HYDRAULIC MODELING AND ANALYSIS

MIDDLE FORK SNOQUALMIE RIVER
Tanner to Three Forks Natural Area

King County

Department of Natural Resources and Parks

Water and Land Resources Division

HYDRAULIC MODELING AND ANALYSIS

MIDDLE FORK SNOQUALMIE RIVER
Tanner to Three Forks Natural Area

Prepared for

King County

Department of Natural Resources and Parks
Water and Land Resources Division
201 S Jackson Street, Suite 600
Seattle WA 98104

by

WATERSHED Science & Engineering, Inc.
110 Prefontaine Pl. S, Suite 508
Seattle, Washington 98104
Telephone: 206/521-3000

07-12-2013

[This page intentionally left blank]

ACKNOWLEDGMENTS

We would like to thank the following King County staff who participated in this investigation:

- Mark Ruebel, Project Manager
- John Bethel
- Kyle Comanor
- Clint Loper
- Phyllis Meyers
- Richelle Rose

The following consultant staff participated in the project:

- **Watershed Science & Engineering**:
  Larry Karpack, Project Manager, Hydrology and Hydraulics
  Jeff Johnson, Hydraulics and Geomorphology
  Bob Elliot, Numerical Modeling
  Shaina Sabatine, Numerical Modeling, Hydraulics
  Erika Ottenbreit, GIS

- **Herrera Environmental Consultants**:
  Mark Ewbank, Project Manager
  Wes Lauer, Senior Geomorphologist Reviewer
  Ian Mostrenko, Hydraulic Model Development Support

[This page intentionally left blank]

CONTENTS

Acknowledgments i

Contents iii

Table of Tables iv

Table of Figures iv

Glossary of Terms v

Introduction 1

Hydrologic Data Development 1

- Summary of Current and Historical Peak Discharges 2
- Flood Frequency Analysis 4
- Additional Hydrologic Analyses 5

Hydraulic Model Development 6

- Topographic Surface Development 6
- Computational Mesh Development 7
- Boundary Conditions 7
- Model Calibration 8
- Initial (low flow) Model Calibration 9
- High Flow Model Calibration 10

Flood and Erosion Hazard Assessment 13

- Flood Hazard Assessment 13
- Depth-Velocity Hazard and Public Safety on the Floodplain 16
- Erosion Hazard Assessment 17
- Review of Erosion Hazard Data 18

Summary and Conclusion 21

References 22

Figures 23

Plates 49

Appendix A

Table of Tables

Table 1. Observed Peak Annual Flows at USGS Gage 12141300 2
Table 2. Current and Historical Gages on Various Reaches of the Snoqualmie River 3
Table 3. Flood Flow Quantiles for Middle Fork Snoqualmie River 5
Table 4: Calibration Results for Low Flow Calibration Event (4,200 cfs)..... 10
Table 5: Calibration Results for High Flow Events. 12
Table 6: Flows Simulated for Flood and Erosion Hazard Assessment 13
Table 7: Number of Homes and Large Buildings Potentially Inundated During Flood Events... 16
Table 8: Number of Homes and Large Buildings Within Depth-Velocity Hazard Areas 17

Table of Figures

Figure 1: Middle Fork Snoqualmie River Flood Frequency Analysis (observed data record).... 25
Figure 2: Middle Fork Snoqualmie River Flood Frequency Analysis (extended data record) ... 27
Figure 3: Middle Fork Snoqualmie River Flow Duration Analysis..... 28
Figure 4: Extents of the 2D model created for the Middle Fork Snoqualmie River 31
Figure 5: Survey data and delineated elevation contours (feet) 33
Figure 6: Interpolated channel bathymetric surface (elevations in feet) 33
Figure 7: Composite topographic surface (note difference in scale from Figures 5 and 6)..... 33
Figure 8: Example of relative mesh sizes. 34
Figure 9: Stage-Discharge Rating Curve for the Snoqualmie River at River Mile (RM) 0.06..... 37
Figure 10: Distribution of Manning's n throughout low flow model domain. 39
Figure 11: Photo of the upstream end of the model near Tanner showing large boulders 41
Figure 12: Distribution of Manning's "n" throughout high flow model domain..... 43
Figure 13: High water marks used for calibration near the Mason-Thorson Extension Levee .. 45
Figure 14: Criteria for Depth-Velocity Hazard Areas 47

GLOSSARY OF TERMS

1 Percent Annual Chance Flood. The flood that has a 1 percent chance of being equaled or exceeded in any given year

Aquatic Area. Any non-wetland water feature including all shorelines of the state, rivers, streams, marine waters, inland bodies of open water including lakes and ponds, reservoirs and conveyance systems and impoundments of these features if any portion of the feature is formed from a stream or wetland and if any stream or wetland contributing flows is not created solely as a consequence of stormwater pond construction. "Aquatic area" does not include water features that are entirely artificially collected or conveyed storm or wastewater systems or entirely artificial channels, ponds, pools or other similar constructed water features.

Alluvial Fan. A radially symmetric geomorphic surface created by an alluvial sedimentation. Alluvial fans are usually characterized by active and sometimes unpredictable channel movement and channel avulsions.

Anabranching River. A river that contains multiple mid-channel bars, vegetated islands, and multiple channel courses. In many gravel bed rivers, anabranching rivers experience relatively frequent and somewhat unpredictable changes in channel position as mid channel bars form and erode. They are thus sometimes referred to as wandering rivers.

Armor. A relatively coarse layer at the surface of a sedimentary deposit that results from the winnowing of fine material out of the underlying deposit.

Avulsion. A rapid change in channel course that results in the abandonment of the original channel. Avulsions can result in the creation of a new channel or, more frequently, in the reoccupation of an old channel that was abandoned by a previous channel avulsion.

Bank Erosion. Fluvial erosion of a river bank.

Bar. An in-channel sedimentary structure that is elevated relative to the rest of the channel bed and generally has horizontal dimensions that are not significantly larger or smaller than the width of the channel.

Basin. A geographic area that contains and drains to a stream named and noted on common maps or a geographic area that drains to a non-flowing water body, such as a lake or marine area, named and noted on common maps.

Bed Material. Sediment with a size gradation similar to that found on the channel bed. In the study area, bed material consists of sand, gravel, cobble, and boulder-size material.

Bed/Bar Material. Sediment with a size gradation similar to that found on the channel bed or in channel bars. In the study area, bed/bar material probably contains more sand than bed material.

Bedload. Sediment that moves near the channel bed and not high in the water column.

Breakout Flow. Any flow that overtops the channel banks and travels away from the river.

Channel Migration. Change in channel position through bank erosion on one side of a channel and deposition on the opposite bank.

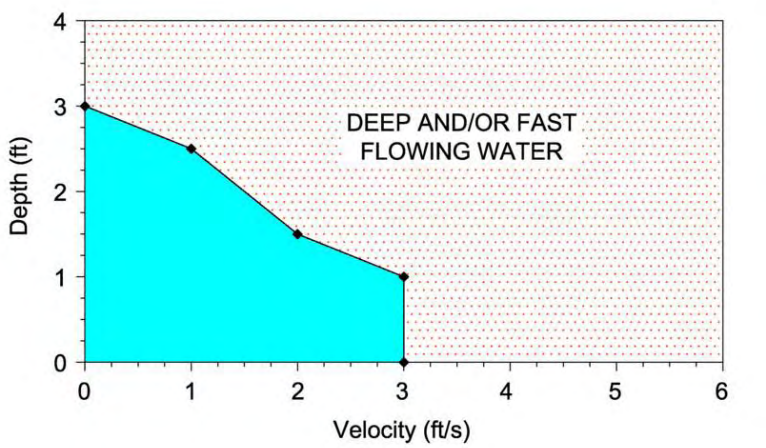
Corridor. The area of a river and surrounding lands that is essential to the storage and conveyance of floodwaters and is integral to natural riverine processes. A river corridor is a larger geographic area that includes one or more river segments (see River Segment), which are made up of one or more river reaches (see River Reach).

Debris Flow. A fast-moving slurry of sediment and water and sometimes plant material.

Debris Flow Fan. An alluvial fan formed by debris flow processes. Debris flow fans are present where steep colluvial channels divulge sediment onto a relatively flat alluvial floodplain or terrace. One debris flow fan occurs in the study area, at the base of a steep channel on the west side of Mount Si. Because the debris flow fan is forested, it is not clear how active the fan has been during the historic period.

Delta. A sedimentary structure formed at the transition between a river and standing water such as a lake or the ocean.

Deep and/or Fast Flowing Water – Areas of public safety hazard characterized by water depths greater than 3 feet, flow velocities greater than 3 feet per second, or a combination of depth and velocity greater than a threshold as shown on the figure below (adapted from USBR, 1988)



Development. Any man-made change to improved or unimproved real estate, including, but not limited to, buildings and other structures, mining, dredging, filling, grading, paving, extraction or drilling operations, farming, or storage of equipment or materials.

Digital Elevation Model (DEM). A three-dimensional digital representation of the ground (or other) surface based upon a regularly spaced grid of elevation data points.

Distal Floodplain/Fan. Relatively low elevation areas near and potentially below the lower limit of an alluvial fan that are either potentially inundated during a flood or exhibit evidence of past overbank deposition of sediment.

Distributary Channel: A channel that conveys flow away from the main channel, usually on an alluvial fan or fan delta.

Embankment. A large glacially-derived sedimentary structure. Near the study area embankment moraines block all or part of the valleys of the Middle Fork Snoqualmie River, South Fork Snoqualmie river, and the Cedar River.

Erosion. The wearing away of ground surface as the result of the movement of wind, water or ice.

Extent. The size of an area affected by a hazard.

Fan Delta. An alluvial fan whose lower limit is a delta.

Flood or **Flooding.** A general and temporary condition of partial or complete inundation of normally dry land areas from the overflow of inland or tidal waters or the unusual and rapid accumulation of runoff of surface waters from any source.

Flood Protection Infrastructure. Structures that provide protection from flood damage, including but not limited to the following:

- Dams or water diversions, regardless of primary purpose, if the structures provide flood protection benefits
- Flood containment structures such as levees, dikes, berms, walls and raised banks, including pump stations, flood closure devices, and other supporting structures
- Bank stabilization structures, often called revetments.

Flood Risk Reduction. An action taken to decrease exposure of people and property to flood or channel migration hazards.

Floodplain. The area potentially subject to inundation due to high river levels. The floodplain encompasses geomorphically active areas near the channel, alluvial fans (whether active or inactive), and low-elevation surfaces which may be flooded by the river. As used in this report, the term does not necessarily distinguish between land surfaces that are currently protected from flooding by flood protection infrastructure and surfaces that have no such protection.

Floodplain Swale. A channel that is usually smaller than the main river channel and crosses a floodplain surface. Floodplain swales are typically mantled by fine-grained silt/clay sediment.

Geomorphology. The study of landforms.

Glacial Outwash. Glacially-derived sediment deposited by a fluvial action, usually by meltwater flowing out of the glacier.

Glacial Till. Unsorted sediment deposited directly by a glacier. Usually includes a wide range of sediment sizes ranging from boulders down to clay. The weight of overlying glacial ice usually consolidates glacial till so that it is relatively resistant to erosion.

Glide. Glide habitats are characterized by moderately shallow water with an even flow that lacks pronounced turbulence. Glides are most frequently located at the transition between a pool and the head of a riffle. The typical substrate is gravel and cobble. Glides are commonly referred to as "runs."

Groundwater Channel. Groundwater channels are often relict river and/or flood channels fed by groundwater, although surface flow from higher terraces can also contribute. They include several subtypes of channels that include, but are not limited to:

- Channels originating from the exfiltration of main channel surface water (i.e., very shallow groundwater associated with the main river); they are sometimes called backwater channels or sloughs
- Channels fed by the floodplain aquifer (hyporheic zone); they are sometimes called percolation channels
- Channels fed by lateral groundwater supplied from adjacent terraces; they are sometimes called wall-base channels

Some groundwater channels can also be classified as overflow channels. For the purposes of this study, they are classified as groundwater channels if the dominant source of hydrology is from groundwater. The size of groundwater channels will have some seasonal variation through tempered from the range of change associated with the hydrograph. Groundwater channels are typically vegetated and commonly contain upland forests or wetlands (forested, scrub-shrub, emergent, and aquatic bed).

Hazard. An event or physical condition that has the potential to cause fatalities, injuries, property damage, infrastructure damage, agricultural loss, damage to the environment, interruption of business, and other types of loss or harm.

Hazard Mitigation. Reduction or alleviation of the loss of life, personal injury, and property damage that could result from a disaster through long- and short-term strategies. Hazard mitigation involves strategies such as planning, policy changes, programs, projects, and other activities that could mitigate the impacts of hazards.

Headcut. An erosive landform that occurs where water spills across a locally steep drop. Headcuts can migrate upstream when material at the toe is removed by the highly erosive flow at the base of the headcut.

Hillslope. Hillslopes are comprised of the valley walls and convex surfaces at the toe of the valley slopes.

In-channel Island. In-channel islands are composed of floodplain benches that are entirely surrounded by the main channel and/or active side channels. They occupy an elevation at or above typical annual high flows and are commonly inundated by larger floods. They are indicative of active channel formation processes. In-channel islands are typically forested or dominated by shrubs and provide extensive riparian edge habitat.

Large Wood. Large pieces of wood including logs, pieces of logs, root wads of trees, and other large chunks of wood that are in or partially in the channel or floodplain of rivers and streams. The term does not include rooted, standing vegetation. Large wood can stabilize streambeds and riverbanks, provide cover and refuge for fish, and create complex in-stream habitat by forming pools, regulating sediments, and dispersing stream energy.

Lateral migration. Progressive, usually gradual change of position of a geomorphic feature. Channel migration is the lateral migration of a river channel.

Levee. A manmade structure, usually an earthen embankment, designed and constructed to contain, control, or divert the flow of water so as to provide protection from temporary flooding.

Lidar. Shorthand for **l**ight **d**etection **a**nd **r**anging, which is a remote sensing method that uses light in the form of a pulsed laser mounted in aircraft to measure ranges (variable distances from the sensor) to the earth's surface. The resultant topographic mapping is typically precise, high resolution information that can be used cost-effectively in lieu of on-the-ground or other photgrammetric survey data for analysis encompassing large areas.

Meandering River. A sinuous single-thread river. Meandering rivers often are characterized by meander bends that migrate across the floodplain.

Meandering River Floodplain. Floodplain formed by a meandering river. Meandering river floodplains are usually characterized by lateral accretion of point bars and subsequent deposition of suspended sediment. They also usually contain abandoned meander bends or oxbow lakes.

Moraine. A geomorphic feature formed by deposition of sediment at the edge or front of a glacier.

Native Vegetation. Plant species indigenous to the Puget Sound region that reasonably could be expected to occur naturally on a site.

Natural Resource Lands. Lands designated under requirements of the Growth Management Act that include the following: 1) agricultural lands with long-term significance for the commercial production of food or other agricultural products; 2) forest lands with long-term significance for the commercial production of timber; and 3) mineral resource lands with long-term significance for the extraction of minerals. The King County Comprehensive Plan designates Agricultural Production Districts, Forest Production Districts, and Mineral Resource Sites.

Open Space. Areas left predominantly in a natural state to create urban separators and greenbelts, sustain native ecosystems, connect and increase protective buffers for environmentally sensitive

areas, provide a visual contrast to continuous development, reinforce community identity and aesthetics, or provide links between important environmental or recreational resources.

Overflow Channel. Overflow channels represent flood swales, often an abandoned mainstem or side channel, carrying surface water and directly connected to the primary channel at its upstream end. Some side channels may have formed or at least been enhanced by head-cutting that was initiated where the side channel reconnects with the main river at its downstream end. For purposes of this study, overflow channels are characterized as hydraulically connected to the primary channel at modeled flows corresponding to flows above 1 year floods, but at or below two-year peak flows.

Plane Bed Channel. Plane bed channels generally lack regularly repeating bedforms and are characterized by long stretches of relatively featureless bed encompassing glide, riffle, and rapid morphologies. Plane bed channels lack discrete bars, a condition associated with low width-to-depth ratios. Plane bed channels typically exhibit armored bed surfaces dominated by gravel and cobble.

Point Bar. A bar located on the inside of a meander bend.

Pool. Pool habitats are topographic depressions within the channel that include several types formed under a variety of different conditions. Within the main channel of the river, pool-riffle channels are typical, where pools are rhythmically spaced between riffles. Pools are also found in association with bars generated by flow convergence and divergence either freely formed by cross-river flow and sediment transport, or forced by channel bends and obstructions (e.g., large woody debris). Pool types affected by obstructions include backwater pools, trench pools, and lateral scour pools. Substrate size in pools varies from sand to cobble, but it typically is gravel-sized in pool-riffle channels.

Regulatory Floodplain. An area regulated by King County as floodplain through its land-use regulations. It includes, but is not limited to, areas identified by FEMA and published on Flood Insurance Rate Maps and additional areas identified by King County as being susceptible to flooding using best available flood information.

Relict Channel. Former river channels, side channels, or floodplain swales that are disconnected from frequent flooding. For the purposes of this study, relict channels are characterized as only showing signs of inundation at modeled flows corresponding to greater than two-year flood events. Relict channels occur in historic floodplains at higher elevations that are no longer flooded except at extreme flows. These channels are typically entirely vegetated and lack visible signs of flow (e.g., no scour evident).

Revetment. A facing of stone, broken rock, or other material placed on a streambank or slope to minimize erosion by moving water.

Riffle. Riffle habitats are characterized by shallow reaches with moderate current velocity and moderate turbulence. Substrate is usually composed of gravels, cobbles, and boulders. The upper gradient limit for this habitat is approximately 4 percent.

Riparian Area. The area adjacent to flowing water such as rivers, perennial or intermittent streams, seeps or springs that contains elements of both aquatic and terrestrial ecosystems that mutually influence each other.

River Reach. A length of river through which similar physical or geomorphic conditions exist

Riverine. Of or produced by a river. Riverine floodplains have readily identifiable channels.

River and Floodplain Management Section. A section within King County's Water and Land Resources Division, Department of Natural Resources and Parks, and funded by the King County

Flood Control District and Inter-County River Improvement Fund, to conduct the following activities:

- Structural capital improvement projects
- Relocation and elevation projects
- Maintenance and monitoring
- River planning
- Flood hazard education
- Flood warning and emergency response
- Complaint response and enforcement
- Interlocal coordination.

Salmonid. Members of the fish family *Salmonidae*, including, but not limited to:

- Chinook, coho, chum, sockeye and pink salmon
- Rainbow, steelhead and cutthroat salmon, which are also known as trout
- Brown trout
- Brook, bull trout, which is also known as char, and Dolly Varden char
- Kokanee
- Pygmy whitefish.

Sediment. Mineral and rock materials that are eroded, transported and deposited by rivers, in sizes that range from clay and silt through sand and gravel to cobble and boulders. Sediment may also include waterlogged organic debris.

Sediment Yield. The amount of sediment supplied by a watershed to a given location.

Sediment Transport Capacity. The rate at which a channel could transport sediment without leading to significant net sediment deposition, assuming sediment supply is sufficiently high.

Sedimentation. The deposition of sediment.

Setback Levee. A levee that is set away from a river in a manner to allow the river channel to migrate, increasing the connection between the river and floodplain to accommodate a floodplain that can store and convey flood flows.

Side Channel. Side channels contain a portion of the riverflow from the main or primary river channel at flows less than 1 year floods, and are partially or entirely surrounded by vegetated or stable island(s). The channel may remain connected at its upstream end through all flows less than bankfull, or it may become disconnected at some point as flows decline. When flowing, the channel is connected to the main channel at its upstream and downstream ends. The primary channel carries the greatest volume of water when there is one (or more) secondary channel with flowing surface water. Side channels can contain a variety of sub-habitats including riffles, pools, glides, and bars. They have an un-vegetated substrate indicative of regular scour.

Single-thread River. A river channel that ordinarily is characterized by single main channel course.

Sinuosity. Total channel length divided by straight-line distance (or sometimes along-valley distance) between two points.

Structural Solution. Reducing flood hazard through physical means, such as dams, levees, revetments or channelization of rivers and streams.

Suspended Sediment. Sediment that is mixed throughout the water column.

Terrace. Terraces are relatively planar surfaces that do not show evidence of recent reworking by the main river channel and are elevated above any adjacent floodplain.

Tributary. Tributaries are defined as stream systems that flow into the main river channel. Tributaries often flow through side channels of the main stem as they approach their confluence.

Vashon Ice Sheet. The large ice sheet that advanced through the Puget Sound area approximately 17,000 years ago.

Wandering River. See anabranching river.

Wandering River Floodplain. Floodplain formed by a wandering river. Wandering river floodplains typically contain multiple abandoned channel bars and abandoned channels. In the study area, the transition between wandering river floodplain and distal floodplain/fan surfaces is not always distinct.

Water Resource Inventory Area (WRIA). Area designations formalized under WAC 173-500-040 and authorized under the Water Resources Act of 1971, RCW 90.54. The original WRIA boundary agreements and judgments were jointly reached in 1970 by Washington's Departments of Ecology, Natural Resources, and Fish and Wildlife. The Washington Department of Ecology is responsible for developing and managing these administrative and planning areas.

Water Year. Analysis of hydrologic data is typically done on a Water Year (WY) basis rather than on a Calendar Year (CY) basis. For peak annual flow data in the United States the water year is typically taken to be October 1st of one year through September 30th of the following year. The Water Year is generally identified as the calendar year in which the largest portion of the water year occurs (i.e. October 1, 1990 – September 30, 1991 is Water Year 1991).

Watershed. A land area that drains to a single outlet and is separated from other watersheds by a divide.

[This page intentionally left blank]

INTRODUCTION

King County is responsible for several flood and erosion protection facilities in the Middle Fork Snoqualmie River between the community of Tanner (upstream) and the Three Forks Natural Area (downstream) near North Bend, Washington. The County is developing a comprehensive corridor management plan to prioritize and implement future actions to reduce flood and erosion hazards in this 5-mile reach of the river. The Corridor Management Plan will be used by King County to develop a prioritized implementation strategy for near-term and long-term actions for the lower Middle Fork Snoqualmie River with the following objectives:

- Reduce risks to life and property from flood and channel migration/avulsion hazards;
- Improve the natural environment through sound and sustainable flood hazard management;
- Protect and restore fish and wildlife habitat through restoration of riverine processes;
- Reduce the long-term cost of public flood hazard management.

The Corridor Management Plan requires characterization of baseline geomorphic and hydraulic conditions, flood and erosion hazards, and ecological resources in the study reach. One element of this work is the development and calibration of a detailed hydraulic model of the study area. The model will be used to develop hydraulic data necessary as input to flood and erosion hazard evaluations, geomorphic investigations, and aquatic habitat assessments. This report documents the development of the hydraulic model and its use in the flood and erosion hazard assessment. Section 2 of this report describes the hydrology of the Middle Fork Snoqualmie and the development of hydrologic data for use in the hydraulic modeling. Section 3 describes the development and calibration of the hydraulic model. Section 4 describes the application of the model to assess flood and erosion hazards in the study reach.

Watershed Science & Engineering (WSE) performed the work described herein as subconsultant to Herrera Environmental Consultants. Herrera served as a resource to provide continuity with the geomorphic and ecological studies of the Middle Fork Snoqualmie River being conducted for King County by Herrera as part of the corridor management planning effort.

HYDROLOGIC DATA DEVELOPMENT

Hydrology influences the geomorphic character, riparian ecosystem quality, flood hazard, and flood risk along the Middle Fork Snoqualmie River. As such, it is necessary to gain an adequate understanding of the river's hydrology as a basis for corridor plan investigations. The hydrology for the Middle Fork Snoqualmie Corridor Management Plan was based primarily on USGS gage 12141300, Middle Fork Snoqualmie River near Tanner, WA. Flow quantiles were developed using this gage and then used as inputs to the hydraulic modeling to evaluate existing flood and erosion hazards, existing habitat characteristics, and geomorphic conditions. Daily flow data for the Tanner gage were also used to develop information on seasonal flow timing, magnitude, and duration as needed to support aquatic habitat evaluations and other tasks.

Summary of Current and Historical Peak Discharges

USGS gage 12141300 is approximately 7 miles upstream of the upstream limit, has a 52 year period of record starting in Water Year (WY) 1961, and includes data for several very high flow events including November 2006 and January 2009. Flow frequency analyses were conducted on the observed discharge records for the Tanner gage using various theoretical distributions fit to the data. Although the period of record for gage 12141300 is long, an examination was also made to determine if extension of the record to include periods prior to 1961 would capture additional extreme flood events that might affect the upper tail of the frequency distribution, i.e., the estimates of lower-frequency, higher magnitude events. These analyses are described below.

The observed peak discharges for the Middle Fork Snoqualmie River near the Tanner gage are shown in Table 1. The four highest observed discharges, in descending order, occurred in November 2006, January 2009, December 1977, and November 1990. Each of these events had a peak discharge in excess of 30,000 cubic feet per second (cfs) (approximately a 4 percent annual chance flood (25-year return period event) based on previous analyses). Other large flood events are known to have occurred in the Snoqualmie River basin, most notably in November 1959, February 1932, and November 1909. Considering that these events occurred prior to installation of the Middle Fork gage, an analysis was undertaken to determine if any events prior to the gaging period could significantly affect flood quantiles.

Table 1. Observed Peak Annual Flows at USGS Gage 12141300

Date	Discharge cfs	Gage Height (feet)	Date	Discharge cfs	Gage Height (feet)
02/21/1961	14,000	10.5	11/23/1986	28,900	14.68
01/03/1962	11,600	9.66	12/09/1987	15,900	11.31
11/19/1962	22,800	13.14	10/16/1988	23,100	13.29
11/26/1963	9,520	8.9	11/09/1989	24,400	13.63
01/29/1965	15,800	11.05	11/24/1990	30,100	14.97
05/06/1966	6,860	7.82	09/25/1992	11,900	n.a.
12/13/1966	10,900	9.41	01/25/1993	15,900	n.a.
01/20/1968	18,000	11.75	06/14/1994	5,370	7.26
01/05/1969	21,200	12.66	02/19/1995	18,300	12
04/09/1970	8,070	8.33	11/29/1995	27,400	14.35
01/19/1971	12,300	9.91	03/19/1997	15,600	11.22
02/28/1972	15,100	10.83	10/30/1997	15,700	11.24
12/26/1972	16,400	11.28	12/29/1998	18,200	11.97
01/15/1974	16,400	11.26	12/15/1999	18,200	11.99
01/18/1975	24,900	13.67	03/19/2001	5,090	7.05
12/03/1975	23,700	13.37	04/14/2002	14,200	10.76
01/18/1977	11,800	9.72	01/31/2003	14,200	10.76
12/02/1977	30,200	14.93	10/21/2003	18,400	12.03
11/08/1978	9,360	8.84	01/18/2005	22,200	13.07
12/15/1979	18,100	11.79	01/10/2006	10,900	9.61
12/26/1980	21,700	12.82	11/06/2006	31,700	15.32
01/24/1982	18,600	11.93	12/03/2007	14,800	10.91
12/03/1982	18,500	11.91	01/07/2009	31,200	15.22
01/24/1984	20,000	12.35	10/26/2009	12,200	10.05
06/07/1985	10,900	9.42	01/16/2011	22,100	13.03
11/01/1985	17,900	11.71	02/22/2012	14,300	10.76

As listed in Table 2, there are eight USGS gages in the Snoqualmie River basin that provide reasonable sites for comparison with historical peak discharges on the Middle Fork Snoqualmie River near Tanner (USGS gage 12141300). These include long-term gages on the three forks of the Snoqualmie River in addition to the two long-term gages downstream of the confluence of the forks. Data from these gages facilitate an examination of the 52-year record versus longer or older records to determine the likelihood that the Middle Fork has experienced larger events than seen in the observed record at gage 12141300. Note that for purposes of the analyses described herein provisional peak flow data for WY 2012 were included at each of the active gage sites, allowing the analysis at these locations to be extended through 2012.

Table 2. Current and Historical Gages on Various Reaches of the Snoqualmie River

USGS Gage Number	Location	Drainage Basin (sq. miles)	Water Years in Peak Flow Record	Total Years of Record
12141300	MF Snoqualmie near Tanner (RM 10.45)	154	1961-2012	52
12141500	MF Snoqualmie near North Bend (RM 2.67)	169	1909-1910, 1912-1926, & 1930-1932	20
12142000	NF Snoqualmie near Snoqualmie (RM 9.45)	64	1930-1956 & 1959-2012	81
12143000	NF Snoqualmie near North Bend (RM 2.17)	95.7	1909-1912, 1914-1920, 1922-1926, 1930-1938, & 1961-1978	43
12143400	SF Snoqualmie near Garcia (RM 17.35)	41.6	1961 -2012	52
12143600	SF Snoqualmie at Edgewick (RM 9.05)	65.9	1964-1965 & 1984-2011	30
12144000	SF Snoqualmie at North Bend (RM 2.87)	81.7	1946-1950, 1961- 1978, & 1985-2011	75
12144500	Snoqualmie near Snoqualmie (RM 38.08)	375	1959-2012	54
12149000	Snoqualmie near Carnation (RM 21.87)	603	1930-2012	83

As shown in Table 2 there are six active gages that span the period since 1961, including the Tanner gage (USGS 12141300). Of these six gages, three have 75 years or more of peak flow data. Comparing the Tanner gage data to these longer-term sites we observe that the four largest flow events at the Tanner gage are among the top five events in the 75 year record of flows on the South Fork Snoqualmie River at North Bend. The only other flood in the top five at that site occurred in 1975, when the Tanner gage reported its seventh highest flood. Three of the four largest events in the Tanner record (2009, 2006, and 1990) rank as the three largest events in the 83 year record at the Carnation gage. The fact that the largest events recorded in the 52 year record on the Middle Fork are also the largest events in the longer records at other basin gages increases our confidence that these events adequately capture the magnitude of high flows in this basin.

However, it was still felt to be informative to extend the Tanner gage record to include floods prior to 1961. While it is not possible to build a complete record of pre-gage flows it is relatively straightforward to extend the Tanner gage record to include an additional 20 years based on the data from the Middle Fork near North Bend gage (USGS gage 12141500). Data from this gage

were transposed to the Tanner site using the ratio of basin areas (USGS, 1998). This resulted in a 72-year record that included all significant floods (i.e. top 10 events) in the basin since 1909 with the possible exceptions of 1951 and 1959. Data for those events would have had to be derived from the downstream gages at Snoqualmie or Carnation. Since those gage records could not be reliably parsed to the three forks, transposition of main stem data was not attempted. Furthermore, the 1959 and 1951 events were only the 5th and 8th largest events on the nearby North Fork gage near Snoqualmie (the only gage on any of the forks for which data for these events is available) indicating that inclusion of the 1951 and 1959 events would only have a moderate impact on flood frequency analyses. Therefore, despite the missing data for two relatively large flood events, the frequency analysis of the 72-year extended record was felt to provide a reasonable evaluation of the effects of including events prior to installation of the Tanner gage.

Flood Frequency Analysis

Several previous flood frequency analyses have been conducted recently for the Middle Fork Snoqualmie River near Tanner - USGS Gage 12141300 (King County 2009, NHC 2010, and NHC 2011). The County's analysis was completed shortly after the large flood in January 2009 and covered the period WY 1961-2009. The NHC analyses extended the analysis first through WY 2010, and subsequently to include WY 2011. The current analysis extends the period of record to include WY 2012 and also evaluates extending the record back in time using data transposed from the earlier Middle Fork Snoqualmie River near North Bend gage (USGS gage 12141500). Available observed maximum annual peak flow data for gage 12141300 are summarized in Table 1.

In their 2009 analysis, the County fit the gage data using a Log Pearson Type III distribution and the methods of Bulletin 17B (IACWD, 1982). The work by NHC extended the period of record but also evaluated various alternative flood frequency distributions. NHC found that while several of the theoretical distributions do a reasonable job of fitting the data, the Bulletin 17B methodology tends to overestimate flood quantiles. NHC found that the 3-Parameter Lognormal Distributions appeared to be slightly superior to the others in terms of their match to the observed data. NHC's final flood flow quantiles (Table 3) were based on the 3-Parameter Lognormal distributions fit using the method of Maximum Likelihood.

Using the observed flow record for gage 12141300, and the record extension based on gage 12141500, flood frequency quantiles were estimated again using the methods of Bulletin 17B and the same alternative distributions tested by NHC. The results of these analyses are shown in Table 3 and plotted in Figures 1 and 2. As can be seen in Table 3, adding one additional year to the record (2012) does not have a very significant effect on the results. The estimated 1 percent annual chance flood (100-year event) is 35,400 cfs and the estimated 50 percent annual chance flood (2-year event) is 16,800 cfs. These values are within 1 percent of the values estimated by NHC in 2011. Extending the record back in time using gage 12141500 results in a 3 percent increase in the estimate of the 1 percent annual chance flood (100-year event) (36,300 v. 35,400 cfs) and a 9 percent decrease in the estimate of the 50 percent annual chance flood (2-year event) (15,300 v. 16,800 cfs). Essentially, what happens is that the central portion of the frequency distribution is lower causing a slight upward rotation in the upper tail resulting in a slightly higher 1 percent annual chance flood (100-year event)estimate even though the highest flow added to the extended record (November 1909) is only the 8th highest flow in the composite record. Considering these results, and recognizing that data transposition increases uncertainty

in the results, we recommend using the observed Tanner record without extension with the 3-Parameter Lognormal distribution for frequency analyses for this project.

In addition to the recent flood frequency analysis results Table 3 also shows the flood flow quantiles from the effective FEMA study for the Middle Fork (HRI, 1995). FEMA flood flows were reported for a location near the Mount Si Bridge (just downstream of the Tanner gage) and at the mouth. Note that the current estimate of the 1 percent annual chance flood (100-year event) is significantly lower than the value at the Mount Si Bridge reported in the 1995 FEMA study. Supporting documentation for the FEMA hydrology is not available so the reasons for this difference could not be investigated. However, all of the recently completed flood frequency analyses have resulted in similar estimated flow quantiles, increasing our confidence in the values used in this study.

Table 3. Flood Flow Quantiles for Middle Fork Snoqualmie River

Annual Percent Chance Exceedance	Return Period	FEMA 1995		KC 2009 [1]	NHC 2010 [2]	NHC 2011 [2]	WSE 2012 [2,3]	WSE 2012 [2]
		at Mount Si Bridge	at Mouth	Near Tanner 1961-2009	Near Tanner 1961-2010	Near Tanner 1961-2011	Near Tanner 1961-2012	Near Tanner 1909-2012
		(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)
99	1.01-year						4,400	4,300
50	2-year			16,700	16,900	16,900	16,800	15,300
20	5-year			23,200	22,900	22,800	22,700	21,500
10	10-year	28,000	26,900	27,100	26,400	26,300	26,100	25,300
4	25-year			31,600	30,400	30,200	30,100	29,900
1	100-year	43,800	38,600	37,400	35,700	35,500	35,400	36,300
0.2	500-year	55,800	46,900	43,300	41,300	41,000	41,000	43,400

Notes:
[1] Log Pearson Type III Distribution using Methods of Bulletin 17B
[2] 3-Parameter Log Normal Distribution using Method of Maximum Likelihood
[3] Recommended flood frequency quantiles for use in the hydraulic analyses in this study

Additional Hydrologic Analyses

In addition to the estimation of peak flow quantiles, USGS daily streamflow data for gage 12141300 for the period October 1, 1961 through August 15, 2012 were obtained and uploaded to a hydrologic database. Using these data an annual flow duration analysis was conducted with the results shown in Figure 3. The flow duration analysis shows the portion of each year that flows exceed a specified threshold. This information can be useful for evaluating geomorphic conditions and/or aquatic habitat issues in the study reach. It should be noted that the bottom x-axis in Figure 3, labeled "Percent chance exceedence", indicates the percent of the historical period that the specified flow rate is exceeded (e.g. a 1% exceedence flow would be exceeded 1% of the time or, *on average*, about 3.65 days per year [or about 90 hours per year as shown in the upper x-axis in Figure 3]). In reality, each year will be different and some years will have more than 3.65 days above the specified flow while others may not reach this flow level at all. This is quite different from the lower x-axis in Figures 1 and 2, which are also labeled "Percent chance exceedence". In the case of annual frequency analysis this term refers to the percent chance that the specified flow level is exceeded for any amount of time in a given year (e.g. a 1% chance exceedence flow has a 1 percent (1 in 100) chance of being exceeded in any given year, hence this is commonly termed a 100-year flood).

HYDRAULIC MODEL DEVELOPMENT

WSE developed a two-dimensional (2D) hydraulic model covering approximately five miles of the Middle Fork Snoqualmie River extending from about 300 feet upstream of its confluence with the North Fork Snoqualmie River to approximately a half mile upstream of where the river flows alongside SE North Bend Way near Tanner. The downstream study limit was selected to include all areas where detailed hydraulic information is desired while excluding the North Fork confluence and hydrologic and hydraulic complexities associated with this area. The upstream limit was defined at a location where flow is generally uniform, which is required to ensure accurate hydraulic modeling at the upstream end of the study reach. The model domain included sufficient area in the overbanks to capture significant side channels, potential avulsion paths previously identified (Herrera 2013), and flow that would be lost from the Middle Fork to the South Fork or North Fork Snoqualmie River. Figure 4 shows the extents of the model domain.

The model was created to analyze river characteristics for flows ranging from the 99 percent annual chance flood (1.01-year event) of 4,400 cfs to the 0.2 percent annual chance flood (500-yr event) of 41,000 cfs and was developed using the June 2012 build of RiverFLO-2D Version 3.0. RiverFLO-2D is a numerical model developed and supported by Hydronia, LLC and is able to simulate hydrodynamics in 2D space throughout the model domain by routing flow over ground topography represented by a triangular mesh. Details of the model's development are described below.

Topographic Surface Development

The 2D model geometry was developed using the following data:

- Lidar topographic coverage (2010)
- Aerial photograph (2010)
- Existing cross sections spaced about 500 feet apart (closer in some key areas like bridge crossings and bends) obtained from King County (2010)
- Bathymetric data in the low area near and behind the Lower Norman Levee provided by King County (2012)
- Top and toe survey of the actively eroding bend near the Mason-Thorson Extension Levee (2011)

The topographic surface for the RiverFLO-2D model was developed by combining an interpolated bathymetric channel surface with the 2010 lidar coverage which was found to provide an accurate and sufficiently refined representation of the channel banks, larger in-channel islands and gravel bars, and the floodplain. The channel topography was produced by delineating and then interpolating between 1 foot elevation contours that were drawn using information from the survey data and the lidar data as well as WSE's and King County's best engineering judgment regarding in-channel topographic features in this reach. Points from the lidar just outside the interpolation boundary were used in the creation of the channel topography as well to create a smooth transition between the interpolated surface and the lidar. Spline interpolation was used and produced a channel bed surface that adequately represents the measured data and known features and characteristics of this river. Figures 5 - 7 illustrate the topographic surface creation

process showing contours delineated between surveyed cross sections (Figure 5), the interpolated surface (Figure 6), and the final composite surface that includes the interpolated channel and the surrounding ground surface taken from the lidar data (Figure 7).

Computational Mesh Development

A conceptual model consisting of "feature arcs", or polylines delineating features in the channel and on the floodplain, was developed using Aquaveo's Surface-water Modeling System (SMS) interface. This conceptual model guided the creation of the triangular mesh used by the RiverFLO-2D model to delineate the ground topography. Feature arcs were drawn along significant features such as channel bank and toe, bars, side channels, topographic breaks and roads, as well as the locations of obvious changes in roughness (e.g. bed material, bank vegetation, etc.). These arcs acted as breaklines during the creation of the mesh and helped produce a mesh that follows the physical topography and accurately represents the elevations of key features. From the network of connected arcs, polygons are automatically created and occupy the interior space between the arcs. Each polygon was then assigned a preliminary Manning's "n" roughness value, based upon aerial photography, on-site field inspection, and professional judgment.

The arc network and resulting mosaic of interior polygons also provide the means for developing the computational mesh of nodes and elements. Specifically, vertices of the feature arc polylines can be redistributed within SMS to a user-defined spacing. These vertices become computational nodes in the model, with the line segments between each node forming one triangular side of an element. Patches of triangular elements are then formed or "meshed" within each polygon, resulting in a complete computational mesh throughout the model domain. The spacing and distribution of the vertices along each arc determines the overall computational density or refinement of the final mesh. The level of refinement of the topographic mesh (i.e. the spacing of nodes and size of the elements) was an important consideration in the creation of the 2D model because it affects the stability of the model, the results, and the computation time of a simulation. Finer elements may increase the stability and accuracy of the model while capturing more detail in the topography, but also increase the time required to complete a simulation. Considerable testing and sensitivity runs were conducted to develop a mesh density that is accurate and highly refined where necessary (e.g. along channel features and possible future project areas) and less refined in other areas such as the outer floodplain so as to not unnecessarily increase computational time. Elements in the main channel and the side channels are relatively fine and had triangle edge lengths (i.e. node spacing) of 10 feet. Elements in the floodplain were increasingly coarser further from the channel, with edge lengths between 15 and 150 feet. Elements near the edge of the model boundary that were rarely activated and a significant distance away from potential project areas were generally the largest as illustrated in Figure 8.

Boundary Conditions

By default, the exterior boundary of the 2D computational mesh is assumed to be closed to inflows or outflows unless specified otherwise. Open flow boundaries, which permit flow to pass into or out of the model domain, were therefore required along the model boundaries at the upstream and downstream ends of the main channel as well as at areas where water could potentially flow out of the model boundary over the floodplain. The upstream channel boundary condition at the inlet is specified in terms of river discharge, the downstream channel boundary

condition at the outlet is specified as stage (water surface elevation) information, and the floodplain boundary conditions are defined assuming uniform flow (normal depth) at the boundary based on the general slope of the ground perpendicular to and adjacent to the edge of the model boundary (see Figure 4). Figure 9 shows the stage-discharge rating curve used to estimate water surface elevations for the downstream channel boundary based upon selected inflows at the upstream boundary. This curve is unique to the cross-section where the edge of the model boundary crosses the river (at River Mile [RM] 0.06 defined by King County, referenced relative to RM 0.0 being at the confluence with the North Fork) and was obtained from a HEC-RAS hydraulic model of this area developed by Northwest Hydraulic Consultants in 2010. The discharges and associated return periods used in this study were taken from the flood frequency analysis described in Section 2. These are indicated on Figure 9.

Model Calibration

Provisional discharge data reported by the USGS at the gage near Tanner, WA for the event that occurred on May 15, 2012 (4,200 cfs) along with high water marks set and surveyed by King County were used for low flow model calibration (low in this case being defined as flows below the 2-year event). The County observed and recorded the water surface elevations at 15 locations along the project reach during this event. Five other flows and associated surveyed water surface elevation observations were used as verification events to supplement the information from this event for the calibration including the following: 5,600 cfs (4 observations), 1,200 cfs (10 observations), 950 cfs (1 observation), 900 cfs (5 observations), and 850 cfs (2 observations).

A separate high flow calibration, for events equal to or exceeding a 2-year event, was also performed. As discussed below this was done because preliminary runs using the model calibrated to low flows did not do a good job of matching high water mark data for larger flood events. A short period of record of stage data (December 2010 – present) is available from a USGS gage at the Mount Si Road Bridge. These data, as well as data based on photos and videos of several larger flood events and past observations by King County staff and basin residents were used to perform the high flow calibration.

Stage data available at the Mount Si Road Bridge includes the January 2011 flood event, which had a peak discharge of 22,100 cfs. Additional high flow data are also available for the large flood events of November 2008, January 2009, and December 2010. The January 7, 2009 event had a peak flow of 31,200 cfs (approximately equal to a 25-year event) at the Tanner gage. Four high water marks were estimated from photographs or anecdotal information from this the flood (i.e. locations of levee overtopping, recollections about water depths in the floodplain, etc.). A second event for which high water marks were derived occurred on December 12, 2010 and had a peak flow of 12,500 cfs at the Tanner gage. Three high water marks were estimated for this event based on field observations and photographs taken by WSE during the rising limb of the event. The locations of observed high water marks for these two events are on or near the Mason-Thorson Extension Levee (RM 1.5), which is an area where the river channel, banks, and bars have been actively evolving over the last several years. Because of the changes in channel geometry occurring in this area it is somewhat difficult to know the exact topographic conditions that existed at the time of the floods. Nevertheless, these anecdotal high water marks provided valuable information about how well the high flow calibrated model simulated larger flood events. Photos from a third event that occurred on November 12, 2008 and had a magnitude of

27,500 cfs provided additional information about flood flows near the Mason-Thorson Ells Levee (RM 2), an area of the study reach that has remained relatively unchanged over the last several years (Herrera 2013). One high water mark was estimated near the downstream end of this levee.

A well-calibrated 2D model is generally considered to be one that simulates water surface elevations at calibration points within ±0.5 feet of the measured values. Differences of this magnitude can be attributed to various factors including:

1. waves that cause fluctuations in actual water levels especially at higher flows
2. localized topographic or hydraulic conditions finer than the resolution of the model
3. errors in flow estimates (the USGS considers flow estimates within ± 5 percent of actual flows to be excellent)
4. uncertainty inherent in identifying high water marks along the channel after a flood event or from historical photos.

Initial (low flow) Model Calibration

For each calibration event, the RiverFLO-2D model was run in transient (unsteady) mode using a fixed time step to route flows over an initially dry bed using the preliminary Manning's "n" roughness values assigned during the creation of the conceptual model. Using a fixed time step as opposed to a variable time step, which is also an option in RiverFLO-2D, minimizes uncertainty that may be introduced in a model with a continually changing time step. The "unsteady" model was run until steady-state conditions were attained throughout the model, under constant boundary conditions for each event simulated. Preliminary values were set for numerical parameters including: the time step increment DT, the selective lumping parameter EPSILON (determines the smoothness of depth and velocity gradients), and the minimum nodal depth limit HMIN (defines the water depth below which a node is considered dry). Repeated simulations were conducted during the calibration process to identify the best roughness values and numerical parameters within reasonable limits for this model. Adjustments to these values were made until the model simulated water surface elevations as close as possible to the calibration data and reasonably close to the verification data. Note that Manning's "n" (roughness) is a parameter that typically encompasses many forms of roughness including bed roughness, internal friction, variations in the shape and size of the channel, obstructions, and river meanders. By using a mesh to define the topography, 2D models are able to capture some of these items that 1D models cannot, namely the shape and size of the channel, obstructions, and river meanders. As a result, Manning's "n" values in a 2D model can be 30 percent lower than those normally used for 1D models (Hydronia, 2012).

Figure 10 shows the final distribution of Manning's "n" values throughout the low flow model domain. Note that the roughness of the main channel bed decreases from upstream to downstream reflecting decreases in average bed material size and average channel slope along the reach. In the upper reaches, the larger bed material has a significant effect on low flows in the channel. Increased resistance as well as flow blockage from large boulders (Figure 11) is incorporated into the higher channel "n" value for the upper reach.

Table 4 shows the measured and simulated water surface elevations at each location (see Figure 4 for map) observed during the low flow event of 4,200 cfs and the difference between the two

values (Difference = Simulated – Observed). Note that this model was calibrated based on data associated with a relatively low discharge (less than the mean annual flow), and is therefore only valid for comparably low in-channel flows.

Table 4: Calibration Results for Low Flow Calibration Event (4,200 cfs).

King County Observation Location ID	River Mile / L or R Bank	Observed Water Surface Elevation (ft)	Simulated Water Surface Elevation (ft)	Difference (ft)
HWM-WA-MFS-002	0.39 / R	421.6	421.5	-0.1
HWM-WA-MFS-004	0.47 / R	420.8	421.7	+0.9
HWM-WA-MFS-006	0.65 / R	422.8	423.2	+0.4
HWM-WA-MFS-008	0.73 / R	424.0	424.3	+0.3
HWM-WA-MFS-010	0.94 / R	428.9	429.0	+0.1
HWM-WA-MFS-012	0.98 / R	428.8	429.3	+0.5
HWM-WA-MFS-005	1.38 / L	435.8	435.4	-0.4
HWM-WA-MFS-003	1.45 / L	436.0	436.3	+0.3
HWM-WA-MFS-001	1.51 / L	438.2	438.7	+0.5
HWM-WA-MFS-007	1.58 / L	440.6	440.4	-0.2
HWM-WA-MFS-009	1.93 / L	445.2	445.2	+0.0
HWM-WA-MFS-011	2.07 / L	452.7	452.9	+0.2
HWM-WA-MFS-013	2.17 / L	453.8	455.0	+1.2
HWM-WA-MFS-015	2.82 / L	471.2	471.3	+0.1
HWM-WA-MFS-017	4.35 / L	521.1	521.0	-0.1

Note: The table lists the observations in order starting with the most downstream point and moving upstream.

Of the 15 observations above, 13 are simulated within ±0.5 feet of the measured values, which indicates a well-calibrated 2D model. HWM-WA-MFS-004 is located about 450 feet upstream of both the 428th Avenue SE Bridge and HWM-WA-MFS-002; however, the measured water surface elevation at HWM-WA-MFS-004 is 0.8 feet lower than that of HWM-WA-MFS-002. Because of this, confidence in the accuracy of the measured value at HWM-WA-MFS-004 is low and the high simulation error at this location was discounted. Throughout the low flow calibration process, RiverFLO-2D consistently simulated HWM-WA-MFS-013 one foot or more above the measured value. The modeled topography at this location was presumed accurate given the general quality of the data and the model results were stable at this location, so the simulation error at this location could not be easily explained. It is possible that the mark was set or surveyed incorrectly or that some localized feature affected the observation but was too small to be captured by the model. Regardless, the good fit to the other 13 observation points gives confidence in the low flow model calibration.

High Flow Model Calibration

Since it was not possible to match anecdotal high water mark data for large flood events using the model with main channel Manning's *n* values calibrated to the low flow event, a separate high flow model calibration was conducted. The justification for this separate calibration was the observation that, at least within the upstream steeper portion of the study reach (subreach MF2), the large boulders in the main channel become fully submerged (i.e. washed out) at higher flows and are thus hydraulically less significant (i.e. have less impact on cross sectional area and roughness) which results in a lower apparent Manning's "n" value.

The high flow model calibration attempted to achieve the best match to available high water mark data while maintaining simulated Froude numbers within reasonable limits. Generally it is expected that Froude numbers in the main channel would not exceed 1.0 (flow would not become supercritical for extended reaches). This threshold for natural river channels with mobile beds has been cited by several authors (Grant, 1997; Trieste, 1992). These authors' observations indicate that as Froude numbers approach or exceed 1.0 the associated high flow velocities dissipate energy through additional turbulence or cause channel enlargement (scour) such that supercritical flow is not seen over extended reaches.

The high flow model calibration kept the same Manning's "n" value below RM 1.1 (Confluence and MF1a Subreaches) as was determined from the low flow calibration (0.02). The size of the bed material in these reaches is smaller than that seen in the reaches above RM 1.1 and therefore there is less justification for lowering Manning's "n" values at higher flows. Manning's "n" values for the high flow calibration in the reach between RM 1.1 and RM 2.3 (subreaches MF1b and part of MF2) were reduced from the low flow calibration values (0.03 or 0.045) to a value of 0.02. All high water marks and anecdotal information available for this reach, including data along the Mason-Thorson Extension and Mason-Thorson Ells levees, support the reduced "n" values. In particular, this value was required to match the County's observation that the Mason-Thorson Ells levee did not overtop during the flood events in November 2008 and January 2009. Even with the lowered Manning's "n" value, simulated Froude numbers in this reach were maintained within reasonable limits.

Upstream of RM 2.3 to RM 2.6 in subreach MF2 the Manning's "n" value was adjusted to 0.03 to keep Froude numbers below 1.0 and limit maximum velocities. There are no high water mark data available for calibration within this reach but the generally larger nature of the bed material supports the increased "n" value relative to the downstream subreaches. Between approximately RM 2.6 to 3.1, the Manning's "n" value was varied within a range of 0.02 and 0.03. The stage information from the USGS gage at the Mount Si Bridge was used in conjunction with simulated main channel Froude numbers to set these values.

Upstream of RM 3.1 in subreach MF2, the roughness of the channel bed was decreased from the low flow calibrated value of 0.045 to a value of 0.035 for the high flow calibration. Since there are no high flow high water mark observations available in the main channel in this reach, the "n" value was set based on anecdotal evidence of high water marks observed in side channels across from the Tanner revetment (RM 3.8). Evidence observed in these side channels suggests that water surface elevations for the largest event during water year 2012 (January 2012 event of 14,300 cfs) was approximately bankfull in the side channel (Wozniak, personal communication, 2013). Setting the main channel Manning's "n" value in the model to 0.035 allows the model to match this observation. Manning's "n" values lower than about 0.035 in this reach resulted in a poorer match to the side channel data as well as unreasonably long extents of supercritical flow.

It should be noted that the model still shows a few locations with Froude numbers exceeding 1.0, particularly for nodes near the channel centerline. However, Froude numbers along the banks in these areas are much lower than 1.0 and average cross-sectional Froude numbers generally remain below 1.0. Correspondence via e-mail with Reinaldo Garcia (the lead developer of the RiverFLO-2D model) suggests that his modeling experience on other projects shows that it is not uncommon to find localized areas with high Froude numbers like this.

Figure 12 shows the final distribution of Manning's "n" values established during the high flow model calibration, which is to be used for flood events greater than about 12,500 cfs (including the 50 percent annual chance flood (2-year event) of 16,800 cfs). Table 5 shows the simulated and observed water surface elevations for the four flows used to calibrate the high flow model and the associated differences (Difference = Simulated – Observed). Additional outputs from the RiverFLO-2D model are provided in Appendix A. These include cross sectional plots of flow velocities and Froude numbers at ¼ mile increments along the study reach as well as longitudinal profiles of these data plus bed slope, friction slope, depth, and shear stress.

Table 5: Calibration Results for High Flow Events.

ID #	Flow (cfs)	Year of Event	Location	Anecdotal WSEL (ft)	Simulated WSEL (ft)	Difference (ft)
1	12,500	2010	Gravel bar in channel across from Mason-Thorson Extension Levee[1]	442	442	0
2			Near camera on Mason-Thorson Extension Levee[1]	443.5	443.3	-0.2
3			In woods on floodplain in low area behind Mason-Thorson Extension Levee[1]	443.5	443.6	+0.1
4	27,500	2008	Downstream end of Mason-Thorson Ells Levee[2]	453.5	453.5	0
5	31,200	2009	Levee overtop on Mason-Thorson Extension Levee[1]	448	448.1	+0.1
6			Upstream of Mason-Thorson Extension Levee[1] overtop bank	448	448.9	+0.9
7			Driveway of house directly behind Mason-Thorson Extension Levee[1]	447	448	+1.0
8			Storage tank behind Mason-Thorson Extension Levee[1]	445.5	447.3	+1.8
9	22,100	2011	Mount Si Bridge Gage	478	478.9	+0.9

[1]Mason-Thorson Extension Levee (RM 1.5)
[2]Mason-Thorson Ells Levee (RM 2)

Of the 9 calibration points, 5 are simulated within ±0.2 feet of the anecdotal high water marks, 3 are simulated within ±1.0 feet, and one point on the floodplain is simulated 1.8 feet too high. The high water mark at the downstream end of the Mason-Thorson Ells Levee (ID #4 in Table 2) should be quite reliable since it is located in an area of the river that has remained relatively stable for the past several years. Table 5 shows the simulation error at this location to be zero. High water marks 1, 2, and 5 are all located in areas where the channel has not changed much and all have low simulation errors. High water marks 6, 7, and 8 have the highest errors but are all located along the same breakout flow path behind the eroding bank (see Figure 13) near the Mason-Thorson Extension levee. High water mark 3 is also located near the Mason-Thorson Extension levee, but is upstream of the levee along a different flow path.

The calibration points in the vicinity of the Mason-Thorson Extension Levee (RM 1.5) were taken from two different flood events that occurred in 2009 and 2010. The channel near this levee has been actively eroding for the past several years (Herrera 2013). Figure 13 shows the approximated bank edge at this location in 2008, 2010 and 2011 as well as the locations of anecdotal high water marks and their corresponding ID numbers from Table 5. The calibration points with the largest simulation errors are all located near or landward of the eroding bank,

which may be the reason for the large differences between simulated and observed values at this location. Calibration point 9 is considered very reliable as it comes from a USGS gage. Manning's "n" values at and near this area were adjusted to the extent possible to match this high water mark reasonably well while maintaining predominantly subcritical flow. The high flow model is considered to be reasonably well calibrated since simulation errors for high water marks in areas where the channel is stable (which should be the most reliable) are reasonable.

Flood and Erosion Hazard Assessment

The hydrologic data described in Section 2 were used as input to the RiverFLO-2D hydraulic model described in Section 3 to analyze hydraulic conditions on the Middle Fork Snoqualmie River study reach. Data from the modeling were used together with a GIS coverage outlining homes and large buildings on the floodplain to characterize flood and erosion hazards as described below. In addition to generating baseline hydraulic data, the model provides a tool that can be used in the future to quantify hydraulic conditions associated with potential floodplain management actions, allowing comparisons of post-project conditions to the baseline information described below.

Flood Hazard Assessment

Flood events corresponding to the 10 percent, 4 percent, 2 percent, 1 percent, and 0.2 percent annual chance exceedance (i.e., the 10-, 25-, 50-, 100-, and 500-year floods) were simulated with the hydraulic model. Table 6 shows the corresponding flows for each of these events. Plates 1 through 5 (provided at the end of the report) show the resultant simulated water surface elevations and Plates 6 through 10 show the flow depths for each of the simulated flood events (note that each plate is divided into a northern portion (Confluence, MF1a, and MF1b Subreaches) and a southern portion (MF2 Subreach) to allow the data to be plotted at a larger scale than would fit on a single page). Note that small isolated areas of water may be present in some figures. The RiverFLO-2D method that determines which nodes are wet and which ones are dry includes a parameter (HMIN) which defines the depth below which nodes are considered dry. This value must be greater than zero (Hydronia, 2012). The developers of RiverFLO-2D suggest a value of 0.3 feet (Hydronia, 2012), however, the models developed for this study set HMIN equal to 0.1 feet allowing nodes with a depth greater than 0.1 feet to be considered (and therefore displayed) as wet. In areas where flow is very shallow and close to the value of HMIN, small isolated areas of water may be displayed in the results, suggesting a small amount of flow with depth less than 0.1 feet is being conveyed to these spots.

Table 6: Flows Simulated for Flood and Erosion Hazard Assessment

Annual Percent Chance Exceedance	Return Period	Middle Fork Snoqualmie River Near Tanner 1961-2012 (cfs)
10	10-year	26,100
4	25-year	30,100
2	50-year	32,800
1	100-year	35,400
0.2	500-year	41,000

As can be seen in Plates 1 through 10 flow in subreach MF2 is generally contained within the main channel up to and including the 10 percent annual chance flood (10-year event, 26,100 cfs). However, there is one area along the right bank near RM 2.6 just upstream of the Mason-Thorson Ells Levee that starts to overtop at about the 10 percent annual chance flood (10-year event) and may threaten several residences. Also, there are two large side channels to river right of the main channel near RM 4.1 that would carry flow during the 10 percent chance flood event.

In subreach MF1 some flow exits the channel during the 10 percent annual chance flood (10-year event) and low lying areas of the floodplain are inundated. The first significant areas of breakout flow occur between the Mason-Thorson Ells and Mason-Thorson Extension Levees. Although much of the flooding in this area is confined to low lying flat areas on the left bank near the channel, the modeling indicates that some flow would leave the main river near the Mason-Thorson Extension Levee (RM 1.5) and travel generally towards the northwest then north eventually rejoining the river at Reid Slough. Simulated floodplain depths for the 10 percent annual chance flood (10-year event) are less than 4 feet deep in almost all locations and less than 2 feet in many places. The major side channel near the left bank of the main channel just downstream of the Mason-Thorson Extension Levee would also convey flow during the 10 percent annual chance flood (see Plate 6a). Simulated depths in this channel are 4 to 10 feet deep. Some flow would break out of the side channel towards the northwest and ultimately join the flow from upstream entering Reid Slough. Flows in Reid Slough rejoin the Middle Fork Snoqualmie River near its confluence with the North Fork. Areas on the floodplain between the major side channel and Reid Slough would generally experience flow depths less than 2 feet in the 10 percent annual chance flood (10-year event) although the floodplain swales near 428th Avenue SE could reach depths of 4 to 6 feet. While the model results for the 10-year event indicate that overbank flow would be mostly contained in floodplain swales and low lying areas, up to 67 residences may be at risk of some flooding in this event[1].

Simulations of the 4 percent annual chance flood (25-year event) show that floodwaters would occupy areas along the left bank upstream and downstream of the Mount Si Bridge near RM 2.8. Some of this flow would break out overland towards the northwest, eventually reaching the SE 120th Street floodplain channel (described further in Herrera [2013]). Flows in this floodplain channel would travel westerly towards the South Fork Snoqualmie River. The model shows that approximately 30 cfs would exit the model domain towards the west near SE 120th Street. The area along the right bank near RM 2.6 sees more flow in the 4 percent annual chance flood (25-year event) and may threaten nine additional residences.

In subreaches MF1a and MF1b the 4 percent annual chance flood (25-year event) shows similar patterns of flooding on the left bank floodplain to that seen in the 10 percent annual chance flood but with more widespread flooding up to 2 feet deep and some floodplain depths as much as 6 feet. Although the greatest flow depths are still in floodplain swales and undeveloped low lying areas, a total of 115 structures or residences are in the mapped 25-year floodplain. Like the rest of the area in these subreaches the large side channel north of the Mason-Thorson Extension Levee would see greater flows and more flow would breakout towards the northwest.

---

[1] Data on finished floor elevations are not available. The analysis of homes at risk of flooding compared the building footprints to the mapped inundation limits and identified each home in the flooded area as "at risk" of flooding. In actuality, some of these homes may be constructed with finished floors above the simulated water surface elevation and would therefore not flood.

Depths in the floodplain would range from 0 to 4 feet, and nearly 8 feet deep in the floodplain swales in the 25-year event.

Plates 3 through 5 and 8 through 10 show simulated water surface elevations and flood depths for the 2 percent (50-year event), 1 percent (100-year event), and 0.2 percent (500-year event) annual chance floods, respectively. The same patterns of flooding seen in the 10 percent (10-year event) and 4 percent (25-year event) annual chance floods are repeated in these simulations although (as expected) each increase in flood quantile shows greater depths and areas of inundation on the floodplain. Major differences observed in the simulated floodplain inundation during these larger, less frequent flood events are as follows:

- Overtopping of the Mason-Thorson Ells Levee near its downstream end (near RM 2.0) starts at the 2 percent annual chance flood (50-year event) and shows significant overtopping in the 1 percent and 0.2 percent annual chance floods (100-year and 500-year events). Overtopping of the levee further upstream, near RM 2.1, is seen in the 1 percent and 0.2 percent annual chance flood (100-year and 500-year events) but even in those floods the amount of flow leaving the main channel at this location is minor. It is worth noting that all hydraulic modeling conducted for this study assumed that the existing levees were in place and did not breach. Levee breaches or removal could dramatically alter the amount of flow on the floodplain. It is anticipated that potential modifications to the levees will be evaluated in a future phase of work.

- Overtopping of the left bank upstream of the Mason-Thorson Ells Levee near RM 2.4 is not seen in the 10 percent chance flood but begins with the 4 percent chance flood and becomes substantial for the 2, 1 and 0.2 percent annual chance floods (50-, 100-, and 500-year events). Flood waters overtopping the bank here would enter the SE 120th Street floodplain channel and flow toward the South Fork Snoqualmie River. The flood depth mapping shown in Figures 9b and 10b indicates that 38 to 56 structures may be at risk of flooding from these breakout flows in the 1 and 0.2 percent annual chance floods, respectively.

- Flooding on the right bank of the river upstream of the Mason-Thorson Ells Levee near RM 2.6 gets progressively worse at the higher return periods and more homes are in or near the simulated inundation area. Fourteen to 15 residences may be at risk of flooding in this area in the 1 percent and 0.2 percent annual chance exceedance floods, respectively.

- A third remnant side channel on the right bank near the upstream end of the model at RM 4.2 sees flow in all simulated flood events but the depths do not appear to threaten any structures until the 4 percent annual chance flood (25-year event). Flow in this side channel during smaller events could, however, isolate (i.e., create an island around) at least one residence.

- Five residences along 428th Avenue SE near the Middle Fork Bridge (RM 0.4) would be at risk of inundation in both the 10 percent annual chance flood (10-year event) and the 1 percent annual chance flood (100-year event).

Table 7 summarizes the number of homes and large buildings in the Middle Fork Snoqualmie River study reach that would be at risk of flooding for each event analyzed. As noted in the footnote on page 24 it is not possible to say if any of these buildings are elevated out of the floodwaters

but the modeling indicates that at a minimum the building footprints would be subject to inundation.

The 1 percent annual chance flood (100-year event) is particularly important with regard to floodplain management. The model predicts that 167 homes and large buildings are at risk of inundation by flood waters from the Middle Fork Snoqualmie River during this event. Flow (up to 4 feet in depth) overtops three arterial roads: 428th Avenue SE, NE 12th Street, and SE Mount Si Road as well as several smaller roads that run through North Bend. Significant flow breaks over the right bank in subreach MF1a (see Plate 9a) and flows north, sending about 500 cfs toward the North Fork Snoqualmie River in the 1 percent annual chance flood.

Table 7: Number of Homes and Large Buildings Potentially Inundated During Flood Events

Annual Percent Chance Exceedance	Return Period	Middle Fork Snoqualmie River Near Tanner 1961-2012 (cfs)	Number of Homes / Large Buildings Inundated [1]
10	10-year	26,100	67
4	25-year	30,100	115
2	50-year	32,800	162
1	100-year	35,400	167
0.2	500-year	41,000	194

Note: [1] Homes/structures delineated using King County Assessor data and 2011 aerial photo

Depth-Velocity Hazard and Public Safety on the Floodplain

Public safety is a significant concern associated with flooding. In addition to inundation, high flow velocities in the floodplain can also create significant public safety hazards. To provide an assessment of depth-velocity hazards to people, areas of deep and/or fast flowing water were delineated using information developed by the US Bureau of Reclamation (USBR). The USBR's classification guidelines for hazard areas downstream of dams (USBR, 1988), includes depth-velocity hazard curves for various age groups. For this study the depth-velocity hazard curve for children was used. The tail ends of the curve were truncated (i.e. all areas with depths above 3 feet or velocities above 3 feet per second were included in the depth-velocity hazard area). The curve was then linearized to facilitate numerical analysis; the final depth-velocity hazard curve is shown in Figure 14. Areas that meet this definition of depth-velocity hazard are mapped on Plates 11 through 15. King County code also includes regulations to restrict development within areas of both deep and fast water, where depths are greater than 3 feet and velocities are greater than 3 feet per second (KCC 21A.24.240). Development within the floodplain fringe requires a base flood depth and velocity analysis to determine which areas might be subject to restrictions under KCC 21A.24.240. These areas were also delineated based on the hydraulic model results as shown on Plates 11 through 15.

The depth-velocity hazard maps in Plates 11 through 15 identify areas that are likely to be particularly hazardous for people and infrastructure. It should be noted that areas adjacent to the mapped depth-velocity hazard areas might still have flow depths approaching 3 feet deep (see Plates 6 – 10) which could still be hazardous, however these do not meet the criterion used herein. While most areas within the main channel and significant side channels meet the deep and/or fast flowing hazard criteria, the information for the overbank floodplain is perhaps more

useful. Deep and fast hazard areas on the floodplain are generally limited, and confined to the northern half of the study reach (MF1a, MF1b Subreaches) in the 10 percent annual chance flood (10-year event) while these areas cover a much broader portion of the study area in the 0.2 percent annual chance flood (500-year event). Areas subject to regulation under KCC 21A.24.240 are mostly confined to the main channel and large side channels – e.g. very few areas on the floodplain have both depths greater than 3 feet and velocities greater than 3 feet per second.

To quantify the depth-velocity hazards in the study area, the number of homes and large buildings that fall within areas identified as deep and/or fast flowing water (based on the graphic in Figure 14) were calculated for each flood event analyzed. Table 8 summarizes the results of this analysis. Of the 167 homes and large buildings that lie within the simulated inundation area of the 1 percent annual chance event (100-year flood), 33 of them (20 percent of the inundated structures) are within the mapped depth-velocity hazard area. This number increases to 50 (30 percent of the inundated structures) for the 0.2 percent annual chance event (500-year flood).

Table 8: Number of Homes and Large Buildings Within Depth-Velocity Hazard Areas

Annual Percent Chance Exceedance	Return Period	Middle Fork Snoqualmie River Near Tanner 1961-2012 (cfs)	Number of Homes / Large Buildings in Depth-Velocity Hazard Area[1]
10	10-year	26,100	1
4	25-year	30,100	9
2	50-year	32,800	25
1	100-year	35,400	33
0.2	500-year	41,000	50

Note: [1] Homes/structures delineated using King County Assessor data and 2011 aerial photo

Erosion Hazard Assessment

Erosion hazards for the existing channel condition were evaluated using velocity and shear stress data generated with the RiverFLO-2D hydraulic model. Plates 16 through 20 show velocity magnitude and direction for the 10 percent through 0.2 percent annual chance floods (10-year through 500-year flood events).

Review of the simulated flow velocity data shows the following:

1. Average in-channel velocities in the southern portion of the study area (MF2 Subreach) are as high as 15 feet per second (fps) in the 10 percent annual chance flood (10-year event) and range as high as 16.5 fps in the 1 percent and 0.2 percent annual chance floods. The highest point velocities (up to 25 fps) are generally concentrated near the center of the channel and velocities along the banks are typically much lower than in the center of the channel. Simulated velocities near the bank are typically less than 6 fps in the 10 percent annual chance flood (10-year event) and less than 8 fps in the 1 percent annual chance flood (100-year event). Velocities show greater variation in wider reaches of the river, for example near the Mason-Thorson Ells Levee at RM 2.0, but even at this location the center of the main channel still sees point velocities in excess of 18 fps.

2. Average in-channel velocities in the northern portion of the study area (MF1a and MF1b Subreaches) range from 4 to 10 fps in the 10-year event and up to 11 fps in the 1 percent

annual chance flood (100-year event). The lowest average in-channel velocities (4-6 fps) occur at the upstream end of the Mason-Thorson Extension Levee, just downstream of this levee, and at the gravel bar near RM 0.7. Similar to subreach MF2, the highest point velocities (up to 18 fps at RM 1) are concentrated near the center of the main channel in straight reaches while velocities near the banks are generally much lower (4 fps or less). The channel geometry is more complex in the downstream subreaches and therefore velocities vary more in those subreaches. Also note that RiverFLO-2D ignores turbulence terms when solving the governing equations (Hydronia, 2012), which may affect the lateral distribution of simulated velocities in areas of the river where high turbulence may be present such as at RM 1.9 just downstream of the Mason-Thorson Ells levee.

3. Simulated overbank velocities are high (up to 10 fps) in major side channels (see side channels near RM 0.8, RM 1.6, and RM 1.95 on Plate 19c and RM 3.5 and 3.8 on Plate 19d) but are generally low (less than 2 fps) throughout the broader floodplain. There are, however, a few locations near existing residential development where velocities may be as high as 4 fps in the 1 percent chance exceedence event. These include near 446th Ave SE south of 132nd Street, near 428th Ave SE and SE 104th Street, and near SE 102nd Street approximately 0.2 miles west of 428th Ave SE (see plates 19c and 19d).

It should be noted that the velocity magnitudes simulated in the model for the channel might be overestimated somewhat for reasons described at the end of the following section.

Significant bank erosion has been observed at several places along the main channel in the study reach. These include a location on the left bank near the upstream end of the Mason-Thorson Extension Levee at RM 1.5 and a location on the left bank just downstream of the Mason-Thorson Ells levee near RM 1.9. While neither of these locations showed especially high velocities in the hydraulic modeling (velocities near both were less than about 8 fps) both of these locations are very complex hydraulically. The Mason-Thorson Extension levee creates a hydraulic constriction at its downstream end which has likely contributed to the formation of the large gravel bar across from the levee, which in turn has directed flow towards the left bank exacerbating bank erosion (NHC, 2011). At Mason-Thorson Ells there is a large gravel bar across from the levee, a bedrock outcrop from the right bank just downstream of the levee, and deep pool in the main channel just downstream of RM 1.9. The erosion appears to be related to flow eddies resulting from the complex hydraulics created by the levee/bar/scour pool. Both of these sites will likely be the subject of further analysis during evaluation of corridor management alternatives. It is interesting to note that much of the reach between the Mason-Thorson Ells and Mason-Thorson Extension levees (RM 1.55 to RM 1.85) is comprised of a straight, somewhat incised, single thread channel that is quite different from the complex bar and side channel geometries at the two levees. The channel planform in this reach is likely a result of the constrictions imposed by the two levees. Simulated flow velocities in the channel in this reach are as high as 23 fps in the 1 percent chance exceedence event, as compared to maximum velocities in the range of 8 – 18 fps at the two levees.

Review of Erosion Hazard Data

Based on the modeled velocities the Middle Fork Snoqualmie River, particularly in subreach MF2, carries high energy during large floods. Despite this, review of planform data (Herrera, 2013) shows that the channel in this subreach has remained stable for many years, indicating that the high velocities have not led to significant widespread bank erosion. It is particularly interesting

that the unprotected outside banks of several meander bends have not eroded. The reason that these banks have remained so stable is not exactly clear. However, there are several factors that we believe play a role in this, as follows:

1. Revetments or levees exist along the outside bank of nearly half of the meander bends. These include the Tanner Road Revetment, Mount Si Bridge, and Mason-Thorson Ells Levee. We believe that these revetments, particularly the Tanner Road revetment along the old railroad grade (RM 3.8 to 4.1) have played a significant role in the observed lateral stability of the channel. The hydraulic modeling indicates that the overall effect of these anthropogenic features also tends to reduce hydraulic complexity and concentrate high velocities towards the center of the channel, reducing stress on the banks.

2. The geomorphic field data collection (Herrera, 2013) suggests that in several locations the channel has incised itself into glacially derived material, which contains relatively large boulders. These boulders tend to armor the channel bed and banks, providing a level of natural protection against erosion along the toe of the banks.

3. Where the river has incised, most flow is contained within the channel even during large floods (Herrera, 2013). This containment increases the discharge intensity (energy per unit width), which increases the stream's ability to transport sediment. Subreach MF2 is a transport reach; large active bars are not present and the bars that do exist remain small and stable.

4. Existing revetments also decrease the local input of sediment from the outside of bends in the MF2 Subreach. The lack of local sediment input contributes to the absence of large bars, which allows the swiftest flows to be concentrated near the center of the channel rather than being pushed toward the banks, which would lead to greater bank erosion.

Each of the reasons cited above may play a role in limiting bank erosion and channel migration in the southern portion of the study area (subreach MF2). However, the contribution of each is not well understood. The lack of significant bank erosion and channel migration in subreach MF2 may warrant further investigation. Additional field work and analysis (in particular at RM 3.3 on the right bank, and RM 3.0 and RM 2.45 on the left bank) would be helpful to improve our understanding of the absence of significant historical bank erosion in this reach. Additional field work might include velocity measurements and depth soundings during floods and bed material sampling and observation before and after large flood events.

In the northern portion of the study area downstream from about RM 2.0 (Confluence, MF1a, and MF1b Subreaches), the channel planform has not remained as stable as in subreach MF2. There are several reasons for this, including:

1. The slope of the channel decreases in the vicinity of RM 1.6. This reduces velocities and therefore, a portion of the coarse sediment that is transported through the upstream reach deposits here. The large bars and subsequent channel instabilities that have persisted just upstream from the Mason-Thorson Extension Levee (RM 1.5 to 1.7) are directly related to this deposition. The model output velocity plots also reveal that the downstream end of the Mason-Thorson Extension Levee together with the opposite valley wall at the base of Mount Si form a hydraulic constriction, which backwaters and slows upstream velocities during large floods. This anthropogenic impact appears to play a

significant role in growth of the gravel bar immediately upstream and therefore the lateral movement of the channel.

2. Downstream from the Mason-Thorson Extension Levee, the river maintains a relatively straight alignment for approximately one-half mile as the channel flows along the base of Mount Si. This appears to be a relatively stable reach which tends to transport most sediment (Herrera 2013). However, if it were not for the downstream end of the Mason-Thorson Extension Levee directing the flow toward and along the base of Mount Si, we would expect the river in this reach to be much more laterally active. Remnant channel scars and recent river alluvium adjacent to the active channel along the left floodplain are clear evidence that the channel formerly naturally migrated within this zone.

3. Between RM 1 and RM 0.6, sediment deposits have formed large in-channel bars and, as one would expect, channel migration and lateral movement has been much more active than in other locations.

4. Downstream from RM 0.6, the river bends to the left and the outside bank of the bend is protected by the Lower Norman Levee, which has prevented lateral channel migration. As shown by the modeled velocity plots (Plates 16 through 20), velocities within this reach can be quite high during major floods and therefore, lateral erosion potential would be high as well if not for the bank treatment.

It should be noted that there are some areas where the RiverFLO-2D model simulates very high localized velocities (for example near RM 1.8, RM 2.7, and RM 3.25). The highest simulated velocities are seen near RM 2.7 with a maximum of about 25 fps (the maximum Froude number at this location reaches 1.2 in the center of the channel, indicating the potential for supercritical flow near the channel centerline). This reach of the river is steep and has a relatively confined channel, so it is assumed reasonable to have small pockets of supercritical flow, especially near the channel centerline. As noted earlier it is possible that the channel enlarges in these areas during periods of high flow (and perhaps infills again on the receding limb or between flood events). However, without field velocity measurements or depth observations during large floods it is not possible to say if modeled velocities are accurate or there is some other phenomena at play during high flow events.

In recent modeling of the North Fork Nooksack River in Whatcom County by Herrera for another project, a RiverFLO-2D model produced what were interpreted to be artificially high velocities in major floods due to flow “skimming” over an aggraded bed composed of substrate material of a size range that would be expected to mobilize during such high energy flow. In that river incision of the bed likely occurs in flood events, expanding the flow cross sectional area and reducing velocities; but the fixed bed model could not capture those dynamic changes in cross-sectional area and thus overpredicted velocities in localized areas within the model (I. Mostrenko, personal communication, April 9, 2013). Despite the possibility that the model is overestimating velocities in some isolated locations, potential velocity anomalies in the Middle Fork Snoqualmie River model appear to be limited in extent and thus do not have an undue influence on predicted flooding.

SUMMARY AND CONCLUSION

Watershed Science & Engineering developed and calibrated a 2-dimensional RiverFlo-2D hydraulic model for a reach of the Middle Fork Snoqualmie River extending from just upstream of the confluence with the North Fork Snoqualmie River to a location near Tanner, a distance of approximately 4.25 miles. King County is preparing a Corridor Management Plan for the Middle Fork Snoqualmie River to develop a prioritized implementation strategy for near-term and long-term actions intended to:

- Reduce risks to life and property from flood and channel migration/avulsion hazards;
- Avoid or minimize environmental impacts of flood hazard management on fish and wildlife habitat and other environmental resources;
- Protect and restore fish and wildlife habitat through restoration of riverine processes;
- Reduce the long-term cost of public flood hazard management.

The hydraulic model is being used to generate data for use in characterization of baseline geomorphic and hydraulic conditions and ecological resources in the study reach. The model was also used to evaluate flood and erosion hazards in the study area as described in Section 4 of this report. The evaluation showed that up to 167 homes could be at risk of flooding in the 1 percent chance flood (100-year event) and that as many as 33 of these would be in areas of deep and or fast flowing water. Simulations of the 10 percent thorough 0.2 percent chance exceedance floods (10-year event through 500-year event) show between 67 and 194 homes subject to inundation. Simulations of the 10 percent chance flood showed 1 home in the depth-velocity hazard zone while simulations of the 0.2 percent chance flood showed up to 50 homes might be subject to deep and/or fast flowing water.

Model results indicate that flow velocities in the floodplain would be 4 fps or less, although a few large swales show localized velocities of up to 6 fps or more. Simulated centerline velocities within the main channel range as high as 25 fps (at RM 2.7) in the 1 percent chance flood (100-year event) and show substantial variation from an average of about 10 fps downstream of RM 1.6 to 14-20 fps upstream of RM 1.9. Variations are particularly large in areas where the channel widens. Simulated velocities near the main channel banks range from 0 to 14 fps depending on location and event but are generally less than about 8 fps in most locations. These velocities can create significant localized stresses on the channel banks resulting in bank erosion as seen near the downstream end of the Mason-Thorson Ells Levee and upstream of the Mason-Thorson Extension levee. However, in general the channel planform is relatively stable, particularly in subreach MF2 in the southern half of the study area.

In addition to providing data to support baseline characterizations, the model provides a tool that can be used in future work to quantify hydraulic conditions associated with potential floodplain management actions allowing comparisons to baseline conditions. Potential actions such as levee modifications or setbacks, side channel reconnection projects, bank protection, and habitat restoration projects incorporating large woody debris or other significant hydraulic roughness features all lend themselves to analysis with the model. As such, the model should provide a useful tool for evaluating and refining project proposals and improving river and floodplain management along the Middle Fork Snoqualmie River study reach.

REFERENCES

Grant, Gordon E., February 1997, "Critical Flow Constraints in Mobile-bed Streams: A New Hypothesis", Water Resources Research, Volume 33, Issue 2, pages 349-358

Herrera, 2013. "Geomorphic Assessment, Middle Fork Snoqualmie River, Tanner to Three Forks Natural Area." Report prepared for King County Department of Natural Resources and Parks, River and Floodplain Management Section by Herrera Environmental Consultants, Inc., Seattle, WA.

HRI, 1995. "Preliminary Middle Fork Snoqualmie River Flood Study." Report by Harper Righellis, Inc. for King County Surface Water Management Division, Seattle, WA. (As referenced in the King County 1996 report).

Hydronia, 2012. "RiverFLO-2D v3 Two-Dimensional Finite-Element River Dynamics Model User's Guide".

King County, 2009. "Flood Frequency Analysis for the Middle Fork Snoqualmie River at USGS gauge 12141300 for the period of Water Years 1961-2009". King County Department of Natural Resources, Surface Water Management Division, River Management Section, Seattle, WA.

King County Code, 2013, available online at: http://www.kingcounty.gov/council/legislation/kc_code.aspx

NHC, 2011. "Middle Fork Snoqualmie River, Mason-Thorson Extension Levee Erosion/Avulsion Final Report." Prepared for King County Department of Natural Resources and Parks, River and Floodplain Management Section by Northwest Hydraulic Consultants, Seattle, WA.

Trieste, D., 1992, "Evaluation of Supercritical/Subcritical Flows in High Gradient Channels", Journal of Hydraulic Engineering, Volume 118(8), pages 1107-1118

US Bureau of Reclamation, December 1988. "ACER Technical Memorandum No. 11 - Downstream Hazard Classification Guidelines."

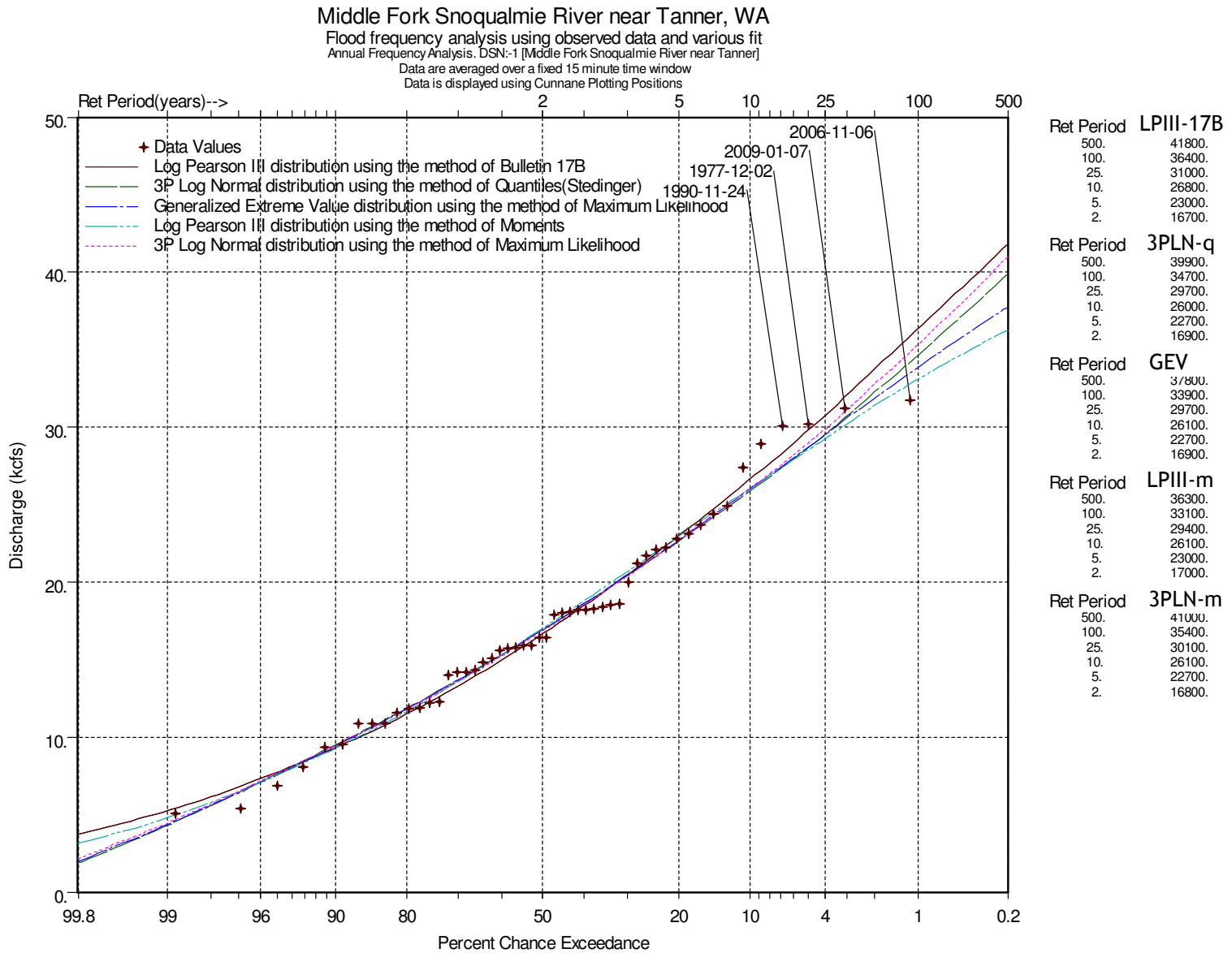
US Geological Survey, 1998. "Magnitude and Frequency of Floods in Washington, Water Resources Investigations Report."

US Interagency Advisory Committee on Water Data, 1982. "Guidelines for Determining Flood Flow Frequency." Bulletin 17-B of the Hydrology Subcommittee: Reston Virginia, US Geological Survey, Office of Water Data Coordination.

FIGURES

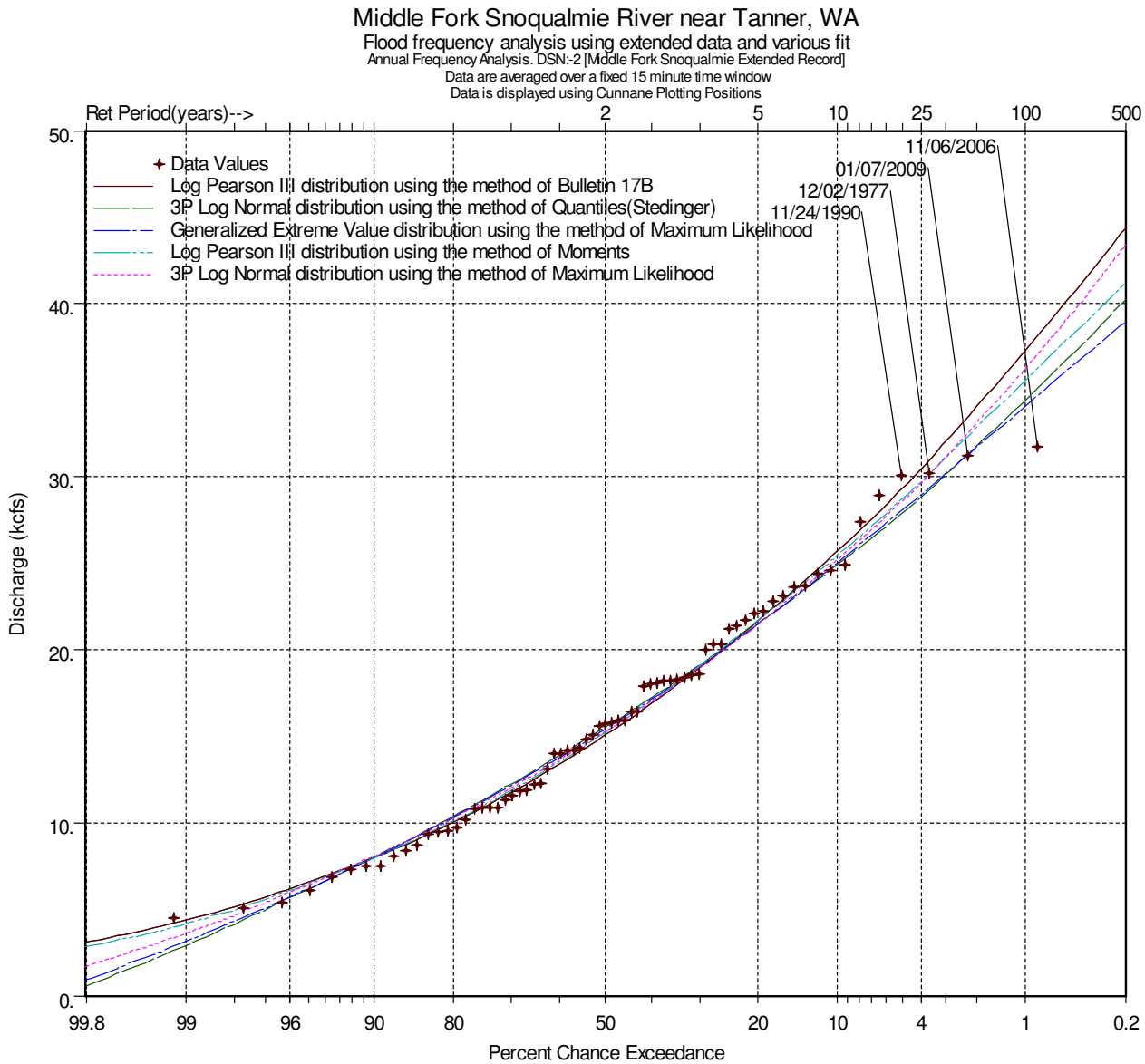
[This page intentionally left blank]

Figure 1: Middle Fork Snoqualmie River Flood Frequency Analysis (observed data record)



[This page intentionally left blank]

Figure 2: Middle Fork Snoqualmie River Flood Frequency Analysis (extended data record)



Ret Period	LPIII-17B
500.	44400.
100.	37400.
25.	30700.
10.	25800.
5.	21700.
2.	15100.

Ret Period	3PLN-q
500.	40200.
100.	34500.
25.	29100.
10.	25000.
5.	21500.
2.	15500.

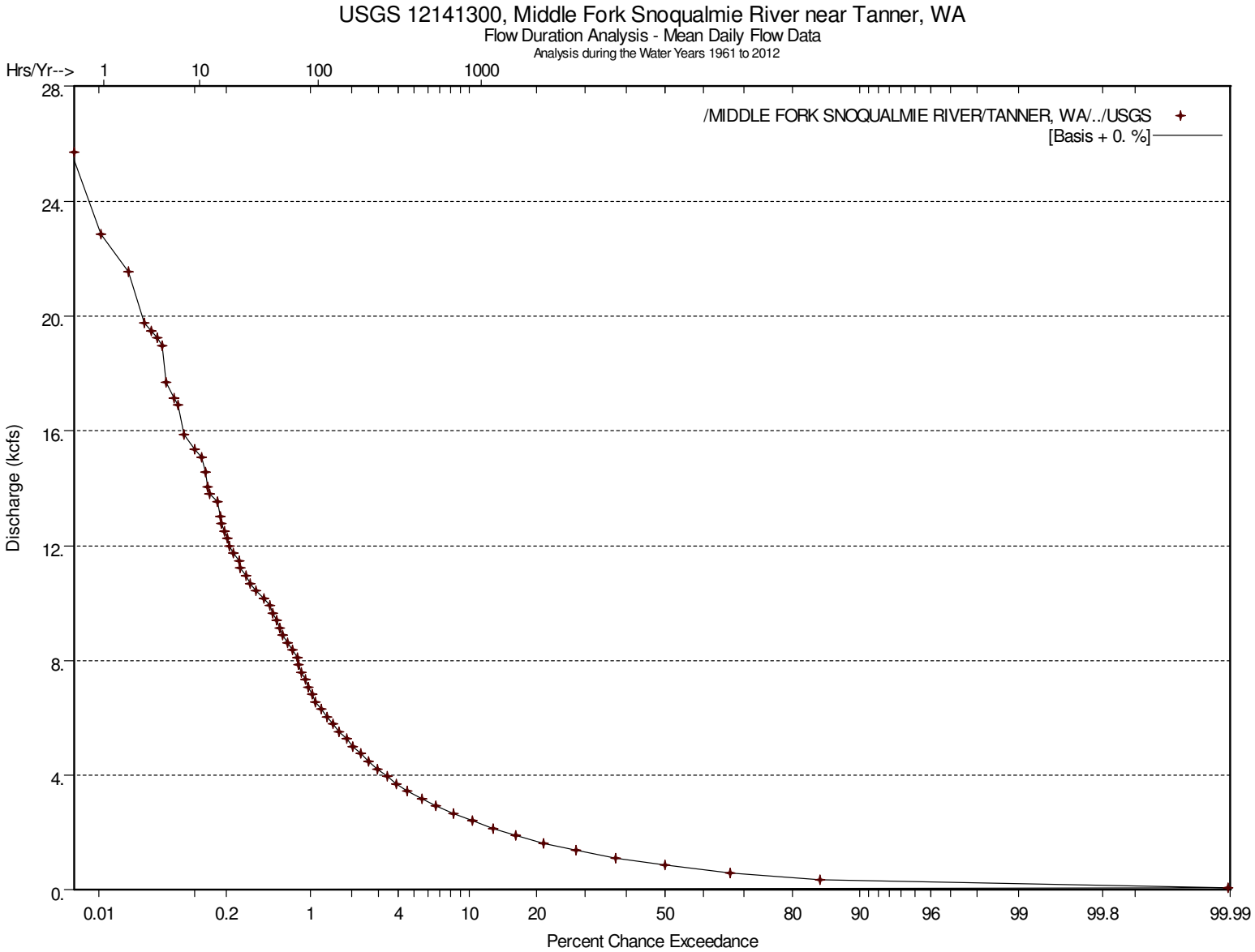
Ret Period	GEV
500.	39000.
100.	34100.
25.	29200.
10.	25100.
5.	21500.
2.	15400.

Ret Period	LPIII-m
500.	41200.
100.	35600.
25.	30000.
10.	25600.
5.	21700.
2.	15200.

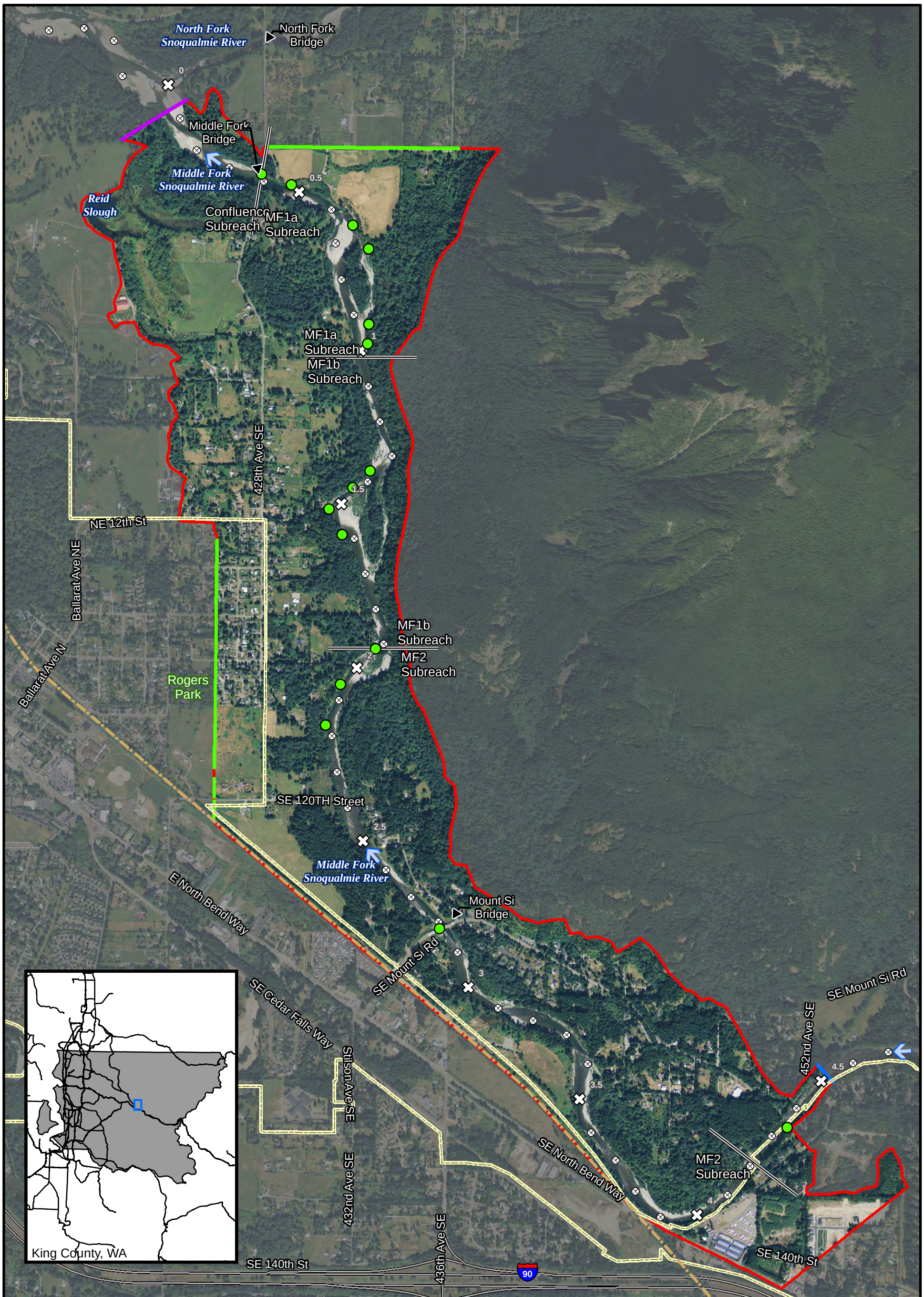
Ret Period	3PLN-m
500.	43400.
100.	36300.
25.	29900.
10.	25300.
5.	21500.
2.	15300.

[This page intentionally left blank]

Figure 3: Middle Fork Snoqualmie River Flow Duration Analysis Using USGS Mean Daily Flow Data



[This page intentionally left blank]



Legend

- Low Flow Calibration Point
- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Flow direction
- Highway
- City of North Bend boundary
- Model Extents
- Model Extent Location

Boundary Conditions

- Inlet - Discharge
- Outlet - Water Surface Elevation
- Floodplain - Normal Depth

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Figure 4. Extents of the 2D model created for the Middle Fork Snoqualmie River

N

0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Figure4_Model_Extents.mxd (7/12/2013)

[This page intentionally left blank]

Figure 5: Survey data and delineated elevation contours (feet)

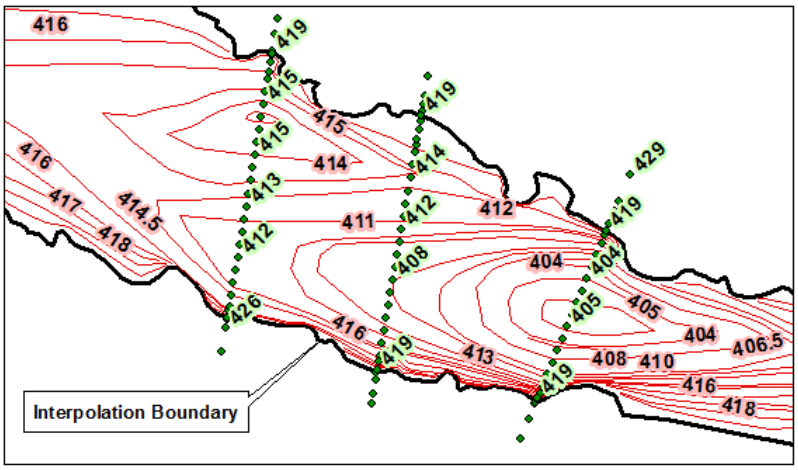


Figure 6: Interpolated channel bathymetric surface (elevations in feet)

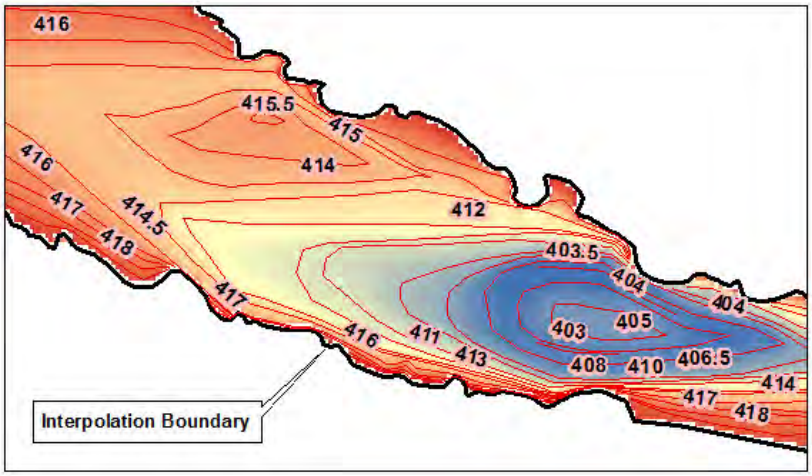
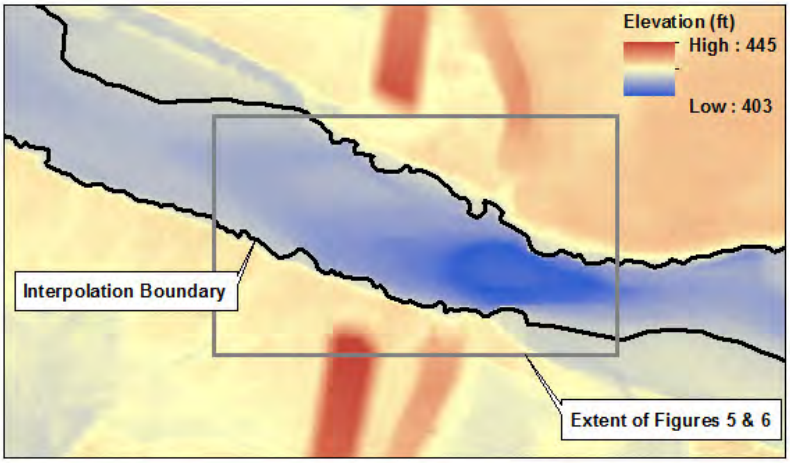
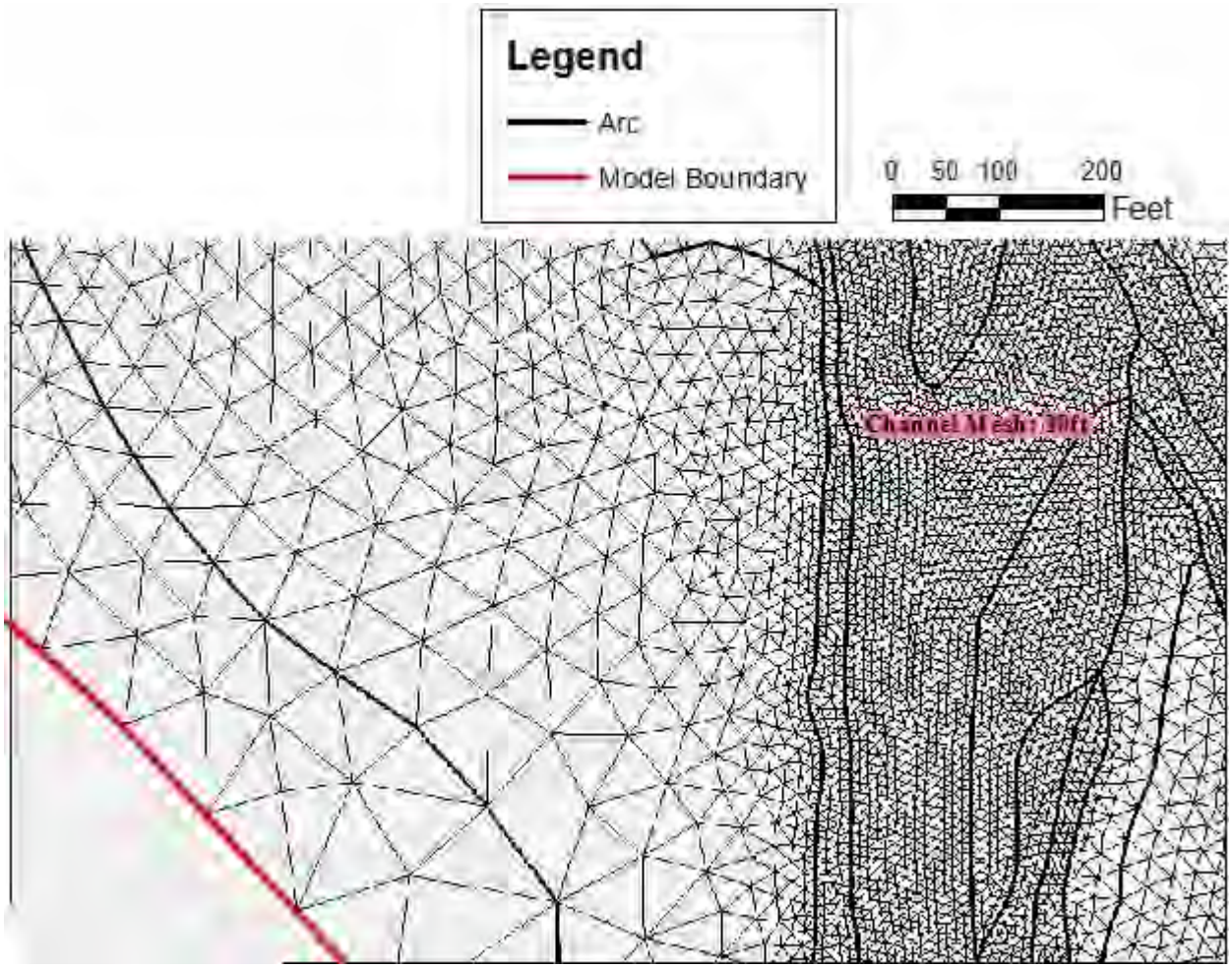


Figure 7: Composite topographic surface (note difference in scale from Figures 5 and 6)



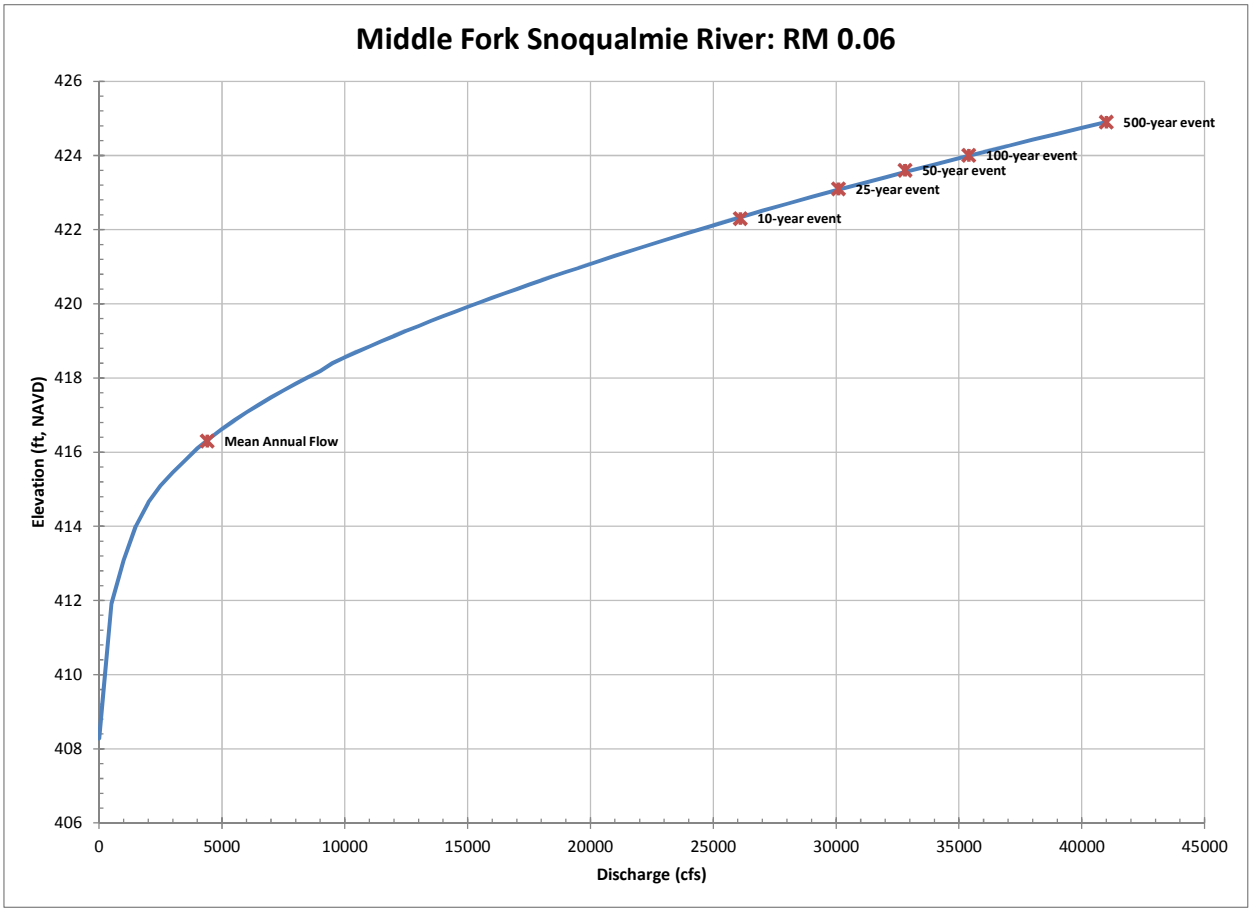
[This page intentionally left blank]

Figure 8: Example of relative mesh sizes.

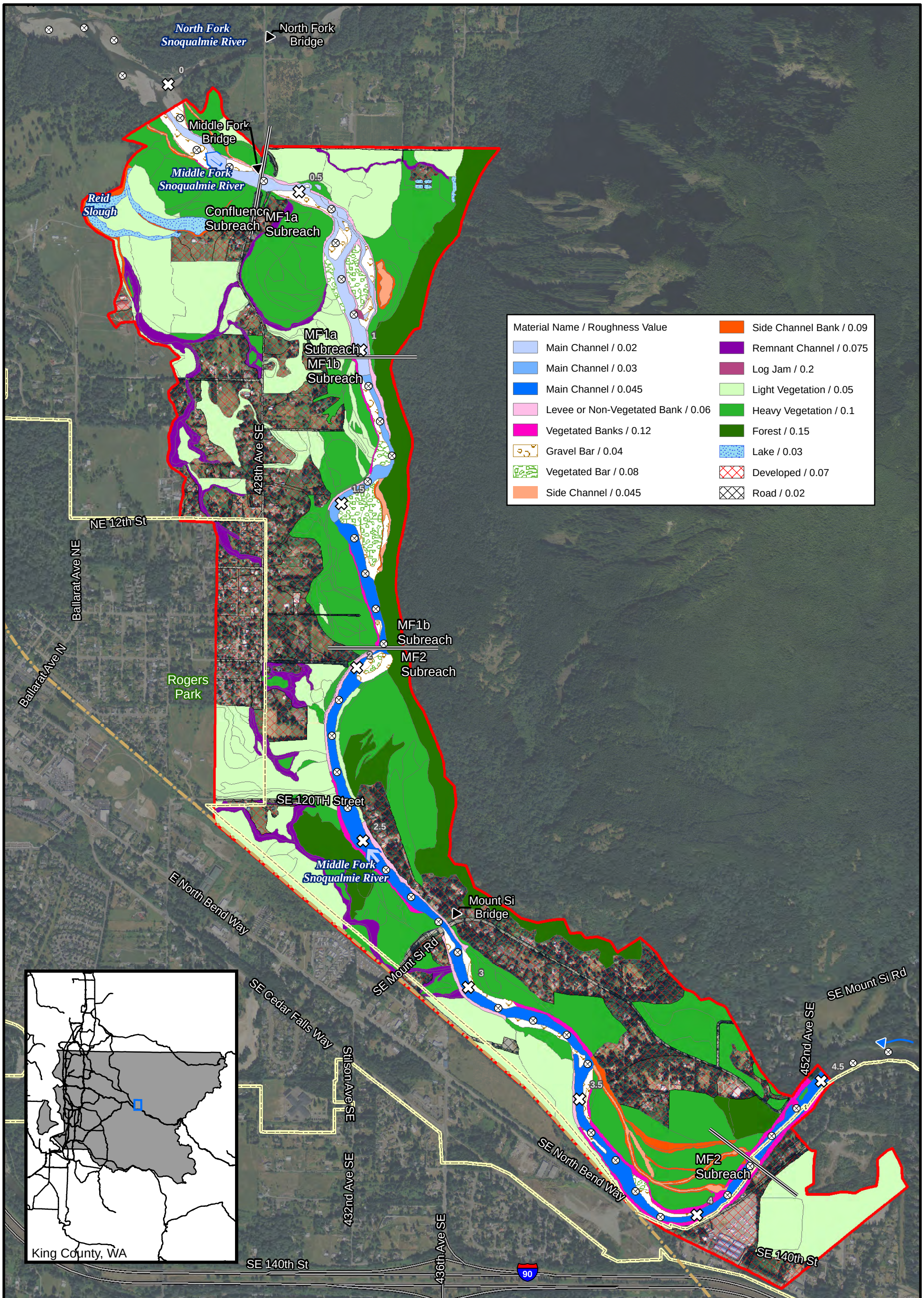


[This page intentionally left blank]

Figure 9: Stage-Discharge Rating Curve for the Snoqualmie River at River Mile (RM) 0.06



[This page intentionally left blank]



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents
- Model Extent Location

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Figure 10. Distribution of Manning's n throughout the low flow model domain

N

0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

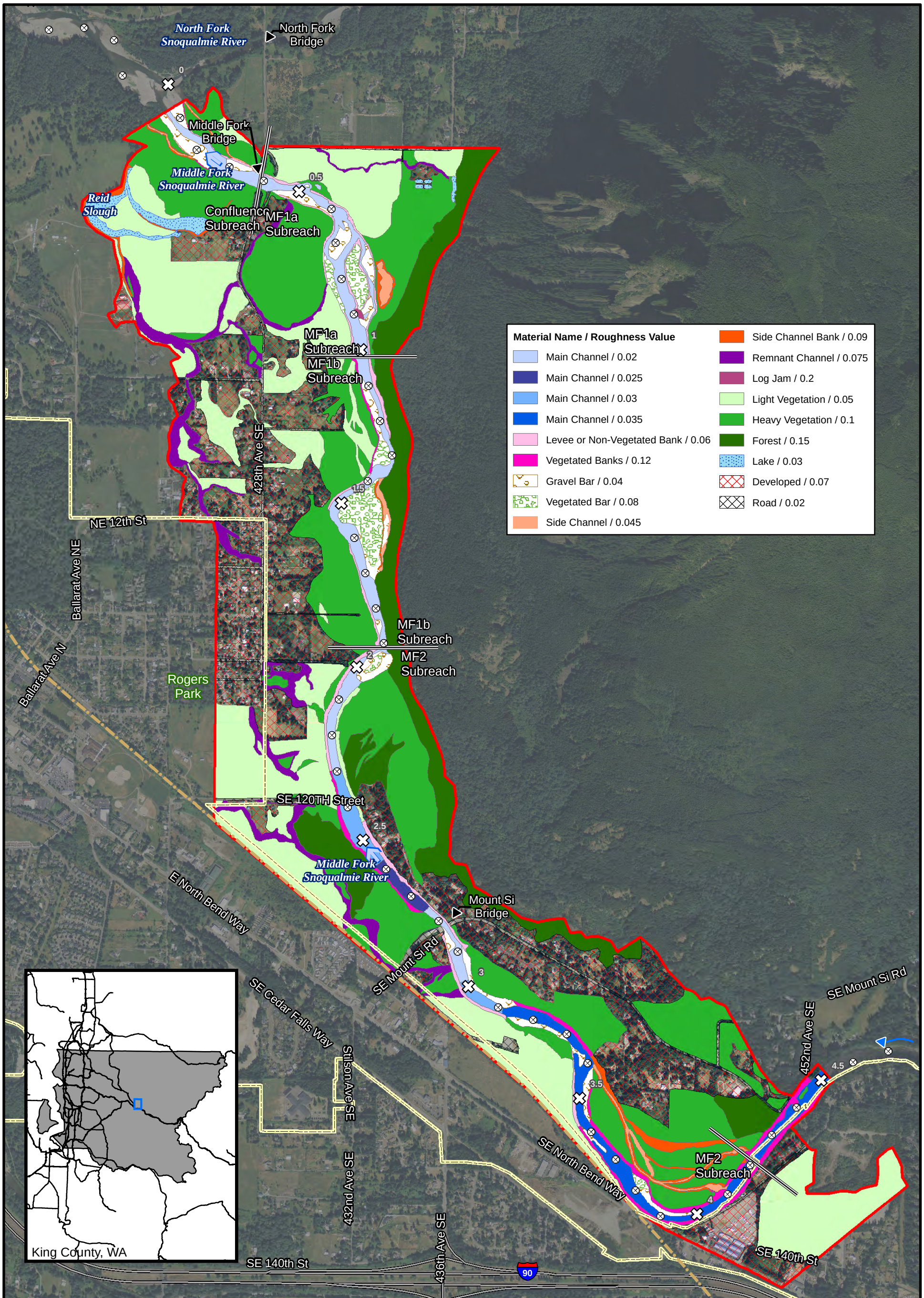
Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Figure10_Roughness_Low_Flow.mxd (7/1/2013)

[This page intentionally left blank]

Figure 11: Photo of the upstream end of the model near Tanner showing large boulders

[This page intentionally left blank]



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents
- Model Extent Location

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Figure 12. Distribution of Manning's n throughout the high flow model domain

0 450 900 1,800 Feet

N

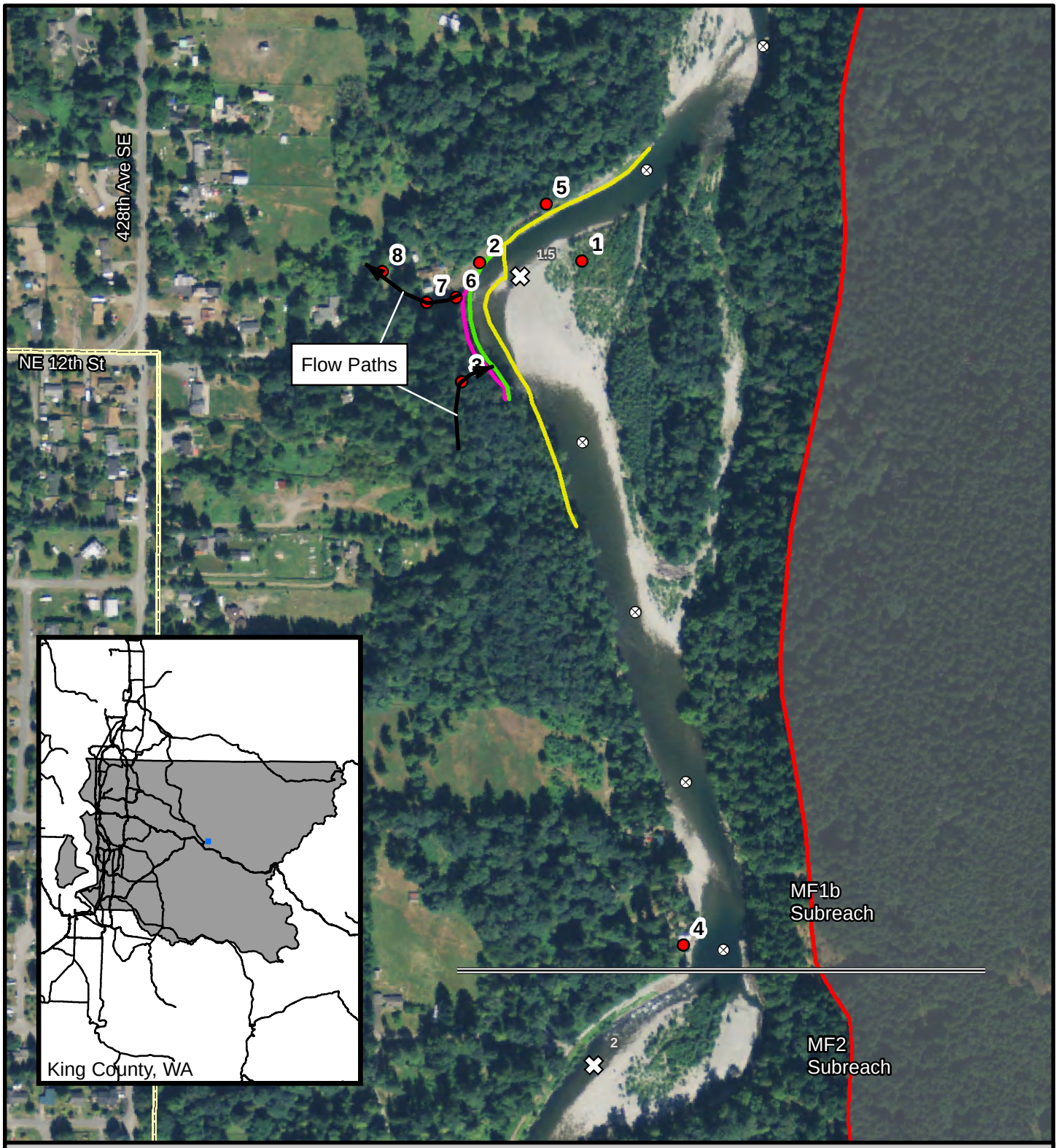
King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Figure12_Roughness_High_Flow.mxd (7/12/2013)

[This page intentionally left blank]



Legend

- River mile
- 1/10th river mile
- High Water Mark
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- City of North Bend boundary
- Model Extents
- Bank 2008
- Bank 2010
- Bank 2011
- Model Extent Location

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Figure 13. High water marks used for calibration near the Mason-Thorson Extension Levee

N

0 250 500 1,000 Feet

King County

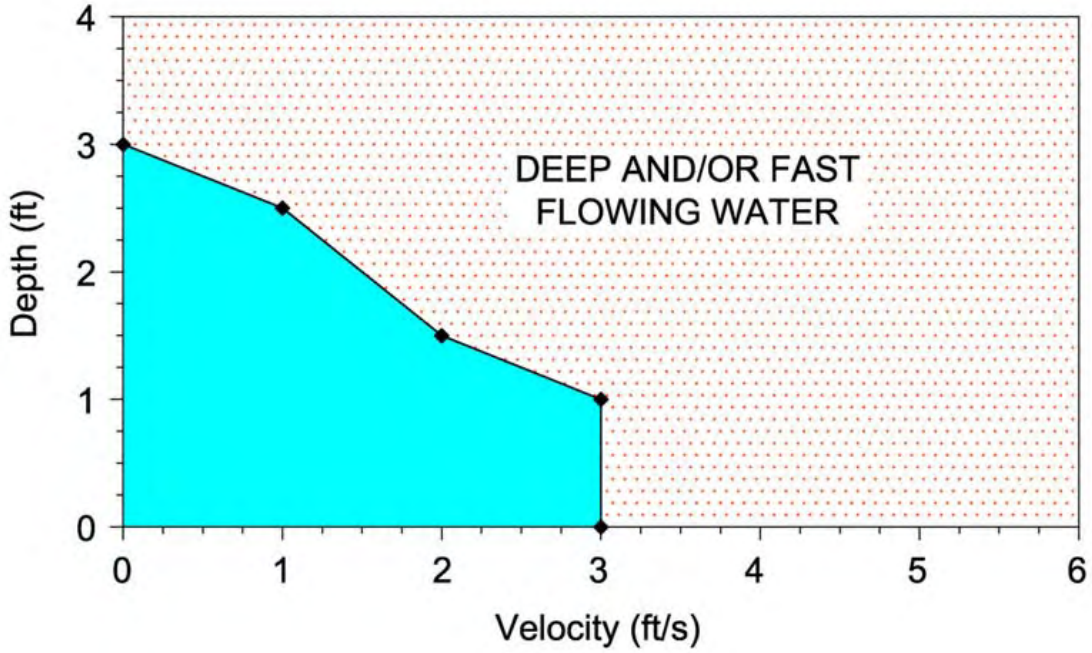
Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Figure13_Anecdotal_HWM.mxd (7/1/2013)

[This page intentionally left blank]

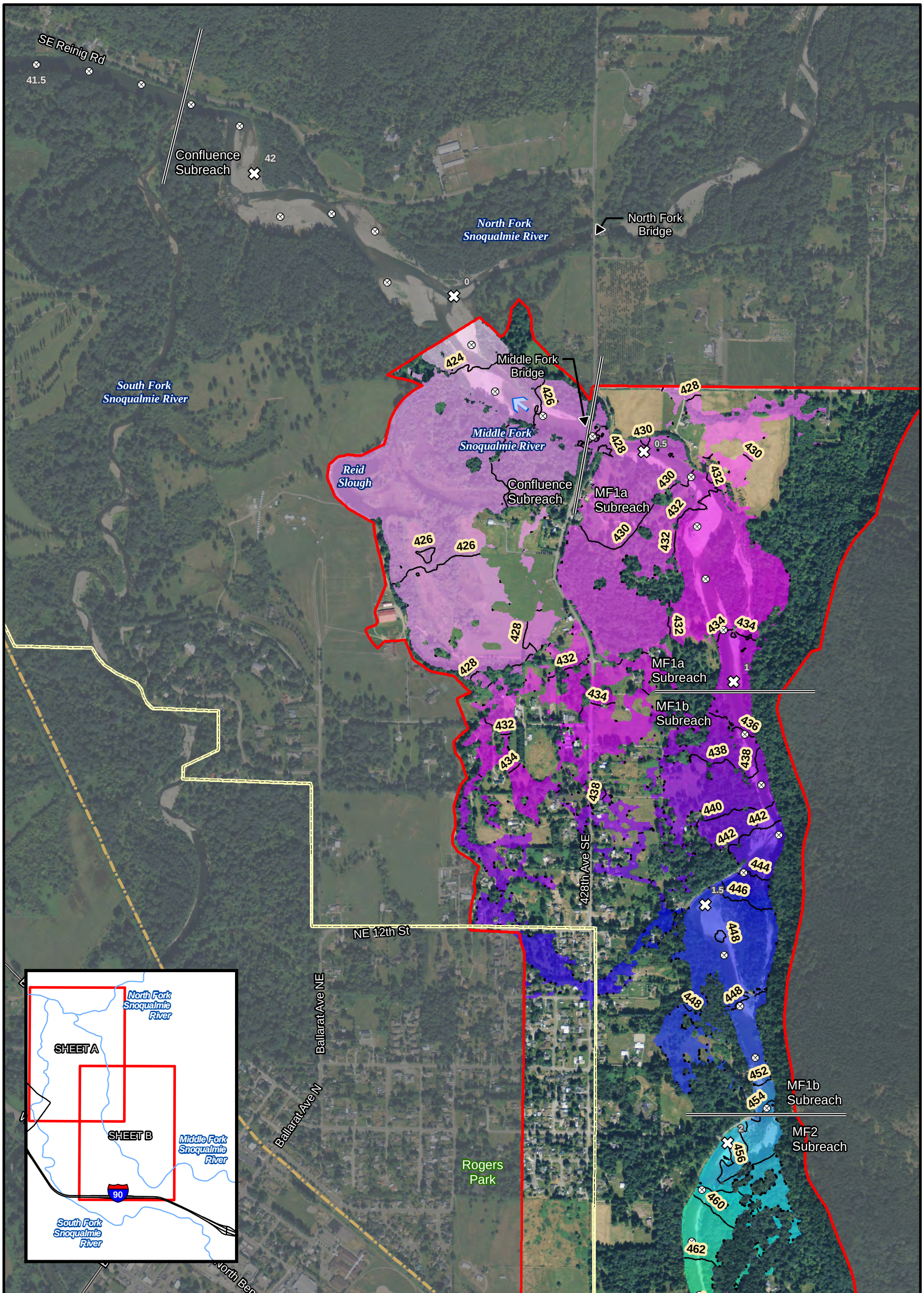
Figure 14: Criteria for Depth-Velocity Hazard Areas (adapted from USBR, 1988)



[This page intentionally left blank]

Plates

[This page intentionally left blank]



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents
- WSE contour

Water Surface Elevation (ft)
High : 535
Low : 420

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 1a. Water Surface Elevation
10 Percent Annual Chance Flood
(10-year Event - 26,100 cfs)
(Sheet 1 of 2)

0 450 900 1,800 Feet

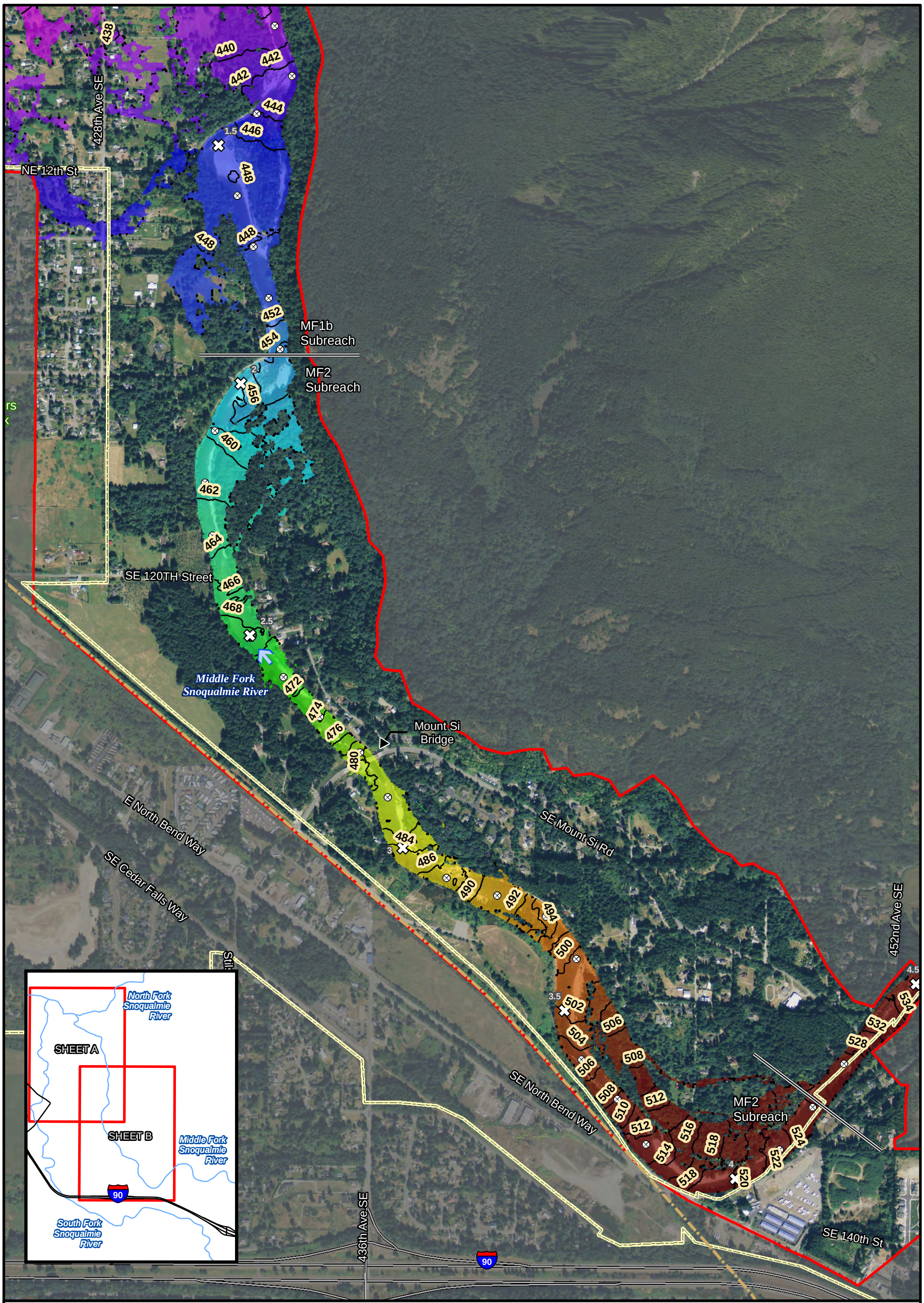
N

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate1a.mxd (5/28/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents
- WSE contour

Water Surface Elevation (ft)
High : 535
Low : 420

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 1b. Water Surface Elevation
10 Percent Annual Chance Flood
(10-year Event - 26,100 cfs)
(Sheet 2 of 2)

0 450 900 1,800 Feet

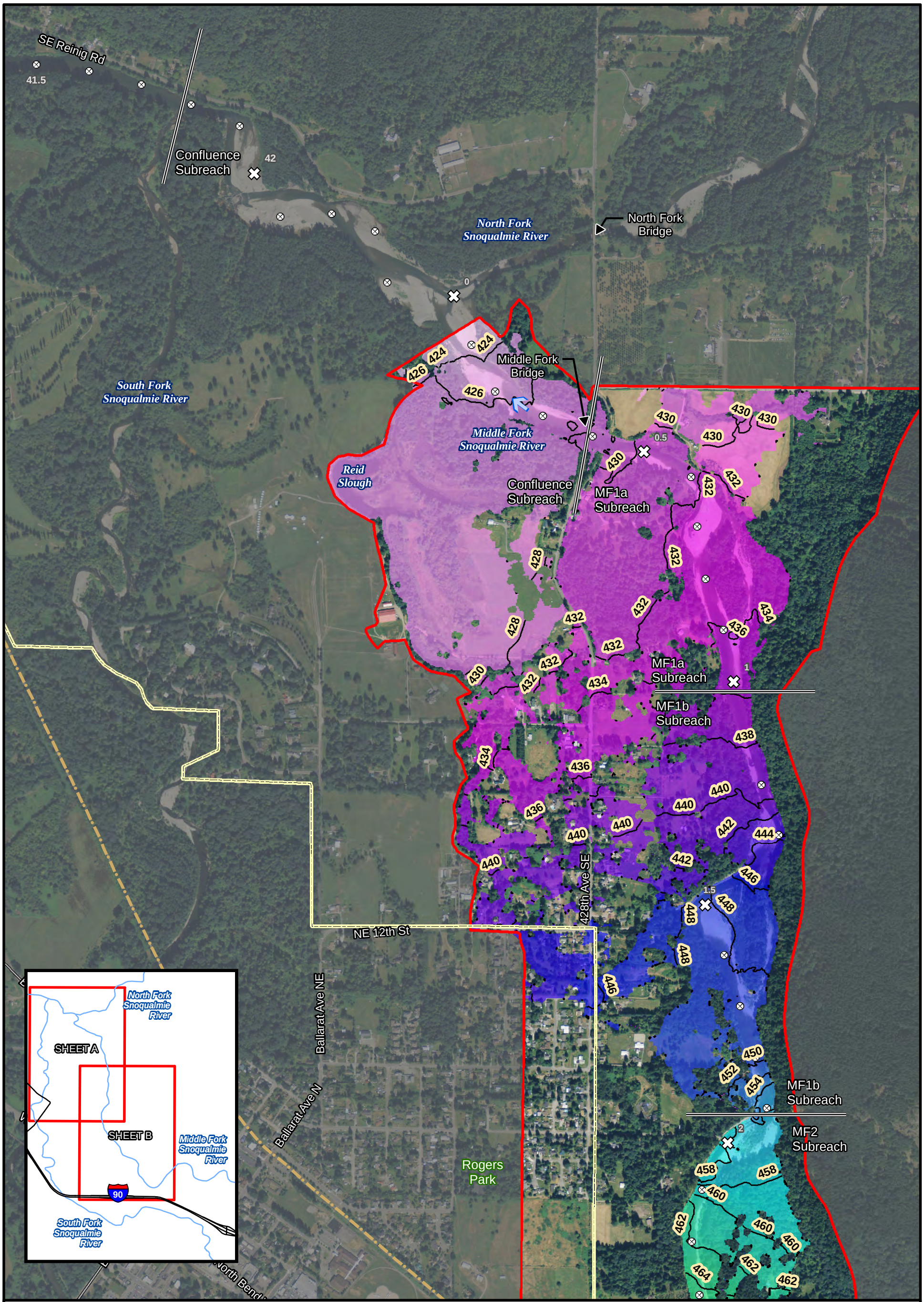
N

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate1b.mxd (5/28/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents
- WSE contour

Water Surface Elevation (ft)
High : 535
Low : 420

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 2a. Water Surface Elevation
4 Percent Annual Chance Flood
(25-year Event - 30,100 cfs)
(Sheet 1 of 2)

0 450 900 1,800 Feet

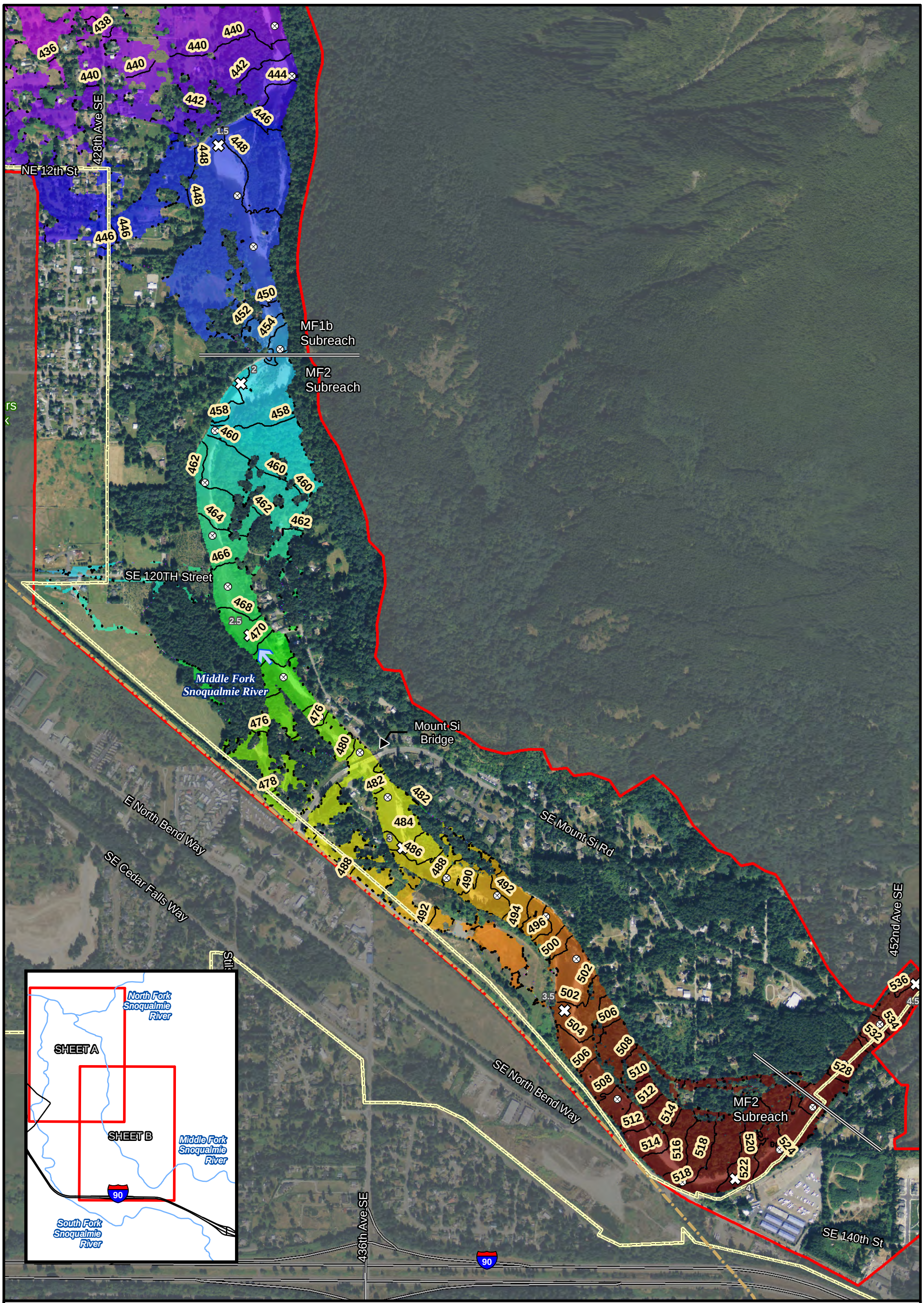
N

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate2a.mxd (5/28/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents
- WSE contour

Water Surface Elevation (ft)
High : 535
Low : 420

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 2b. Water Surface Elevation
4 Percent Annual Chance Flood
(25-year Event - 30,100 cfs)
(Sheet 2 of 2)

0 450 900 1,800 Feet

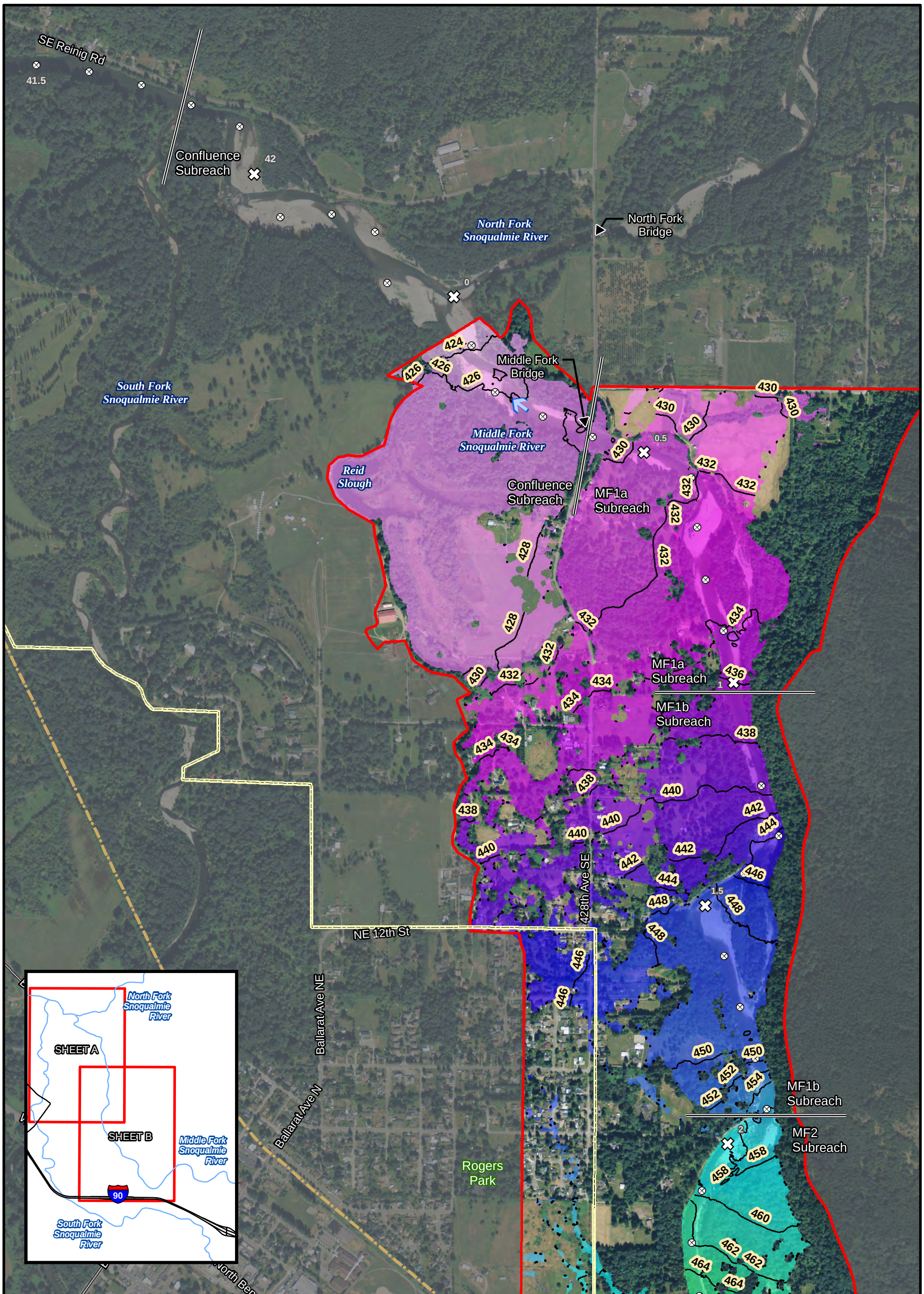
N

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate2b.mxd (5/28/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents
- WSE contour
- Water Surface Elevation (ft)
  - High : 535
  - Low : 420

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 3a. Water Surface Elevation
2 Percent Annual Chance Flood
(50-year Event - 32,800 cfs)
(Sheet 1 of 2)

0 450 900 1,800 Feet

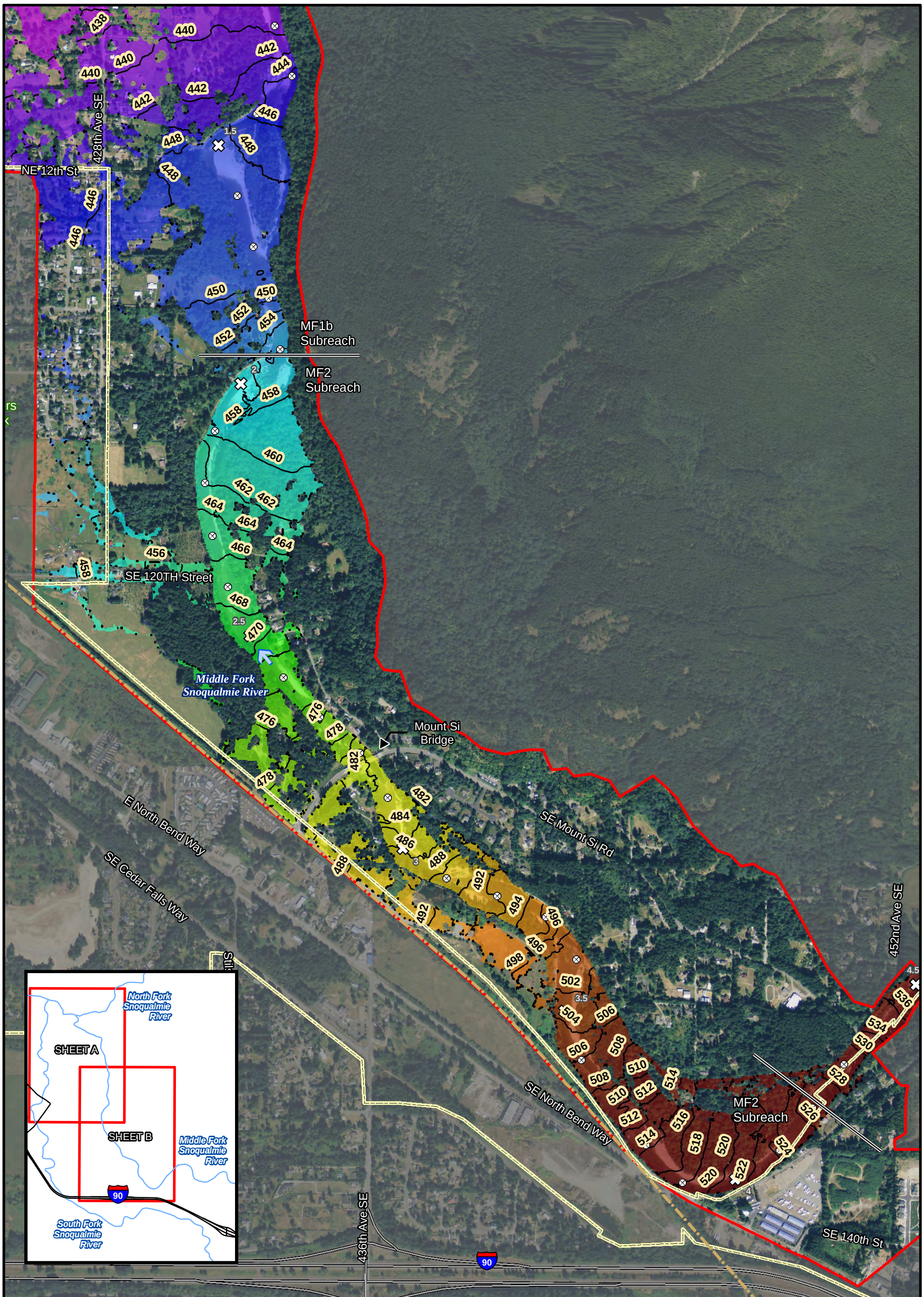
N

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate3a.mxd (5/28/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents
- WSE contour

Water Surface Elevation (ft)
High : 535
Low : 420

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 3b. Water Surface Elevation
2 Percent Annual Chance Flood
(50-year Event - 32,800 cfs)
(Sheet 2 of 2)

0 450 900 1,800 Feet

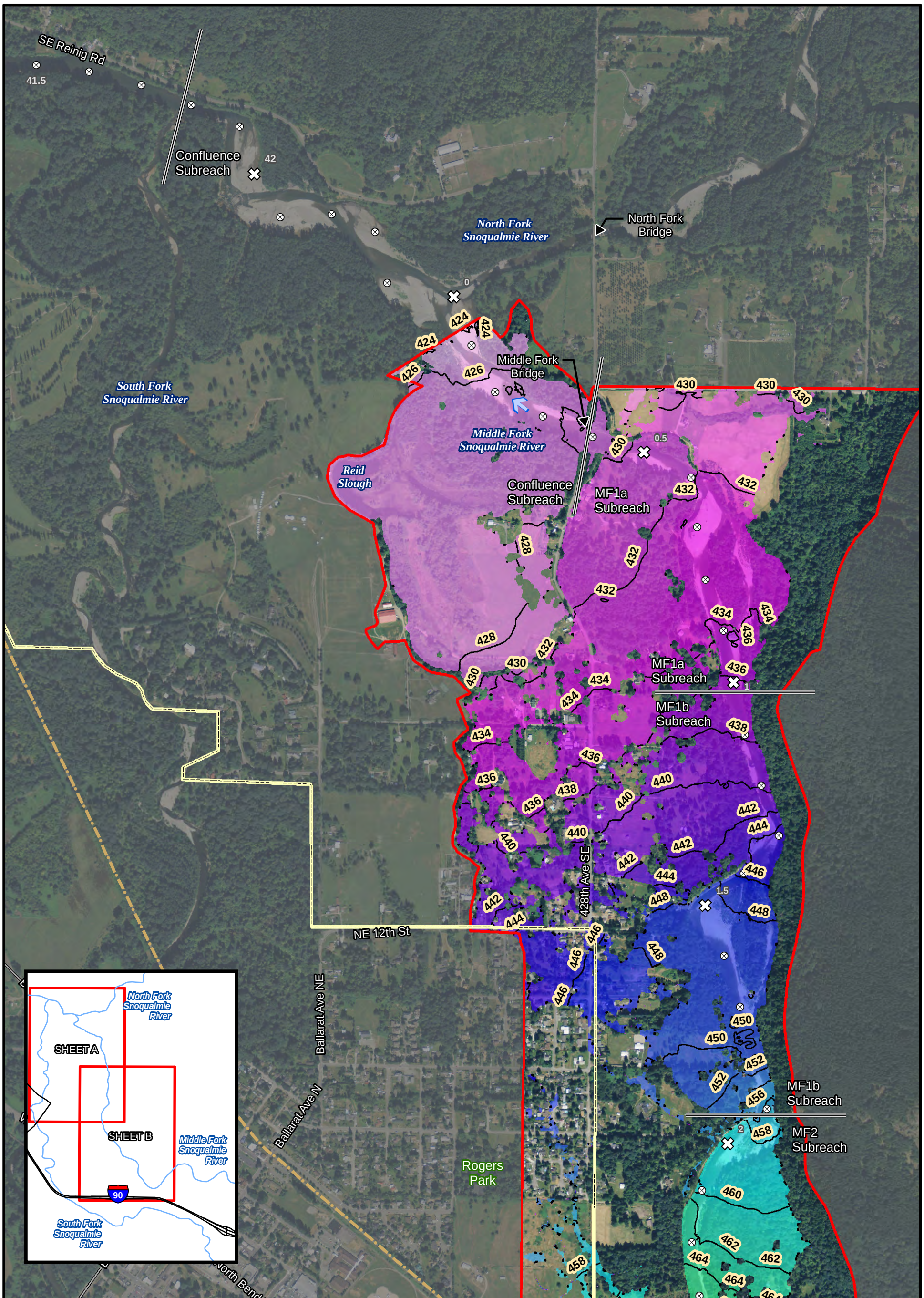
N

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate3b.mxd (5/28/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents
- WSE contour
- Water Surface Elevation (ft)
  - High : 535
  - Low : 420

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 4a. Water Surface Elevation
1 Percent Annual Chance Flood
(100-year Event - 35,400 cfs)
(Sheet 1 of 2)

0 450 900 1,800 Feet

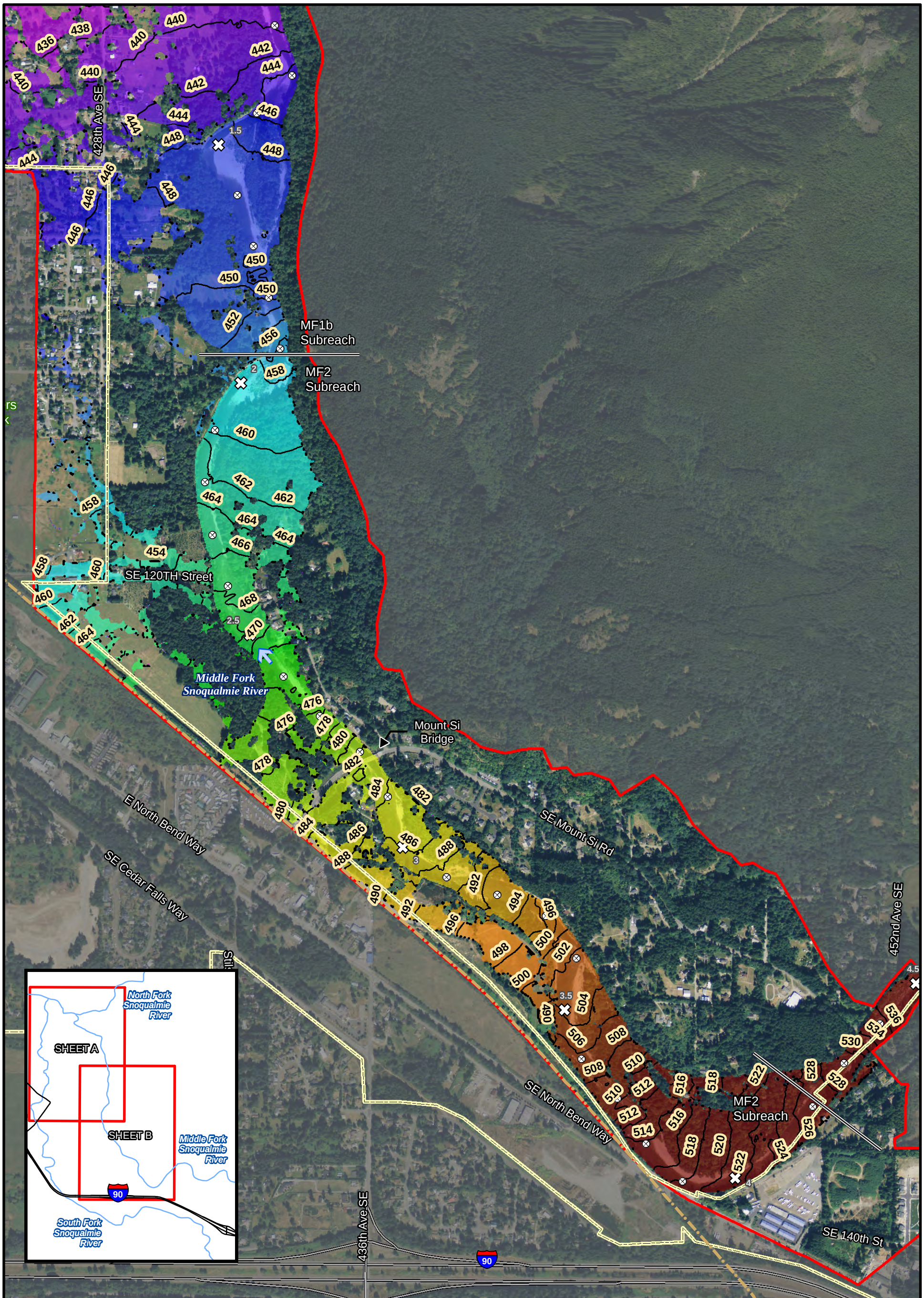
N

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate4a.mxd (5/28/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents
- WSE contour

Water Surface Elevation (ft)
High : 535
Low : 420

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 4b. Water Surface Elevation
1 Percent Annual Chance Flood
(100-year Event - 35,400 cfs)
(Sheet 2 of 2)

0 450 900 1,800 Feet

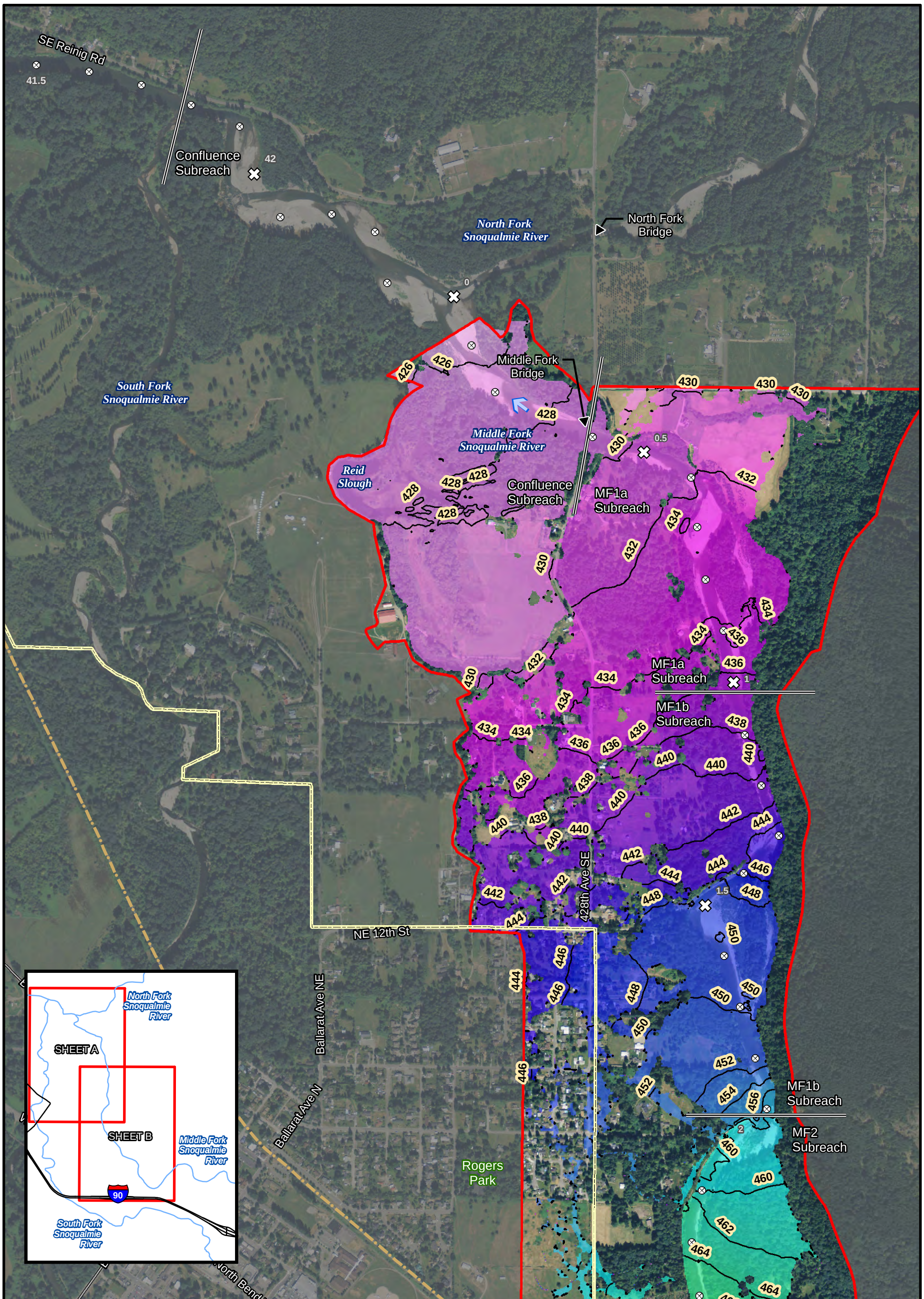
N

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate4b.mxd (5/28/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents
- WSE contour
- Water Surface Elevation (ft)
  - High : 535
  - Low : 420

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 5a. Water Surface Elevation
0.2 Percent Annual Chance Flood
(500-year Event - 41,000 cfs)
(Sheet 1 of 2)

0 450 900 1,800 Feet

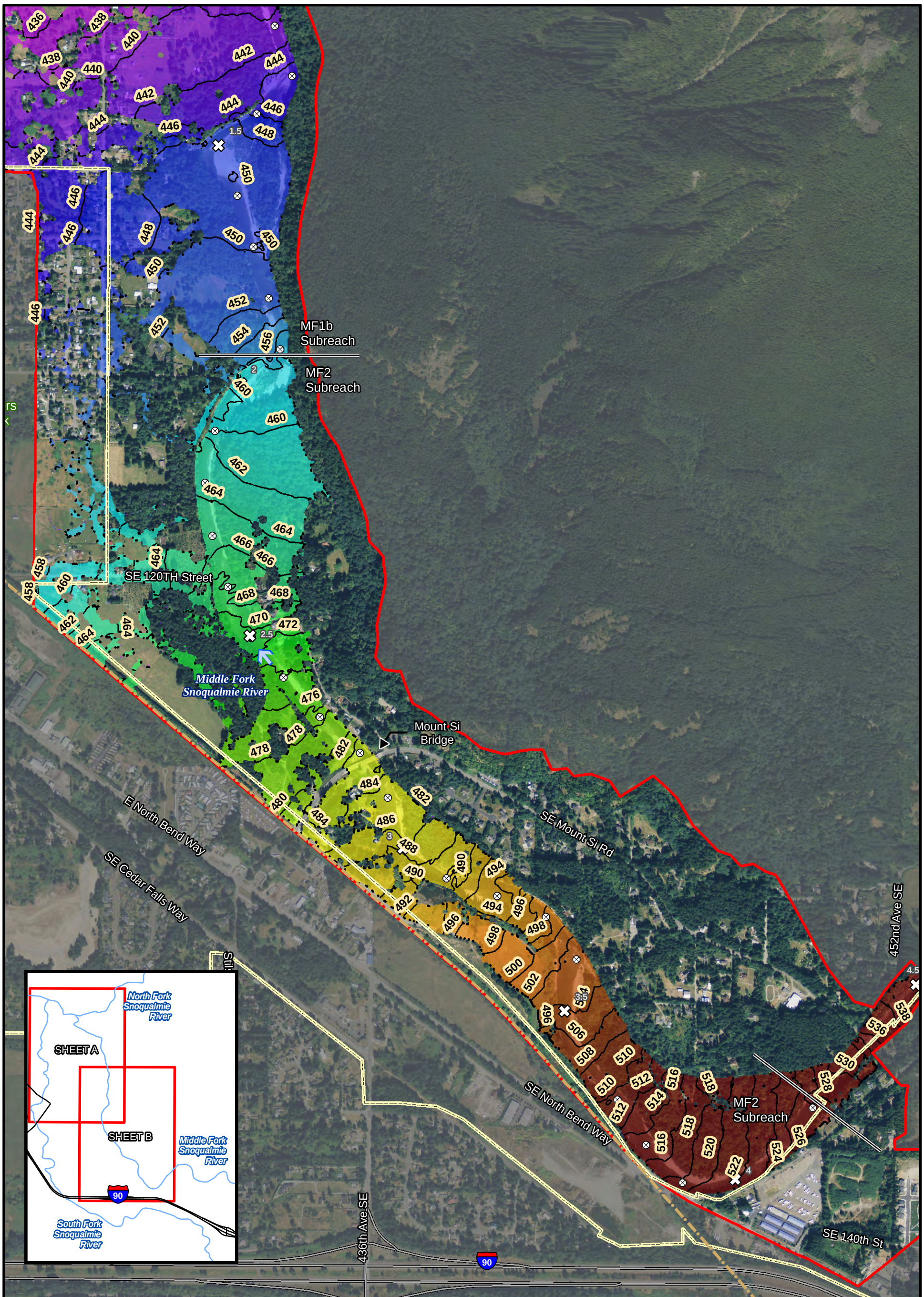
N

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate5a.mxd (5/28/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents
- WSE contour

Water Surface Elevation (ft)
High : 535
Low : 420

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 5b. Water Surface Elevation
0.2 Percent Annual Chance Flood
(500-year Event - 41,000 cfs)
(Sheet 2 of 2)

0 450 900 1,800 Feet

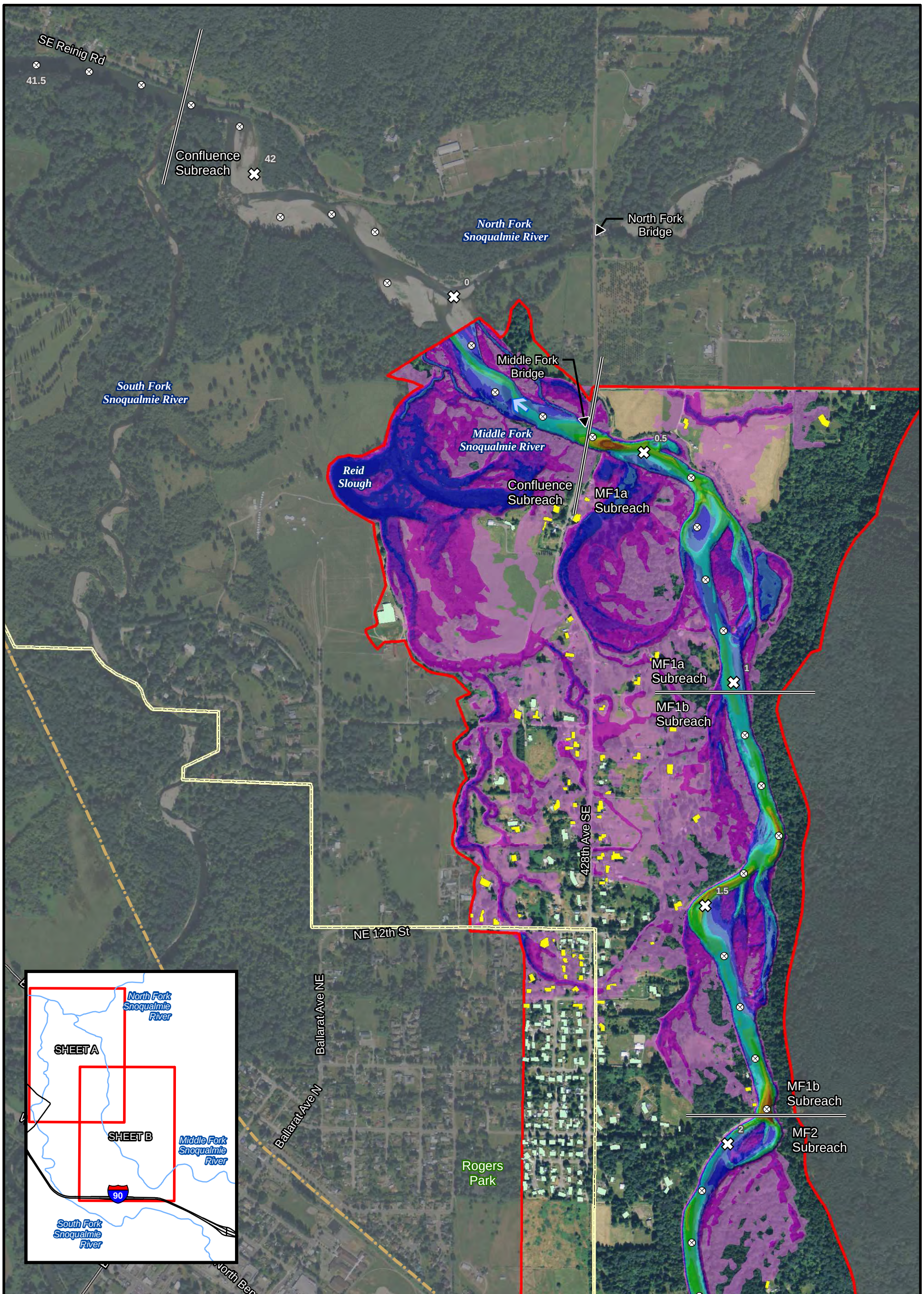
N

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate5b.mxd (5/28/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Potentially Inundated Buildings
- Building Boundary
- Model Extents

Depth (ft)

28 - 32	16 - 18	6 - 8
24 - 28	14 - 16	4 - 6
22 - 24	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 6a. Depth
10 Percent Annual Chance Flood
(10-year Event - 26,100 cfs)
(Sheet 1 of 2)

N

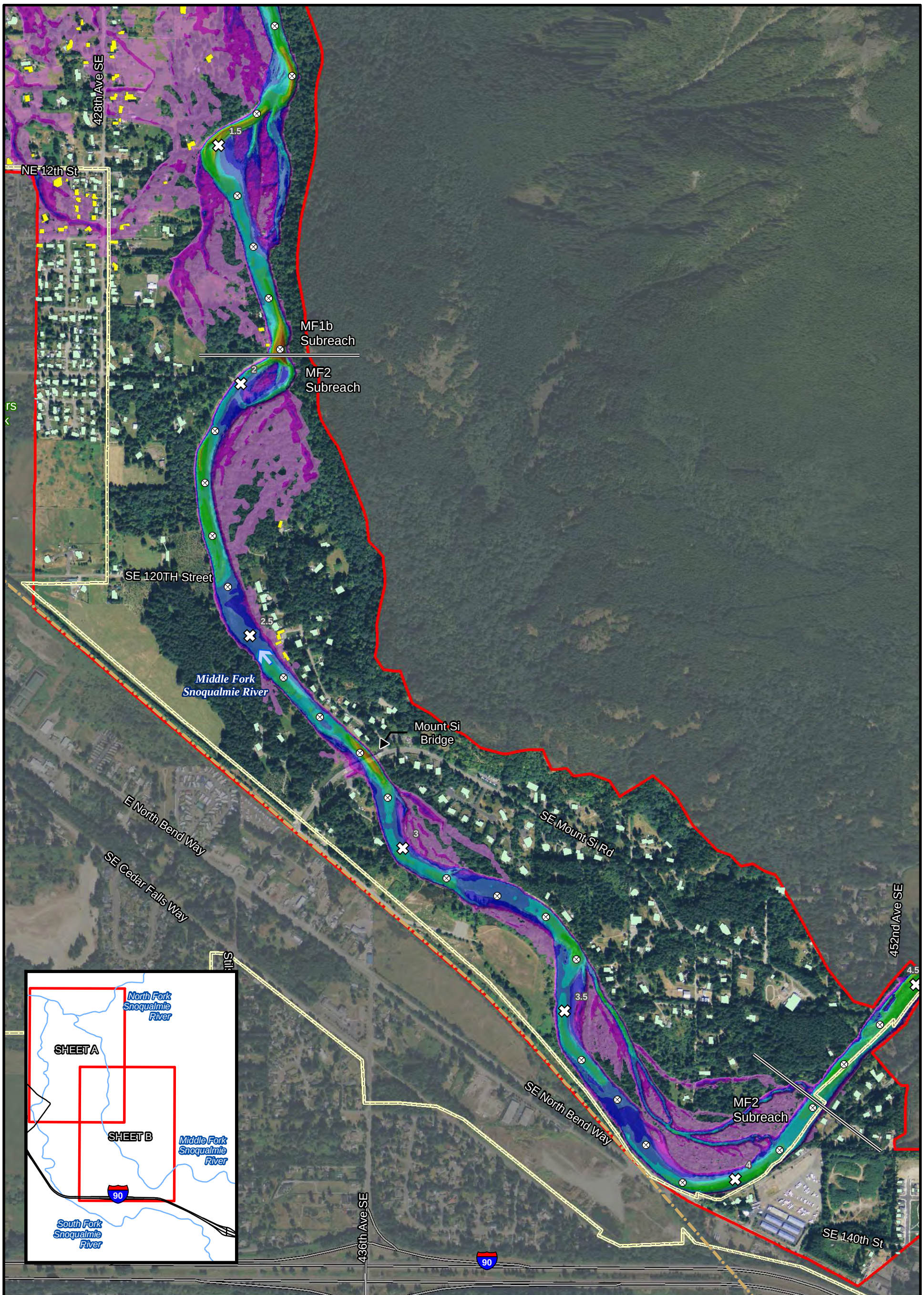
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.watershedse.000\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate6a.mxd (8/2/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Potentially Inundated Buildings
- Building Boundary
- Model Extents

Depth (ft)

28 - 32	16 - 18	6 - 8
24 - 28	14 - 16	4 - 6
22 - 24	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 6b. Depth
10 Percent Annual Chance Flood
(10-year Event - 26,100 cfs)
(Sheet 2 of 2)

N

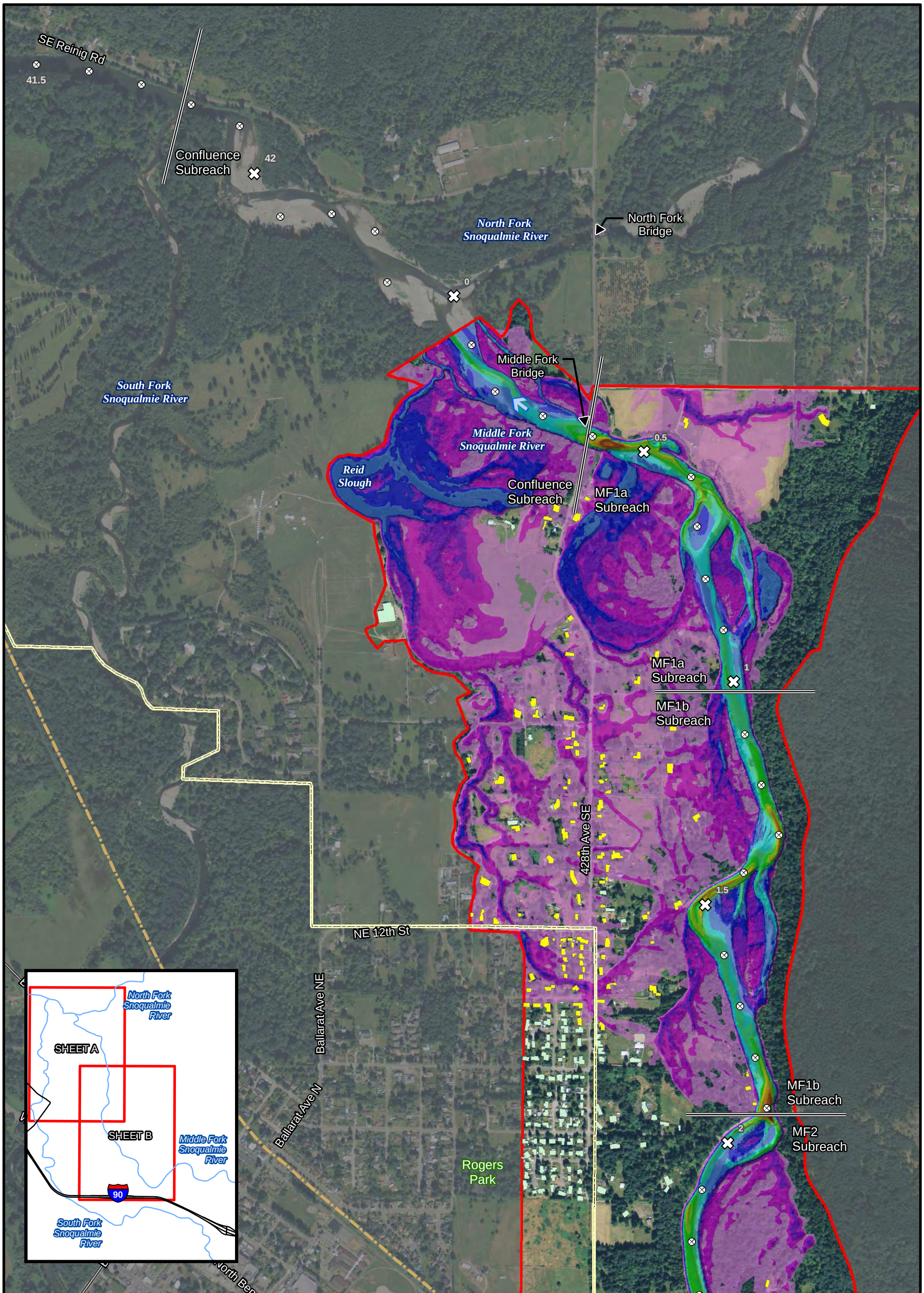
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.watershedse.000\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate6b.mxd (8/2/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Potentially Inundated Buildings
- Building Boundary
- Model Extents

Depth (ft)

28 - 32	16 - 18	6 - 8
24 - 28	14 - 16	4 - 6
22 - 24	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 7a. Depth
4 Percent Annual Chance Flood
(25-year Event - 30,100 cfs)
(Sheet 1 of 2)

N

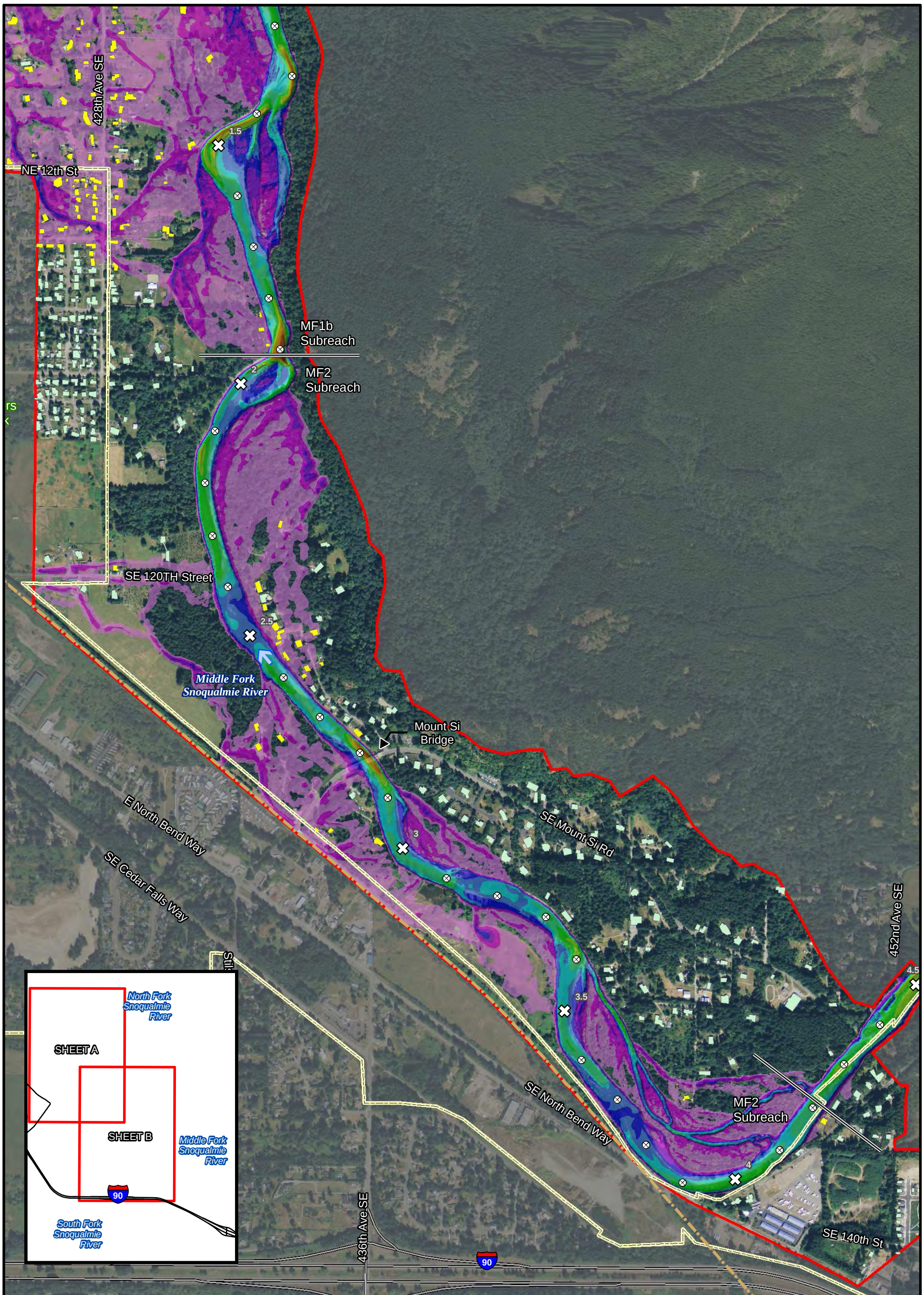
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.watershedse.000\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate7a.mxd (8/2/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Potentially Inundated Buildings
- Building Boundary
- Model Extents

Depth (ft)

28 - 32	16 - 18	6 - 8
24 - 28	14 - 16	4 - 6
22 - 24	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 7b. Depth
4 Percent Annual Chance Flood
(25-year Event - 30,100 cfs)
(Sheet 2 of 2)

N

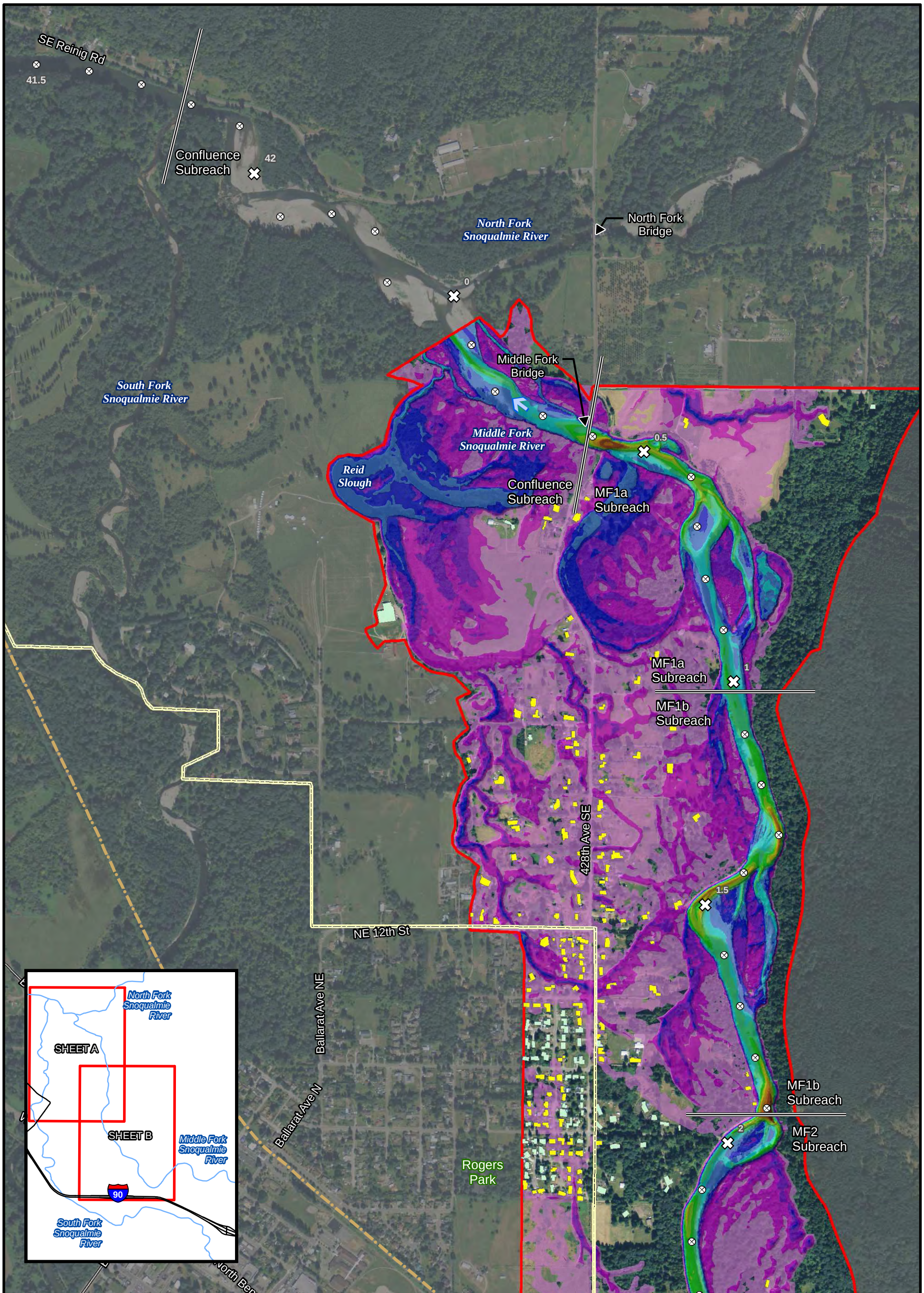
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.watershedse.000\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate7b.mxd (8/2/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Potentially Inundated Buildings
- Building Boundary
- Model Extents

Depth (ft)

28 - 32	16 - 18	6 - 8
24 - 28	14 - 16	4 - 6
22 - 24	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 8a. Depth
2 Percent Annual Chance Flood
(50-year Event - 32,800 cfs)
(Sheet 1 of 2)

N

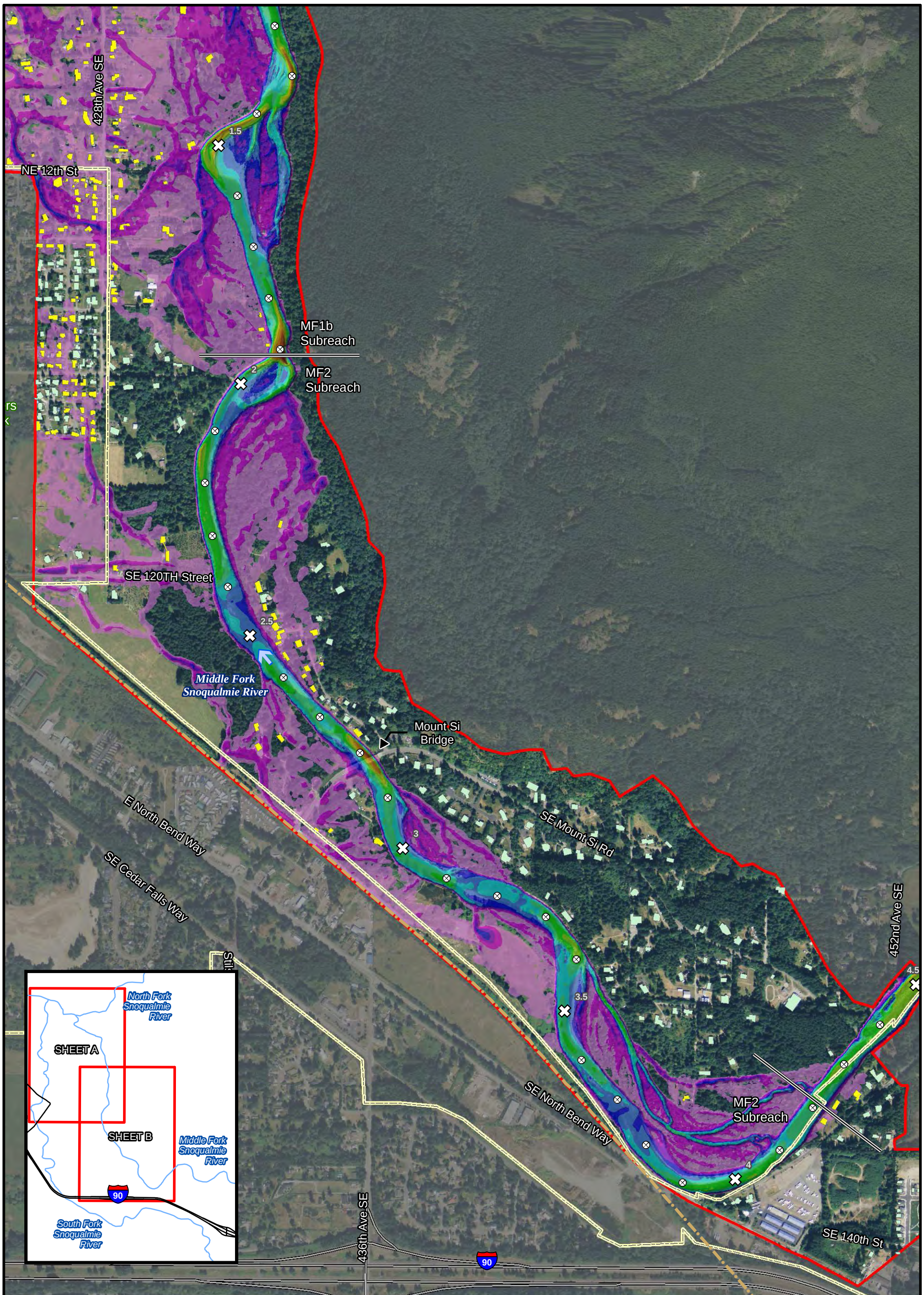
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.watershedse.000\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate8a.mxd (8/2/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Potentially Inundated Buildings
- Building Boundary
- Model Extents

Depth (ft)

28 - 32	16 - 18	6 - 8
24 - 28	14 - 16	4 - 6
22 - 24	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 8b. Depth
2 Percent Annual Chance Flood
(50-year Event - 32,800 cfs)
(Sheet 2 of 2)

N

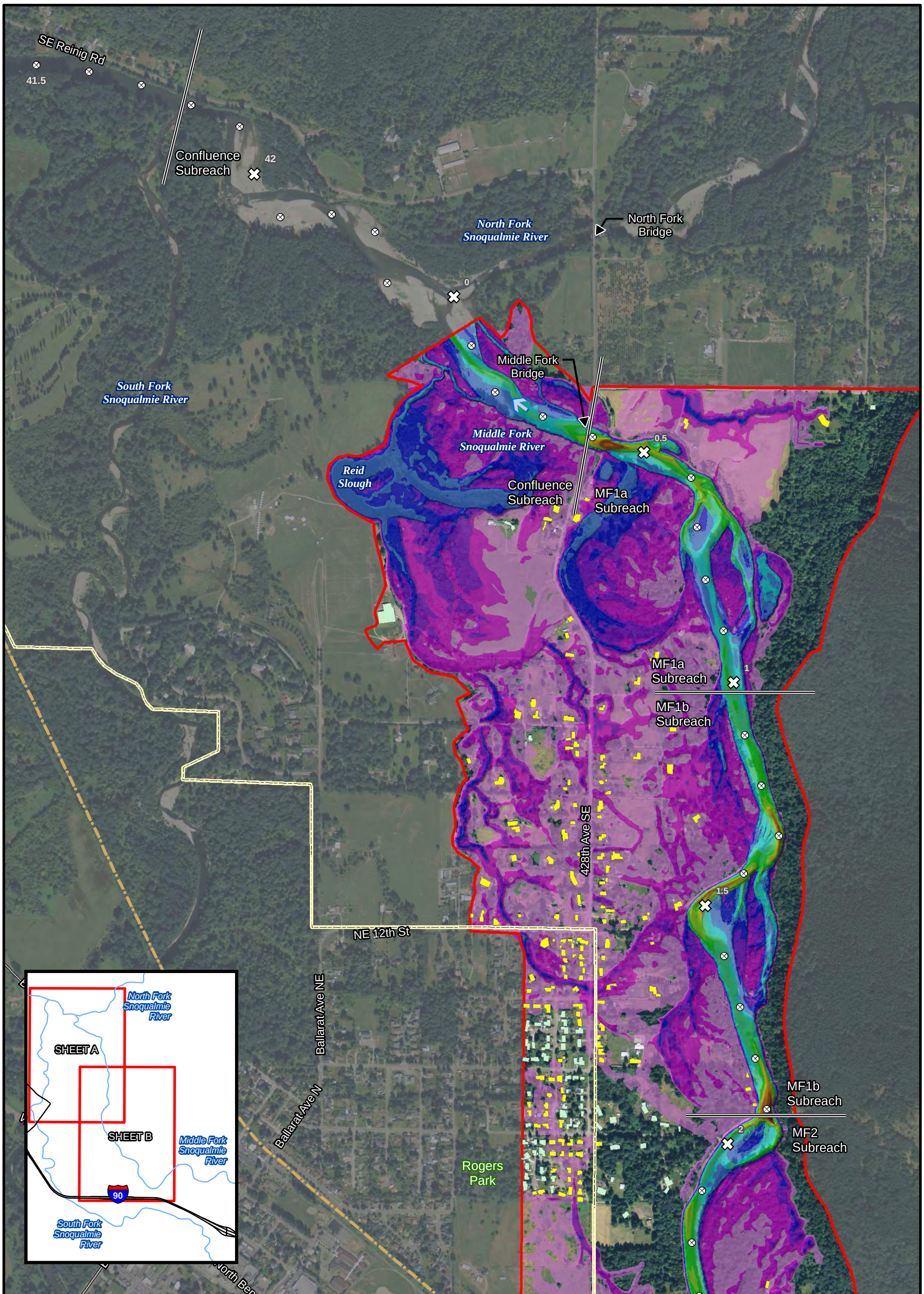
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.watershedse.000\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate8b.mxd (8/2/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Potentially Inundated Buildings
- Building Boundary
- Model Extents

Depth (ft)

28 - 32	16 - 18	6 - 8
24 - 28	14 - 16	4 - 6
22 - 24	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 9a. Depth
1 Percent Annual Chance Flood
(100-year Event - 35,400 cfs)
(Sheet 1 of 2)

N

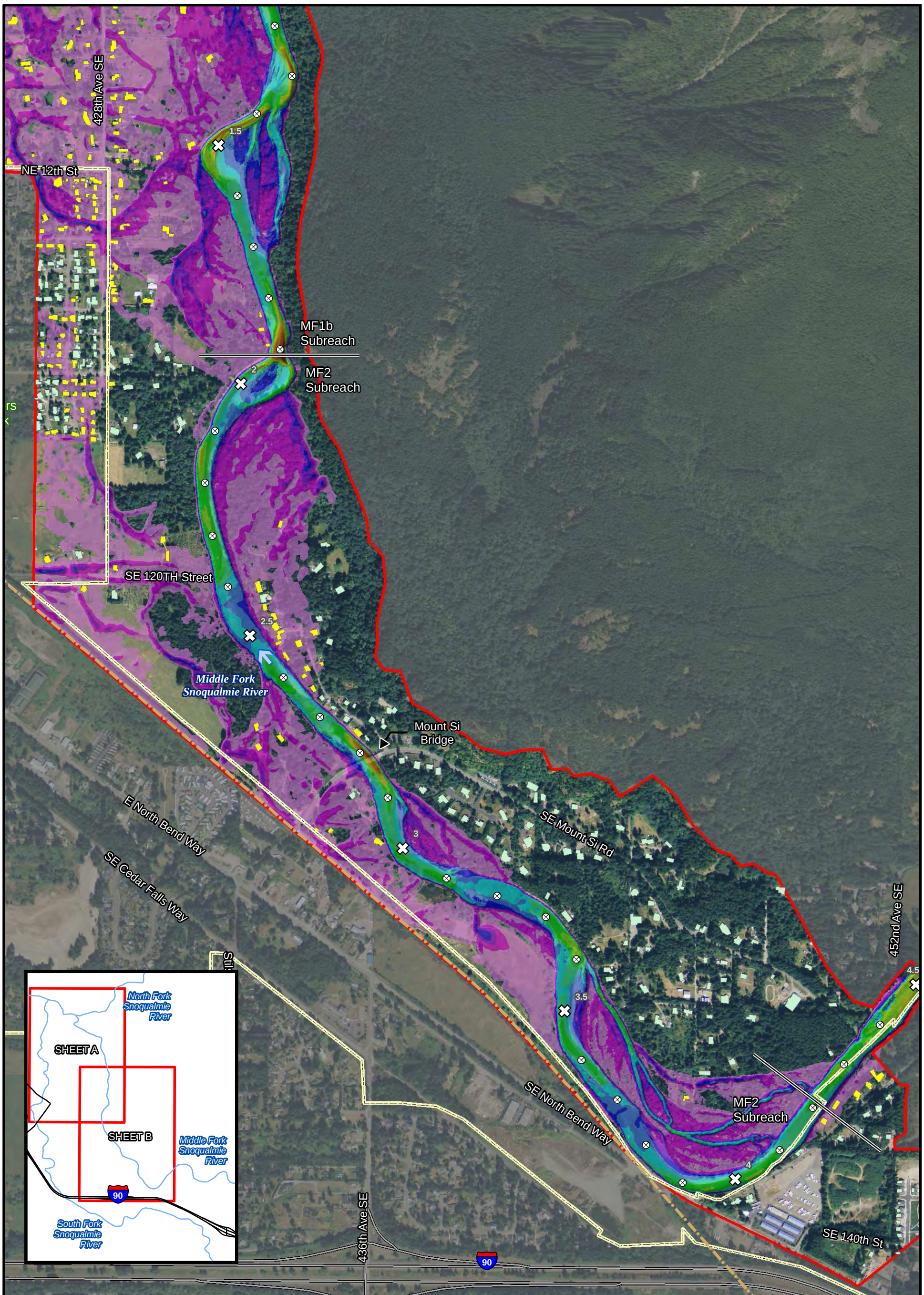
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.watershedse.000\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate9a.mxd (8/2/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Potentially Inundated Buildings
- Building Boundary
- Model Extents

Depth (ft)

28 - 32	16 - 18	6 - 8
24 - 28	14 - 16	4 - 6
22 - 24	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 9b. Depth
1 Percent Annual Chance Flood
(100-year Event - 35,400 cfs)
(Sheet 2 of 2)

N

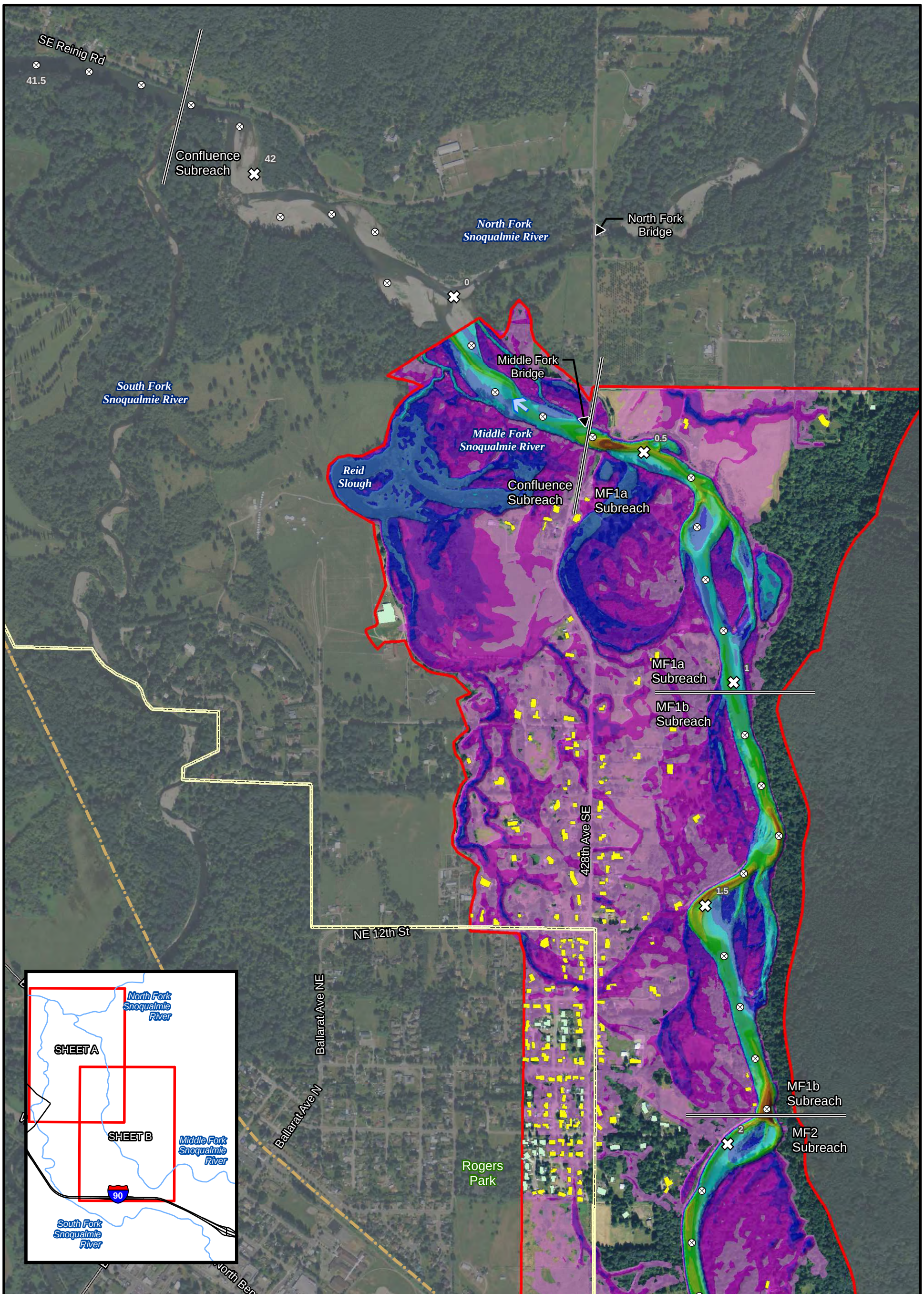
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.watershedse.000\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate9b.mxd (8/2/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Potentially Inundated Buildings
- Building Boundary
- Model Extents

Depth (ft)

28 - 32	16 - 18	6 - 8
24 - 28	14 - 16	4 - 6
22 - 24	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 10a. Depth
0.2 Percent Annual Chance Flood
(500-year Event - 41,000 cfs)
(Sheet 1 of 2)

N

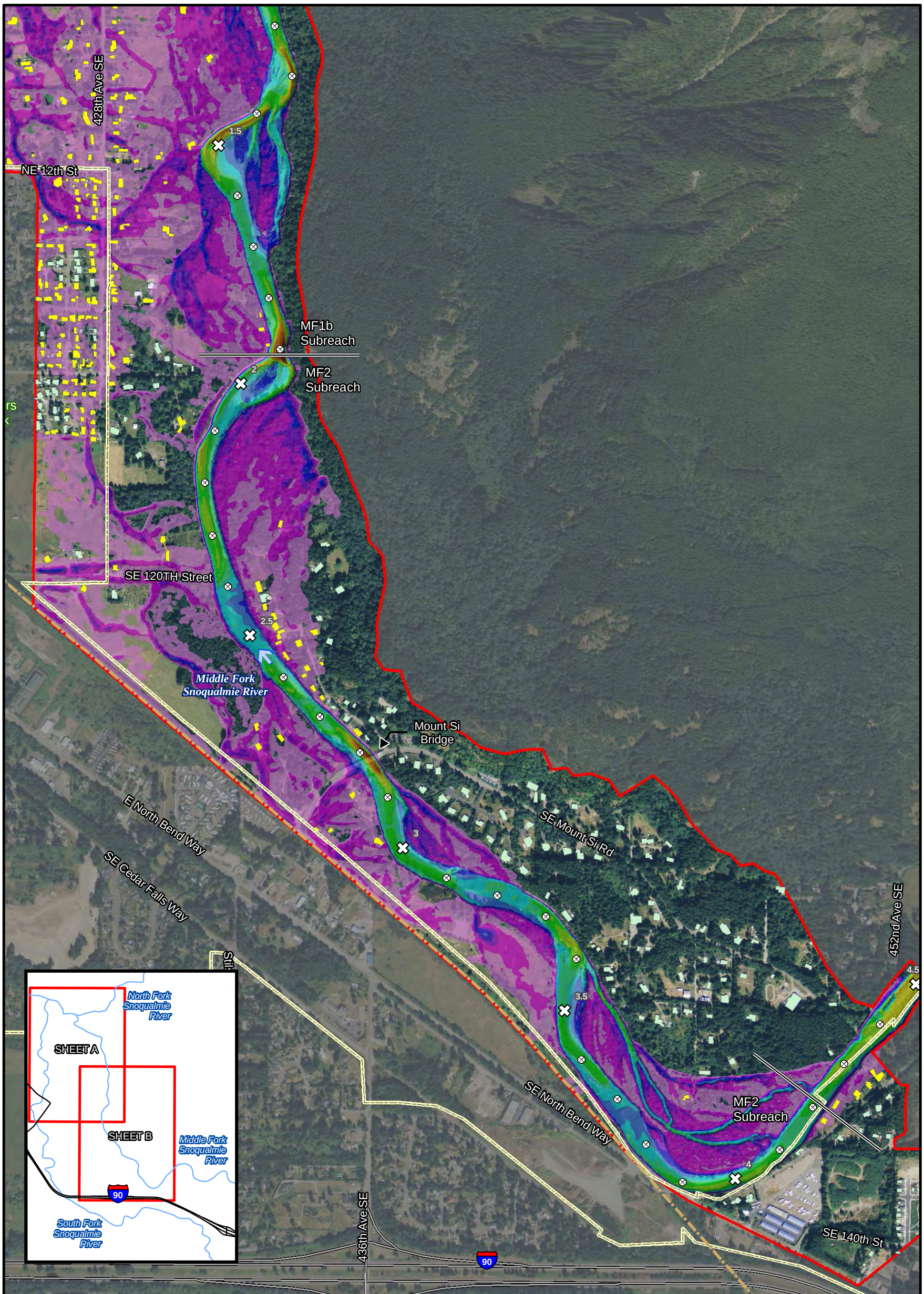
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.watershedse.000\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate10a.mxd (8/2/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Potentially Inundated Buildings
- Building Boundary
- Model Extents

Depth (ft)

28 - 32	16 - 18	6 - 8
24 - 28	14 - 16	4 - 6
22 - 24	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 10b. Depth
0.2 Percent Annual Chance Flood
(500-year Event - 41,000 cfs)
(Sheet 2 of 2)

N

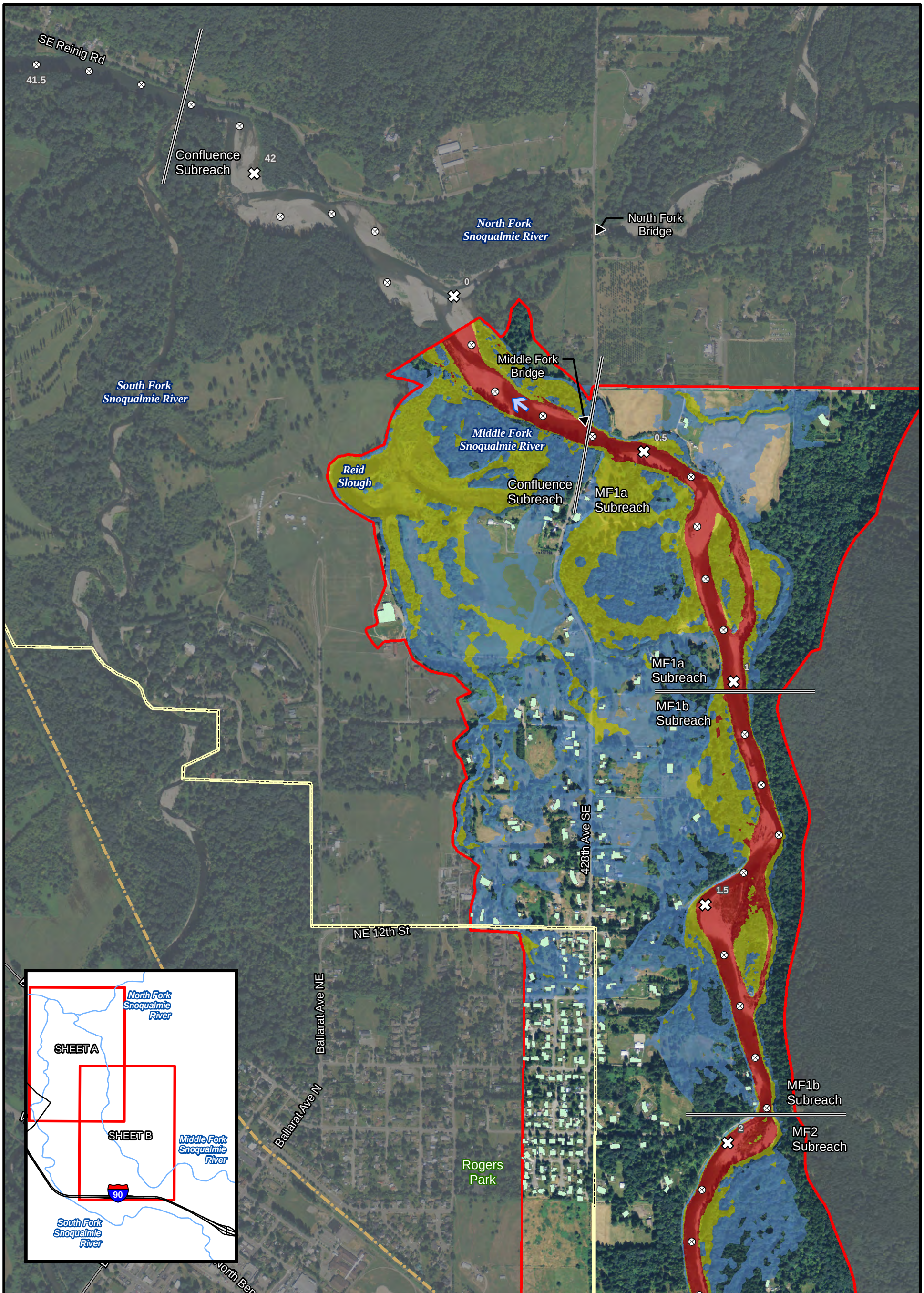
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.watershedse.000\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate10b.mxd (8/2/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Buildings in Hazard Areas
- Building Boundary
- Model Extents
- ***Exceeds King County Regulatory Depth-Velocity Standards (Deep and Fast)***
- ***Depth-Velocity Hazards based on USBR approach (Deep and/or Fast)***
- ***Inundated from 10 Percent Annual Chance Flood***

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 11a. Depth-Velocity Hazard Areas
10 Percent Annual Chance Flood
(10-year Event - 26,100 cfs)
(Sheet 1 of 2)

N

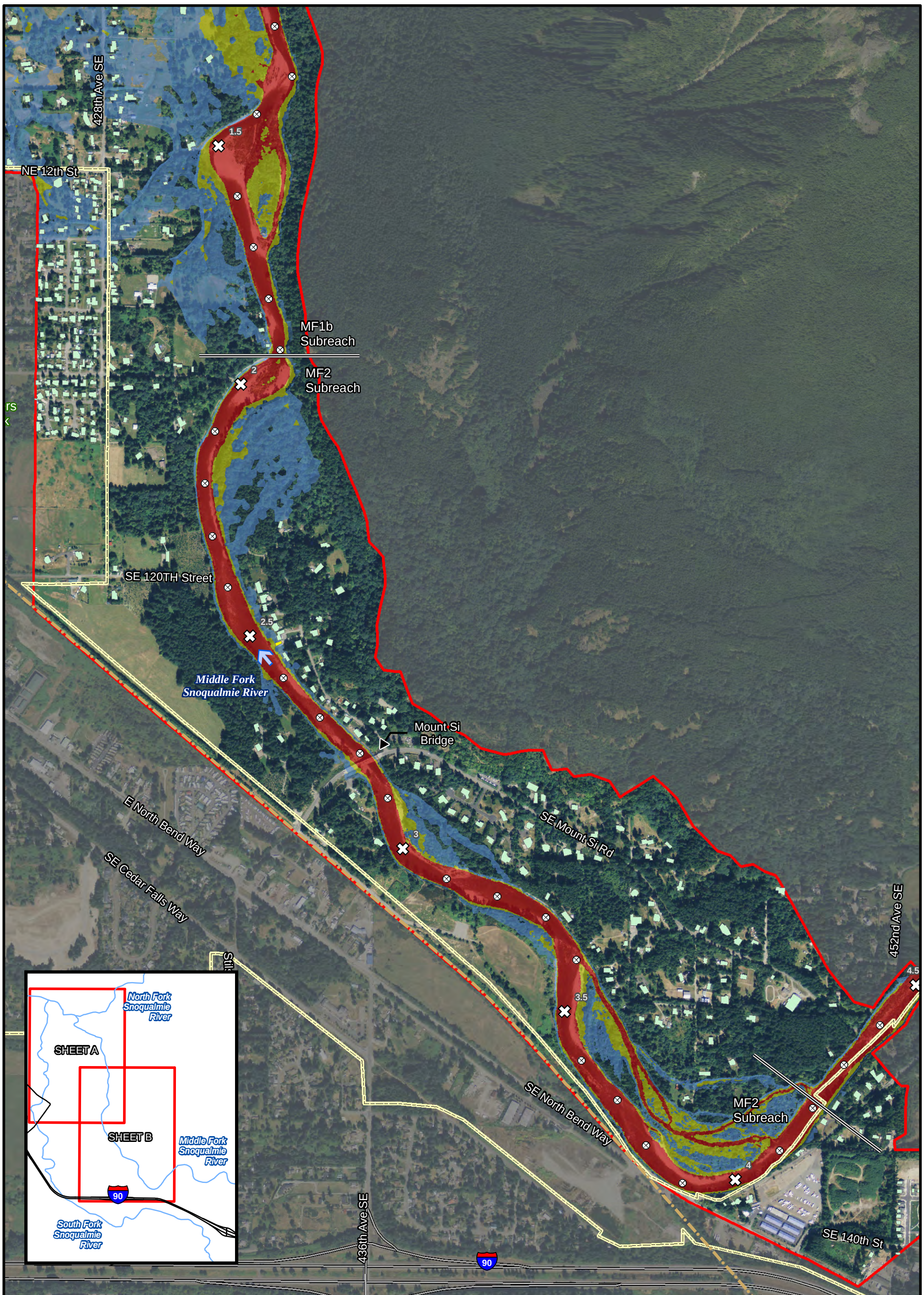
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate11a.mxd (7/12/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Buildings in Hazard Areas
- Building Boundary
- Model Extents
- ***Exceeds King County Regulatory Depth-Velocity Standards (Deep and Fast)***
- ***Depth-Velocity Hazards based on USBR approach (Deep and/or Fast)***
- ***Inundated from 10 Percent Annual Chance Flood***

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 11b. Depth-Velocity Hazard Areas
10 Percent Annual Chance Flood
(10-year Event - 26,100 cfs)
(Sheet 2 of 2)

N

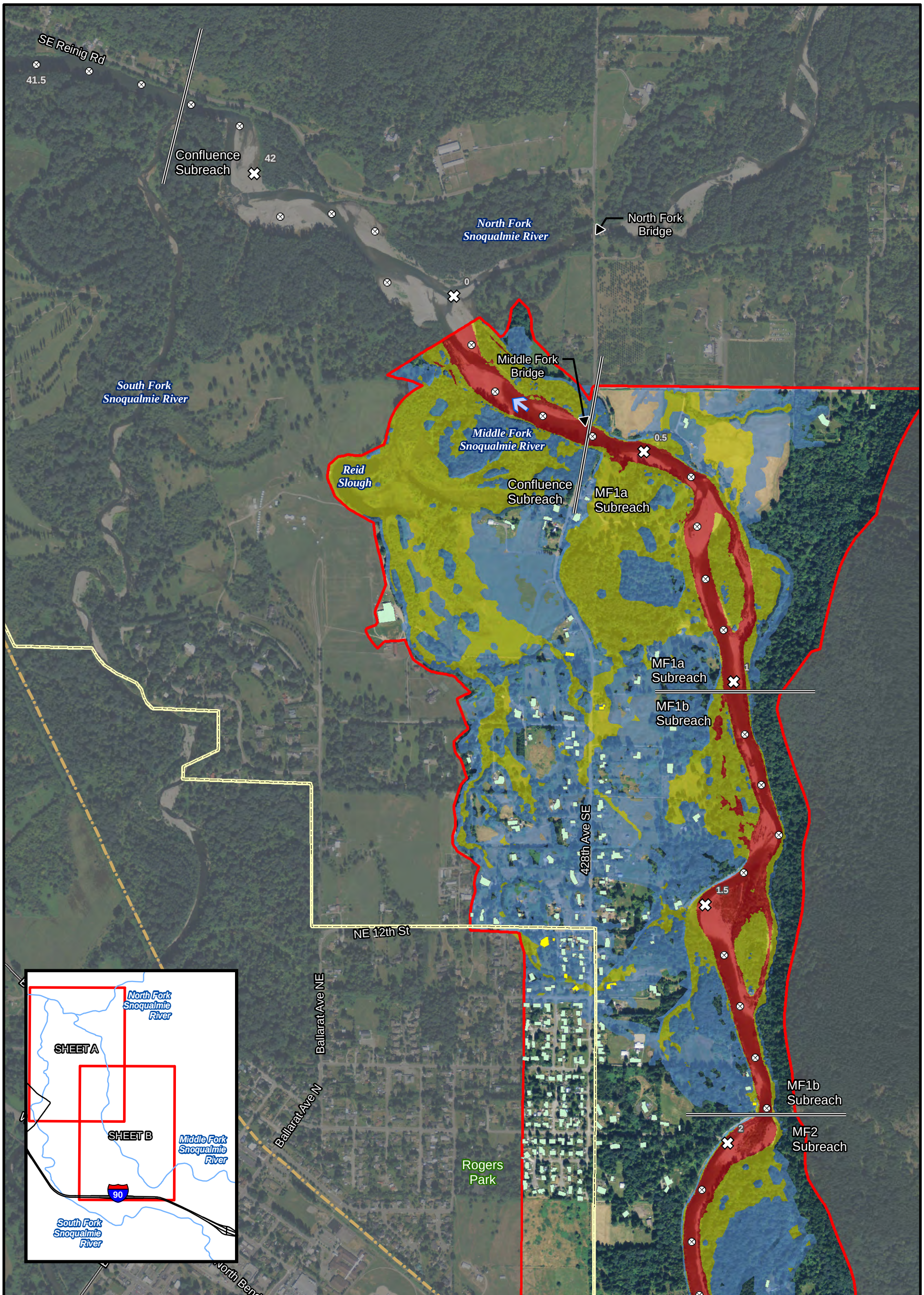
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate11b.mxd (7/12/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Buildings in Hazard Areas
- Building Boundary
- Model Extents
- ***Exceeds King County Regulatory Depth-Velocity Standards (Deep and Fast)***
- ***Depth-Velocity Hazards based on USBR approach (Deep and/or Fast)***
- ***Inundated from 4 Percent Annual Chance Flood***

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 12a. Depth-Velocity Hazard Areas
4 Percent Annual Chance Flood
(25-year Event - 30,100 cfs)
(Sheet 1 of 2)

N

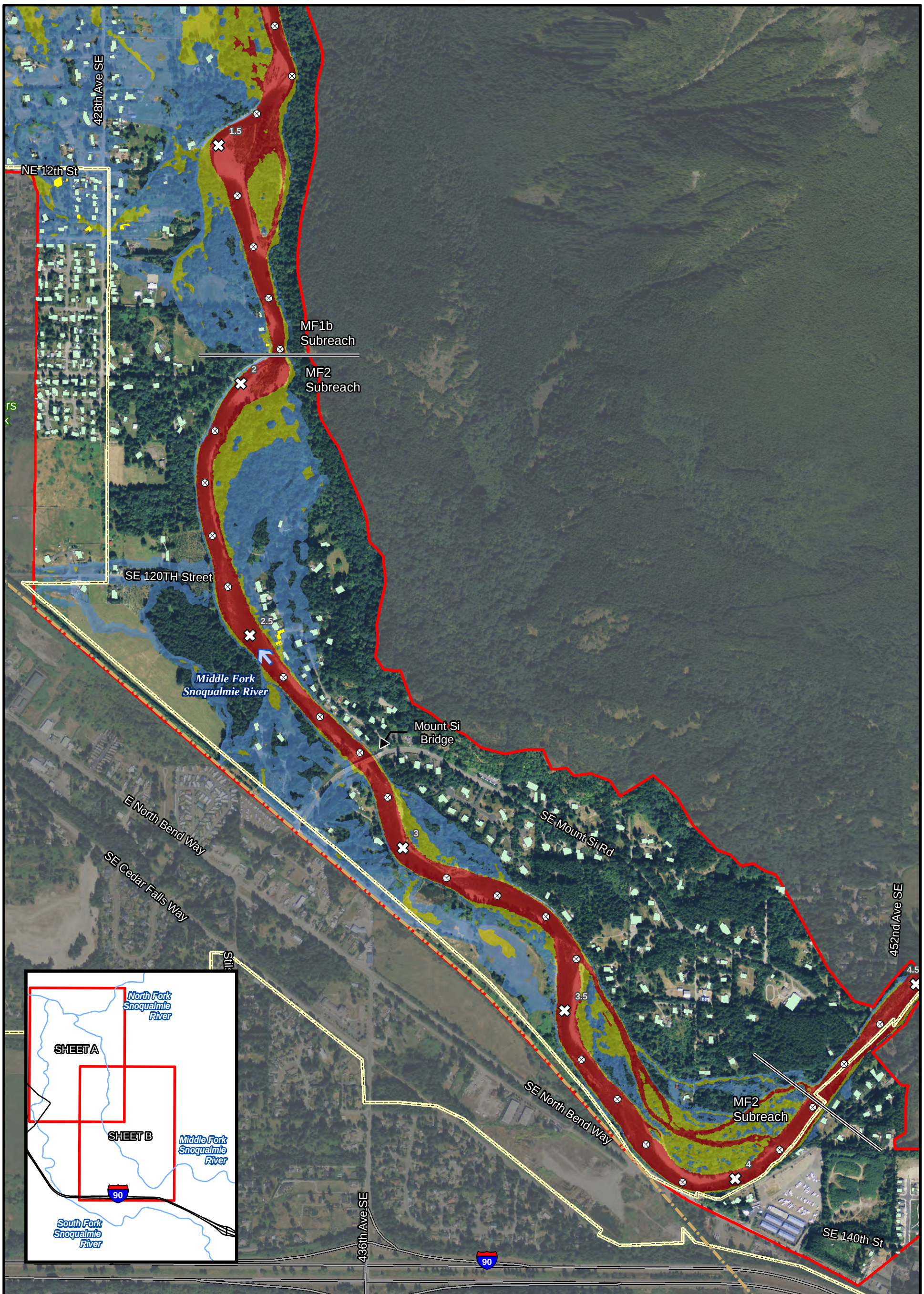
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate12a.mxd (7/12/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Buildings in Hazard Areas
- Building Boundary
- Model Extents
- ***Exceeds King County Regulatory Depth-Velocity Standards (Deep and Fast)***
- ***Depth-Velocity Hazards based on USBR approach (Deep and/or Fast)***
- ***Inundated from 4 Percent Annual Chance Flood***

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 12b. Depth-Velocity Hazard Areas
4 Percent Annual Chance Flood
(25-year Event - 30,100 cfs)
(Sheet 2 of 2)

N

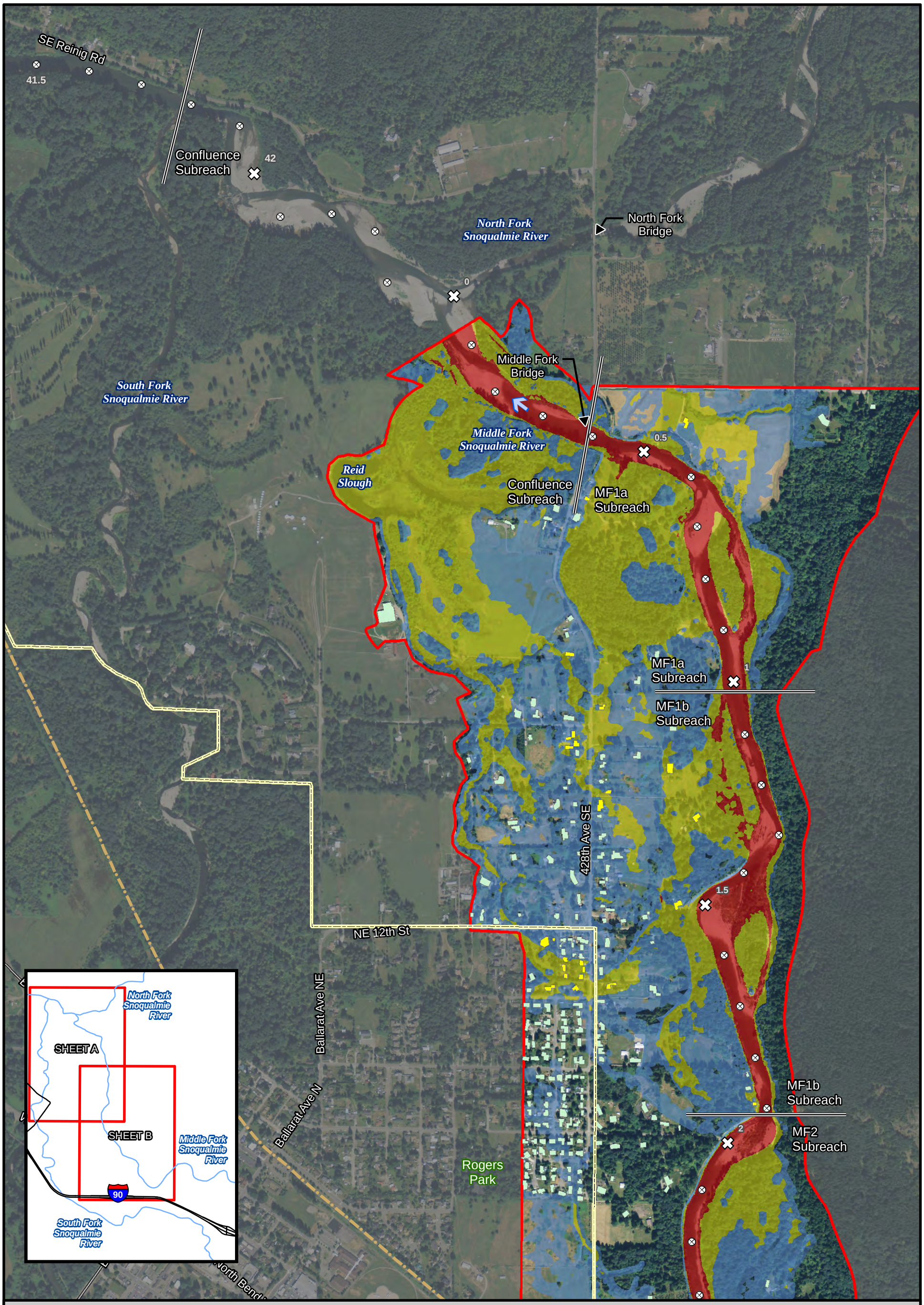
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate12b.mxd (7/12/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Buildings in Hazard Areas
- Building Boundary
- Model Extents
- ***Exceeds King County Regulatory Depth-Velocity Standards (Deep and Fast)***
- ***Depth-Velocity Hazards based on USBR approach (Deep and/or Fast)***
- ***Inundated from 2 Percent Annual Chance Flood***

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 13a. Depth-Velocity Hazard Areas
2 Percent Annual Chance Flood
(50-year Event - 32,800 cfs)
(Sheet 1 of 2)

N

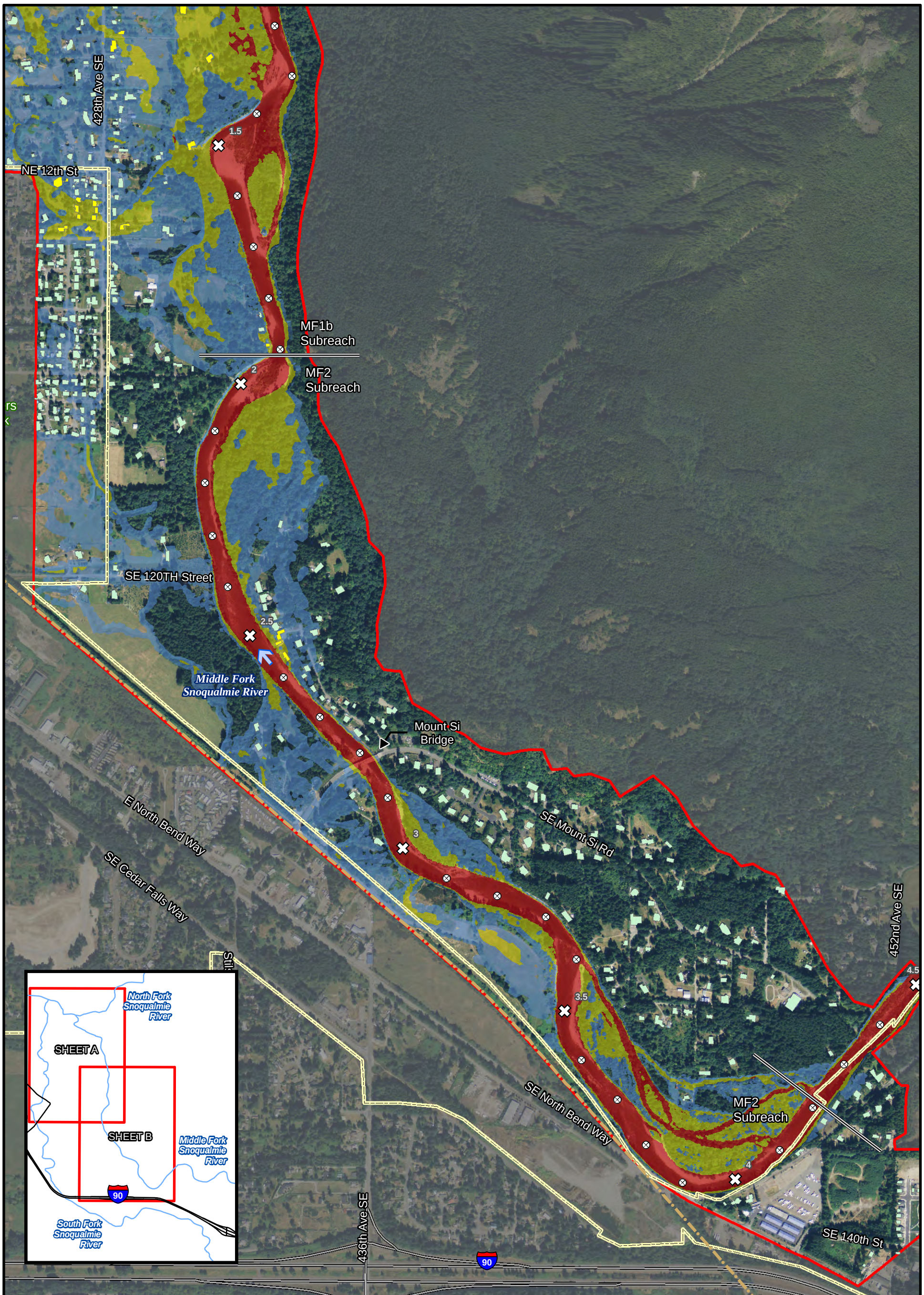
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate13a.mxd (7/12/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Buildings in Hazard Areas
- Building Boundary
- Model Extents
- ***Exceeds King County Regulatory Depth-Velocity Standards (Deep and Fast)***
- ***Depth-Velocity Hazards based on USBR approach (Deep and/or Fast)***
- ***Inundated from 2 Percent Annual Chance Flood***

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 13b. Depth-Velocity Hazard Areas
2 Percent Annual Chance Flood
(50-year Event - 32,800 cfs)
(Sheet 2 of 2)

N

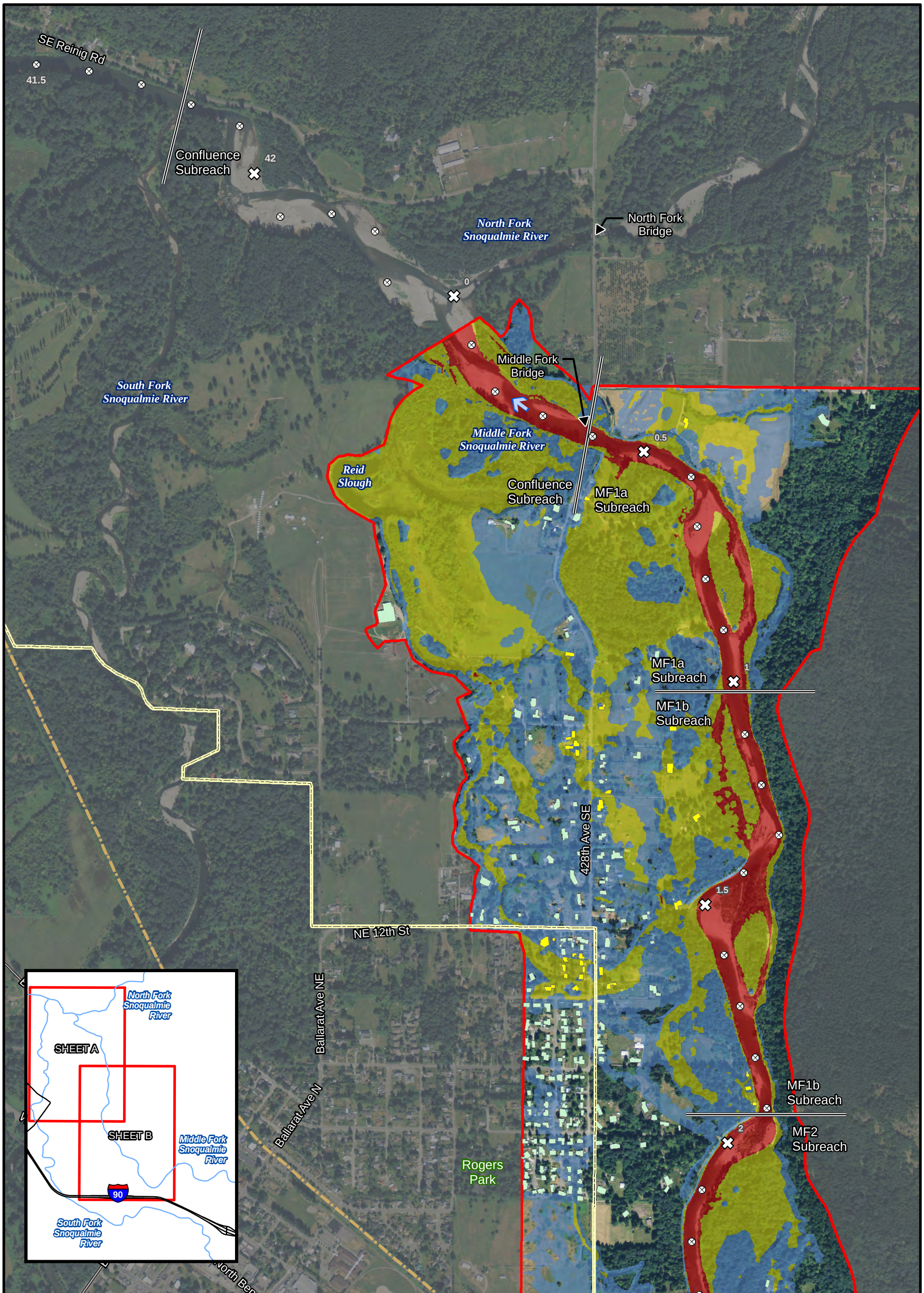
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate13b.mxd (7/12/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Buildings in Hazard Areas
- Building Boundary
- Model Extents
- ***Exceeds King County Regulatory Depth-Velocity Standards (Deep and Fast)***
- ***Depth-Velocity Hazards based on USBR approach (Deep and/or Fast)***
- ***Inundated from 1 Percent Annual Chance Flood***

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 14a. Depth-Velocity Hazard Areas
1 Percent Annual Chance Flood
(100-year Event - 35,400 cfs)
(Sheet 1 of 2)

N

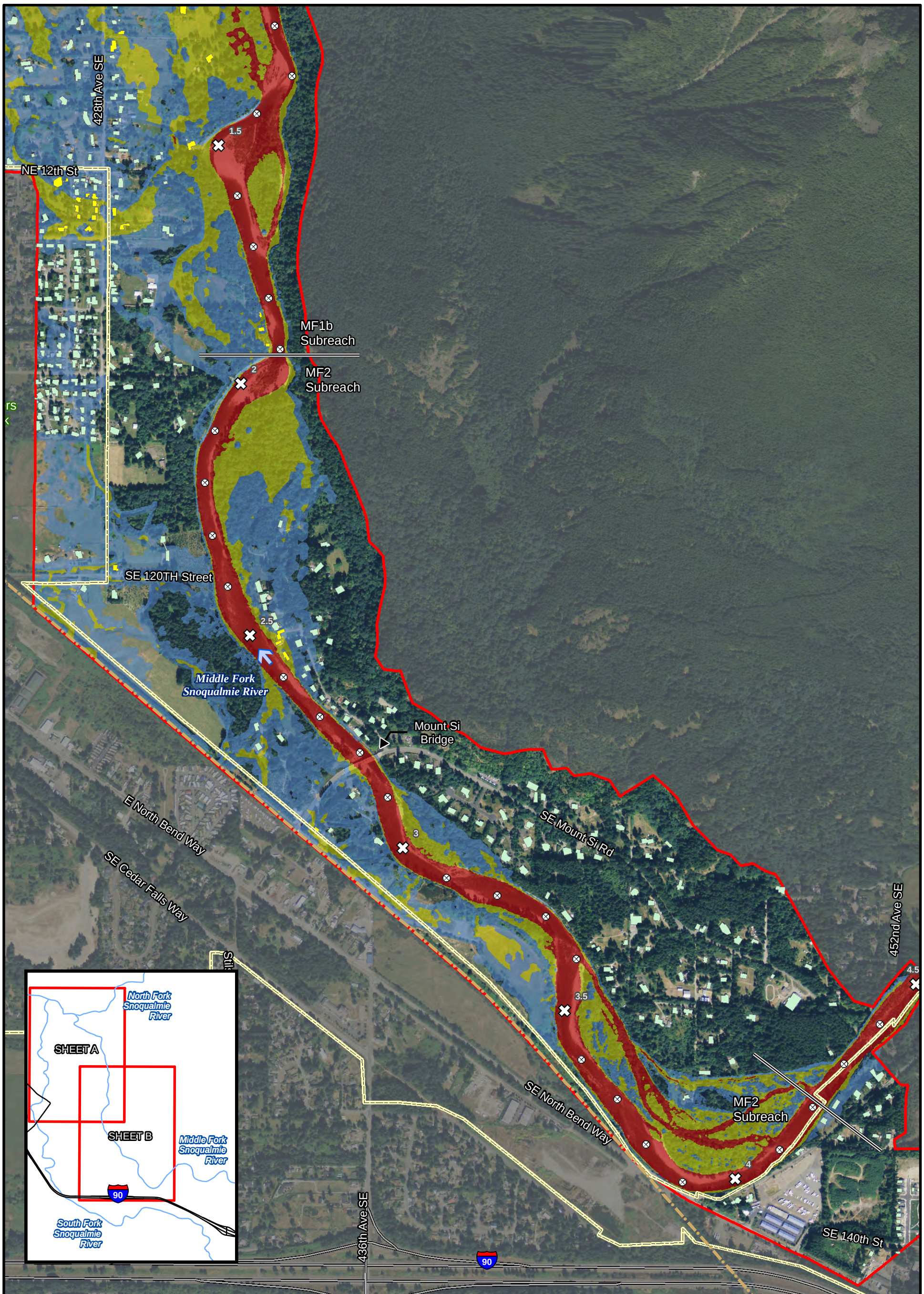
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate14a.mxd (7/12/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Buildings in Hazard Areas
- Building Boundary
- Model Extents
- ***Exceeds King County Regulatory Depth-Velocity Standards (Deep and Fast)***
- ***Depth-Velocity Hazards based on USBR approach (Deep and/or Fast)***
- ***Inundated from 1 Percent Annual Chance Flood***

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 14b. Depth-Velocity Hazard Areas
1 Percent Annual Chance Flood
(100-year Event - 35,400 cfs)
(Sheet 2 of 2)

N

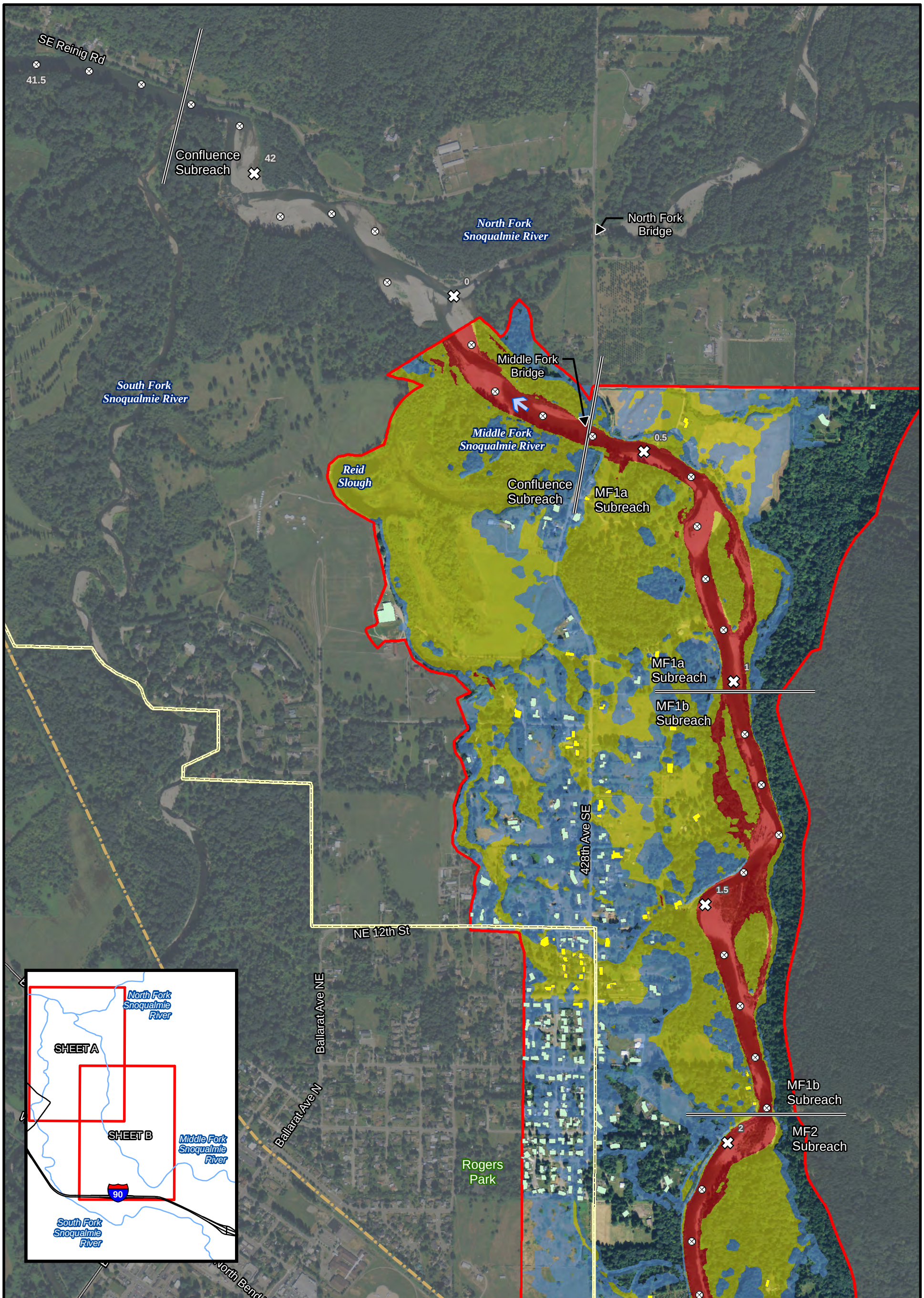
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate14b.mxd (7/12/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Buildings in Hazard Areas
- Building Boundary
- Model Extents
- *Exceeds King County Regulatory Depth-Velocity Standards (Deep **and** Fast)*
- *Depth-Velocity Hazards based on USBR approach (Deep **and/or** Fast)*
- *Inundated from 0.2 Percent Annual Chance Flood*

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 15a. Depth-Velocity Hazard Areas
0.2 Percent Annual Chance Flood
(500-year Event - 41,000 cfs)
(Sheet 1 of 2)

N

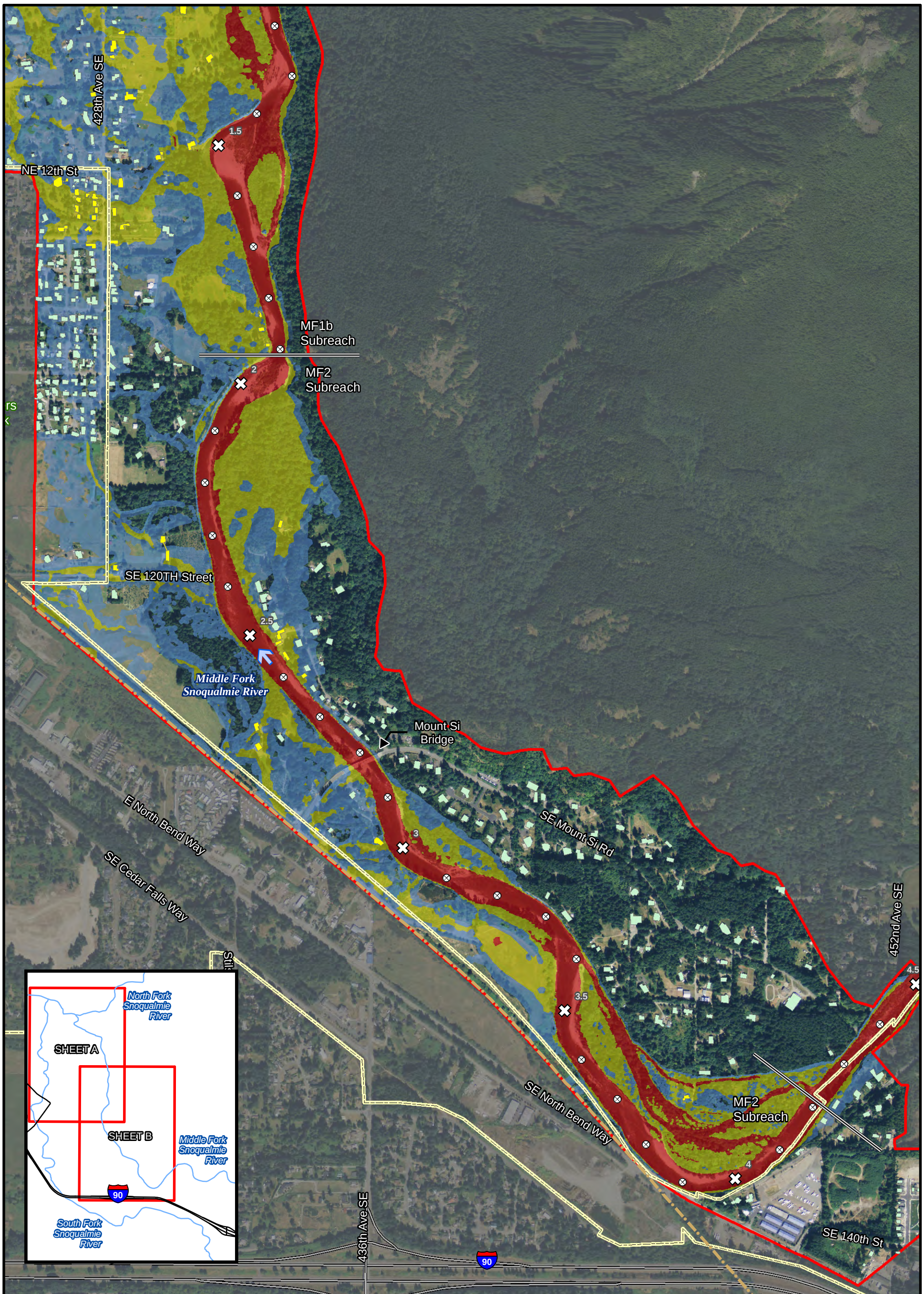
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate15a.mxd (7/12/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Buildings in Hazard Areas
- Building Boundary
- Model Extents
- *Exceeds King County Regulatory Depth-Velocity Standards (Deep **and** Fast)*
- *Depth-Velocity Hazards based on USBR approach (Deep **and/or** Fast)*
- *Inundated from 0.2 Percent Annual Chance Flood*

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 15b. Depth-Velocity Hazard Areas
0.2 Percent Annual Chance Flood
(500-year Event - 41,000 cfs)
(Sheet 2 of 2)

N

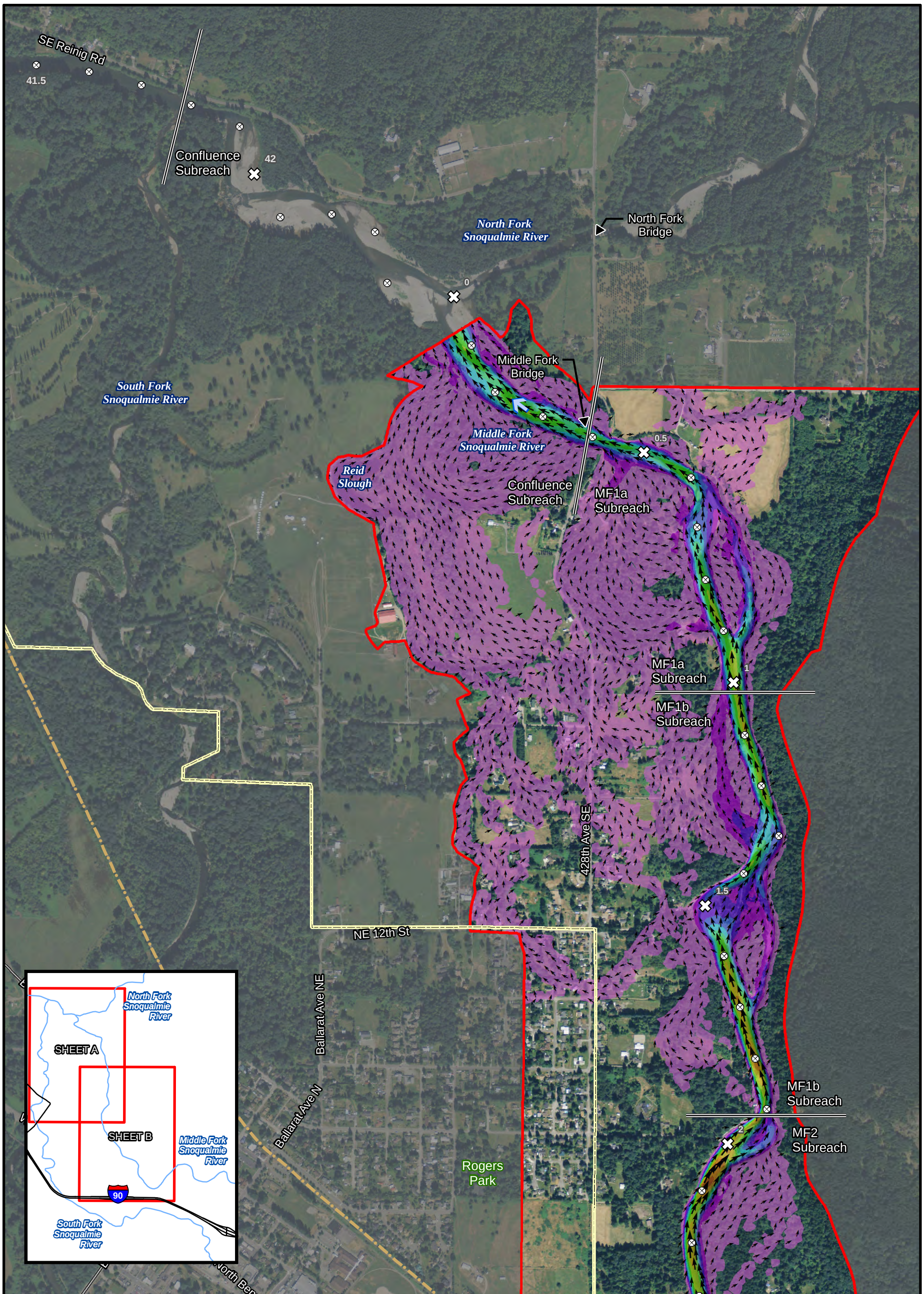
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate15b.mxd (7/12/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents

Velocity (ft/s)

22 - 25	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	
16 - 18	6 - 8	
14 - 16	4 - 6	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 16a. Velocity
10 Percent Annual Chance Flood
(10-year Event - 26,100 cfs)
(Sheet 1 of 2)

N

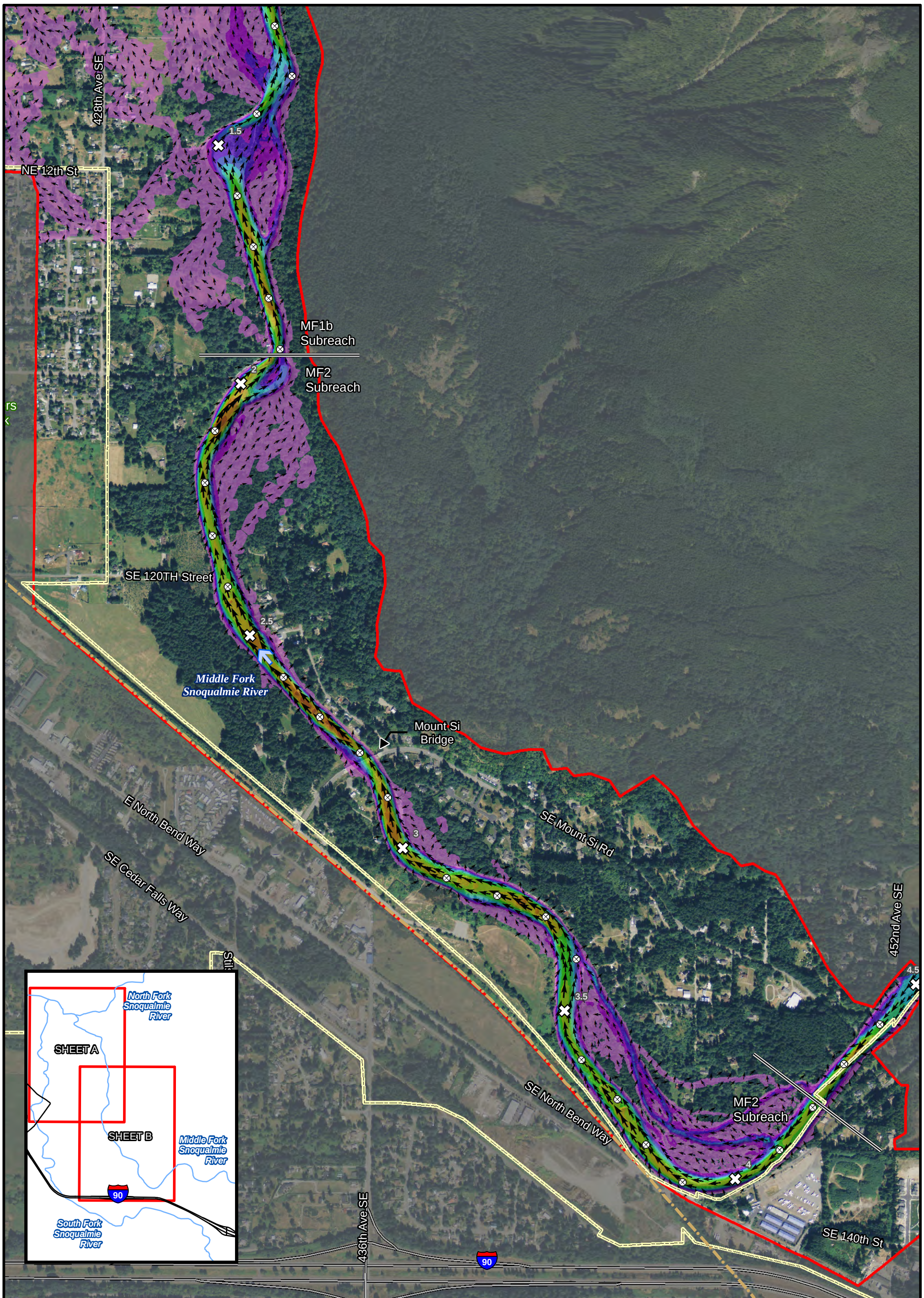
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate16a.mxd (5/31/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents

Velocity (ft/s)

22 - 25	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	
16 - 18	6 - 8	
14 - 16	4 - 6	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 16b. Velocity
10 Percent Annual Chance Flood
(10-year Event - 26,100 cfs)
(Sheet 2 of 2)

N

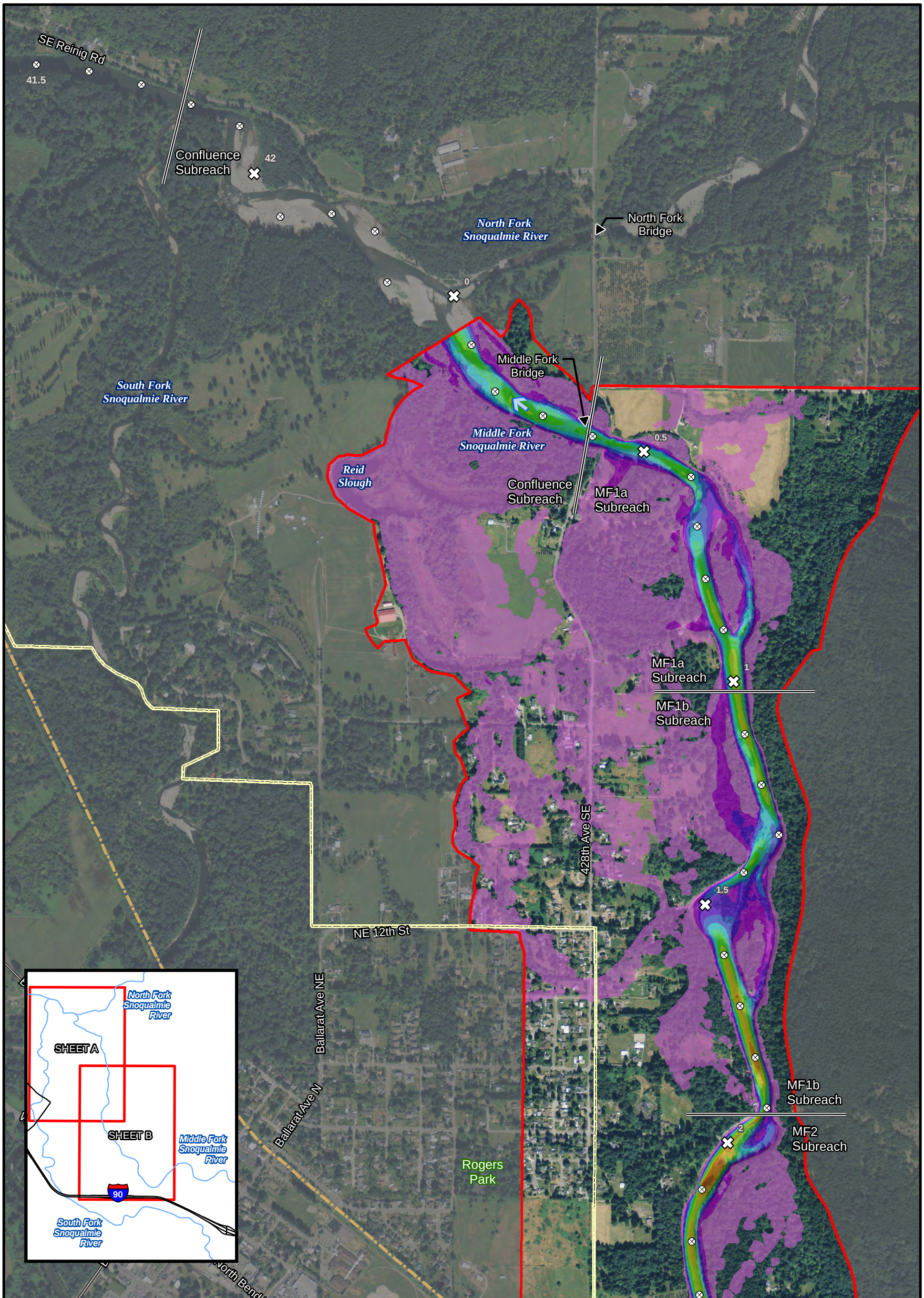
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate16b.mxd (5/31/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents

Velocity (ft/s)

22 - 25	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	
16 - 18	6 - 8	
14 - 16	4 - 6	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 16c. Velocity Magnitude
10 Percent Annual Chance Flood
(10-year Event - 26,100 cfs)
(Sheet 1 of 2)

N

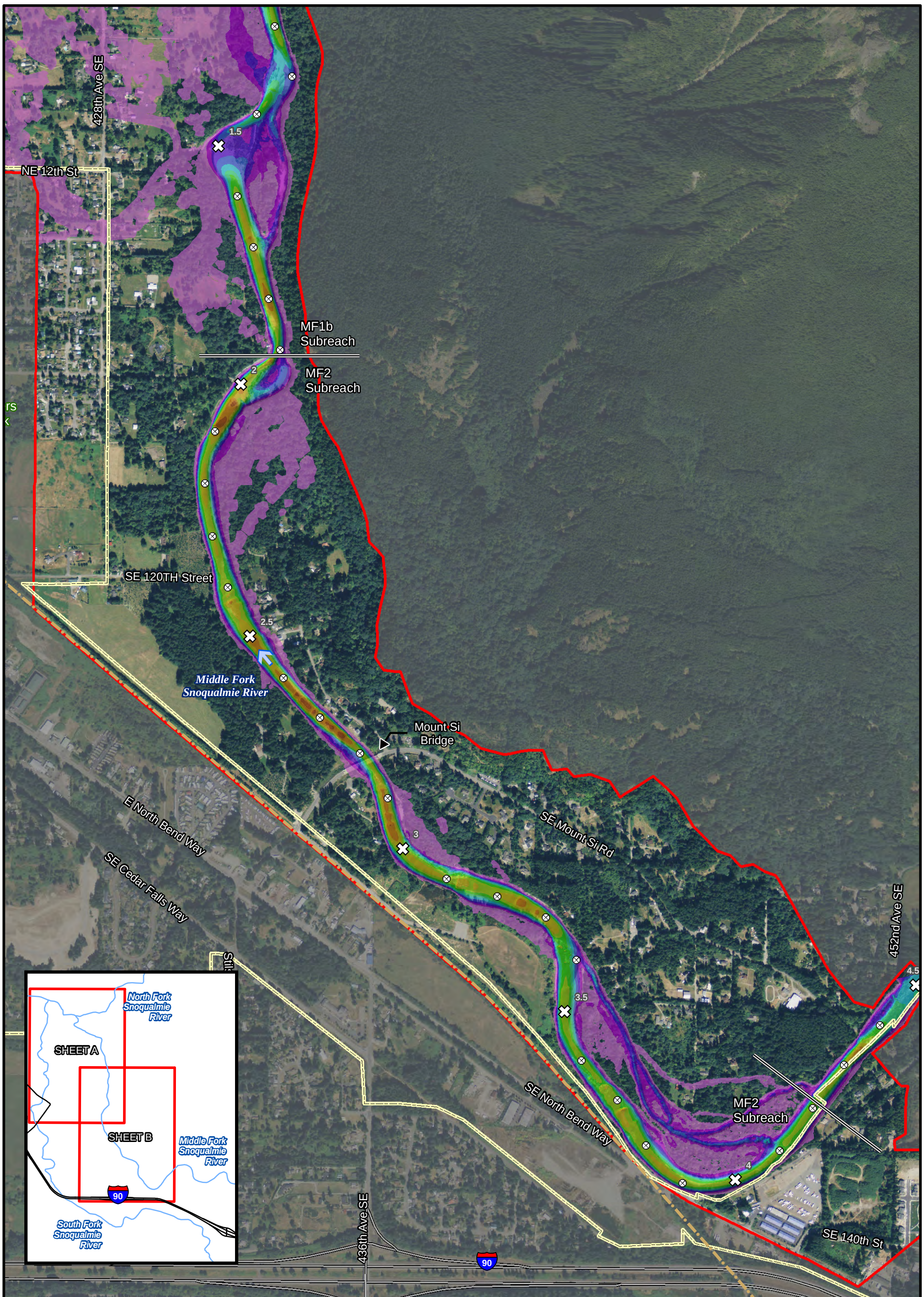
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate16c.mxd (5/31/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents

Velocity (ft/s)

22 - 25	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	
16 - 18	6 - 8	
14 - 16	4 - 6	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 16d. Velocity Magnitude
10 Percent Annual Chance Flood
(10-year Event - 26,100 cfs)
(Sheet 2 of 2)

N

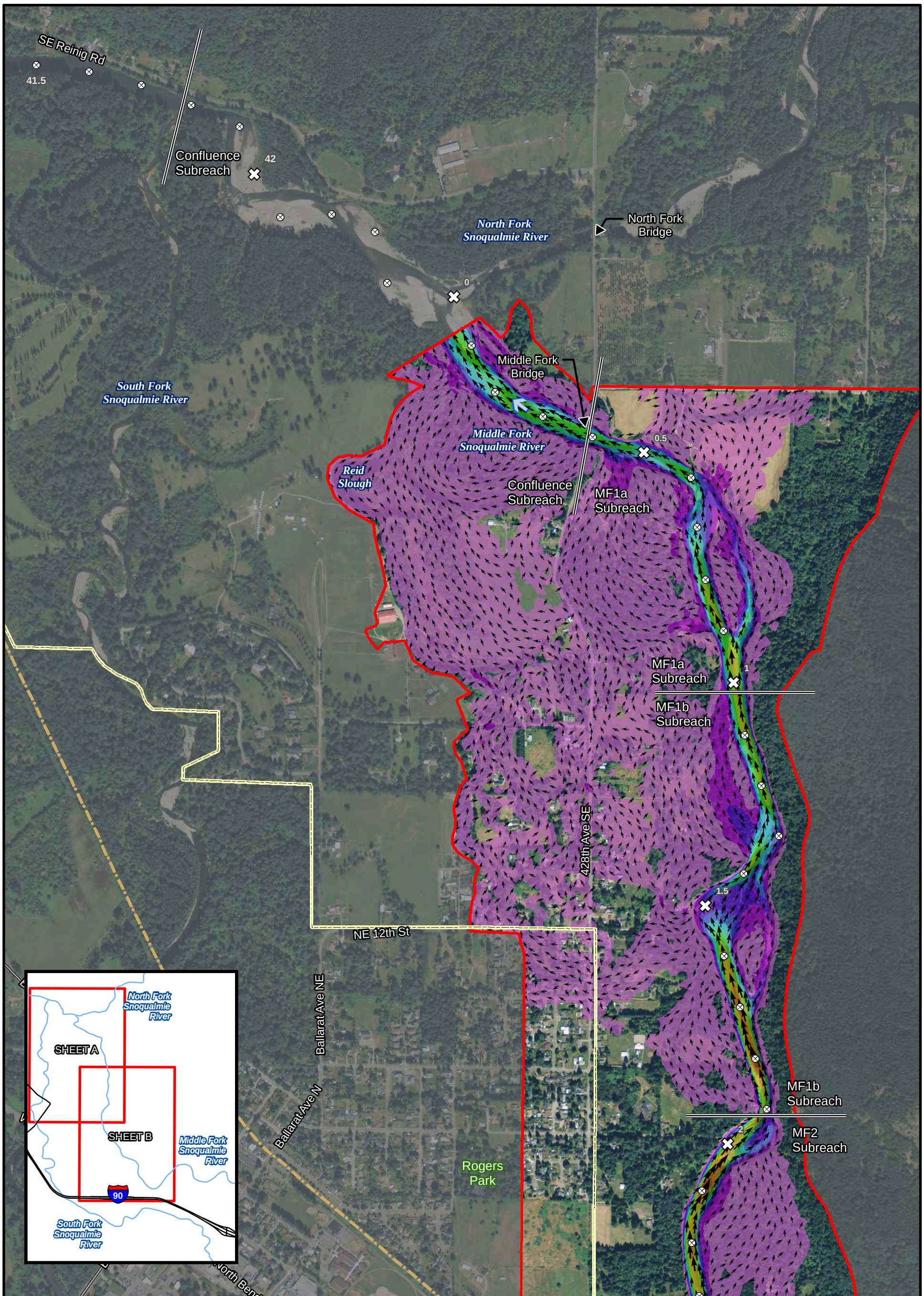
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate16d.mxd (5/31/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents

Velocity (ft/s)

22 - 25	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	
16 - 18	6 - 8	
14 - 16	4 - 6	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 17a. Velocity
4 Percent Annual Chance Flood
(25-year Event - 30,100 cfs)
(Sheet 1 of 2)

N

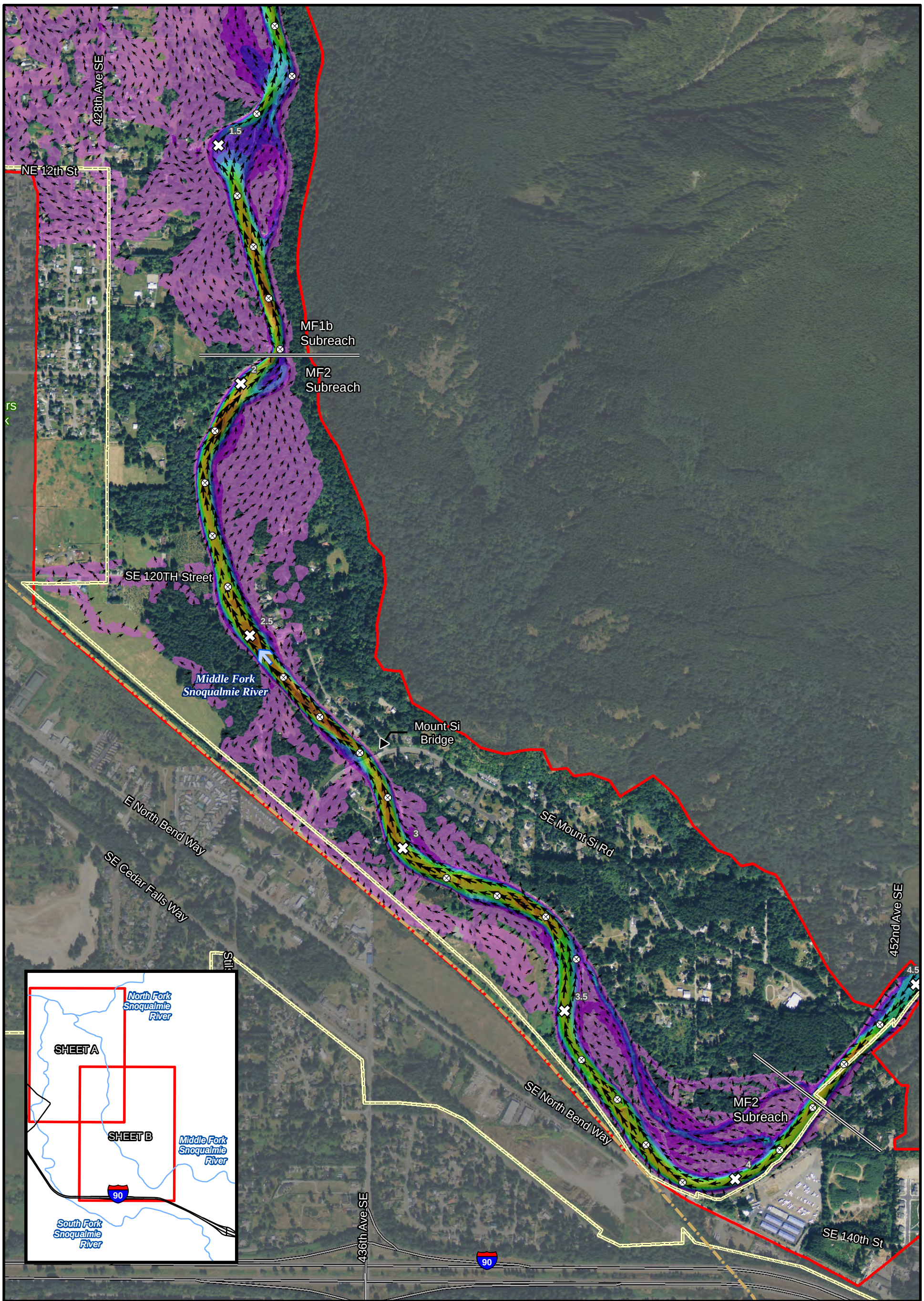
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate17a.mxd (5/31/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents

Velocity (ft/s)

22 - 25	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	
16 - 18	6 - 8	
14 - 16	4 - 6	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 17b. Velocity
4 Percent Annual Chance Flood
(25-year Event - 30,100 cfs)
(Sheet 2 of 2)

N

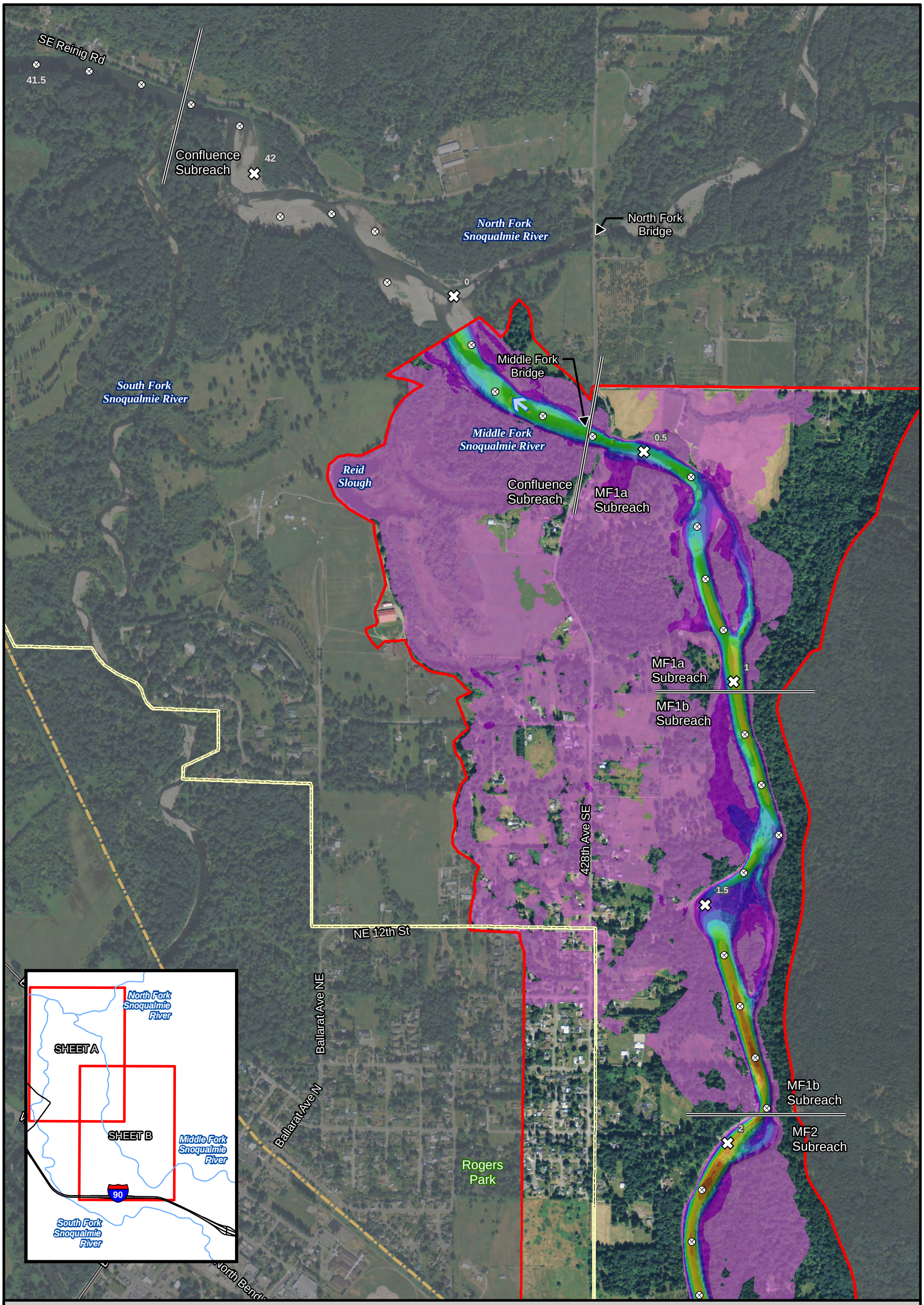
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate17b.mxd (5/31/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents

Velocity (ft/s)

22 - 25	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	
16 - 18	6 - 8	
14 - 16	4 - 6	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 17c. Velocity Magnitude
4 Percent Annual Chance Flood
(25-year Event - 30,100 cfs)
(Sheet 1 of 2)

N

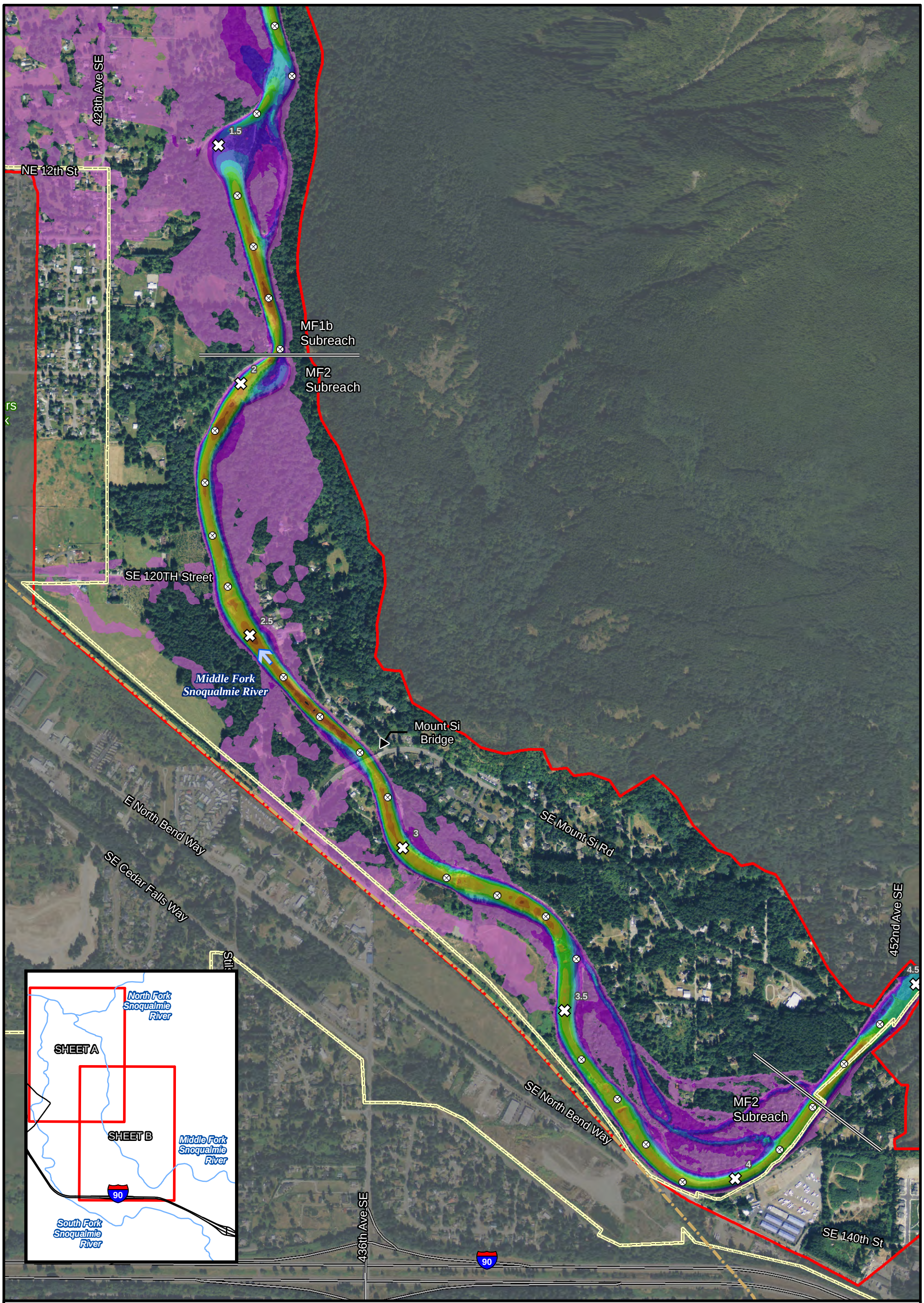
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate17c.mxd (5/31/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents

Velocity (ft/s)

22 - 25	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	
16 - 18	6 - 8	
14 - 16	4 - 6	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 17d. Velocity Magnitude
4 Percent Annual Chance Flood
(25-year Event - 30,100 cfs)
(Sheet 2 of 2)

N

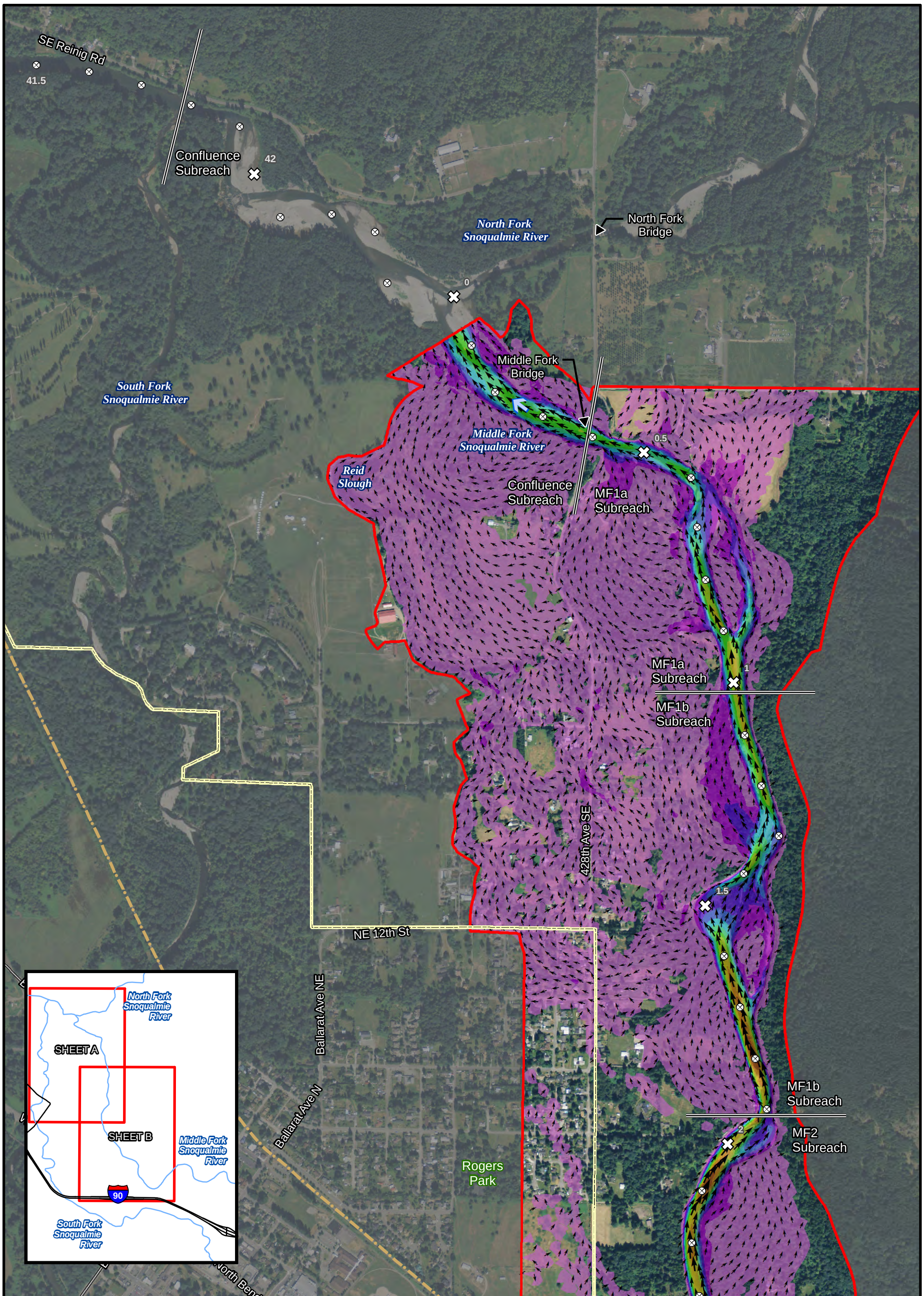
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate17d.mxd (5/31/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents

Velocity (ft/s)

22 - 25	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	
16 - 18	6 - 8	
14 - 16	4 - 6	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 18a. Velocity
2 Percent Annual Chance Flood
(50-year Event - 32,800 cfs)
(Sheet 1 of 2)

N

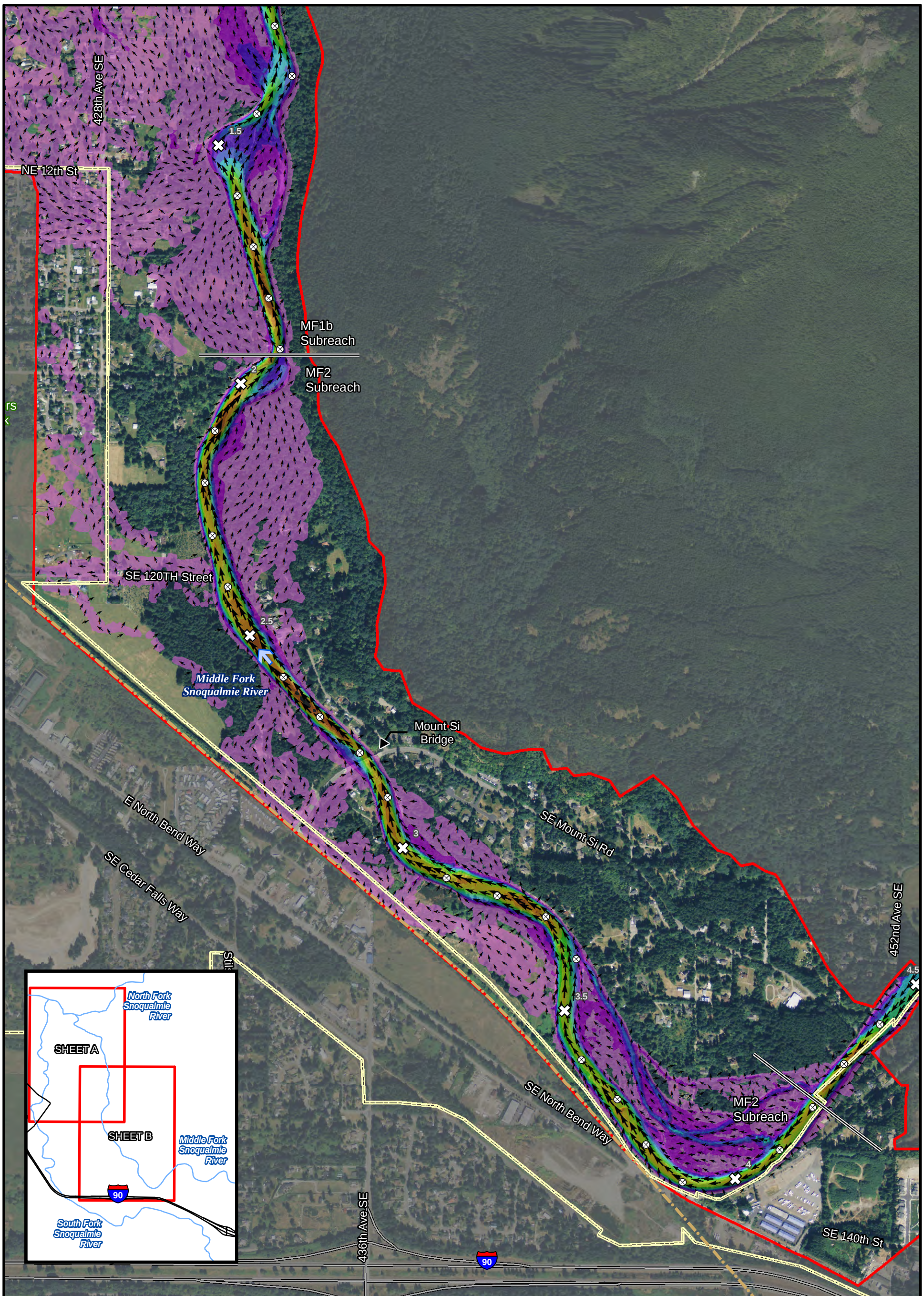
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate18a.mxd (5/31/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents

Velocity (ft/s)

22 - 25	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	
16 - 18	6 - 8	
14 - 16	4 - 6	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 18b. Velocity
2 Percent Annual Chance Flood
(50-year Event - 32,800 cfs)
(Sheet 2 of 2)

N

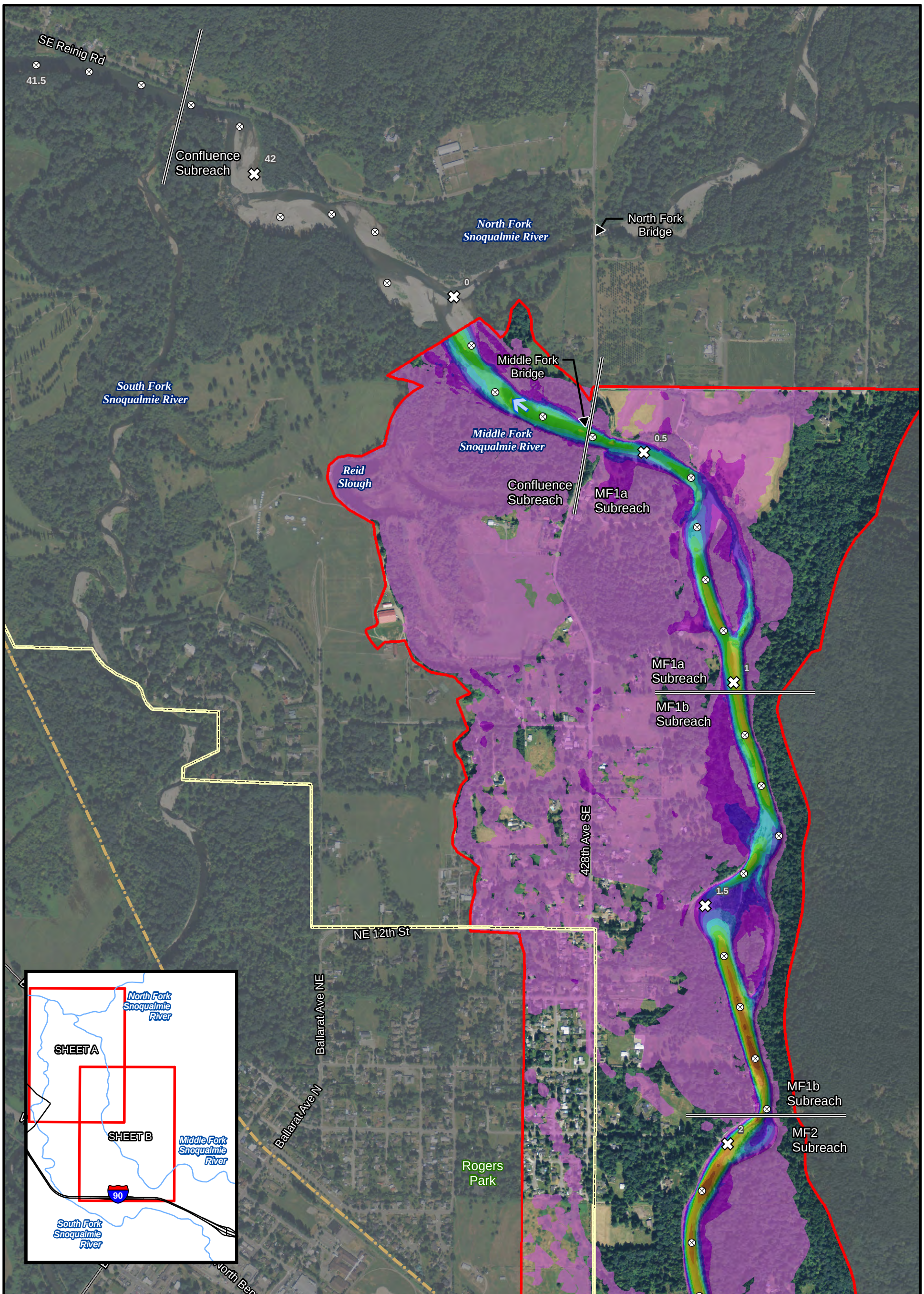
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate18b.mxd (5/31/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents

Velocity (ft/s)

22 - 25	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	
16 - 18	6 - 8	
14 - 16	4 - 6	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 18c. Velocity Magnitude
2 Percent Annual Chance Flood
(50-year Event - 32,800 cfs)
(Sheet 1 of 2)

N

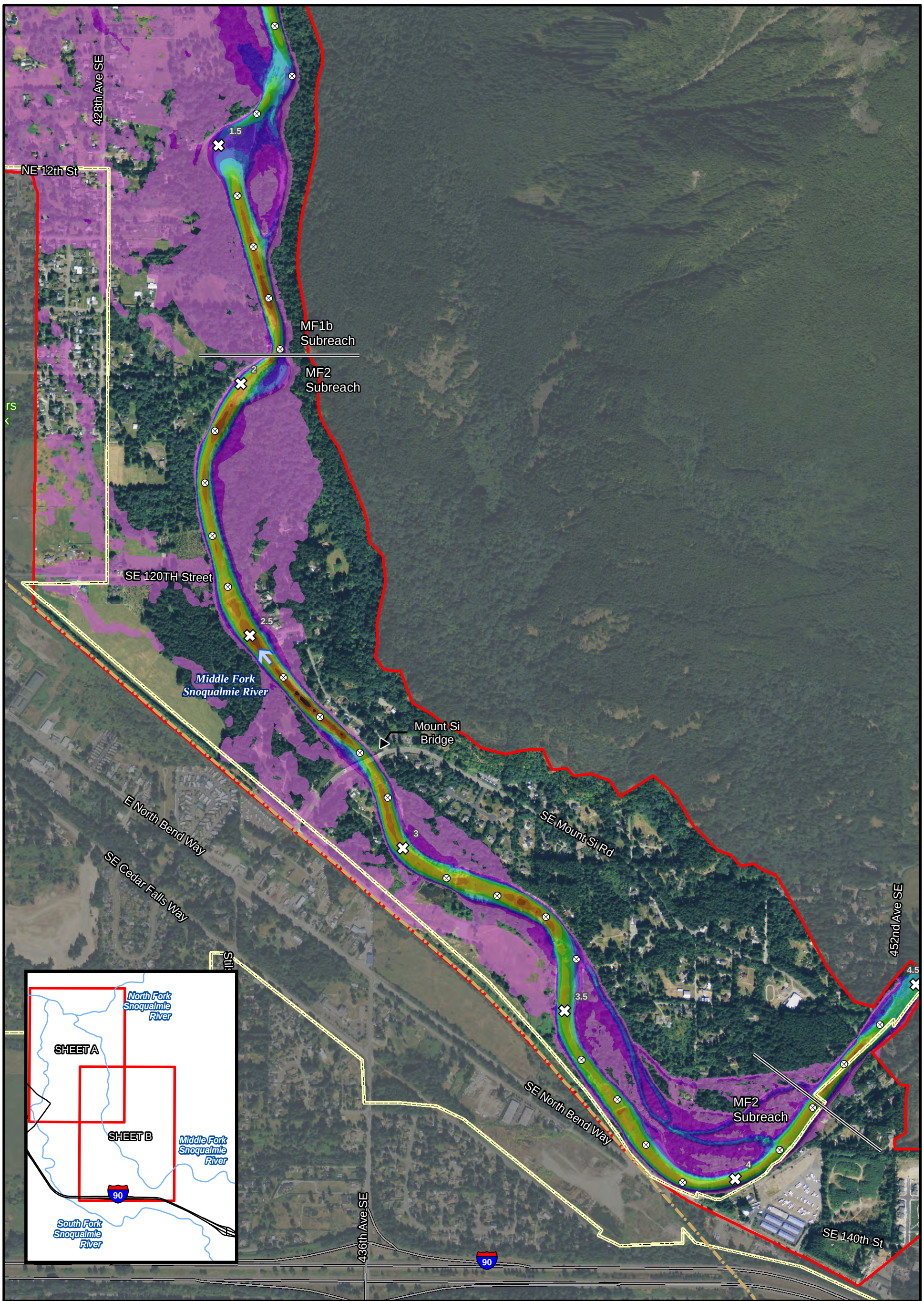
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate18c.mxd (5/31/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents

Velocity (ft/s)

22 - 25	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	
16 - 18	6 - 8	
14 - 16	4 - 6	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 18d. Velocity Magnitude
2 Percent Annual Chance Flood
(50-year Event - 32,800 cfs)
(Sheet 2 of 2)

N

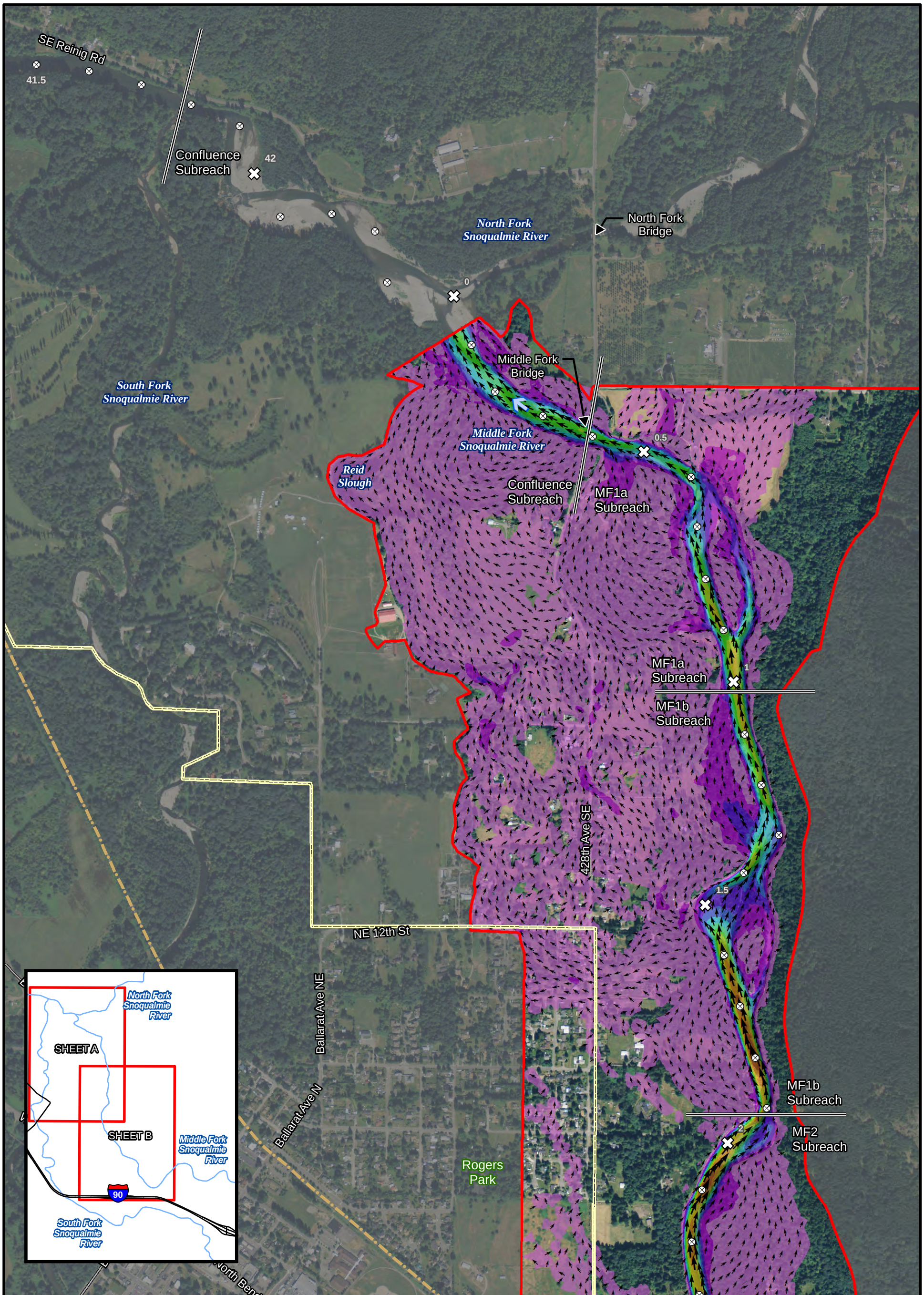
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate18d.mxd (5/31/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents

Velocity (ft/s)

22 - 25	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	
16 - 18	6 - 8	
14 - 16	4 - 6	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 19a. Velocity
1 Percent Annual Chance Flood
(100-year Event - 35,400 cfs)
(Sheet 1 of 2)

N

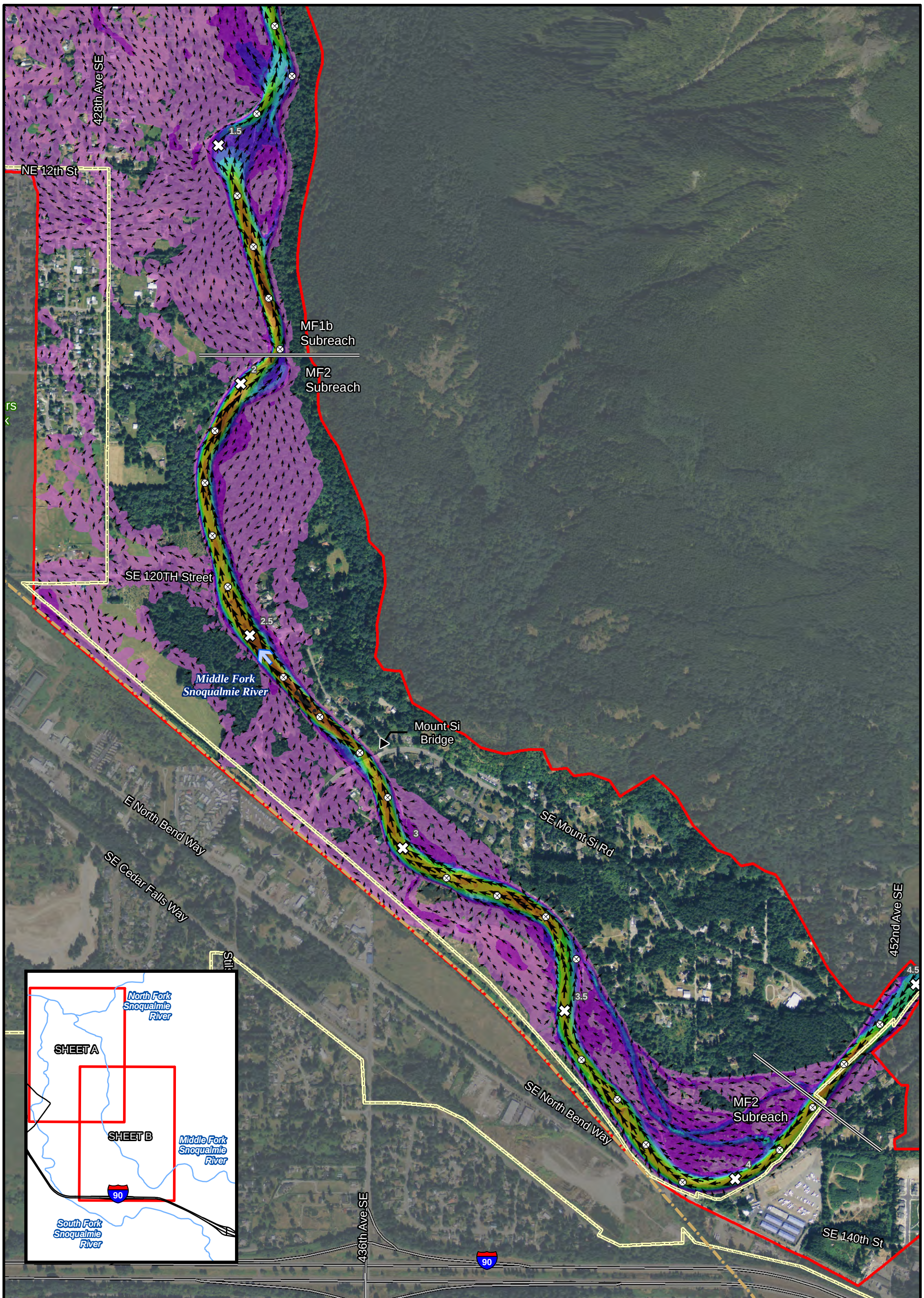
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate19a.mxd (5/31/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents

Velocity (ft/s)

22 - 25	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	
16 - 18	6 - 8	
14 - 16	4 - 6	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 19b. Velocity
1 Percent Annual Chance Flood
(100-year Event - 35,400 cfs)
(Sheet 2 of 2)

N

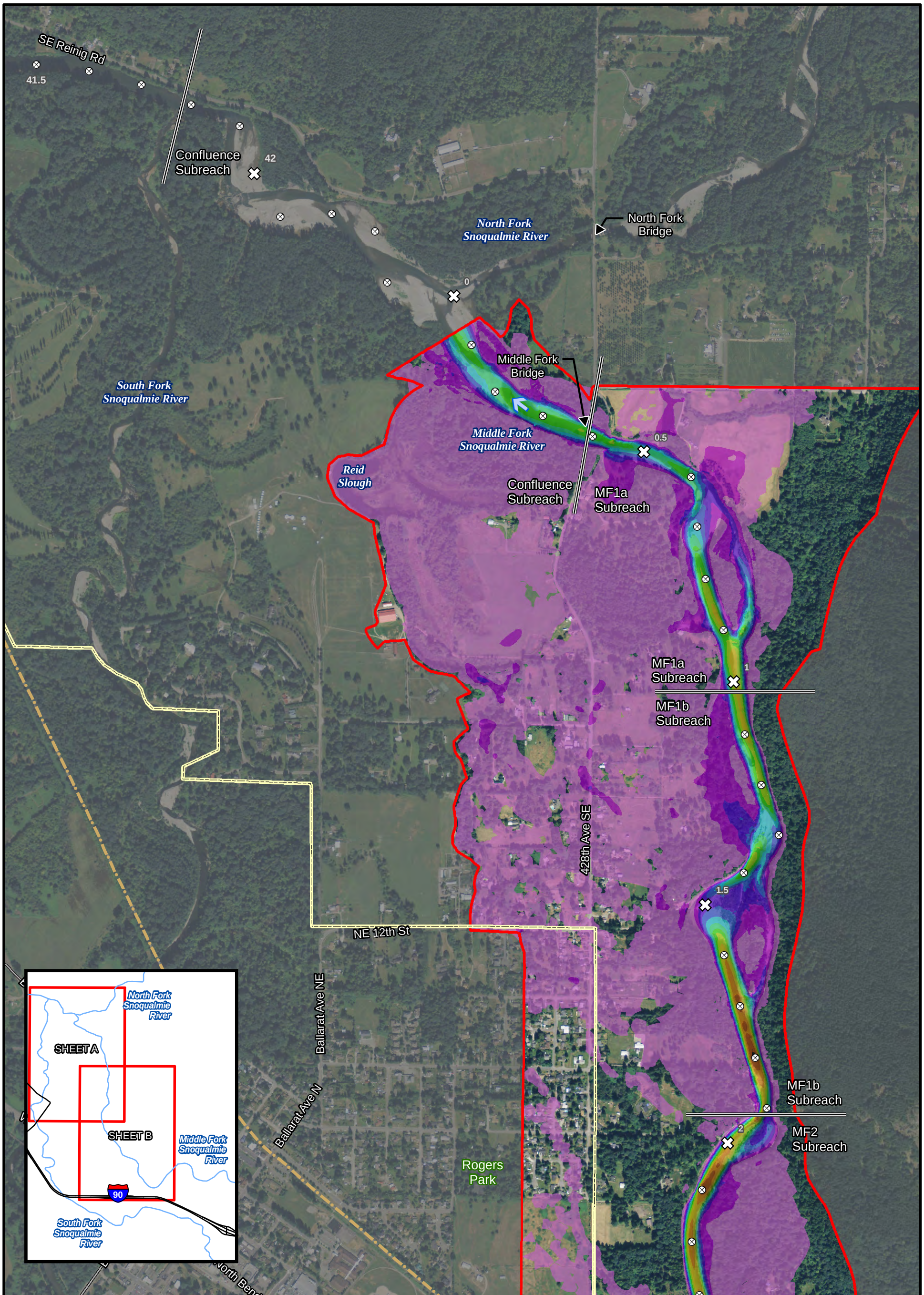
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate19b.mxd (5/31/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents

Velocity (ft/s)

22 - 25	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	
16 - 18	6 - 8	
14 - 16	4 - 6	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 19c. Velocity Magnitude
1 Percent Annual Chance Flood
(100-year Event - 35,400 cfs)
(Sheet 1 of 2)

N

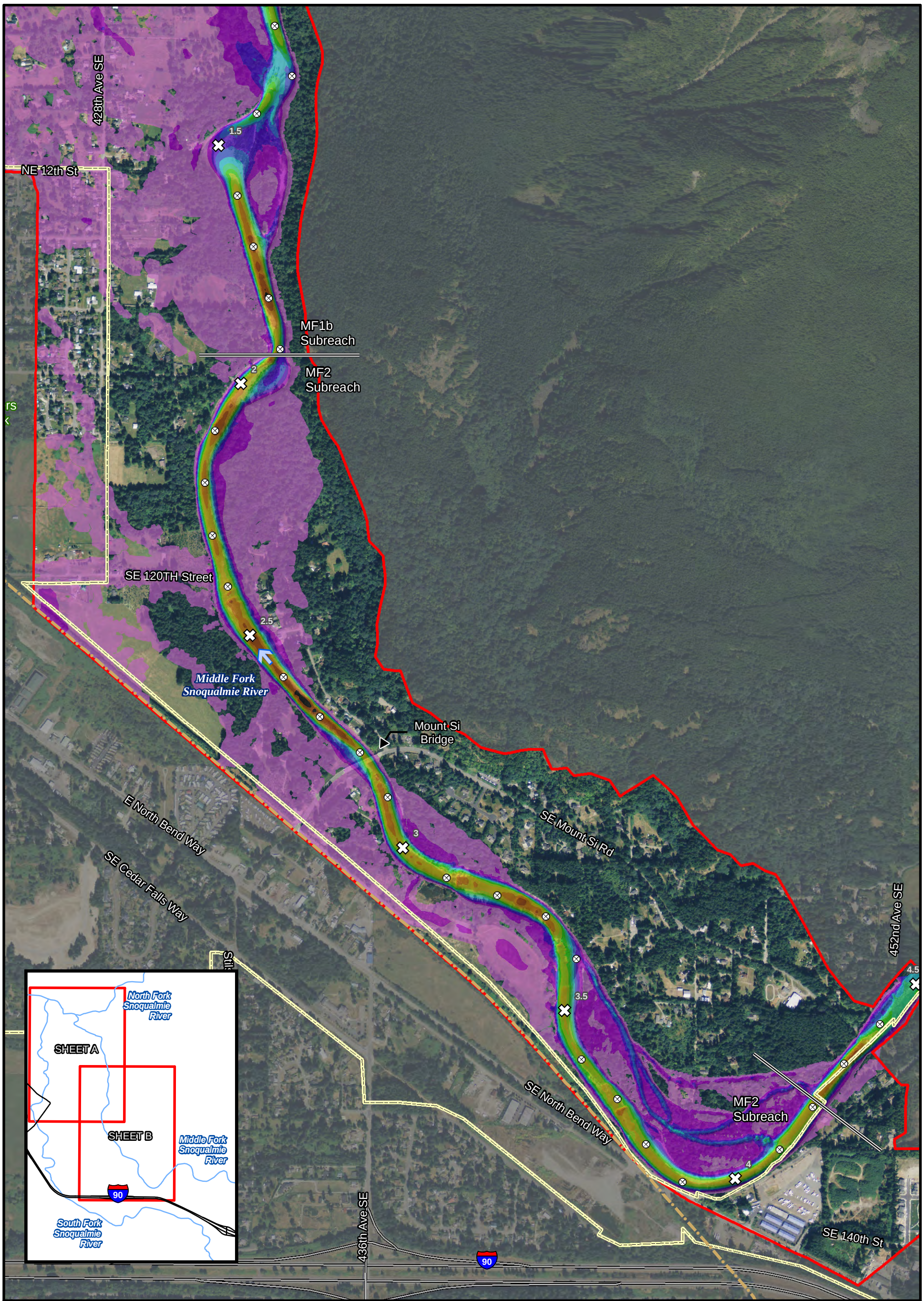
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate19c.mxd (5/31/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents

Velocity (ft/s)

22 - 25	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	
16 - 18	6 - 8	
14 - 16	4 - 6	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 19d. Velocity Magnitude
1 Percent Annual Chance Flood
(100-year Event - 35,400 cfs)
(Sheet 2 of 2)

N

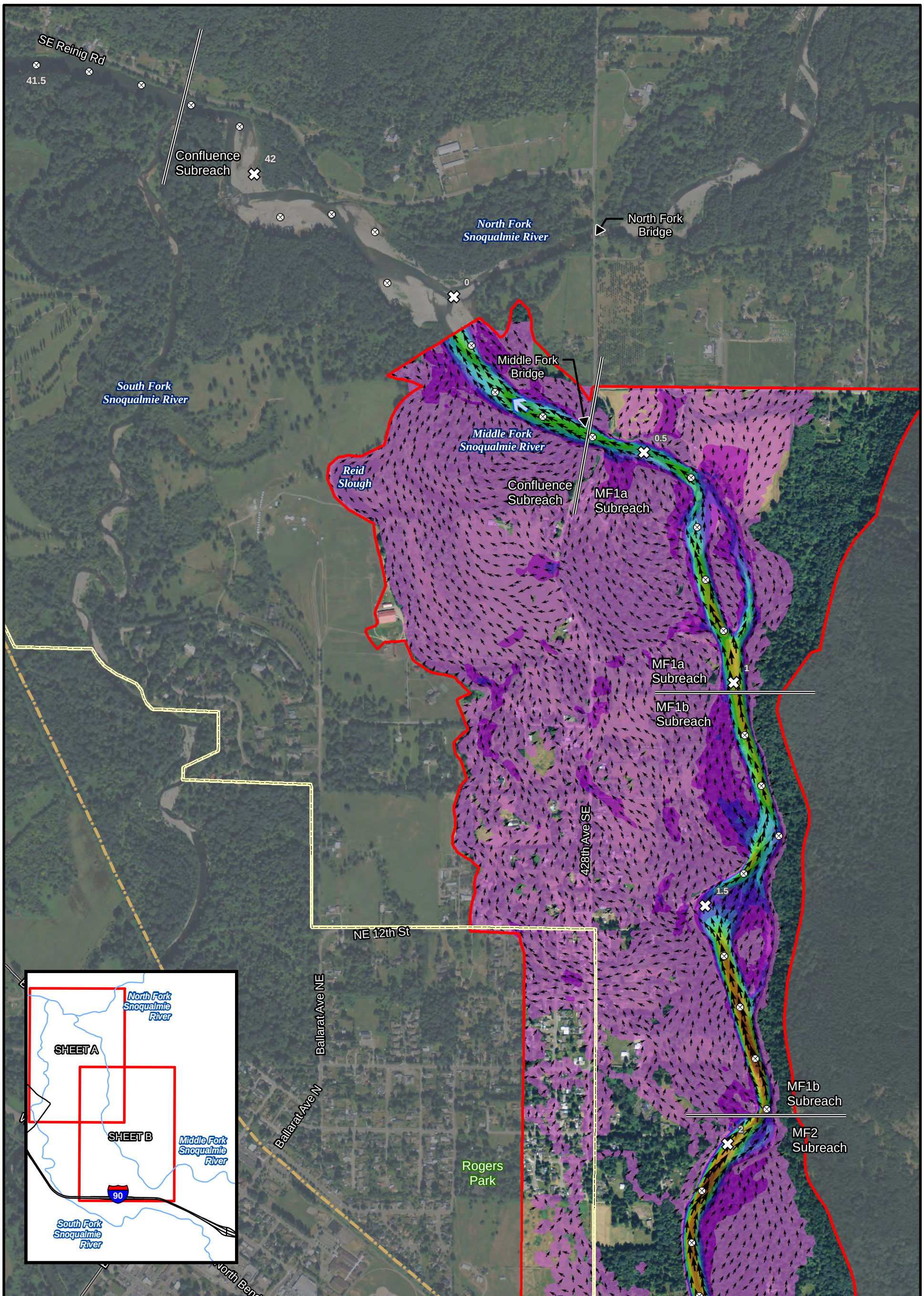
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate19d.mxd (5/31/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents

Velocity (ft/s)

22 - 25	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	
16 - 18	6 - 8	
14 - 16	4 - 6	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 20a. Velocity
0.2 Percent Annual Chance Flood
(500-year Event - 41,000 cfs)
(Sheet 1 of 2)

N

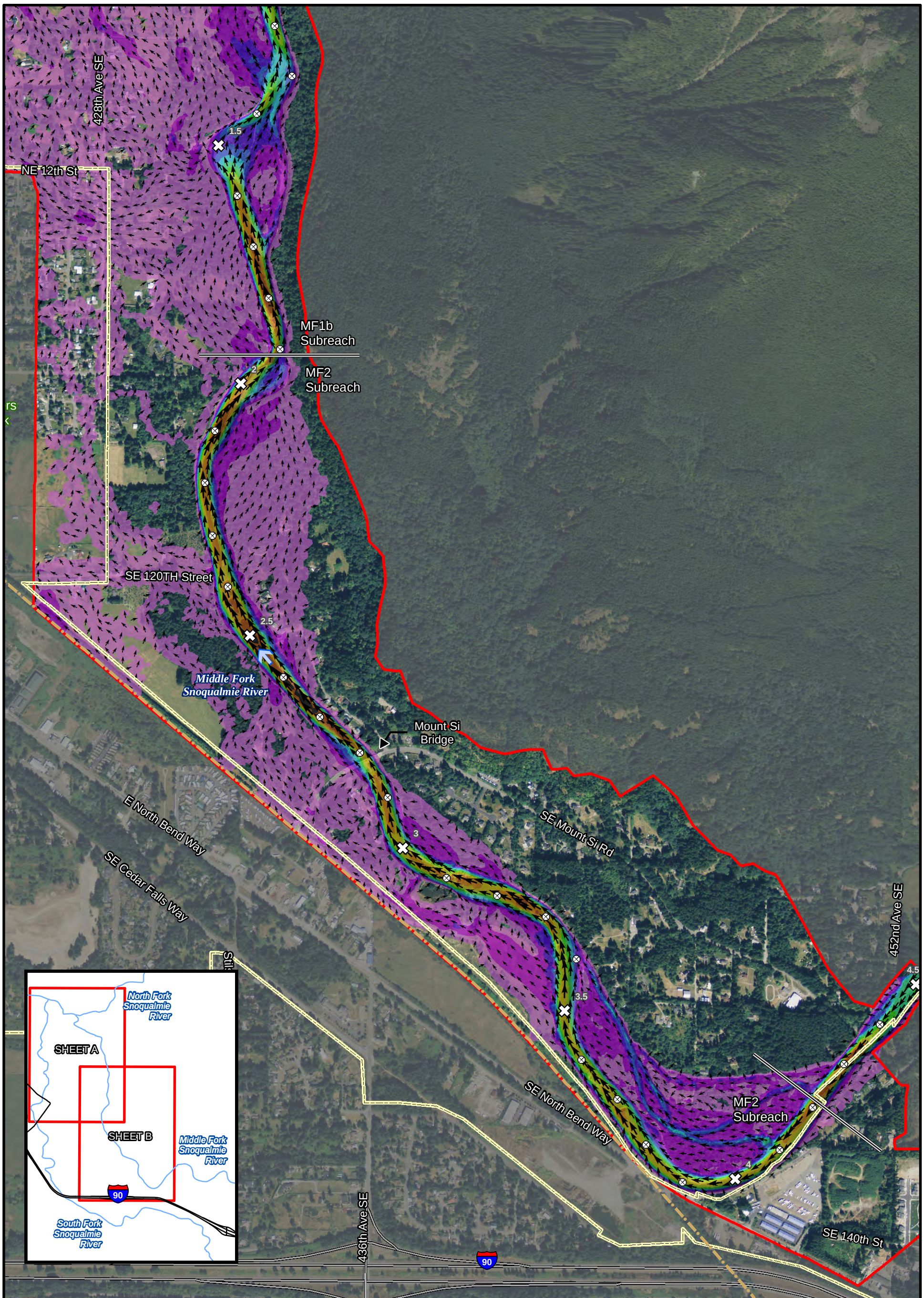
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate20a.mxd (5/31/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents

Velocity (ft/s)

22 - 25	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	
16 - 18	6 - 8	
14 - 16	4 - 6	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 20b. Velocity
0.2 Percent Annual Chance Flood
(500-year Event - 41,000 cfs)
(Sheet 2 of 2)

N

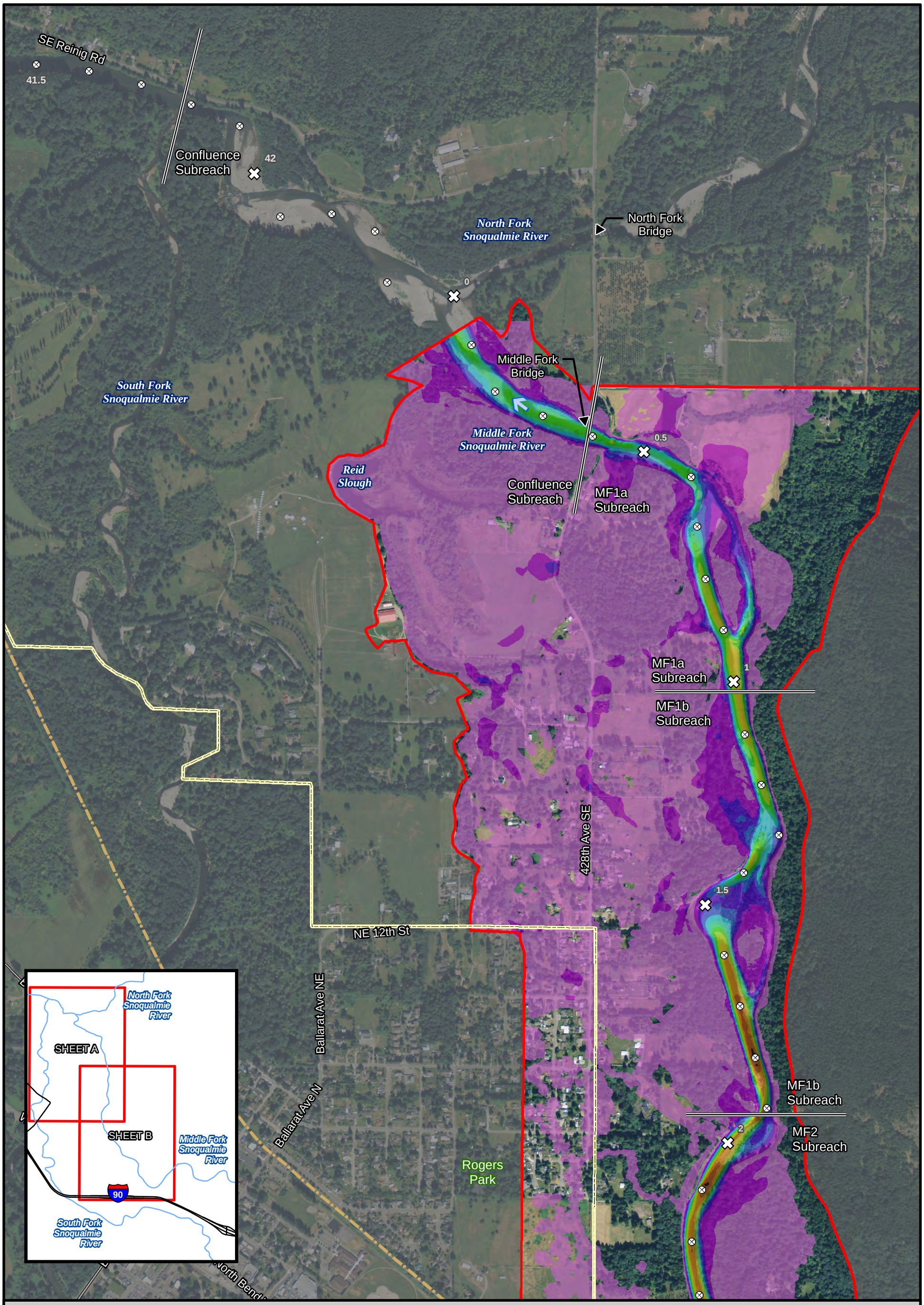
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate20b.mxd (5/31/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents

Velocity (ft/s)

22 - 25	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	
16 - 18	6 - 8	
14 - 16	4 - 6	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 20c. Velocity Magnitude
0.2 Percent Annual Chance Flood
(500-year Event - 41,000 cfs)
(Sheet 1 of 2)

N

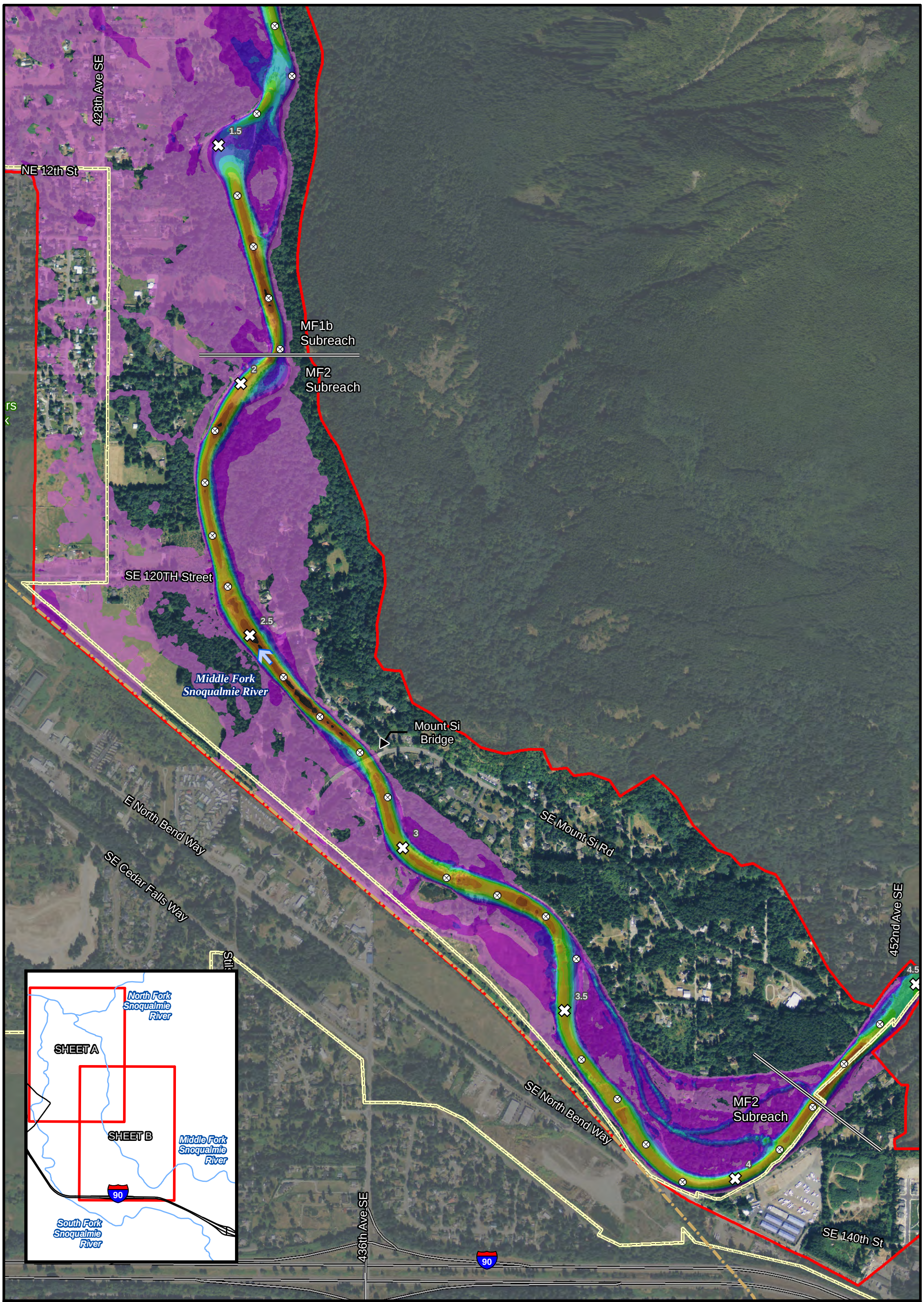
0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate20c.mxd (5/31/2013)



Legend

- River mile
- 1/10th river mile
- Subreach boundary
- Snoqualmie Valley Trail
- Highway
- Flow direction
- City of North Bend boundary
- Model Extents

Velocity (ft/s)

22 - 25	12 - 14	2 - 4
20 - 22	10 - 12	0 - 2
18 - 20	8 - 10	
16 - 18	6 - 8	
14 - 16	4 - 6	

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Plate 20d. Velocity Magnitude
0.2 Percent Annual Chance Flood
(500-year Event - 41,000 cfs)
(Sheet 2 of 2)

N

0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\Plate20d.mxd (5/31/2013)

APPENDIX A

Cross Section Plots of Velocity & Froude Number Model Outputs and Centerline Profile Plots

[This page intentionally left blank]

Velocity and Froude number outputs were extracted from the RiverFlo-2D model developed for high flow calibration along the main channel for cross sections located approximately every 0.25 mile along the study reach. These data were plotted to help explain trends associated with these outputs. Area-weighted cross sectional average velocities and average Froude numbers were also calculated at each cross section. A summary of the results is given in Table A-1.

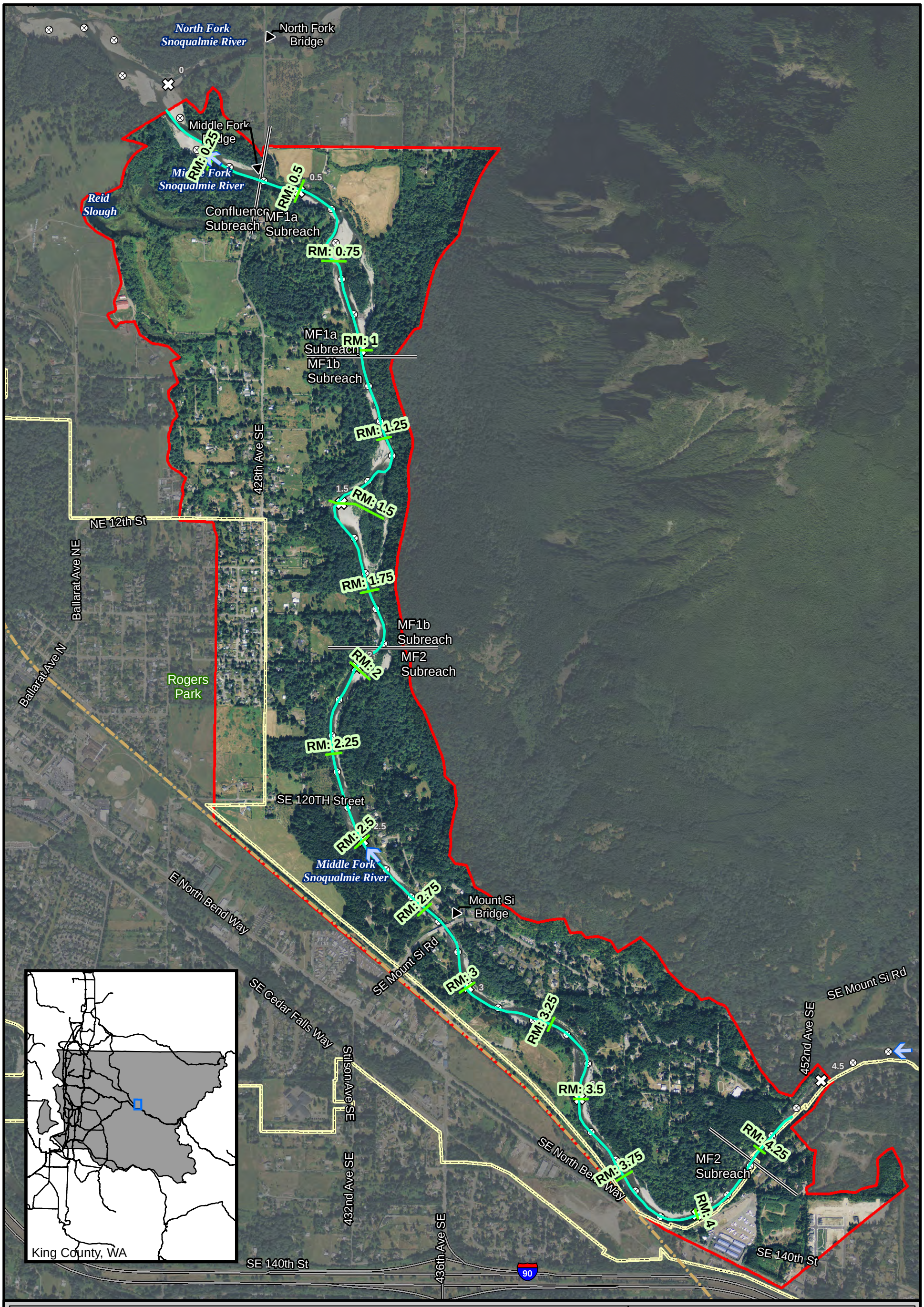
Table A-1: Summary of Average Cross Sectional Velocities and Froude Numbers in the Calibrated High Flow Model

Event	Highest Average Velocity (ft/s)	Lowest Average Velocity (ft/s)	Highest Average Froude Number	Lowest Average Froude Number
10-year	15.17 (RM 3.25)	5.87 (RM 0.75)	0.95 (RM 3.25)	0.26 (RM 1.5)
25-year	15.80 (RM 3.25)	6.14 (RM 0.75)	0.94 (RM 3.25)	0.25 (RM 1.5)
50-year	16.27 (RM 3.25)	6.26 (RM 0.75)	0.95 (RM 3.25)	0.25 (RM 1.5)
100-year	16.50 (RM 3.25)	6.39 (RM 0.75)	0.95 (RM 3.25)	0.25 (RM 1.5)
500-year	16.86 (RM 3.25)	6.62 (RM 0.75)	0.93 (RM 3.25)	0.25 (RM 1.5)

The high velocities and Froude numbers seen at river mile 3.25 are localized and isolated to within about ± 0.05 miles of that location. The low velocities seen in the model results at RM 0.75 and the low Froude numbers seen in the results at RM 1.5 are due to large bars present within the channel at those two locations.

Energy slope, bed slope, Froude number, velocity, depth, and shear stress were averaged longitudinally (every 50 nodes along the centerline profile) and plotted versus river mile stationing to create the centerline profile plots. In general, energy slope, bed slope, Froude number, velocity, and shear stress increase upstream of river mile 1.6 while depth decreases. The highest velocities, depths, and Froude numbers are generally seen near the center of the channel and are thus are represented in the longitudinal profile data.

[This page intentionally left blank]



Legend

- Cross Section
- River Centerline
- River mile
- 1/10th river mile
- Subreach boundary
- Flow direction
- Snoqualmie Valley Trail
- Highway
- City of North Bend boundary
- Model Extents
- Model Extent Location

Note: For portions of the study area below the confluence with the North Fork, which serves as the origin for the King County Middle Fork Snoqualmie River channel coordinate system, river miles are based on the King County Snoqualmie River Mile system, which has its origin at the confluence with the Skykomish River.

Figure A-1. Quarter mile cross section locations and centerline profile

N

0 450 900 1,800 Feet

King County

Aerial: USDA (2011)

Prepared for King County by WSE

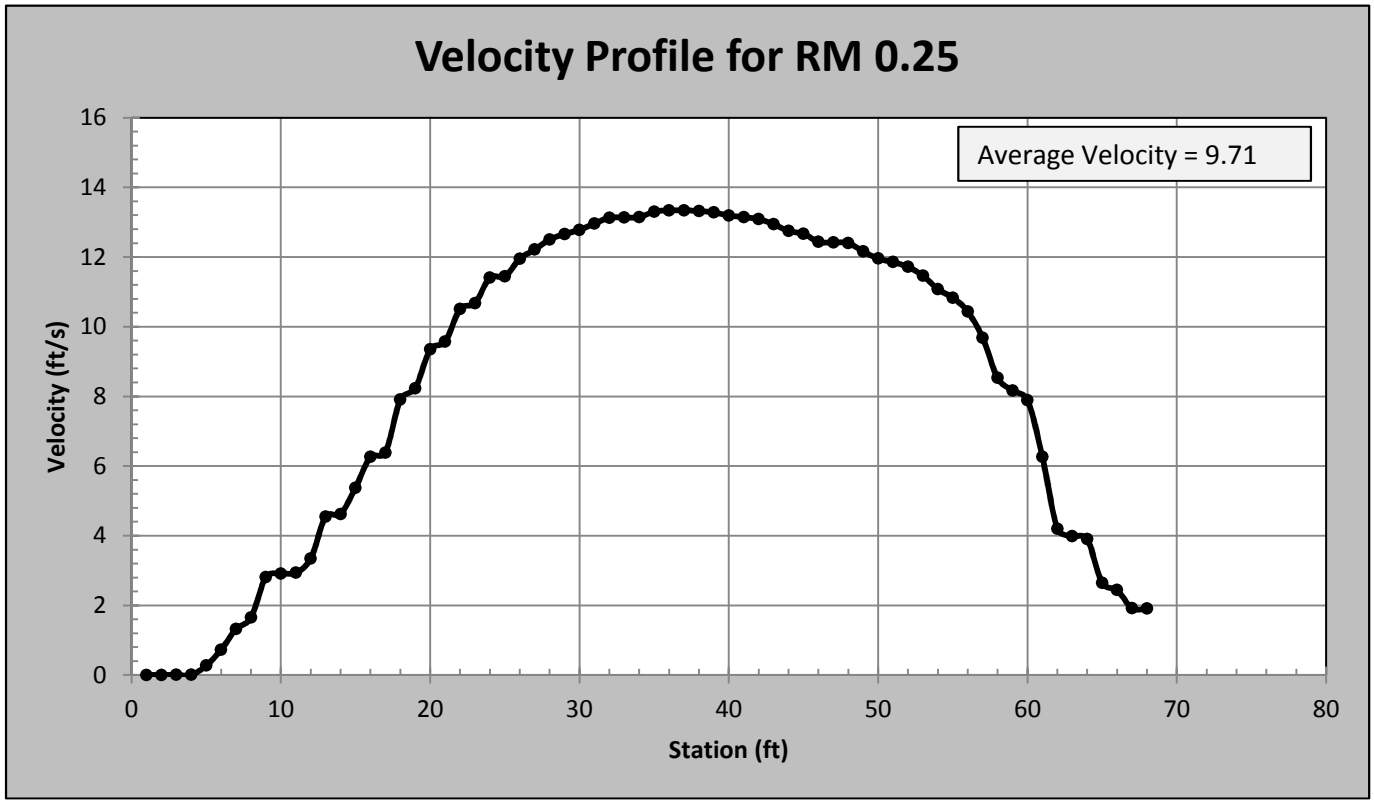
C:\Users\shaina.WATERSHEDSE\Documents\ArcGIS\Projects\12-017 MF Snoqualmie\Figures\Final Report Figures\QuarterMileXS_CenterlineProfile.mxd (7/12/2013)

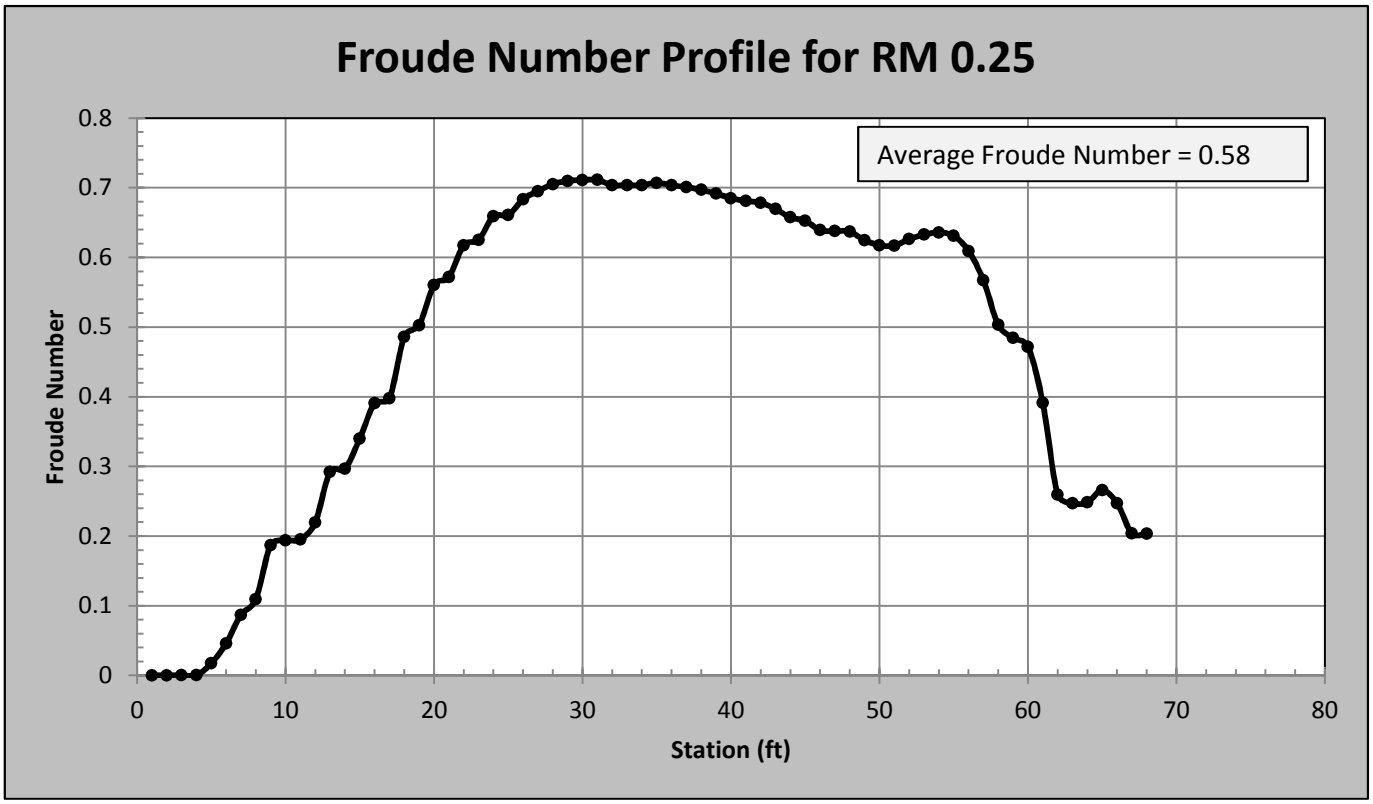
[This page intentionally left blank]

Cross Section Plots

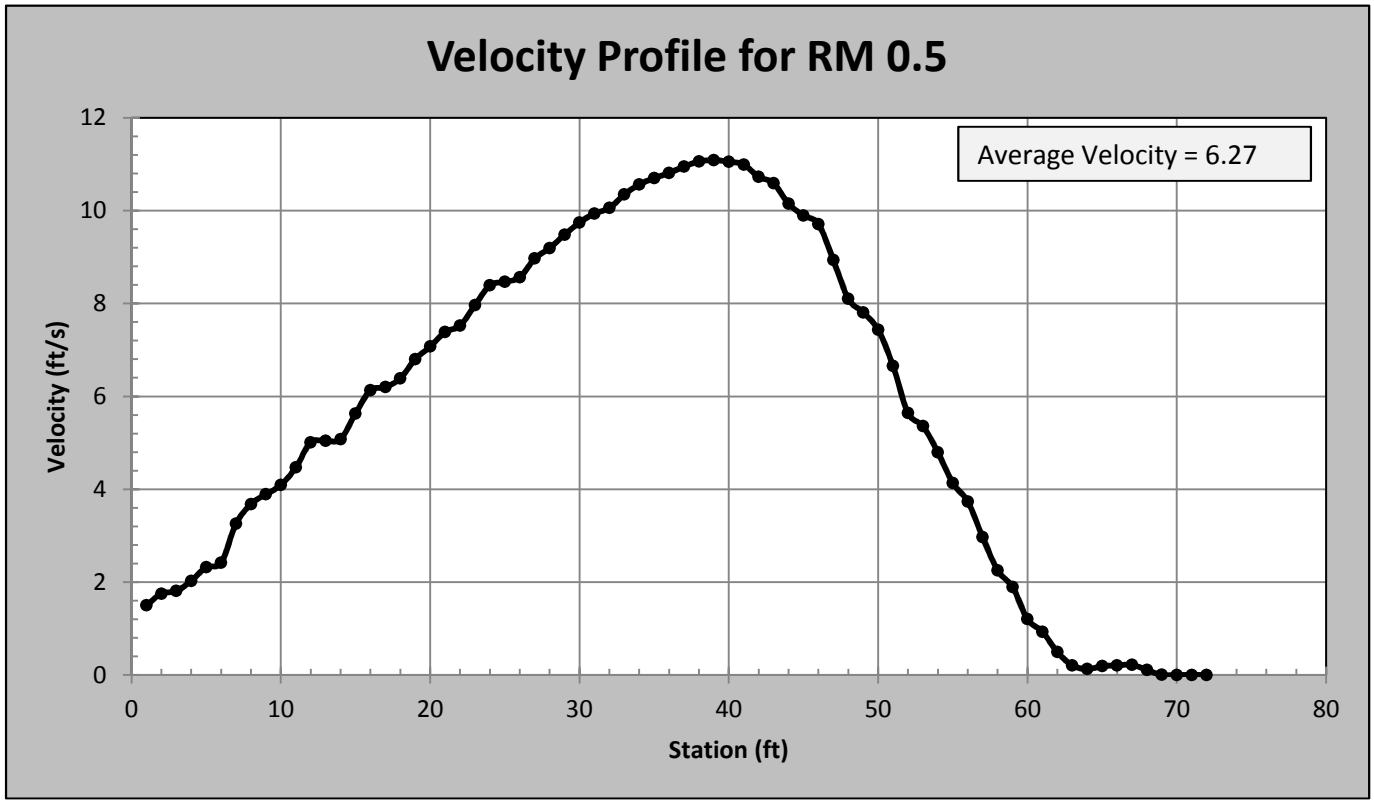
[This page intentionally left blank]

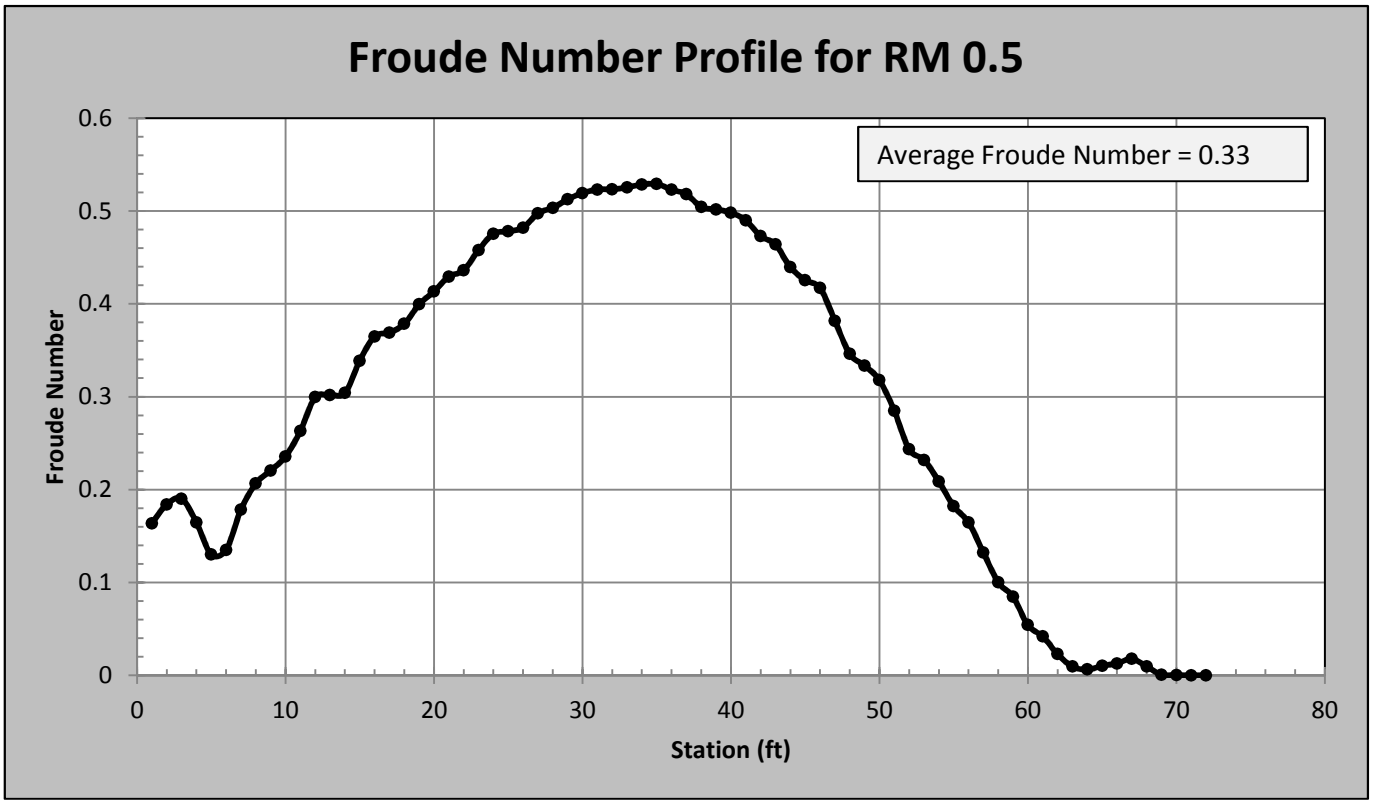
10-Year Event: 26,100cfs - River Mile 0.25



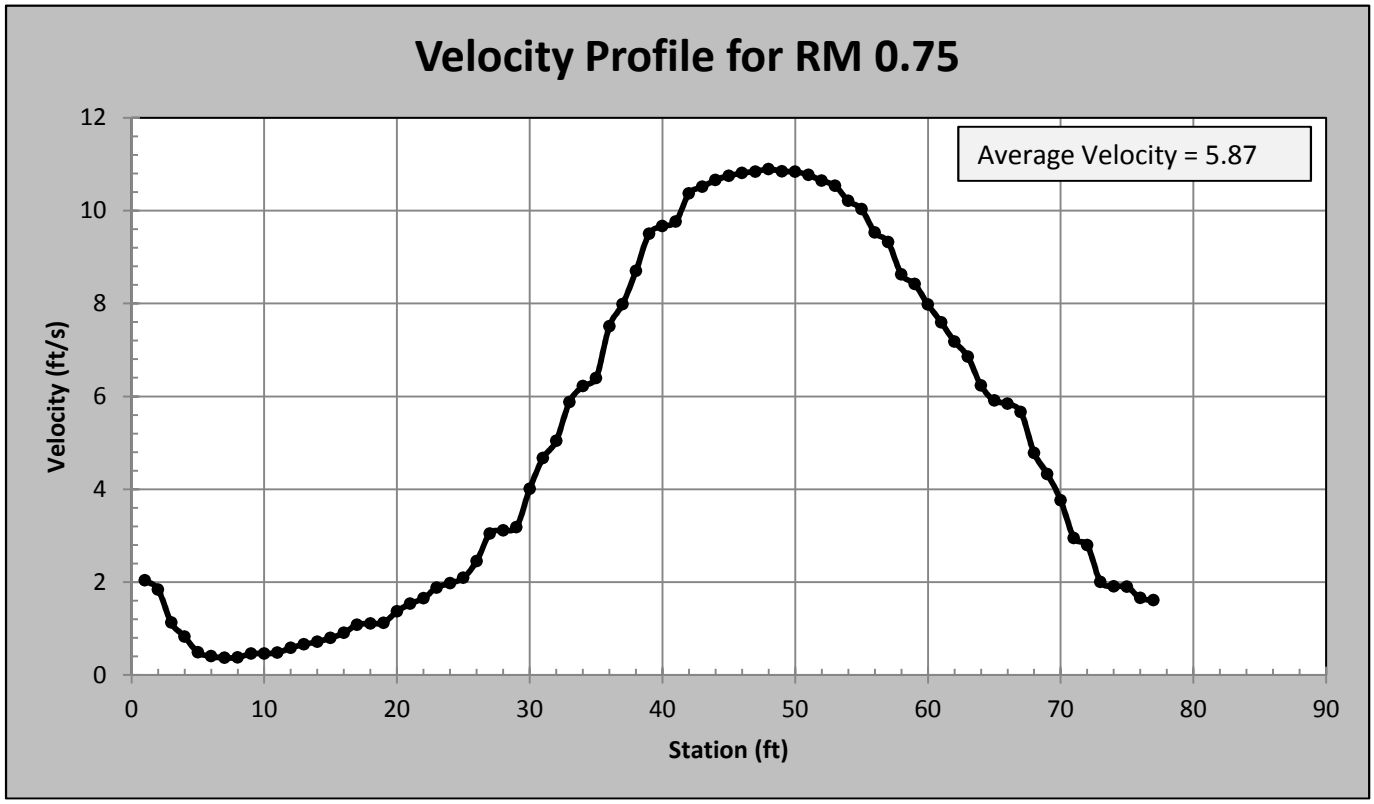


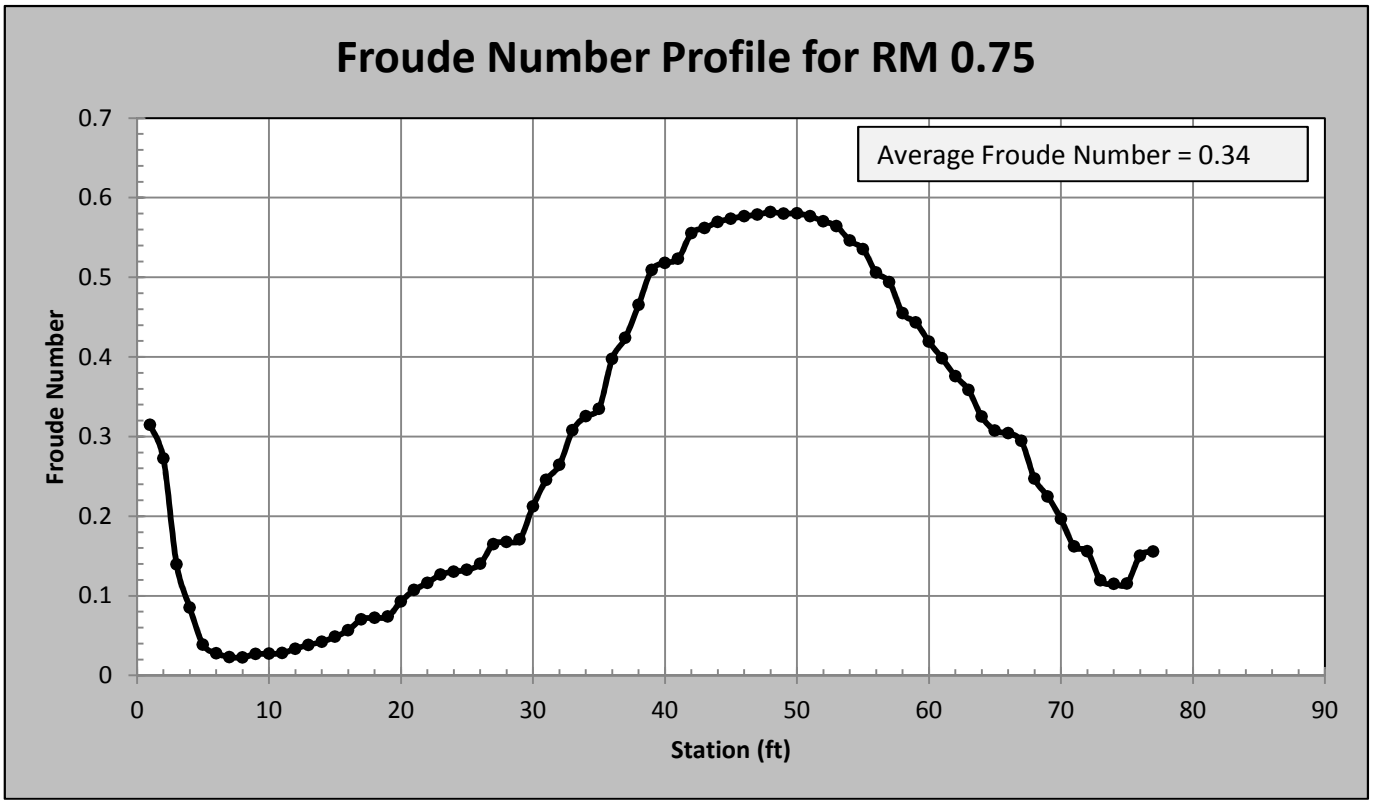
10-Year Event: 26,100cfs - River Mile 0.5



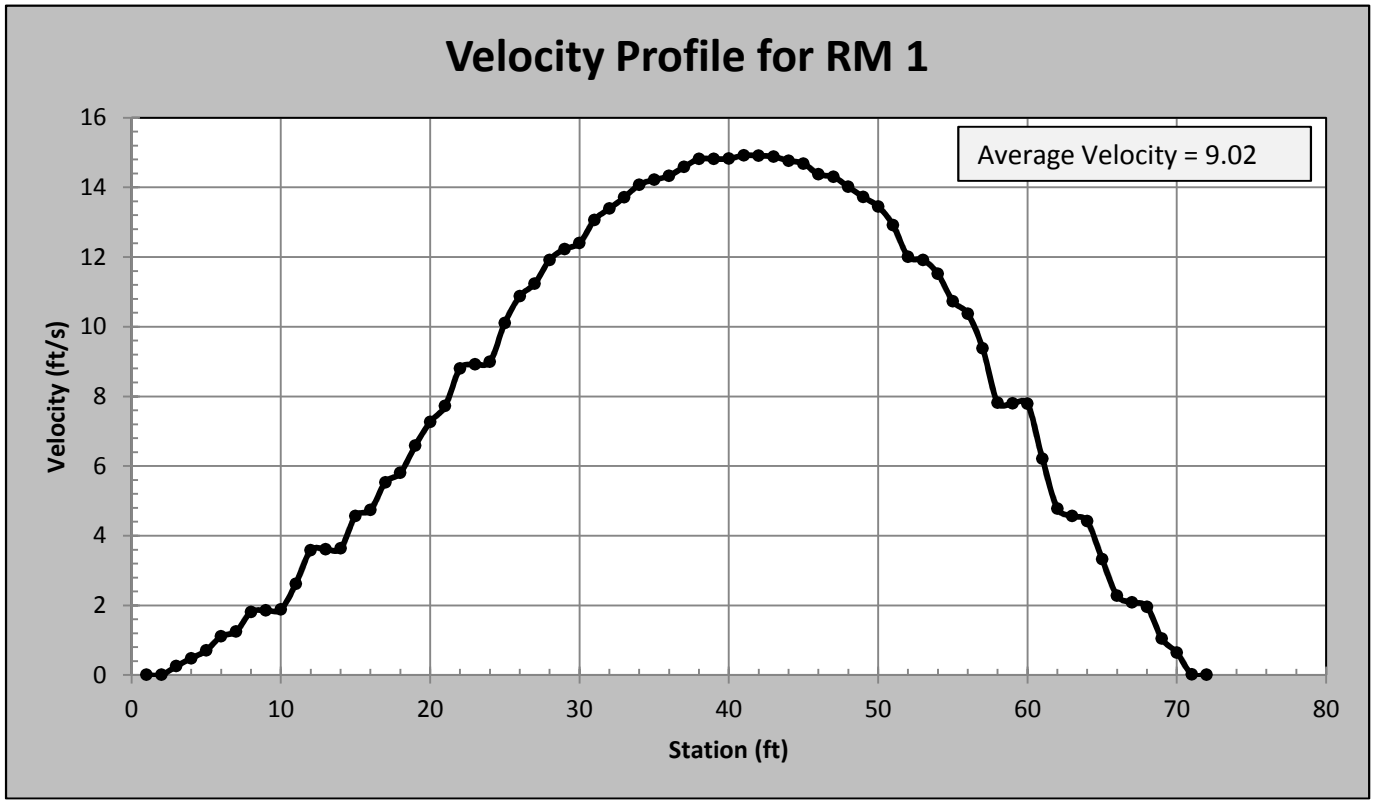


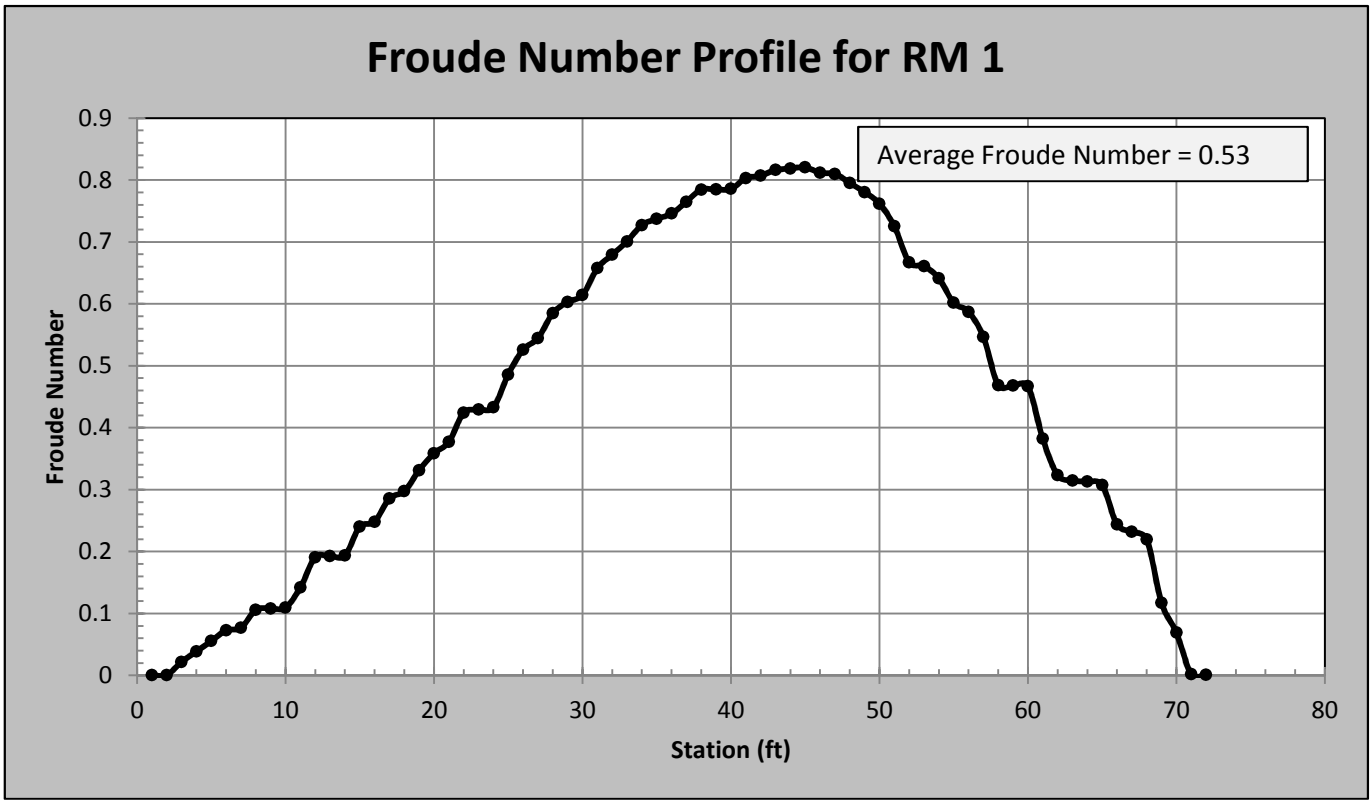
10-Year Event: 26,100cfs - River Mile 0.75



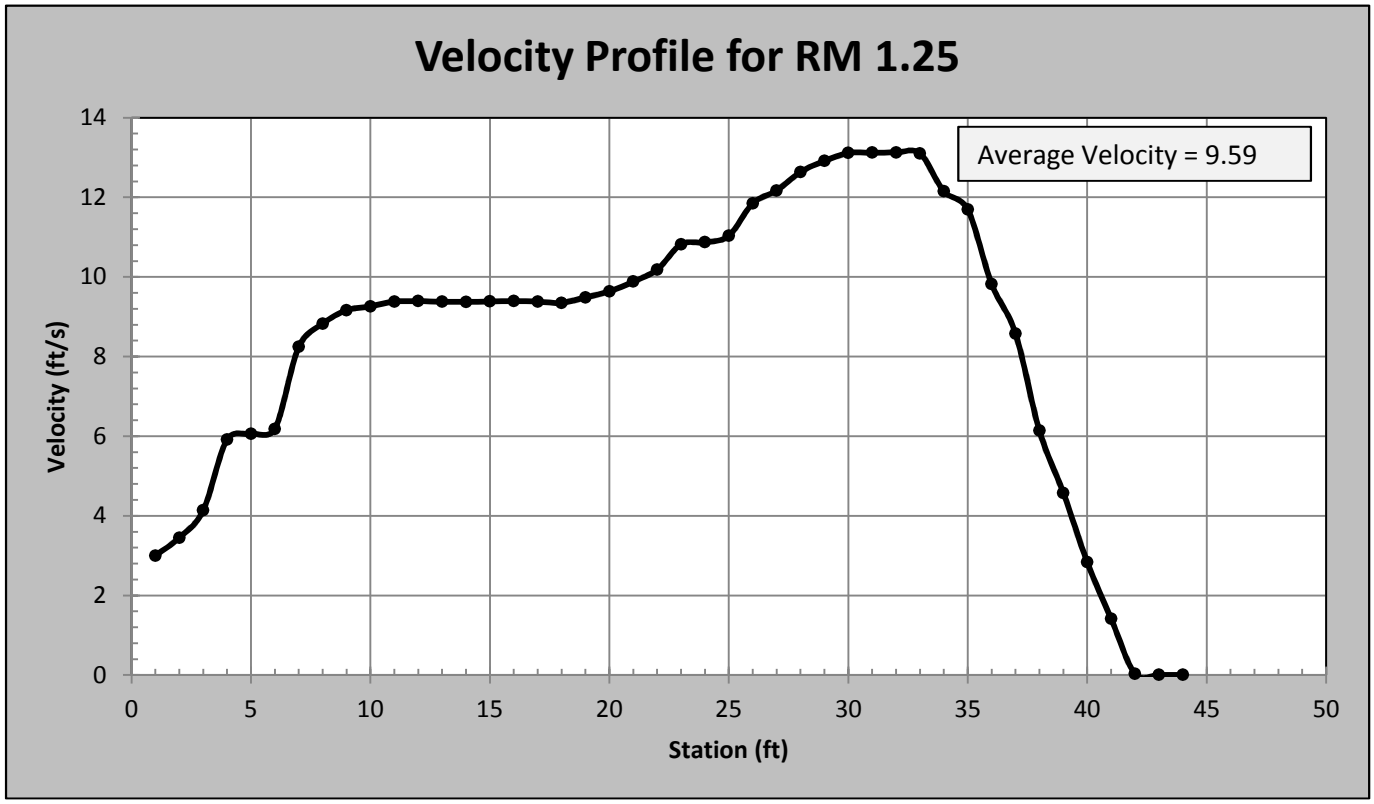


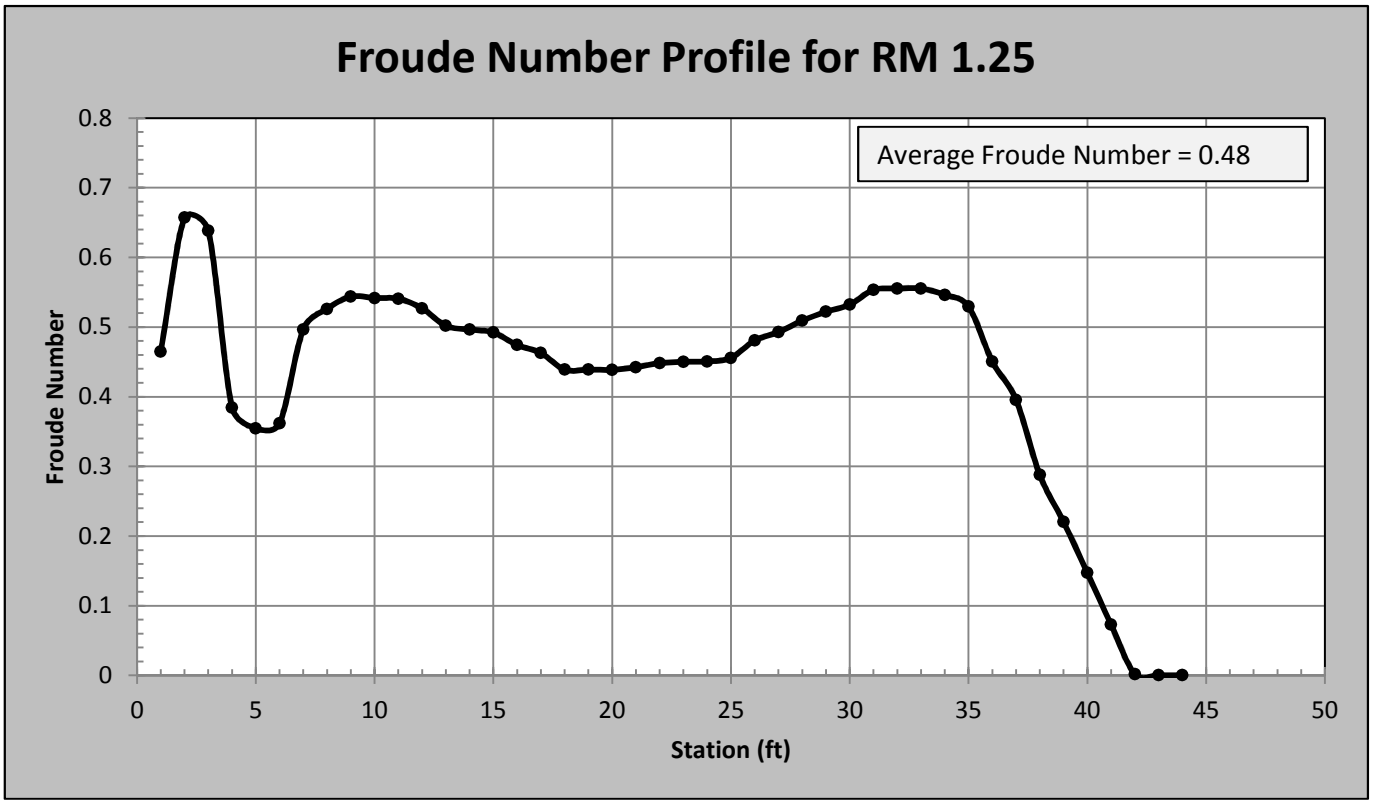
10-Year Event: 26,100cfs - River Mile 1



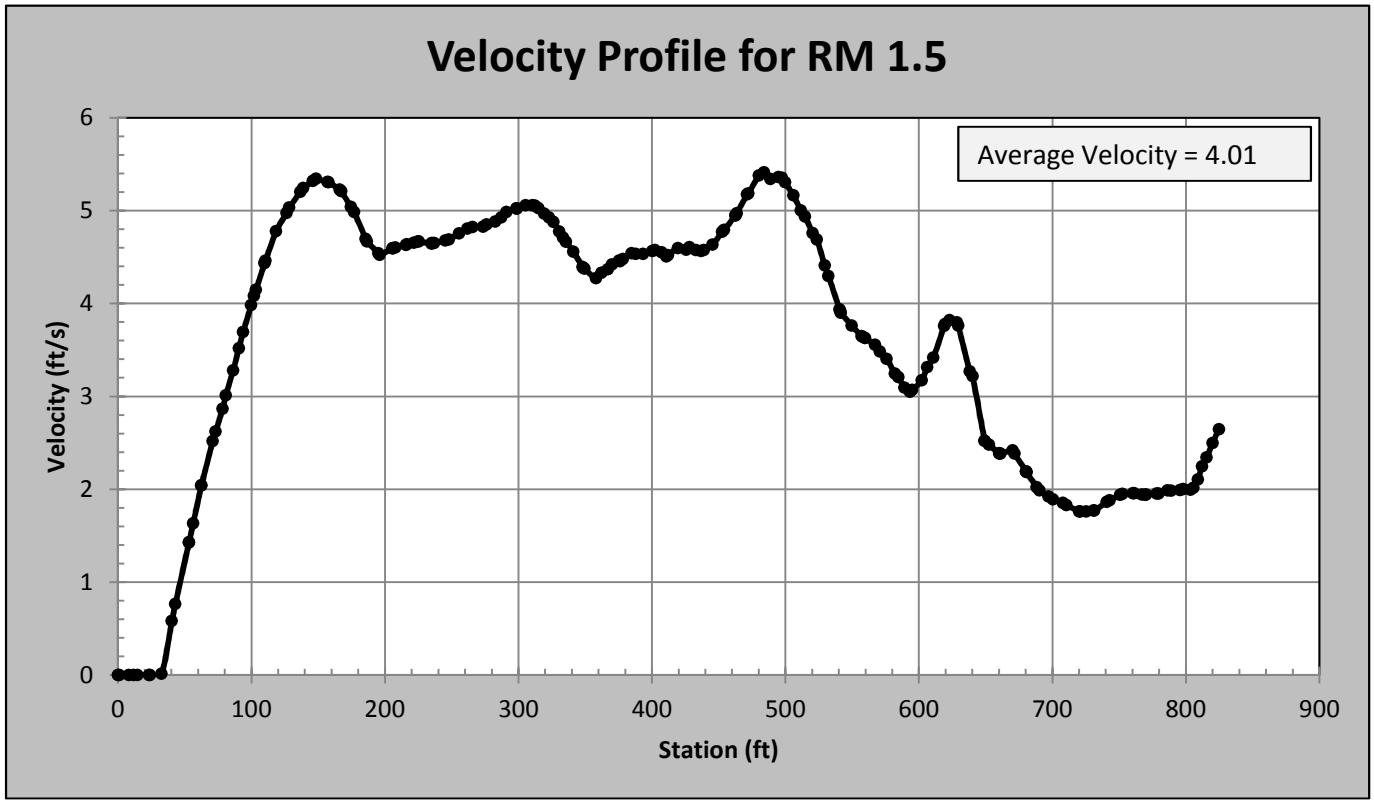


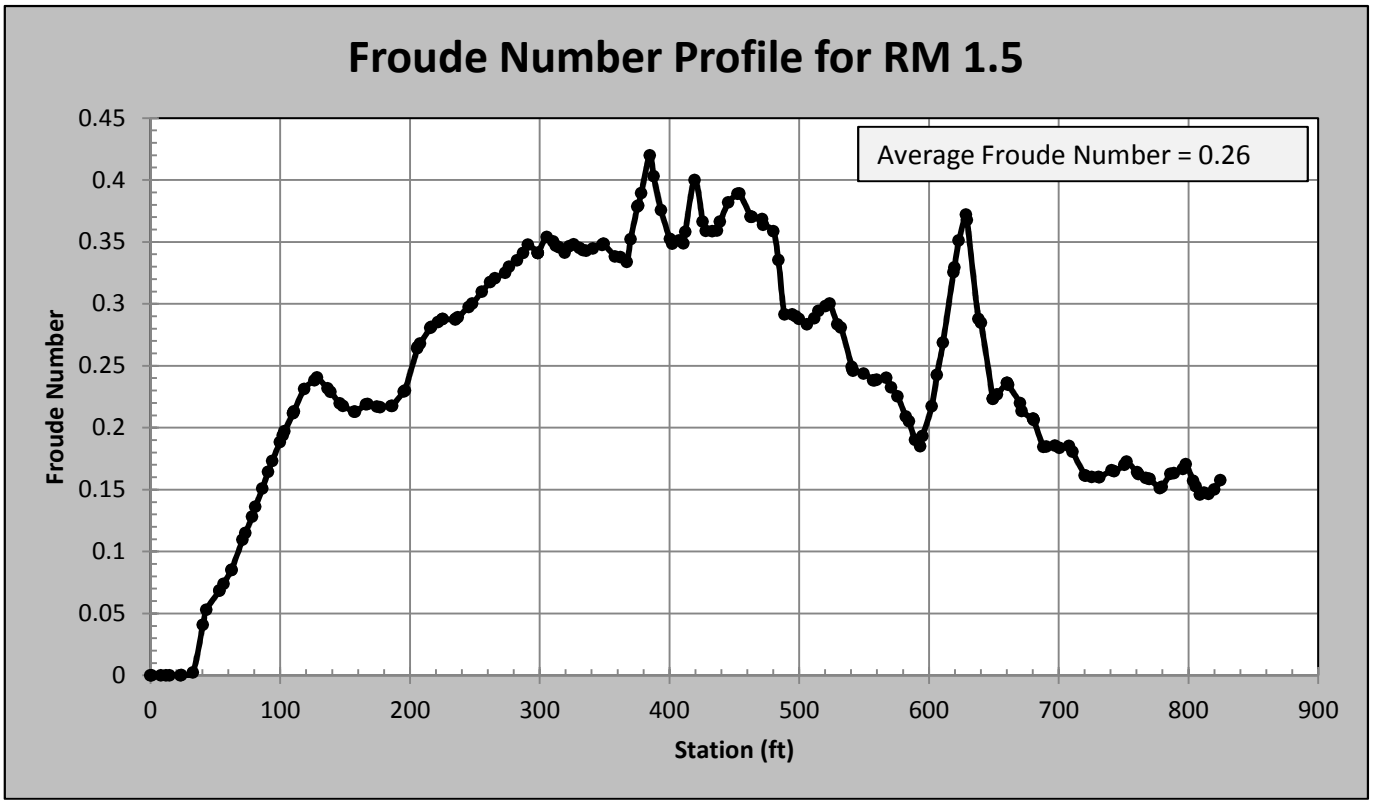
10-Year Event: 26,100cfs - River Mile 1.25



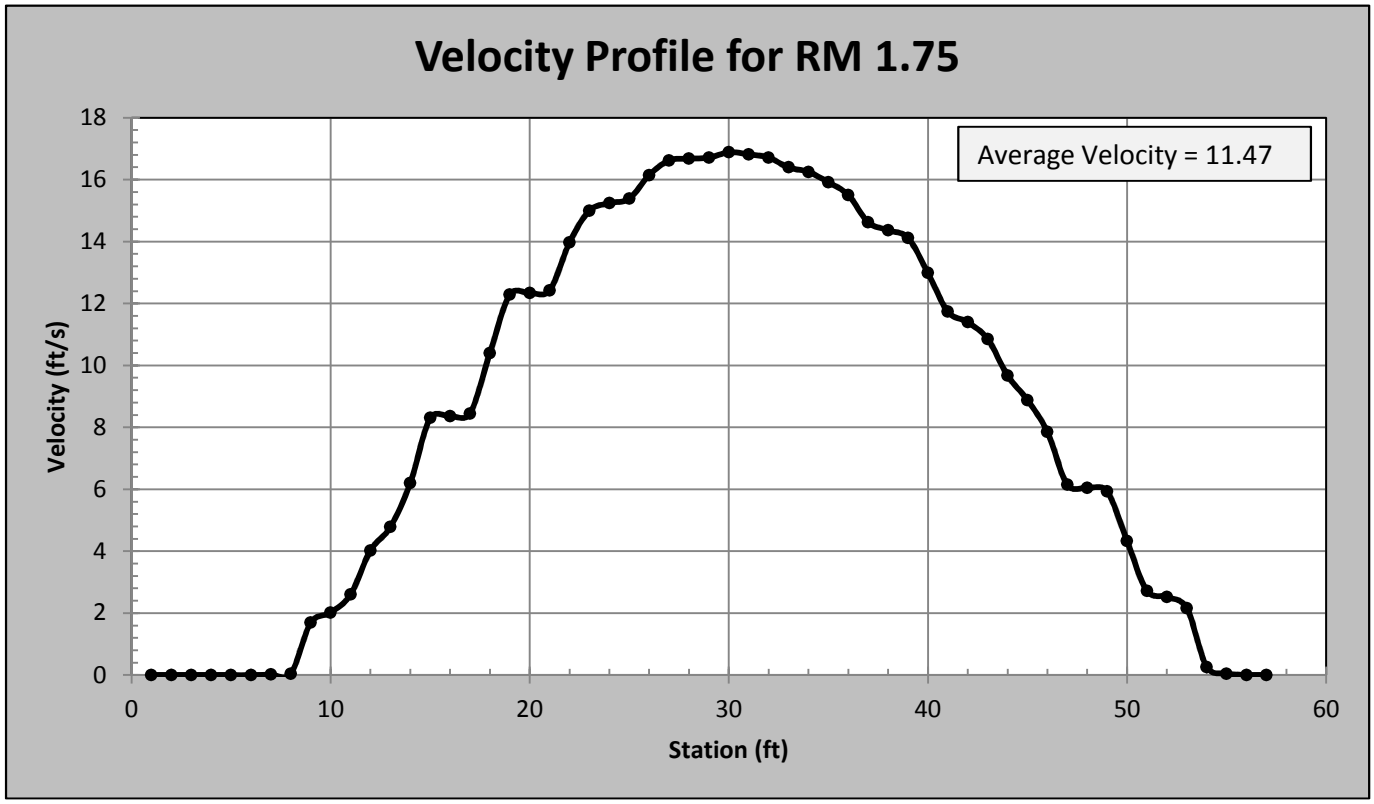


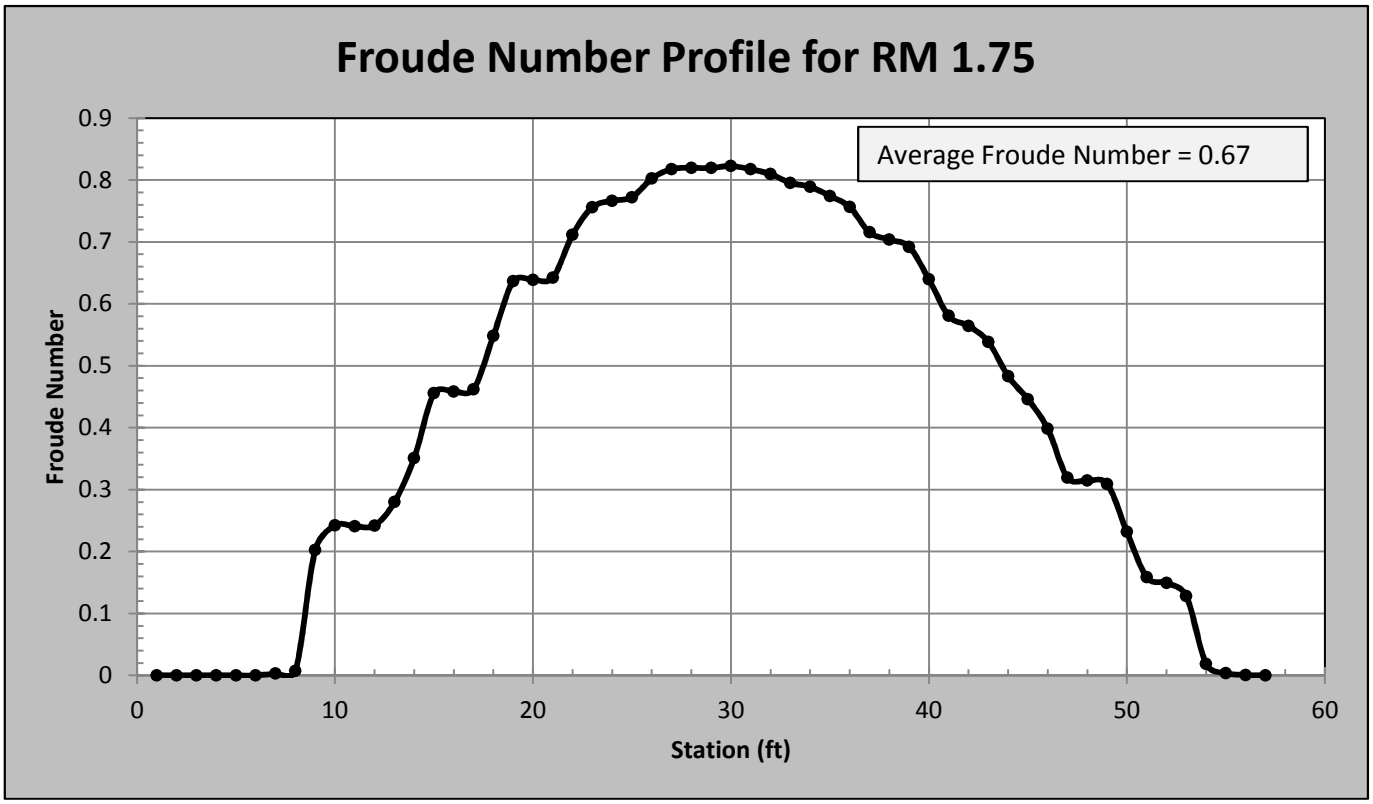
10-Year Event: 26,100cfs - River Mile 1.5



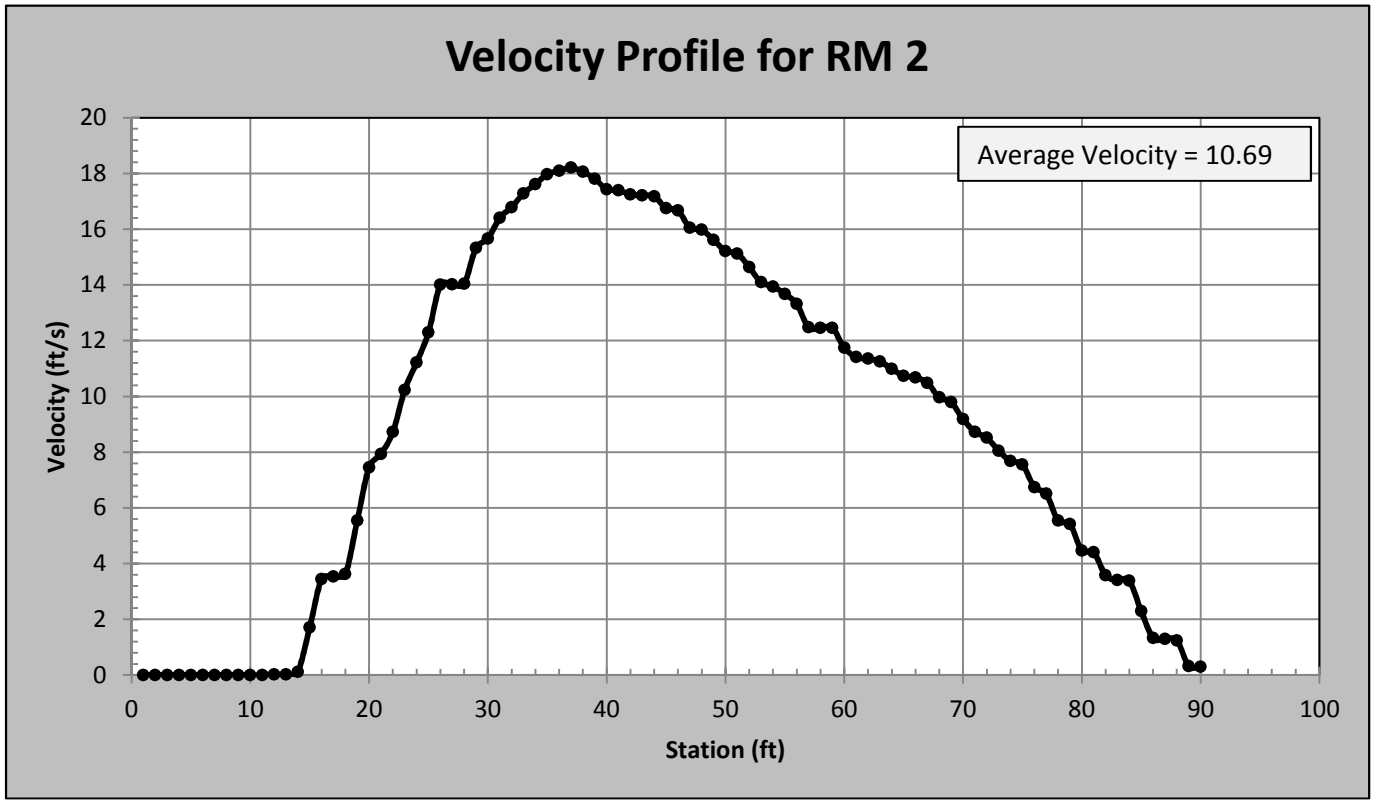


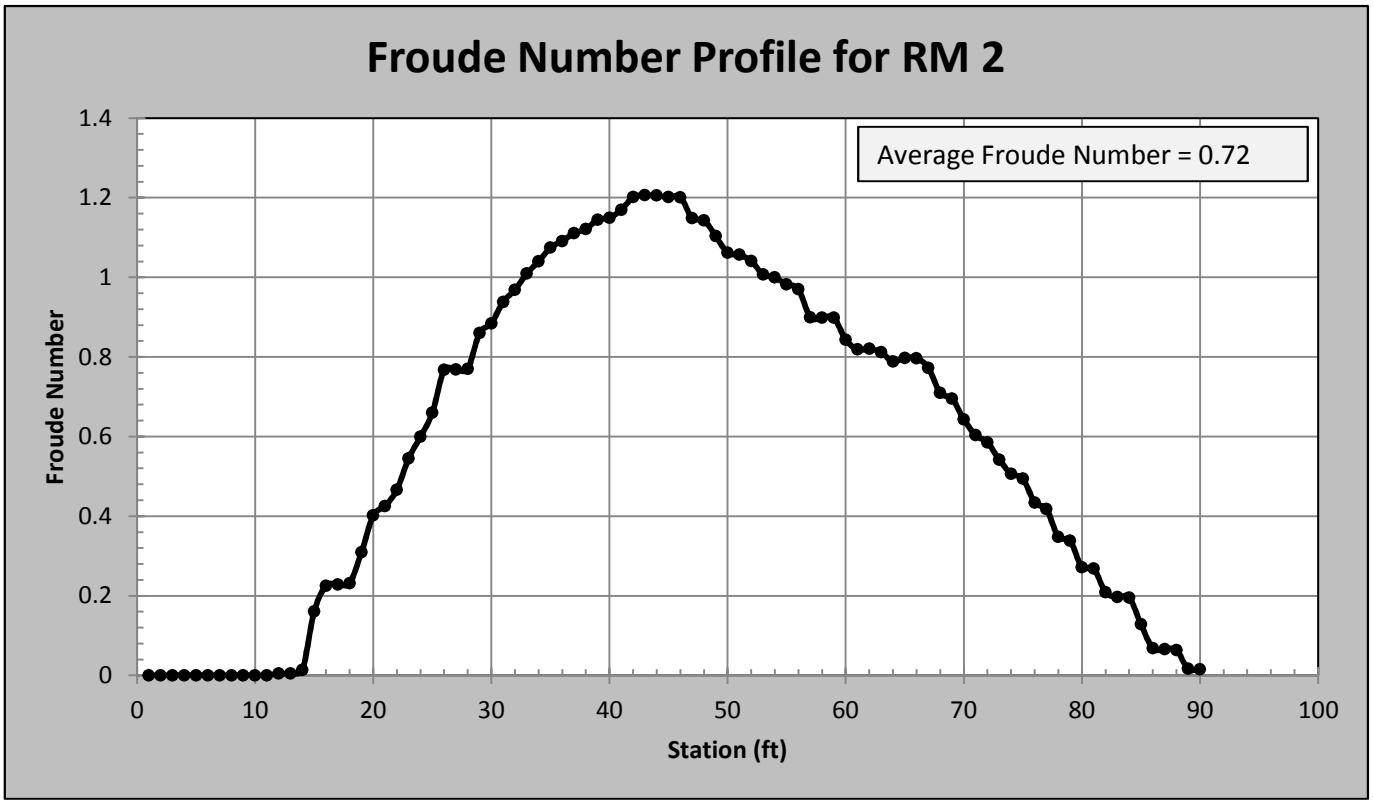
10-Year Event: 26,100cfs - River Mile 1.75



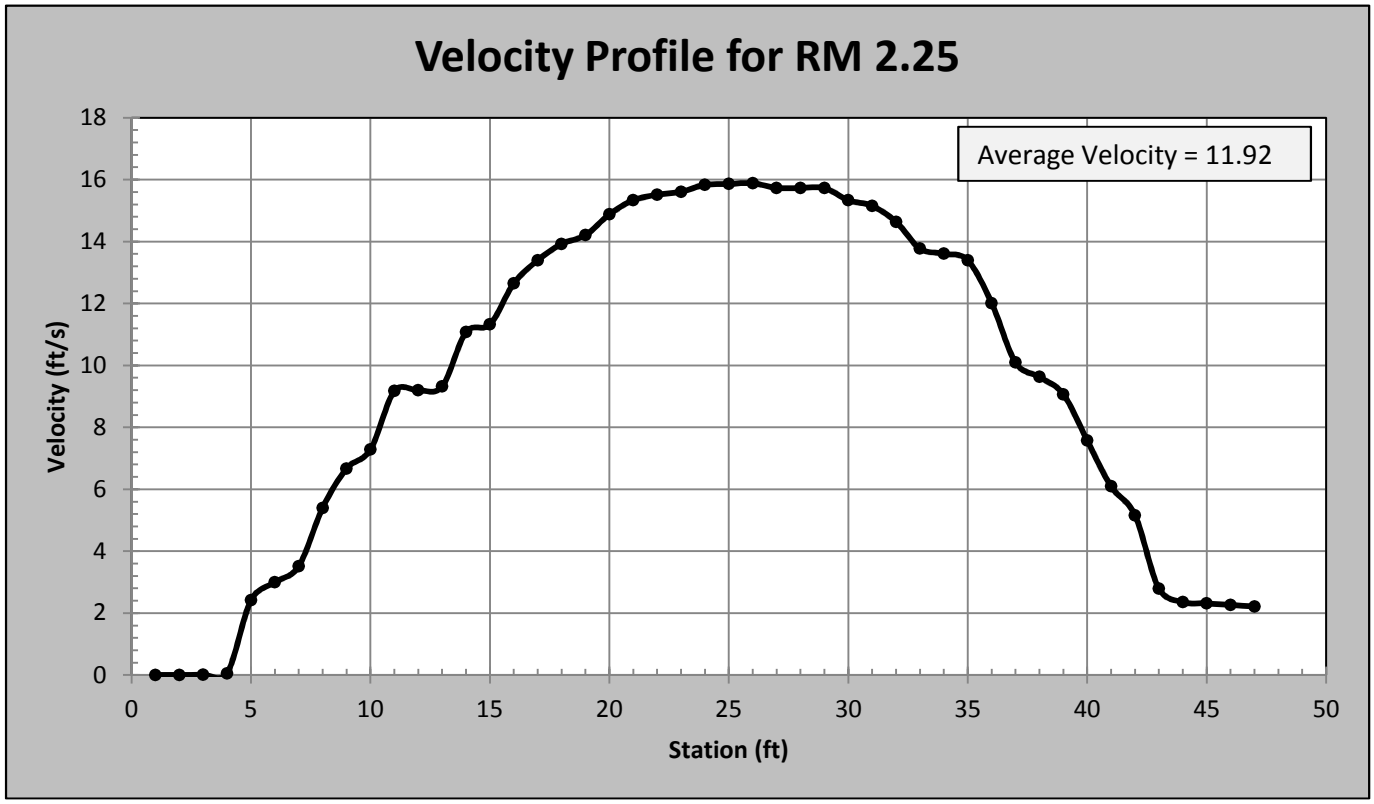


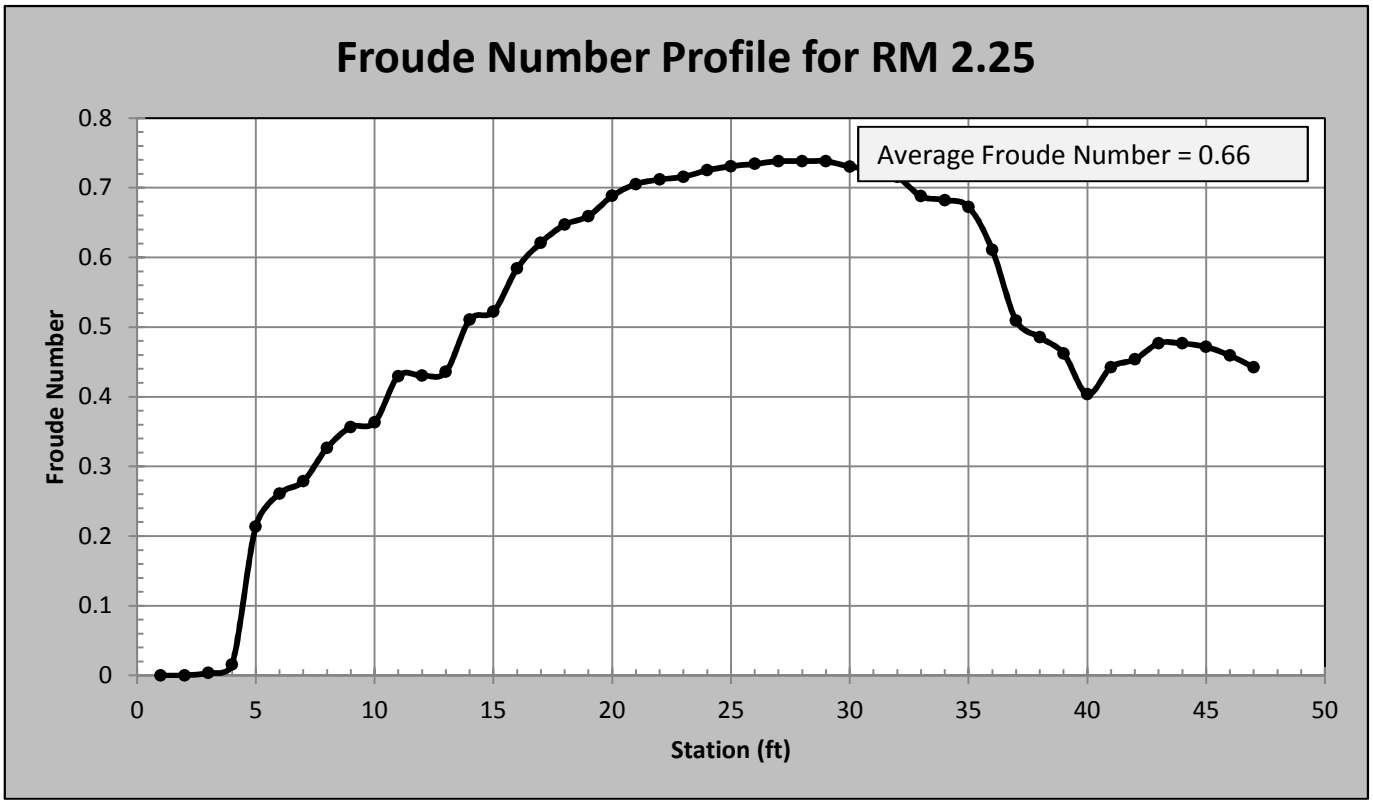
10-Year Event: 26,100cfs - River Mile 2



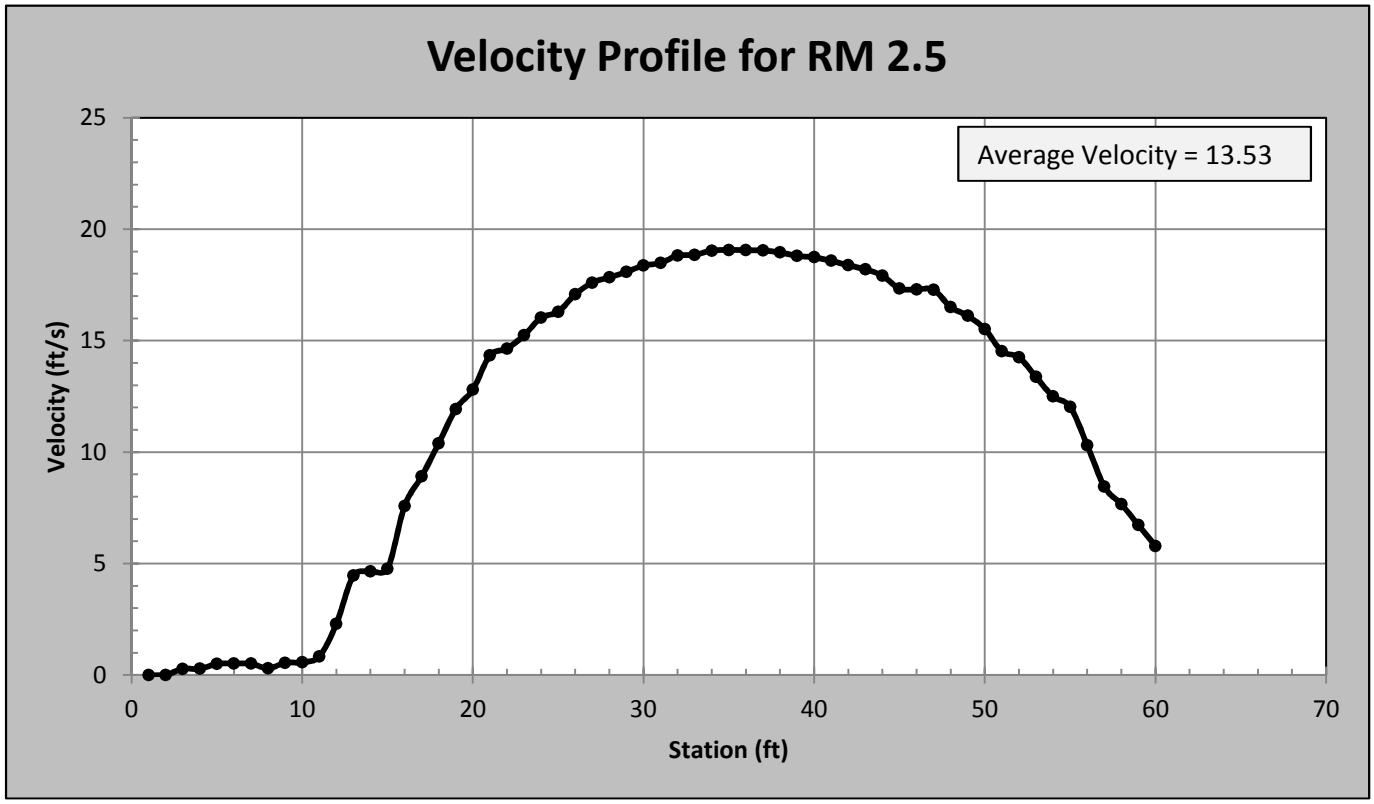


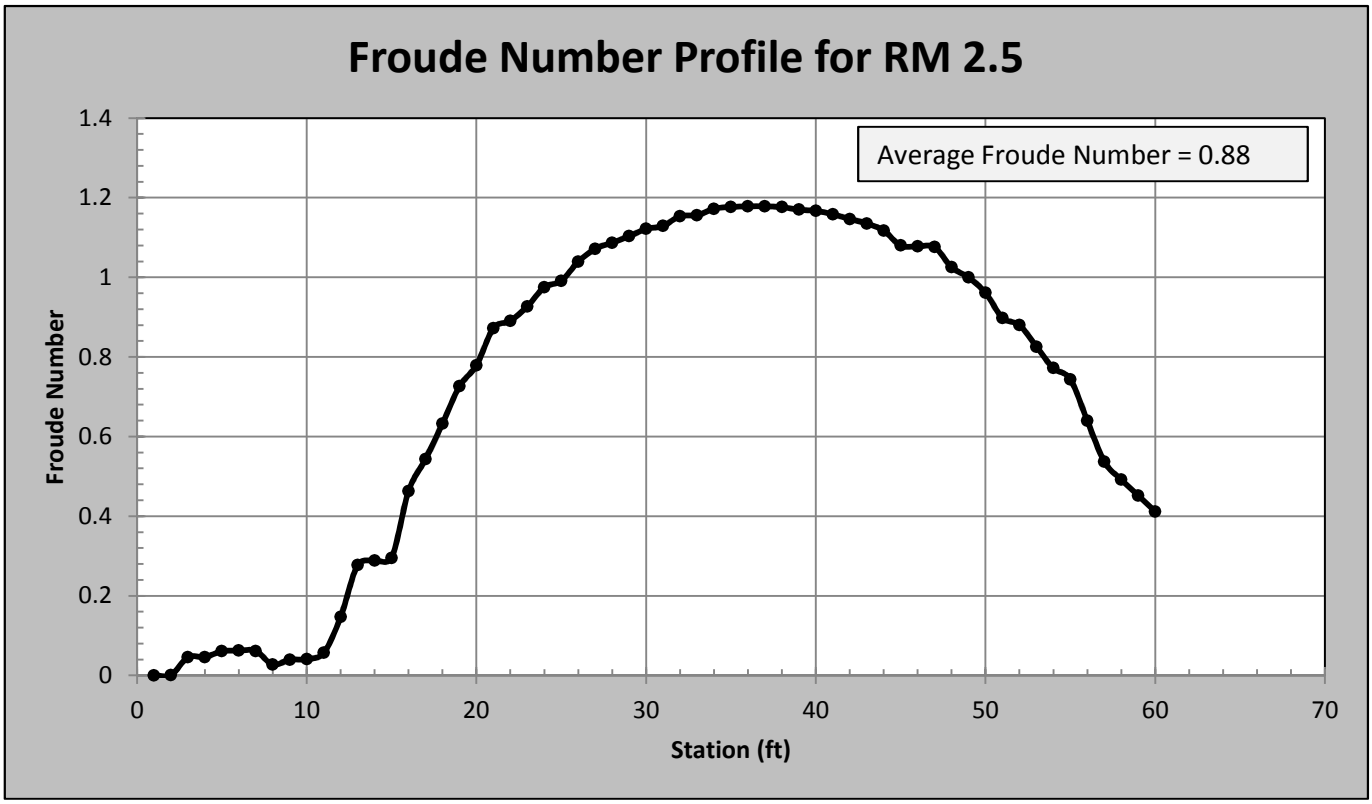
10-Year Event: 26,100cfs - River Mile 2.25



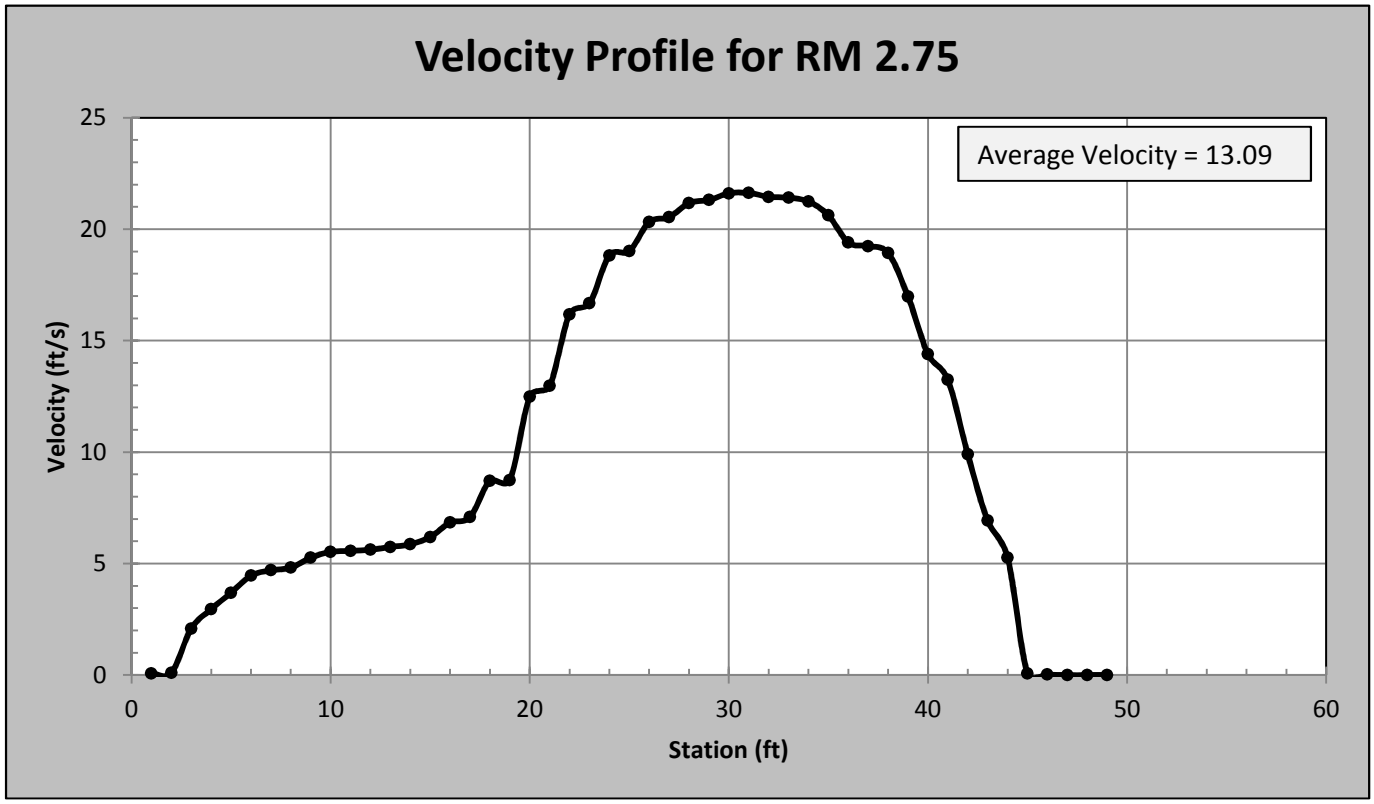


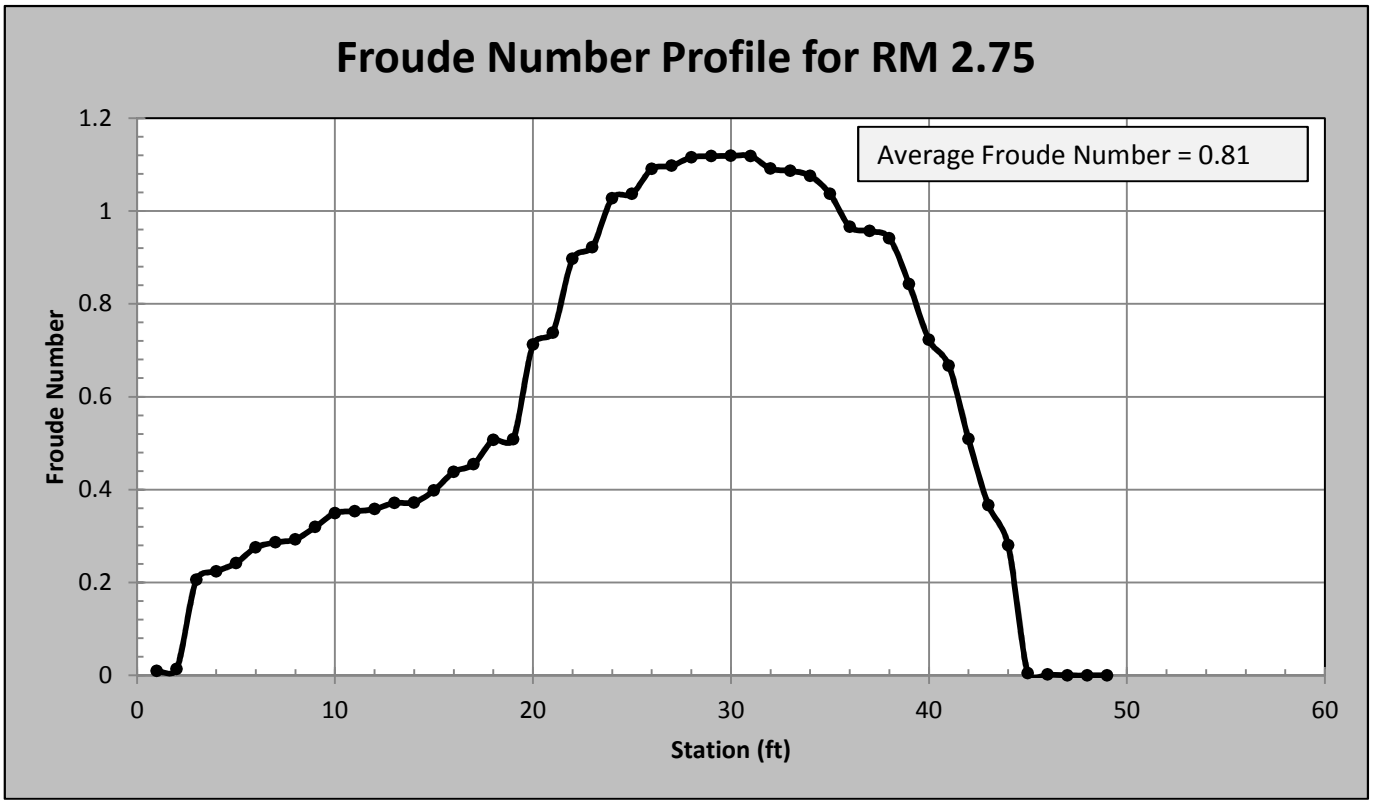
10-Year Event: 26,100cfs - River Mile 2.5



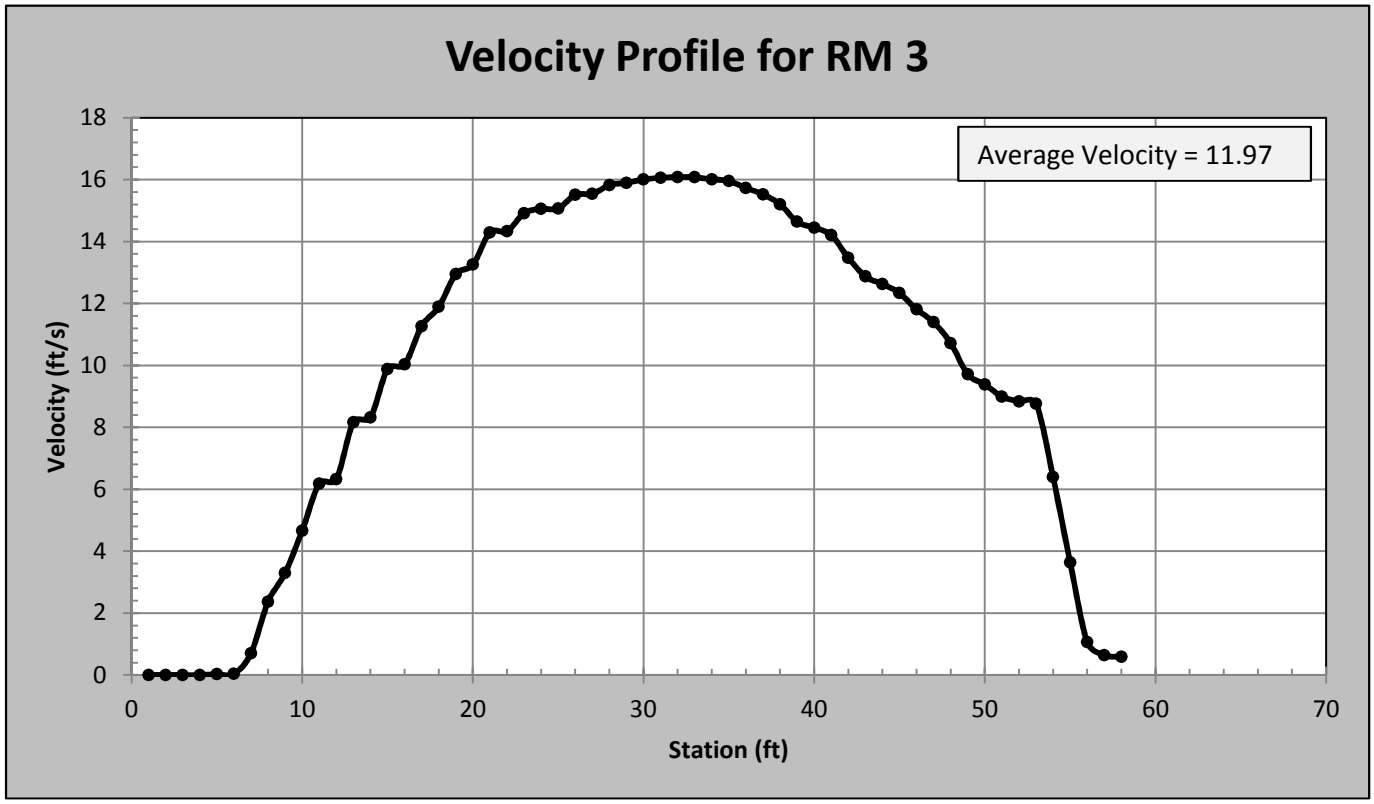


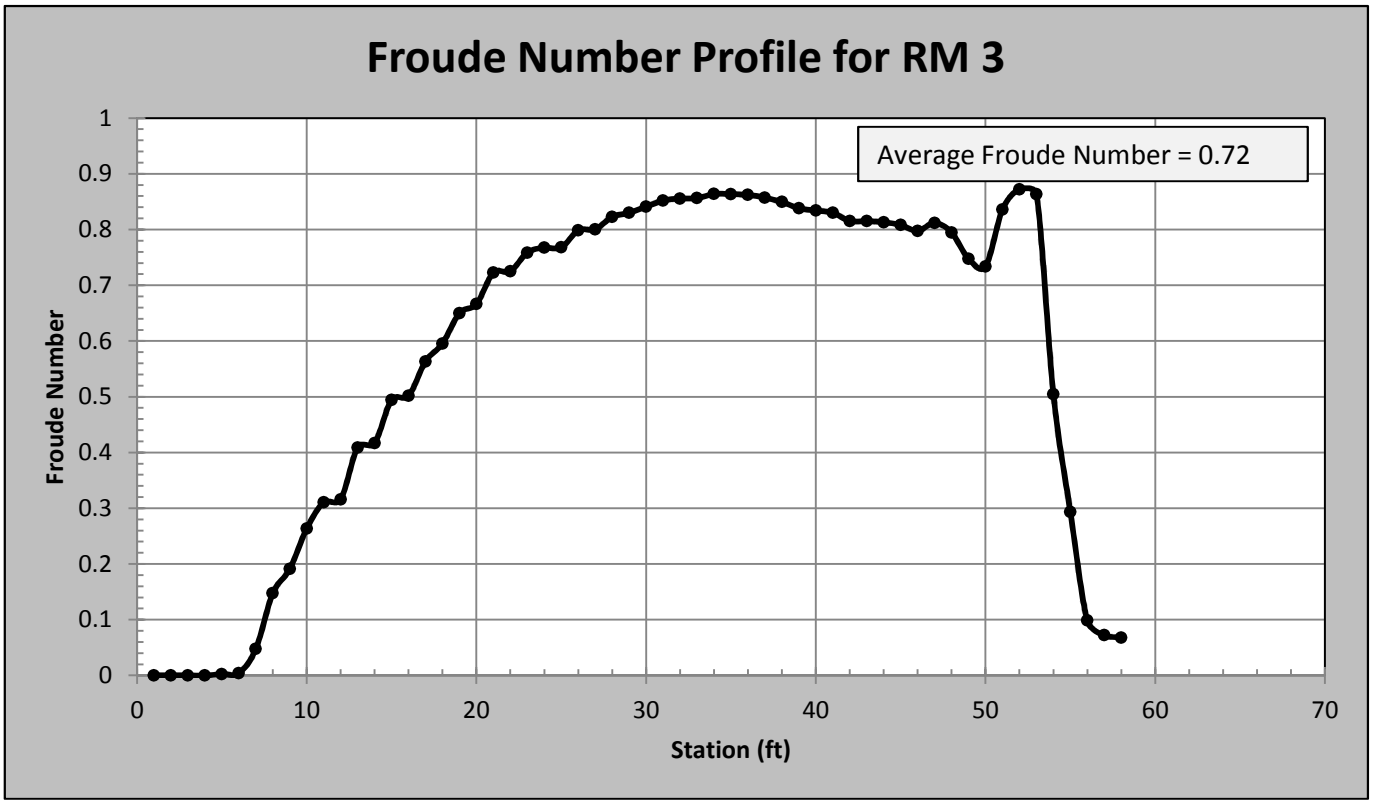
10-Year Event: 26,100cfs - River Mile 2.75



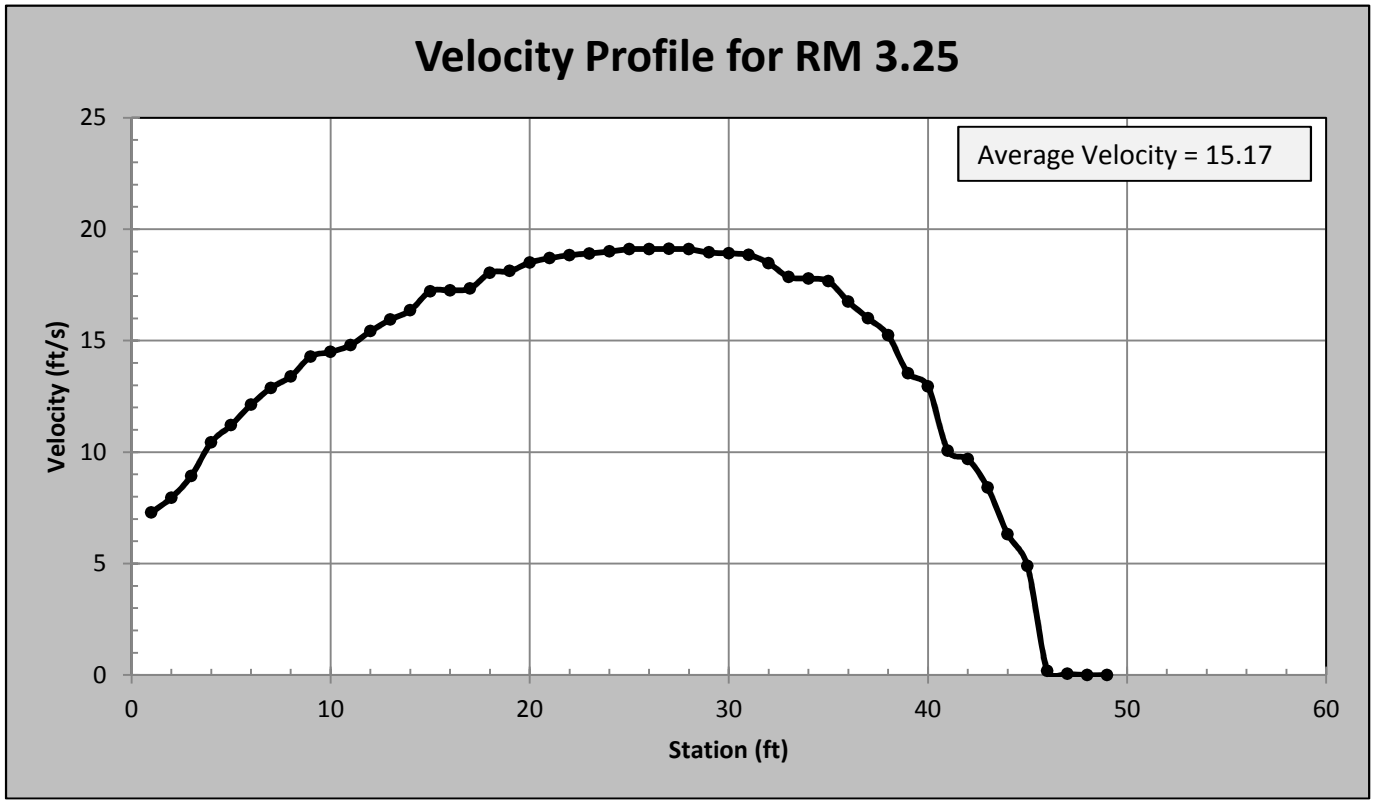


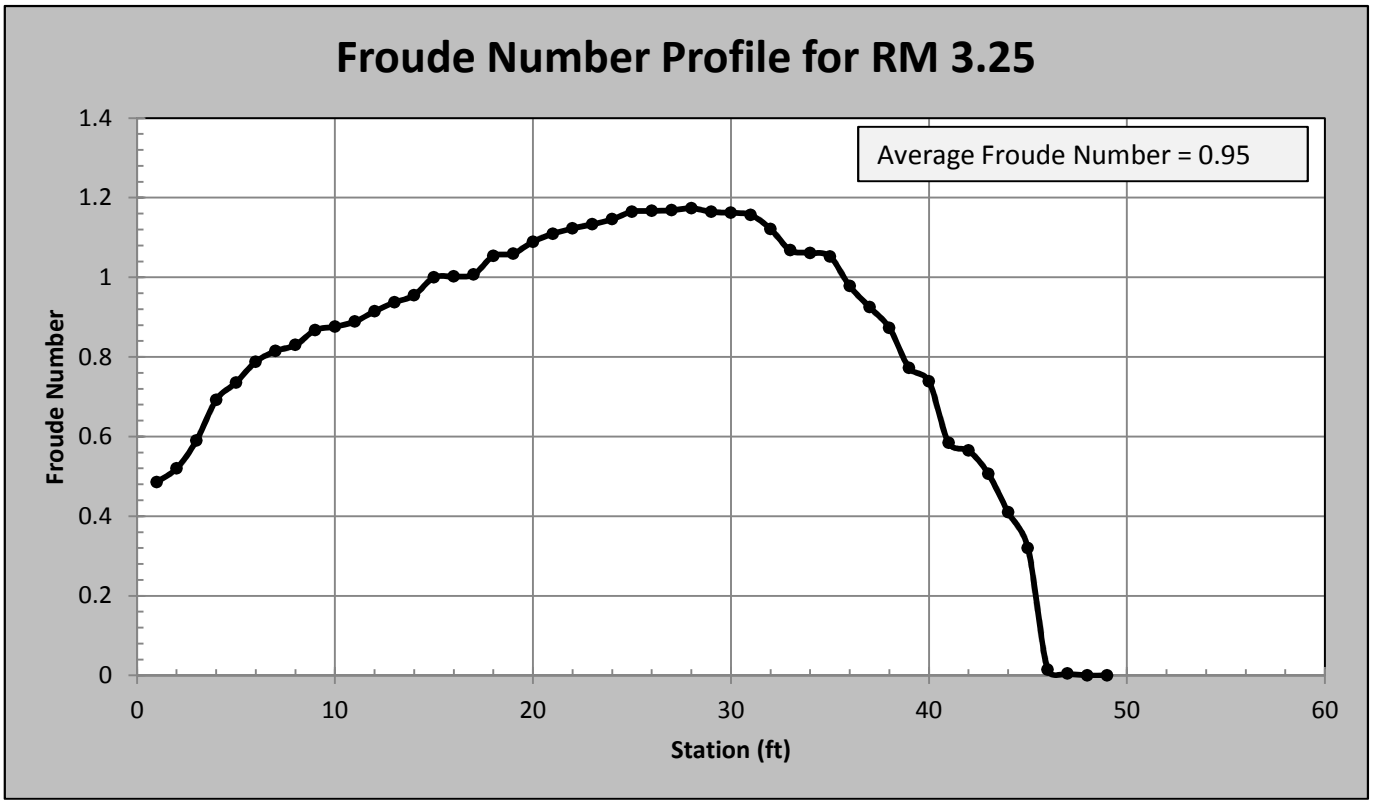
10-Year Event: 26,100cfs - River Mile 3



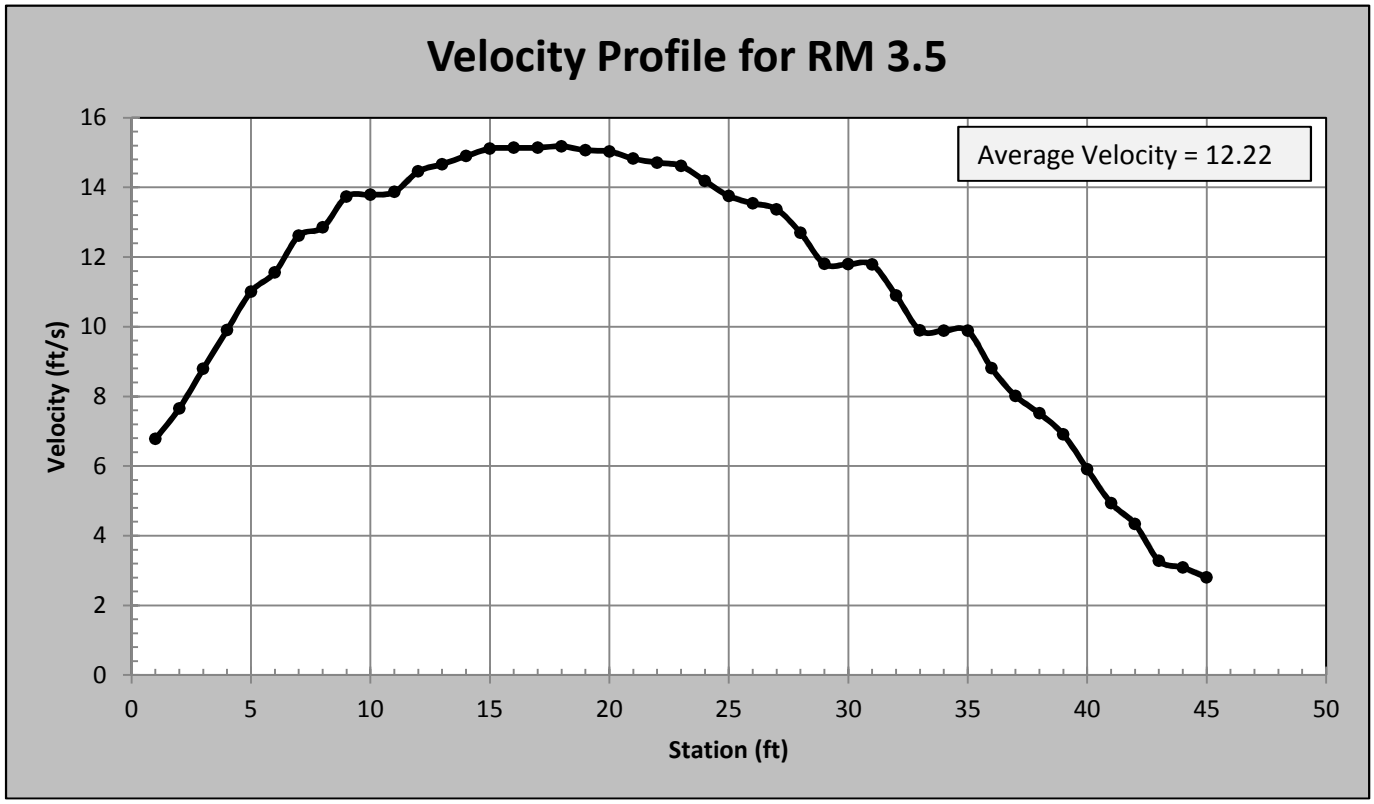


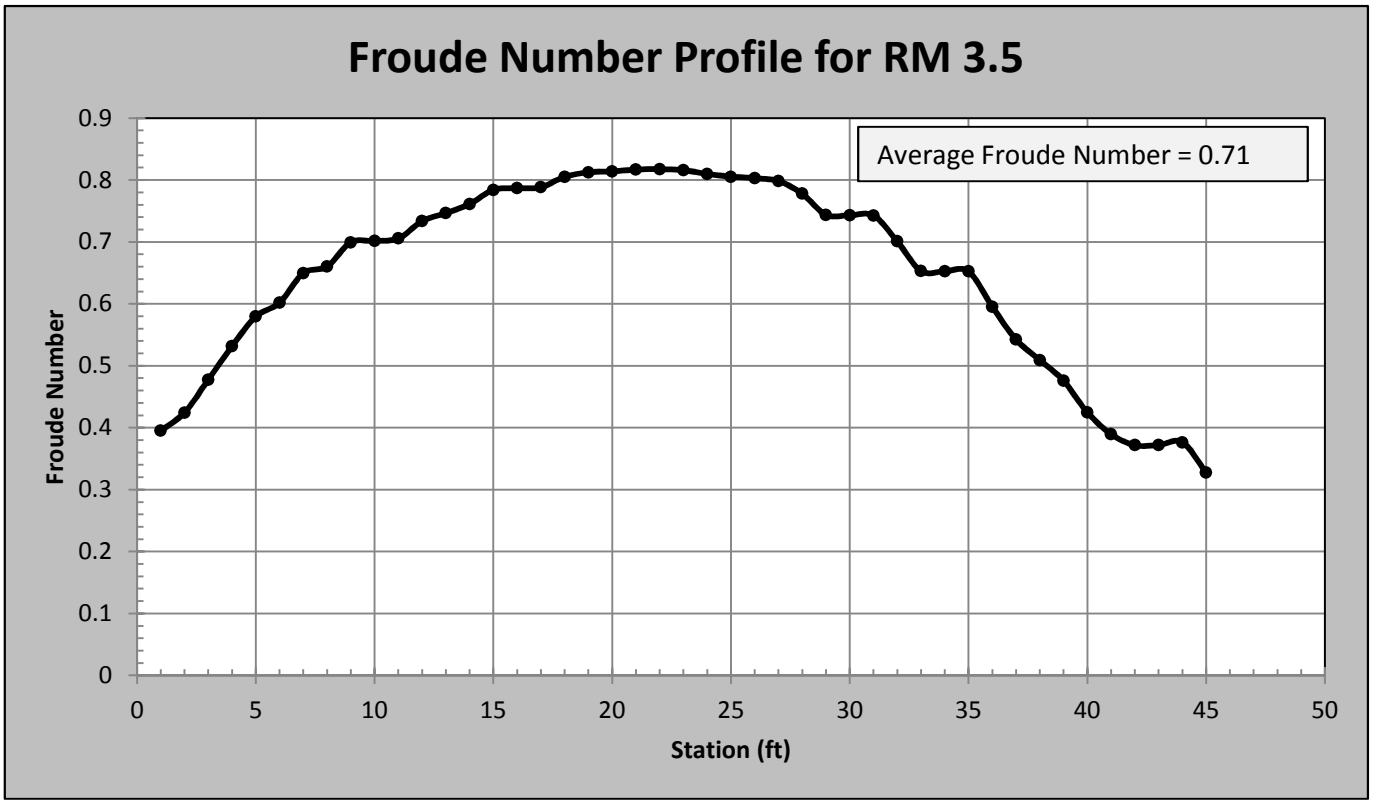
10-Year Event: 26,100cfs - River Mile 3.25



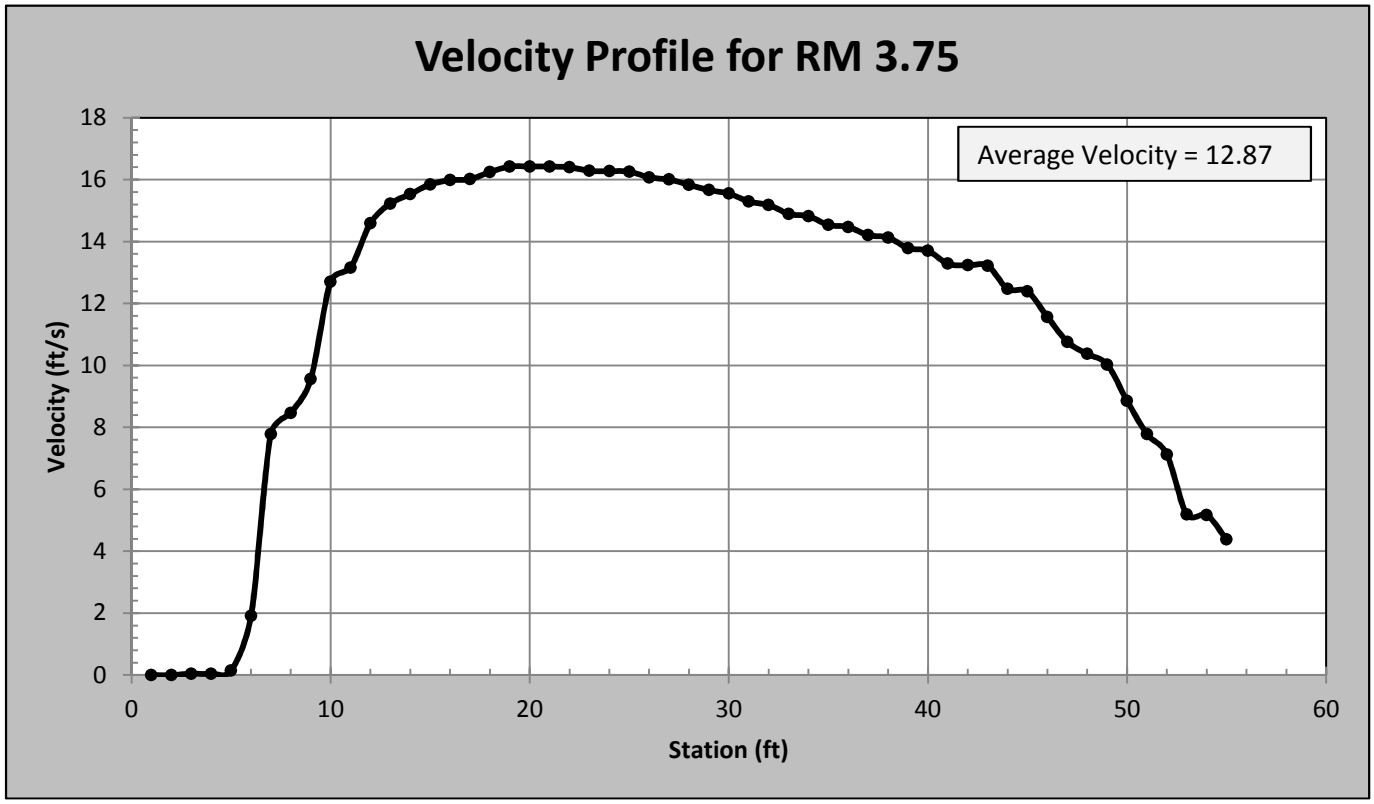


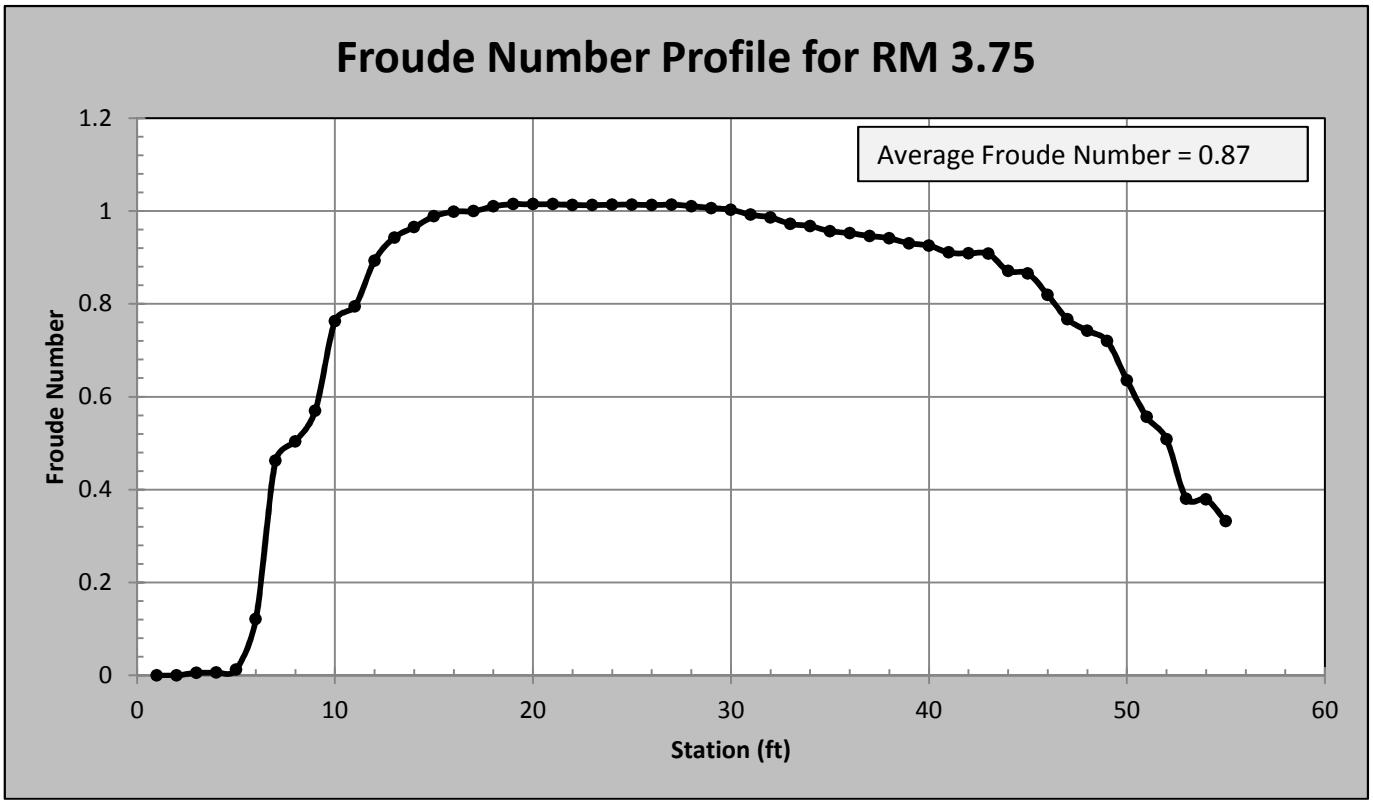
10-Year Event: 26,100cfs - River Mile 3.5



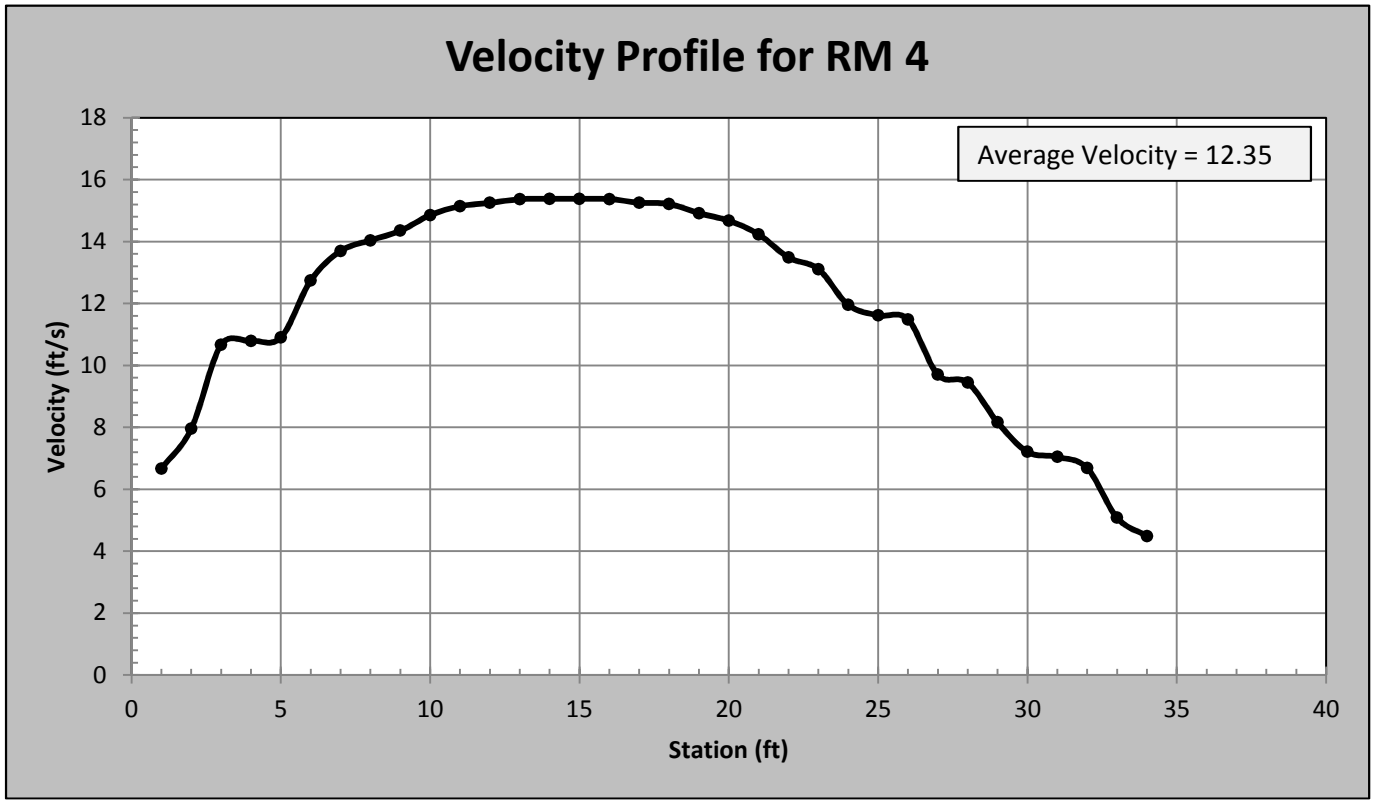


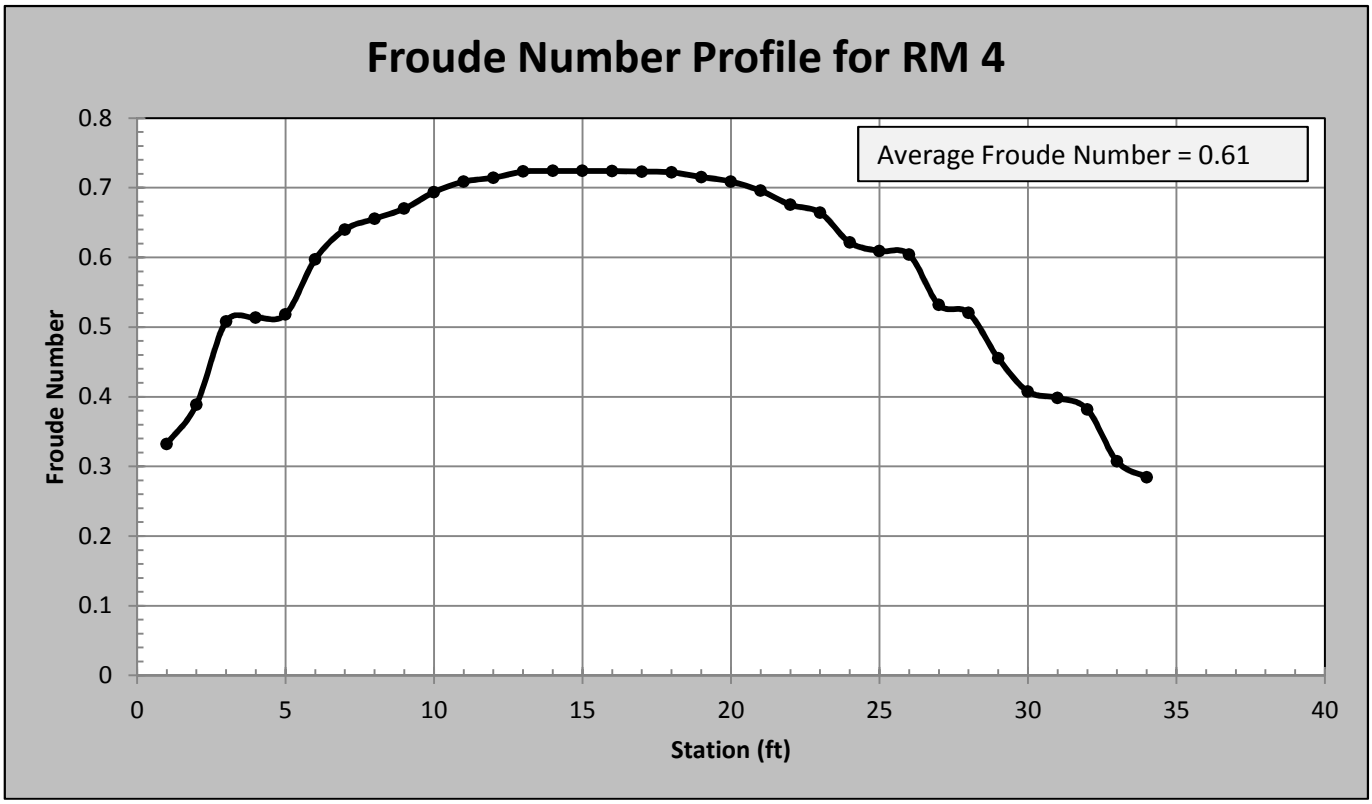
10-Year Event: 26,100cfs - River Mile 3.75



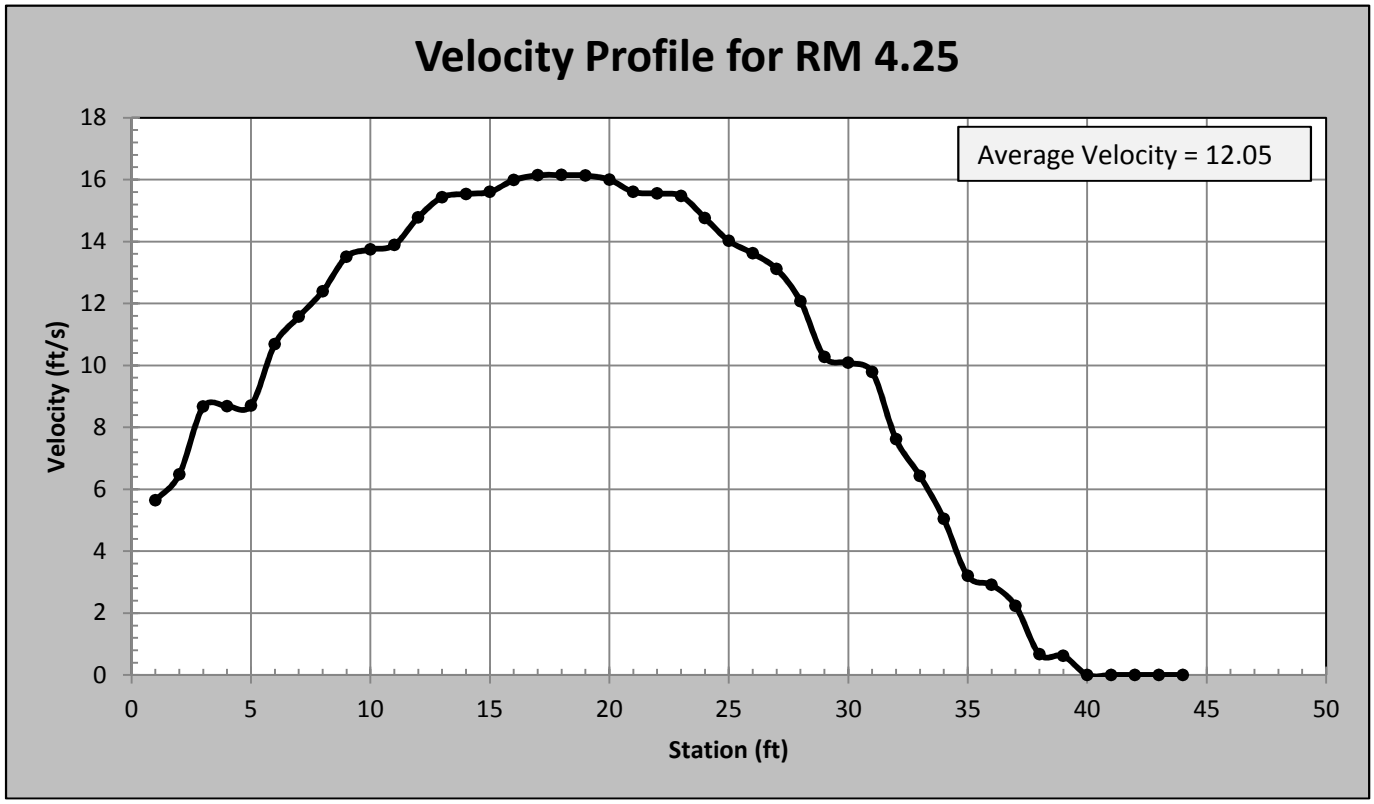


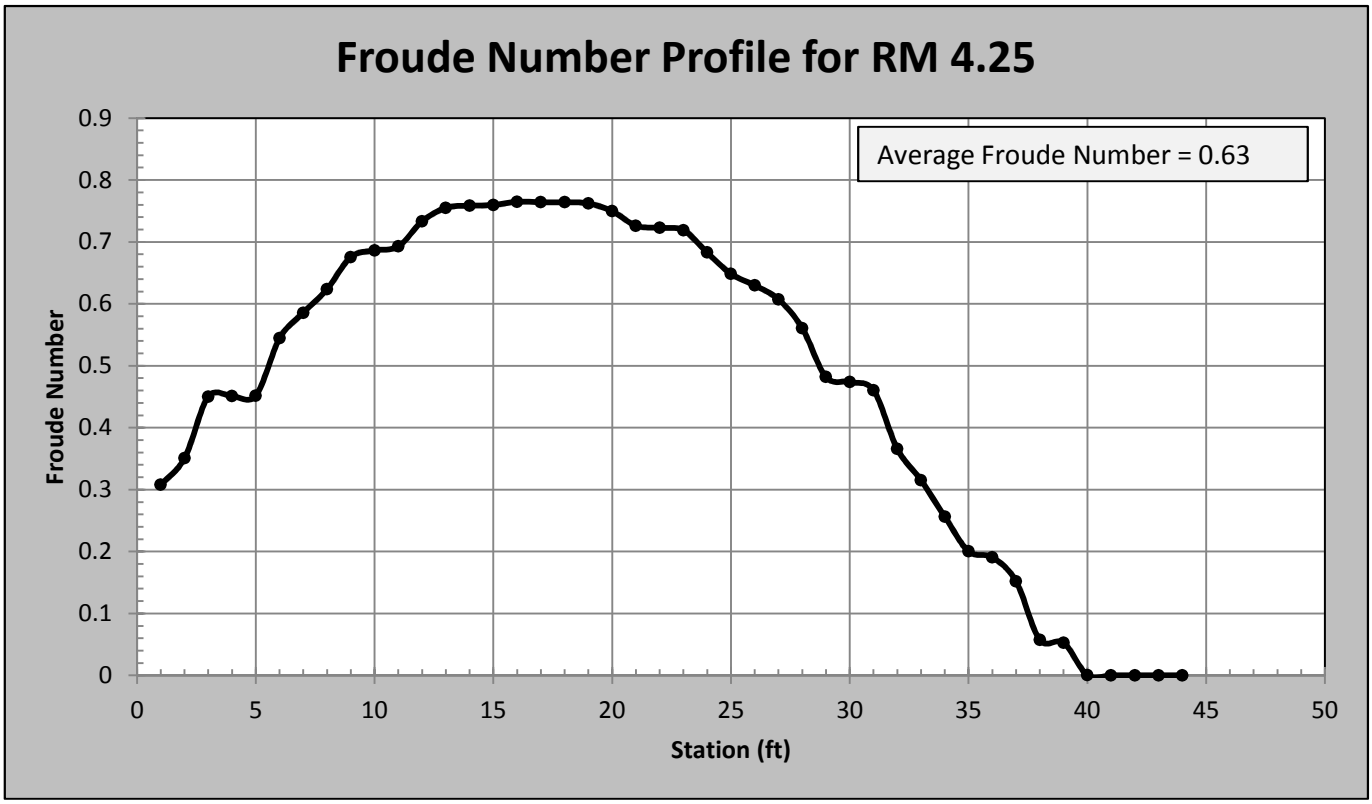
10-Year Event: 26,100cfs - River Mile 4



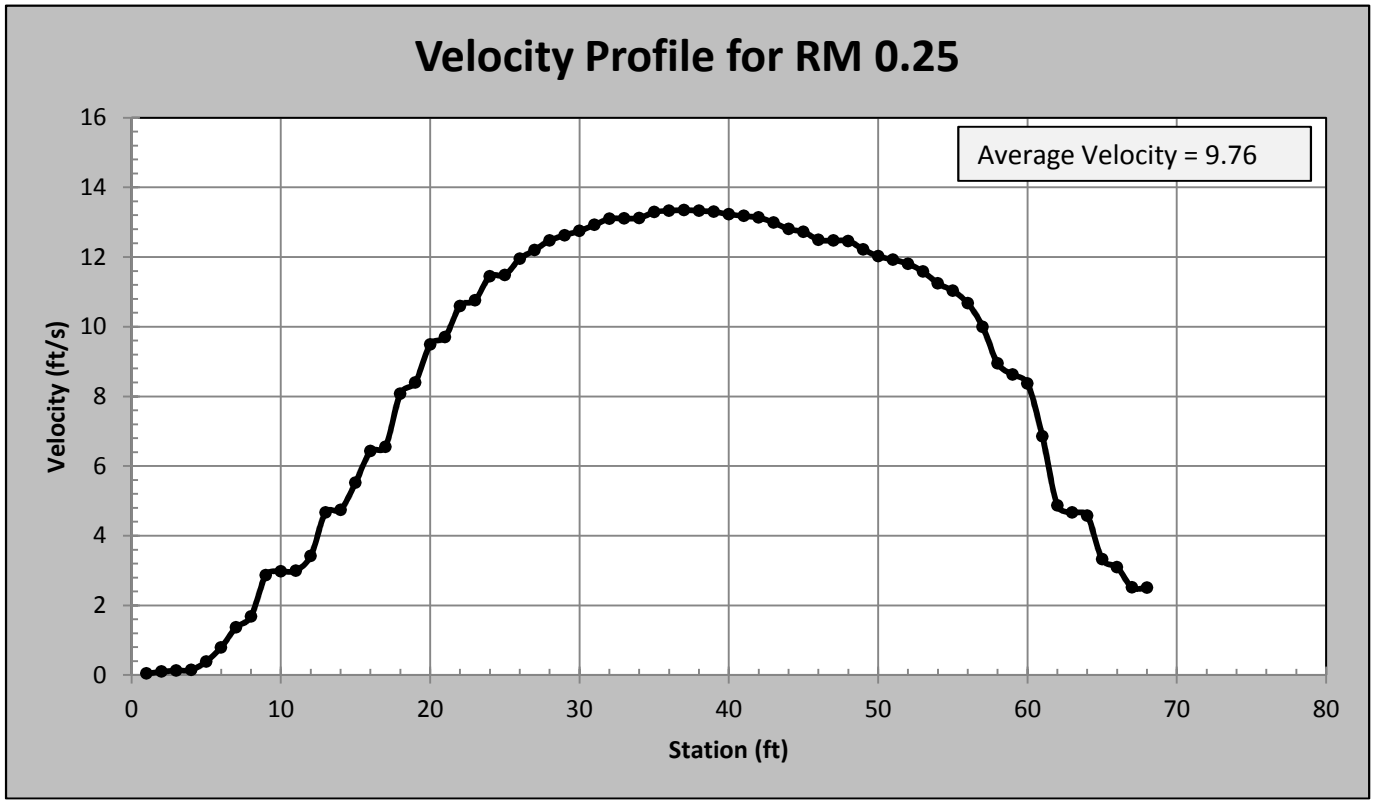


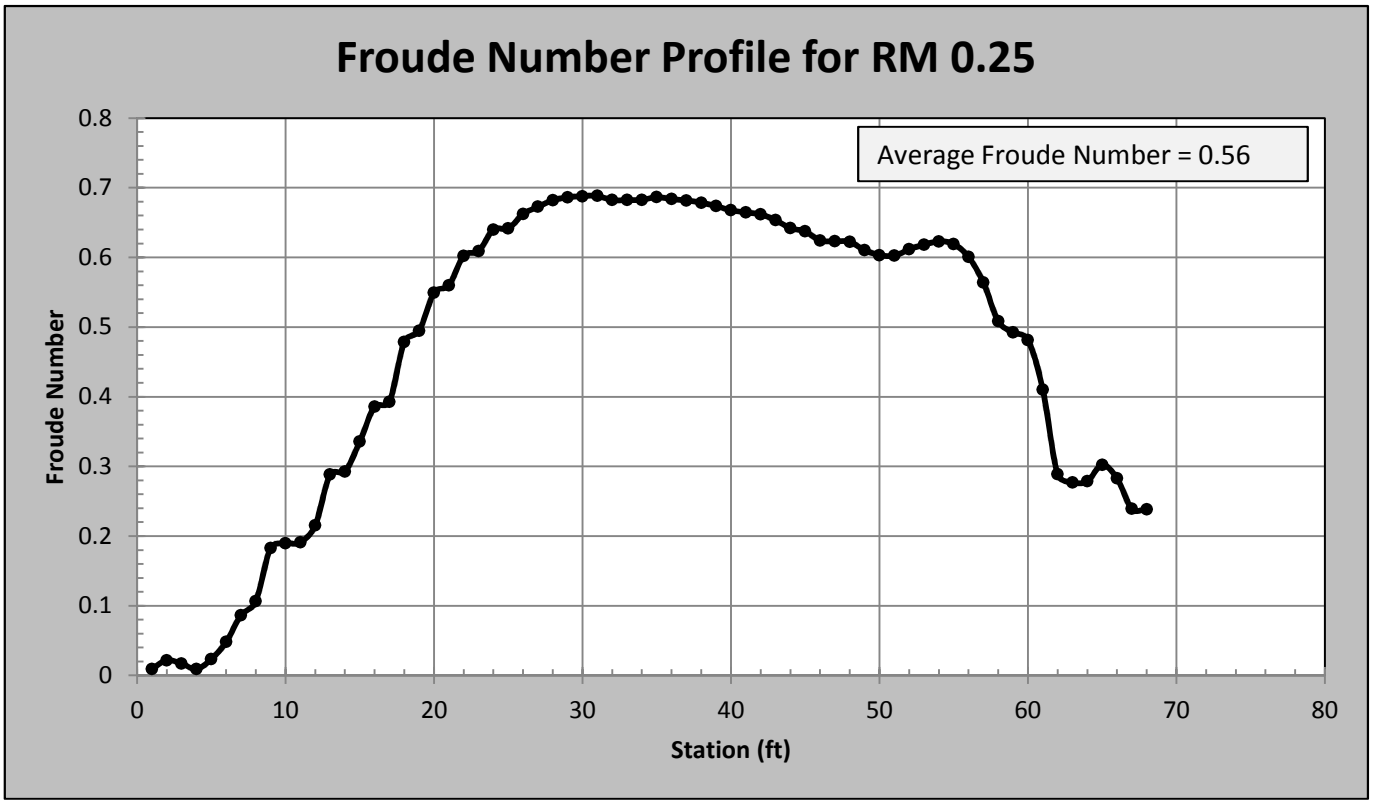
10-Year Event: 26,100cfs - River Mile 4.25



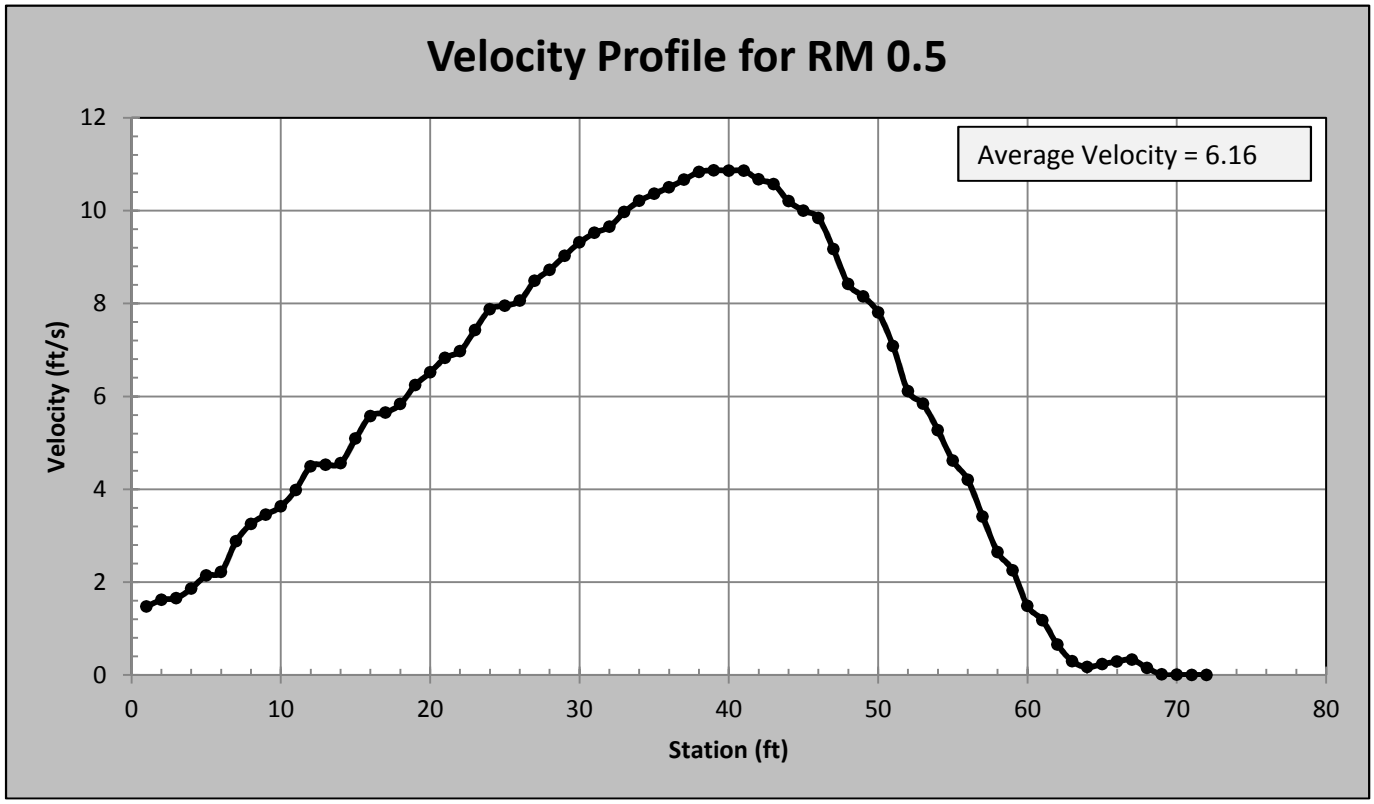


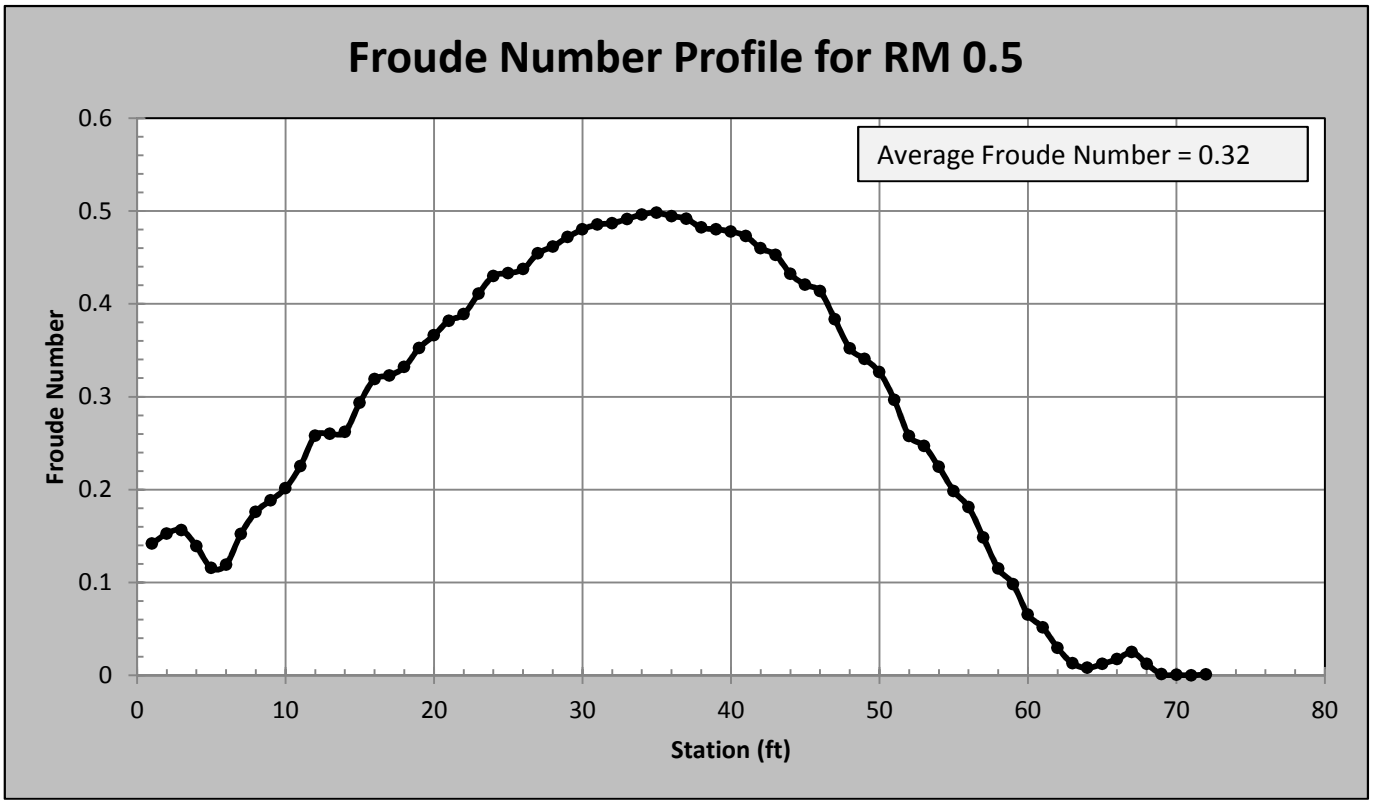
25-Year Event: 30,100cfs - River Mile 0.25



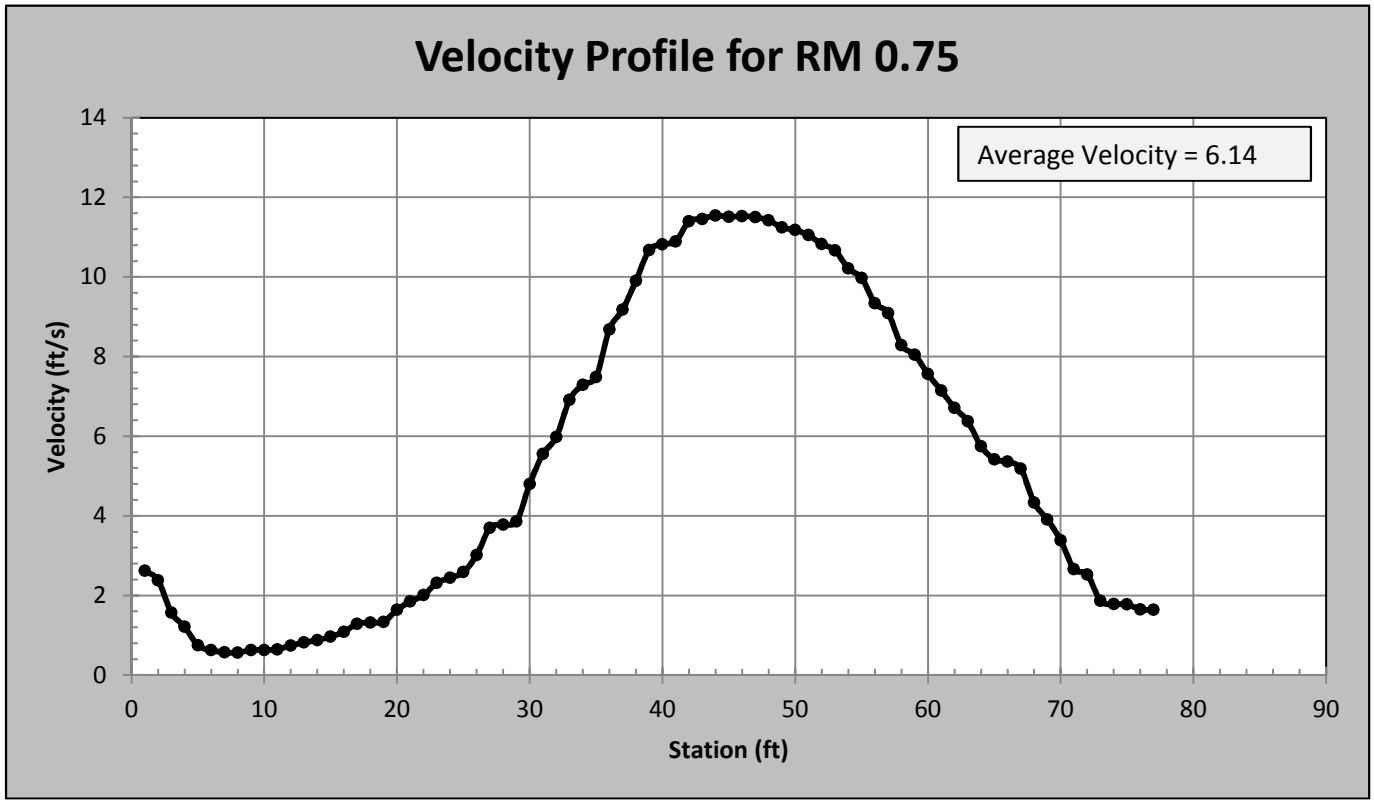


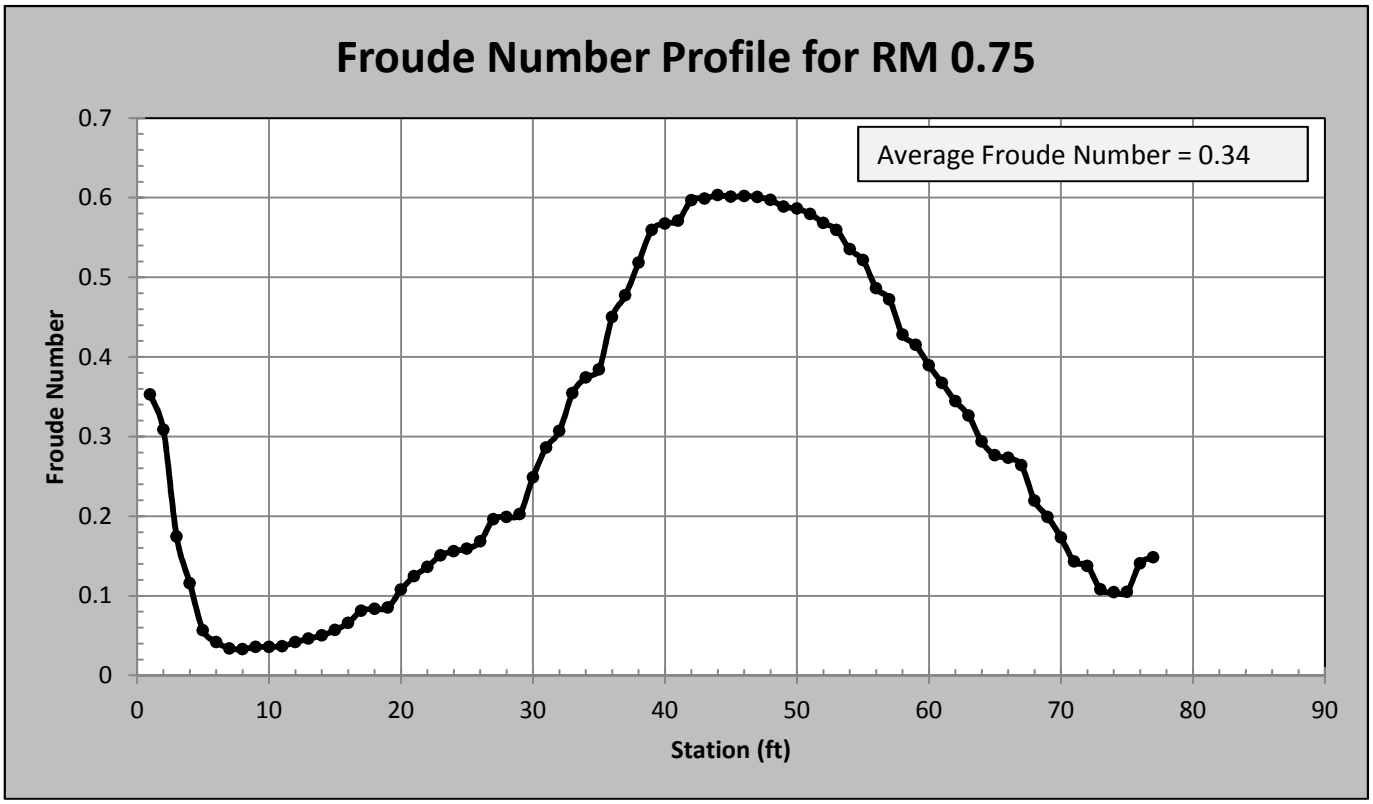
25-Year Event: 30,100cfs - River Mile 0.5



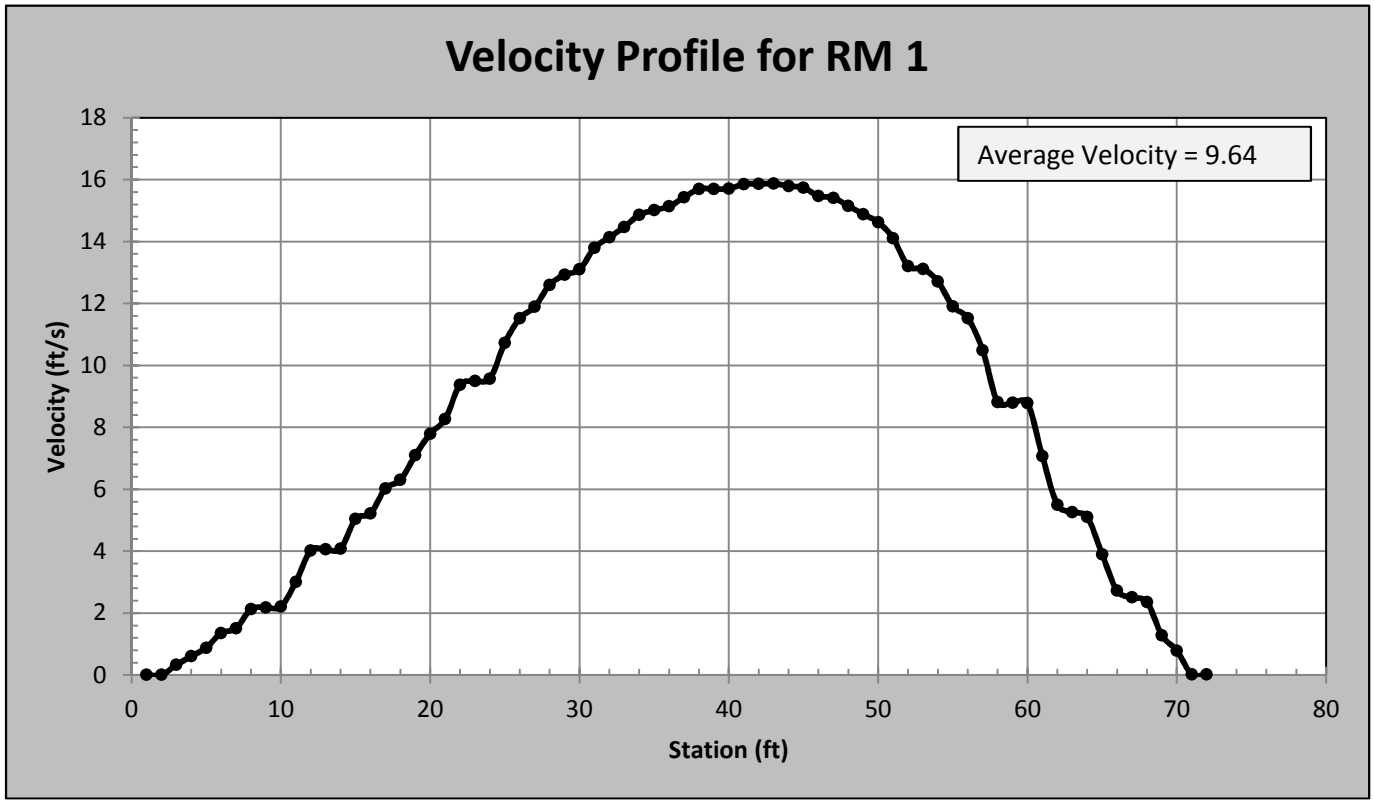


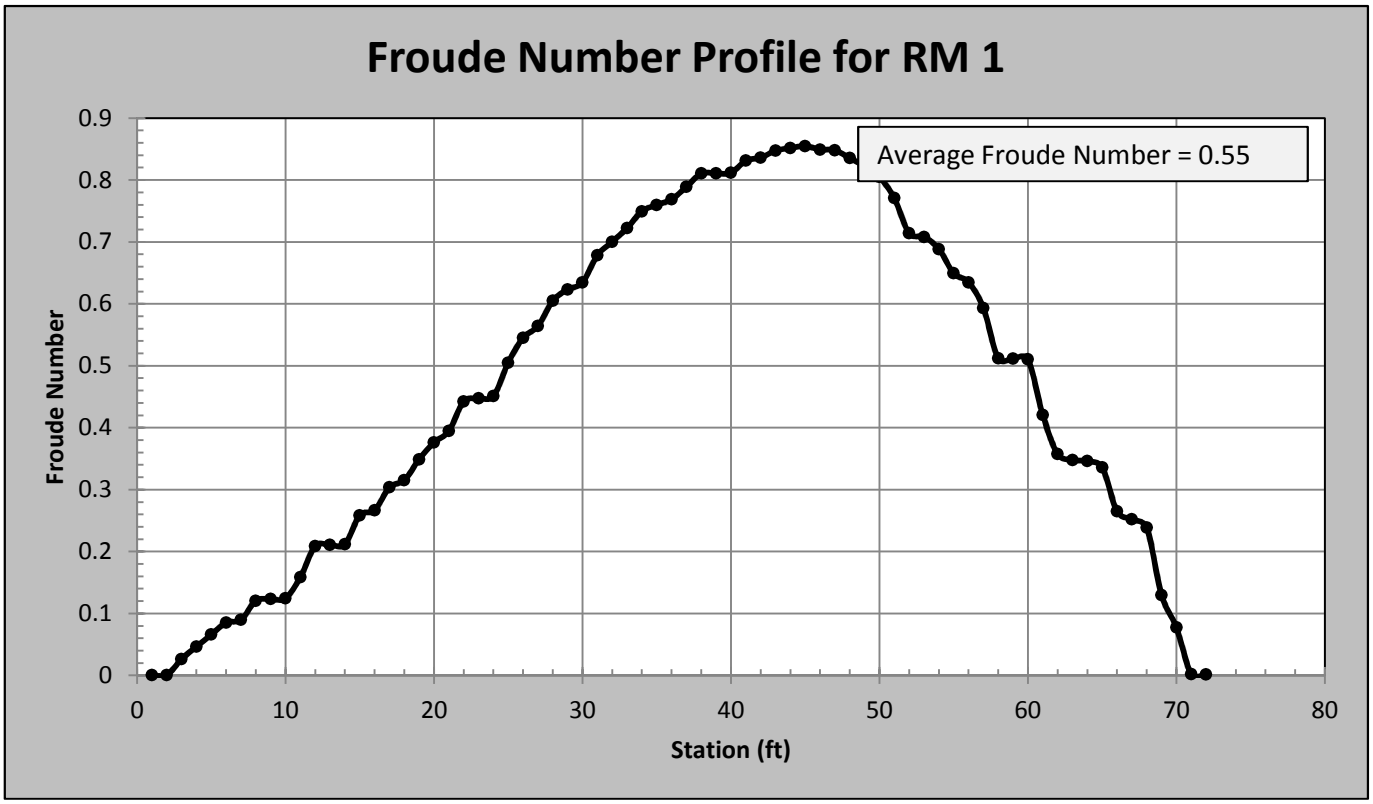
25-Year Event: 30,100cfs - River Mile 0.75



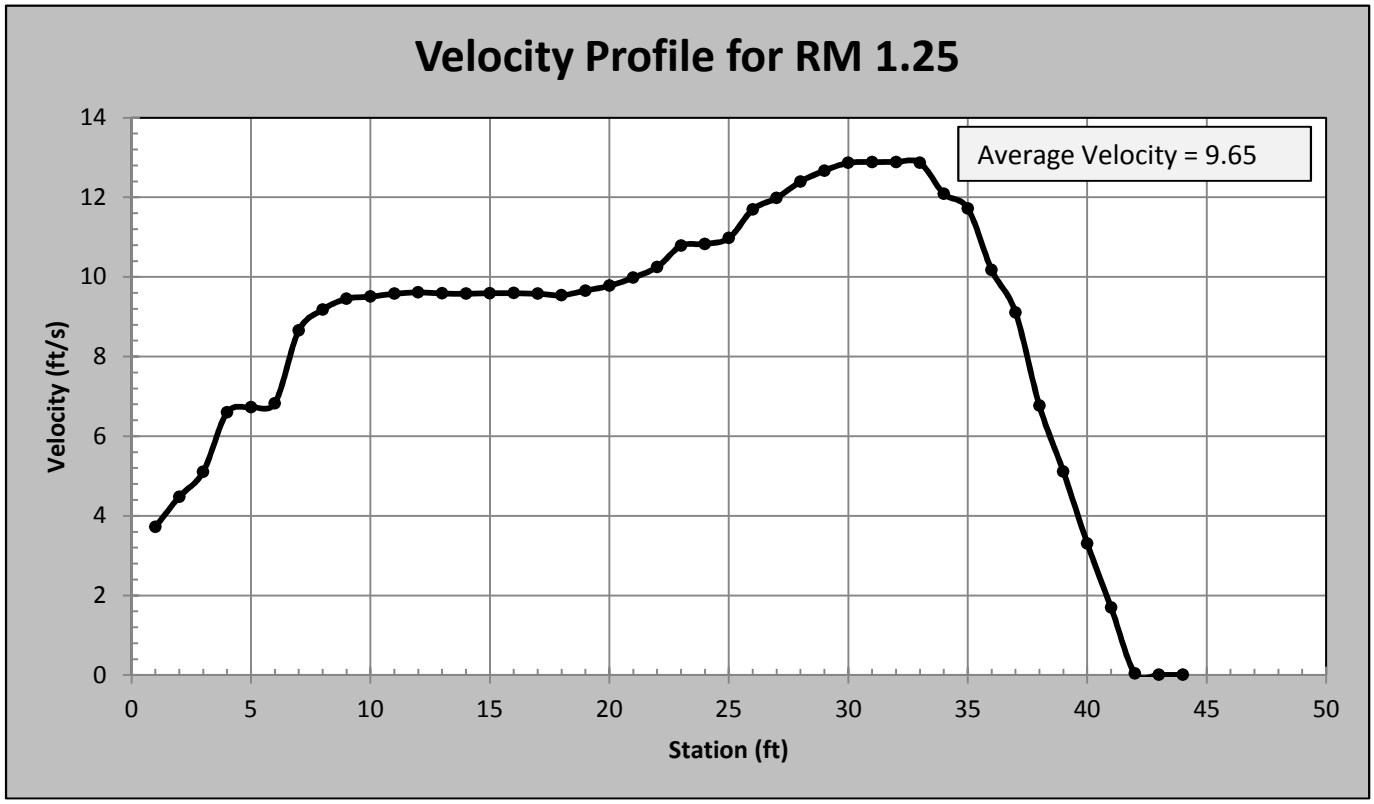


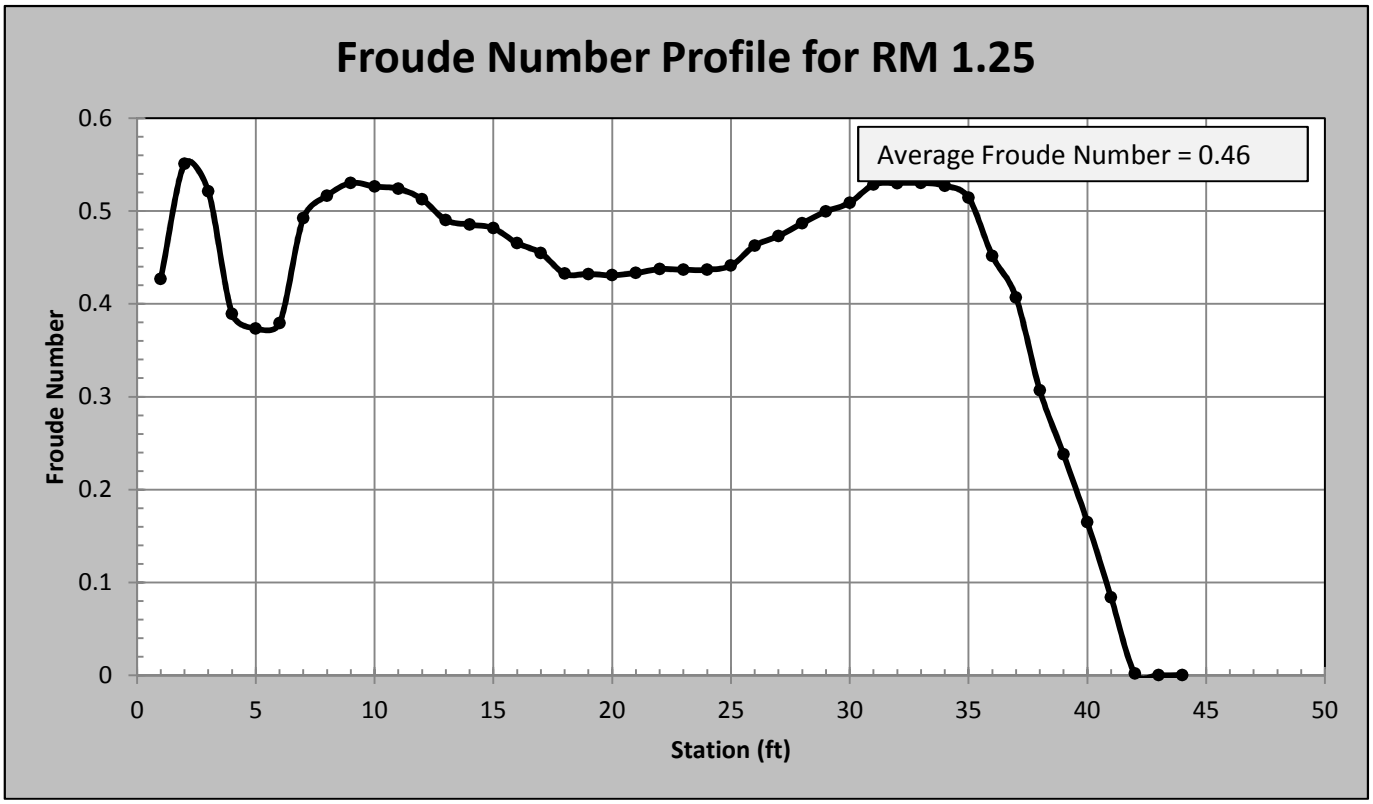
25-Year Event: 30,100cfs - River Mile 1



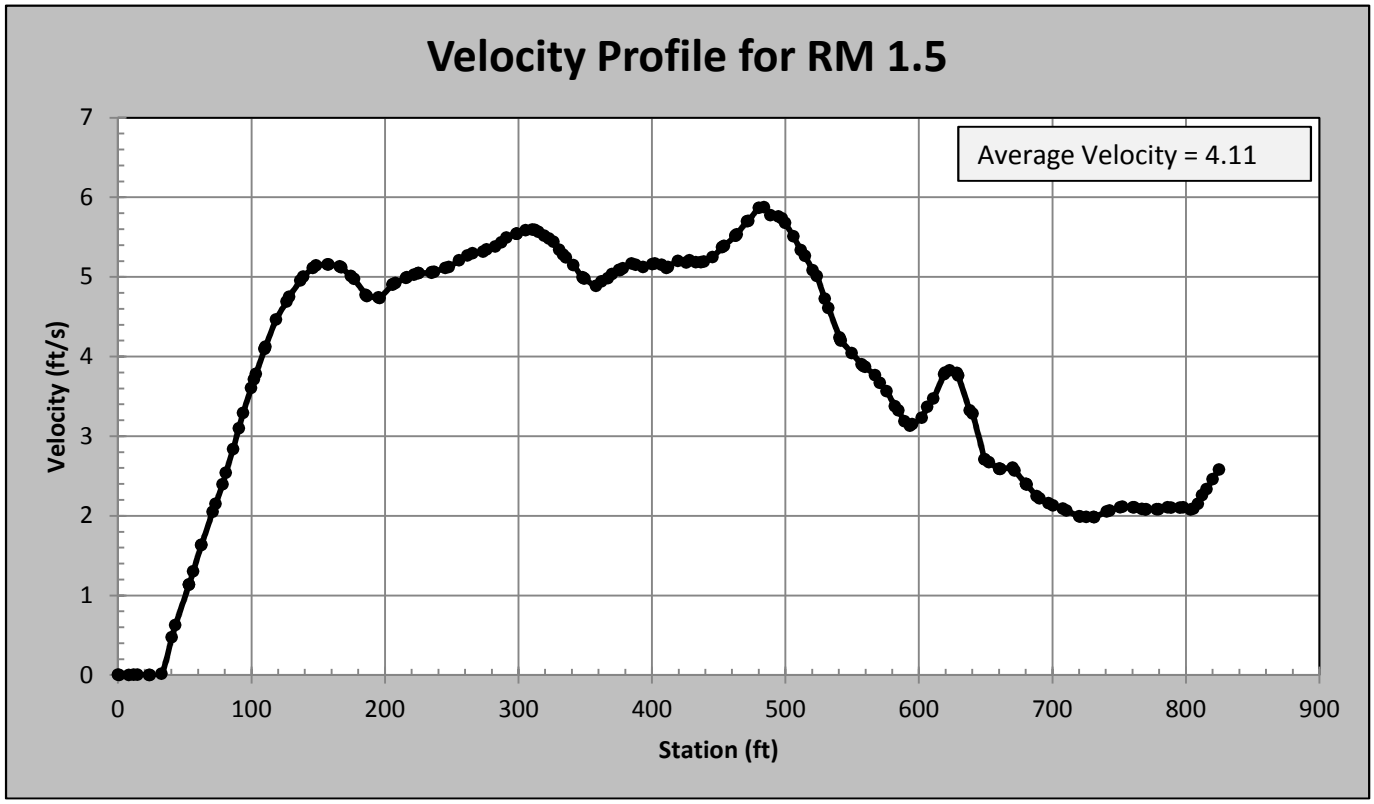


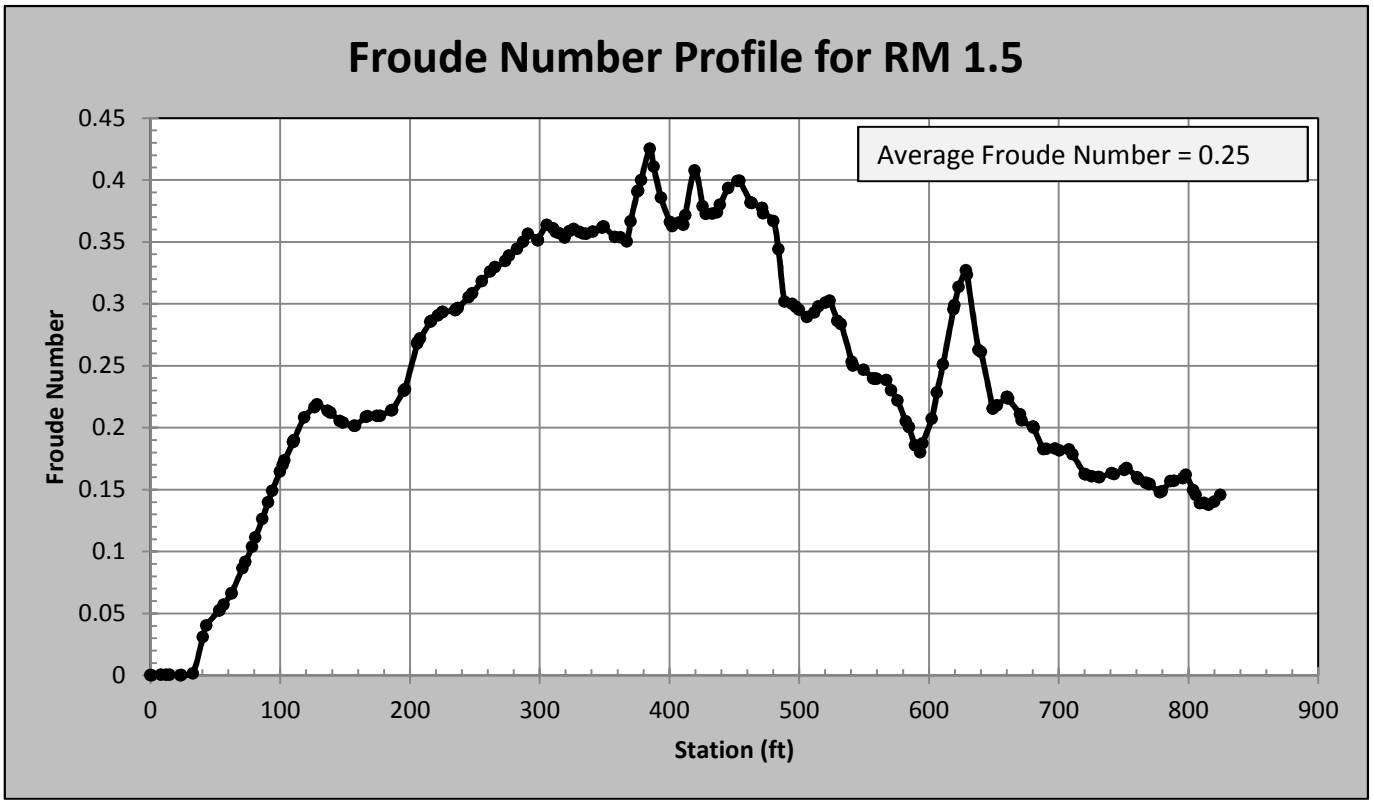
25-Year Event: 30,100cfs - River Mile 1.25



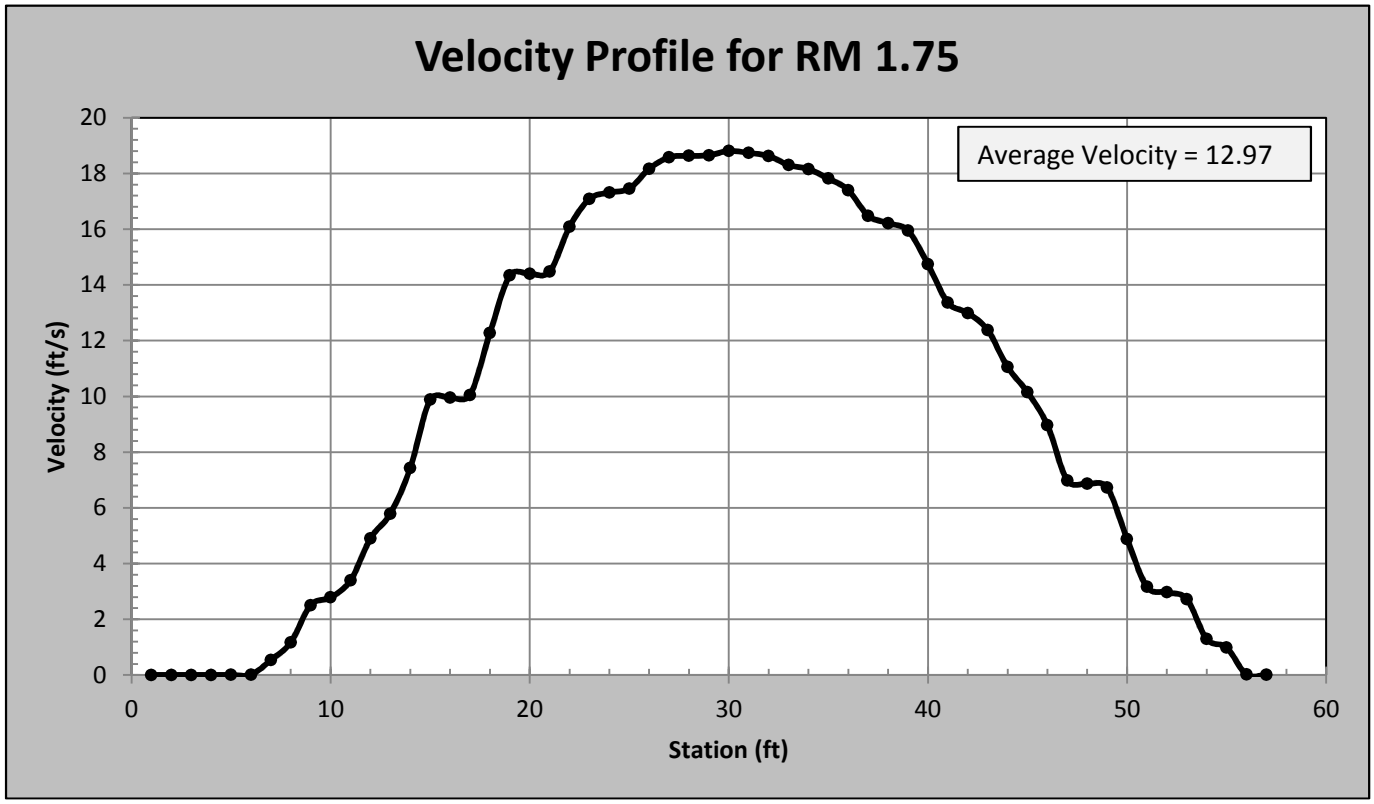


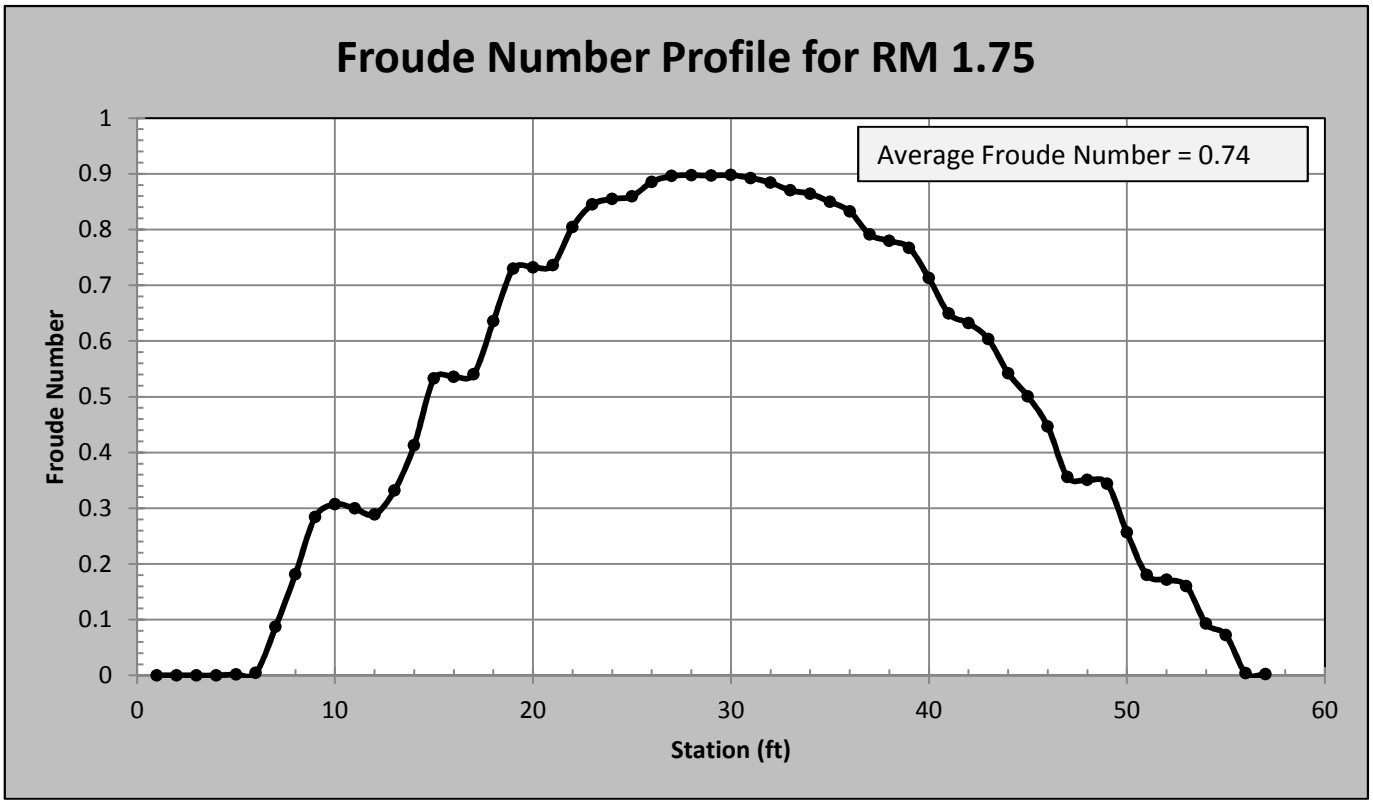
25-Year Event: 30,100cfs - River Mile 1.5



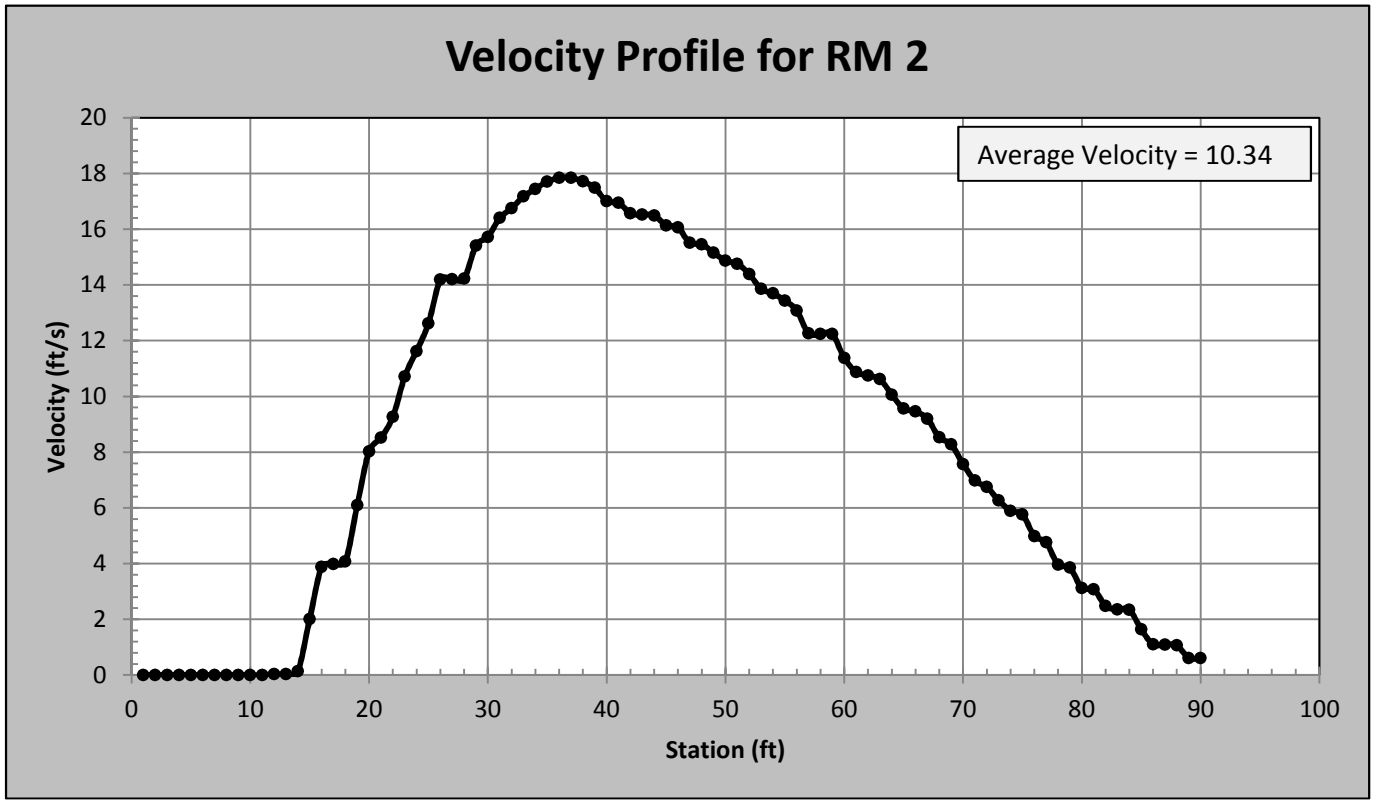


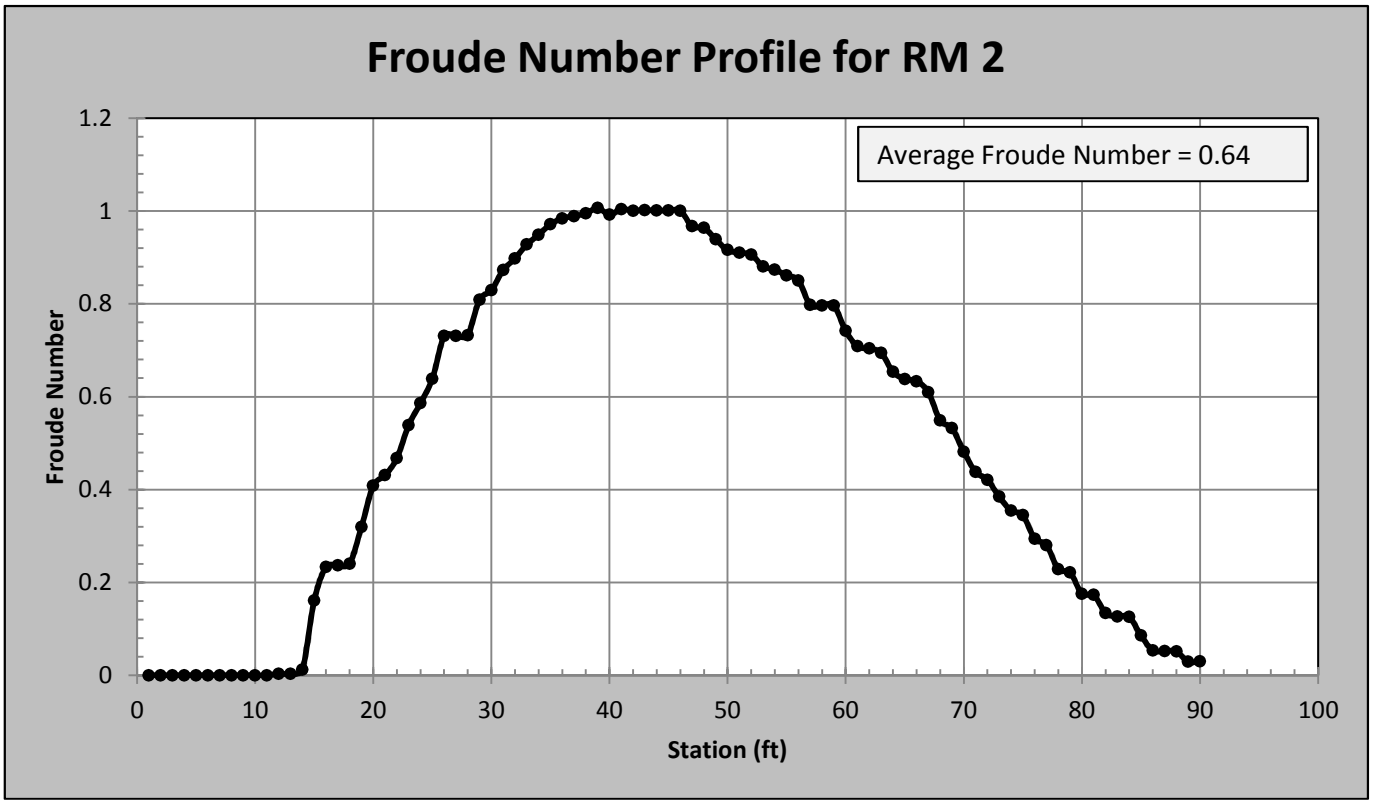
25-Year Event: 30,100cfs - River Mile 1.75



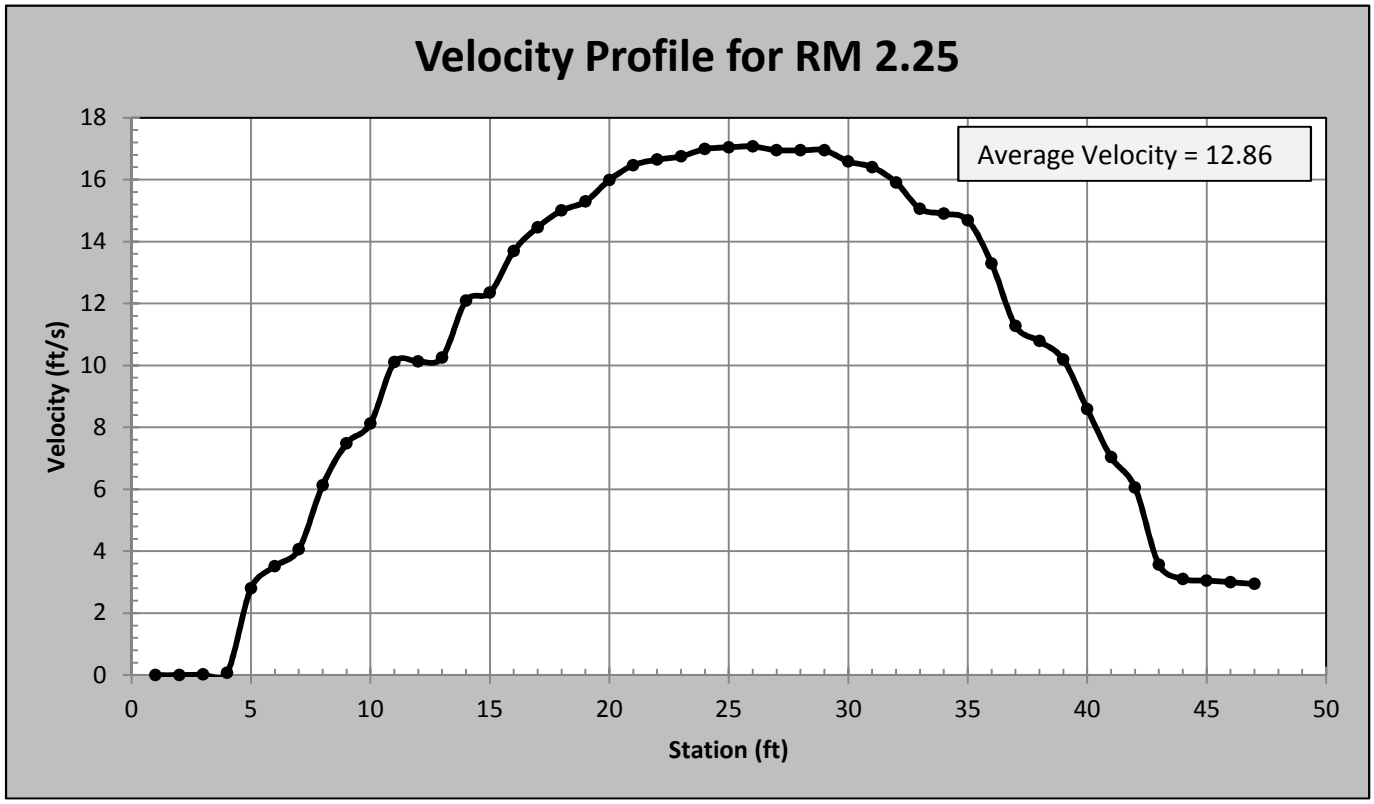


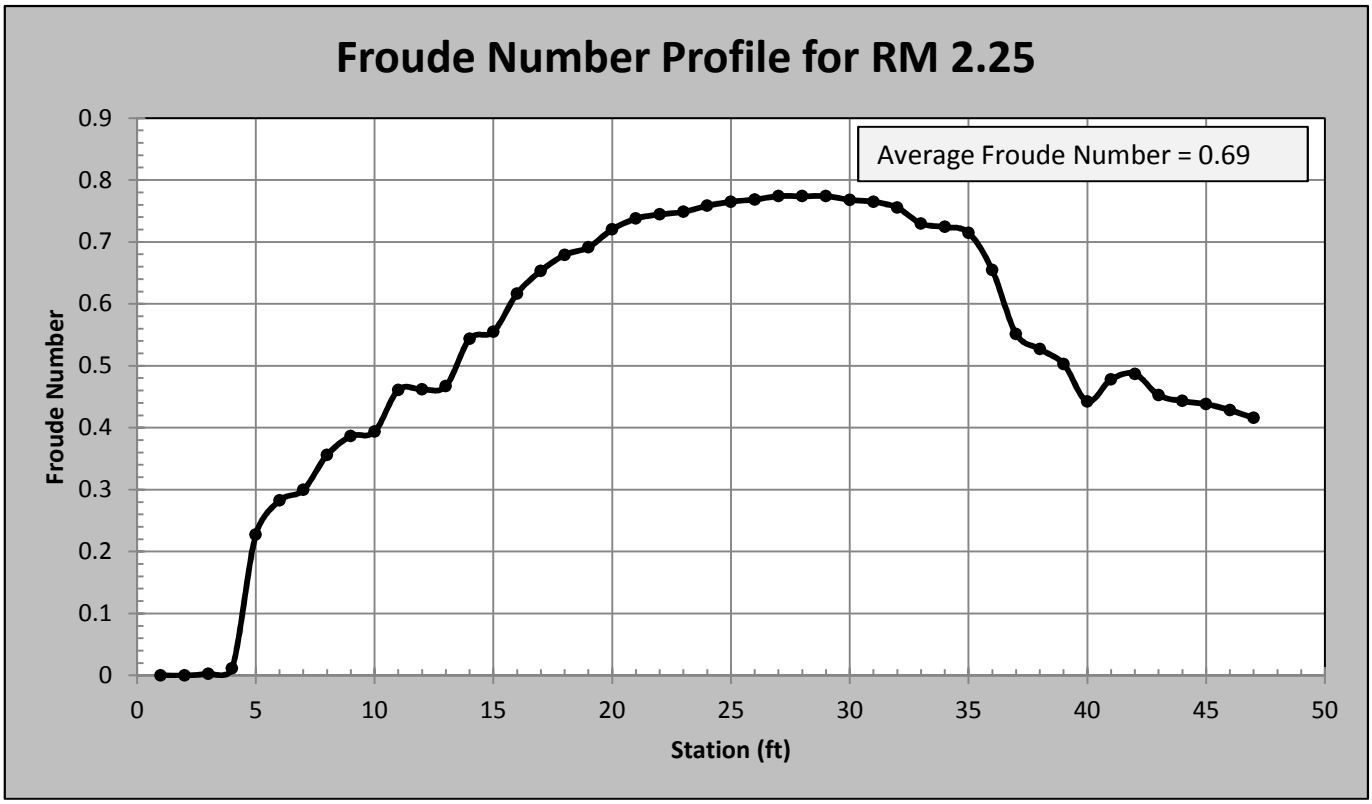
25-Year Event: 30,100cfs - River Mile 2



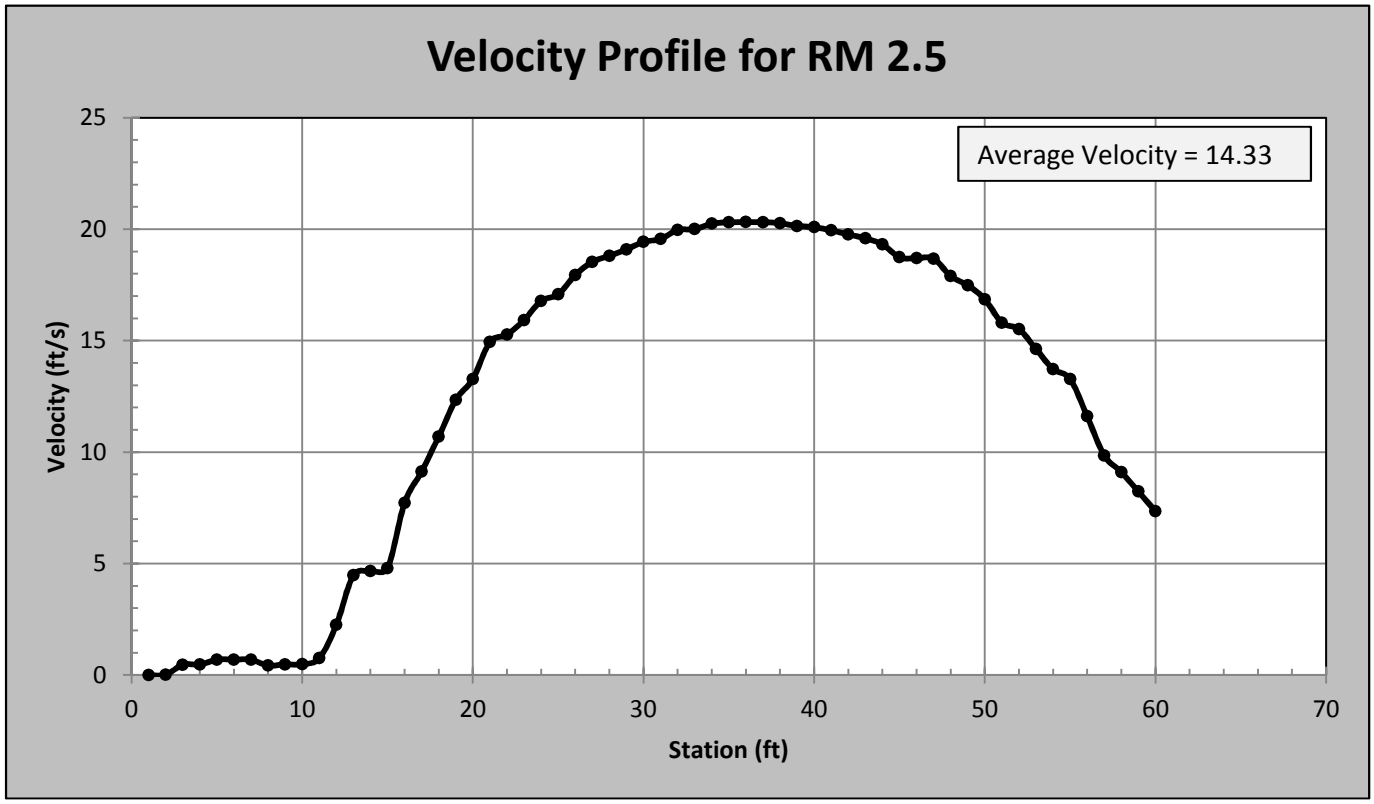


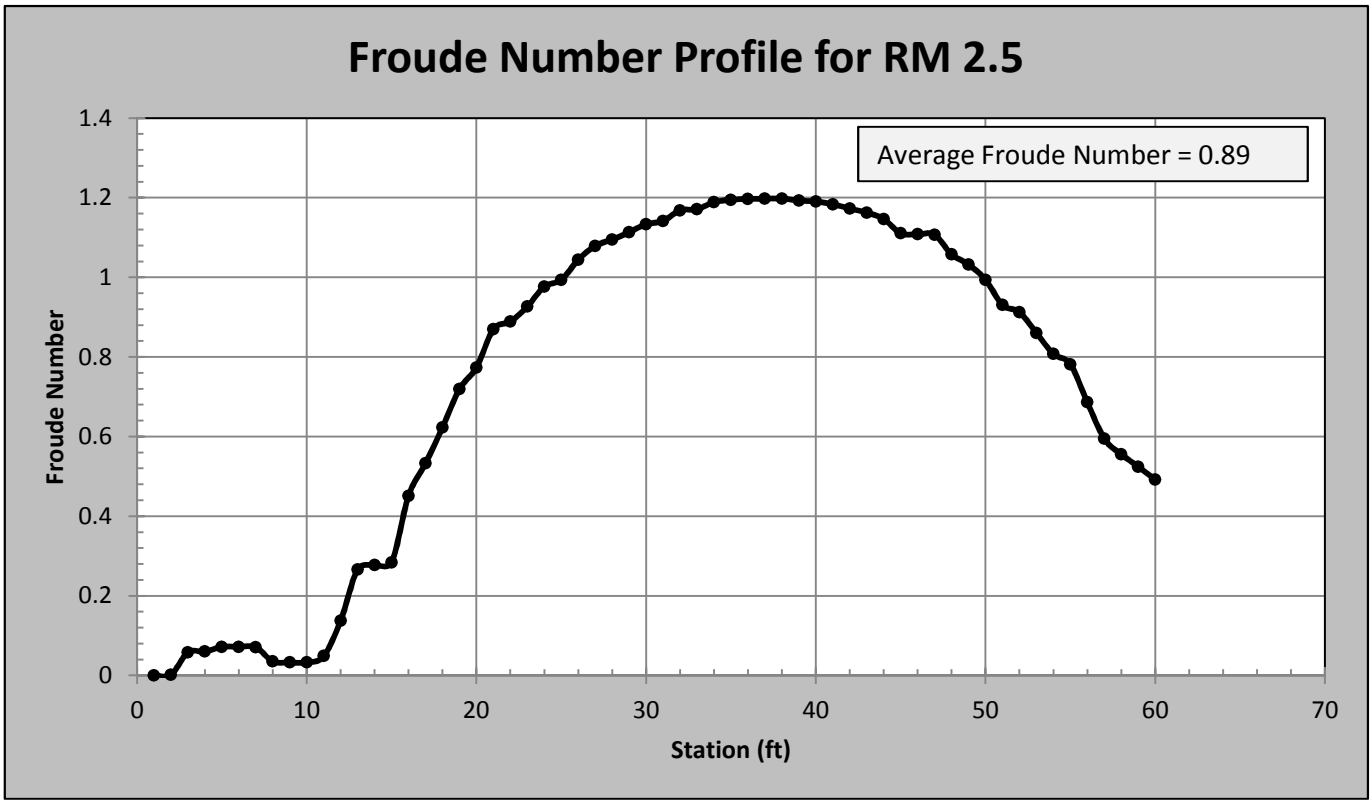
25-Year Event: 30,100cfs - River Mile 2.25



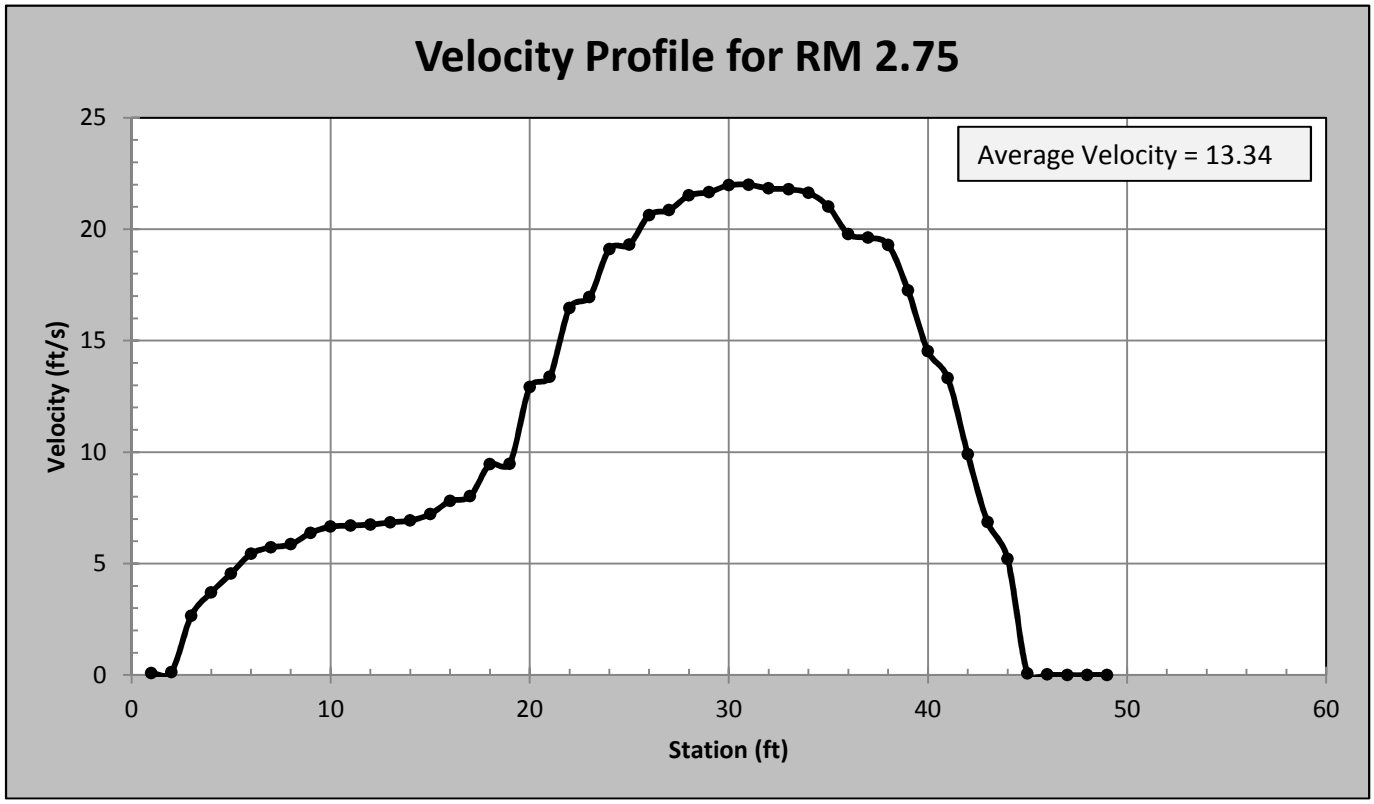


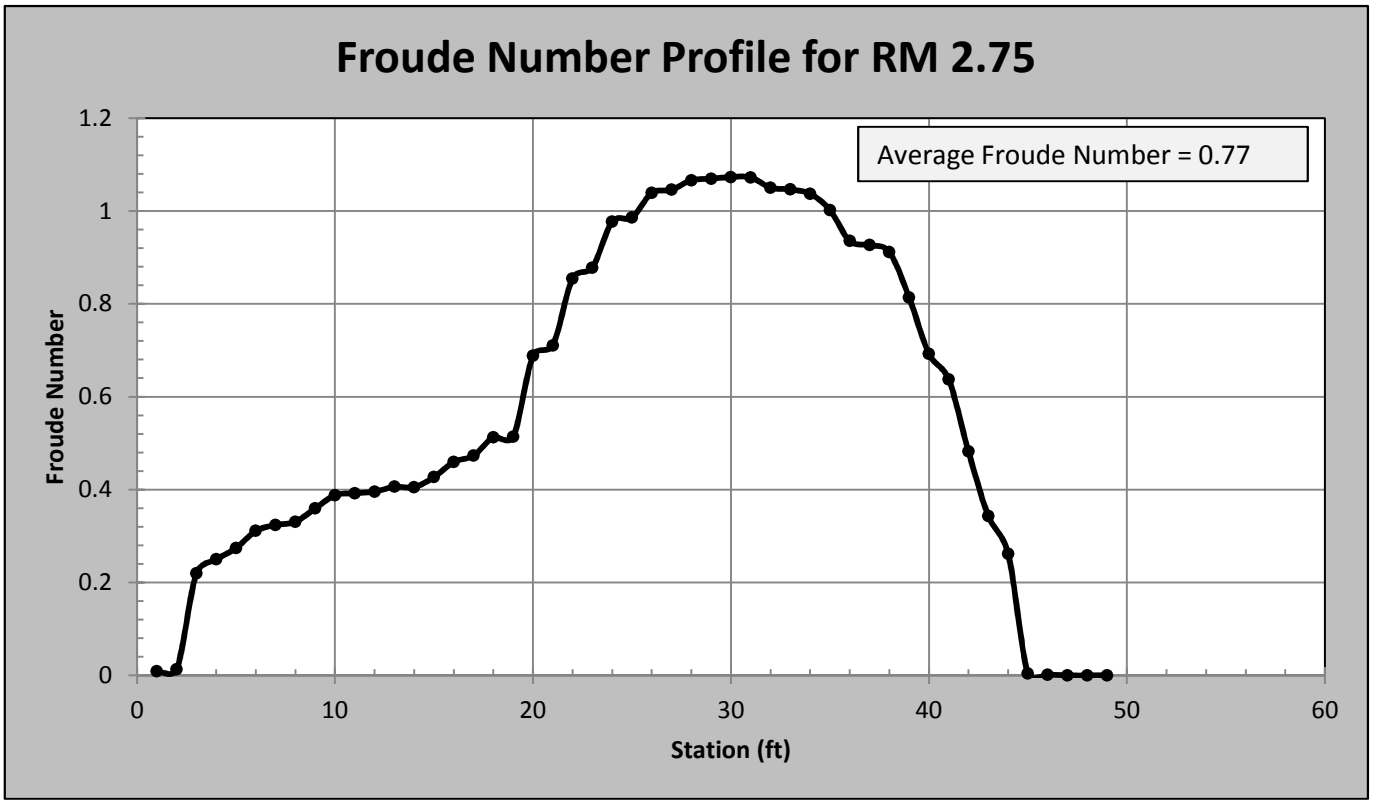
25-Year Event: 30,100cfs - River Mile 2.5



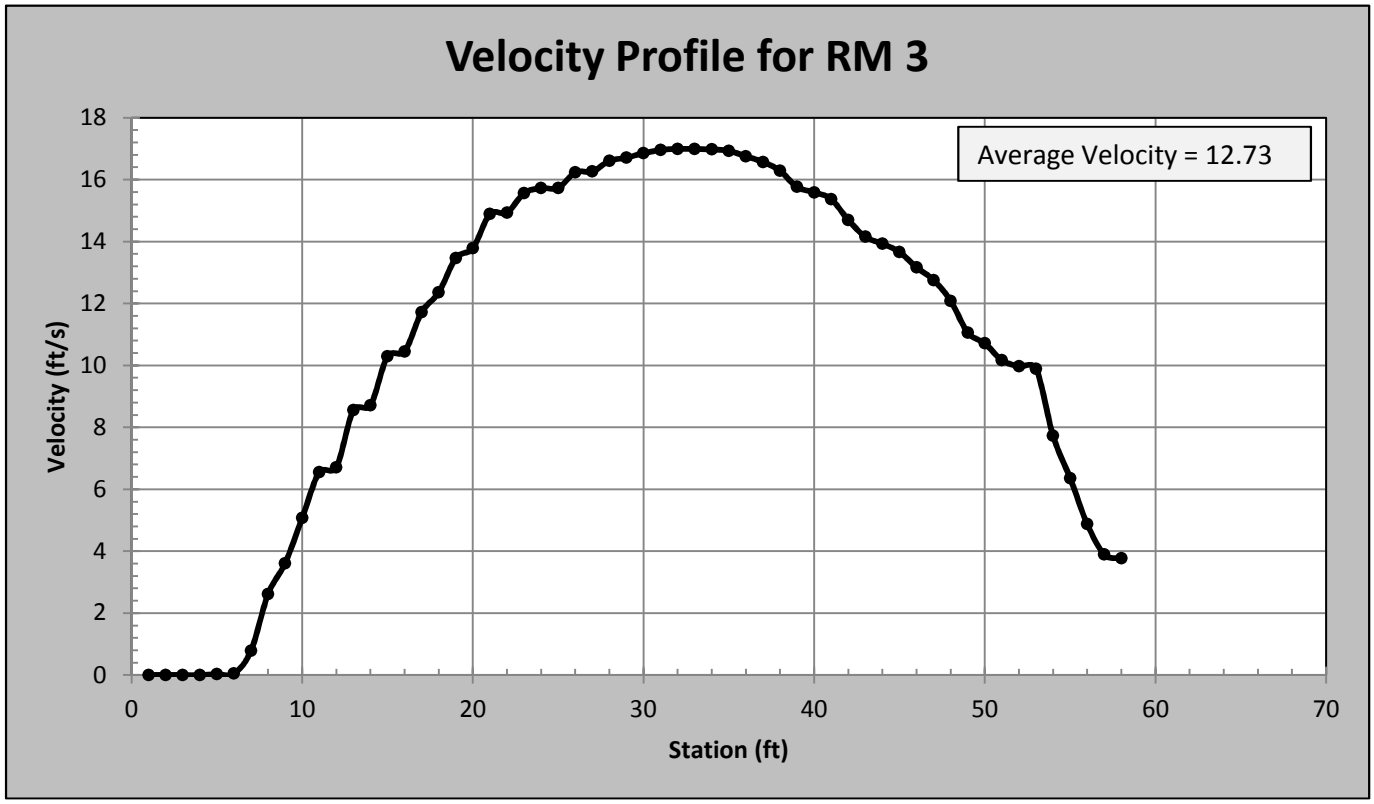


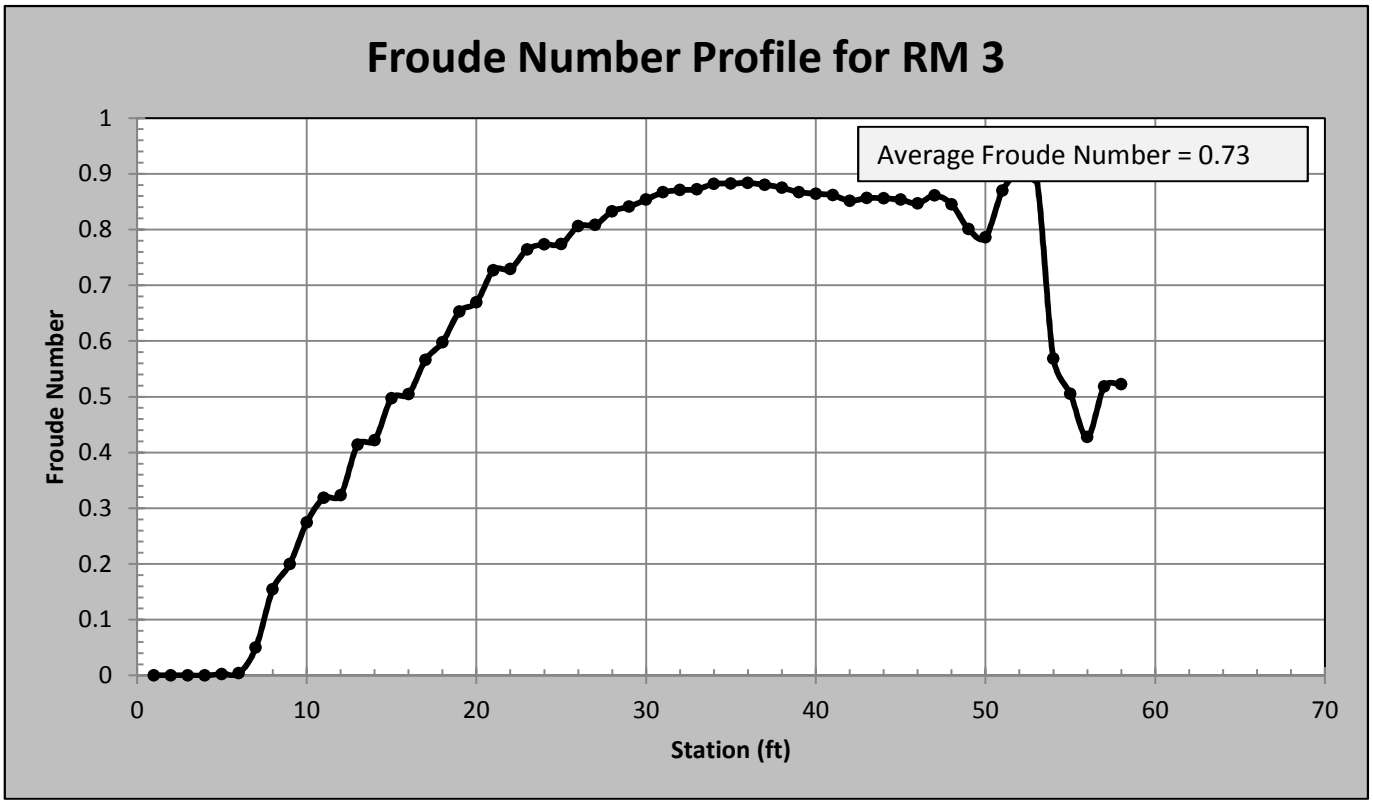
25-Year Event: 30,100cfs - River Mile 2.75



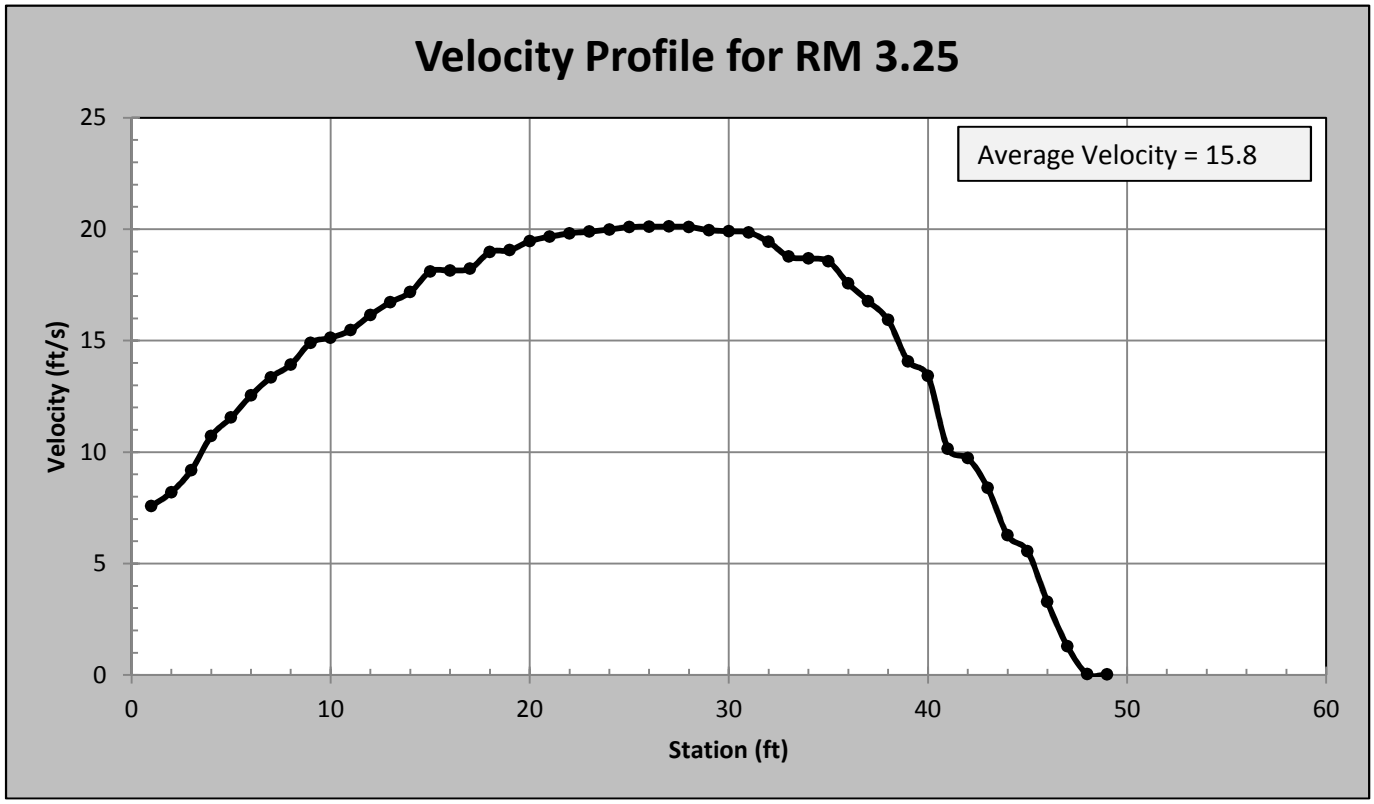


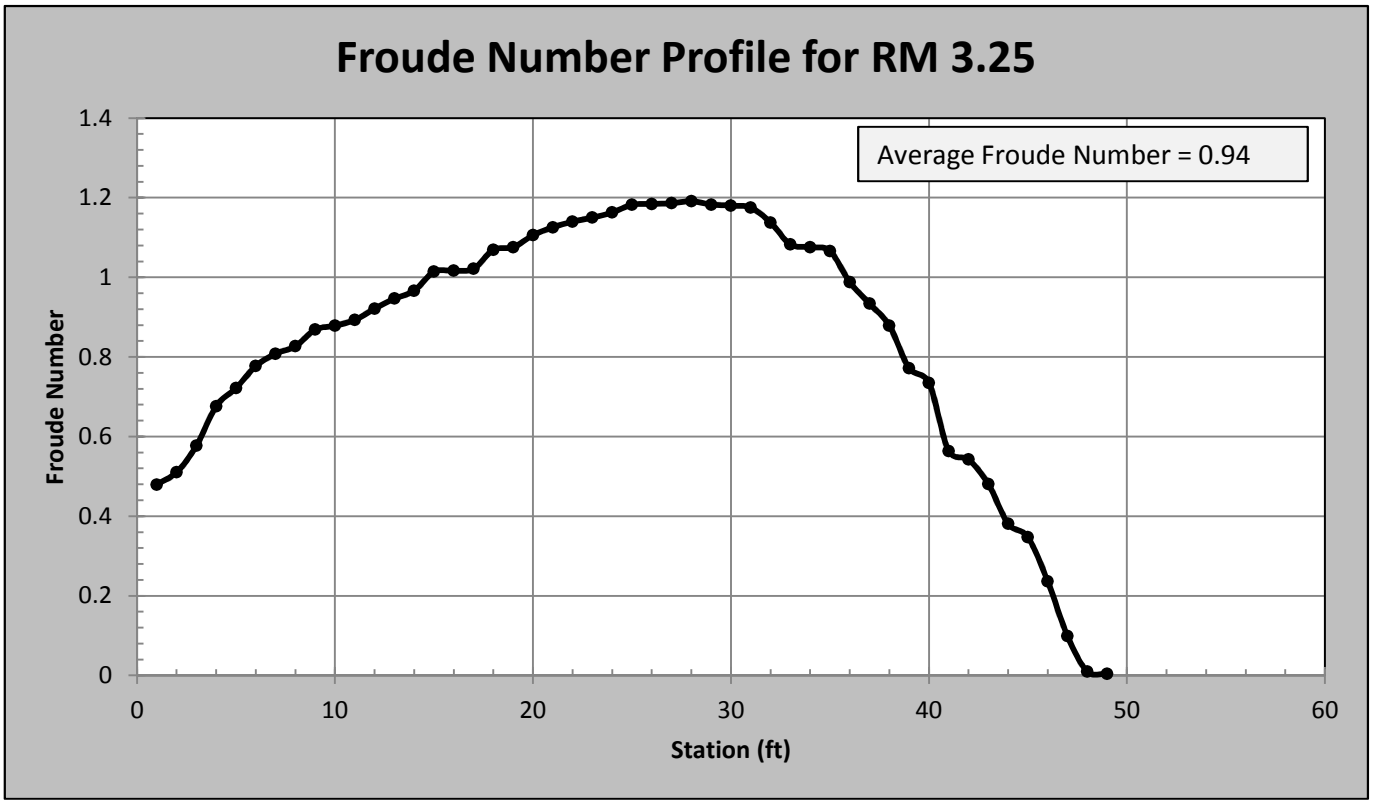
25-Year Event: 30,100cfs - River Mile 3



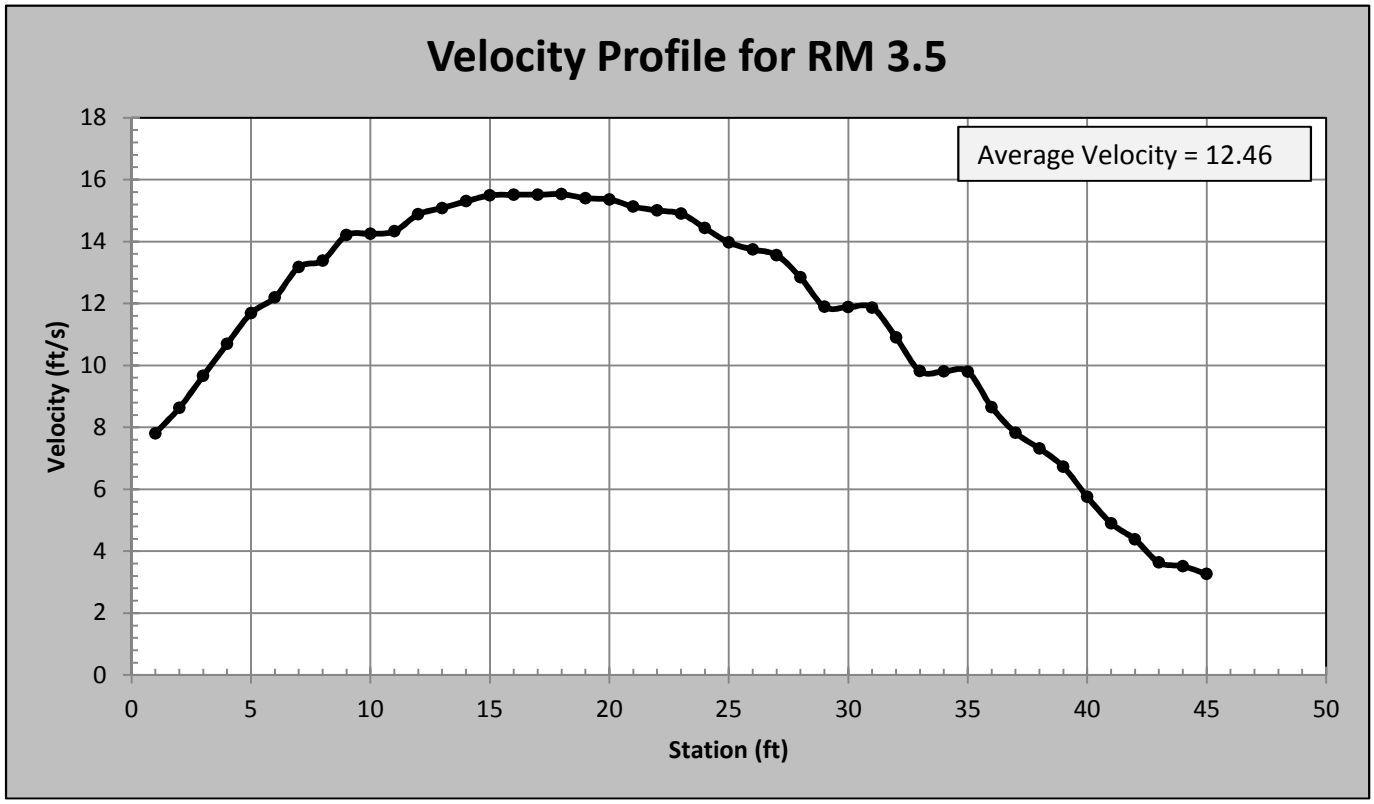


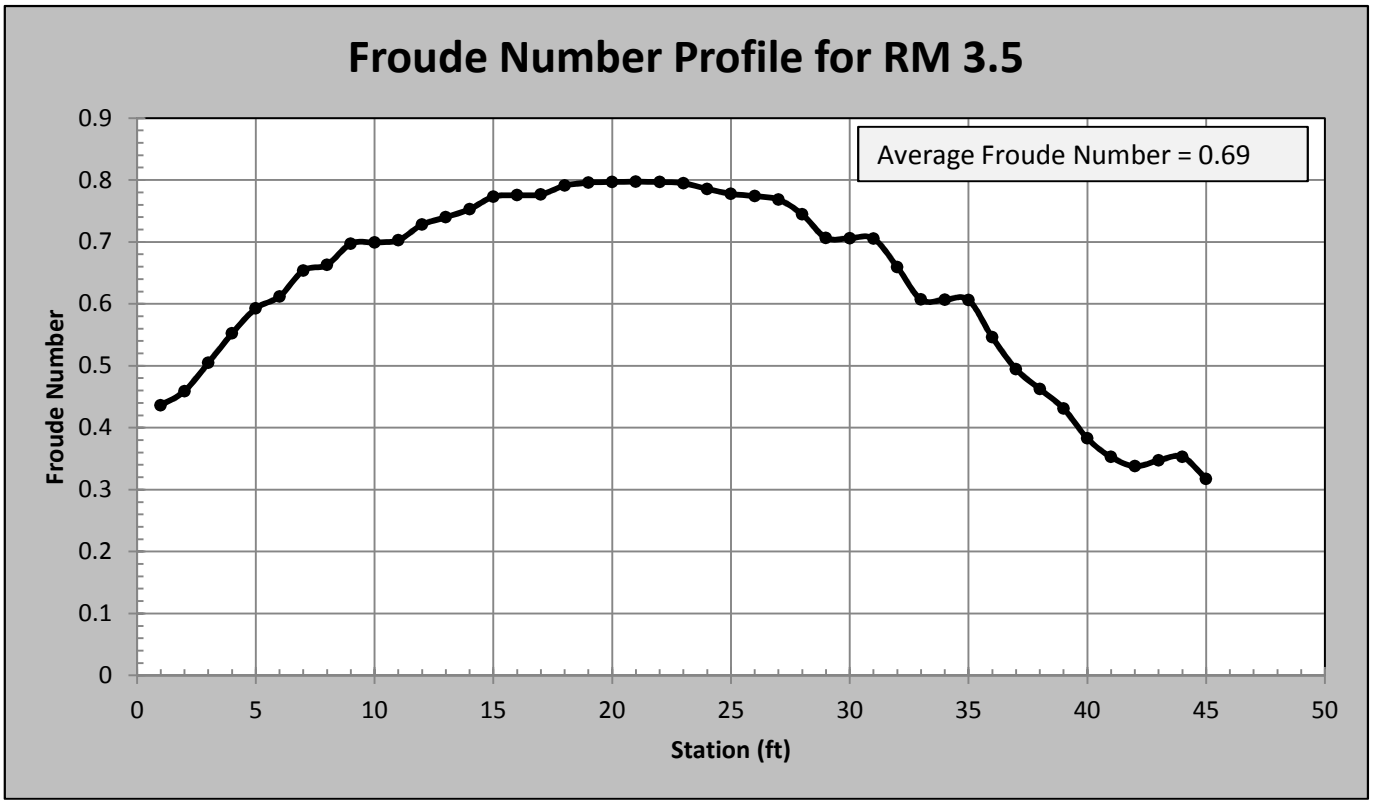
25-Year Event: 30,100cfs - River Mile 3.25



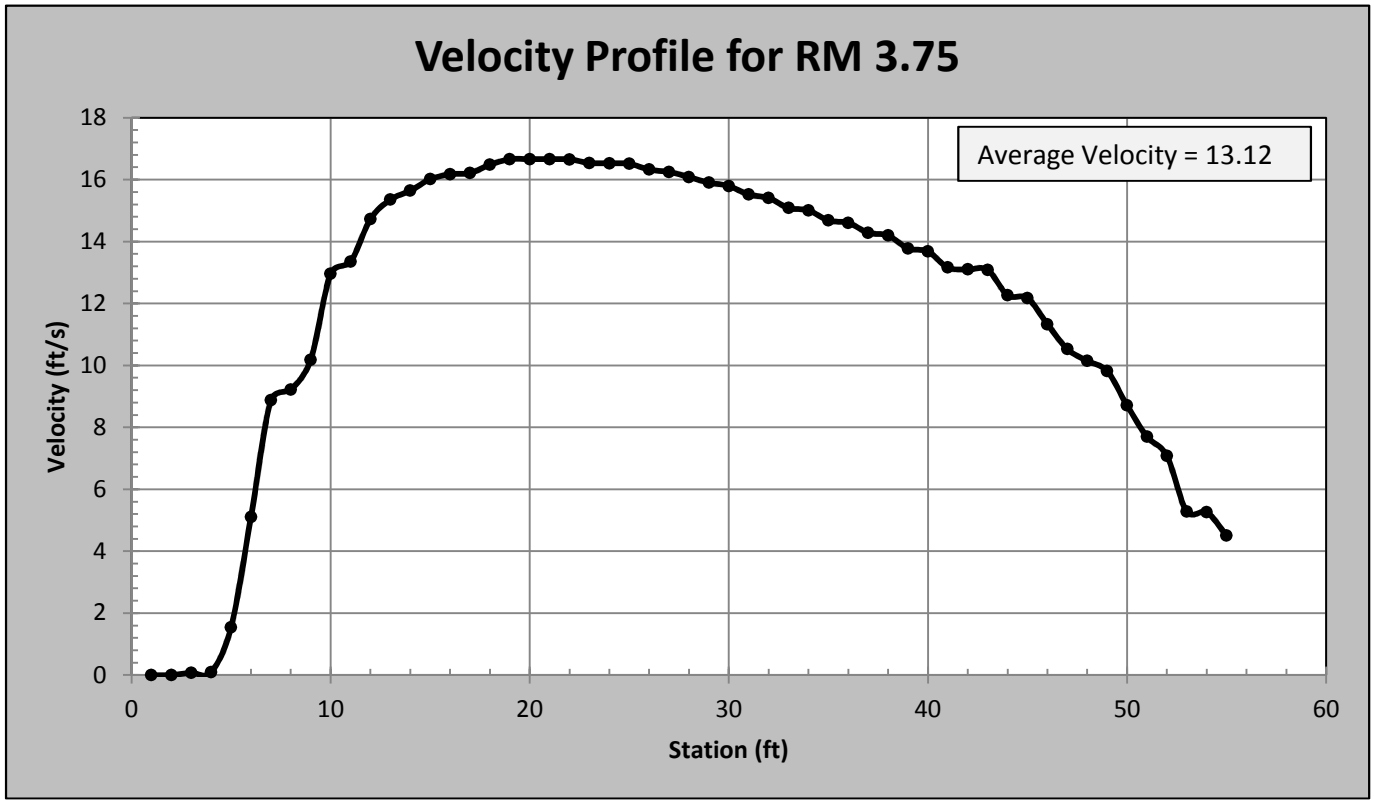


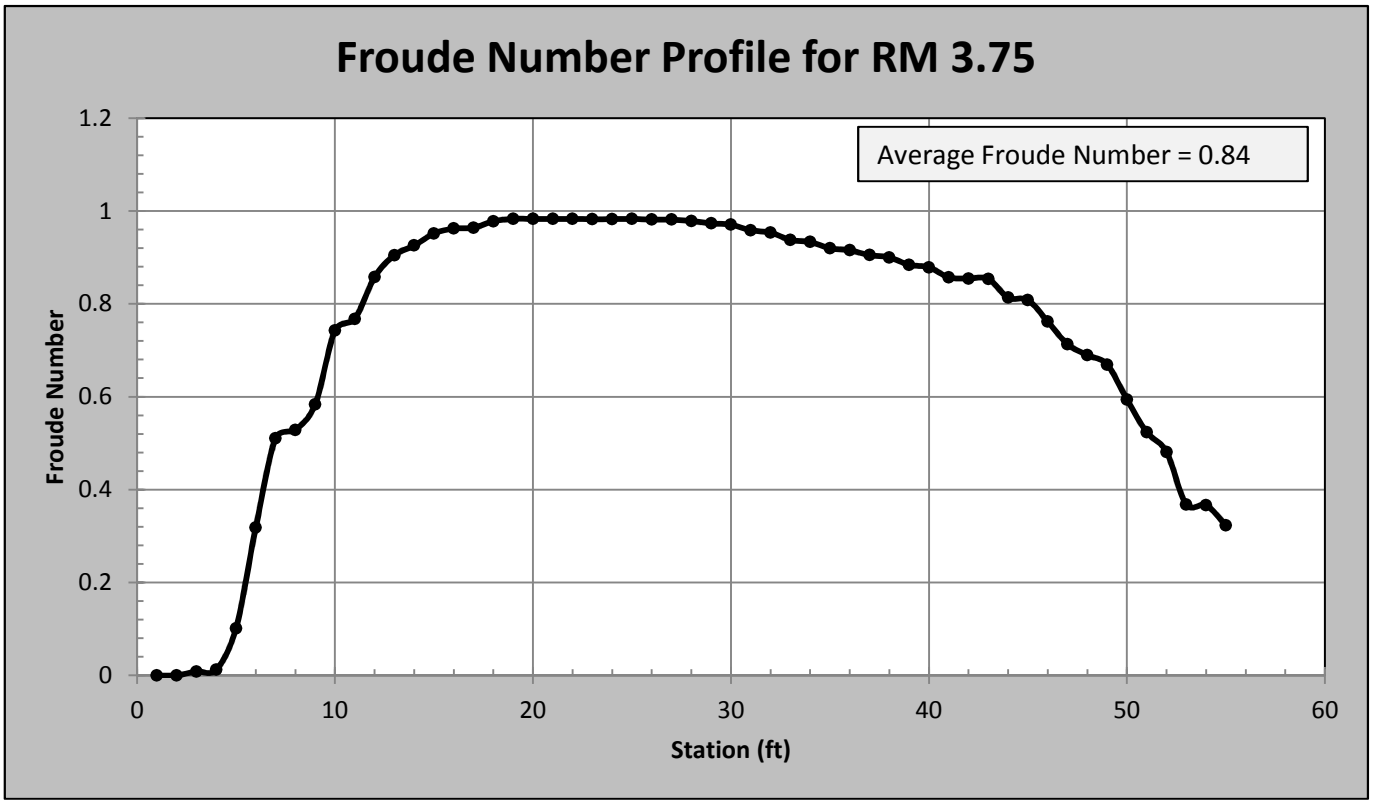
25-Year Event: 30,100cfs - River Mile 3.5



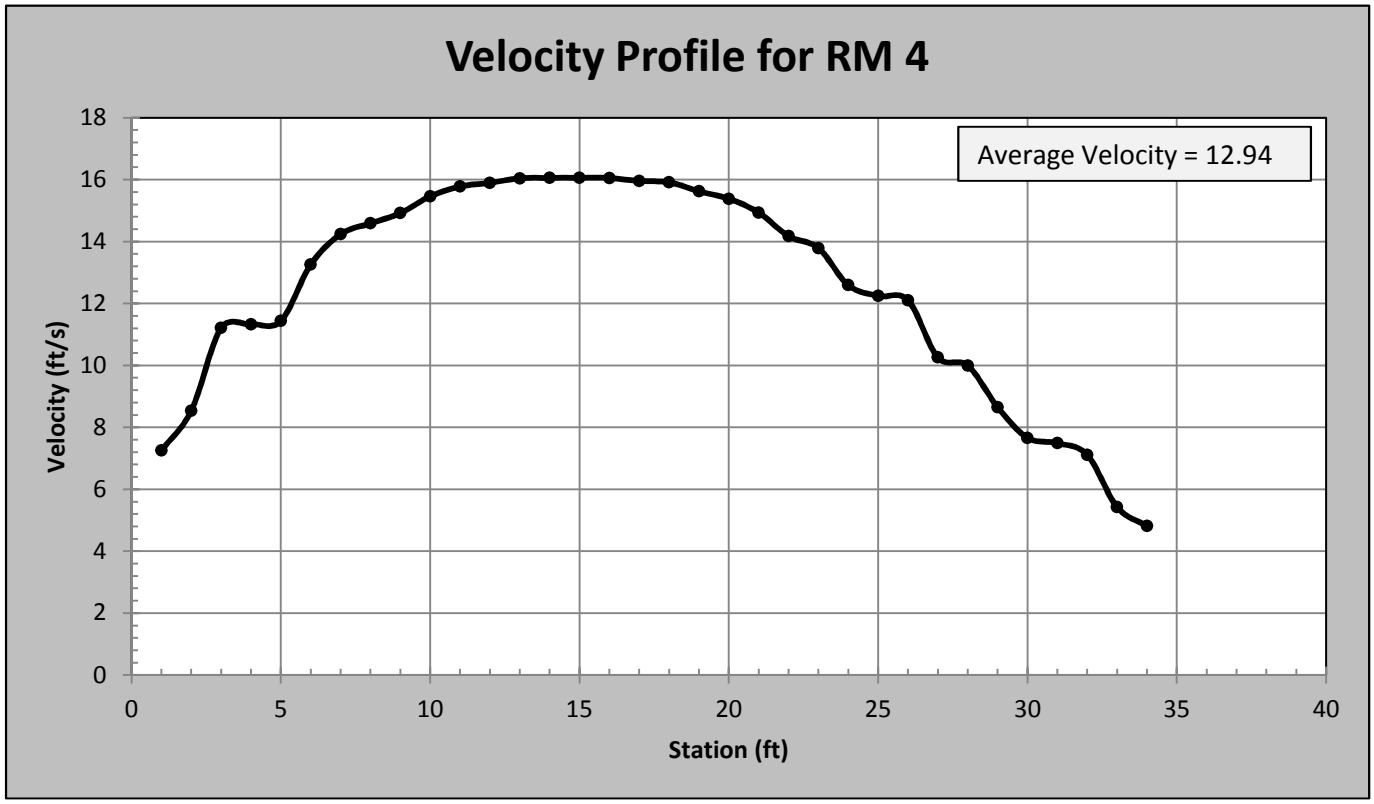


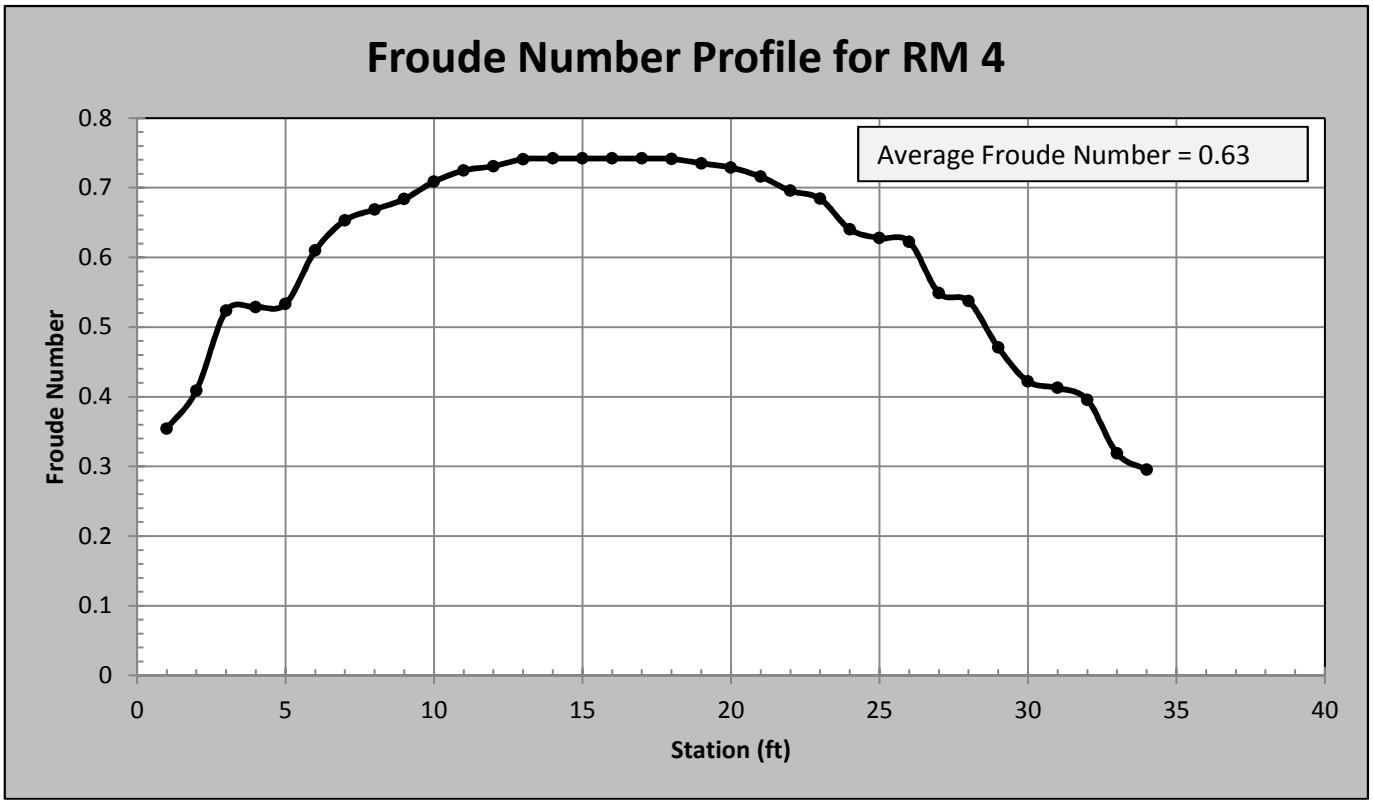
25-Year Event: 30,100cfs - River Mile 3.75



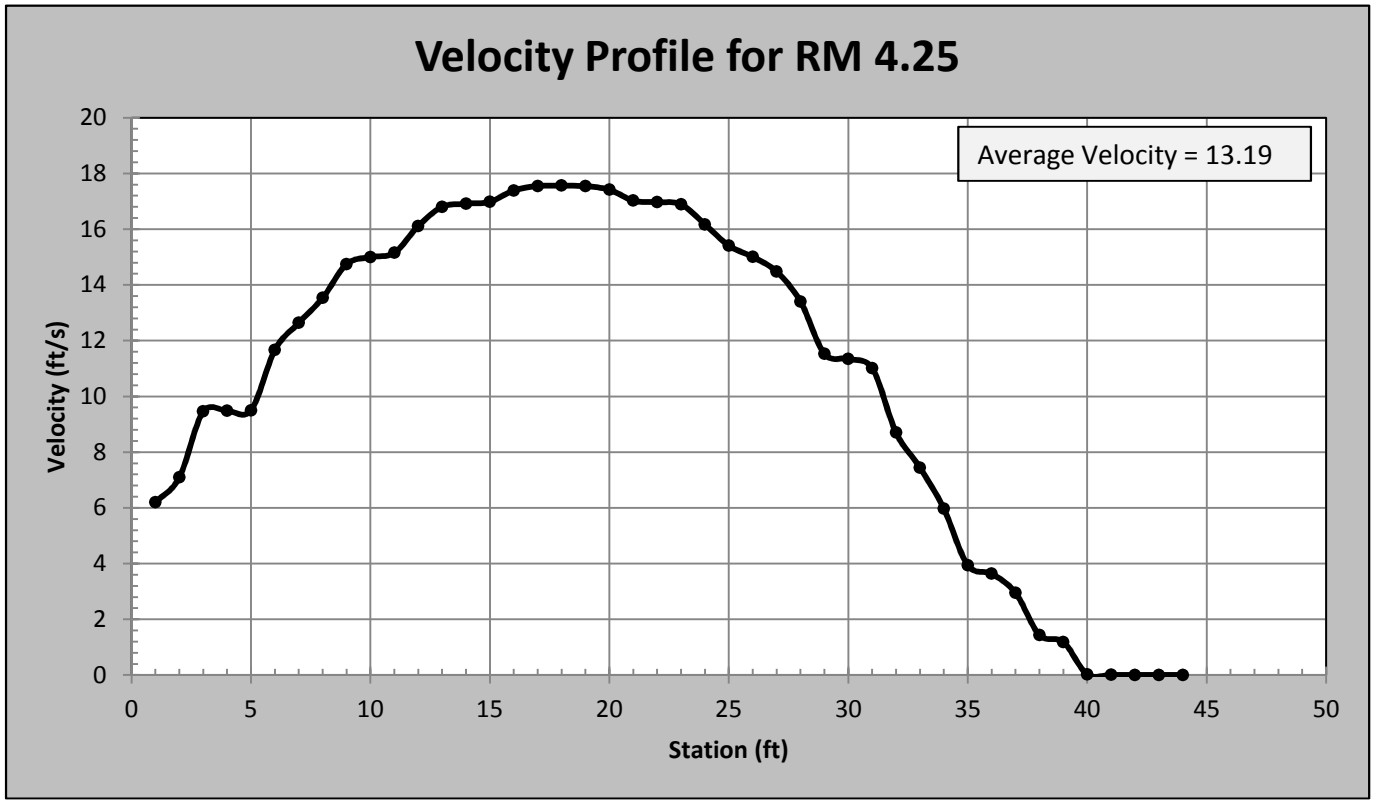


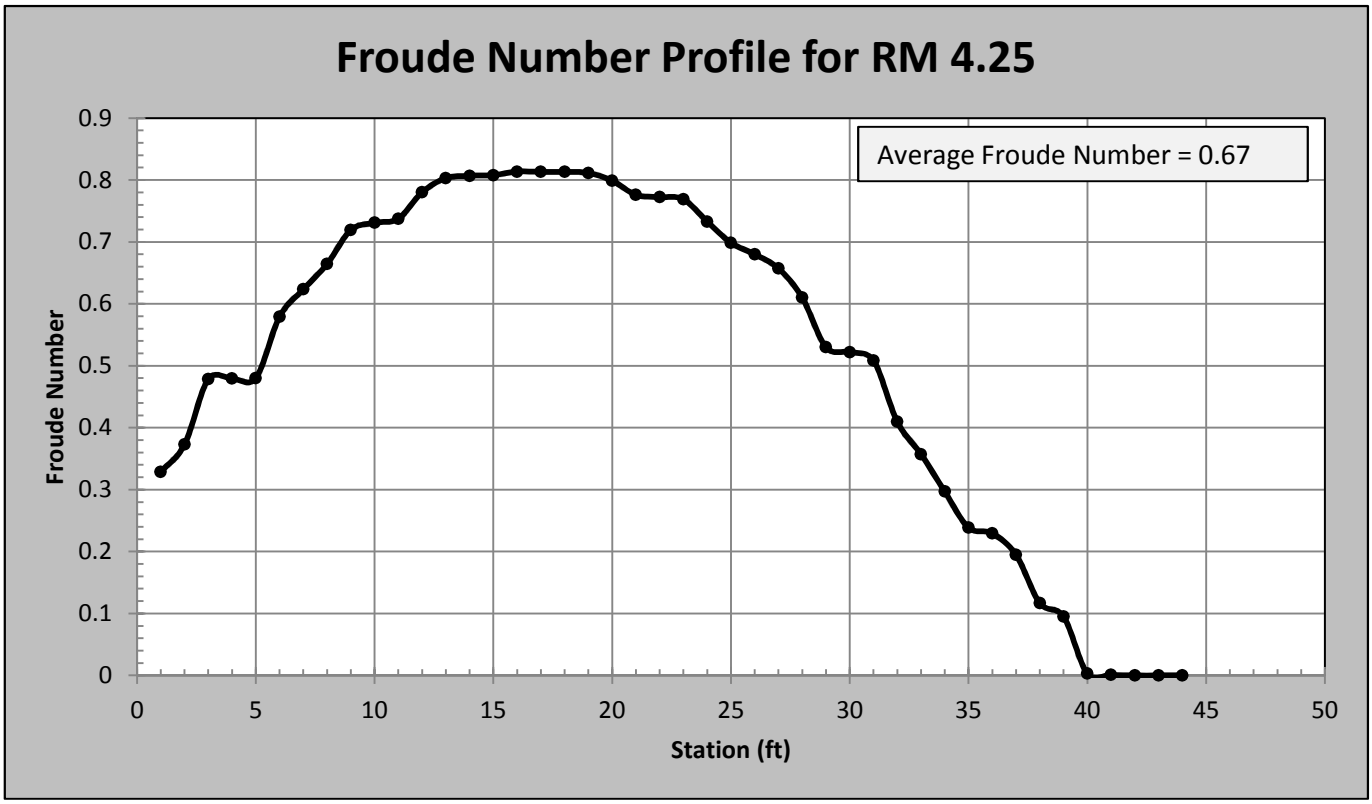
25-Year Event: 30,100cfs - River Mile 4



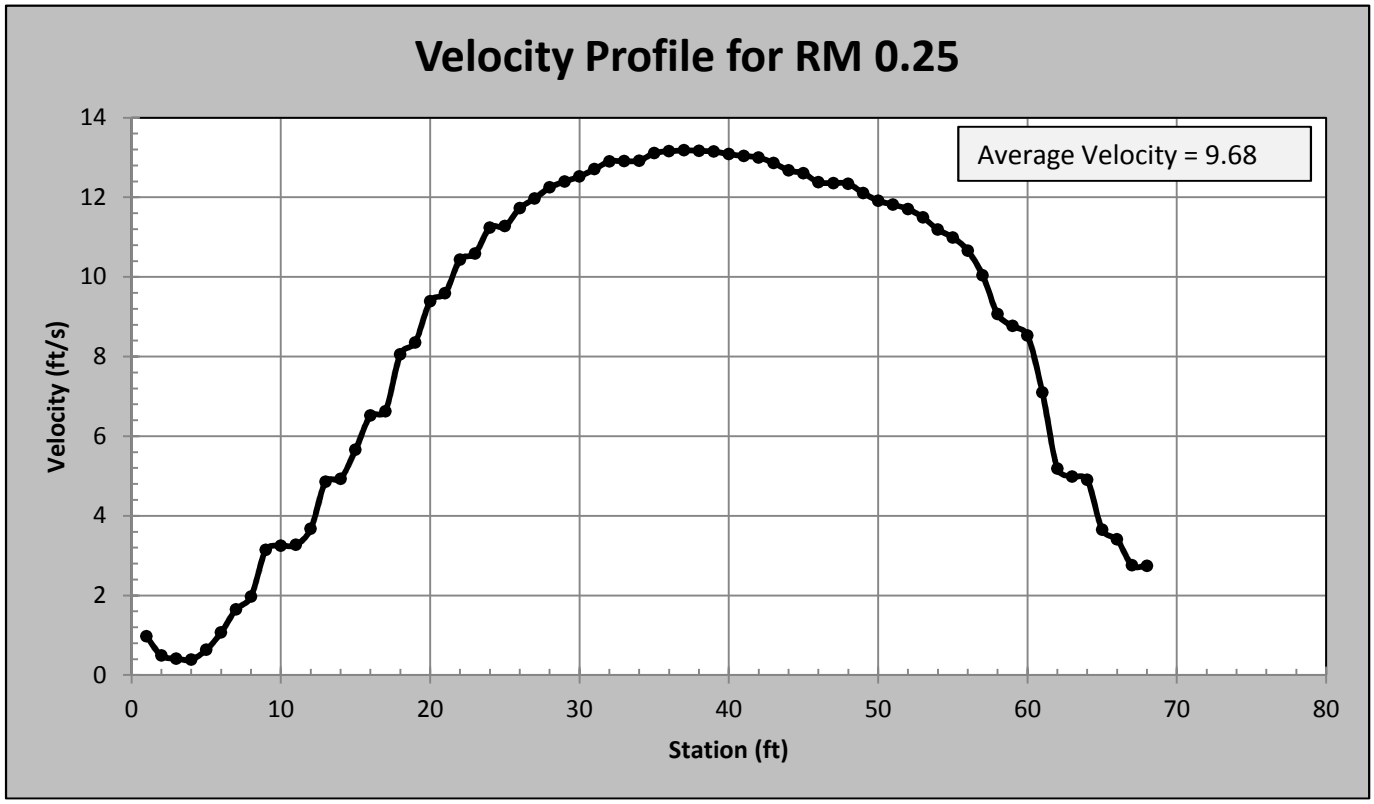


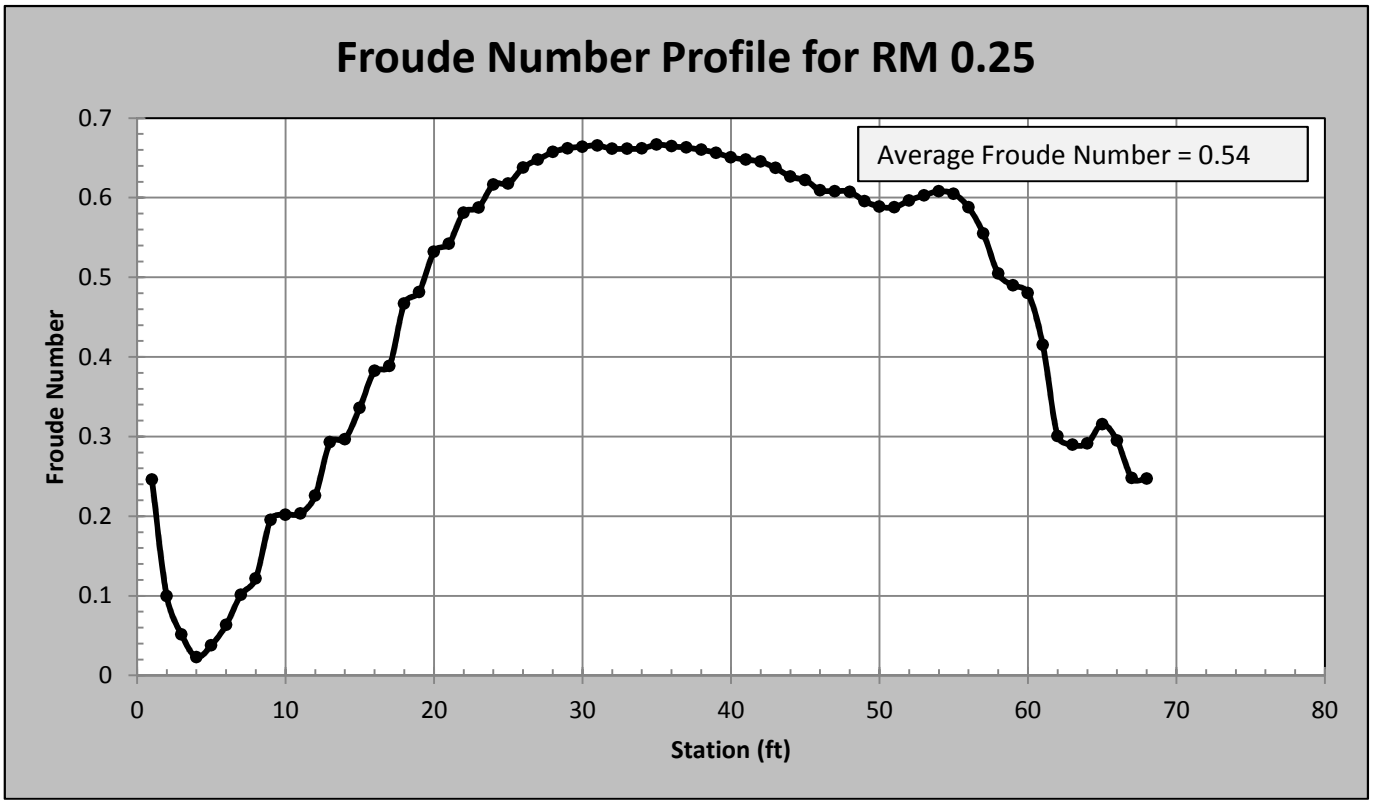
25-Year Event: 30,100cfs - River Mile 4.25



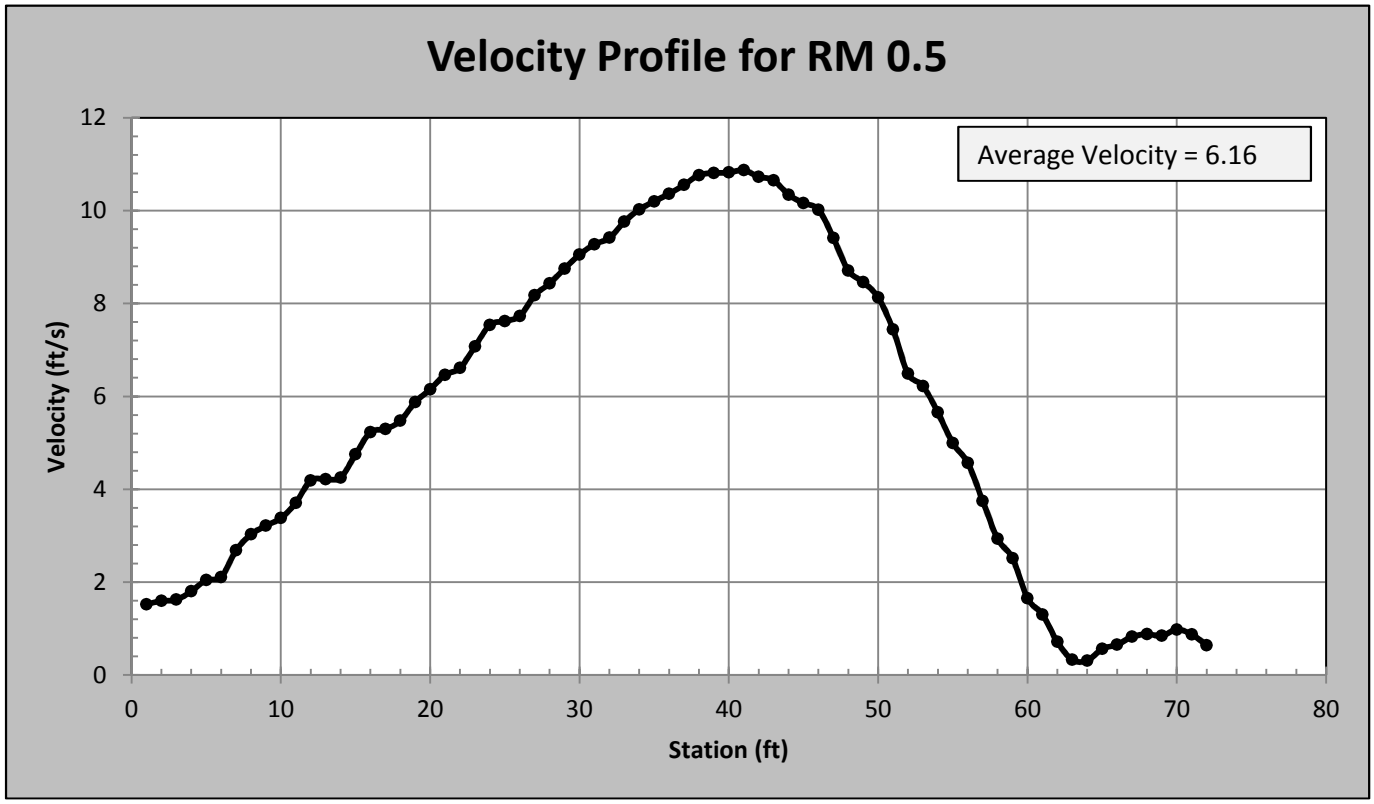


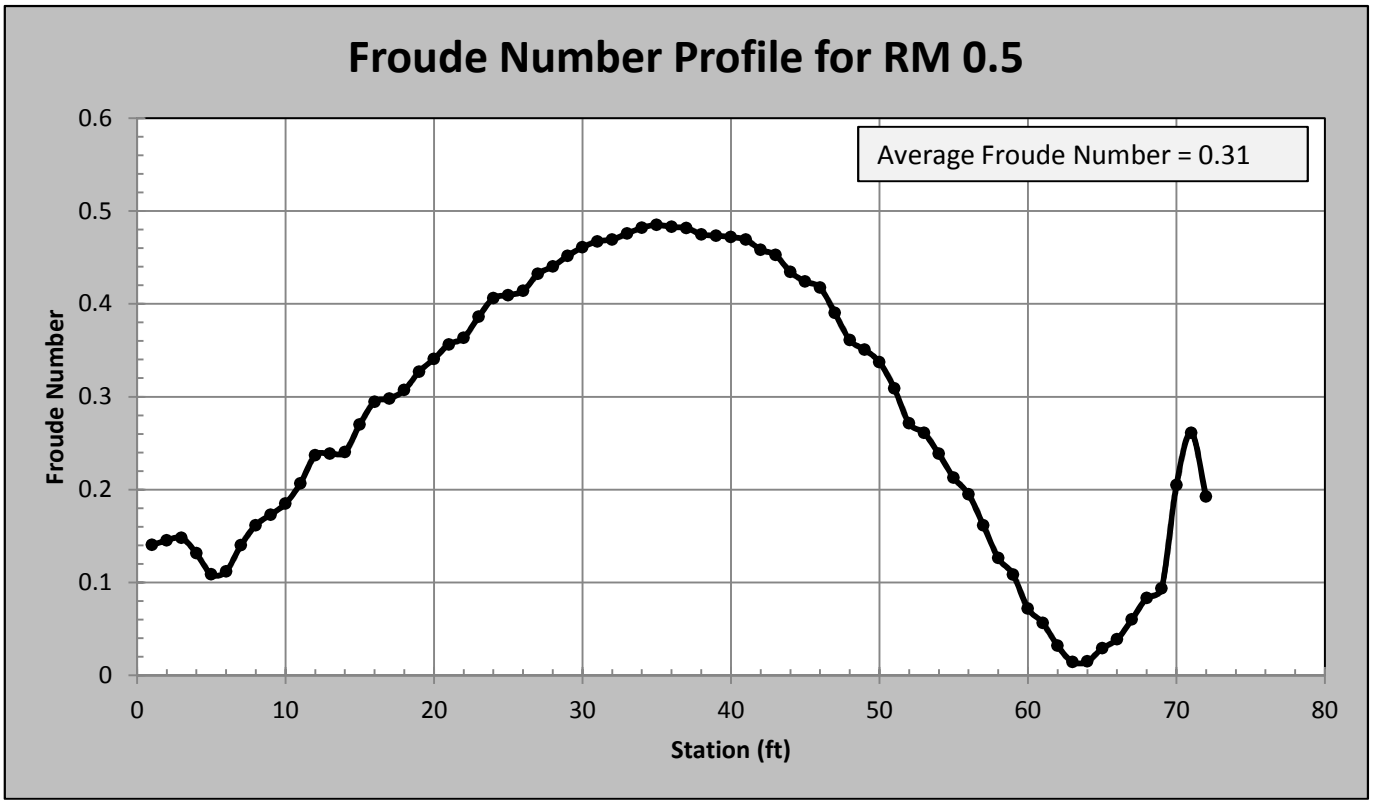
50-Year Event: 32,800cfs - River Mile 0.25



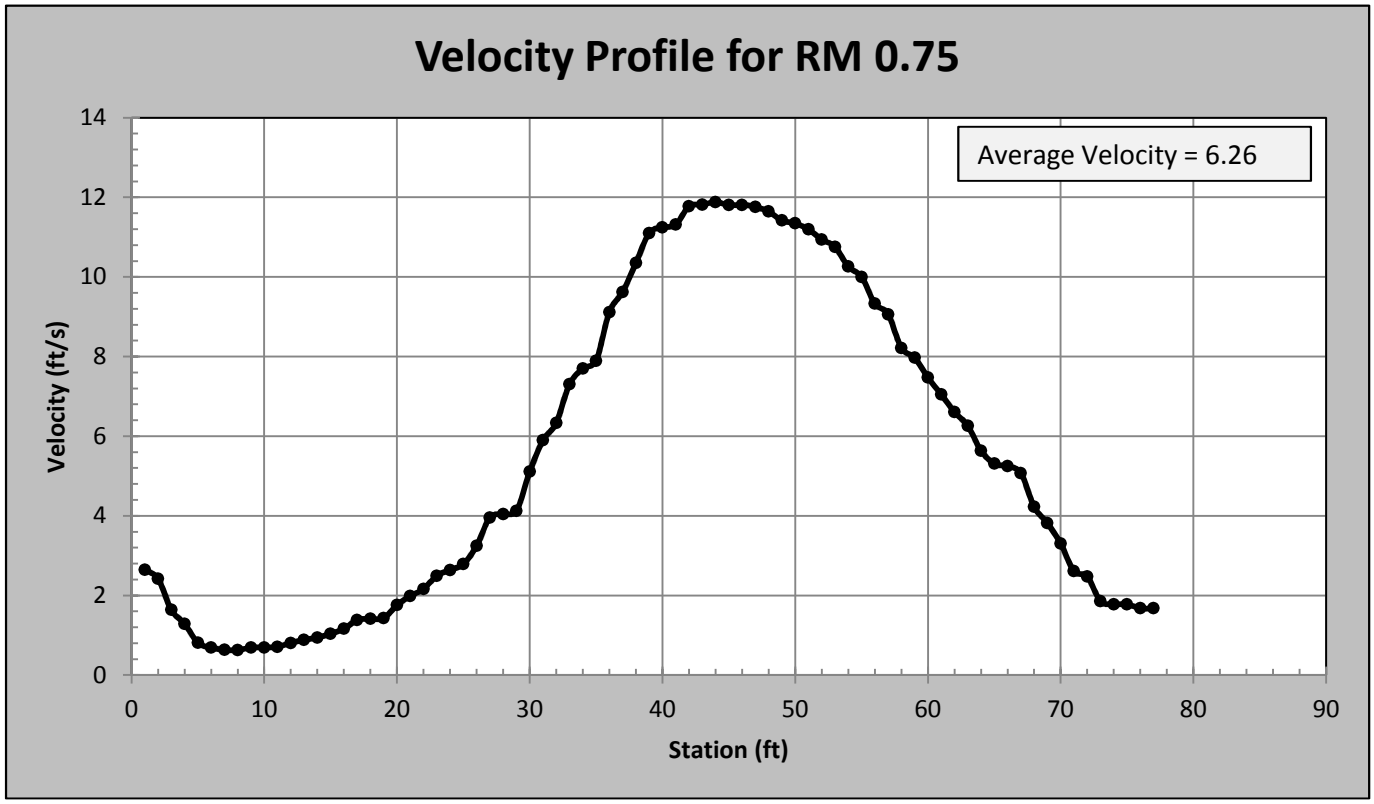


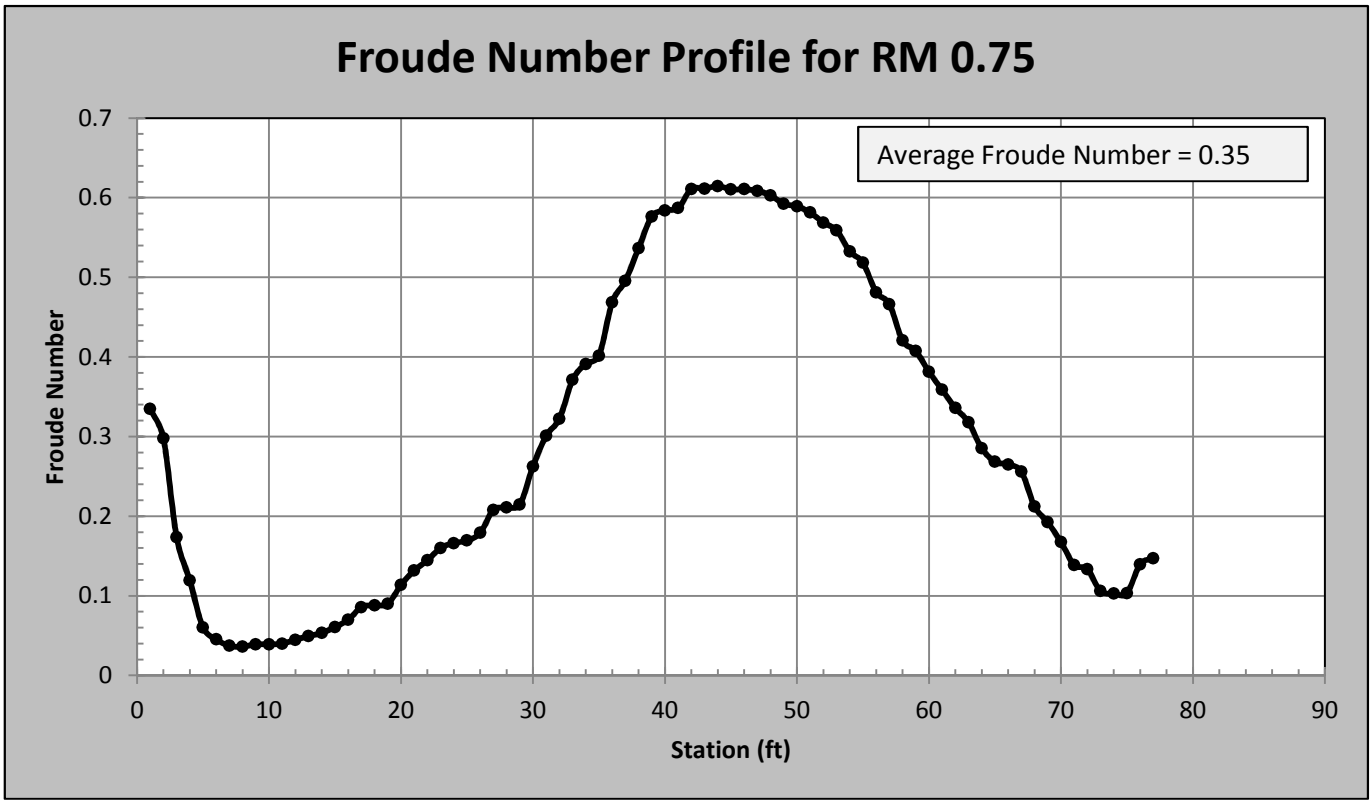
50-Year Event: 32,800cfs - River Mile 0.5



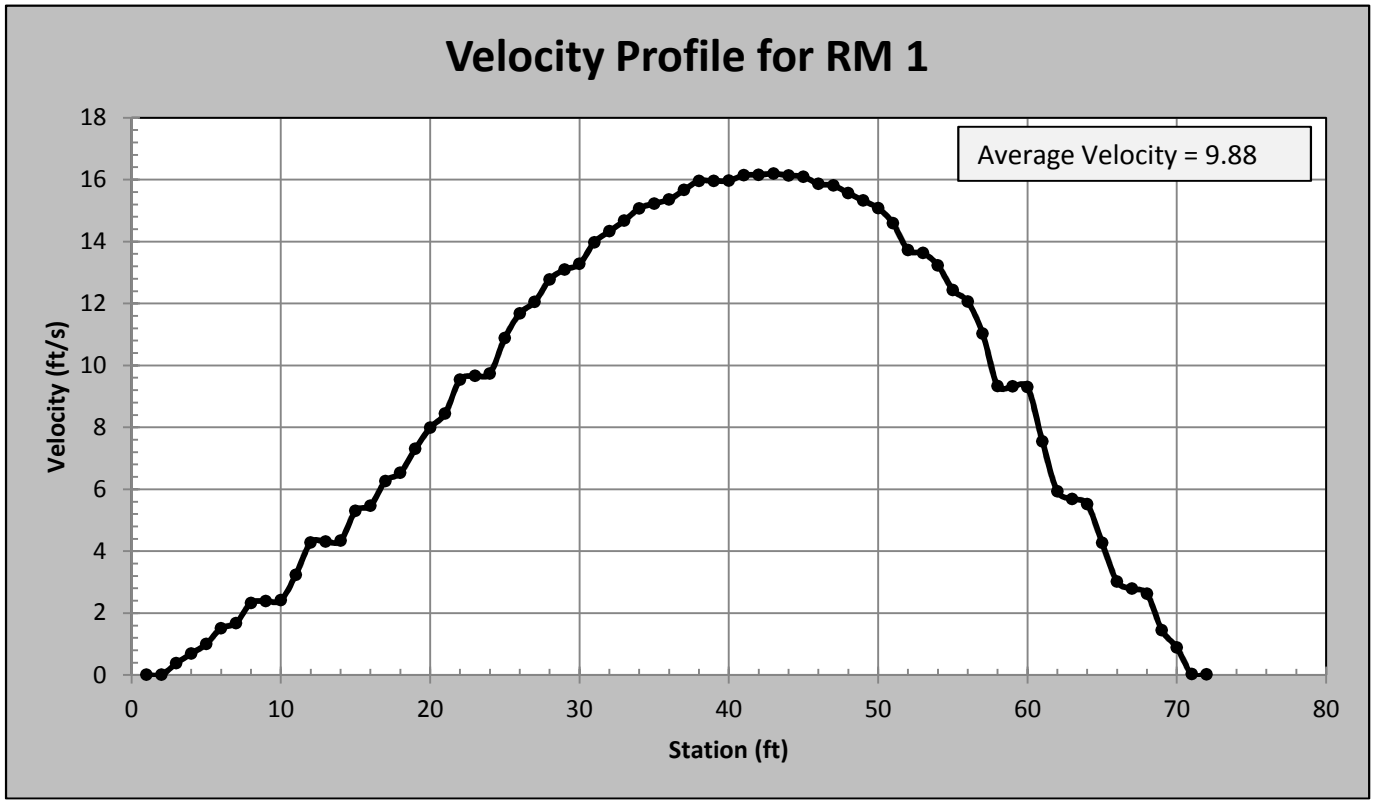


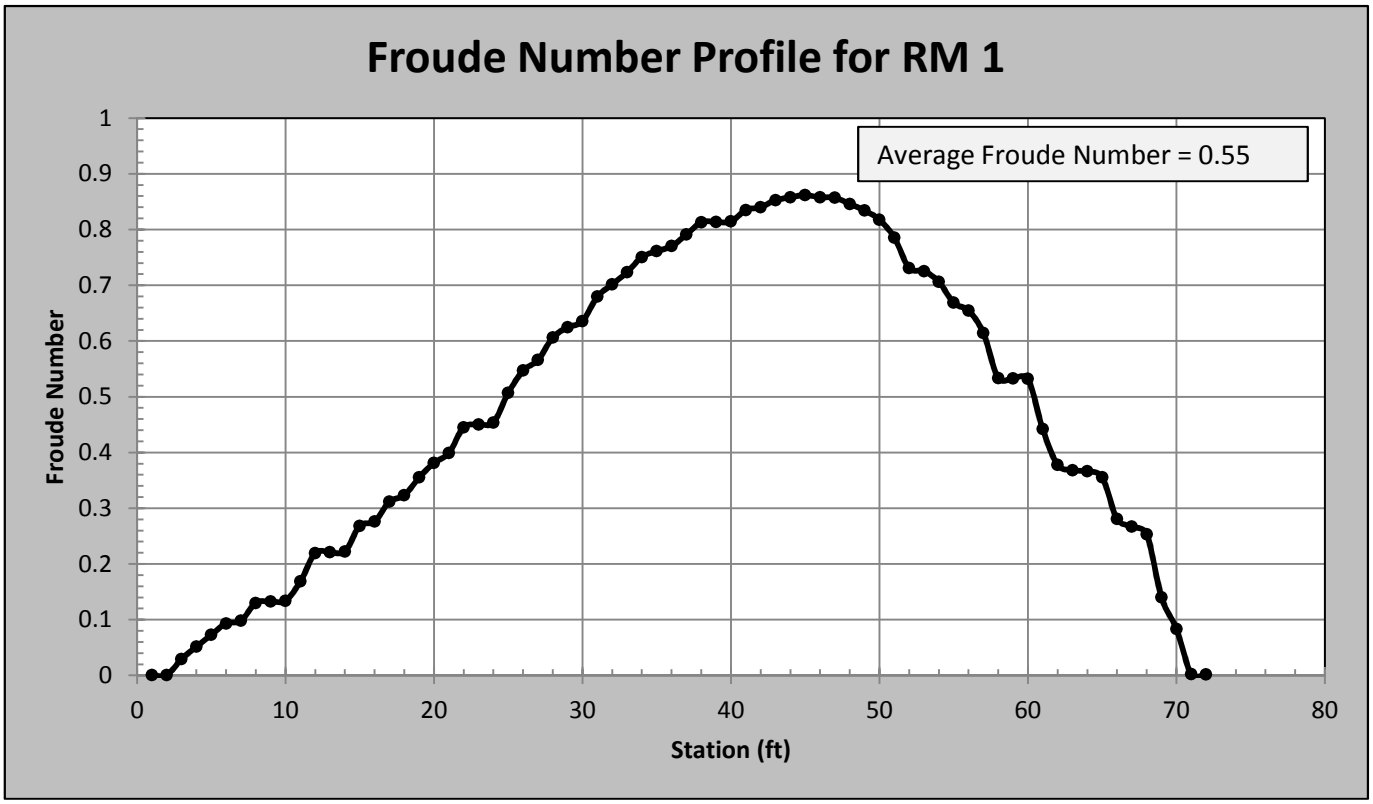
50-Year Event: 32,800cfs - River Mile 0.75



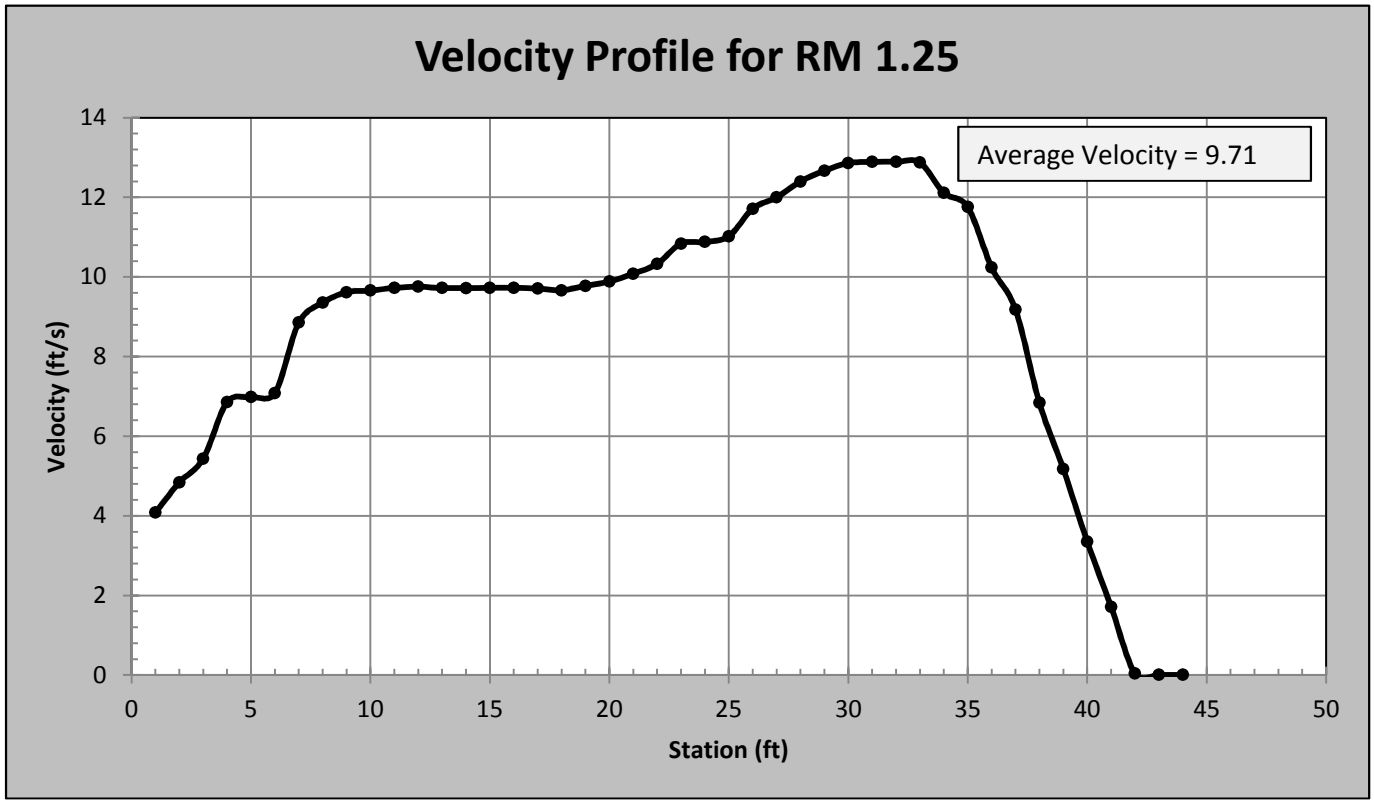


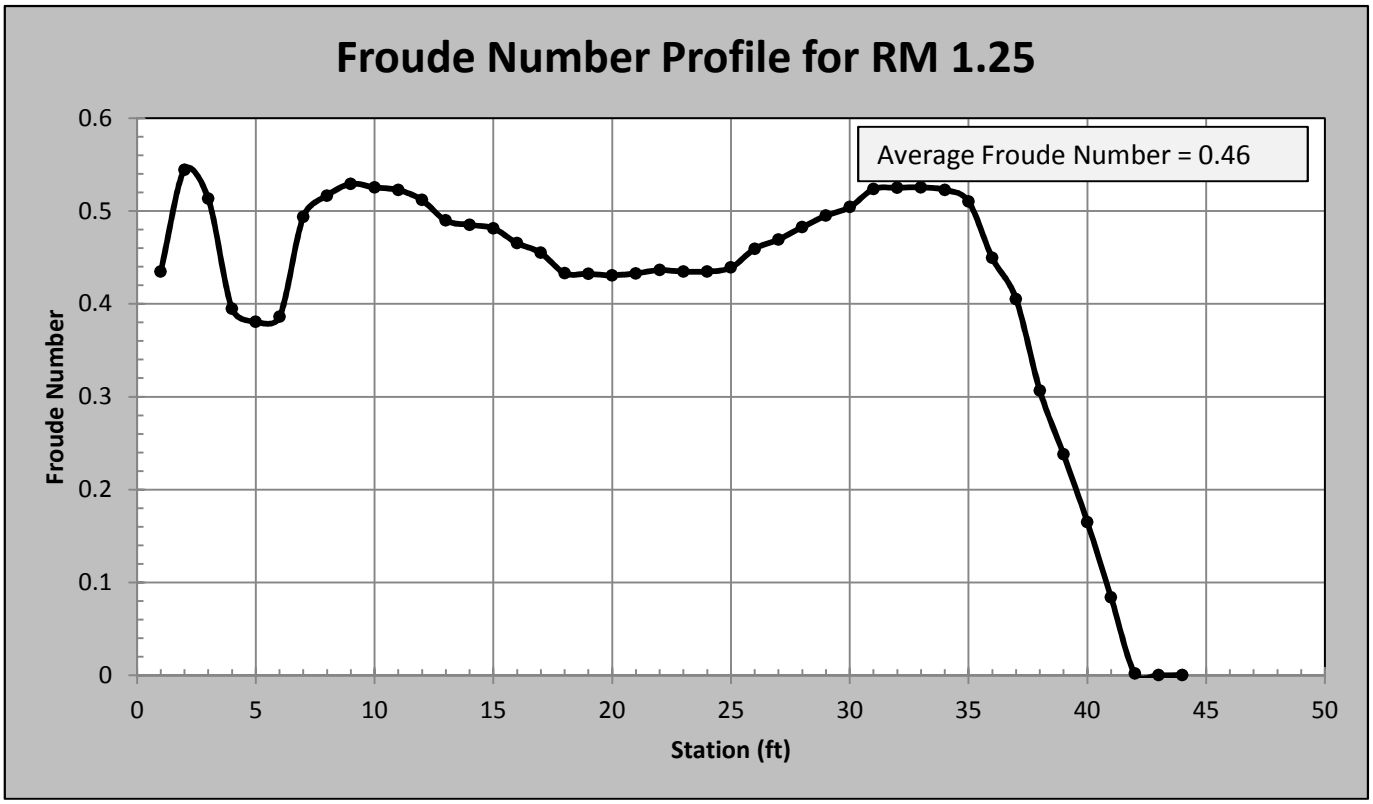
50-Year Event: 32,800cfs - River Mile 1



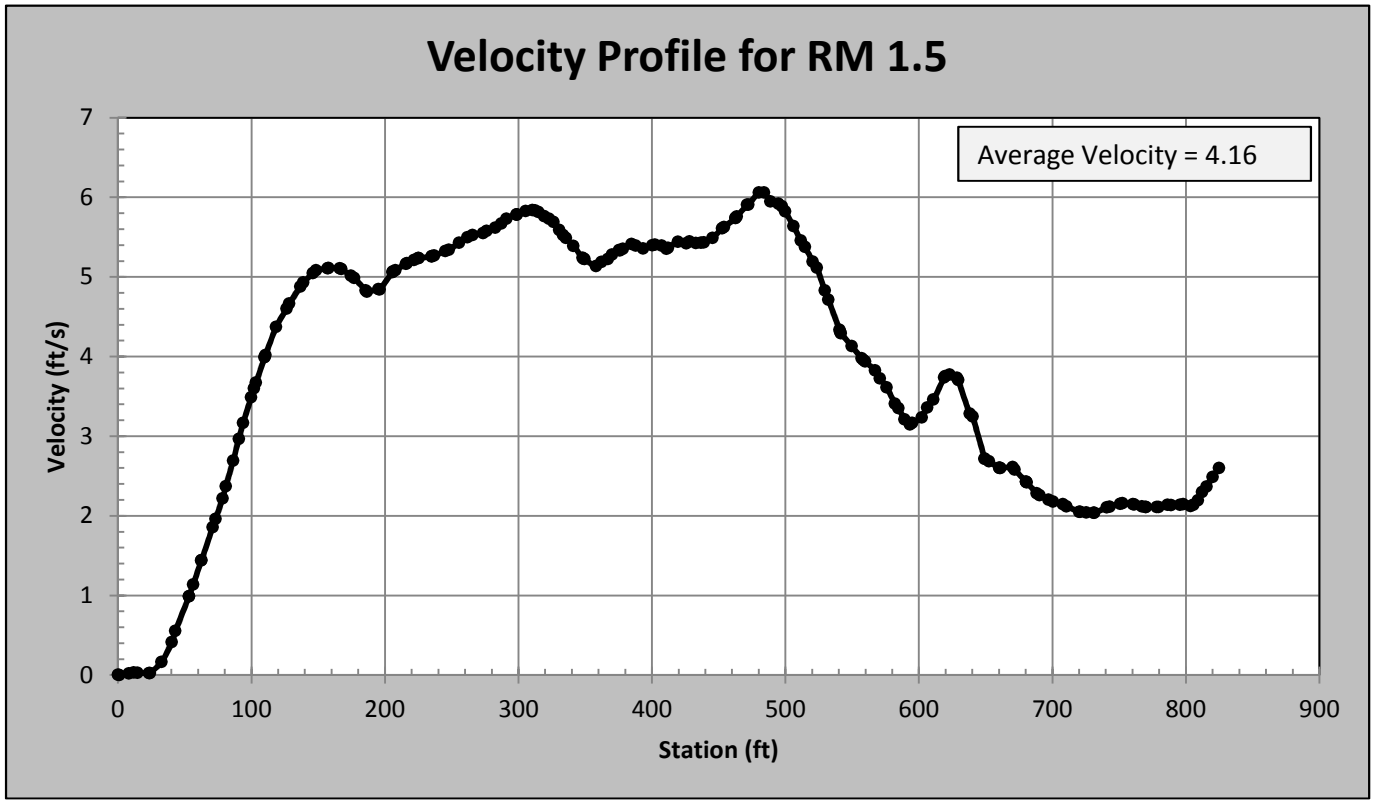


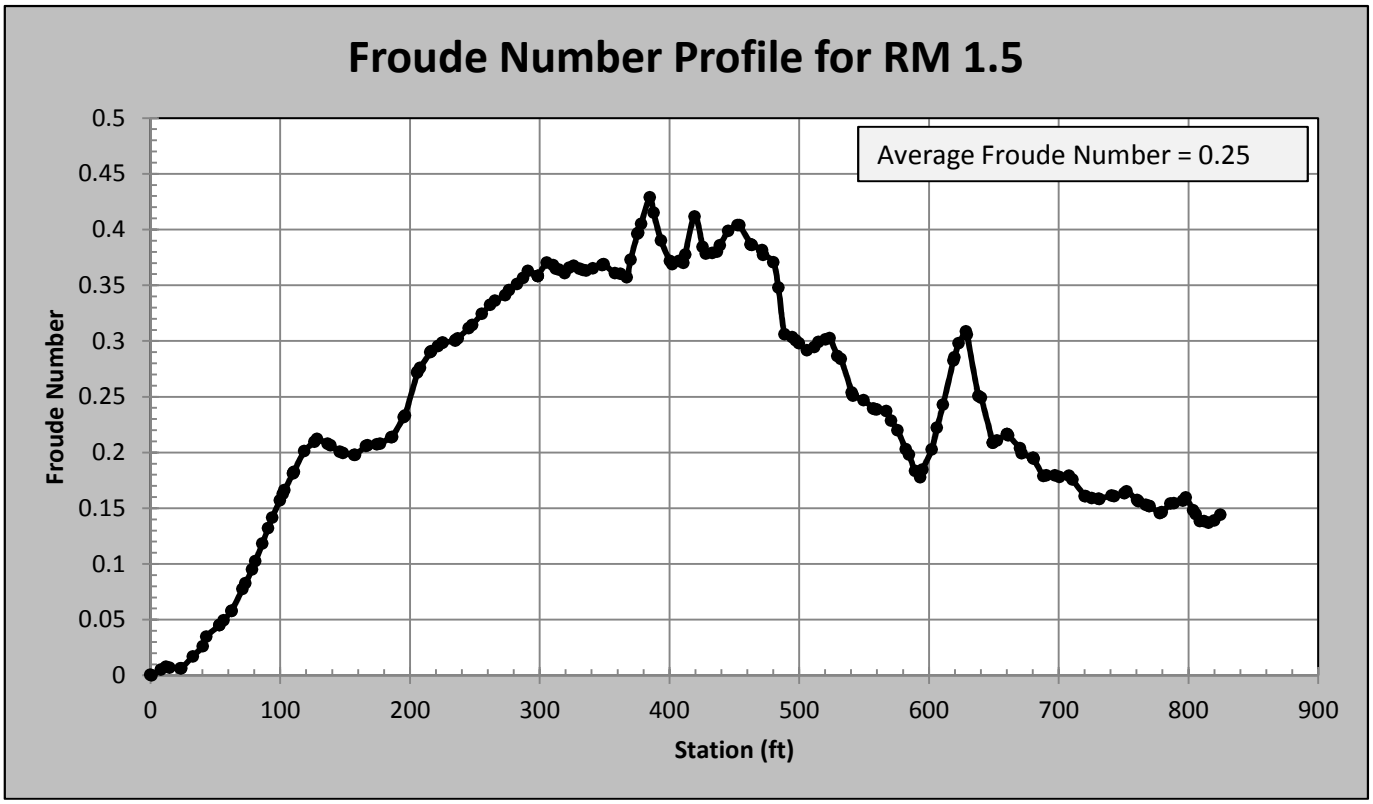
50-Year Event: 32,800cfs - River Mile 1.25



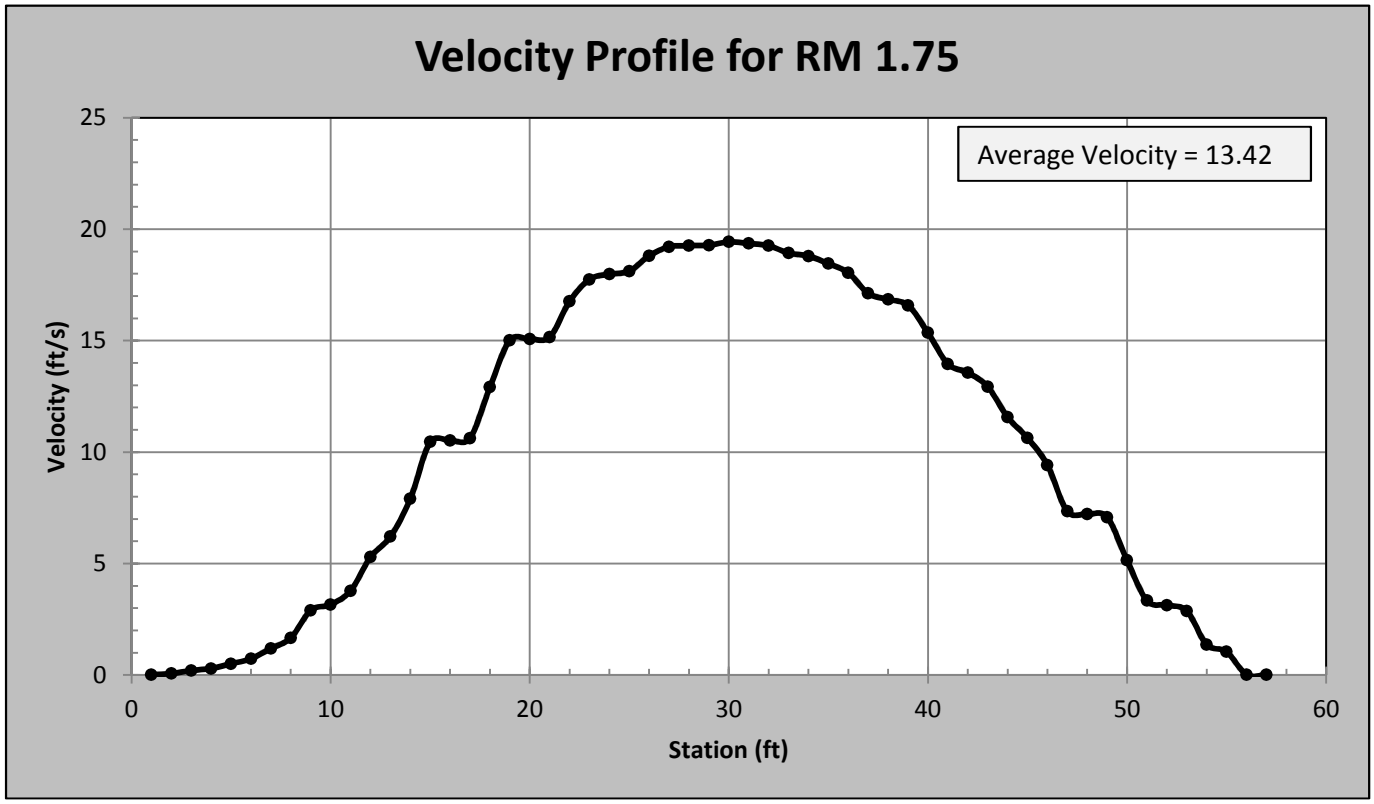


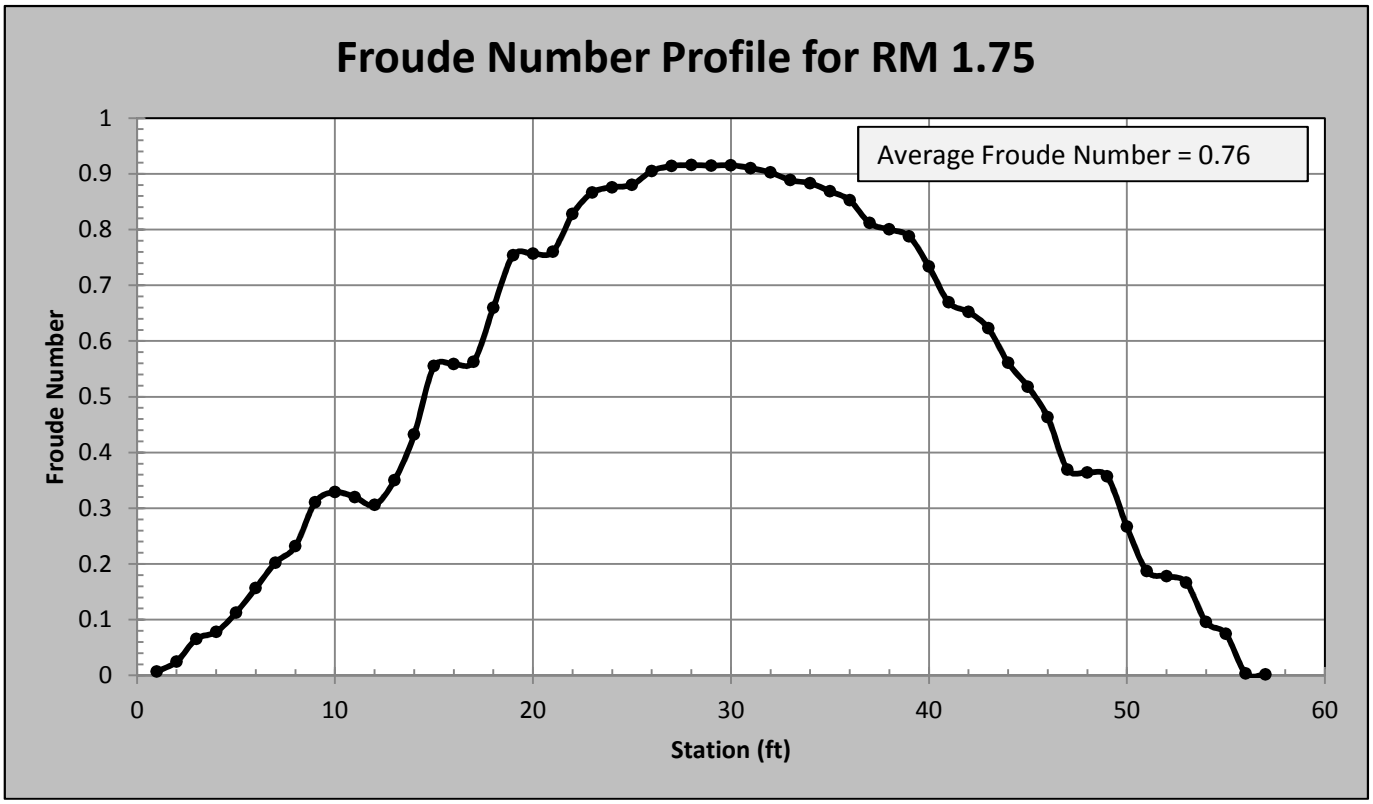
50-Year Event: 32,800cfs - River Mile 1.5



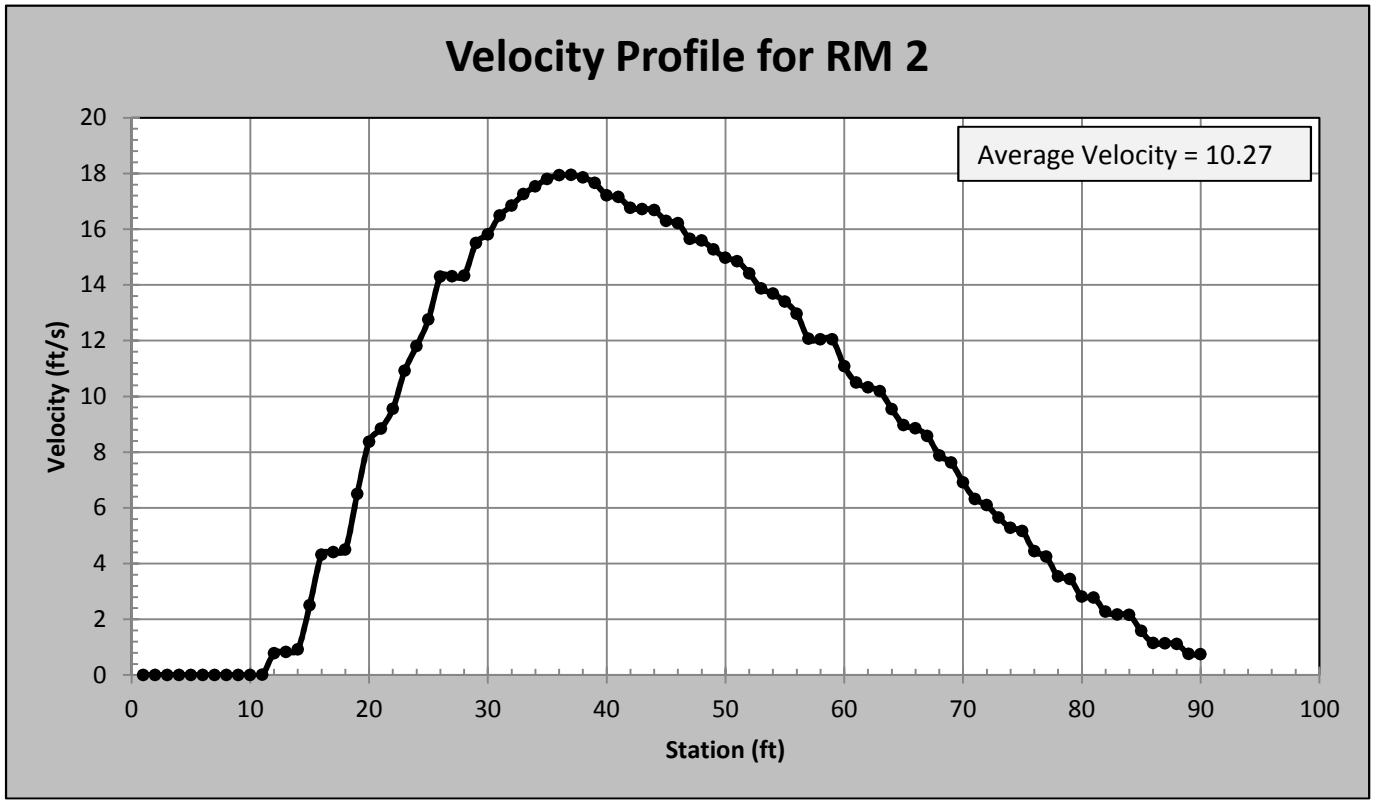


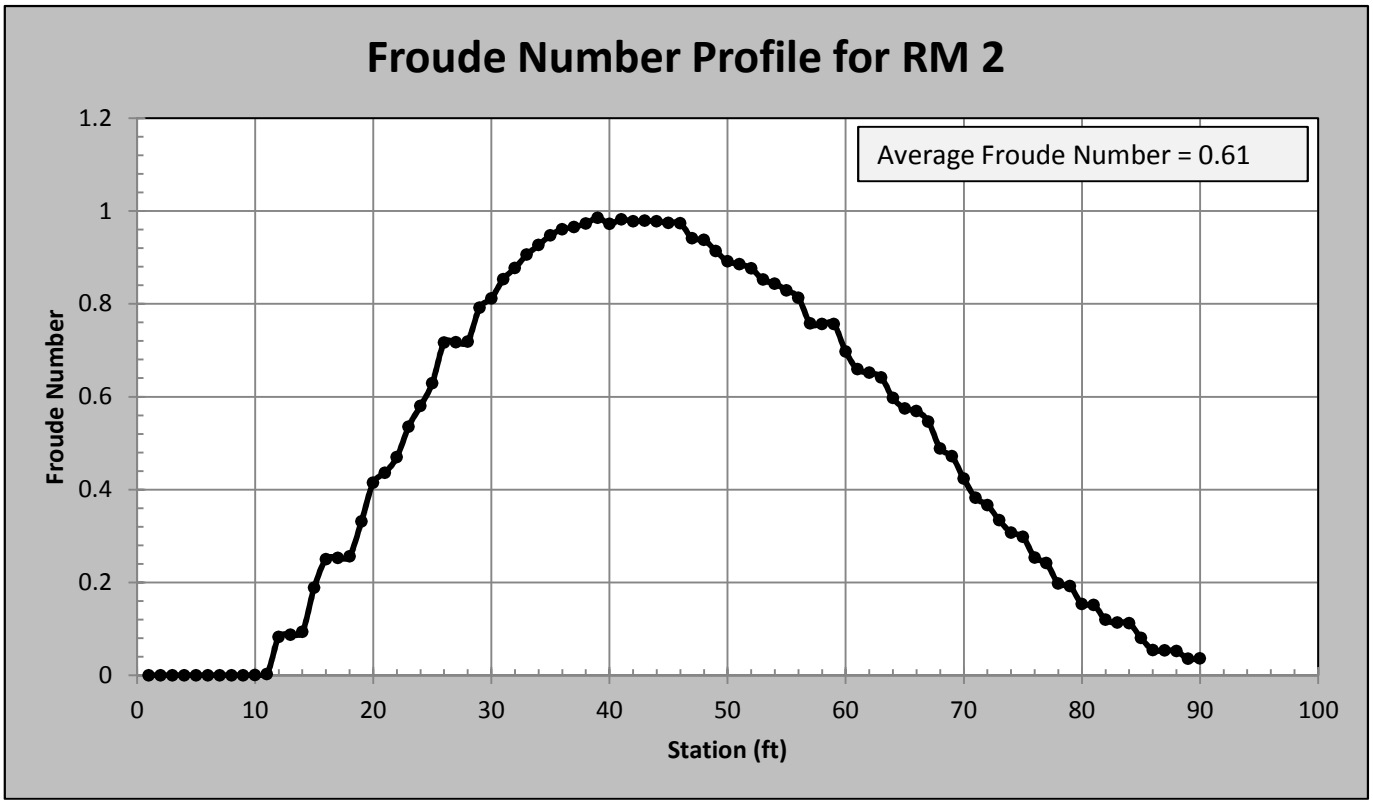
50-Year Event: 32,800cfs - River Mile 1.75



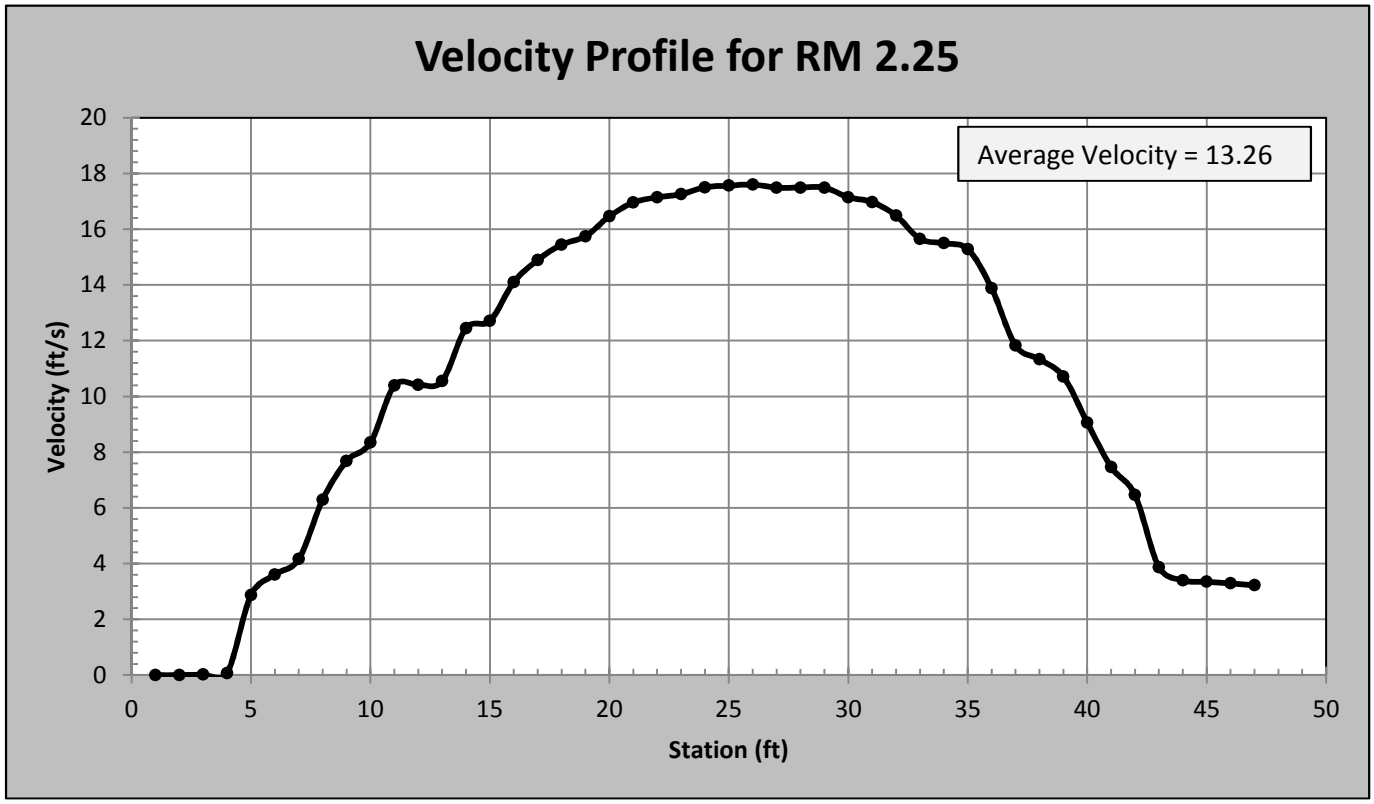


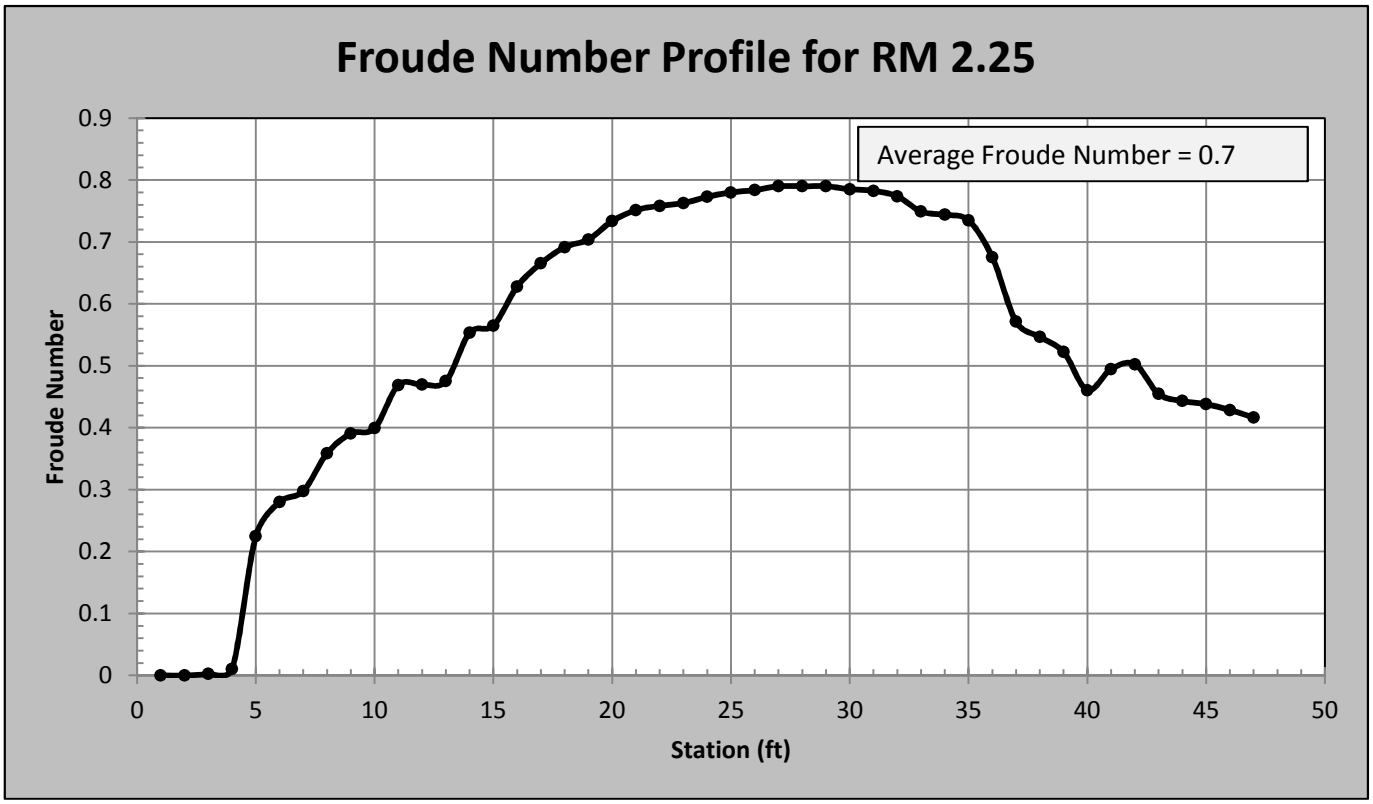
50-Year Event: 32,800cfs - River Mile 2



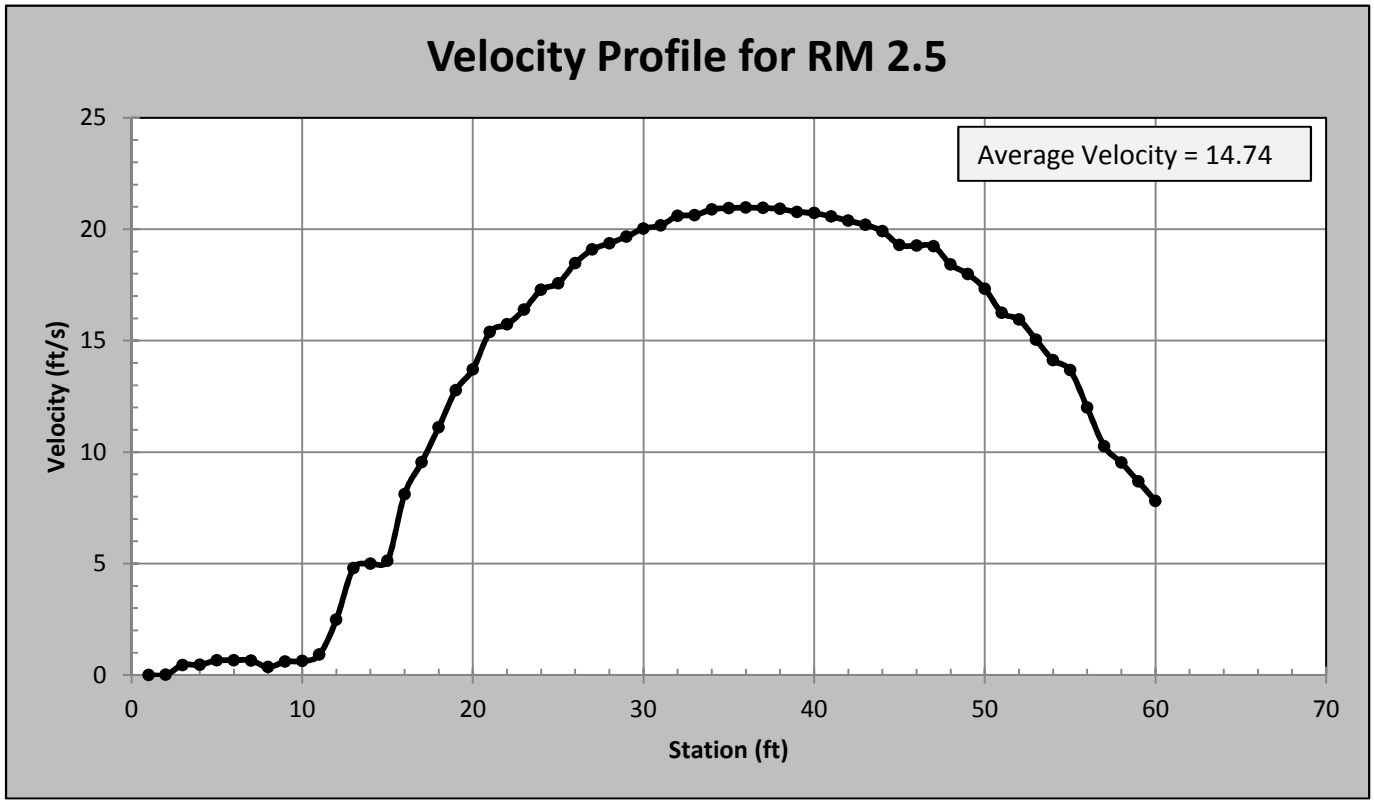


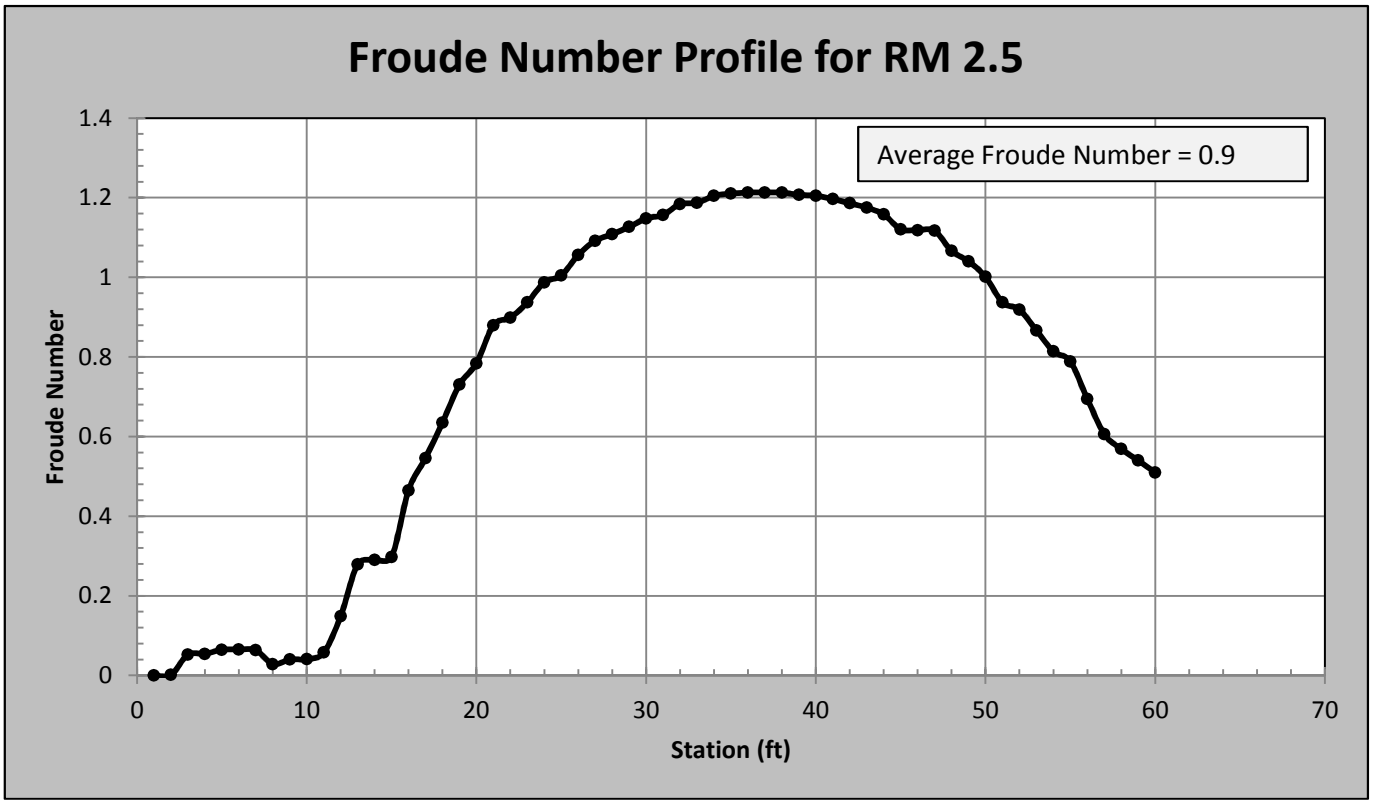
50-Year Event: 32,800cfs - River Mile 2.25



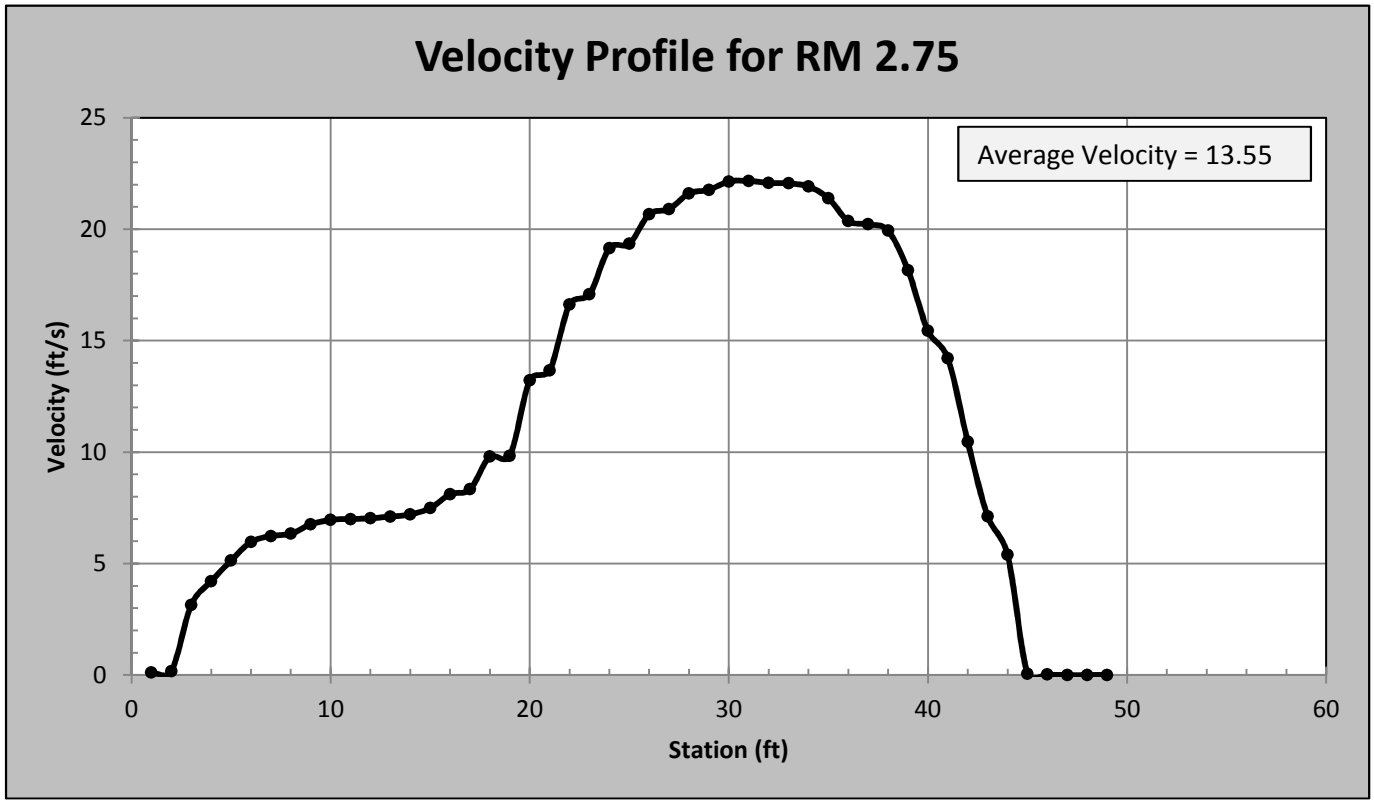


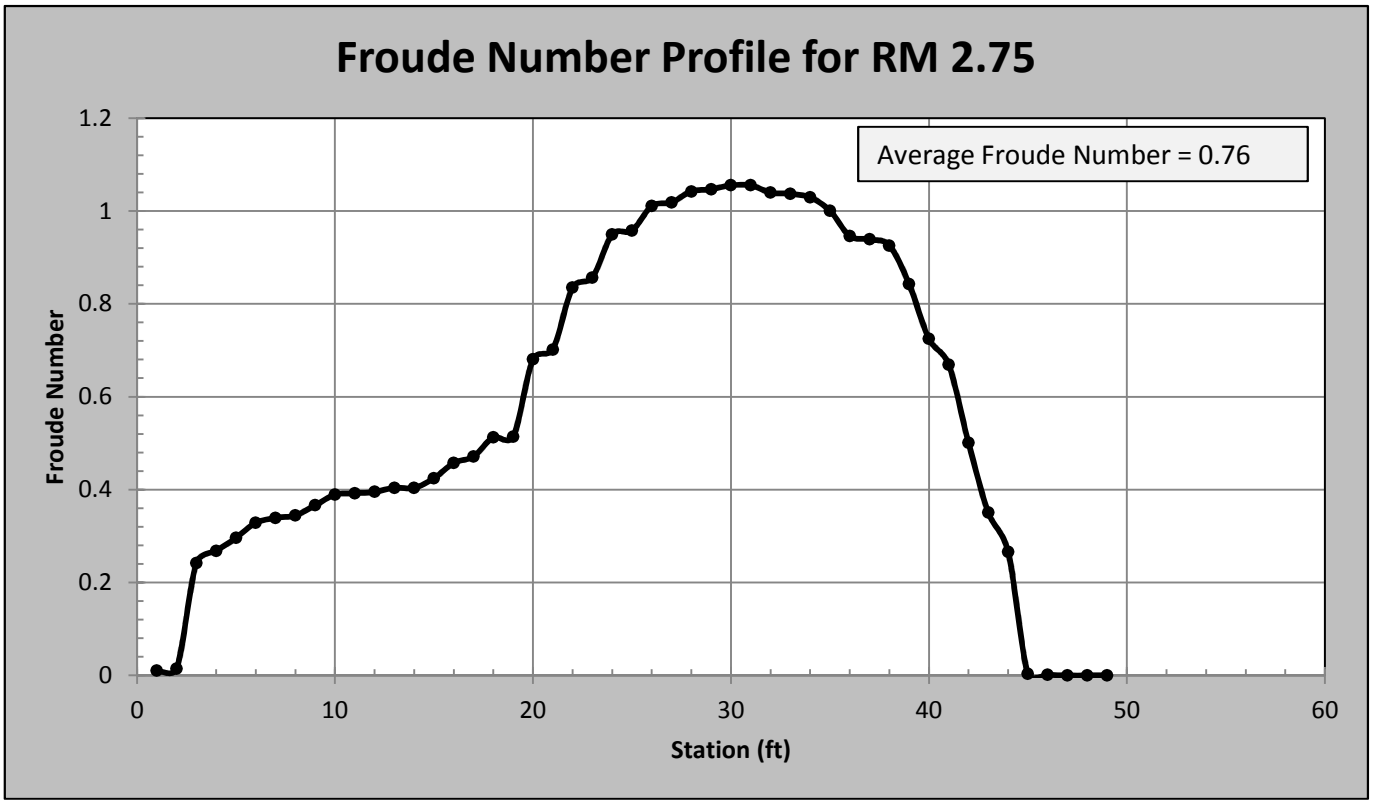
50-Year Event: 32,800cfs - River Mile 2.5



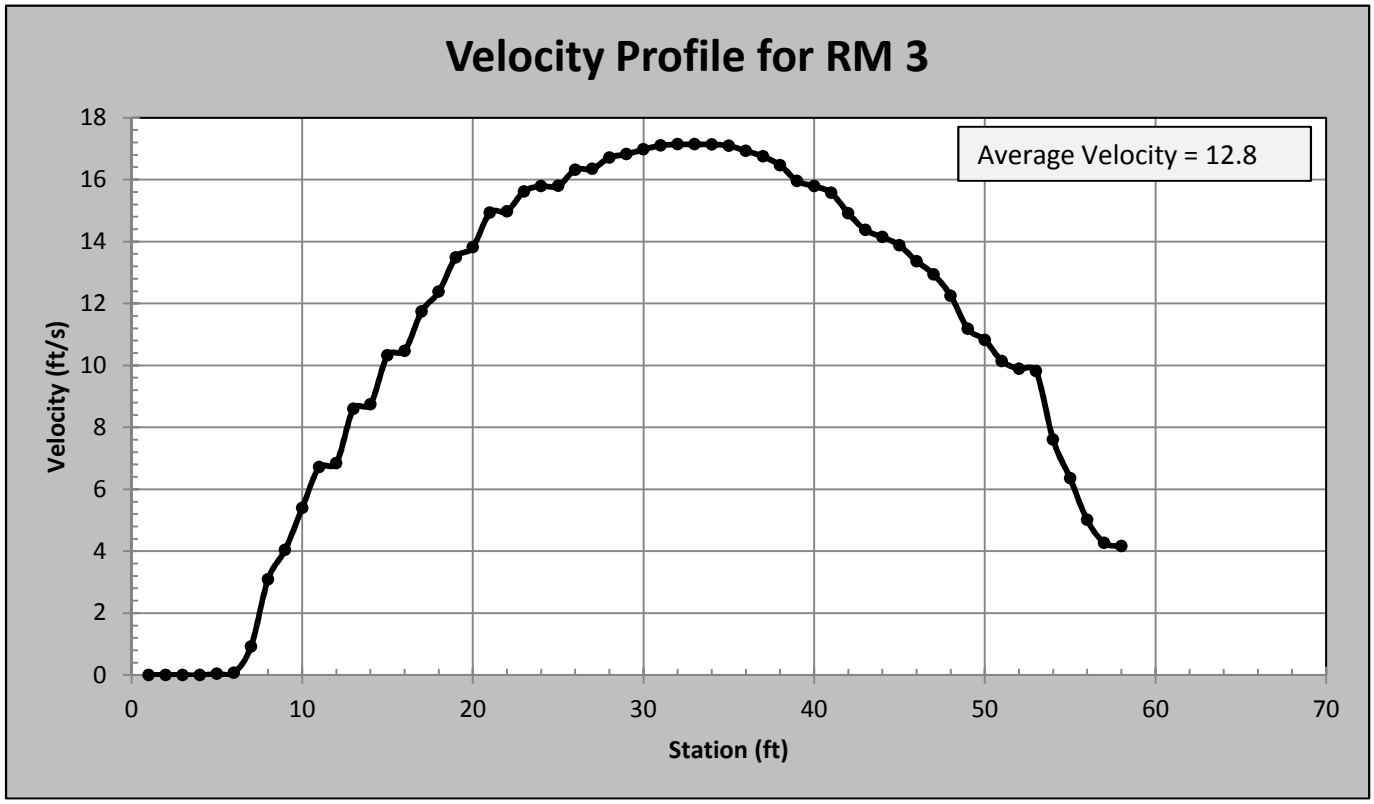


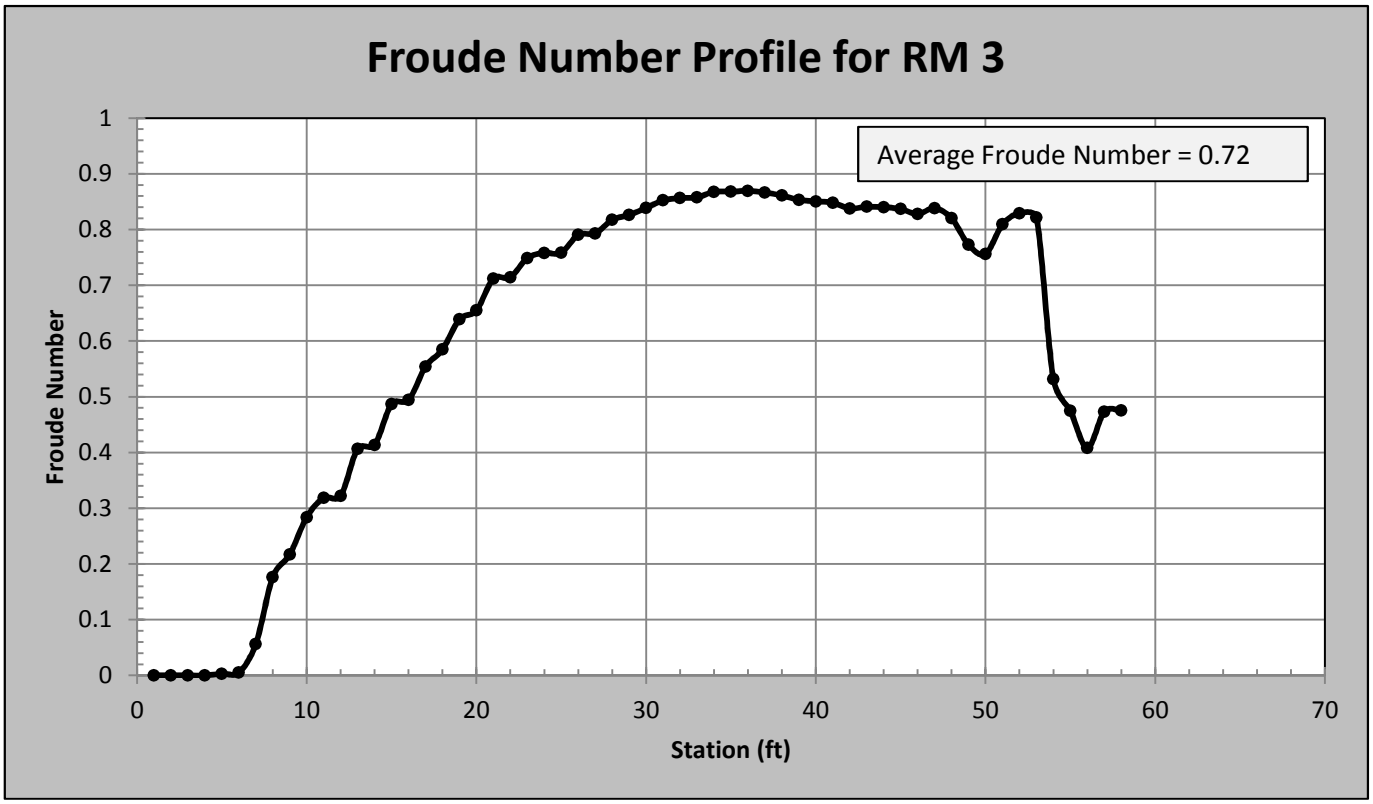
50-Year Event: 32,800cfs - River Mile 2.75



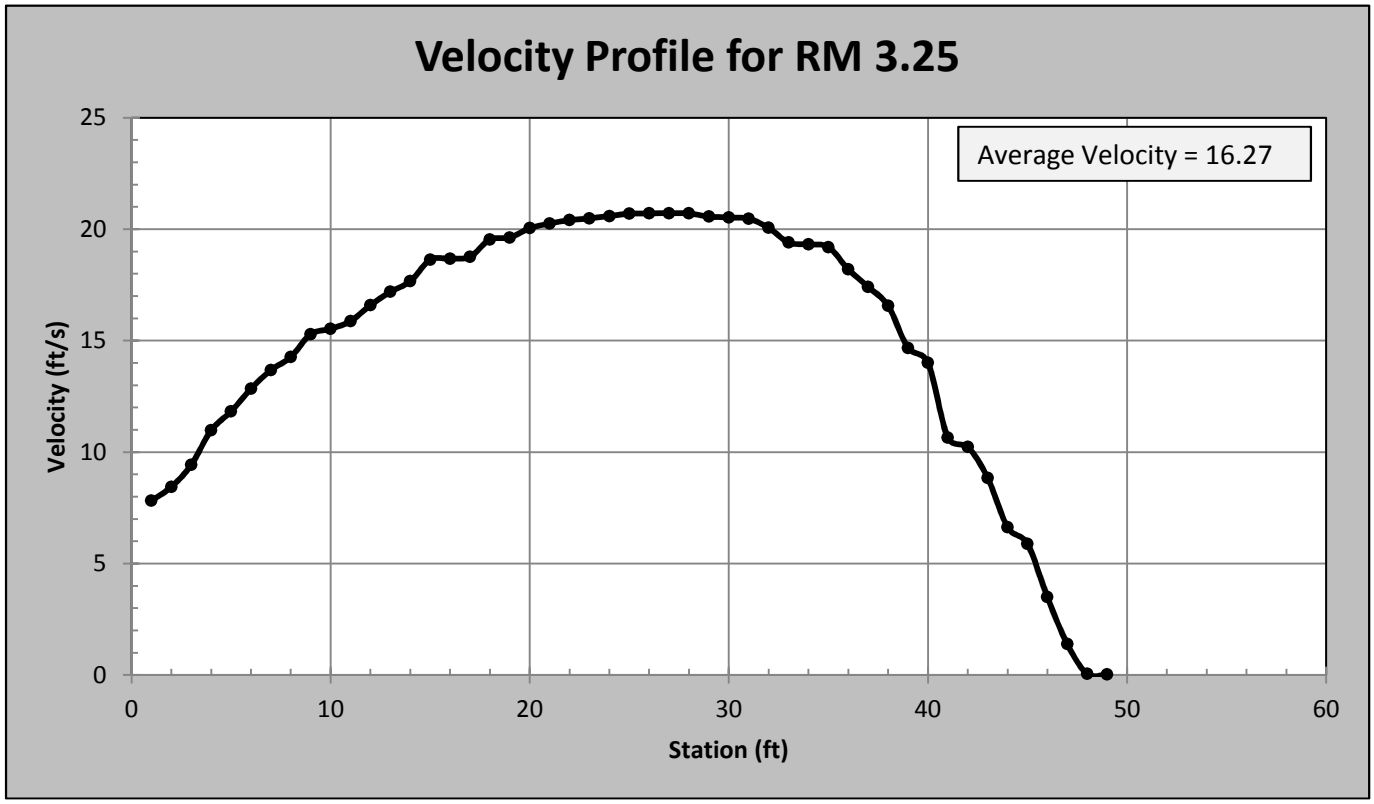


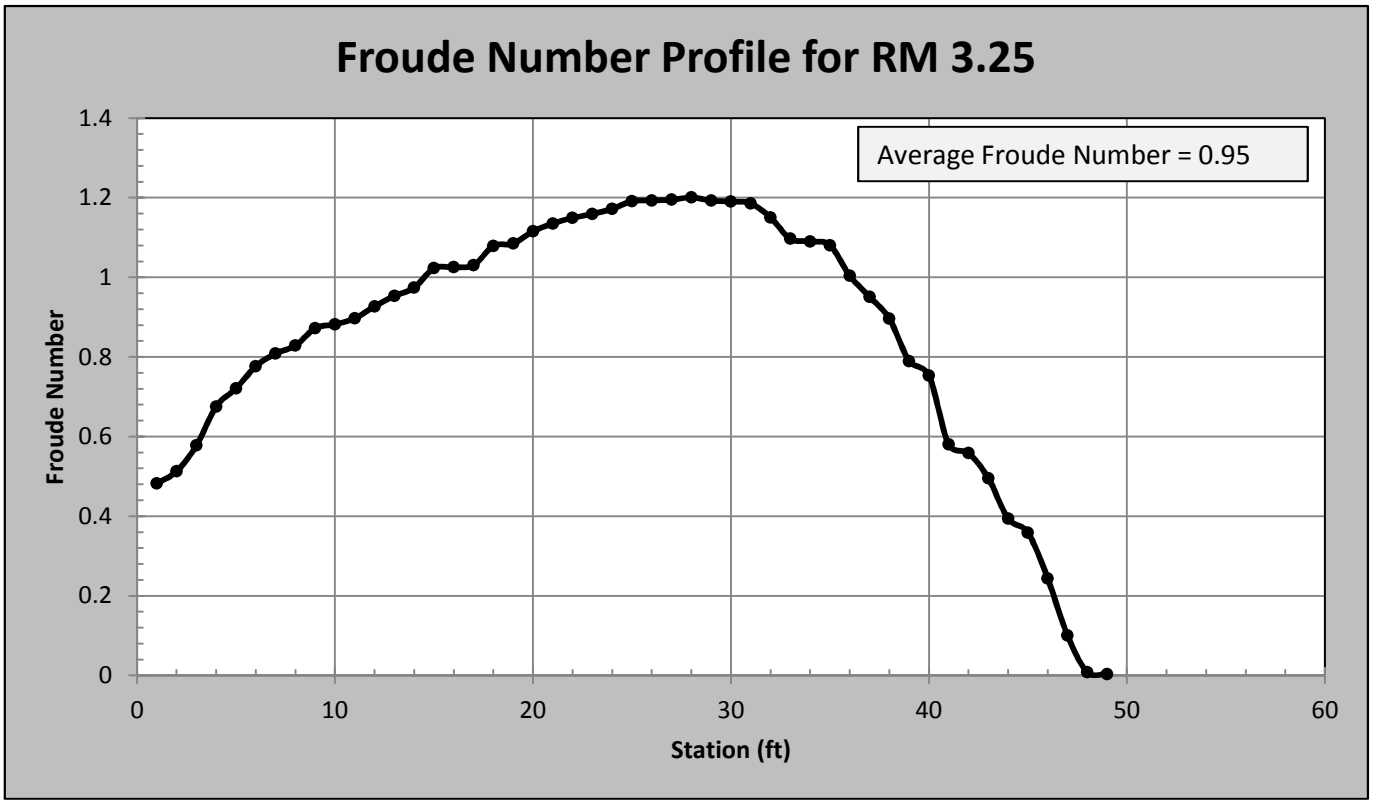
50-Year Event: 32,800cfs - River Mile 3



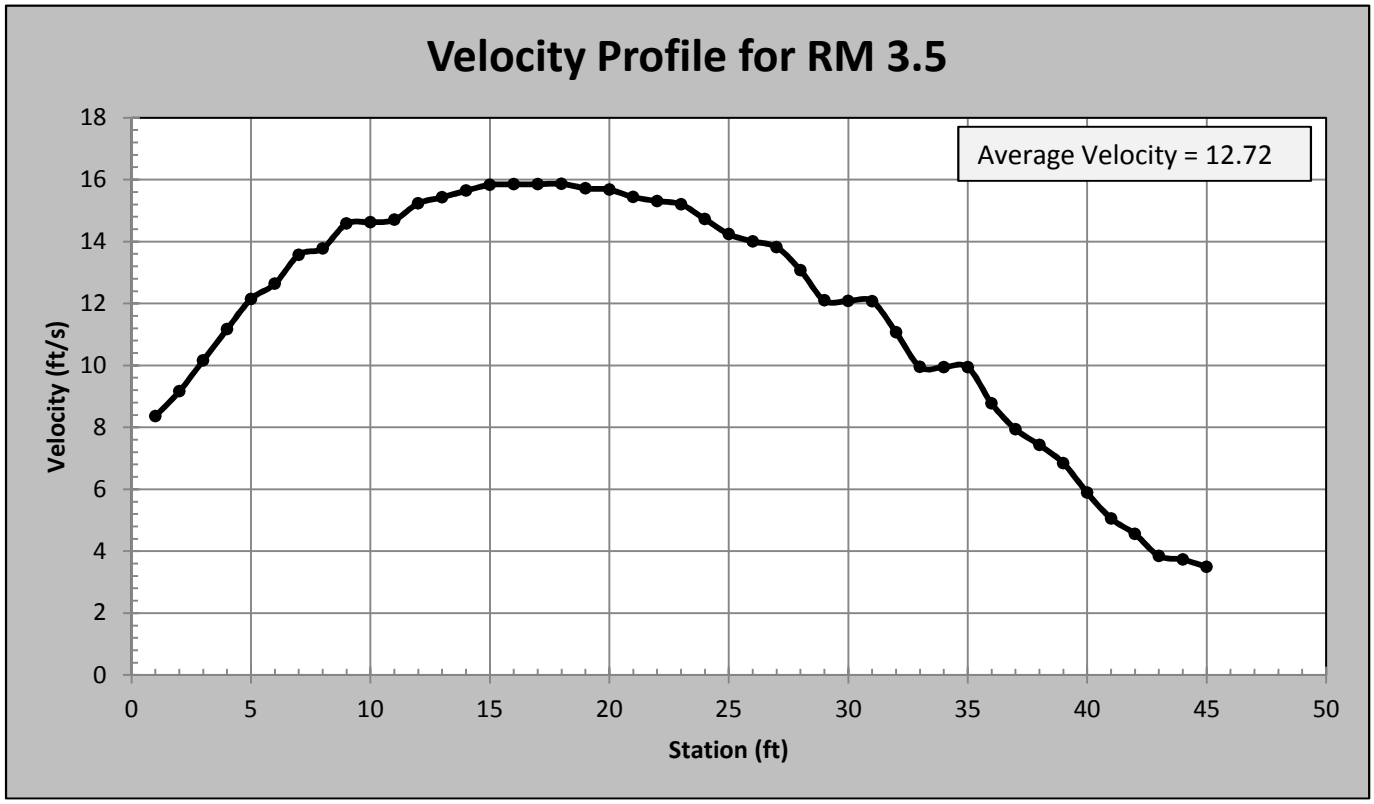


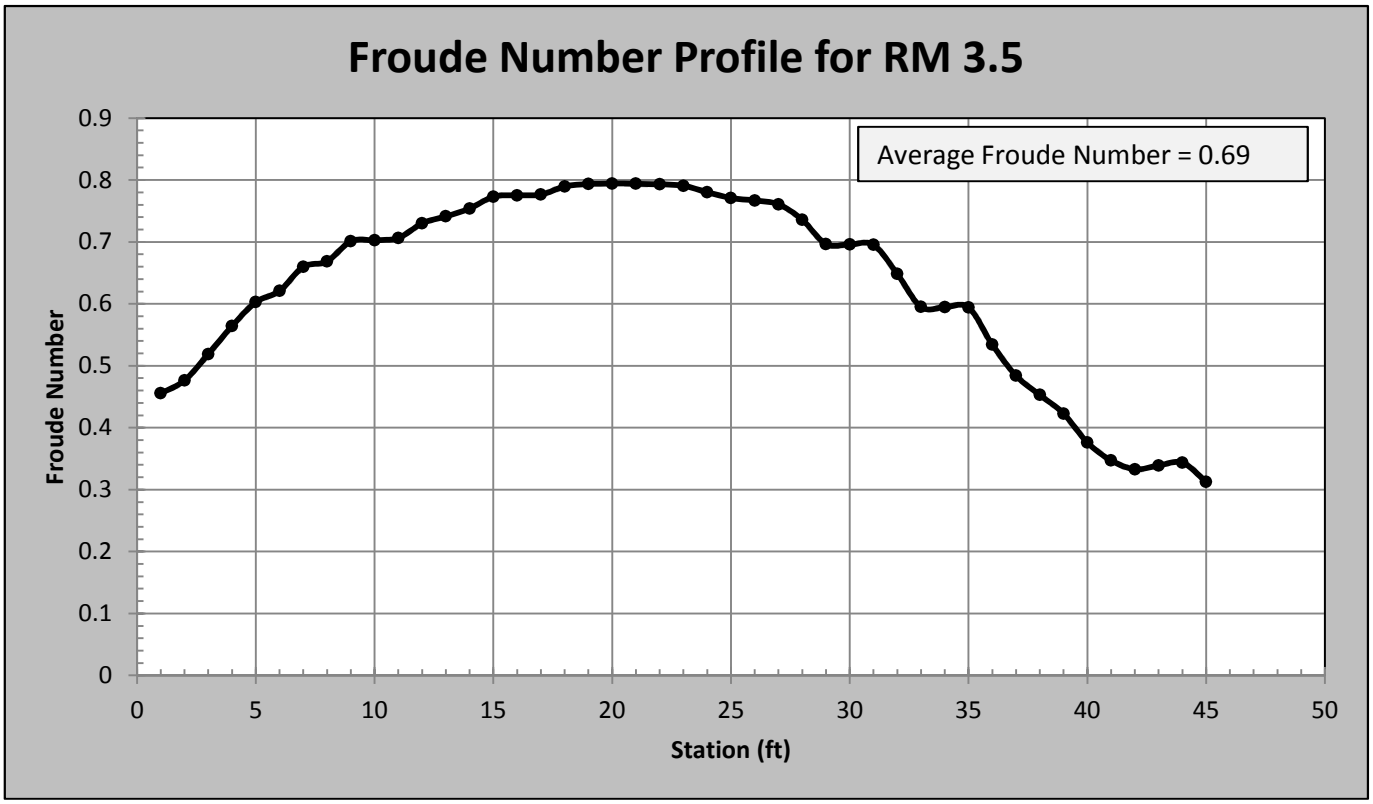
50-Year Event: 32,800cfs - River Mile 3.25



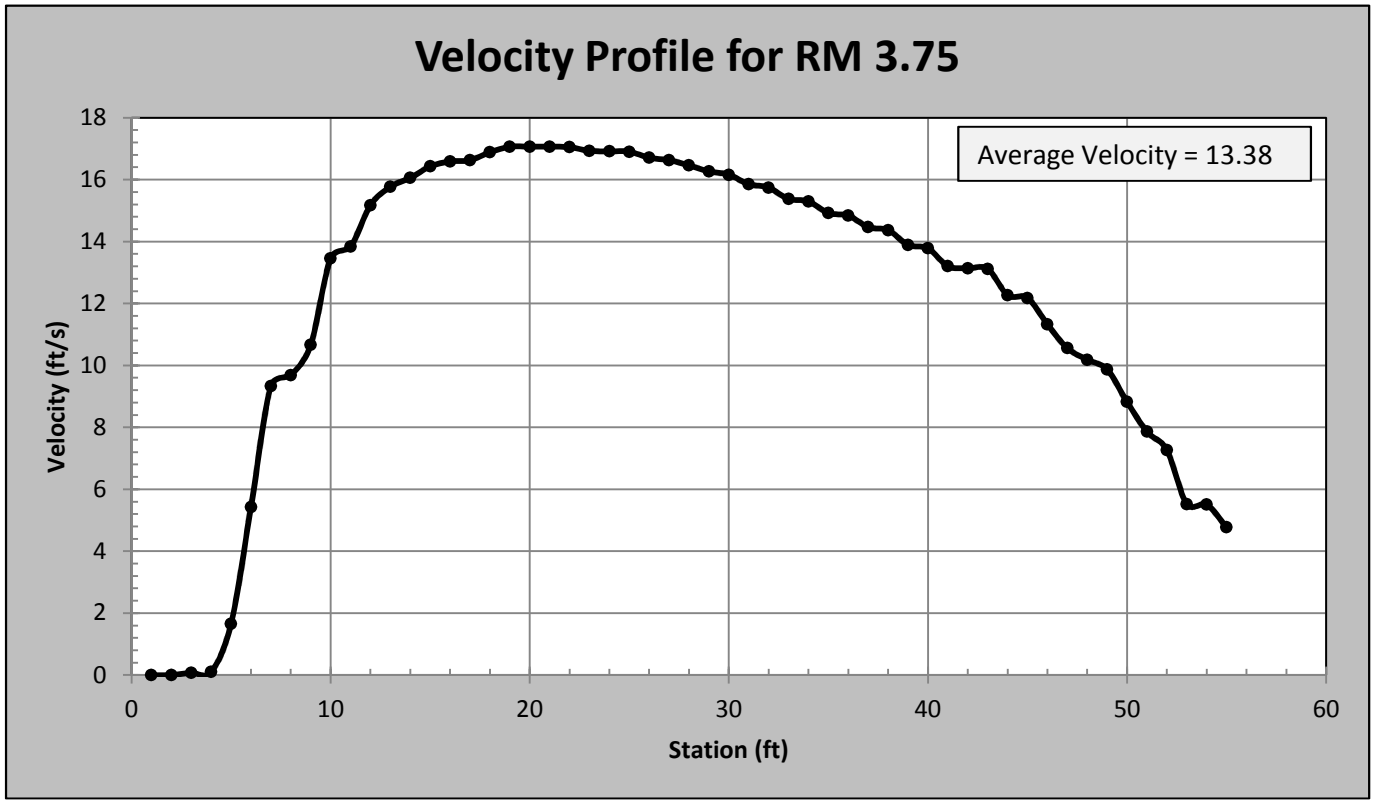


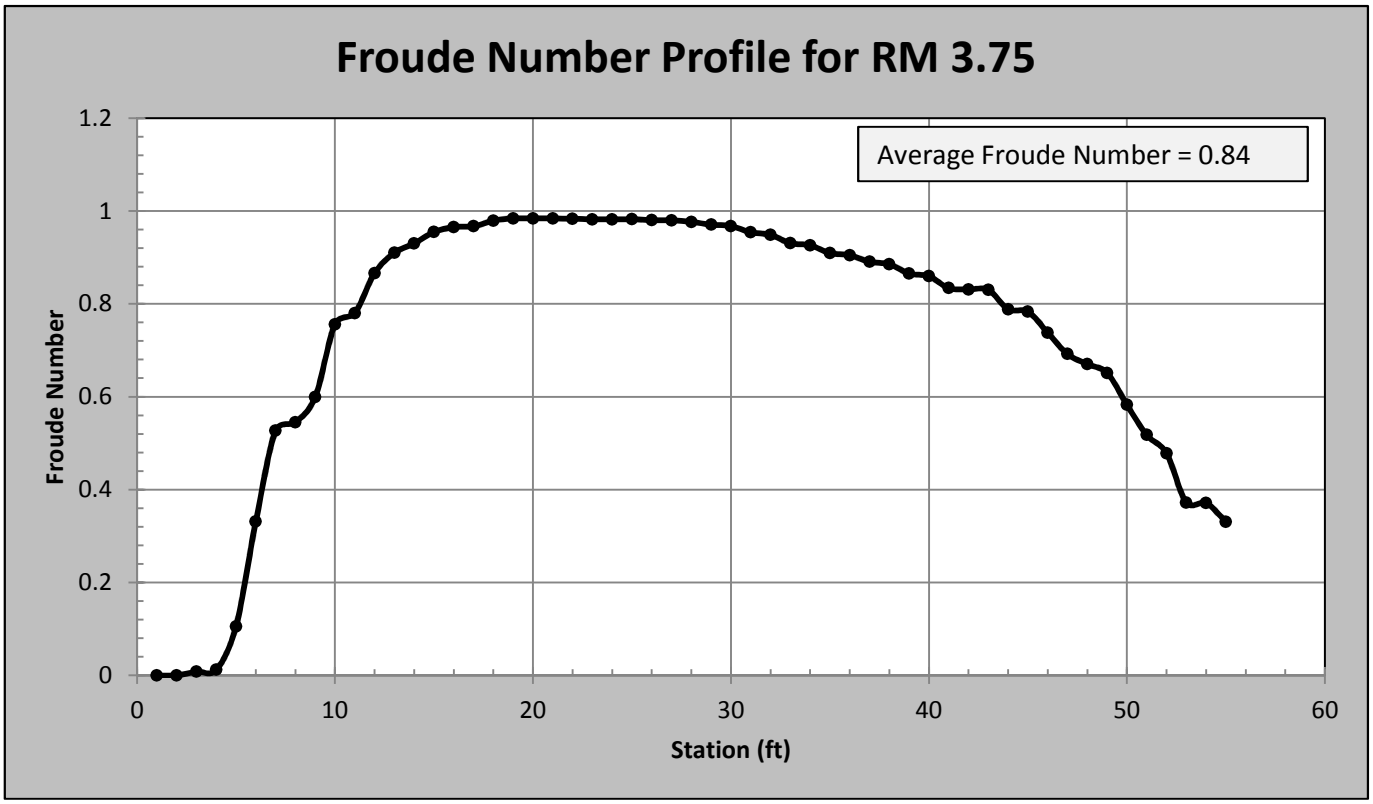
50-Year Event: 32,800cfs - River Mile 3.5



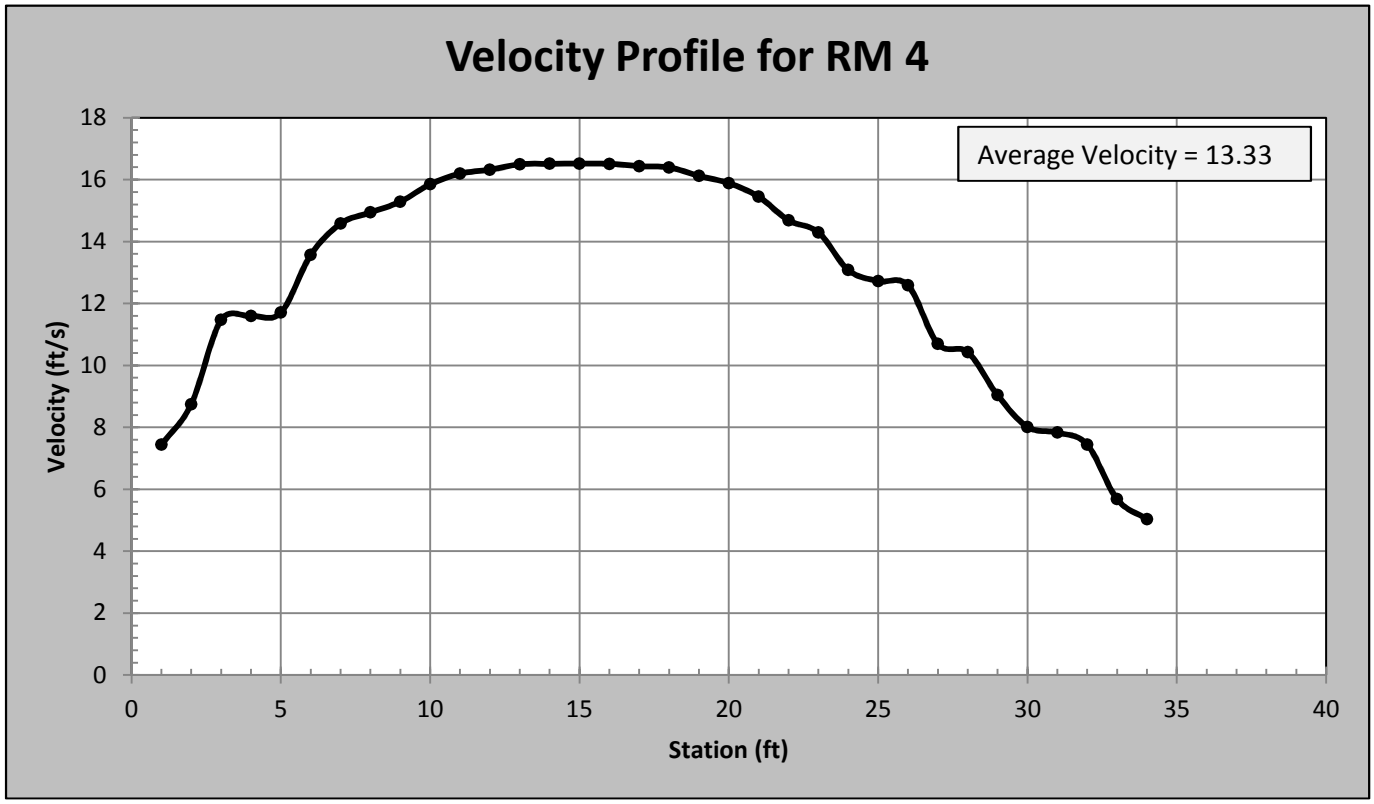


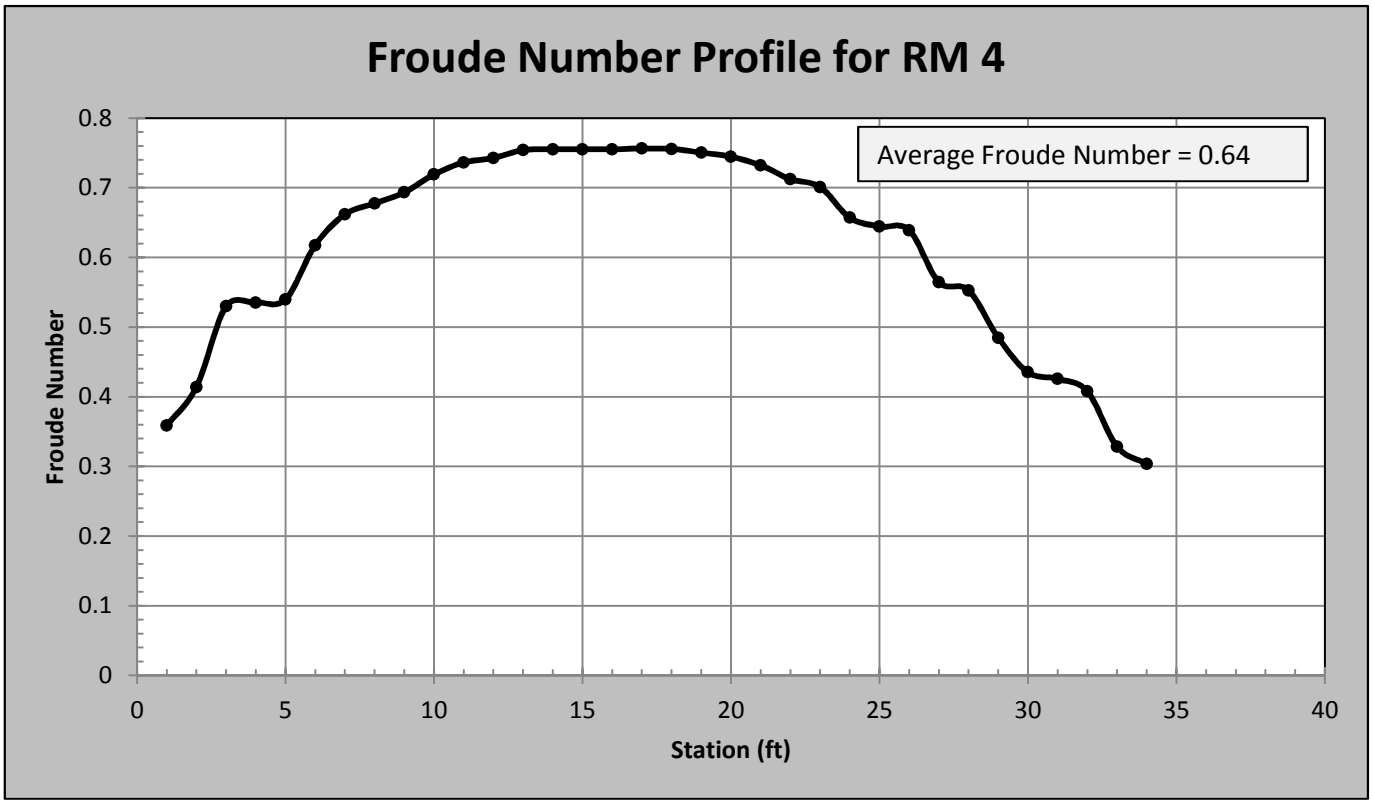
50-Year Event: 32,800cfs - River Mile 3.75



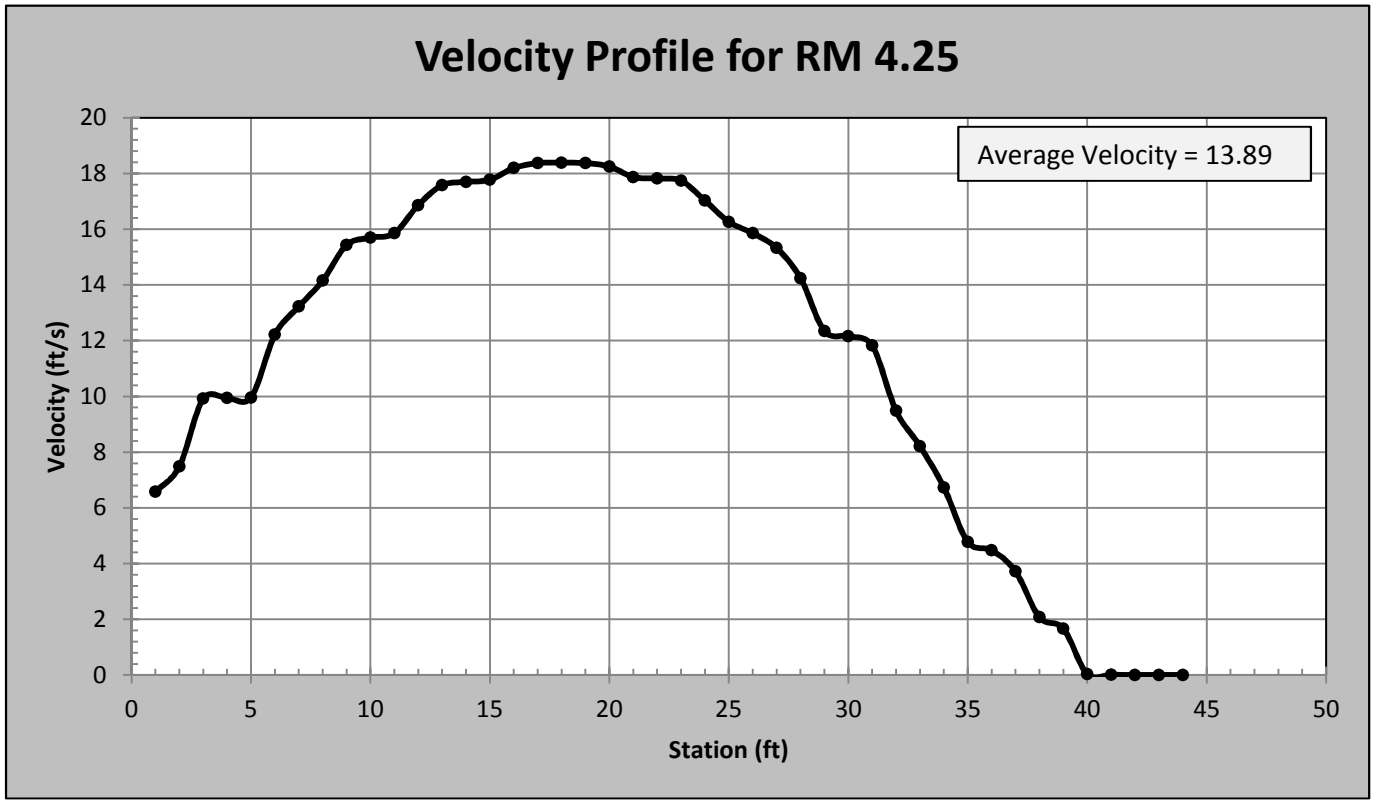


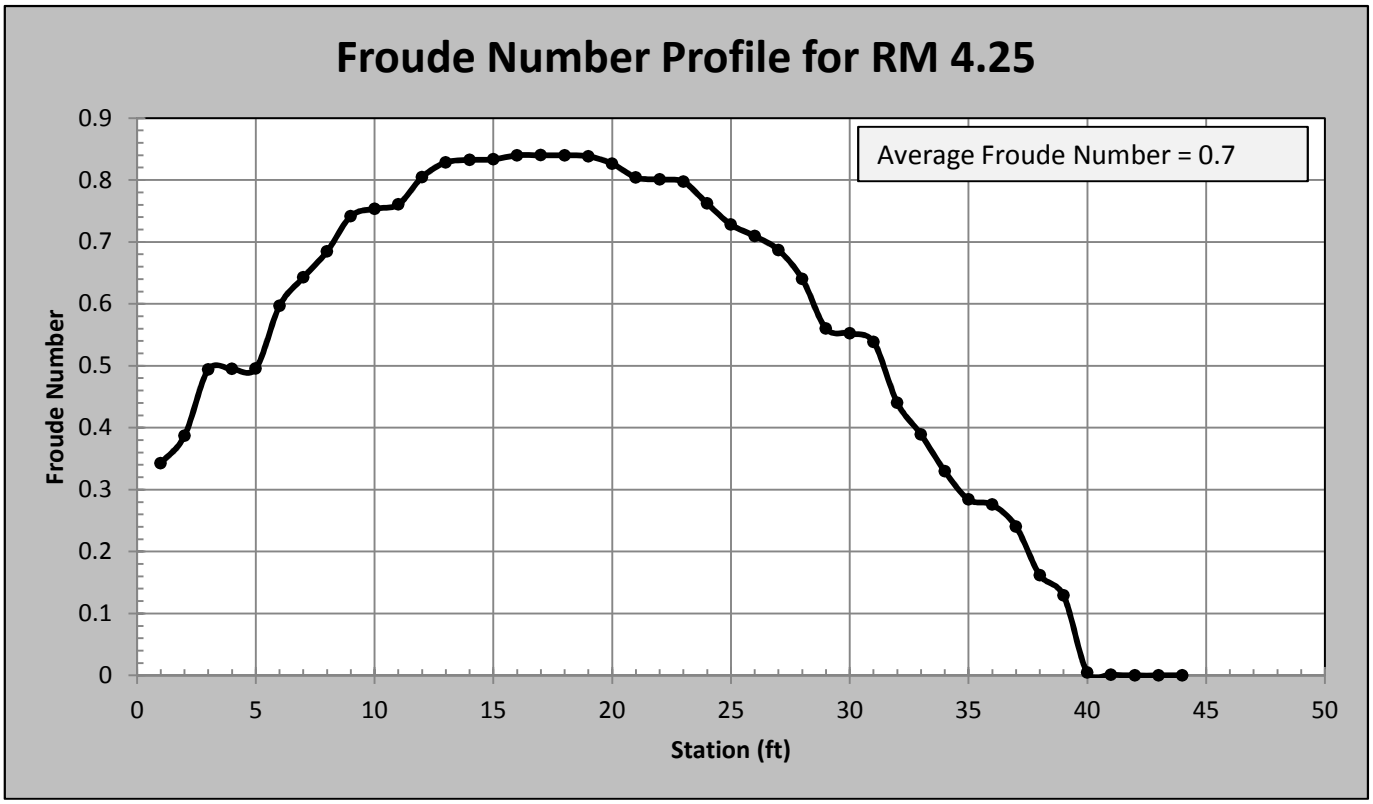
50-Year Event: 32,800cfs - River Mile 4



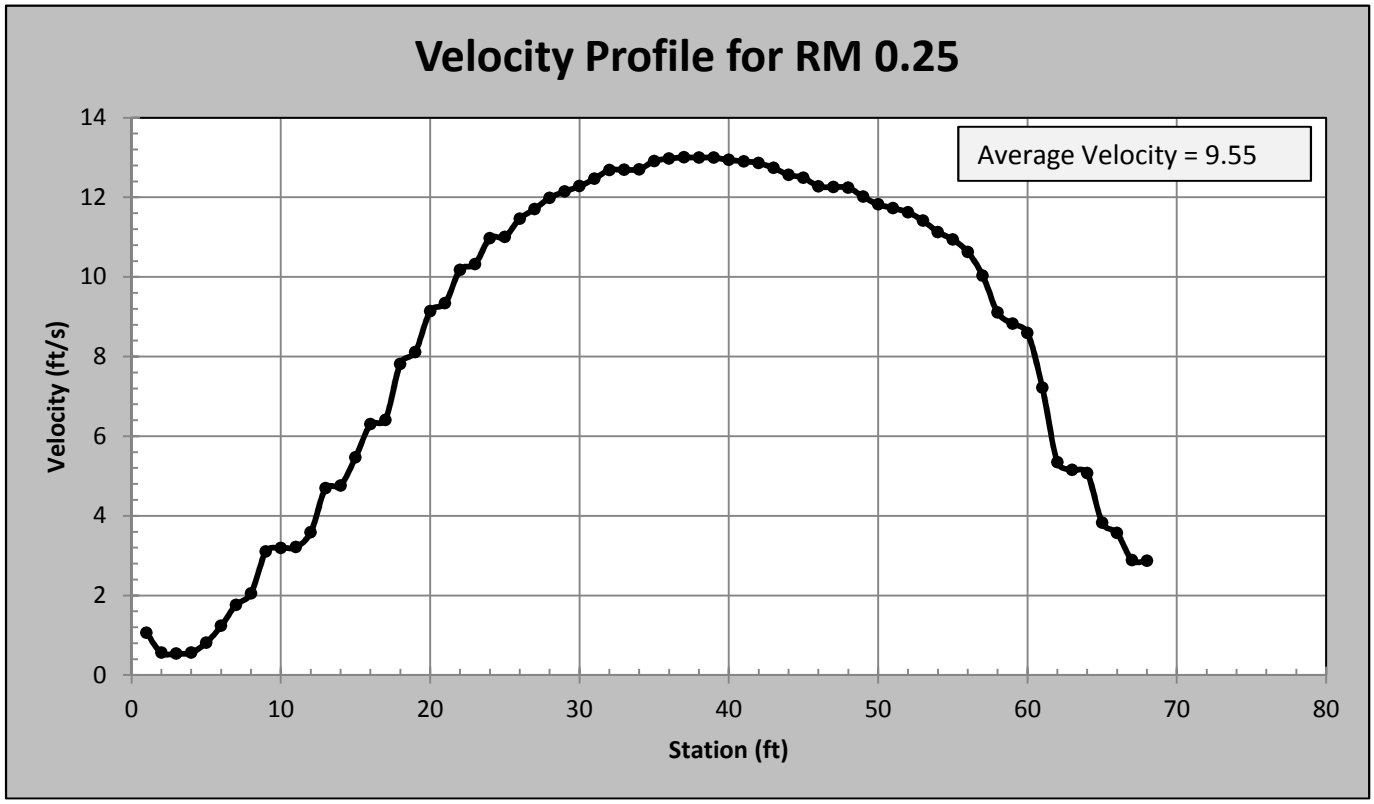


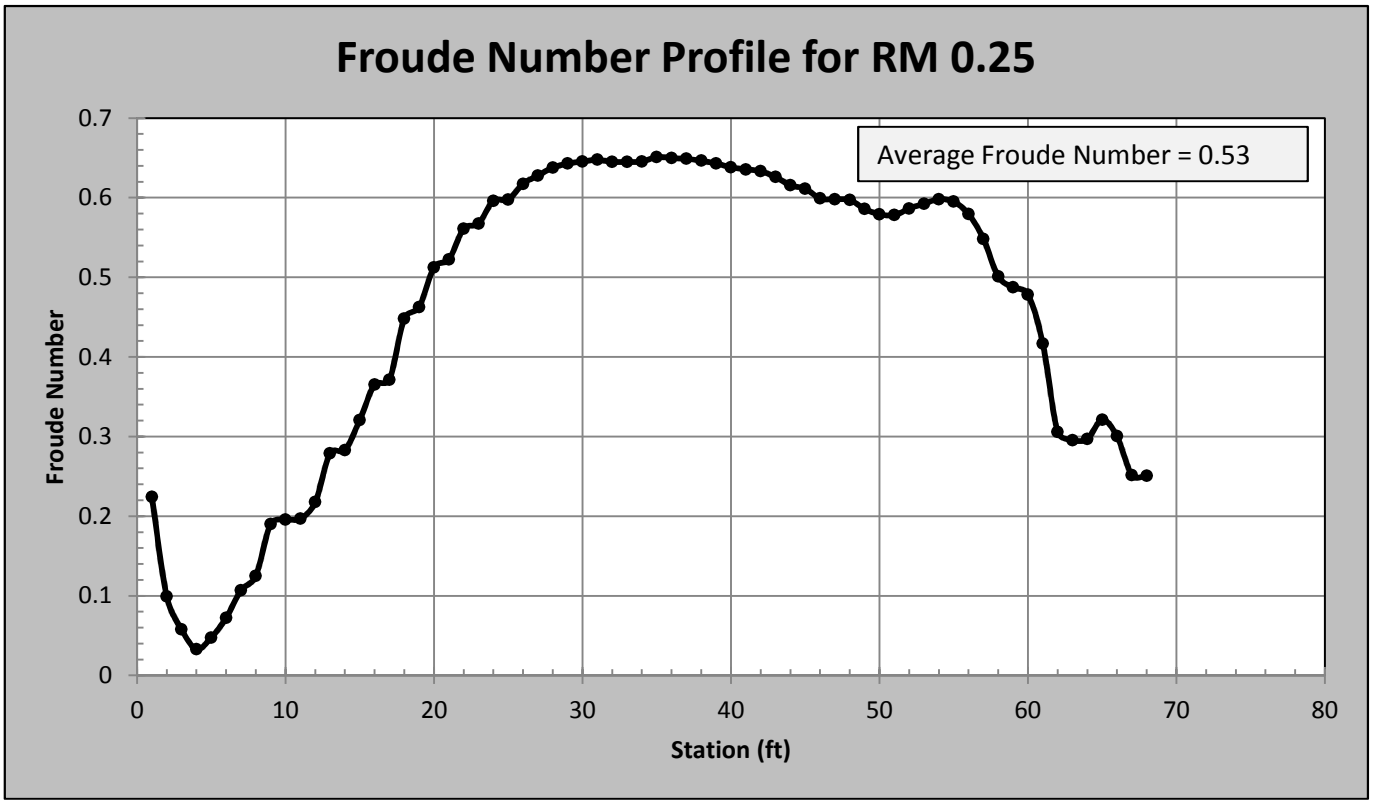
50-Year Event: 32,800cfs - River Mile 4.25



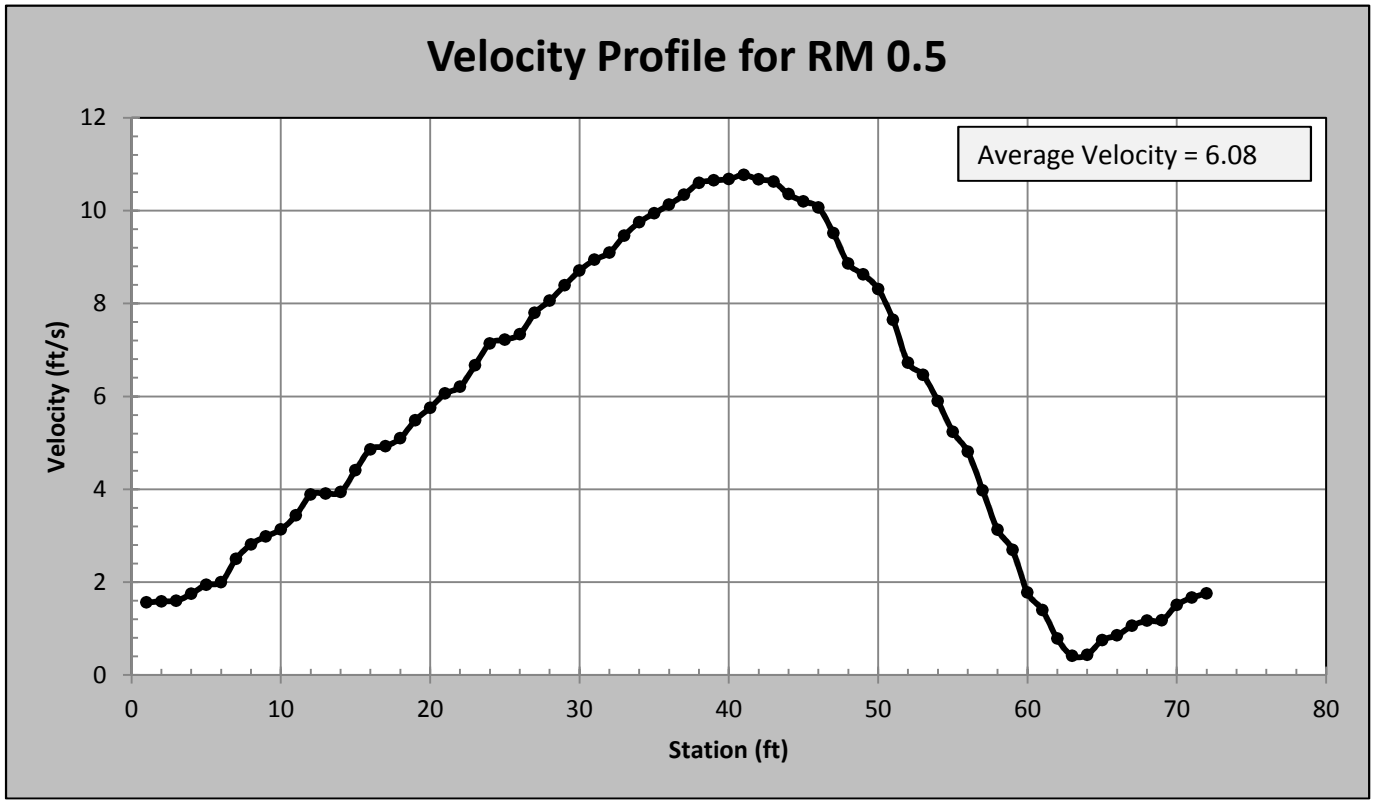


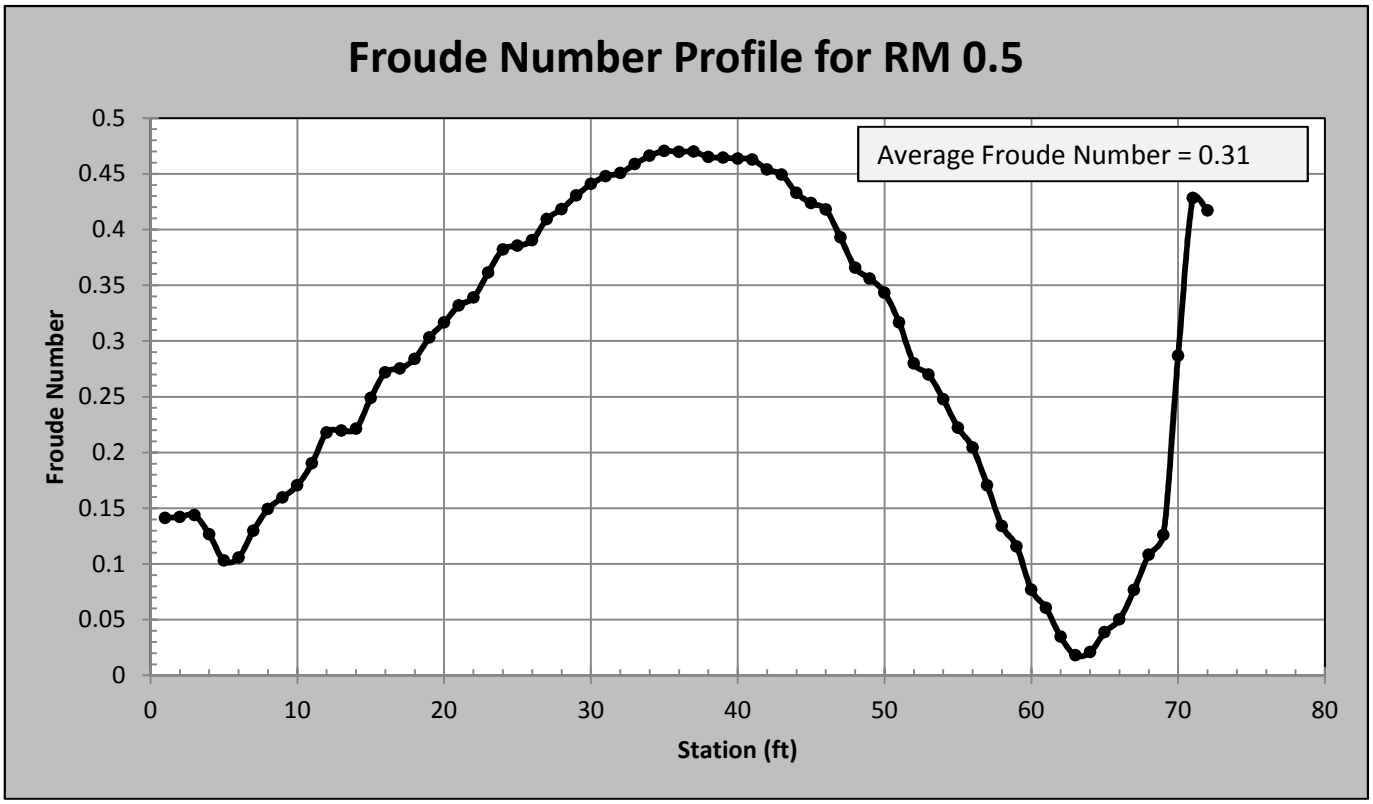
100-Year Event: 35,400cfs - River Mile 0.25



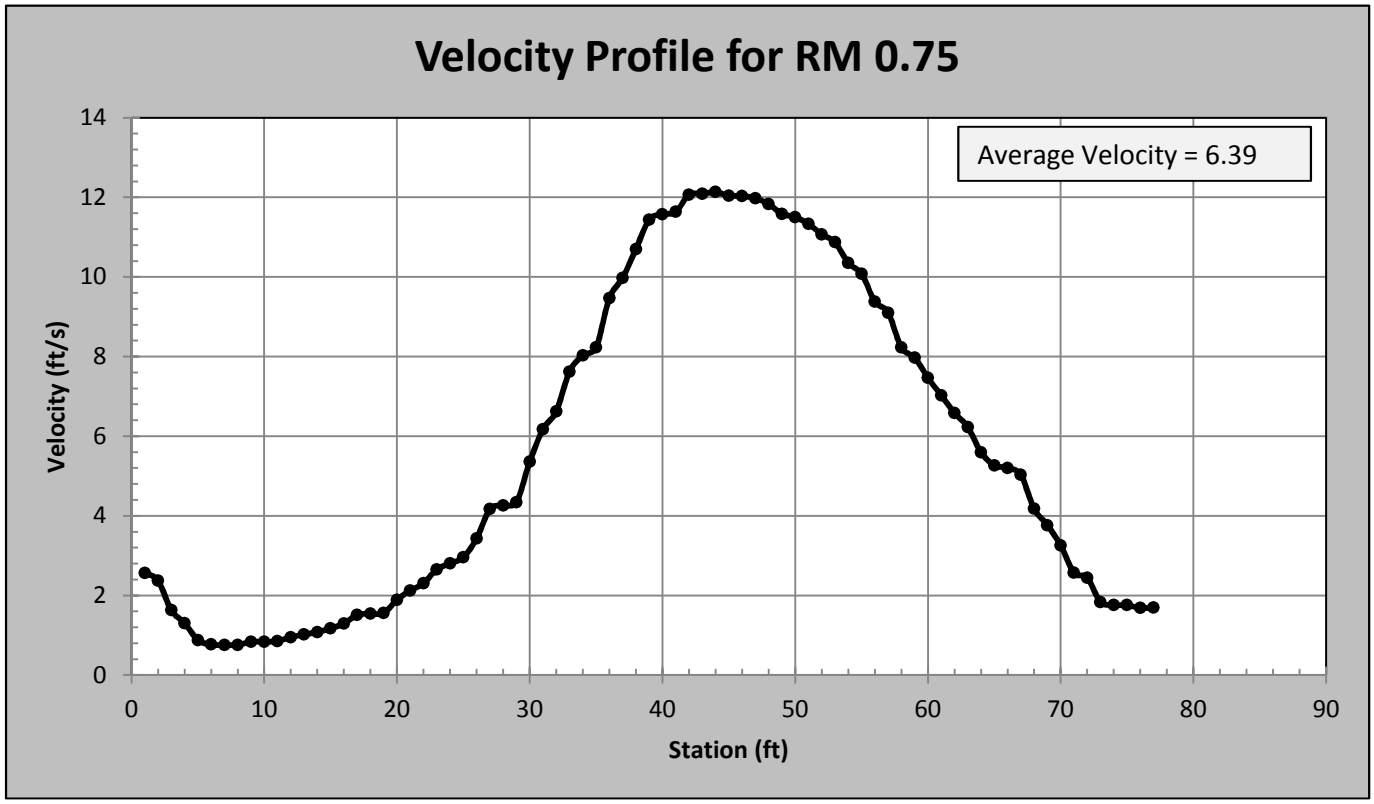


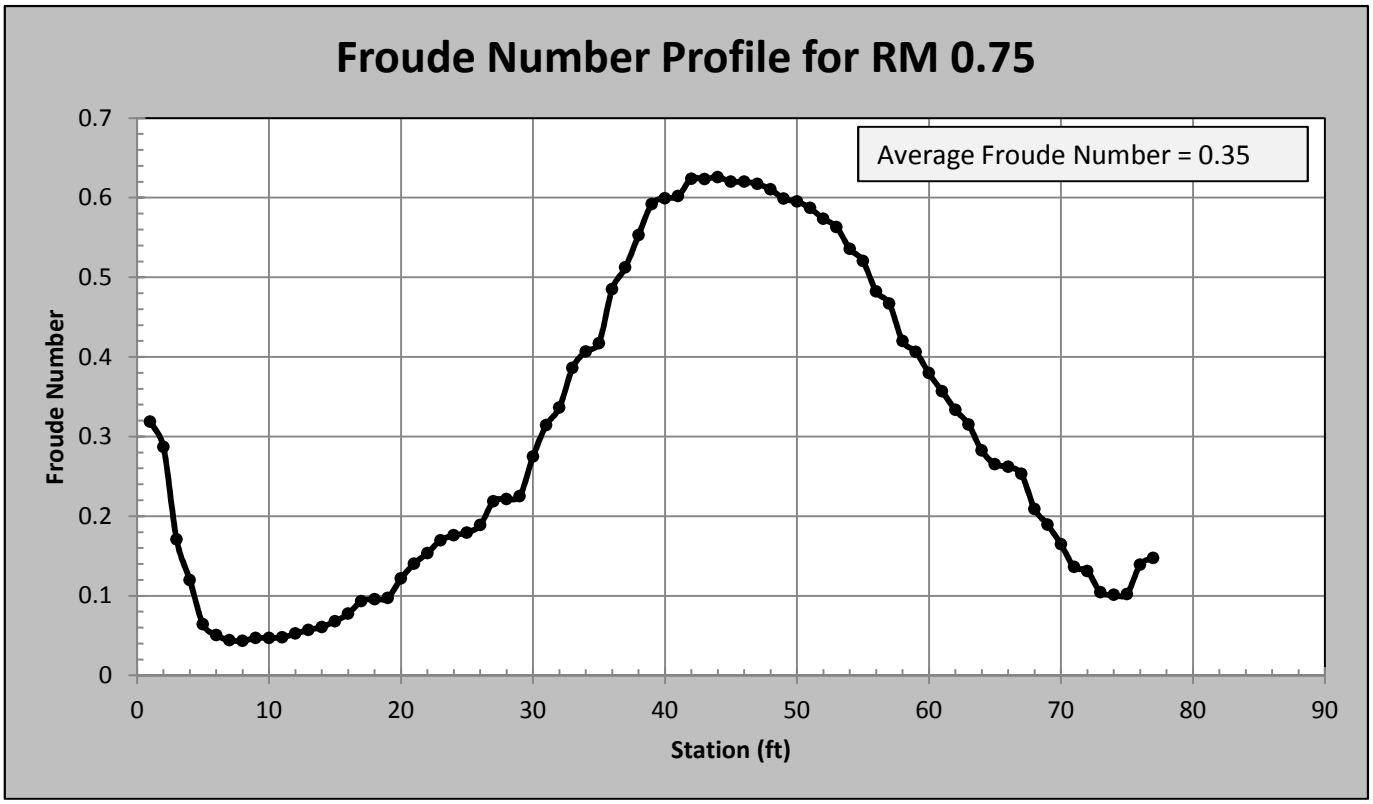
100-Year Event: 35,400cfs - River Mile 0.5



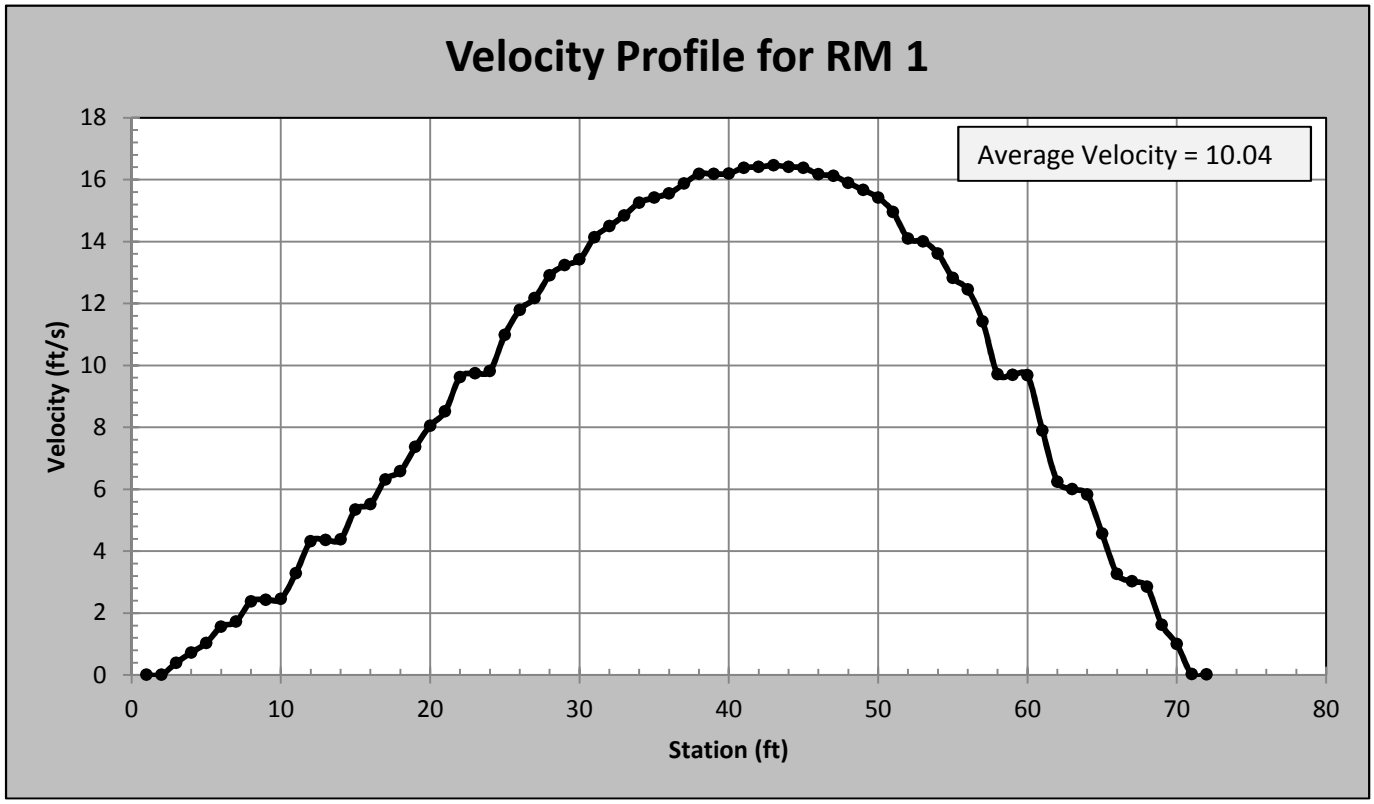


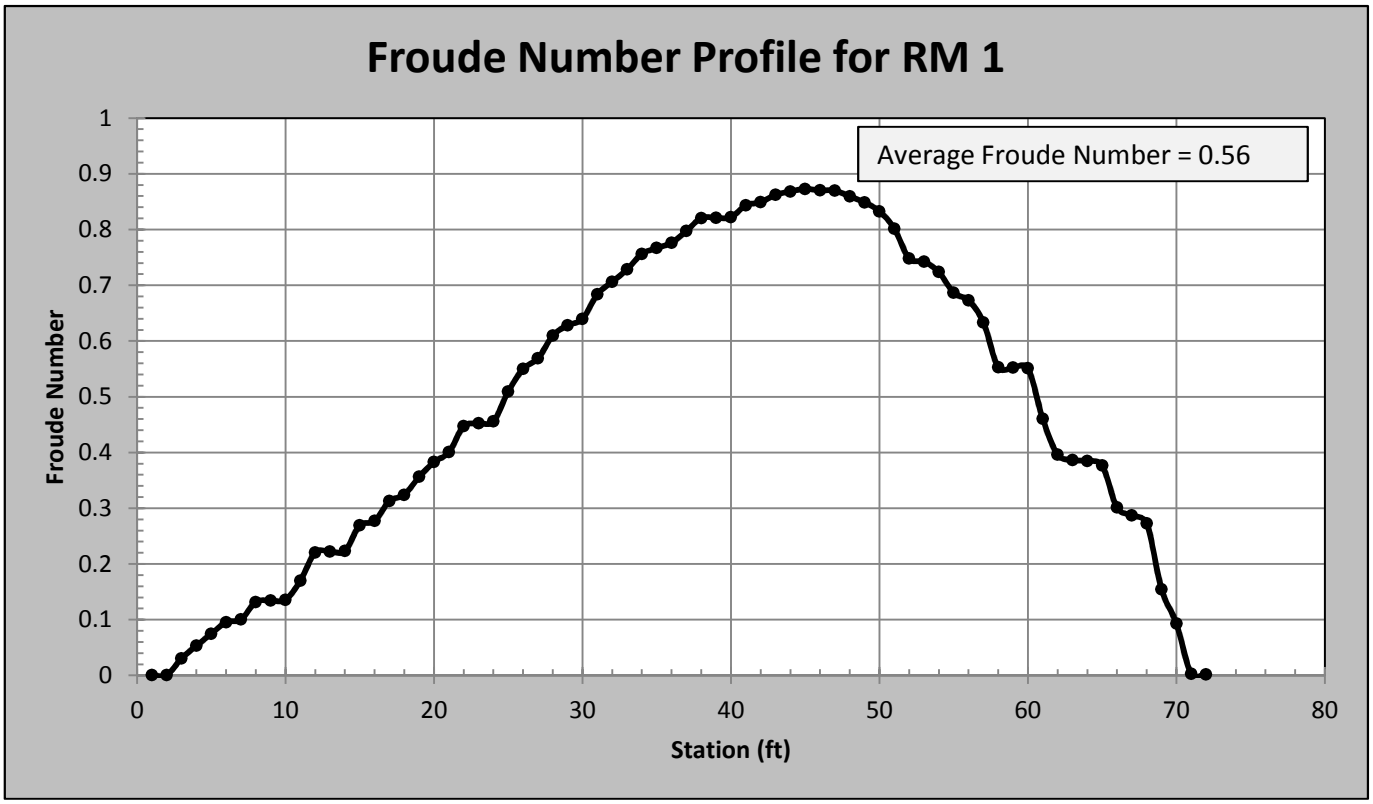
100-Year Event: 35,400cfs - River Mile 0.75



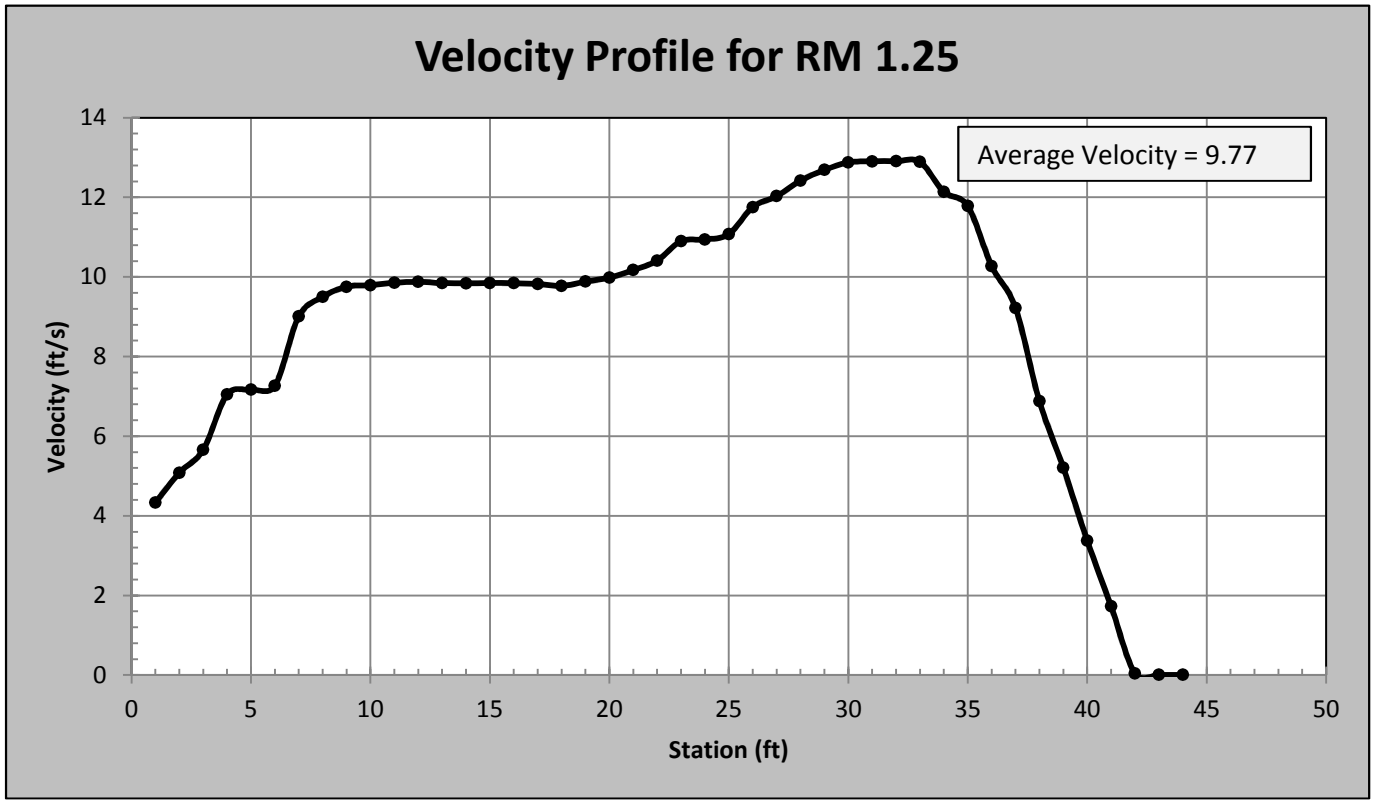


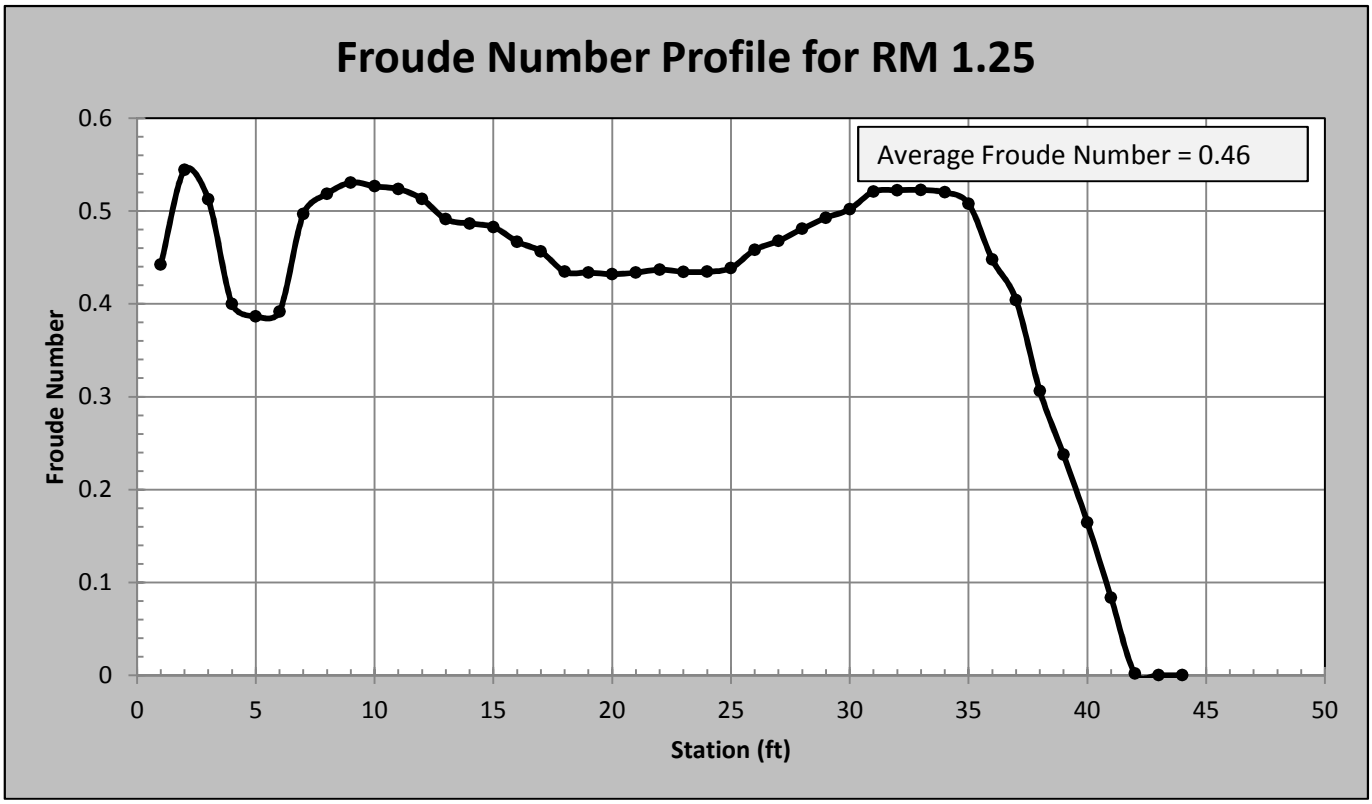
100-Year Event: 35,400cfs - River Mile 1



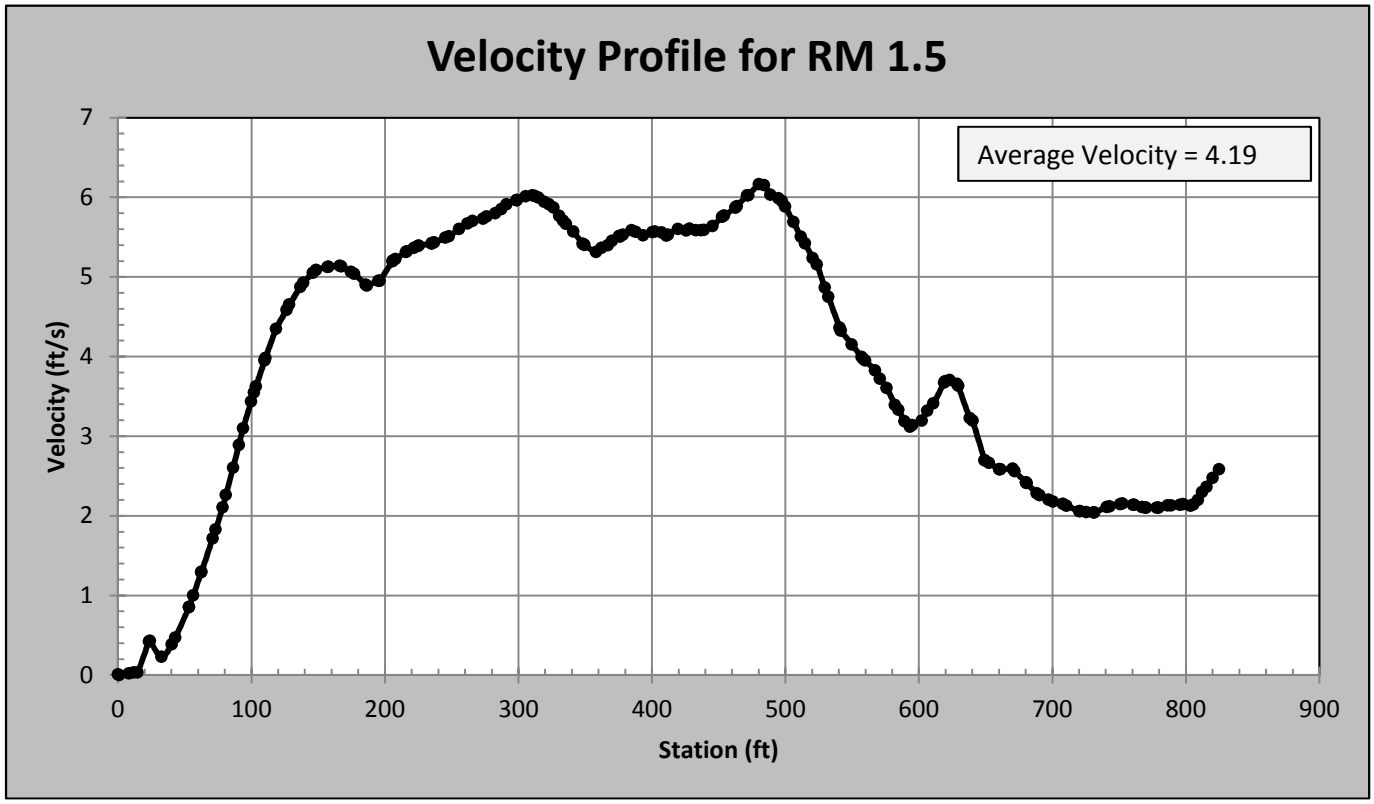


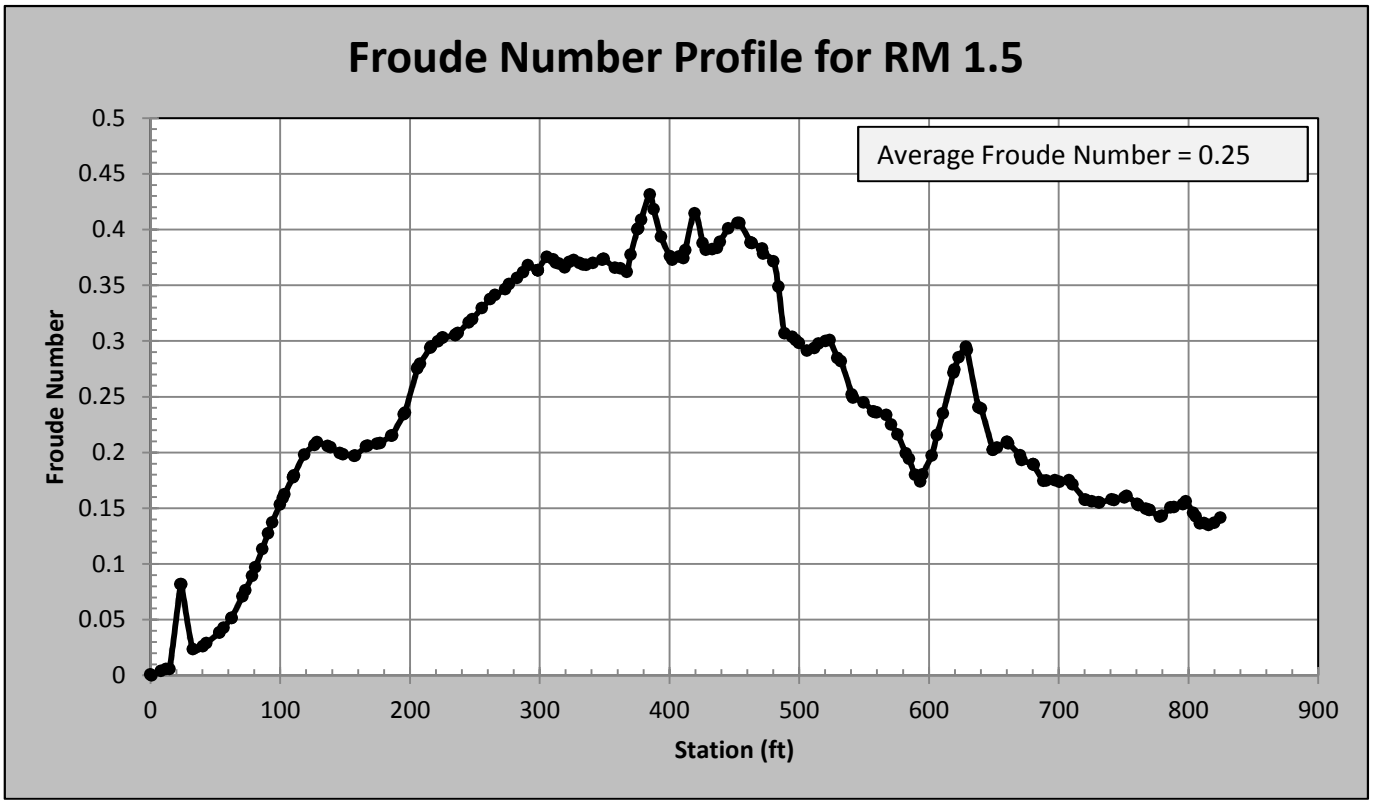
100-Year Event: 35,400cfs - River Mile 1.25



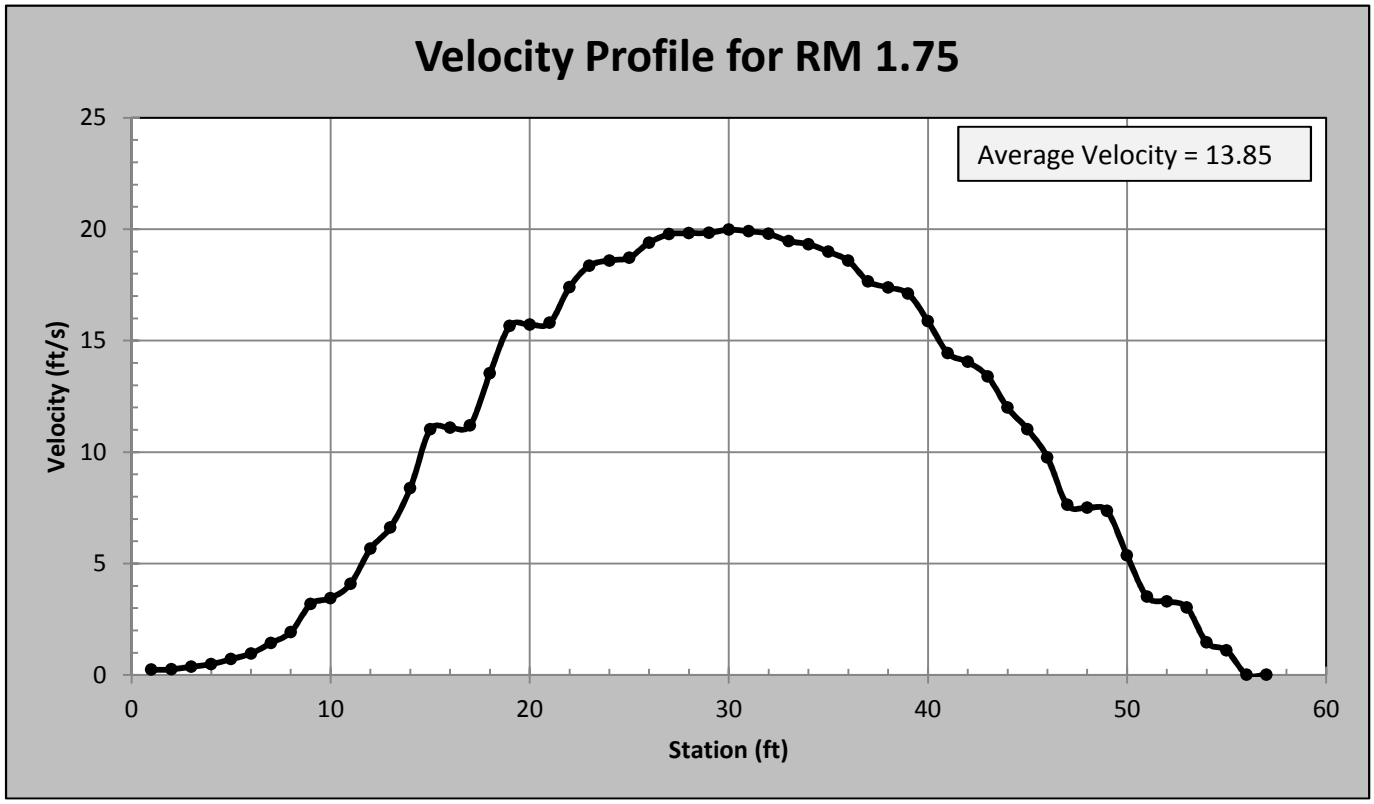


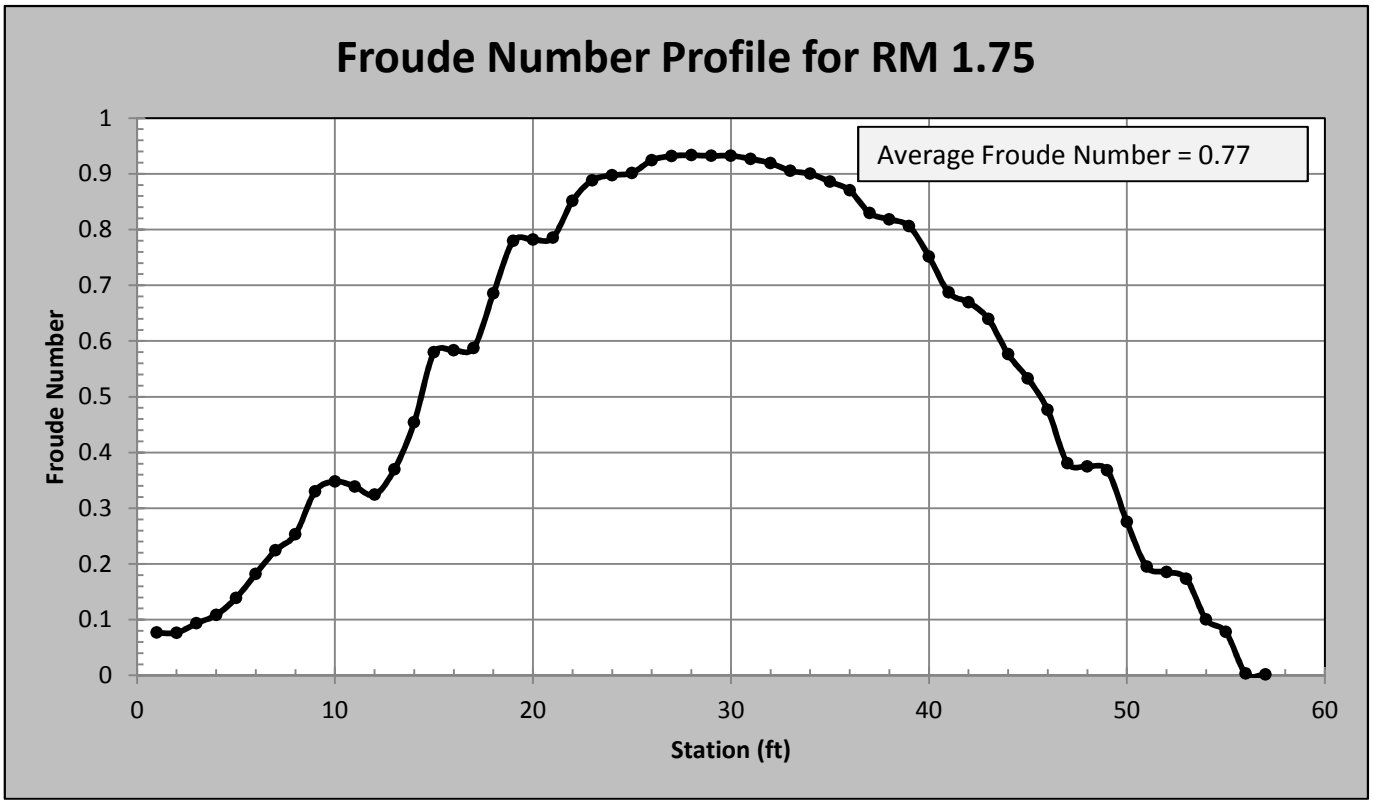
100-Year Event: 35,400cfs - River Mile 1.5



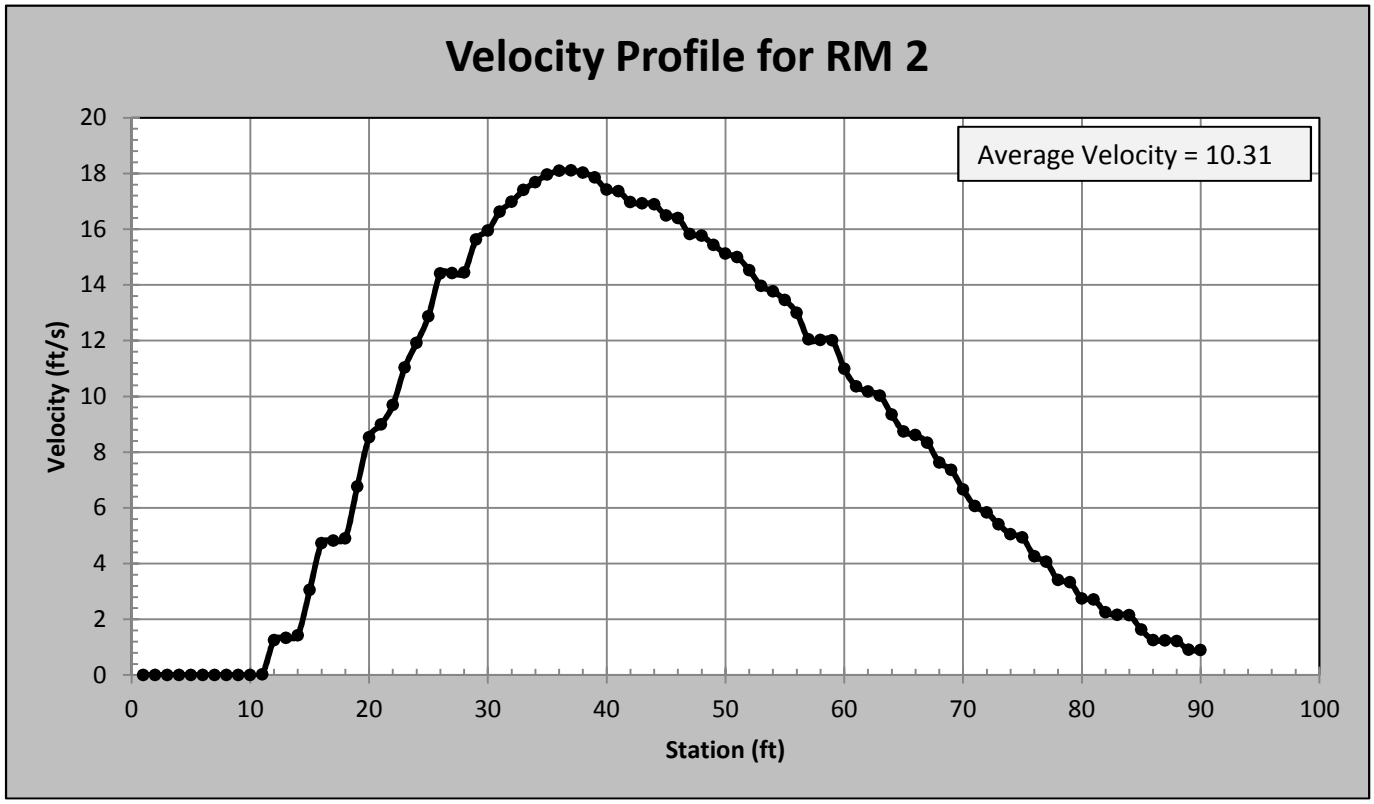


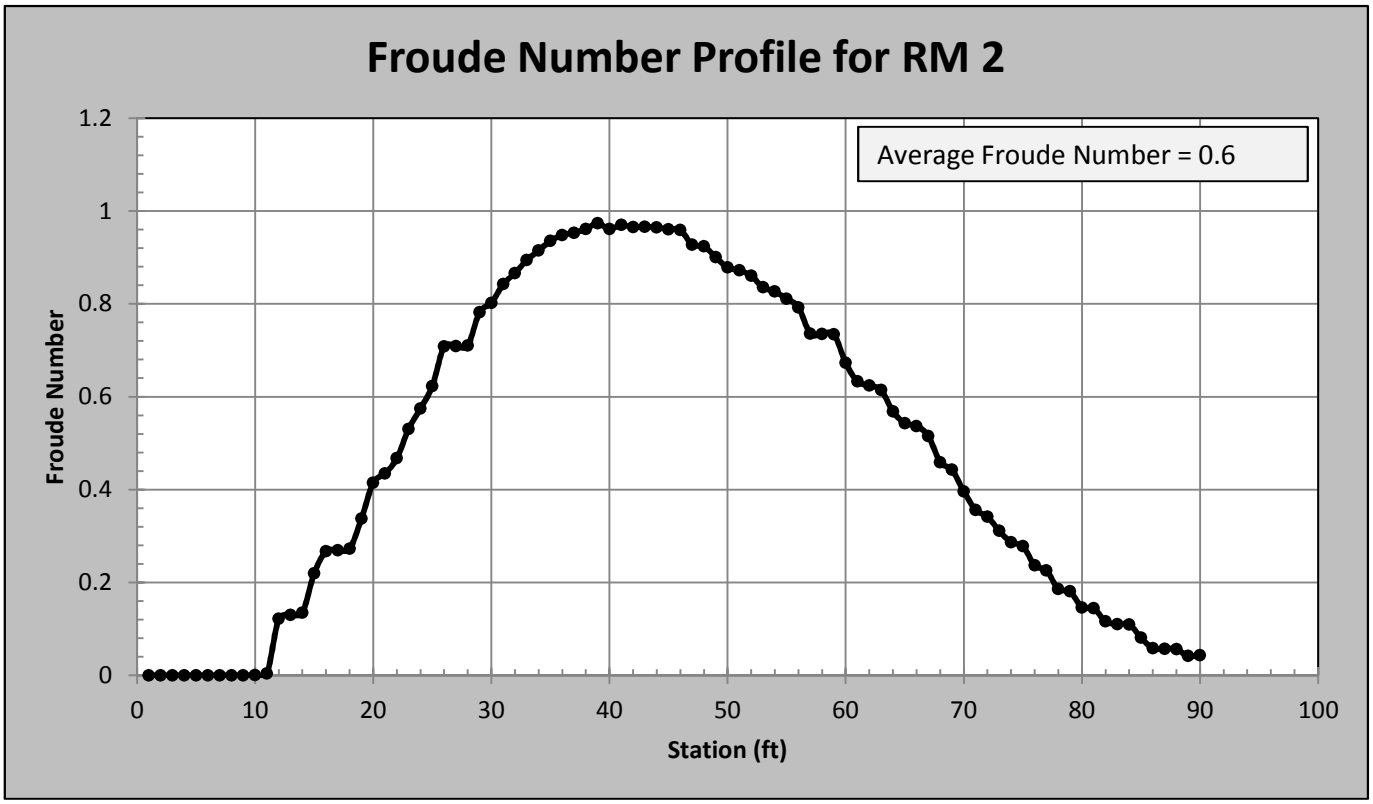
100-Year Event: 35,400cfs - River Mile 1.75



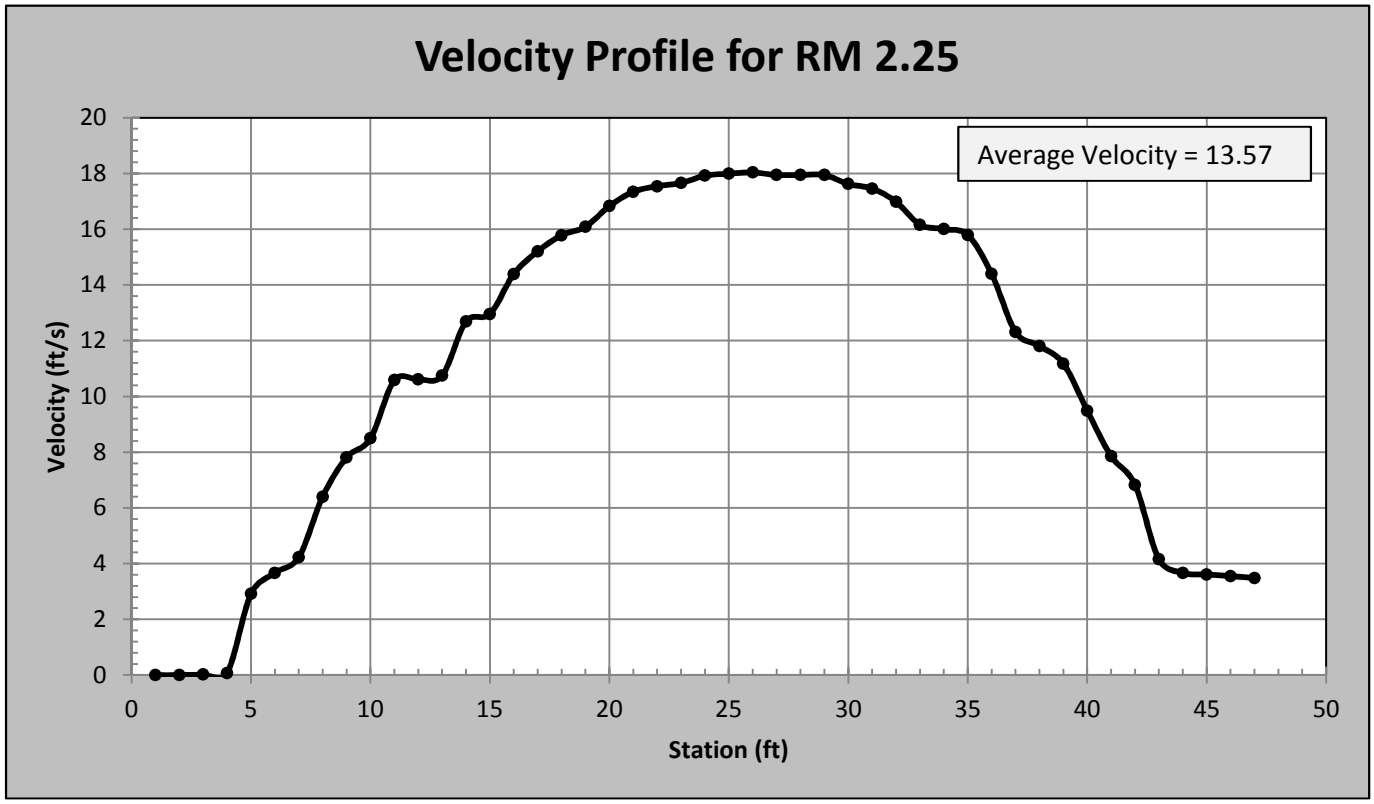


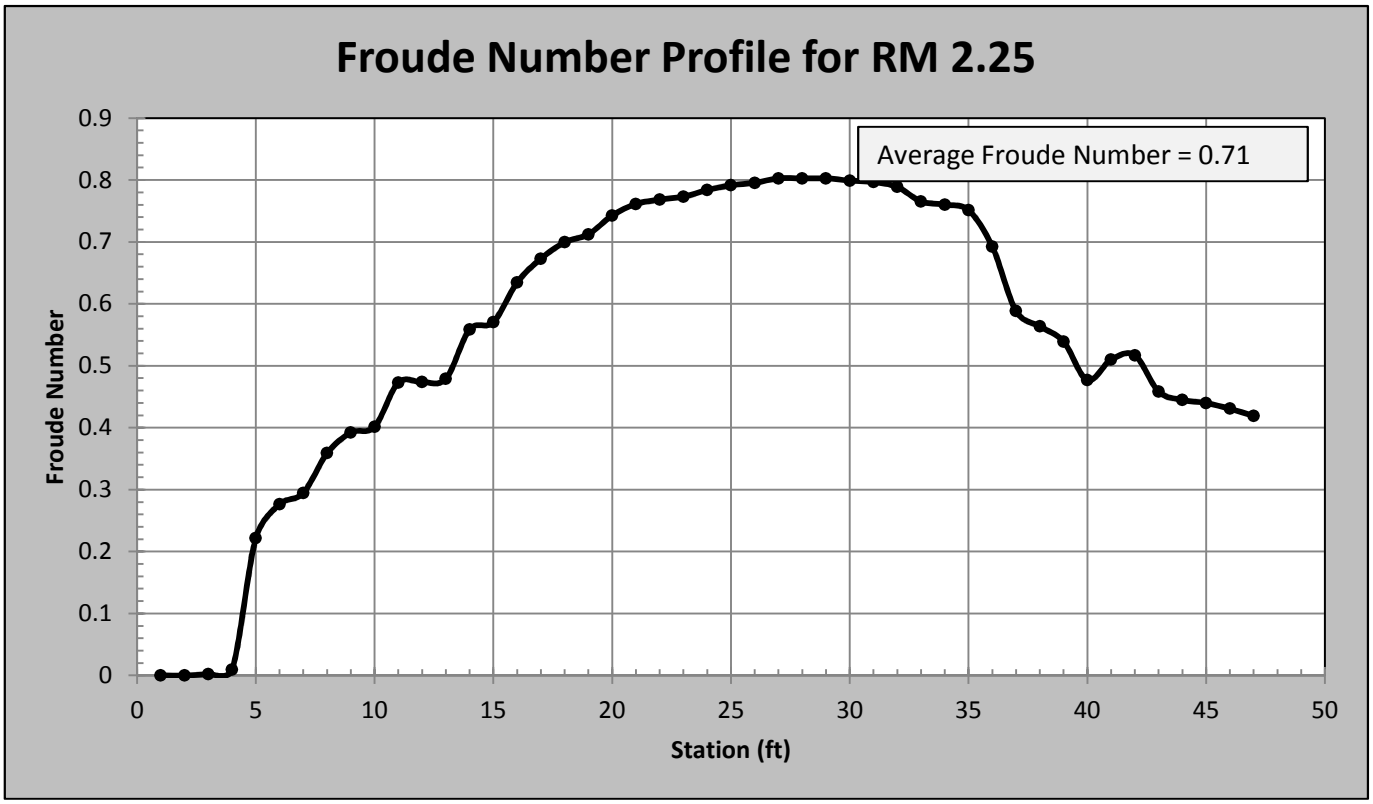
100-Year Event: 35,400cfs - River Mile 2



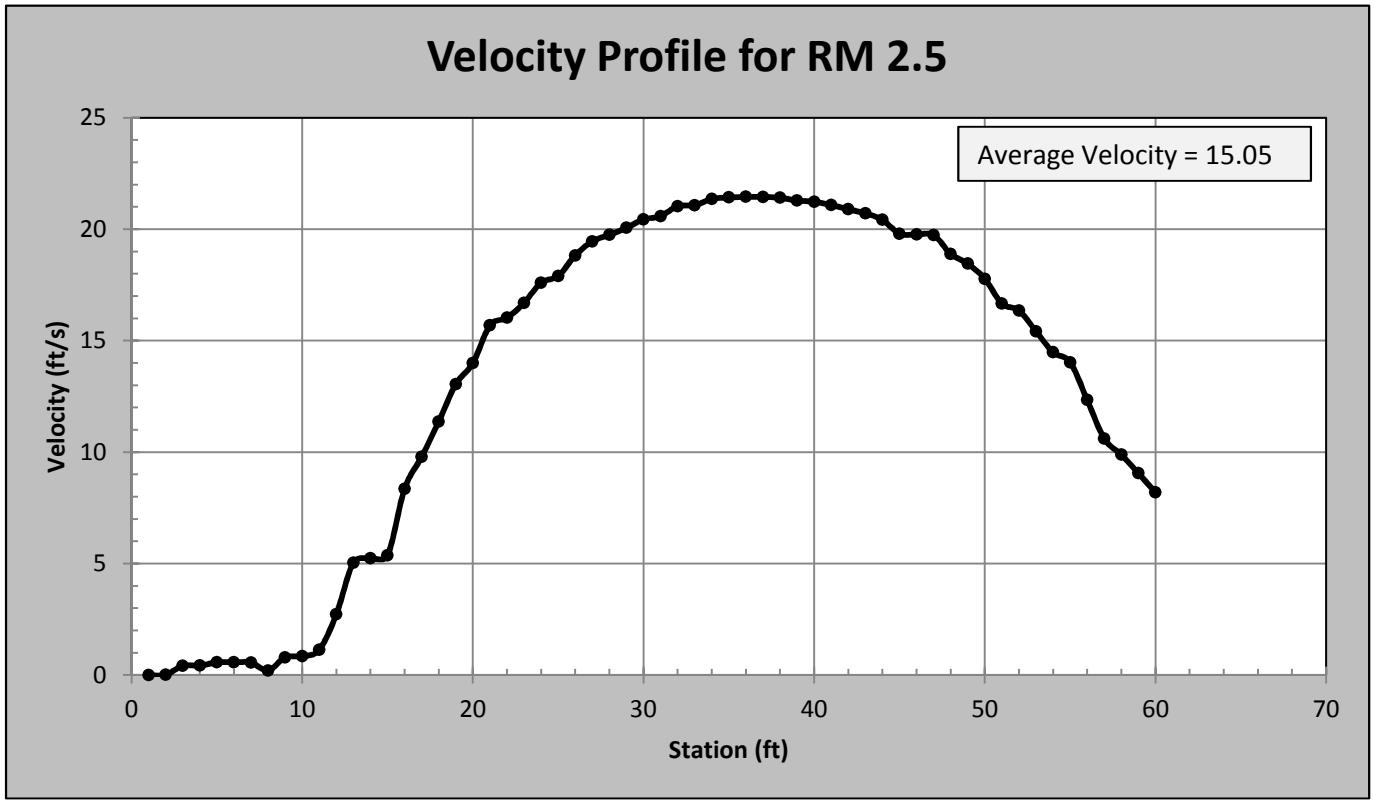


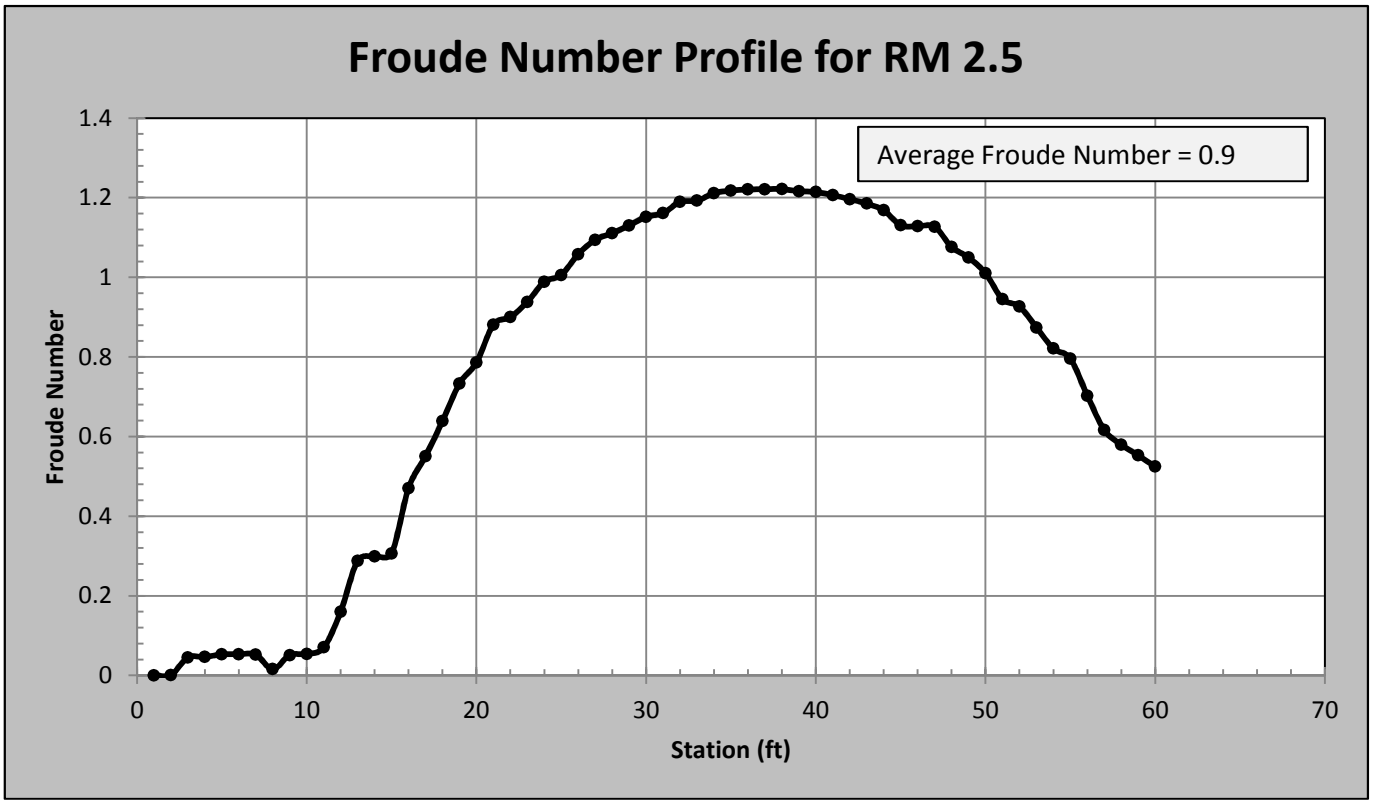
100-Year Event: 35,400cfs - River Mile 2.25



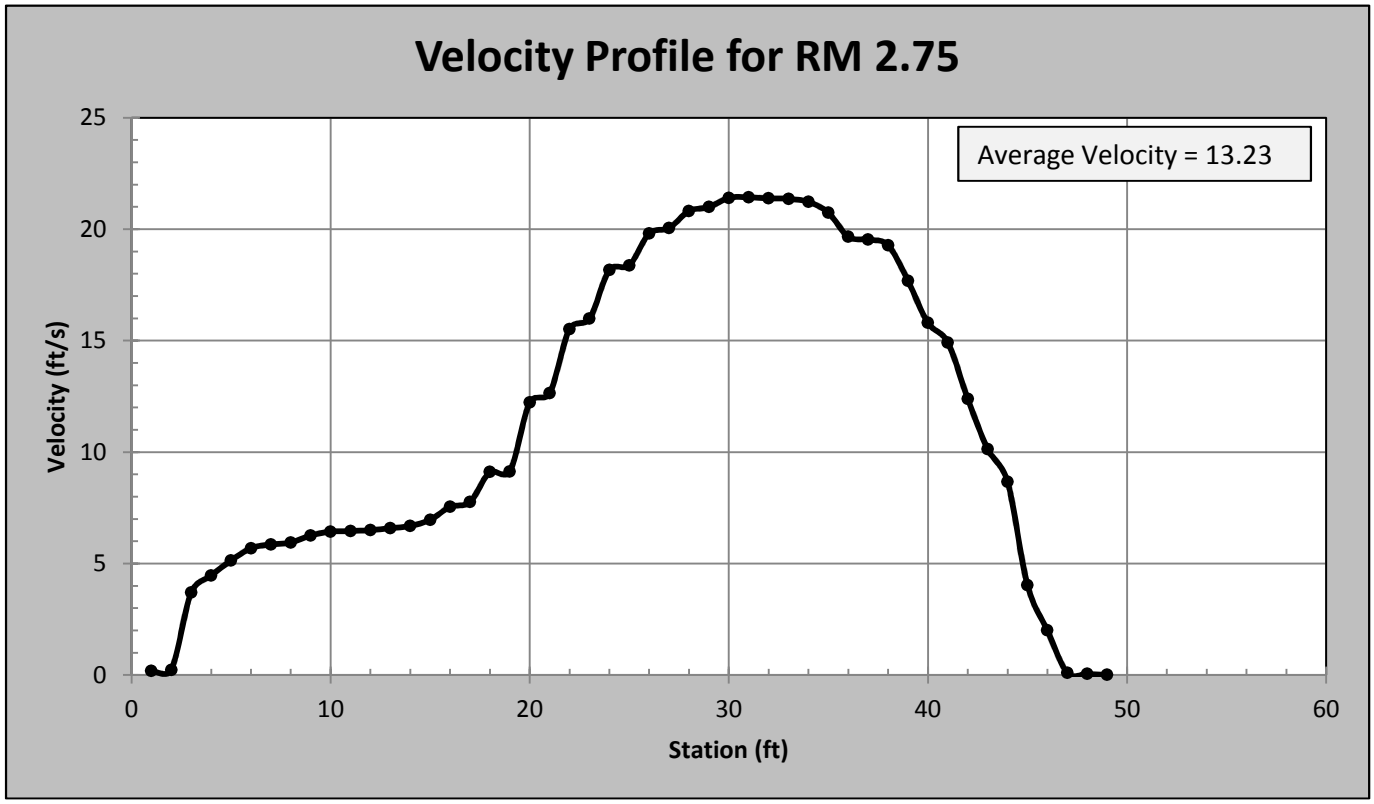


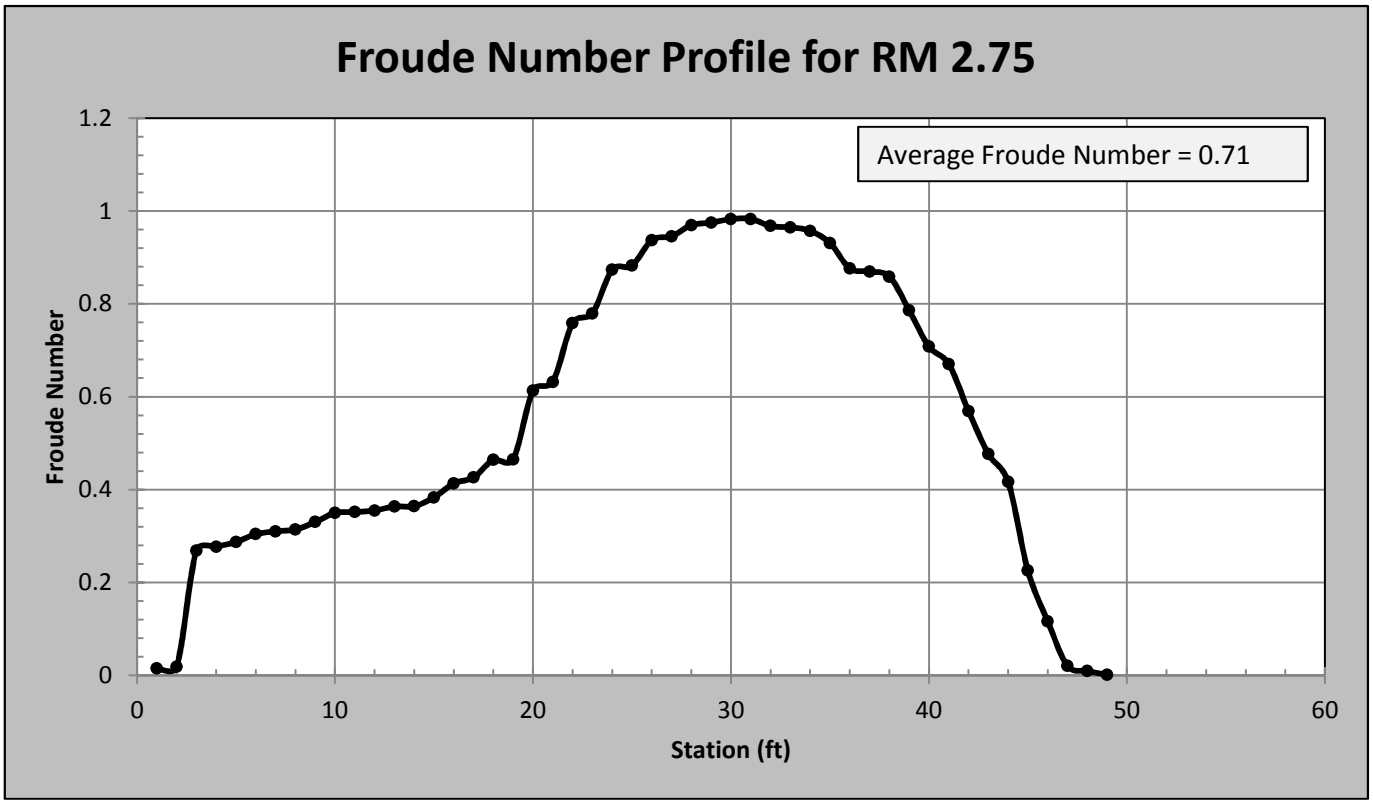
100-Year Event: 35,400cfs - River Mile 2.5



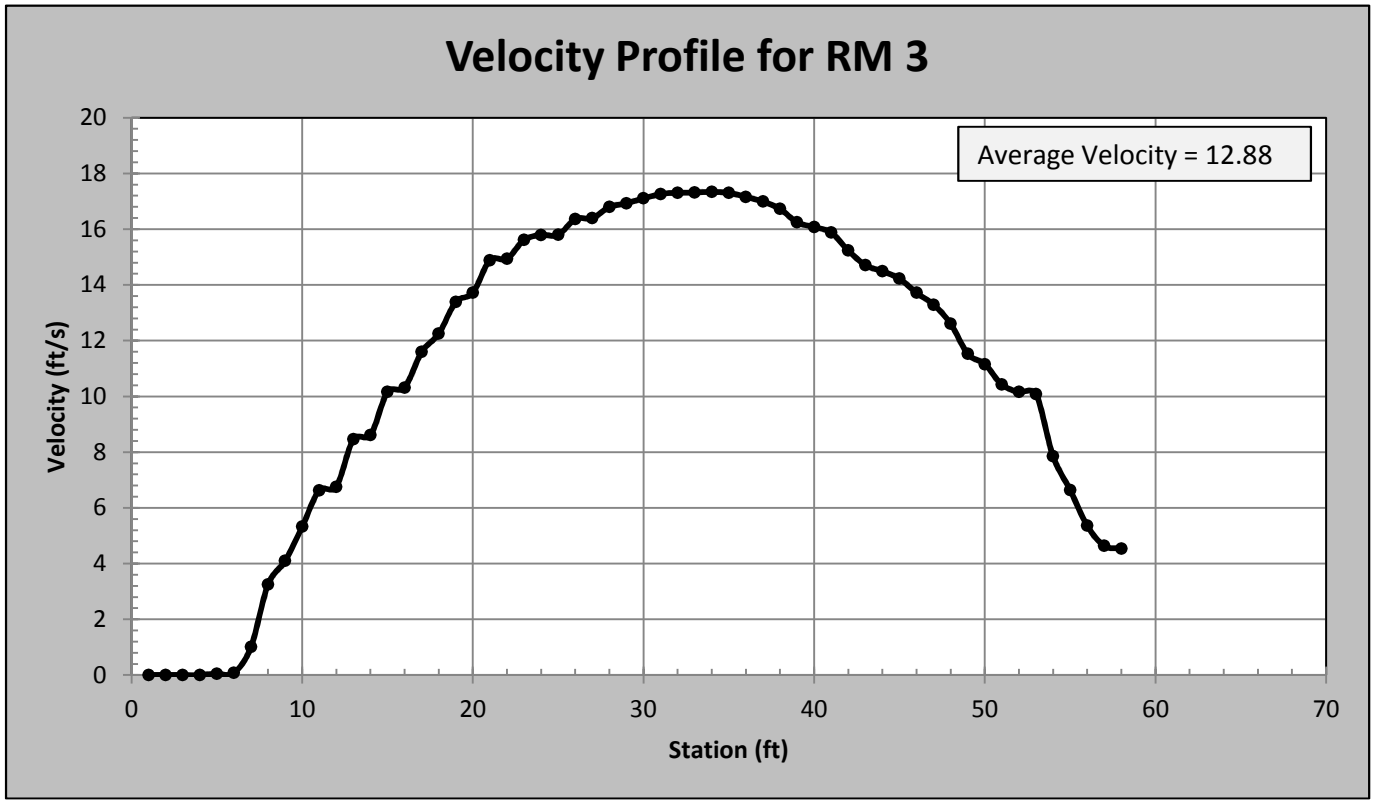


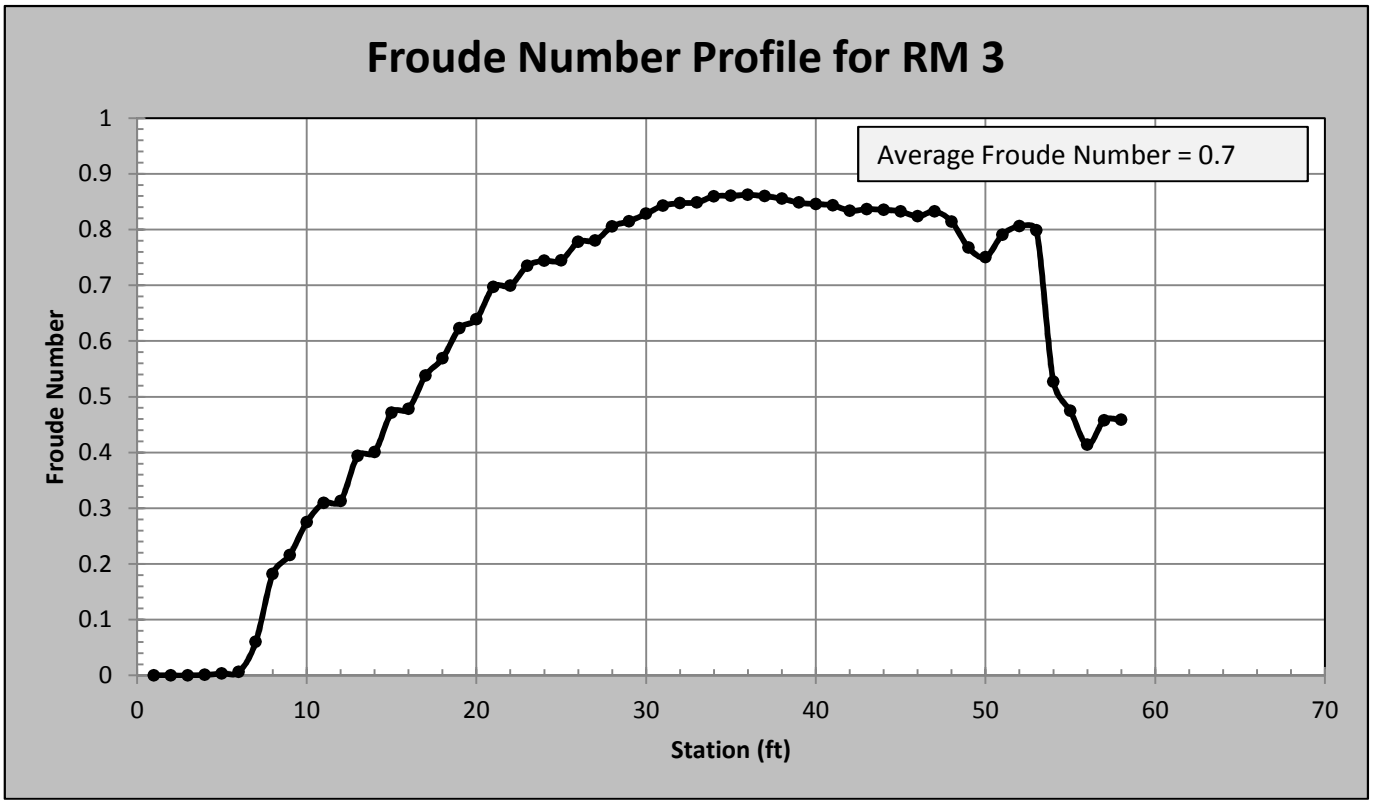
100-Year Event: 35,400cfs - River Mile 2.75



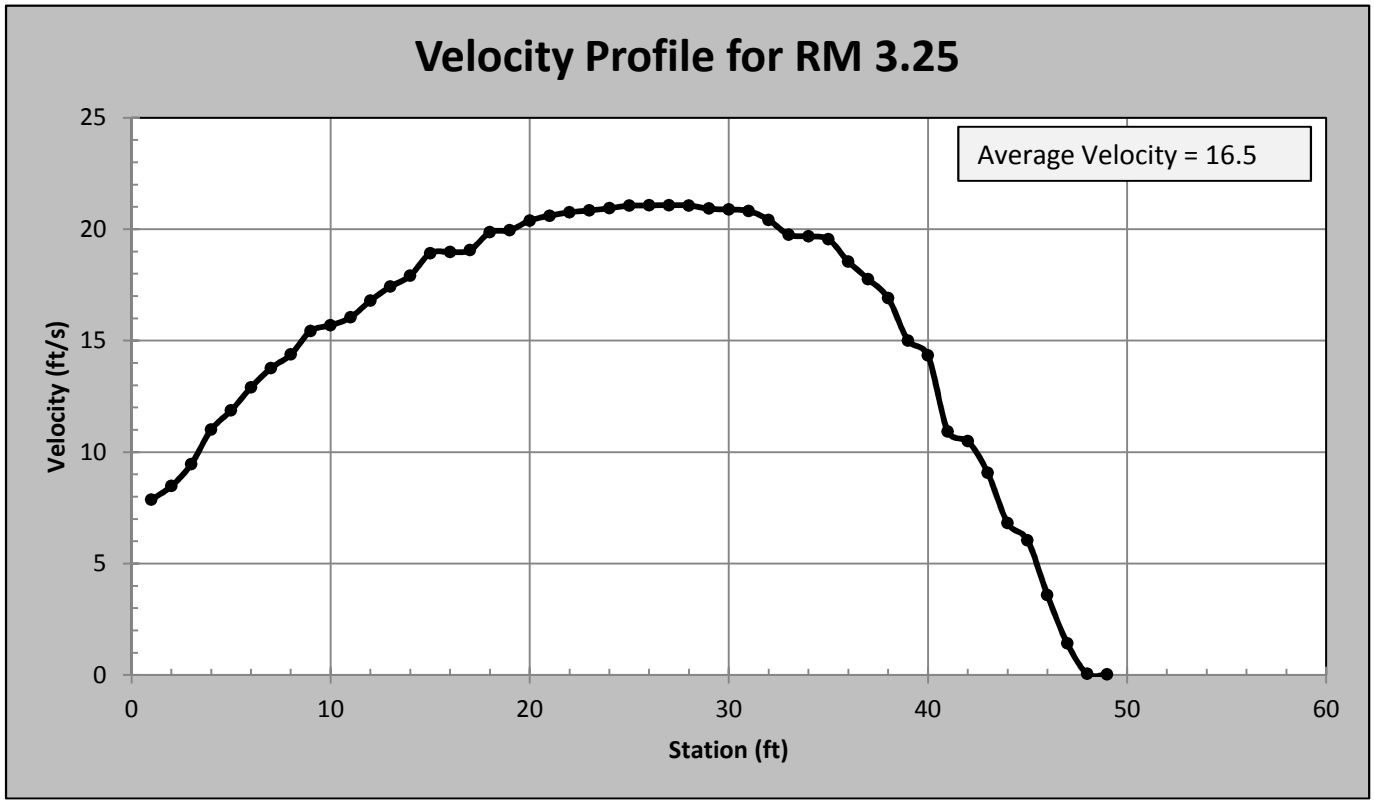


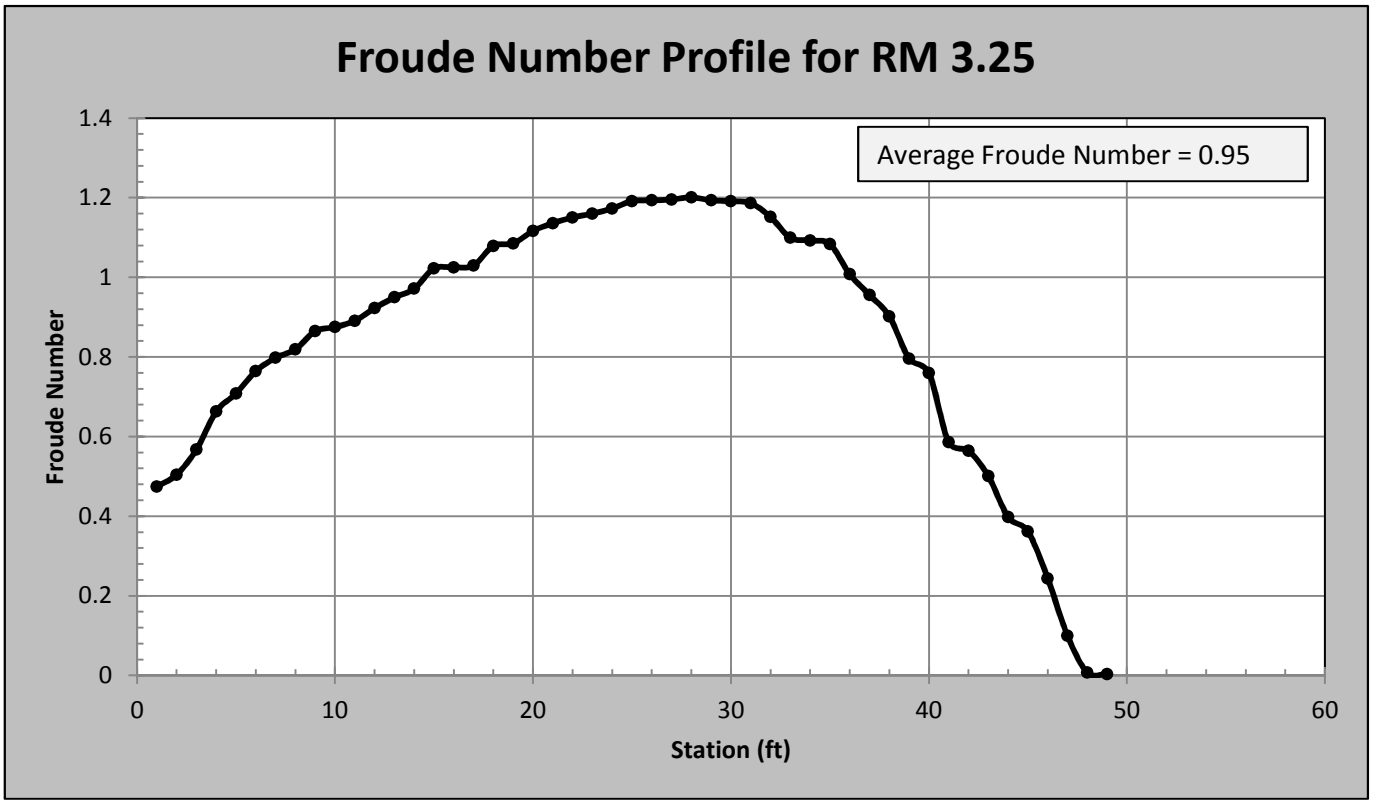
100-Year Event: 35,400cfs - River Mile 3



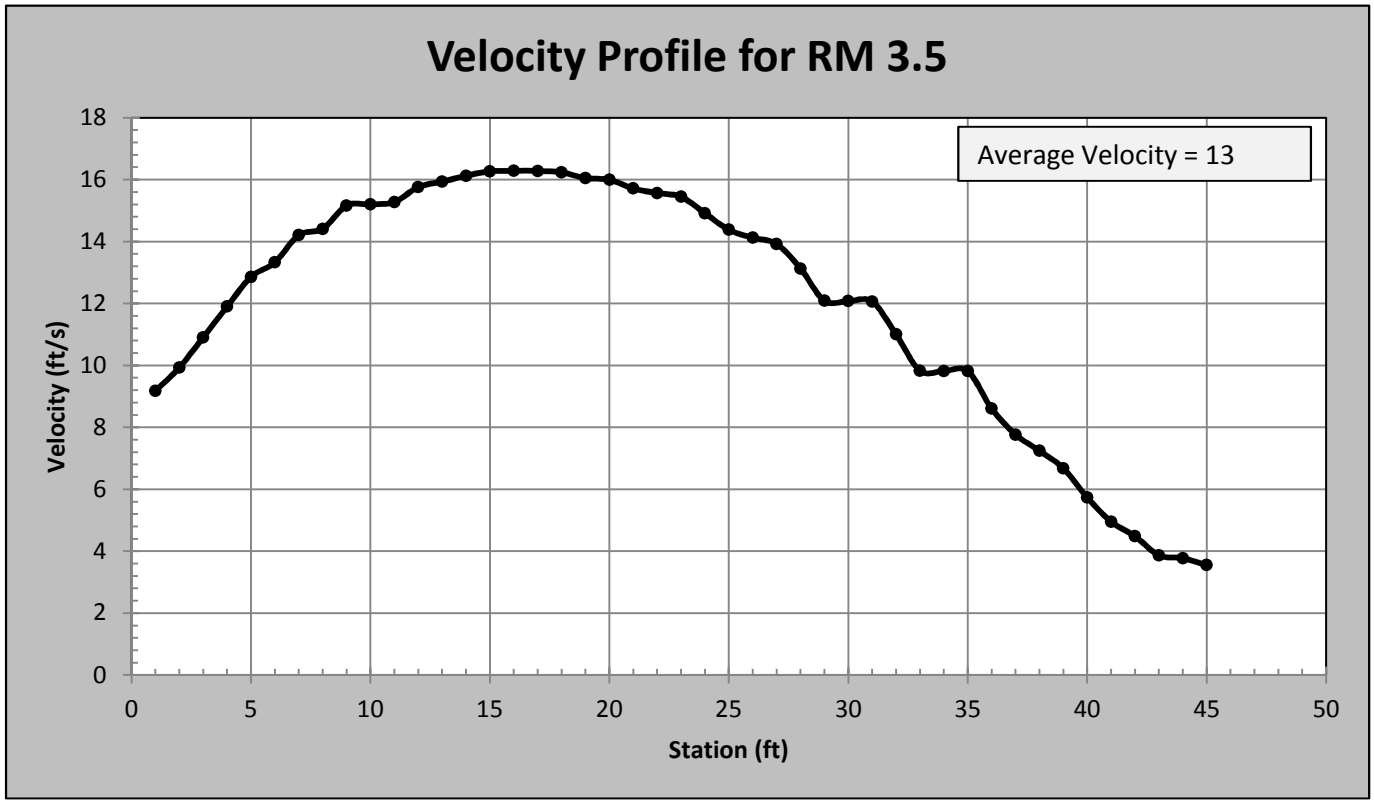


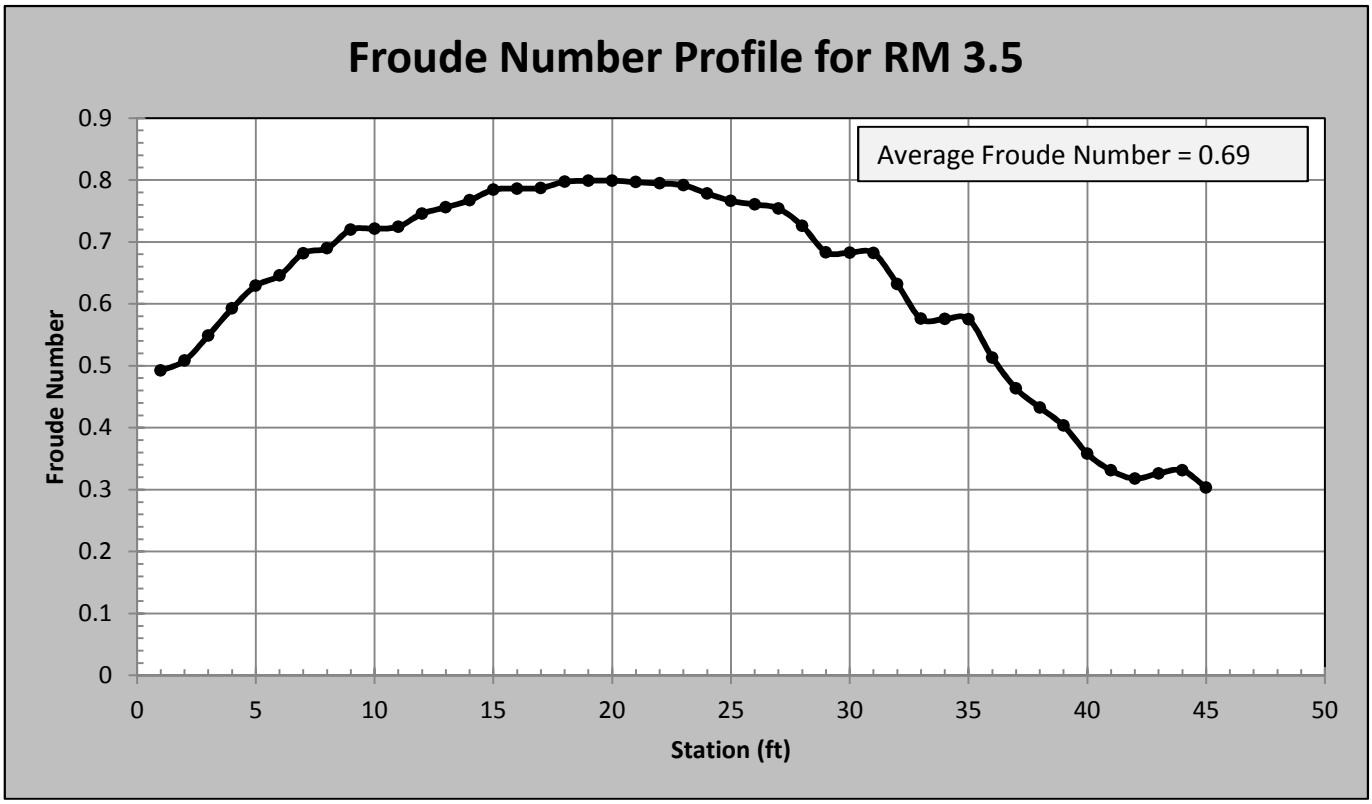
100-Year Event: 35,400cfs - River Mile 3.25



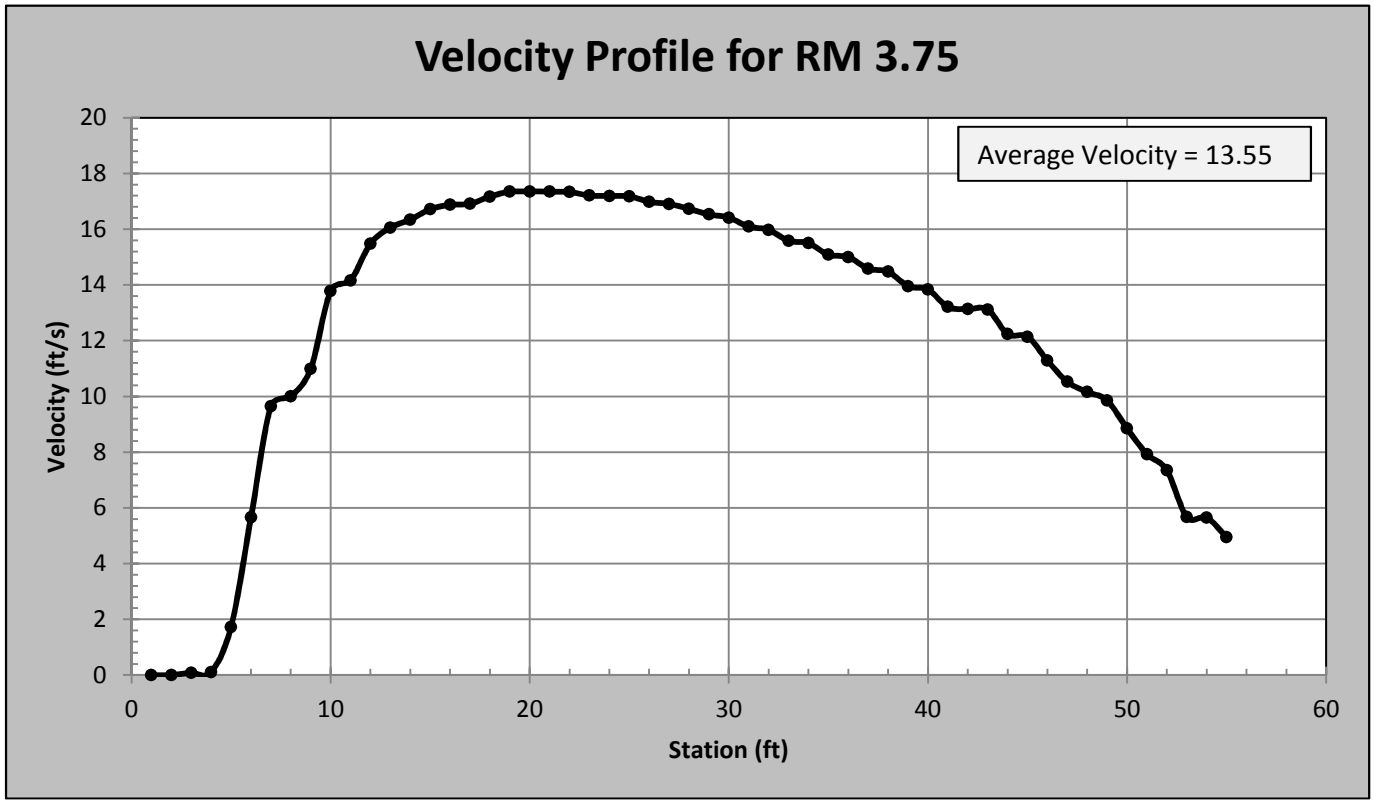


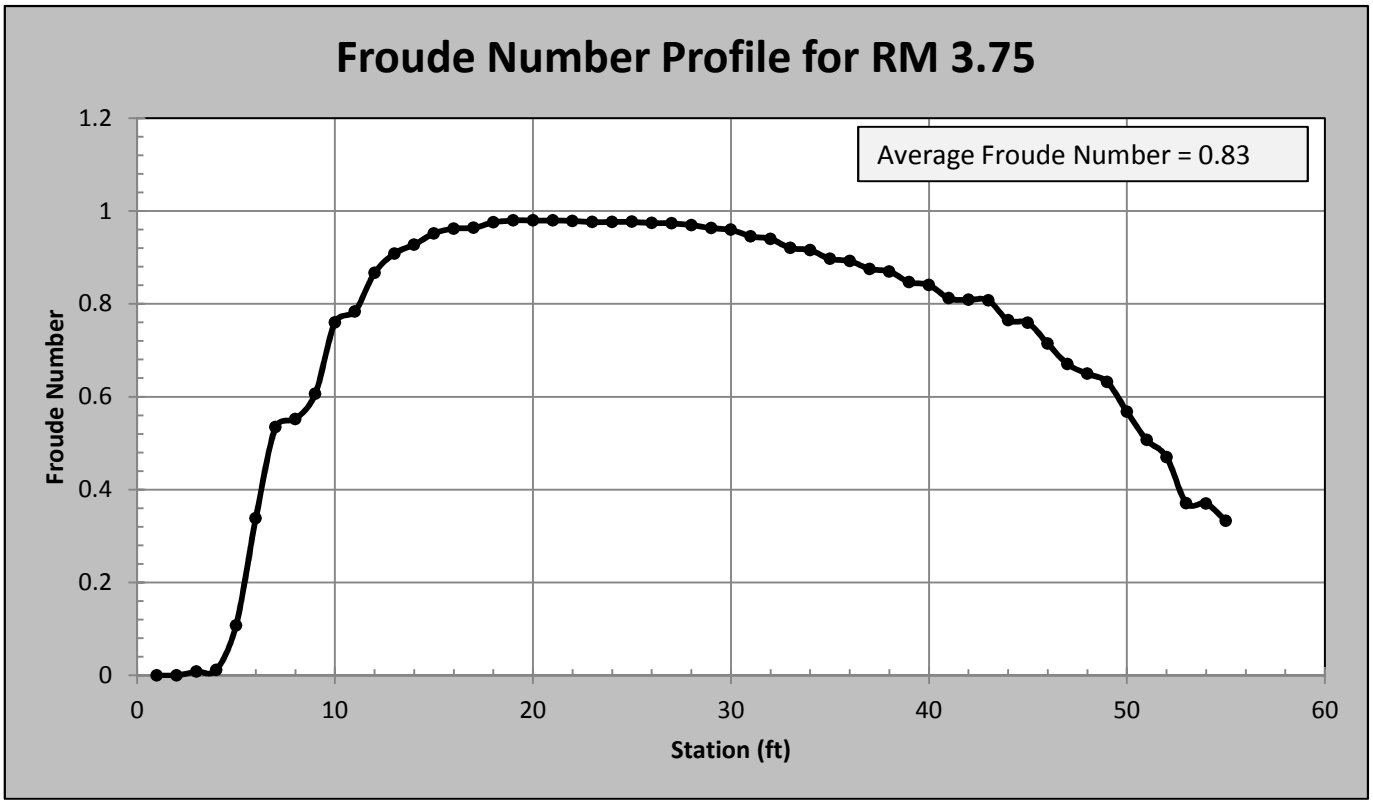
100-Year Event: 35,400cfs - River Mile 3.5



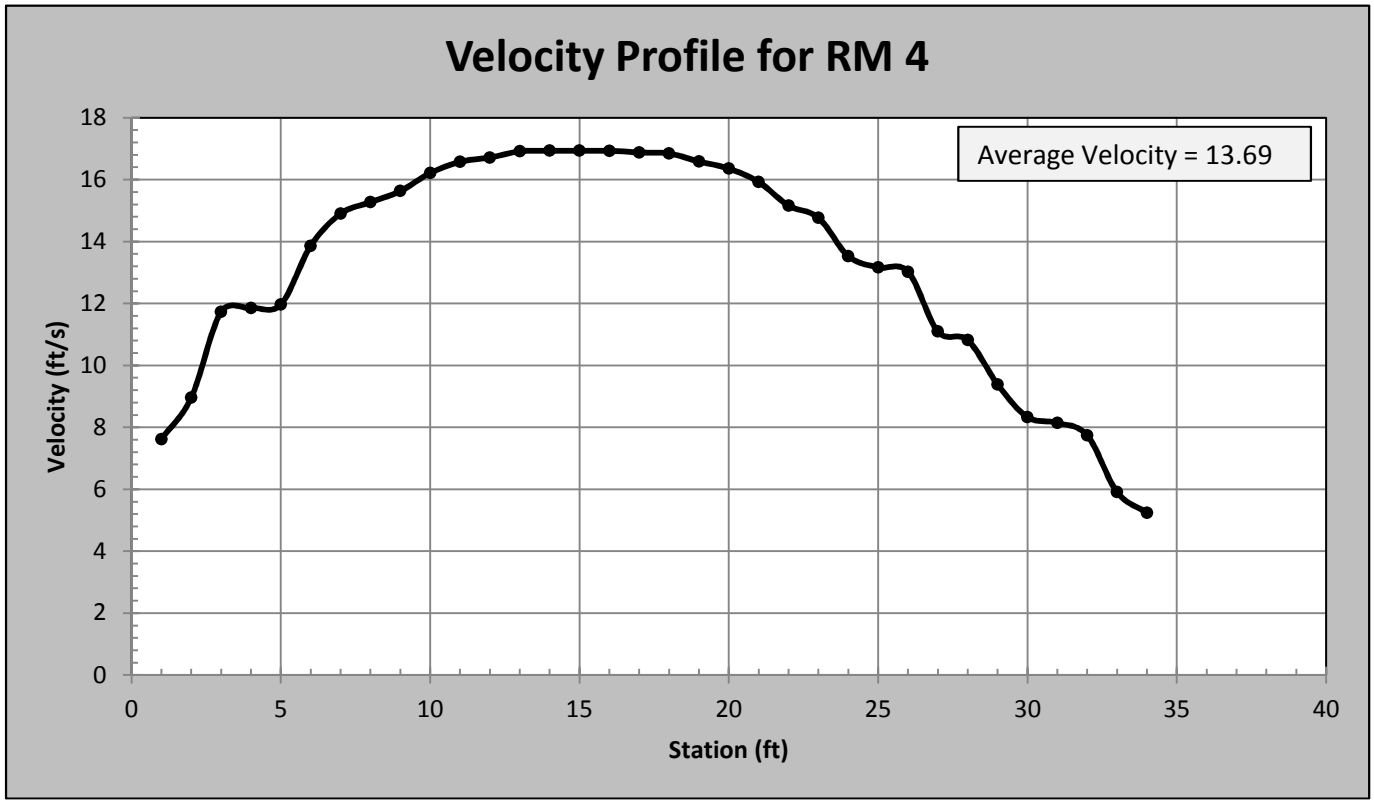


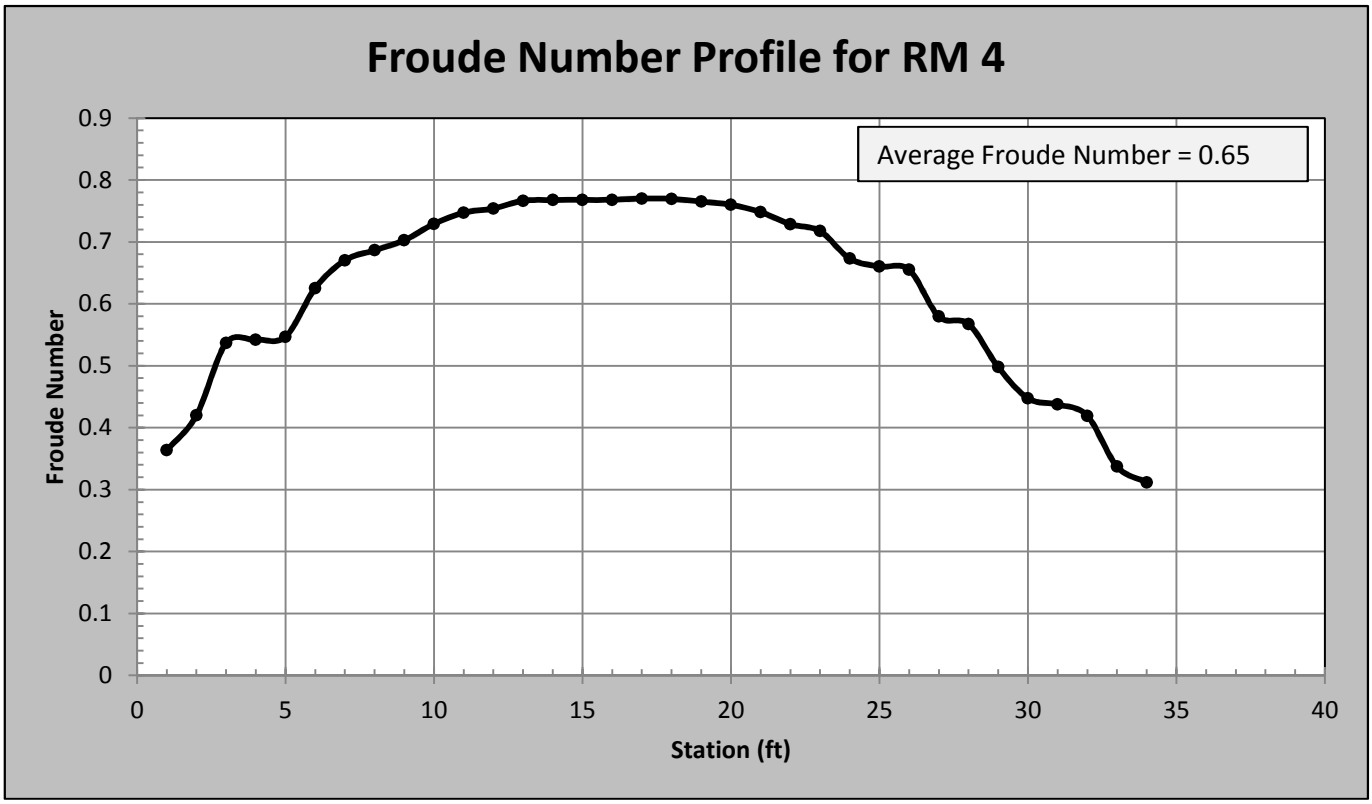
100-Year Event: 35,400cfs - River Mile 3.75



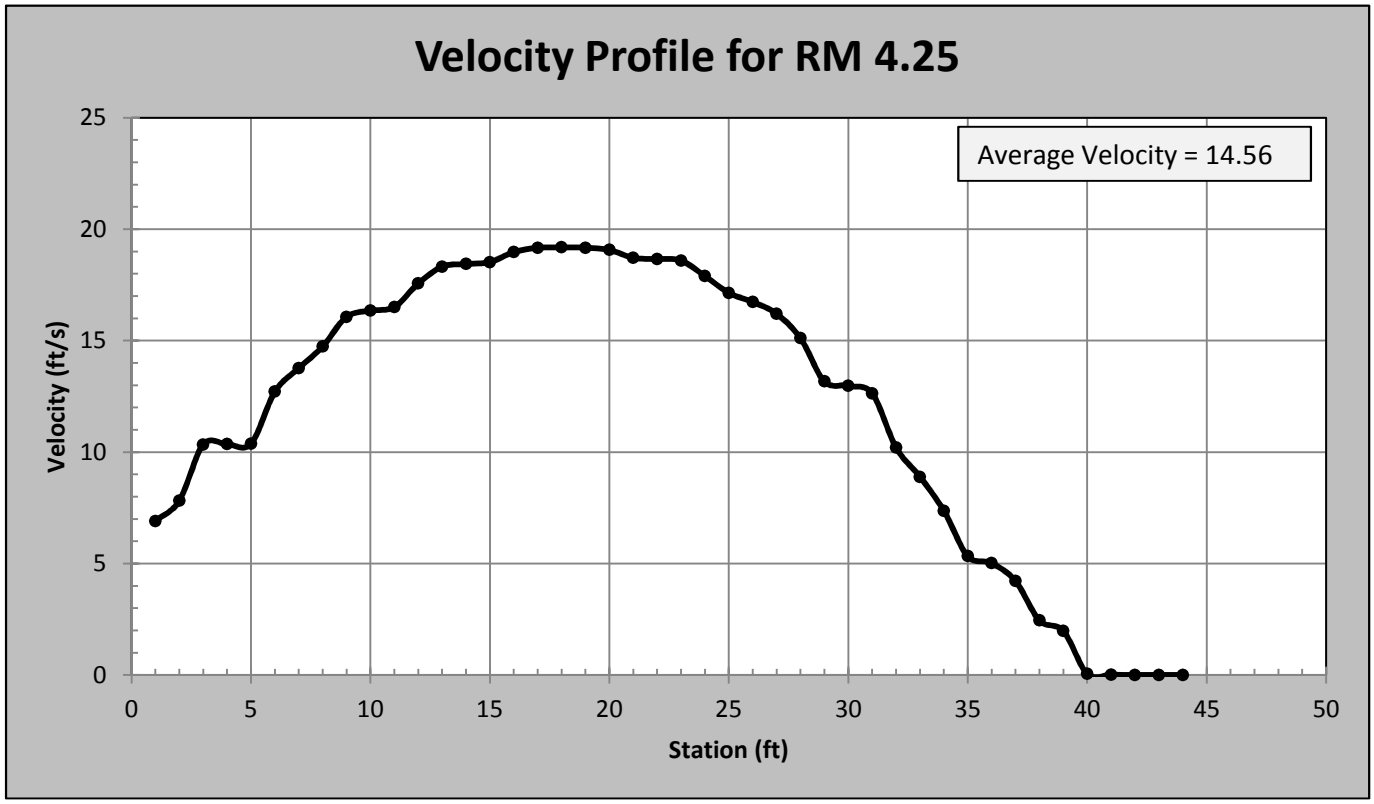


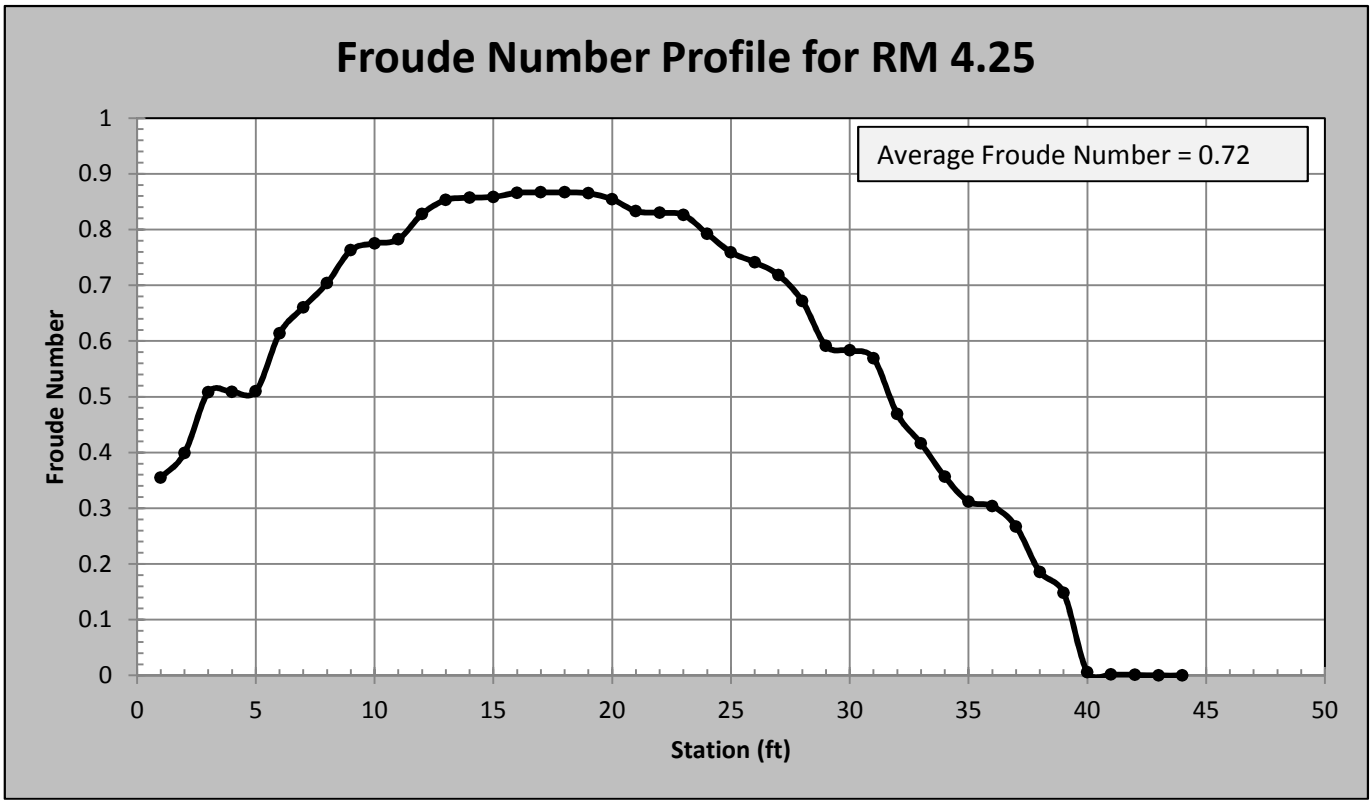
100-Year Event: 35,400cfs - River Mile 4



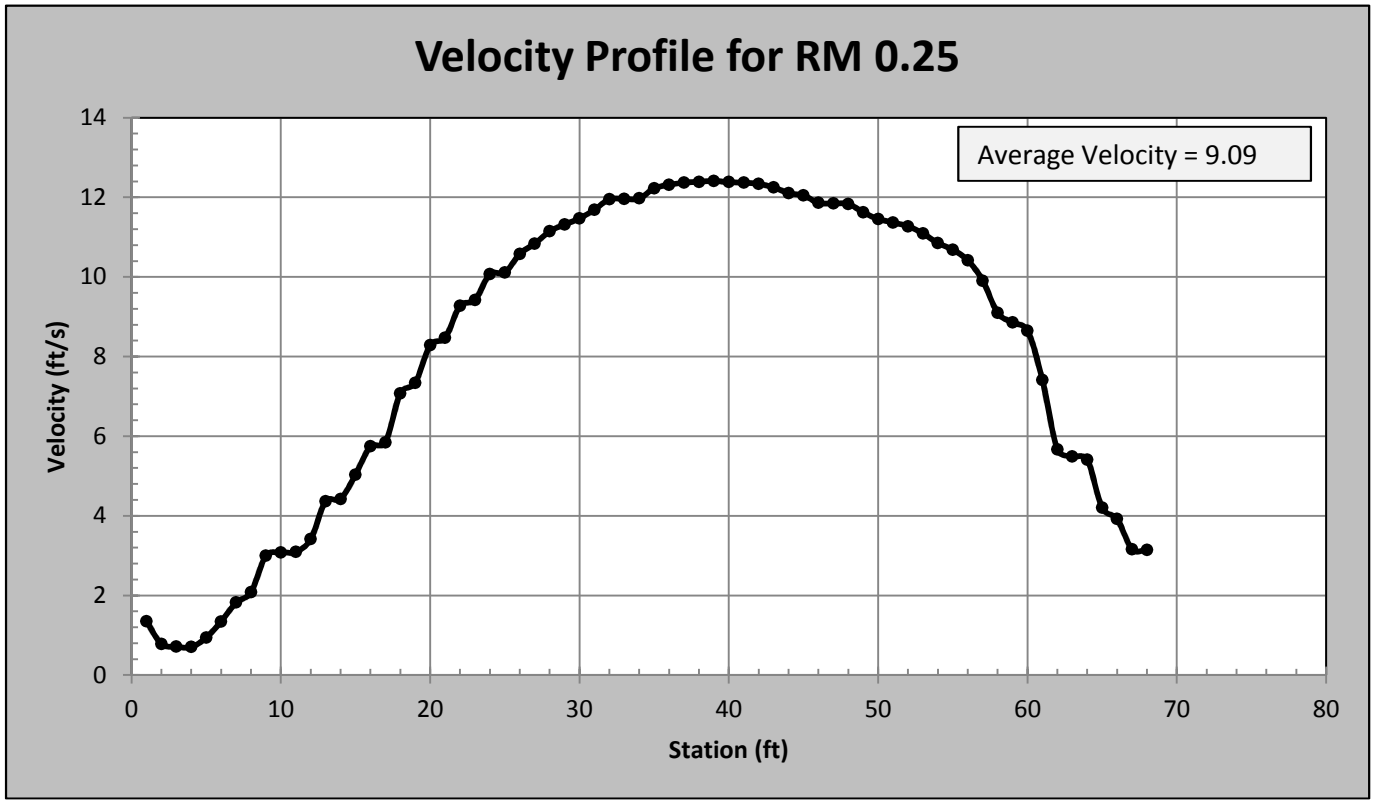


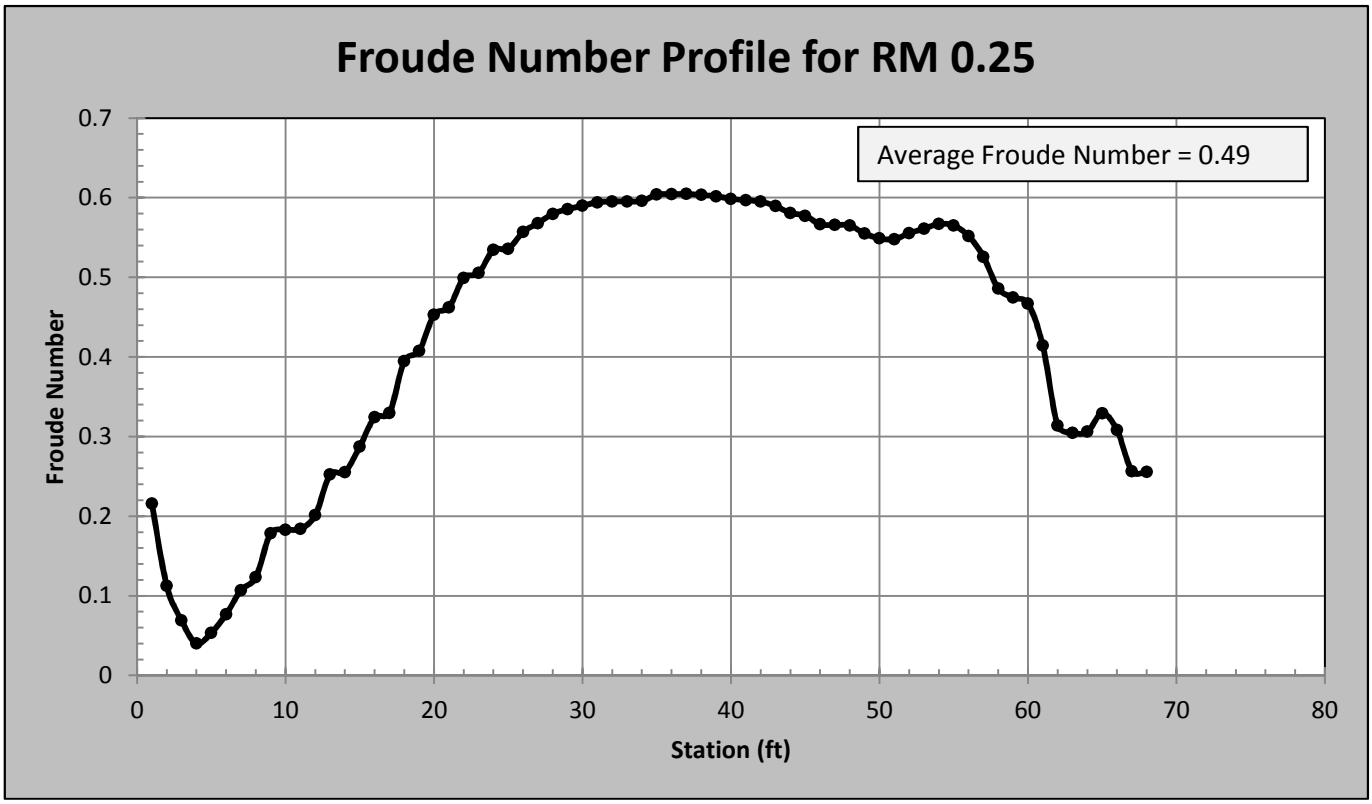
100-Year Event: 35,400cfs - River Mile 4.25



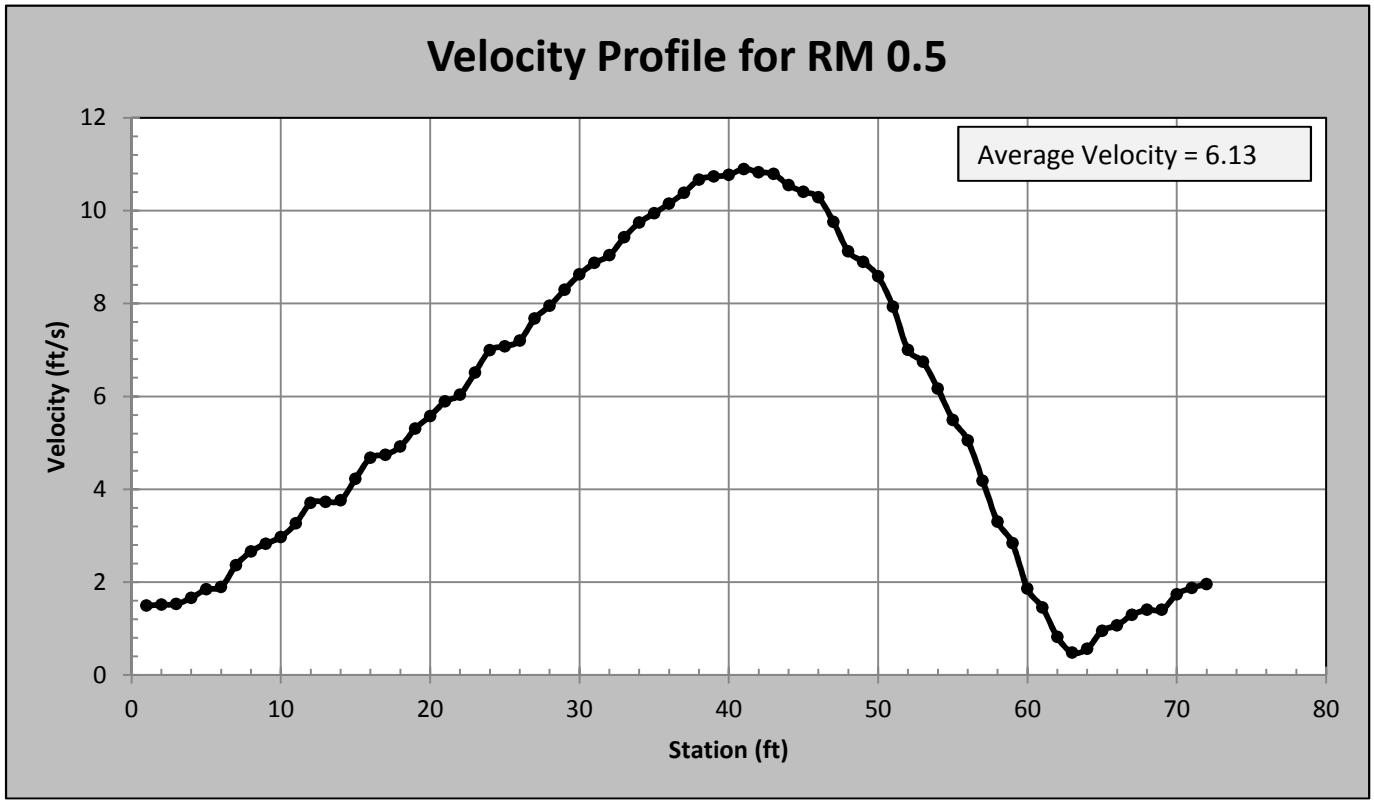


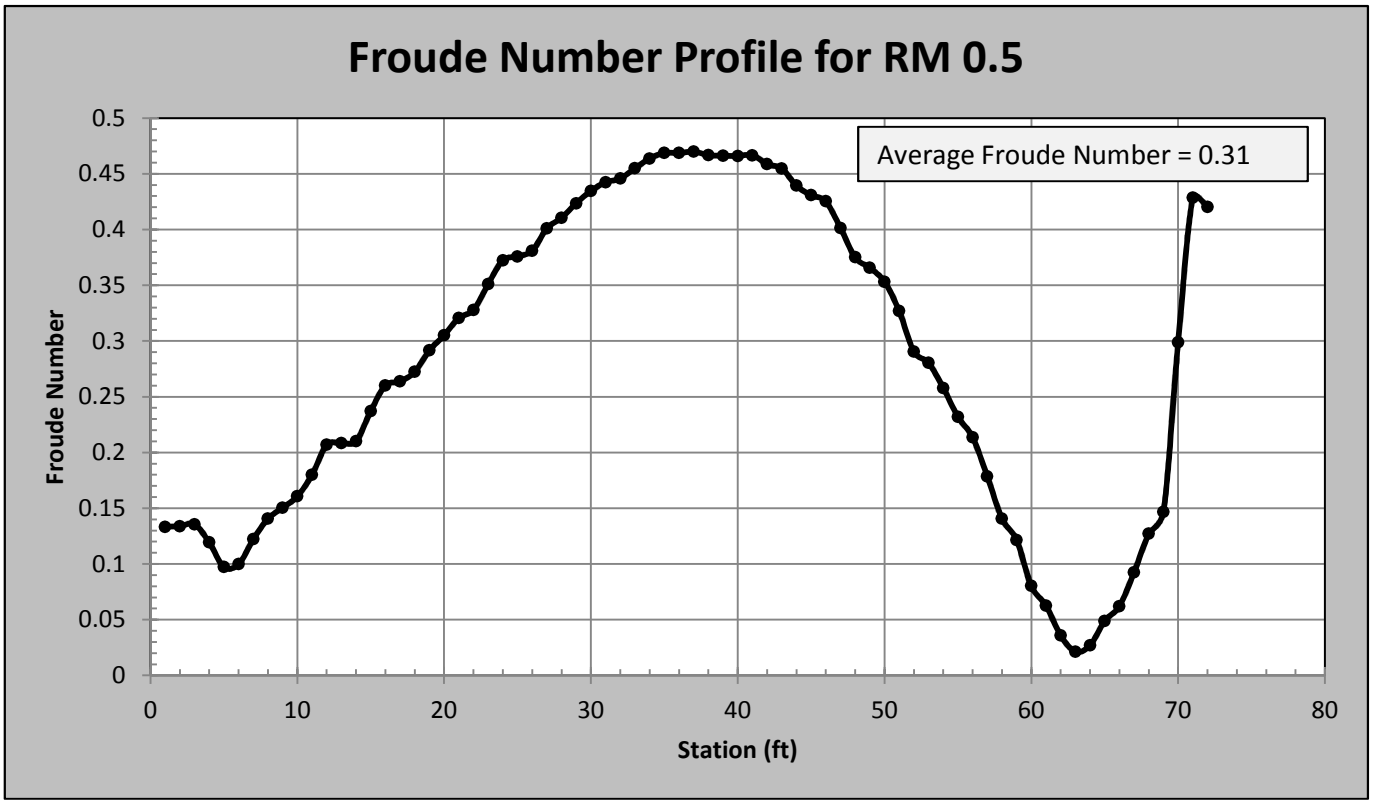
500-Year Event: 41,000cfs - River Mile 0.25



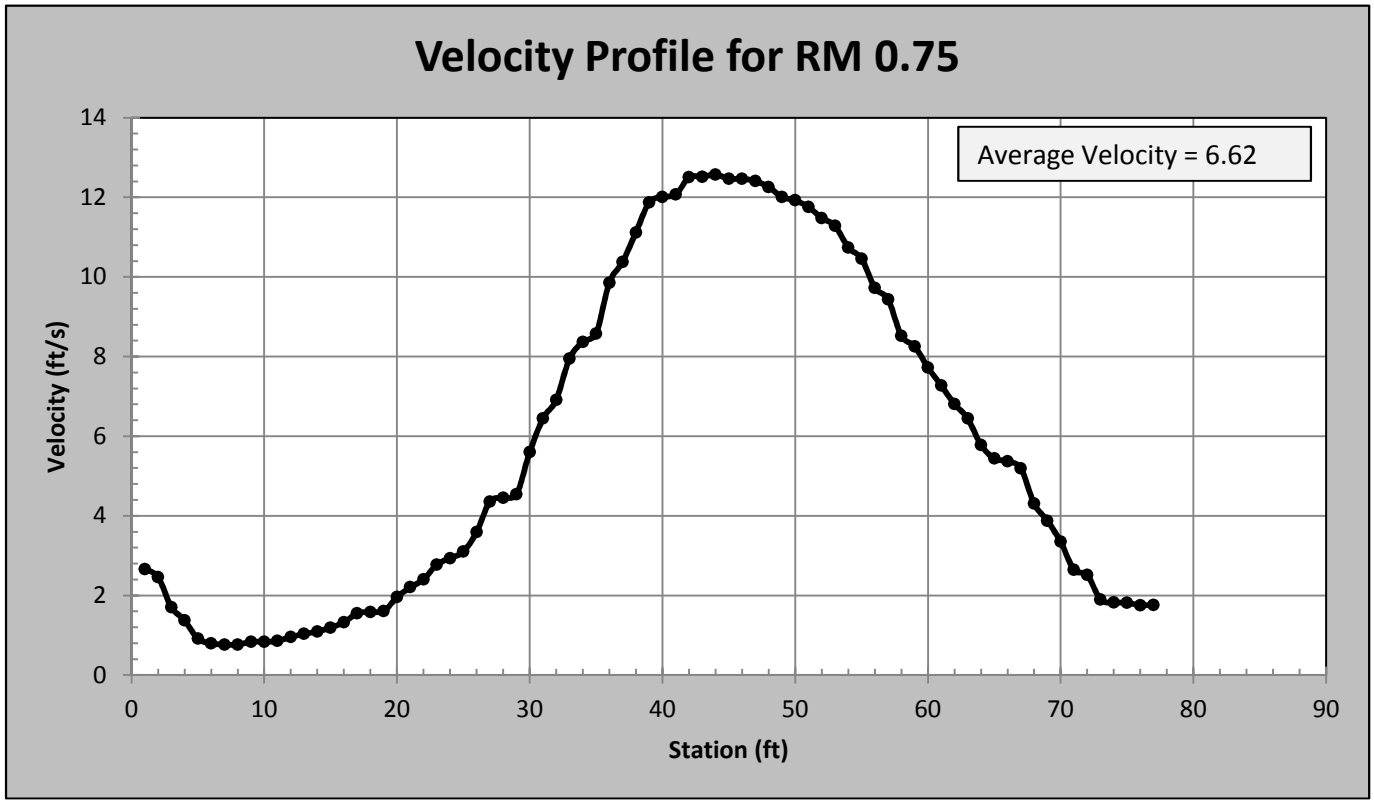


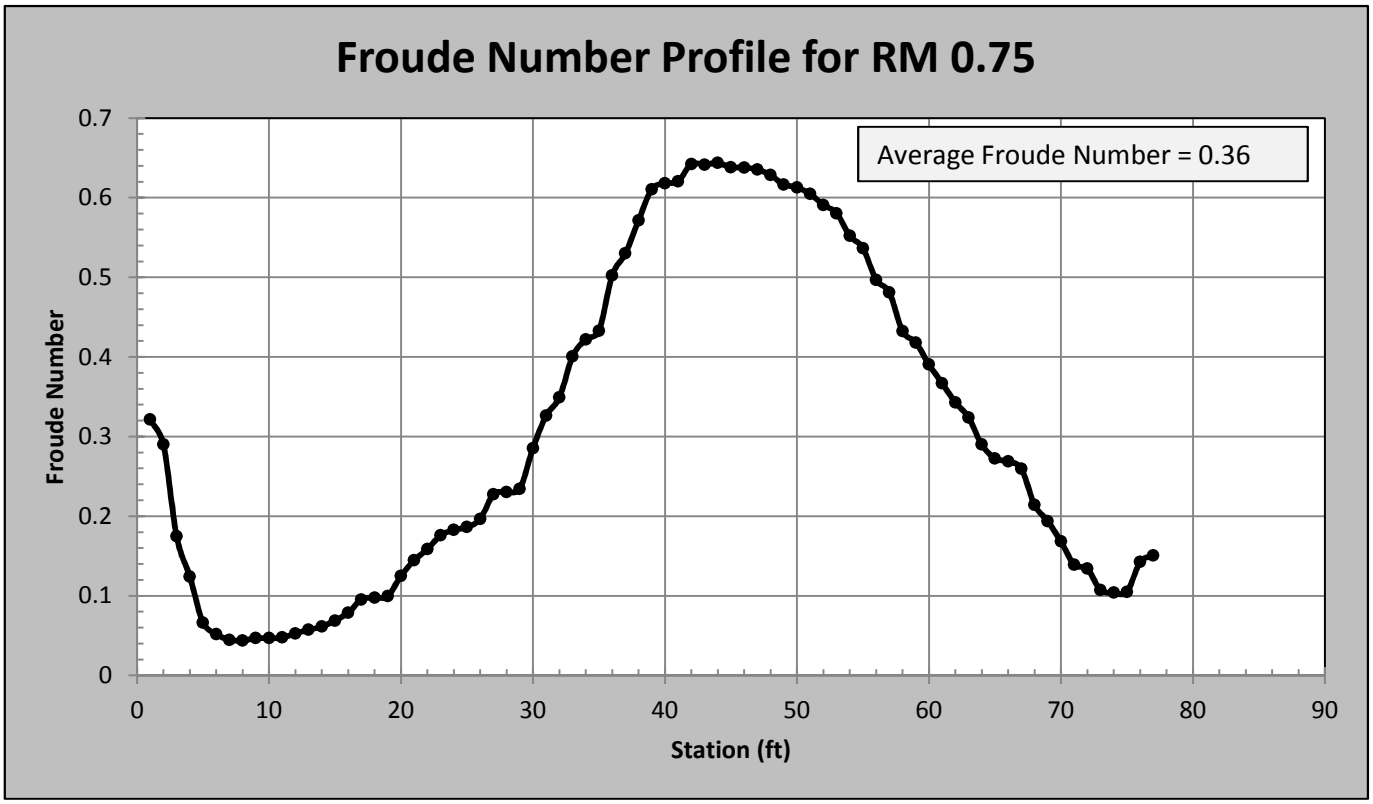
500-Year Event: 41,000cfs - River Mile 0.5



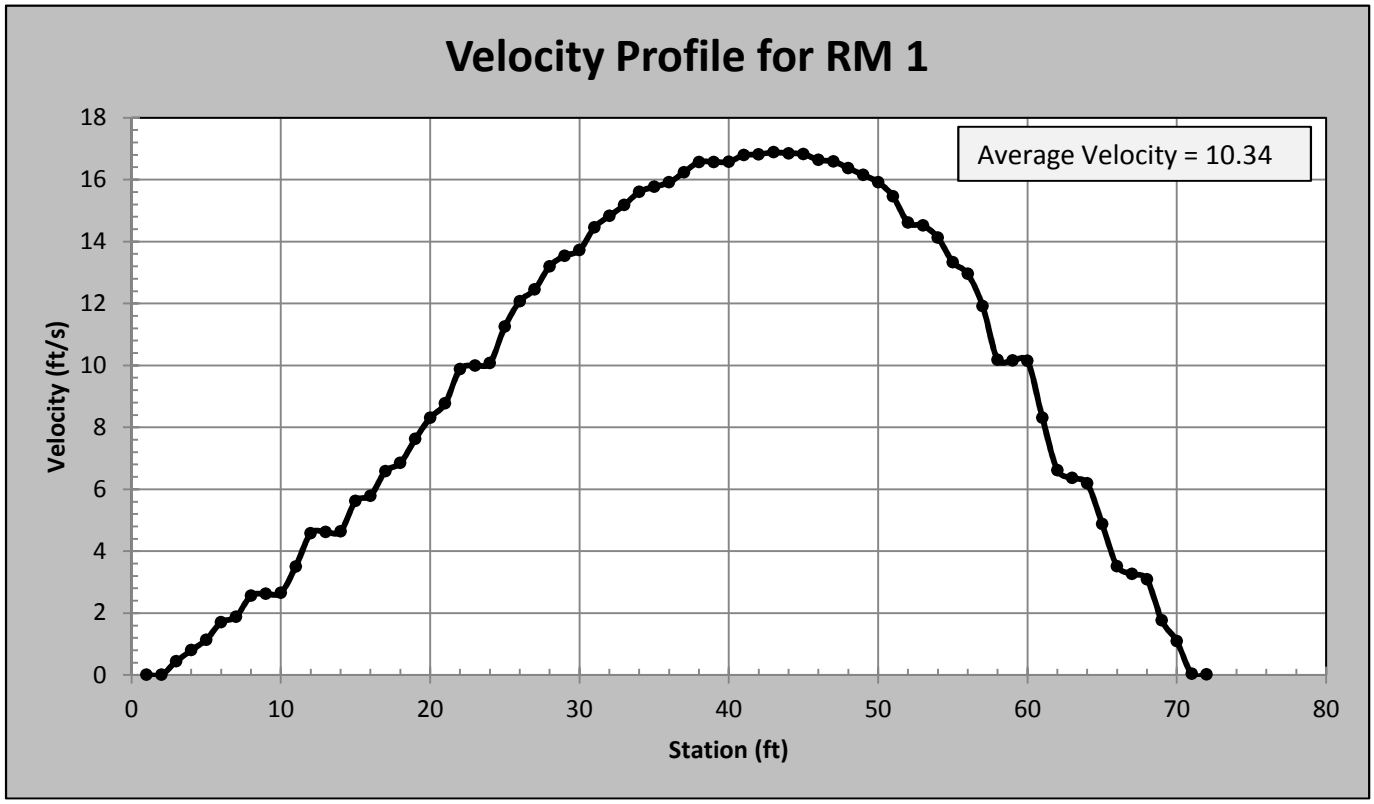


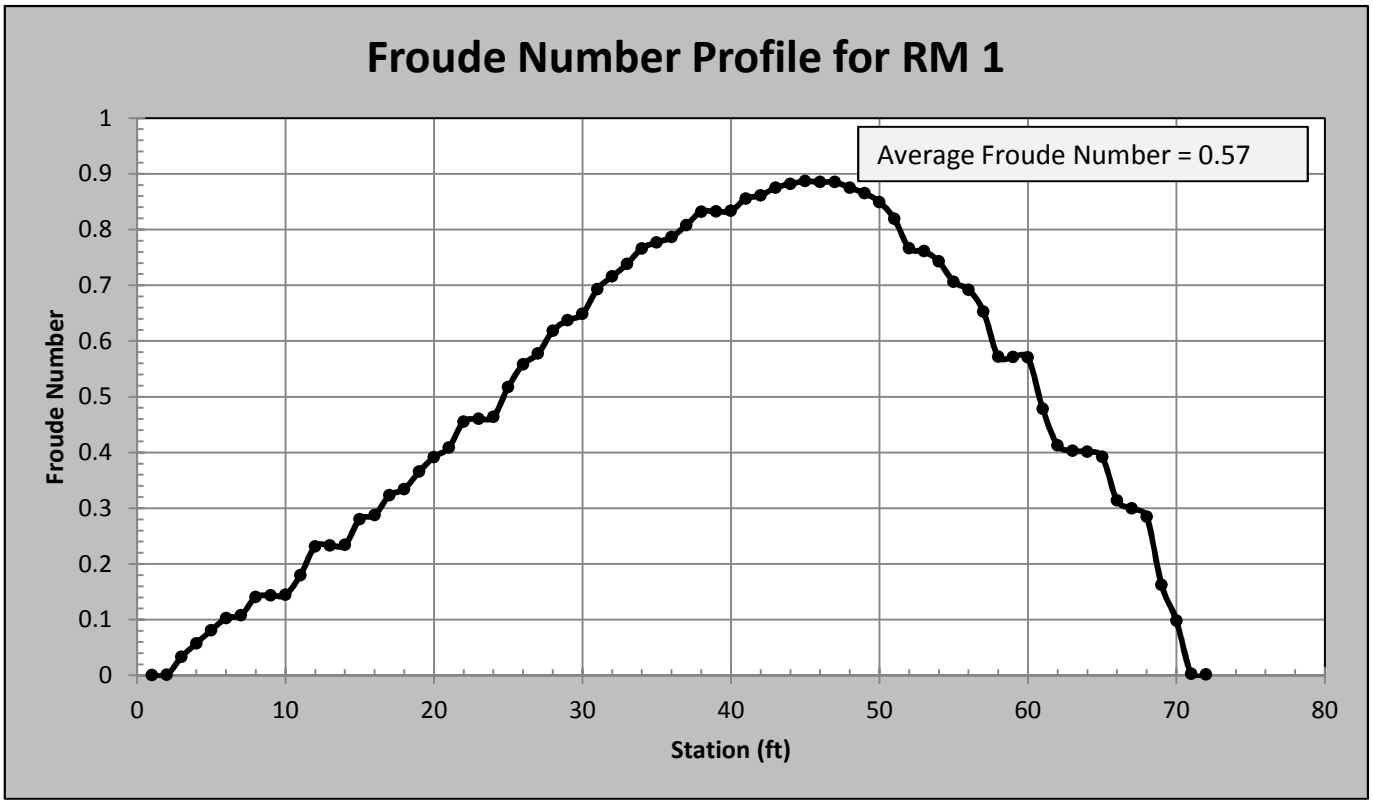
500-Year Event: 41,000cfs - River Mile 0.75



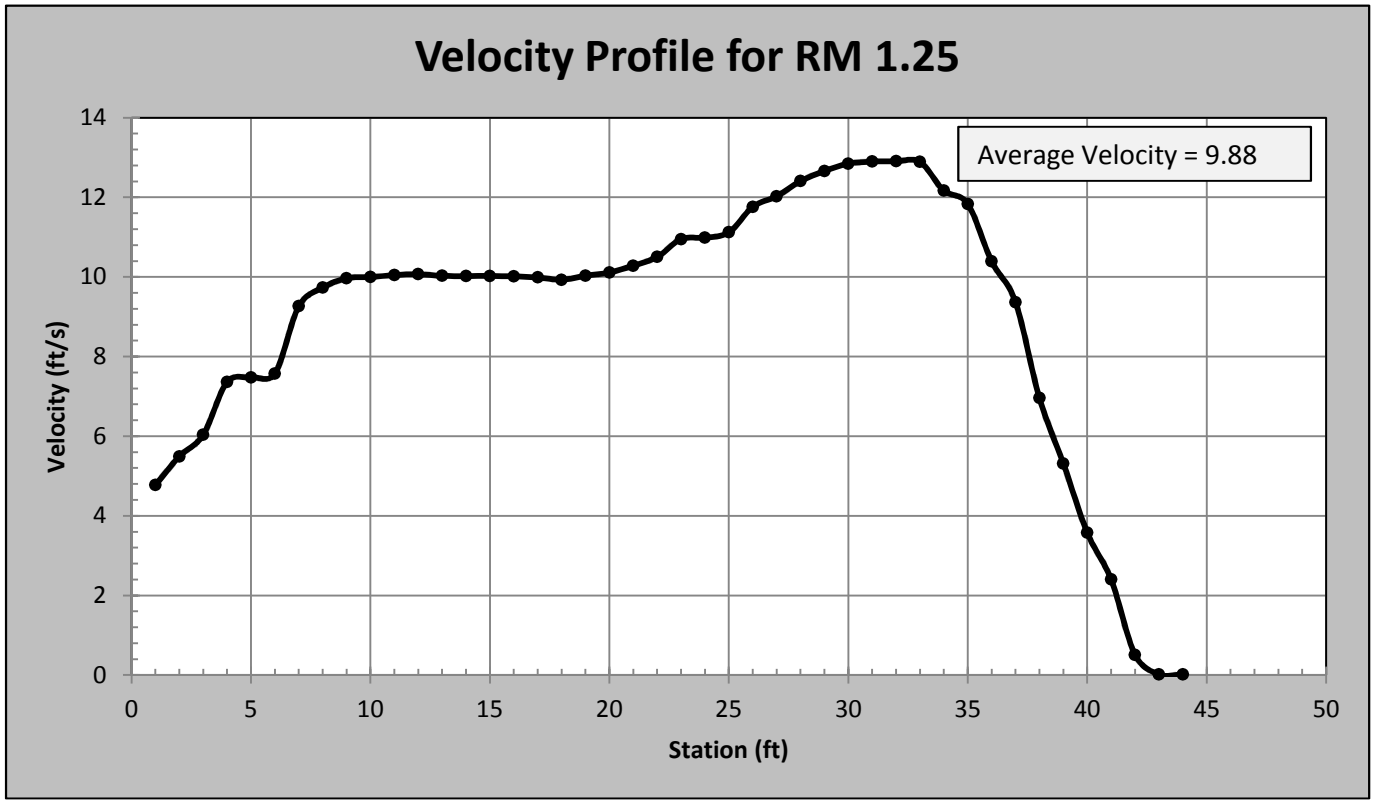


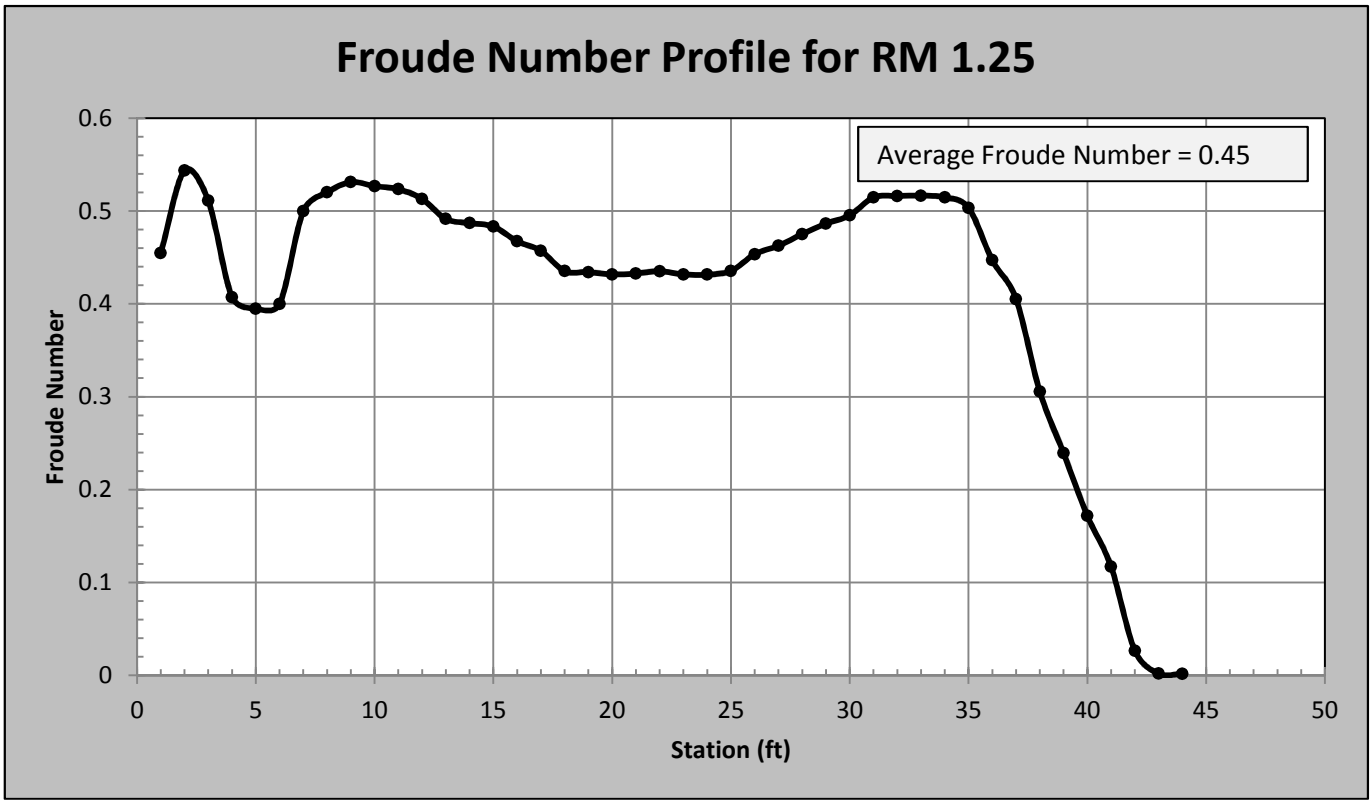
500-Year Event: 41,000cfs - River Mile 1



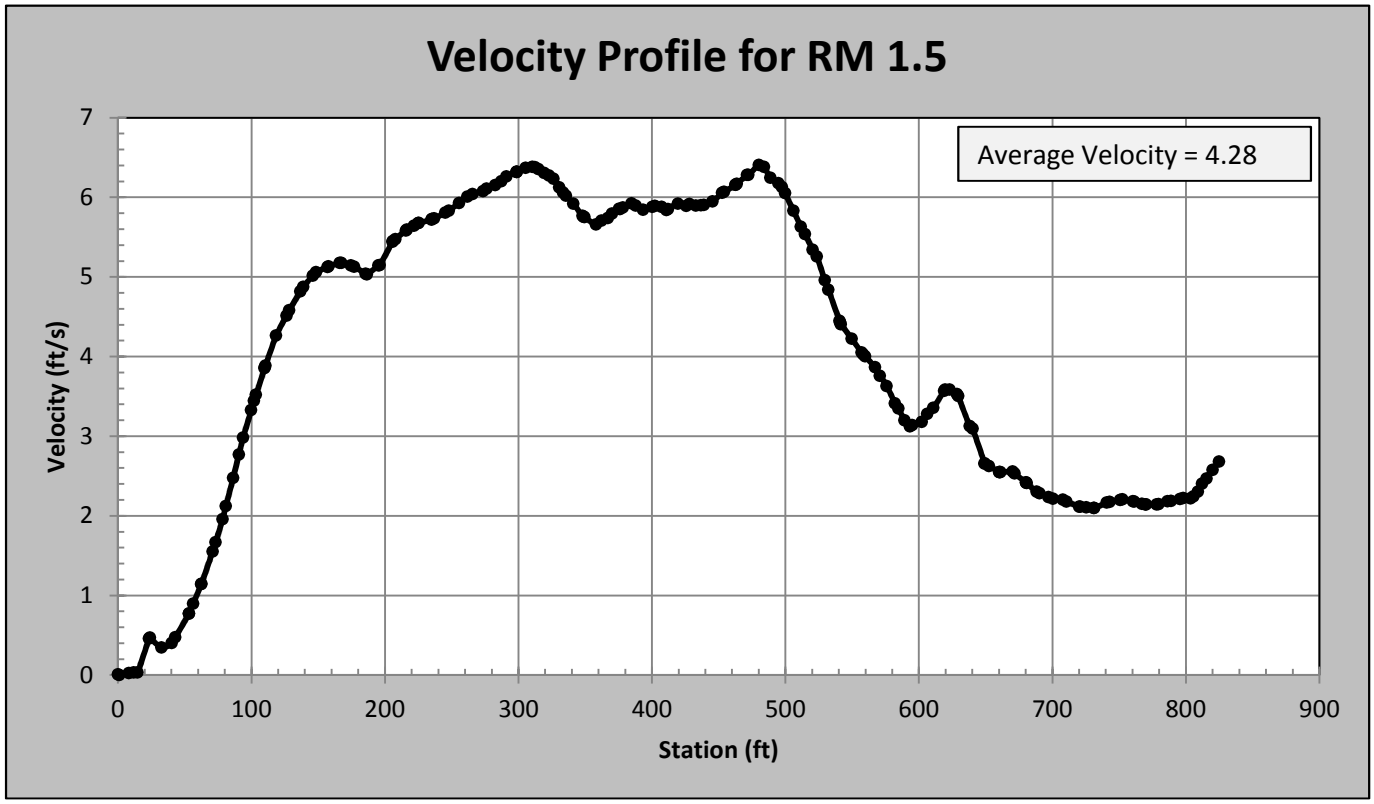


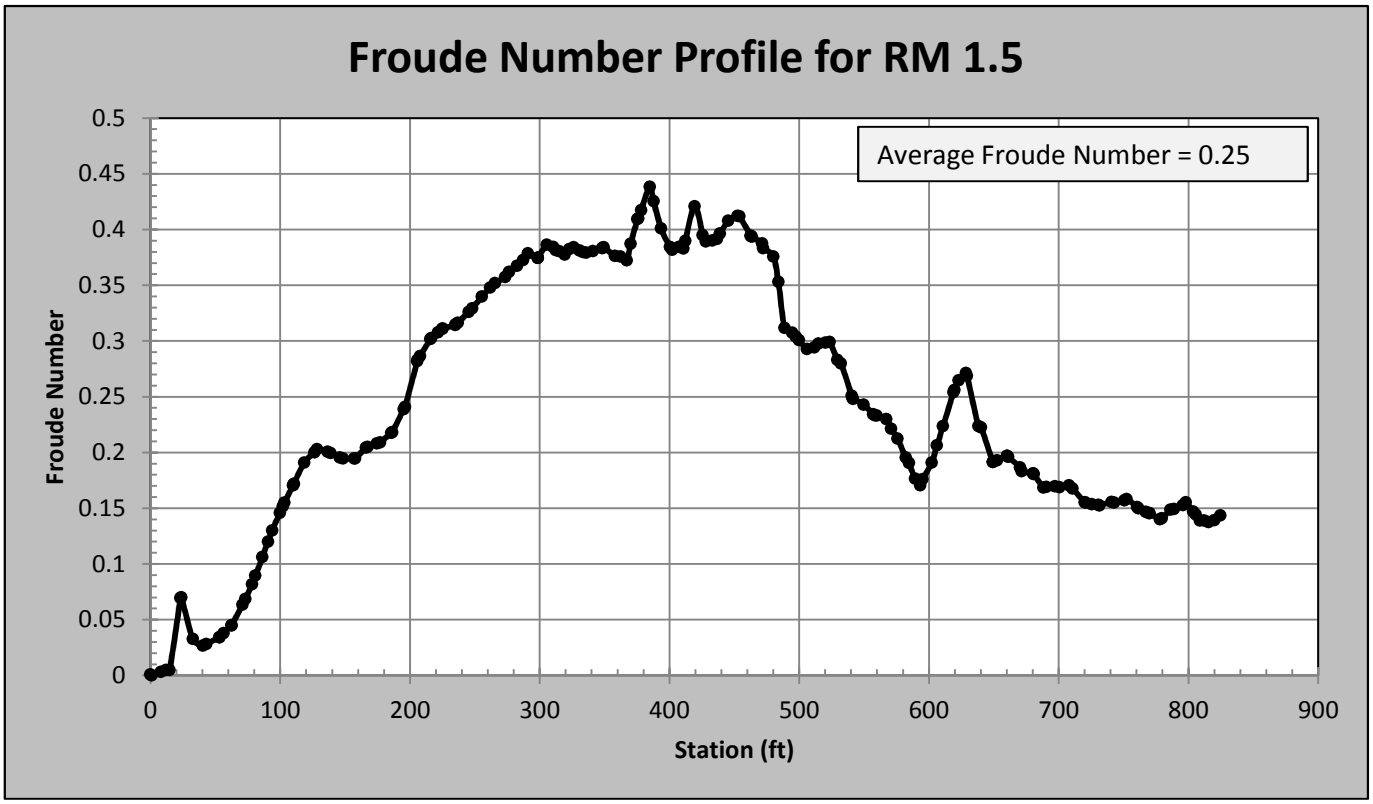
500-Year Event: 41,000cfs - River Mile 1.25



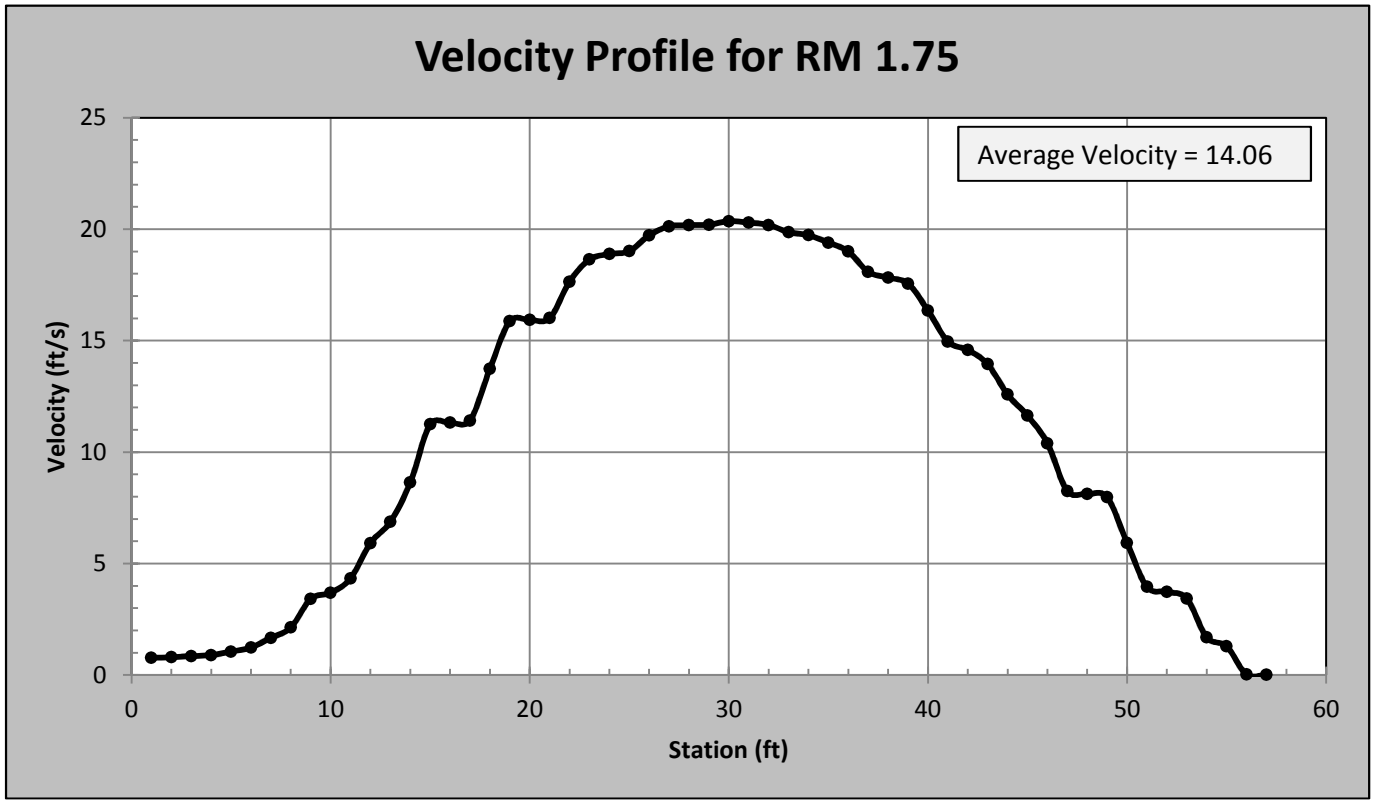


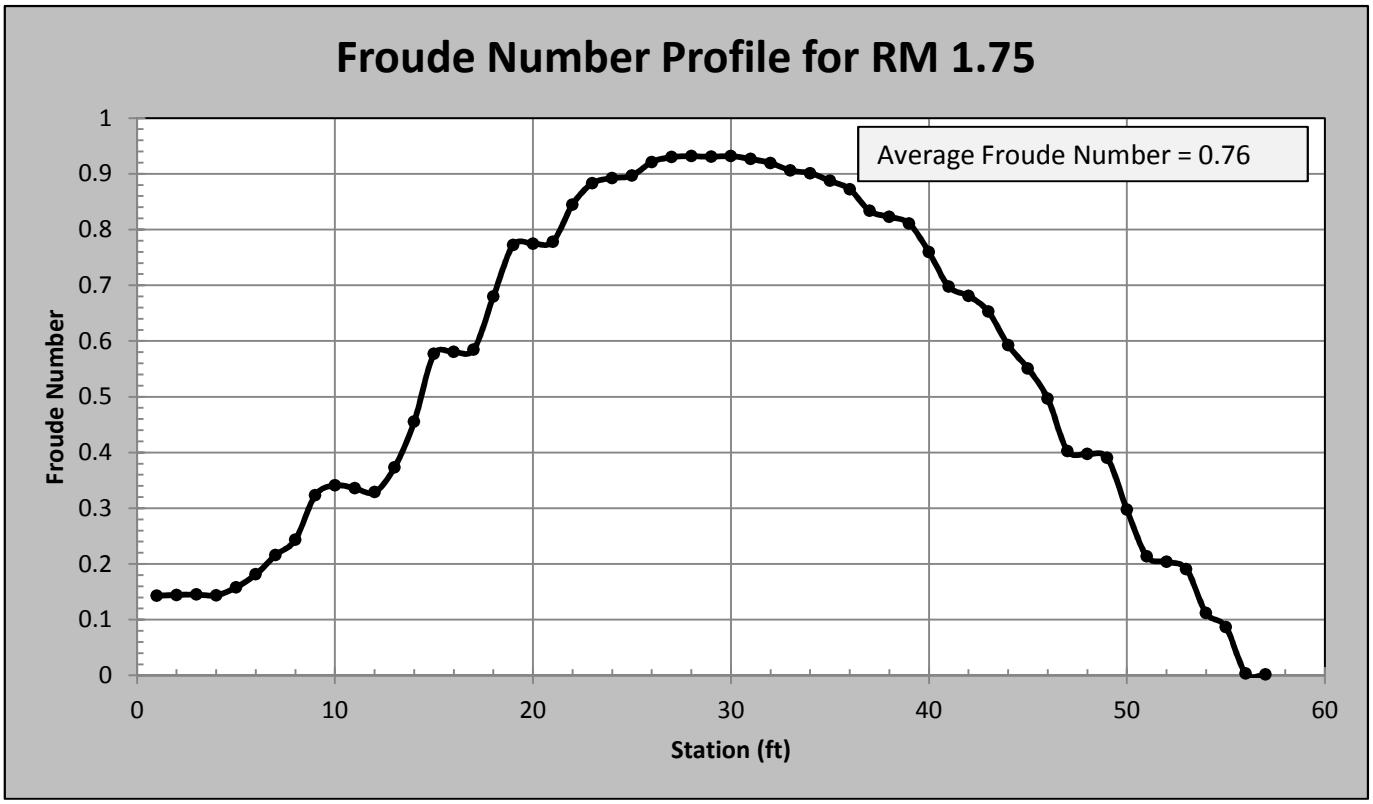
500-Year Event: 41,000cfs - River Mile 1.5



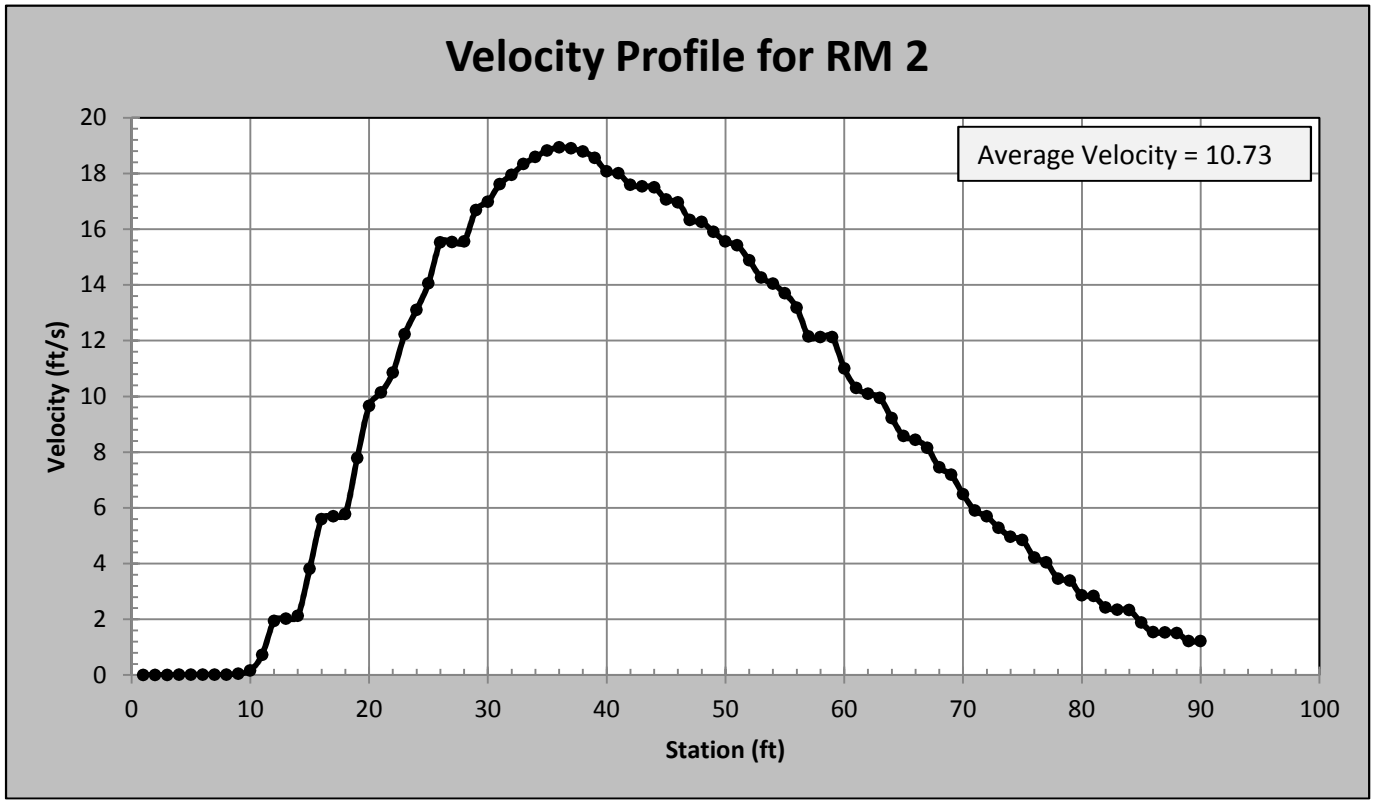


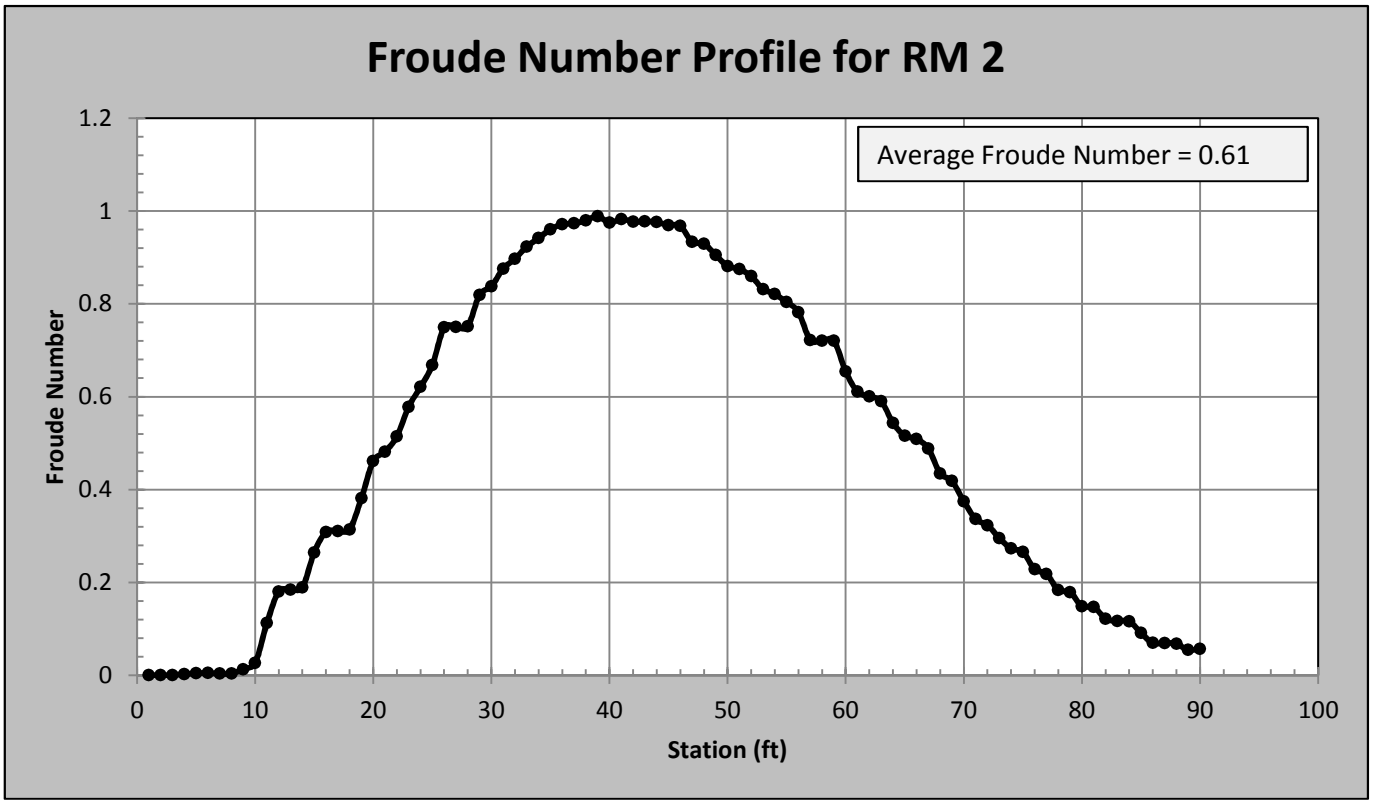
500-Year Event: 41,000cfs - River Mile 1.75



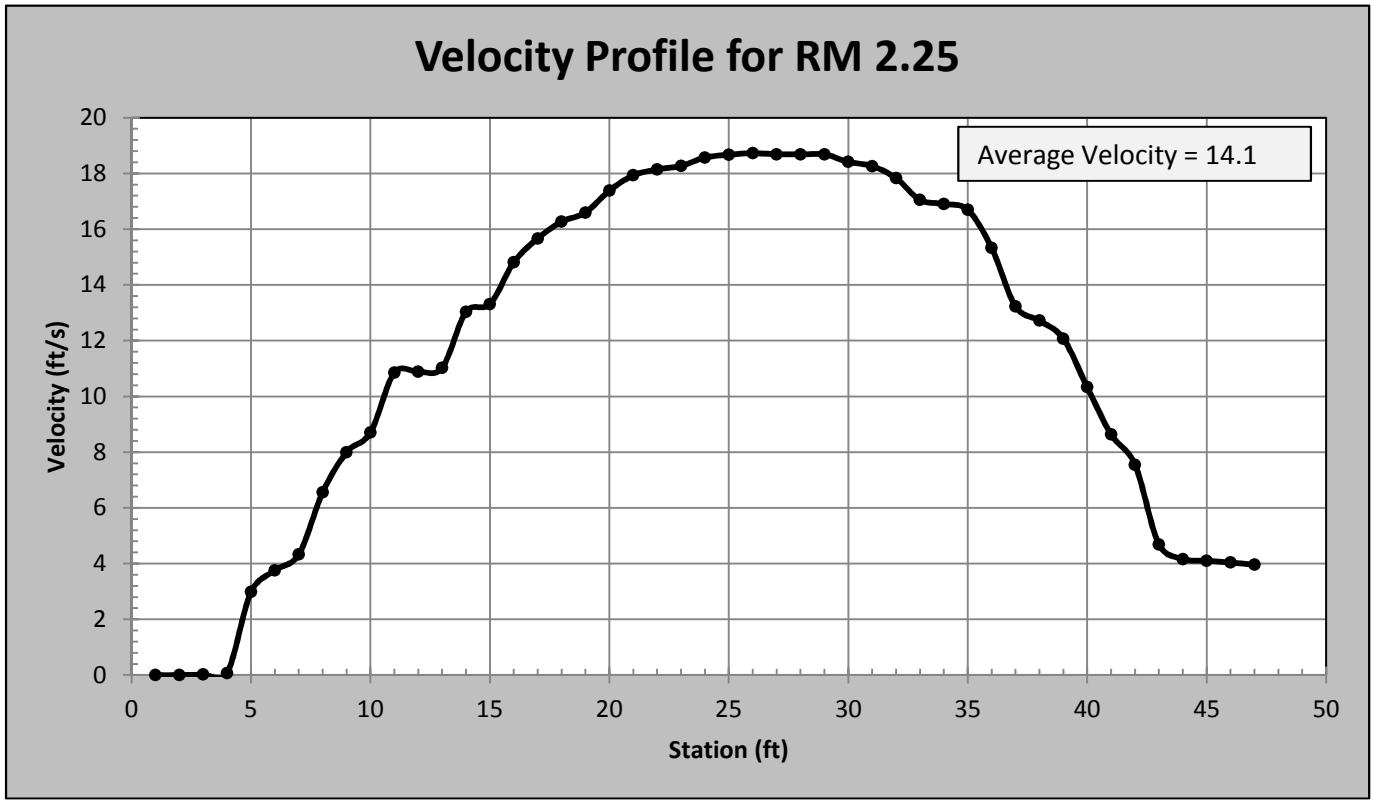


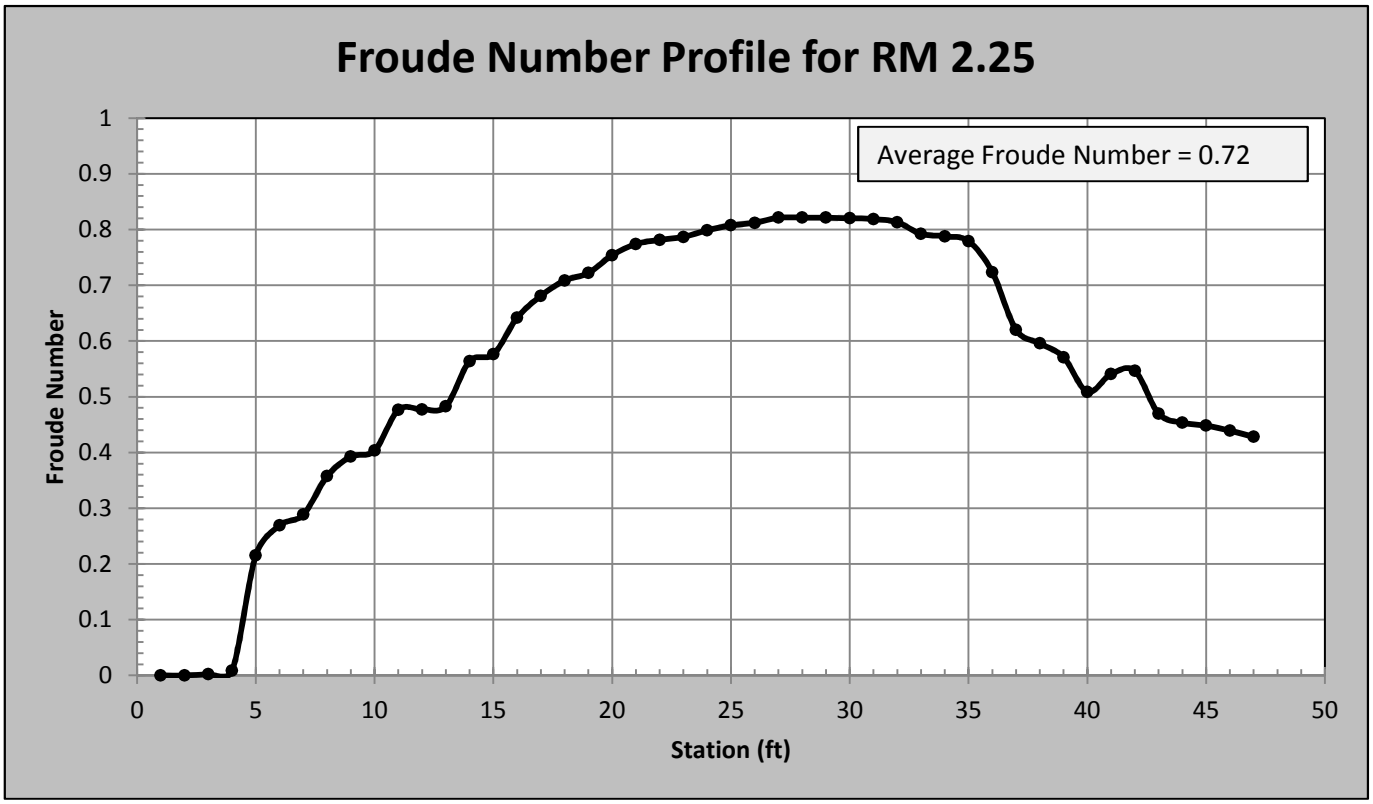
500-Year Event: 41,000cfs - River Mile 2



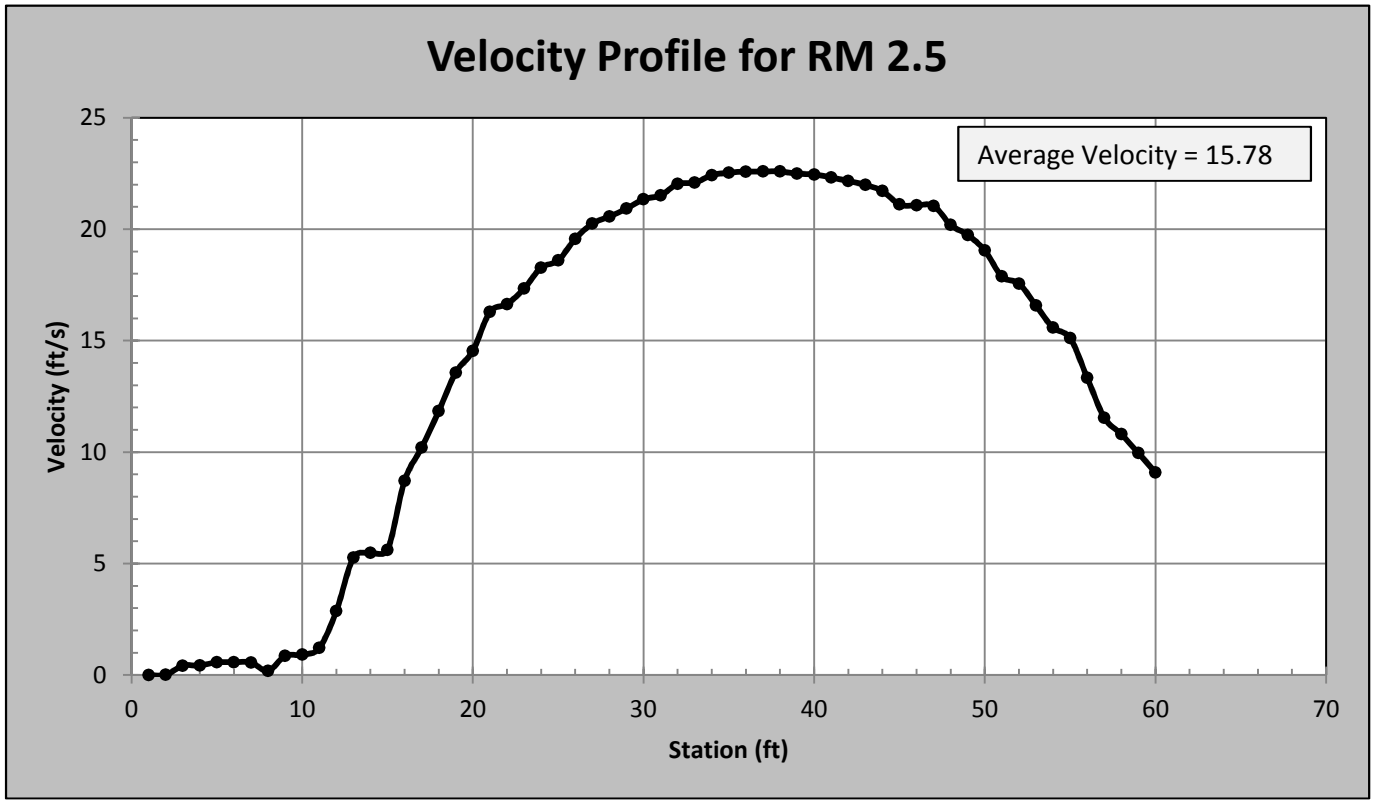


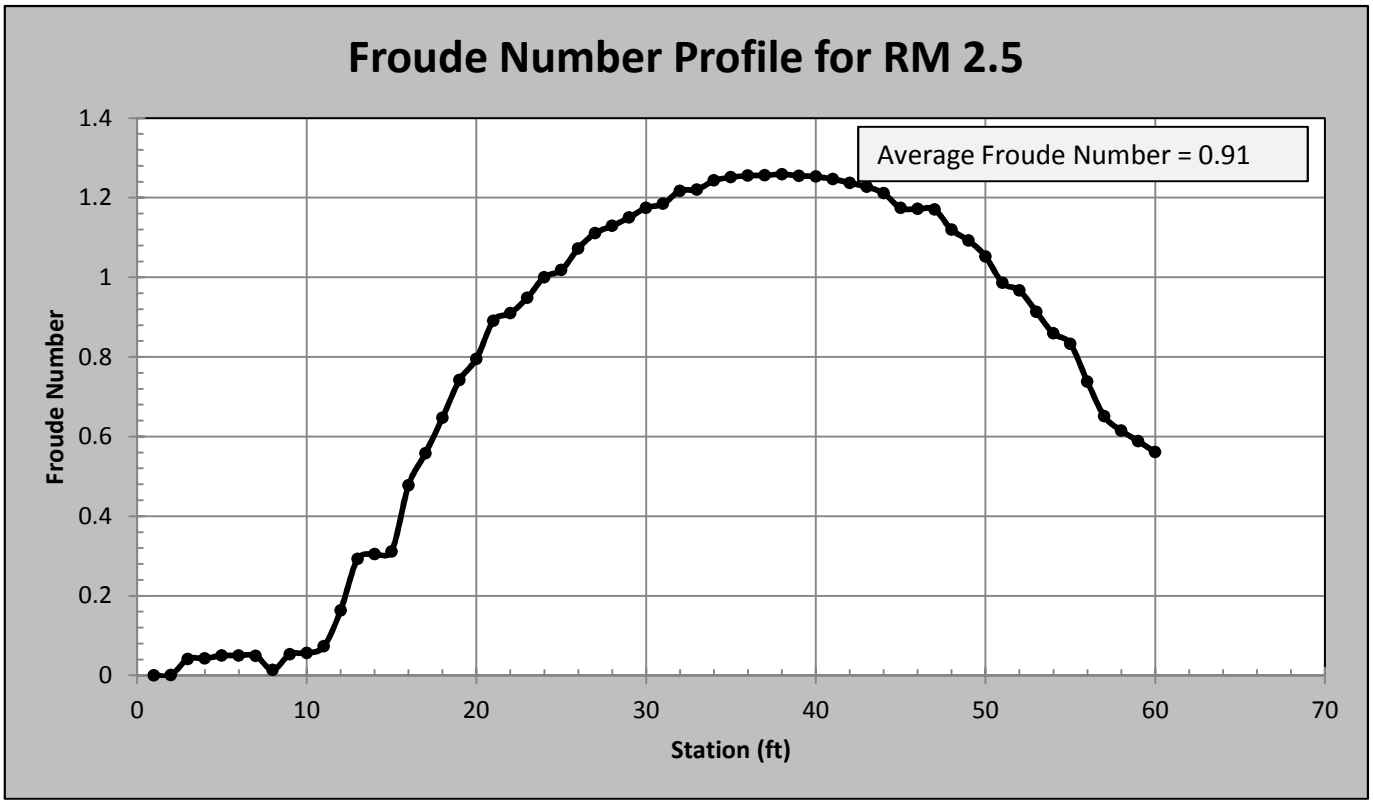
500-Year Event: 41,000cfs - River Mile 2.25



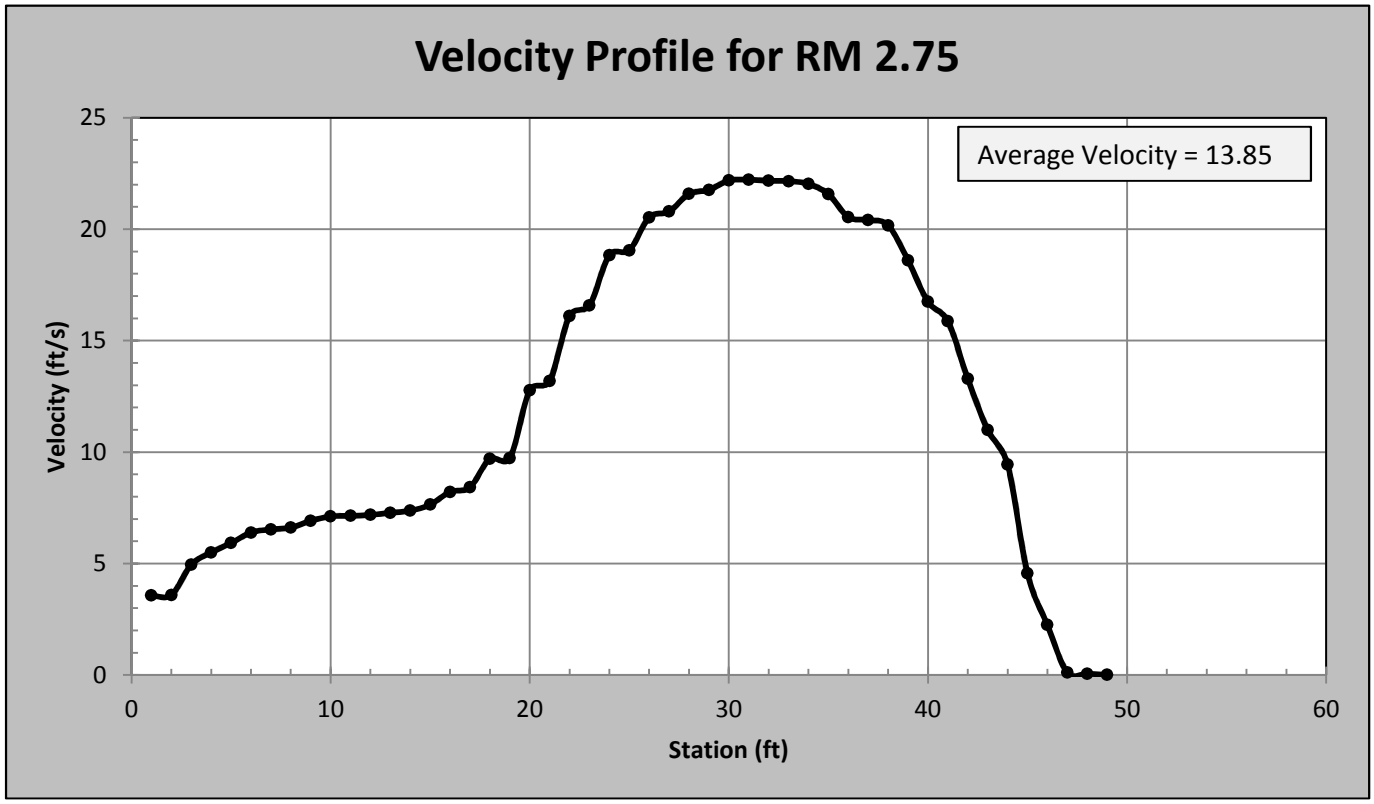


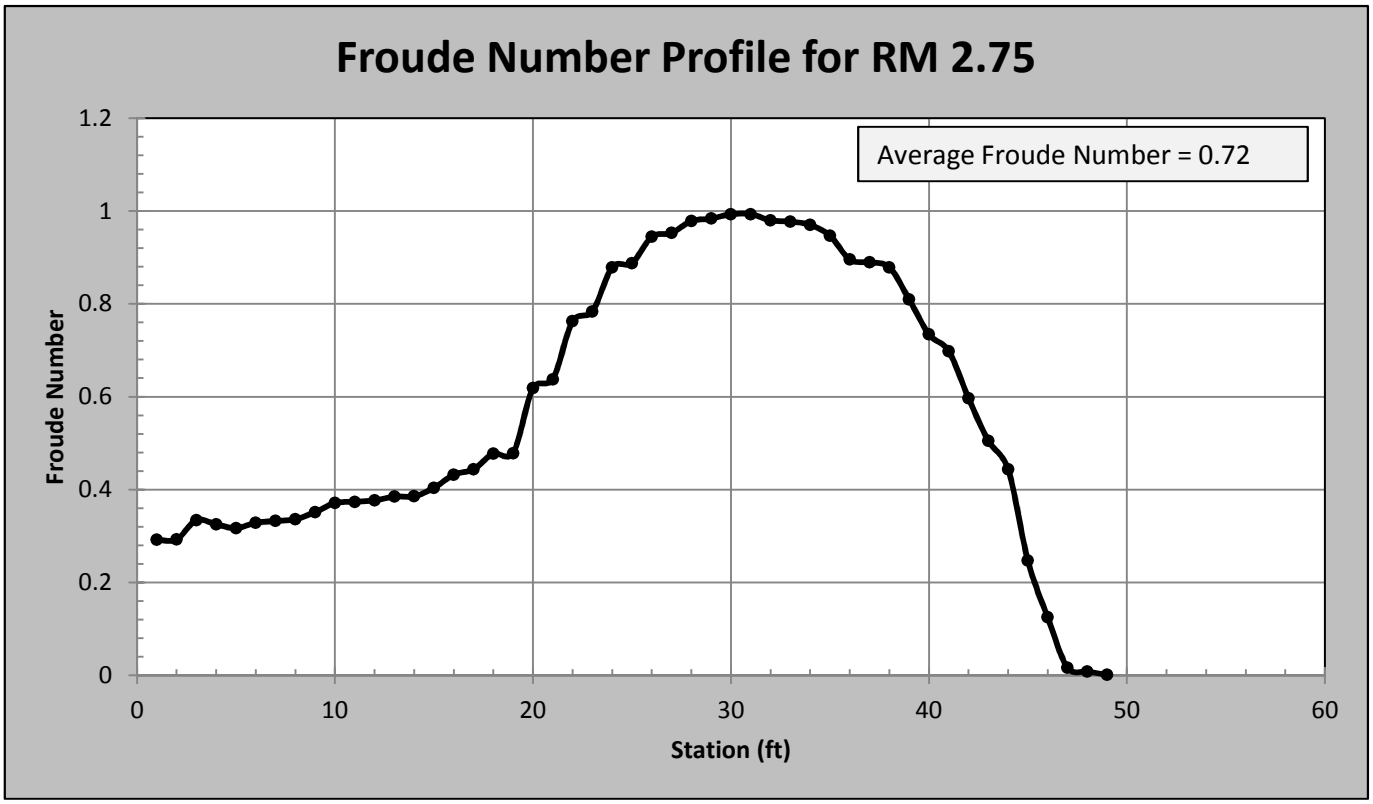
500-Year Event: 41,000cfs - River Mile 2.5



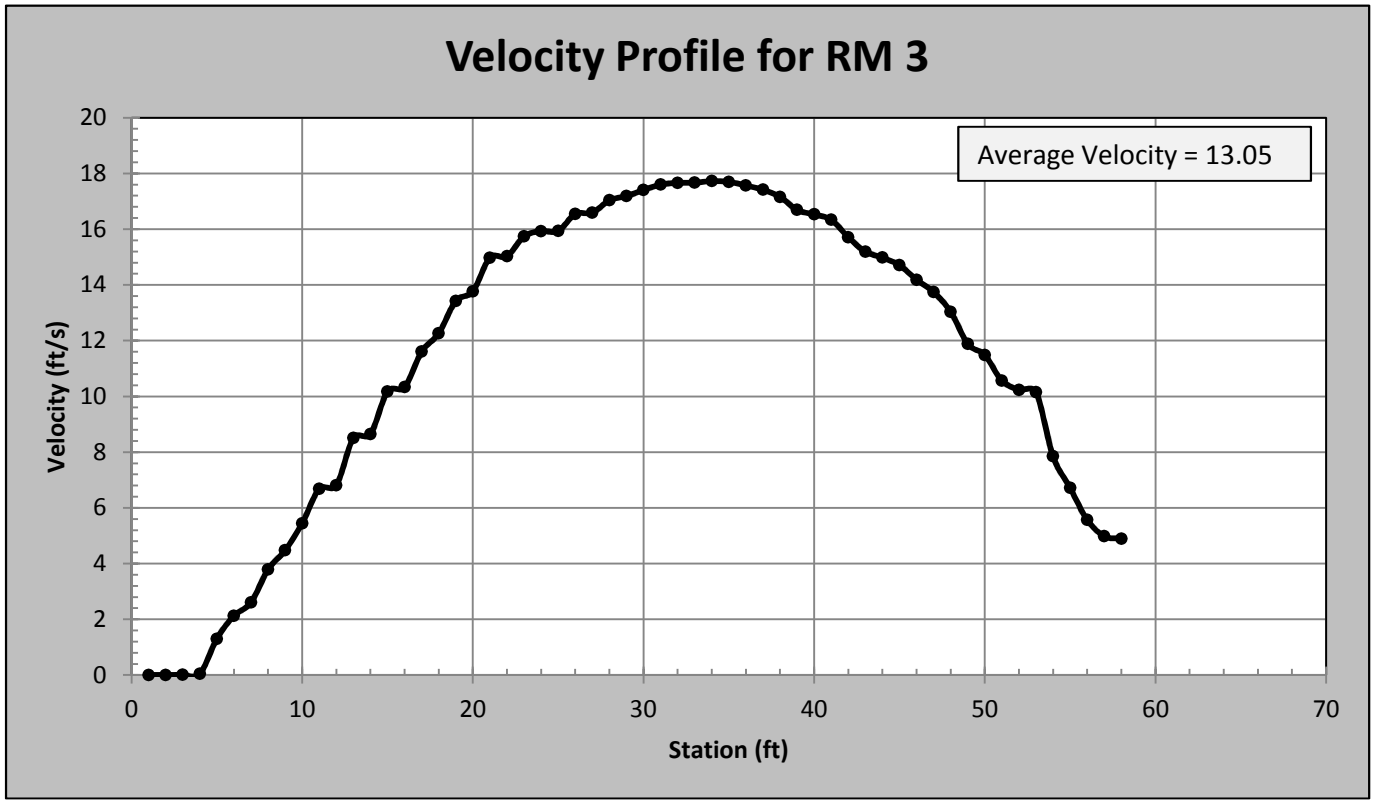


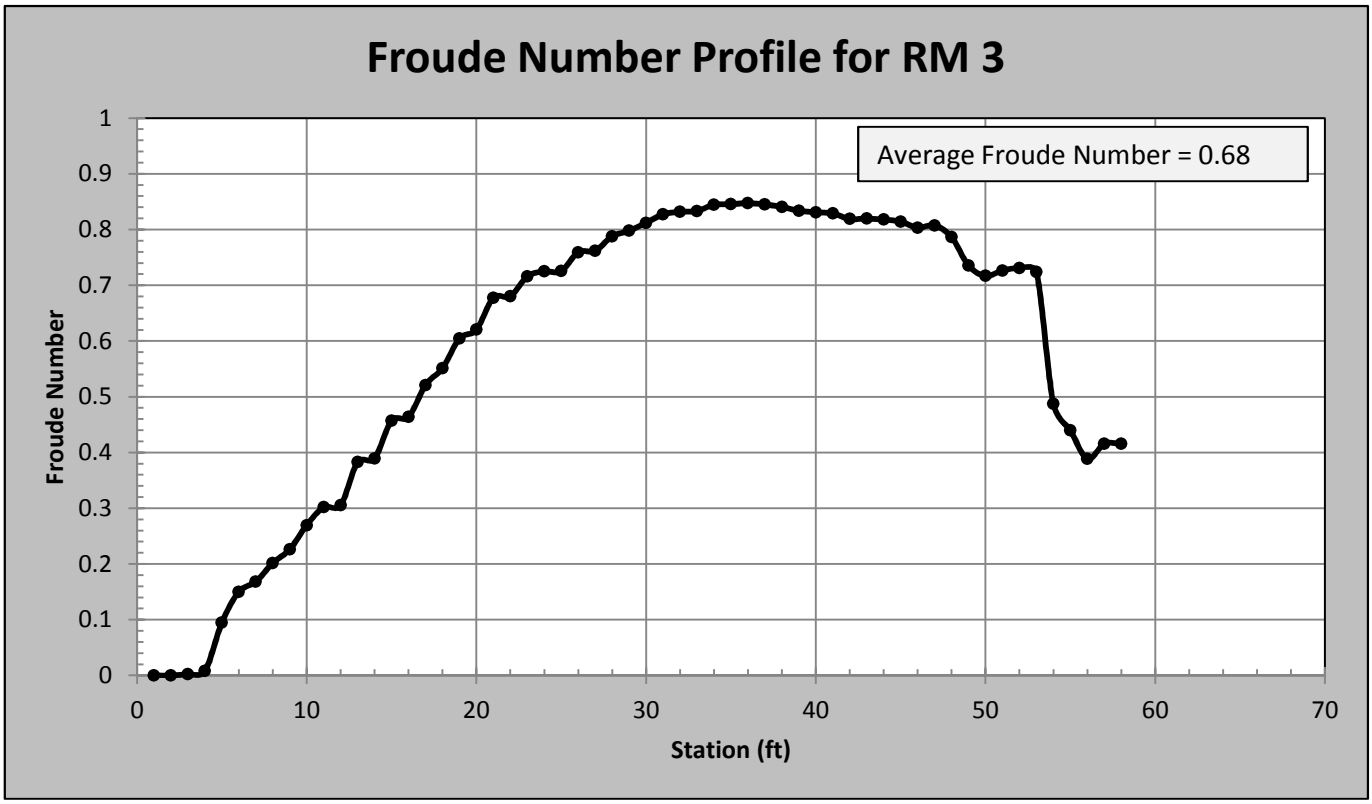
500-Year Event: 41,000cfs - River Mile 2.75



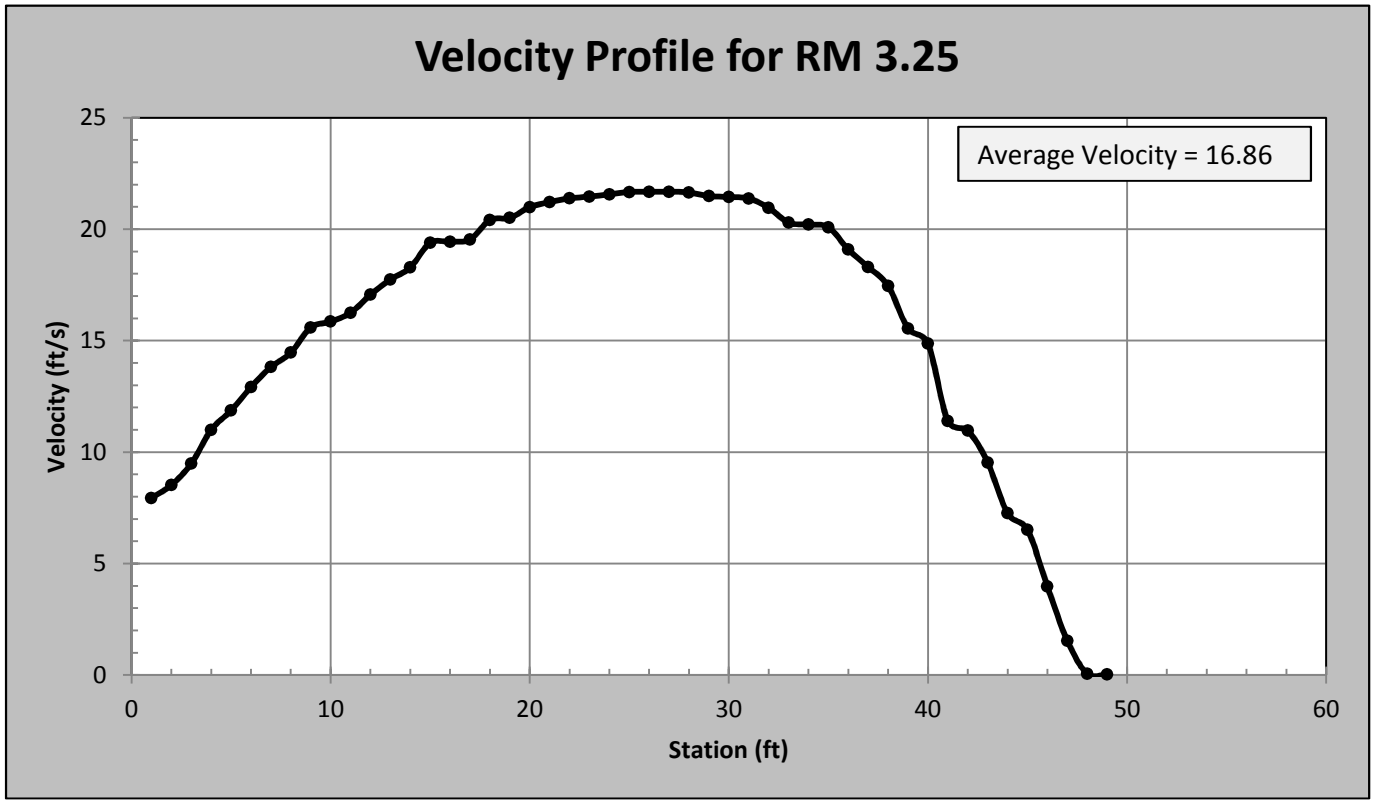


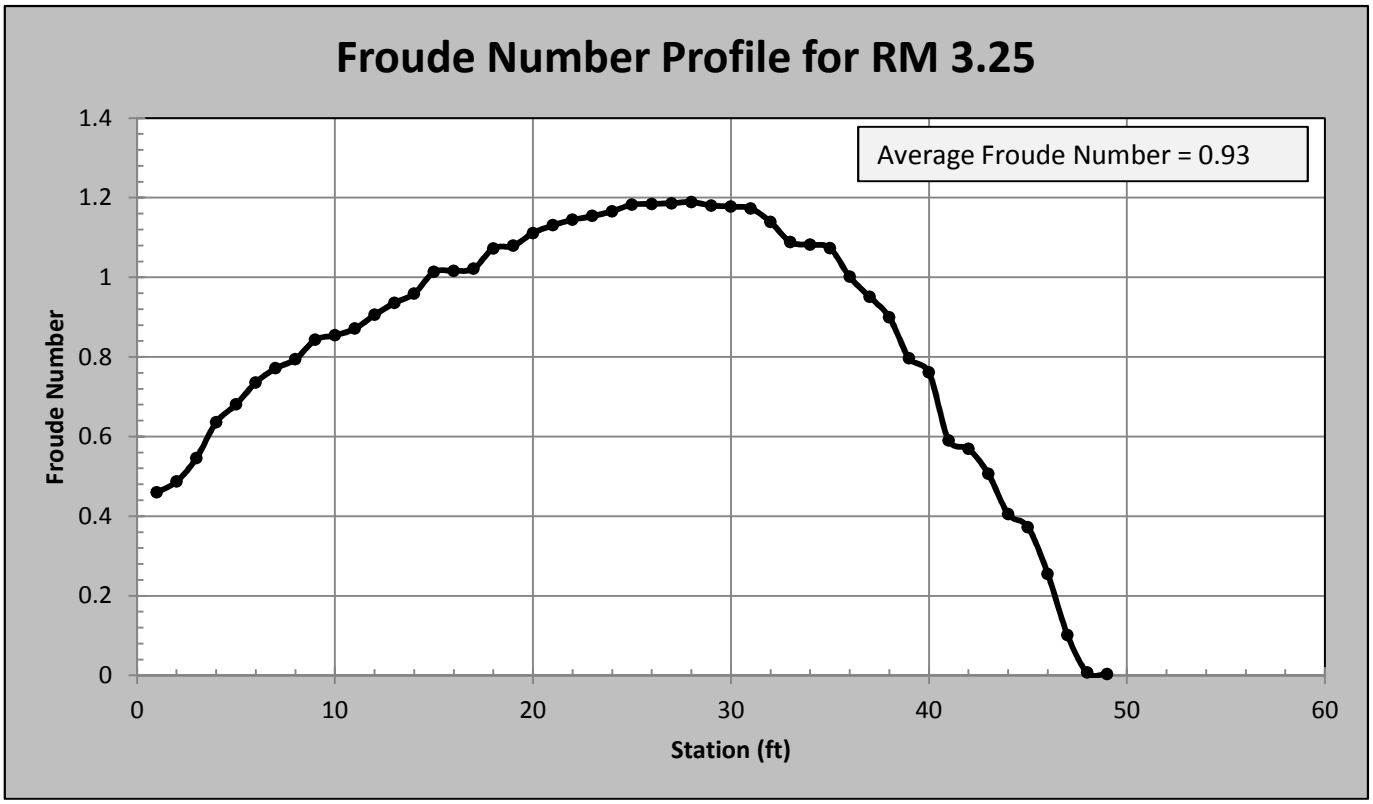
500-Year Event: 41,000cfs - River Mile 3



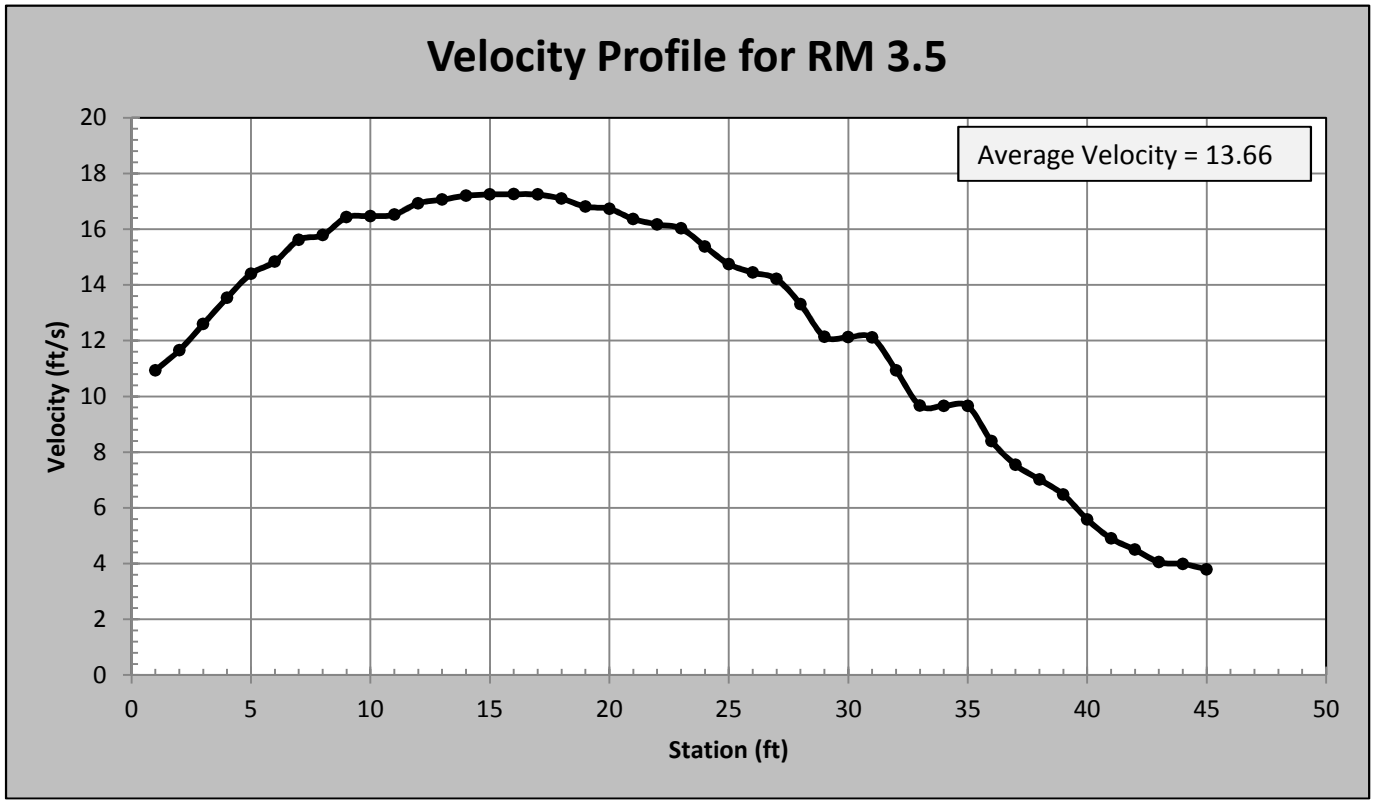


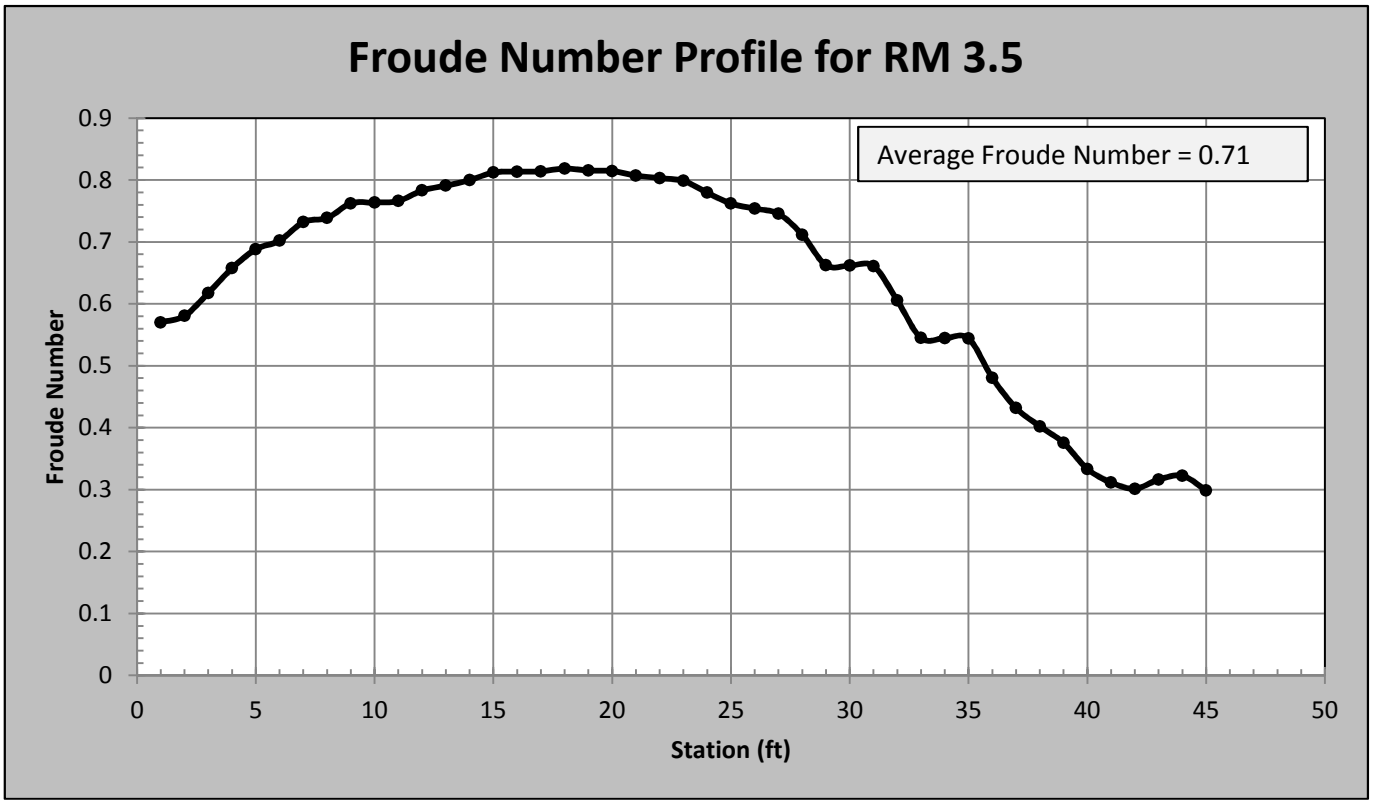
500-Year Event: 41,000cfs - River Mile 3.25



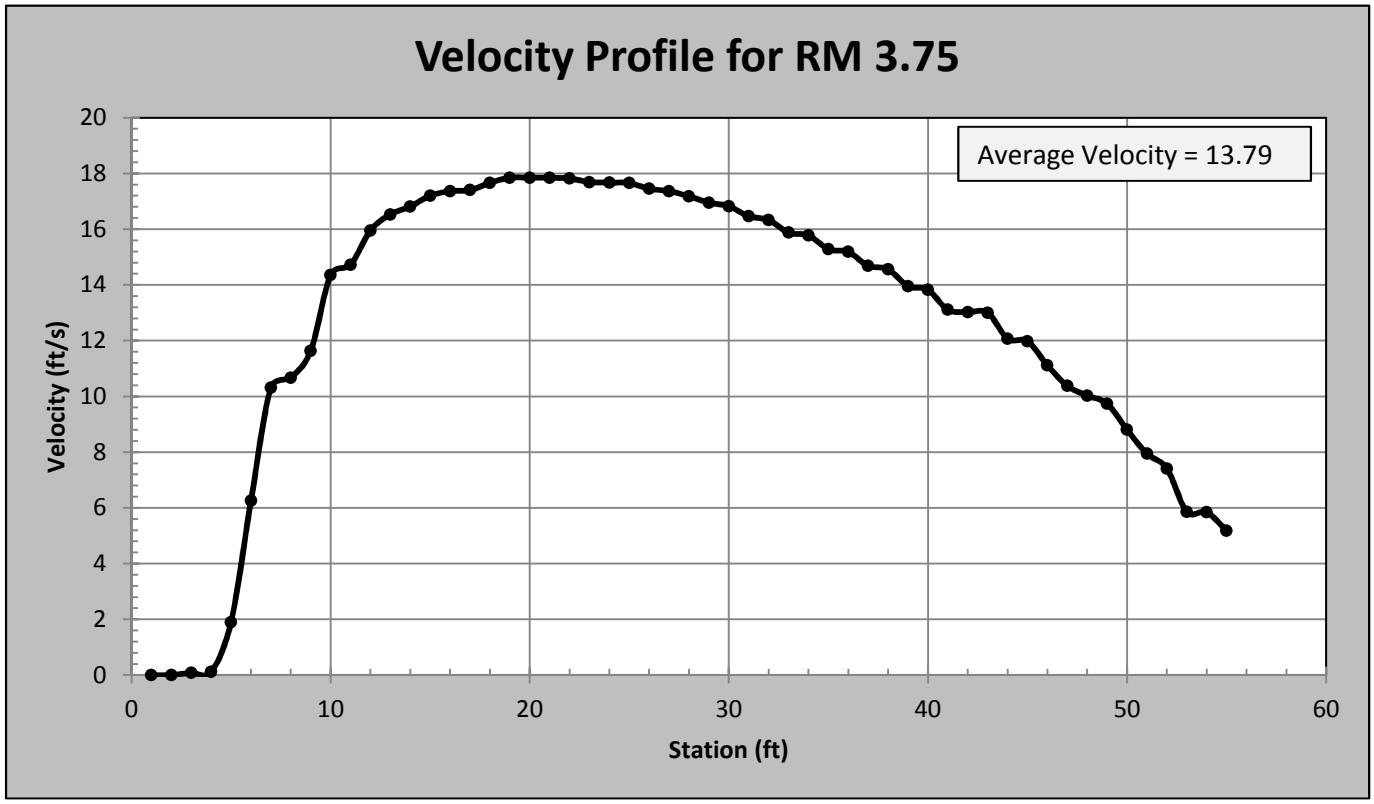


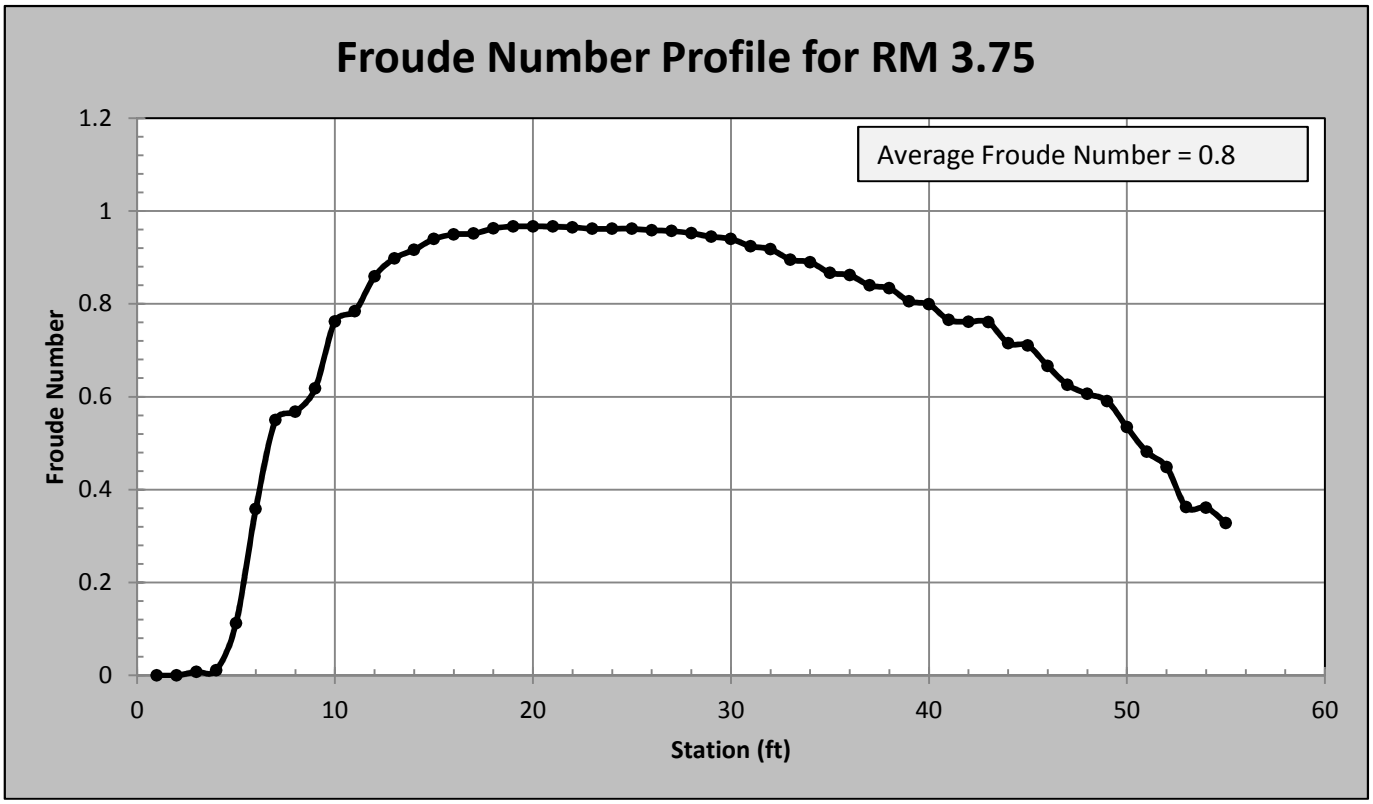
500-Year Event: 41,000cfs - River Mile 3.5



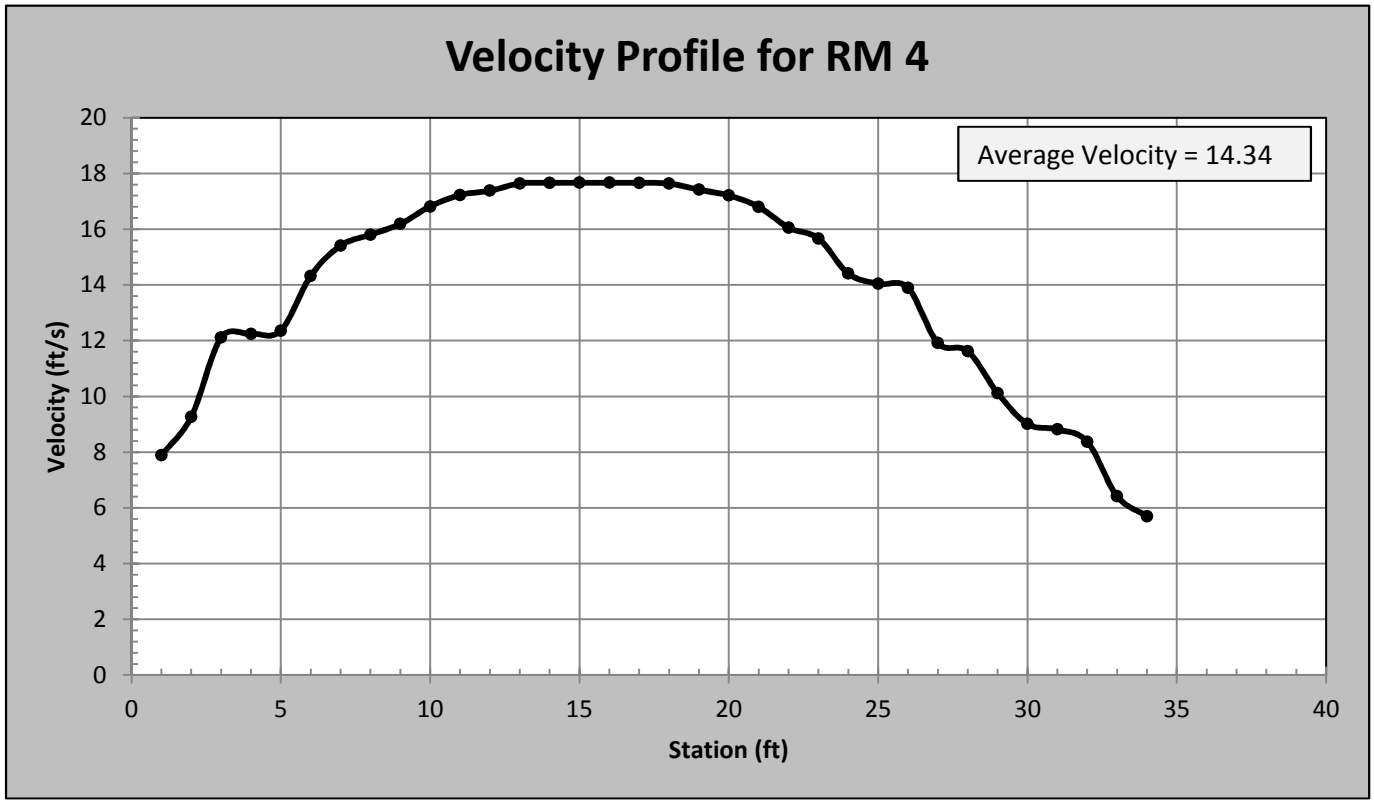


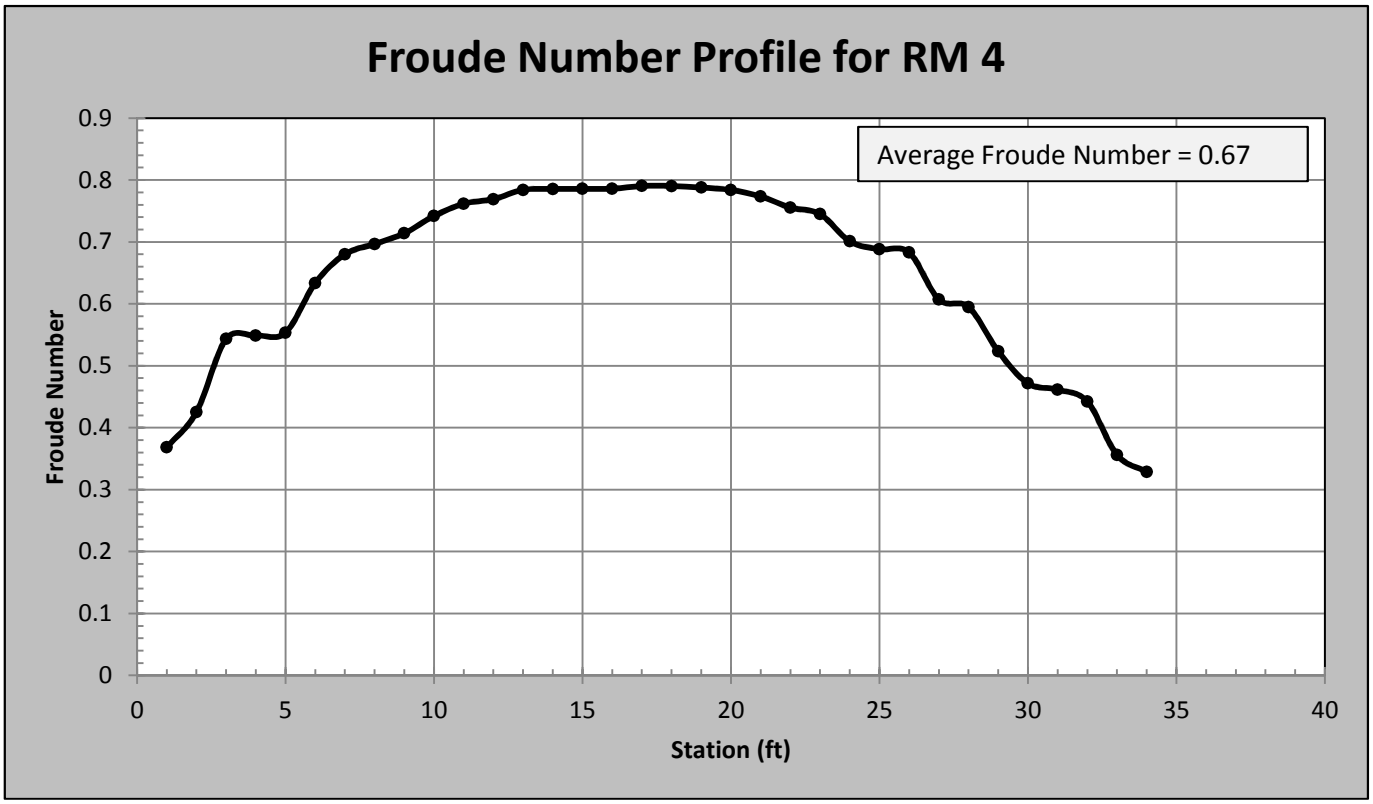
500-Year Event: 41,000cfs - River Mile 3.75



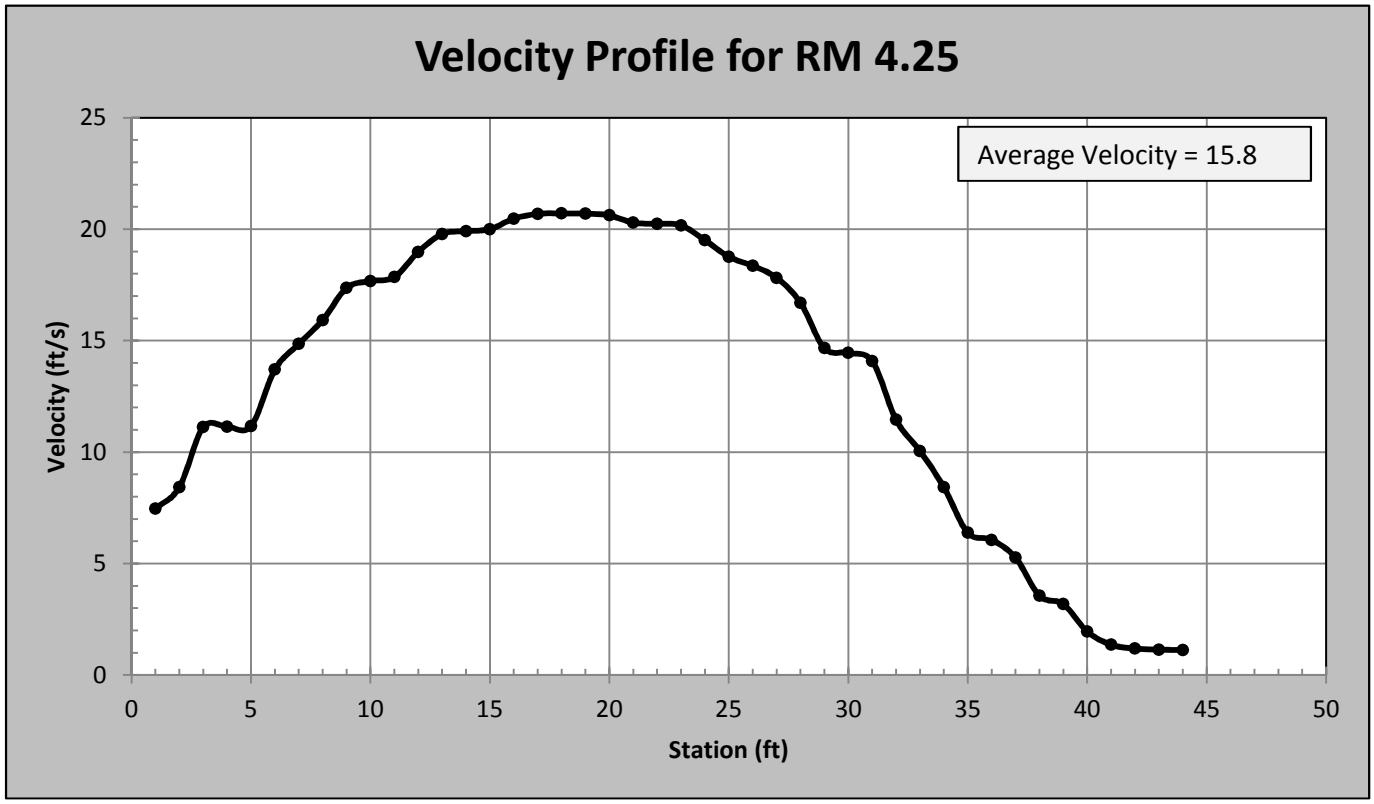


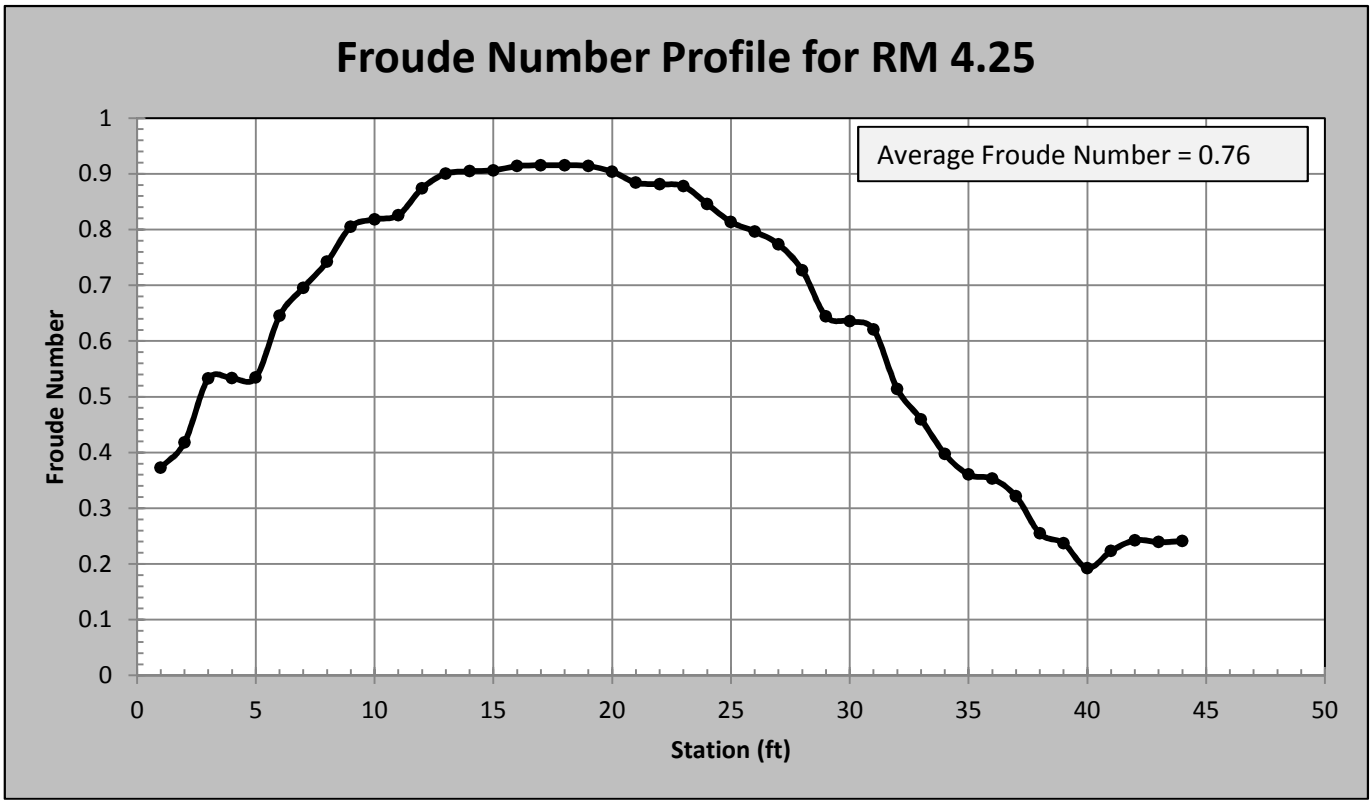
500-Year Event: 41,000cfs - River Mile 4





500-Year Event: 41,000cfs - River Mile 4.25

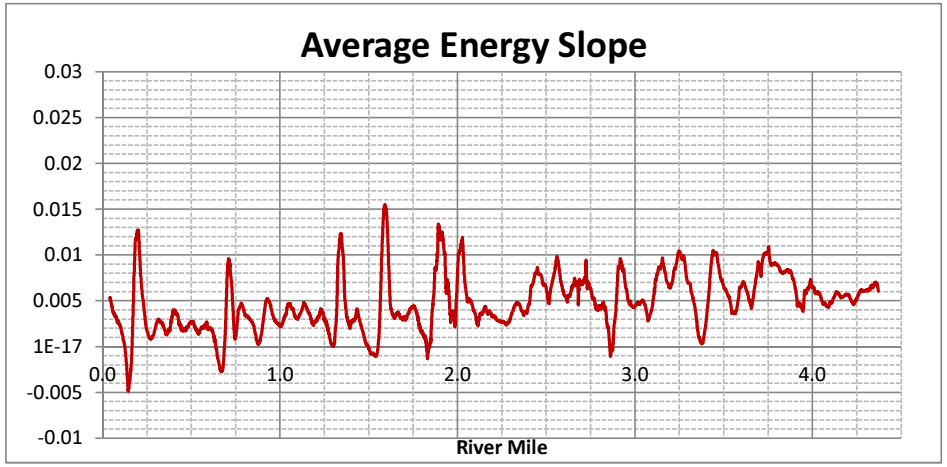


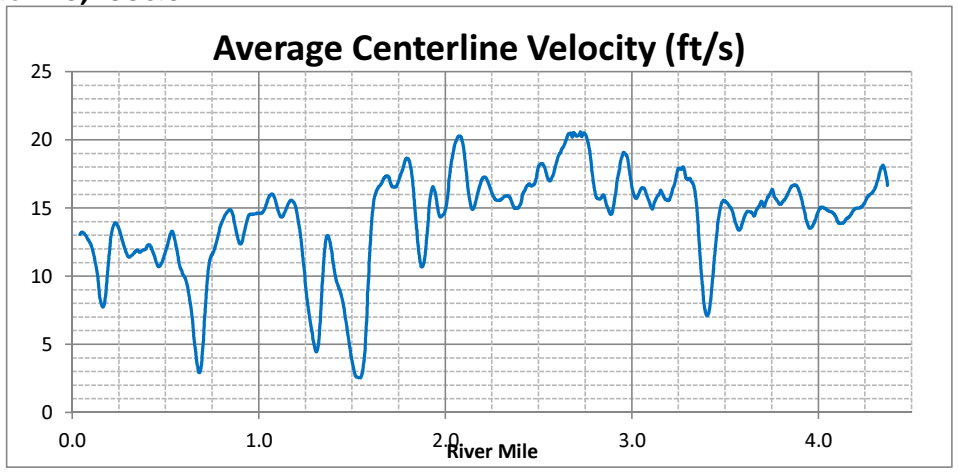


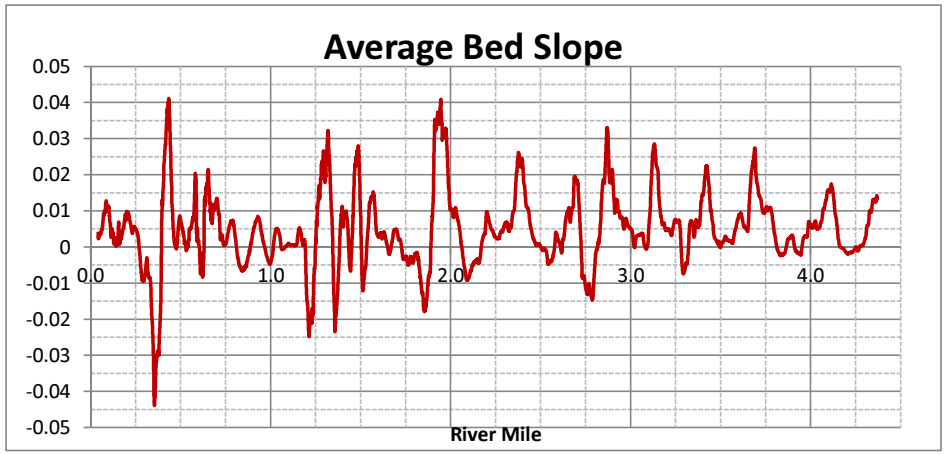
Profile Plots

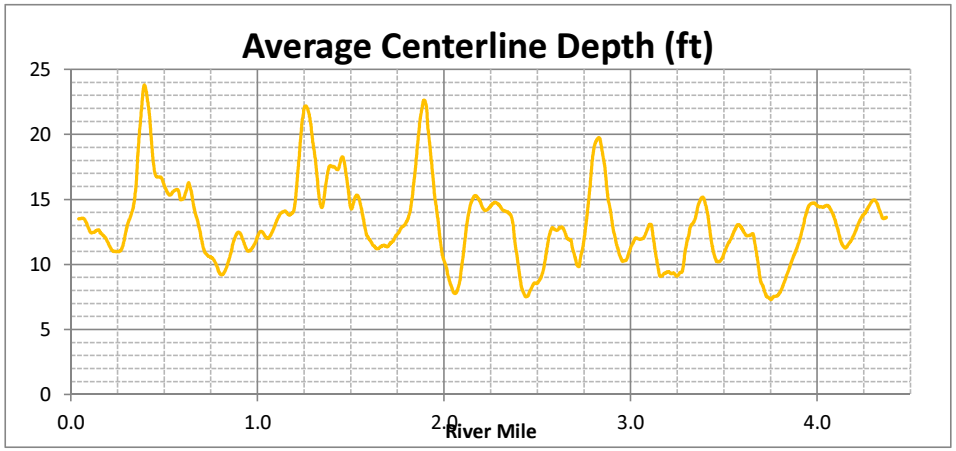
[This page intentionally left blank]

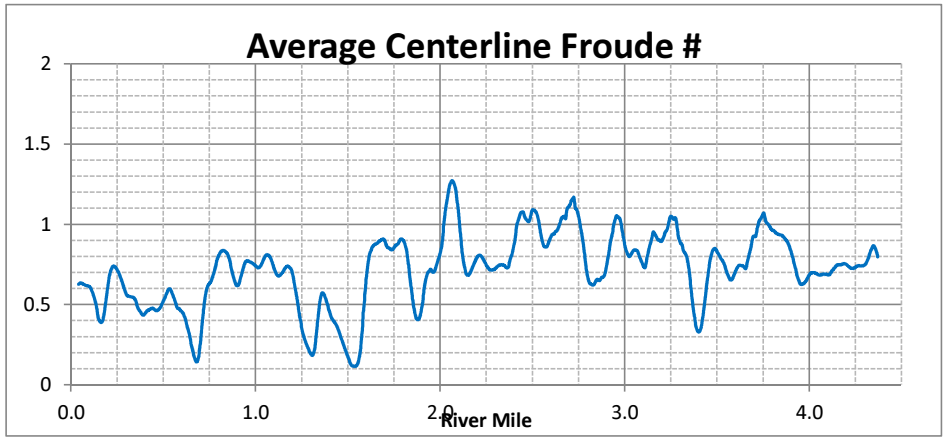
10 Year Event - 26,100cfs

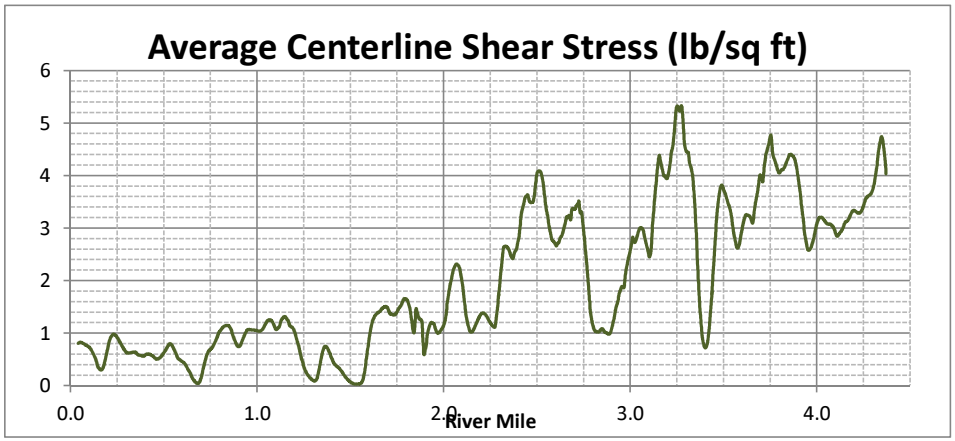




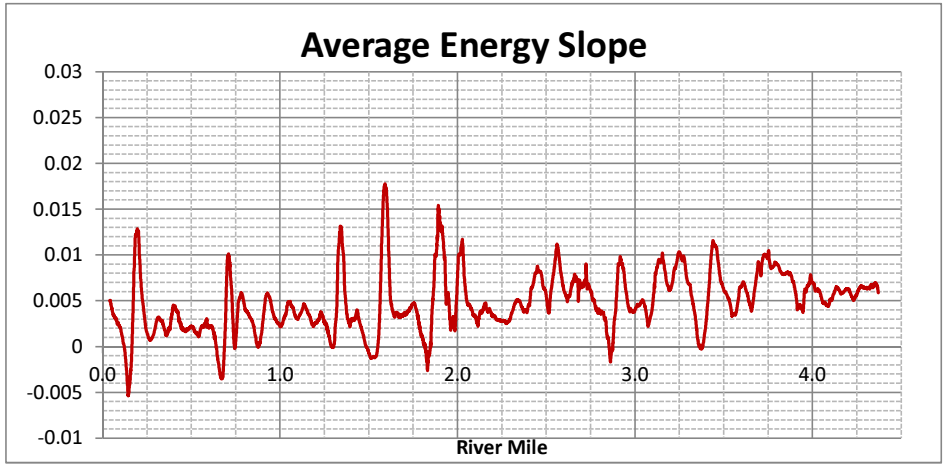


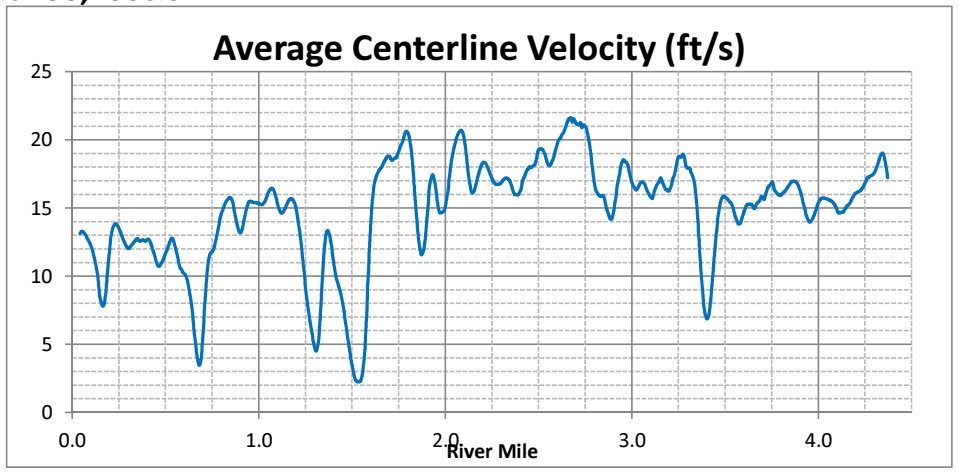


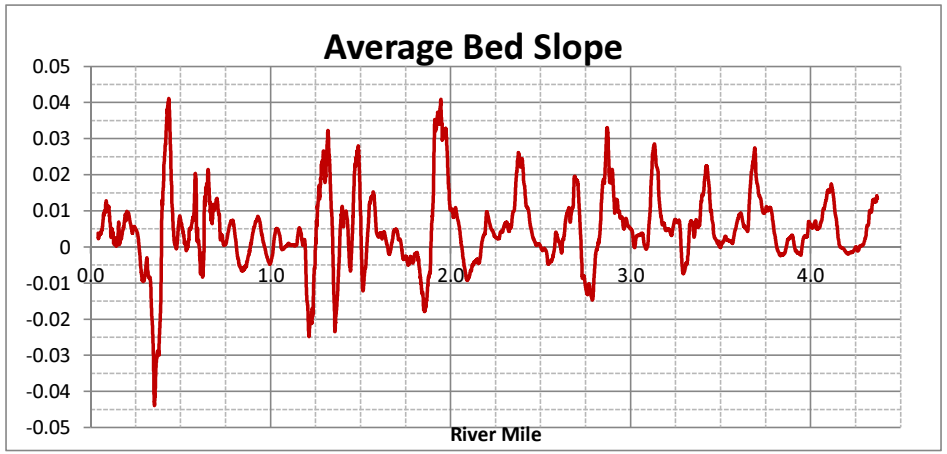


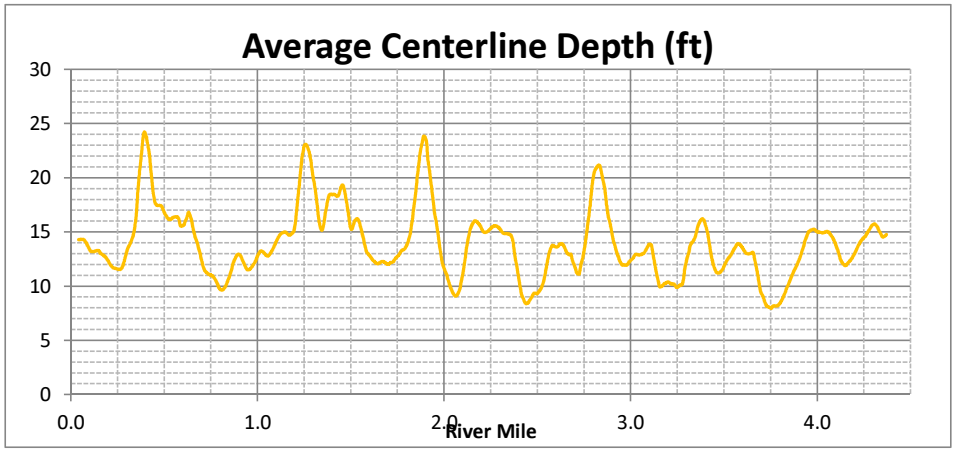


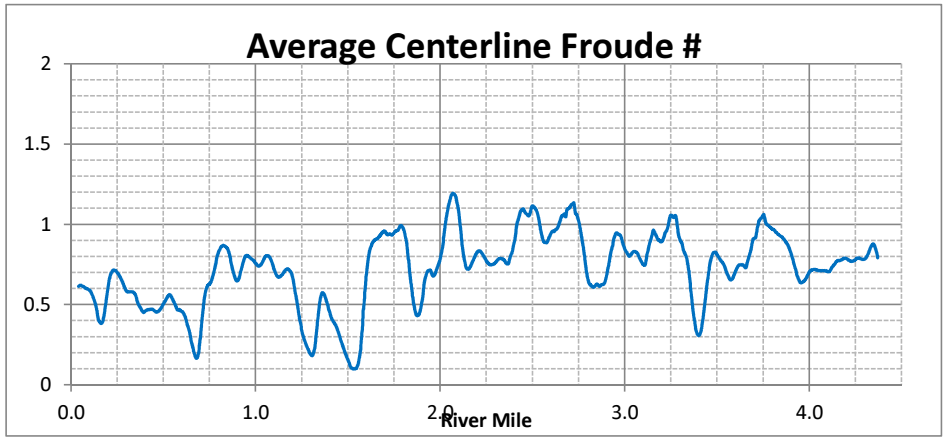
25 Year Event - 30,100cfs

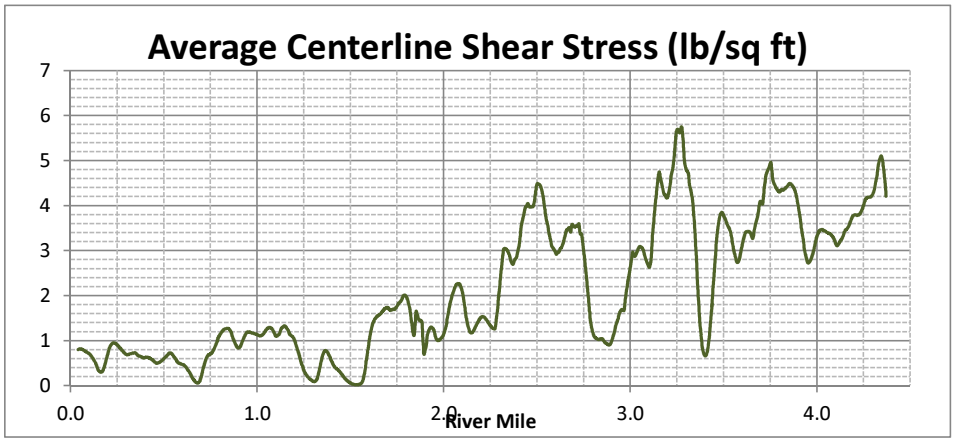




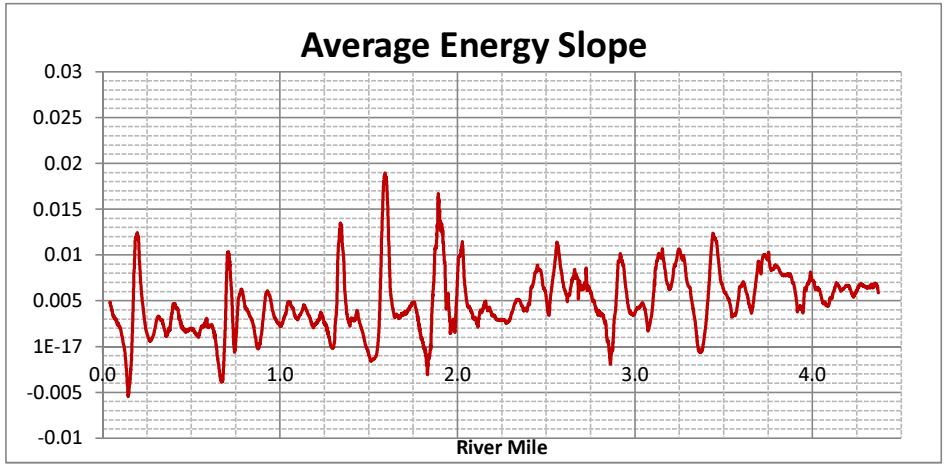


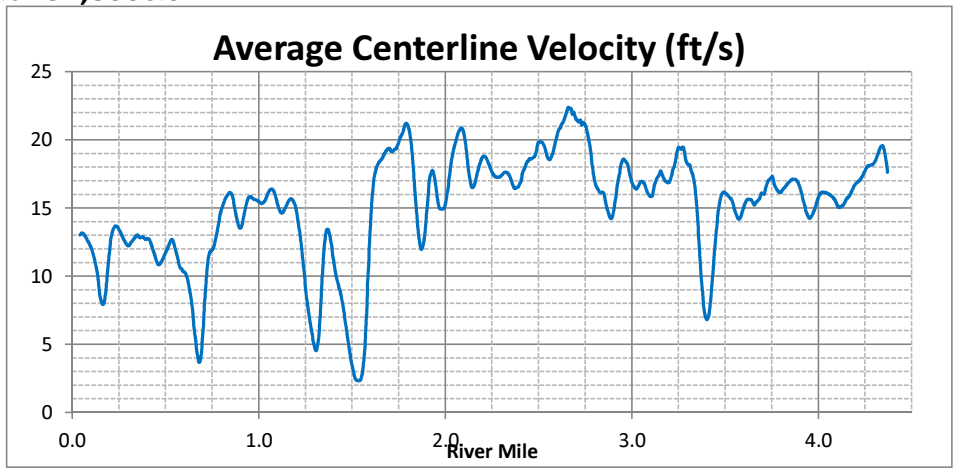


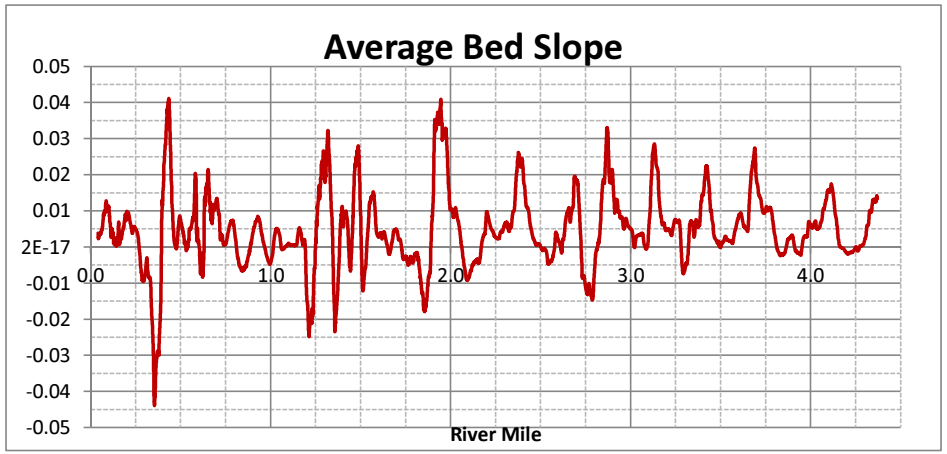


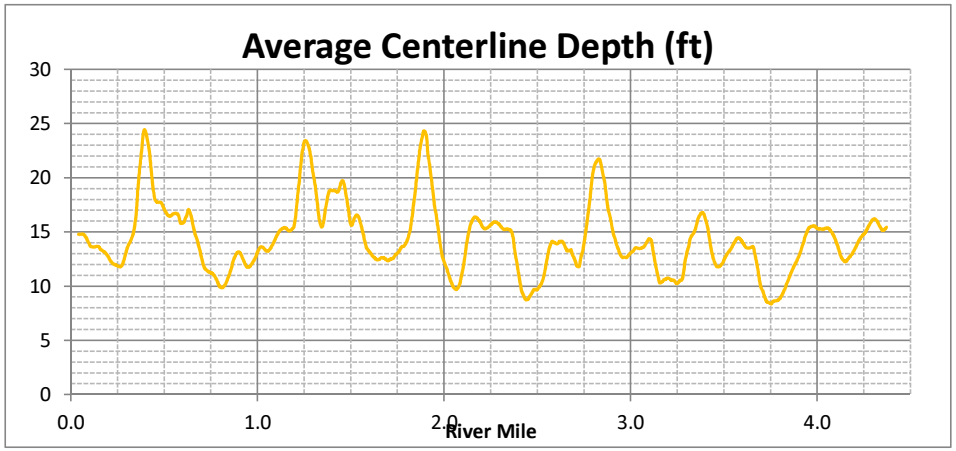


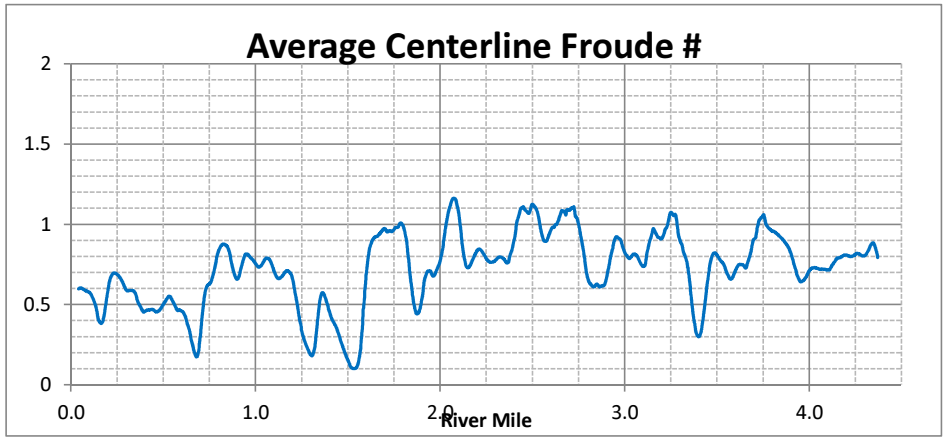
50 Year Event - 32,800cfs

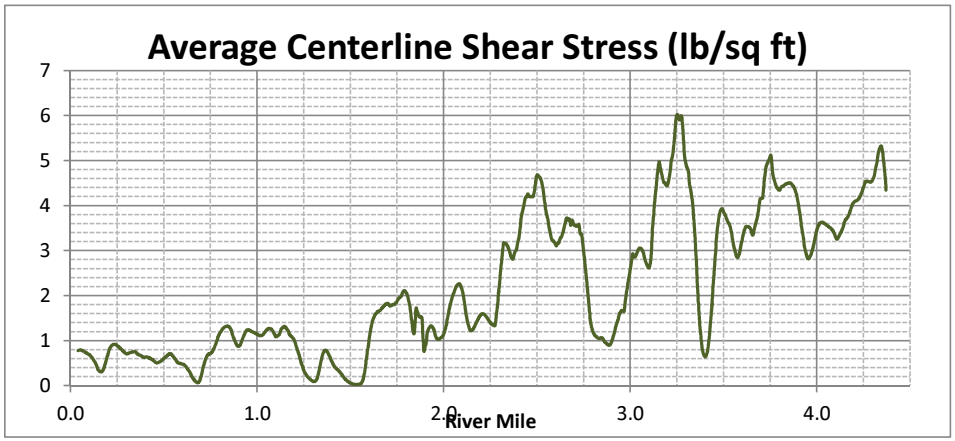




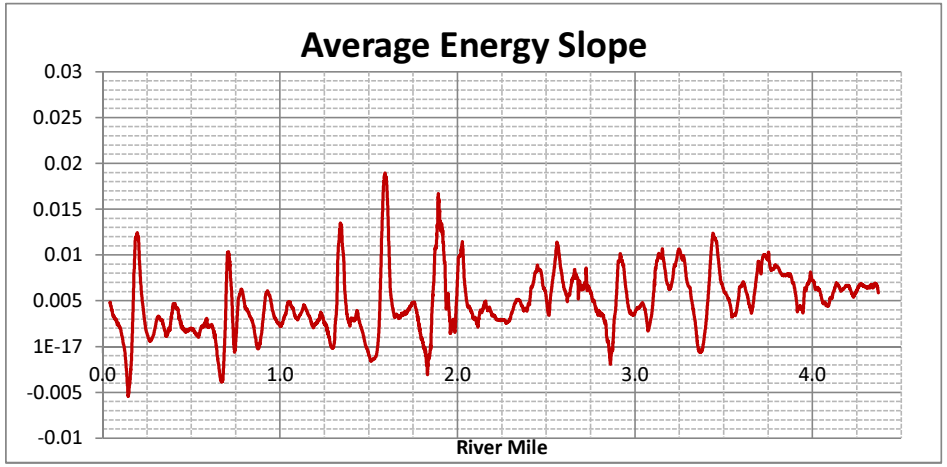


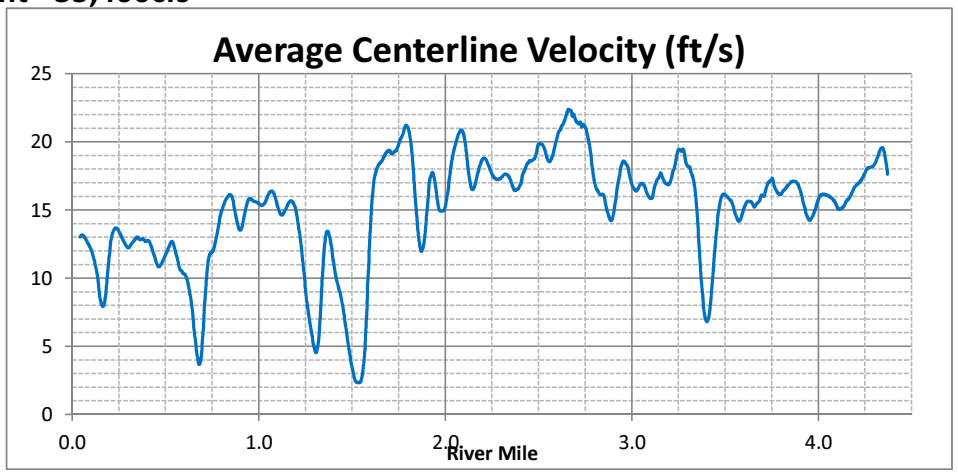


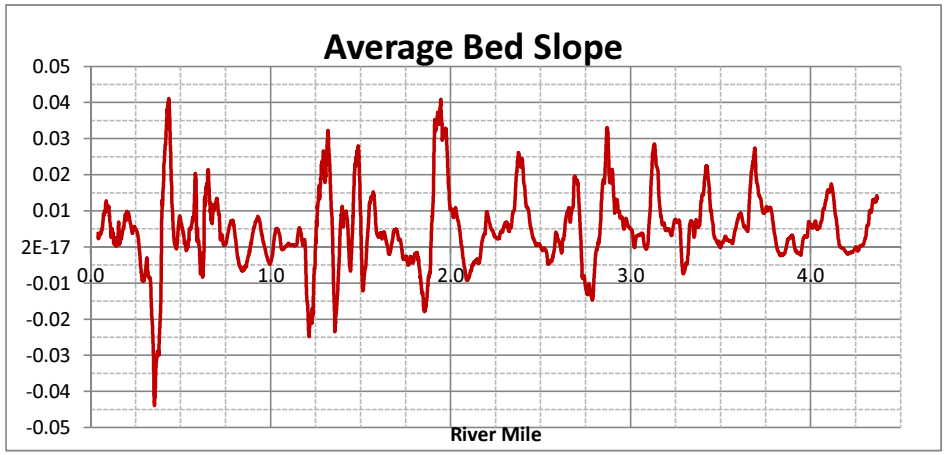


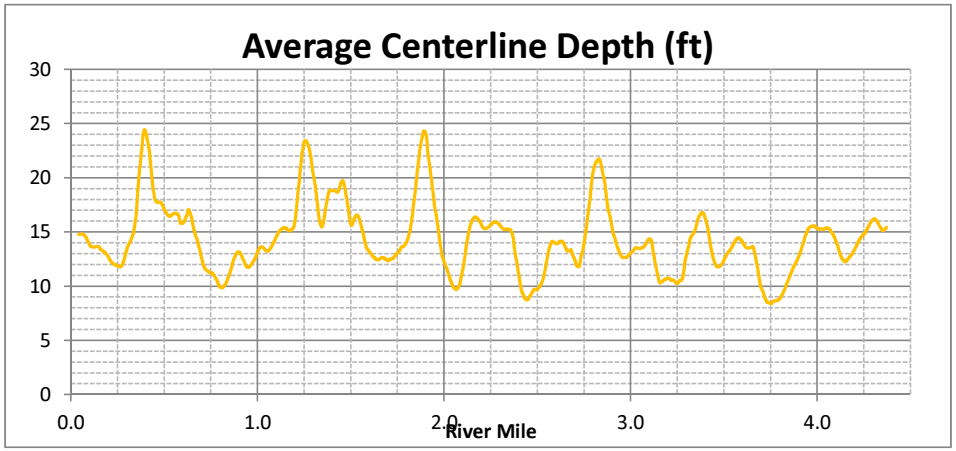


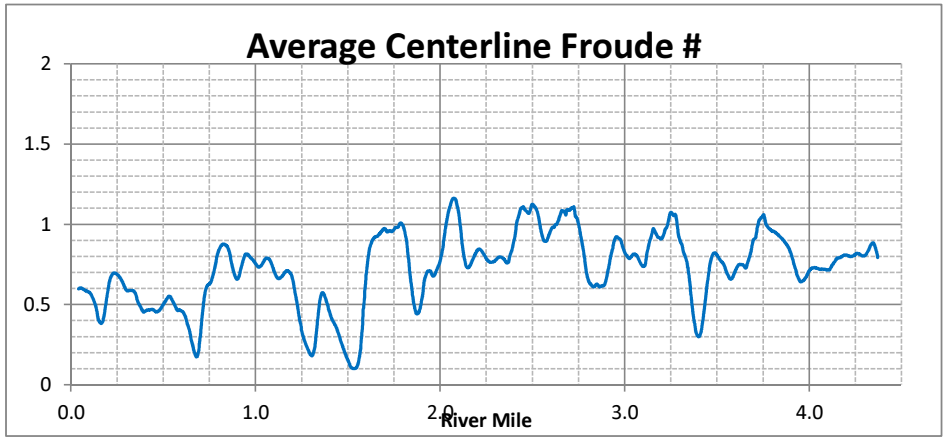
100 Year Event - 35,400cfs

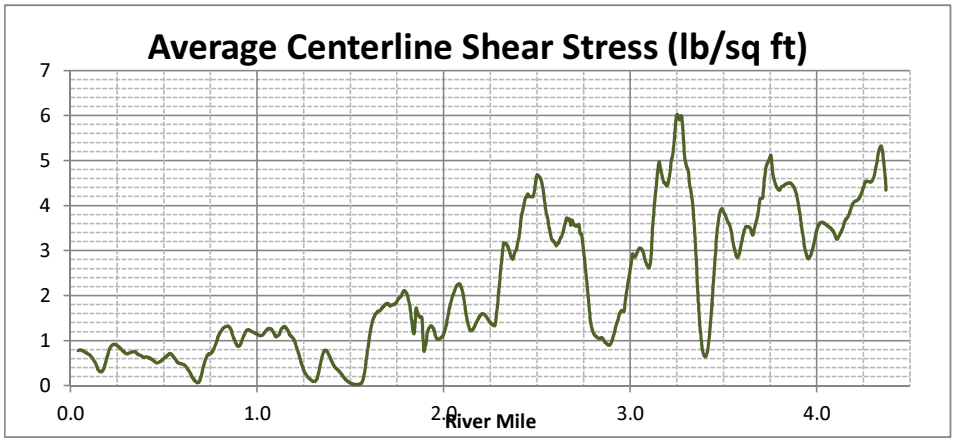
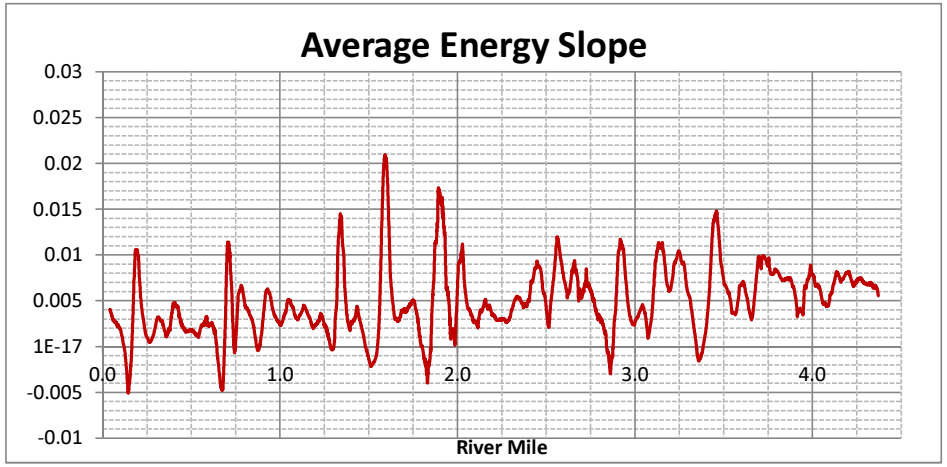
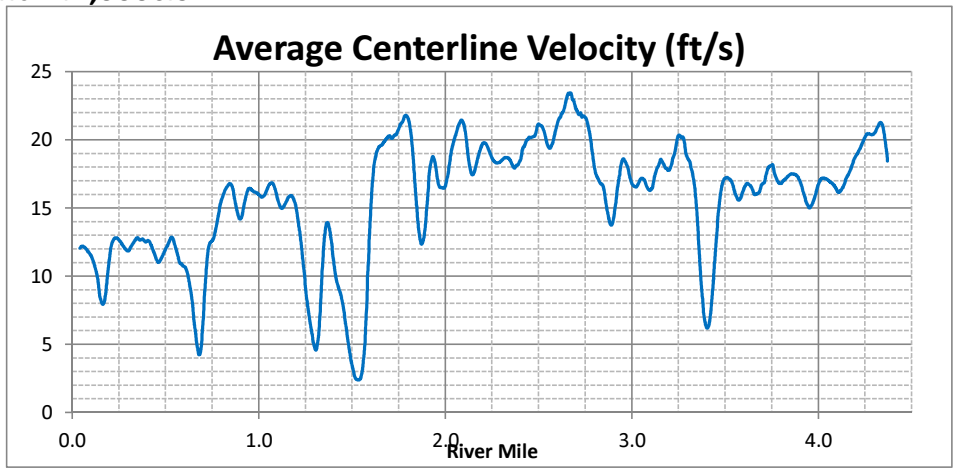
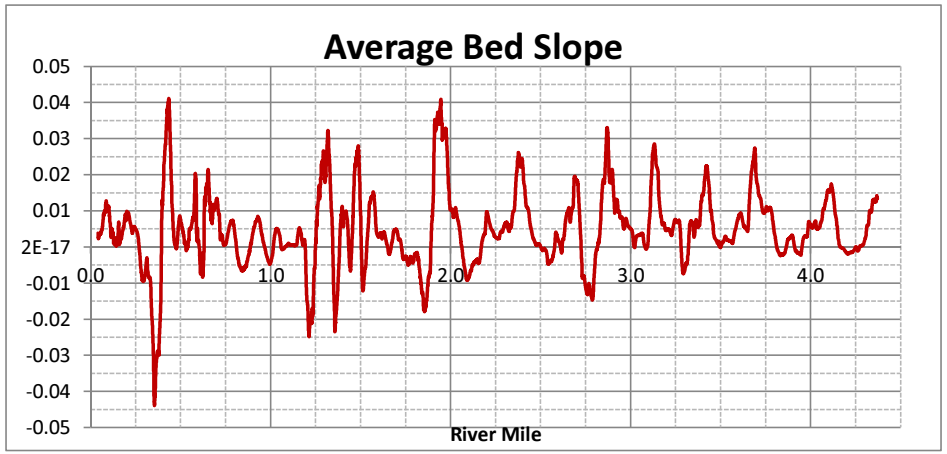
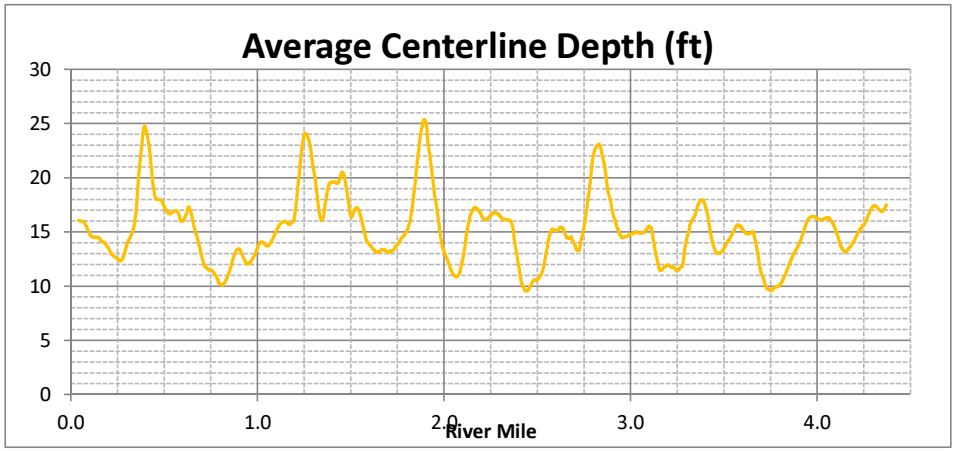
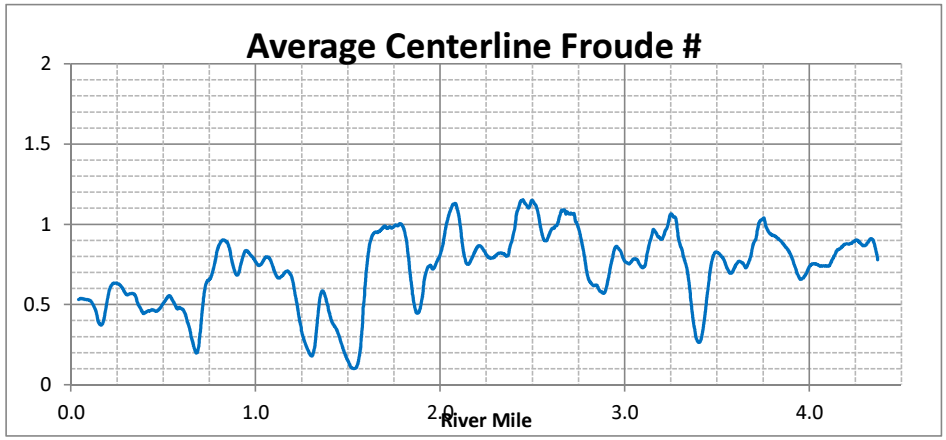
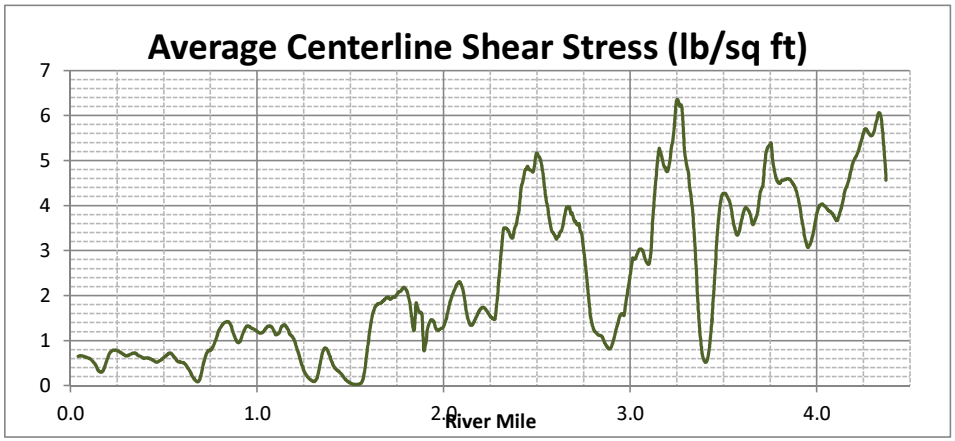












500 Year Event - 41,000cfs