Plan B Dam Breach Assessment

Introduction

In support of the Local Sponsor permit applications to the states of Minnesota and North Dakota, a dam breach analysis for the Plan B alignment of the Fargo-Moorhead Flood Risk Management project was completed by the US Army Corps of Engineers (USACE). Dam breach locations, methods, and results presented in this memorandum build off numerous collaborative discussions held between representatives of the Minnesota Department of Natural Resources, North Dakota State Water Commission, Diversion Authority, and USACE. It is understood from the collaborative discussions that the State of Minnesota criteria for evaluating impacts from dam breaches rely on defining areas with a depth and velocity product (D*V) of greater than 7 as well as defining overall inundation extents. The State of North Dakota has indicated a desire to follow the same impacts assessment methodology. Therefore, these were the criteria used to evaluate dam breach impacts for the purposes of this memorandum. A formal dam breach evaluation will be conducted by USACE at a later time as part of the Emergency Action Plan development. HEC-LifeSim will be used to characterize the consequences associated with the project at that time. The hydraulic models and breach parameters employed for the formal USACE dam breach evaluation will be the same or very similar to those reported in this memorandum.

Existing and Proposed Conditions

Both existing and proposed conditions were evaluated as part of this analysis. For the purposes of this memorandum, all levees and emergency measure installations surrounding the Fargo, ND and Moorhead, MN areas were assumed to be constructed to the water surface elevation profile associated with a stage of 44 feet at USGS gage 05054000 – Red River of the North at Fargo under both existing and proposed conditions. The levees included in this line of protection extended beyond the formal line of protection to include locally-constructed levees that tie into the existing system. This expanded line of protection was selected as it provides protection to developed residential areas. Using this line of protection would therefore provide the greatest differences in inundation when comparing the existing and with-breach scenarios. The proposed conditions include the micro-sited Plan B alignment of the proposed dam embankment. It is noted that the formal USACE dam breach evaluation will assume that no emergency measures are in place under existing or proposed conditions.

Hydraulic Modeling Approach

Model Setup

A two-dimensional (2D) HEC-RAS model was created to provide detailed information on the depths and velocities of flows throughout the modeled area. **Figure 1** (all Figures are shown in Appendix A) shows the extents of the modeled area, which encompasses the population centers of Fargo, ND, West Fargo, ND, Horace, ND, Oxbow, ND, Moorhead, MN, Comstock, MN, and Oakport, MN. For the existing conditions, the entire area was simulated with a single 2D computational mesh while the proposed conditions were modeled using two separate 2D meshes: one upstream of the dam and another one downstream of the dam. A 2D element spacing of 800 feet was specified throughout a majority of the modeled area, with an element spacing of 100 feet used near the levees surrounding Fargo, ND, Moorhead, MN, and Oakport, MN. Elevations for the model were determined using a combination of surveyed channel cross sections and overbank LiDAR data. Breaklines and internal 2D area connections were created to define levees, roadways, and other embankments throughout the area. Bridge openings along the Wild Rice River and Red River were included in the model. Culverts and bridges along local drains were not incorporated into the model. Resistance to flow was represented using Manning's n roughness values. The spatial distribution of roughness was defined using the 2011 National Land

Cover Database (NLCD). Manning's n values were associated with each NLCD classification type, with n values ranging from 0.03 to 0.10. A variable timestep was used throughout each simulation, ranging from 7.5 seconds to 60 seconds.

Boundary Conditions

Two events were assessed as part of this effort: the 1% annual chance exceedance (ACE) event, commonly referred to as the 100-year event, and the 90,000 cfs peak inflow event, which is slightly smaller than the ½ Probable Maximum Flood (PMF) event. It is noted that the 1% ACE event hydrograph is based on the expert opinion elicitation (EOE) hydrology, with a peak flow of 34,700 cfs. The 1% ACE event was selected because it produces the highest pool elevation when releases into town produce a stage of no greater than 37 feet at the Fargo gage. The 90,000 cfs inflow event was selected because hydraulic modeling completed outside the scope of this dam breach effort indicates that inflows higher than this would require abandoning the strategy to hold a stage of 40 feet at the Fargo gage. Abandoning this strategy would dramatically increase flow releases from the Red River Structure (RRS) and Wild Rice River Structure (WRRS), resulting in reduced head differential across the breach locations. Therefore, the 90,000 cfs event would show the greatest discrepancy in flooding and flood impacts when comparing existing and proposed (with breach) D*V conditions.

Existing conditions boundary conditions for the model were set as the appropriate inflow hydrograph at the upstream end of the modeled area and a normal depth slope downstream boundary condition. For proposed conditions, the same downstream normal depth slope boundary condition was used. However, because the gate operations for the proposed conditions could not be explicitly modeled in the 2D model (due to the operations being developed for a 1D modeling environment), boundary condition assumptions were required for the proposed conditions. These assumptions are detailed in the following paragraphs.

A flat pool was assumed for both events because initial condition sloping pool elevations cannot currently be specified in HEC-RAS version 5.0.4. Assuming a flat pool will provide the appropriate hydraulic loading of the embankment for breach simulation purposes. The 1% ACE event pool was assumed to be at an elevation of 921.0 feet while the 90,000 cfs event pool elevation was assumed as 923.5 feet. Because breach location 3 is located over 3 miles upstream of the east-west portion of the dam, a different flat pool elevation assumption was used for location 3. During the 1% ACE event, the maximum pool does not reach the toe of the embankment at breach location 3, so no breach is possible at this location during the event. Breach location 3 was assumed to be 925.1 feet for the 90,000 cfs event based on hydraulic analyses conducted outside the scope of this effort. **Table 1** summarizes the flat pool elevation assumptions for each event.

Outflow boundary conditions for the computational mesh representing the area upstream of the dam were specified to represent Diversion Inlet Structure (DIS), RRS, and WRRS releases. Inflow boundary conditions for the computational mesh representing the area downstream of the dam were specified to represent RRS and WRRS releases along with Wolverton Creek inflows. Releases into the protected area were specified such that a stage of 37 feet (corresponding to 21,000 cfs) was achieved during the 1% ACE event and a stage of 40 feet (corresponding to 27,000 cfs) was achieved during the 90,000 cfs event. RRS, WRRS, and Wolverton Creek flows were defined to be consistent with flows determined in the project 1D model that utilizes the gate operations scheme. These releases were assumed constant throughout the simulation. **Table 1** shows the upstream computational mesh outflow and downstream computational mesh inflow boundary conditions.

Table 1. Proposed Conditions Hydrology Summary

Event	Pool WSE	DIS Outflow	RRS Outflow/Inflow	WRRS Outflow/Inflow	Wolverton Creek Inflow	Total Protected Area Inflow
1% ACE	921.0 ft	20,000 cfs	12,200 cfs	6,100 cfs	2,700 cfs	21,000 cfs
90,000 cfs	923.5 ft 925.1 ft (Location 3)	45,000 cfs	13,667 cfs	6,833 cfs	6,500 cfs	27,000 cfs

Because the pool was assumed to be at its maximum elevation at the start of the model simulation (which is also the time at which the breach was specified to occur), an assumption regarding the inflow hydrograph after the maximum pool elevation was reached was necessary. Flow requires approximately 1 day to travel from the upstream end of the model to the dam embankment. The maximum pool elevation was assumed to occur as a result of the peak inflow reaching the dam embankment, which is 1 day after the peak inflow occurs at the upstream end of the model. Therefore, the inflow hydrograph at the upstream end of the model was begun 1 day after the peak inflow to ensure the appropriate volume was introduced to the pool over the course of the breach formation. **Figure 2** and **Figure 3** show the inflow hydrographs used for the existing and proposed conditions simulations, respectively. The dashed blue line represents the inflow hydrograph for the existing conditions simulation, while the solid orange line represents the inflow hydrograph for the proposed conditions simulations, beginning 1 day after the hydrograph peak.

Breach Location Definition

Five locations along the dam embankment were identified as locations where breaches should be evaluated. **Figure 4** shows the Plan B alignment represented as a solid red line and the five dam breach locations represented as green dots. Location 1 is located at a low spot along Cass County Drain 27. Location 2 is considered a representative location for a majority of the dam, as it is located along relatively flat ground. Location 3 is located along the eastern edge of the Plan B embankment and was selected due to its proximity to Comstock, MN. Additional breaches were simulated at the existing channel locations next to the Wild Rice River Structure (WRRS) and the Red River Structure (RRS). To assess whether a breach of the Fargo levee resulted in significantly different depths and velocities within the levee-protected area of Fargo, additional scenarios were evaluated in which the Fargo levee was breached. **Figure 5** shows the selected location of the Fargo levee breach. This location was selected based on the hydraulic loading of the levee as well as the high density of residential structures located immediately downstream of the levee breach location.

Breach Parameter Definition

The dam embankment is designed to not overtop during events up to and including the PMF. Therefore, in the unlikely event a breach occurs, the failure mechanism is expected to be piping failure. Piping failure can be used with the simplified physical breach method, which is a physically-based method that calculates the breach formation rate based on flow velocity through the breach opening. Simulating piping failure with the simplified physical breach method requires a number of input parameters, including breach horizontal and vertical erosion rates, maximum possible bottom width, minimum possible bottom elevation, side slopes, breach weir flow coefficient, and orifice piping flow coefficient. **Table 2** summarizes the breach parameters used for the breach simulations, along with the reference recommending the selected value or method.

Table 2. Breach Parameter Approach

Variable	Value	Reference
Breach Method	Simplified Physical	MMC (2017)
Horizontal Erosion Rate Relationship	Shown in **Table 3**	WEST (2013)
Vertical Erosion Rate Relationship	Shown in **Table 4**	WEST (2013)
Maximum Possible Breach Bottom Width	30.2 * Headwater Depth[1]	WEST (2013)
Breach Side Slope	0.5H:1V[2]	HEC (2016)
Breach Weir Coefficient	2.6	MMC (2016)
Piping Orifice Flow Coefficient	0.5	MMC (2016)
Initial Piping Elevation	Bottom of Embankment	MMC (2017)
Initial Piping Diameter	1 foot	MMC (2017)

Notes: [1]For the RRS and WRRS, the maximum breach bottom width was specified as the width of the existing channel bottom.
[2]For the RRS and WRRS, the breach side slope was assumed to be 1H:1V to more closely match the shape of the existing channel where fill will be placed.

Table 3. Horizontal Erosion Rate Relationship (WEST, 2013)

Velocity (feet/second)	Erosion Rate for Clay Material (feet/hour)
0	0
3	0
4	0.1
6	0.3
8	0.6
10	1.1
15	3.1
30	16.8

Table 4. Vertical Erosion Rate Relationship (WEST, 2013)

Velocity (feet/second)	Erosion Rate for Clay Material (feet/hour)
0	0
1	0
1.5	0.1
2	0.2
3	0.4
4	0.6
6	1.2
8	2.0
10	3.0
15	6.1
30	20.4

Results

90,000 cfs Event Scenarios

As part of a dam breach analysis in which the dam is part of the proposed project, it is important to consider the flood and life safety impacts if the project were not constructed. Therefore, existing conditions maps were created to display the maximum inundation depths and areas with maximum D*V values greater than 7 ft^2/s throughout the modeled area. As shown in **Figure 6**, a large portion of the area downstream of the proposed dam is expected to be inundated under existing conditions during the 90,000 cfs event. All figures showing maximum depths throughout the modeled area use a discrete color scheme, where depths of 0-2 feet are light blue, 2-6 feet are dark blue, 6-15 feet are orange, and 15+ feet are red. **Figure 7** shows that the maximum D*V values for the event generally occur along rivers, ditches, low-lying areas, and roadway overtopping areas. For comparison, under the proposed conditions without a dam breach, the flood extents are greatly reduced, as shown in **Figure 8**.

Figure 9 through **Figure 23** show the maximum flow depth, global maximum D*V, and maximum D*V in the vicinity of the breach location for the five proposed conditions breach scenarios during the 90,000 cfs event. Generally, the inundation depths and D*V values are globally reduced under the proposed (with breach) conditions, with the exception being in the near vicinity of the dam when a failure occurs. A breach of the embankment next to the RRS results in the greatest inundation extents and largest extents of D*V values greater than 7 ft^2/s compared to the other dam breach locations. Of particular note, breach location 2 is considered to be representative of the majority of the dam embankment because it is located near generally flat ground and not along a major river/ditch. As shown in **Figure 14**, the area with D*V values greater than 7 ft^2/s just downstream of breach location 2 extends approximately 0.25 miles downstream of the dam, while the D*V values under existing conditions are less than 7 ft^2/s in this area. This can be considered to be the typical downstream extent of high D*V zone wherever the embankment is not crossing a local drain or river. Finally, it is noted that a breach of the levee at location 3 does not result in overtopping of the Fargo, ND or Moorhead, MN levee systems due to the relatively small volume of flow passing through the breach at this location. All other breach scenarios do result in overtopping of the levee systems.

While all but breach scenario 3 result in overtopping of the levee systems during the 90,000 cfs event, the high depths and high D*V zones within the levee-protected areas of Fargo, ND and Moorhead, MN occur a number of hours after the dam breaches occur. The number of hours after the dam is breached that the Fargo, ND levee overtopping is initiated is summarized in **Table 5**. As shown in the table, a breach of the RRS location would result in overtopping occurring approximately 10 hours after the breach begins. However, the levee overtopping due to breaches at the three other locations occurs well after the dam breach begins. Due to the time difference between the time of the dam breach and the time at which the D*V values exceed 7 ft^2/s within the levee-protected area, it is likely that persons within the levee-protected area could at a minimum vertically evacuate to the second story or roof of their property to be above the floodwaters when life loss risk was highest. There is also a high likelihood that persons living in the affected areas would be able to evacuate out of the expected inundation area.

Table 5. Time Difference between Dam Breach and Fargo Levee Overtopping for 90,000 cfs Event under Proposed Conditions

Dam Breach Location	Time Difference Between Dam Breach and Fargo Levee Overtopping (hour)
1	71
2	100
3	Not Overtopped
WRRS	39
RRS	10

Because the RRS dam breach resulted in the greatest inundation and largest D*V extents, this failure scenario would be the most likely of the considered dam breach scenarios to cause a cascading failure where the Fargo levee breaches as a result of a dam breach. Therefore, an additional scenario was simulated in which the RRS location was breached, followed by a piping failure breach of the Fargo levee when the water surface elevation at the failure location reached the levee top. Piping failure was selected as the levee breach method because the maximum overtopping depth was approximately 0.5 feet, which resulted in slow overtopping breach formation and relatively small overtopping breach flows. **Figure 24** through **Figure 26** show the maximum inundation depths and global and Fargo levee-vicinity maximum D*V values during the 90,000 cfs event. The Fargo levee breach D*V zone of greater than 7 ft^2/s extends approximately 50 feet further downstream of the Fargo breach location than it does under the RRS breach scenario where the Fargo levee is not breached. Depths in the immediate vicinity of the breach are increased approximately 0.1 feet under the scenario where the Fargo levee is breached. Very little difference is noted in the overall inundation extents compared to the scenario where only the RRS is breached.

Table 6 summarizes whether D*V values are greater than 7 ft^2/s for any of the five breach simulations for any property located within the following populated areas: Comstock, MN; Rustad, MN; St. Benedict, ND; Wild Rice, ND; and Horace, ND.

Table 6. Summary of D*V Values for Populated Areas near Dam Alignment during 90,000 cfs Event

Populated Area	Are D*V values greater than 7 ft^2/s at any property within the populated area for any of the breaches simulated?
Comstock, MN	No
Rustad, MN	No
St. Benedict, ND	*
Wild Rice, ND	No
Horace, ND	No

**While none of the breaches simulated as part of this effort resulted in D*V values greater than 7 ft^2/s in St. Benedict, it is assumed that because most of the properties within St. Benedict are located within 0.25 miles of the embankment, D*V values would be greater than 7 ft^2/s at these properties.*

1% ACE Event Scenarios

During the 1% ACE event under existing conditions, the levee system protecting the cities of Fargo, ND and Moorhead, MN is not overtopped, as shown in **Figure 27**. Zones with D*V values greater than 7 ft^2/s for the 1% ACE event, as shown in **Figure 28**, are limited to the Red River and Wild Rice River channels. While no levees are overtopped under the existing conditions, the inundation extents under proposed conditions (without breach) show a reduced inundation extent downstream of the dam, as shown in **Figure 29**.

A breach of the Fargo levee under existing conditions was simulated to understand inundation extents and D*V under such a scenario. The 1% ACE event was selected for this evaluation due to the fact that the Fargo levee system is not overtopped during the event (compared to the 90,000 cfs event causing Fargo levees to overtop), which results in the greatest difference between the with and without breach scenario. **Figure 30** shows the maximum flow depths under this existing conditions Fargo levee failure scenario. **Figure 31** and **Figure 32** show the maximum D*V globally and in the near-vicinity of the breach, respectively. As shown in the figures, the additional inundation resulting from such a breach is widespread. However, the high D*V zone is limited in extent, spreading roughly 150 feet downstream of the levee embankment. It is noted that the high D*V zone appears minutes after the breach initiates, limiting the ability of any persons to evacuate out of the impacted area.

The RRS dam breach was the only dam breach simulated for the 1% ACE event, because this breach will show the greatest inundation and largest D*V extents. Results of the RRS dam breach are shown in **Figure 33** through **Figure 35**. The D*V zone with values greater than 7 ft^2/s in the vicinity of the breach under this scenario is slightly smaller than the greater than 7 ft^2/s D*V zone under the 90,000 cfs event scenario. The inundation extents under both the RRS breach location 1% ACE and 90,000 cfs event scenarios are generally similar.

Failure of the Fargo levee in combination with failure of the RRS for the 1% ACE event was also simulated; results for this failure scenario are shown in **Figure 36** through **Figure 38**. The zone in which the D*V is greater than 7 ft^2/s in the vicinity of the Fargo levee breach location extends approximately 200 feet further downstream under this failure scenario than it does when only the RRS is breached and this section of levee is simply overtopped without breaching.

Peak Breach Flow Comparison

To verify that the simplified physical breach methodology provided reasonable peak flow values, the results produced by the hydraulic model were compared to an envelope curve generated from historic failures. This verification process was developed collaboratively during discussions amongst Minnesota Department of Natural Resources, North Dakota State Water Commission,, Local Sponsor, and USACE representatives. The USACE Hydrologic Engineering Center (HEC) developed an envelope curve from 14 observed dam breaches that have occurred throughout the United States (HEC, 1980). The envelope curve was determined by HEC using the following equation:

$$Q_{max} = 75D^{1.85}$$

where Q_{max} is the maximum dam breach flow and D is the depth at the time of failure. The *minimum* maximum dam breach discharge recommended by the NRCS in TR-60 (NRCS, 2005) follows a similar equation type:

$$Minimum\ Q_{max} = 65D^{1.85}$$

Table 7 compares the maximum breach flows obtained from the HEC-RAS models to the values calculated using the HEC (1980) and NRCS (2005) equations. As shown in **Table 7**, the modeled and calculated maximum breach flows are generally similar, providing confidence in the dam breach parameter definition approach.

Table 7. Breach Flow Comparison

Event	Conditions	Location	Headwater Depth (feet)	Modeled Max. Breach Flow (cfs)	HEC Envelope Curve Max. Breach Flow (cfs)	NRCS Minimum Max. Breach Flow (cfs)
90,000 cfs	Proposed	1	16.7	17,400	13,800	11,900
90,000 cfs	Proposed	2	14.7	12,400	10,800	9,300
90,000 cfs	Proposed	3	3.3	70	700	600
90,000 cfs	Proposed	WRRS	33.7	27,900	50,300	43,600
90,000 cfs	Proposed	RRS	50.5	67,300	106,200	92,000
90,000 cfs	Proposed	RRS Fargo Levee	50.5 8.0	67,300 4,600	106,200 3,500	92,000 3,000
1% ACE	Existing	Fargo Levee	6.6	1,100	2,500	2,100
1% ACE	Proposed	RRS	14.2	59,600	96,700	83,800
1% ACE	Proposed	RRS Fargo Levee	14.2 8.0	59,600 6,200	96,700 3,500	83,800 3,000

Summary

Dam breach assessment results are presented in this memorandum that illustrate the impacts of a number of dam breach scenarios. The following items were concluded from this assessment:

- Flood extents and D*V zones of greater than 7 ft^2/s under the "no dam breach" scenario are greatly reduced compared to existing conditions.
- Failure of the dam embankment does not produce global increases in flood extents or D*V zones of greater than 7 ft^2/s under the considered breach scenarios; however, it does increase flood depths and D*V zones of greater than 7 ft^2/s in the breach vicinity.
- Failure of the dam embankment near breach location 2, considered to be representative of a majority of the dam embankment, results in a D*V zone of greater than 7 ft^2/s extended approximately 0.25 miles downstream of the breach location.

- Failure of the dam embankment near the Red River Structure results in the greatest flooding extents and D*V zones of greater than 7 ft^2/s.
- Overtopping of the Fargo levee system does not occur until many hours after a dam breach, providing substantial warning time for evacuation notification.
- Substantial changes in the global inundation extents and D*V zones of greater than 7 ft^2/s do not occur as a result of a cascading failure scenario where the Fargo levee fails after the dam embankment fails.
- Peak flows determined using the simplified physical breach approach are similar to the peak flows predicted using envelope curves.

References

Hydrologic Engineering Center (HEC). Hydrologic Engineering Center River Analysis System (HEC-RAS) Hydraulic Reference Manual, Version 5.0. February 2016.

Hydrologic Engineering Center (HEC). Flood Emergency Plans – Guidelines for Corps Dams. June 1980.

Modeling, Mapping, and Consequences (MMC) Production Center. Technical Manual for Levees. January 2017.

Modeling, Mapping, and Consequences (MMC) Production Center. FY2016 Technical Manual (SOP) for Dams: Appendix 3.1.21 – Breach Parameter Estimation. January 2016.

Natural Resources Conservation Service (NRCS). TR-60: Earth Dams and Reservoirs. July 2005.

WEST Consultants, Inc. (WEST). Technical Memorandum for Record: Updated Levee Breach Characteristics for MMC SOP. July 2013.

Appendix A: Figures

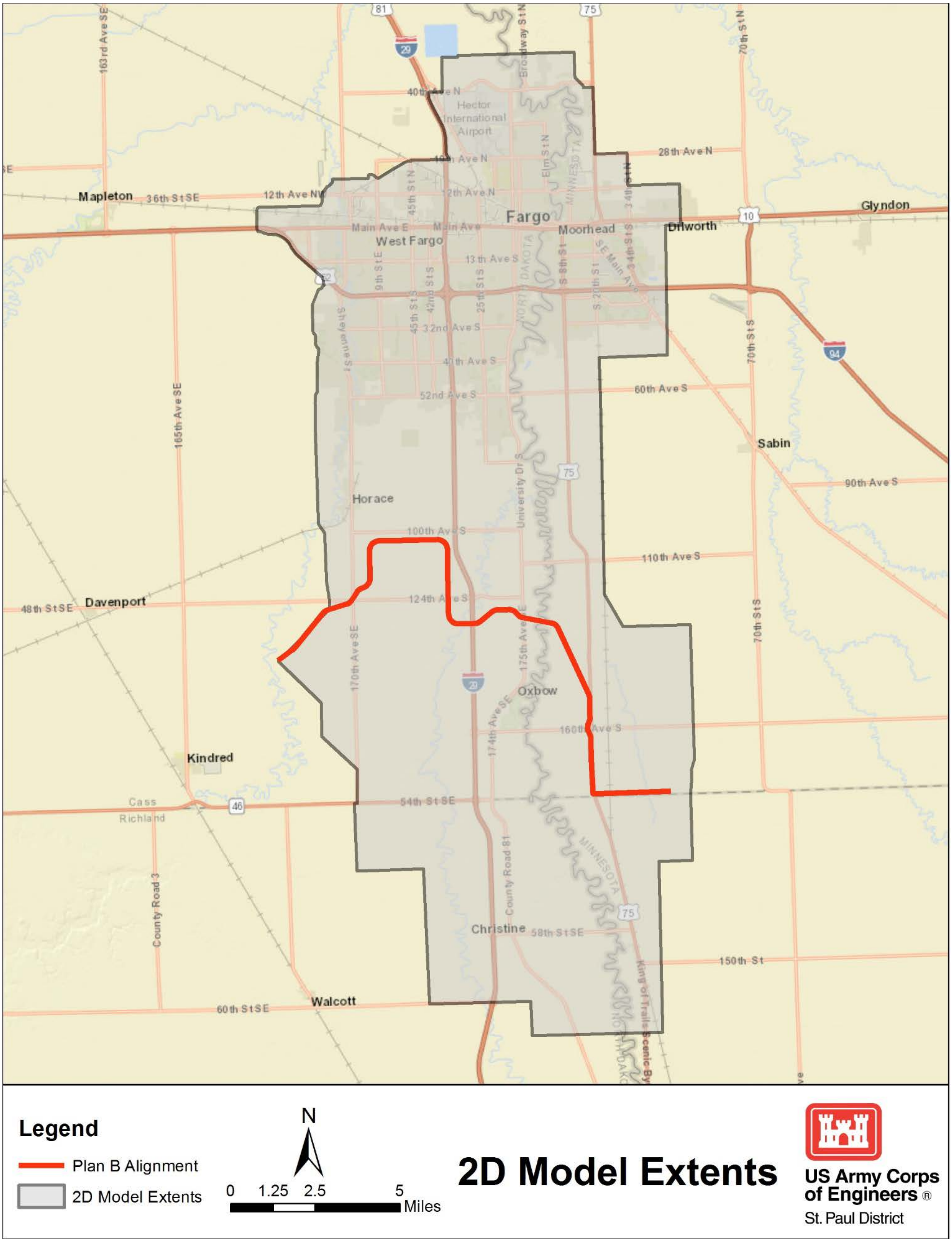

Figure 1. 2D Dam Breach Model Extents

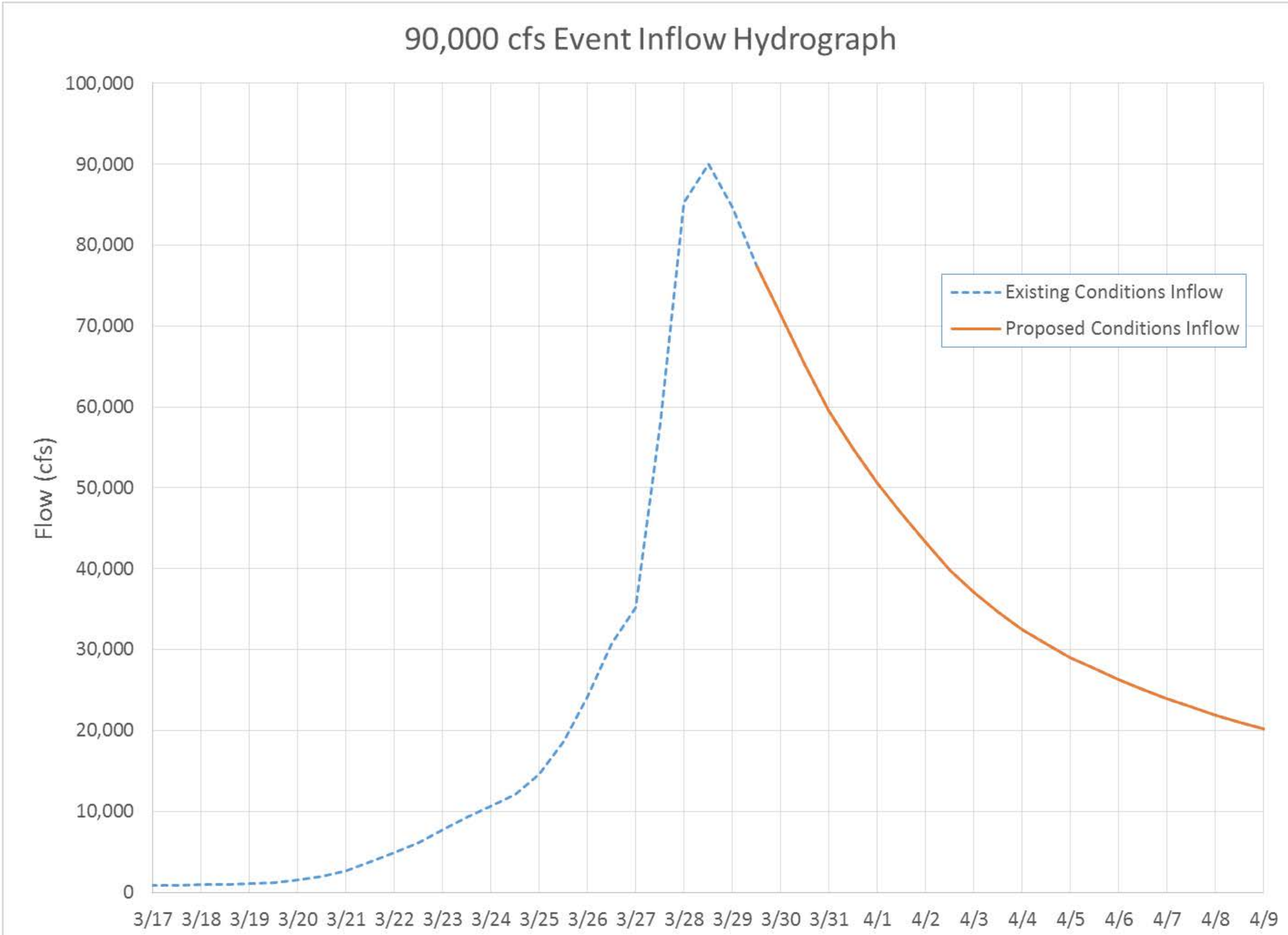

Figure 2. Inflow Hydrograph for 90,000 cfs Event

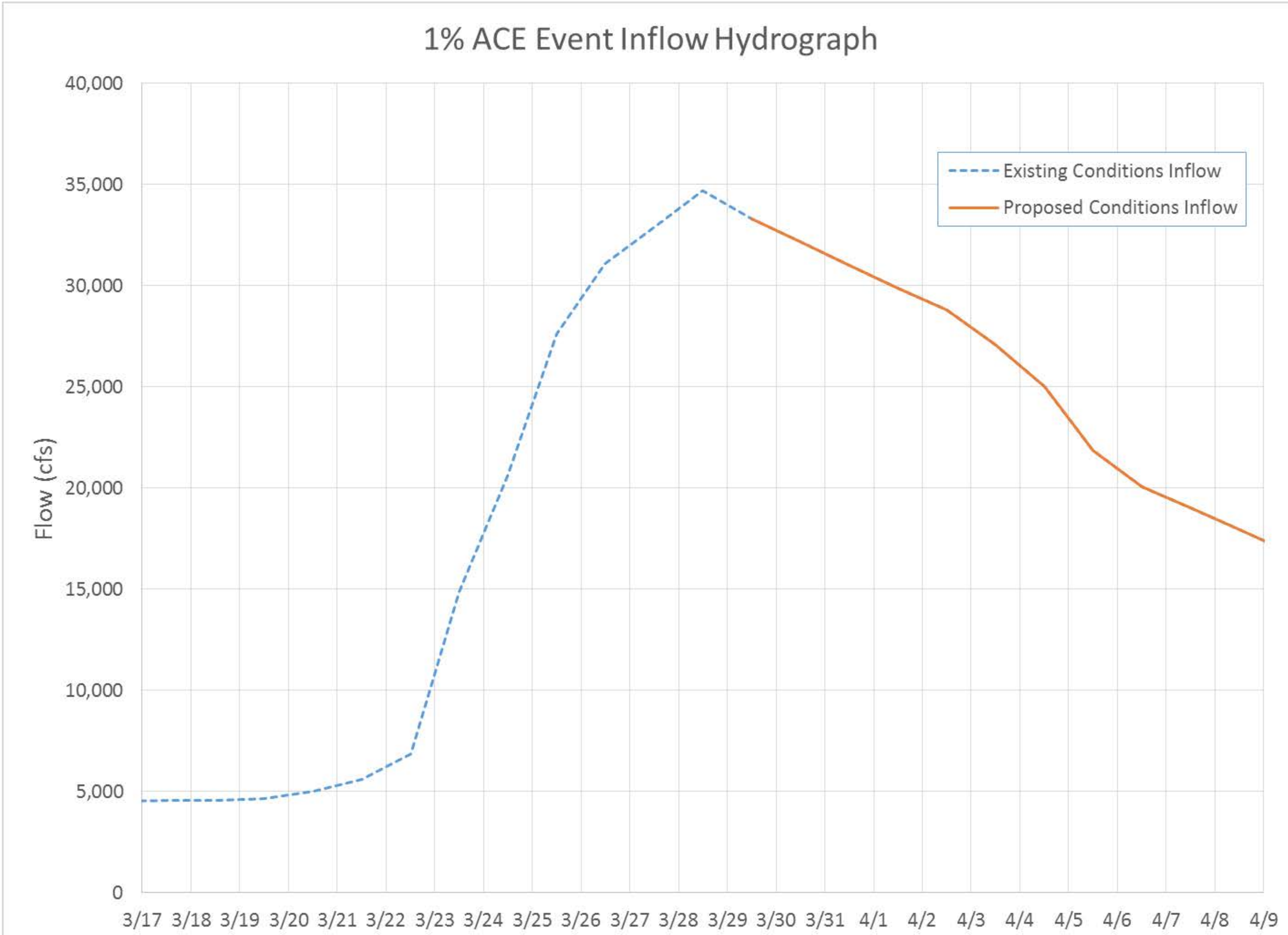

Figure 3. Inflow Hydrograph for 1% ACE Event

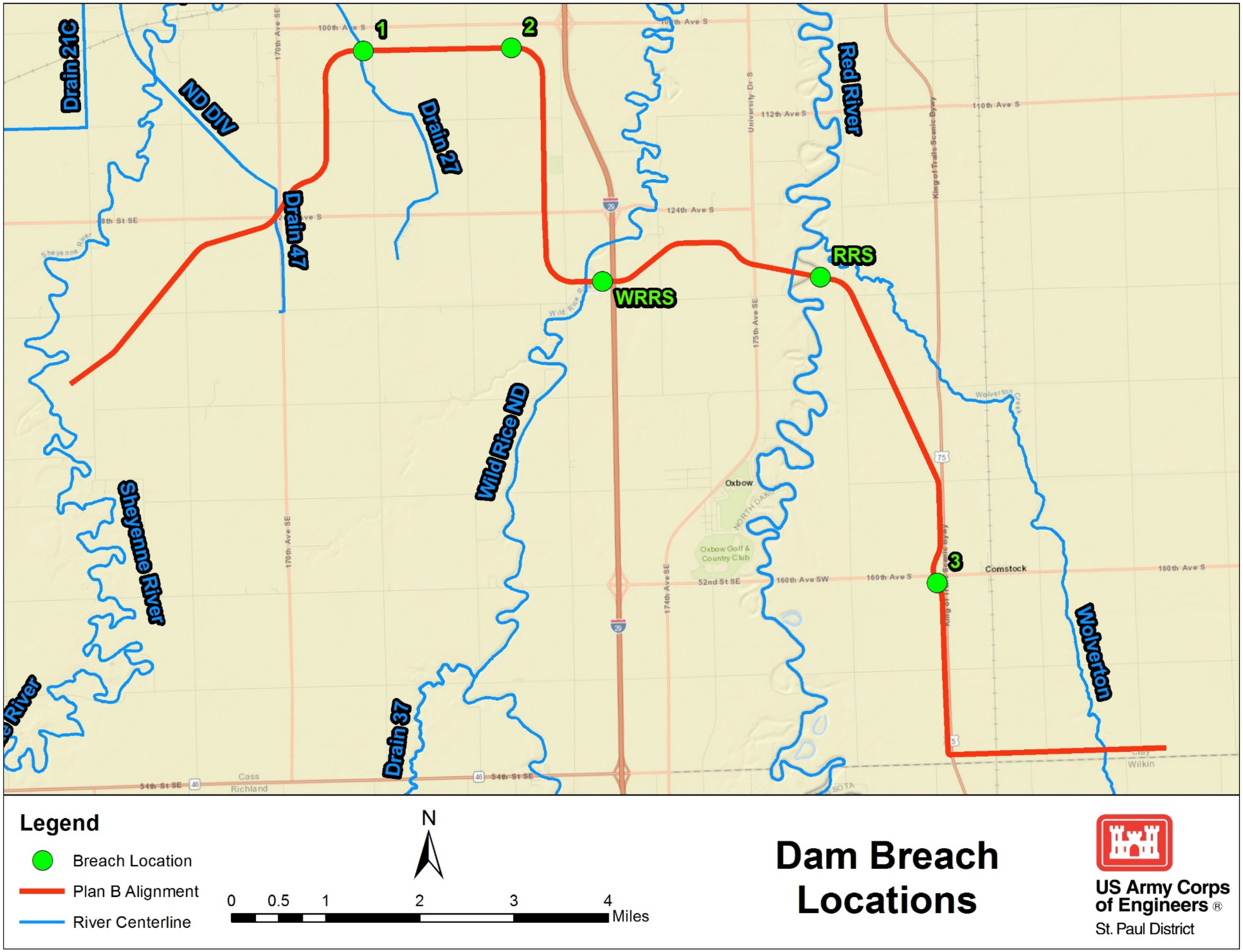

Figure 4. Dam Breach Locations

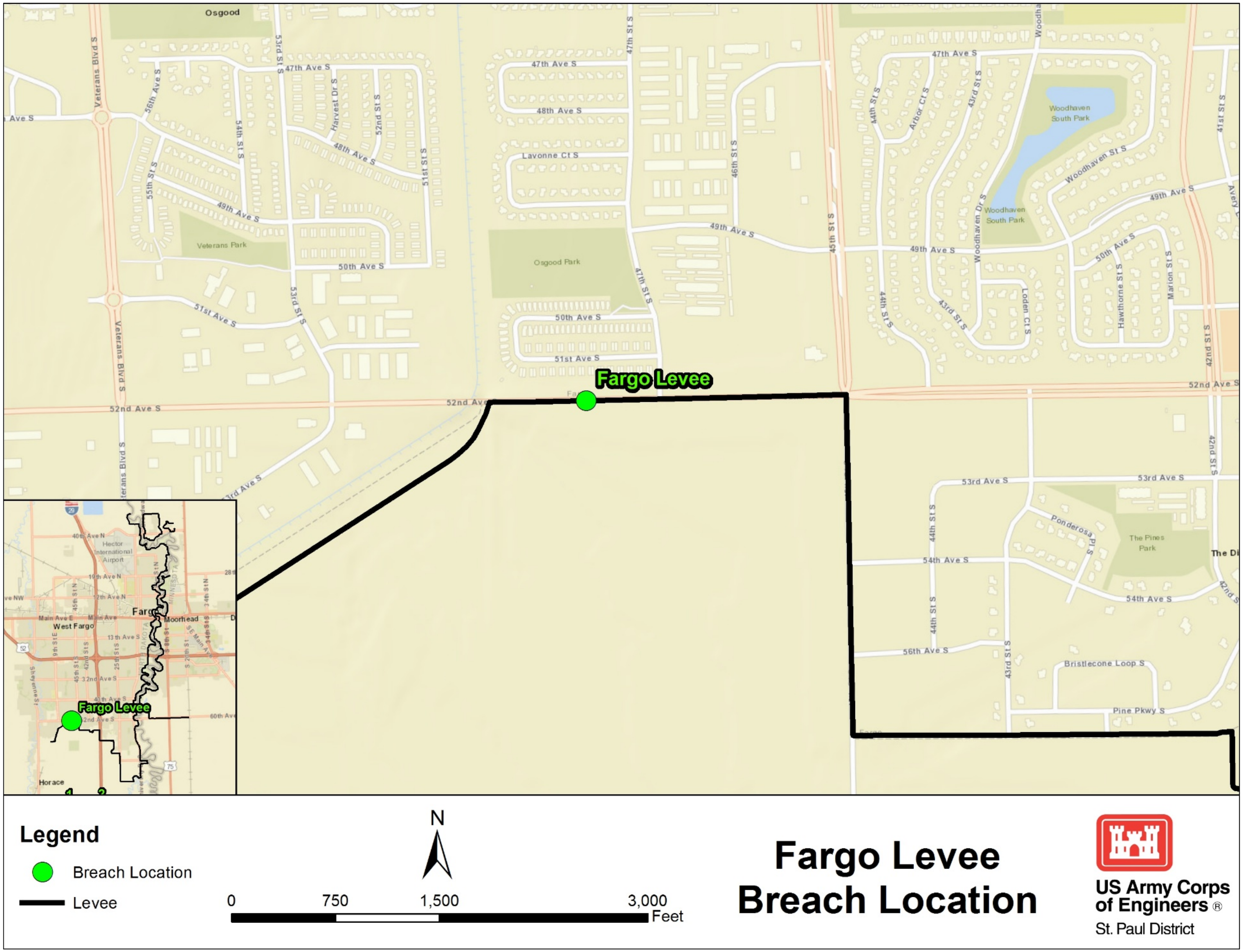

Figure 5. Fargo Levee Breach Location

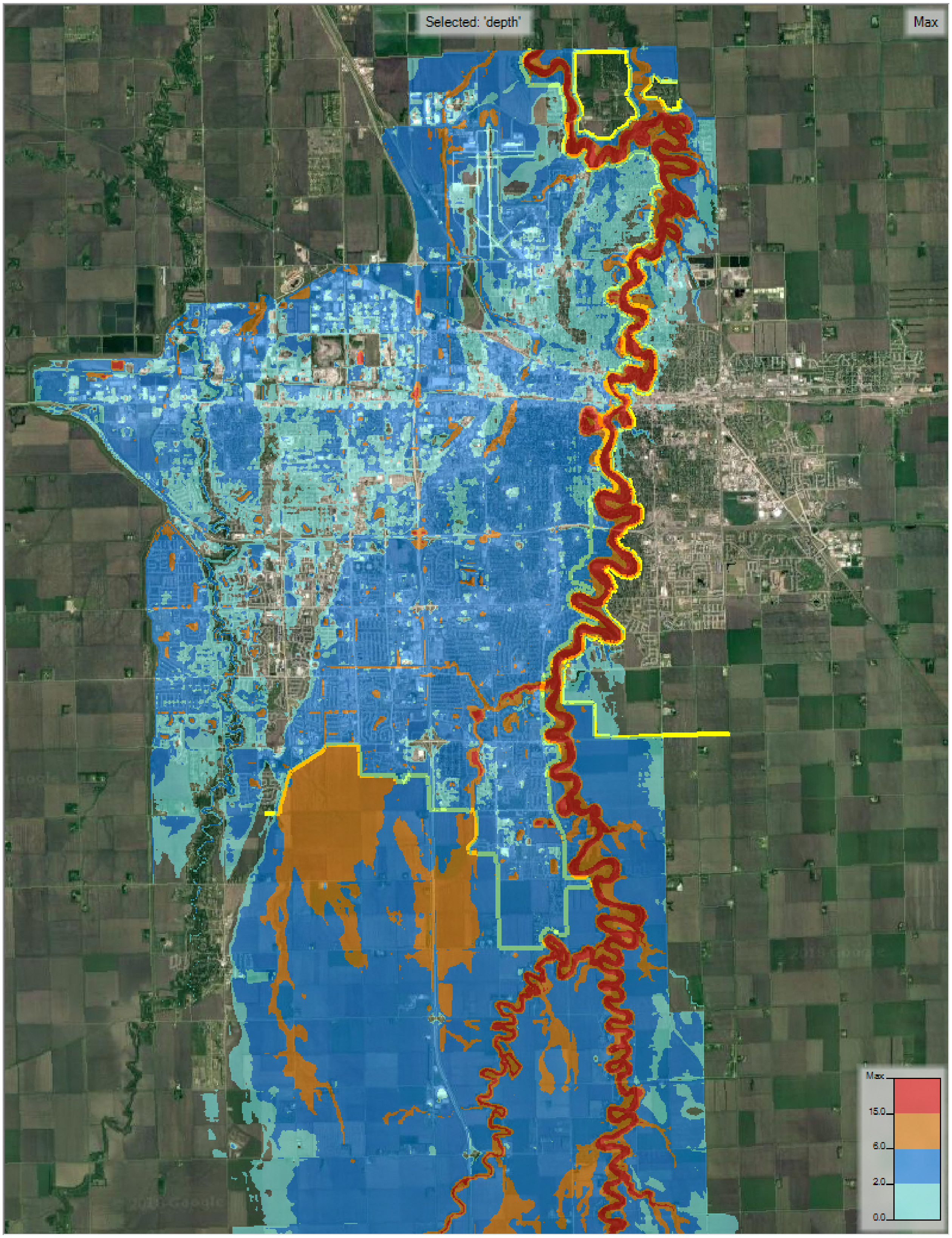

Figure 6. Existing Conditions Maximum Flow Depths for 90,000 cfs Event

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

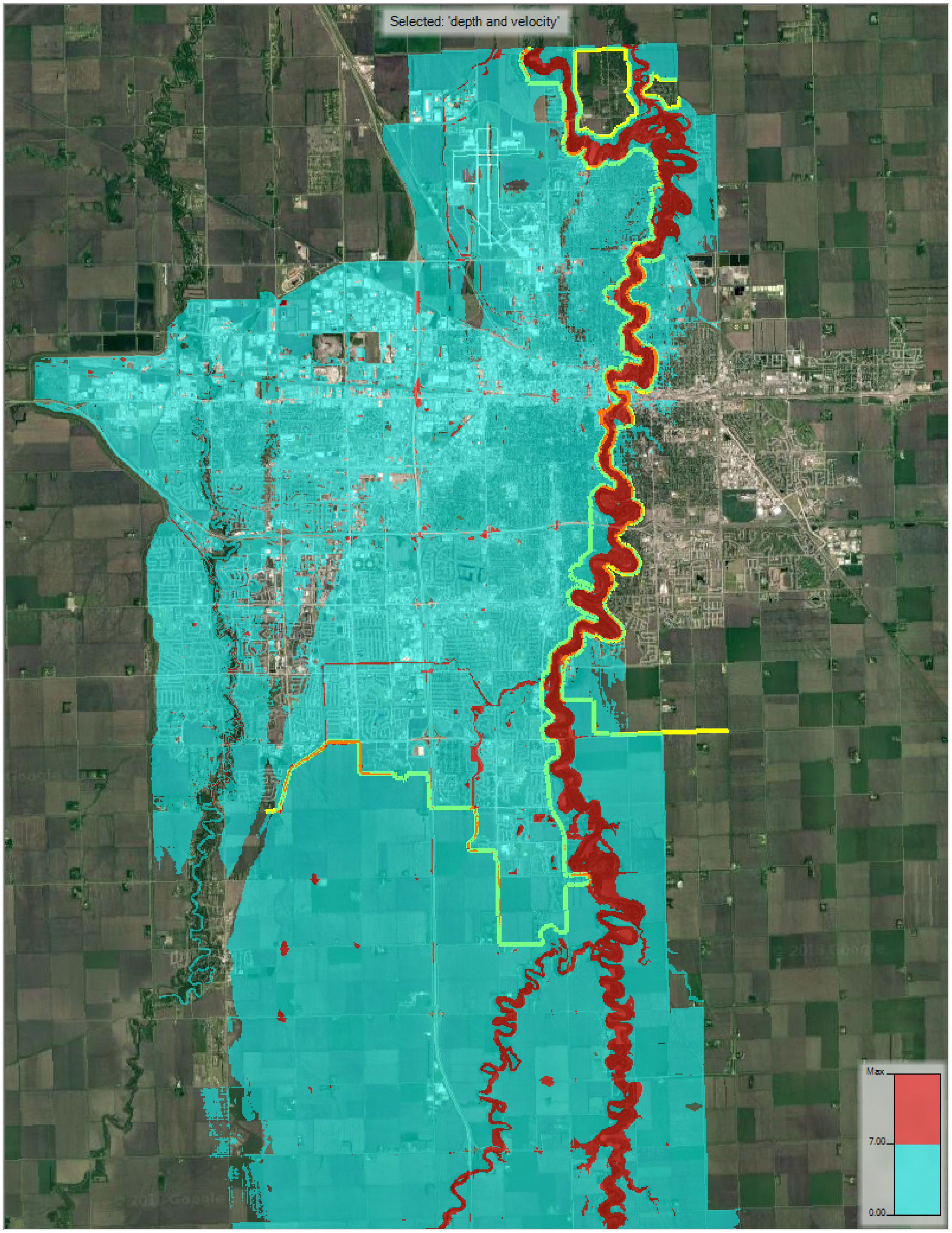

Figure 7. Existing Conditions Maximum D*V for 90,000 cfs Event

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

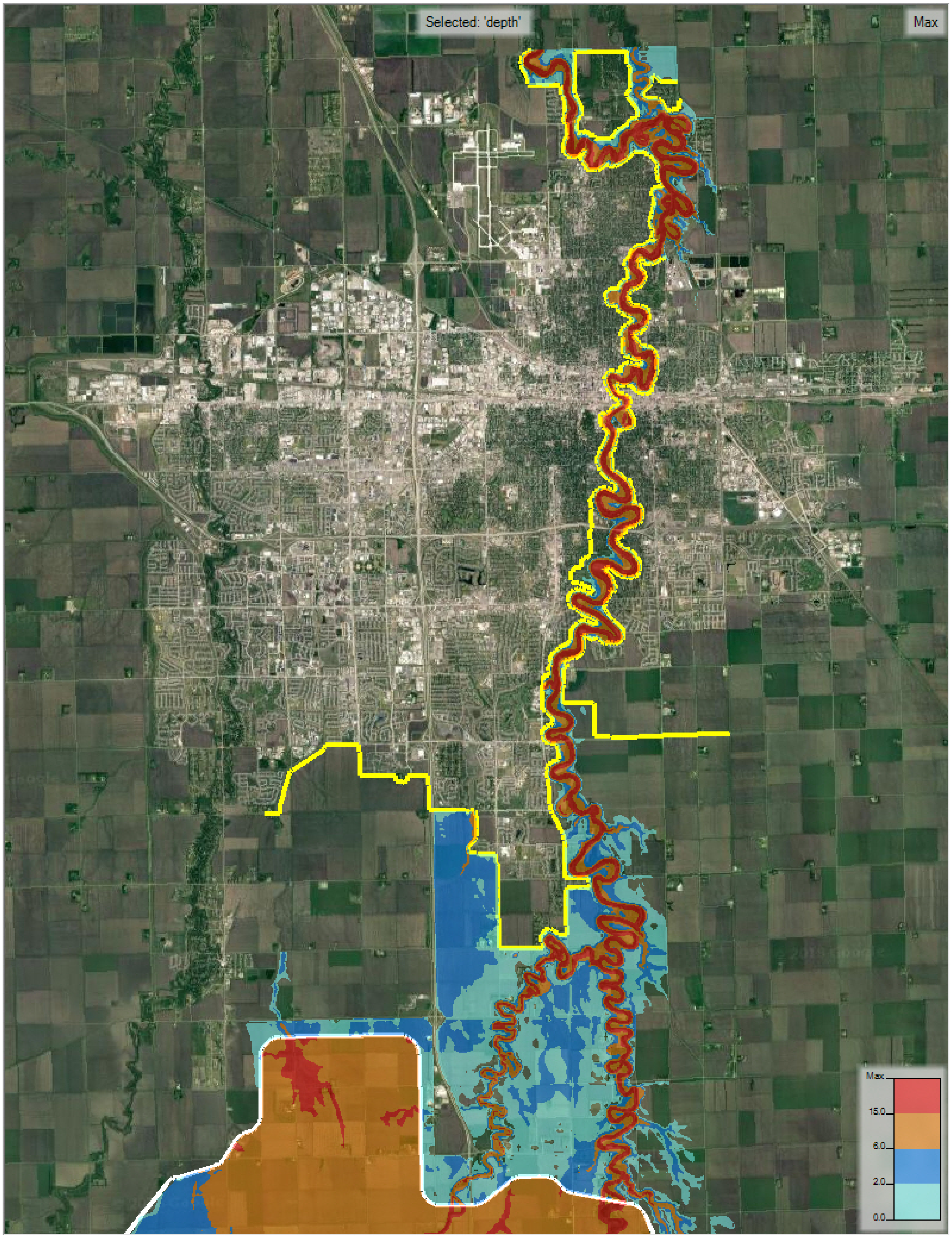

Figure 8. Proposed Conditions Maximum Flow Depths for 90,000 cfs Event (No Dam or Levee Breach)

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

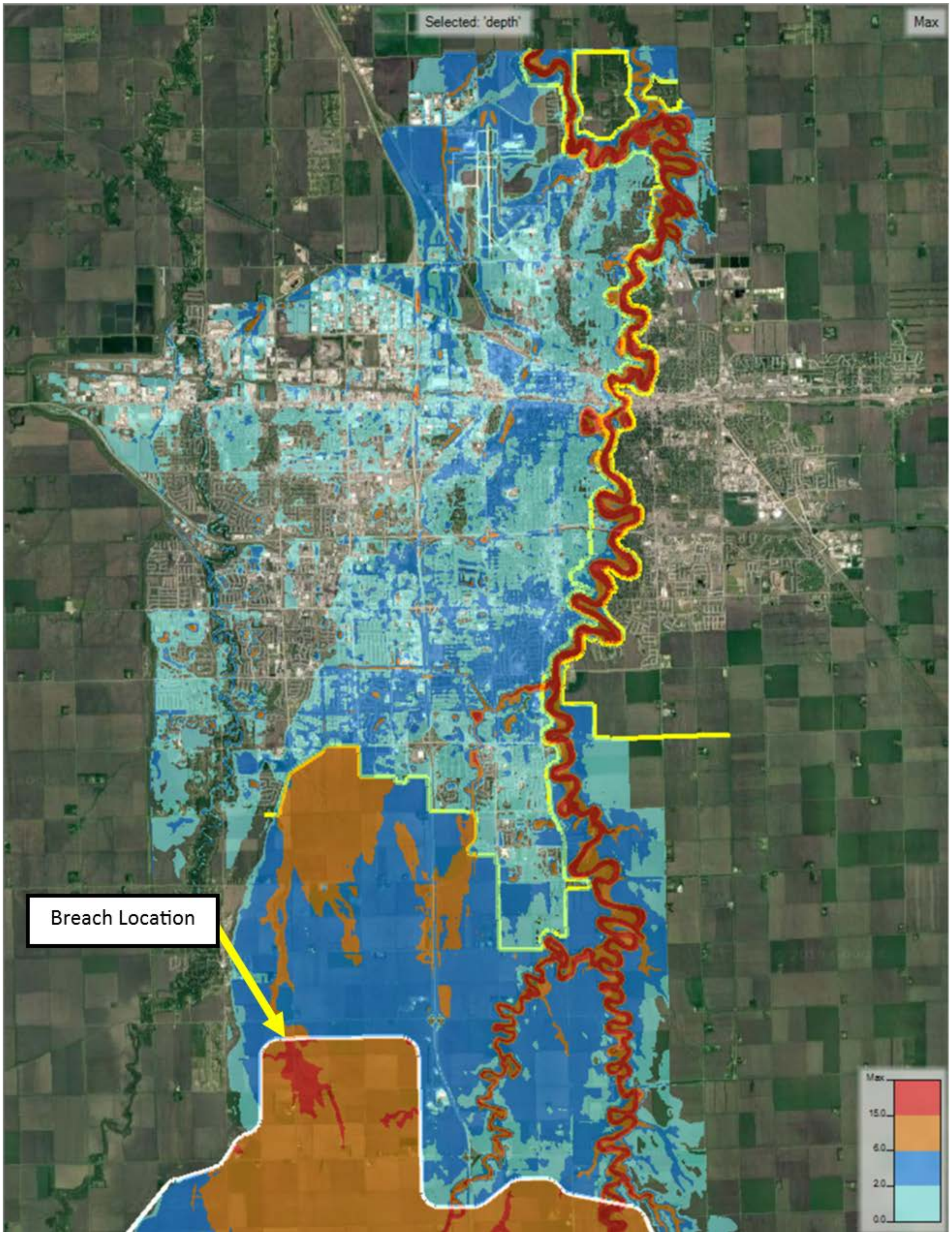

Figure 9. Proposed Conditions Maximum Flow Depths for 90,000 cfs Event after Dam Breach at Location 1

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

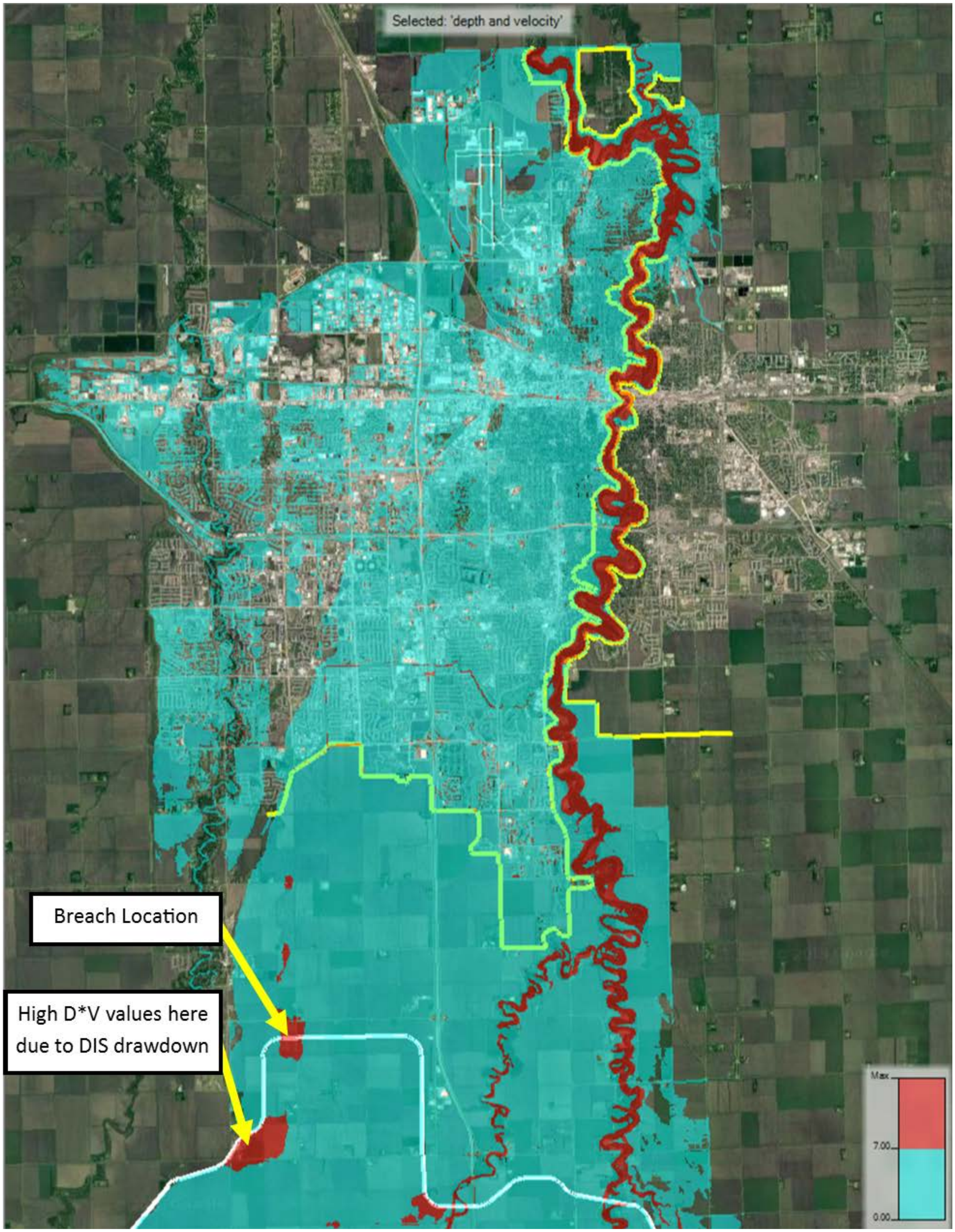

Figure 10. Proposed Conditions Maximum D*V for 90,000 cfs Event after Dam Breach at Location 1

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

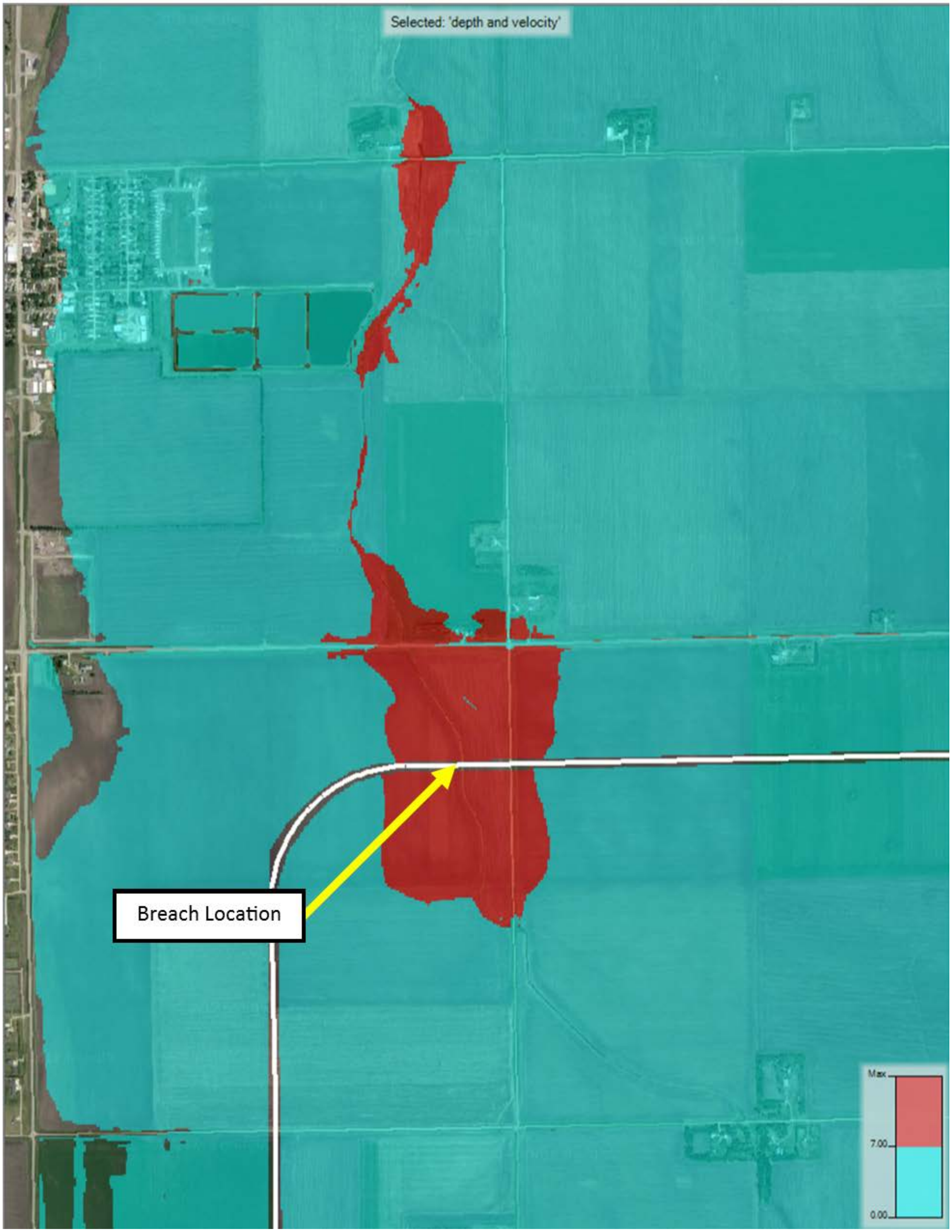

Figure 11. Proposed Conditions Near-Vicinity Maximum D*V for 90,000 cfs Event after Dam Breach at Location 1

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

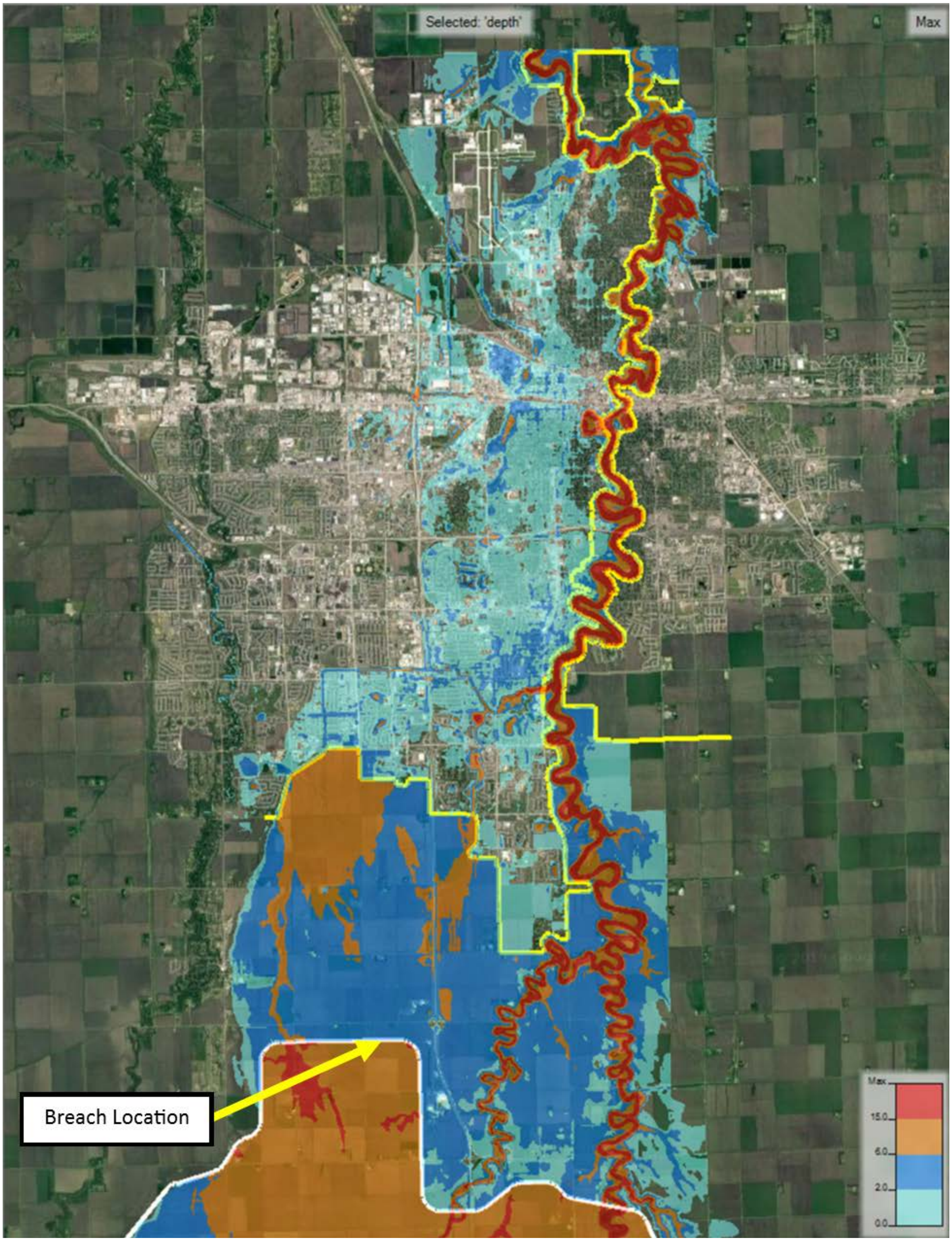

Figure 12. Proposed Conditions Maximum Flow Depths for 90,000 cfs Event after Dam Breach at Location 2

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

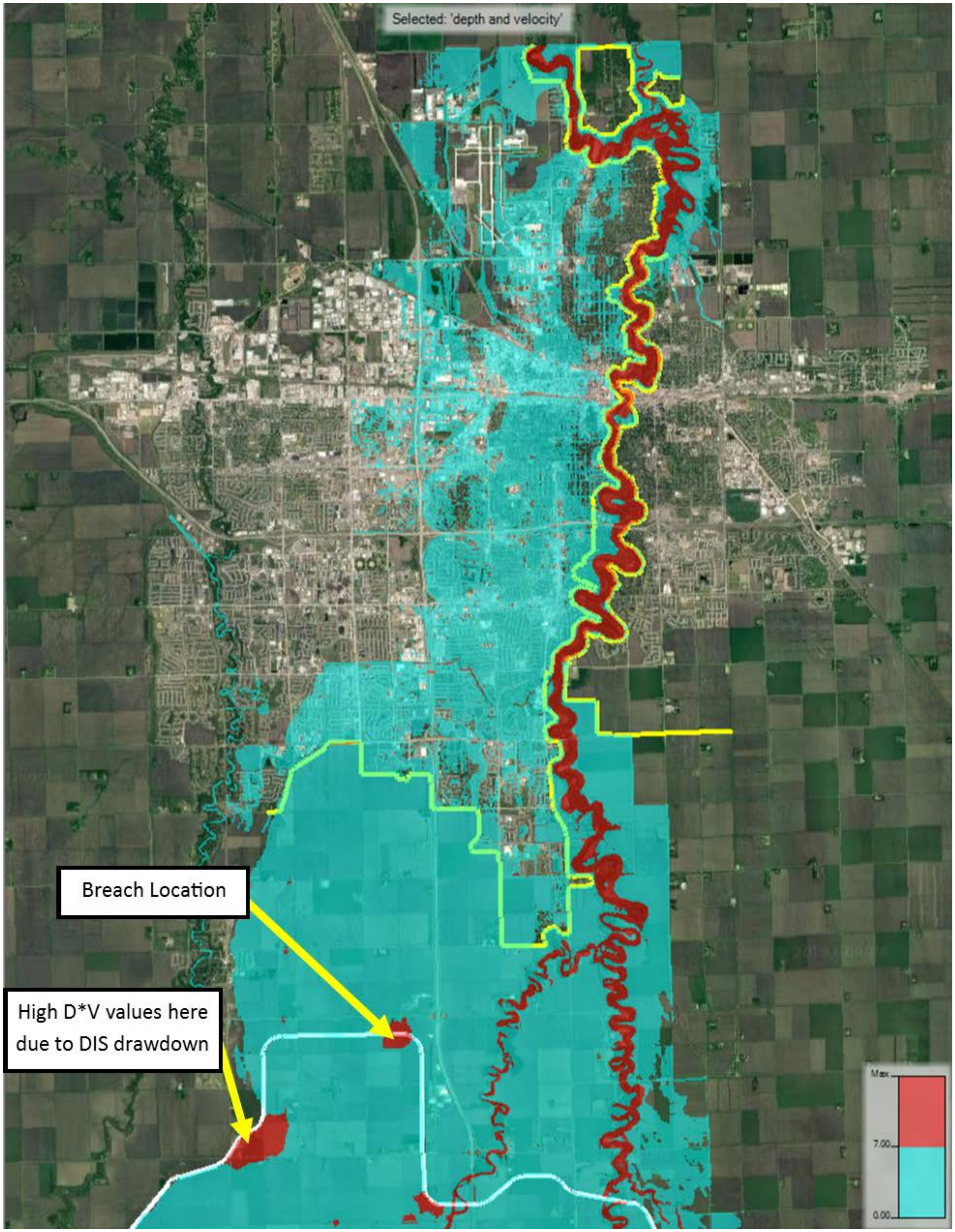

Figure 13. Proposed Conditions Maximum D*V for 90,000 cfs Event after Dam Breach at Location 2

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

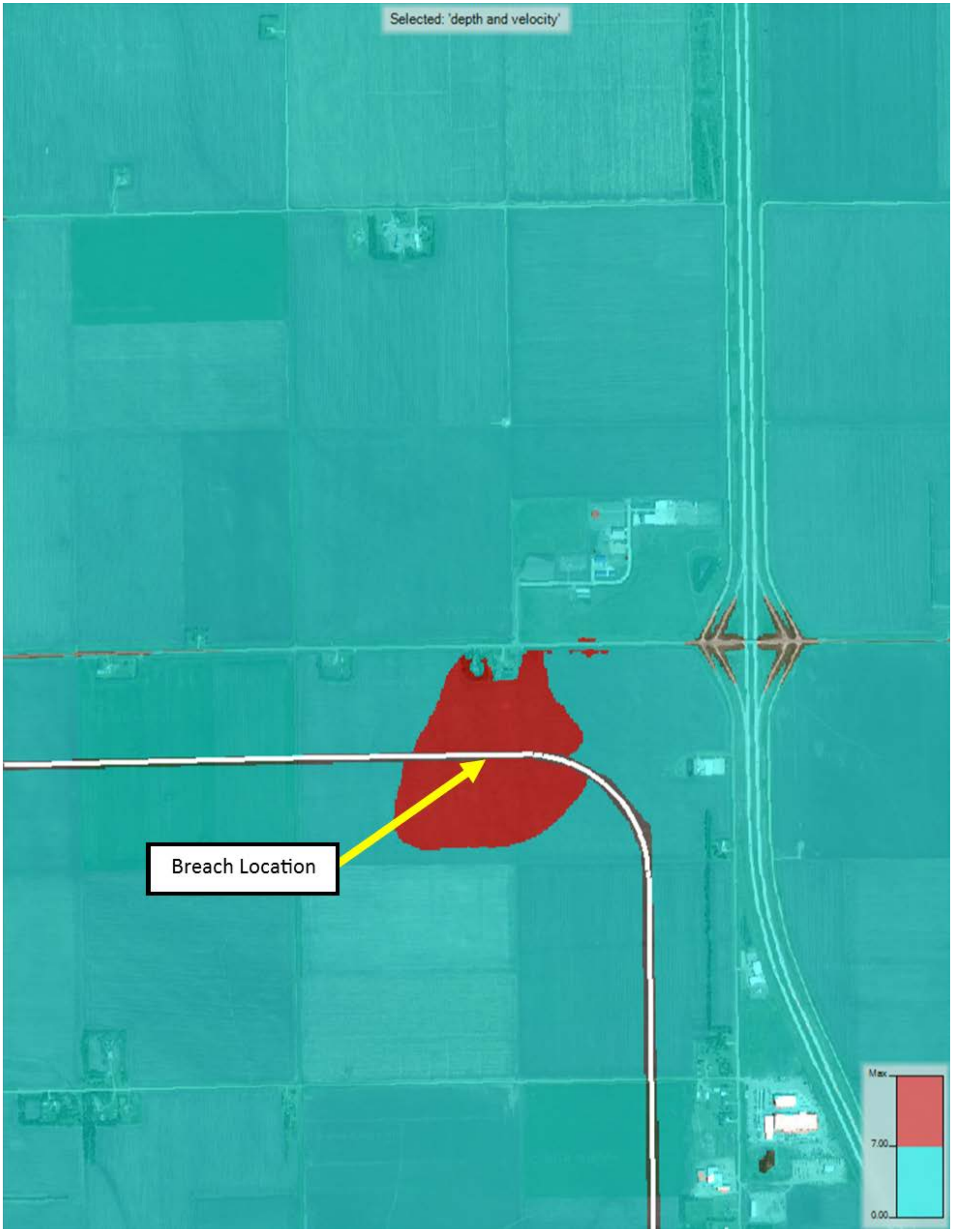

Figure 14. Proposed Conditions Near-Vicinity Maximum D*V for 90,000 cfs Event after Dam Breach at Location 2

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

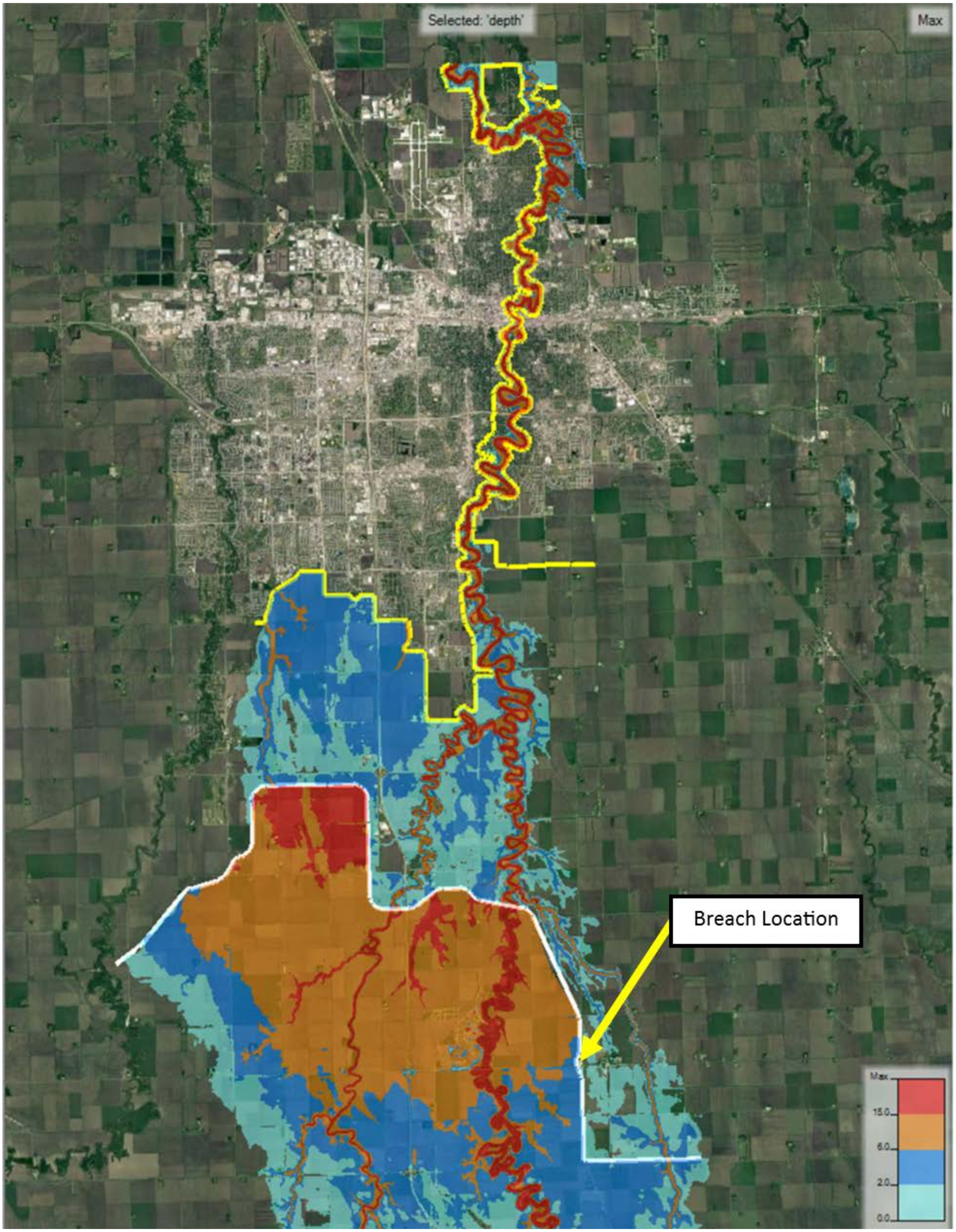

Figure 15. Proposed Conditions Maximum Flow Depths for 90,000 cfs Event after Dam Breach at Location 3

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

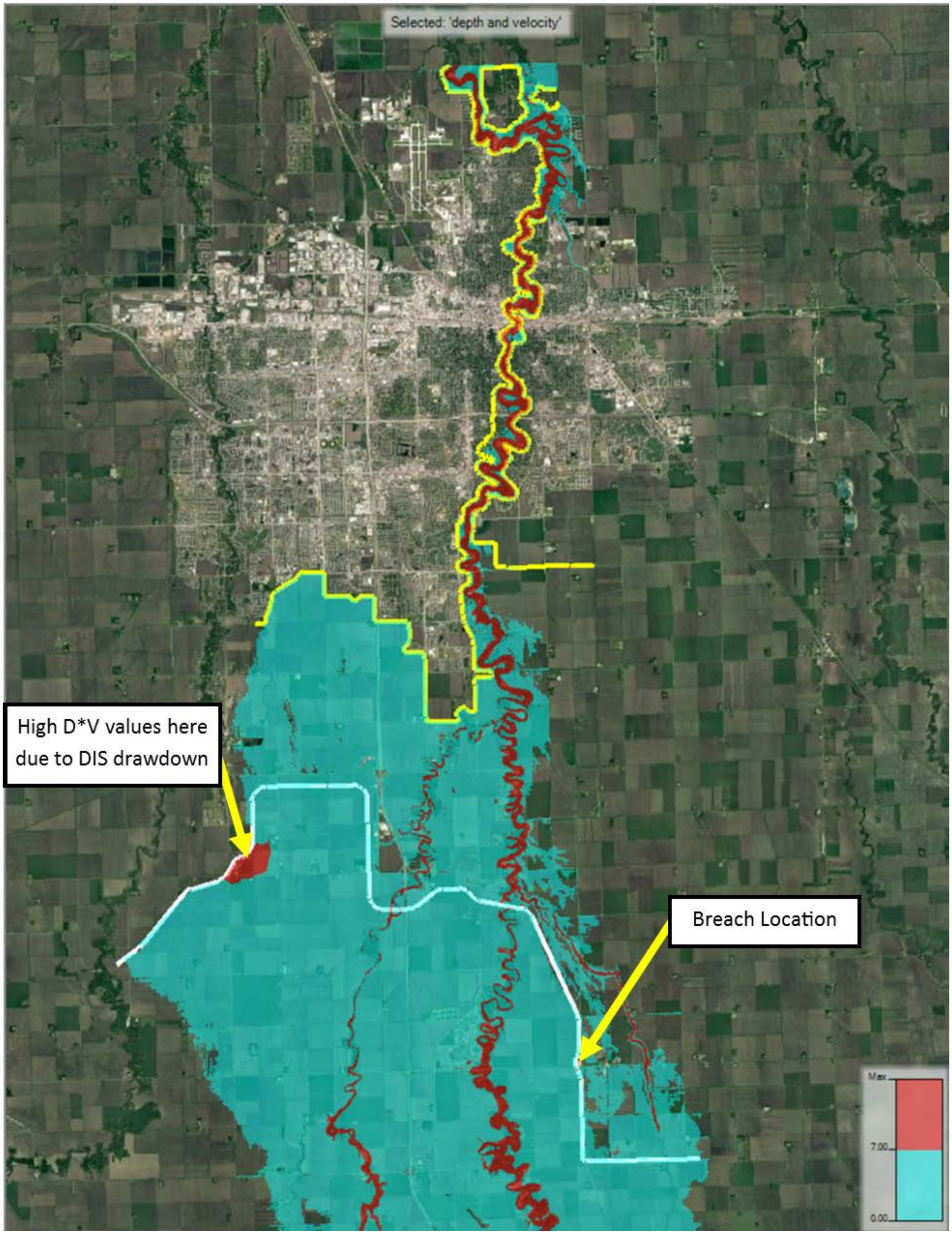

Figure 16. Proposed Conditions Maximum D*V for 90,000 cfs Event after Dam Breach at Location 3

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

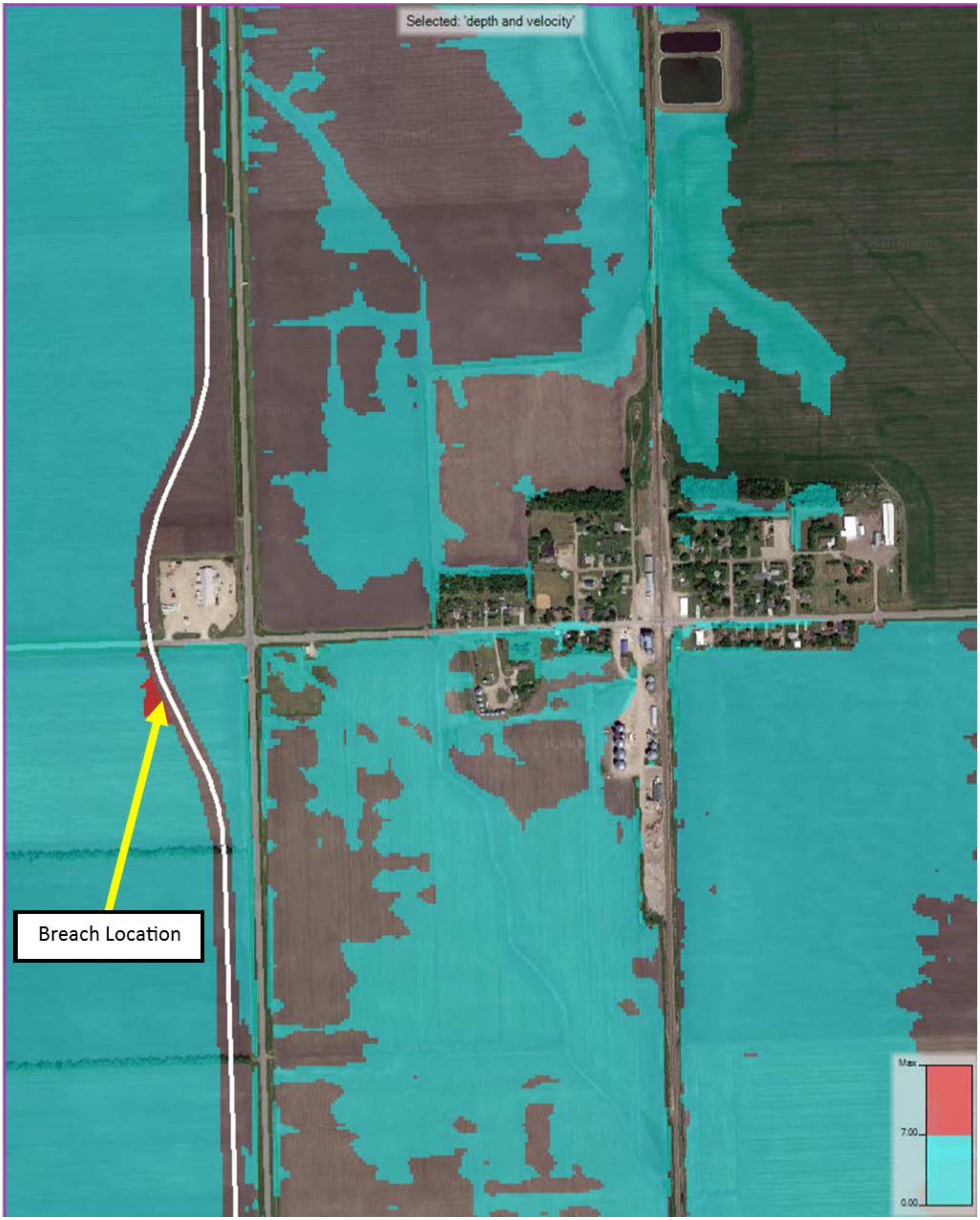

Figure 17. Proposed Conditions Near-Vicinity Maximum D*V for 90,000 cfs Event after Dam Breach at Location 3

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

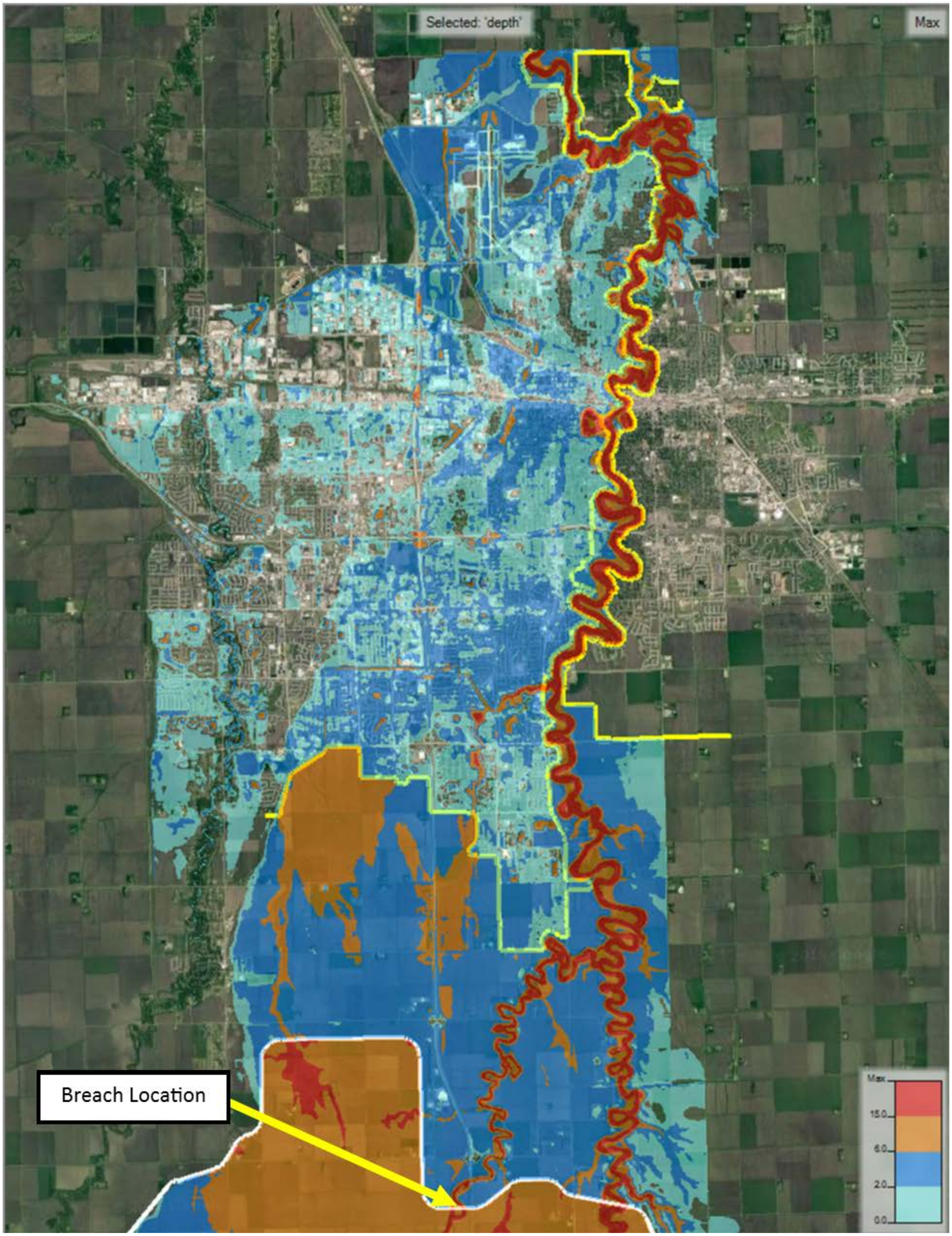

Figure 18. Proposed Conditions Maximum Flow Depths for 90,000 cfs Event after Dam Breach at WRRS

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

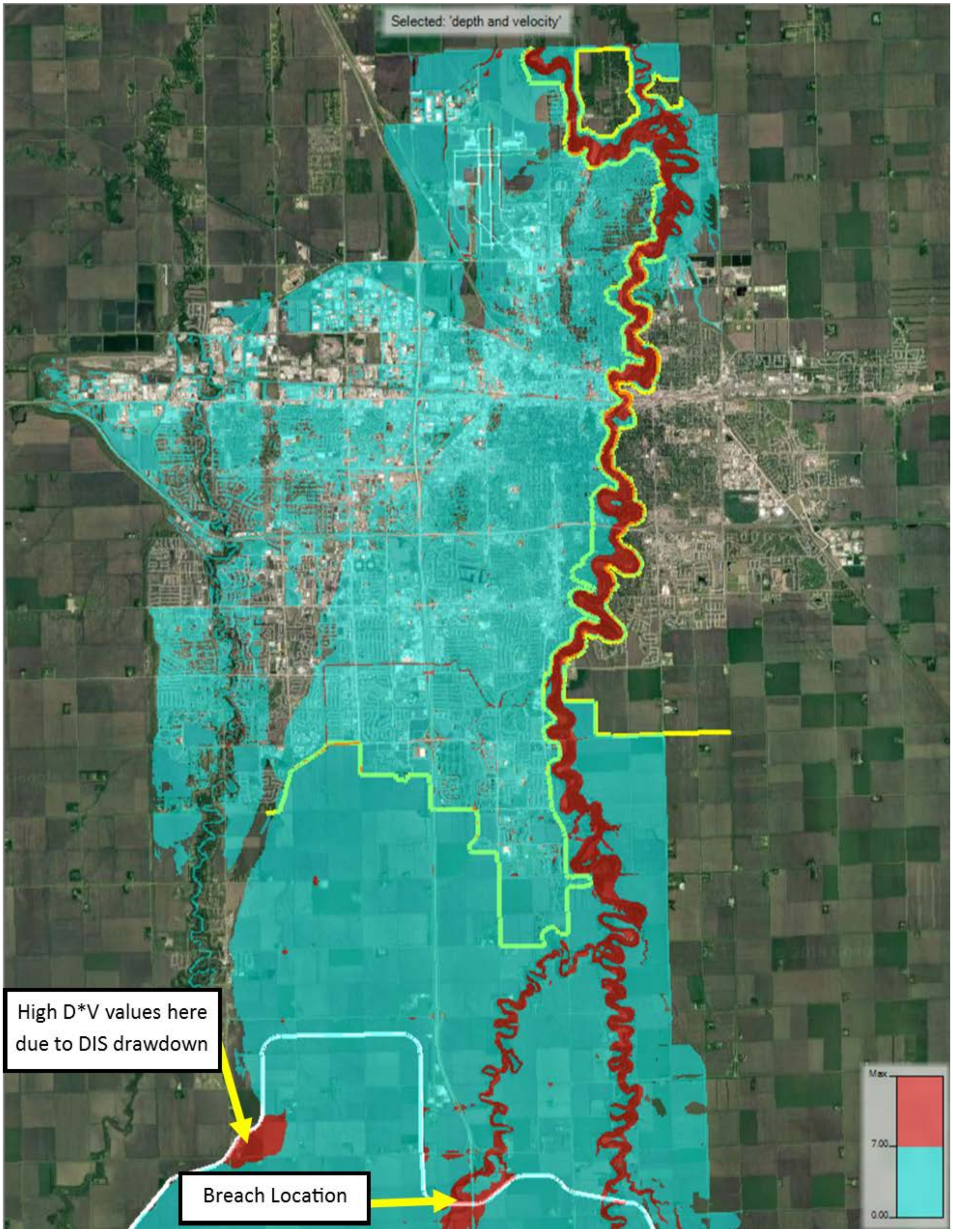

Figure 19. Proposed Conditions Maximum D*V for 90,000 cfs Event after Dam Breach at WRRS

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

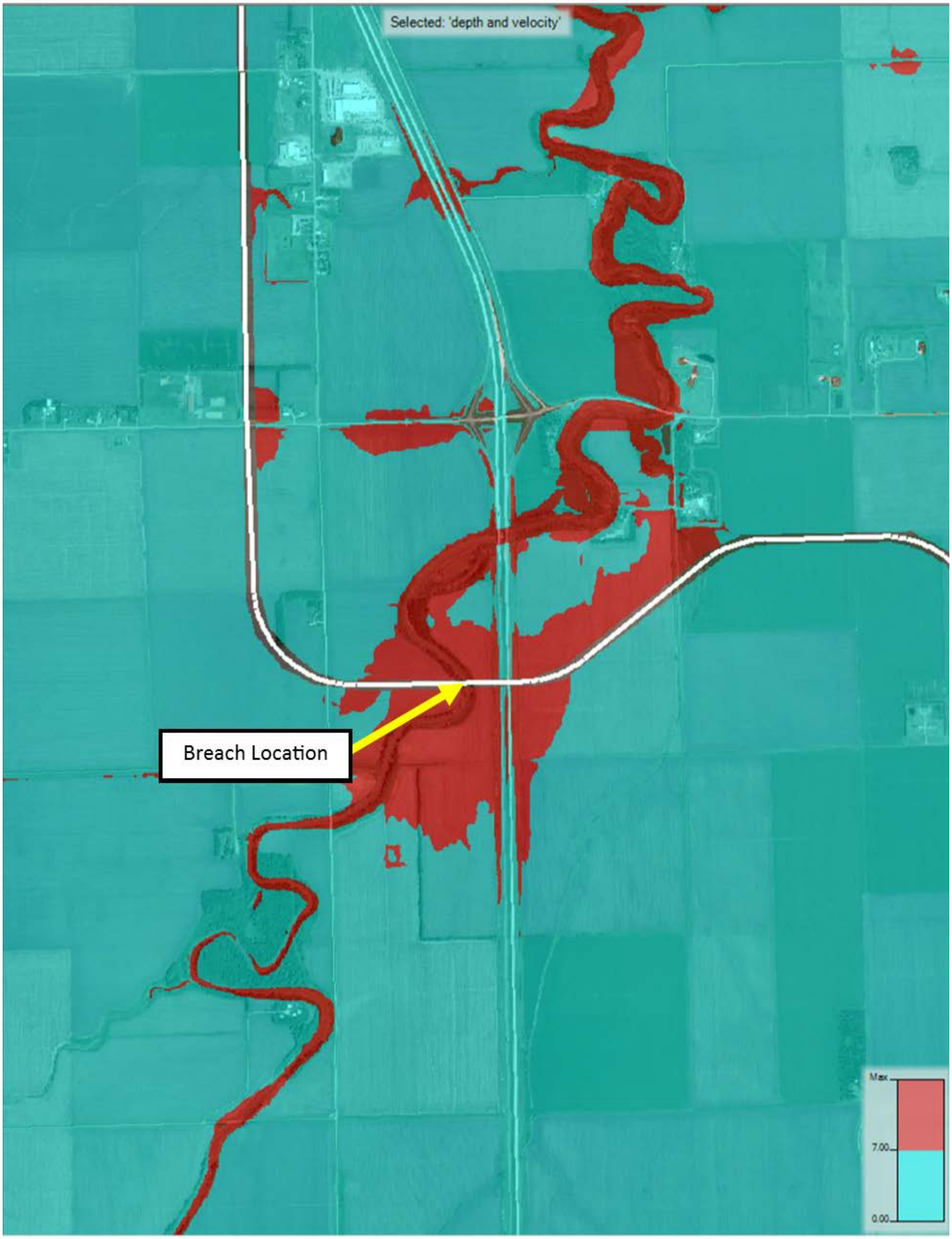

Figure 20. Proposed Conditions Near-Vicinity Maximum D*V for 90,000 cfs Event after Dam Breach at WRRS

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

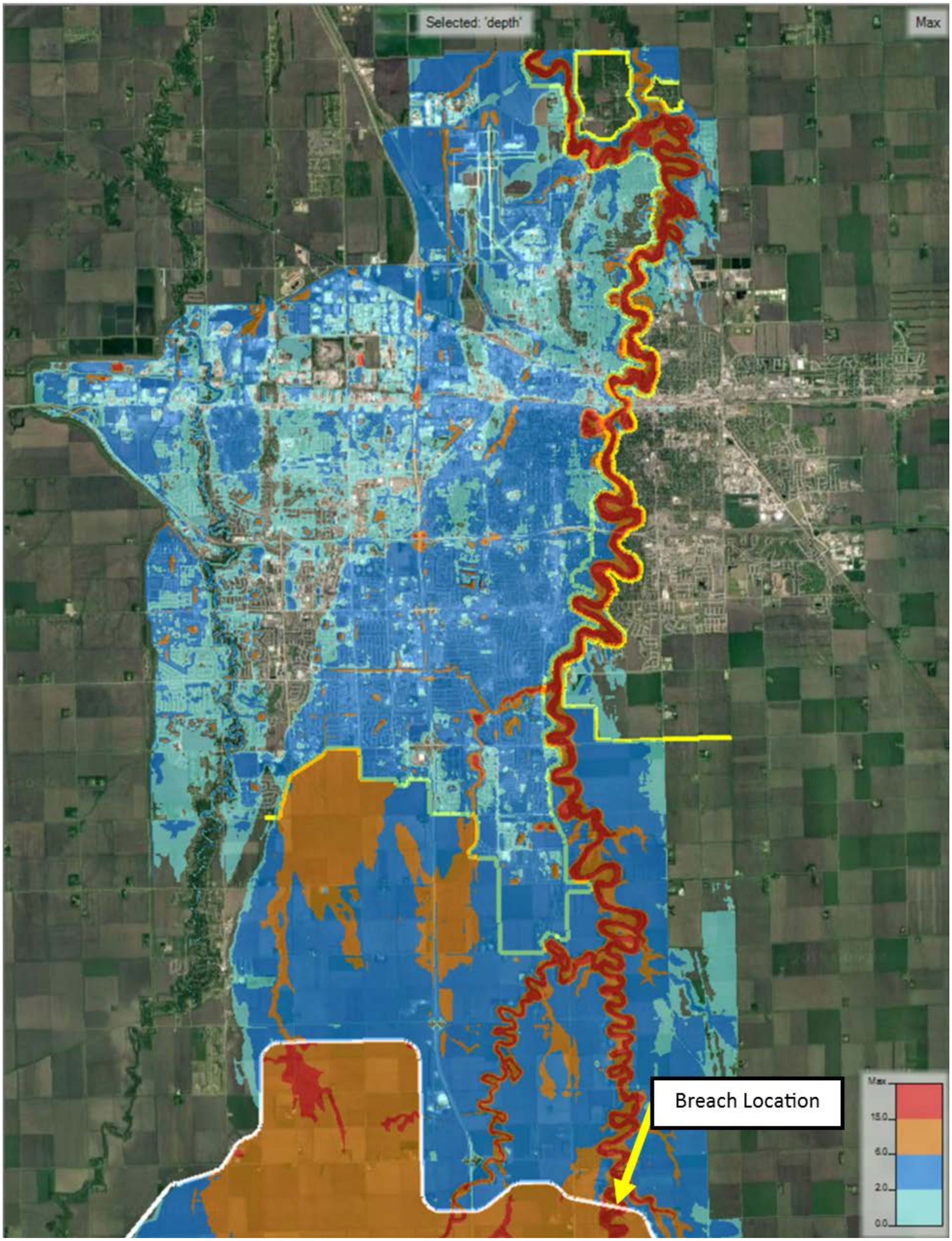

Figure 21. Proposed Conditions Maximum Flow Depths for 90,000 cfs Event after Dam Breach at RRS

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

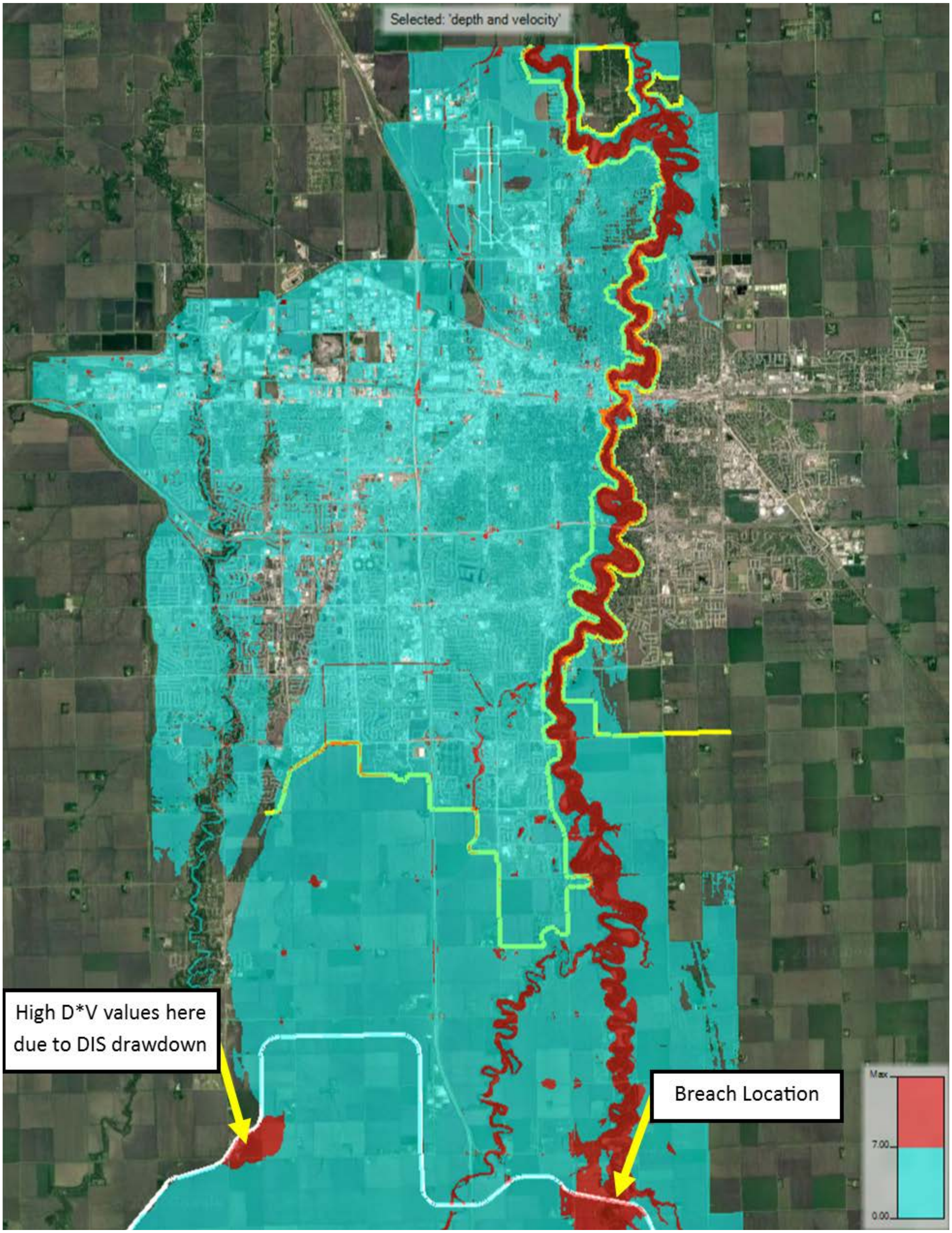

Figure 22. Proposed Conditions Maximum D*V for 90,000 cfs Event after Dam Breach at RRS

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

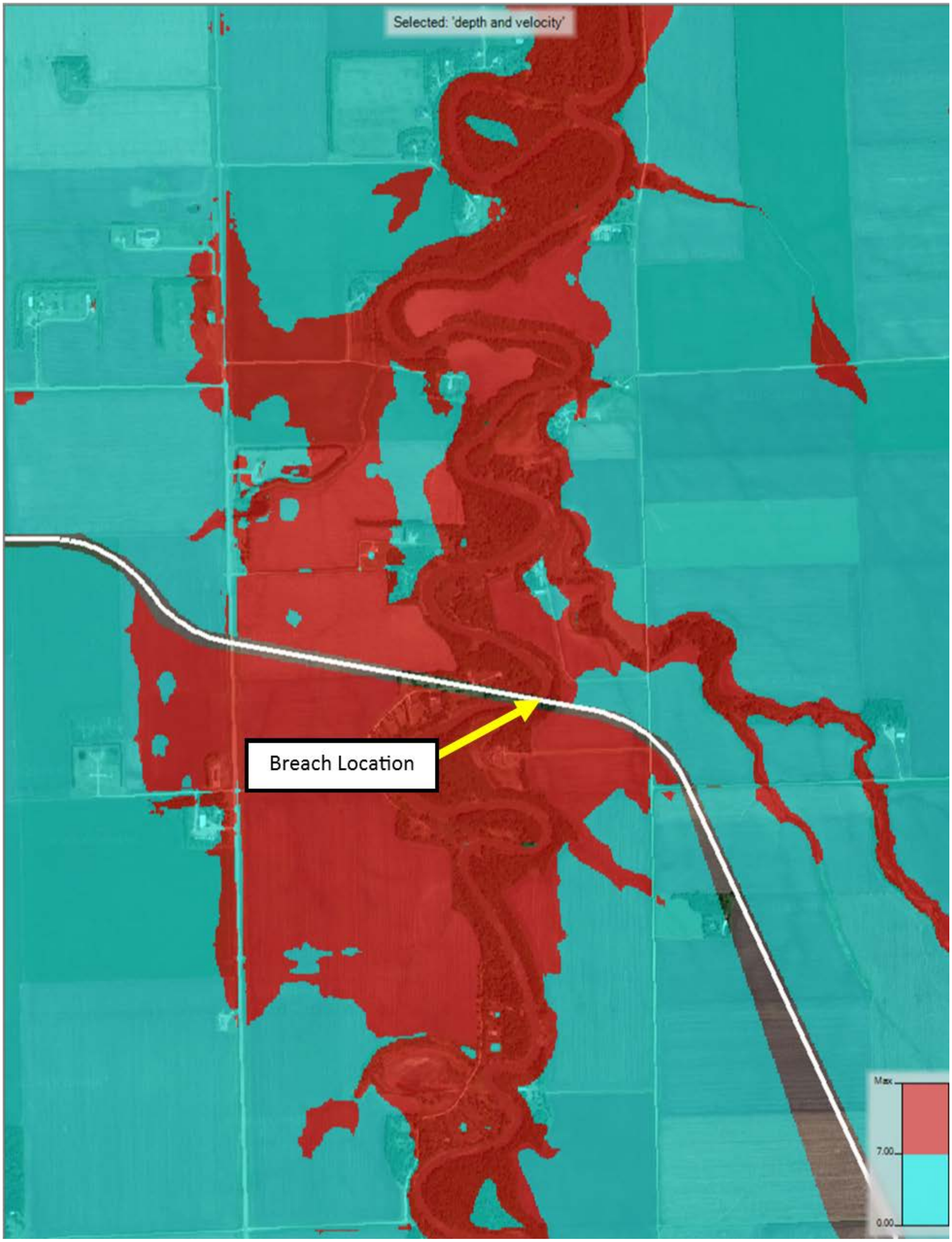

Figure 23. Proposed Conditions Near-Vicinity Maximum D*V for 90,000 cfs Event after Dam Breach at RRS

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

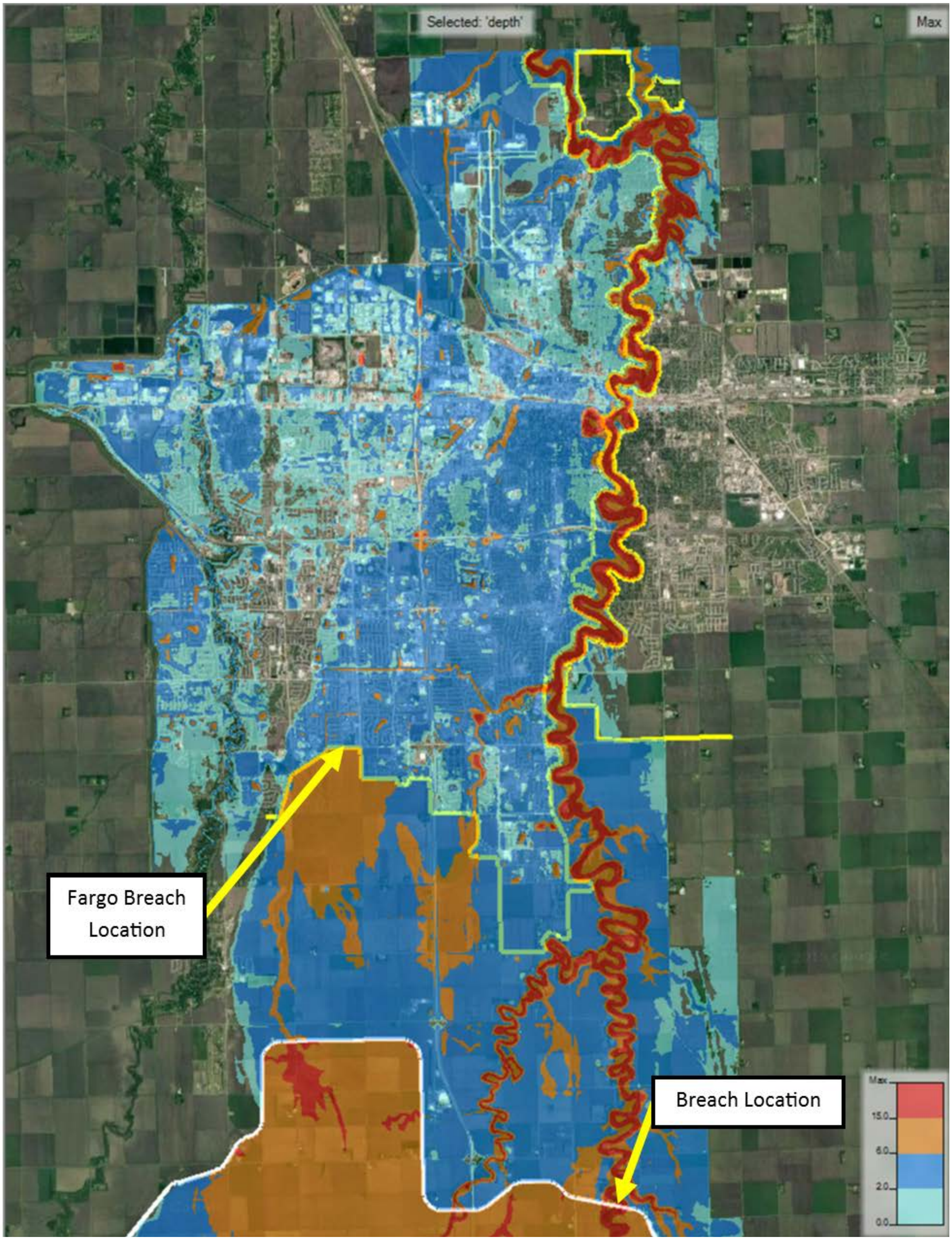

Figure 24. Proposed Conditions Maximum Flow Depths for 90,000 cfs Event after Dam Breach at RRS and Fargo Levee

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

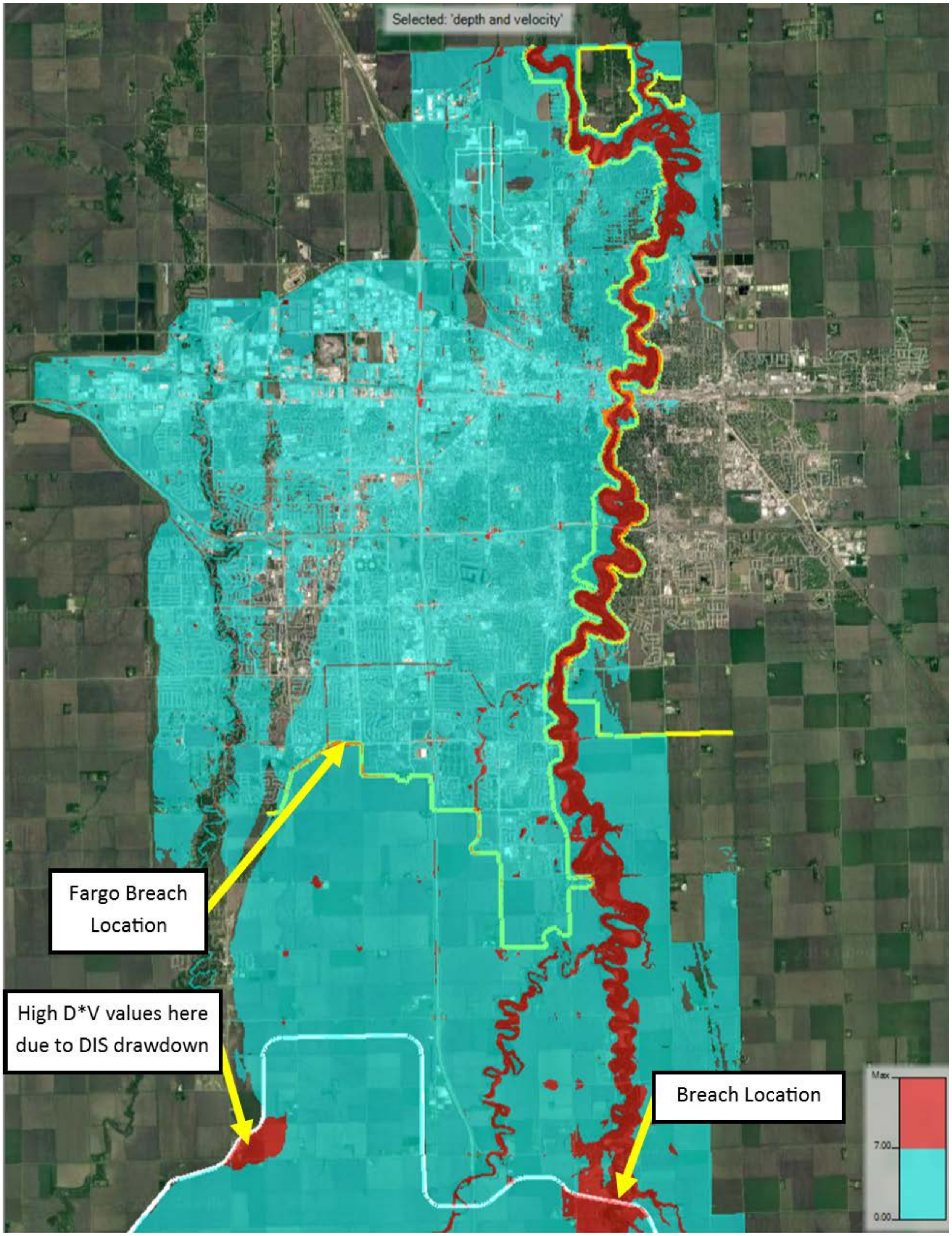

Figure 25. Proposed Conditions Maximum D*V for 90,000 cfs Event after Dam Breach at RRS and Fargo Levee

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

Figure 26. Proposed Conditions Near-Vicinity Maximum D*V for 90,000 cfs Event after Dam Breach at RRS and Fargo Levee

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

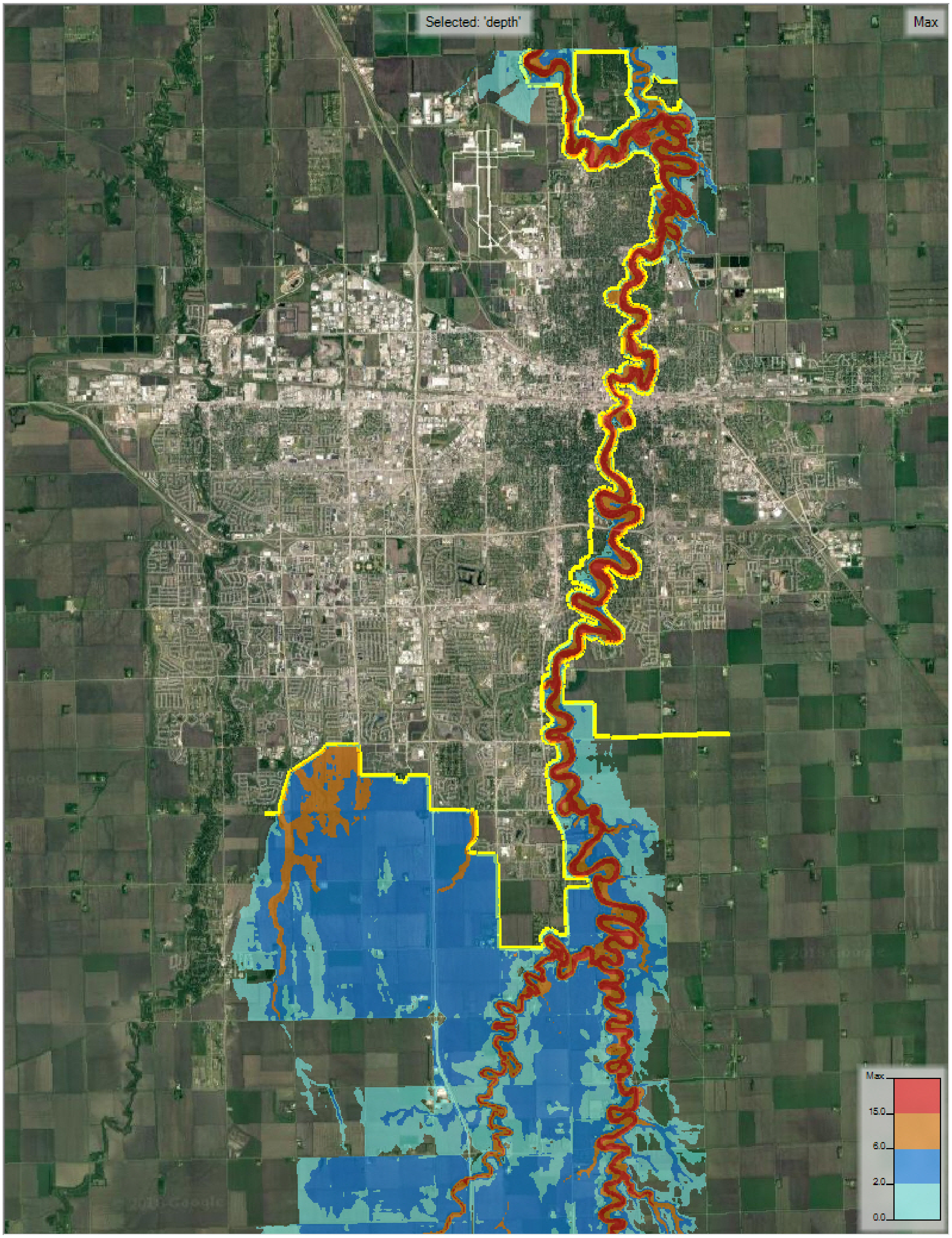

Figure 27. Existing Conditions Maximum Flow Depths for 1% ACE Event

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

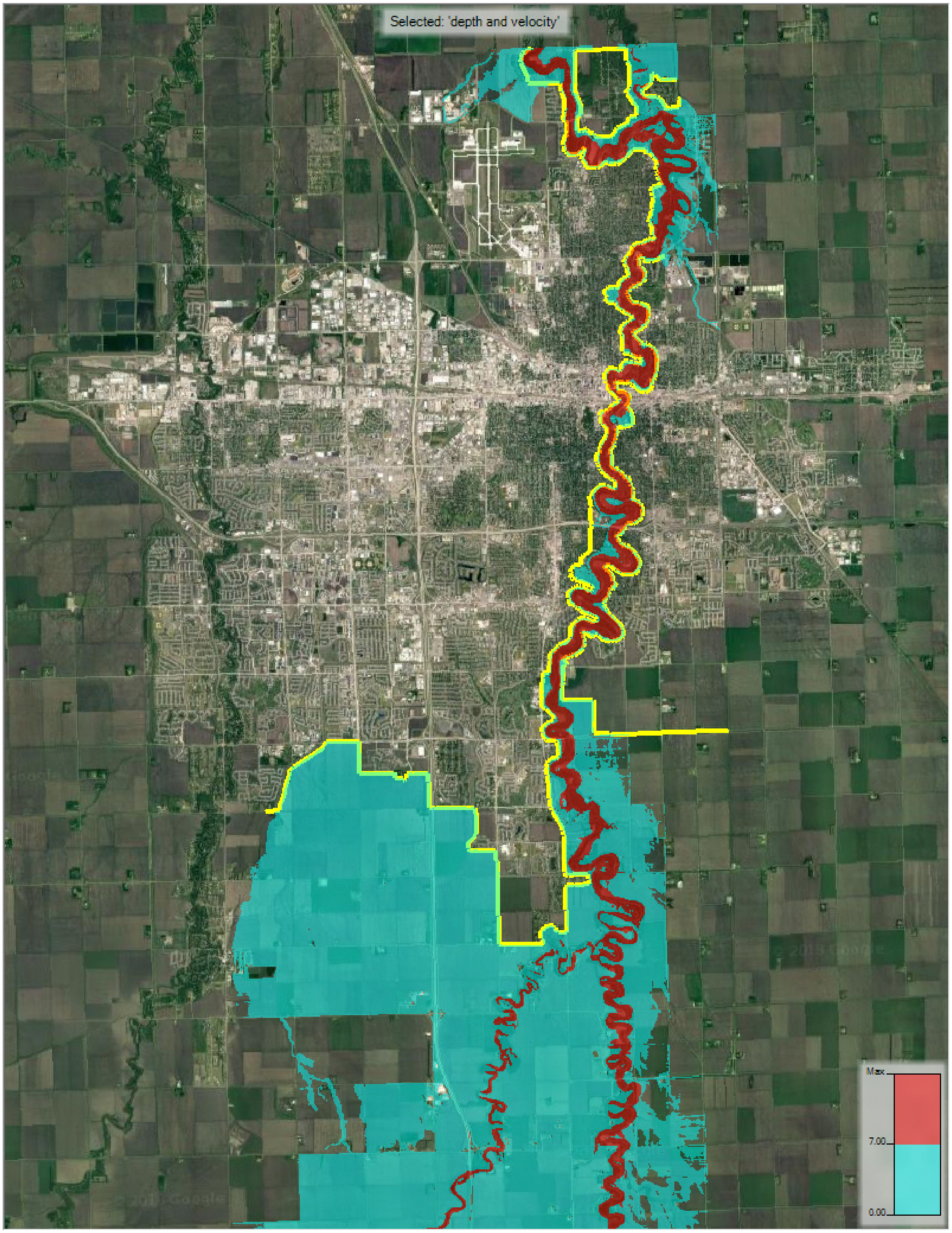

Figure 28. Existing Conditions Maximum D*V for 1% ACE Event

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

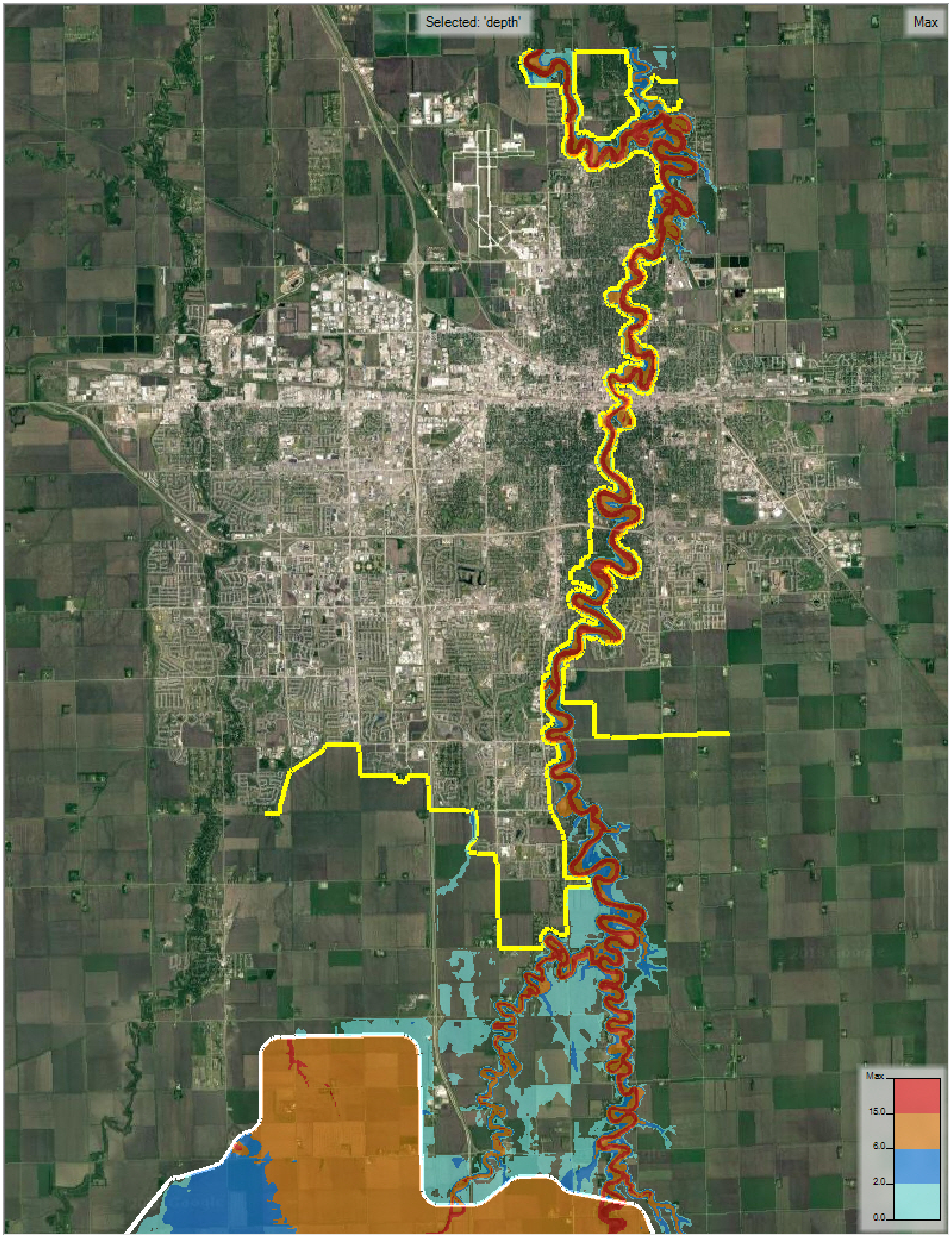

Figure 29. Proposed Conditions Maximum Flow Depths for 1% ACE Event (No Dam or Levee Breach)

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

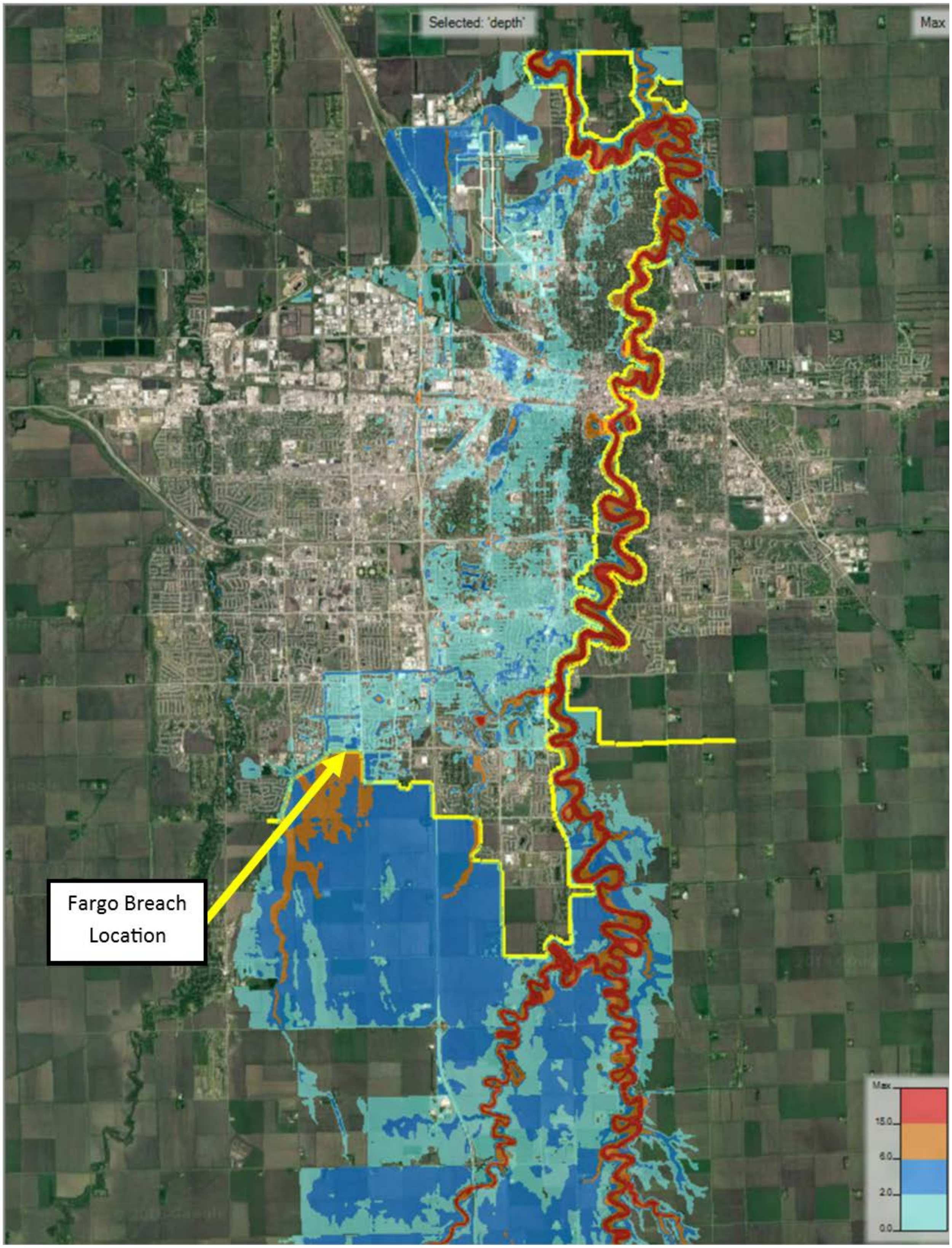

Figure 30. Existing Conditions Maximum Flow Depths for 1% ACE Event after Fargo Levee Breach

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

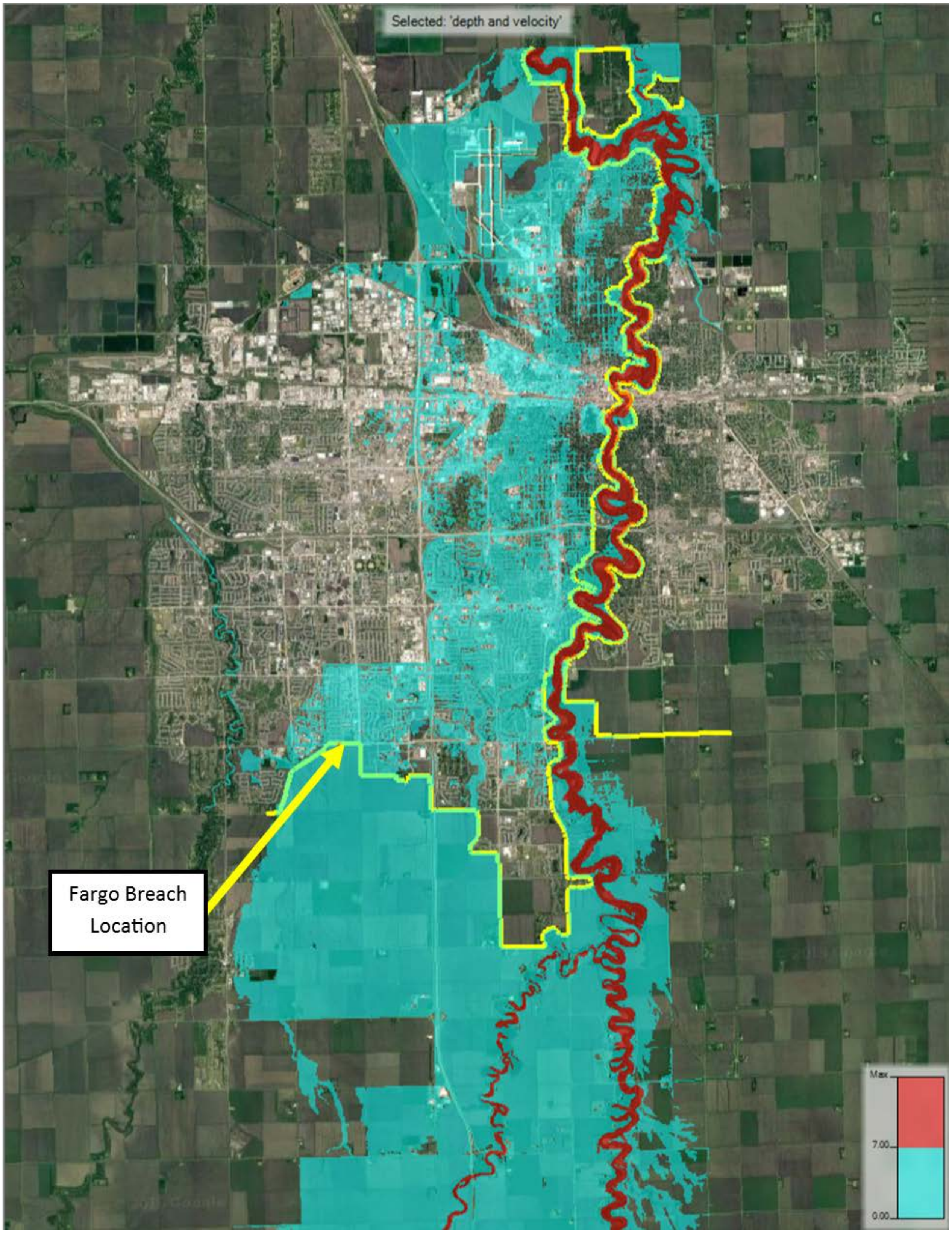

Figure 31. Existing Conditions Maximum D*V for 1% ACE Event after Fargo Levee Breach

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

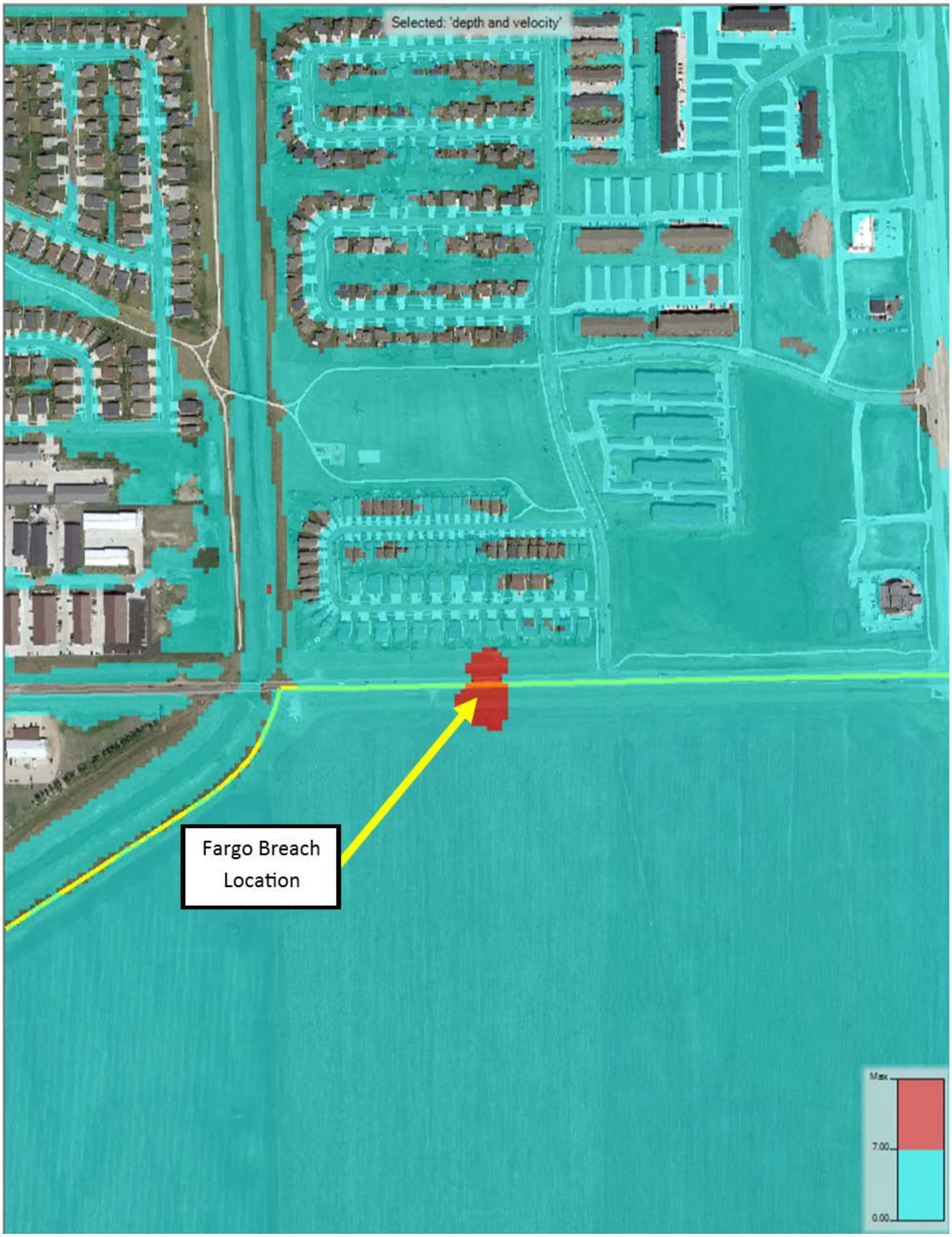

Figure 32. Existing Conditions Near-Vicinity Maximum D*V for 1% ACE Event after Fargo Levee Breach

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

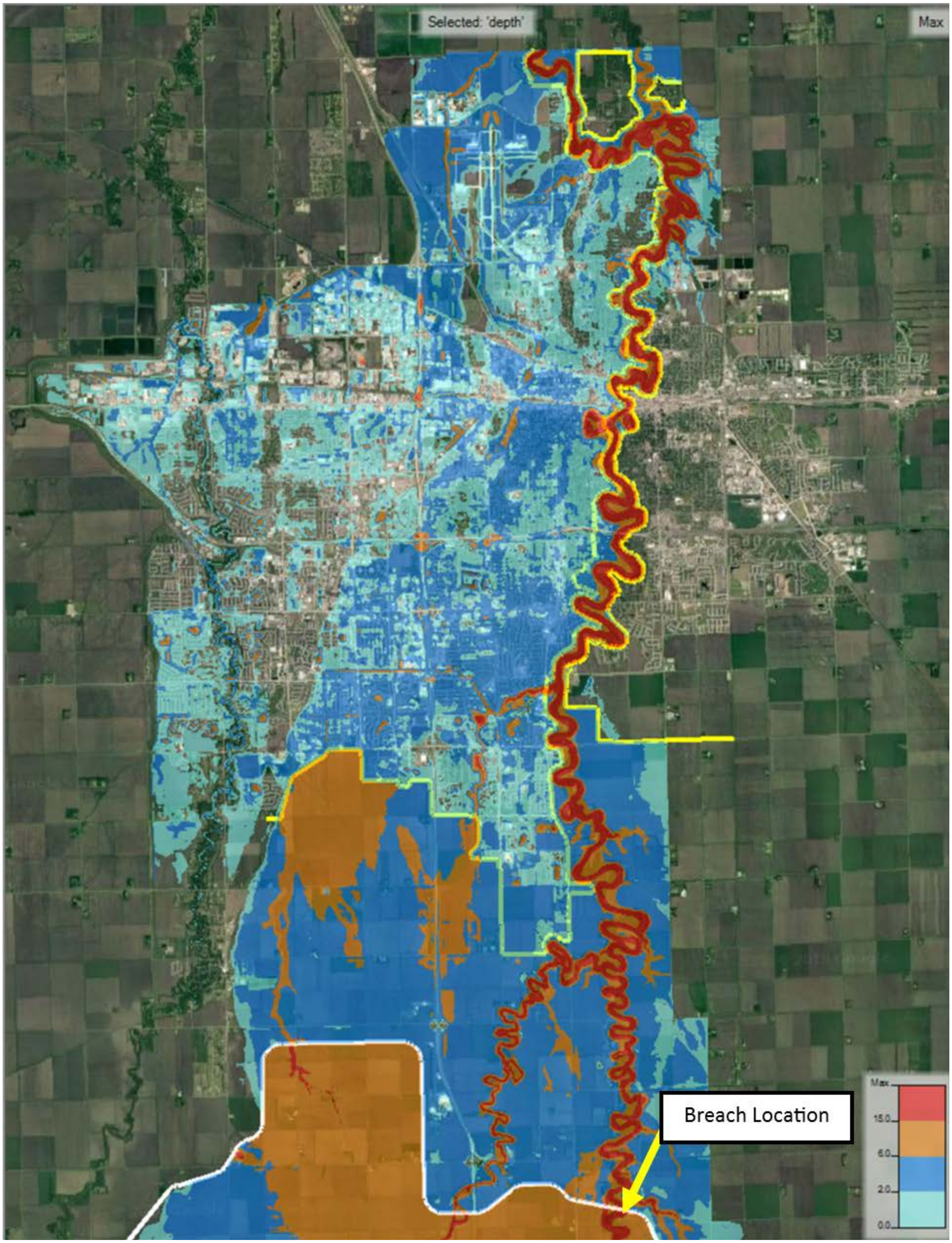

Figure 33. Proposed Conditions Maximum Flow Depths for 1% ACE Event after Dam Breach at RRS

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

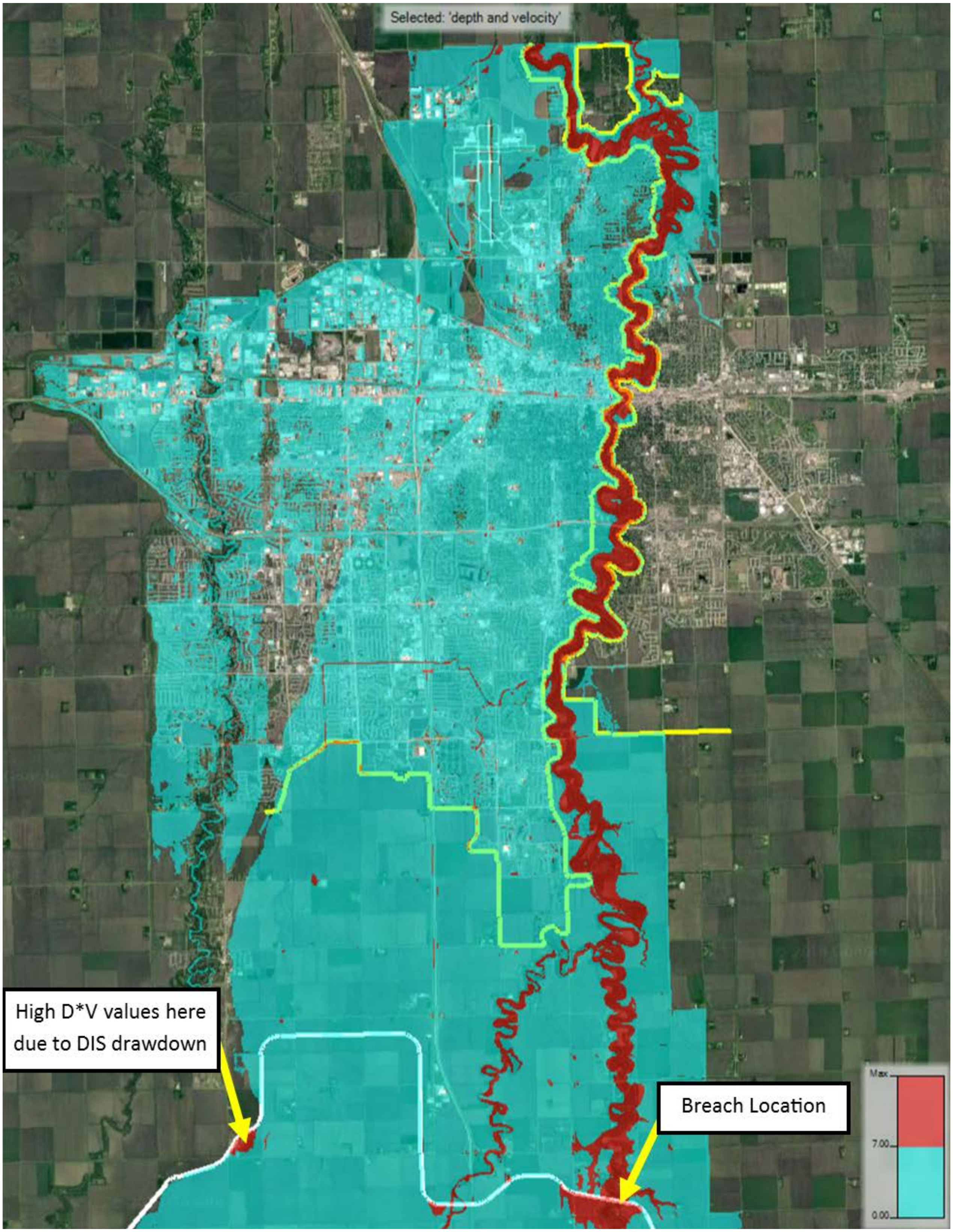

Figure 34. Proposed Conditions Maximum D*V for 1% ACE Event after Dam Breach at RRS

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

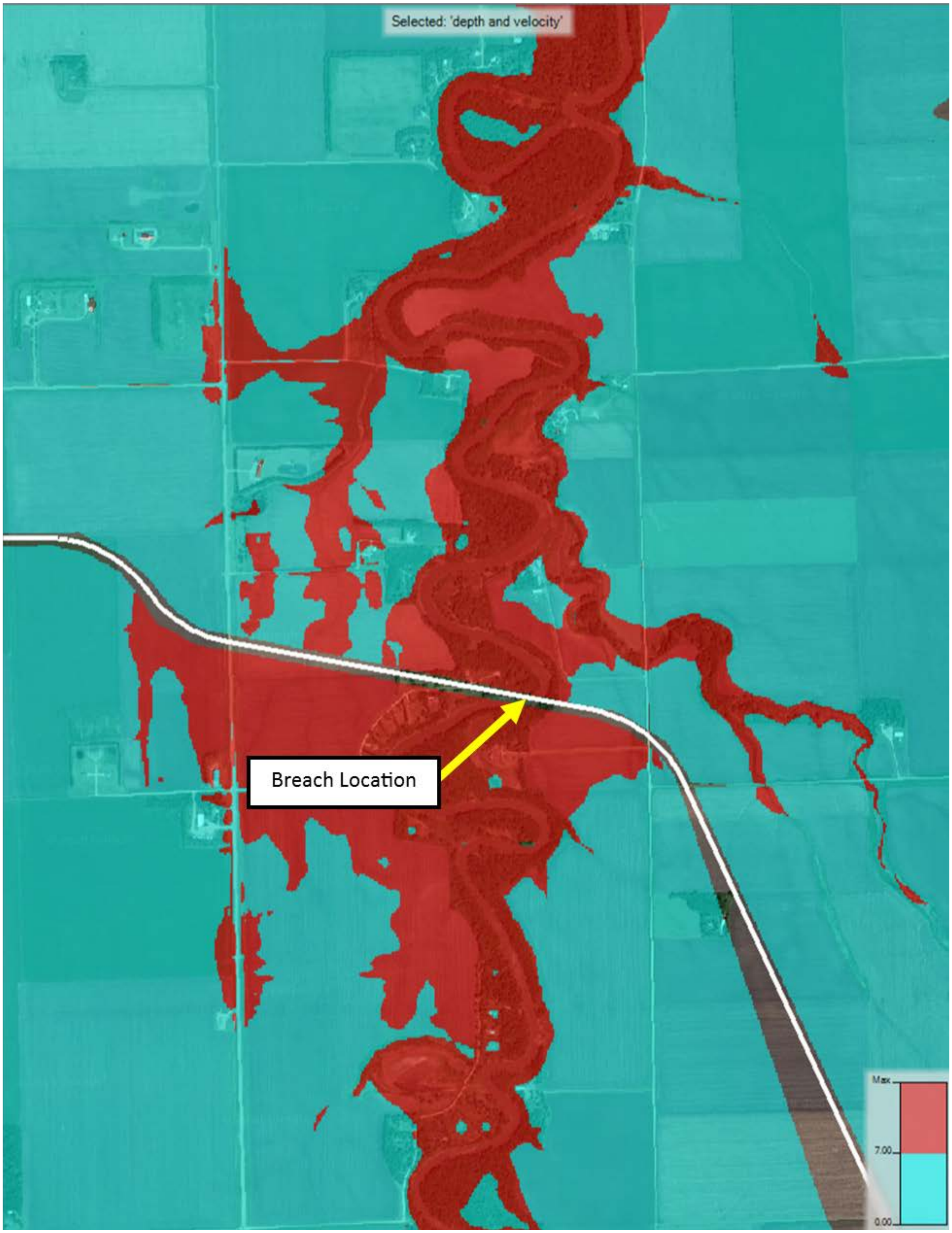

Figure 35. Proposed Conditions Near-Vicinity Maximum D*V for 1% ACE Event after Dam Breach at RRS

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

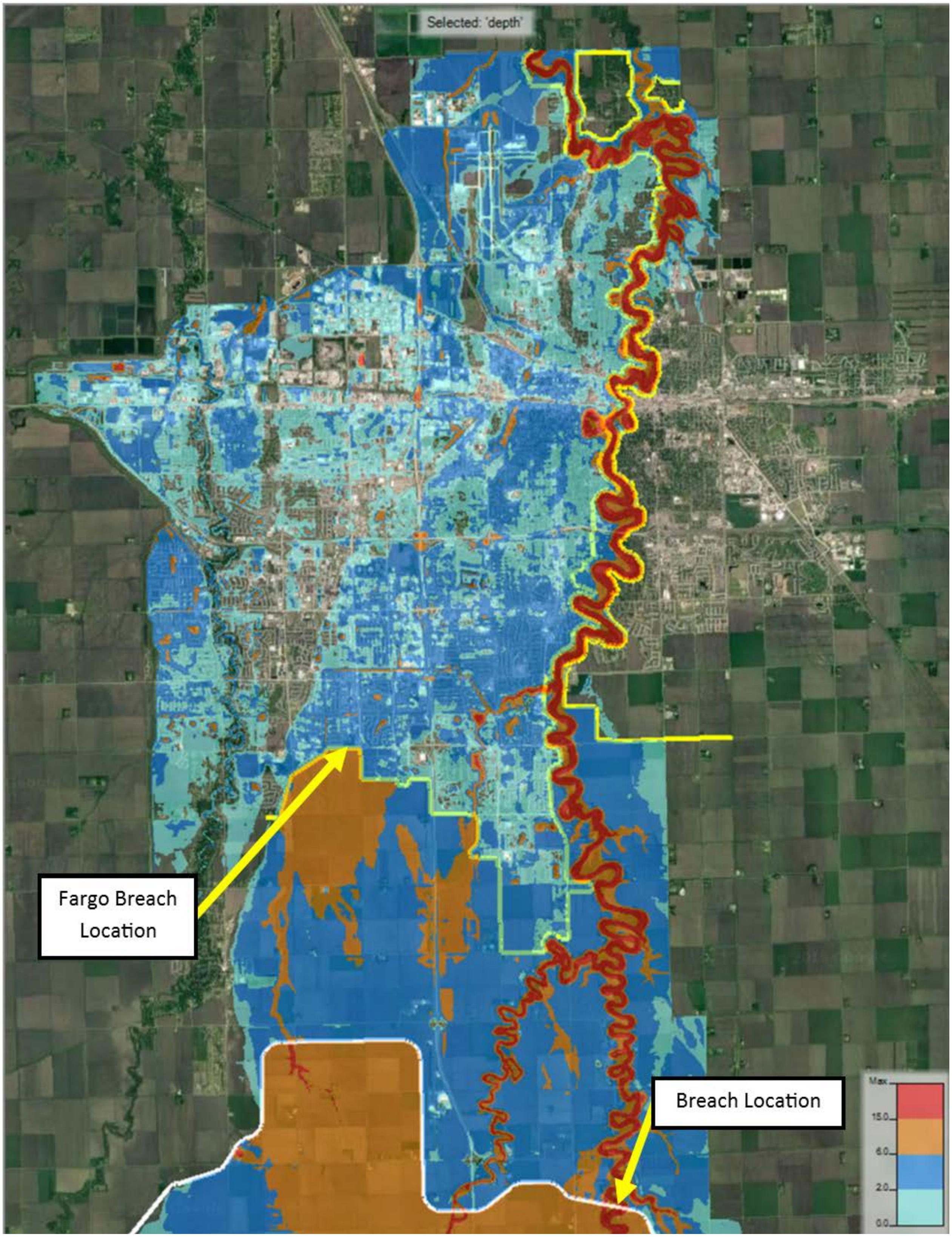

Figure 36. Proposed Conditions Maximum Flow Depths for 1% ACE Event after Dam Breach at RRS and Fargo Levee

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

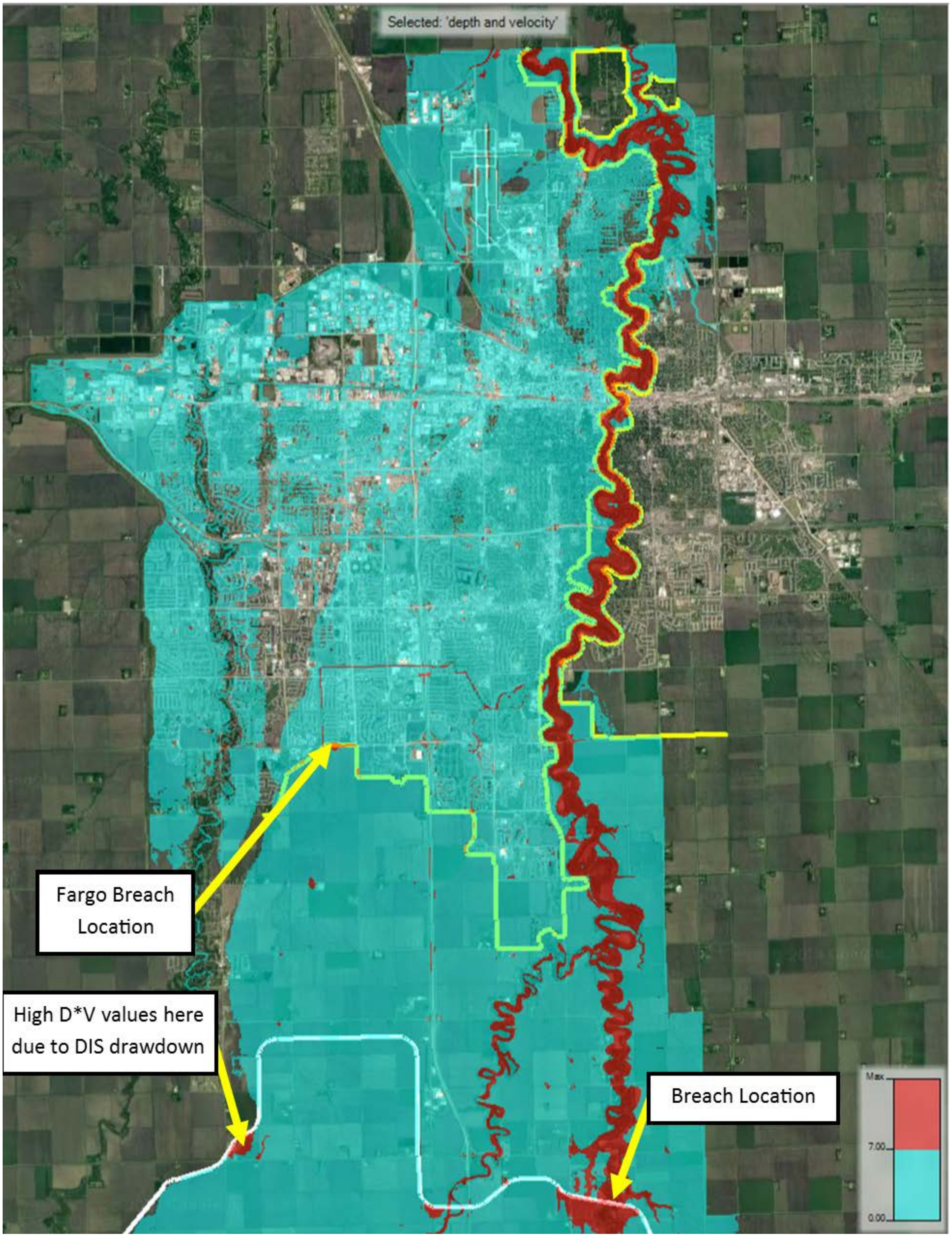

Figure 37. Proposed Conditions Maximum D*V for 1% ACE Event after Dam Breach at RRS and Fargo Levee

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.

Figure 38. Proposed Conditions Near-Vicinity Maximum D*V for 1% ACE Event after Dam Breach at RRS and Fargo Levee

This map has been compiled using the best information available and is believed to be accurate; however, its preparation required many assumptions. The results shown should only be used as a guideline for emergency planning and response actions. Actual areas inundated will depend on specific flooding and failure conditions and may differ from the areas shown on the maps.