpolation patches were added to the terrain to represent bridge piers associated with high bridges that would not experience pressure flow during the 1% chance flood event. Other manual patches were added to allow the model to accurately represent elevations of hydraulic structures that are set below the elevations recorded by the LiDAR data sets.

The 2014 green bathymetric LiDAR and the 2018 sonar data did not capture channel data for the tributary reaches (Steamboat Creek and Dry Creek). Due to the lack of accurate bathymetric data for the tributary channels, prior hydraulic modeling information was used to supplement the channel elevations for portions of these streams. These data were taken from a HEC-RAS V4.1 model of the Truckee River and tributaries developed by WRC Nevada, Inc., circa 2000. This was a validated model that was developed in concert with the USACE Hydrologic Engineering Center. The model was later adopted by USACE and was used as the basis of the USACE Truckee Meadows Flood Control Project.

Bathymetric data for the NTD were developed based upon a combination of as-built plan data and surveyed elevations. The artificially constructed channel was assumed to have a constant slope between the numerous culverts along its length. A channel interpolation patch was created using the HEC-RAS interpolation option and the patch was added to the final HEC-RAS terrain. Channel bottom width was set to match as-built plans in the reaches where the available plans specify the width. In reaches where no plans were available or the plans did not specify bottom width, the width was set to match the bounding culvert bottom widths. Channel inverts were set to match the inverts of the culverts at each end of the open reaches of the NTD channel. The model simulates the current alignment of the NTD, which enters a pair of large box culverts after passing under I-80 and is conveyed underground to its revised confluence with the Truckee River, downstream of the Vista Narrows.

Below is a summary of the data sources used to develop the composite terrain:

- Bathymetric LiDAR data collected in October 2014 by Quantum Geospatial for TRFMA were used to represent the Truckee River channel and near overbanks.
- Sonar bathymetry collected in June 2018 by HDR for a prior Truckee River modeling effort. This data set includes bathymetric data for the Truckee River from the historic confluence of the NTD with the Truckee River, downstream to a point just below the second RR bridge downstream of Sparks, NV.
- Conventional IR LiDAR data collected in 2017 by the USGS were used to represent most of the overbank regions.
- The Southeast Connector roadway and associated features are represented based upon TIN data provided by RTC.
- NTD bathymetry is represented using a HEC-RAS interpolation patch based upon available as-built plans and surveyed channel invert elevations.
- Buildings in the model domain are represented as elevated features, based upon building footprints provided by Washoe County GIS department.
- Portions of the tributary channels use bathymetry developed from previous 1D hydraulic modeling.

- Manual patches to represent piers associated with non-pressure flow bridges, and culvert inverts below the LiDAR surface elevation, were added to improve the accuracy of the terrain.

These data sets were all projected into the North American Datum of 1983 (NAD83) State Plane Feet Nevada West FIPS 2703 coordinate system using both ESRI ArcMap and GeoCue Group Inc. LP360 software. The vertical datum for all topographic data, as well as for all hydraulic structures simulated within the hydraulic model, is NAVD88. The 2017 LiDAR and Sonar data were processed into 1 ft resolution floating point grid or "float files" (*.flt). The 2014 bathymetric LiDAR data were compiled into a 3 ft resolution float file during a prior modeling effort, this resolution was retained for the PMR modeling work. The pier data were processed into 0.5 ft float files. The float files were merged into a single terrain data set in HEC-RAS Mapper for use in the hydraulic model. The extents of the topographic data sources used is shown in Figure 2.

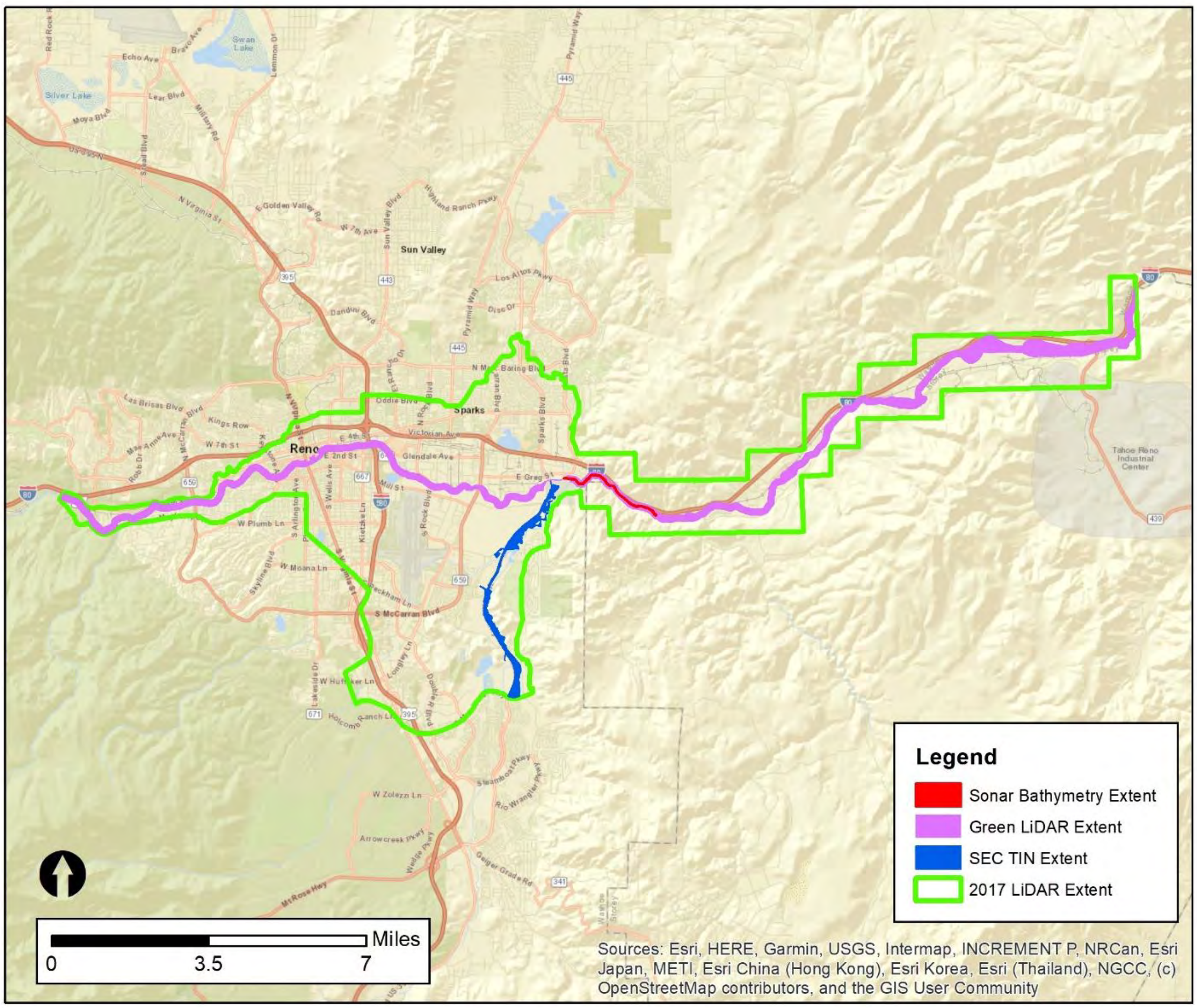

Figure 2. Truckee Meadows Terrain Data Sources

Manning's n roughness values were delineated from aerial photos using ArcMap editing tools. Table 1 lists the land use designations and corresponding Manning's n roughness values that were assigned to polygons of homogeneous land use. Channel regions using different Manning's n roughness values are often indicated by including the associated Manning's n roughness value within the land use description (e.g., "Truckee Channel 028", or "Lower Truckee 026"). Many of these Manning's n roughness values were validated to the 2005 flood event during development of the Regional Model. Figure 3 is a map showing the level of detail used in representing Manning's n roughness values.

Table 1. Truckee Meadows Reach Manning's n Roughness Values

Land Use Description	Manning's n Roughness Value
Agricultural	0.04
Airport	0.02
Apartment Complex, Building in Terrain	0.02
Apartment Complex, Landscaped	0.085
Bank Slope	0.035
Boulders	0.06
Cemetery	0.035
Channel	0.03
Church	0.035
Commercial	0.02
Dirt Lot	0.035
Dirt Road	0.032
Ditch	0.035
Golf Course	0.04
Grass	0.025
High Density Residential	0.05
Highway	0.018
Hospital	0.03
Industrial, Buildings in Terrain	0.02
Landscaped	0.035
Left Bank 1	0.038
Low Density Residential	0.04
Lower Truckee 026	0.026
Lower Truckee 028	0.028
Lower Truckee 031	0.031
Lower Truckee 032	0.032
Lower Truckee 033	0.033
Lower Truckee 035	0.035
Lower Truckee 038	0.038
Lower Truckee 039	0.039

Land Use Description	Manning's n Roughness Value
Lower Truckee 040	0.04
Lower Truckee 055	0.055
Medium Density Residential	0.05
Mixed Use Landscaped	0.065
Mowed Grass	0.022
NTD Channel	0.04
Overbanks 1	0.044
Overbanks 2	0.042
Overbanks 3	0.04
Overbanks 4	0.035
Overbanks 5	0.037
Park	0.05
Park_045	0.045
Parking	0.015
Plaza	0.02
Railroad	0.05
Rest Stop	0.022
Right Bank 1	0.038
Riparian	0.06
Riprap	0.045
Riprap A	0.041
River Corridor	0.048
River Corridor 050	0.05
Roadway	0.015
Rock Outcrop	0.06
Rock Slabs	0.03
Rural	0.05
Sage Grass	0.055
Sage Grass_04	0.04
SBC Right Bank	0.035
School	0.035
Soil	0.04
Steamboat Channel	0.03
Trailer Homes	0.02
Truckee Channel 028	0.028
Truckee Channel 033	0.033
Truckee Channel 038	0.038
Truckee Channel 048	0.048
University	0.035
Vacant Lot	0.045

Land Use Description	Manning's n Roughness Value
Vacant Lot Vegetated	0.06
Vacant Lot_04	0.04
Water	0.01

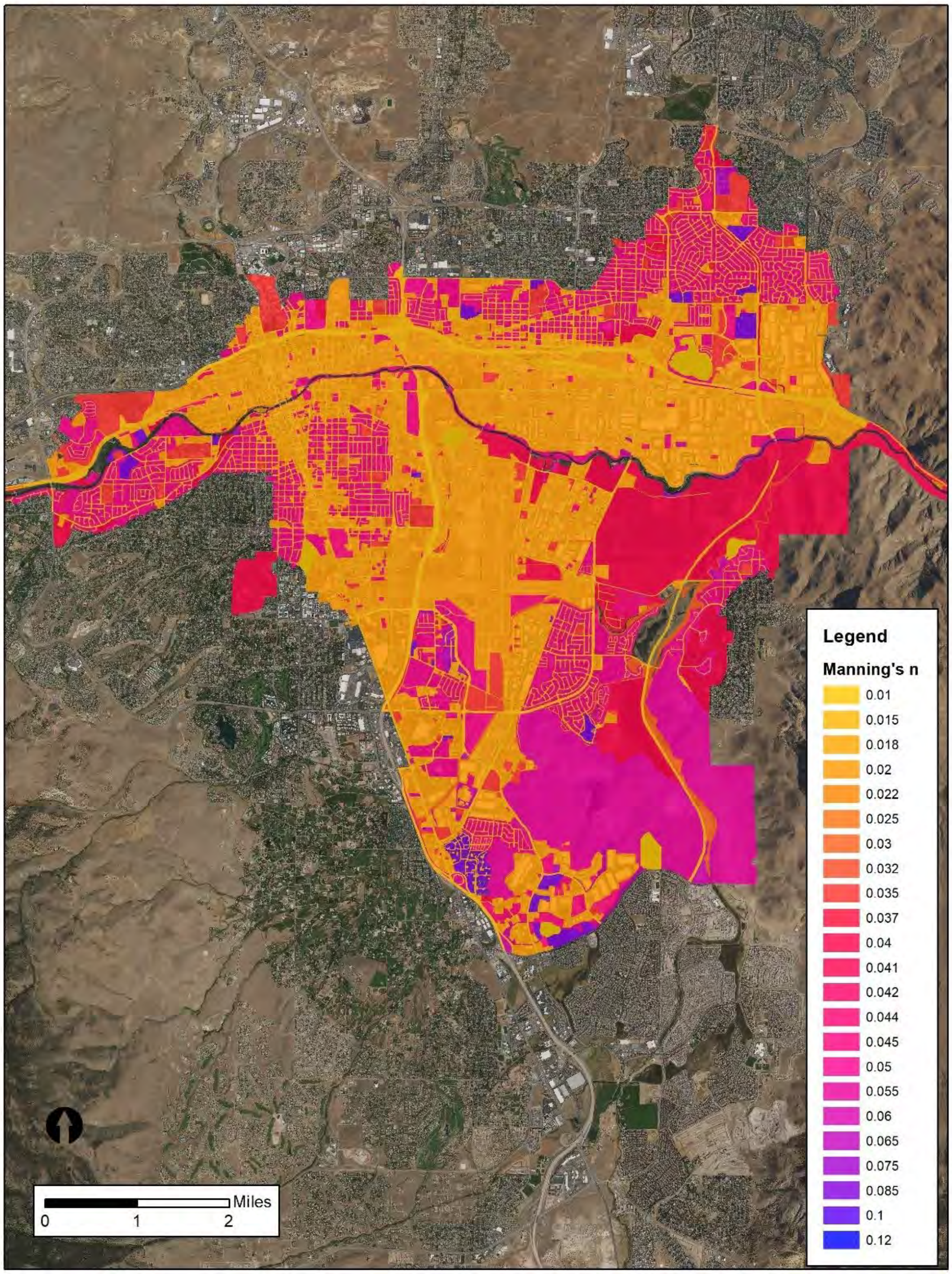

Figure 3. Truckee Meadows Manning's n Roughness Values

Truckee River Lower Reach Model

The reach of the Truckee River downstream of Vista down to Wadsworth is generally known as the Lower Reach and exhibits markedly different hydraulic behavior than the Truckee River within the Truckee Meadows reach. The river flows through a relatively narrow canyon and has a fairly small floodplain compared to the wide floodplain within the Truckee Meadows reach. Due to these conditions, a 1D model accurately represents hydraulic conditions within this reach. Figure 4 provides an overview of the Lower Reach 1D HEC-RAS model extent and configuration.

Figure 4. Lower Reach HEC-RAS Model Configuration

The topographic data sources used to represent the channel and overbanks are generally similar to the data used for the Truckee Meadows reach model. The overbank regions rely upon the 2017 USGS IR LiDAR, while the channel is generally represented using the 2014 green and IR LiDAR collected by Quantum Spatial for TRFMA.

Two sets of survey data available for the Lower Reach were used to supplement these data sources. In 2010, USACE contracted Towill Surveying, Mapping and GIS Services to develop a detailed terrain surface to support hydraulic engineering studies and analysis for the USGS. The hydrographic survey for the 52 mile long section of the Truckee River east of Sparks, NV extending from Lockwood downstream to Pyramid Lake was performed between October 2010 and January 2011. Cross sections of the river channel were collected along the Truckee River by field survey teams, on foot and within boats, at variable spacing as necessary to accurately document channel morphology. During the spring and summer of 2019 Atkins surveyed transects of the Truckee River from the Washoe/Storey County line to just upstream of Pyramid Lake. Conventional survey equipment was used to gather points along the bank and within the river at shallow depths. For deeper portions of the river, a Seafloor Systems Hydrolite/Hydrone echosounder was used in conjunction with a Trimble R10 Global Navigation Satellite Systems (GNSS) Receiver, and Trimble TSC3 Field Controller. These two survey data sets, 2010 USGS and 2019 Atkins, were not directly used in the terrain data provided. However, a dummy terrain was created using these survey points and that surface was used to make the appropriate updates in the channel bathymetry. The final terrain data all use the NAD83 State Plane Feet Nevada West FIPS 2703 coordinate system. The vertical datum for all topographic data, as well as for all hydraulic structures simulated within the hydraulic model, is NAVD88. The extents of the topographic data sources used are shown in Figure 5.

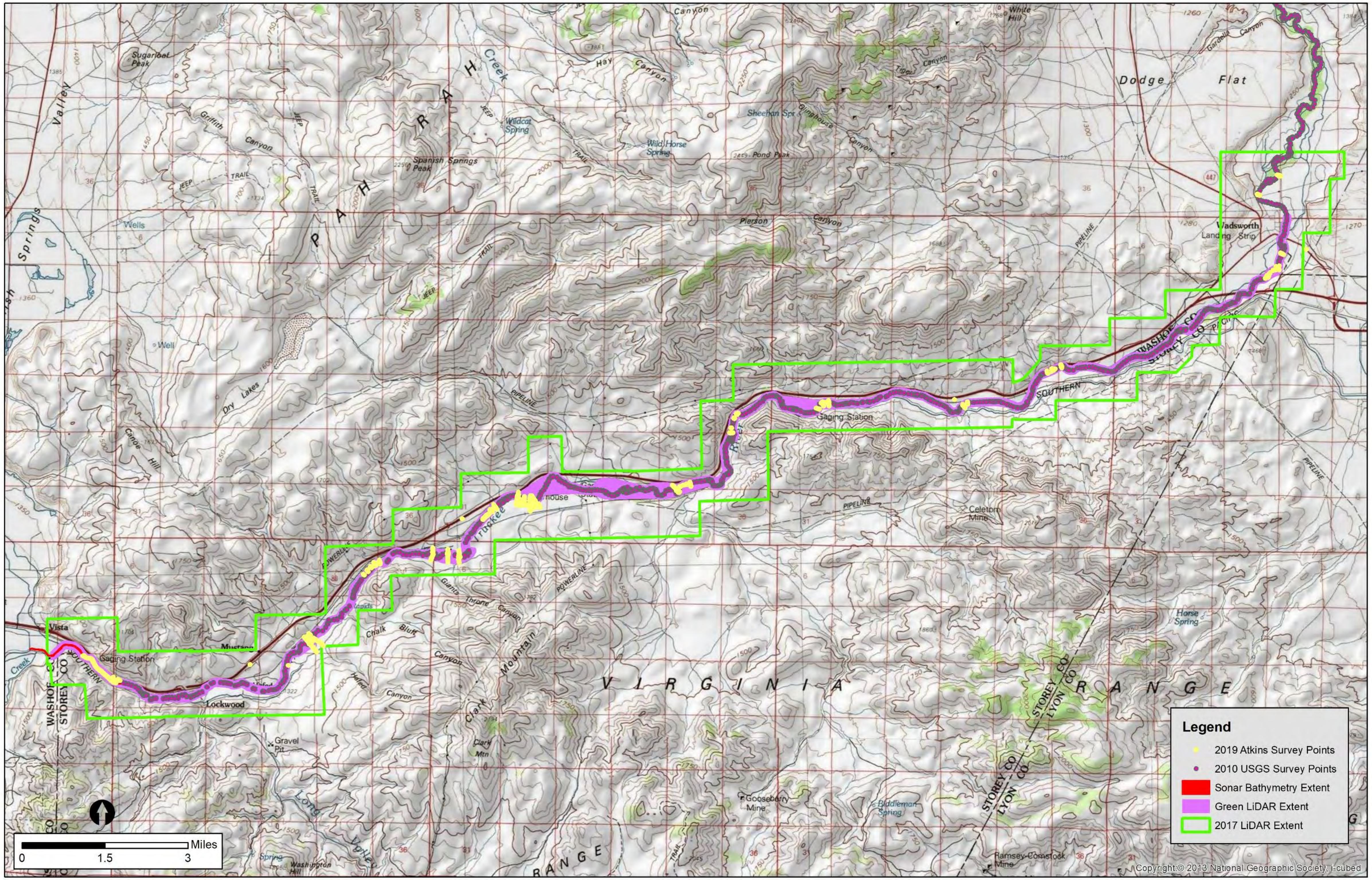

Figure 5. Lower Reach Terrain Data Sources

Manning's n roughness values were estimated from available aerial imagery of land use types. Where necessary, a horizontal variation in Manning's n roughness values for cross sections was used to describe Manning's n roughness in the main channel and floodplains. Table 2 gives the details of Manning's n roughness values used in the model.

Table 2. Truckee River Lower Reach Manning's n Roughness Values

Land Use Description	Manning's n Roughness Value
Light Brush	0.04
Medium Brush	0.042-0.05
Pond	0.035
Channel	0.039-0.042
Developed Medium Density	0.07

The Manning's n roughness values used in this reach are generally comparable to the effective model. The effective model (in detailed study reaches) uses a channel Manning's n roughness of 0.035-0.045 and overbank Manning's n roughness of 0.033-0.045. Reasonableness of the selected values was evaluated using gage data for a range of discharges that include channel and overbank flow at USGS gaged locations.

Flood Event Flow and Gage Height Data Sets

Streamflow and gage height data sets used in hydraulic model calibration and validation were collected for seven USGS streamgages located along the Truckee River within the reaches to be analyzed. The gage names and ID numbers are shown in Table 3. Due to a lack of available data, particularly for the 1997 flood event, data from the Mogul gage was not utilized during this study.

Table 3. USGS Streamgages Utilized

Gage Name	Gage ID
Truckee River near Mogul	10347460
Truckee River at Reno	10348000
Truckee River at Vista	10350000
Truckee River near Tracy	10350340
Truckee River below Tracy	10350400

Gage Name	Gage ID
Truckee River below Derby Dam	10351600
Truckee River at Wadsworth	10351650

Figure 6 and Figure 7 show the locations of the USGS stream gages, along with important tributary confluences with the Truckee River within the reaches analyzed.

Data representing five Truckee River flood events in the near past were collected. The approximate dates of these events, along with the peak flow recorded at the Reno gage, are shown in Table 4. Some peak flow estimates at the Reno gage produced by the USGS have been found to be unreliable and conflict with best available data. Table 4 presents revised peak flow estimates based upon additional analysis by HDR and others. The peak flow estimate for the 1997 flood event shown in Table 4 is based upon hydraulic modeling done by WRC Nevada, Inc., in collaboration with HEC USACE personnel. This estimate has been accepted by USACE and was used in their hydrologic analysis of the Truckee River. The peak flow estimate for the 2005 flood event is based upon hydraulic modeling and analysis in the downtown Reno area performed circa 2014 by HDR as part of a hydraulic modeling and flood management project for TRFMA. Details of these analyses are presented in the model calibration and validation portions of this report.

Table 4. Truckee River Flood Events

Approximate Date of Flood Event	Peak Flow at Reno Gage (cfs)
Early March 1995	6,390
Late December 1996 to early January 1997*	23,216
Late March 1998	5,540
Late December 2005 to early January 2006*	14,766
Early January 2017	12,800
Early April 2018	6,690
Early April 2019	5,160
* Peak flow estimate shown differs significantly from USGS peak flow estimate	

All discharge and gage height data available online were downloaded from the USGS website for each streamgage and compiled into a USACE Hydrologic Engineering Center Data Storage System (HEC-DSS) file for ease of use in data storage, plotting, and utilization in HEC-RAS modeling. The data were stored using standard Part A through Part F naming conventions. Part A indicates the river name, Part B indicates the gage location, and Part C indicates the data type, such as flow or stage (gage height). Parts D and E define the period of record and timestep associated with the data, respectively. Part F indicates the data source or sources.

One issue is that no gage height data for any of the sites are available on the USGS website for dates before October 1, 2007. Communication with USGS personnel at the Carson City office revealed that due to issues with the database used by the USGS prior to that time, there was no way to flag unreliable gage height values, while questionable discharge values could be highlighted. Because of this problem, the USGS decided to no longer publish older gage height results, rather than possibly have users rely on potentially inaccurate data.

HDR made a request to the data management officer at the USGS Carson City office for the pertinent gage height data from flood events before 10/1/2007 and received these data in spreadsheet format. Following receipt of these data, the gage height data were compiled into the HEC-DSS file used to store all of the flow and gage height data for this task. Comparison of the flow and gage height data revealed some gaps in the flow records for which gage height data were available. The USGS data management officer indicated that these gaps exist because the associated gage heights may have been judged to be unreliable, and no discharge estimates were developed for these unit values. The data gaps seen were of relatively short duration and occurred during the rising or descending limbs of the flood hydrographs. The data interpolation tools within the HEC-DSSVue software package were used to develop estimated flow or gage height values for any missing data within the time periods being cataloged.

The initial project scope stated that three flood events would be used for model calibration. These were:

- March 1998 (Peak flow at Reno gage: 5,540 cfs)
- December 2005 (Peak flow at Reno gage: 16,400 cfs)
- January 2017 (Peak flow at Reno gage: 12,800 cfs)

Examination of available USGS stream gage data revealed that for the 1998 event, no gage data are available for Truckee River tributaries within the Truckee Meadows. Therefore, HDR suggested that the flood event that occurred in April 2019 be substituted for the March 1998 event for model calibration. The 2019 event occurred during spring runoff season and had a similar peak discharge to the 1998 event (5,160 cfs at the Reno gage), and tributary flow data are available for the 2019 flood event. The project team agreed that this approach would provide a reasonable substitute for the March 1998 event.

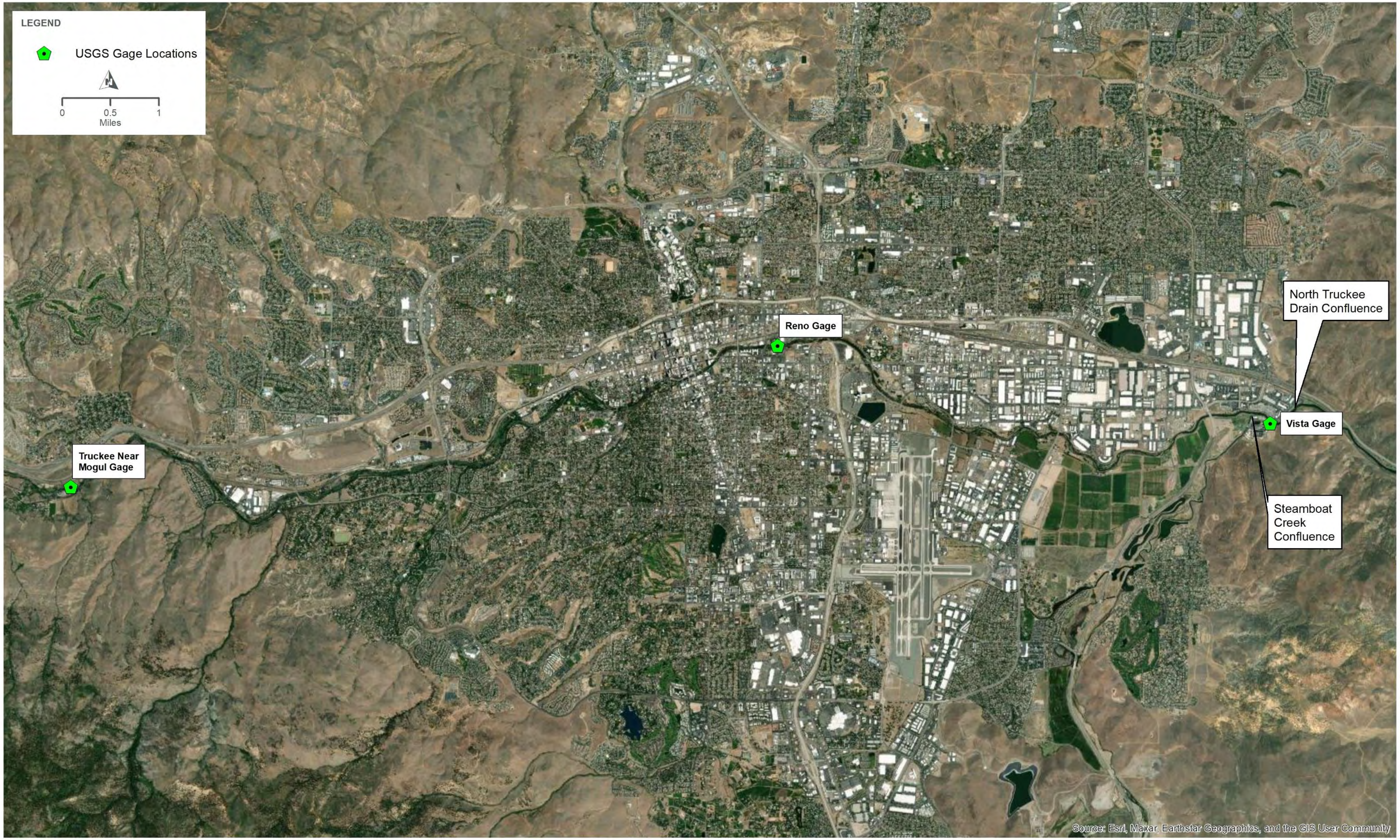

Figure 6. USGS Gage Locations Within Truckee Meadows

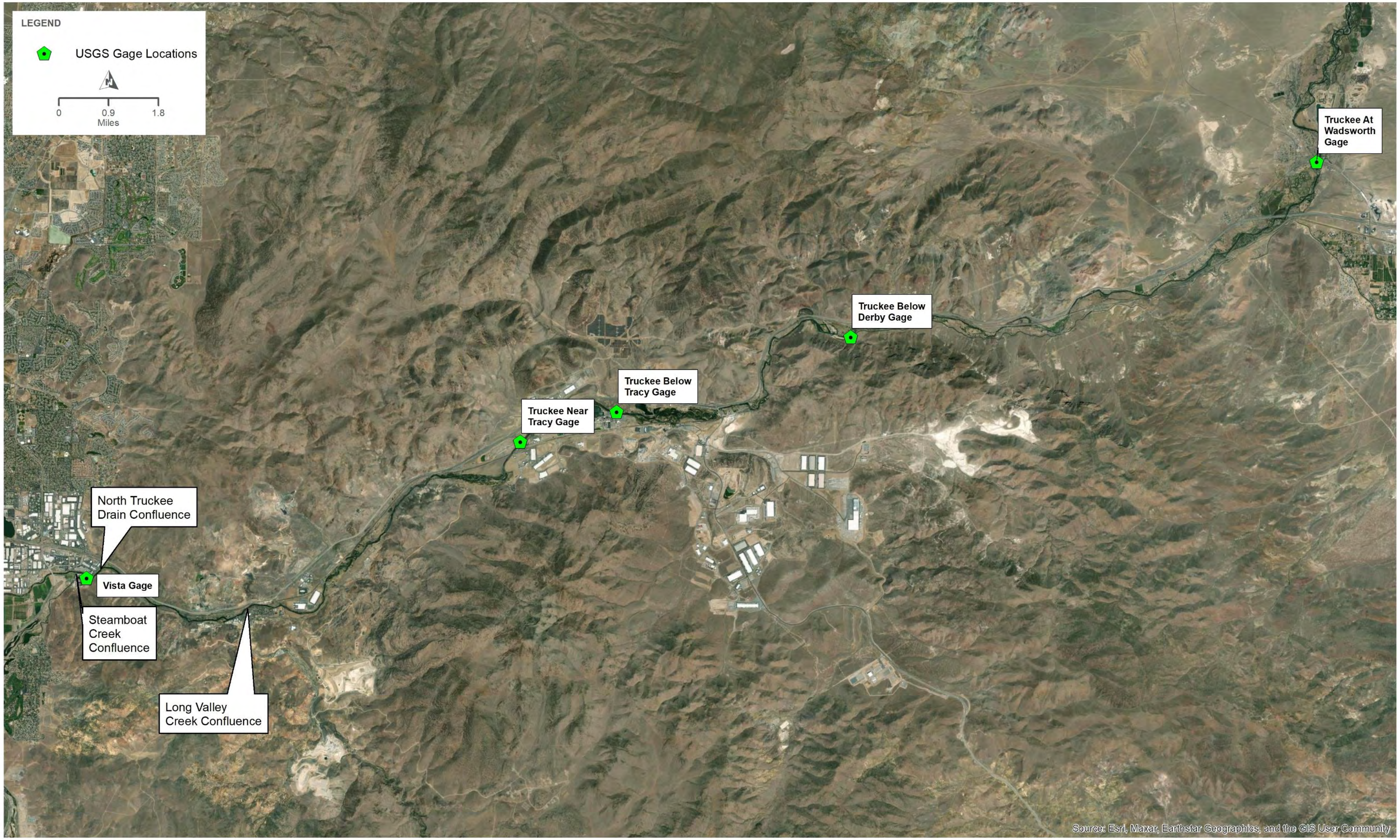

Figure 7. USGS Gage Locations Within the Lower Reach

Review of the USGS data for the 2019 event revealed that there is a time offset when comparing the data imported into HEC-DSSVue using the Data Entry/Import/USGS Web utility, relative to the flow records seen when accessing the gage data through the USGS website for the pertinent stream gage. The website records show the same flow values, but with a one hour offset. For instance, the peak flow at the Vista gage during the 2019 flood event is shown in the DSS file data as 5,100 cfs, occurring at 4/9/2019 12:15. The USGS website for the Vista gage shows the same flow rate of 5,100 cfs occurring at 4/9/2019 13:15. This same offset is consistent for the other flow and stage values at the Vista gage. This discrepancy is consistent for all stream gages used in the Truckee Meadows modeling. While it is not possible to determine which data set is correct without further investigation and coordination with USGS, the fact that the DSS data are internally consistent means that the calibration is still valid, as the time offset exists for the input data as well as for the data used to check the calibration.

The initial project scope detailed that two flood events would be used for model validation. These were:

- March 1995 (Peak flow at Reno gage: 6,390 cfs)
- January 1997 (USGS Peak flow at Reno gage: 18,100 cfs)

Examination of available USGS stream gage data revealed that for the 1995 event, no gage data are available for Truckee River tributaries within the Truckee Meadows. This complicates the analysis for this reach of the river.

HDR suggested that the flood event that occurred in April 2018 be substituted for the March 1995 event in the validation effort. The 2018 event occurred during spring runoff season and had a similar peak discharge to the 1995 event (6,190 cfs at the Vista gage). Tributary flow data are available for this event, simplifying the calibration effort within the Truckee Meadows portion of the modeling domain. The project team agreed that this approach would provide a reasonable substitute for the March 1995 event.

Another issue that was discovered during this data compilation was the fact that the Truckee River below Tracy gage was damaged during the 1997 flood event and was replaced by the Truckee River near Tracy gage in June 1997. Therefore, there is no complete record of the 1997 flood event flow or gage height for the Tracy reach.

Following the compilation of all available flow and gage height data sets for the gages and events of concern, charts plotting flow and gage height for each event at each gage site were prepared to present the data in graphical format. These plots are included in Appendix A of this document.

Hydraulic Model Calibration

Truckee River Truckee Meadows Reach

As mentioned above, the Truckee Meadows HEC-RAS 2D unsteady-state hydraulic model includes that reach of the Truckee River which extends from the White Fir St. bridge across the Truckee River upstream of Reno down to the endpoint approximately 2.5 miles downstream of Vista. Three tributaries, Steamboat Creek, Dry Creek, and the NTD, contribute to this Truckee River study reach (Figure 8).

Figure 8. Truckee Meadows Model Area

Model inputs include unsteady state flow hydrographs for the 2005, 2017, and 2019 events. USGS stream gage data collected earlier in this project were used to provide these input flow hydrographs for use in the HEC-RAS model. Data recorded at the Reno stream gage (Gage #10348000) were used at the upper end of the model. The Reno inflow time series data were shifted to reflect their arrival 60 minutes earlier at the upstream end of the model, relative to their recorded arrival time at the Reno gage location. A flow multiplier was applied to the Truckee River inflow hydrographs to account for attenuation within the model reach. The multiplier values used range from 1.018 to 1.028, these values were found through iteration of the model runs until flows reached a reasonable match to the recorded flow data at the Reno gage. For the 2005 event, the Truckee River model inflow is based upon a revised flow hydrograph developed by HDR during prior simulation of this event.

Tributary inflows for Dry Creek, Steamboat Creek, and the NTD were added at the locations where these channels enter the model domain. Flow data for Steamboat Creek are based on records from the Steamboat Creek at Short Lane stream gage (Gage #10349849). NTD flows were based upon records from the NTD at Spanish Springs Road site (Gage #10348245). No streamgage data are available for Dry Creek in the model domain. A synthetic hydrograph used in prior HEC-RAS simulation of the Truckee Meadows by HDR was added to the Dry Creek channel at the edge of the model domain. Following an initial model run, the peak discharge and timing of the Dry Creek hydrograph were adjusted to improve the match between the HEC-RAS stage and flow hydrographs to the recorded data at the Vista gage (Gage #10350000).

Prior to any calibration modifications, a shapefile representing the base Manning's n roughness values and corresponding land use descriptions used in the PMR model was saved to document the hydraulic parameters. Several iterations of the land use file were developed for each flood event during the calibration process. A final land use file was developed that includes an average Manning's n roughness for each land use category based on the final values established for each flood event analyzed.

In order to compare the model results to the USGS gage data, it was necessary to convert recorded stage to water surface elevations (WSE) based upon the USGS gage height data. Gage height represents water surface elevation above an arbitrary gage datum, which varies for each gage site. The process of determining the absolute elevation of the gage datum for each gage used in the calibration is described below.

- Truckee River at Reno (Gage #10348000):
  - The USGS website for this site previously listed the gage datum for this site as 4,444.53 ft in the National Geodetic Vertical Datum of 1929 (NGVD29) vertical datum.
  - The Google Earth Vertcon plug-in was used to find the vertical conversion factor to shift the NGVD29 gage datum elevation to NAVD88 datum. The factor for this site was found to be +3.527 ft.
  - The NAVD88 gage datum elevation based on the datum shown on the website was found to be 4,448.06 ft.
  - Several reference marks at this gage site were surveyed by Washoe County personnel in 2013 in support of prior hydraulic analysis for TRFMA.
  - Station descriptions for the Reno gage provided by the USGS include gage heights for the surveyed reference marks.
  - Based on the survey data and gage heights for the surveyed reference marks, several gage datum values can be calculated. These vary between 4,447.64 and 4,447.97 (ft, NAVD88).
  - Reference Mark 11 (RM-11) is listed as "active, origin point" in the station description. This point, with a gage height of 23.975 ft, was used along with the surveyed elevation for RM-11 to develop the gage datum elevation used for this effort (4,447.83 ft, NAVD88).
  - Using HEC-DSSVue, the NAVD88 gage datum elevation calculated based on the surveyed value for RM-11 was added to the stage heights provided by the USGS to produce water surface elevation records for this gage.
  - In recent communication with River Focus personnel, USGS has stated the gage datum is 4448.04 ft, NAVD88. The USGS website has been revised and now lists this as the gage datum elevation. No further investigation of this issue has been made.

- Truckee River at Vista (Gage #10350000):
    - The USGS website for this gage lists the gage datum as 4,371.16 ft, using the NAVD88 vertical datum.
    - A station description for the site provided by USGS with a revision date of 9/29/2014 lists a ground elevation for Reference Mark 15 (RM-15) of 4,393.075 ft in the NAVD88 vertical datum. The stated gage datum height for RM-15 is 22.032 ft.
    - Based on the stated RM-15 elevation, the gage datum elevation was found to be 4,371.04 ft (NAVD88).
    - Because this result is quite close to the gage datum stated upon the USGS website, the website gage datum of 4,371.16 ft (NAVD88) was selected for use in developing WSE values.
    - Using HEC-DSSVue, the NAVD88 gage datum elevation was added to the stage heights provided by the USGS to produce water surface elevation records for this gage.

The recorded discharge and WSE data were added to the HEC-RAS unsteady flow files as observed data, using the reference lines option. This allows the direct comparison of HEC-RAS model results with the recorded data in HEC-RAS hydrograph plots.

Final WSE results reported were extracted from HEC-RAS Mapper at points in the river channel near the USGS gage housings, rather than being based upon the model WSE results produced by the reference line plots. The reference line plots and tables appear to be averaging WSE across the channel. This can change the WSE results one or two tenths of a foot, depending upon the slope of the water surface across the channel at the gage site.

It should be noted that because the 2D model runs begin with no water present in the river channel, the results during the first few hours of each run do not match well to the observed USGS gage data. The Nash-Sutcliffe Efficiency (NSE) statistics and results plots provided below are based upon simulation results extracted at a time beginning three to ten hours after the beginning of the simulation, to allow water to arrive at the gage site and the flows and stages to stabilize. NSE is a statistical measure for assessing the goodness of fit of a model to an observed data set. NSE is calculated as one minus the ratio of the error variance of the simulated time-series to the variance of the observed time-series. An NSE value of 1.0 indicates a perfect match between the model results and the observed data, while an NSE value of less than zero indicates the observed mean value is a better predictor than the model. The NSE results are classified based upon performance rating ranges taken from Moriasi, *et.al*, 2007, which provides guidelines for classification of the quality of a calibration or validation result based upon the calculated NSE values for a given simulation run. This document specifically addresses the use of NSE and other statistics for assessing the results of watershed simulations, but it is assumed that the ranges presented can reasonably be applied to the results of these hydraulic models. The performance rating terms and the associated NSE value ranges are shown in Table 5.

Table 5. NSE Performance Ratings

Performance Rating	**NSE Value Range**
Very Good	0.75<NSE≤1.00
Good	0.65<NSE≤0.75
Satisfactory	0.50<NSE≤0.65
Unsatisfactory	NSE≤0.50

The first calibration event considered was the 2005 flood event. A copy of the original PMR model geometry was created, adding the event year to the geometry file name. Calibration began with running the model with the base geometry configuration and comparing the flow and WSE results with the observed USGS data at the gage sites. Following the initial run, Manning's n roughness values for the channel were adjusted in the area of the gages, as well as for a reach of the river up and downstream assumed to represent the reach where conditions are similar and where calibration adjustments should be applied.

During prior simulation of the 2005 Truckee River flood event for TRFMA, HDR determined that the USGS published peak flow rate for the Truckee River at Reno gage is likely an over-estimate of the peak flow that occurred during this event. The Reno gage was relocated to its current location in October 1998. Due to the short period of record for this site prior to the 2005 flood, the rating curve for the new Reno gage was not very reliable when the flow estimate for this event was developed. HDR developed a revised peak flow estimate based upon a surveyed 2005 high water mark at the old Reno gage and the revised rating curve for that gage. The published USGS peak flow for the 2005 event at the Reno gage is 16,400 cfs. The revised 2005 peak flow for the Reno gage site developed by HDR is 14,766 cfs. The WMOP study model uses an inflow hydrograph with this revised peak flow rate, rather than the published USGS data for the Truckee at Reno gage.

A discussion of the calibration process and results for each flood event analyzed is presented in bullet format below.

- **Manning's n roughness values**
    - All event simulations used the preliminary "Base" Manning's n roughness value layer developed for previous PMR project.
    - Channel and near bank values were altered for each event separately.
    - Overbank values were unchanged from Base values.
    - For the 2005 flood event, 3 iterations of Manning's n roughness values (A, B, and C) were investigated.
    - For the 2017 flood event, 3 iterations of Manning's n roughness values (A, B, and C) were investigated.

- For the 2019 flood event, 4 iterations of Manning's n roughness values (A, B, C, and D) were investigated.
- For the 2005 and 2017 events, Version C was the final calibration selection for these events, while Version D was used for the 2019 event.
- Manning's n roughness values were averaged using GIS capabilities to develop a single Manning's n roughness value layer.

- **2005 Flood Event**
  - Time period simulated: 12/30/2005 to 1/1/2006.
  - Peak discharge at Reno gage=14,766 cfs.
  - **Truckee at Reno gage site 2005 event results discussion:**
    - Simulation results were compared to the USGS recorded flow and stage data, rather than data based upon the revised 2005 event inflows used as the model input.
    - Initial simulation results showed water surface elevations over one foot lower than USGS recorded data for this site.
    - Raised Manning's n roughness values for channel by ~0.002-0.004.
    - Subsequent simulations with revised channel Manning's n roughness values improved the match to recorded values, but results are still approximately one foot below USGS WSE during the peak of the hydrograph.
    - One possible reason for this discrepancy is that the modeled conditions in this reach of the river may be different than the specific conditions during the flood event modeled.
    - Another possible issue could be a backwater effect taking place in the region of the Reno gage location that the HEC-RAS model does not capture.
    - Sensitivity testing indicates that Manning's n roughness values in the range of 0.055 to 0.065 within the channel region would be required to achieve a better match to gage records. These values are outside the range of typical Manning's n roughness values for the channel conditions at this site.
    - Water surface NSE results (0.699) rated as Good.
    - Discharge NSE result (0.935) rated as Very Good.
  - **Truckee at Vista gage site 2005 event results discussion:**
    - Initial results showed peak WSE lower than observed.
    - Raised Manning's n roughness values for channel by ~0.003-0.005.
    - Peak WSE matched to within 0.3 ft of observed record following n value adjustment.
    - Peak discharge matched to observed within 100 cfs.
    - Comparison of HEC-RAS rating curve at gage site with USGS direct measurements shows good agreement for flows above 3,000 cfs.
    - Simulation results show calculated WSE is slightly low for a given flow rate below 3,000 cfs.
    - Water surface NSE results (0.967) rated as Very Good.
    - Discharge NSE result (0.964) rated as Very Good.

- **2017 Flood Event**
  - Time period simulated: 1/7/2017 to 1/9/2017.
  - Peak discharge at Reno gage=12,800 cfs.
  - **Truckee at Reno gage site 2017 event results discussion**:
    - Initial simulated peak WSE was lower than observed.
    - Raised Manning's n roughness values for channel by ~0.002-0.004.
    - Subsequent simulations with revised channel Manning's n roughness values improved the match to recorded values, but results are still just under one foot below USGS WSE during the peak of the hydrograph.
    - One possible reason for this discrepancy is that the modeled conditions in this reach of the river may be different than the specific conditions during the flood event modeled.
    - Another possible issue could be a backwater effect taking place in the region of the Reno gage location that the HEC-RAS model does not capture.
    - Sensitivity testing indicates that Manning's n roughness values in the range of 0.055 to 0.065 within the channel region would be required to achieve a better match to gage records. These values are outside the range of typical Manning's n roughness values for the channel conditions at this site.
    - Water surface NSE results (0.757) rated as Very Good.
    - Discharge NSE result (0.995) rated as Very Good.
  - **Truckee at Vista gage site 2017 event results discussion**:
    - Initial results showed peak WSE lower than observed.
    - Raised Manning's n roughness values for channel by ~0.003-0.005.
    - Peak WSE matched to within 0.2 ft of observed record following n value adjustment.
    - Peak discharge matched to observed value within 60 cfs.
    - Comparison of HEC-RAS rating curve at gage site with USGS direct measurements shows good agreement throughout flow range.
    - Water surface NSE results (0.989) rated as Very Good.
    - Discharge NSE result (0.974) rated as Very Good.
- **2019 Flood Event**
  - Time period simulated: 4/8/2019 to 4/10/2019.
  - Peak discharge at Reno gage=5,160 cfs.
  - **Truckee at Reno gage site 2019 event results discussion**:
    - Initial simulated peak WSE was lower than observed.
    - Raised Manning's n roughness values for channel by 0.002-0.004.
    - Peak discharge matched to observed within 20 cfs.
    - Subsequent simulations with revised channel Manning's n roughness values improved the match to recorded values, but results are still approximately one foot below USGS WSE during the peak of the hydrograph.

    - One possible reason for this discrepancy is that the modeled conditions in this reach of the river may be different than the specific conditions during the flood event modeled.
    - Another possible issue could be a backwater effect taking place in the region of the Reno gage location that the HEC-RAS model does not capture.
    - Sensitivity testing indicates that Manning's n roughness values in the range of 0.055 to 0.065 within the channel region would be required to achieve a better match to gage records. These values are outside the range of typical Manning's n roughness values for the channel conditions at this site.
    - Water surface NSE results (-11.817) rated as Unsatisfactory.
    - Discharge NSE result (0.956) rated as Very Good.
  - **Truckee at Vista gage site 2019 event results discussion**:
    - Initial results showed peak WSE lower than observed.
    - Raised Manning's n roughness values for channel by ~0.002-0.006.
    - Peak WSE matched to within 0.1 ft of observed record following n value adjustment.
    - Peak discharge matched to observed within 100 cfs.
    - Comparison of HEC-RAS rating curve at gage site with USGS direct measurements shows good agreement for flows above 3,000 cfs.
    - Simulation results show calculated WSE is slightly low for a given flow rate below 3,000 cfs.
    - Water surface NSE results (0.891) rated as Very Good.
    - Discharge NSE result (0.962) rated as Very Good.

Statistical summaries of the Truckee Meadows model calibration results, including Nash-Sutcliffe efficiency values, are presented in Table 6, Table 7, and Table 8. A comparison of USGS observed data and modeled results for peak water surface elevations and discharge values is provided in Table 13. Calibration charts comparing the HEC-RAS Truckee Meadows model calibration run results to recorded flow and WSE values are presented in Appendix B. Tables presenting the initial Manning's n roughness values, calibrated Manning's n roughness values, and the final averaged Manning's n roughness values are attached in electronic format in Appendix C. Appendix C also includes a land use shapefile including these data in electronic format.

Table 6. Truckee Meadows 2005 Calibration Event Results

2005 Event Results at Truckee River at Reno Gage			
Average Observed WSE (ft, NAVD88)	**Average Observed Flow (cfs)**	**Water Surface Elevation NSE**	**Discharge NSE**
4,458.01	8,302	0.699	0.935
2005 Event Results at Truckee River at Vista Gage			
Average Observed WSE (ft, NAVD88)	**Average Observed Flow (cfs)**	**Water Surface Elevation NSE**	**Discharge NSE**
4,387.49	9,053	0.967	0.964

Table 7. Truckee Meadows 2017 Calibration Event Results

2017 Event Results at Truckee River at Reno Gage			
Average Observed WSE (ft, NAVD88)	**Average Observed Flow (cfs)**	**Water Surface Elevation NSE**	**Discharge NSE**
4,457.51	6,652	0.757	0.995
2017 Event Results at Truckee River at Vista Gage			
Average Observed WSE (ft, NAVD88)	**Average Observed Flow (cfs)**	**Water Surface Elevation NSE**	**Discharge NSE**
4,386.94	8,080	0.989	0.974

Table 8. Truckee Meadows 2019 Calibration Event Results

2019 Event Results at Truckee River at Reno Gage			
Average Observed WSE (ft, NAVD88)	**Average Observed Flow (cfs)**	**Water Surface Elevation NSE**	**Discharge NSE**
4,456.66	4,278	-11.817	0.956
2019 Event Results at Truckee River at Vista Gage			
Average Observed WSE (ft, NAVD88)	**Average Observed Flow (cfs)**	**Water Surface Elevation NSE**	**Discharge NSE**
4,383.06	4,557	0.891	0.962

Truckee River Lower Reach

The initial FEMA PMR Lower Reach model uses steady-state flow simulation for ease of use in simulating floodways and in future floodplain management activities. The initial task required for the Lower Reach model calibration effort was the conversion of the 1D steady-state model to using unsteady-state flow data, in order to simulate the rising and descending limbs of the flow hydrographs of the flood events to be simulated, as well as the peak flow rate. During this process, the largest modification made to the model geometry was to add additional detail to the hydraulic table parameters for all cross sections. This involved updating the tables to use a vertical increment of 0.2 ft and to include a sufficient number of points to capture the cross-sectional geometry to an elevation higher than computed water surface elevation for the event simulations. In addition, ineffective flow areas and levee points were added and modified to better reflect the full range of flow conditions that the model must consider for the unsteady event simulations, which is different than the steady peak flow conditions considered as part of the FEMA modeling and mapping for which the Lower Reach HEC-RAS model was originally developed. Another modification made to the model geometry was the creation of additional cross sections within the Derby Dam reach that represents the flowpath downstream of the emergency spillway of the dam. This change was made to improve model stability.

The initial scope detailed that three flood events would be used for model calibration. These were:

- March 1998 (Peak flow at Vista gage: 6,090 cfs)
- December 2005 (Peak flow at Vista gage: 13,700 cfs)
- January 2017 (Peak flow at Vista gage: 11,800 cfs)

As previously mentioned, the Truckee Meadows modeling effort substituted the flood event that occurred in April 2019 for the March 1998 event. To provide a consistent analysis for both Truckee River reaches being simulated, the same approach was used for the Lower Reach simulations, with the 2019 event being substituted for the 1998 event in the calibration process.

Unsteady flow data files were created to represent the calibration events represented in this effort. The USGS stream gage data DSS file developed earlier in this project was used to provide input flow hydrographs into the HEC-RAS model. Data recorded at the Vista stream gage were added to the most upstream cross section of the model.

Prior to any calibration modifications, the initial Manning's n roughness values used in the PMR model were recorded into a spreadsheet to document the hydraulic parameters prior to any changes.

In order to compare the model results to the USGS gage data, it was necessary to develop WSE records based upon the USGS gage height data. Gage height represents water surface elevation above an arbitrary gage datum, which varies for each gage site. The process of determining the absolute elevation of the gage datum for each gage used in the calibration is described below.

- Truckee River near Tracy (Gage #10350340):
    - The USGS website for this site lists the gage datum for this site as 4,300 ft. Other data sources contradict this value.
    - A station description provided by USGS for this site, which lists a date revised of 9/26/2006 for the Reference Marks section, lists a ground elevation for Reference Mark 1 (RM-1) using the NGVD29 datum (4,282.565 ft, NGVD29) as well as a gage datum height (31.237 ft) for this reference mark.
    - The elevation value for RM-1 was used to develop a gage datum elevation in feet above sea level (NGVD29) by subtracting the stated gage height from the stated elevation above sea level for RM-1. The gage datum elevation was found to be 4,251.328 (ft, NGVD29).
    - The Google Earth Vertcon plug-in was used to find the vertical conversion factor to shift the NGVD29 gage datum elevation to NAVD88 datum. The factor for this site was found to be +3.474 ft.
    - The NAVD88 gage datum elevation was found to be 4,254.80 ft.
    - Using HEC-DSSVue, the NAVD88 gage datum elevation was added to the stage heights provided by the USGS to produce water surface elevation records for this gage.
    - This site is located immediately upstream of the Waltham Way bridge across the Truckee in the area of Tracy. The HEC-RAS model cross section nearest this gage is Station 235118.
- Truckee below Derby Dam (Gage #10351600):
    - The USGS website for this gage lists the gage datum as 4,200 ft. Other data sources contradict this value.
    - A station description for the site provided by USGS with a revision date of 5/25/2016 lists a ground elevation for Reference Mark 4 (RM-4) with no vertical datum stated. The stated elevation for RM-4 is 4,201.671 ft. The stated gage datum height for RM-4 is 16.408 ft.
    - Assuming the stated RM-4 elevation is in NAVD88, the gage datum elevation was found to be 4,185.263 ft.
    - Examination of initial model WSE results confirms assumption that the RM-4 elevation is most likely in NAVD88 datum, as adding the NAVD88 conversion factor would result in observed WSE values far above the WSE results of the model.

- Using HEC-DSSVue, the NAVD88 gage datum elevation was added to the stage heights provided by the USGS to produce water surface elevation records for this gage.
- This site is located approximately 2,000 feet downstream of Derby Dam. The HEC-RAS model cross section nearest this gage is Station 189892.

- Truckee at Wadsworth (Gage #10351650):
  - The USGS website for this gage lists the gage datum as 4,039.00 ft.
  - The provided station descriptions do not include any absolute elevations of reference marks or reference points that could be used to determine the gage datum elevation in feet above sea level.
  - During the Truckee River PMR modeling effort, survey data for this gage were acquired by Atkins. This survey provided an elevation of Reference Mark 1 (RM-1) of 4,065.33 ft in the NAVD88 vertical datum. The station description provides a gage height for RM-1 of 20.739 ft.
  - By subtracting the stated RM-1 gage height from the surveyed elevation of RM-1, the NAVD88 gage datum elevation was found to be 4,044.59 ft.
  - Using HEC-DSSVue, the NAVD88 gage datum elevation was added to the stage heights provided by the USGS to produce water surface elevation records for this gage.
  - This site is located immediately upstream of the Nevada Highway 427 bridge across the Truckee in the area of Wadsworth. The HEC-RAS model cross section nearest this gage is Station 133809.

The recorded discharge and WSE data were added to the HEC-RAS unsteady flow files as observed data, allowing the direct comparison of HEC-RAS model results with the recorded data.

The first calibration event considered was the 2005 flood event. A copy of the original PMR model geometry was created, adding the event year to the geometry file name. Calibration began with running the model with the base geometry configuration and comparing the flow and WSE results with the observed USGS data at the gage sites. Following the initial run, Manning's n roughness values were adjusted for the gage cross section, as well as for a set of cross sections up and downstream assumed to represent the reach where conditions are similar and where calibration adjustments should be applied. The calibration reaches were determined based upon examination of aerial imagery and the channel invert profile. Riffles or other changes in channel roughness, along with changes in overbank roughness, as well as changes in channel slope, were considered when defining the calibration reaches. The channel segments adjusted based upon results at the stream gages are listed in Table 9 below.

Table 9. Lower Reach Stream Gages and Calibration Reaches

Stream Gage	**Truckee near Tracy**	**Truckee below Derby Dam**	**Truckee at Wadsworth**
Gage ID Number	10350340	10351600	10351650
HEC-RAS Station nearest gage	235118	189892	133809
Range of Cross Sections adjusted based upon results at gage	238617-221023	191005-180542	140512-126756

A discussion of the calibration process and results for each flood event analyzed is presented in bullet format below.

- **2005 Flood event**
  - Time period simulated: 12/30/2005 to 1/2/2006.
  - Peak discharge at Vista gage=13,700 cfs.
  - Initial simulation results showed significantly lower calculated flow at Truckee near Tracy gage than USGS recorded data for this site.
  - This indicates flow entered the Truckee River between Vista and near Tracy gages during the 2005 event.
  - The only substantial drainage in this reach is Long Valley Creek (LVC).
  - Examination of Long Valley Creek near Happy Valley peak streamflow USGS gage (#10350100) records indicated a peak flow of 2,600 cfs at that gage on 12/31/2005, during the 2005 calibration event.
  - A synthetic flow hydrograph was developed by shifting the Truckee near Tracy flow records backward in time by 2.5 hours to be roughly simultaneous with the Vista flow record.
    - The Vista flow hydrograph was subtracted from the near Tracy flow hydrograph to produce a synthetic flow hydrograph representing inflow to the Truckee River from Long Valley Creek. This synthetic hydrograph has a peak flow rate of 3,300 cfs.
    - The LVC gage is over 2.5 miles upstream of the LVC confluence with the Truckee River, it is assumed that the additional contributing area downstream of the LVC gage accounts for the additional flow above that recorded at the gage.
    - This flow hydrograph was added to the HEC-RAS model as a lateral inflow at the cross section immediately downstream of the confluence between Long Valley Creek and the Truckee.
  - HEC-RAS flow results at the Truckee near Tracy gage location matched closely to recorded flow data following the addition of the LVC flow hydrograph (Peak simulation results approximately 315 cfs lower than observed, Observed peak Q=15,200 cfs).
  - **Truckee near Tracy gage site 2005 event results discussion:**
    - Initial results showed peak WSE ~0.7 ft higher than observed.
    - Lowered Manning's n roughness values for channel and overbanks by 0.004 for XS 238617-221023.
    - Final channel n generally 0.035.
    - Peak WSE matched to within 0.1 ft of observed record following n value adjustment.
    - Comparison of HEC-RAS rating curve for cross section at gage site with USGS direct measurements shows good agreement throughout flow range.
    - Water surface NSE results (0.991) rated as Very Good.
    - Discharge NSE result (0.995) rated as Very Good.
  - **Truckee below Derby Dam gage site 2005 event results discussion:**
    - Flow hydrograph shows peak Q simulation results ~400 cfs lower than observed
    - Initial results showed peak WSE ~1.3 ft lower than observed.

        - Raised Manning's n roughness values for channel and overbanks by a total of 0.007 for XS 191005-180542 in two iterations.
        - Final channel n generally 0.046.
        - Peak WSE was ~0.5 ft lower than observed data following n value adjustment.
        - Comparison of HEC-RAS rating curve for cross section at gage site with USGS direct measurements shows good agreement for flows below 8,000 cfs and with high flows (>18,000 cfs) if results are extrapolated.
        - USGS rating curve shows an irregular form based on a single direct measurement of 11,600 cfs, that data point appears to have distorted the rating.
        - Water surface NSE results (0.981) rated as Very Good.
        - Discharge NSE result (0.986) rated as Very Good.
    - **Truckee at Wadsworth gage site 2005 event results discussion:**
        - Flow hydrograph shows peak Q simulation results ~330 cfs lower than observed.
        - Initial results showed peak WSE ~1.3 ft higher than observed.
        - Lowered Manning's n roughness values for channel and overbanks by a total of 0.008 for XS 140512-126756 in two iterations.
        - Final channel n generally 0.031.
        - Peak WSE was ~0.6 ft lower than observed data following n value adjustment.
        - Examination of HEC-RAS profile shows large impact of the Highway 427 bridge and RR bridge immediately downstream of the gage site.
            - HEC-RAS bridge option can unrealistically increase WSE upstream of the structure.
            - Tested deleting one or both of these bridges and re-running the model.
            - The highway bridge includes a pier, while the RR bridge is a clear span and the low chord is above the 100-yr water surface elevation, and thus less likely to impact WSE during lower flows.
            - Deleting the RR bridge resulted in a good match to the peak WSE of the observed data, within 0.1 ft.
        - Comparison of a HEC-RAS rating curve for the model cross section at this gage site with the USGS direct measurements shows model estimates of stage are slightly above observed data in lower flow range (2,000-8,000 cfs), but match well for flows above 12,000 cfs.
        - The RR bridge was deleted from all other calibration geometries.
        - Water surface NSE results (0.911) rated as Very Good.
        - Discharge NSE result (0.952) rated as Very Good.
- **2017 Flood Event**
    - Time period simulated: 1/8/2017 to 1/11/2017.
    - Peak discharge at Vista gage=11,800 cfs.
    - Similar flow discrepancy to that seen for 2005 event, between Vista and Truckee near Tracy gages, indicates inflow from Long Valley Creek and other contributing watershed area between these gages.
        - LVC gage records show peak Q of 3,030 cfs on 1/9/2017.

    - Synthetic inflow hydrograph for LVC with a peak flow of 4,310 cfs developed using same approach as used for 2005 event.
    - The LVC gage is over 2.5 miles upstream of the LVC confluence with the Truckee River, it is assumed that the additional contributing area downstream of the LVC gage as well as other contributing area along the Truckee River in the reach between the Vista gage and the Truckee near Tracy gage accounts for the additional flow above that recorded at the gage.
  - Peak flow also increased downstream of Tracy during this flood event. Truckee below Derby Dam recorded flow hydrograph shows rapid fluctuations in discharge that may be unreliable. Due to this issue, calibration efforts at this focused only on stage, and no extended effort was made to match model flow results to recorded flow records.
    - The Truckee at Wadsworth gage does not show the same rapid fluctuations in flow.
    - A synthetic flow hydrograph with a peak flow of 1,400 cfs was developed based on comparison between recorded flow hydrographs for the Truckee near Tracy and Truckee at Wadsworth gages. This hydrograph was added to the model immediately downstream of the USA Parkway, where a relatively large drainage flows to the north to join the Truckee River. This is referred to as the USA Parkway tributary for the remainder of this document.
  - **Truckee near Tracy gage site 2017 event results discussion**:
    - Initial results showed simulated peak Q was ~130 cfs lower than observed.
    - Initial simulated peak WSE was 0.6 ft higher than observed.
    - Lowered Manning's n roughness values for channel and overbanks by 0.005 for XS 238617-221023.
    - Final channel n generally 0.034.
    - Peak WSE matched to within 0.1 ft following n value adjustment.
    - Comparison of a HEC-RAS rating curve for the model cross section at this gage site with the USGS direct measurements shows good agreement throughout flow range.
    - Water surface NSE results (0.991) rated as Very Good.
    - Discharge NSE result (0.991) rated as Very Good.
    -
  - **Truckee below Derby Dam gage site 2017 event results discussion**:
    - Before adding USA Parkway tributary hydrograph and using base geometry, model peak WSE was 2.2 ft lower than observed.
    - Raised Manning's n roughness values for channel and overbanks by a total of 0.008 for XS 191005-180542 in two iterations.
    - Final channel n generally 0.047.
    - Following n value adjustment and addition of USA Parkway tributary inflow, peak simulation Q was ~1,600 cfs lower than observed.

            - Because the USGS flow records for this gage vary so rapidly during this event, the record was assumed to unreliable and no further attempt was made to match the recorded peak flow at this location.
        - Model peak WSE is 1.2 ft lower than observed.
        - Comparison of HEC-RAS rating curve for cross section at gage site with USGS direct measurements shows good agreement for flows below 8,000 cfs and with high flows (>18,000 cfs) if results are extrapolated.
        - USGS rating curve shows an irregular form based on a single direct measurement of 11,600 cfs, that data point appears to have distorted the rating.
        - Water surface NSE results (0.883) rated as Very Good.
        - Discharge NSE result (0.973) rated as Very Good.
    - **Truckee at Wadsworth gage site 2017 event results discussion:**
        - Geometry used does not include Wadsworth RR bridge as discussed above.
        - Flow hydrograph shows peak Q simulation results ~100 cfs lower than observed, following addition of Long Valley Creek & USA Parkway tributary inflow.
        - Initial results showed peak WSE ~1.3 ft higher than observed, before addition of USA Parkway tributary inflow.
        - Lowered Manning's n roughness values for channel and overbanks by a total of 0.008 for XS 140512-126756 in two iterations.
        - Final channel n generally 0.031.
        - Peak WSE matched observed data to within 0.2 ft following n value adjustment and addition of USA Parkway tributary flow.
        - Comparison of a HEC-RAS rating curve for the model cross section at this gage site with the USGS direct measurements shows model estimates of stage are slightly above observed data in lower flow range (2,000-8,000 cfs), but match well for flows above 12,000 cfs.
        - Water surface NSE results (0.870) rated as Very Good.
        - Discharge NSE result (0.959) rated as Very Good.
- **2019 Flood Event**
    - Time period simulated: 4/8/2019 to 4/10/2019.
    - Peak discharge at Vista gage=5,100 cfs.
    - Flow records indicate smaller increase in discharge between Vista and Truckee near Tracy gages, but it appears that inflow did occur within this reach.
        - LVC gage records for 2019 show the annual peak flow for that water year occurred on 2/14/2019, no other LVC flow record is available.
        - Synthetic inflow hydrograph for LVC with a peak flow of 240 cfs developed using same approach as used for 2005 and 2017 events.
    - **Truckee near Tracy gage site 2019 event results discussion:**
        - Simulation peak discharge ~30 cfs lower than observed peak flow.
        - Initial results showed peak WSE ~0.7 ft higher than observed.
        - Lowered Manning's n roughness values for channel and overbanks by 0.008 for XS 238617-221023.
        - Final channel n generally 0.032.

        - Peak WSE matched to within 0.1 ft of observed record following n value adjustment.
        - Water surface NSE results (0.991) rated as Very Good.
        - Discharge NSE result (0.994) rated as Very Good.
    - **Truckee below Derby Dam gage site 2019 event results discussion:**
        - Flow hydrograph shows peak Q simulation results ~90 cfs higher than observed data.
            - Flow diversions into irrigation ditches may have been occurring during this event.
        - Initial results showed peak WSE ~1.0 ft lower than observed data.
        - Raised Manning's n roughness values for channel and overbanks by a total of 0.008 for XS 191005-180542 in two iterations.
        - Final channel n generally 0.047.
        - Peak WSE was ~0.3 ft lower than observed data following n value adjustment.
        - Comparison of a HEC-RAS rating curve for the model cross section at this gage site with the USGS direct measurements shows good agreement with USGS data.
        - Water surface NSE results (0.812) rated as Very Good.
        - Discharge NSE result (0.944) rated as Very Good.
    - **Truckee at Wadsworth gage site 2019 event results discussion:**
        - Geometry used does not include Wadsworth RR bridge as discussed above.
        - Flow hydrograph shows peak Q simulation results ~100 cfs higher than observed.
            - Flow diversions into irrigation ditches may have been occurring during this event.
        - Initial results before removing Wadsworth RR bridge showed peak WSE ~2.1 ft higher than observed.
        - Lowered Manning's n roughness values for channel and overbanks by a total of 0.013 for XS 140512-126756 in two iterations.
        - Final channel n generally 0.026.
        - Peak WSE matched observed data to within 0.1 ft following n value adjustment and removal of RR bridge.
        - Comparison of a HEC-RAS rating curve for the model cross section at this gage site with the USGS direct measurements shows simulation estimates of stage match well to observed data.
        - Water surface NSE results (0.937) rated as Very Good.
        - Discharge NSE result (0.878) rated as Very Good.

Statistical summaries of the Lower Reach model calibration results, including Nash-Sutcliffe efficiency values, are presented in Table 10, Table 11, and Table 12. A comparison of USGS observed data and modeled results for peak water surface elevations and discharge values is provided in Table 13. Tables presenting the initial Manning's n roughness values, calibrated Manning's n roughness values, and the final averaged Manning's n roughness values are attached in electronic format in Appendix C. Calibration charts comparing the HEC-RAS Lower Reach model calibration run results to recorded flow and WSE values are presented in Appendix D.

Table 10. Lower Reach 2005 Calibration Event Results

2005 Event W/Long Valley Creek Flow Results at Truckee River near Tracy Gage (XS 235118) Summary Stats			
Average Observed WSE (ft, NAVD88)	**Average Observed Flow (cfs)**	**Water Surface Elevation NSE**	**Discharge NSE**
4,268.60	7,989	0.991	0.995
2005 Event Results W/Long Valley Creek Flow at Truckee River below Derby Dam Gage (XS 189892) Summary Stats			
Average Observed WSE (ft, NAVD88)	**Average Observed Flow (cfs)**	**Water Surface Elevation NSE**	**Discharge NSE**
4,195.31	8,133	0.981	0.986
2005 Event Results W/Long Valley Creek Flow at Truckee River at Wadsworth Gage (XS 133809) W/W Wads RR Bridge Removed Summary Stats			
Average Observed WSE (ft, NAVD88)	**Average Observed Flow (cfs)**	**Water Surface Elevation NSE**	**Discharge NSE**
4,056.99	8,466	0.911	0.952

Table 11. Lower Reach 2017 Calibration Event Results

2017 Event W/Long Valley Creek & USA Pkwy tributary Flow Results at Truckee River near Tracy Gage (XS 235118) Summary Stats			
Average Observed WSE (ft, NAVD88)	**Average Observed Flow (cfs)**	**Water Surface Elevation NSE**	**Discharge NSE**
4,268.70	8,087	0.991	0.991
2017 Event Results W/Long Valley Creek & USA Pkwy tributary Flow at Truckee River below Derby Dam Gage (XS 189892) Summary Stats			
Average Observed WSE (ft, NAVD88)	**Average Observed Flow (cfs)**	**Water Surface Elevation NSE**	**Discharge NSE**
4,195.96	8,088	0.883	0.973
2017 Event Results W/Long Valley Creek & USA Pkwy tributary Flow at Truckee River at Wadsworth Gage (XS 133809) W/Wads RR Bridge Removed Summary Stats			
Average Observed WSE (ft, NAVD88)	**Average Observed Flow (cfs)**	**Water Surface Elevation NSE**	**Discharge NSE**
4,057.34	7,799	0.870	0.959

Table 12. Lower Reach 2019 Calibration Event Results

2019 Event W/Long Valley Creek Flow Results at Truckee River near Tracy Gage (XS 235118) Summary Stats			
Average Observed WSE (ft, NAVD88)	**Average Observed Flow (cfs)**	**Water Surface Elevation NSE**	**Discharge NSE**
4,266.31	4,507	0.991	0.994
2019 Event Results W/Long Valley Creek Flow at Truckee River below Derby Dam Gage (XS 189892) Summary Stats			
Average Observed WSE (ft, NAVD88)	**Average Observed Flow (cfs)**	**Water Surface Elevation NSE**	**Discharge NSE**
4,193.59	4,386	0.812	0.944
2019 Event Results W/Long Valley Creek Flow at Truckee River at Wadsworth Gage (XS 133809) W/W Wads RR Bridge Removed Summary Stats			
Average Observed WSE (ft, NAVD88)	**Average Observed Flow (cfs)**	**Water Surface Elevation NSE**	**Discharge NSE**
4,054.90	4,310	0.937	0.878

Table 13. Model Calibration Peak Results Summary

Gage Name	Truckee River at Reno	Truckee River at Vista	Truckee River near Tracy	Truckee River below Derby Dam	Truckee River at Wadsworth
Gage ID	**10348000**	**10350000**	**10350340**	**10351600**	**10351650**
2005 USGS Peak Observed WSE (ft)	4,461.21	4,391.44	4,272.19	4,198.70	4,061.48
2005 Peak Model Results WSE (ft)	4,460.32	4,391.75	4,272.21	4,198.23	4,061.43
2005 USGS Peak Observed Flow (cfs)	16,400	13,700	15,200	14,900	14,800
2005 Peak Model Results Flow (cfs)	14,706	13,686	14,918	14,542	14,471
2017 USGS Peak Observed WSE (ft)	4,460.28	4,390.60	4,271.70	4,199.53	4,061.58

Gage Name	Truckee River at Reno	Truckee River at Vista	Truckee River near Tracy	Truckee River below Derby Dam	Truckee River at Wadsworth
2017 Peak Model Results WSE (ft)	4,459.57	4,390.40	4,271.62	4,198.27	4,061.38
2017 USGS Peak Observed Flow (cfs)	12,800	11,800	13,900	16,058	14,500
2017 Peak Model Results Flow (cfs)	12,748	11,851	13,773	14,366	14,344
2019 USGS Peak Observed WSE (ft)	4,457.17	4,383.78	4,266.87	4,194.28	4,055.62
2019 Peak Model Results WSE (ft)	4,456.09	4,384.00	4,266.88	4,193.96	4,055.56
2019 USGS Peak Observed Flow (cfs)	5,160	5,100	5,270	5,140	5,130
2019 Peak Model Results Flow (cfs)	5,172	5,199	5,244	5,238	5,236

Hydraulic Model Validation

Truckee River Truckee Meadows Reach

In the process of the hydraulic model calibration effort, three sets of Manning's n roughness values were produced, one each for the three calibration events. These values were averaged to create the revised Manning's n roughness layer to be used in the hydraulic model validation effort. The averaged Manning's n roughness layer was associated with the HEC-RAS validation model geometry. In general, only a few modifications were made from the calibration geometries when developing the validation geometry. Revisions were made to bridge modeling maximum discharges to simulate the high flows that occurred during the 1997 flood event. The validation model was executed using the latest version of the HEC-RAS software, HEC-RAS V6.2, which was released in March 2022, following the completion of the calibration modeling task.

Model inputs include unsteady flow hydrographs for the 1997 and 2018 events. For the 2018 event, USGS stream gage data collected earlier in this project were used to provide these input flow hydrographs into the HEC-RAS model. Data recorded at the Reno stream gage (Gage #10348000) were used at the upper end of the model. The inflow hydrograph was shifted to reflect its arrival 60 minutes earlier to account for travel time from the upstream end of the model to the Reno gage site. A flow multiplier of 1.02 was applied to the Truckee River inflow hydrograph to account for attenuation within the model reach. This multiplier is based on findings during the model calibration effort through iteration of the simulations until flows reached a reasonable match to the recorded flow data at the Reno gage. Flow data used for the 1997 event are discussed below.

Previous hydraulic analysis of the 1997 flood within the Truckee Meadows reach indicates that the USGS flow estimates at the Reno and Vista gages for the 1997 event are erroneous. A calibrated HEC-RAS model of the 1997 flood within the Truckee Meadows reach was developed circa 2000 by the consulting firm WRC Nevada, Inc., in collaboration with the USACE Hydrologic Engineering Center (HEC). This model was used to revise the flow hydrographs for the Reno and Vista gages. These revised hydrology data have been adopted by USACE as part of the Truckee Meadows General Reevaluation Report (GRR) (USACE, 2012). It should be noted that the USGS flow estimates have not been revised following this analysis. The USGS 1997 peak flow estimates, as well as the revised peak flows adopted by USACE, are listed in Table 14 below.

Table 14. 1997 Flood Event Peak Flow Estimates

Site	USGS 15-minute Data Peak Flow (cfs)	USACE 15-minute Data Peak Flow (cfs)
Truckee at Reno Gage	18,100	23,216
Truckee at Vista Gage	18,500	21,184

A 1997 Truckee Meadows HEC-RAS model provided to HDR by USACE included these revised flow hydrographs for the Reno and Vista stream gages within a DSS file included with the model. The Reno gage flow hydrograph was used as the flow input for the Truckee River at the upstream end of the study reach, near White Fir St. To account for the travel time between the input location and the Reno gage, the Reno inflow time series data were shifted to reflect their arrival 60 minutes earlier at the upstream end of the model, relative to their recorded arrival time at the Reno gage location. A similar approach was applied during the calibration analysis. Similar to the approach used for the 2018 validation plan, a flow multiplier was applied to the 1997 Truckee River inflow hydrograph to compensate for flow attenuation within the reach. The USACE flow hydrographs were used as observed data associated with reference lines placed at the stream gage locations. Simulation stage results were compared to WSE values based upon stage data provided by the USGS.

Tributary inflow hydrographs for the tributary streams were also taken from the USACE 1997 HEC-RAS model DSS input file mentioned above.

Several large-scale physical changes have taken place within the Truckee Meadows in the time following the 1997 flood event. The Wingfield Park whitewater park was constructed, resulting in significant changes to both the north and south channels at Wingfield Island. The original Virginia St. bridge, which was a three-span masonry arch bridge posing a large blockage to flow, has been replaced with a clear-span pony truss bridge. A levee associated with the Wal-Mart store within the Reno-Sparks Indian Colony was constructed along the south bank of the Truckee immediately downstream of the I-80/I-580 interchange. The Glendale Dam slightly farther downstream of the I-80/I-580 interchange has been reconfigured at least twice since 1997. The Pioneer Ditch Diversion Dam, just upstream of the Greg St. bridge, has been reconfigured. The construction of the Southeast Connector, completing the Veteran's Parkway arterial roadway, includes an elevated roadway along much of Steamboat Creek within the model domain. Finally, the confluence of the NTD has been relocated to downstream of the Vista Narrows.

The Truckee Meadows HEC-RAS model geometry used for the validation modeling described here includes all of these modern features. No effort has been made to modify the geometry to reflect the conditions that existed when the 1997 flood event occurred. An assessment of the overall impact of these features upon the 1997 validation model results would be difficult, as some features, such as the Virginia St. bridge, would act to keep flows within the channel and pass them downstream, while others could alter overbank flooding patterns, as well as tributary inflow magnitude and timing. Because revising the HEC-RAS model geometry to represent the physical condition at the time of the 1997 flood was beyond the scope of the project, the model results for this event cannot be expected to precisely match the recorded values at the gage sites.

Tributary inflows for Dry Creek, Steamboat Creek, and the NTD were added at the locations where these channels enter the model domain. For the 2018 flood event, flow data for Steamboat Creek are based on records from the Steamboat Creek at Short Lane stream gage (Gage #10349849). NTD flows were based upon records from the NTD at Spanish Springs Road site (Gage #10348245). No streamgage data are available for Dry Creek in the area of the model domain. A synthetic hydrograph used in prior HEC-RAS simulation of the Truckee Meadows by HDR was added to the Dry Creek channel at the edge of the model domain.

As previously discussed, a land use file was developed that includes Manning's n roughness values for each land use category based on the average of the final values established for each of the three calibration flood events. This land use file was used to analyze both the 1997 and 2018 flood events during the validation effort.

WSE records based upon the USGS gage height data were developed for the validation events at each site in the same manner described for the calibration effort.

The recorded discharge and WSE data were added to the HEC-RAS unsteady flow files as observed data, using the reference lines option. This allows for the direct comparison of HEC-RAS simulation results with the recorded data in HEC-RAS hydrograph plots.

Final WSE results reported were extracted from HEC-RAS Mapper at points in the river channel near the USGS gage housings, rather than being based upon the simulation WSE results produced by the reference line plots. The reference line plots and tables appear to be averaging WSE across the channel. This can change the WSE results one or two tenths of a foot, depending upon the variation of the water surface across the channel at the gage site. Simulation results for the 1997 event were compared to records for the old Reno gage, as this instrument was active at the time of this event.

It should be noted that because the 2D simulations begin with no water present in the river channel, the results during the first few hours of each run do not match well to the reference data used. The NSE statistics and results plots provided below are based upon simulation results several hours after the beginning of the simulation, to allow water to arrive at the gage site and the flows and stages to stabilize.

A discussion of the validation process and results for each flood event analyzed is presented in bullet format below.

- **1997 Flood Event**
  - Time period simulated: 12/31/1996 to 1/5/1997.
  - Peak discharge at Reno gage=23,216 cfs.
  - **Truckee at Reno old gage site 1997 event results discussion:**
    - Simulation inputs were based on flow hydrographs developed from the circa 2000 calibrated 1D HEC-RAS model, rather than USGS flow data. Flow results were compared to the flow hydrographs from the 1D model, while stage results were compared to USGS stage records.
    - The Reno streamgage was in a different location than the current gage during the 1997 flood event. The old gage was located at the I-580 bridge over the Truckee River. Simulation results were extracted at this location for the 1997 event, while results for all other calibration and validation events were extracted at the new gage location, near the Waste Management transfer station.
    - Simulation results showed water surface elevations in the range of 1.1 to 1.8 feet higher than USGS recorded data for this site for a large period during the validation run.
      - The modifications to the river system since 1997 may have impacted the validation results. In particular, the construction of the levee at the Wal-Mart store, and modifications to the Glendale Dam, have potential to raise water surface elevations at the Old Reno gage site, relative to conditions in 1997. In addition, the new Virginia St. bridge is able to pass more flow downstream to the gage site relative to the old bridge that was in place during the actual flood event. This change would have the potential to increase water surface elevations at the gage location.
    - Simulation discharges match well to the values developed from the WRC 1D modeling effort. Peak simulation discharge matches to observed peak within 70 cfs.
    - Water surface NSE results (0.868) rated as Very Good.
    - Discharge NSE result (0.998) rated as Very Good.
  - **Truckee at Vista gage site 1997 event results discussion:**
    - Simulation flow results are compared to the flow hydrograph developed from the calibrated 1997 1D model, rather than to USGS flow records. Simulation WSE results are compared to USGS stage records.
    - Simulation discharge results match fairly well to the flow results from the calibrated 1D simulation effort during the rising and descending limbs of the flood event, but during the peak of the event, the simulation results show a large dip in flow at the Vista gage.
      - Examination of simulation results in the floodplain around the Vista gage indicate that a flow split is occurring upstream of the Vista gage, with a significant amount of flow bypassing the gage and moving through the

Sparks Industrial area in the north overbank. This flow then spills over the levee along the east side of the industrial area and rejoins the main channel.

      - A flow hydrograph extracted from the model downstream of the levee does not show the dip in flow seen at the Vista gage, indicating that the overall flow hydrograph is being translated downstream in a reasonable manner.
      - A chart comparing the simulation discharge results just downstream of the levee to the 1D model reference discharge values for the Vista gage is included with the validation charts at the end of this memo. This chart shows a higher maximum discharge in the simulation results relative to the reference data. This indicates that the fully-2D model is resulting in less flow attenuation through the Truckee Meadows reach than was expected during the development of the calibrated 1D HEC-RAS model.
    - Simulation stage results show WSE generally higher than observed during the peak of the flood event, up to maximum of ~1.9 feet above observed records.
    - Physical changes in the Truckee Meadows channel and floodplain may have altered the flow behavior within this reach, resulting in the higher stages and discharges predicted by the fully-2D 1997 validation model versus recorded values.
      - The elevated embankment of the Veteran's Parkway bisects the Steamboat Creek floodplain, potentially altering flood behavior within the Steamboat Creek flood pool and at the Vista gage site.
      - The re-location of the NTD confluence with the Truckee River to a point downstream of the Vista gage also has the potential to alter flood behavior at the Vista gage site.
    - Water surface NSE results (0.916) rated as Very Good.
    - Discharge NSE result (0.921) rated as Very Good.

- **2018 Flood Event**
  - Time period simulated: 4/6/2018 to 4/8/2018.
  - Peak discharge at Reno gage=6,690 cfs.
  - **Truckee at Reno gage site 2018 event results discussion**:
    - Simulated WSE results are lower than observed, as was seen in the calibration simulations. Simulated peak WSE is ~1.2 ft lower than observed peak WSE.
      - This offset persists throughout the validation run.
      - This consistent offset heavily impacts NSE statistics for WSE at this site.
    - One possible reason for this discrepancy is that the modeled conditions in this reach of the river may be different than the specific conditions during the flood event modeled.
    - Another possible issue could be a backwater effect taking place in the region of the Reno gage location that the HEC-RAS model does not capture.
    - Sensitivity testing indicates that Manning's n roughness values in the range of 0.055 to 0.06 within the channel region would be required to achieve a better match to gage records. These values are outside the range of typical Manning's n roughness values for the channel conditions at this site.

    - Simulation discharge results match well to observed throughout the validation run.
        - Peak simulated discharge is ~40 cfs lower than peak observed discharge.
    - Water surface NSE results (-6.147) rated as Unsatisfactory.
    - Discharge NSE result (0.979) rated as Very Good.
- **Truckee at Vista gage site 2018 event results discussion**:
    - USGS records for this time period are in 5 minute intervals, while the model output is set to use a 15 minute time interval, as this is the reporting interval used for all other sites and time periods.
        - The 2018 USGS flow and stage records for the Vista site were processed to a 15 minute time interval using an HEC-DSSVue math function to allow for direct comparison to simulation results.
    - Simulated WSE results generally match well to observed records throughout the validation run.
    - Simulated peak WSE matches observed peak WSE to within 0.1 ft.
    - Model discharge is slightly lower than observed during rising limb of the 2018 validation event but matches well to observed records during the peak of the event.
    - Peak model discharge matches observed flow to within 20 cfs.
    - Water surface NSE results (0.979) rated as Very Good.
    - Discharge NSE result (0.882) rated as Very Good.

Statistical summaries of the Truckee Meadows simulation validation results, including Nash-Sutcliffe efficiency values, are presented in Table 15 and

Table 16. Calibration charts comparing the HEC-RAS Truckee Meadows simulation validation run results to recorded flow and WSE values are presented in Appendix E.

Table 15. Truckee Meadows 1997 Validation Event Results

1997 Event Results at Truckee River at Old Reno Gage			
Average Observed WSE (ft, NAVD88)	**Average Observed Flow (cfs)**	**Water Surface Elevation NSE**	**Discharge NSE**
4,446.45	10,968	0.868	0.998
1997 Event Results at Truckee River at Vista Gage			
Average Observed WSE (ft, NAVD88)	**Average Observed Flow (cfs)**	**Water Surface Elevation NSE**	**Discharge NSE**
4,390.24	12,648	0.916	0.921

Table 16. Truckee Meadows 2018 Validation Event Results

2018 Event Results at Truckee River at Reno Gage			
Average Observed WSE (ft, NAVD88)	**Average Observed Flow (cfs)**	**Water Surface Elevation NSE**	**Discharge NSE**
4,456.81	4,425	-6.147	0.979
2018 Event Results at Truckee River at Vista Gage			
Average Observed WSE (ft, NAVD88)	**Average Observed Flow (cfs)**	**Water Surface Elevation NSE**	**Discharge NSE**
4,383.31	4,983	0.979	0.882

Truckee River Lower Reach

The validation effort for the Lower Reach hydraulic model used the same approach employed for the Truckee Meadows reach, in which the three sets of Manning's n roughness values developed during the model calibration task were averaged to produce the Manning's n roughness values assigned to the HEC-RAS validation model geometry. The Lower Reach validation geometry matched to the calibration task model geometries in every other way, with the exception of adjustments to bridge modeling discussed below.

The initial project scope detailed that the Lower Reach model would be validated to the March 1995 and January 1997 flood events, as was proposed for the Truckee Meadows reach validation task. Following initiation of the project, the Truckee Meadows simulation effort substituted the flood event that occurred in April 2018 for the March 1995 event. To provide a consistent analysis for both Truckee River reaches being simulated, the same approach was used for the Lower Reach simulation, with the 2018 event being substituted for the 1995 event in the validation process.

WSE records based upon the USGS gage height data were developed for the validation events at each site in the same manner described for the calibration effort. It should be noted that the Truckee River below Tracy gage was damaged during the 1997 flood event, resulting in only a partial data set being available for that event at Tracy. Following the 1997 flood, a new stream gage was installed upstream of the old gage site. The new gage is titled Truckee River near Tracy, this is the gage used for all other calibration and validation analyses of events occurring after 1997. The process of determining the absolute elevation of the gage datum for the Truckee near Tracy gage site is described below.

- Truckee River near Tracy (Gage #10350340):
    - The USGS website for this site lists the gage datum for this site as 4,300 ft. Other data sources contradict this value.
    - A station description provided by USGS for this site, which lists a date revised of 9/26/2006 for the Reference Marks section, lists a ground elevation for Reference Mark 1 (RM-1) using the NGVD29 datum (4,282.565 ft, NGVD29) as well as a gage datum height (31.237 ft) for this reference mark.
    - The elevation value for RM-1 was used to develop a gage datum elevation in feet above sea level (NGVD29) by subtracting the stated gage height from the stated elevation above sea level for RM-1. The gage datum elevation was found to be 4,251.328 (ft, NGVD29).
    - The Google Earth Vertcon plug-in was used to find the vertical conversion factor to shift the NGVD29 gage datum elevation to NAVD88 datum. The factor for this site was found to be +3.474 ft.
    - The NAVD88 gage datum elevation was found to be 4,254.80 ft.
    - Using HEC-DSSVue, the NAVD88 gage datum elevation was added to the stage heights provided by the USGS to produce water surface elevation records for this gage.
    - This site is located immediately upstream of the Waltham Way bridge across the Truckee in the area of Tracy. The HEC-RAS model cross section nearest this gage is Station 235118.
    - This gage was installed following the 1997 flood event, which damaged the Truckee River below Tracy gage.

The recorded discharge and WSE data were added to the HEC-RAS unsteady flow files as observed data, allowing the direct comparison of HEC-RAS simulation results with the recorded data.

The first validation event considered was the 1997 flood event. As discussed above, previous hydraulic analysis of the 1997 flood within the Truckee Meadows reach indicates that the USGS flow estimates at the Reno and Vista gages for the 1997 event are erroneous.

The Vista gage flow hydrograph included in the 1997 Truckee Meadows HEC-RAS model provided to HDR by USACE was used as the flow input for the Truckee River at the upstream end of the Lower Truckee study reach.

While the 1997 event flow input to the Lower Reach is based upon flow estimates that differ from the published USGS estimates, no similar estimates exist for the Lower Reach USGS gages. This validation effort compares the simulation results to the available 1997 event USGS flow and stage records for those gages.

No modification was made to the USGS data record for the 2018 validation event. The inflow hydrograph is based upon USGS records for the Vista gage.

Initial 1997 validation simulation results for the Truckee at Wadsworth gage showed a calculated peak stage around 0.9 feet below the recorded peak stage at this site. This large deviation may be due to the deletion of the Wadsworth RR bridge during the calibration effort. This bridge was removed from the model geometries due its large impact upon WSE profiles during smaller flood events, when the bridge should not have caused a significant rise in WSE. The model geometry used for the 1997 flood validation was modified by adding the RR bridge back in, to test its effect during the high flows that occurred in 1997. The simulation results with the RR bridge in place match to the USGS observed peak stage within about 0.1 feet. The 1997 flood event validation results for the Truckee at Wadsworth gage reflect the inclusion of the Wadsworth RR bridge, but the 2018 validation results are based on a model geometry that does not include this bridge. For the channel capacity analysis that will follow the model validation, it is recommended that the RR bridge not be included in the HEC-RAS model geometry, as that analysis will only consider flows between 6,000 and 14,000 cfs. In this range of flows, the inclusion of the RR bridge in the model would likely cause unrealistically high maximum WSE results upstream of the Wadsworth bridges.

One other minor change was made to the HEC-RAS geometry during the validation effort, involving the hydraulic bridge parameters. A maximum discharge value can be assigned to bridges within the model geometry. This value defines the upper flow limit of the hydraulic property tables that HEC-RAS develops for each structure. During the calibration process, different maximum discharge values were defined for the different model geometries developed for each calibration event. The validation effort is intended to develop one model geometry that will be used for the channel capacity analysis. To simulate the large 1997 flood event, the maximum discharge values were increased to 23,000 cfs, slightly above the maximum inflow value added to the model at the upstream end of the Truckee River. These values were used for both the 1997 and 2018 validation simulation runs. It is recommended that these values be revised for channel capacity analysis, down to just over the maximum 14,000 cfs flow rate to be analyzed. While applying a single flow maximum just above 14,000 cfs to all synthetic hydrograph flows will not provide the maximum possible resolution of hydraulic property tables when simulating the smaller synthetic flow hydrographs, this is unlikely to have a substantial impact on simulation results.

A discussion of the validation process and results for each flood event analyzed is presented in bullet format below.

- **1997 Flood event**
    - Time period simulated: 12/31/1996 to 1/4/1997.
    - Peak USACE discharge at Vista gage=21,184 cfs.
    - The Truckee near Tracy gage was installed after the 1997 flood, no data are available for this site.
    - The Truckee below Tracy USGS gage was damaged during the 1997 flood event, recorded data are only available during the rising limb of the flood, up to a maximum flow of 12,900 cfs.
        - No NSE statistics were developed for this site, due to the incomplete data set.
    - Recorded peak flow decreased in downstream direction at gages below Vista, indicating no significant tributary inflow took place during this event.
    - **Truckee below Derby Dam gage site 1997 event results discussion:**
        - Flow hydrograph shows peak Q simulation results ~1,000 cfs higher than observed.
        - Simulation results showed peak WSE ~0.2 ft lower than observed.
        - Water surface NSE results (0.801) rated as Very Good.
        - Discharge NSE result (0.857) rated as Very Good.
    - **Truckee at Wadsworth gage site 1997 event results discussion:**

        - Flow hydrograph shows peak Q simulation results ~1,600 cfs higher than observed.
        - Initial results showed peak WSE ~0.9 ft lower than observed.
        - Assumed large deviation in stage is due to prior deletion of downstream RR bridge for simulation of smaller events. Added RR bridge back into 1997 event geometry.
        - Peak simulated WSE was within 0.1 ft of observed peak stage data following replacement of RR bridge.
        - Water surface NSE results (0.828) rated as Very Good.
        - Discharge NSE result (0.923) rated as Very Good.
- **2018 Flood Event**
    - Time period simulated: 4/7/2018 to 4/8/2018.
    - Peak discharge at Vista gage=6,190 cfs.
    - Recorded peak flow decreased in downstream direction at gages below Vista, indicating no significant tributary inflow took place during this event.
    - **Truckee near Tracy gage site 2018 event results discussion**:
        - Simulated peak Q was ~75 cfs higher than observed.
        - Simulated peak WSE was ~0.2 ft higher than observed.
        - Water surface NSE results (0.369) rated as Unsatisfactory.
            - Although the difference between the modeled and observed peak WSE is relatively small, the WSE hydrographs are offset by a similar amount for the entire event simulation. This results in the Unsatisfactory calculated NSE value.
        - Discharge NSE result (0.882) rated as Very Good.
    - **Truckee below Derby Dam gage site 2018 event results discussion**:
        - Peak simulation Q was ~340 cfs higher than observed.
        - Simulation peak WSE is ~0.3 ft lower than observed.
        - Water surface NSE results (0.637) rated as Satisfactory.
        - Discharge NSE result (0.474) rated as Unsatisfactory.
    - **Truckee at Wadsworth gage site 2018 event results discussion:**
        - Peak Q simulation results ~60 cfs higher than observed.
        - Peak WSE ~0.5 ft higher than observed.
        - Water surface NSE results (-1.385) rated as Unsatisfactory.
            - Although the difference between the modeled and observed peak WSE is relatively small, the WSE hydrographs are offset by a similar amount for the entire event simulation. This results in the Unsatisfactory calculated NSE value.
        - Discharge NSE result (0.786) rated as Very Good.

Statistical summaries of the Lower Reach model validation results, including Nash-Sutcliffe efficiency values, are presented in Table 17 and Table 18. A comparison of USGS observed data and modeled results for peak water surface elevations and discharge values is provided in

Table *19*. Calibration charts comparing the HEC-RAS Lower Reach model validation run results to recorded flow and WSE values are presented in Appendix F.

Table 17. Lower Reach 1997 Validation Event Results

1997 Event Results at Truckee River below Derby Dam Gage (XS 189892) Summary Stats			
Average Observed WSE (ft, NAVD88)	**Average Observed Flow (cfs)**	**Water Surface Elevation NSE**	**Discharge NSE**
4,197.04	12,289	0.801	0.857
1997 Event Results at Truckee River at Wadsworth Gage (XS 133809) W/Wadsworth RR Bridge in Place Summary Stats			
Average Observed WSE (ft, NAVD88)	**Average Observed Flow (cfs)**	**Water Surface Elevation NSE**	**Discharge NSE**
4,060.42	12,845	0.828	0.923

Table 18. Lower Reach 2018 Validation Event Results

2018 Event Results at Truckee River near Tracy Gage (XS 235118) Summary Stats			
Average Observed WSE (ft, NAVD88)	**Average Observed Flow (cfs)**	**Water Surface Elevation NSE**	**Discharge NSE**
4,266.79	5,111	0.369	0.882
2018 Event Results at Truckee River below Derby Dam Gage (XS 189892) Summary Stats			
Average Observed WSE (ft, NAVD88)	**Average Observed Flow (cfs)**	**Water Surface Elevation NSE**	**Discharge NSE**
4,194.13	4,983	0.637	0.474
2018 Event Results at Truckee River at Wadsworth Gage (XS 133809) W/Wadsworth RR Bridge Removed Summary Stats			
Average Observed WSE (ft, NAVD88)	**Average Observed Flow (cfs)**	**Water Surface Elevation NSE**	**Discharge NSE**
4,055.51	5,028	-1.385	0.786

Table 19. Model Validation Peak Results Summary

Gage Name	Truckee River at Reno	Truckee River at Vista	Truckee River near Tracy	Truckee River below Derby Dam	Truckee River at Wadsworth
Gage ID	**10348000**	**10350000**	**10350340**	**10351600**	**10351650**
1997 USGS Peak Observed WSE* (ft)	4,450.44*	4,395.27	N/A	4,199.83	4,064.23
1997 Peak Model Results WSE* (ft)	4,451.90*	4,397.02	N/A	4,200.07	4,064.22
1997 USGS Peak Observed Flow* (cfs)	23,216*	21,184	N/A	19,700	19,100
1997 Peak Model Results Flow* (cfs)	23,144*	18,945	N/A	20,687	20,679
2018 USGS Peak Observed WSE (ft)	4,458.07	4,385.01	4,267.50	4,194.84	4,056.30
2018 Peak Model Results WSE (ft)	4,456.90	4,385.07	4,267.69	4,194.50	4,056.84
2018 USGS Peak Observed Flow (cfs)	6,690	6,190	6,070	5,750	6,020
2018 Peak Model Results Flow (cfs)	6,652	6,173	6,146	6,086	6,077

*1997 Reno values represent Old Reno Gage location

Synthetic Incremental Flow Hydrograph Development

The purpose of this portion of the study was to evaluate a series of incrementally increasing flow events to assess areas of flow breakout or channel capacity on the Truckee River. Synthetic flow hydrographs for use in the channel capacity analysis were developed using the Truckee Meadows 2D unsteady-state HEC-RAS model developed for the model validation portion of the WMOP study.

The hydraulic model was executed using the latest version of the HEC-RAS software, HEC-RAS V6.2.

Seventeen sets of unsteady synthetic flow hydrographs were developed for this task and used to assess channel capacity in the Truckee Meadows reach and Lower Reach for peak flows 6,000-14,000 cfs in 500 cfs intervals. These hydrograph flow values were assumed to be at the USGS Truckee River at Reno stream gage location (Gage #10348000).

The Truckee Meadows model synthetic inflow hydrographs for the Truckee River and associated tributaries use pattern hydrographs taken from the USACE 100-year hydrology data. These data were contained in a DSS file associated with an HEC-RAS model provided to HDR by USACE circa 2013 in support of an update to the USACE General Re-Evaluation Report for the Truckee Meadows. Tributary peak flows were developed based on USACE flow data for smaller flood events, ranging from 5-year to 50-year return periods. These hydrographs were scaled such that the Truckee River peak inflow was based upon the associated target synthetic hydrograph peak flow, and the peak flow rates of the tributary streams were based on a ratio of the target flow rate and the peak Truckee River flow rate of the associated return periods. This approach was used because the ratios of the tributary peak flows to the Truckee River peak flow vary between the various return period data sets. Table 20 shows the Truckee River and tributary streams peak flow rates for the USACE hydrology flood events ranging from 5-year to 100-year recurrence intervals. It can be seen in Table 20 that the ratio of the 5-year Steamboat Creek peak flow to the 5-year Truckee River peak flow is about 0.08:1, while the same ratio for the 50-year event peak flows is 0.22:1. Using the 100-year event peak flow rates to develop the synthetic flow analysis tributary peak inflow values would tend to exaggerate the impact of the tributaries relative to the Truckee River for the smaller return period events.

Table 20. USACE Hydrology Peak Flow Rates

USACE Hydrology Return Period (years)	Truckee River Peak Flow Rate (cfs)	Dry Creek Peak Flow Rate (cfs)	NTD Peak Flow Rate (cfs)	Steamboat Creek Peak Flow Rate (cfs)
5	5,949	131	107	484
10	7,540	181	147	667
20	9,150	380	309	1,399
50	13,721	818	666	3,014
100	20,734	1,325	1,078	4,883

As an example, the 100-year Truckee River hydrograph has a peak flow of 20,734 cfs. The 100-year hydrograph was used as the pattern hydrograph and was multiplied by the ratio of 6,000 cfs/20,734 cfs, or 0.289, to produce an input flow hydrograph for the Truckee River having a peak flow rate of 6,000 cfs. While the USACE hydrology data set does include flow hydrographs for the smaller return intervals, comparison of these hydrographs with the 100-year event hydrographs shows that the peak flow during the 100-year event persists for several hours longer than the duration of the peak flow that occurs during the smaller events. Based on discussion with the WMOP Study Technical Team, the decision was made to use the 100-year event hydrographs as the pattern hydrographs for all synthetic events simulated for this task. This approach provides a conservative simulation of the potential flooding conditions during the synthetic flood events, due to the increased flow volume entering the model domain, relative to a simulation using the USACE smaller event flow hydrographs.

The 6,000 cfs target flow event was associated with the Truckee River 5-year return period, as the USACE hydrology indicates that the 5-year event has a peak flow of 5,949 cfs at the Reno gage. The ratio of the 6,000 cfs target flow rate to the 5-year Truckee River peak flow rate is 1.009 (6,000/5,949=1.009). The 5-year tributary peak flows were multiplied by this ratio to develop the tributary peak flows to be input during the 6,000 cfs target flow rate simulation run. The Steamboat Creek 5-year peak flow rate is 484 cfs. The Steamboat Creek peak inflow during the 6,000 cfs target flow rate simulation run was 484 cfs*1.009=488 cfs. The Steamboat Creek 100-year peak flow rate is 4,883 cfs. The USACE 100-year tributary flow hydrograph was then used as a pattern hydrograph with a flow multiplier (488/4,883=0.1) to develop the tributary flow input hydrograph for Steamboat Creek during the 6,000 cfs target flow rate simulation run. The same approach was used for the other tributary streams (Dry Creek & NTD) and the other target Truckee River synthetic peak flow rates. Table 21 provides a summary of the recurrence event associated with each target flow, as well as the tributary peak flow rates.

The Truckee River return period event associated with a given synthetic peak flow rate simulation was selected by comparing the average of the Truckee River return period event peak flows with the target peak flow rate and selecting the return period event that has an average flow greater than the target flow rate. For example, when comparing the 5-year and 10-year Truckee River peak flows, the average value is 6,745 cfs. The average of the 10-year and 20-year Truckee River peak flows is 8,345. Based on this, the 6,000 and 6,500 cfs synthetic peak flow simulation plans were associated with the 5-year return period, while the 7,000 through 8,500 cfs simulation plans were associated with the 10-year return period data set.

The use of the USACE pattern hydrographs to simulate tributary inflows during the synthetic hydrograph model runs assumes relatively high flow events upon those tributaries, taking place at the same time or nearly simultaneously with the synthetic high flows in the Truckee River. Cursory examination of gage records for the tributaries indicates that large flows in Steamboat Creek and the NTD are rare, usually of short duration, and may not occur simultaneously with peak flows upon the Truckee River. The inundation mapping results based upon this analysis may be somewhat conservative due to these issues but would likely not show significant differences in inundation extent along the Truckee River if lower tributary inflows were used.

Table 21. Synthetic Flow Hydrographs Peak Flow Rates

Synthetic Flow Hydrograph Calculations				
Target Truckee River Peak Flow Rate (cfs)	**Truckee River Recurrence Event Applied**	**Dry Creek Associated Peak Flow Rate (cfs)**	**NTD Associated Peak Flow Rate (cfs)**	**Steamboat Creek Associated Peak Flow Rate (cfs)**
6,000	5 Year	132	108	488
6,500	5 Year	143	117	529
7,000	10 Year	168	136	619
7,500	10 Year	180	146	663

Synthetic Flow Hydrograph Calculations				
Target Truckee River Peak Flow Rate (cfs)	**Truckee River Recurrence Event Applied**	**Dry Creek Associated Peak Flow Rate (cfs)**	**NTD Associated Peak Flow Rate (cfs)**	**Steamboat Creek Associated Peak Flow Rate (cfs)**
8,000	10 Year	192	156	708
8,500	20 Year	353	287	1,300
9,000	20 Year	374	304	1,376
9,500	20 Year	395	321	1,453
10,000	20 Year	415	338	1,529
10,500	20 Year	436	355	1,605
11,000	20 Year	457	371	1,682
11,500	50 Year	686	558	2,526
12,000	50 Year	715	582	2,636
12,500	50 Year	745	607	2,746
13,000	50 Year	775	631	2,856
13,500	50 Year	805	655	2,965
14,000	50 Year	835	680	3,075

To account for the travel time between the input location and the Reno gage, the Truckee River inflow time series data were shifted to reflect their arrival 60 minutes earlier at the upstream end of the model, relative to the un-edited USACE pattern hydrograph data. No modifications were made to the tributary inflow pattern hydrographs.

During the model calibration and validation tasks, a flow multiplier of 1.02 was applied to the Truckee River inflow hydrograph to account for attenuation within the model reach between the upstream boundary and the Reno gage location. Initial simulations using the synthetic flow hydrographs showed little to no attenuation when examining peak flow results at the Reno gage location. Based on this observation, no flow multiplier was applied to the Truckee River inflow hydrographs. It is assumed this difference occurred because the USACE 100-year pattern hydrograph maintains the peak flow rate for several hours, allowing the peak flow rate to translate downstream to the Reno gage site, while the natural events used for the calibration and validation tasks tended to have much shorter periods of peak flow, resulting in the reduction in peak flow at the Reno gage seen during those simulations.

The synthetic inflow hydrographs to be used for the channel capacity analysis for both the Truckee Meadows and Lower Reach HEC-RAS models were compiled into a single DSS file. Flow hydrographs to be used as flow inputs to the Lower Reach model were extracted from the Truckee Meadows model at the downstream end of the Truckee Meadows model domain and stored in the DSS file to be used in the channel capacity analysis for the Lower Reach. Although the original project scope specified that the output flow hydrographs be extracted at the USGS Truckee River at Vista stream gage location, this approach was modified following consultation with the WMOP Study Technical Team because results developed at this location would ignore the impacts of the NTD, which now has its confluence with the Truckee River downstream of the Vista gage.

Channel Capacity Identification and Inundation Mapping

During the previous task, seventeen unsteady synthetic flow hydrographs for peak flows 6,000-14,000 cfs (500 cfs intervals), taken at the USGS Truckee River at Reno stream gage location (Gage #10348000), were developed using the Truckee Meadows HEC-RAS model. Upon initiation of the channel capacity analysis task, a version of the Lower Reach model was created that uses the outflow hydrographs from the 2D Truckee Meadows synthetic hydrograph simulations as the flow inputs. Due to the addition of tributary flows to the Truckee River within the Truckee Meadows model, the actual peak inflows to the Lower Reach are greater than the target peak flow rates at the Reno gage. For instance, the peak inflow to the Lower Reach for the 6,000 cfs simulation at Reno is 6,495 cfs. Once the Lower Reach model plans had been executed, inundation boundaries for each of the target flows were created within HEC-RAS Mapper using the Truckee Meadows and Lower Reach HEC-RAS models.

These inundation boundaries were examined in ESRI ArcMap, using US Department of Agriculture (USDA) National Aerial Imagery Program (NAIP) aerial imagery acquired in 2019 to determine channel extent. Results were also examined in HEC-RAS Mapper, using the model terrain files and available online imagery to locate flow breakout.

Locations where flow breaks out of the channel at each incremental flow model were documented by developing polyline shapefiles, with the breakout extent indicated based upon the lowest flow rate causing breakout. An attribute field was added to the breakout shapefiles, with the lowest associated peak flow rate causing channel breakout being entered for each feature. While the extent of flow breakout at a given location tends to increase with increasing peak flow rate, the length of each shapefile feature was based upon the width of the initial flow breakout observed. If a nearby separate, distinct flow breakout point was observed when displaying the inundation boundaries for larger peak flows, a separate polyline feature was created to document this secondary breakout location.

It should be noted that in some portions of the Truckee Meadows, overbank flow can parallel the Truckee River channel for long distances, giving the appearance of additional flow breakout locations, while the actual breakout location may have been significantly upstream. This is seen along Riverside Drive in downtown Reno, and in the Sparks industrial area in the north overbank region east of the I-580 interchange. This can result in significant overbank inundation being seen with no nearby flow breakout location indicating the source of this flooding.

Although this task is focused upon channel capacity of the Truckee River, locations of breakout flow along Steamboat Creek and Dry Creek were also assessed. Because flow breaks out into the University of Nevada, Reno (UNR) Farms floodplain region at numerous locations at a relatively low flow rate, the only breakout locations that were cataloged during this assessment were those that appeared to potentially threaten existing homes. Prior hydraulic simulation of this system has indicated that the backwater influence of the Truckee River upstream along Steamboat Creek generally ends around the Mira Loma Drive crossing of the creek. Hence, no flow breakout locations were added upstream (south) of this crossing.

Along the Lower Reach of the Truckee River, several restoration areas have been constructed in the recent past. These projects are intended to return the river back to a more natural, undisturbed condition, with a relatively low, frequently inundated floodplain. These areas, and some other naturally occurring low-lying riparian areas, show significant inundation at the 6,000 cfs target peak flow rate. No flow breakout has been documented in these areas, as it is assumed that these regions of frequent inundation do not constitute exceedance of channel capacity as it is being considered for this task.

Another issue in the Lower Reach is the fact that a 1D model was used to simulate this reach. Because a 1D model assumes a constant water surface across the length of each cross section, the inundation boundaries produced by HEC-RAS Mapper can show water present in areas that do not actually have a hydraulic connection to the main channel. This can result in low-lying ponded areas being shown as inundated, even though they are isolated from the river by berms or other elevated features. Although the inundation boundaries produced by HEC-RAS Mapper have not been edited to remove these areas, this issue has been considered when developing the flow breakout location shapefiles. Due to this, there may be some locations where the inundation mapping indicates channel capacity has been exceeded, but no flow breakout location is indicated.

The Truckee River Flood Control Project (Flood Project) includes numerous levees, floodwalls, and other features intended to reduce or eliminate flooding associated with the Truckee River within the Truckee Meadows. Several important features that are part of or related to the Flood Project have already been constructed and are represented in the Truckee Meadows reach HEC-RAS model used to produce the results presented in this document. These include the new Virginia St. bridge, the Reno-Sparks Indian Colony levee downstream of the I-80/I-580 interchange, and the relocated NTD. There are numerous proposed features of the Flood Project which are not represented in the HEC-RAS model but do have the potential to significantly alter the behavior of the Truckee River system if they were to be constructed. In general, the Flood Project features would tend to retain floodwaters within the Truckee River channel and near overbanks in the Truckee Meadows reach, especially during large flood events. Hydraulic analysis conducted during the 65% design effort for the Vista Narrows portion of the Flood Project indicates that the overall Flood Project would have little to no impact upon peak discharge downstream of Vista for events smaller than 10,000 cfs. For the 100-year flood event, the peak discharge downstream of Vista was found to increase by ~2,400 cfs when all Flood Project features were represented. No detailed analysis of the potential impact of the proposed Flood Project features has been made as part of the hydraulic modeling performed during the WMOP study effort.

Due to the large number of flow breakout locations identified over the range of hydrographs, an exhaustive text description of these locations has not been produced for all flow rates analyzed. Based on discussion with the WMOP study technical team, results based on flow rates between 6,000 cfs and 8,000 cfs are of particular interest. Breakout locations for each of the flow rates within that range are discussed below. These descriptions are based on comparison of the HEC-RAS inundation extents with aerial photography and do not constitute a detailed examination of possible impacts at individual structures.

Based on results of the 6,000 cfs flow rate modeling, the most upstream flow breakout in the Truckee Meadows reach occurs at Oxbow Park, upstream of downtown Reno. Overlaying the inundation boundary upon aerial imagery indicates that this flow breakout extends about 200 feet outside the natural channel banks and does not impact constructed park features aside from walking trails. The next downstream location where flow breakout occurs is in the reach between Rock Blvd. and McCarran Blvd. Channel capacity is exceeded at two locations within this reach, with flooding in the south overbank being seen in the Ferrari Farms area and along Edison Way north of Mill St. Flooding associated with the 6,000 cfs flow rate does not extend south of Mill St. No other flow breakout is seen within the Truckee Meadows at the 6,000 cfs peak flow rate. Within the Lower Reach, numerous flow breakouts are seen in the 6,000 cfs target peak flow rate inundation boundary. A total of 29 flow breakout locations associated with the 6,000 cfs inundation boundary were cataloged in the Lower Reach. These occur throughout the reach, beginning in the Lockwood area and continuing on downstream to the Wadsworth area at the downstream end of the reach. In general, the extents of the Lower Reach flow breakouts associated with the 6,000 cfs inundation boundary inundate low-lying undeveloped areas adjacent to the active channel. Based upon comparison with 2019 NAIP aerial imagery, no existing roadways or insurable structures appear to be threatened by the flooding that occurs due to the 6,000 cfs flow rate. It should be noted that the farm fields on the north bank of the river just upstream of Wadsworth do show significant inundation at the 6,000 cfs flow rate. Flow breakout into the right overbank in the Wadsworth area downstream of the Highway 427 and RR bridges was noted at 6,000 cfs, but this flow enters an existing canal and appears to be contained by that channel.

The results of the 6,500 cfs flow rate modeling indicate only one additional breakout location in the Truckee Meadows reach relative to the 6,000 cfs inundation extents. This occurs at the downstream end of the reach, on the north bank below the second RR bridge, upstream of Lockwood and appears to result in only minor flooding. In the reach between Rock Blvd. and McCarran Blvd., additional inundation associated with this flow rate compared to the 6,000 cfs inundation extents ponds against the Mill St. and McCarran Blvd. embankments, but not does not overtop these roadways. In the Lower Reach, a total of seven additional breakouts at the 6,500 cfs flow rate were noted. The most upstream location is just upstream of Lockwood, with the most downstream occurring immediately south of the I-80 rest area just west of Wadsworth. Similar to the Lower Reach 6,000 cfs breakout extents, the overbank inundation associated with these flow breakouts appears minor, with no roadways or structures being threatened.

Examination of the results of the 7,000 cfs flow rate mapping shows only one additional breakout site within the Truckee Meadows reach. This is a small region just upstream of the second RR bridge below Vista and does not result in significant flooding. Inundation due to additional flooding at the 7,000 cfs flow rate between Rock Blvd. and McCarran Blvd. is seen to overtop Mill St. and extend to south of Energy Way. Four additional breakout locations along the Lower Reach were identified when assessing the 7,000 cfs flow rate results. The most upstream of these is seen just above Mustang, and the most downstream site is an additional breakout of flow into the left (north) bank farm fields just upstream of Wadsworth. No structures or roadways at these locations were seen to be impacted by the inundation results.

The 7,500 cfs flow rate results indicate one Truckee Meadows additional flow breakout location; this occurs into the north overbank immediately upstream of the eastern McCarran Blvd. bridge. In the Lower Reach, additional breakout associated with the 7,500 cfs flow rate occurs at two locations, one in the Lockwood area and one downstream of Derby Dam. The inundation at these locations does not appear to threaten any roadways or structures.

The results of the 8,000 cfs flow rate modeling show five additional breakout locations in the Truckee Meadows. The most upstream is an additional breakout into the south overbank just downstream of Rock Blvd. Moving downstream, an additional breakout is seen into the north bank upstream of the eastern McCarran Blvd. bridge. Just downstream of the McCarran Blvd. bridge, flow breaks out into the south overbank at two distinct locations near each other. The most downstream breakout location is a minor breakout into the south overbank just downstream of TMWRF. Seven additional flow breakout locations associated with the 8,000 cfs flow rate were noted within the Lower Reach. These occur starting just below the Lockwood bridge and extend downstream to the I-80 bridges upstream of Wadsworth. No roadways or structures appear to be threatened when examining the inundation extents at these locations.

Inundation maps presenting the HEC-RAS inundation boundaries for the various peak flow rates, along with the flow breakout locations, are presented in Appendix G. The maps for peak flow rates greater than 6,000 cfs display the inundation boundary associated with the target peak flow named in the map title, as well as the inundation boundary for the next smaller peak flow increment. For example, the 6,500 cfs maps also display the 6,000 cfs inundation extents, to illustrate the magnitude of the change in inundation extent with each increase in peak flow. The maps only display additional flow breakout locations associated with the target peak flow rate named in the map title. Flow breakout locations associated with other target peak flow rates are not plotted, in order to show only those flow breakout locations that occur when the target peak flow reaches the flow rate stated in the map title.

Sustained Flow Analysis

Following the channel capacity analysis described above, the potential impact of sustained elevated reservoir outflows was assessed by developing new HEC-RAS model runs that simulated a relatively long period of elevated flow on the Truckee River within the Truckee Meadows. The calibrated HEC-RAS model developed and used for the channel capacity analysis was revised for this purpose. This approach better represents the expected conditions during reservoir control operations than the inflow hydrographs used for the channel capacity analysis, which are based on incremental USACE pattern hydrographs and represent a relatively short period of peak flow.

Three model runs were created to simulate Truckee River peak flows of 6,500 cfs, 7,000 cfs, and 7,500 cfs at the Reno USGS stream gage location, each with a simulated duration of 21 days. The inflow on the Truckee River used a constant flow hydrograph fixed at the target peak flow rate for the entire simulation time window. Tributary flow rates were based upon winter baseflows, because large flood events on the Truckee River tend to occur during the winter season, and this is the time of year when elevated reservoir outflows could be useful to maintain flood storage within the upstream reservoirs. Inflows on the NTD and Steamboat Creek were also held steady during the 21-day simulation and were based upon averaged winter baseflows recorded during the winters of 2015 and 2017. These periods were selected because winter precipitation and streamflow in the Truckee Meadows and contributing watersheds were relatively high during these years, and it was assumed that these results would represent elevated winter baseflows for the tributary streams. The mean flow rates used in the model runs are shown in Table 22. The same flow rate was used for all three simulations for each tributary.

Table 22. Tributary Baseflow Values

Tributary Stream	Winter 2015 Mean Discharge (cfs)	Winter 2017 Mean Discharge (cfs)	Final Baseflow (cfs)
North Truckee Drain	1	10	6
Steamboat Creek	5	97	61
Dry Creek	N/A	N/A	0

Winter baseflow for the NTD was developed based upon 15-minute flow records for the NTD at the Spanish Springs Road USGS gage (Gage #10348245). HEC-DSSVue V3.2.3 was used to download and catalog all flow data. The period of record used for the winter of 2015 was 11/1/2014 to 4/30/2015. HEC-DSSVue tools were used to estimate flow values for a period of missing data in December 2014 and January 2015. The period of record used for the winter of 2017 was 11/1/2016 to 4/30/2017. Mean flow values for this gage were calculated using the statistics tools within HEC-DSSVue. Mean NTD flow for the winter of 2015 was 1 cfs, while mean flow for the winter of 2017 was 10 cfs. These results were averaged to compute a mean NTD baseflow of 6 cfs.

The Steamboat Creek at Short Lane USGS gage (Gage #10348949) was used to calculate baseflow for this tributary stream. The 2015 winter baseflow was estimated based upon records extending from 11/1/2014 to 4/30/2015. When investigating flow data for the winter of 2017, it was discovered that no flow data for this gage are available from 5/23/2016 until 12/21/2016. It is possible that construction of the Veterans Parkway roadway impacted the gage during this period. Flow records from 12/21/2016 to 4/30/2017 were used to estimate Steamboat Creek baseflow for the winter of 2017. Records for the gage upstream of the Short Lane gage, Steamboat Creek at Steamboat, NV (Gage #10349300) and the gage downstream of the Short Lane gage, Steamboat Creek at Cleanwater Way (Gage #10349980), were examined to assess whether large magnitude events occurred on Steamboat Creek during the period of missing data at the Short Lane gage. Two flood events that significantly exceeded median flows during the period of interest were observed in the records for these other gages; these occurred on 12/11/2016 and 12/16/2016. The 12/11/2016 peak flow at the Cleanwater Way gage was 309 cfs, while the 12/16/2016 peak flow at this gage was 419 cfs. Both events were relatively short, with elevated flows persisting for about one day. Because several much larger flood events with longer periods of elevated flow occurred later in the winter of 2017 and are included in the gage records used to calculate baseflow for Steamboat Creek, the lack of these two events would be unlikely to have a significant impact upon the calculated mean baseflow for this tributary. Mean flow for the winter of 2015 was found to be 5 cfs. Mean flow for the winter of 2017 was found to be 97 cfs. These values were averaged to arrive at a baseflow rate for Steamboat Creek of 61 cfs.

Because no stream gage exists on Dry Creek within the study area, no flow data are available for this tributary. Given the relatively small contributing area of this stream, Dry Creek winter baseflow is unlikely to be significant relative to the elevated Truckee River flows being simulated. Discharge inputs for Dry Creek were set to zero for the sustained flow model simulations.

Maximum inundation boundaries for the sustained flow model runs were developed in HEC-RAS Mapper. These boundaries were used to produce inundation maps for the Truckee Meadows reach; these maps are included with this report in Appendix H. The sustained-flow inundation boundaries were also compared to the maximum inundation boundaries simulated using the incremental USACE Truckee River pattern hydrographs, to identify any differences in breakout locations and inundation extents.

In general, there were no new channel breakout locations associated with the sustained flow runs, relative to the channel capacity analysis simulations using the incremental USACE Truckee River pattern hydrographs with equivalent peak flows. Changes in the maximum inundation extents for the sustained flow simulations were limited to an increase in ponding in the overbank areas.

For the 6,500 and 7,000 cfs model runs, essentially no change in inundation was seen for the portion of the Truckee River upstream of Greg St. Downstream of Greg St., right bank channel breakout similar to that seen in the model simulation based on the USACE Truckee River pattern hydrographs was observed, with some increases in flooding extent observed in the overbank region north of Mill St. The 6,500 cfs sustained flow run showed flow overtopping Mill St. and moving to the south, which did not occur in the 6,500 cfs simulation based on the USACE Truckee River pattern hydrographs.

While the 7,000 cfs simulation based on the USACE Truckee River pattern hydrographs did show some flooding in the region south of Mill Street, the 7,000 cfs sustained flow simulation showed increased inundation in this area, in particular along Corporate Blvd. and Capitol Blvd. In addition, the sustained flow simulation indicated that flow would overtop McCarran Blvd. near Capitol Blvd. and move to the east into the UNR Farms region. This overtopping was not seen in the 7,000 cfs simulation based on the USACE Truckee River pattern hydrographs.

For the 7,500 cfs model simulation, increased inundation was seen at Oxbow Park, on the right bank of the Truckee River upstream of Downtown Reno, relative to the simulation based on the USACE Truckee River pattern hydrographs. No other increase in flooding was seen for this model simulation in the reach upstream of Greg St. The right bank flooding between Greg St. and McCarran Blvd. showed larger extents than the 7,500 cfs simulation based on the USACE Truckee River pattern hydrographs. In addition, the left (north) bank flooding just west of McCarran Blvd was seen to increase in extent, relative to the 7,500 cfs simulation based on the USACE Truckee River pattern hydrographs. A simulated increase in flow volume overtopping Mill St. during the sustained flow analysis resulted in additional inundation to the south, relative to the simulation based on the USACE Truckee River pattern hydrographs. Flow also overtopped McCarran Blvd. and moved to the east, as was seen in the 7,000 cfs sustained flow simulation. This did not occur in the 7,500 cfs simulation based on the USACE Truckee River pattern hydrographs.

simulations are compared to the simulations based on the incremental USACE Truckee River pattern hydrographs.

In general, the results of the sustained flow model simulations showed that there is a potential for additional flow volume to cross south over Mill St. and enter the commercial area relative to the results of the simulations based on the incremental USACE Truckee River pattern hydrographs. This additional volume ponds in the overbank area, increasing the maximum inundation extents.

The change in inundated area in the region south of Mill St. and west of McCarran Blvd. was calculated for each of the sustained flow model simulations. For the 6,500 cfs model simulation, the sustained flow results showed an inundated area of 1.8 acres, while no inundation was seen for this flow increment when using the incremental USACE Truckee River pattern hydrographs. The 7,000 cfs results indicated an increase in inundated area from 6.2 acres up to 41.4 acres, while the 7,500 cfs simulation results indicated an increase in inundated area from 19.8 acres up to 49.8 acres.

Plotting WSE time series results at several locations in this overbank region indicated that flooding in this area increased over a period of several days to about one week after the start of the model simulation, then stabilized to produce the maximum inundation. It should be noted that in the areas of increased inundation south of Mill St., the HEC-RAS model does not include a high level of detail in the 2D model grid. The mapped inundation extents do not account for potential impacts of storm drains, roadway crowns, and other physical features that could impact flow patterns or the extent of inundation during a sustained flow event.

Summary

This work is intended to support the Truckee Basin WMOP study by providing an updated analysis of the channel capacity of the Truckee River in the Truckee Meadows Reach and the Lower Reach, extending from upstream of Reno downstream to Wadsworth. Existing HEC-RAS hydraulic models developed for updating the FEMA floodplain mapping along the Truckee River were adopted and modified for this effort. When these models were developed, the focus was upon modeling and mapping the 1% annual chance exceedance event, which has a peak flow of over 20,000 cfs on the Truckee River. The model geometries have not been extensively refined during the WMOP study hydraulic modeling effort. Minor barriers to flow, such as unofficial floodwalls or berms, may not be represented by the models at all locations. These features may have impacted localized flooding during historical flood events but are outside the level of detail captured in the HEC-RAS models used for this study.

The models were calibrated to three flood events, which occurred in 2005, 2017, and 2019. Calibration was based upon updates to the Manning's n roughness values used to represent the hydraulic resistance to flow. The Manning's n roughness values developed for each calibration flood event were averaged to create a final set of Manning's n roughness values for each model. The hydraulic models using the averaged Manning's n roughness values were validated by simulating two other historical flood events. These events occurred in 1997 and 2018. Channel capacity was assessed by using the validated hydraulic models to simulate the impacts of a series of synthetic flow hydrographs representing peak flow rates at the Reno USGS streamgage. A total of seventeen assessed by using the validated hydraulic models to simulate the impacts of a series of synthetic flow hydrographs representing peak flow rates at the Reno USGS streamgage. A total of seventeen events, ranging in peak flow from 6,000 cfs up to 14,000 cfs, at an increment of 500 cfs, were simulated. Inundation boundaries representing the peak flooding occurring from each synthetic flood event were developed using the HEC-RAS Mapper utility. These boundaries were examined using GIS software, and the locations where channel capacity was exceeded at each peak flow rate were cataloged in shapefile format.

Within the Truckee Meadows, channel capacity was exceeded at the 6,000 cfs peak flow rate in two separate locations. One is a minor breakout at the Oxbow Park, upstream of downtown Reno. The other flow breakout noted at the 6,000 cfs peak flow rate is into the south overbank in the reach between Rock Blvd. and McCarran Blvd. near Edison Way. This appears to be the crucial location for the WMOP study, as this is the first site where substantial flow breakout occurs. The extent of inundation in this area increases substantially when examining results of higher flow rates. In the Lower Reach, channel capacity was exceeded in numerous locations, beginning at the 6,000 cfs flow rate and increasing with higher discharge, but no existing roads or structures appeared to be threatened by flows in the 6,000 cfs to 11,500 cfs range. As flows increased, the results of the 12,000 cfs peak flow rate inundation mapping showed several homes in the developed area upstream of the I-80 bridges to potentially be at risk of flooding. A final set of inundation maps displaying the inundation extents and flow breakout locations for the channel capacity analysis is included in Appendix G of this document.

An additional set of model runs simulated peak flow rates of 6,500, 7,000, and 7,500 cfs at the Reno USGS streamgage location, held steady for 21 days each. These simulations were created to assess potential flooding impacts in the Truckee Meadows reach due to sustained, elevated outflows from upstream reservoirs. The results indicated that sustained flows would produce the same flow breakout locations along the Truckee River channel as those identified when using incremental USACE Truckee River pattern hydrographs and larger tributary flows. They also illustrated that the region between Rock Blvd. and McCarran Blvd. is the critical area within the Truckee Meadows, with additional flow volume overtopping Mill St. and moving into the commercial area south of this region. The sustained flow results indicated that additional overbank inundation could occur during sustained flow events, relative to the equivalent mainstem flows at Reno using the USACE Truckee River pattern hydrographs, even with relatively low tributary inflows reflecting an average winter baseflow condition. The change in inundated area in the region south of Mill St. and west of McCarran Blvd. was calculated for each of the sustained flow model simulations. For the 6,500 cfs model simulation, the sustained flow results showed an inundated area of 1.8 acres, while no inundation was seen for this flow increment when using the incremental USACE Truckee River pattern hydrographs. The 7,000 cfs results indicated an increase in inundated area from 6.2 acres up to 41.4 acres, while the 7,500 cfs simulation results indicated an increase in inundated area from 19.8 acres up to 49.8 acres.

It should be noted that these results do not include a high level of model detail in the overbank commercial region, nor do they account for the potential impact of storm drains upon final inundation extents. These factors could impact the actual inundation that may occur during a sustained flow event.

A final set of inundation maps displaying the inundation extents and flow breakout locations for the sustained flow analysis is included in Appendix H of this document.

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Appendix A. USGS Flow and Gage Height Charts

Charts presenting USGS flow and gage height data for all streamgages and flood events of concern.

Appendix B. Truckee River Truckee Meadows Reach Model Calibration Charts

Plots comparing HEC-RAS Truckee Meadows reach calibration simulation results with USGS recorded flow and WSE values.

Appendix C. Truckee River Truckee Meadows Reach and Lower Reach Model Calibration Data

Electronic files including an Excel file containing tables presenting the initial Manning's n roughness values, calibrated Manning's n roughness values, and the final averaged Manning's n roughness values for the Truckee Meadows Reach and the Lower Reach. Also included is a land use shapefile including all of these Manning's n roughness data for the Truckee Meadows Reach in electronic format.

Appendix D. Truckee River Lower Reach Model Calibration Charts

Plots comparing HEC-RAS Lower Reach calibration simulation results with USGS recorded flow and WSE values.

Appendix E. Truckee River Truckee Meadows Reach Model Validation Charts

Plots comparing HEC-RAS Truckee Meadows validation simulation results with USGS recorded flow and WSE values.

Appendix F. Truckee River Lower Reach Model Validation Charts

Plots comparing HEC-RAS Lower Reach validation simulation results with USGS recorded flow and WSE values.

Appendix G. Truckee River Channel Capacity Analysis Maps

Maps displaying the channel capacity analysis inundation boundaries and flow breakout locations for the Truckee Meadows and Lower Reach models, based on the incremental USACE Truckee River pattern hydrographs.

Available for download (2.2 GB) from WeTransfer: https://we.tl/t-g6ikM2hdxX

Appendix H. Truckee River Sustained Flow Analysis Maps

Maps displaying the channel capacity analysis inundation boundaries and flow breakout locations for the Truckee Meadows model, based on sustained flow inputs.

Available for download (135 MB) from WeTransfer: https://we.tl/t-TlMnY6o0pl