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Memorandum

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DATE: 22 May 2014 NHC PROJECT: 200177

TO: Dan Lefeber

COMPANY/AGENCY: Skagit County Dike, Drainage and Irrigation Improvement District 12 (DD12)

FROM: Alex Anderson, P.E.; Malcolm Leytham, Ph.D., P.E.

SUBJECT: Hydraulic Effects of Proposal to Improve Dike District 12 Levee from SR-20 to the BNSF Bridge

Introduction

The Skagit River Valley is subject to periodic flooding, and seeking ways to manage the flood risk is a task undertaken by local municipalities, Skagit County, and federal agencies. The City of Mount Vernon is constructing a floodwall to increase the level of flood protection in their downtown area, and the U.S. Army Corps of Engineers (USACE), with Skagit County as local sponsor, recently completed a draft Skagit River General Investigation Study (Skagit G.I.) that looked at various valley-wide flood control alternatives.

Northwest Hydraulic Consultants (NHC) has served as the hydrology and hydraulics contractor for both Skagit County and the USACE on the Skagit G.I. study, and as a result has a thorough and up-to-date understanding of the hydraulic models developed for the Skagit River. In late 2013, the City of Burlington retained NHC to use the most recent hydraulic models from the Skagit G.I. study to evaluate the impact of improving a portion of the Dike District 12 levee. In early 2014, DD12 became the contracting entity for this work.

Project Description

The proposed levee improvements would take place along Burlington's eastern flank. The upstream end would be along Lafayette Road near where the road abuts State Route 20, and the project would follow the existing levee alignment downstream to Whitmarsh Road, just upstream from where the levee ties in to the BNSF railroad embankment upstream of the BNSF Bridge. Figure 1 shows the location of the proposed work.

The improvements would consist of raising the height of the levee by around 3-4 feet in most areas. The width would also be increased as needed to accommodate the extra height.

Model Description

To simulate the effects of the proposed works, NHC used the most recent (2013) "existing condition[1]" hydraulic models and followed the same methodology developed for the Skagit G.I. study. A one-

[1] The existing condition model includes the Mount Vernon floodwall, which is still under construction.

dimensional HEC-RAS v 4.1 model is used to simulate the main river channel, Harts Slough and Nookachamps areas. A two-dimensional Flo2D model is used to simulate flooding in overbank areas landward of existing levees. These two models are linked such that the HEC-RAS channel model first computes the river hydraulics and how much, if any, water spills over the levees onto the floodplain. Flo2D then simulates the depths and extents of overbank flooding as the levee overflow waters spread across the floodplain. It is assumed for current purposes that overtopping of levees occurs without resulting in a levee breach.

The storm event selected to analyze the project impact is the 100-year flood developed for the Skagit G.I. study. This 100-year flood is slightly larger than the prior estimated 100-year flood that was used to develop the FEMA flood maps, primarily because the new estimate incorporates the possibility of a flood occurring when the upstream reservoirs do not yet have their full flood control storage capacity in place (i.e., in early-mid fall). At Sedro-Woolley, the peak flow in the Skagit G.I. 100-year flood is around 236,000 cfs, compared to 215,000 cfs for the prior FEMA estimated 100-year flood.

The only change in the hydraulic models from the Skagit G.I. study is the assumed debris loading at the BNSF Bridge. When evaluating flood management measures upstream of the BNSF Bridge, the G.I. study assumed 6,000 sq. ft. of debris would accumulate across the bridge piers, restricting flow. There is considerable uncertainty around this estimate, as debris loads vary greatly from flood to flood with little correlation to flood size, and channel scour may mitigate the effects of debris blockage. For the current study two debris loading assumptions were used to better encapsulate this uncertainty: the G.I. Study's 6,000 sq. ft. debris blockage, and no debris blockage.

Project Impact

The City of Burlington provided NHC with engineering drawings (dated 3-3-2011) of the proposed works, which were incorporated into the models. The models were then used to simulate the 100-year flood with and without the proposed project, to determine the effect on flood levels in various locations due to the project.

Table 1 shows the impact that the project has on peak water levels at several key locations, under both debris assumptions. All values are from the HEC-RAS model with the exception of United General Hospital, which is from Flo2D.

Table 1: Impact of Proposed Levee Improvement on 100-Year Flood Peak Water Levels. All elevations are in feet and are relative to the NAVD88 vertical datum.

	No Bridge Debris			6,000 sq. ft. Bridge Debris		
Location	Existing	Project	Difference	Existing	Project	Difference
Sedro-Woolley WWTP	52.68	52.73	0.05	53.61	53.69	0.08
United General Hospital	47.00	47.23	0.23	47.45	48.11	0.66
Town of Clear Lake	49.56	49.70	0.14	49.77	50.20	0.43
Upstream face of BNSF Bridge	46.52	46.69	0.17	47.26	47.98	0.72
Division St. Bridge	36.63	36.68	0.05	36.05	36.15	0.10

Figure 2 is a profile view of the river and levee system upstream from the BNSF Bridge, with existing and proposed conditions. The figure reiterates the data in Table 1, and shows that the rise associated with the project is primarily contained within the BNSF Bridge – State Route 9 bridge section of river. The proposed project would eliminate overtopping of the raised section of levee during a 100-year flood, and the effect of this is to increase water levels elsewhere in the system. Note that the river miles in

Figure 2 are based on distance measured in the latest Skagit G.I. HEC-RAS model. These river miles may differ slightly from other sources.

The effect of the project on the volume of water spilled from the main channel to the floodplain upstream from the BNSF Bridge is summarized in Table 2. Table 2 shows that the total amount of water leaving the main channel between the BNSF Bridge (river mile 17.54) and the State Route 9 Bridge (river mile 22.29) is reduced by 4,000-5,000 acre-feet, though certain levee segments experience an increase in overtopping.

Table 2: Volume of Water Spilt from Main Channel onto Floodplain in 100-year Flood between BNSF and State Route 9 bridges, Right Bank

	Total Volume Onto Floodplain (acre-feet)			
	With Debris		No Debris	
Levee Segment	Existing	Project	Existing	Project
State Route 9 to Upstream End of Project	49,774	66,659	39,618	45,835
Project Segment	35,363	0	18,245	0
Downstream End of Project to BNSF Bridge	22,403	36,945	12,528	19,336
Total	**107,539**	**103,604**	**70,391**	**65,171**

Table 3 shows the impact of the project on the 100-year peak flow downstream from the BNSF Bridge for the two debris assumptions. Differences between the 100-year peak flow at Sedro-Woolley and below the BNSF bridge are the combined result of storage of flood waters upstream from the BNSF bridge (primarily in the Nookachamps area) and spill from the river channel onto the floodplain. The increased water level upstream from the BNSF Bridge with the project in place results in an increase in flow through the bridge opening of roughly 2,000 cfs with debris load and about 3,000 cfs without debris. The effect of the debris load is to reduce the peak flow passing the BNSF Bridge by about 16,000 cfs under existing conditions and by 18,000 cfs with the project in place.

Table 3: Peak Flow Downstream of BNSF Bridge

	Peak 100-Yr Flow Downstream of BNSF Bridge (cfs)	
	No Bridge Debris	6,000 sq. ft. Bridge Debris
Existing	182,930	166,360
Project	186,320	168,350

Maps showing the difference in 100-year flood level at every point in the valley are shown in Figures 3 and 4 for zero and 6,000 sq. ft. bridge debris, respectively. Black dots representing population aid in understanding the distribution of positively and negatively impacted parties. As the figures show, reduction in flood depth occurs in the densely populated areas of Burlington, while the depth increases are in more rural settings. Figures 5-6 show the existing condition absolute depths, rather than depth differences, to provide a baseline condition to keep in mind when evaluating the differences.

As shown in Figures 3 and 4, the improved levee would be expected to lower flood levels in the urban core of Burlington by around 0.3 feet to 1 foot (no debris), or 0.5 feet to 1 foot (with debris). Note, however, that flooding would still occur in Burlington, just at a lesser depth. The remnant flooding that would still occur is a result of water spilling over SR-20 upstream of the project and flowing southwest behind the levee, as well as spill over the short unimproved segment between the BNSF Bridge and the downstream end of the project. Smaller reductions in flood level also occur in the floodplain west of Burlington on either side of Bayview Ridge. The remnant flooding on the right bank (i.e., the Burlington & Sedro-Woolley side) was quantified in Table 2.

The proposed project would cause an increase in flood depth in other areas of the floodplain. The floodwaters that under existing conditions overtop into Burlington in the project reach are displaced, resulting in increased river levels and hence larger overtopping flows elsewhere. The increase is around 0.2 feet (without debris) to 0.6 feet (with debris) in the river channel immediately adjacent to the project, and generally diminishes with distance from the project. The areas that generally see the most widespread increases are the rural areas west of Sedro-Woolley and east of I-5 south of Mount Vernon.

In the rural areas west of Sedro-Woolley, increased overtopping of SR-20 from Harts Slough results in increases of greater than 0.5 feet (with debris) over a fairly large extent. Without bridge debris, the increase in this area is less than 0.5 feet and limited in extent.

South of Mount Vernon, I-5 experiences increased overtopping which results in depth increases of up to 3 feet (with debris).

Examining Figures 3 through 6, it is apparent that larger differences in flood depth occur in the "with debris" scenario than "without debris" for areas both upstream and downstream from the BNSF bridge. However, the total inundated acreage downstream from the BNSF Bridge is less with debris than without debris due to the lower flows, with or without the project.

Areas that experience the largest changes in depth are typically areas where there is simply no flooding in the existing case, but where inundation is experienced with the project in place, or vice versa. These areas of large change tend to be located near the edge of the flood's footprint area.

The large changes near the edge of the footprint are caused primarily by elevated roadways or natural high ground barriers that protect lower lying areas behind them. If the water level under existing conditions is just on the cusp of overtopping these high ground barriers, small increases in water level can lead to large changes in flood depth and extent in the low lying areas behind them. Examples include the area along the Samish River just upstream of I-5 and the area east of I-5 south of Mount Vernon. In the case of the area east of I-5 and south of Mount Vernon, water is just beginning to overtop I-5 in the existing case (with debris). With the project, water is only marginally higher west of I-5, but the increase in overtopping is enough to raise water levels east of the highway by up to several feet. The large difference does not occur in the "without debris" scenario because I-5 is already overtopped by the higher flows experienced without debris. Note that the inverse situation also occurs, resulting in sections of land with large reductions in flood depth, such as the area east of La Conner.

Discussion

The impact of the proposed levee improvement was studied using a hypothetical 100-year flood. It is useful to provide some context on the magnitude of this flood compared with other recent floods. Table 4 shows the peak flows at Sedro-Woolley of the 10 through 100-year hypothetical floods, as well as the historic floods of 1995, 2003, and 2006. Estimated return intervals based on these peak flows are also shown. It is evident that the 100-year flood used for project impact analysis is very large in comparison to any of the recent floods that have occurred, which are equivalent to approximately 15 to 25-year floods.

Table 4: Peak Flows at Sedro-Woolley: 100-Year Flood and Selected Historic Floods

Flood Event	Peak Flow (cfs)	Estimated Average Return Interval (years)
November 1995	160,100	20
October 2003	166,200	23
November 2006	146,300	15
100-Year Flood	**235,800**	**100**
75-Year Flood	220,100	75
50-Year Flood	197,500	50
25-Year Flood	169,600	25
10-Year Flood	133,300	10

*Peak flows in this table are extracted from the calibrated HEC-RAS model. These are not measured values. Measured flow values are not available at Sedro-Woolley.

To visualize what these flow differences mean in terms of flood extent and depth, a valley-wide figure of the November 1995 event with bridge debris (Figure 7) was prepared in the same manner as the 100-year flood figures. Flooding in the 1995 simulation is limited to primarily the Nookachamps area, though there is some spillage over Highway 20 northeast of Burlington, and overtopping in the South Fork south of Conway.

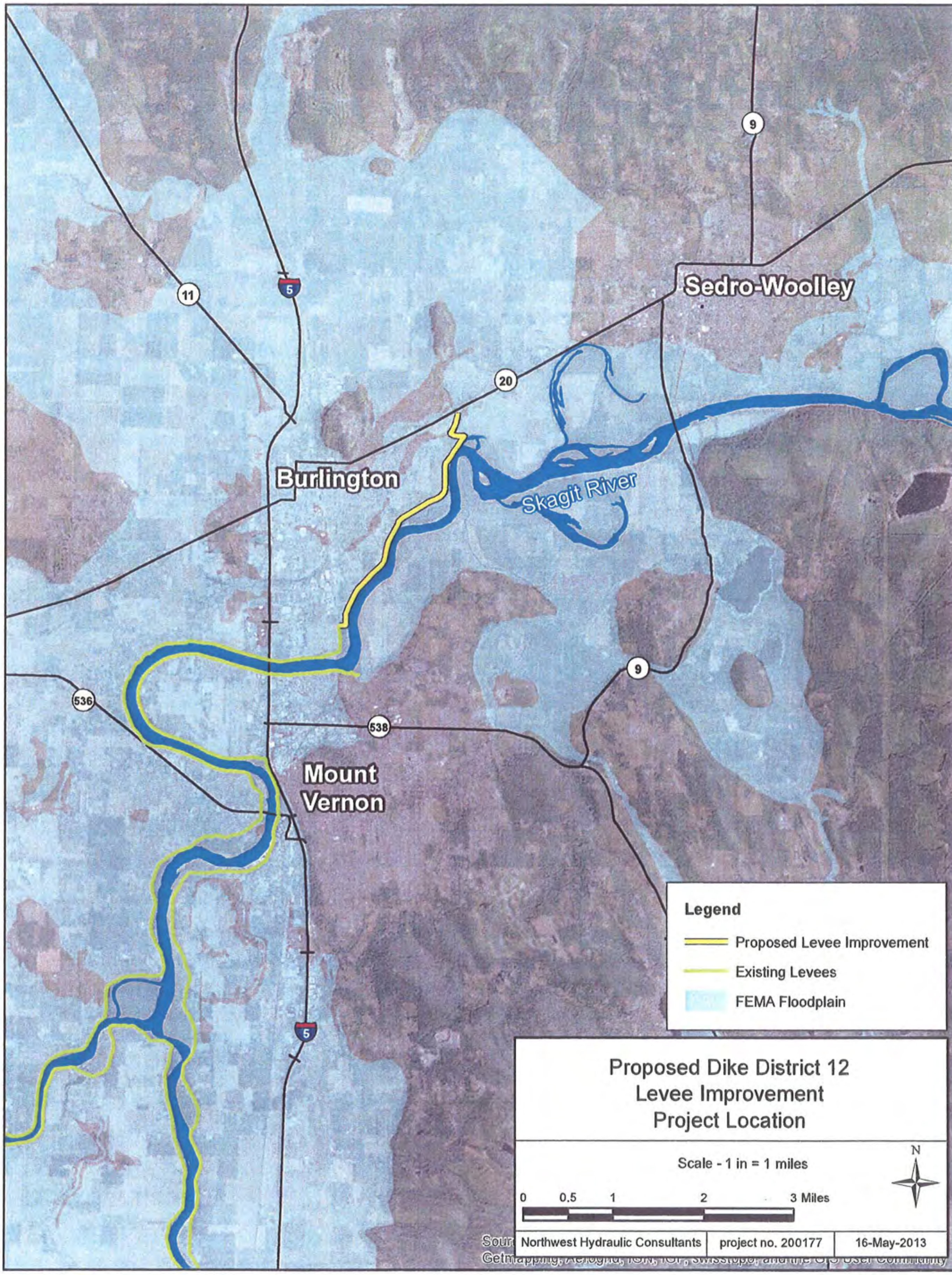
The levee segment proposed for improvement currently has an approximate 50-year level of protection (with BNSF Bridge debris- without debris the level of protection is higher), so increasing the height of the levee will only have an impact during floods larger than this. There would be no project impact in the recent historic floods. One question that naturally follows from this is: at what flood magnitude (or return interval) does the project begin to have an impact at key upstream locations? All we can say definitively is that the river will begin to "feel" the project at around the 50-year flood level (again, with debris). The impacts for the 100-year flood have already been discussed in Table 1. The only intermediate flood for which flows are available is the 75-year flood, which was not included in this study but was part of the G.I. study. Examination of the G.I. study river profiles shows the existing DD12 levee overtops by around 0.4 feet over a distance of over two miles in the 75-year flood. The 75-year water surface profile is closer to the 100-year profile than it is the 50-year, so project impacts at the key locations in the 75-year flood could reasonably be estimated to be closer to the 100-year impacts in Table 1 than the "no impact" during the 50-year flood.

The magnitude of the 100-year flood is further illustrated in the Figure 8 charts, which show peak water levels during the historic floods and the 100-year flood, with and without the proposed project, and with and without bridge debris. River profile plots for these floods are also available, shown in Figures 9-11. The water levels for the historic floods are taken from the "existing condition" HEC-RAS model, so they represent the water levels that would occur today if a flood of that magnitude occurred. It is clear from the profile figures and charts that a) the 100-year flood has much higher water levels than any of the historic floods, and 2) the project would have no impact during the historic floods.

In summary, the project would eliminate levee overtopping within the project reach during the 100-year flood. A natural consequence of this type of partial levee improvement is decreased flooding behind the improved levee, and increased flooding elsewhere.

There are several sources of uncertainty in the analysis presented above. The level of debris that accumulates on bridge piers is one significant variable, but was dealt with directly by modeling two debris conditions. Sediment scour is a related source of uncertainty - some riverbed scour would be expected in a large flood such as the 100-year, and would be exacerbated around bridges with debris buildup. The HEC-RAS model uses a fixed bed, which is analogous to assuming the debris loads at the bridges are the net blocked area (i.e., total area blocked by debris less additional flow conveyance area resulting from scour) rather than the gross area. The HEC-RAS model was calibrated based on the historic floods shown above, but these floods were all significantly smaller than the 100-year flood being used to evaluate the project. The Flo2D model of the floodplain is not calibrated since there is insufficient flooding data on the floodplain to do so. We have not included any emergency flood fighting measures that may or may not be performed in practice. Additionally, there is uncertainty in the magnitude of the 100-year flood, as it was derived from a weighted-average approach from a range of possibilities, and it makes no attempt to account for effects of future climate change.

Figures



Sedro-Woolley
Burlington
Mount Vernon
Skagit River
9
11
5
20
536
538
Legend
Proposed Levee Improvement
Existing Levees
FEMA Floodplain
Proposed Dike District 12
Levee Improvement
Project Location
Scale - 1 in = 1 miles
0 0.5 1 2 3 Miles
N
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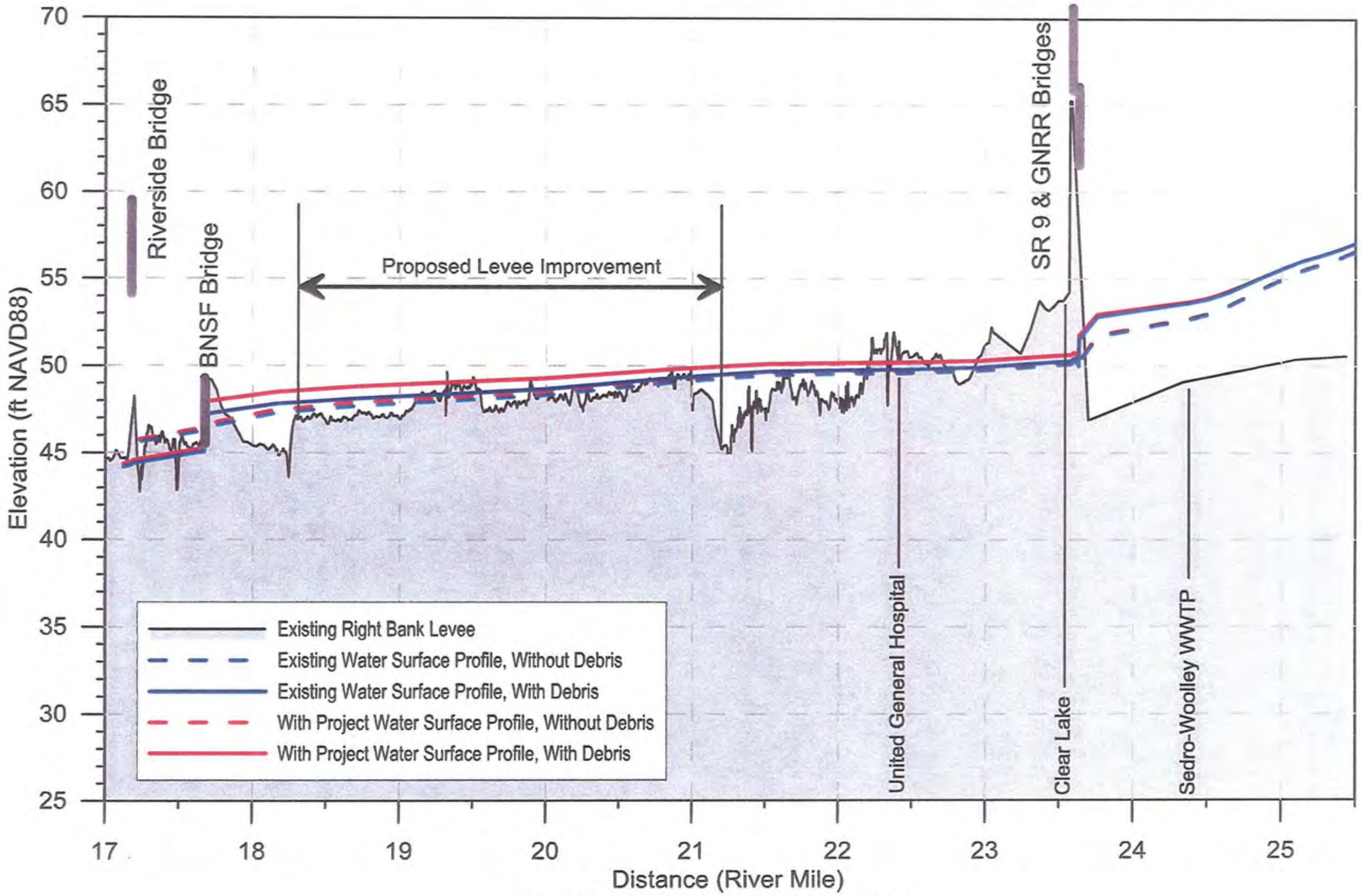
project no. 200177
16-May-2013

Figure 1

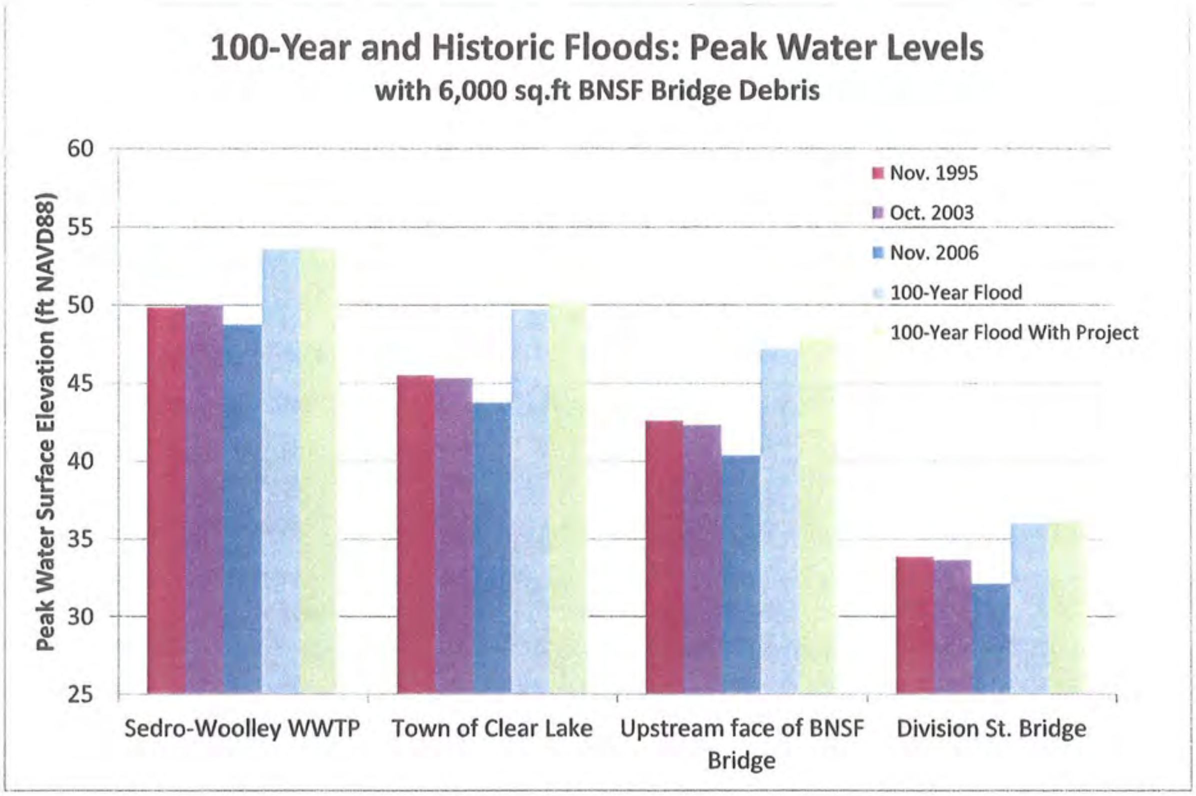
100-Year Flood Water Surface Profiles, With and Without Proposed Levee Improvement
Skagit River, River Mile 17.5 - 25.5



River Mile based on 2012 HEC-RAS model

Notes:
1) Existing levee profiles based on 2012 HEC-RAS model developed for the Skagit River General Investigation project. These profiles differ slightly from existing levee profile in plans provided by City.
2) Zero and 6,000 sq. ft. debris blockages were assumed for the BNSF bridge.

Figure 2



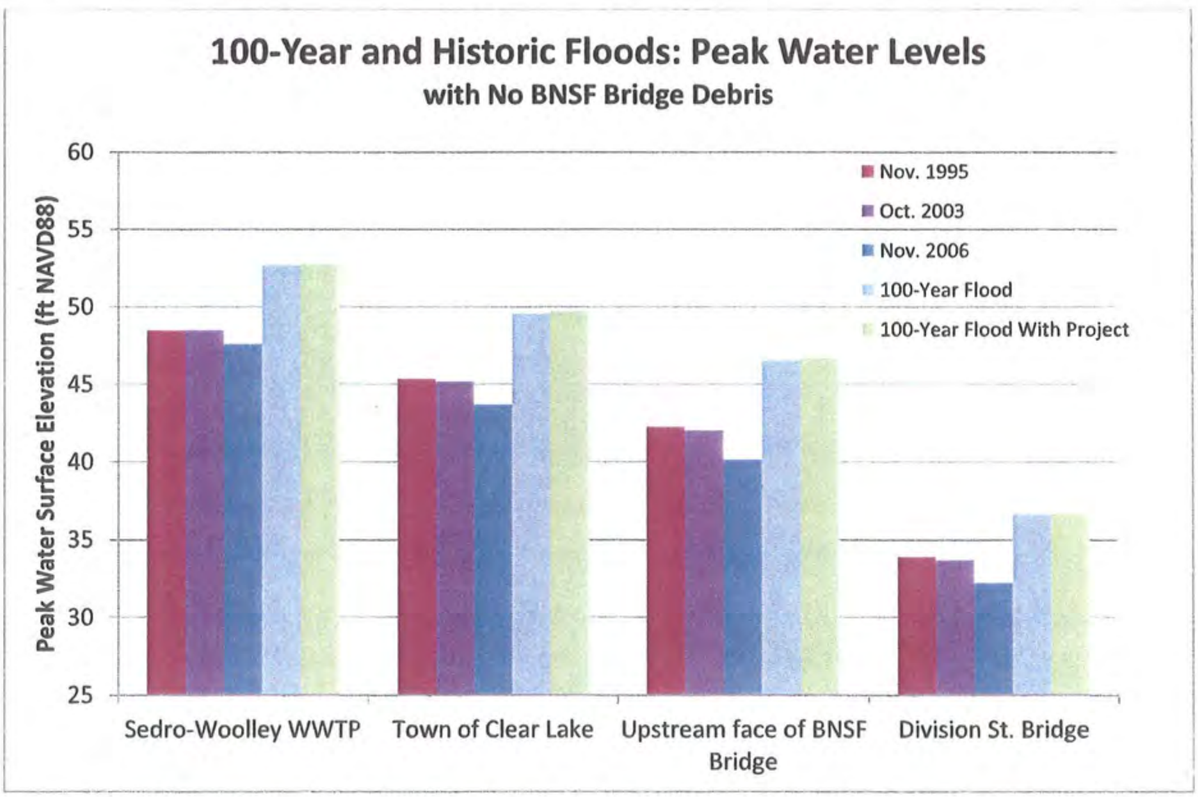
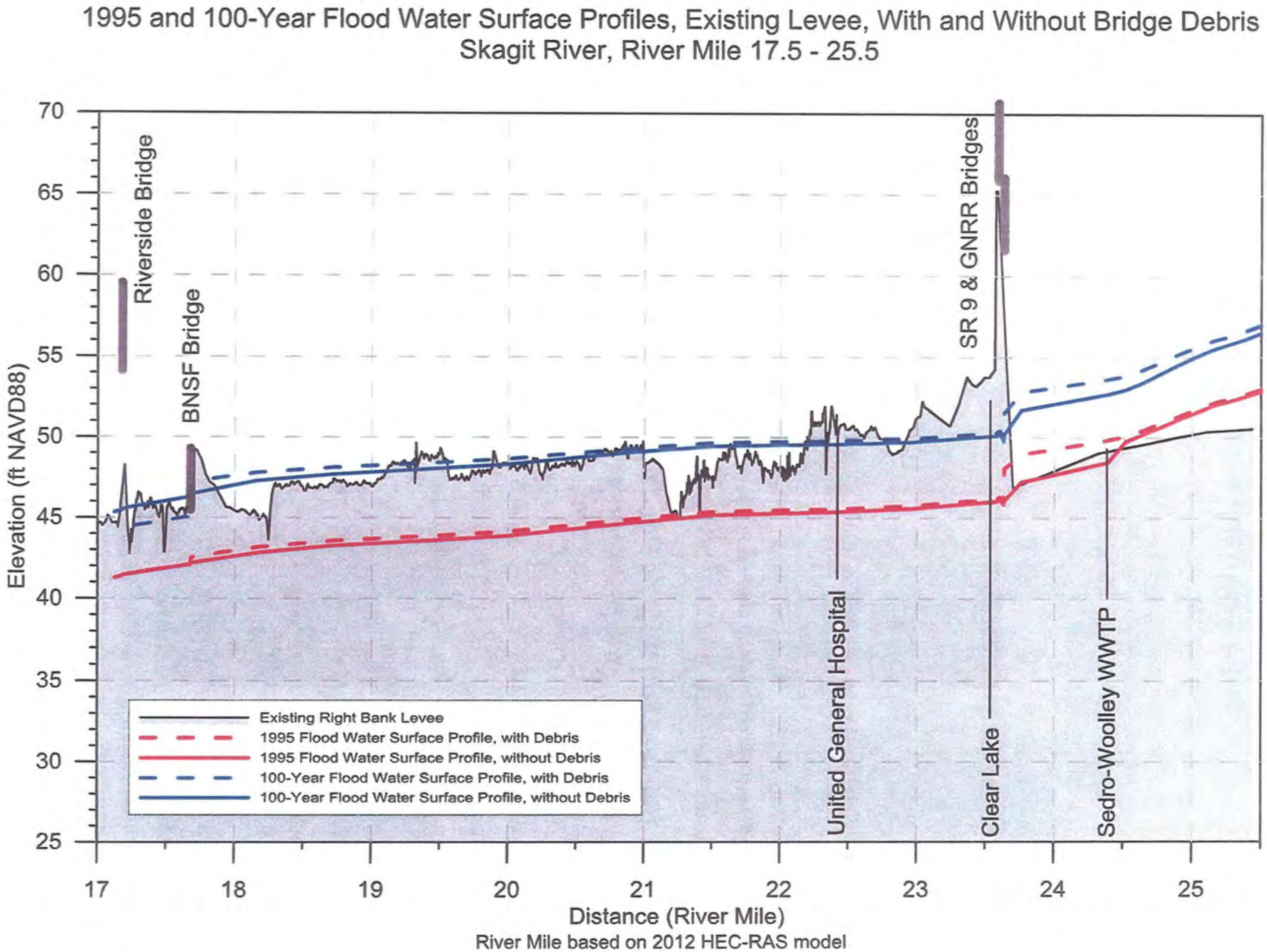


Figure 8: Comparison of Modeled Peak Water Levels in Historic and 100-Year Floods

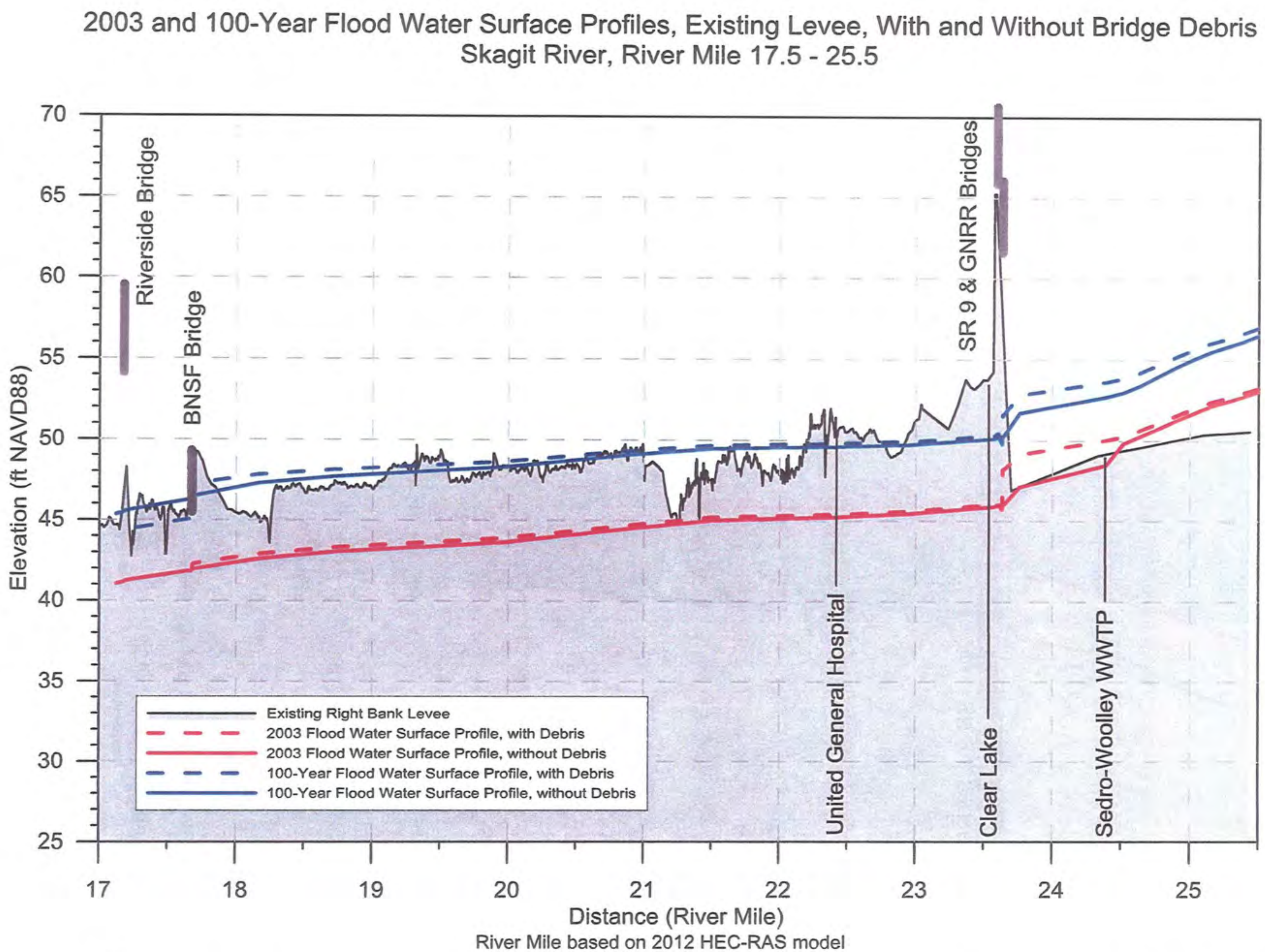


Notes:

1) Levee profiles are based on the 2012 HEC-RAS model "existing condition" developed for the Skagit River General Investigation project. These profiles differ slightly from the existing levee profile in plans provided by the City of Burlington.

2) A zero and 6,000 sq. ft. debris blockage was assumed for the BNSF bridge.

Figure 9



Notes:
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Figure 10

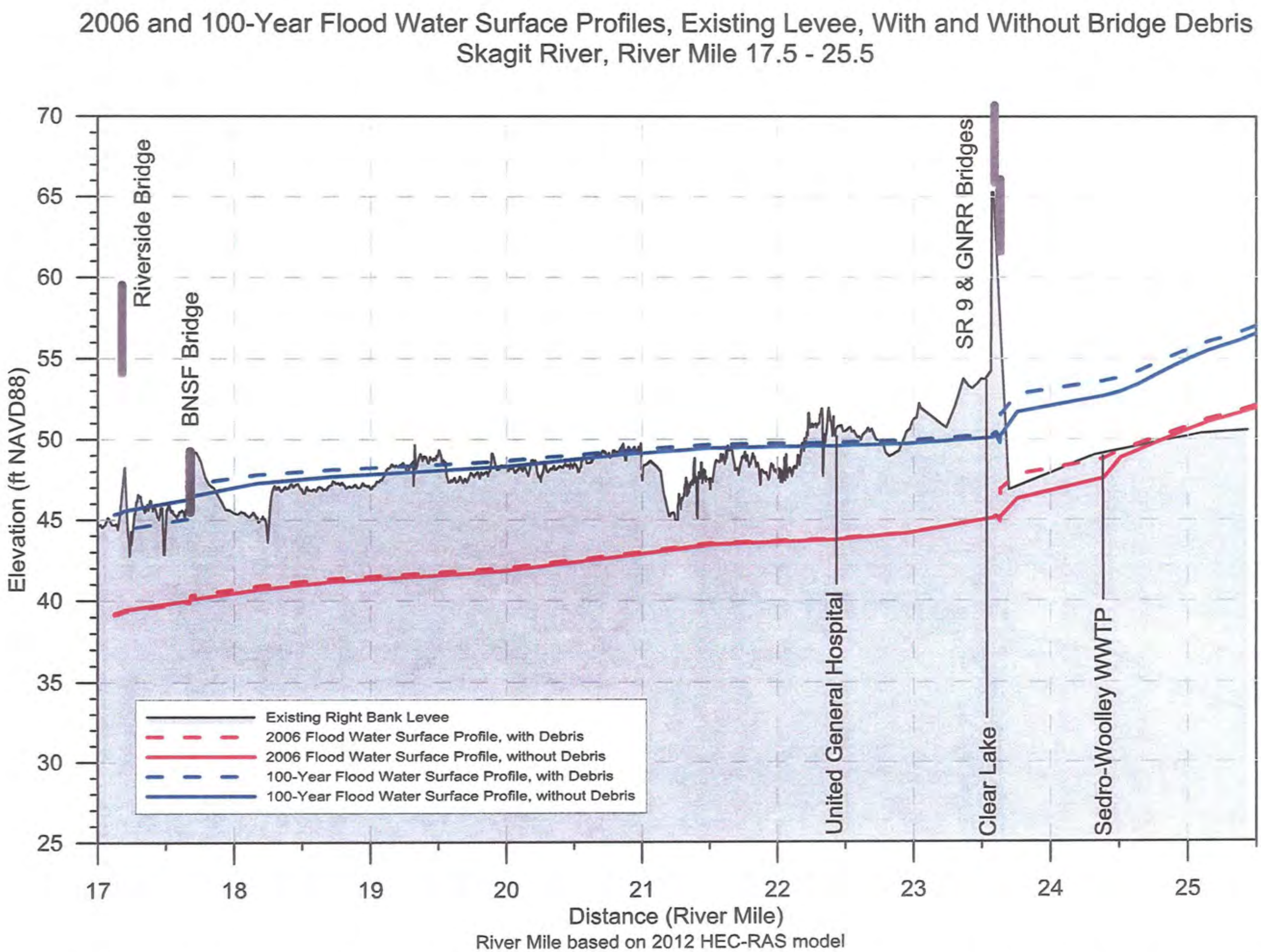

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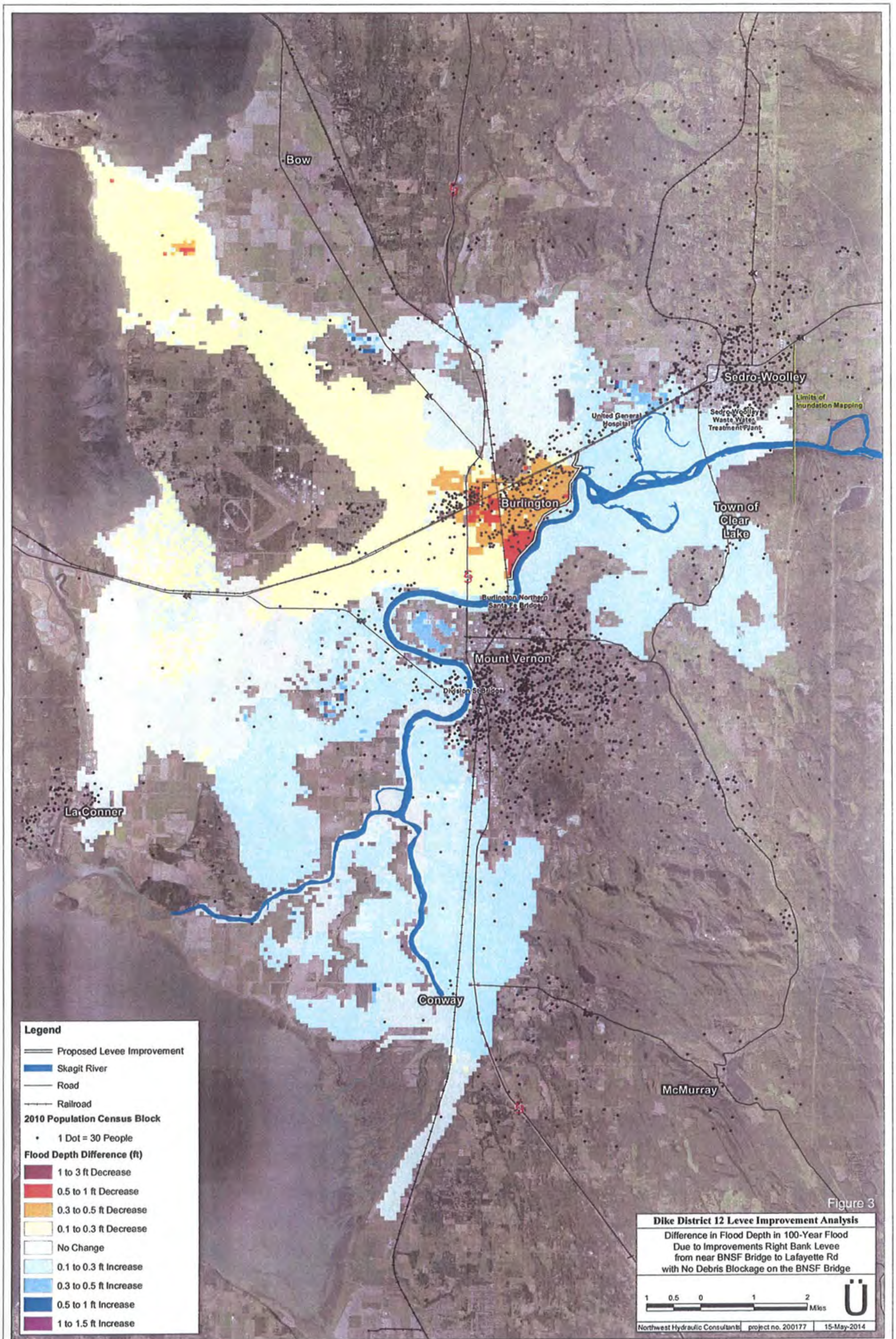
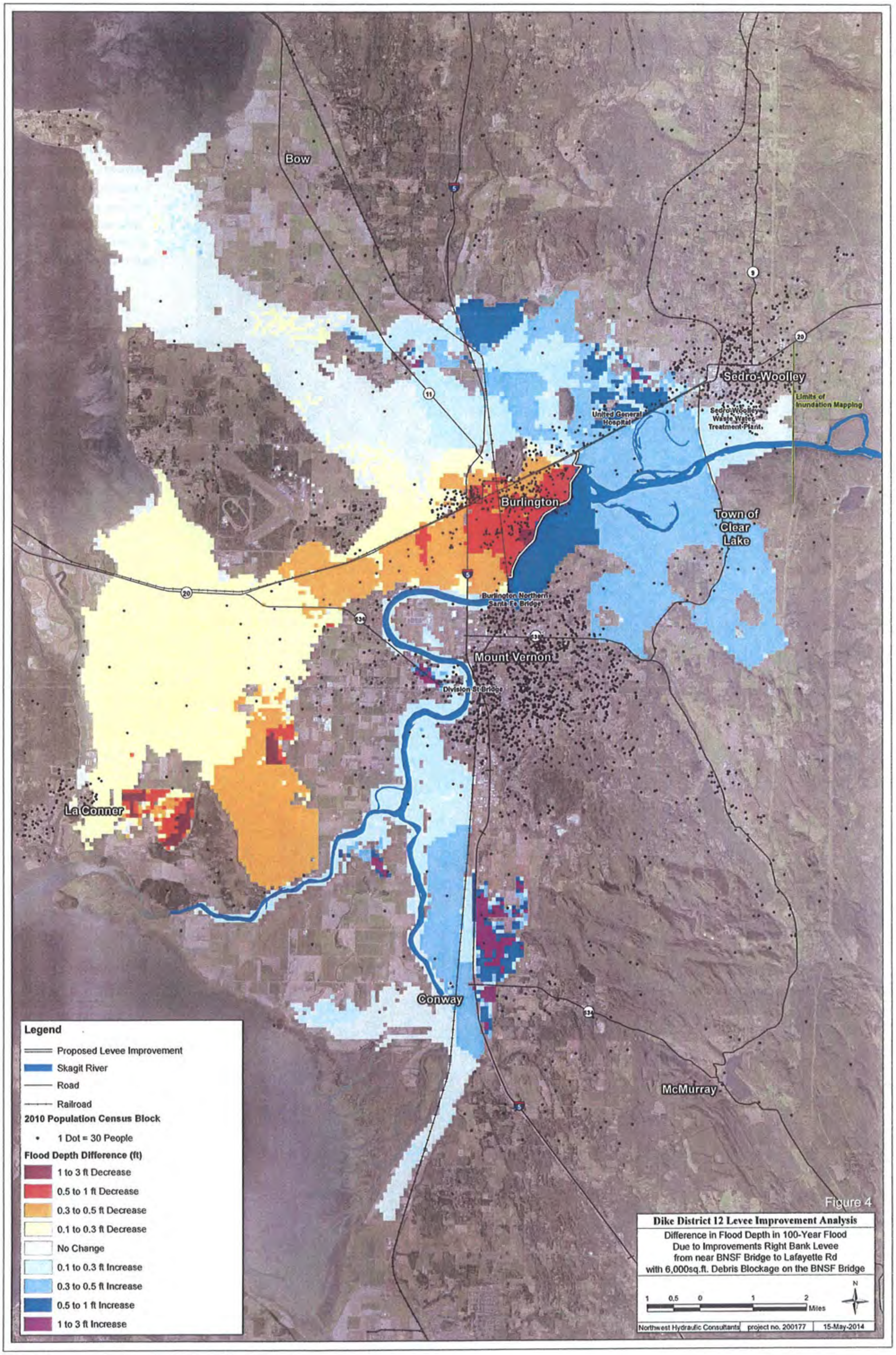
Figure 11



Bow
Sedro-Woolley
Limits of Inundation Mapping
United General Hospital
Sedro-Woolley Waste Water Treatment Plant
Burlington
Town of Clear Lake
Burlington Northern Santa Fe Bridge
Mount Vernon
Division St Bridge
La Conner
Conway
McMurray
Legend
Proposed Levee Improvement
Skagit River
Road
Railroad
2010 Population Census Block
1 Dot = 30 People
Flood Depth Difference (ft)
1 to 3 ft Decrease
0.5 to 1 ft Decrease
0.3 to 0.5 ft Decrease
0.1 to 0.3 ft Decrease
No Change
0.1 to 0.3 ft Increase
0.3 to 0.5 ft Increase
0.5 to 1 ft Increase
1 to 1.5 ft Increase
Figure 3
Dike District 12 Levee Improvement Analysis
Difference in Flood Depth in 100-Year Flood
Due to Improvements Right Bank Levee
from near BNSF Bridge to Lafayette Rd
with No Debris Blockage on the BNSF Bridge
1 0.5 0 1 2
Miles
Northwest Hydraulic Consultants
project no. 200177
15-May-2014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0.3 to 0.5 ft Increase
0.5 to 1 ft Increase
1 to 3 ft Increase
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Dike District 12 Levee Improvement Analysis
Difference in Flood Depth in 100-Year Flood
Due to Improvements Right Bank Levee
from near BNSF Bridge to Lafayette Rd
with 6,000sq.ft. Debris Blockage on the BNSF Bridge
1 0.5 0 1 2 Miles
N
Northwest Hydraulic Consultants
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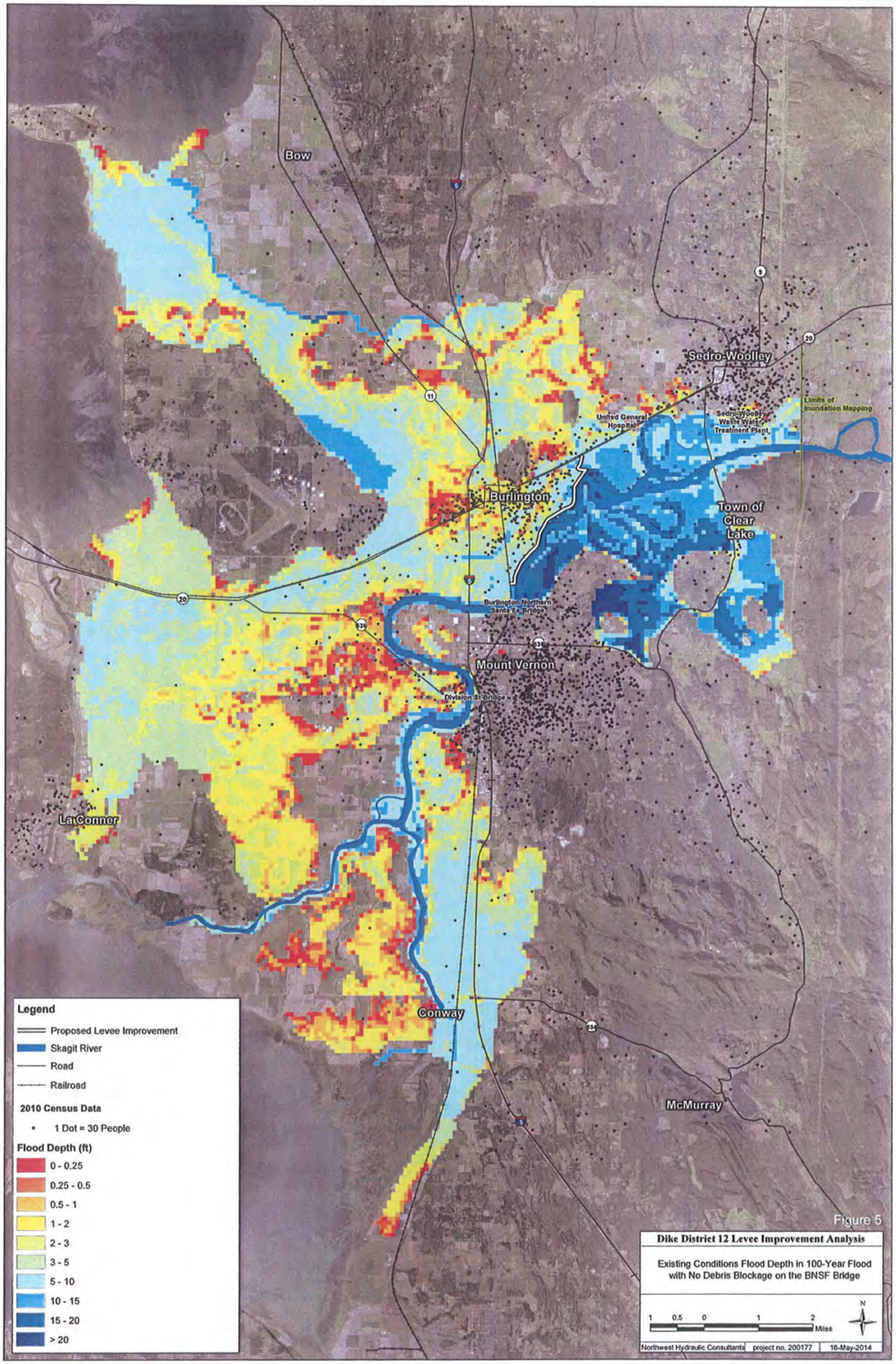
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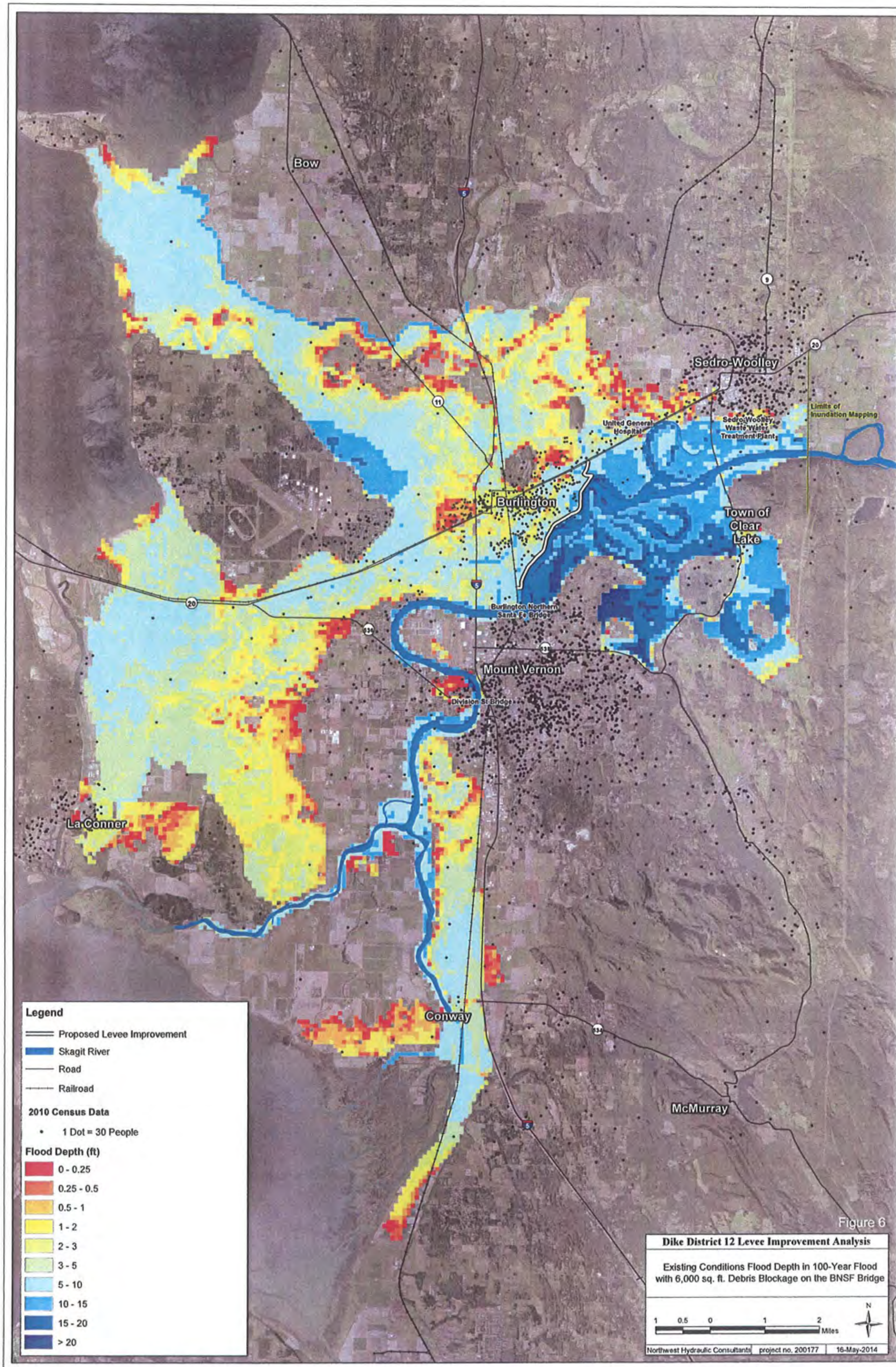
Conway
McMurray
Legend
Proposed Levee Improvement
Skagit River
Road
Railroad
2010 Census Data
1 Dot = 30 People
Flood Depth (ft)
0 - 0.25
0.25 - 0.5
0.5 - 1
1 - 2
2 - 3
3 - 5
5 - 10
10 - 15
15 - 20
> 20
Figure 5
Dike District 12 Levee Improvement Analysis
Existing Conditions Flood Depth in 100-Year Flood with No Debris Blockage on the BNSF Bridge
1 0.5 0 1 2 Miles
N
Northwest Hydraulic Consultants project no. 200177 16-May-2014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Proposed Levee Improvement
Skagit River
Road
Railroad
2010 Census Data
1 Dot = 30 People
Flood Depth (ft)
0 - 0.25
0.25 - 0.5
0.5 - 1
1 - 2
2 - 3
3 - 5
5 - 10
10 - 15
15 - 20
> 20
Figure 6
Dike District 12 Levee Improvement Analysis
Existing Conditions Flood Depth in 100-Year Flood with 6,000 sq. ft. Debris Blockage on the BNSF Bridge
1 0.5 0 1 2 Miles
N
Northwest Hydraulic Consultants
project no. 200177
16-May-2014

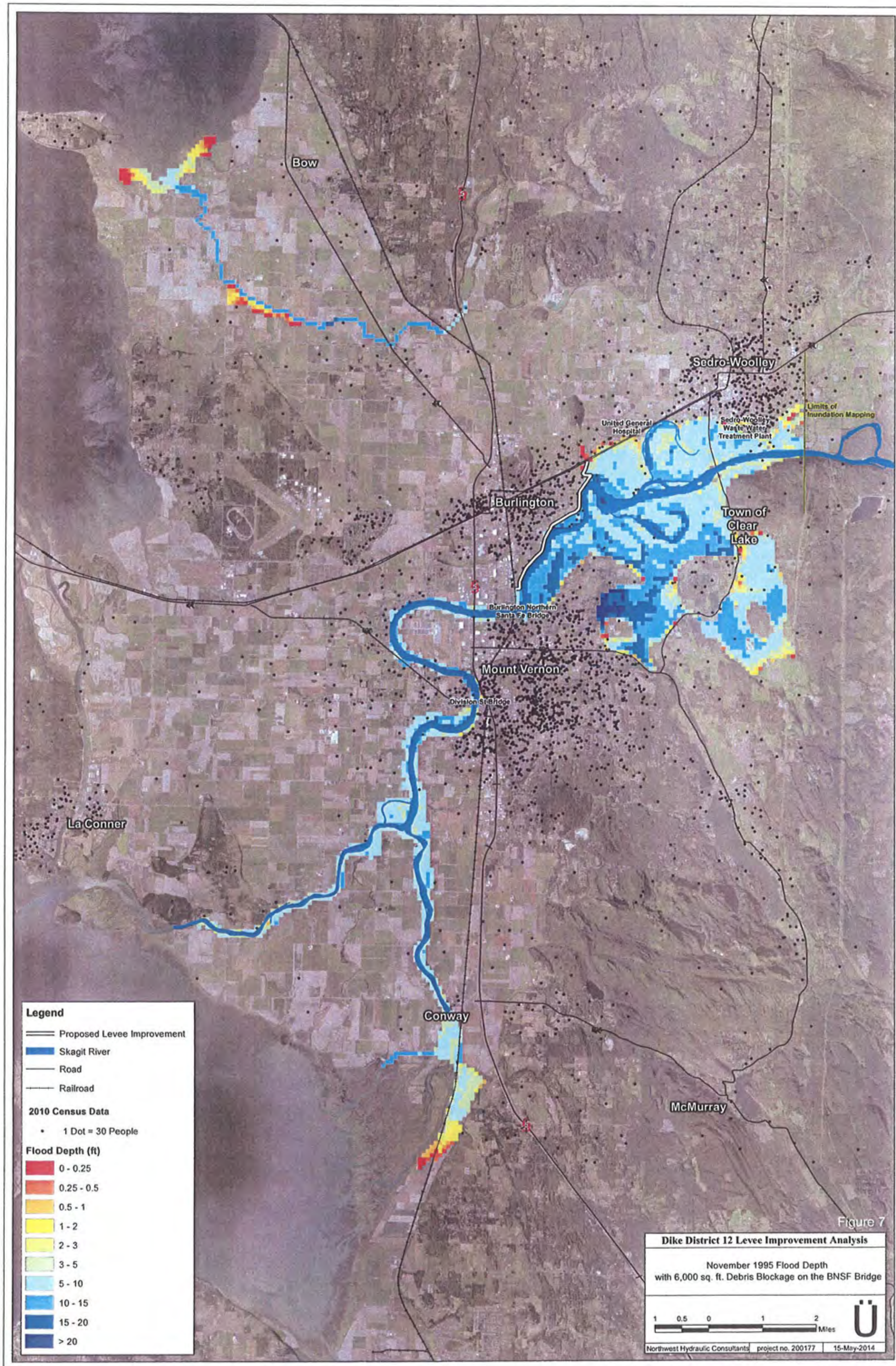

Figure 7

Dike District 12 Levee Improvement Analysis

November 1995 Flood Depth
with 6,000 sq. ft. Debris Blockage on the BNSF Bridge