APPENDIX C

GEOMORPHIC ASSESSMENT

GEOMORPHIC ASSESSMENT

1. Introduction

Michael Baker Corporation (Baker) conducted a geomorphic assessment for the Fourmile Creek Watershed, which included Fourmile Creek and Gold Run. The definition and level of detail for a given geomorphic assessment varies based on assessment objectives and application of results. For the purposes of this project Baker performed a planning-level geomorphic assessment which can be defined by a general classification of valley geology, channel materials and shape, and channel stability. The purpose of this assessment was to define the post-flood geomorphic conditions in the Fourmile Creek Watershed in order to gain an understanding of the processes that occurred during the September 2013 flood and to identify preliminary restoration strategies to assist with the development of the master plan. Baker supplemented the planning-level geomorphic assessment with erosion and deposition mapping, and a channel migration zone (CMZ) assessment.

2. Field Assessment

This initial step in the geomorphic assessment of a watershed is to divide the main channel and tributaries into sub-reaches using aerial photography, topography, and prior knowledge of the watershed. Sub reaches were delineated with the intention of identifying areas of similar physical characteristics and impairment. For assessment purposes, Baker divided the watershed into 26 sub-reaches, shown on Figure B-1, using the following criteria:

- Changes in channel dimension
- Changes in channel pattern
- Changes in channel profile
- Changes in valley width and channel confinement
- Tributary confluences
- Changes in land use

Field assessment work was performed over a period of four days between September 12th and 17th. The Baker team assessed multiple locations within each sub-reach in order to identify the geomorphic characteristic outlined below.

- Valley Type – Identification of valley type is required for subsequent geomorphic assessments and assists with identifying post-flood and reference stream conditions. Valley types were classified using the criteria outlined in Rosgen 2008.
- Post-Flood Stream Type – The classification of post-flood stream type assists in identifying the geomorphic processes that took place during the September 2013 flood that resulted in the departure from stable (reference) stream conditions. Post-flood stream types were classified using Rosgen 2008.
- Reference (Stable) Stream Type – The classification of reference stream type assists with identifying the geomorphic variables that likely existed prior to impairment, and will result in a stable channel in the present valley type. Reference stream types were classified using Rosgen 2008.
- Dominant Bed Material – The average (d50) grain size was identified by visual observation. The size of dominant bed material influences the classification of stream type.
- Channel Bed Form – The types of channel bed form can vary greatly. For the purposes of this study, channel bed forms were identified as step-pool or riffle-pool. According to Rosgen 2008, step-pool features generally exist in system with a slope of greater than 4% and riffle-pool features generally exist in systems with a slope of less than 4%.
- Channel Evolution process - The channel evolution model described by Schumm, et. al. (1984) was used to assess the current channel condition and active processes associated with streambed adjustment.

The representative assessment information for each sub-reach is documented in Table C-1. Due to the time and scope constraints of this project, all geomorphic assessment work was completed using industry-accepted qualitative evaluations. The qualitative assessments represent the general geomorphic conditions of each sub-reach and are suitable for planning purposes. However, it is recommended that more detailed geomorphic and ecologic assessments be completed prior to proceeding with additional design work within this watershed.

3. Erosion and Deposition Mapping

Baker mapped zones of erosion and deposition throughout the Fourmile Canyon Watershed using pre- and post-flood LiDAR information. Approximations of both erosion and deposition were estimated by intersecting pre- and post-flood topographic information. This mapping assisted with understanding the channel processes that occurred during flooding and also assisted with developing restoration strategies. The maps are includes in this Appendix, starting on page C-4.

4. Channel Migration Zone Assessment

A channel migration zone (CMZ) is defined as the area within which a river channel is likely to move over a period of time (Washington State Department of Ecology, 2003). Channel migration zones consist of the following elements:

- Historical Migration Zone (HMZ) – The collective area the channel occupied in the historical record.
- Avulsion Hazard Zone (AHZ) – The area not included in the HMZ that is at risk of avulsion.
- Erosion Hazard Area (EHA) – The area not included in the in the HMZ or AHZ that is at risk of bank erosion from stream flow or mass wasting.
- Disconnected Migration Area (DMA) – The portion of the CMZ where man-made structures physically eliminate channel migration.

Ideally, the CMZ should consist of a zone where the construction of homes and infrastructure is prohibited. The reason for this is that the stream or river system will eventually need this entire envelope of area to migrate in order to achieve long-term stability. If homes and/or infrastructure are placed in a currently inactive portion of the CMZ, they may be at risk for future damage during future channel migration.

Pre- and post-flood channel alignments were delineated using LiDAR data, which showed that there were very few locations where the two alignments differed drastically. Additional mapping of the HMZ past 2012 was unable to be completed because of lack, and quality, of available data. Therefore, channel migration zones were not delineated for the Fourmile Canyon Watershed. Since the Fourmile Canyon Watershed consists of a very narrow and confined canyon, lateral migration will be limited by the canyon walls and the 100-year floodplain mapping, shown in Appendix D, can be used as a surrogate for the CMZ for this project. As previously mentioned, it would be ideal to locate all homes and infrastructure outside of the CMZ. However, much of this watershed is already developed and already within the CMZ. Therefore, it is recommended to place infrastructure the will be reconstructed outside of the CMZ where feasible.

5. Results and Recommendations

A summary of the qualitative assessment for each reach is provided below and includes a general description of post-flood conditions, fluvial processes, and potential restoration strategies. Assessment information for each sub-reach is also documented in Table C-1. Representative photographs for each reach are provided in Appendix B.

Reach 1 - HWY 119 to Poorman Road

This reach of Fourmile Creek consists of a cobble-bed system with low to moderate sinuosity that flows to the southeast in a narrow alluvial valley. Development exists adjacent to the right bank of the reach and Fourmile Canyon Drive is adjacent to the left bank. Portions of development and Fourmile Canyon Road are within the 100-year floodplain and are restricting lateral channel movement. The channel in this reach is generally attempting to widen, which is evidenced by the fact that there are several locations where bank stabilization has been implemented throughout the reach, generally consisting of concrete and rip rap. There are small portions of this reach that have degraded to the point where the floodplain is entrenched, and is resulting in local channel instability in sub-reaches 1c and 1d. The existing bed form consists of riffle-pool sequences; however, some of these features have been damaged or washed out

as a result of recent flooding. The results of the erosion and deposition mapping show minor deposition and few sporadic pockets of deep erosion.

Recommendations

Restoration recommendations for this reach include restoring the low flow channel and riffle-pool sequences consistent with the valley type and reference stream type. Additionally, there are several opportunities to add complexity to the system by adding rock clusters to riffles, large woody debris (LWD) adjacent to banks, and moving existing boulders that were relocated by recent flooding. Complexity assists with re-establishing habitat, but also assists with dissipating erosive forces from flooding. Opportunities to eliminate or move floodplain restrictions caused by adjacent development or infrastructure should be evaluated where feasible. Expanding the floodplain will assist with dissipating erosive forces from flooding and also reduce flooding potential while providing more room for the channel to laterally migrate without causing damage to homes or infrastructure.

Reach 2 – Poorman Road to Mile Marker 4

This reach of Fourmile Creek consists of a cobble-bed system with low to moderate sinuosity that flows to the southeast in a narrow alluvial valley. Development and infrastructure do not confine this reach until the reach enters Crisman, where both development and Fourmile Canyon Drive restrict lateral channel movement. Most of the development in Crisman is within the 100-year floodplain. The bottom half of this reach is stable. However, the upper half of the reach is unstable with sub-reach 2d being severely aggraded, sub-reach 2e actable incising, and sub-reach 2f widening. There are small portions of this reach that have degraded to the point where the floodplain is entrenched, and is contributing to local channel instability in sub-reaches 2d, 2e, and 2f. The existing bed form in the stable portions of this reach consists of riffle-pool sequences; however, some of these features have been damaged or washed out as a result of recent flooding. The results of the erosion and deposition mapping show moderate erosion and deposition throughout the entire reach.

Recommendations

No restoration is recommended for sub-reaches 2a, 2b, or 2c. Restoration recommendations for sub-reaches 2d, 2e, and 2f include restoring the low flow channel and riffle-pool sequences consistent with the valley type and reference stream type. Additionally, there are several opportunities to add complexity to the system by adding rock clusters to riffles, LWD adjacent to banks, and moving existing boulders that were relocated by recent flooding. Complexity assists with re-establishing habitat, but also assists with dissipating erosive forces from flooding. Opportunities to eliminate or move floodplain restrictions caused by adjacent development or infrastructure should be evaluated where feasible. Expanding the floodplain will assist with dissipating erosive forces from flooding and also reduce flooding potential while providing more room for the channel to laterally migrate without causing damage to homes or infrastructure. Lastly, it is recommended that sediment be removed from depositional areas to restore flood capacity where needed. Some of this sediment can be used to fill eroded areas to reduce the risk of avulsion.

Reach 3 (Fourmile Creek) – Mile Marker 4 to Salina

This reach of Fourmile Creek consists of a cobble-bed system with moderate sinuosity that flows to the southeast in a narrow alluvial valley. A small amount of development exists adjacent to the right bank of the reach and Fourmile Canyon Drive is adjacent to the left bank. Portions of Fourmile Canyon Road are within the 100-year floodplain and are restricting lateral channel movement. The channel in this reach appears to have gone through a widening process and is now transitioning towards more of a stable condition. Most portions of this reach have degraded to the point where the floodplain is entrenched, and is resulting in local channel instability in all sub-reaches. The existing bed form consists of riffle-pool step-pool sequences; however, some of these features have been damaged or washed out as a result of recent flooding. The results of the erosion and deposition mapping show significant zones of both erosion and deposition. There is a mine tailings pile downstream of Salina that the EPA has investigated for contaminants.

Recommendations

Restoration recommendations for this reach include restoring the low flow channel and riffle-pool/step-pool sequences consistent with the valley type and reference stream type. Additionally, there are several opportunities to add complexity to the system by adding rock clusters to riffles, large woody debris (LWD) adjacent to banks, and moving existing boulders that were relocated by recent flooding. Complexity assists with re-establishing habitat, but also assists with dissipating erosive forces from flooding. Opportunities to eliminate or move floodplain restrictions caused by adjacent development or infrastructure should be evaluated where feasible. Expanding the floodplain will assist with dissipating erosive forces from flooding and also reduce flooding potential while providing more room for the channel to laterally migrate without causing damage to homes or infrastructure.

Reach 3 (Gold Run) – Salina to Upstream Gold Run Study Limit

This reach of Gold Run mostly consists of an engineered channel that was constructed during post-flood restoration efforts. The channel sinuosity is moderate in most locations. Development exists adjacent to both channel banks and Gold Run Road is adjacent to the left bank. Both the development and Gold Run Road are mostly within the 100-year floodplain and are restricting lateral channel movement. The channel in this reach is generally attempting to widen, which is evidenced by the fact that there are several locations where bank stabilization has been implemented throughout the reach, generally consisting of concrete and rip rap. There are no natural identifiable channel bed form features except for in sub-reach 4g, where some step-pool features exist. The results of the erosion and deposition mapping show significant erosion throughout the reach.

Recommendations

A significant amount of post-flood restoration effort has already occurred in this reach, which includes the reconstruction of portions of Gold Run Road. The channel was relocated to areas that would optimize road reconstruction and community redevelopment, which have subsequently limited opportunities for a natural restoration. Therefore, it is recommended to coordinate with ongoing Gold Run Road improvements to improve channel condition, in-stream habitat, and riparian zone to the maximum extent possible.

Reach 4 – Salina to Upstream Study Limit

This reach of Fourmile Creek consists of a cobble-bed system with low to moderate sinuosity that flows to the northeast in a narrow alluvial valley. Although the valley floor is still narrow in this reach, it is nearly twice as wide as in the lower reaches. Development generally exists adjacent to the right bank of the reach and Fourmile Canyon Drive is adjacent to the left bank. Portions of development and Fourmile Canyon Road are within the 100-year floodplain and are restricting lateral channel movement. The channel is stable or stabilizing for over have of the reach length, and widening in the remaining sections. There are small portions of this reach that have degraded to the point where the floodplain is entrenched, and is resulting in local channel instability in sub-reach 4a. The existing bed form consists of riffle-pool and step-pool sequences; however, some of these features have been damaged or washed out as a result of recent flooding. The results of the erosion and deposition mapping show moderate deposition and erosion areas up to mile marker 8.

Recommendations

No restoration is recommended for sub-reaches 4b or 4g. Restoration recommendations for all other sub-reaches include restoring the low flow channel and riffle-pool/step-pool sequences consistent with the valley type and reference stream type. Additionally, there are several opportunities to add complexity to the system by adding rock clusters to riffles, large woody debris (LWD) adjacent to banks, and moving existing boulders that were relocated by recent flooding. Complexity assists with re-establishing habitat, but also assists with dissipating erosive forces from flooding. Opportunities to eliminate or move floodplain restrictions caused by adjacent development or infrastructure should be evaluated where feasible. Expanding the floodplain will assist with dissipating erosive forces from flooding and also reduce flooding potential while providing more room for the channel to laterally migrate without causing damage to homes or infrastructure. Lastly, it is recommended that sediment be removed from depositional areas to restore flood capacity where needed. Some of this sediment can be used to fill eroded areas to reduce the risk of avulsion.

Table C-1 Geomorphic Assessment - Fourmile Master Plan

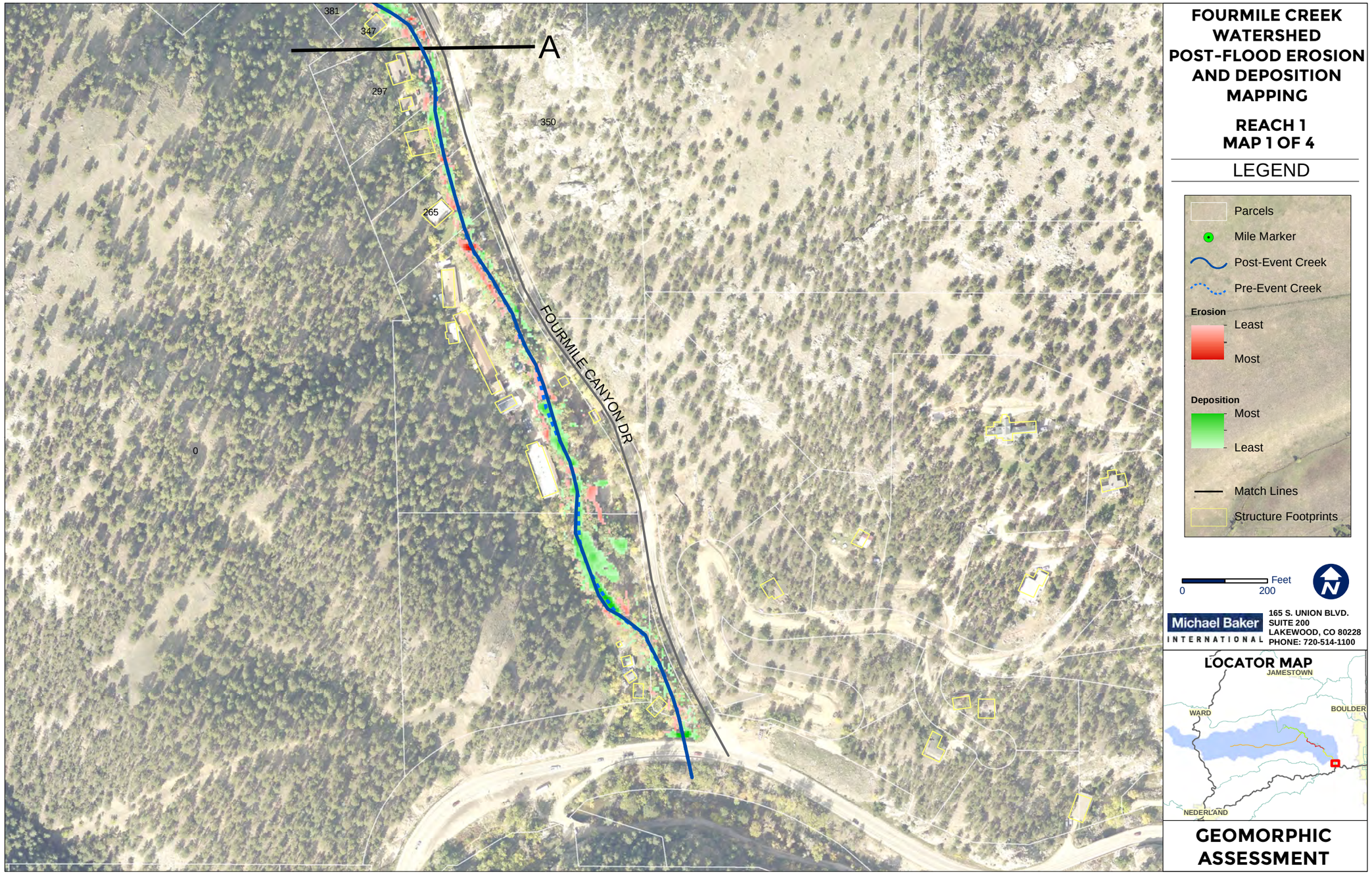
Sub Reach	Approx. DA (mi2)	Channel Condition*	Channel Evolution Stage**	Bed Material	Post-Flood Stream Classification***	Reference Stream Type***	Existing Bed Form	Reference Bed Form	Valley Length (ft)	Stream Length (ft)	Sinuosity	Slope (ft/ft)	Departure Description
1a	21.5	4	III - Widening	Cobble	C3	C3	Riffle-Pool	Riffle-Pool	942	1,060	1.13	0.015	
1b	21.5	4	III - Widening	Cobble	C3	C3	Riffle-Pool	Riffle-Pool	1,831	1,872	1.02	0.019	
1c	21.5	4	III - Widening	Cobble	F3	C3	Riffle-Pool	Riffle-Pool	2,375	2,620	1.10	0.020	
1d	21.5	4	III - Widening	Cobble	F3b	C3b	Riffle-Pool	Riffle-Pool	2,526	2,778	1.10	0.025	
1e	21.5	4	III - Widening	Cobble	C3b	C3b	Riffle-Pool	Riffle-Pool	3,022	4,125	1.36	0.025	
1f	21.5	4	III - Widening	Cobble	C3	C3	Riffle-Pool	Riffle-Pool	614	610	1.00	0.013	
2a	21.5	6	IV - Stabilizing	Cobble	C3	C3	Riffle-Pool	Riffle-Pool	2,260	2,485	1.10	0.015	
2b	18.7	6	IV - Stabilizing	Cobble	C3	C3	Riffle-Pool	Riffle-Pool	2,661	3,383	1.27	0.015	
2c	18.7	9	I - Stable	Cobble	B3c	B3c	Riffle-Pool	Riffle-Pool	823	884	1.07	0.015	
2d	18.7	2	N/A - Aggrading	Cobble	D3	C3	N/A	Riffle-Pool	1,959	2,455	1.25	0.015	
2e	18.7	2	II - Incision	Cobble	F3b	C3b	Riffle-Pool	Riffle-Pool	1,946	2,201	1.13	0.025	
2f	18.7	4	III - Widening	Cobble	F3b	C3b	Riffle-Pool	Riffle-Pool	1,955	2,192	1.12	0.025	
3a	18.7	5	IV - Stabilizing	Cobble	G3	B3	Step-Pool	Step-Pool	2,513	3,262	1.30	0.034	
3b	18.7	5	IV - Stabilizing	Cobble	G3	B3	Step-Pool	Step-Pool	1,463	2,374	1.62	0.038	
3c	18.7	5	IV - Stabilizing	Cobble	F3b	C3b	Riffle-Pool	Riffle-Pool	466	484	1.04	0.025	
3d	16.0	5	III - Widening	Cobble	F3b	C3b	Riffle-Pool	Riffle-Pool	1,247	1,241	1.00	0.023	
3e	2.7	4	III - Widening	Cobble	G3a	B3a	Engineered	Step-Pool	3,563	4,987	1.40	0.061	
3f	2.7	4	III - Widening	Cobble	G3a	B3a	Engineered	Step-Pool	4,393	5,409	1.23	0.076	
3g	2.7	3	II - Incision	Cobble	F3	C3	Step-Pool	Step-Pool	1,404	1,971	1.40	0.053	
4a	16.0	4	III - Widening	Cobble	F3b	C3b	Step-Pool	Step-Pool	1,752	1,991	1.14	0.035	
4b	16.0	7	V - Stable	Cobble	C3b	C3b	Riffle-Pool	Riffle-Pool	11,463	12,578	1.10	0.025	
4c	16.0	4	IV - Stabilizing	Cobble	C3b	C3b	Step-Pool	Step-Pool	1,322	1,320	1.00	0.039	
4d	16.0	4	III - Widening	Cobble	C3b	C3b	Riffle-Pool	Riffle-Pool	3,947	4,211	1.07	0.029	
4e	13.2	4	III - Widening	Cobble	C3b	C3b	Riffle-Pool	Riffle-Pool	4,790	5,087	1.06	0.028	
4f	13.2	6	IV - Stabilizing	Cobble	C3b	C3b	Riffle-Pool	Riffle-Pool	5,328	6,122	1.15	0.025	
4g	6.9	7	V - Stable	Cobble	C3b	C3b	Step-Pool	Step-Pool	9,951	11,335	1.14	0.041	

Notes:

* Stream Visual Assessment Protocol Version 2, USDA NRCS 2009

** Incised Channels: Morphology, Dynamics and Control, Schum 1984

*** River Stability Field Guide, Wildland Hydrology 2008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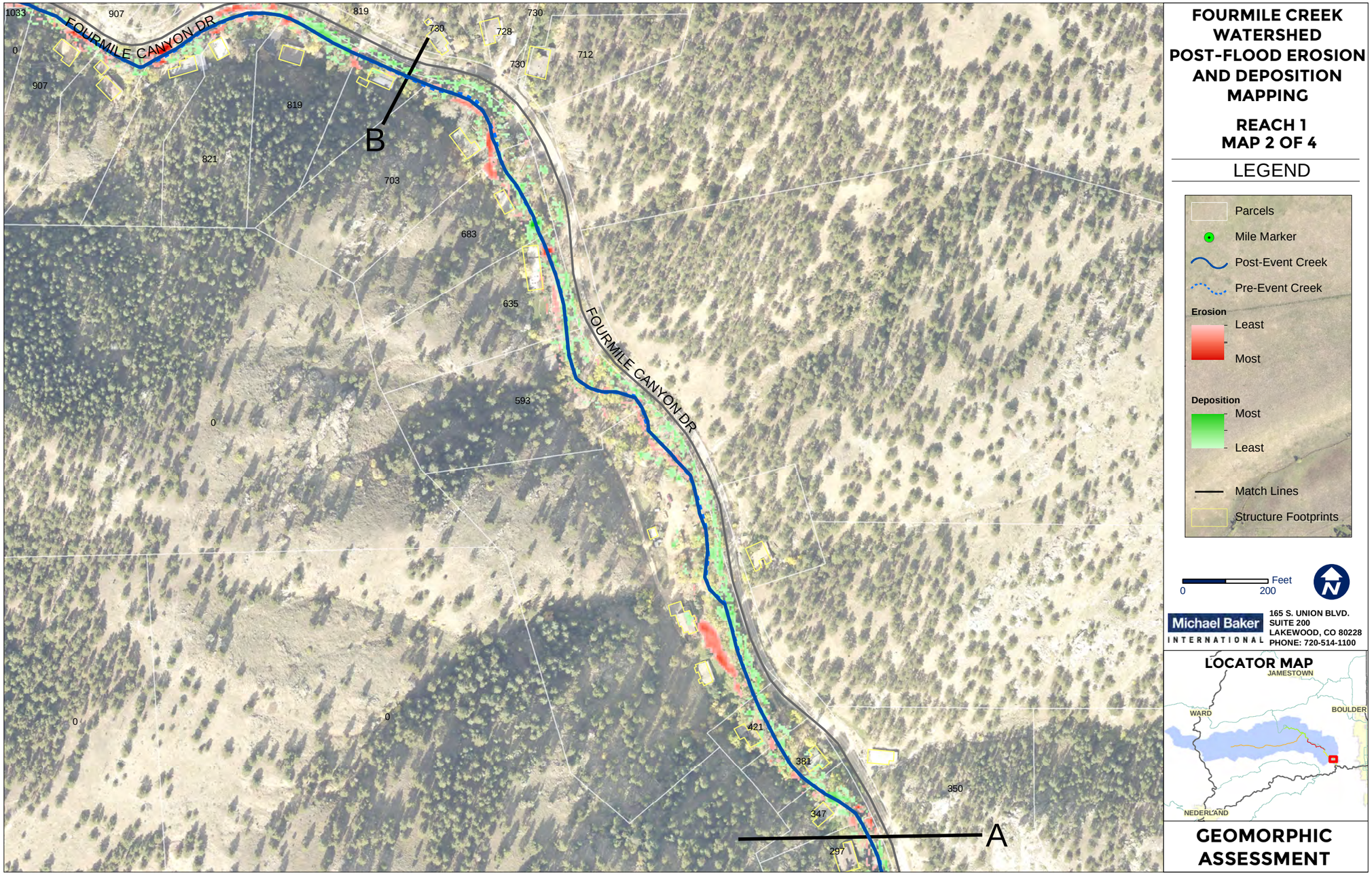
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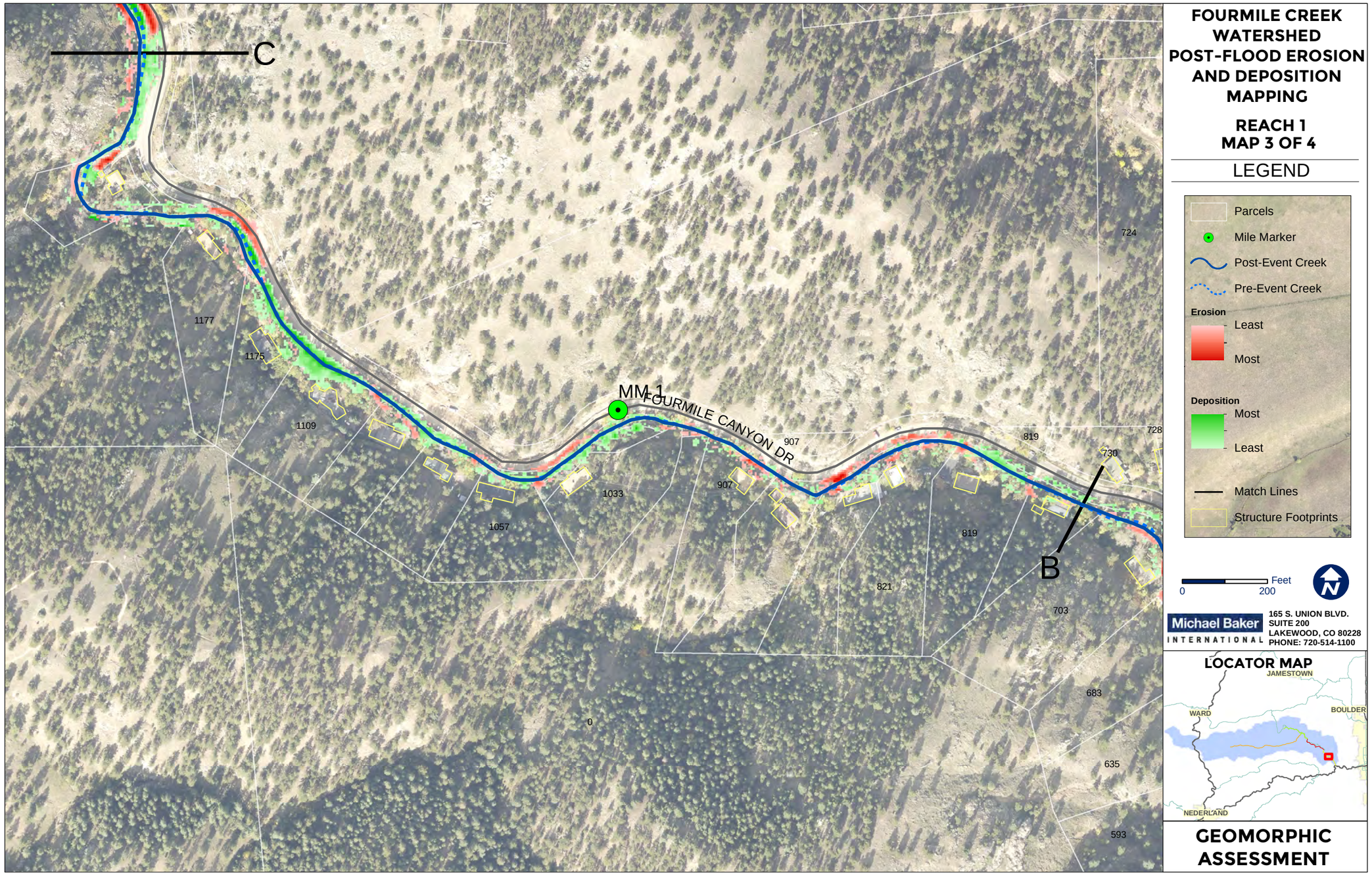
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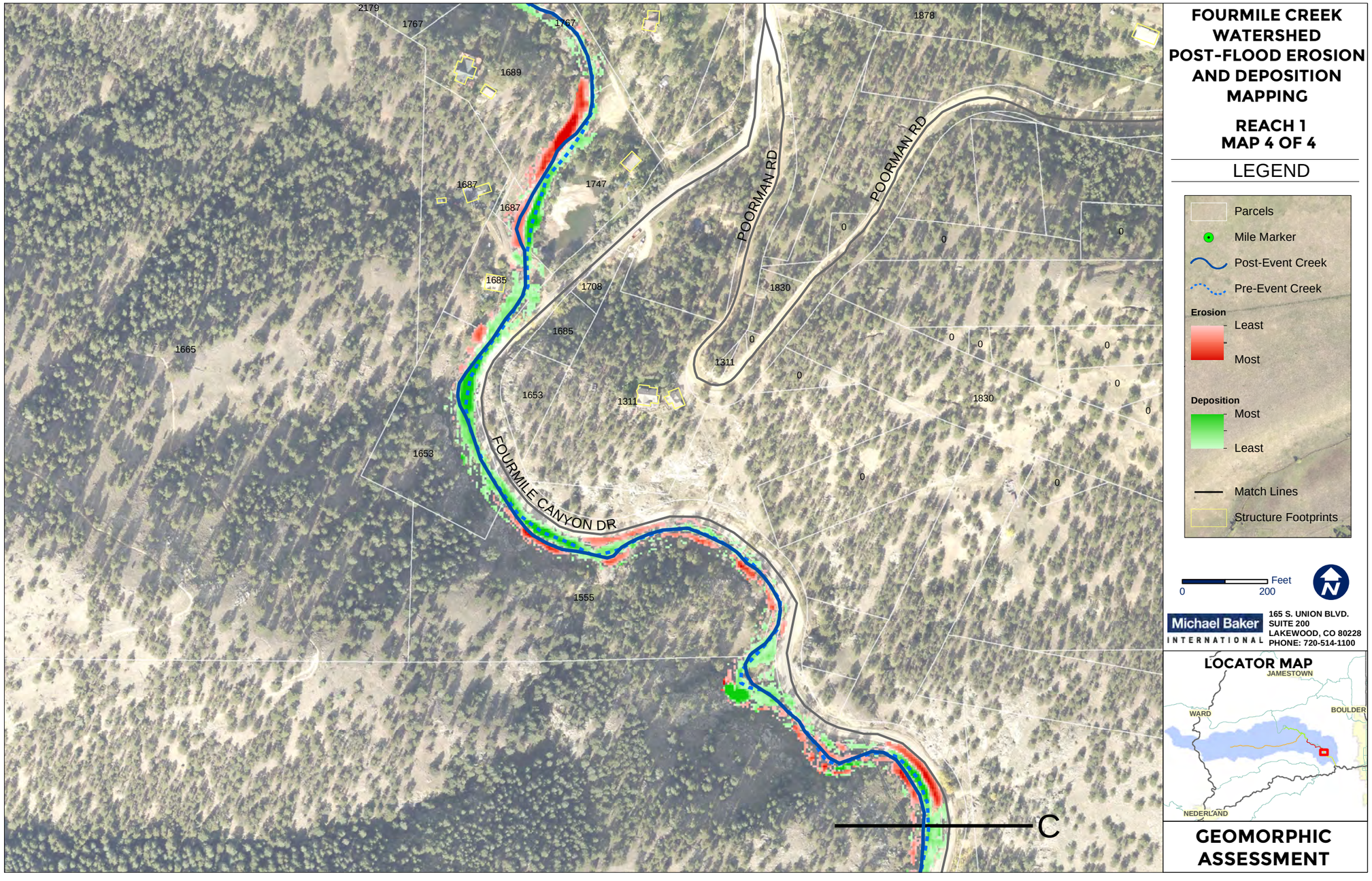
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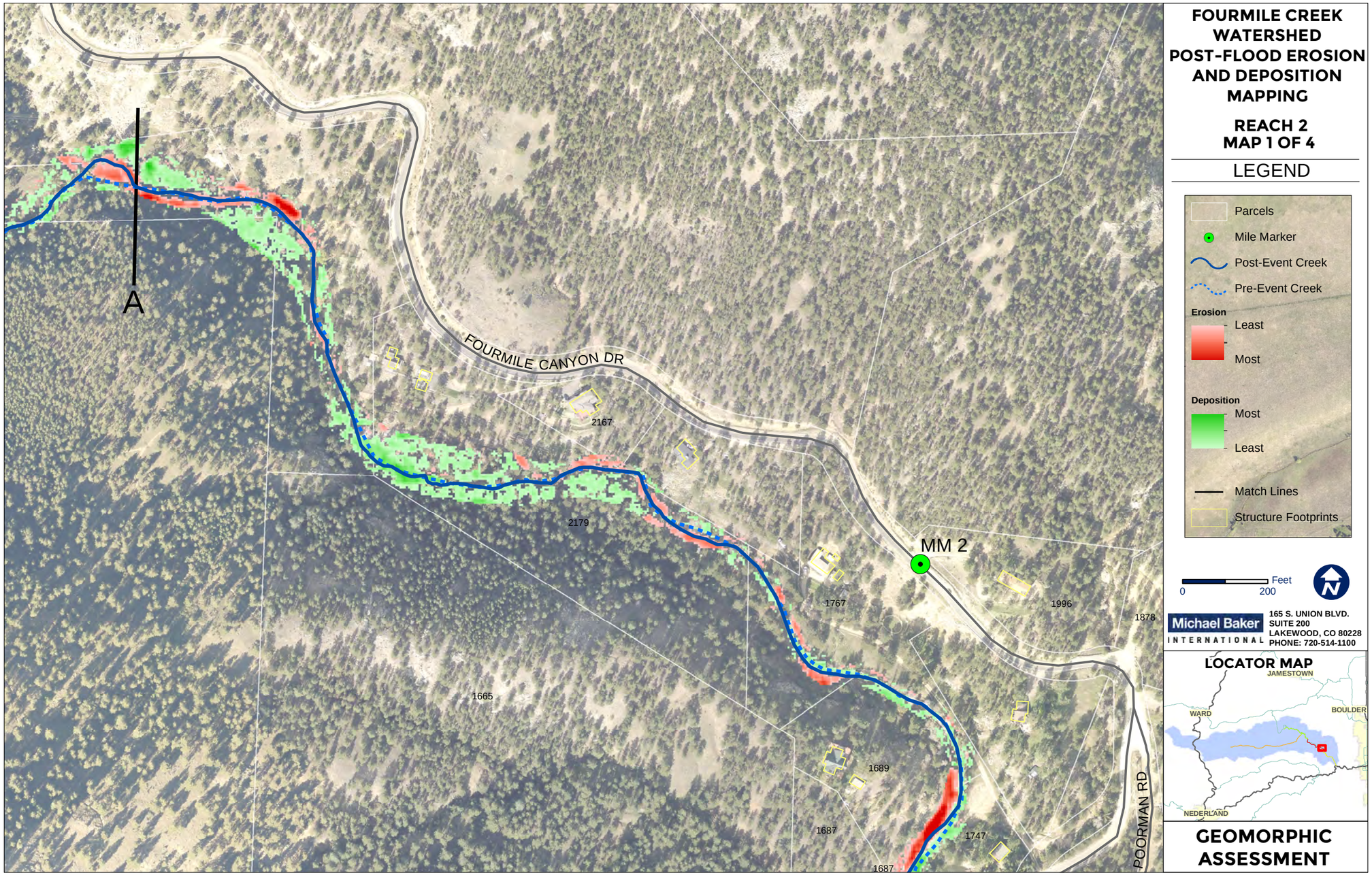
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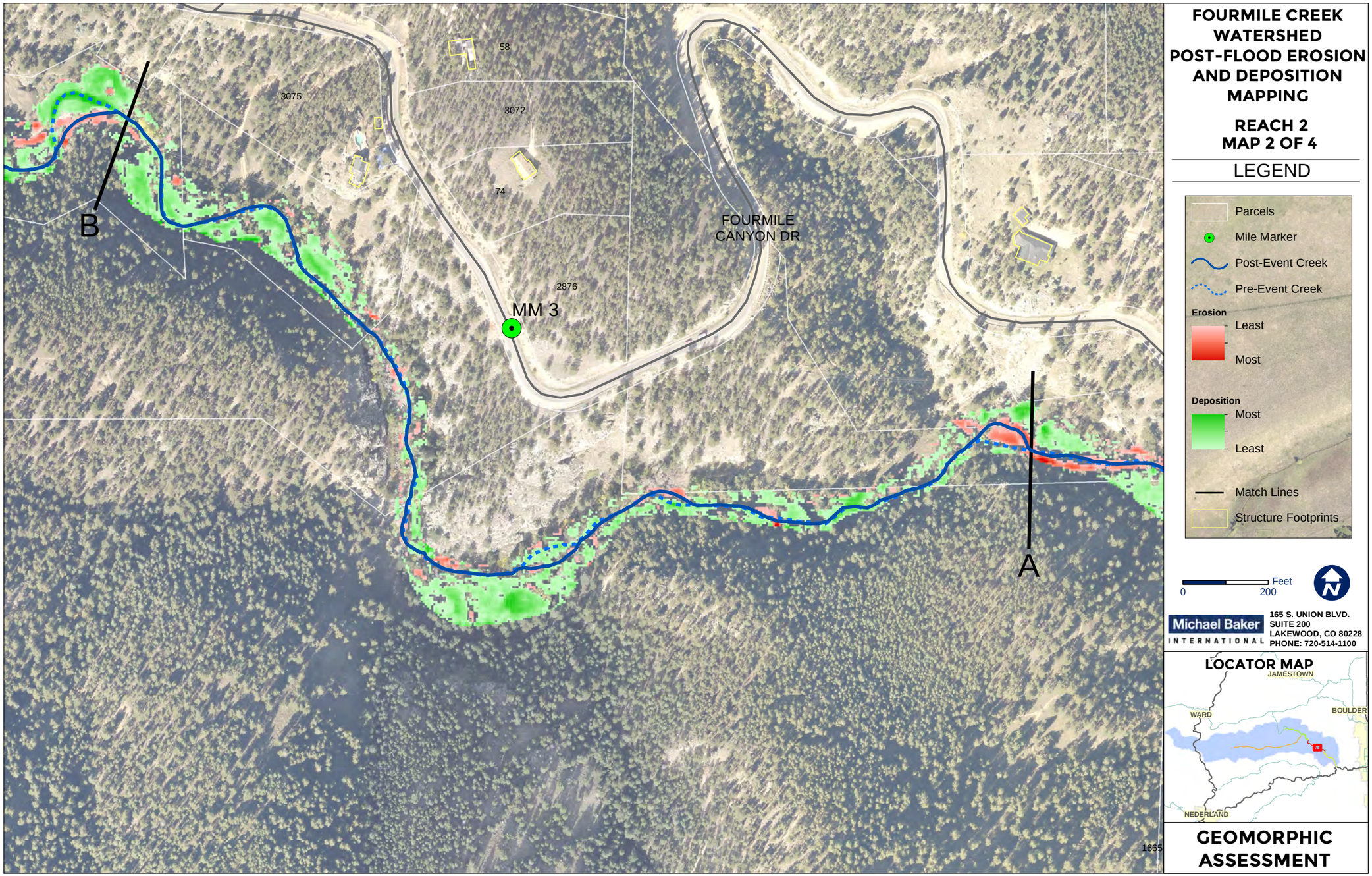
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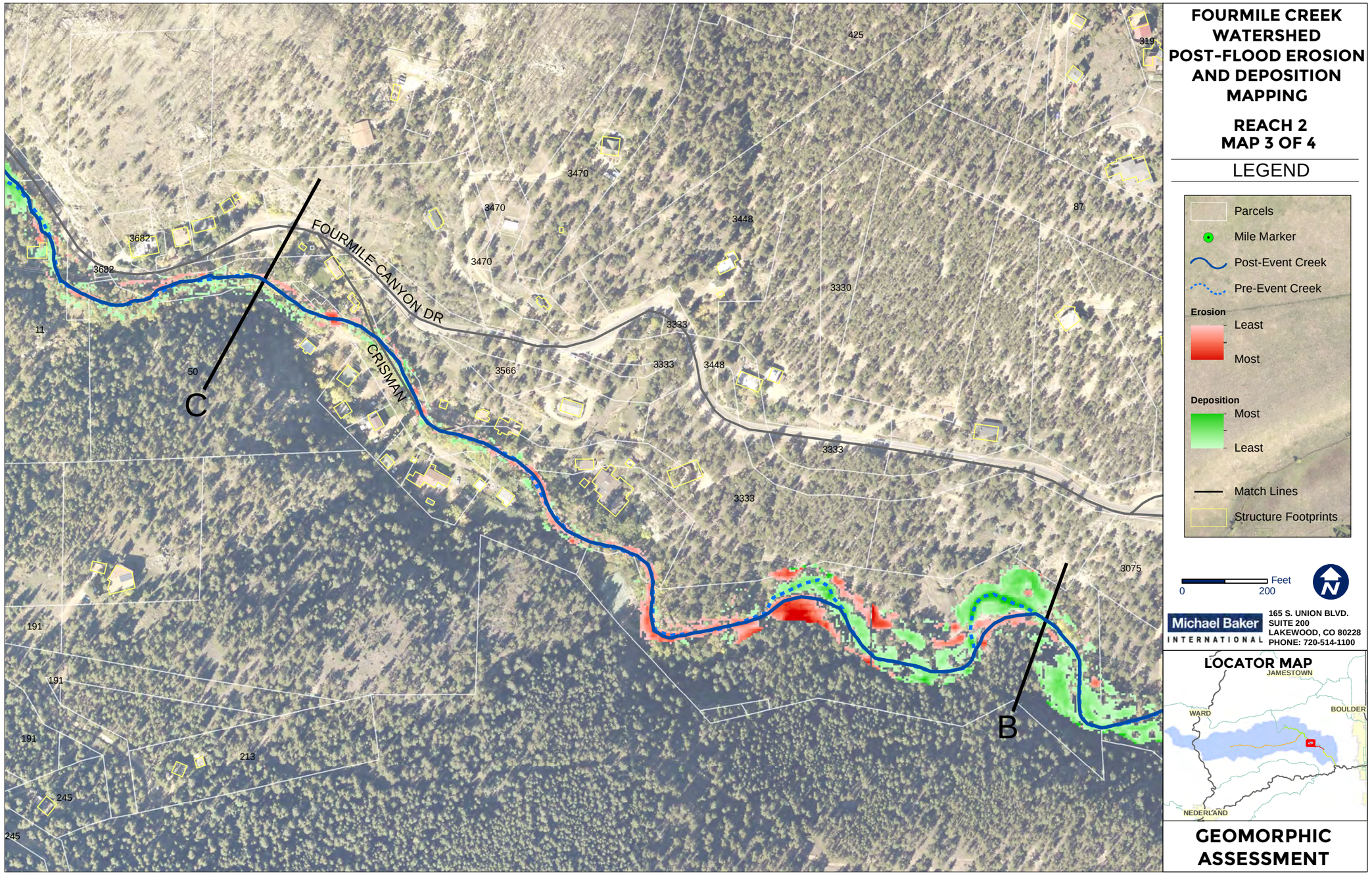
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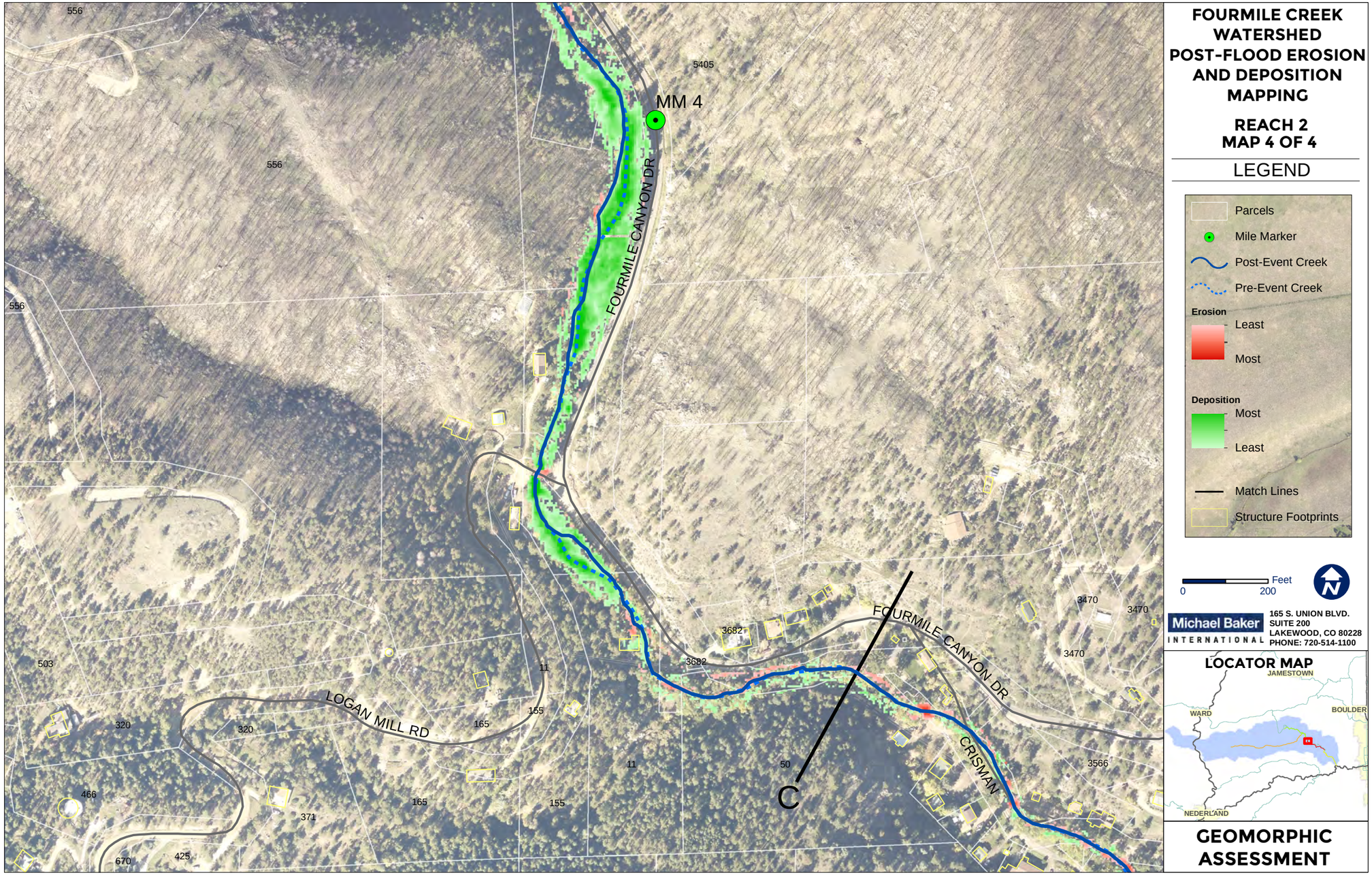
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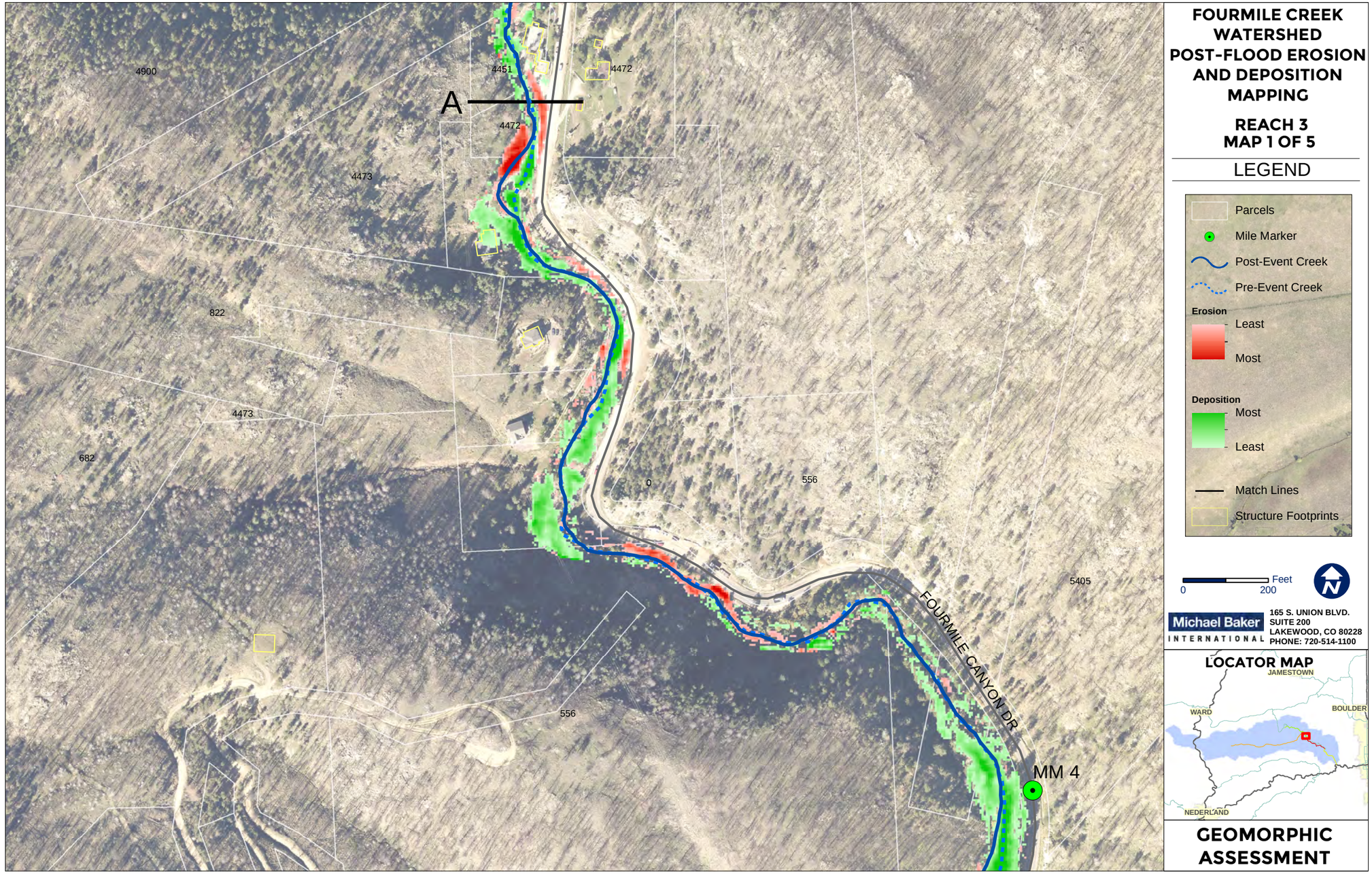
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MAP 1 OF 5
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Post-Event Creek
Pre-Event Creek
Erosion
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Deposition
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Match Lines
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NEDERLAND
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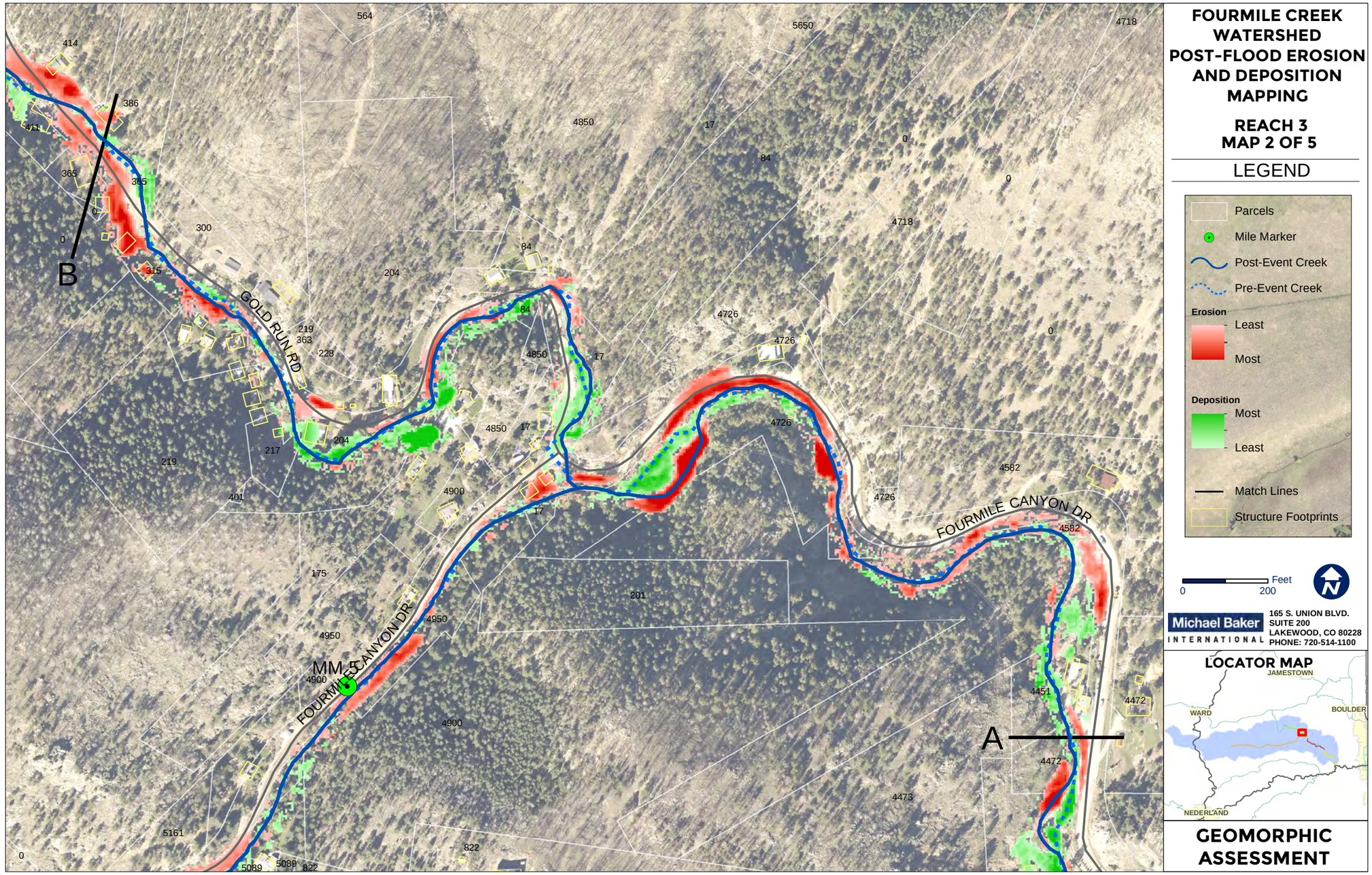
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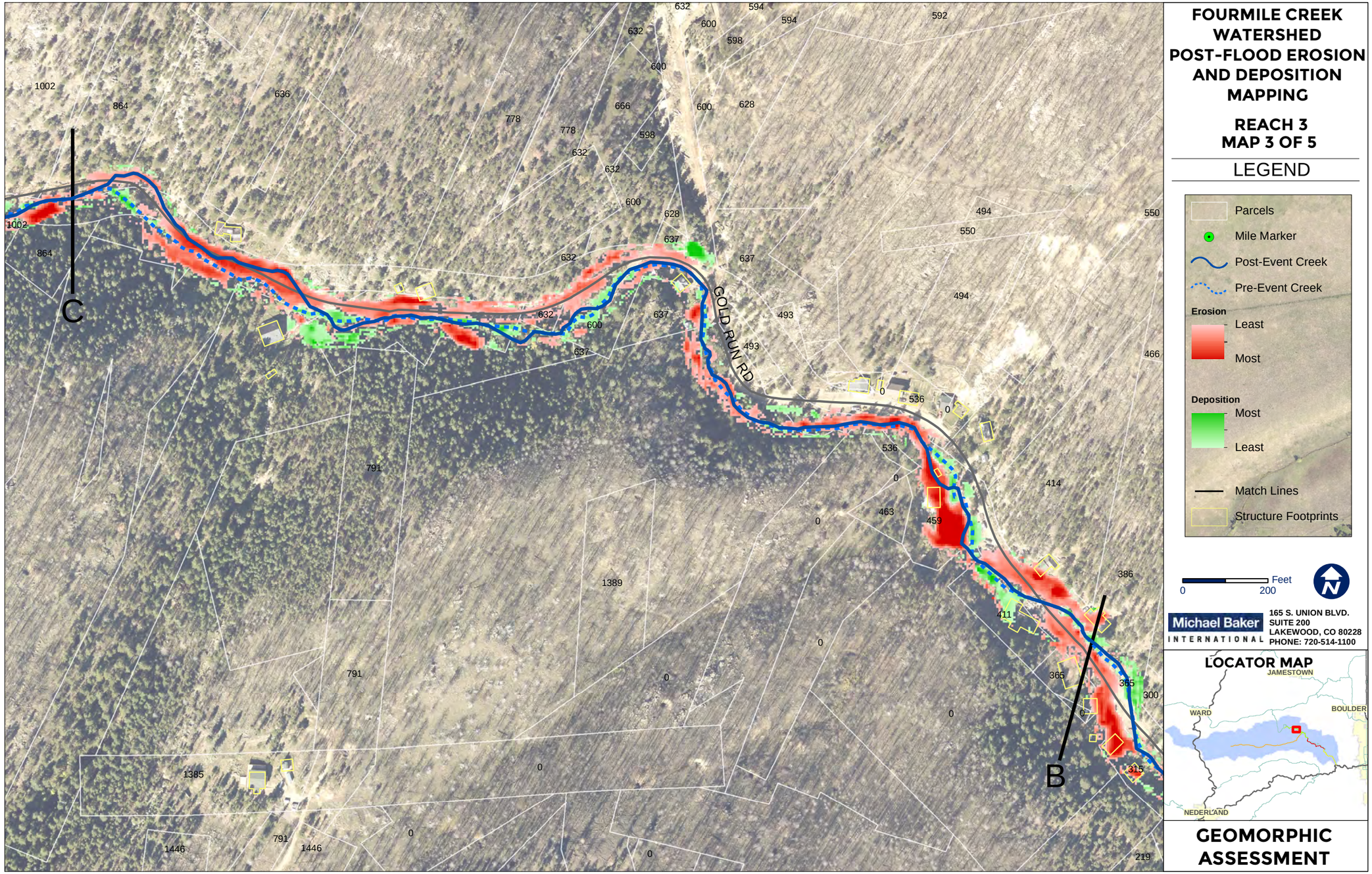
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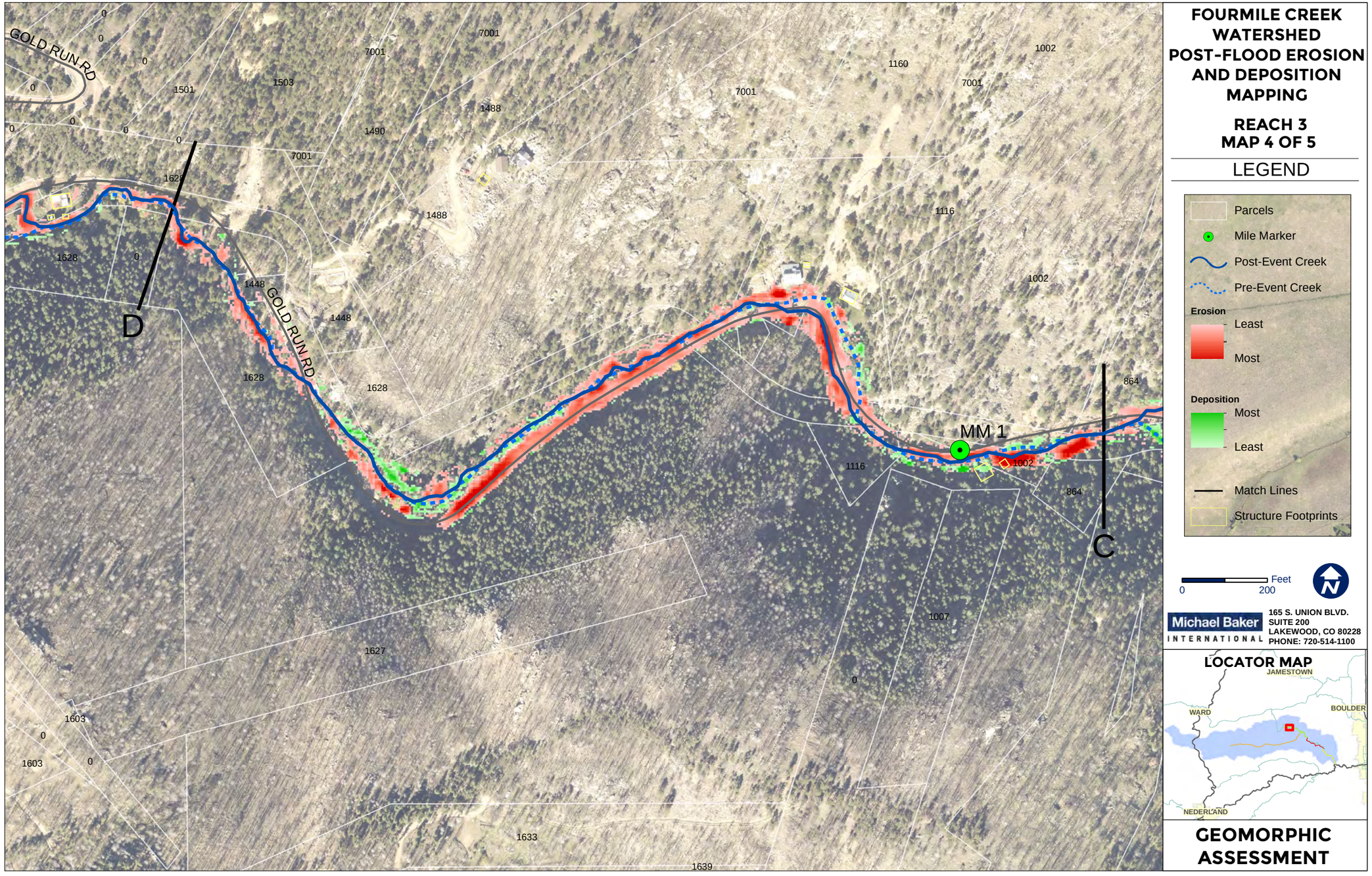
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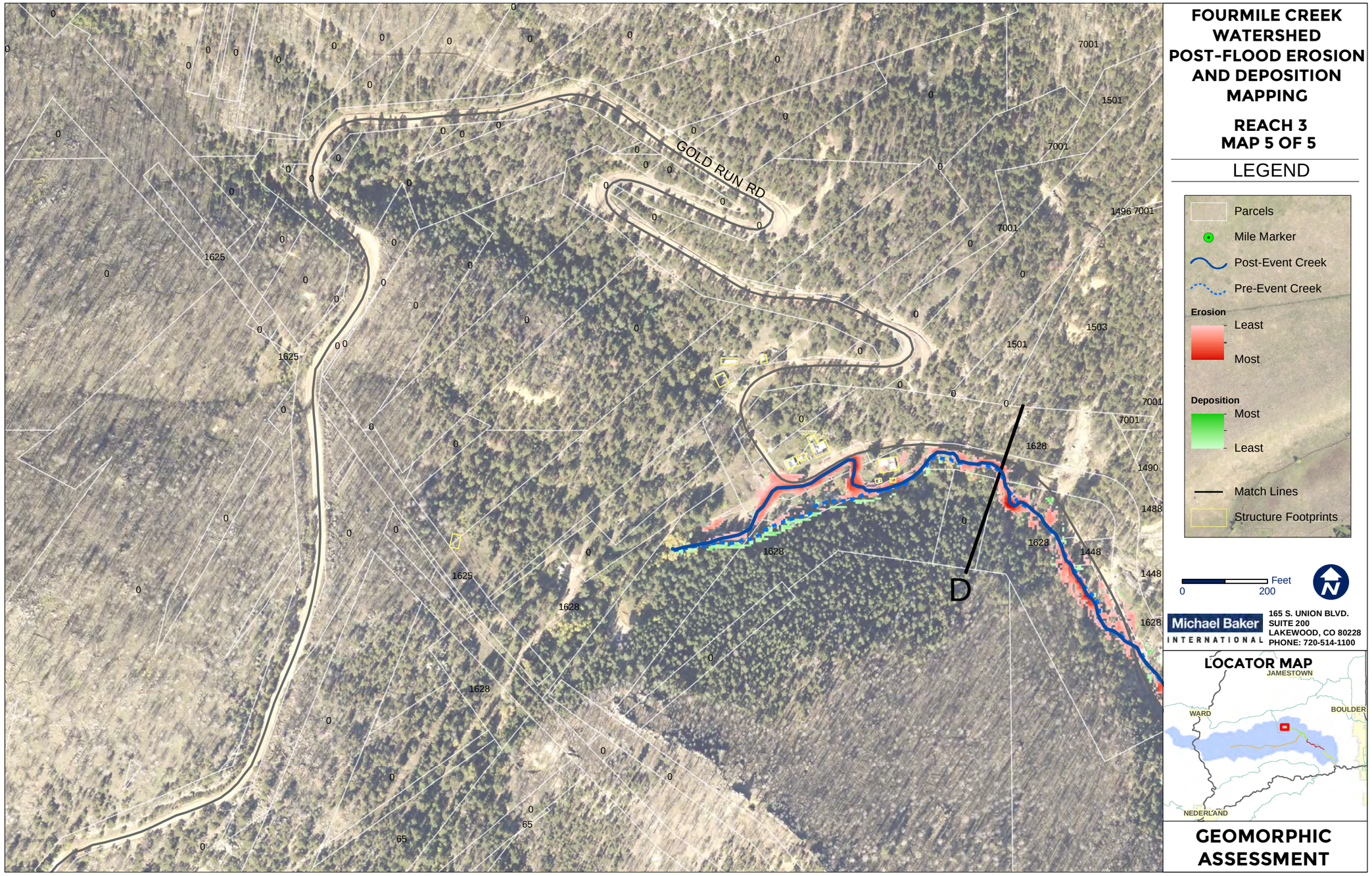
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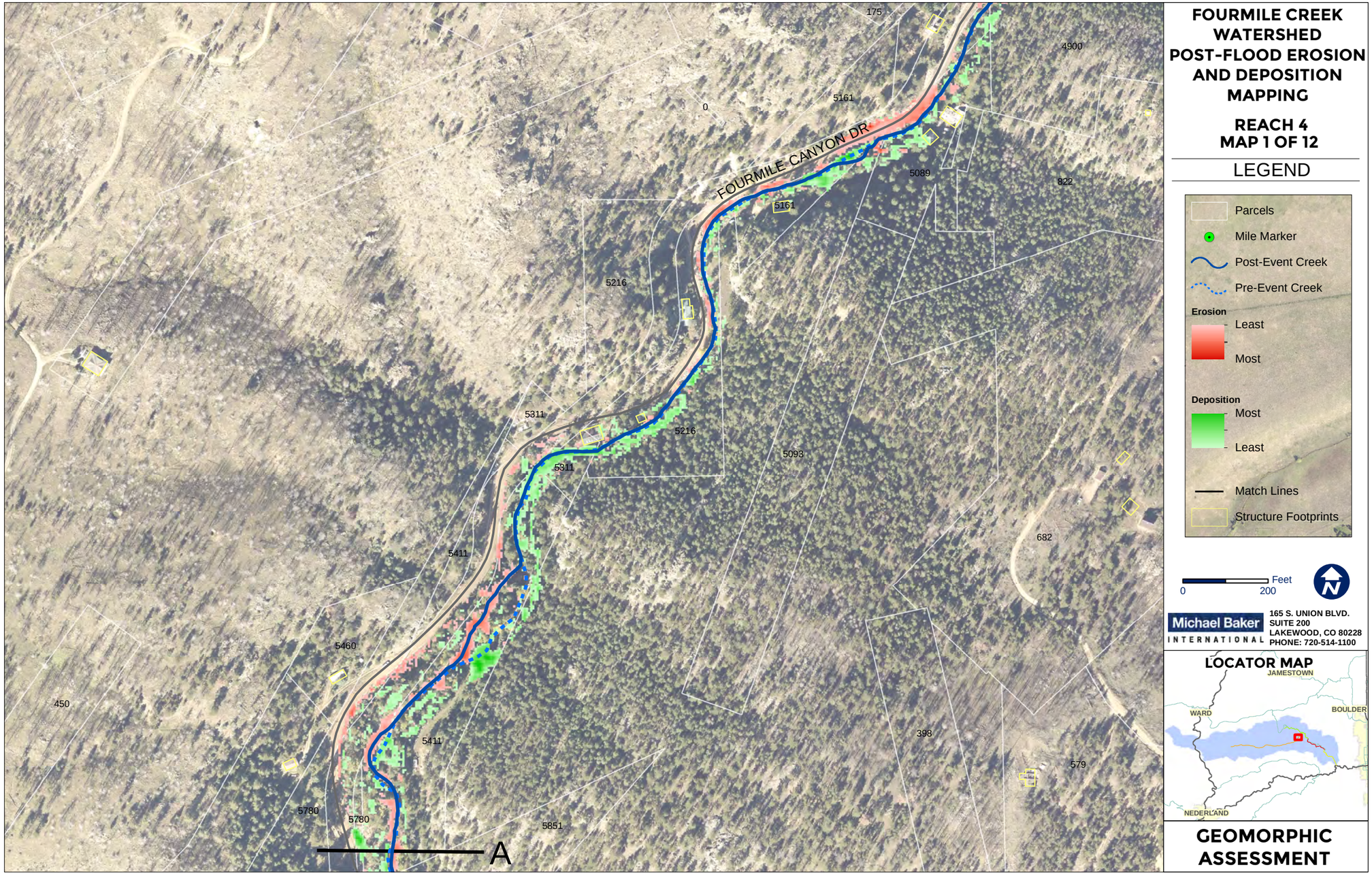
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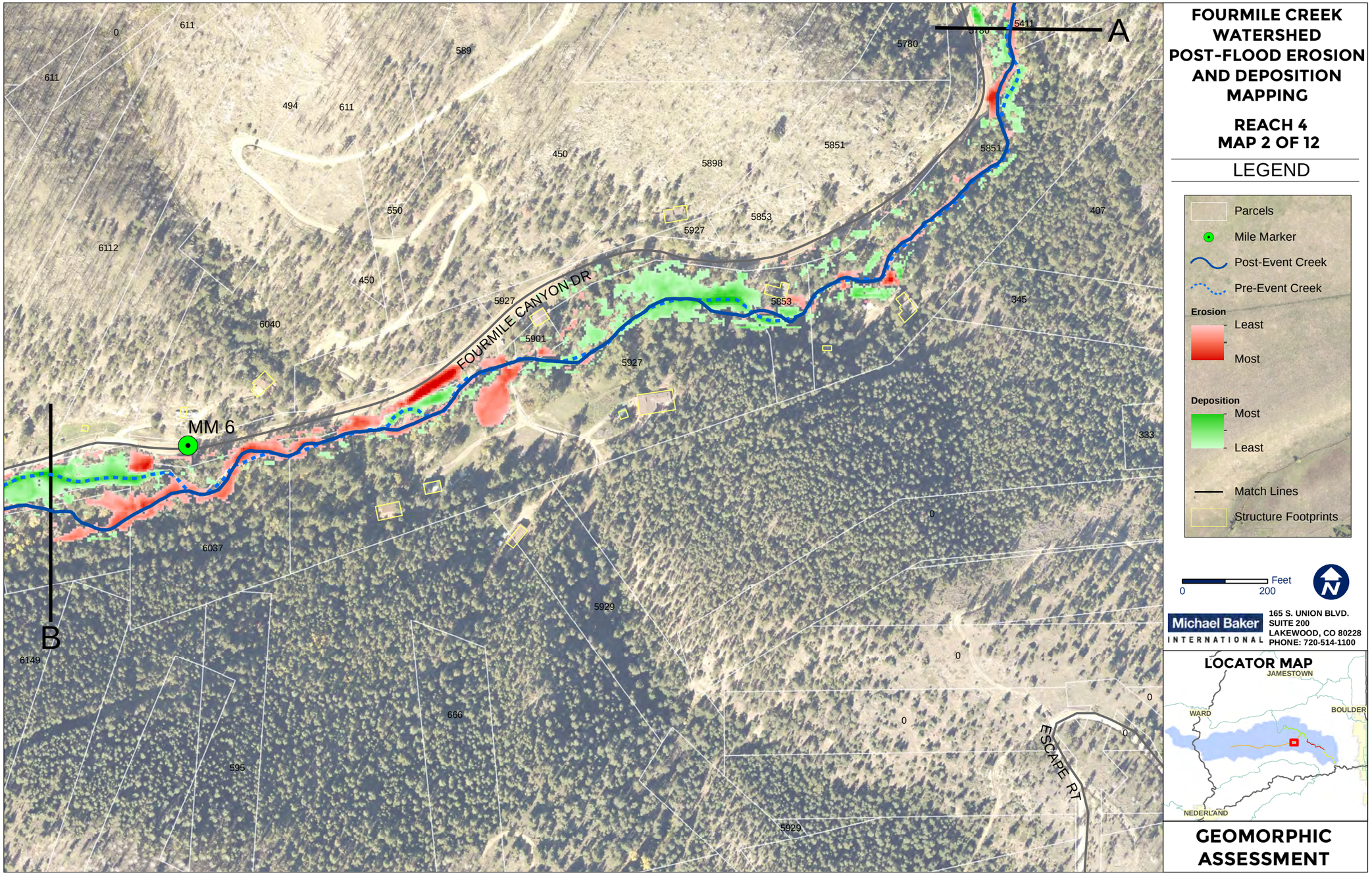
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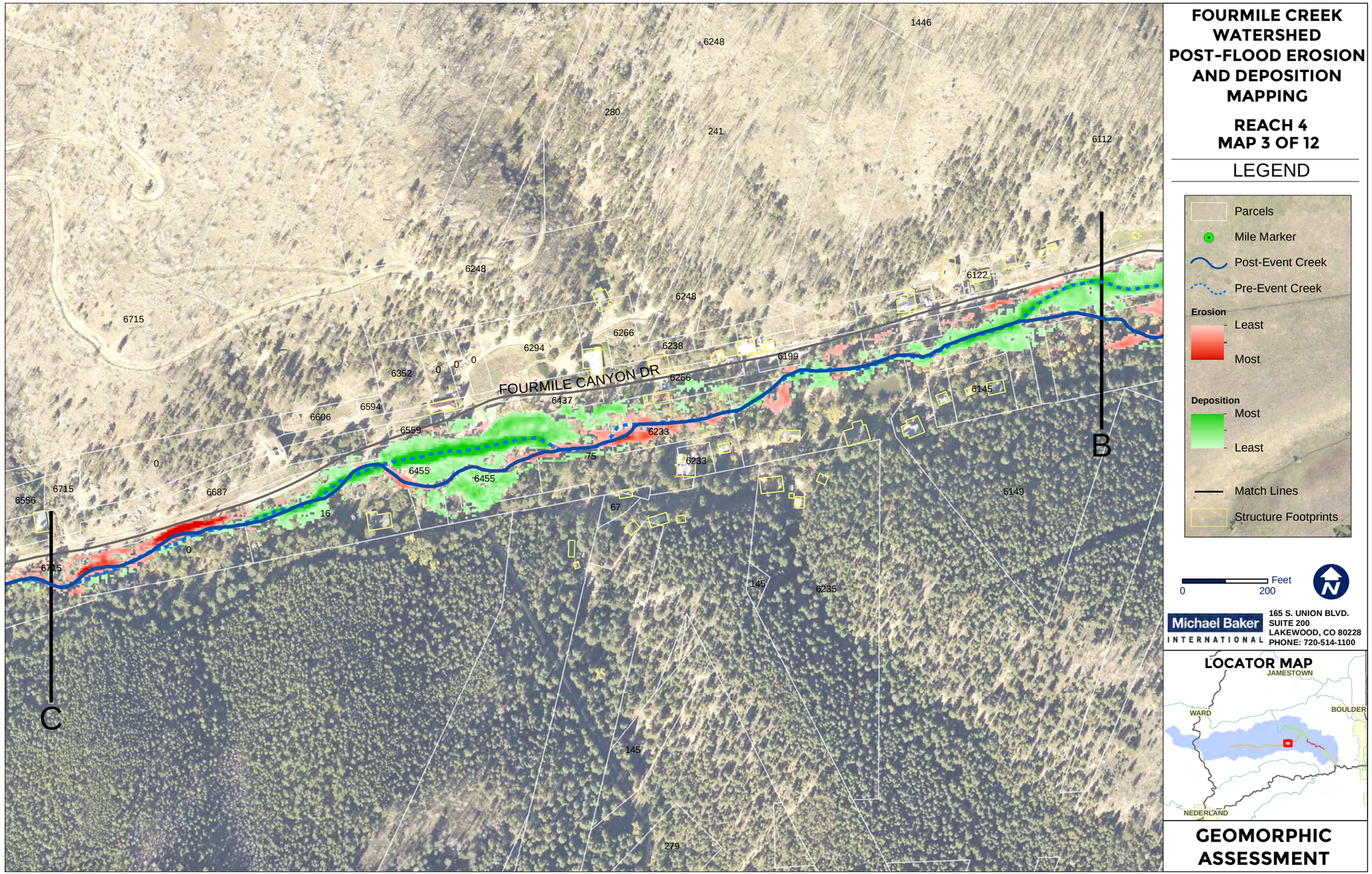
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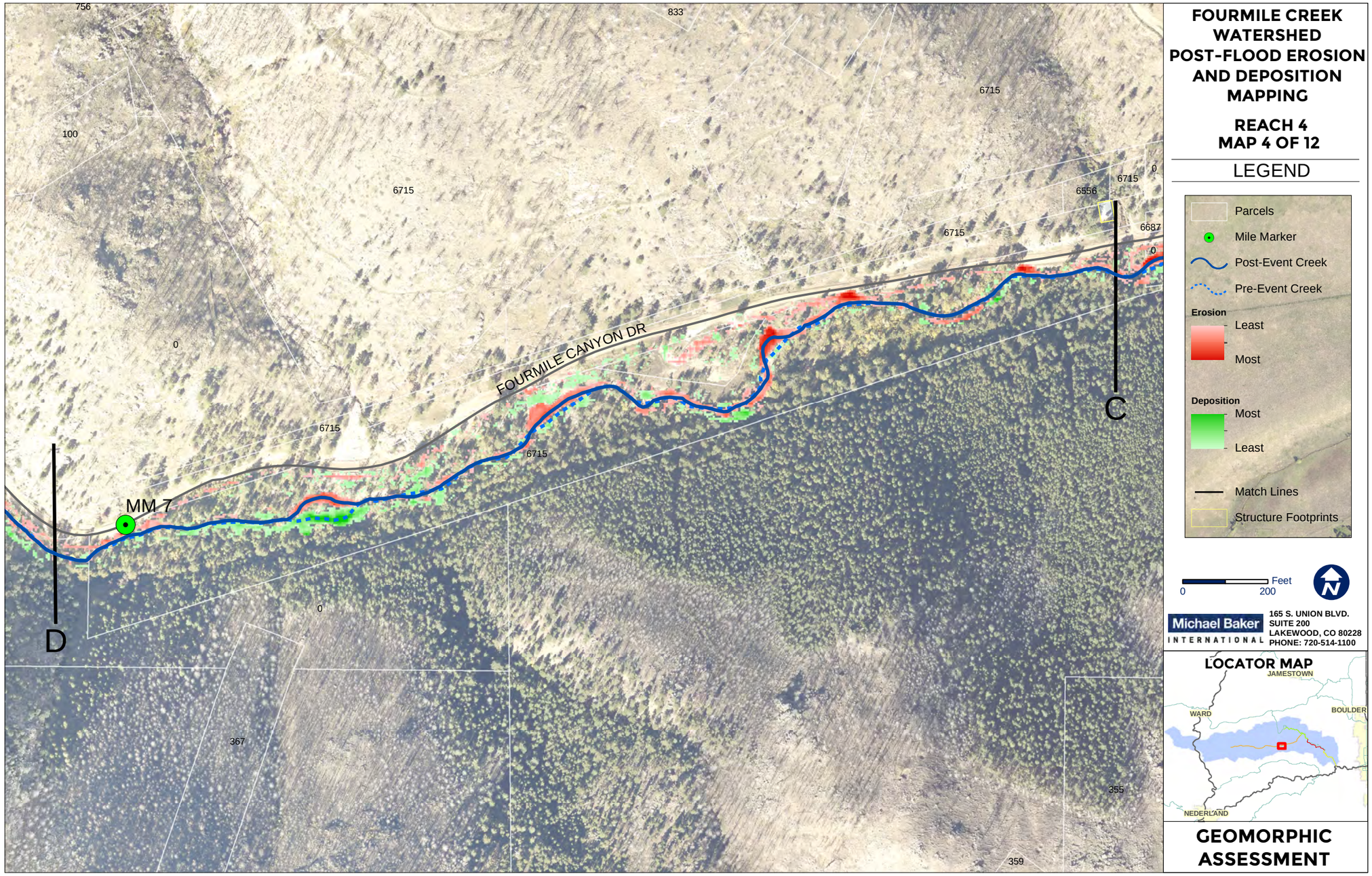
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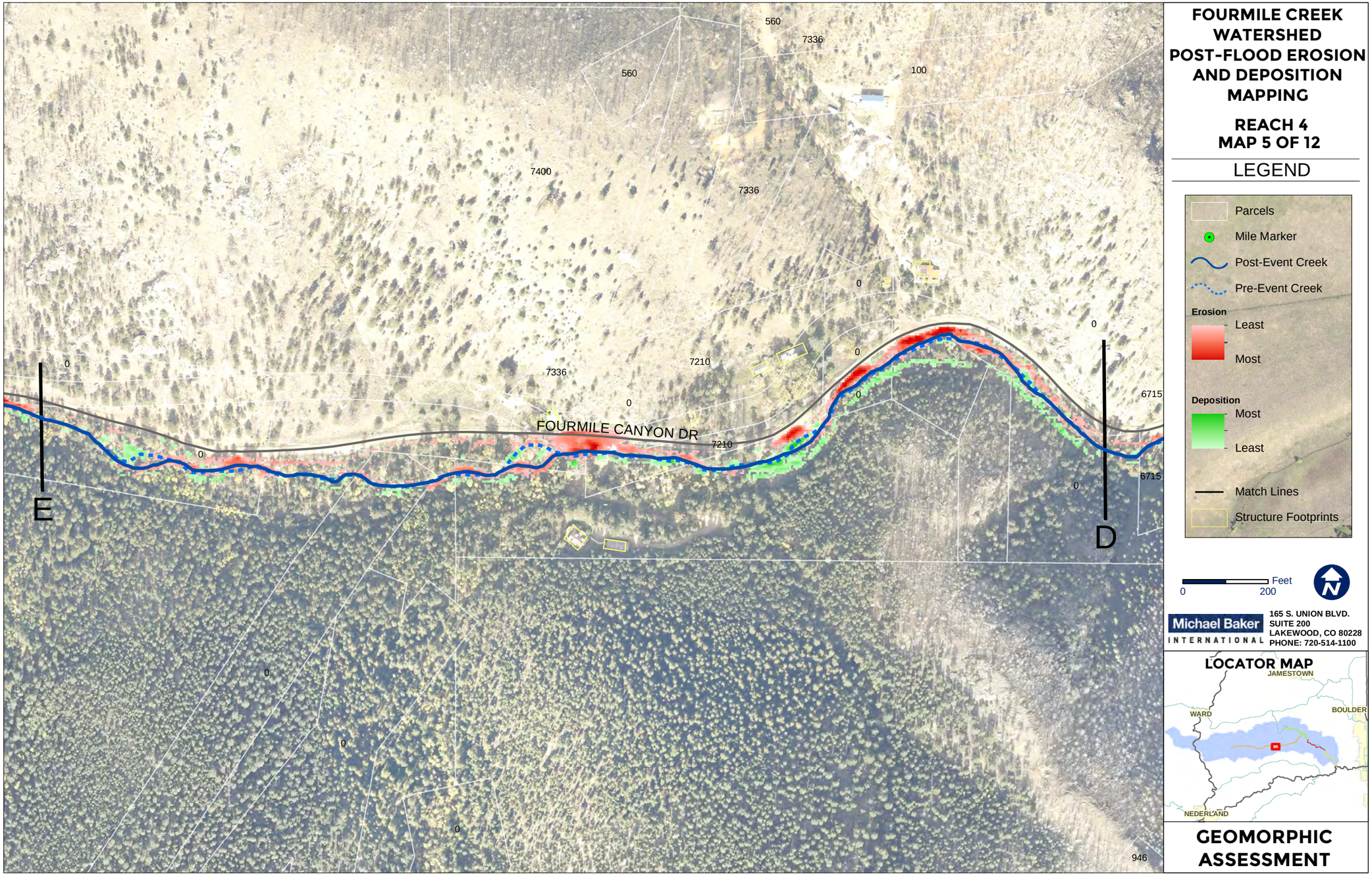
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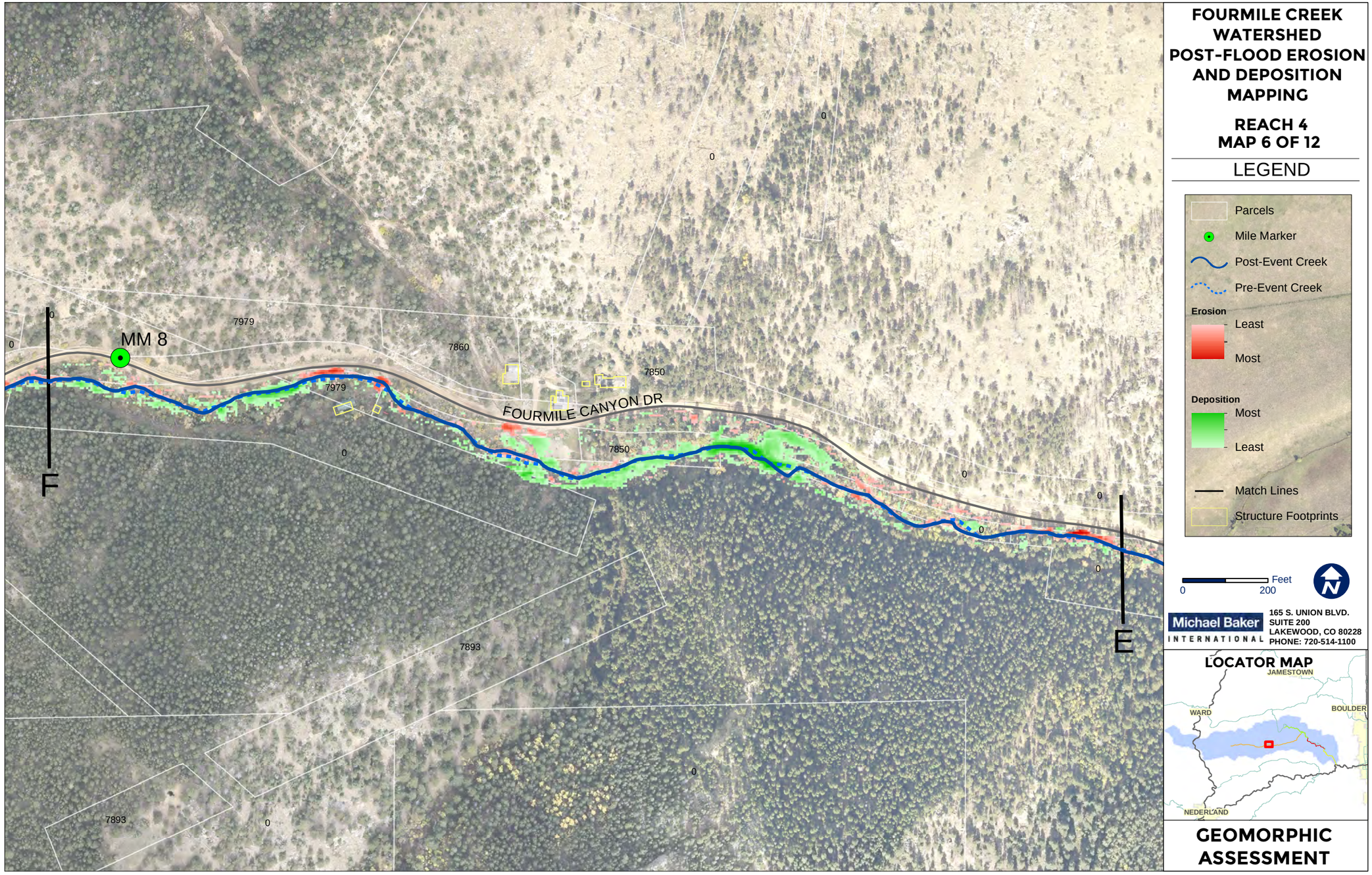
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MAP 6 OF 12
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FOURMILE CREEK WATERSHED POST-FLOOD EROSION AND DEPOSITION MAPPING
REACH 4
MAP 7 OF 12
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Mile Marker
Post-Event Creek
Pre-Event Creek
Erosion
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FOURMILE CREEK WATERSHED POST-FLOOD EROSION AND DEPOSITION MAPPING
REACH 4
MAP 8 OF 12
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Parcels
Mile Marker
Post-Event Creek
Pre-Event Creek
Erosion
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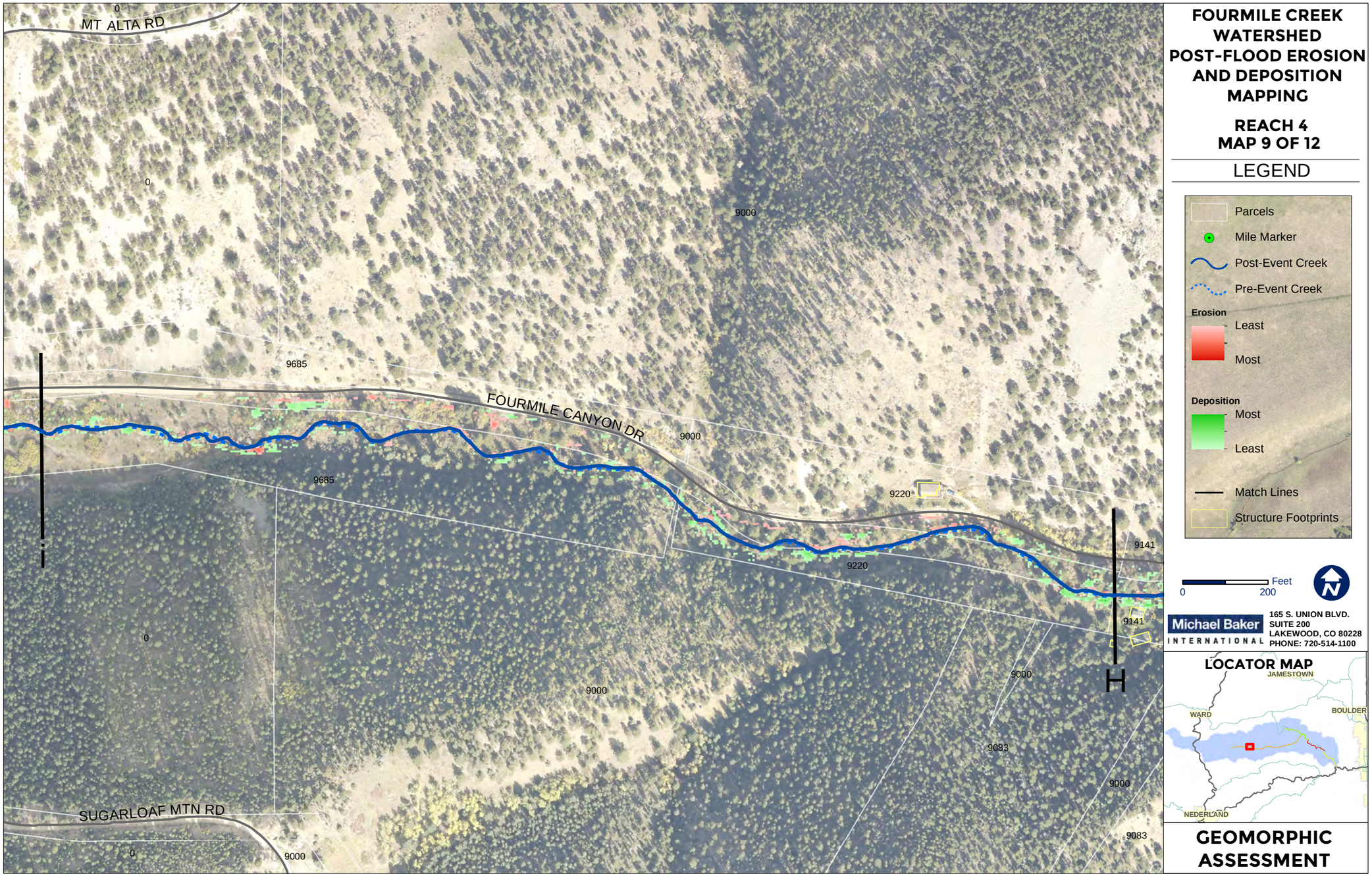
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Post-Event Creek
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GEOMORPHIC ASSESSMENT

FOURMILE CREEK WATERSHED POST-FLOOD EROSION AND DEPOSITION MAPPING
REACH 4
MAP 10 OF 12
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Parcels
Mile Marker
Post-Event Creek
Pre-Event Creek
Erosion
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FOURMILE CREEK WATERSHED POST-FLOOD EROSION AND DEPOSITION MAPPING
REACH 4
MAP 11 OF 12
LEGEND
Parcels
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Post-Event Creek
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FOURMILE CREEK WATERSHED POST-FLOOD EROSION AND DEPOSITION MAPPING
REACH 4
MAP 12 OF 12
LEGEND
Parcels
Mile Marker
Post-Event Creek
Pre-Event Creek
Erosion
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APPENDIX D

HYDRAULIC ANALYSIS RESULTS

HYDRAULIC ANALYSIS SUMMARY

1.1 Introduction

The Baker Team completed a hydraulic analysis for various flooding sources within the Fourmile Creek watershed as part of the Fourmile Creek Watershed Master Plan. After reviewing the existing sources of flood risk information for the watershed, it was determined that an updated flood risk analysis should be performed in order to accurately depict the flood risk in the post-flood (September 2013) environment. This appendix documents the methodology and results associated with the updated post-flood hydraulic analysis.

Scope of Work

The Baker Team performed hydraulic analyses and produced floodplain mapping for various flooding sources in the Fourmile Canyon Watershed in Boulder County, Colorado. The flooding sources studied are presented in Table D.1.

Table D.1 Flooding Sources Studied

Flooding Source	Reach	Stream Miles
Fourmile Creek	From the confluence with Boulder Creek to just upstream of Switzerland Trail (Sunset).	10.9
Gold Run	From the confluence Fourmile Creek to Summerville	1.7
	Total:	**12.6**

The hydrologic design points used to develop these hydraulic analyses were obtained from multiple sources and are discussed in more detail in the following Hydrologic Analysis section.

1.2 Methodology

Data Acquisition

The following existing data sources were used for the compilation of the hydraulics data:

- Fourmile Fire Department – Fourmile Fire Department Creek Crossings – Spring 2011.
- Colorado Department of Transportation – Structure D-15-AG As-built Plans – Fourmile Creek Culvert under Boulder Canyon Dr.
- Pictometry International – Post-Flood Aerial Imagery – Fall 2013.
- Photo Science – 2013 Post-Flood LiDAR data – Fall 2013.
- David Evans and Associates, Inc. – Structure roadway survey data – November 2013
- David Evans and Associates, Inc. – Structure roadway survey data – August 2014

Hydrologic Analysis

An updated hydrologic analysis was not performed as part of the Fourmile Creek Watershed Master Plan. Rather, a review of previous hydrologic studies was performed. These studies include:

Effective FEMA Flood Insurance Study – USACE (1977) - The Effective FEMA Flood Insurance Study on Fourmile Creek is based on study performed in 1977 by the USACE entitled, "Water and Related Land Resources Management Study, Metropolitan Denver and South Platte River and Tributaries, Colorado, Wyoming, and Nebraska, Volume V – Supporting Technical Reports Appendices, Appendix H – Hydrology (USACE, 1977 and Review Report, Boulder Creek." The study estimated discharges for the 10, 4, 2, 1, and 0.2 percent annual chance events along Boulder Creek and Fourmile Creek utilizing rainfall-runoff modeling (EPA's SWMM model for the upper basin). The study did not include any published discharges for Gold Run. The results of this hydrologic analysis are readily available; however, the hydrologic model is not available.

Hydrology Verification Report for Boulder Creek – Anderson Consulting Engineers, Inc (2009) - As part of an updated hydraulic study on Boulder Creek for the City of Boulder, Anderson Consulting was asked to evaluate the 1977 USACE hydrologic model for the Boulder Creek watershed. The effort was performed to determine whether or not a revised hydrologic modeling effort would be justified prior to conducting the hydraulic analysis. Anderson concluded that the 1-percent annual chance discharges produced by the 1977 USACE study are reasonable and appropriate for conducting the current hydraulic analysis for Boulder Creek.

Fourmile Canyon Post-Fire Hydrology – WWE (2011) - Wright Water Engineers, Inc. (WWE) performed a hydrologic analysis of the post-wildfire Fourmile Canyon watershed for the Boulder County Transportation Department. The analysis computed discharges utilizing rainfall-runoff modeling as employed by the USACE HEC-HMS model. The Curve Numbers used in the model represented the extremely high runoff potential in the post-wildfire condition. The modeling included discharge estimates for numerous locations along Fourmile Creek and Gold Run.

Boulder Creek Hydrologic Analysis – CH2M HILL (August 2014) - The Colorado Department of Transportation (CDOT) worked, in partnership with the Colorado Water Conservation Board (CWCB), on development of new hydrologic models in the watersheds affected by the September 2013 floods. This involved creation of new hydrologic models using a rainfall-runoff methodology as employed by the USACE HEC-HMS model. A significant amount of data was captured during the flood event and this data was used in calibrating the new models. In addition, the newly collected topographic (LiDAR) data and new rainfall data from the recently released NOAA Atlas 14 was used.

CH2M Hill developed a hydrologic model that was calibrated to observed September 2013 peak discharges by adjusting model input values that represent land cover and soil information. The calibrated model was then used to create a predictive model by modifying the precipitation, along with some other parameters, to estimate the 10-, 4-, 2-, 1- and 0.2 percent annual chance event at various points in the watershed.

The analysis performed by CH2M Hill is well documented. The report, backup data, and models are all available from the State of Colorado.

Discharges used in the hydraulic model

Our review of previous studies in the watershed indicated that the effective FEMA study on Fourmile Creek based on the 1977 USACE study may be conservative. In addition the study does not recommend any discharges for Gold Run. The recommended discharges from the CDOT/CWCB study are consistent with the WWE post-wildfire study (2011) for locations upstream of the burn area and the modeling is calibrated to the 2013 event. The discharges from the CDOT/CWCB study appear to represent the flood risk in the Fourmile Creek watershed better than the 1977 USACE study. However, until the regulatory discharges, based on the 1977 USACE study, are changed through an updated FEMA Flood Insurance Study, they are still the governing discharges from a floodplain management perspective. For that reason, the Baker Team included both the effective regulatory discharges (FEMA) and the CDOT/CWCB discharges in the hydraulic model.

The Baker Team obtained the regulatory discharges from the effective hydraulic model output contained in the report entitled "Floodplain Information Report - Upper Boulder Creek and Fourmile Creek," performed by Gingery Associates, Inc., dated 1981 and entered the discharges in to the hydraulic model at the appropriate locations. Additionally, the Team obtained discharges from the HEC-HMS model developed by CH2M Hill and entered them into the hydraulic model at the appropriate locations. Tables D.2 and D.3 summarize the discharges included in the hydraulic model at key locations.

Table D.2 Summary of Effective FEMA Discharges for Various Locations (USACE 1977)					
Location	Drainage Area (Square Miles)	Effective FEMA Flood Insurance Study			
		10% annual chance	2% annual chance	1% annual change	0.2% annual chance
Fourmile Creek @ mouth	24	1,420 cfs	4,440 cfs	6,230 cfs	11,640 cfs
Fourmile Creek Downstream of Emerson Gulch	16	1,020 cfs	3,460 cfs	4,870 cfs	8,850 cfs
Fourmile Creek Upstream of Long Gulch	13	790 cfs	2,670 cfs	3,750 cfs	7,060 cfs
Gold Run @ Salina Junction	2.7	-	-	-	-

Table D.3 Summary of Discharges for Various Locations (2014 CDOT/CWCB Study)					
Location	Drainage Area (Square Miles)	Recommended Discharges (2014 CDOT/CWCB Study)			
		10% annual chance	2% annual chance	1% annual change	0.2% annual chance
Fourmile Creek @ mouth	24	923 cfs	2,442 cfs	3,426 cfs	6,377 cfs
Fourmile Creek Upstream of Gold Run	16	455 cfs	1,372 cfs	1,969 cfs	3,335 cfs
Fourmile Creek Upstream of Long Gulch	13	340 cfs	1,048 cfs	1,509 cfs	2,975 cfs
Gold Run @ Salina Junction	2.7	117 cfs	296 cfs	403 cfs	718 cfs

1.3 Topographic Data and Field Survey

Post-flood LiDAR data was collected by Photo Science under contract with the USGS. The LiDAR data was collected for the approximately 4,616 square miles of flooded area in Colorado, including the entire Fourmile Creek Watershed. The LiDAR specifications were based on the U.S. Geological Survey National Geospatial Program Base LIDAR Specification, Version 1. The data was developed based on a horizontal projection/datum of UTM Zone 13 North, NAD83, meters and vertical datum of NAVD1988 (GEOID12A), meters. LiDAR data was delivered in RAW flight line swath format, Hydro Flattened Raster DEM Files, Intensity Images, and Hydro-Flattening Breaklines. The LiDAR was collected in Fall 2013 while no snow was on the ground and rivers were at or below normal levels. In order to post process the LiDAR data to meet task order specifications, Photo Science established a total of 229 control points that were used to calibrate the LIDAR to known ground locations established throughout the project area.

The post-flood LiDAR data was used as the basis for development of the hydraulic model and was supplemented with field survey in two locations:

- A field survey of the existing road, right-of-way, and culverts for Salina Junction was performed by David Evans and Associates, Inc. in November of 2013. The survey was based on a horizontal datum of the North America Datum of 1983-2011 (NAD 83 (2011)) U.S. Survey Feet and a vertical datum of the North America Vertical Datum of 1988 (NAVD 88).
- A field survey of the existing road, right-of-way, and temporary culverts and channel for Logan Mill Road was performed by David Evans and Associates, Inc. in August of 2014. The survey was based on a horizontal datum of the North America Datum of 1983-2011 (NAD 83 (2011)) U.S. Survey Feet and a vertical datum of the North America Vertical Datum of 1988 (NAVD 88).

The hydraulic model was updated in both these locations to reflect the field survey as opposed to the post-flood LiDAR data. Any work, by property owners or other agencies (ex. NRCS), that was completed after the collection of the LiDAR data or field survey, was not be reflected in the hydraulic model.

1.4 Hydraulic Analysis

A hydraulic analysis was performed on two streams (Fourmile Creek and Gold Run) within the Fourmile Creek Watershed. All reaches are located in the Unincorporated Areas of Boulder County, Colorado. The U.S. Army Corps of Engineers (USACE) HEC-RAS program, Version 4.1, was used to prepare the hydraulic modeling. Topographic data used to define the stream geometry consisted of detailed survey data obtained by David Evans and Associates and LiDAR data as described in the section above.

Geometric data for the studied reaches were adapted from the topographic information using the USACE HEC-GeoRAS program and input into HEC-RAS for model development.

As part of the data collection for the Master Plan, the Baker Team collected information on Pre-Flood vs Post-Flood creek crossings, GIS layers from Boulder County on the locations of private and public structures, and an inventory of pre-flood creek crossings from the Fourmile Fire Department. Baker combined these data sources, field confirmed all structures, and created a GIS layer summarizing the location of all creek crossings. The Team also collected survey on the Salina Junction culvert and the Logan Mill Road temporary crossing, and obtained as-built plans from CDOT on the Hwy 119 (Boulder Canyon Dr.) crossing.

Cross sections were manually placed upstream and downstream of all identified structures. Additional cross sections were placed in between structures as required to develop a reasonable hydraulic model. Cross section locations from the effective FEMA study were used as a guide for placing intermediate cross sections. The Salina Junction, Logan Mill Rd, and Hwy 119 crossings were inserted into the model based on the survey and as-built data. Additional crossings were added to the model as detailed by Table 4.2.

The Manning's 'n' roughness value represents the roughness or friction that is applied to the flow by the channel. Manning's 'n' roughness values were evaluated using aerial imagery and compared to previous studies. The roughness values were horizontally varied at each cross section with values ranging from 0.015 (roadway areas) to 0.08 (heavy vegetation). The field work performed by the Baker Team provided additional verification of site conditions and confirmation that the chosen roughness values were reasonable.

Expansion and contraction coefficients are used to evaluate the amount of energy loss that occurs because of a flow expansion or contraction. The losses due to expansion and contraction of flow at short abrupt transitions are larger than losses from gradual transitions. To account for this, expansion and contraction coefficients were set to 0.5 and 0.3 (respectively) at all crossings. All other locations were set to 0.3 and 0.1.

The model was run in the subcritical flow regime so only downstream boundary conditions were required. As a result of the steepness of both creeks, there may be locations where supercritical flow exists; however, based on FEMA's Guidelines and Specifications, critical flow depth was computed for these locations. The downstream boundary condition for Fourmile Creek was established using the Normal Depth approach with an energy grade line slope of 0.03, while Gold Run used a slope of 0.08. These slopes were calculated via inspection of the LiDAR data.

A Floodway analysis was not performed for Fourmile Creek or Gold Run.

The hydraulic analysis for Fourmile Creek and Gold Run assumed gradually varied flow, fixed bed, and unobstructed flow. Flood risk can vary in areas where these assumptions are violated.

Table D.4 presents the results of the hydraulic model for Fourmile Creek and Gold Run. Peak discharges and computed water surface elevations for the 10- (10 yr), 2- (50yr) and 1-percent-annual-chance (100-yr) events are provided at each cross section in the hydraulic model. The cross sections are numbered in feet from the confluence with Boulder Creek, for Fourmile Creek, and from the confluence with Fourmile Creek, for Gold Run. The cross section locations are also shown on the maps included in this appendix.

1.5 Mapping Information

The floodplain mapping was performed using HEC-GeoRAS by intersecting the 3-dimensional LiDAR surface with a triangulated irregular network (TIN) representing the water surface profile of the hydraulic cross sections for the 1-percent-annual-chance event. Floodplain mapping was performed for the 1-percent-annual-chance event based on the regulatory discharges and based on the CWCB/CDOT discharges. The resulting floodplains for the studied streams are displayed on the hydraulic analysis results maps included in this appendix.

Along with the two floodplain extents from the post-flood hydraulic analysis, the work maps also display the effective FEMA 1-percent-annual-chance floodplain, stream centerlines, hydraulic cross sections, bridge/culvert locations, and structures at risk. The structures at risk are defined as a structure that is intersected by any of the three floodplains included on the maps.

Table D.1 Floodplain Data Table – Fourmile Creek and Gold Run

Reference Location	River Station	Cross Section	Thalweg Elevation (ft.)	Regulatory Discharges						CWCB/CDOT Discharges					
				Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)			Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)		
				10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr
Fourmile Creek	+21	21	5717.4	1420	4440	6230	5722.8	5724.5	5725.3	923	2442	3426	5722.3	5723.5	5724.0
Fourmile Creek	1+00	100		Culvert											
Fourmile Creek	1+84	184	5721.5	1410	4410	6180	5727.6	5740.4	5744.2	923	2442	3426	5726.4	5732.2	5736.2
Fourmile Creek	3+49	349	5726.3	1410	4410	6180	5732.9	5740.5	5744.3	923	2442	3426	5731.7	5734.2	5736.6
Fourmile Creek	5+21	521	5734.0	1410	4410	6180	5736.9	5740.9	5744.5	923	2442	3426	5736.3	5738.2	5738.5
Fourmile Creek	6+92	692	5736.9	1410	4410	6180	5741.6	5743.5	5744.9	923	2442	3426	5741.1	5742.3	5743.3
Fourmile Creek	8+08	808	5738.9	1410	4410	6180	5744.4	5748.5	5749.7	923	2442	3426	5743.3	5746.6	5747.7
Fourmile Creek	8+20	820		Bridge											
Fourmile Creek	8+36	836	5741.3	1410	4410	6180	5747.4	5749.9	5751.0	923	2442	3426	5746.8	5748.3	5749.1
Fourmile Creek	9+03	903	5742.3	1410	4410	6180	5748.5	5751.1	5752.2	923	2442	3426	5747.8	5749.6	5750.4
Fourmile Creek	11+13	1113	5745.8	1410	4410	6180	5751.6	5755.7	5757.0	923	2442	3426	5750.6	5753.0	5754.1
Fourmile Creek	12+87	1287	5749.1	1410	4410	6180	5756.3	5759.5	5760.6	923	2442	3426	5755.1	5757.9	5759.1
Fourmile Creek	13+84	1384	5750.6	1410	4410	6180	5757.7	5761.5	5763.4	923	2442	3426	5756.4	5759.5	5760.7
Fourmile Creek	14+00	1400		Bridge											
Fourmile Creek	14+10	1410	5750.7	1410	4410	6180	5759.6	5763.4	5763.8	923	2442	3426	5756.9	5762.0	5762.6
Fourmile Creek	14+71	1471	5753.0	1410	4410	6180	5760.3	5763.7	5764.4	923	2442	3426	5758.3	5762.3	5763.0
Fourmile Creek	15+98	1598	5757.4	1410	4410	6180	5762.7	5766.2	5767.4	923	2442	3426	5761.8	5764.2	5765.4
Fourmile Creek	16+15	1615		Bridge											
Fourmile Creek	16+31	1631	5756.9	1410	4410	6180	5764.6	5768.4	5769.8	923	2442	3426	5763.6	5766.2	5767.4
Fourmile Creek	16+98	1698	5759.5	1410	4410	6180	5765.4	5768.8	5770.4	923	2442	3426	5764.4	5766.8	5767.9
Fourmile Creek	17+32	1732	5760.3	1410	4410	6180	5766.3	5770.2	5772.4	923	2442	3426	5765.2	5767.8	5769.1
Fourmile Creek	17+50	1750		Bridge											
Fourmile Creek	17+61	1761	5760.2	1410	4410	6180	5769.1	5773.5	5775.1	923	2442	3426	5766.3	5768.9	5773.0
Fourmile Creek	18+78	1878	5763.5	1410	4410	6180	5770.7	5774.9	5776.3	923	2442	3426	5769.0	5773.3	5774.2
Fourmile Creek	19+62	1962	5765.5	1410	4410	6180	5772.2	5776.7	5777.8	923	2442	3426	5771.1	5774.3	5775.9
Fourmile Creek	20+00	2000		Bridge											
Fourmile Creek	20+13	2013	5767.2	1410	4410	6180	5775.3	5779.2	5780.6	923	2442	3426	5774.7	5777.7	5778.3
Fourmile Creek	20+68	2068	5768.1	1410	4410	6180	5776.5	5780.1	5781.4	923	2442	3426	5775.3	5778.4	5779.3
Fourmile Creek	22+07	2207	5772.1	1410	4410	6180	5777.9	5780.8	5782.2	923	2442	3426	5776.9	5779.0	5779.9
Fourmile Creek	22+43	2243	5772.9	1410	4410	6180	5779.2	5782.3	5783.8	923	2442	3426	5778.6	5780.4	5781.4
Fourmile Creek	22+50	2250		Bridge											
Fourmile Creek	22+70	2270	5774.1	1410	4410	6180	5781.2	5784.1	5785.4	923	2442	3426	5780.4	5782.1	5783.2
Fourmile Creek	23+68	2368	5775.0	1410	4410	6180	5782.1	5784.9	5786.6	923	2442	3426	5781.2	5783.3	5784.2
Fourmile Creek	25+16	2516	5781.1	1410	4410	6180	5785.3	5789.8	5791.5	923	2442	3426	5784.4	5787.0	5788.4

Table D.1 Floodplain Data Table – Fourmile Creek and Gold Run

Reference Location	River Station	Cross Section	Thalweg Elevation (ft.)	Regulatory Discharges						CWCB/CDOT Discharges					
				Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)			Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)		
				10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr
Fourmile Creek	27+43	2743	5785.3	1410	4410	6180	5792.1	5793.7	5794.7	923	2442	3426	5791.6	5792.6	5793.1
Fourmile Creek	29+76	2976	5792.8	1410	4410	6180	5797.4	5799.5	5800.1	923	2442	3426	5796.8	5798.4	5799.0
Fourmile Creek	31+47	3147	5798.1	1410	4410	6180	5802.9	5804.6	5805.4	923	2442	3426	5802.5	5803.6	5804.1
Fourmile Creek	31+60	3160		Bridge											
Fourmile Creek	31+80	3180	5800.5	1410	4410	6180	5805.0	5807.5	5808.6	923	2442	3426	5804.7	5806.0	5806.8
Fourmile Creek	33+67	3367	5803.9	1410	4410	6180	5808.9	5810.9	5812.6	923	2442	3426	5808.3	5809.7	5810.3
Fourmile Creek	35+16	3516	5806.0	1410	4410	6180	5812.4	5815.9	5816.6	923	2442	3426	5811.6	5814.0	5815.4
Fourmile Creek	35+35	3535	5806.0	1410	4410	6180	5813.2	5816.4	5817.2	923	2442	3426	5812.2	5814.6	5815.9
Fourmile Creek	35+45	3545		Bridge											
Fourmile Creek	35+62	3562	5806.7	1410	4410	6180	5814.1	5818.0	5819.1	923	2442	3426	5814.1	5817.0	5817.3
Fourmile Creek	36+03	3603	5807.7	1410	4410	6180	5815.6	5819.0	5820.4	923	2442	3426	5814.7	5817.5	5818.2
Fourmile Creek	36+62	3662	5810.5	1410	4410	6180	5815.7	5819.1	5820.5	923	2442	3426	5814.8	5817.6	5818.3
Fourmile Creek	38+10	3810	5813.2	1410	4410	6180	5818.4	5821.8	5823.9	923	2442	3426	5817.8	5819.7	5821.1
Fourmile Creek	38+36	3836	5814.0	1410	4410	6180	5819.3	5823.7	5825.3	923	2442	3426	5818.3	5821.2	5822.8
Fourmile Creek	38+50	3850		Bridge											
Fourmile Creek	38+65	3865	5814.8	1410	4410	6180	5823.2	5825.9	5827.6	923	2442	3426	5822.1	5825.6	5826.3
Fourmile Creek	39+67	3967	5817.9	1370	4310	6030	5824.6	5828.3	5828.9	923	2442	3426	5823.4	5826.4	5827.2
Fourmile Creek	41+30	4130	5821.5	1370	4310	6030	5827.1	5831.1	5832.9	923	2442	3426	5826.2	5828.8	5830.1
Fourmile Creek	42+40	4240	5825.0	1370	4310	6030	5831.4	5835.6	5837.4	923	2442	3426	5830.5	5833.2	5834.6
Fourmile Creek	42+50	4250		Bridge											
Fourmile Creek	42+69	4269	5826.2	1370	4310	6030	5836.2	5841.7	5842.9	923	2442	3426	5834.0	5839.9	5840.9
Fourmile Creek	42+97	4297	5827.3	1370	4310	6030	5836.3	5841.7	5843.0	923	2442	3426	5834.1	5839.9	5840.9
Fourmile Creek	44+17	4417	5831.1	1370	4310	6030	5837.9	5841.6	5843.0	923	2442	3426	5836.5	5839.8	5840.8
Fourmile Creek	44+25	4425		Bridge											
Fourmile Creek	44+39	4439	5831.7	1370	4310	6030	5841.4	5844.2	5845.3	923	2442	3426	5839.5	5842.6	5843.4
Fourmile Creek	46+13	4613	5837.6	1370	4310	6030	5842.0	5846.4	5848.6	923	2442	3426	5841.1	5843.7	5845.1
Fourmile Creek	47+36	4736	5841.0	1370	4310	6030	5846.8	5851.4	5852.3	923	2442	3426	5845.9	5848.7	5850.1
Fourmile Creek	47+50	4750		Bridge											
Fourmile Creek	47+66	4766	5842.0	1370	4310	6030	5850.3	5854.1	5854.7	923	2442	3426	5848.6	5853.1	5854.0
Fourmile Creek	48+63	4863	5845.5	1370	4310	6030	5852.0	5855.5	5857.6	923	2442	3426	5850.8	5854.1	5854.6
Fourmile Creek	48+95	4895	5847.6	1370	4310	6030	5854.4	5858.0	5859.8	923	2442	3426	5852.5	5855.2	5856.7
Fourmile Creek	49+00	4900		Bridge											
Fourmile Creek	49+31	4931	5849.8	1370	4310	6030	5857.2	5864.9	5867.3	923	2442	3426	5856.8	5861.8	5863.5
Fourmile Creek	49+50	4950		Bridge											

Table D.1 Floodplain Data Table – Fourmile Creek and Gold Run

Reference Location	River Station	Cross Section	Thalweg Elevation (ft.)	Regulatory Discharges						CWCB/CDOT Discharges					
				Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)			Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)		
				10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr
Fourmile Creek	49+64	4964	5850.1	1370	4310	6030	5858.0	5865.1	5867.4	923	2442	3426	5857.4	5861.9	5863.6
Fourmile Creek	51+30	5130	5855.8	1370	4310	6030	5862.4	5866.4	5868.5	923	2442	3426	5861.1	5863.3	5865.1
Fourmile Creek	52+70	5270	5862.4	1370	4310	6030	5867.7	5870.3	5871.7	923	2442	3426	5867.2	5868.6	5869.5
Fourmile Creek	54+28	5428	5867.0	1370	4310	6030	5872.1	5874.9	5876.0	923	2442	3426	5871.5	5873.7	5874.4
Fourmile Creek	55+26	5526	5871.0	1370	4310	6030	5875.8	5878.5	5880.0	923	2442	3426	5874.9	5876.5	5877.5
Fourmile Creek	55+50	5550		Bridge											
Fourmile Creek	55+61	5561	5871.9	1370	4310	6030	5878.2	5883.8	5885.7	923	2442	3426	5878.2	5879.2	5879.5
Fourmile Creek	56+81	5681	5873.9	1370	4310	6030	5879.3	5883.5	5885.5	923	2442	3426	5878.5	5880.1	5881.2
Fourmile Creek	57+00	5700		Bridge											
Fourmile Creek	57+13	5713	5875.0	1370	4310	6030	5881.9	5884.5	5885.3	923	2442	3426	5881.5	5883.1	5883.8
Fourmile Creek	58+36	5836	5878.9	1370	4310	6030	5883.2	5886.1	5887.6	923	2442	3426	5882.5	5884.4	5885.4
Fourmile Creek	59+65	5965	5880.5	1370	4310	6030	5887.2	5889.0	5889.8	923	2442	3426	5886.6	5887.9	5888.5
Fourmile Creek	59+75	5975		Bridge											
Fourmile Creek	59+87	5987	5882.0	1370	4310	6030	5888.6	5891.1	5891.9	923	2442	3426	5887.5	5889.9	5890.5
Fourmile Creek	61+01	6101	5887.7	1370	4310	6030	5891.7	5894.1	5895.4	923	2442	3426	5891.2	5892.3	5893.3
Fourmile Creek	62+43	6243	5891.0	1370	4310	6030	5896.6	5899.3	5901.3	923	2442	3426	5895.9	5897.3	5898.1
Fourmile Creek	63+37	6337	5893.0	1370	4310	6030	5898.7	5900.9	5903.2	923	2442	3426	5898.0	5899.9	5900.8
Fourmile Creek	63+69	6369	5894.2	1370	4310	6030	5900.1	5903.2	5904.5	923	2442	3426	5899.7	5901.2	5902.3
Fourmile Creek	63+80	6380		Bridge											
Fourmile Creek	63+94	6394	5895.2	1370	4310	6030	5901.3	5908.1	5910.0	923	2442	3426	5900.8	5905.4	5906.9
Fourmile Creek	64+32	6432	5895.7	1370	4310	6030	5902.1	5908.5	5910.6	923	2442	3426	5901.3	5905.7	5907.2
Fourmile Creek	65+54	6554	5900.7	1370	4310	6030	5905.3	5909.4	5911.0	923	2442	3426	5904.4	5907.5	5908.6
Fourmile Creek	66+76	6676	5903.0	1370	4310	6030	5909.3	5912.7	5913.6	923	2442	3426	5908.3	5910.9	5911.9
Fourmile Creek	69+18	6918	5910.4	1370	4310	6030	5915.3	5918.4	5920.1	923	2442	3426	5914.5	5916.5	5917.6
Fourmile Creek	71+10	7110	5919.6	1370	4310	6030	5924.1	5927.8	5928.5	923	2442	3426	5923.5	5925.4	5926.4
Fourmile Creek	71+96	7196	5922.7	1370	4310	6030	5928.5	5932.0	5933.0	923	2442	3426	5927.4	5930.9	5931.5
Fourmile Creek	73+46	7346	5926.6	1370	4310	6030	5932.6	5935.6	5936.8	923	2442	3426	5931.6	5933.8	5934.8
Fourmile Creek	74+99	7499	5932.5	1370	4310	6030	5937.5	5941.9	5942.6	923	2442	3426	5936.8	5939.0	5940.1
Fourmile Creek	76+99	7699	5938.7	1370	4310	6030	5945.6	5951.2	5951.8	923	2442	3426	5944.6	5947.6	5950.0
Fourmile Creek	78+07	7807	5942.5	1370	4310	6030	5949.6	5953.1	5955.5	923	2442	3426	5948.3	5952.0	5952.7
Fourmile Creek	78+91	7891	5948.0	1370	4310	6030	5952.0	5957.1	5958.1	923	2442	3426	5951.2	5954.2	5955.7
Fourmile Creek	79+73	7973	5952.2	1370	4310	6030	5955.9	5958.9	5959.7	923	2442	3426	5955.3	5957.2	5958.2
Fourmile Creek	81+07	8107	5956.3	1370	4310	6030	5961.7	5965.0	5966.5	923	2442	3426	5960.9	5963.5	5964.2
Fourmile Creek	82+66	8266	5961.5	1370	4310	6030	5967.4	5970.7	5973.0	923	2442	3426	5966.4	5969.5	5970.0

Table D.1 Floodplain Data Table – Fourmile Creek and Gold Run

Reference Location	River Station	Cross Section	Thalweg Elevation (ft.)	Regulatory Discharges						CWCB/CDOT Discharges					
				Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)			Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)		
				10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr
Fourmile Creek	84+60	8460	5969.7	1370	4310	6030	5975.6	5979.8	5982.4	923	2442	3426	5974.5	5977.2	5977.6
Fourmile Creek	86+43	8643	5978.8	1370	4310	6030	5982.8	5986.0	5987.3	923	2442	3426	5982.1	5984.1	5985.1
Fourmile Creek	88+25	8825	5982.7	1370	4310	6030	5988.1	5991.5	5993.2	923	2442	3426	5987.2	5989.5	5990.6
Fourmile Creek	89+96	8996	5986.5	1370	4310	6030	5991.4	5994.9	5996.6	923	2442	3426	5991.0	5992.5	5993.8
Fourmile Creek	91+32	9132	5991.6	1370	4310	6030	5996.0	5999.3	6000.7	923	2442	3426	5995.3	5997.7	5998.6
Fourmile Creek	92+70	9270	5994.2	1370	4310	6030	5998.6	6001.9	6003.3	923	2442	3426	5998.1	6000.0	6001.1
Fourmile Creek	94+40	9440	5997.2	1370	4310	6030	6003.2	6005.0	6005.8	923	2442	3426	6002.3	6004.2	6004.7
Fourmile Creek	94+82	9482	5997.5	1370	4310	6030	6004.4	6006.4	6007.5	923	2442	3426	6003.7	6004.9	6005.9
Fourmile Creek	95+00	9500		Bridge											
Fourmile Creek	95+05	9505	5998.1	1370	4310	6030	6006.1	6007.4	6008.6	923	2442	3426	6005.4	6007.2	6006.6
Fourmile Creek	96+59	9659	6003.6	1230	4030	5680	6007.1	6009.7	6010.8	923	2442	3426	6006.4	6008.3	6009.1
Fourmile Creek	98+43	9843	6006.5	1230	4030	5680	6011.1	6013.8	6014.8	923	2442	3426	6010.7	6012.6	6013.4
Fourmile Creek	99+77	9977	6008.9	1230	4030	5680	6015.4	6019.7	6020.7	923	2442	3426	6014.8	6017.0	6019.2
Fourmile Creek	101+58	10158	6012.6	1230	4030	5680	6019.6	6023.3	6024.6	923	2442	3426	6018.7	6022.0	6022.8
Fourmile Creek	104+07	10407	6020.4	1230	4030	5680	6025.4	6028.2	6028.8	923	2442	3426	6024.7	6026.7	6027.8
Fourmile Creek	106+40	10640	6025.4	1230	4030	5680	6031.3	6033.8	6034.7	923	2442	3426	6030.7	6033.1	6033.4
Fourmile Creek	108+26	10826	6029.6	1230	4030	5680	6034.7	6037.9	6038.9	923	2442	3426	6034.0	6036.4	6037.5
Fourmile Creek	109+72	10972	6034.4	1230	4030	5680	6038.7	6041.8	6043.1	923	2442	3426	6038.2	6040.4	6041.2
Fourmile Creek	111+83	11183	6039.1	1230	4030	5680	6047.1	6049.8	6050.6	923	2442	3426	6046.4	6048.6	6049.5
Fourmile Creek	114+05	11405	6050.7	1230	4030	5680	6054.4	6056.3	6057.2	923	2442	3426	6053.9	6055.4	6055.9
Fourmile Creek	116+08	11608	6056.7	1230	4030	5680	6062.3	6064.3	6065.1	923	2442	3426	6061.8	6063.4	6064.0
Fourmile Creek	117+77	11777	6064.4	1230	4030	5680	6068.6	6071.2	6072.3	923	2442	3426	6068.0	6070.0	6070.7
Fourmile Creek	119+31	11931	6066.4	1230	4030	5680	6072.4	6076.0	6078.0	923	2442	3426	6071.7	6074.3	6075.4
Fourmile Creek	120+80	12080	6070.5	1230	4030	5680	6076.8	6081.4	6083.2	923	2442	3426	6076.1	6079.0	6080.5
Fourmile Creek	122+04	12204	6074.0	1230	4030	5680	6080.0	6083.1	6084.2	923	2442	3426	6079.5	6081.9	6082.7
Fourmile Creek	123+32	12332	6077.8	1230	4030	5680	6083.6	6086.6	6087.8	923	2442	3426	6082.8	6085.2	6086.1
Fourmile Creek	124+83	12483	6082.4	1230	4030	5680	6088.5	6091.7	6092.9	923	2442	3426	6087.9	6090.1	6091.2
Fourmile Creek	127+02	12702	6092.1	1230	4030	5680	6096.6	6099.3	6100.8	923	2442	3426	6096.1	6098.1	6098.9
Fourmile Creek	128+77	12877	6097.7	1230	4030	5680	6103.5	6108.1	6109.5	702	1984	2799	6102.1	6105.5	6106.8
Fourmile Creek	130+42	13042	6102.8	1230	4030	5680	6109.6	6113.5	6115.3	702	1984	2799	6108.2	6111.0	6112.1
Fourmile Creek	131+79	13179	6109.4	1230	4030	5680	6113.4	6116.8	6118.2	702	1984	2799	6112.5	6114.8	6115.7
Fourmile Creek	133+07	13307	6112.7	1230	4030	5680	6119.1	6121.6	6122.7	702	1984	2799	6118.3	6120.0	6120.7
Fourmile Creek	134+54	13454	6119.4	1230	4030	5680	6124.4	6127.5	6128.8	702	1984	2799	6123.5	6125.4	6126.3
Fourmile Creek	135+18	13518	6123.5	1230	4030	5680	6127.6	6130.1	6131.1	702	1984	2799	6126.7	6128.4	6129.1

Table D.1 Floodplain Data Table – Fourmile Creek and Gold Run

Reference Location	River Station	Cross Section	Thalweg Elevation (ft.)	Regulatory Discharges						CWCB/CDOT Discharges					
				Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)			Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)		
				10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr
Fourmile Creek	136+03	13603	6125.8	1230	4030	5680	6131.7	6134.0	6135.1	702	1984	2799	6130.7	6132.5	6133.3
Fourmile Creek	137+58	13758	6131.7	1230	4030	5680	6137.0	6140.7	6141.9	702	1984	2799	6135.7	6138.3	6139.4
Fourmile Creek	139+24	13924	6140.6	1230	4030	5680	6144.2	6147.4	6148.9	702	1984	2799	6143.6	6145.4	6146.3
Fourmile Creek	140+50	14050	6145.2	1230	4030	5680	6150.4	6152.0	6152.8	702	1984	2799	6149.7	6150.9	6151.4
Fourmile Creek	141+69	14169	6147.6	1230	4030	5680	6154.8	6158.7	6159.6	702	1984	2799	6153.5	6156.1	6158.0
Fourmile Creek	142+66	14266	6153.9	1230	4030	5680	6159.7	6162.8	6163.8	702	1984	2799	6158.3	6161.0	6161.9
Fourmile Creek	143+43	14343	6158.8	1230	4030	5680	6163.6	6167.6	6169.3	702	1984	2799	6162.5	6165.0	6166.2
Fourmile Creek	144+65	14465	6167.9	1230	4030	5680	6172.2	6175.6	6177.1	702	1984	2799	6171.2	6173.4	6174.4
Fourmile Creek	146+12	14612	6175.3	1230	4030	5680	6180.3	6184.4	6186.3	702	1984	2799	6179.1	6181.6	6182.9
Fourmile Creek	147+58	14758	6189.6	1230	4030	5680	6194.8	6198.8	6200.5	702	1984	2799	6193.6	6196.1	6197.3
Fourmile Creek	148+69	14869	6196.6	1230	4030	5680	6201.8	6206.2	6207.9	702	1984	2799	6200.5	6203.3	6204.7
Fourmile Creek	150+10	15010	6203.4	1230	4030	5680	6209.5	6213.0	6214.8	702	1984	2799	6208.3	6210.6	6211.6
Fourmile Creek	152+21	15221	6209.5	1230	4030	5680	6215.4	6217.7	6218.7	702	1984	2799	6214.5	6216.2	6216.8
Fourmile Creek	153+93	15393	6213.9	1230	4030	5680	6219.5	6222.3	6223.5	702	1984	2799	6218.5	6220.4	6221.3
Fourmile Creek	155+61	15561	6218.5	1230	4030	5680	6223.8	6227.0	6228.5	702	1984	2799	6222.8	6224.8	6225.8
Fourmile Creek	156+61	15661	6221.1	1230	4030	5680	6226.4	6228.8	6230.5	702	1984	2799	6225.3	6227.3	6228.1
Fourmile Creek	157+83	15783	6224.9	1230	4030	5680	6230.7	6234.3	6234.9	702	1984	2799	6229.8	6231.9	6232.8
Fourmile Creek	159+25	15925	6230.4	1230	4030	5680	6235.7	6238.0	6239.0	702	1984	2799	6234.3	6236.4	6237.3
Fourmile Creek	160+57	16057	6237.7	1230	4030	5680	6240.9	6243.2	6244.2	702	1984	2799	6240.3	6241.9	6242.2
Fourmile Creek	161+90	16190	6240.9	1230	4030	5680	6245.3	6247.8	6248.8	702	1984	2799	6244.4	6245.9	6246.9
Fourmile Creek	163+37	16337	6244.2	1230	4030	5680	6248.9	6251.3	6252.4	702	1984	2799	6248.1	6249.8	6250.4
Fourmile Creek	165+05	16505	6251.0	1230	4030	5680	6255.5	6258.3	6259.5	702	1984	2799	6254.5	6256.3	6257.2
Fourmile Creek	166+71	16671	6253.9	1230	4030	5680	6260.1	6262.7	6263.8	702	1984	2799	6259.2	6261.0	6261.7
Fourmile Creek	167+44	16744	6256.8	1230	4030	5680	6263.0	6266.2	6267.0	702	1984	2799	6261.5	6264.1	6265.2
Fourmile Creek	168+43	16843	6261.1	1230	4030	5680	6266.9	6269.7	6270.9	702	1984	2799	6265.8	6268.0	6268.7
Fourmile Creek	171+38	17138	6270.2	1230	4030	5680	6275.9	6278.6	6279.7	702	1984	2799	6274.5	6276.9	6277.7
Fourmile Creek	173+05	17305	6274.7	1230	4030	5680	6280.5	6282.8	6283.8	702	1984	2799	6279.5	6281.2	6281.8
Fourmile Creek	175+11	17511	6280.3	1230	4030	5680	6286.6	6290.0	6290.9	702	1984	2799	6285.1	6287.9	6289.0
Fourmile Creek	176+50	17650	6285.2	1230	4030	5680	6291.2	6293.9	6294.7	702	1984	2799	6290.3	6292.0	6292.8
Fourmile Creek	176+75	17675		Bridge											
Fourmile Creek	176+89	17689	6286.2	1230	4030	5680	6294.1	6297.0	6297.9	702	1984	2799	6292.0	6295.4	6296.2
Fourmile Creek	178+38	17838	6291.0	1230	4030	5680	6296.4	6298.9	6299.5	702	1984	2799	6295.1	6298.0	6298.4
Fourmile Creek	179+62	17962	6295.2	1230	4030	5680	6301.6	6304.2	6305.0	702	1984	2799	6300.2	6302.8	6303.4
Fourmile Creek	179+75	17975		Bridge											

Table D.1 Floodplain Data Table – Fourmile Creek and Gold Run

Reference Location	River Station	Cross Section	Thalweg Elevation (ft.)	Regulatory Discharges						CWCB/CDOT Discharges					
				Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)			Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)		
				10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr
Fourmile Creek	179+97	17997	6295.7	1230	4030	5680	6303.4	6309.5	6309.8	702	1984	2799	6301.8	6306.1	6308.7
Fourmile Creek	182+03	18203	6303.0	1230	4030	5680	6309.1	6311.1	6312.1	702	1984	2799	6307.7	6309.5	6310.3
Fourmile Creek	183+94	18394	6308.7	1230	4030	5680	6315.6	6319.0	6319.8	702	1984	2799	6314.4	6317.1	6318.1
Fourmile Creek	185+83	18583	6316.6	1230	4030	5680	6322.8	6325.9	6327.0	702	1984	2799	6321.6	6323.8	6324.8
Fourmile Creek	187+37	18737	6324.2	1230	4030	5680	6329.1	6332.1	6333.3	702	1984	2799	6328.2	6330.2	6331.0
Fourmile Creek	189+42	18942	6332.5	1230	4030	5680	6337.6	6341.5	6343.0	702	1984	2799	6336.4	6338.8	6340.0
Fourmile Creek	191+27	19127	6340.1	1230	4030	5680	6344.3	6347.2	6348.3	702	1984	2799	6343.5	6345.2	6346.0
Fourmile Creek	191+87	19187	6341.2	1230	4030	5680	6346.3	6349.2	6350.2	702	1984	2799	6345.4	6347.2	6348.1
Fourmile Creek	192+00	19200		Culvert											
Fourmile Creek	192+67	19267	6343.4	1230	4030	5680	6351.9	6356.3	6357.0	702	1984	2799	6349.4	6354.3	6355.3
Fourmile Creek	193+23	19323	6344.5	1230	4030	5680	6352.4	6356.6	6357.4	702	1984	2799	6349.9	6354.6	6355.6
Fourmile Creek	194+66	19466	6347.1	1230	4030	5680	6353.5	6358.1	6359.4	702	1984	2799	6352.0	6355.5	6356.7
Fourmile Creek	196+64	19664	6357.1	1230	4030	5680	6360.6	6363.4	6365.1	702	1984	2799	6360.0	6361.2	6362.1
Fourmile Creek	197+96	19796	6360.0	1230	4030	5680	6365.0	6367.3	6368.3	702	1984	2799	6364.2	6365.9	6366.5
Fourmile Creek	199+81	19981	6365.0	1230	4030	5680	6370.5	6373.3	6374.4	702	1984	2799	6369.7	6371.2	6372.1
Fourmile Creek	201+76	20176	6370.5	1230	4030	5680	6376.1	6379.1	6380.5	702	1984	2799	6374.9	6377.2	6378.0
Fourmile Creek	203+45	20345	6373.1	1230	4030	5680	6379.9	6383.1	6384.3	702	1984	2799	6378.4	6381.0	6382.0
Fourmile Creek	205+20	20520	6379.5	1230	4030	5680	6385.1	6388.8	6390.2	702	1984	2799	6383.6	6386.4	6387.4
Fourmile Creek	206+76	20676	6390.3	1210	3990	5630	6394.4	6397.8	6399.3	702	1984	2799	6393.5	6395.6	6396.6
Fourmile Creek	209+12	20912	6402.9	1210	3990	5630	6408.5	6411.4	6412.5	702	1984	2799	6407.3	6409.5	6410.3
Fourmile Creek	210+90	21090	6416.2	1210	3990	5630	6420.0	6423.6	6425.2	702	1984	2799	6419.1	6421.3	6422.3
Fourmile Creek	212+57	21257	6425.1	1210	3990	5630	6430.9	6435.9	6438.0	702	1984	2799	6429.4	6432.5	6434.0
Fourmile Creek	213+71	21371	6430.3	1210	3990	5630	6435.7	6440.4	6442.1	702	1984	2799	6434.5	6437.3	6438.7
Fourmile Creek	214+37	21437	6432.0	1210	3990	5630	6437.8	6441.6	6443.4	702	1984	2799	6436.7	6438.9	6440.0
Fourmile Creek	215+26	21526	6435.8	1210	3990	5630	6441.6	6444.3	6445.3	702	1984	2799	6440.2	6442.7	6443.4
Fourmile Creek	216+32	21632	6438.7	1210	3990	5630	6445.6	6448.1	6449.1	702	1984	2799	6443.8	6446.5	6447.2
Fourmile Creek	217+80	21780	6442.1	1190	3950	5570	6448.7	6451.8	6452.9	702	1984	2799	6447.2	6450.0	6450.8
Fourmile Creek	219+52	21952	6451.6	1190	3950	5570	6456.9	6460.1	6461.6	702	1984	2799	6455.8	6458.1	6459.0
Fourmile Creek	220+57	22057	6455.9	1190	3950	5570	6461.2	6465.7	6468.1	702	1984	2799	6460.1	6462.7	6464.1
Fourmile Creek	221+24	22124	6458.3	1190	3950	5570	6464.2	6469.7	6471.3	702	1984	2799	6462.9	6466.4	6467.9
Fourmile Creek	221+35	22135		Bridge											
Fourmile Creek	221+47	22147	6459.6	1190	3950	5570	6466.8	6474.1	6475.3	702	1984	2799	6464.9	6468.6	6470.1
Fourmile Creek	222+02	22202	6462.5	1190	3950	5570	6468.1	6474.7	6476.2	702	1984	2799	6466.5	6470.0	6471.6
Fourmile Creek	223+49	22349	6468.4	1190	3950	5570	6474.2	6477.8	6478.6	702	1984	2799	6472.8	6476.9	6477.2

Table D.1 Floodplain Data Table – Fourmile Creek and Gold Run

Reference Location	River Station	Cross Section	Thalweg Elevation (ft.)	Regulatory Discharges						CWCB/CDOT Discharges					
				Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)			Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)		
				10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr
Fourmile Creek	223+85	22385	6470.8	1190	3950	5570	6476.3	6479.0	6480.1	702	1984	2799	6474.8	6477.5	6478.1
Fourmile Creek	224+79	22479	6477.3	1190	3950	5570	6480.5	6483.1	6484.2	702	1984	2799	6479.8	6481.4	6482.2
Fourmile Creek	226+81	22681	6483.6	1190	3950	5570	6488.7	6492.0	6493.5	702	1984	2799	6487.9	6489.7	6490.7
Fourmile Creek	228+51	22851	6491.2	1190	3950	5570	6496.0	6499.0	6500.3	702	1984	2799	6494.7	6497.1	6497.9
Fourmile Creek	230+11	23011	6496.5	1190	3950	5570	6501.8	6504.2	6505.2	702	1984	2799	6500.9	6502.6	6503.3
Fourmile Creek	231+07	23107	6500.6	1190	3950	5570	6504.6	6507.6	6509.0	702	1984	2799	6503.8	6505.7	6506.6
Fourmile Creek	232+70	23270	6509.2	1190	3950	5570	6514.4	6518.3	6519.9	702	1984	2799	6513.3	6515.8	6517.0
Fourmile Creek	234+67	23467	6520.3	1190	3950	5570	6524.6	6527.9	6529.2	702	1984	2799	6523.6	6525.9	6526.8
Fourmile Creek	236+72	23672	6528.1	1190	3950	5570	6533.2	6537.0	6538.7	702	1984	2799	6532.2	6534.4	6535.6
Fourmile Creek	238+31	23831	6539.0	1190	3950	5570	6544.2	6548.7	6550.6	702	1984	2799	6542.9	6545.8	6547.1
Fourmile Creek	239+69	23969	6549.0	1190	3950	5570	6552.9	6557.5	6558.5	702	1984	2799	6551.9	6554.2	6555.3
Fourmile Creek	241+69	24169	6557.1	1190	3950	5570	6561.5	6565.5	6567.2	702	1984	2799	6560.5	6562.8	6564.0
Fourmile Creek	243+23	24323	6563.5	1190	3950	5570	6569.0	6573.8	6574.3	702	1984	2799	6567.8	6570.4	6571.6
Fourmile Creek	245+08	24508	6574.0	1190	3950	5570	6578.1	6580.5	6581.8	702	1984	2799	6577.3	6579.1	6579.9
Fourmile Creek	247+49	24749	6582.4	1190	3950	5570	6587.0	6590.3	6592.1	702	1984	2799	6586.0	6588.1	6589.0
Fourmile Creek	248+57	24857	6587.7	1020	3460	4870	6593.8	6597.7	6599.1	455	1372	1969	6591.8	6594.7	6595.8
Fourmile Creek	250+00	25000	6590.9	990	3370	4720	6598.1	6602.1	6603.6	455	1372	1969	6596.1	6599.1	6600.2
Fourmile Creek	252+62	25262	6598.9	990	3370	4720	6605.2	6608.6	6609.5	455	1372	1969	6603.3	6606.1	6607.1
Fourmile Creek	255+71	25571	6609.4	990	3370	4720	6614.9	6618.0	6619.2	455	1372	1969	6613.0	6615.6	6616.3
Fourmile Creek	257+87	25787	6617.3	990	3370	4720	6622.5	6625.4	6626.5	455	1372	1969	6621.2	6623.2	6624.0
Fourmile Creek	259+68	25968	6624.7	990	3370	4720	6630.4	6633.2	6634.3	455	1372	1969	6628.5	6631.0	6631.8
Fourmile Creek	259+80	25980		Bridge											
Fourmile Creek	259+94	25994	6627.4	990	3370	4720	6633.5	6636.4	6637.6	455	1372	1969	6632.3	6634.2	6635.1
Fourmile Creek	260+20	26020	6628.6	990	3370	4720	6634.0	6637.3	6638.6	455	1372	1969	6632.7	6634.8	6635.8
Fourmile Creek	262+56	26256	6641.8	990	3370	4720	6646.5	6649.0	6650.0	455	1372	1969	6644.7	6647.1	6647.8
Fourmile Creek	263+99	26399	6650.3	990	3370	4720	6656.1	6659.0	6660.3	455	1372	1969	6654.2	6656.8	6657.6
Fourmile Creek	264+20	26420	6650.9	990	3370	4720	6656.9	6659.8	6661.2	455	1372	1969	6655.3	6657.6	6658.4
Fourmile Creek	264+83	26483	6652.7	990	3370	4720	6658.7	6661.9	6663.4	455	1372	1969	6657.0	6659.4	6660.3
Fourmile Creek	265+88	26588	6658.2	990	3370	4720	6663.3	6666.7	6668.2	455	1372	1969	6661.4	6664.3	6665.2
Fourmile Creek	267+16	26716	6663.3	990	3370	4720	6668.8	6671.8	6673.2	455	1372	1969	6667.3	6669.2	6670.1
Fourmile Creek	269+85	26985	6672.9	990	3370	4720	6678.1	6681.3	6682.3	455	1372	1969	6676.9	6679.0	6679.7
Fourmile Creek	272+96	27296	6684.0	990	3370	4720	6688.2	6690.4	6691.6	455	1372	1969	6687.2	6688.6	6689.2
Fourmile Creek	273+82	27382	6686.2	990	3370	4720	6690.7	6693.2	6694.1	455	1372	1969	6689.5	6691.4	6692.0
Fourmile Creek	276+10	27610	6691.6	990	3370	4720	6696.4	6699.5	6700.6	455	1372	1969	6694.9	6696.9	6697.9

Table D.1 Floodplain Data Table – Fourmile Creek and Gold Run

Reference Location	River Station	Cross Section	Thalweg Elevation (ft.)	Regulatory Discharges						CWCB/CDOT Discharges					
				Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)			Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)		
				10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr
Fourmile Creek	277+61	27761	6696.1	990	3370	4720	6700.9	6703.2	6704.2	455	1372	1969	6699.6	6701.4	6702.0
Fourmile Creek	278+37	27837	6698.4	990	3370	4720	6703.8	6705.7	6706.5	455	1372	1969	6702.9	6704.2	6704.7
Fourmile Creek	278+62	27862	6699.3	990	3370	4720	6705.0	6707.2	6708.1	455	1372	1969	6704.1	6705.4	6706.0
Fourmile Creek	279+37	27937	6702.0	990	3370	4720	6706.7	6708.9	6709.8	455	1372	1969	6705.6	6707.2	6707.8
Fourmile Creek	282+18	28218	6709.9	990	3370	4720	6715.5	6717.8	6718.7	455	1372	1969	6714.2	6716.0	6716.6
Fourmile Creek	285+74	28574	6722.4	990	3370	4720	6726.5	6728.4	6729.2	455	1372	1969	6725.8	6726.9	6727.5
Fourmile Creek	288+98	28898	6730.0	990	3370	4720	6736.1	6738.7	6739.5	455	1372	1969	6734.5	6736.9	6737.5
Fourmile Creek	291+66	29166	6737.0	990	3370	4720	6742.3	6744.6	6745.5	455	1372	1969	6741.0	6742.8	6743.4
Fourmile Creek	292+40	29240		Bridge											
Fourmile Creek	292+59	29259	6740.5	990	3370	4720	6748.7	6751.0	6751.9	455	1372	1969	6746.0	6749.3	6749.9
Fourmile Creek	294+51	29451	6749.7	990	3370	4720	6753.6	6755.4	6756.1	455	1372	1969	6752.7	6754.2	6754.7
Fourmile Creek	297+87	29787	6758.0	990	3370	4720	6762.7	6764.6	6765.4	455	1372	1969	6761.8	6763.1	6763.6
Fourmile Creek	300+61	30061	6765.8	990	3370	4720	6769.3	6772.6	6773.9	455	1372	1969	6768.3	6769.9	6770.7
Fourmile Creek	301+00	30100		Bridge											
Fourmile Creek	301+16	30116	6766.8	990	3370	4720	6774.7	6779.3	6780.1	455	1372	1969	6771.9	6776.4	6778.5
Fourmile Creek	304+34	30434	6779.0	990	3370	4720	6782.9	6784.5	6785.1	455	1372	1969	6782.1	6783.2	6783.6
Fourmile Creek	307+70	30770	6787.0	990	3370	4720	6792.5	6795.0	6795.9	455	1372	1969	6790.8	6793.3	6794.0
Fourmile Creek	311+07	31107	6798.3	990	3370	4720	6804.0	6806.3	6807.0	455	1372	1969	6802.9	6804.4	6805.1
Fourmile Creek	313+76	31376	6811.8	990	3370	4720	6815.2	6816.6	6817.2	455	1372	1969	6814.6	6815.6	6816.0
Fourmile Creek	316+19	31619	6819.6	990	3370	4720	6823.0	6824.8	6825.5	455	1372	1969	6822.3	6823.3	6823.8
Fourmile Creek	316+50	31650		Culvert											
Fourmile Creek	316+76	31676	6820.9	990	3370	4720	6827.3	6829.0	6829.7	455	1372	1969	6826.6	6827.6	6828.1
Fourmile Creek	319+69	31969	6829.6	990	3370	4720	6834.1	6836.2	6837.0	455	1372	1969	6833.2	6834.5	6835.1
Fourmile Creek	320+62	32062	6833.7	990	3370	4720	6837.8	6840.1	6840.9	455	1372	1969	6836.8	6838.4	6839.0
Fourmile Creek	320+90	32090		Culvert											
Fourmile Creek	321+10	32110	6835.4	990	3370	4720	6845.2	6847.0	6847.8	455	1372	1969	6844.5	6845.6	6846.1
Fourmile Creek	322+94	32294	6838.7	990	3370	4720	6844.7	6847.8	6848.4	455	1372	1969	6844.3	6845.4	6846.9
Fourmile Creek	326+35	32635	6851.5	920	3170	4470	6857.1	6860.4	6861.2	455	1372	1969	6854.9	6858.0	6858.1
Fourmile Creek	329+70	32970	6866.1	920	3170	4470	6869.3	6871.6	6872.1	455	1372	1969	6868.7	6870.0	6871.2
Fourmile Creek	330+00	33000		Culvert											
Fourmile Creek	330+50	33050	6869.4	920	3170	4470	6874.7	6876.6	6877.4	455	1372	1969	6874.0	6875.2	6875.8
Fourmile Creek	333+09	33309	6875.7	920	3170	4470	6879.0	6881.2	6882.1	455	1372	1969	6878.1	6879.6	6880.2
Fourmile Creek	335+47	33547	6881.7	920	3170	4470	6886.9	6889.5	6890.3	455	1372	1969	6886.1	6887.5	6888.4
Fourmile Creek	338+40	33840	6891.8	920	3170	4470	6896.1	6899.8	6901.5	455	1372	1969	6894.7	6897.1	6898.1

Table D.1 Floodplain Data Table – Fourmile Creek and Gold Run

Reference Location	River Station	Cross Section	Thalweg Elevation (ft.)	Regulatory Discharges						CWCB/CDOT Discharges					
				Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)			Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)		
				10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr
Fourmile Creek	340+92	34092	6901.7	920	3170	4470	6907.4	6910.6	6911.8	455	1372	1969	6905.9	6908.2	6909.0
Fourmile Creek	343+68	34368	6910.6	920	3170	4470	6916.2	6918.8	6919.5	455	1372	1969	6914.1	6916.7	6917.6
Fourmile Creek	346+73	34673	6919.8	920	3170	4470	6925.9	6928.7	6929.4	455	1372	1969	6923.6	6926.7	6927.8
Fourmile Creek	350+25	35025	6931.7	920	3170	4470	6936.6	6938.9	6939.6	455	1372	1969	6935.1	6937.4	6938.0
Fourmile Creek	353+34	35334	6944.7	920	3170	4470	6949.3	6951.0	6951.6	455	1372	1969	6948.0	6949.7	6950.2
Fourmile Creek	356+01	35601	6953.5	920	3170	4470	6959.7	6962.0	6962.9	455	1372	1969	6958.4	6960.6	6961.2
Fourmile Creek	358+39	35839	6962.6	920	3170	4470	6968.4	6971.4	6972.6	455	1372	1969	6967.0	6969.4	6970.1
Fourmile Creek	361+23	36123	6975.0	920	3170	4470	6979.9	6982.3	6983.2	455	1372	1969	6978.5	6980.7	6981.3
Fourmile Creek	363+35	36335	6982.7	920	3170	4470	6987.7	6990.0	6990.7	455	1372	1969	6986.5	6988.4	6989.1
Fourmile Creek	365+20	36520	6992.5	920	3170	4470	6998.5	7000.5	7001.3	455	1372	1969	6997.4	6999.1	6999.6
Fourmile Creek	367+23	36723	7002.9	920	3170	4470	7009.0	7012.3	7013.7	455	1372	1969	7007.4	7009.9	7010.8
Fourmile Creek	369+88	36988	7019.4	920	3170	4470	7024.9	7028.7	7030.0	455	1372	1969	7023.3	7026.0	7027.1
Fourmile Creek	372+61	37261	7032.5	920	3170	4470	7037.5	7041.7	7043.2	455	1372	1969	7036.1	7038.6	7039.8
Fourmile Creek	374+78	37478	7041.8	920	3170	4470	7046.4	7049.8	7051.0	455	1372	1969	7044.8	7047.4	7048.4
Fourmile Creek	377+82	37782	7052.9	920	3170	4470	7055.3	7057.4	7058.0	455	1372	1969	7054.6	7055.9	7056.5
Fourmile Creek	380+34	38034	7063.1	920	3170	4470	7067.8	7070.2	7071.0	455	1372	1969	7066.7	7068.4	7069.1
Fourmile Creek	380+50	38050		Bridge											
Fourmile Creek	380+64	38064	7063.6	920	3170	4470	7069.6	7073.2	7074.2	455	1372	1969	7068.1	7070.5	7071.5
Fourmile Creek	383+17	38317	7075.8	920	3170	4470	7080.4	7082.5	7083.3	455	1372	1969	7079.4	7081.0	7081.6
Fourmile Creek	385+62	38562	7084.8	920	3170	4470	7091.1	7093.5	7094.5	455	1372	1969	7090.1	7091.8	7092.4
Fourmile Creek	388+35	38835	7097.3	920	3170	4470	7101.2	7104.1	7104.9	455	1372	1969	7100.2	7102.1	7103.0
Fourmile Creek	390+89	39089	7107.2	920	3170	4470	7112.1	7115.2	7116.0	455	1372	1969	7110.7	7113.1	7114.1
Fourmile Creek	393+41	39341	7117.3	920	3170	4470	7122.0	7124.9	7126.2	455	1372	1969	7120.7	7122.9	7123.6
Fourmile Creek	396+07	39607	7129.2	920	3170	4470	7134.4	7136.7	7137.7	455	1372	1969	7133.5	7134.9	7135.6
Fourmile Creek	398+51	39851	7139.1	920	3170	4470	7143.9	7146.4	7147.5	455	1372	1969	7143.0	7144.6	7145.2
Fourmile Creek	401+46	40146	7152.2	920	3170	4470	7156.8	7158.8	7159.6	340	1048	1509	7156.0	7157.0	7157.5
Fourmile Creek	404+11	40411	7165.6	920	3170	4470	7168.8	7170.9	7171.8	340	1048	1509	7167.9	7169.0	7169.4
Fourmile Creek	406+92	40692	7172.0	920	3170	4470	7177.2	7179.5	7180.4	340	1048	1509	7175.7	7177.4	7178.1
Fourmile Creek	409+30	40930	7182.1	810	2760	3910	7186.9	7189.7	7190.5	340	1048	1509	7185.4	7187.3	7188.2
Fourmile Creek	411+08	41108	7189.3	790	2670	3750	7194.8	7197.3	7198.4	340	1048	1509	7193.4	7195.2	7195.9
Fourmile Creek	412+31	41231	7195.9	790	2670	3750	7199.6	7202.2	7203.1	340	1048	1509	7198.5	7200.1	7200.8
Fourmile Creek	412+45	41245		Culvert											
Fourmile Creek	412+58	41258	7196.8	790	2670	3750	7205.0	7207.5	7208.6	340	1048	1509	7203.8	7205.5	7206.2
Fourmile Creek	413+25	41325	7197.8	790	2670	3750	7205.3	7208.1	7209.2	340	1048	1509	7203.9	7205.8	7206.6

Table D.1 Floodplain Data Table – Fourmile Creek and Gold Run

Reference Location	River Station	Cross Section	Thalweg Elevation (ft.)	Regulatory Discharges						CWCB/CDOT Discharges					
				Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)			Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)		
				10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr
Fourmile Creek	415+40	41540	7208.2	790	2670	3750	7210.7	7213.0	7214.0	340	1048	1509	7209.9	7211.1	7211.7
Fourmile Creek	417+47	41747	7213.4	790	2670	3750	7220.6	7222.9	7223.8	340	1048	1509	7218.4	7221.0	7221.6
Fourmile Creek	419+43	41943	7223.2	790	2670	3750	7227.6	7230.1	7231.1	340	1048	1509	7225.7	7228.1	7228.8
Fourmile Creek	421+48	42148	7229.8	790	2670	3750	7235.3	7238.6	7239.7	340	1048	1509	7233.7	7236.0	7236.9
Fourmile Creek	423+74	42374	7237.7	790	2670	3750	7242.4	7245.8	7247.2	340	1048	1509	7240.6	7243.0	7243.9
Fourmile Creek	424+19	42419	7239.5	790	2670	3750	7244.9	7248.0	7249.1	340	1048	1509	7243.1	7246.1	7246.7
Fourmile Creek	424+30	42430		Culvert											
Fourmile Creek	424+52	42452	7240.3	790	2670	3750	7250.9	7253.1	7253.9	340	1048	1509	7249.8	7251.4	7252.0
Fourmile Creek	426+55	42655	7249.0	790	2670	3750	7253.8	7255.5	7256.1	340	1048	1509	7252.2	7254.1	7254.6
Fourmile Creek	429+04	42904	7256.3	790	2670	3750	7261.2	7263.8	7264.7	340	1048	1509	7259.6	7261.8	7262.6
Fourmile Creek	431+53	43153	7265.1	790	2670	3750	7269.9	7272.7	7273.4	340	1048	1509	7268.2	7270.4	7271.1
Fourmile Creek	434+26	43426	7272.3	790	2670	3750	7279.0	7282.0	7282.9	340	1048	1509	7277.5	7279.8	7280.7
Fourmile Creek	436+30	43630	7279.3	790	2670	3750	7285.5	7287.8	7288.8	340	1048	1509	7283.8	7285.9	7286.6
Fourmile Creek	439+22	43922	7290.4	790	2670	3750	7295.5	7297.8	7298.7	340	1048	1509	7293.9	7295.8	7296.5
Fourmile Creek	440+81	44081	7297.5	790	2670	3750	7302.5	7306.6	7307.7	340	1048	1509	7300.7	7303.3	7305.2
Fourmile Creek	441+00	44100		Bridge											
Fourmile Creek	441+14	44114	7298.0	790	2670	3750	7304.7	7308.4	7309.7	340	1048	1509	7302.7	7306.0	7307.8
Fourmile Creek	441+47	44147	7298.1	790	2670	3750	7305.8	7309.1	7310.3	340	1048	1509	7303.5	7306.7	7308.2
Fourmile Creek	444+40	44440	7310.4	790	2670	3750	7315.3	7319.1	7319.9	340	1048	1509	7313.5	7317.1	7317.2
Fourmile Creek	446+49	44649	7320.6	670	2310	3270	7324.5	7326.7	7327.8	340	1048	1509	7323.6	7324.7	7325.8
Fourmile Creek	448+35	44835	7326.7	670	2310	3270	7331.0	7334.6	7335.5	340	1048	1509	7330.1	7332.6	7333.0
Fourmile Creek	450+85	45085	7333.5	670	2310	3270	7338.6	7341.7	7342.7	340	1048	1509	7337.0	7339.4	7340.6
Fourmile Creek	453+05	45305	7342.0	670	2310	3270	7345.8	7348.4	7349.6	340	1048	1509	7344.6	7346.5	7347.3
Fourmile Creek	455+34	45534	7347.2	670	2310	3270	7353.4	7356.8	7358.1	340	1048	1509	7352.2	7354.4	7355.4
Fourmile Creek	457+38	45738	7353.3	670	2310	3270	7358.1	7361.1	7362.4	340	1048	1509	7356.9	7359.0	7359.8
Fourmile Creek	459+94	45994	7362.8	670	2310	3270	7366.6	7368.3	7369.1	340	1048	1509	7365.9	7367.1	7367.6
Fourmile Creek	462+18	46218	7370.5	670	2310	3270	7373.8	7375.5	7376.2	340	1048	1509	7373.1	7374.3	7374.8
Fourmile Creek	464+52	46452	7376.3	670	2310	3270	7381.4	7383.4	7384.2	340	1048	1509	7380.1	7382.0	7382.6
Fourmile Creek	465+00	46500		Culvert											
Fourmile Creek	465+23	46523	7381.5	670	2310	3270	7390.4	7392.4	7393.1	340	1048	1509	7386.8	7391.2	7391.8
Fourmile Creek	466+90	46690	7387.9	670	2310	3270	7390.4	7392.6	7393.3	340	1048	1509	7389.7	7391.2	7391.9
Fourmile Creek	469+43	46943	7395.4	670	2310	3270	7397.7	7399.3	7400.0	340	1048	1509	7397.3	7398.0	7398.5
Fourmile Creek	472+46	47246	7403.1	670	2310	3270	7407.1	7409.1	7409.9	340	1048	1509	7405.9	7407.8	7408.4
Fourmile Creek	475+41	47541	7413.8	670	2310	3270	7417.7	7420.0	7420.8	340	1048	1509	7417.0	7418.5	7419.1

Table D.1 Floodplain Data Table – Fourmile Creek and Gold Run

Reference Location	River Station	Cross Section	Thalweg Elevation (ft.)	Regulatory Discharges						CWCB/CDOT Discharges					
				Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)			Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)		
				10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr
Fourmile Creek	477+13	47713	7418.0	670	2310	3270	7423.1	7425.5	7426.5	340	1048	1509	7421.7	7423.8	7424.5
Fourmile Creek	477+30	47730		Bridge						Bridge	Bridge	Bridge			
Fourmile Creek	477+45	47745	7419.5	670	2310	3270	7424.2	7426.3	7427.2	340	1048	1509	7423.5	7424.7	7425.4
Fourmile Creek	478+32	47832	7420.4	670	2310	3270	7426.1	7428.1	7429.2	340	1048	1509	7425.0	7426.8	7427.2
Fourmile Creek	479+85	47985	7425.2	670	2310	3270	7430.8	7432.2	7432.8	340	1048	1509	7429.8	7431.3	7431.8
Fourmile Creek	480+00	48000		Bridge											
Fourmile Creek	480+22	48022	7426.3	670	2310	3270	7432.1	7435.4	7436.3	340	1048	1509	7430.9	7432.6	7434.5
Fourmile Creek	481+05	48105	7429.7	670	2310	3270	7433.8	7435.9	7436.9	340	1048	1509	7433.1	7434.5	7435.0
Fourmile Creek	484+14	48414	7440.0	670	2310	3270	7445.1	7445.8	7448.0	340	1048	1509	7444.3	7445.4	7445.8
Fourmile Creek	487+17	48717	7449.9	670	2310	3270	7454.5	7458.6	7458.5	340	1048	1509	7453.4	7456.2	7457.1
Fourmile Creek	489+81	48981	7459.8	670	2310	3270	7465.1	7467.4	7469.6	340	1048	1509	7463.7	7466.0	7466.7
Fourmile Creek	492+16	49216	7469.0	670	2310	3270	7473.3	7475.9	7476.4	340	1048	1509	7472.1	7474.1	7474.9
Fourmile Creek	495+11	49511	7476.9	670	2310	3270	7482.2	7483.4	7484.3	340	1048	1509	7481.5	7482.6	7483.0
Fourmile Creek	497+82	49782	7486.6	670	2310	3270	7489.9	7492.0	7492.6	340	1048	1509	7489.4	7490.5	7491.0
Fourmile Creek	500+69	50069	7495.6	670	2310	3270	7500.1	7501.1	7501.9	340	1048	1509	7499.5	7500.5	7500.8
Fourmile Creek	503+37	50337	7504.5	670	2310	3270	7508.5	7510.2	7510.7	340	1048	1509	7507.9	7509.0	7509.4
Fourmile Creek	506+00	50600	7512.9	670	2310	3270	7517.3	7518.4	7518.8	340	1048	1509	7516.6	7517.8	7518.1
Fourmile Creek	509+04	50904	7523.9	670	2310	3270	7528.7	7530.3	7530.9	340	1048	1509	7528.0	7529.2	7529.6
Fourmile Creek	512+03	51203	7534.0	670	2310	3270	7538.3	7539.5	7540.0	340	1048	1509	7537.5	7538.8	7539.2
Fourmile Creek	513+89	51389	7541.4	670	2310	3270	7544.5	7546.7	7547.4	340	1048	1509	7543.5	7545.4	7545.9
Fourmile Creek	514+00	51400		Culvert											
Fourmile Creek	514+31	51431	7543.1	670	2310	3270	7546.6	7547.3	7548.1	340	1048	1509	7546.1	7547.0	7547.4
Fourmile Creek	514+86	51486	7545.5	670	2310	3270	7548.0	7549.6	7550.0	340	1048	1509	7547.4	7548.4	7548.7
Fourmile Creek	517+45	51745	7551.0	670	2310	3270	7554.9	7556.4	7557.3	340	1048	1509	7554.0	7555.7	7556.3
Fourmile Creek	520+06	52006	7559.4	670	2310	3270	7563.3	7566.6	7567.4	340	1048	1509	7562.3	7564.6	7565.3
Fourmile Creek	522+83	52283	7568.7	670	2310	3270	7573.3	7574.8	7575.5	340	1048	1509	7572.3	7574.0	7574.5
Fourmile Creek	525+66	52566	7577.8	670	2310	3270	7581.7	7583.7	7584.3	340	1048	1509	7580.8	7582.2	7582.8
Fourmile Creek	528+14	52814	7584.0	670	2310	3270	7588.9	7590.3	7590.9	340	1048	1509	7588.0	7589.5	7589.9
Fourmile Creek	530+11	53011	7593.3	670	2310	3270	7596.1	7597.7	7598.3	340	1048	1509	7595.3	7596.5	7596.9
Fourmile Creek	532+66	53266	7600.0	670	2310	3270	7604.7	7606.7	7607.5	340	1048	1509	7603.9	7605.4	7606.1
Fourmile Creek	536+22	53622	7612.0	580	2020	2860	7616.4	7619.4	7620.5	340	1048	1509	7615.6	7617.5	7618.3
Fourmile Creek	536+50	53650		Bridge											
Fourmile Creek	536+73	53673	7615.3	580	2020	2860	7620.9	7626.4	7630.7	340	1048	1509	7619.6	7623.1	7624.7
Fourmile Creek	538+04	53804	7621.7	580	2020	2860	7624.0	7627.9	7630.8	340	1048	1509	7623.7	7624.9	7626.3

Table D.1 Floodplain Data Table – Fourmile Creek and Gold Run

Reference Location	River Station	Cross Section	Thalweg Elevation (ft.)	Regulatory Discharges						CWCB/CDOT Discharges					
				Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)			Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)		
				10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr
Fourmile Creek	540+11	54011	7628.2	580	2020	2860	7631.3	7632.2	7632.9	340	1048	1509	7630.8	7631.7	7631.7
Fourmile Creek	540+50	54050		Culvert											
Fourmile Creek	540+93	54093	7630.7	580	2020	2860	7634.7	7636.5	7637.2	340	1048	1509	7634.2	7635.4	7635.9
Fourmile Creek	543+02	54302	7636.4	580	2020	2860	7640.0	7641.2	7641.6	340	1048	1509	7639.3	7640.5	7640.9
Fourmile Creek	545+50	54550	7644.9	580	2020	2860	7649.0	7650.7	7651.3	340	1048	1509	7648.5	7649.7	7650.2
Fourmile Creek	547+82	54782	7657.3	580	2020	2860	7659.0	7660.0	7660.4	340	1048	1509	7658.7	7659.4	7659.7
Fourmile Creek	550+02	55002	7665.7	580	2020	2860	7667.9	7669.1	7669.6	340	1048	1509	7667.5	7668.3	7668.7
Fourmile Creek	553+16	55316	7673.3	580	2020	2860	7677.5	7679.7	7680.3	340	1048	1509	7676.9	7678.6	7679.2
Fourmile Creek	555+64	55564	7683.1	520	1780	2510	7687.2	7689.2	7689.9	148	460	668	7685.6	7687.2	7687.8
Fourmile Creek	558+52	55852	7695.0	520	1780	2510	7698.8	7701.7	7702.6	148	460	668	7696.9	7698.4	7699.3
Fourmile Creek	561+25	56125	7708.2	520	1780	2510	7711.3	7713.2	7713.9	148	460	668	7710.1	7711.2	7711.6
Fourmile Creek	563+61	56361	7715.0	520	1780	2510	7718.9	7720.7	7721.4	148	460	668	7717.1	7718.7	7719.3
Fourmile Creek	564+87	56487	7719.0	490	1320	1850	7723.0	7724.6	7725.1	148	460	668	7721.2	7722.9	7723.4
Fourmile Creek	565+00	56500		Culvert											
Fourmile Creek	565+30	56530	7723.6	490	1320	1850	7727.9	7729.5	7730.2	148	460	668	7725.4	7727.8	7728.4
Fourmile Creek	567+79	56779	7734.5	490	1320	1850	7738.0	7739.0	7739.3	148	460	668	7737.2	7737.8	7738.3
Fourmile Creek	569+46	56946	7741.3	490	1320	1850	7745.2	7746.5	7746.9	148	460	668	7743.4	7745.2	7745.5
Fourmile Creek	571+26	57126	7748.1	490	1320	1850	7751.9	7753.3	7753.8	148	460	668	7750.8	7751.8	7752.3
Fourmile Creek	573+19	57319	7756.9	490	1320	1850	7760.4	7761.5	7762.1	148	460	668	7759.1	7760.4	7760.7
Gold Run	+7	7	6583.7	-	-	-	-	-	-	117	296	403	6585.5	6586.4	6586.8
Gold Run	1+00	100		-	-	-	-	-	-						
Gold Run	1+47	147	6601.7	-	-	-	-	-	-	117	296	403	6604.4	6604.9	6605.2
Gold Run	1+97	197	6605.7	-	-	-	-	-	-	117	296	403	6607.4	6608.7	6608.9
Gold Run	2+44	244	6609.0	-	-	-	-	-	-	117	296	403	6610.8	6611.6	6612.0
Gold Run	3+23	323	6612.5	-	-	-	-	-	-	117	296	403	6615.1	6615.7	6616.1
Gold Run	3+91	391	6618.5	-	-	-	-	-	-	117	296	403	6620.2	6620.8	6621.1
Gold Run	4+39	439	6620.0	-	-	-	-	-	-	117	296	403	6621.9	6622.8	6623.2
Gold Run	5+09	509	6623.0	-	-	-	-	-	-	117	296	403	6624.4	6625.5	6625.9
Gold Run	5+44	544	6624.3	-	-	-	-	-	-	117	296	403	6626.6	6628.1	6628.8
Gold Run	6+00	600		Culvert	-	-	-	-	-						
Gold Run	6+46	646	6633.6	-	-	-	-	-	-	117	296	403	6637.0	6639.7	6640.2
Gold Run	7+06	706	6634.8	-	-	-	-	-	-	117	296	403	6637.9	6640.1	6640.6
Gold Run	8+09	809	6651.4	-	-	-	-	-	-	117	296	403	6653.9	6655.1	6655.6
Gold Run	9+66	966	6664.9	-	-	-	-	-	-	117	296	403	6666.8	6667.8	6668.3

Table D.1 Floodplain Data Table – Fourmile Creek and Gold Run

Reference Location	River Station	Cross Section	Thalweg Elevation (ft.)	Regulatory Discharges						CWCB/CDOT Discharges					
				Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)			Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)		
				10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr
Gold Run	10+57	1057	6674.4	-	-	-	-	-	-	117	296	403	6676.7	6678.3	6678.6
Gold Run	10+75	1075		Culvert	-	-	-	-	-						
Gold Run	10+87	1087	6677.0	-	-	-	-	-	-	117	296	403	6681.0	6682.1	6682.6
Gold Run	11+53	1153	6680.1	-	-	-	-	-	-	117	296	403	6682.1	6683.2	6683.7
Gold Run	13+36	1336	6694.3	-	-	-	-	-	-	117	296	403	6696.0	6696.7	6696.9
Gold Run	14+13	1413	6697.3	-	-	-	-	-	-	117	296	403	6699.7	6700.2	6700.5
Gold Run	14+50	1450		Culvert	-	-	-	-	-						
Gold Run	14+66	1466	6700.8	-	-	-	-	-	-	117	296	403	6703.3	6704.0	6704.2
Gold Run	15+51	1551	6705.9	-	-	-	-	-	-	117	296	403	6708.7	6710.6	6710.8
Gold Run	15+75	1575		Culvert	-	-	-	-	-						
Gold Run	15+88	1588	6709.4	-	-	-	-	-	-	117	296	403	6712.8	6713.8	6714.2
Gold Run	16+24	1624	6710.7	-	-	-	-	-	-	117	296	403	6713.0	6713.7	6714.2
Gold Run	16+50	1650		Culvert	-	-	-	-	-						
Gold Run	16+66	1666	6713.1	-	-	-	-	-	-	117	296	403	6718.6	6719.7	6720.0
Gold Run	17+44	1744	6719.2	-	-	-	-	-	-	117	296	403	6722.2	6723.2	6723.7
Gold Run	17+90	1790		Culvert	-	-	-	-	-						
Reach: Downstream of Quincy Reservoir															
Gold Run	18+05	1805	6722.0	-	-	-	-	-	-	117	296	403	6726.2	6729.1	6729.7
Gold Run	19+19	1919	6727.5	-	-	-	-	-	-	117	296	403	6729.8	6731.1	6731.7
Gold Run	19+96	1996	6735.9	-	-	-	-	-	-	117	296	403	6737.1	6737.7	6738.0
Gold Run	21+00	2100		Culvert	-	-	-	-	-						
Gold Run	21+99	2199	6752.7	-	-	-	-	-	-	117	296	403	6753.6	6754.1	6754.5
Gold Run	22+93	2293	6756.4	-	-	-	-	-	-	117	296	403	6758.7	6759.8	6760.5
Gold Run	23+35	2335	6759.5	-	-	-	-	-	-	117	296	403	6761.9	6763.2	6763.8
Gold Run	23+45	2345		Bridge	-	-	-	-	-						
Gold Run	23+56	2356	6763.1	-	-	-	-	-	-	117	296	403	6766.4	6768.6	6768.8
Gold Run	23+75	2375	6765.8	-	-	-	-	-	-	117	296	403	6767.5	6768.8	6769.3
Gold Run	24+00	2400		Culvert	-	-	-	-	-						
Gold Run	24+66	2466	6774.6	-	-	-	-	-	-	117	296	403	6778.1	6779.2	6779.6
Gold Run	25+14	2514	6780.0	-	-	-	-	-	-	117	296	403	6780.7	6781.5	6781.8
Gold Run	26+55	2655	6788.7	-	-	-	-	-	-	117	296	403	6791.0	6791.9	6792.3
Gold Run	27+70	2770	6798.2	-	-	-	-	-	-	117	296	403	6799.8	6800.6	6800.9
Gold Run	28+08	2808	6802.9	-	-	-	-	-	-	117	296	403	6805.3	6805.8	6805.9

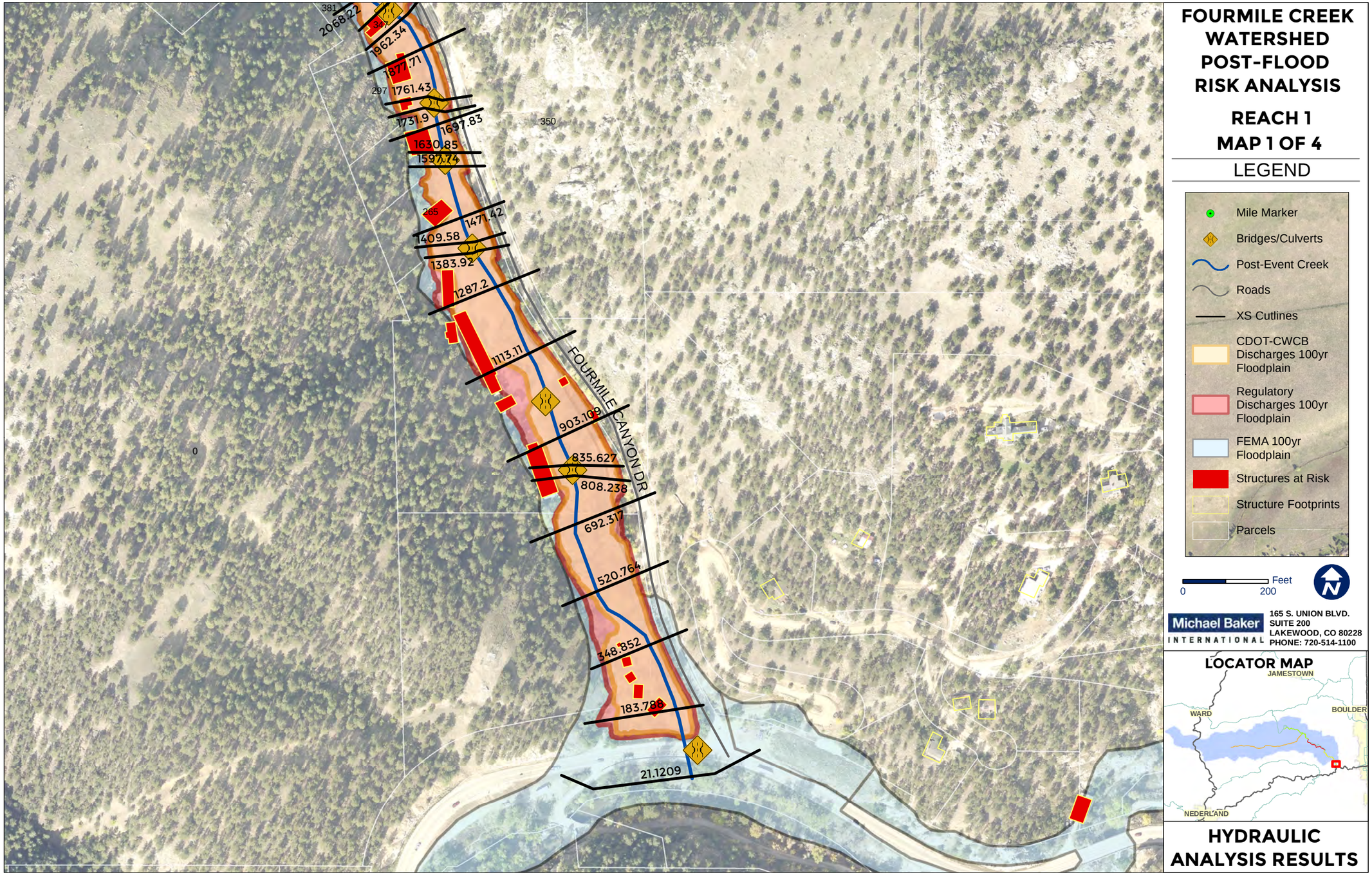
Table D.1 Floodplain Data Table – Fourmile Creek and Gold Run

Reference Location	River Station	Cross Section	Thalweg Elevation (ft.)	Regulatory Discharges						CWCB/CDOT Discharges					
				Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)			Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)		
				10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr
Gold Run	28+69	2869	6807.3	-	-	-	-	-	-	117	296	403	6808.5	6809.2	6809.5
Gold Run	29+62	2962	6811.4	-	-	-	-	-	-	117	296	403	6813.6	6814.4	6814.9
Gold Run	30+75	3075	6823.1	-	-	-	-	-	-	117	296	403	6825.1	6826.2	6826.7
Gold Run	32+25	3225	6832.0	-	-	-	-	-	-	117	296	403	6834.0	6835.3	6835.8
Gold Run	33+87	3387	6855.4	-	-	-	-	-	-	117	296	403	6857.1	6858.2	6858.7
Gold Run	34+93	3493	6865.2	-	-	-	-	-	-	117	296	403	6866.9	6868.0	6868.4
Gold Run	35+92	3592	6874.5	-	-	-	-	-	-	117	296	403	6876.2	6877.3	6877.7
Gold Run	36+86	3686	6882.8	-	-	-	-	-	-	117	296	403	6884.4	6885.5	6886.0
Gold Run	37+17	3717	6885.8	-	-	-	-	-	-	117	296	403	6888.4	6889.9	6890.8
Gold Run	37+25	3725		Culvert	-	-	-	-	-						
Gold Run	37+42	3742	6881.9	-	-	-	-	-	-	117	296	403	6889.5	6890.9	6891.3
Gold Run	38+11	3811	6891.2	-	-	-	-	-	-	117	296	403	6893.6	6894.5	6894.7
Gold Run	39+11	3911	6901.9	-	-	-	-	-	-	117	296	403	6904.1	6905.0	6905.4
Gold Run	40+50	4050	6911.3	-	-	-	-	-	-	117	296	403	6912.5	6913.0	6913.3
Gold Run	42+03	4203	6922.0	-	-	-	-	-	-	117	296	403	6923.7	6924.7	6925.1
Gold Run	42+62	4262	6929.0	-	-	-	-	-	-	117	296	403	6930.7	6931.4	6931.6
Gold Run	43+21	4321	6933.5	-	-	-	-	-	-	117	296	403	6935.7	6936.7	6937.0
Gold Run	44+27	4427	6942.4	-	-	-	-	-	-	117	296	403	6944.8	6946.3	6946.7
Gold Run	45+26	4526	6951.4	-	-	-	-	-	-	117	296	403	6953.3	6953.8	6954.1
Gold Run	46+32	4632	6958.8	-	-	-	-	-	-	117	296	403	6960.9	6961.9	6962.2
Gold Run	46+92	4692	6966.2	-	-	-	-	-	-	117	296	403	6967.6	6968.3	6968.5
Gold Run	47+50	4750		Culvert	-	-	-	-	-						
Gold Run	48+23	4823	6973.0	-	-	-	-	-	-	117	296	403	6977.2	6982.7	6983.0
Gold Run	48+73	4873	6978.0	-	-	-	-	-	-	117	296	403	6979.5	6982.7	6983.0
Gold Run	48+90	4890		Culvert	-	-	-	-	-						
Gold Run	49+01	4901	6980.4	-	-	-	-	-	-	117	296	403	6983.1	6984.0	6984.4
Gold Run	49+42	4942	6983.7	-	-	-	-	-	-	117	296	403	6985.7	6986.5	6986.8
Gold Run	50+73	5073	6996.3	-	-	-	-	-	-	117	296	403	6998.4	6999.1	6999.4
Gold Run	51+94	5194	7012.0	-	-	-	-	-	-	117	296	403	7013.9	7014.8	7015.1
Gold Run	52+97	5297	7022.8	-	-	-	-	-	-	117	296	403	7024.0	7024.9	7025.3
Gold Run	53+35	5335	7025.5	-	-	-	-	-	-	117	296	403	7027.4	7028.0	7028.3
Gold Run	53+50	5350		Culvert	-	-	-	-	-						
Gold Run	53+66	5366	7026.3	-	-	-	-	-	-	117	296	403	7029.4	7030.2	7030.6
Gold Run	54+08	5408	7027.3	-	-	-	-	-	-	117	296	403	7029.5	7030.6	7031.2

Table D.1 Floodplain Data Table – Fourmile Creek and Gold Run

Reference Location	River Station	Cross Section	Thalweg Elevation (ft.)	Regulatory Discharges						CWCB/CDOT Discharges					
				Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)			Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)		
				10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr
Gold Run	55+23	5523	7037.7	-	-	-	-	-	-	117	296	403	7039.5	7040.7	7041.2
Gold Run	56+73	5673	7052.1	-	-	-	-	-	-	117	296	403	7054.3	7055.6	7056.1
Gold Run	58+01	5801	7064.4	-	-	-	-	-	-	117	296	403	7066.4	7067.4	7067.9
Gold Run	58+98	5898	7075.3	-	-	-	-	-	-	117	296	403	7077.0	7077.9	7078.3
Gold Run	60+03	6003	7086.4	-	-	-	-	-	-	117	296	403	7088.3	7089.5	7090.1
Gold Run	60+84	6084	7096.9	-	-	-	-	-	-	117	296	403	7099.5	7100.5	7100.8
Gold Run	61+24	6124	7101.9	-	-	-	-	-	-	117	296	403	7103.1	7103.8	7104.1
Gold Run	62+19	6219	7110.9	-	-	-	-	-	-	117	296	403	7112.1	7113.0	7113.4
Gold Run	63+09	6309	7124.0	-	-	-	-	-	-	117	296	403	7126.4	7128.1	7128.7
Gold Run	63+55	6355	7136.5	-	-	-	-	-	-	117	296	403	7138.4	7139.7	7140.0
Gold Run	64+15	6415	7144.0	-	-	-	-	-	-	117	296	403	7145.5	7146.3	7146.6
Gold Run	64+20	6420		Culvert	-	-	-	-	-						
Gold Run	64+30	6430	7144.8	-	-	-	-	-	-	117	296	403	7146.1	7146.8	7147.4
Gold Run	65+65	6565	7157.6	-	-	-	-	-	-	117	296	403	7159.4	7160.6	7161.4
Gold Run	65+70	6570		Culvert	-	-	-	-	-						
Gold Run	66+00	6600	7162.6	-	-	-	-	-	-	117	296	403	7165.3	7166.3	7166.7
Gold Run	67+21	6721	7172.5	-	-	-	-	-	-	117	296	403	7174.2	7175.2	7175.7
Gold Run	68+85	6885	7188.1	-	-	-	-	-	-	117	296	403	7189.7	7190.6	7191.1
Gold Run	70+38	7038	7202.1	-	-	-	-	-	-	117	296	403	7204.1	7205.2	7205.6
Gold Run	72+10	7210	7212.4	-	-	-	-	-	-	117	296	403	7214.5	7215.6	7216.2
Gold Run	73+51	7351	7225.6	-	-	-	-	-	-	117	296	403	7227.0	7227.9	7228.3
Gold Run	74+17	7417	7237.9	-	-	-	-	-	-	117	296	403	7239.9	7240.9	7241.4
Gold Run	74+65	7465	7242.6	-	-	-	-	-	-	117	296	403	7244.4	7245.4	7245.9
Gold Run	75+77	7577	7258.1	-	-	-	-	-	-	117	296	403	7260.5	7261.8	7262.3
Gold Run	77+21	7721	7288.6	-	-	-	-	-	-	117	296	403	7291.3	7292.7	7293.3
Gold Run	77+88	7788	7297.5	-	-	-	-	-	-	117	296	403	7299.4	7300.6	7300.8
Gold Run	78+00	7800		Culvert	-	-	-	-	-						
Gold Run	78+17	7817	7301.5	-	-	-	-	-	-	117	296	403	7303.4	7304.4	7304.9
Gold Run	78+79	7879	7305.7	-	-	-	-	-	-	117	296	403	7307.2	7308.2	7308.8
Gold Run	80+31	8031	7316.0	-	-	-	-	-	-	117	296	403	7318.7	7320.0	7320.6
Gold Run	81+85	8185	7329.6	-	-	-	-	-	-	117	296	403	7331.5	7332.6	7333.1
Gold Run	83+78	8378	7343.6	-	-	-	-	-	-	117	296	403	7345.9	7346.9	7347.4
Gold Run	85+78	8578	7358.2	-	-	-	-	-	-	117	296	403	7360.2	7361.3	7361.8

Table D.1 Floodplain Data Table – Fourmile Creek and Gold Run																
				Regulatory Discharges						CWCB/CDOT Discharges						
				Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)			Peak Discharge (cfs)			Water Surface Elevation (ft-NAVD88)			
Reference Location	River Station	Cross Section	Thalweg Elevation (ft.)	10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr	10yr	50yr	100yr	
Gold Run	87+56	8756	7371.0	-	-	-	-	-	-	117	296	403	7372.7	7373.9	7374.4	
Gold Run	88+04	8804	7376.1	-	-	-	-	-	-	117	296	403	7378.0	7378.8	7379.2	
Gold Run	89+67	8967	7389.4	-	-	-	-	-	-	117	296	403	7391.5	7392.2	7392.5	
Gold Run	91+55	9155	7402.1	-	-	-	-	-	-	117	296	403	7404.2	7405.3	7405.7	


FOURMILE CREEK WATERSHED POST-FLOOD RISK ANALYSIS
REACH 1
MAP 1 OF 4
LEGEND
Mile Marker
Bridges/Culverts
Post-Event Creek
Roads
XS Cutlines
CDOT-CWCB Discharges 100yr Floodplain
Regulatory Discharges 100yr Floodplain
FEMA 100yr Floodplain
Structures at Risk
Structure Footprints
Parcels
0
200
Feet
Michael Baker INTERNATIONAL
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100
LOCATOR MAP
JAMESTOWN
WARD
BOULDER
NEDERLAND
HYDRAULIC ANALYSIS RESULTS
FOURMILE CANYON DR
2068.22
1962.34
1877.71
1761.43
1731.9
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1630.85
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692.317
520.764
348.852
183.788
21.1209
381
347
297
265
350
0

FOURMILE CREEK WATERSHED POST-FLOOD RISK ANALYSIS
REACH 1
MAP 2 OF 4
LEGEND
Mile Marker
Bridges/Culverts
Post-Event Creek
Roads
XS Cutlines
CDOT-CWCB Discharges 100yr Floodplain
Regulatory Discharges 100yr Floodplain
FEMA 100yr Floodplain
Structures at Risk
Structure Footprints
Parcels
0
200
Feet
Michael Baker INTERNATIONAL
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100
LOCATOR MAP
JAMESTOWN
WARD
BOULDER
NEDERLAND
HYDRAULIC ANALYSIS RESULTS
FOURMILE CANYON DR
4439.13
4417.35
4296.96
4130.18
3967.42
3865.47
3809.66
3661.75
3602.74
3561.82
3367.3
3180.19
3147.16
2975.57
2743.01
2516.41
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2269.99
2213.24
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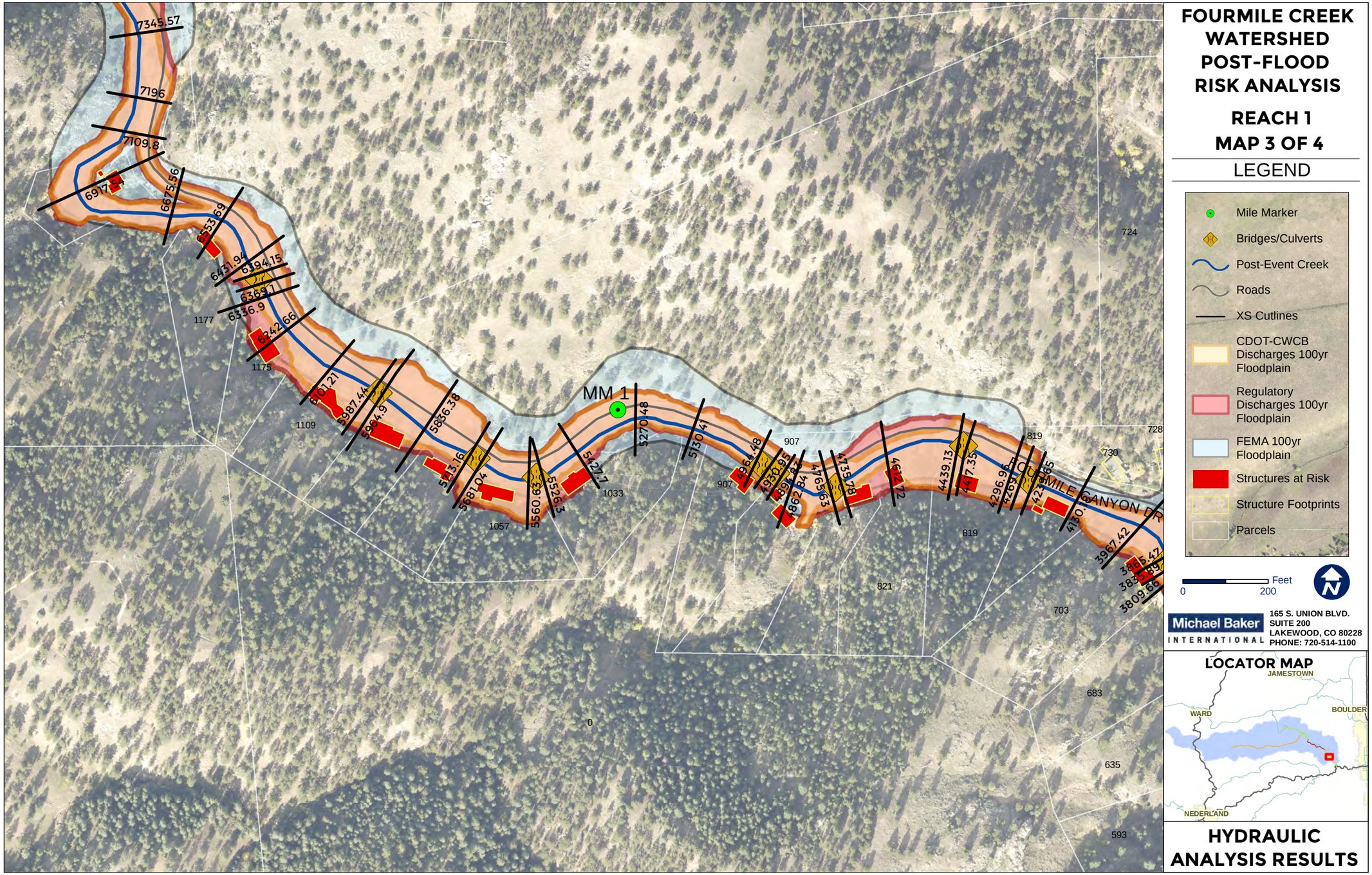
2068.22
2012.89
1962.34
1877.71


FOURMILE CREEK WATERSHED POST-FLOOD RISK ANALYSIS
REACH 1
MAP 3 OF 4
LEGEND
Mile Marker
Bridges/Culverts
Post-Event Creek
Roads
XS Cutlines
CDOT-CWCB Discharges 100yr Floodplain
Regulatory Discharges 100yr Floodplain
FEMA 100yr Floodplain
Structures at Risk
Structure Footprints
Parcels
0
200
Feet
Michael Baker INTERNATIONAL
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100
LOCATOR MAP
JAMESTOWN
WARD
BOULDER
NEDERLAND
HYDRAULIC ANALYSIS RESULTS
MM 1
7345.57
7196
7109.8
6917.54
6675.56
6553.69
6431.94
6394.15
6363.1
6336.9
6242.66
6101.21
5987.44
5964.9
5836.38
5713.16
5681.04
5560.63
5526.3
5427.7
5270.48
5130.41
4964.48
4931.95
4891.42
4862.84
4765.63
4735.78
4612.72
4439.13
4417.35
4296.96
4269.71
4230.85
4130.16
3967.42
3865.47
3835.89
3809.66
1177
1175
1109
1057
1033
907
819
821
703
683
635
593
0
724
728
730

FOURMILE CREEK WATERSHED POST-FLOOD RISK ANALYSIS
REACH 1
MAP 4 OF 4
LEGEND
Mile Marker
Bridges/Culverts
Post-Event Creek
Roads
XS Cutlines
CDOT-CWCB Discharges 100yr Floodplain
Regulatory Discharges 100yr Floodplain
FEMA 100yr Floodplain
Structures at Risk
Structure Footprints
Parcels
Feet
0
200
Michael Baker INTERNATIONAL
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100
LOCATOR MAP
JAMESTOWN
WARD
BOULDER
NEDERLAND
HYDRAULIC ANALYSIS RESULTS
FOURMILE CANYON DR
POORMAN RD
POORMAN RD
10158
9976.76
9843.06
9658.71
9505.22
9482.08
9440.1
9270.42
9131.54
8995.88
8825.02
8642.63
8469.41
8265.71
8106.9
7973.32
7891.18
7807.43
7698.87
7499.14
7345.57
7196
2179
1767
1767
1689
1687
1687
1747
1685
1708
1665
1685
1653
1653
1311
1311
1555
1878
1830
1830
0

FOURMILE CREEK WATERSHED POST-FLOOD RISK ANALYSIS
REACH 2
MAP 1 OF 4
LEGEND
Mile Marker
Bridges/Culverts
Post-Event Creek
Roads
XS Cutlines
CDOT-CWCB Discharges 100yr Floodplain
Regulatory Discharges 100yr Floodplain
FEMA 100yr Floodplain
Structures at Risk
Structure Footprints
Parcels
0
200
Feet
Michael Baker INTERNATIONAL
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100
LOCATOR MAP
JAMESTOWN
WARD
BOULDER
NEDERLAND
HYDRAULIC ANALYSIS RESULTS
FOURMILE CANYON DR
POORMAN RD
MM 2
13041.9
12877.3
12701.7
12483.4
12331.6
12204.1
12079.7
11931.2
11776.9
11608.3
11405.3
11182.8
10972.1
10826.2
10639.8
10407.1
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2167
2179
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1996
1878
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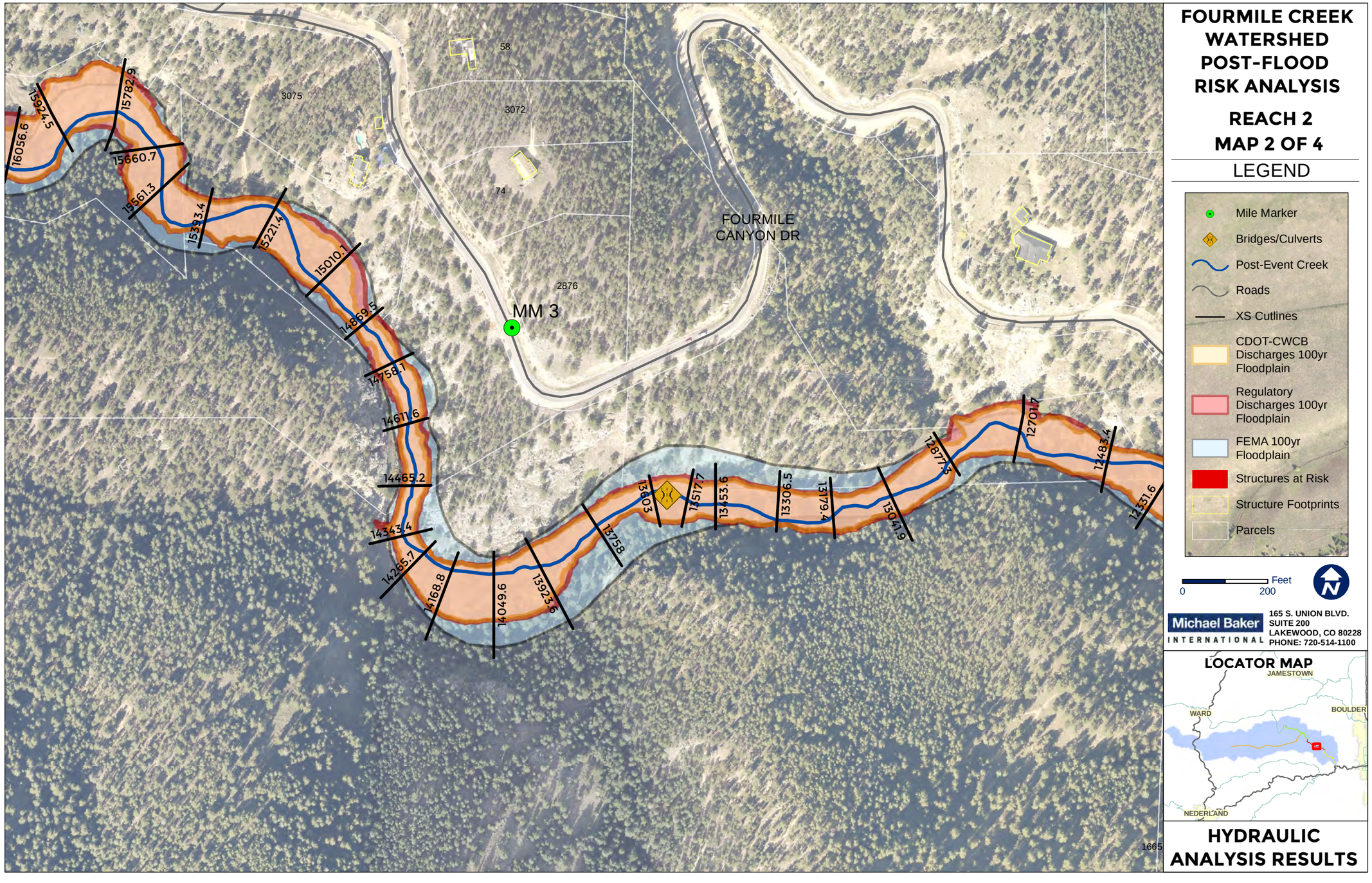
1687
1747


FOURMILE CREEK WATERSHED POST-FLOOD RISK ANALYSIS
REACH 2
MAP 2 OF 4
LEGEND
Mile Marker
Bridges/Culverts
Post-Event Creek
Roads
XS Cutlines
CDOT-CWCB Discharges 100yr Floodplain
Regulatory Discharges 100yr Floodplain
FEMA 100yr Floodplain
Structures at Risk
Structure Footprints
Parcels
0
200
Feet
Michael Baker INTERNATIONAL
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100
LOCATOR MAP
JAMESTOWN
WARD
BOULDER
NEDERLAND
HYDRAULIC ANALYSIS RESULTS
FOURMILE CANYON DR
MM 3
58
3075
3072
74
2876
1665
16056.6
15924.5
15782.9
15660.7
15561.3
15393.4
15221.4
15010.1
14869.5
14758.1
14611.6
14465.2
14343.4
14265.7
14168.8
14049.6
13923.6
13758
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13517.7
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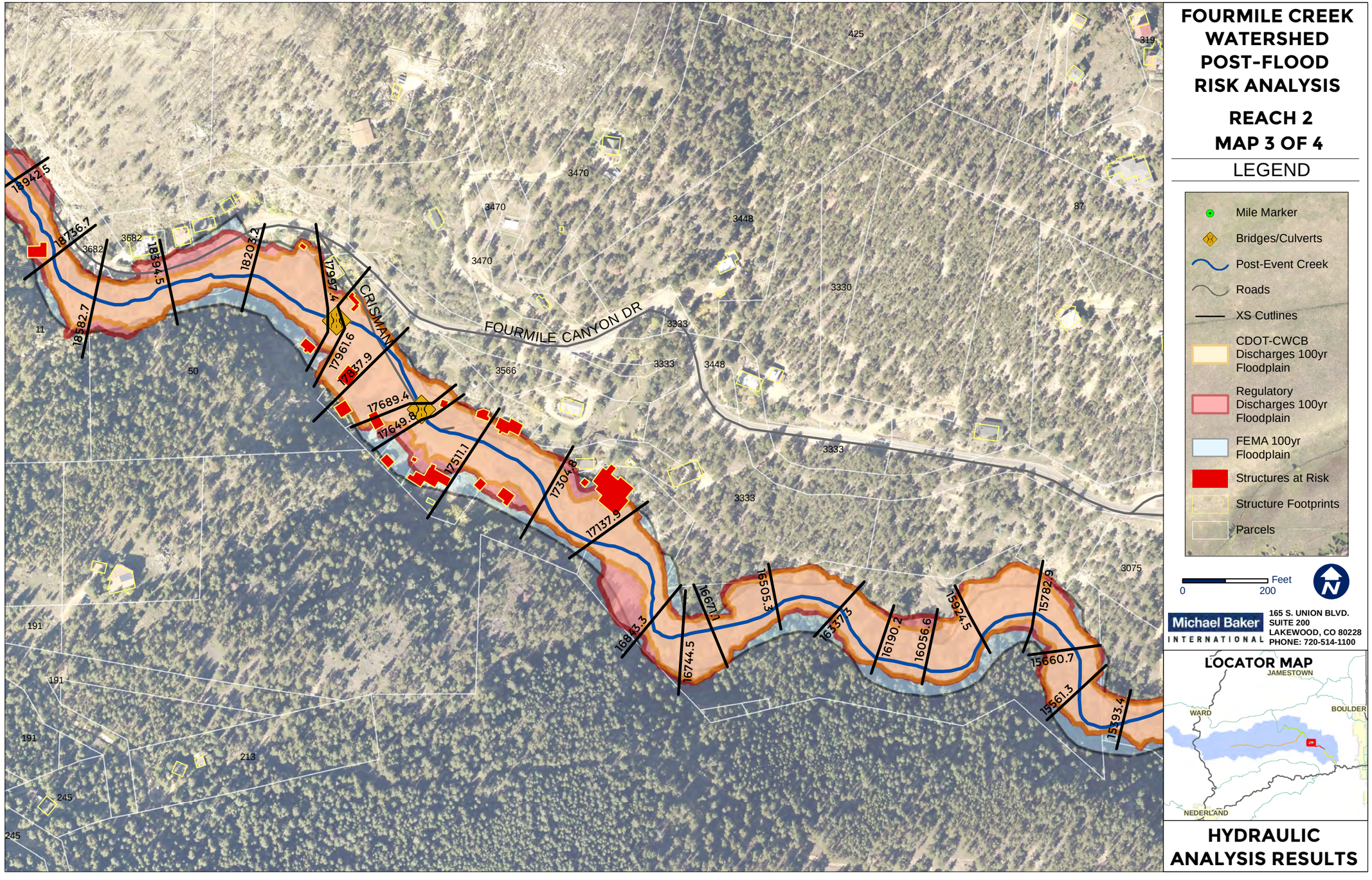
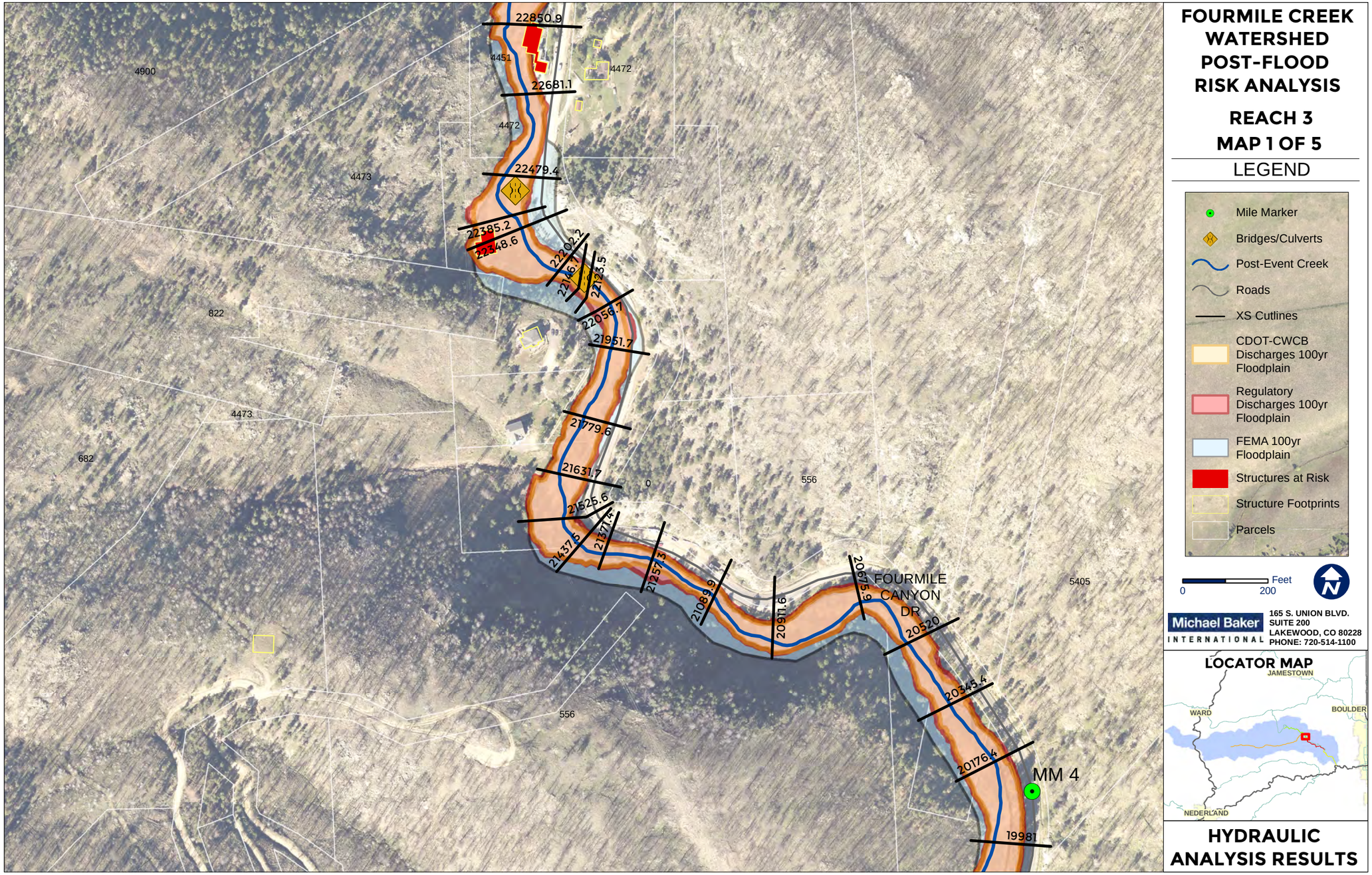

FOURMILE CREEK WATERSHED POST-FLOOD RISK ANALYSIS
REACH 2
MAP 3 OF 4
LEGEND
Mile Marker
Bridges/Culverts
Post-Event Creek
Roads
XS Cutlines
CDOT-CWCB Discharges 100yr Floodplain
Regulatory Discharges 100yr Floodplain
FEMA 100yr Floodplain
Structures at Risk
Structure Footprints
Parcels
0
200
Feet
Michael Baker INTERNATIONAL
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100
LOCATOR MAP
JAMESTOWN
WARD
BOULDER
NEDERLAND
HYDRAULIC ANALYSIS RESULTS
FOURMILE CANYON DR
CRISMAN
18942.5
18736.7
18582.7
18394.5
18203.2
17997.4
17961.6
17837.9
17689.4
17649.8
17511.1
17304.8
17137.9
16843.3
16744.5
16671.1
16505.3
16337.3
16190.2
16056.6
15924.5
15782.9
15660.7
15561.3
15393.4

FOURMILE CREEK WATERSHED POST-FLOOD RISK ANALYSIS
REACH 2
MAP 4 OF 4
LEGEND
Mile Marker
Bridges/Culverts
Post-Event Creek
Roads
XS Cutlines
CDOT-CWCB Discharges 100yr Floodplain
Regulatory Discharges 100yr Floodplain
FEMA 100yr Floodplain
Structures at Risk
Structure Footprints
Parcels
0
200
Feet
Michael Baker INTERNATIONAL
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100
LOCATOR MAP
JAMESTOWN
WARD
BOULDER
NEDERLAND
HYDRAULIC ANALYSIS RESULTS
MM 4
20345.4
20176.4
19981
19796.1
19663.5
19466.3
19323.1
19266.8
19186.6
19126.9
18942.5
18736.7
18582.7
18394.5
18203.2
17997.4
17961.6
17837.9
17689.4
17649.8
17511.1
FOURMILE CANYON DR
CRISMAN
LOGAN MILL RD
556
5405
503
320
466
371
670
425
165
155
11
50
3682
3470
3566


FOURMILE CREEK WATERSHED POST-FLOOD RISK ANALYSIS
REACH 3
MAP 1 OF 5
LEGEND
Mile Marker
Bridges/Culverts
Post-Event Creek
Roads
XS Cutlines
CDOT-CWCB Discharges 100yr Floodplain
Regulatory Discharges 100yr Floodplain
FEMA 100yr Floodplain
Structures at Risk
Structure Footprints
Parcels
0
200
Feet
Michael Baker INTERNATIONAL
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100
LOCATOR MAP
JAMESTOWN
WARD
BOULDER
NEDERLAND
HYDRAULIC ANALYSIS RESULTS
22850.9
22681.1
22479.4
22385.2
22348.6
22202.2
22146.7
22123.5
22056.7
21951.7
21779.6
21631.7
21525.6
21437.5
21371.4
21257.3
21089.9
20911.6
20695.9
20520
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20176.4
19981
FOURMILE CANYON DR
MM 4
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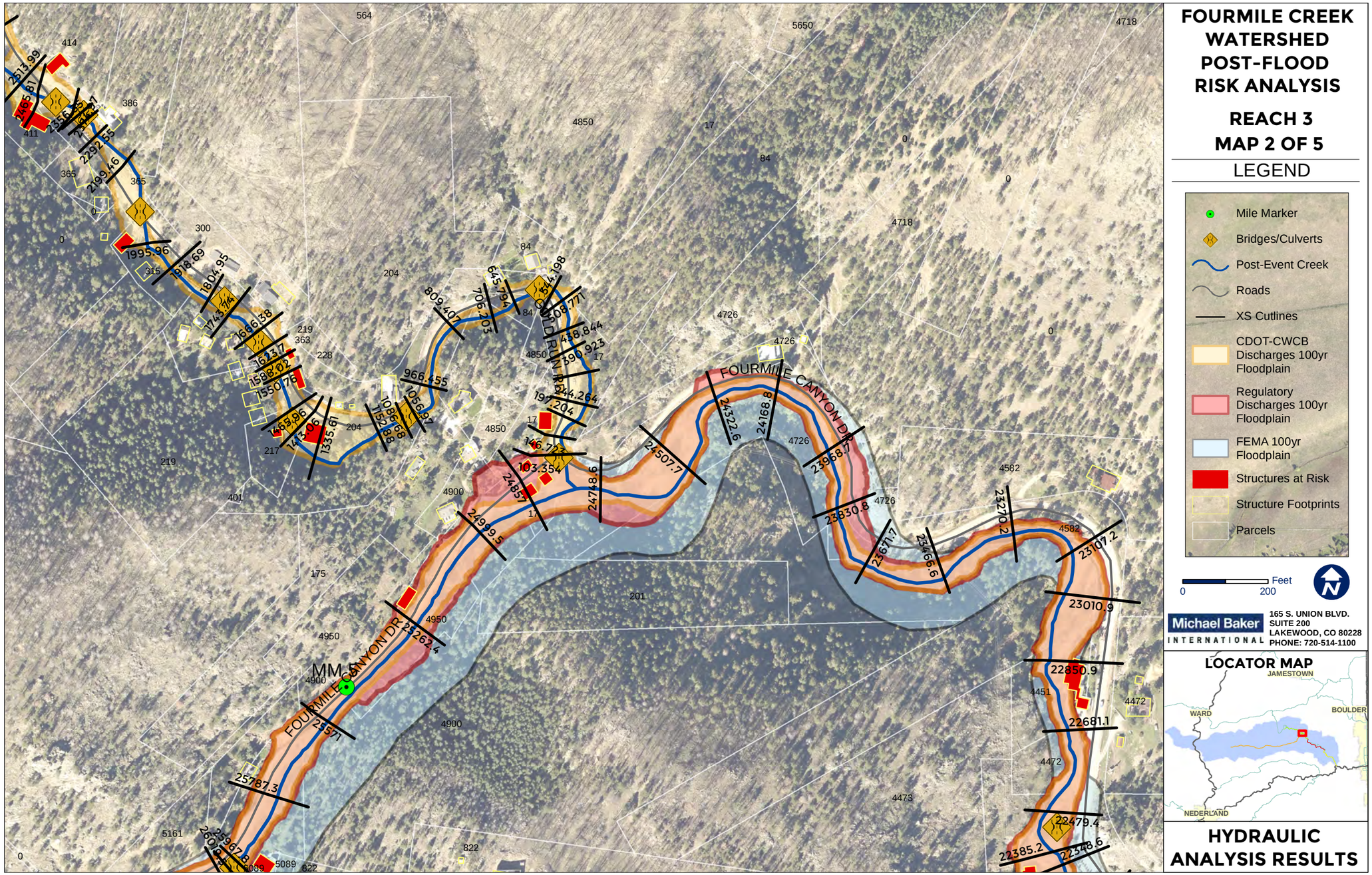
4472
4473
822
682
556
0
5405


FOURMILE CREEK WATERSHED POST-FLOOD RISK ANALYSIS
REACH 3
MAP 2 OF 5
LEGEND
Mile Marker
Bridges/Culverts
Post-Event Creek
Roads
XS Cutlines
CDOT-CWCB Discharges 100yr Floodplain
Regulatory Discharges 100yr Floodplain
FEMA 100yr Floodplain
Structures at Risk
Structure Footprints
Parcels
0
200
Feet
Michael Baker INTERNATIONAL
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100
LOCATOR MAP
JAMESTOWN
WARD
BOULDER
NEDERLAND
HYDRAULIC ANALYSIS RESULTS
FOURMILE CANYON DR
MM

FOURMILE CREEK WATERSHED POST-FLOOD RISK ANALYSIS
REACH 3
MAP 3 OF 5
LEGEND
Mile Marker
Bridges/Culverts
Post-Event Creek
Roads
XS Cutlines
CDOT-CWCB Discharges 100yr Floodplain
Regulatory Discharges 100yr Floodplain
FEMA 100yr Floodplain
Structures at Risk
Structure Footprints
Parcels
0
200
Feet
Michael Baker INTERNATIONAL
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100
LOCATOR MAP
JAMESTOWN
WARD
BOULDER
NEDERLAND
HYDRAULIC ANALYSIS RESULTS
GOLD RUN RD
5513.22
5408.38
5365.81
5334.55
5297.08
5194.04
5072.99
4942.27
4901.45
4875.21
4825.35
4692.02
4632.42
4525.57
4427.37
4321.38
4261.89
4202.93
4049.89
3911.38
3871.19
3774.89
3706.94
3686.28
3592.4
3493.74
3387
3224.83
3074.84
2962.18
2868.57
2807.65
2770
2654.62
2513.99
2465.81
2356.32
2292.55
2199.46
1995.96
1915.59

FOURMILE CREEK WATERSHED POST-FLOOD RISK ANALYSIS
REACH 3
MAP 4 OF 5
LEGEND
Mile Marker
Bridges/Culverts
Post-Event Creek
Roads
XS Cutlines
CDOT-CWCB Discharges 100yr Floodplain
Regulatory Discharges 100yr Floodplain
FEMA 100yr Floodplain
Structures at Risk
Structure Footprints
Parcels
0
200
Feet
Michael Baker INTERNATIONAL
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100
LOCATOR MAP
JAMESTOWN
WARD
BOULDER
NEDERLAND
HYDRAULIC ANALYSIS RESULTS
GOLD RUN RD
MM 1
8755.82
8577.96
8378.2
8185.05
8030.67
7879.04
7817.41
7787.76
7721.18
7577.07
7465.06
7417.09
7351.34
7209.78
7037.79
6885.74
6721.39
6591.35
6536.57
6429.9
6414.74
6354.88
6309.23
6219.17
6124.01
6083.88
6003.29
5898.04
5800.01
5672.96
5523.22
5408.38
5334.55
5297.08

FOURMILE CREEK WATERSHED POST-FLOOD RISK ANALYSIS

REACH 3
MAP 5 OF 5

LEGEND

- Mile Marker
- Bridges/Culverts
- Post-Event Creek
- Roads
- XS Cutlines
- CDOT-CWCB Discharges 100yr Floodplain
- Regulatory Discharges 100yr Floodplain
- FEMA 100yr Floodplain
- Structures at Risk
- Structure Footprints
- Parcels

0 200 Feet

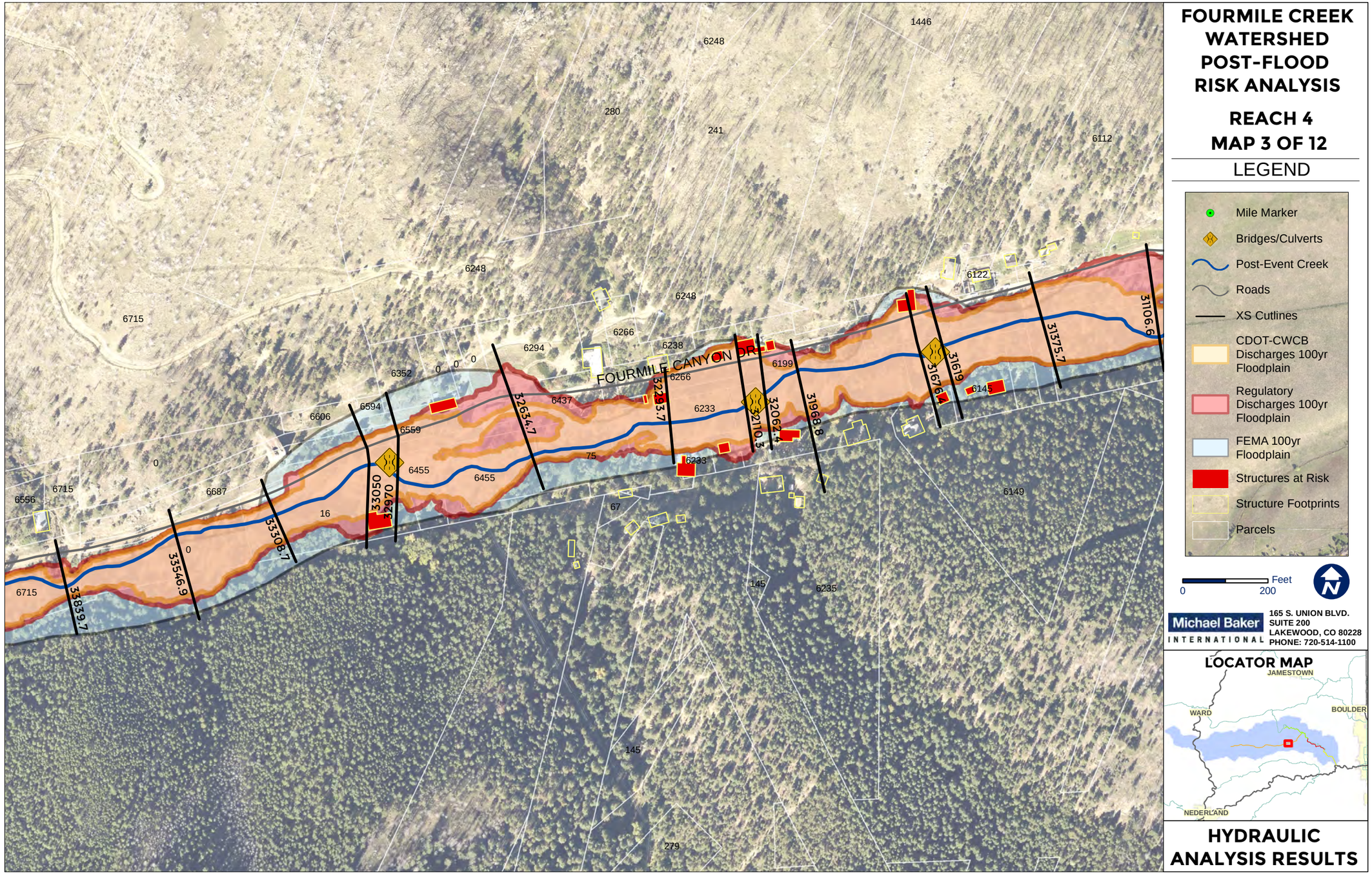
Michael Baker INTERNATIONAL
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100

LOCATOR MAP

HYDRAULIC ANALYSIS RESULTS

FOURMILE CREEK WATERSHED POST-FLOOD RISK ANALYSIS
REACH 4
MAP 1 OF 12
LEGEND
Mile Marker
Bridges/Culverts
Post-Event Creek
Roads
XS Cutlines
CDOT-CWCB Discharges 100yr Floodplain
Regulatory Discharges 100yr Floodplain
FEMA 100yr Floodplain
Structures at Risk
Structure Footprints
Parcels
0
200
Feet
Michael Baker INTERNATIONAL
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100
LOCATOR MAP
JAMESTOWN
WARD
BOULDER
NEDERLAND
HYDRAULIC ANALYSIS RESULTS
FOURMILE CANYON DR
25787.3
25967.8
26019.5
26255.8
26399.3
26419.5
26483.2
26587.9
26716
26985
27295.8
27382.5
27609.6
27760.5
27837.1
27861.6
27931.2
28218.3
175
4900
0
5161
5089
822
5161
5216
5216
5311
5311
5093
682
5411
5460
450
398
579
5411
5780
5780
5851

FOURMILE CREEK WATERSHED POST-FLOOD RISK ANALYSIS
REACH 4
MAP 2 OF 12
LEGEND
Mile Marker
Bridges/Culverts
Post-Event Creek
Roads
XS Cutlines
CDOT-CWCB Discharges 100yr Floodplain
Regulatory Discharges 100yr Floodplain
FEMA 100yr Floodplain
Structures at Risk
Structure Footprints
Parcels
Feet
0
200
Michael Baker INTERNATIONAL
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100
LOCATOR MAP
JAMESTOWN
WARD
BOULDER
NEDERLAND
HYDRAULIC ANALYSIS RESULTS
MM 6
28573.6
28898.2
29165.8
29258.6
29451
29786.8
30060.6
30115.8
30434.1
30770.4
31106.6
31375.7
ESCARE RT


FOURMILE CREEK WATERSHED POST-FLOOD RISK ANALYSIS
REACH 4
MAP 3 OF 12
LEGEND
Mile Marker
Bridges/Culverts
Post-Event Creek
Roads
XS Cutlines
CDOT-CWCB Discharges 100yr Floodplain
Regulatory Discharges 100yr Floodplain
FEMA 100yr Floodplain
Structures at Risk
Structure Footprints
Parcels
0
200
Feet
Michael Baker INTERNATIONAL
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100
LOCATOR MAP
JAMESTOWN
WARD
BOULDER
NEDERLAND
HYDRAULIC ANALYSIS RESULTS
FOURMILE CANYON DR
33839.7
33546.9
33308.7
33050
32970
32634.7
32293.7
32110.3
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31968.8
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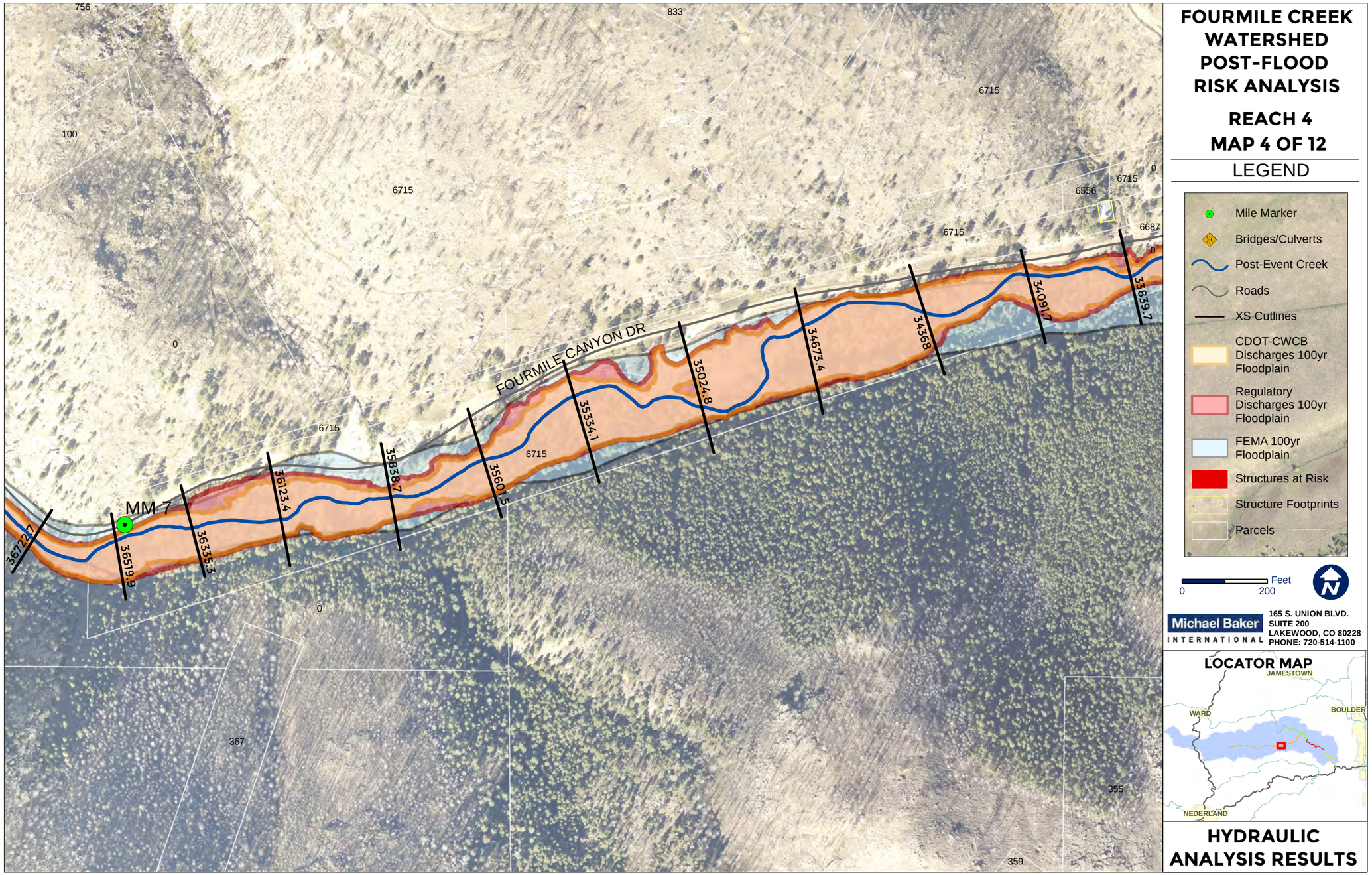
31106.6


FOURMILE CREEK WATERSHED POST-FLOOD RISK ANALYSIS
REACH 4
MAP 4 OF 12
LEGEND
Mile Marker
Bridges/Culverts
Post-Event Creek
Roads
XS Cutlines
CDOT-CWCB Discharges 100yr Floodplain
Regulatory Discharges 100yr Floodplain
FEMA 100yr Floodplain
Structures at Risk
Structure Footprints
Parcels
0
200
Feet
Michael Baker INTERNATIONAL
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100
LOCATOR MAP
JAMESTOWN
WARD
BOULDER
NEDERLAND
HYDRAULIC ANALYSIS RESULTS
FOURMILE CANYON DR
MM 7
36722.7
36519.9
36335.3
36123.4
35838.7
35601.5
35334.1
35024.8
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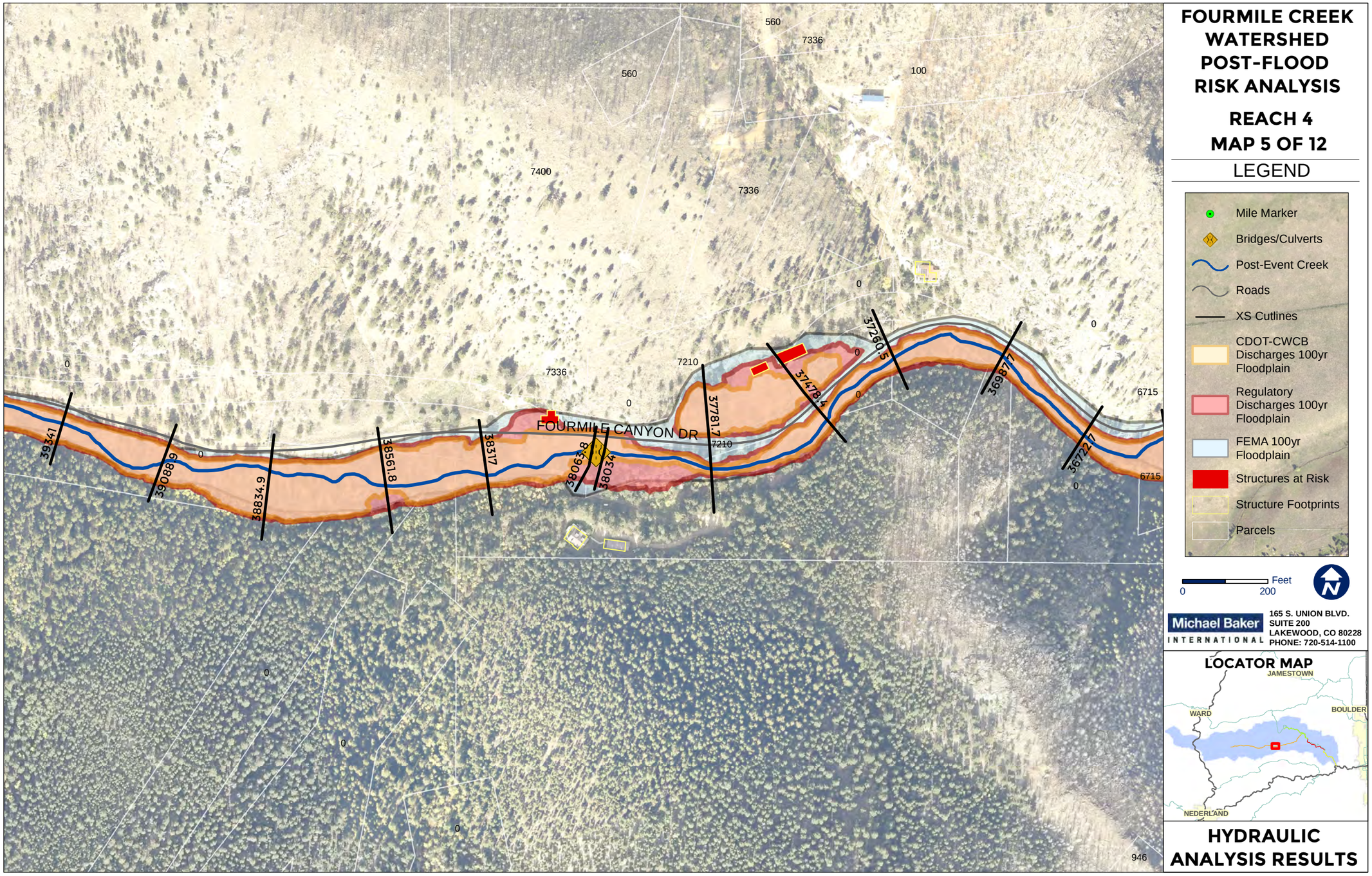
FOURMILE CREEK WATERSHED POST-FLOOD RISK ANALYSIS
REACH 4
MAP 5 OF 12
LEGEND
Mile Marker
Bridges/Culverts
Post-Event Creek
Roads
XS Cutlines
CDOT-CWCB Discharges 100yr Floodplain
Regulatory Discharges 100yr Floodplain
FEMA 100yr Floodplain
Structures at Risk
Structure Footprints
Parcels
Feet
0
200
Michael Baker INTERNATIONAL
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100
LOCATOR MAP
JAMESTOWN
WARD
BOULDER
NEDERLAND
HYDRAULIC ANALYSIS RESULTS
FOURMILE CANYON DR
39341
39088.9
38834.9
38561.8
38317
38063.8
38034
37781.7
37478.4
37260.5
36987.7
36722.7
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7336
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7210
6715
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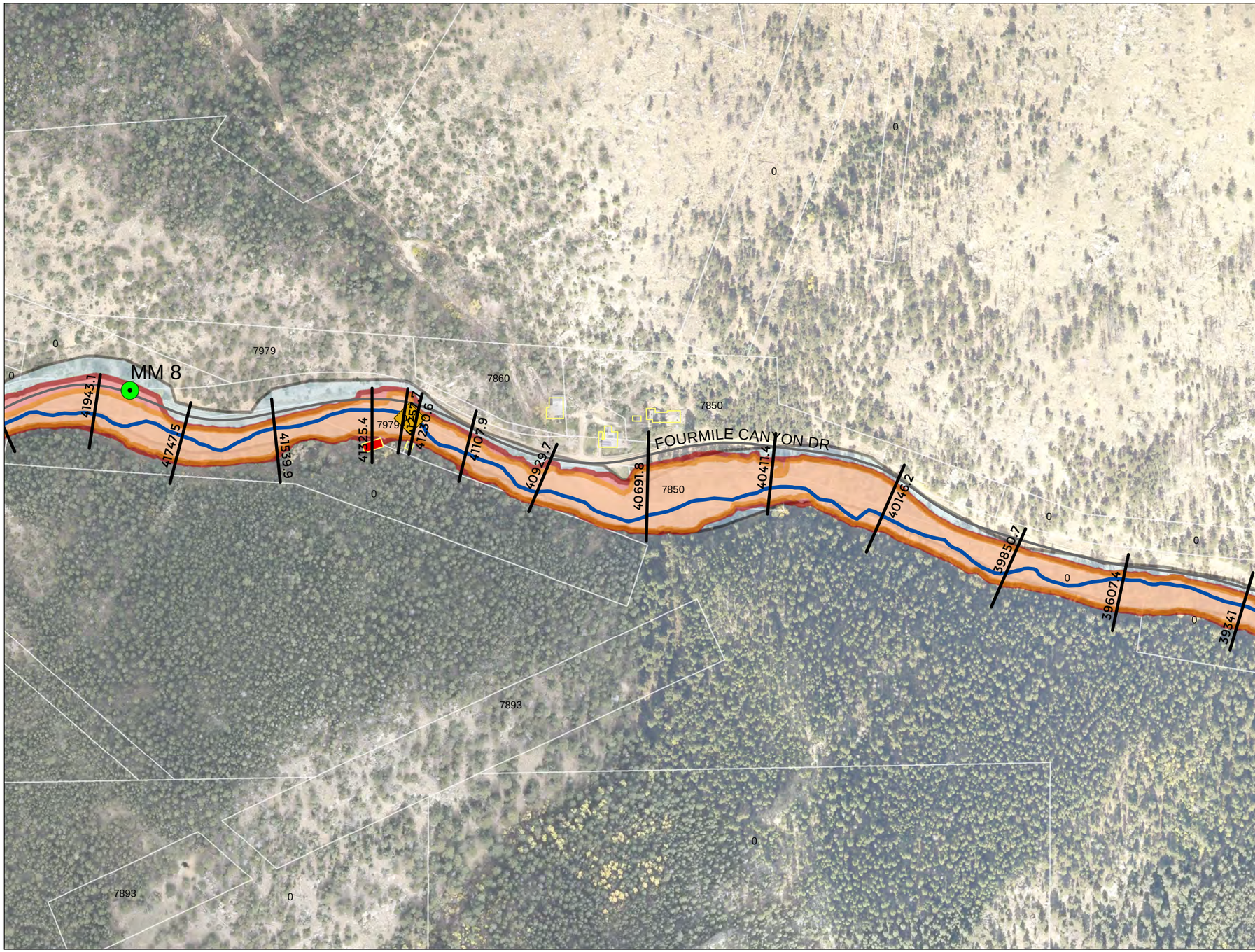


FOURMILE CREEK WATERSHED POST-FLOOD RISK ANALYSIS

REACH 4
MAP 6 OF 12

LEGEND

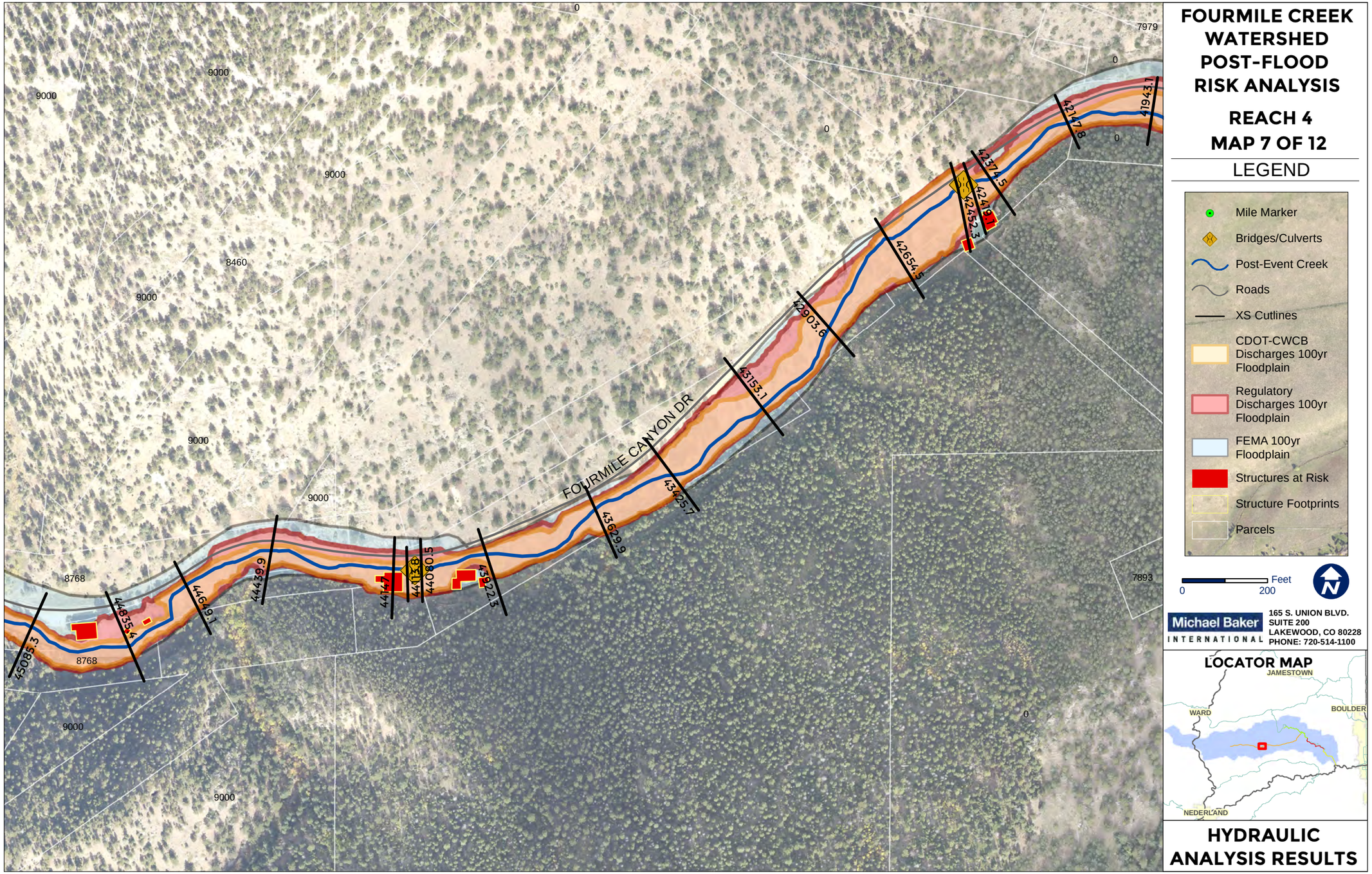
- Mile Marker
- Bridges/Culverts
- Post-Event Creek
- Roads
- XS Cutlines
- CDOT-CWCB Discharges 100yr Floodplain
- Regulatory Discharges 100yr Floodplain
- FEMA 100yr Floodplain
- Structures at Risk
- Structure Footprints
- Parcels

0 200 Feet

Michael Baker INTERNATIONAL
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100

LOCATOR MAP

HYDRAULIC ANALYSIS RESULTS


FOURMILE CREEK WATERSHED POST-FLOOD RISK ANALYSIS
REACH 4
MAP 7 OF 12
LEGEND
Mile Marker
Bridges/Culverts
Post-Event Creek
Roads
XS Cutlines
CDOT-CWCB Discharges 100yr Floodplain
Regulatory Discharges 100yr Floodplain
FEMA 100yr Floodplain
Structures at Risk
Structure Footprints
Parcels
0
200
Feet
Michael Baker INTERNATIONAL
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100
LOCATOR MAP
JAMESTOWN
WARD
BOULDER
NEDERLAND
HYDRAULIC ANALYSIS RESULTS
FOURMILE CANYON DR
45085.3
44855.4
44649.1
44439.9
44147
44138
44080.5
43922.3
43629.9
43425.7
43153.1
42903.6
42654.5
42452.3
42419.1
42374.5
42147.8
41943.1
9000
8460
8768
7979
7893
0

FOURMILE CREEK WATERSHED POST-FLOOD RISK ANALYSIS
REACH 4
MAP 8 OF 12
LEGEND
Mile Marker
Bridges/Culverts
Post-Event Creek
Roads
XS Cutlines
CDOT-CWCB Discharges 100yr Floodplain
Regulatory Discharges 100yr Floodplain
FEMA 100yr Floodplain
Structures at Risk
Structure Footprints
Parcels
0
200
Feet
Michael Baker INTERNATIONAL
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100
LOCATOR MAP
JAMESTOWN
WARD
BOULDER
NEDERLAND
HYDRAULIC ANALYSIS RESULTS
MM 9
FOURMILE CANYON DR
48105.2
48022.1
47985.3
47831.9
47744.6
47713
47540.8
47246.4
46942.6
46689.7
46523.3
46452.4
46218.4
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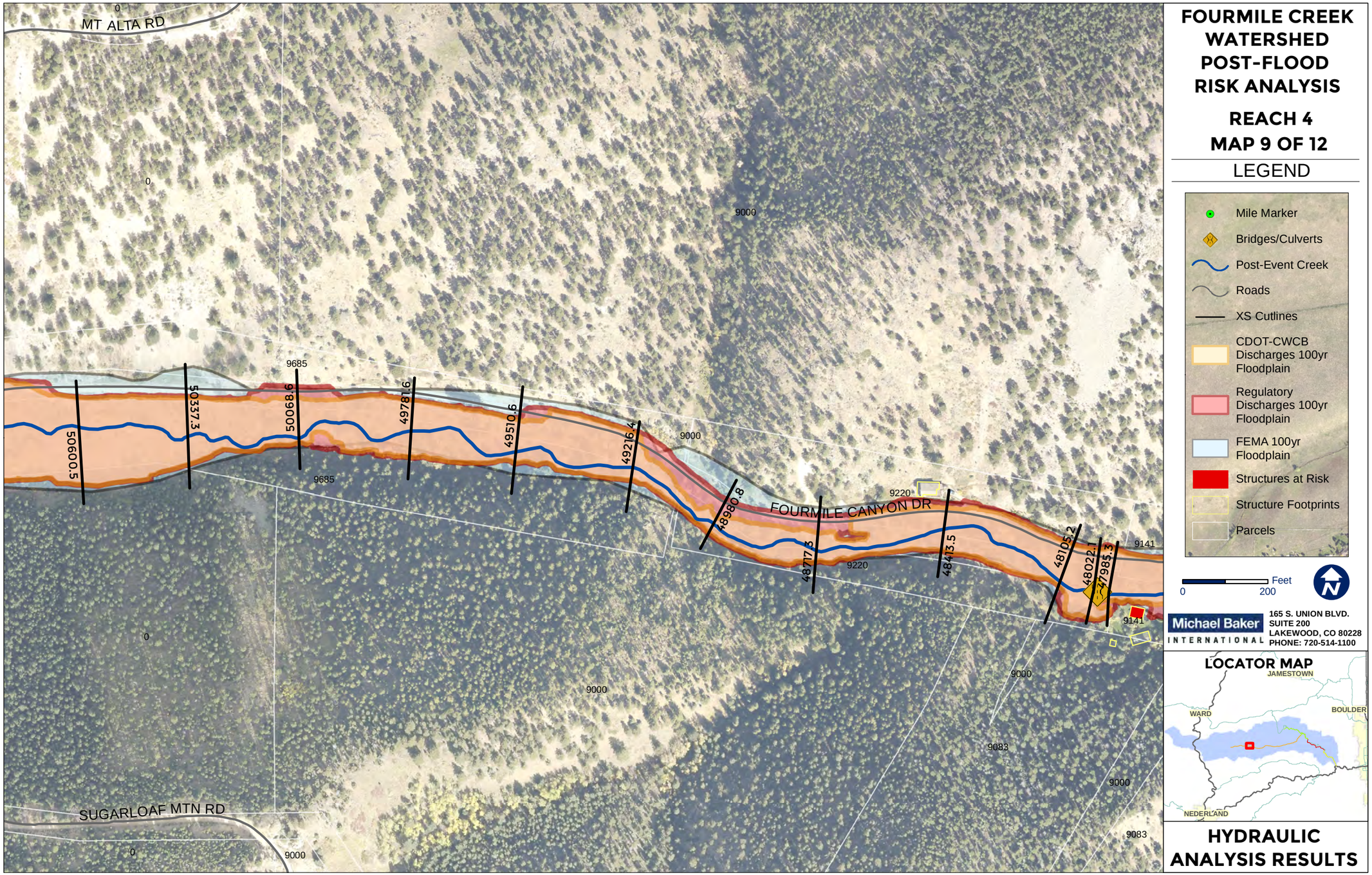
FOURMILE CREEK WATERSHED POST-FLOOD RISK ANALYSIS
REACH 4
MAP 9 OF 12
LEGEND
Mile Marker
Bridges/Culverts
Post-Event Creek
Roads
XS Cutlines
CDOT-CWCB Discharges 100yr Floodplain
Regulatory Discharges 100yr Floodplain
FEMA 100yr Floodplain
Structures at Risk
Structure Footprints
Parcels
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200
Feet
Michael Baker INTERNATIONAL
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100
LOCATOR MAP
JAMESTOWN
WARD
BOULDER
NEDERLAND
HYDRAULIC ANALYSIS RESULTS
MT ALTA RD
FOURMILE CANYON DR
SUGARLOAF MTN RD
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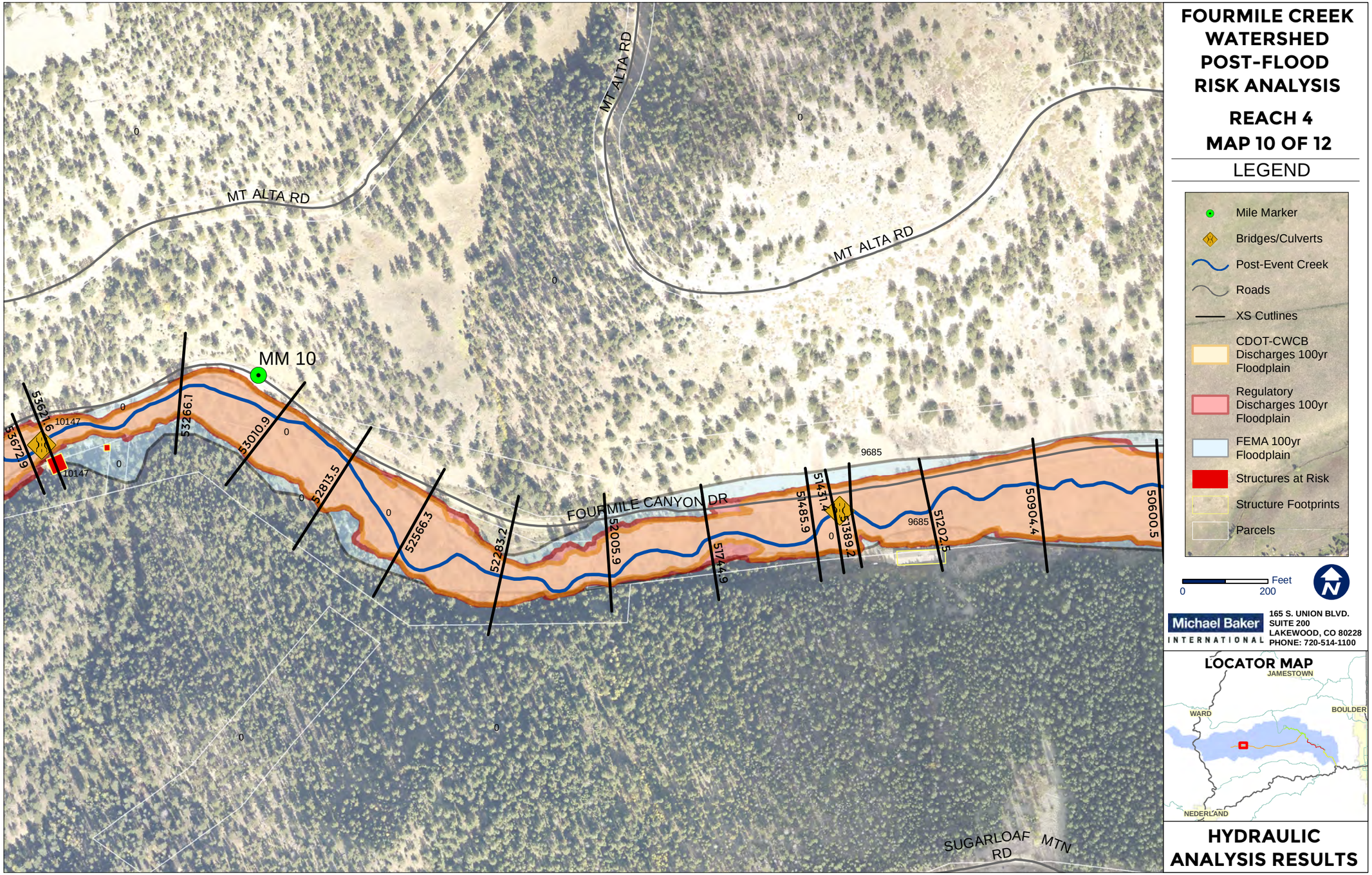
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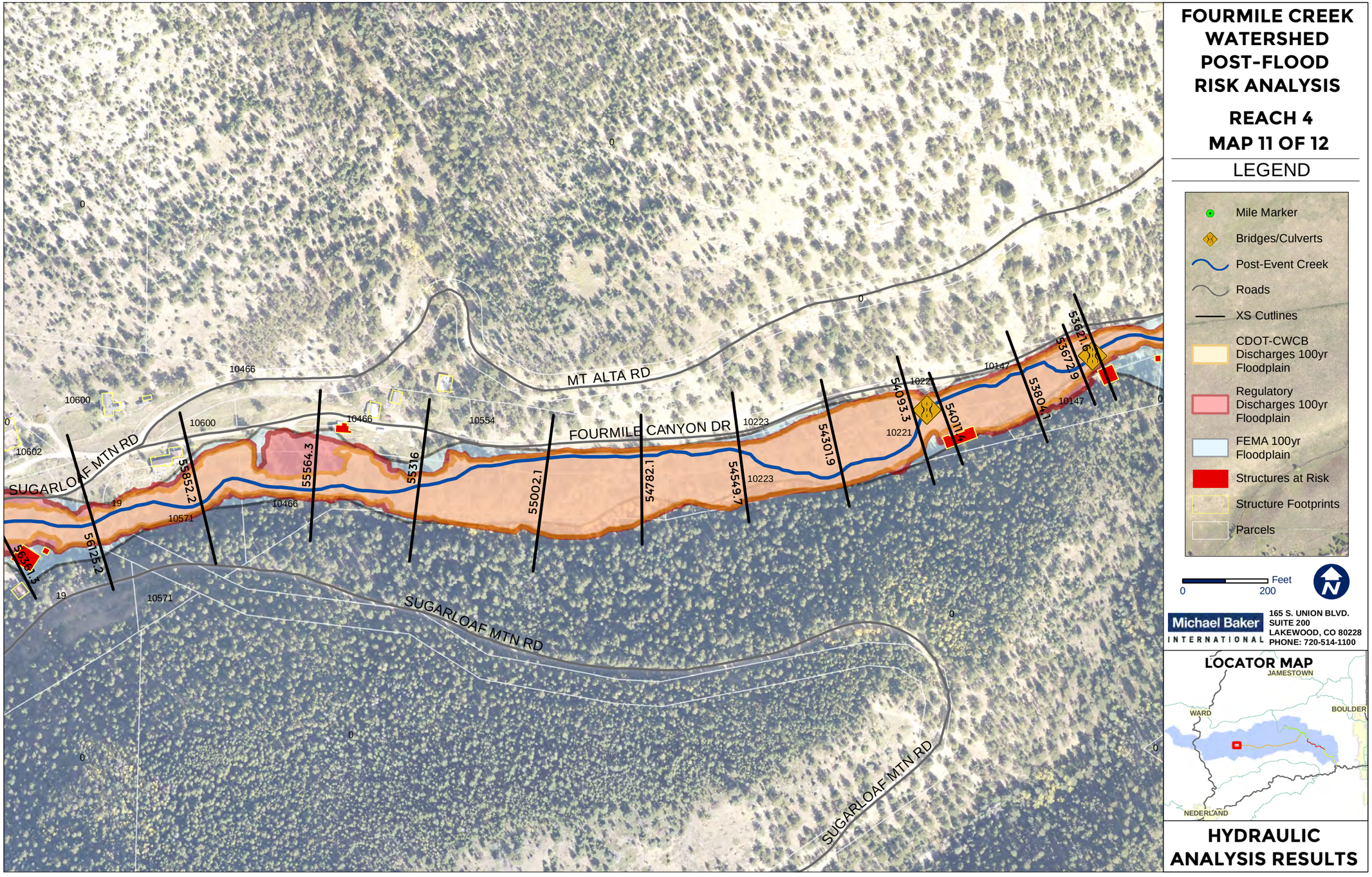
FOURMILE CREEK WATERSHED POST-FLOOD RISK ANALYSIS
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MAP 11 OF 12
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HYDRAULIC ANALYSIS RESULTS
MT ALTA RD
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SUGARLOAF MTN RD
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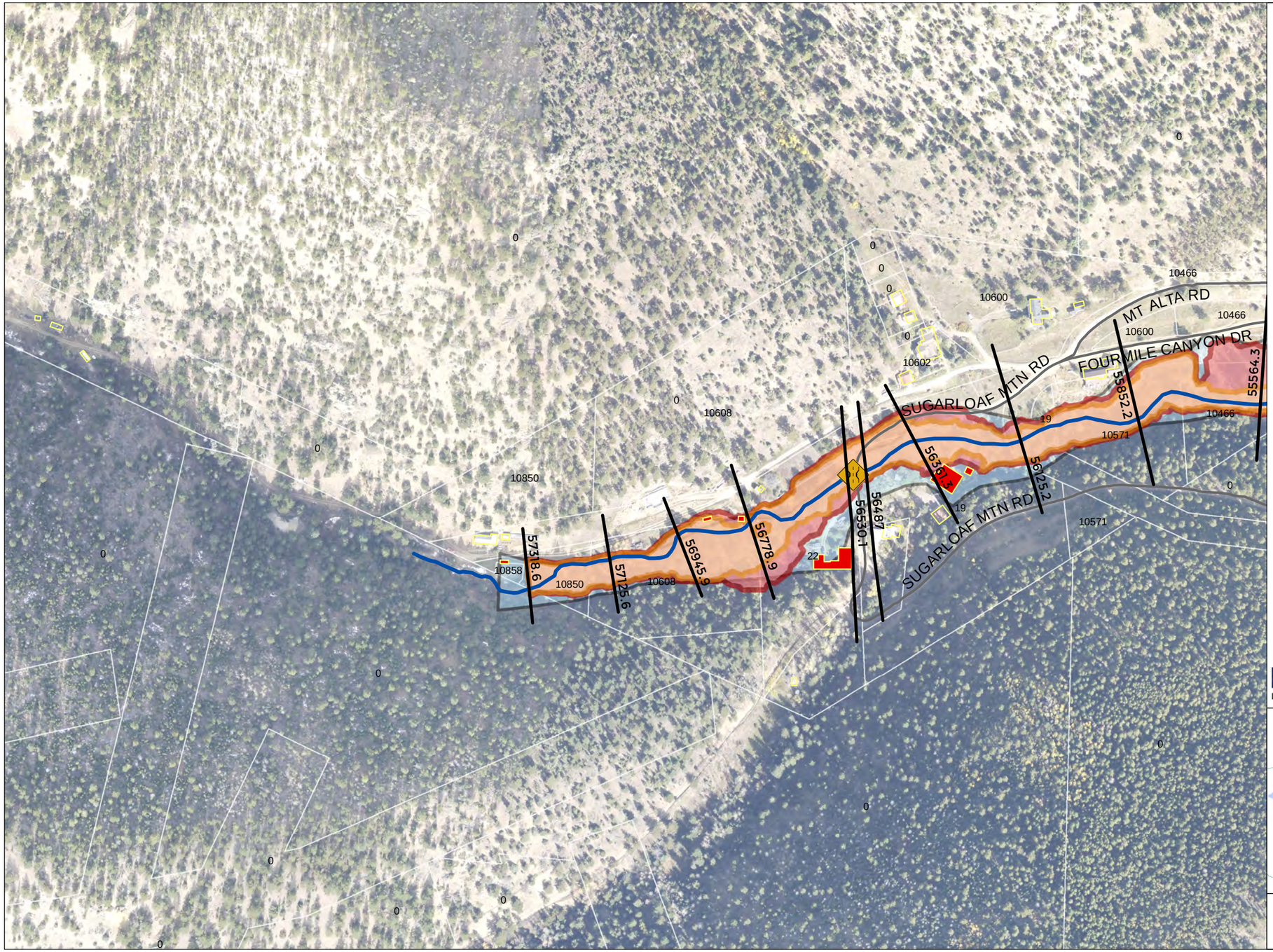

FOURMILE CREEK WATERSHED POST-FLOOD RISK ANALYSIS

REACH 4
MAP 12 OF 12

LEGEND

- Mile Marker
- Bridges/Culverts
- Post-Event Creek
- Roads
- XS Cutlines
- CDOT-CWCB Discharges 100yr Floodplain
- Regulatory Discharges 100yr Floodplain
- FEMA 100yr Floodplain
- Structures at Risk
- Structure Footprints
- Parcels

0 200 Feet

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LOCATOR MAP

HYDRAULIC ANALYSIS RESULTS

APPENDIX E

PLAN ROLL-UP

PLAN ROLL-UP

Throughout the planning process, the Fourmile Creek Watershed project team consulted existing plans, studies, and reports to the to identify unmet needs, to inform recommendations, and to guide next steps. The project team conducted a review of existing plans, studies, and reports at the start of the master planning project. A tabular plan "roll-up" method was used to manage the large amount of data and help identify gaps and data needs.

The following tables were extracted from the project team's plan roll-up spreadsheets. Used as an internal organizational document, the excel file from which these tables are derived provided a method for sharing and synthesizing large amounts of planning information in a short period of time. The existing plans were organized into one of three general categories: Land Use, Engineering, and Ecological. The tables below are not a comprehensive list of all of the information used to develop the Fourmile Creek Watershed Master Plan over the course of the project. However, the plan roll-up method was successful at providing the planning team with a preliminary understanding of the pre- and post-flood planning and assessment efforts in the region.

Table E. 1 Plan Roll-Up: Existing Plans

Document	Plan Category			
	Engineering	Ecological	Land Use	GIS Layers
Situational Awareness Meeting--Handout on St Vrain Runoff.docx -- AKA. Colorado Water Conservation Board (CWCB) Average Daily Flow data	X			
Colorado Water Conservation Board (CWCB), hydrologic analysis for Boulder Creek, draft report, and final report	X			
Boulder Valley Comprehensive Plan			X	
Boulder County Transportation Master Plan (2012)			X	
Boulder County Multimodal Transportation Standards (2011)			X	
Arapaho and Roosevelt National Forests and Pawnee National Grassland's 1997 Revision of the Land and Resource Management Plan,			X	
Boulder County Comprehensive Creek Planning Initiative. Boulder County has developed an extensive data base that includes emergency mitigation sites and pre- and post-flood LiDAR analysis of reaches of Fourmile Creek in unincorporated Boulder County.				X
CDOT/CWCB Hydrology Investigation: Phase One – 2013 Flood Peak Flow Determinations (January 2014).	X			
Boulder County Comprehensive Plan			X	
Boulder County Comprehensive Plan update – Environmental Resources Element and Supplemental Materials (Boulder County 2014)			X	
Survey of Critical Biological Resources in Boulder County, Colorado; CSU Natural Heritage Program 2007-2008, published 2009		X		
Riparian Inventory and Assessment, Boulder County Parks and Open Space, 2009, Biohabitats		X		
Natural Resource Conservation Service (NRCS): Colorado Front Range Flood of 2013: Peak Flow Estimates at Selected Mountain Stream Locations (December 2013)	X			

Table E. 1 Plan Roll-Up: Existing Plans

Document	Plan Category			
	Engineering	Ecological	Land Use	GIS Layers
Private Access White Paper -- Path Forward on Private Access/Floodplain Development Permitting in Mountain Canyons (2014 Draft) (Boulder County whitepaper on private access rebuilding requirements)			X	
Boulder County Floodplain regulations (4-400 of the Boulder County Land Use Code)			X	
Boulder County Storm Drainage Criteria Manual	X			
Summary of Findings -- Fourmile Canyon Post-Fire Hydrology and Discussion of Conceptual Mitigation Measures	X			
DRAFT Fourmile Canyon Post-Fire Hydrology -- Routed Runoff Model	X			
State of the Watershed: Water Quality of Boulder Creek (includes report about mine tailing after wildfire)		X		
Boulder County Natural Hazard Mitigation Plan (DRAFT)			X	
Sept 2013 Boulder Rainfall Analysis Memo (Draft) - WWE	X			
Probability and Volume of Potential Post-Wildfire Debris Flows in the 2010 Fourmile Burn Area, BOCO (USGS OFR 2010-1244)	X			
Wildfire Effects on Source-Water Quality -- Lessons from Fourmile Canyon Fire, and Implications for Drinking-Water Treatment		X		
Project Worksheet for the Assay Office project on the Kraft Property, Fourmile Canyon Drive (BCPOS)	X			
Project Worksheet for the Fourmile Bridge project on the Betasso Property (Benjamin Parcel) (BCPOS)	X			
Betasso Preserve Management Plan (BCPOS)			X	
Fourmile Fire Protection District - Map Book of structures, water sources, and evacuation zones	X			X
Fourmile Fire Protection District - Inventory of pre-flood private bridges	X			
BC public health GIS data - abandoned mine sites/tailings piles, wells, septic systems				X
Map of local historic resources				X
Transportation has a list of permitted and non-permitted private crossings. The have plans for some temporary crossings	X			
Fourmile Canyon Fire Rehabilitation Report		X		
Fourmile Fire Treatment Implementation and Evaluation Report		X		
Fourmile Emergency Stabilization Burned Area Report		X		

Table E.2 Plan Category: Land Use

Jurisdiction/ Organization	Plan Name	Scope	Reach #	Pre/Post Flood	Date	Details	Notes
Boulder County Land Use Department	Boulder County Comprehensive Plan (2nd Edition)	Boulder County	All	Pre	5/27/1999		
Boulder County	Boulder County Natural Hazard Mitigation Plan (DRAFT)	Boulder County - Erie, Jamestown, Lafayette, Longmont, Louisville, Lyons, Superior, Ward, Boulder Valley and St. Vrain School Districts	All	Pre	8/27/2013	Revision/Update of 2008 HMP - a plan to guide hazard mitigation planning to better protect the people and property of the County from the effects of hazard events	
Boulder County	Boulder County Multi-Hazard Mitigation Plan	Boulder County - Erie, Jamestown, Lafayette, Longmont, Louisville, Lyons, Superior, Ward, Boulder Valley and St. Vrain School Districts	All	Pre	2008	A plan to guide hazard mitigation planning to better protect the people and property of the County from the effects of hazard events	
Boulder County	Boulder County Comprehensive Plan Update -- Environmental Resources Element	Boulder County	All	Pre	6/19/2013	Element of the comprehensive plan that identifies Species of Special Concern and Critical Wildlife Habitats	
City of Boulder	Boulder Valley Comprehensive Plan	City of Boulder - The planning area encompasses the Boulder Valley, which is generally defined as those areas bounded by the mountain backdrop on the west, 95th Street on the east, Davidson Mesa and the Coal Creek drainage on the southeast, the south county line on the south, Mineral Road on the northeast and Neva Road and Niwot Road on the north,	All	Pre	2010	The Plan provides a general statement of the community's desires for future development and preservation of the Boulder Valley. Sustainability drives the overall framework of the Plan. The plan consists of a list of policies and detailed Land Use Area maps	
Boulder County	Boulder County Transportation Master Plan (2012)	Boulder County	All	Pre	12/11/2012	Vision: Provide high quality, safe, sustainable, and environmentally responsible transportation infrastructure and services across all modes, to meet the mobility and access needs of all users.	

Table E.2 Plan Category: Land Use

Jurisdiction/ Organization	Plan Name	Scope	Reach #	Pre/Post Flood	Date	Details	Notes
Boulder County	Boulder County Multi-modal Transportation Standards (2011)	Boulder County	All	Pre	7/1/2012	1) the Standards govern the planning, design, and construction of transportation facilities within unincorporated Boulder County 2) the Standards encourage a County transportation system consistent with State law and applicable County resolutions or ordinances	Article 1: General Provisions Article 2: Administration Article 3: Transportation Planning Article 4: Transportation System Impact Analysis Article 5: Design Standards Article 6: Construction Specifications
Boulder County	Boulder County Land Use Code - Article 4 (4-400 floodplain Regulations)	Boulder County	All	Post	6/5/2014	A zoning ordinance imposes such reasonable limitations upon the right of a property owner to use his property as he pleases, as may be determined by considerations of public health, safety, and welfare. But he may not use his property as he pleases without regard for his neighbors, or the effect of his actions upon the welfare and prosperity of the whole community of which he is a part. Nor is a zoning ordinance merely a temporary matter. It is an integral part of public planning, which takes the long view. The use of land is a granted right, but the land itself remains long after individuals who have exercised such rights have passed away. Rural zoning contemplates not only benefits in the present, but also seeks to conserve our resources for future generations.	Floodplain Regulations included in this zoning resolution
Boulder County	Private Access White Paper -- Path Forward on Private Access/ Floodplain Development Permitting in Mountain Canyons (2014 Draft)	Boulder County	All	Post	5/12/2014	A recommended path forward to address flood-recovery challenges related to property owner challenges with compliance with permitting and floodplain regulations in mountain environments	Recommendations are based on community feedback
USFS	Arapaho and Roosevelt National Forests and Pawnee National Grassland's 1997 Revision of the Land and Resource Management Plan,	Arapaho and Roosevelt National Forests	All	Pre	6/19/1997	General land use plan for the National Forest -- includes forest-wide goals and objectives; operational goals, standards and guidelines (physical, biological, and recreational resources) that apply to the daily work of the Forests and Grassland; and geographic area directions,	
BCPOS	Betasso Preserve Management Plan - Including the Benjamin Property	1181-acre open space property, located approx. 2 miles up Boulder Canyon	1	Pre	Jun-09	This management plan sets forth the future direction for management of Betasso Preserve.	Includes maps of conceptual trail options, existing social trails, cultural resources map, and an ecological assessment of the property. The plan also includes a summary of initial public comments from 2008.

Table E. 3 Plan Roll-Up
Land Use Plan Goals Summary

Boulder County Comprehensive Plan	1) Design of the region - limit sprawl, maximize open space and habitat connectivity, adequate provision of employment opportunities and affordable housing	2) Environmental management - preserve distinctive natural features and ecosystems including wetlands and critical wildlife habitats, Enviro Conservation Areas, riparian zones; minimize pollution of all kinds	3) Parks and Open Space - encouragement of parks, open space and recreation facilities throughout the county	4) Community Facilities - encourage the preservation of water for agro purposes within the county; development must not place undue burden on existing community; adequate facilities and services for health, safety, welfare, education and social opportunities must be encouraged	5) Residential Goals - diversity of housing types and densities; rehab of existing residential facilities should be promoted; keep unincorporated areas of the county largely rural in character	6) Economic Conditions - promote a balanced, diversified economy, promote growth in commercial and industrial facilities	7) Transportation - ensure safety for all modes; minimize enviro impacts of transportation systems; maintain existing transit infrastructure	8) Public Involvement - encourage public participation in decision-making	9) Government Relations - encourage and promote coordination and cooperation between Federal, State, and Local government entities charged with making decisions which affect land use in the county	10) Solid Waste Management - promote conversion of county's solid waster from liability into public asset by considering solid waster as a viable resource	11) Cultural Resources - i.e. and protect historic sites; further preservation through education and incentives rather than stringent regulatory controls	12) Natural Hazards - reduce/eliminate development in natural hazard areas	13) Agricultural Resources - foster and promote diverse agricultural enterprises and activities; conserve and preserve agricultural lands in the county

Goals / Mitigation Strategy

Boulder County Natural Hazard Mitigation Plan (2013)	1. Reduce the loss of life and personal injuries from hazard events: • create comprehensive evacuation route signage system for County • disaster and shelter-in-place medical supplies/materials for schools • establish emergency shelter centers in Lafayette • continue participation in the NFIP • develop CWPP Plan for Lyons (wildfire hazards)	2. Reduce impacts of hazard events on property, critical facilities/infrastructure, and the environment: • implement architectural improvements in schools • purchase development rights/conservation easements from high hazard properties • replace bridge on N. 61st St over Boulder Creek • develop flood protection for the Lyons Waste Water Treatment Plant • improve storm drain conveyance in Lyons • include stormwater control projects at new school construction sites • create community fuel breaks and along roadways (wildfire) • develop water system loop and install additional fire hydrants in Lyons • continue forest restoration projects to minimize wildfire intensity	3. strengthen intergovernmental coordination, communication, and capabilities in regard to mitigating hazard impacts: • improve communication interoperability between and among public safety agencies, first responders, and school staff • readiness and emergency management in school grant planning and database development • implement comprehensive regional medical surveillance system for early identification of threats to public health • partner with watershed districts and USFS on fuel break projects on large, publicly-owned tracts of land in W. Boulder County	4. improve public awareness regarding hazard vulnerability and mitigation: • conduct all-hazards symposium • expand county-wide recruiting for CERT (also, deliver CERT for teens) • implement outdoor emergency warning system enhancement, emergency email and text notification system (Erie) • develop citizen preparedness guides to distribute and community events; all hazard-education materials for public • crisis management training for school personnel • developed wildfire info kiosks and wildfire danger signage

Table E. 3 Plan Roll-Up
Land Use Plan Goals Summary

	Goals / Mitigation Strategy			
Boulder County Hazard Mitigation Plan (2008)	1. Reduce the loss of life and personal injuries from hazard events • create comprehensive evacuation route signage system for County • disaster and shelter-in-place medical supplies/materials for schools • establish emergency shelter centers in Lafayette • continue participation in the NFIP • develop CWPP plan for Lyons (wildfire hazards)	2. reduce impacts of hazard events on property, critical facilities/ infrastructure, and the environment • implement architectural improvements in schools • purchase development rights/conservation easements from high hazard properties • replace bridge on N. 61st St over Boulder Creek • develop flood protection for the Lyons Waste Water Treatment Plant • improve storm drain conveyance in Lyons • include stormwater control projects at new school construction sites • create community fuel breaks and along roadways (wildfire) • develop water system loop and install additional fire hydrants in Lyons • continue forest restoration projects to minimize wildfire intensity	3. strengthen intergovernmental coordination, communication, and capabilities in regard to mitigating hazard impacts • improve communication interoperability between and among public safety agencies, first responders, and school staff • readiness and emergency management in school grant planning and database development • implement comprehensive regional medical surveillance system for early identification of threats to public health • partner with watershed districts and USFS on fuel break projects on large, publicly-owned tracts of land in W. Boulder County	4. improve public awareness regarding hazard vulnerability and mitigation • conduct all-hazards symposium • expand county-wide recruiting for CERT (also, deliver CERT for teens) • implement outdoor emergency warning system enhancement, emergency email and text notification system (Erie) • develop citizen preparedness guides to distribute and community events; all hazard-education materials for public • crisis management training for school personnel • develop wildfire info kiosks and wildfire danger signage
	Goals of the Environmental Resources Element	**Environmental Resource Policies**	**Air, Soil, Water, Noise, and Light Policies**	**Environmental Conservation Area Policies** / **Natural Landmarks and Natural Areas Policies**

Table E. 3 Plan Roll-Up
Land Use Plan Goals Summary

Boulder County Comprehensive Plan Update (2013) -- Environmental Resources Element	B.1 Boulder County shall conserve and preserve environmental resources including its unique or distinctive natural features, biodiversity, and ecosystems through protection and restoration in recognition of the irreplaceable character of such resources and their importance to the quality of life in Boulder County. B.2 Boulder County sustains and protects native species, natural ecosystems and the biodiversity of the region by designating High Biodiversity Areas, Natural Areas, Natural Landmarks, Significant Natural Communities, Critical Wildlife Habitats, Species of Special Concern, Wetlands, Riparian Areas, and Rare Plant Areas. B.3 Boulder County shall promote the viability and integrity of all naturally occurring ecosystems and their native species populations by applying a variety of environmental resources management strategies in a manner that is consistent with current ecological principles and sustainable conservation practices. B.4 Boulder County recognizes that climate change is having significant impacts on our environmental resources. As the body of climate science knowledge grows and potential effects are better understood, Boulder County shall incorporate the best scientific information into planning and decision-making to adapt to and offset those impacts. B.5 Boulder County shall continue to protect air, water and soil resources and quality, as well as restore resources in a degraded condition to enhance overall environmental health. Pollution of air, water, and soil, and pollution caused by noise or light, shall be eliminated or minimized to the greatest extent possible in order to prevent potential harm to life, health and property, and to reduce incremental degradation of the environment. B.6 Boulder County shall continue to protect prominent natural landmarks and other unique scenic, visual and aesthetic resources in the county. B.7 Boulder County shall conserve and preserve Environmental Conservation Areas (ECAs) in order to perpetuate native species, biological communities, and ecological processes that function over large geographic areas and require a high degree of connectivity to thrive. B.8 Boulder County shall protect environmental resources both at the site-specific scale and landscape scale through a variety of means such as partnerships with private landowners, nongovernmental organizations, and other governmental agencies; education and outreach; advocacy at the state and federal level; and other programs consistent with the goals and policies of the Comprehensive Plan.	ER 1.01 Boulder County plans and attendant regulations shall be formulated to insure that land uses avoid where possible and otherwise minimize the destruction or adverse modification of environmental resources. ER 1.02 Boulder County shall continue to identify and designate environmental resources that have significance to Boulder County. ER 1.03 Scenic vistas shall be preserved as much as possible in their natural state. ER 1.04 Boulder County shall work with federal, state, municipal and other public or quasi-public entities that have a jurisdictional or property interest in unincorporated lands within or surrounding any designated environmental resources to achieve their protection. ER 1.05 Boulder County shall work in partnership with private land owners and nongovernmental organizations to protect, conserve, and restore designated environmental resources using a variety of tools. ER 1.06 Boulder County shall use its open space program as one means of achieving its goals for protecting environmental resources. ER 1.07 Boulder County shall encourage all private landowners to seek assistance from appropriate governmental and non-governmental entities to protect Boulder County's environmental resources. ER 1.08 Boulder County shall modify plans, policies and regulations as necessary to adapt to climate change in order to reduce species and ecosystem vulnerability and other potential adverse impacts on environmental resources.	ER 2.01 Boulder County shall seek to protect overall public and environmental health by enforcing regulations concerning air, soil, water, noise and light pollution at the local level in accordance with applicable law. ER 2.02 Boulder County shall evaluate land use proposals and other planned activities considering their cumulative impacts on public and environmental health. Sufficient mitigation and minimization of any impacts shall be required for the proposal or activity to be approved. These proposals and activities shall at a minimum comply with air, soil, and water quality standards, as well as noise level and lighting standards, established by county and state agencies or the Boulder County Land Use Code. ER 2.03 Boulder County shall take a watershed approach to addressing water quality and water quantity including supporting and participating in local and regional watershed partnerships.	ER 3.01 Boulder County shall designate and map Environmental Conservation Areas as well as Overland and Stream Habitat (Riparian) Corridors at a landscape scale. ER 3.02 Boulder County shall encourage the removal of development rights from ECAs through transfer, donation, acquisition, trade, or other incentives. ER 3.03 Development within ECAs shall be located and designed to minimize the cumulative impacts on the environmental resource values of ECAs. ER 3.04 Development outside of ECAs shall be located and designed to minimize impacts on and connectivity between ECAs. ER 3.05 Boulder County shall encourage and participate with the appropriate public entities and private land owners in the development of coordinated management plans to conserve, preserve and restore the environmental resource values of ECAs.	ER 4.01 Natural Landmarks and Natural Areas identified in the Environmental Resources Element and as may be identified from time to time by the state under the Colorado Natural Areas Act, shall be protected from destruction or harmful alteration. ER 4.02 Boulder County shall submit any County Natural Area that may be of state-wide importance to the Colorado Natural Areas Program for designation as a State Natural Area. ER 4.03 Boulder County shall coordinate with local, state, and federal agencies and municipalities, as well as with willing private landowners, to protect natural resource values within Natural Landmarks and Natural Areas. This may include: identification of specific resources of concern including scenic values; recommendations for long-term management; mitigation of existing or foreseen impacts; or protection through acquisition of land interest.

Table E. 3 Plan Roll-Up
Land Use Plan Goals Summary

	Goals						
Boulder County Transportation Master Plan (2012)	Goal 1 – Ensure Effective and Efficient Management of the Existing Transportation System. Manage and maintain existing transportation infrastructure and services in a cost-effective manner.	Goal 2 – Minimize Environmental Impacts. Minimize the negative environmental impacts of the transportation system such as air pollution, greenhouse gas (GHG) emissions, noise pollution, water pollution, land and wildlife habitat fragmentation, land disturbance, and resource consumption.	Goal 3 – Ensure Safety for All Modes. Provide for transportation system development and operations that result in safe and secure travel by all modes and that enable prompt and effective emergency response.	Goal 4 – Support a Healthy and Sustainable Economy. Develop a transportation system that supports a robust economy and increases resiliency to economic fluctuations.	Goal 5 – Ensure Equitable Access to the Transportation System. Ensure that adequate transportation exists for all users regardless of age, income, or ability.	Goal 6 – Enhance County Identity and Community Character. Promote a transportation system that preserves, highlights, and enhances the county's diverse rural character and the history and culture of its unique communities.	
	Strategies						
	Strategy 1: Develop a Multimodal Transportation System	Strategy 2: Create the Complete Trip	Strategy 3: Invest in Key Transportation Corridors	Strategy 4: Increase Accessibility	Strategy 5: Enhance Mountain Area Connections		
	Implementation Strategy						
Private Access White Paper -- Path Forward on Private Access/Floodplain Development Permitting in Mountain Canyons (2014 Draft)	Evaluate regulatory and interim floodplain/way regulatory change options in the mountain canyons	Evaluate Engineering Options for Mountain Private Crossings	Study and Re-model Creek Floodplains Post Flood with Specified Private Crossings	Flood Recovery Access Permit (FRAP) Policy Changes	Financial Assistance Program for Private Access/Crossings		
	Strategy						
Betasso Preserve Management Plan - Including the Benjamin Property	"To meet the multiple management objectives for the site and to balance visitor use and habitat preservation, BCPOS proposes: - adding 4.6 miles of new multiple use trails within the northeast portion of Betasso Preserve, including the eastern portion of the Benjamin property - setting aside 202 acres of high value wildlife habitat on the Benjamin property within a Habitat Conservation Area (hereafter referred to as the Arkansas Mountain Habitat Conservation Area), which will be closed to all public use. - Vegetation will be managed to promote native diversity, to the extent possible, and to provide high quality habitat for wildlife. - the creation of an on-site caretaker position, continuation of the alternative day use and directional use regulations for mountain bikes for at least two years, rehabilitation of social trails, minor facility improvements, an interpretive loop trail to the Betasso Homestead, and a potential future new link trail between Boulder Canyon and the Canyon Loop Trail if an opportunity arises"						

Table E. 4 Plan Category: Engineering

Jurisdiction/ Organization	Plan Name	Scope	Reach #	Pre/Post Flood	Date	Details	Notes
CDOT/CWCB	CDOT/CWCB Hydrology Investigation: Phase One – 2013 Flood Peak Flow Determinations	Watersheds studied - South Platte River, Coal Creek, Boulder Creek, St. Vrain, Little Thompson, and Big Thompson	All	Post	Jan. 2014	Measures peak flows from the 2013 flood, investigate an update of hydrologic models for watersheds that experienced significant damage	Summary of peak flood discharges from the 2013 flood; comparison to regulatory flows; estimates of the observed flood frequency
Boulder County Transportation Department	Fourmile Canyon Post-Fire Hydrology -- Routed Runoff Model (Wright Water Engineers)	Routed runoff analysis for drainage basins affected by the Fourmile Canyon wildfire. The Fourmile Canyon fire burned approximately 6,200 acres in the foothills west of Boulder in September 2010	All	Pre	Feb. 2011	The routed analysis combines the hydrographs from individual sub basins, accounting for varying travel times, and calculates hydrographs along the main stems of Fourmile Creek and Fourmile Canyon Creek. The results presented in this memorandum represent a reasonable estimation of routed peak flow rates for runoff from areas affected by the Fourmile Canyon wildfire. However, the routed model results do not represent an exhaustive study based on extensive model calibration and validation. In addition, the model results account for routed clearwater flows with a bulking factor added for entrained debris, but the values do not account for debris dams that could potentially form and break, with resulting increased peak flow rates.	WWE performed calculations and developed computer models to estimate the routed runoff peak flow rates resulting from four storm events (2-year, 10-year, 25-year and 100-year, 1-hour events) for the post-fire watershed condition. Drainage basins analyzed were: • The Fourmile Creek basin upstream from its confluence with Boulder Creek. • Portions of the Fourmile Canyon Creek basin affected by the wildfire. WWE reviewed key documents and studies that have been prepared to date, regarding both the pre-fire and post-fire hydrology in this watershed, that are relevant to development of the routed models; • WWE conducted a field visit on February 10 to observe the geometry and other physical characteristics of the stream channels to determine model input parameters

Table E. 4 Plan Category: Engineering

Jurisdiction/ Organization	Plan Name	Scope	Reach #	Pre/Post Flood	Date	Details	Notes
NRCS	Colorado Front Range Flood of 2013: Peak Flow Estimates at Selected Mountain Stream Locations	Larimer and Boulder Counties	All	Post	Dec. 2013	Peak flow estimates were developed in 15 mountain streams for the Front Range Flood of September 2013. These measurements were collected to inform resource managers of the flood severity, aid in the development of revised flow-frequency relationships, and quantify the flood response of key catchments burned during the 2012 High Park Fire. These stream reaches ranged from Jamestown in the South to catchments draining the High Park Fire area in the Poudre Canyon in the North, though are only a sample of the mountain streams impacted by the flooding. The critical depth method was used in this analysis, using replicate cross sections in channels with slopes greater than 1 percent. The highest peak flows were measured in the North Fork of the Big Thompson River upstream of Drake (18,400 cubic feet per second, cfs), the Little Thompson River at Pinewood Springs (14,600 cfs), West Creek upstream of Glen Haven (11,000 cfs) and Buckhorn Creek upstream of Masonville (11,000 cfs). The highest flow yields (peak flow normalized by drainage area) were measured in Fish Creek upstream of Lake Estes (442 cfs/mi2), West Creek upstream of Glen Haven (477 cfs/mi2), Little James Creek upstream of Jamestown (579 cfs/mi2), Fox Creek upstream of Glen Haven (486 cfs/mi2), and Skin Gulch upstream of Stove Prairie Road (720 cfs/mi2). The streams with the highest flow yields correspond to the channels (and adjacent properties) that received a large amount of flood damage, with large disturbances to channel-stabilizing bank vegetation. The highest peak flow yield (Skin Gulch) flowed from a catchment with a substantial amount of high soil burn severity from the 2012 High Park Fire. Overall, the peak flows measured in these 15 reaches correspond to return intervals ranging from a 25-year flood event to approximately 5 times the 100-year flood.	
Boulder County	Boulder County Storm Drainage Criteria Manual	Boulder County	All	Pre	1984	Goals of the Manual: 1. To unify standards and improve the quality of drainage evaluation and design by providing specific and detailed criteria for the local communities. 2. To reduce the effort required to prepare and review drainage designs by simplifying the methodologies and procedures and by providing numerous worked examples. 3. To provide the necessary information to prepare and review a drainage design within a single document that is complete, organized, and easily referenced. 4. To provide a drainage evaluation and design criteria that will prevent future drainage problems and enhance the urban environment within the goals and objectives of the community.	

Table E. 4 Plan Category: Engineering

Jurisdiction/ Organization	Plan Name	Scope	Reach #	Pre/Post Flood	Date	Details	Notes
CDOT	Boulder Creek Hydrologic Analysis	Boulder Creek watershed (study reach is from Barker reservoir near Nederland to the confluence with Fourmile Creek). Four sub watersheds analyzed: Middle Boulder Creek, North Boulder Creek, Fourmile Creek, and Boulder Canyon Creek	1	Post	Aug-14	As part of this effort, CDOT partnered with the Colorado Water Conservation Board (CWCB) to initiate hydrologic analyses in several key river systems impacted by the floods. The work was contracted to three consultant teams (CH2M Hill, Jacobs, URS). The purpose of the analyses is to ascertain the approximate magnitude of the September flood event in key locations throughout the watershed and to prepare estimates of peak discharge that can serve to guide the design of permanent roadway and other infrastructure improvements along the impacted streams.	1. Estimate peak discharges that were believed to have occurred during the flood event at key locations along the study streams. Summarize these discharges along with estimates provided by others in comparison to existing regulatory discharges. Document the approximate return period associated with the September flood event based on current regulatory discharges. 2. Prepare rainfall-runoff models of the study watersheds, input available rainfall data representing the September rainstorm, and calibrate results to provide correlation to estimated peak discharges. 3. Prepare updated flood frequency analyses using available gage data and incorporate the estimated peak discharges from the September event. 4. Use rainfall-runoff models to estimate predictive peak discharges for a number of return periods based on rainfall information published by the National Oceanic and Atmospheric Administration (NOAA) [NOAA Atlas 14, Volume 8, Updated 2013]. Compare results to updated flood frequency analyses and unit discharge information and calibrate as appropriate.
CWCB	Situational Awareness Meeting--Handout on St Vrain Runoff.docx (aka Colorado Water Conservation Board (CWCB) Average Daily Flow data)			Post		CWCB average daily flow data for St. Vrain Creek, Left Hand Creek and Boulder Creek	Line graphs of average daily flows with 2011 levels superimposed
Boulder County Transportation Department	Summary of Findings -- Fourmile Canyon Post-Fire Hydrology and Discussion of Conceptual Mitigation Measures		All	Pre	Jan-11	Summary of projected post-fire hydrology results in the area burned during the Fourmile Canyon wildfire in September 2010. The Fourmile Canyon fire burned approximately 6,200 acres in the foothills west of Boulder	1) Post-fire peak flow rates 2) debris flow volumes 3) probability of occurrence 4) Potential mitigation measures

Table E. 4 Plan Category: Engineering

Jurisdiction/ Organization	Plan Name	Scope	Reach #	Pre/Post Flood	Date	Details	Notes
City of Boulder	September 2013 Boulder Rainfall Analysis		All	Post	9-May-14	UDFCD ALERT rain gages were used to assess maximum 5, 10, 15, 30 minute and 1, 6, 12, 24-hour rainfall depths and associated intensities. This report summarizes the results of analysis of the worst-case rainfall return periods for the September 2013 flood event in Boulder. In addition to the rainfall frequency analysis, WWE also performed comparisons with the CO Urban Hydrograph Procedure (CUHP) to compare hourly rainfall intensities for the design storm with the observed intensities of the actual event. Rainfall during September 2013 event was less intense that assumed in design storms that are used to define regulatory peak flow rates and floodplains	1) Worst Case Rainfall Return Period maps for 5, 10, 15, 30 minute and 1, 6, 12, 24 hour durations (surface raster of depths and associated intensities, GIS data) 2) Comparison of rainfall returns with CO Urban Hydrograph Procedure (CUHP) - this modeling is the basis for the hydraulic modeling that is performed for major drainage way plans, outfall system plans, and FHAD studies (Results: the peak flows experienced during the September 2013 flood event for Boulder Creek, South Boulder Creek, Skunk Creek, etc. were well below the 100-year peak flows projected from CUHP analysis.)
USGS	Probability and Volume of Potential Post-wildfire Debris Flows in the 2010 Fourmile Burn Area, BoCo (USGS OFR 2010-1244)		All	Pre	2010	Report presents a preliminary emergency assessment of the debris-flow hazards from drainage basins burned by the Fourmile Creek fire in Boulder County, Colorado, in 2010. Data for the models include burn severity, rainfall total and intensity for a 2-year-recurrence, 1-hour-duration rainstorm, and topographic and soil property characteristics. Includes probability and volume of potential debris flows. Several of the selected drainage basins in Fourmile Creek and Gold Run were identified as having probabilities of debris-flow occurrence > 60% and many more had probabilities > 45%, in response to the 2-year-recurrence, 1-hour-duration rainfall. None of the Fourmile Canyon Creek drainage basins selected had probabilities >45%. Throughout the Gold Run area and the Fourmile Creek area upstream from Gold Run, the higher probabilities tend to be in the basins with southerly aspects (southeast, south, and southwest slopes). Volume of debris flows predicted from drainage basins with probabilities of occurrence greater than 60 percent ranged from 1,200 to 9,400 m3. The predicted moderately high probabilities and some of the larger volumes responses predicted for the modeled storm indicate a potential for substantial debris-flow effects to buildings, roads, bridges, culverts, and reservoirs located both within these drainages and immediately downstream from the burned area. However, even small debris flows that affect structures at the basin outlets could cause considerable damage.	
BCPOS	Project Worksheet for the Fourmile pedestrian Bridge project on the Betasso Property (Benjamin Parcel) (BCPOS)	South of trail entry at 2715 Fourmile Canyon Drive, Boulder, CO	1	Post	12/16/2013	The proposed scope of work for the Fourmile Pedestrian Bridge is to restore the bridge to its pre-disaster condition by securing a civil engineer's evaluation of the structural integrity of the bridge, repairing the bridge as needed, rebuilding both abutments, resetting the bridge, and rebuilding the trail sections immediately adjacent to the abutments.	Damage data and narrative Repair Cost Estimate XLS spreadsheet Folder of site photos

Table E. 4 Plan Category: Engineering

Jurisdiction/ Organization	Plan Name	Scope	Reach #	Pre/Post Flood	Date	Details	Notes
BCPOS	Project Worksheet for the Wall Street Assay Office Museum property	LAT/LONG of sites 1 and 2 -- N40.03945, W-105.39315	4	Post	2/20/2014	Was a historic site managed by BCPOS and operated as a public museum before the flood. The heavy rains of September caused damage to four distinct areas on the property. The proposed scope of work for the Assay Office is to restore the property to its pre-disaster condition. At the time of the report, no work has been completed. Deliverables include: Damage data and narrative; Repair Cost Estimate XLS spreadsheet; and a Folder of site photos	
Four Mile Fire Protection District	Fourmile Fire Protection District - Map Book of structures, water sources, and evacuation zones	Four Mile Fire Protection District	All	Pre	2/1/2004	Includes maps and inventory of water sources, primary helicopter landing zones, roads and escape routes within four mile fire protection district	
Four Mile Fire Protection District	Fourmile Fire Department Creek Crossings - Inventory of pre-flood private bridges	Four Mile Fire Protection District	All	Pre	Spring 2011	Inventory of pre-flood private bridges and crossings within FPD service area. Includes photos, GPS coordinates, elevation, span, width, free board, construction materials, railings, condition, and notes	
	Transportation has a list of permitted and non-permitted private crossings. The have plans for some temporary crossings	Fourmile Canyon Drive	All	Pre and Post	2014 unknown	Pre and post-flood stream crossing comparison. Pre and post-flood structure description, clear area (sqft), Change (sqft), % change, evaluation of capacity change, 10-yr flow capacity, notes	

Table E.5 Plan Category: Ecological

Organization	Name	Scope	Reach #	Pre/Post Flood	Date	Details	Planning Objectives/Goals	Deliverables
BCPOS	BCPOS Riparian Inventory and Assessment	Boulder County Parks and Open Space	All	Pre	1/1/2009	Covers St. Vrain, Coal, Rock, and Left Hand Creeks. Primary purpose of the evaluation is to inventory and assess the streams that traverse select BOPOS properties	Explanation of reach characteristics and major improvement / restoration opportunities	
CSU Natural Heritage Program	Survey of Critical Biological Resources in Boulder County (2009)	Boulder County	All	Pre	2007-2008	Results of field work done by the Colorado Natural Heritage Program	Provides info on the locations of the most significant biological resources in Boulder County; identifies potential conservation areas	GIS data and report available on the CNHP website: www.cnhp.colostate.edu
City of Boulder; USGS	State of the Watershed: Water Quality of Boulder Creek, CO	Boulder Creek Watershed	All	Pre	6/28/1905	This report, prepared by the U.S. Geological Survey in cooperation with the City of Boulder, presents the state of water quality in the Boulder Creek Watershed in 2005 and how it has changed over the past 160 years, and identifies potential future water-quality concerns		WQ summary report; Water-quality data for the Boulder Creek Watershed are available from the Boulder Area Sustainability Information Network (BASIN) website www.BASIN.org Slightly elevated levels of dissolved solids have been detected in Fourmile Creek, which was once at the heart of gold-mining activity in the watershed (Murphy and others, 2003, chapter 4).

Table E.5 Plan Category: Ecological

Organization	Name	Scope	Reach #	Pre/Post Flood	Date	Details	Planning Objectives/Goals	Deliverables
USGS	Wildfire Effects on Source-Water Quality -- Lessons from Fourmile Canyon Fire, and Implications for Drinking-Water Treatment	Area affected by Fourmile Canyon fire in Boulder County; sampling done in Fourmile creek watershed	All	Pre	7/1/2012	Summary of principal findings from the first year of research. Stream discharge and nitrate concentrations increased downstream of the burned area during snowmelt runoff, but increases were probably within the treatment capacity of most drinking-water plants, and limited changes were observed in downstream ecosystems. During and after high-intensity thunderstorms, however, turbidity, dissolved organic carbon, nitrate, and some metals increased by 1 to 4 orders of magnitude within and downstream of the burned area. Increases of such magnitude can pose problems for water-supply reservoirs, drinking-water treatment plants, and downstream aquatic ecosystems	To assess the potential effects of wildfire on municipal water supplies and downstream aquatic ecosystems	Quantitative results of hydrologic response to post-fire precipitation events; quantitative water-quality projections; report on the implications of drinking water treatment reference list
BCPOS	Fourmile Canyon Fire Rehabilitation Report	Fourmile Canyon Fire Boundary	All	Pre	2011	A total of 1960 acres were aerial mulched to reduce the effects of flooding and debris flows in severe thunderstorm events and their impacts to homes and roads in the burned area. The team also completed the seeding of approximately 422 acres along roads and driveways for weed control. Accomplishments of the weed control efforts will be included in a separate report. Flood mitigation efforts included providing sandbags for residents, installing six debris structures at the base of major watersheds, and providing residence assistance after the July 13th flood and debris flow event. The implementation of the Fourmile Canyon Fire rehabilitation project began on March 19, 2011 with the first volunteer seeding project, though preparation work began in December of 2010	The Fourmile Canyon Fire rehabilitation focused on four major areas: 1) aerial mulching for hill slope stabilization, 2) seeding for weed control along roads and driveways, 3) weed control and 4) flood mitigation efforts.	Details of Planning and Agency Cooperation, Aerial Mulching, Straw Bales, Seeding, and Flood Mitigation activity

Table E.5 Plan Category: Ecological

Organization	Name	Scope	Reach #	Pre/Post Flood	Date	Details	Planning Objectives/Goals	Deliverables
Boulder County	Fourmile Fire Treatment Implementation and Evaluation Report	Fourmile Canyon and Watershed	All	Pre	1/1/2013	Report details the remedial activities conducted by Anders Environmental on behalf of Boulder County, as a result of the Fourmile Fire.	Anders Environmental was contracted to implement the mitigation measures outlined in the Wright Water Engineers (WWE) Fourmile Canyon Debris Flow and Review and Mitigation Analysis, December 2011 report. Goals: to reduce sedimentation rates in the basin to minimize impacts to the local infrastructure during flood events allow for vegetative re-growth in scoured areas	Basin condition, remediation techniques, mitigation, and results of the treatments will be discussed in detail.
BCPOS	Fourmile Emergency Stabilization Burned Area Report (excerpt from the Fourmile Canyon Fire Emergency Stabilization Plan)	Total Acres Burned: 6,179 Private land (4086), BLM (1397), Boulder County/ State Land Board (380), USFS Acres(306), Gold Hill OS (10)	All	Pre	10/10/2010	Report is a funding request for estimated funds to re-stabilized a burned area within Arapaho-Roosevelt forest. Includes damage assessment and cost matrix of selected alternatives	N/A	

APPENDIX F

RESOURCE FOR MANAGEMENT OF WOODY DEBRIS

Management of Large Wood in Streams of Colorado's Front Range: A Risk Analysis Based on Physical, Biological, and Social Factors

by

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Abstract

Instream and floodplain wood can provide many benefits to river ecosystems, but can also create risks to inhabitants, infrastructure, property, and recreational users in the river corridor. In this report we outline a decision process for managing large wood, and particularly for assessing the relative benefits and risks associated with individual wood pieces and with accumulations of wood. This process can be applied at varying levels of effort, from a relatively cursory visual assessment to more detailed numerical modeling. Decisions of whether to retain, remove, or modify wood in a channel or on a floodplain are highly dependent on the specific context: the same piece of wood might require removal in a highly urbanized setting, for example, but provide sufficient benefits to justify retention in a natural area. Our intent is that the decision process outlined here can be used by individuals with diverse technical backgrounds and in a range of urban to natural river reaches.

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I. Introduction

Large wood has been systematically studied and described in the scientific literature since the 1970s (e.g., Swanson et al., 1976; Harmon et al., 1986; Montgomery et al., 2003). The phrase 'large woody debris' (LWD) has been in widespread use for decades, but this phrase is a legacy from timber harvest, when the unused slash was typically left on the ground and in streams as debris. Because debris has very negative connotations, we instead refer to downed wood greater than 10 cm in diameter and 1 m in length simply as large wood.

Rivers in forested regions currently have little wood compared to their condition prior to European settlement of the United States. Historical descriptions of the entire spectrum of rivers across the country, from the smallest headwater creeks in New England to the lower Mississippi and the large rivers of the Pacific Northwest, clearly indicate that much more downed wood was present within channels and across floodplains (Triska, 1984; Harmon et al., 1986; Collins et al., 2002; Wohl, in review). One of the first activities of European settlers in a region was to remove wood from rivers (Sedell et al., 1991), both directly, by pulling wood from channels, and indirectly via deforestation that reduced natural inputs of wood (wood recruitment) into channels. Congress made appropriations to remove wood from rivers as early as 1776 (Harmon et al., 1986), and individuals or small groups of people began wood removal even earlier. In 1824, Congress assigned the 'improvement' of inland rivers to the Army Corps of Engineers (Reuss, 2004). Much of this improvement focused on removing wood.

Direct removal to facilitate navigation and control floods involved the use of snag boats that broke up logjams and pulled up wood pieces partly buried in the streambed or banks (Paskoff, 2007). Indirect removal occurred not only by timber harvest that reduced subsequent recruitment of wood to channels, but also via; channelization (dredging, straightening, bank stabilization) that removed existing wood and reduced the ability of a river to retain subsequently recruited wood; log floating in association with timber harvest, which included removing naturally occurring instream wood, as well as cut logs; and flow regulation, which limited downstream transport of wood. The net effect of these activities was to remove almost all instream and floodplain wood, typically prior to the 20th century (Wohl, 2001). Consequently, most people do not expect downed wood to be abundant in the riverine environment (Chin et al., 2008), and so are not accustomed to seeing the elements that make up a naturally functioning river flowing through a forested region.

Extensive September 2013 rain and post-storm flooding in northern Colorado resulted in abundant wood in river channels and floodplains of streams originating in the Front Range. This event motivated us to seek a dialogue with municipalities and managers of these streams to consider leaving some wood in streams and floodplains because wood is a natural landscape feature with high ecological benefit. In this paper we describe a process that managers can use to evaluate the risks and benefits of instream wood, first presenting the ecological benefits of retention or addition of wood in streams. We first discuss the benefits and risks associated with the presence of large wood in channels and on floodplains, in the context of physical and biological processes occurring within river environments, as well as public safety. The discussion with respect to public safety recognizes that potential risk to humans and infrastructure created by wood is a primary motivation for managers to remove wood. We then present a check-list based decision-making and risk-assessment process for managers to use in order to evaluate the merits of keeping or removing individual pieces of wood or jams. This section further describes wood treatment options that may reduce risk, and tools to measure stability and habitat created by wood left in the channel or floodplain. Decision bands allow managers to further quantify merits and risks of retaining or adding wood to a stream reach. We finish by describing a case study for wood removal or retention in an urban reach of the Cache la Poudre River, near Fort Collins, Colorado, where wood deposition was extensive after flooding.

Extensive September 2013 rain and post-storm flooding in northern Colorado resulted in abundant wood in river channels and floodplains of streams originating in the Front Range. This event motivated us to seek a dialogue with municipalities and managers of these streams to consider leaving some wood in streams and floodplains, because wood is a natural landscape feature with high ecological benefit. However, large wood in rivers also poses risks to human infrastructure and safety. Current practices involve automatically removing all large wood from Front Range rivers. Under this approach, there is no systematic evaluation of benefits and risks, and managers do not differentiate between wood that creates hazards and wood that creates little or no risk. Wood that creates little or no risk is removed at the expense of ecological benefits that might result from this wood. Wood deposited during the September 2013 flood, for example, was almost universally perceived as a risk to infrastructure and safety, irrespective of the actual location and condition of the wood. This underscored the need for a risk assessment framework

that managers can use to systematically and transparently weigh multiple considerations, including safety, infrastructure, recreation, and ecological aspects of wood.

In this paper, we describe a process that managers can use to evaluate the risks and benefits of instream wood. We first discuss the benefits and risks associated with large wood in channels and on floodplains regarding the physical and biological processes occurring within river environments, as well as public safety. For example, potential risk to humans and infrastructure created by wood is a primary motivation for managers to remove wood. We then present a check-list based decision-making and risk-assessment process for managers, to evaluate the merits of keeping or removing individual pieces of wood or jams. This section further describes wood treatment options that may reduce risk, and tools to measure stability and habitat created by wood left in the channel or floodplain. Decision bands allow managers to further evaluate merits and risks of retaining or adding wood to a stream reach. We finish by describing a case study for wood removal or retention in an urban reach of the Cache la Poudre River, near Fort Collins, Colorado, where wood deposition was extensive after flooding.

Our aim is to offer a straightforward management procedure that incorporates realistic analysis of human and infrastructure risk, but also integrates the ecological benefit of wood in streams and floodplains. Thus, goals of human safety and infrastructure preservation may be achieved while also increasing the geomorphic and ecological functioning and environmental health of river systems in settings with high human use.

II. Benefits and Risks associated with Large Wood

This section provides a discussion of the benefits and risks that result from the presence of large wood in channels and on floodplains. We first discuss the beneficial effects of wood on the movement of water and sediment at the surface and within the hyporheic zone that is present beneath the bed of river systems. This is followed by discussion of the biological benefits of wood for fish, stream invertebrates, and other aquatic and terrestrial invertebrates and vertebrates. The final portion discusses public safety considerations associated with wood, in the context of hazard to inhabitants and infrastructure within the river system, and to recreational users of the river environment.

1. Physical benefits of large wood

The physical benefits of large wood result from the interaction of wood with water and sediment moving down the channel. The magnitude of the effects that result from these interactions largely depends on the orientation and stability of the wood, and on the volume of wood within the channel relative to the cross-sectional area of the channel (Klaar et al., 2011): a single piece of wood within a large channel will have only very local effects, whereas a large jam that spans a channel can influence process and form along an entire channel reach. These and other scale considerations are schematically illustrated in Figure 1.

Individual pieces of wood and wood collected into jams create obstructions that can substantially increase the frictional resistance to flow (Shields and Smith, 1992; Shields and Gippel, 1995; Curran and Wohl, 2003; Mutz, 2003). This reduces average flow velocity (Daniels and Rhoads, 2004; Davidson and Eaton, 2013), which can in turn lead to slower passage of flood waves and local storage of sediment and organic matter around the wood (Bilby and Likens, 1980; Nakamura and Swanson, 1993; Faustini and Jones, 2003). If sufficient wood is present within the channel during high flows, the resulting flow obstruction can increase the magnitude, duration, and frequency of overbank flows (Triska, 1984; Brummer et al., 2006). Increased overbank flows enhance the connections of water, sediment, nutrients, and organisms between the channel and floodplain (Collins et al., 2012). This greater “connectivity” can facilitate storage of sediment and nutrients on floodplains, access to floodplain habitat by aquatic organisms, lateral channel movement across the floodplain (O’Connor et al., 2003), and the formation of secondary channels that provide additional, diverse aquatic habitat (Abbe and Montgomery, 2003; Wohl, 2011; Collins et al., 2012).

Wood can increase habitat diversity within channel and on floodplains through various processes. Instream wood typically causes flow separation and localized scour of the bed and banks, resulting in pools and undercut banks (Buffington et al., 2002; Collins et al., 2002). Localized deposition associated with the flow separation creates areas of finer substrate on the streambed (e.g., patches of sand along a cobble-bed stream) (Keller and Swanson, 1979). Larger wood obstructions, such as jams, typically have upstream backwater areas of lower velocity and greater water depth (Brummer et al., 2006). Wood can alter the type and dimensions of bedforms present along a channel. Diverse studies have documented scenarios where wood traps sufficient sediment to create an alluvial channel instead of a bedrock channel (Massong and Montgomery, 2000), for example, and alters the dimensions of pool-riffle and step-pool bedforms (Robison and Beschta, 1990). Wood on floodplains provides substrate and cover for a range of organisms, including aquatic types that prefer wood as a substrate during overbank floods (Benke and Wallace, 1990), plants that use the nutrient-rich decaying logs as germination sites (Schowalter et al., 1998), and small mammals, birds, amphibians and reptiles that use the wood for feeding or nesting sites (Harmon et al., 1986).

The influence of wood on the geomorphic form of stream and river channels commonly results in increased roughness, which results in a more diverse hydraulic gradients not only in the channel, but also between the channel and aquifer. Increased heterogeneity of channel morphology is often associated with enhanced stream-groundwater exchange, and in particular hyporheic exchange (the exchange of stream water through stream-adjacent aquifers in which mixing with groundwater occurs) (Gooseff et al., 2007). Wood-caused steps have been identified as important morphologic features that drive hyporheic exchange in some headwater streams (Kasahara and Wondzell 2003; Wondzell, 2006). Hyporheic zones of streams have been described as analogous to livers for their ability to remove pollutants from stream water (Fischer et al., 2005), thus providing a self-cleansing process to improve water quality. Hyporheic exchange also moderates stream water temperature as a result of interaction with groundwater (Arrigoni et al., 2008).

There is a direct influence of hyporheic exchange on stream aquatic ecosystem condition, habitat, and processes. For example, hyporheic exchange has been shown to influence selection by spawning fish of nest sites, and subsequent embryo survival (Baxter and Hauer, 2000; Malcolm et al., 2004). Hyporheic zones also provide habitat for a variety of macroinvertebrates,

in one or more of their several life stages (Stanley and Boulton, 1993; Williams, 1993). Hence, instream wood has the potential to significantly impact stream ecosystems through its direct influence on hyporheic exchange.

Finally, instream wood is particularly important because of the variable flow velocities created around wood. For example, reduction in flow velocity around wood can increase the retention of particulate organic matter that is the fundamental energy source in many stream ecosystems. If this finer particulate organic matter is stored for even a few hours, rather than remaining in transit, it can be accessed by microbial and macroinvertebrate communities that extract nutrients from the organic matter (Bilby, 1981; Raikow et al., 1995). In addition, large wood commonly traps leaves, sticks, and other plant parts that fall into streams, thereby providing a site for larger macoinvertebrate "shredders" to begin breaking down this coarse particulate organic matter into finer size fractions that can be used by other organisms (Flores et al., 2011, 2013). Slow as well as fast water velocities created by wood provide a variety of habitat for stream fishes and macroinvertebrates because habitat selection is commonly dictated by body size- and velocity-dependent processes (e.g., Fausch, 1984, 2014). Consequently, a variety of flow velocities may provide habitat for several species or life stages.

In contrast to the beneficial physical effects of instream and floodplain wood, removal of wood can create physical risks. Because wood enhances sediment storage, removal of wood and consequent reduced flow resistance and obstruction can result in erosion of stream beds. Wood removal on diverse streams has resulted in significantly increased bed erosion and channel widening, with individual river reaches changing from sediment storage areas when wood is present to sediment source areas when wood is removed (Brooks et al., 2003; Erskine and Webb, 2003).

Figure 1. (A) At spatial scales of stream lengths of 1 to 100 km (10^3 to 10^5 m), the effects of wood strongly depend on valley geometry and location within a drainage basin. In confined, steep headwater valleys, wood primarily affects channel process and form. In lowland channels with floodplains, wood within the channel also affects floodplain process and form.

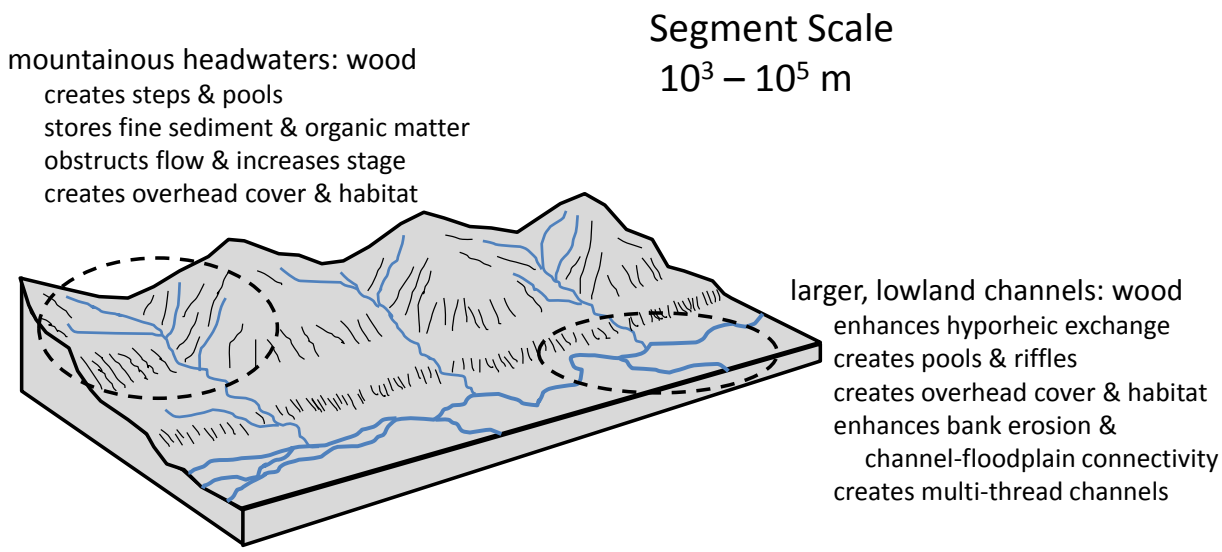


Figure 1. (B) At spatial scales of stream lengths of tens to thousands of meters, wood can strongly influence channel planform and morphology. By forming obstructions to flow, logjams can create backwater pools upstream from the jam and plunge pools downstream from the jam, and enhance overbank flows. Greater overbank flows increase channel-floodplain connectivity, bank erosion, channel avulsion, and the formation of secondary channels (1). Backwater pools enhance storage of finer sediment and organic matter within the stream (2), increasing habitat diversity for stream organisms. Flow separation around individual pieces of wood or jams can create localized bed and bank scour (3). Wood can also create pressure differentials that drive hyporheic exchange (4), with downwelling into the stream bed upstream from the wood and upwelling from the stream bed downstream from the wood.

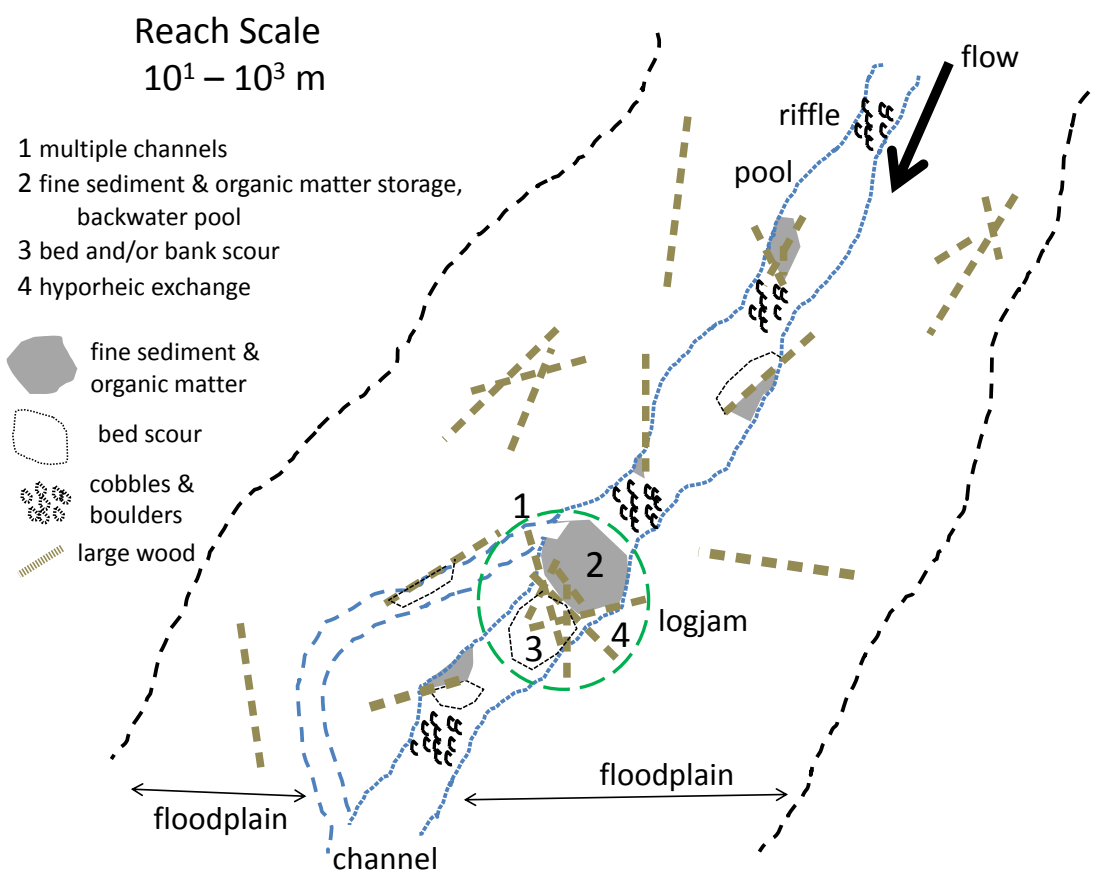
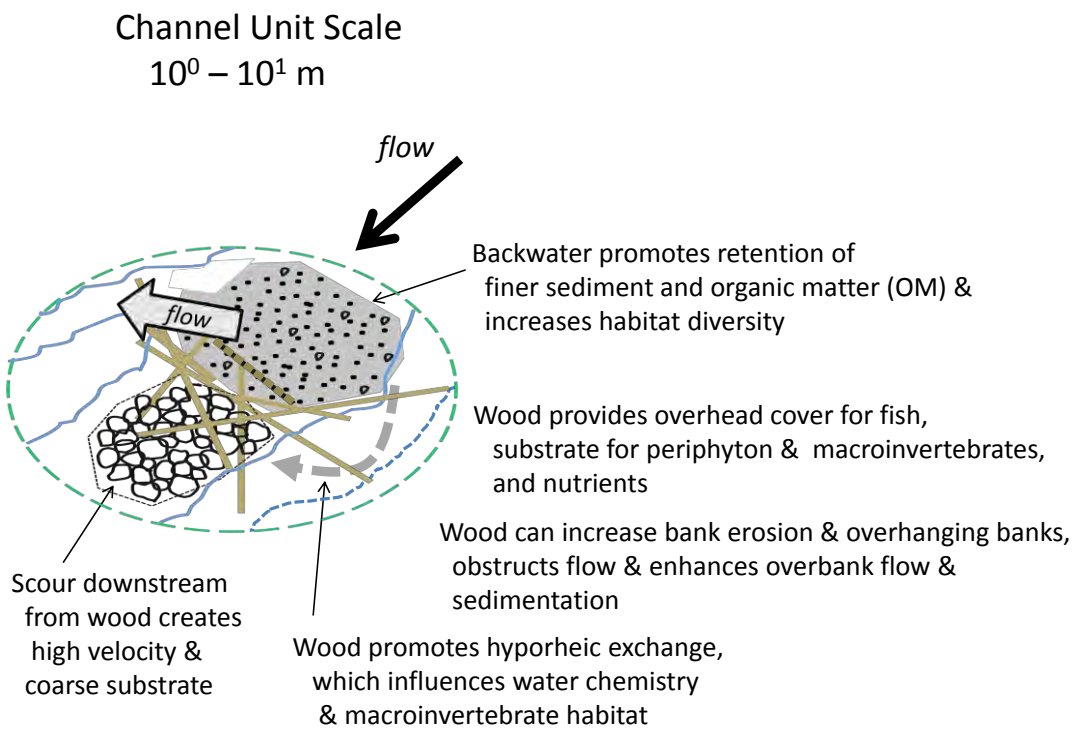


Figure 1. (C) At spatial scales of stream lengths of a meter to tens of meters, individual pieces of wood or logjams create the effects described for the reach scale, and illustrated below. Among these effects are overhead cover, velocity refuges, and visual isolation, all of which are important to fish (Fausch, 1993).



2. Biological benefits of large wood

The benefits of large wood to river organisms like fish and aquatic invertebrates are likely to be of three main types. First, the geomorphic effects of wood on channel structure create pools, runs, and riffles (termed mesohabitats) required by these biota to complete their life cycles, across a range of scales from reaches to riverscapes (Fausch et al. 2002). Second, the habitat complexity created by wood provides critical microhabitats that fish and other organisms need for feeding, resting, and isolation and protection from competitors and predators (e.g., Sechnick et al. 1986; Fausch 1993; Nagayama et al. 2012). And third, stable wood pieces provide hard surfaces that are colonized by aquatic invertebrates that fish eat, and hard surfaces that grow algae that these invertebrates eat (Benke and Wallace 2003). These hard surfaces are particularly scarce in lowland streams that are dominated by silt substrate.

2.1. Fish

Most of what we know about the role and functions of wood that benefit fish is from comparative studies and experiments conducted on salmon and trout in small and medium-sized coldwater streams (e.g., Gowan and Fausch 1996; Lehane et al. 2002; see Whiteway et al. 2010 for a review). Moreover, given the widespread decline in wood in streams owing to clearing and snagging, and deforestation of riparian zones, much of the research has been done to understand what kinds of habitat restoration are most useful to increase numbers of trout and salmon. Nevertheless, there are recent research reports and reviews of the importance of wood in lowland warmwater streams, especially in Australia (Crook and Robertson 1999; Howell et al. 2012) and the southeastern US (Benke and Wallace 2003). The key points of this research will be emphasized here, and placed in the context set by other research on coldwater streams. One main difference is that coldwater streams and rivers are often inhabited by fewer fish species, so the responses measured are simpler than those of the many-species assemblages occupying warmwater lowland streams and rivers. The transition zone of rivers along Colorado's Front Range, after they exit the mouths of canyons, traverse a transition between coldwater segments that support primarily trout throughout the year to cool- and warmwater segments that support more fish species (often 15-20 species total; Fausch and Bestgen 1997). Therefore, research on the benefits of wood in both coldwater and warmwater lowland streams are of relevance here.

Fish typically need different habitats that are dispersed throughout reaches to riverscapes during different stages of their life cycle, and at different times of year (Schlosser 1991), and move among these to fulfill their needs (Fausch et al. 2002; Falke and Fausch 2010). For example, large wood can create pools with overhead cover that are critical for fish to survive during winter, and also provides physical refuges from swift currents that can displace fish during high flows and floods, especially during spring snowmelt runoff (Shuler and Nehring 1993; Crook and Robertson 1999). Adding stable wood structures that create pools in Colorado mountain streams can increase trout biomass by about 50% (Gowan and Fausch 1996) and this increase can be sustained for more than two decades (White et al. 2011). Likewise, in a large lowland river of Australia, two large native predatory fish (both percichthyids, related to striped bass *Morone saxitalis*, in North America) were more often associated with patches of large wood than other habitat types, and this was consistent across four segments of different geomorphic character that spanned about 400 km of the Barwon-Darling River (Boys and Thoms 2006).

Boys and Thoms (2006) hypothesized that large wood provides important foraging sites for these predators, which ambush their prey, as well as hard substrates for invertebrates to colonize in these lowland rivers (see Crook and Robertson 1999 for a review). These relationships are important because 97% of the river length in Australia is in lowland rivers, 83% of which are dryland rivers like those in the lowlands of Colorado.

Both comparative data and experiments also provide strong evidence that fish select locations near large wood and other structures that provide refuges from high current velocities, and visual isolation and overhead cover from competitors and predators. For example, Nagayama et al. (2012) found that an assemblage of coldwater salmon, charr, large minnows, sticklebacks, and lamprey was more abundant and diverse in habitat patches formed by large wood than in patches without wood, in a lowland river in Hokkaido, northern Japan. Of interest was that the four dominant species selected the patches with wood for different habitat features. The salmon and charr selected locations with high current variability, where they can find low-velocity foraging locations close to swift currents (see Fausch 1984), whereas the sticklebacks and lamprey require low velocities with fine substrate. Given that fish in streams and rivers worldwide evolved with much higher loads of wood than are now present, it stands to reason that many different species would be adapted to use the habitat structure created by these natural materials.

Several investigators have used artificial structures to separate the preference of fish for the velocity refuges, visual isolation from other fish, and overhead cover from predators that large wood provides. For example, Fausch (1993) installed artificial structures in a lowland British Columbia stream that isolated these variables, by using clear Plexiglas structures to provide only velocity refuges, and then painting parts of them black to create lateral visual isolation or overhead cover. Results of this research and other studies on charr, salmon, and smallmouth bass (6 species total) showed that all responded most strongly to the overhead cover features, but in many cases also selected structures that offered velocity refuges and visual isolation (see Table 1 in Crook and Robertson, 1999). Many lowland rivers are naturally turbid, and so the overhead cover and visual isolation features of large wood may be less important there.

2.2. Stream invertebrates

As for fish, large wood can create habitat conditions favorable to certain groups of aquatic invertebrates, such as pools or backwaters, but can also provide hard substrate for growth of stream algae and subsequent colonization by invertebrates (Benke and Wallace 2003). Some of these invertebrates scrape algae as a food source, others use the wood as attachment sites from which to filter particles from the water flowing by, and still other taxa gouge and burrow in the wood itself.

Large wood can have profound effects on the diversity, abundance, biomass, and production of stream invertebrates, especially in lowland rivers where most other substrates are shifting sand or silt. Extensive research in low-gradient rivers of the Coastal Plain in the southeastern U.S. showed that large "snags" in several rivers in Georgia supported a unique assemblage of invertebrates, some of which use it for egg-laying sites (above or below the water), to find refuge from predation, or forage across it themselves for other invertebrate prey. Because animals that colonize stable wood substrates are larger than those on sand and silt, biomass of invertebrates on snags in one southeastern Georgia river was 10-60 times greater per square meter than on the bottom substrates, and production ($g/m^2/yr$) was more than 4 times higher. Although the surface area of snags made up only 4% of habitat area, snags contained 60% of the invertebrate biomass per lineal meter of river, and produced 70-80% of the numbers and biomass of drifting invertebrate prey. In turn, the biomass in diets of 5 of 6 fish species examined in detail that ate primarily invertebrates (insectivores) consisted of about 45-75% invertebrates that originated from large wood substrates. Other smaller species of fishes (e.g., minnows and darters) not analyzed ate more prey from the bottom substrates, and the abundance of these fish can increase when wood is removed (Angermeier and Karr 1984).

Across studies, large wood is a hotspot for invertebrate biomass, production, and diversity. Mean annual biomass was higher on wood habitats than in streambed sediments in 6 of 8 studies in lowland streams of the southeastern US and Australia (Benke and Wallace 2003). Likewise, annual invertebrate (secondary) production was higher on wood in 5 of 6 studies in these same locations. When averaged across surface area of substrates, wood often contributed 20% or more of the total numbers of invertebrates and 30-60% of the total biomass of invertebrates in these lowland rivers. Likewise, wood habitat often supports more than half the invertebrate species (i.e., diversity) found in rivers like these where it makes up much of the

stable substrate, such as in southeastern US rivers with sandy habitats and those in New Zealand with pumice substrates (Benke and Wallace 2003). As for fish, various experiments adding wood have been conducted and their effects on invertebrates measured. In several cases, abundance and biomass was significantly higher (often by 2-8 times or more) on the added wood, or in habitats created by it, than on other surrounding substrates like sand, gravel, or cobble (e.g., Wallace et al. 1995; Coe et al. 2009).

2.3. Effects of wood on other aquatic and terrestrial invertebrates, vertebrates, and floodplain vegetation

Although not considered in detail, large wood in streams and in riparian floodplains may have important effects on other vertebrates and invertebrates, from stream and pond-dwelling amphibians to riparian spiders, reptiles, birds, and small mammals. However, these groups have received far less study than fish or macroinvertebrates. Roni (2003) reported no detectable effects of large wood placement on giant salamanders (*Dicamptodon* spp.) in paired treatment-control reaches of 29 coastal streams of Washington and Oregon, based on a careful extensive post-treatment study, although lamprey and sculpins (a bottom-dwelling fish) did increase in various ways (e.g., density and growth). Fish owls (*Bubo blakistoni*) in far-eastern Russia used nesting and foraging locations associated with large old trees and riparian old-growth forests, which the authors inferred were also important in creating suitable river habitat for salmon and charr, their primary prey (Slaght et al. 2013). Small mammals, such as Preble's jumping mouse (*Zapus hudsonius preblei*; listed as Threatened under the Endangered Species Act), also use riparian habitat. Trainor et al. (2007, 2012) reported that this species used habitats close to streams, and detected some evidence that it was associated with large wood, probably because the wood supported both invertebrates and fungi that are food sources. Benjamin et al. (2011, and unpublished data) found that tetragnathid spiders, which live only near and above streams, were especially dense on downed wood that provided web supports directly over the stream, because these spiders eat only insects emerging from streams.

Several studies have demonstrated the importance of large wood to floodplain ecosystems. Floodplain wood creates germination sites for riparian vegetation (Schowalter et al. 1998; Pettit and Naiman 2006). Water-transport of propagules is important to many riparian species, and water-borne seeds are preferentially deposited against floodplain logs (Schneider and Sharitz, 1988). Floodplain wood also enhances nutrient cycling and soil formation (Zalamea

et al. 2007), provides invertebrate habitat (Benke 2001; Braccia and Batzer 2001), and enhances habitat diversity for various species of plants and animals (Harmon et al. 1986).

3. Public safety considerations associated with large wood

3.1. Potential hazards for inhabitants and infrastructure

Physical risks associated with large wood, like benefits from wood, strongly depend on the volume of wood within a channel, and on whether the wood remains stationary or becomes mobile during high discharges. The three primary risks to people and infrastructure are increased flow stage, altered movement of sediment and patterns of erosion and deposition, and mobile debris.

By increasing resistance and obstructions to flow, wood can create higher water levels for any discharge. This can create overbank flooding hazards along segments of a stream where overbank flow is not desirable. Wood can accumulate at bridges, for example, causing increased scour of piers and abutments or exacerbate upstream flooding. Wood can also block culverts, increasing flooding and eroding roadbeds. Large amounts of wood can potentially raise water elevations above existing regulatory mandates, such as the 100-year flood used for FEMA compliance. An indirect effect of wood may be to encourage beaver to build dams that contribute to flooding of adjacent areas.

Because wood alters velocity and sediment transport capacity in its immediate vicinity, the presence of wood can alter localized sediment dynamics. A concentration of wood along one bank can deflect flow toward the opposite bank, for example, accelerating erosion of that bank. Altered sediment dynamics can also result in lateral channel movement across the floodplain or local aggradation or scour, each of which can cause flooding or endanger infrastructure.

Finally, wood within the channel or floodplain can be transported during higher discharges, creating mobile debris that can damage downstream infrastructure such as bridges or pipelines.

3.2. Potential hazards for recreational users

Concerns regarding instream wood and public safety can also apply to river reaches that are frequently visited for such activities as wildlife viewing, fishing, picnicking, swimming, tubing, boating, hiking, walking and jogging, among others. Some instream wood is a risk to recreational users in the channel as an entrapment hazard. However, other instream wood can

make a reach safer for recreational users by providing zones of lower velocity and opportunities to rest, regroup or escape. What follows is a discussion of potential factors which increase or decrease the level of risk that instream wood has on the safety of recreational users. Eight categories are discussed: access, reach characteristics, snagging potential, porosity of jams, placement, anchoring, ability to avoid, and prior knowledge.

The following discussion is based on personal experience of the last author (a professional kayaker), as well as reports on wood and public safety by an advocacy group for kayakers and rafter (American Whitewater; Colburn, n.d.) and by the Bureau of Reclamation (Svoboda et al. 2013). The American Whitewater report is an excellent general reference for understanding river features and risk from the point of view of a boater. The Bureau of Reclamation report goes beyond public safety and outlines research needs for large wood design and placement, structure stability, risk analysis and liability.

1. *Access.* The first considerations are whether the reach is accessible to the general public and what type of recreational user is likely to visit. The risk that instream wood has on public safety increases with the frequency of recreation use because there are more chances for wood-human interaction. However, risk decreases quickly for recreational users experienced in navigating through and around rivers. For example, wood placement is safer along reaches visited only by experienced kayakers and anglers than along favorite family swimming locales or popular tubing destinations.
2. *Reach Characteristics.* Risk increases with water velocity because faster flow decreases the reaction time and capabilities that a swimmer, tuber, or boater has to avoid a hazard. Placing or keeping wood in lower velocity reaches is less risky than placing wood in reaches with swift current. In natural streams, most large log jams and most wood are located along slower rather than higher velocity sections. However, drowning can occur when a swimmer has no chance to reach shore because velocities are swift for long distances. This occurs in straight sections of rivers with uniformly swift velocity from bank to bank. In this scenario, instream wood jams with few dangerous crevices to trap boats or swimmers can be used to increase the safety of a reach by creating areas of lower velocities near shorelines.
3. *Snagging potential.* Although used previously to refer to the historic practice of removing pieces of wood from the channel, snagging to the water enthusiast refers to the potential

of a river hazard, such as wood, to snag a piece of clothing or gear as a swimmer or boat passes. Wood with many larger limbs is more of a risk to swimmers and boaters, especially if the wood is within the channel. Wood can be stripped of large branches and branch stubs to reduce snagging potential, although this may reduce the ecological benefits of the wood (see text in section II.2). If more complex wood with more branches is highly desired for ecological reasons, it should be placed in low risk locations on the margins of the channel or on reaches that are rarely visited by recreationalists or only visited by highly experienced recreationalists.

4. *Porosity of jams.* Although a single piece of wood with few to no branches creates relatively low risk, a porous jam can be hazardous. Jams with high porosity are those in which water runs swiftly through the jam rather than pooling upstream. These are known in the boating community as strainers. A person can be easily pushed up against the jam by water currents and not be able to swim through. However, a jam with enough wood and litter such as twigs and leaves will create an upstream backwater that is an advantageous and safe feature because it creates a safe place away from the swift main current for boaters and swimmers to rest, get out or regroup.
5. *Placement.* The placement of jams and single pieces has important effects on the risk associated with instream wood. For example, wood that is placed close to the water surface creates higher risk than wood far enough above the channel for recreational users to float under, or far enough below the water surface to float over. Because vertical position changes with water level, fluctuations in water level should be taken into account. Wood in contact with the bed so that no water is flowing underneath it has very low risk. Any wood near the bed with some water flowing under creates a foot entrapment hazard. Drownings from foot entrapment can occur in very shallow rivers at low flows because once the foot is entrapped, the person can fall face-first into the stream and not be able move from that position. This is a concern for anglers or for anyone wading in streams. For wood above the water column, American Whitewater (Colburn, n.d.) suggests a generous 3 ft of clearance for kayaks and 6 ft for rafts. Skilled kayakers are adept at safely passing beneath smooth logs as close as 1 ft above the water.
   With respect to the horizontal dimension, wood that spans the entire length of the channel is fairly dangerous unless it is in contact with the bed all the way across. Wood or wood

jams that partially span the channel are much safer because a route around the wood remains open. Vertical orientation of logs (like fenceposts) should be avoided because floating items such as rafts can be wrapped around the wood.

6. *Anchoring.* Although securing wood in place with cables, ropes, rebar, or other artificial material may help to ensure that wood does not threaten infrastructure downstream, these anchoring devices can be hazardous to public safety if they are exposed within the channel. This can occur if the channel scours around secured wood or if the wood becomes detached. It is recommended that wood is secured naturally through burial or weighting with natural materials.
7. *Ability to avoid.* Upstream visibility and an onshore escape route strongly reduce hazards caused by instream wood. Structures just around corners or just downstream of large drops can be difficult for boaters or swimmers to see and avoid. A boater or swimmer should have ample time to see the wood and react by either navigating around it or moving to the shore and getting out above it. A signed route to walk around the wood structure is particularly helpful. If something such as private property or steep terrain prevents avoiding the wood via the shore, the wood should be readily visible from far upstream, with ample room to paddle or swim around it.
8. *Prior knowledge.* Most importantly, prior knowledge of new wood along commonly navigated sections is vitally important to reduce risk. Regardless of location placement, new pieces of wood in previously clear channels typically create the greatest hazards. Boaters become complacent with sections of river that they run often and thus are not as attentive to their surroundings as they navigate downriver. In addition, boaters often become habitualized to navigating through a section of river the same way. Unknown, new wood along the normal route can be dangerous because it is not expected. One of the best risk-reducing measures that can be taken is to make sure that new instream wood is not a surprise to river enthusiasts.

When placing or leaving wood in streams, contacting the local boating community and/or American Whitewater is useful. Boaters often safely navigate many sections of streams with large amounts of wood. Thus, they are a good resource to include in the decision-making process because they can help make decisions about the safe placement of new wood. If boaters are included early in the project, they will be informed about the wood and will be less likely to

remove it. The boating community is well connected and word will spread quickly. In addition to contacting American Whitewater, there are numerous online boating and angling forums that can be useful to managers if they seek public comments. For example, in Colorado, MountainBuzz.com is a very active boating forum.

The perception by the general public is that wood is not natural in a stream and detracts from the esthetics (Piégay et al. 2005), in part because much of the wood historically in streams has been removed and people are not accustomed to seeing it (Chin et al., 2008). It is important that the public becomes knowledgeable and informed about wood structures through signs and public outreach to avoid an outcry against leaving wood in streams, to prevent citizens and boaters from removing carefully placed or retained wood features, and to decrease the risk to public safety associated with new wood installments.

III. Description of Tools that can be Used to Assess Large Wood

As discussed in previous sections, we need to understand the stability of individual wood pieces and jams within channels and on floodplains, and the physical and ecological effects created by this wood, in order to effective manage the wood. This section briefly introduces two categories of tools that can be used to better understand wood stability, benefits, and risks. Section III.1 introduces a spreadsheet-based program designed specifically to evaluate wood. Section III.2 reviews a group of numerical models designed to assess hydraulics and aquatic habitat, which can be applied to the understanding of instream and floodplain wood.

1. Large Wood Structure Stability Analysis Tool

The Large Wood Structure Stability Analysis Tool is a spreadsheet-based tool that can be used to efficiently evaluate wood stability and options for the design and placement of wood, based on factors including the size and species of wood, configurations, and anchor requirements. Users are required to input basic information on channel dimensions, discharge, streambed substrate, and wood characteristics. A companion report summarizes the design rationale, methodologies, procedure, limitations, and example applications to illustrate how the tool can be used to design stable wood structures.
http://www.engr.colostate.edu/~bbledsoe/streamtools/

2. Flow and Habitat Models

Several tools are available to assist with evaluation of the effects of wood on flow and potential benefits of wood for fish in Front Range streams. For example, the HEC-RAS (Hydrologic Engineering Center River Analysis System, http://www.hec.usace.army.mil/software/hec-ras/) software program can be used to model the flow of water in a variety of channel types. Developed mainly to model floodplain management and insurance studies for potential flood damage, an implicit component of HEC-RAS allows modeling one-dimensional changes in water surface elevation (stage) as it varies with flow (discharge). Large wood can impede flow velocity in a stream channel or on an inundated floodplain, and thereby increase the stage and alter channel or floodplain flow dynamics. Thus, when properly applied, HEC-RAS has value in estimating the lateral extent of flooding when wood has been placed or retained in the active river channel or floodplain. The HEC-RAS software may also be used to estimate flow velocities to help predict scour or erosion resulting from placement or retention of wood in the stream channel.

Modeling tools are also available for estimating the quantity and quality of fish habitat. One such tool is the instream flow incremental methodology (IFIM), and the associated physical habitat simulation tool (PHABSIM), which allows estimating usable fish habitat at different stream flows (Stalnaker et al. 1995; Bovee et al. 1998). This technique incorporates curves describing fish use (and assumed preference) of depth, velocity, and substrate microhabitat characteristics, which differ by fish species and life stage (e.g., fry, juveniles, adults, spawning adults). These characteristics are then predicted using hydraulic assessments of the stream cross-section, and the results combined into an index of "weighted usable area" for a given fish species and life stage. Such techniques may be useful in assessing placement or retention of wood in streams, especially to predict how wood affects the diversity of habitat at particular transects. For example, flow and depth variability may be greater in a habitat transect that contains large wood than one without, and these characteristics may be important to certain fish species, as described above. Two key caveats are that 1) hydraulic habitats are characterized by complex three-dimensional flow patterns that are typically poorly represented by one-dimensional simulation models, and 2) habitats that are critical for fish reproduction, growth, and survival may be important at spatial scales larger than the microhabitat scale (Fausch et al. 2002). Thus, such models should be used judiciously.

Flow and habitat assessments based on one-dimensional models can incorporate variable discharge levels but are not useful to assess spatial changes in habitat. Spatially explicit flow models that can be mapped in either two- and three-dimensions are necessary to describe more fully the spatial and temporal heterogeneity in a river system. Such models are useful to predict physical features of the habitat as well as understand relationships between fish, flows, and habitat quality and diversity (Bovee 1996; Ghanem et al. 1996). For example, Stewart et al. (2005) used two-dimensional modeling to correlate meso-habitat variables to fish biomass at a river-reach scale. They also validated the model, predicting fish biomass in different channel types over a range of flows, and attendant depth and velocity conditions.

Mean depth and velocity characteristics of streams can be measured in less time with the simpler one-dimensional models. However, two-dimensional models have the advantage of predicting habitat change as flows fluctuate seasonally and as channel shape changes, and also allows incorporating predictions of biomass as flows and spatial habitat change. This is an

important consideration when evaluating potential effects of large wood addition or retention in a stream reach, because wood effects can be modeled as a spatially explicit variable.

The additional effort and resources involved in using two-dimensional flow models can be justified when detailed information on habitat associated with wood is required. Consequently, users may want to consider the following models, which are in the public domain and can be obtained free of cost:

- RIVER2D: a two-dimensional, depth-averaged, finite element hydrodynamic model that has been customized for fish habitat evaluation studies. The model suite consists of four programs, each of which has a graphical user interface that is supported by any 32-bit version of Windows. http://www.river2d.ualberta.ca/
- SRH-2D: a two-dimensional hydraulic, depth-averaged, finite-volume numerical model for sediment, temperature, and vegetation in systems developed by the U.S. Bureau of Reclamation. The model suite consists of modules for hydraulics (in existence), and bed sediment transport, temperature and vegetation (under development). http://www.usbr.gov/pmts/sediment/model/srh2d/index.html
- Other models are also available commercially: commercial codes include MIKE 21c (http://www.mikebydhi.com/Products/WaterResources/MIKE21C.aspx), but most users would only go to a commercial code for three-dimensional modeling, and this code would likely be FLOW3d (http://www.flow3d.com/) or FLUENT (http://www.ansys.com/Products/Simulation+Technology/Fluid+Dynamics/Fluid+Dynamics+Products/ANSYS+Fluent)

IV. Decision Process for Managing Large Wood

1. Background on Risk Assessment

Engineers have a long tradition of performing risk assessments focused on structural stability or safety. However, it is only recently, with an upsurge in the practice of river restoration involving intentional placement and retention of large wood, that the need for risk assessments focused on wood has become pressing. Given longstanding concerns about public safety, property, and infrastructure in the river environment, risk assessments are increasingly being incorporated into river management and restoration efforts to ensure that the potential adverse consequences of projects have been adequately considered.

Risk is inherent in river management given the range of complexity in channel responses to changes in delivery water, sediment, and large wood. The purpose of any risk assessment is not to eliminate risk, but to objectively evaluate the potential risk elements and assess how a particular design or management action can address and alleviate those risks. It is important to note that there is commonly a significant risk of continued geomorphic and ecological degradation if large wood is not retained or re-introduced to a stream or river, and this risk should be included in every risk assessment. Therefore, a primary purpose of risk assessment is to assure designers, managers, stakeholders, and the general public that the potential short and long term effects of the proposed action have been considered, and that the expected benefits of the project outweigh the potential negative consequences (Abbe et al. 2014).

Risk is commonly defined as the potential of losing something of value, weighed against the potential to gain something of value. Risk may be mathematically defined as the probability of an event happening multiplied by the resulting consequences (cost or benefit) if it does:

$$Risk = P(E) \times \sum(C)$$

in which $P(E)$ is the probability of a specific event (E) or combination of events occurring, and $\sum(C)$ is the summation of the consequences of the event occurring (typically presented as a monetary cost). If there are no negative consequences of a particular event occurring, then there is no risk. If the consequences are grave, then even an event with low probability of occurring may pose more risk than is tolerable.

2. Procedure for Assessing Risks Posed by Large Wood

Risk assessment for large wood in streams is best regarded as an ongoing process because of likely changes in risk through time as a result of natural processes (e.g., high stream flows) and human modifications (e.g., stabilizing or pruning the wood). Consequently, we suggest a process illustrated by the flow chart in Figure 2, which incorporates four "tools." If wood is present in a channel, a simple checklist (Tool 1) can be used for an initial assessment of whether to remove the wood or consider other options. If options other than immediate removal are considered, the Large Wood Structure Stability Analysis tool (Tool 2) can be used to assess the likely stability of the wood during differing discharges. The outcome of Tool 2 can then be used with the Decision Bands (Figure 3; Tool 3) to qualitatively assess the alternative actions listed within the oval in Figure 2. The Decision Bands are used to assign risk to a high, medium or low category with respect to three characteristics: legal/property/infrastructure/inhabitants, recreation, and ecosystem.

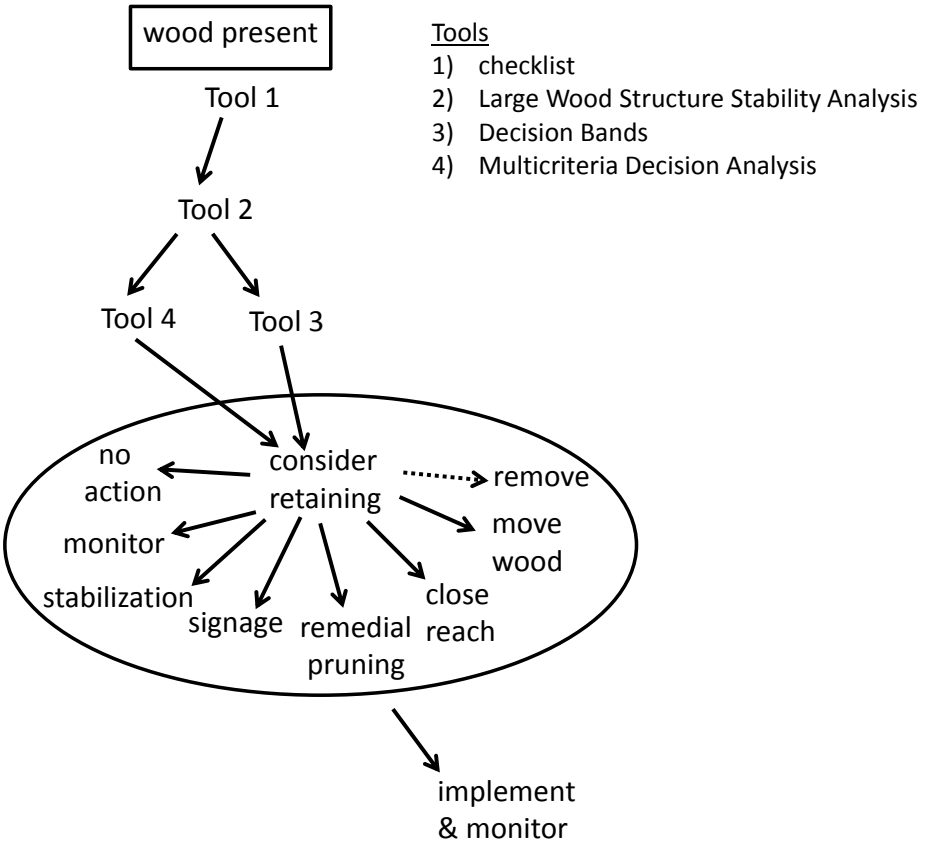
The outcome of Tool 2 can also be used in a more quantitative approach based on a multi-criterion decision analysis (MCDA) approach (e.g., Pomerol and Romero 2000; Kiker et al. 2005; Suedel et al. 2011). MCDA provides a flexible, rational, and transparent means to establish decision-making criteria and prioritize options and typically involves five steps (Chee 2004):

1. Define the goals and objectives.
2. Identify decision options.
3. Select the criteria that measure performance relative to the objectives.
4. Determine the weights for the various criteria.
5. Apply the procedures and perform the mathematical calculations to rank options.

In MCDA, criteria are scored on interval or ratio scales and then transformed to ensure commensurability before ranking options. Then criteria scores are aggregated using weights that reflect values, preferences, and expert judgment to transparently compare and rank options. MCDA is essentially a method for combining multiple criteria and value judgments into a concise set for decision making. The MCDA approach is more structured and defensible than 'best professional judgment,' yet more interpretable and less complex and data intensive than sophisticated optimization schemes. Users can also adapt the system to different decision-making

situations by adjusting the criteria and weights as knowledge and preferences evolve. Thus, the great strengths of MCDA are its transparency and flexibility.

Figure 2. Illustration of the sequence of tasks, and associated tools, which can be used to assess risk created by large wood in streams.



3. Tools

Tool 1. Checklist for Initial Assessment of Wood

1. *Imminent Threat to Public Safety*

a) Has a river recreation accident involving wood been reported?
If yes, remove.
If no, proceed to consider retaining.

b) Does the wood accumulation have crevices that can trap recreational users (i.e., is it porous) and completely spanning the active river channel in a location and season known for high recreational use?
If yes, remove.
If no, proceed to consider retaining.

2. *Imminent Threat to Property and Infrastructure*

a) Has the wood already damaged a flood district facility or public or private structure?
If yes, remove.
If no, proceed to consider retaining.

b) Could the wood potentially create, or increase the extent of, damage to a flood district facility or public or private structure that may cause loss of function to the facility or structure?
If yes, remove.
If no, proceed to consider retaining.

3. *Legalities*
For any reason, are you legally bound to extract the wood?
If yes, remove
If no, proceed to consider retaining

4. *Overall*
If the answer to all of the preceding questions was a clear 'no,' retain wood.
If the answers involved some qualifications, proceed to consider retaining.

Tool 2. Large Wood Structure Stability Analysis (see section III.1)

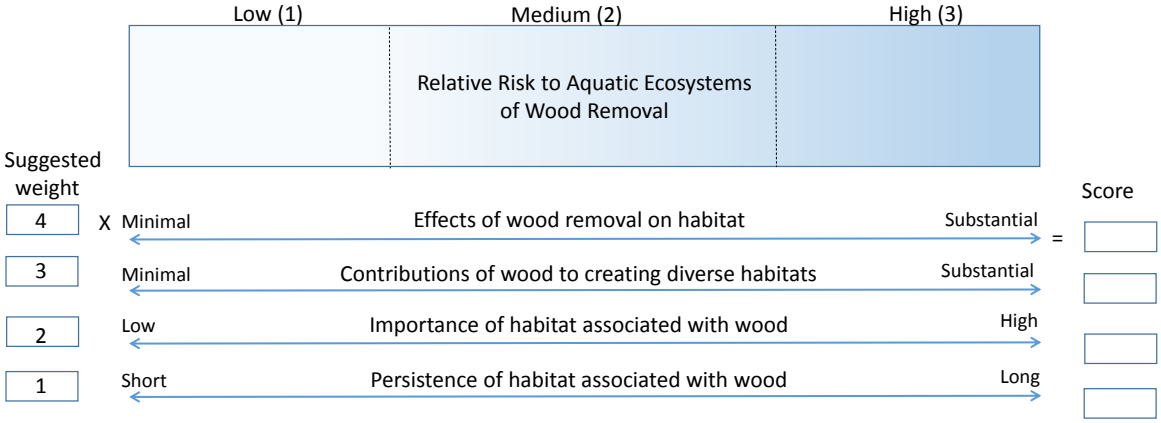
Tool 3. Decision Bands

The decision bands shown in Figure 3 are designed to assist field-based evaluation of the relative risk created by individual pieces of wood or logjams in a channel or on a floodplain. Individual bands focus on aquatic and riparian ecosystems, recreational users, and inhabitants and infrastructure. The suggested weights assigned to each row below the band, which can be altered by the user, can be used to create a weighted score for comparing different sources of risk. We emphasize that these decision bands represent a starting point for a complicated assessment process that is very context-specific. Some river reaches will have minimal recreational use or potential, for example, or no floodplain habitat. Although we briefly explain the characteristics that can be used to assign a score to each decision band, users who want to evaluate these characteristics in more depth are encouraged to consult the relevant technical

literature or disciplinary experts, and to use specific tools such as flow and habitat models (section III.2).

Figure 3. Decision bands for assessing the relative risk to different components of river systems associated with wood removal. Individual bands relate to (A) aquatic or in-channel ecosystems, (B) riparian or floodplain ecosystems, (C) recreational users, (D) water surface rise relative to adjacent floodplain, (E) wood stability and potential mobility, (F) downstream structures, facilities and infrastructure, (G) potential for unintended geomorphic consequences, and (H) a cumulative assessment for property, infrastructure, and public safety. For each band, the suggested weight in the box at the left in each row is multiplied by one of the numbers at the top of the band (1, 2, or 3) to create a score for that row, and these scores are then summed to create a total score for that decision band.

(A) Decision band for assessing the relative risk to aquatic ecosystems of wood removal.



Rationale:

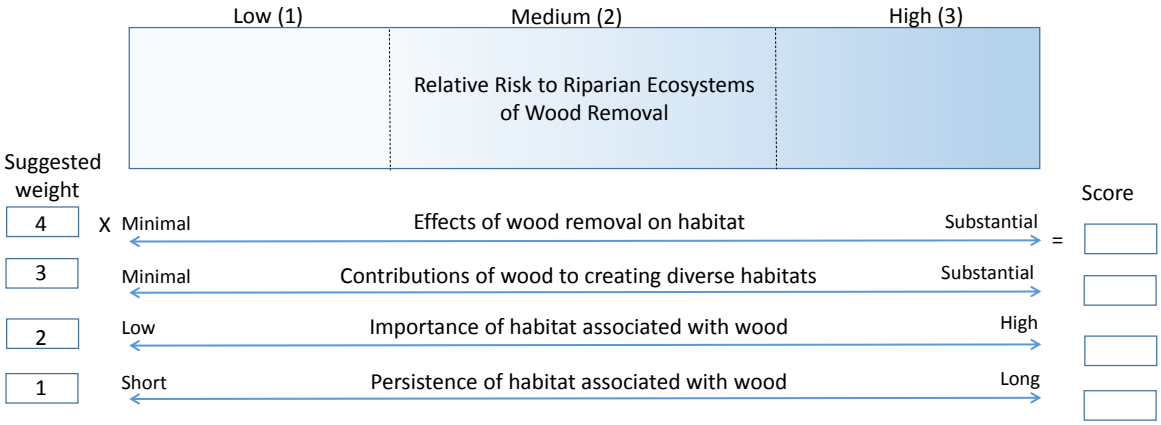
a. Effects of wood removal on habitat assesses whether habitat important to sustain fish or aquatic invertebrates, such as deep pools, is likely to decline as a result of wood removal (which would result in a low score), or is unlikely to be reduced by wood removal (a high score).

b. Contributions of wood to creating diverse habitats assesses whether the wood creates multiple types of habitat, such as pool scour and overhead cover for fish, diverse coarse and fine substrates for macroinvertebrates, perching habitat for birds, or backwater pools for fish and macroinvertebrates. Aquatic habitat diversity primarily requires a diversity of flow depth, flow velocity, streambed substrate, and complex physical structure created by wood.

c. Importance of habitat associated with wood includes considerations such as abundance of wood-related habitat at the reach scale, and the need for this habitat by key species. For example, pools are commonly critical habitats for many fish species, so if the wood creates the only pool habitat for fish within a particular stream reach, then the importance would be rated as high. In contrast, if the wood creates no pool or a very small pool, then the importance could be rated as low. Likewise, wood structures that create critical habitat for an at-risk or desired species equate to a higher score for the importance of habitat.

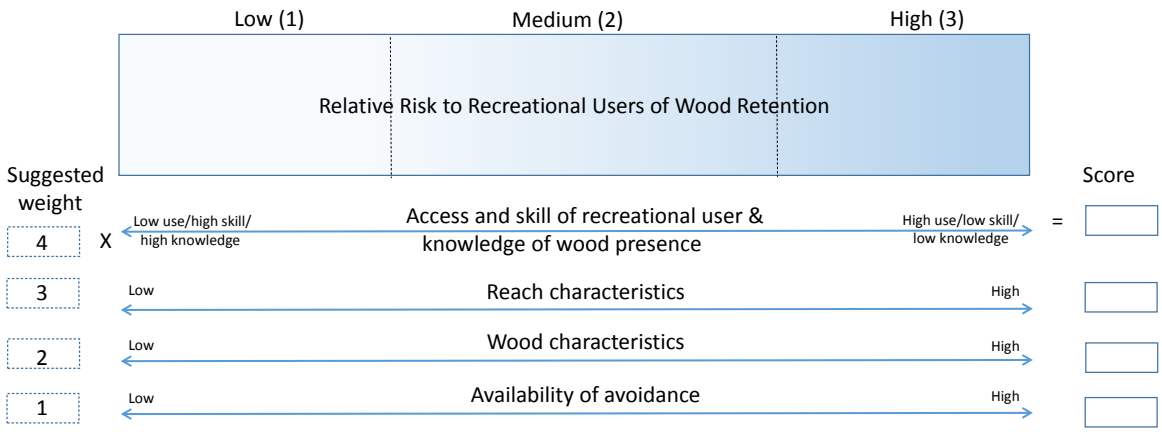
d. Persistence of habitat associated with wood assesses whether the wood-related habitat is likely to persist for a short period (< 5 years) or to persist for longer time periods (5-100 years or more).

(B) Decision band for assessing the relative risk to riparian ecosystems of wood removal.



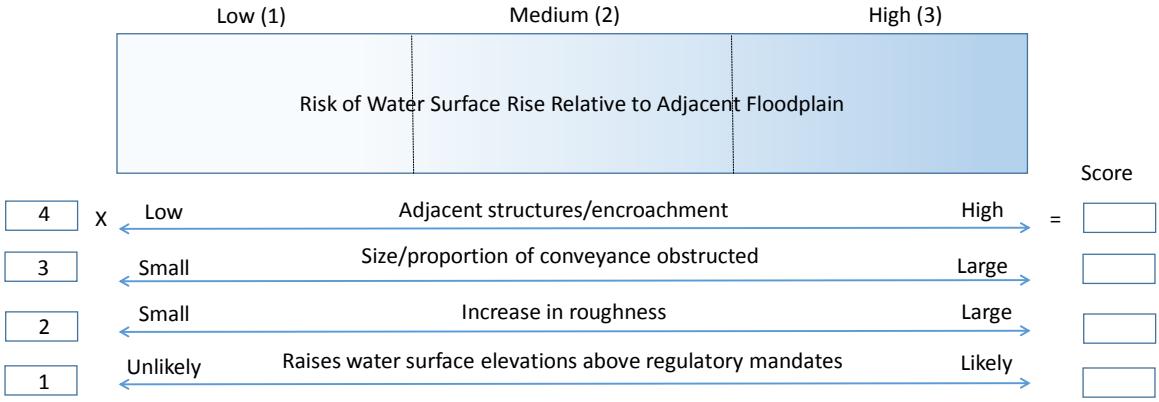
Rationale: The basic characteristics of the features (effects of wood removal, contributions of wood, importance of habitat, and persistence of habitat) are the same as described above for aquatic ecosystems, except they are applied to riparian organisms. As reviewed in section I.2, floodplain wood can create germination sites for riparian vegetation and provide habitat for invertebrates, amphibians, reptiles, small mammals, and birds. Where a long piece of wood spans both the channel and the floodplain, decision bands (A) and (B) should be used together to assess the wood.

(C) Decision band for assessing the relative risk to recreational users of wood retention.



Rationale:
The basic characteristics in this decision band relate to abilities and knowledge of the recreational user, the characteristics of the river reach in which the wood occurs (flow velocity), the characteristics of the wood (snagging potential, porosity of jams, horizontal and vertical placement, anchoring) and the availability of avoidance. Each of these characteristics is described in more detail in section II.3.

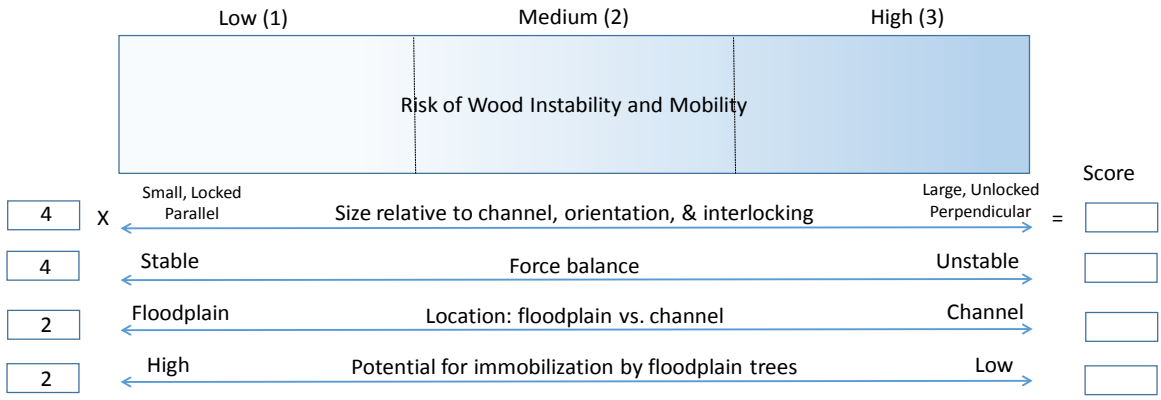
(D) Decision band for assessing the risk of water surface rise relative to the adjacent floodplain if wood is present.



Rationale:
Potential costs and the risk of negative consequences associated with large wood retention and placement depend on site-specific channel and floodplain characteristics. Encroachment by human development, infrastructure, and other valuable assets tend to increase potential costs associated with floodplain inundation and river channel changes. Thus, local encroachment in the vicinity of large wood is a fundamental consideration. Assessing risk also requires an understanding of the physical factors that control flood conveyance. The local extent of channel blockage, flow obstruction, and reduced cross-sectional area that may result from large wood

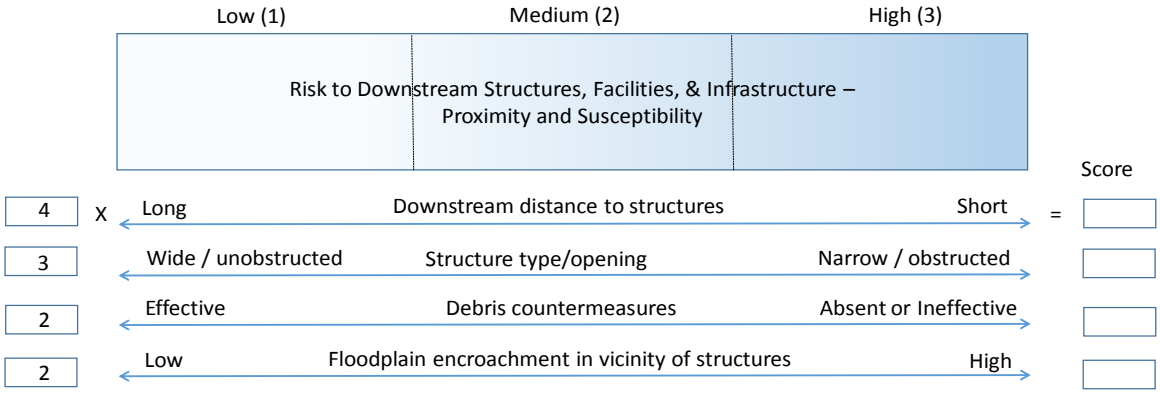
retention are fundamentally important. Flow conveyance is also proportional to flow resistance (a.k.a. roughness) as expressed by the widely used Manning *n*. Obstructions directly influence *n* values, but roughness is included as a separate factor to emphasize the importance of considering relative changes in flow resistance when assessing potential reductions in flood conveyance capacity. A final consideration is whether retention or emplacement of instream wood will alter water surface elevations to an extent that requires regulatory action such as generating a letter of map revision. The impact of such regulatory implications must be evaluated on a case-by-case basis by floodplain managers.

(E) Decision band for assessing the relative risk of wood instability and mobility.



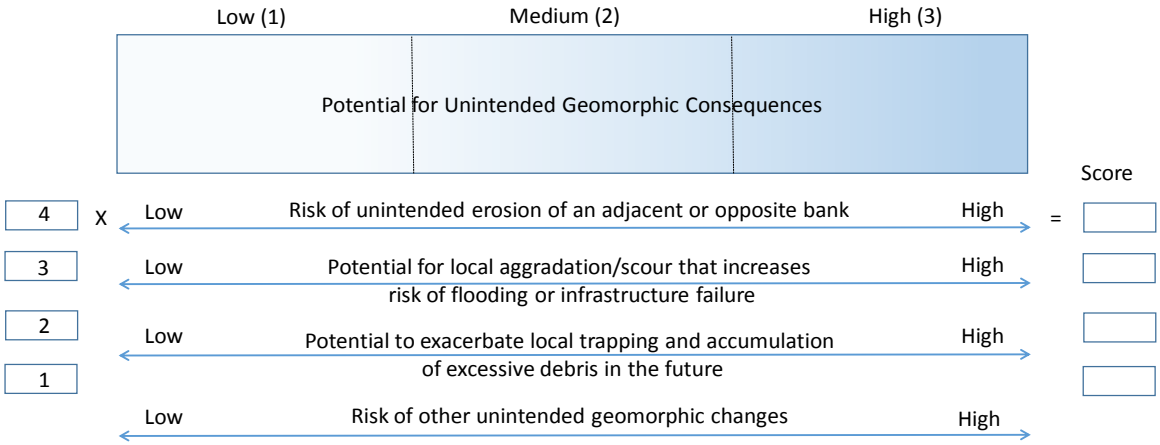
Rationale:
Large wood that presents little risk in its current location may nevertheless produce much greater risks if transported downstream to a location where it could exacerbate flooding and/or threaten property and infrastructure. This decision band is intended to address the likelihood of large wood being mobilized and transported downstream without reference to specific downstream conditions (addressed in decision band F). Individual pieces of wood that are large relative to channel width (e.g., spanning from top of bank to top of bank) may be inherently less mobile for a given amount of flow energy. Wood that is oriented lengthwise along a streambank in the flow direction is likely to be inherently more stable compared to a piece of wood oriented perpendicular to high velocity flow in the center of the channel. Physically-based models that explicitly account for the various forces acting on instream wood can be very useful and informative in assessing stability and the potential for downstream transport. To our knowledge, the spreadsheet-based force balance tool of Rafferty (2014) is the most rigorous and complete model of this type that is currently available. Wood mobility depends on the balance of stream power available to transport the wood versus the resistance of the wood to motion based on its weight, situation, and other factors. Floodplain flows, especially in unconfined valleys, typically have less erosive power than in-channel flows and thus less capacity to transport wood. In addition, forested floodplains may have a high capacity for trapping and immobilizing wood.

(F) Decision band for assessing the relative risk to downstream structures, facilities, and infrastructure resulting from the presence of instream wood.



Rationale:
Once wood is mobilized downstream from the location where it enters a river or stream, its potential for creating hazards depends on the types of hydraulic structures and infrastructure it encounters. The greater the distance wood must be transported before encountering vulnerable structures, the more likely the wood is to be immobilized and thus provide opportunities for re-stabilization or removal. The inherent susceptibility of hydraulic structures to loss of conveyance, damage, and failure is highly variable (FHWA 2005). Factors that affect a structure's capacity to safely convey wood include opening width(s) and height(s) relative to wood size, pier spacing, shape, and orientation, backwater effects, and the presence of debris countermeasures. There are many types of structural and non-structural debris countermeasures for bridges and culverts (FWHA 2005). Assessing structure vulnerability and the potential effectiveness of debris countermeasures requires extensive knowledge of both structures and hydraulic engineering and should be performed by a Professional Engineer. As described above, encroachment by human development, infrastructure, and other valuable assets tends to increase potential costs associated with floodplain inundation and river channel changes. Decision band D focuses on floodplain land use and encroachment in the immediate vicinity of instream wood without consideration of potential downstream effects. Accordingly, this decision band requires an evaluation of the potential consequences of reduced flood conveyance and damage to structures if wood is transported to vulnerable downstream locations.

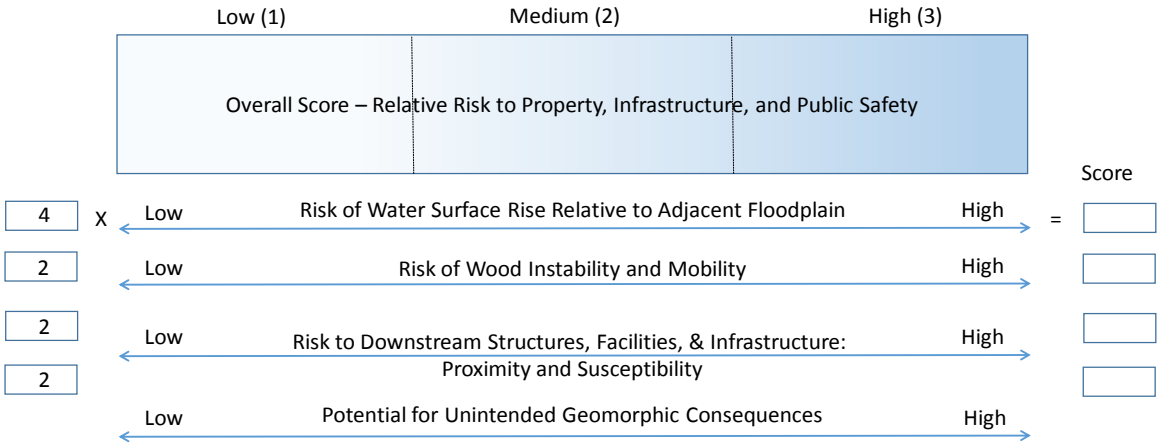
(G) Decision band for assessing the potential for unintended geomorphic consequences as a result of the presence of wood.



Rationale:

Instream wood is widely recognized by river scientists for its capacity to create habitat diversity and channel changes that benefit aquatic ecosystems. However, dynamic channel adjustments are commonly socially unacceptable in river corridors that are highly constrained by human encroachment. In such situations, it is important to evaluate the potential for instream wood to produce channel adjustments that conflict with adjacent property values and floodplain management objectives. Potential responses to inputs of large wood include accelerated bank erosion as a result of increased velocities and/or flow redirection, ongoing accumulation of wood and loss of conveyance, backwater effects, and altered sediment transport capacity and downstream supply that affect patterns of sediment scour and deposition. Such channel responses to instream wood can be difficult to predict, even for experienced fluvial geomorphologists and river engineers. Therefore, evaluations of potential geomorphic consequences are best performed by interdisciplinary teams of experts with direct experience in managing instream wood.

(H) Decision band for assessing the relative risk to property, infrastructure, and public safety associated with the presence of wood.



Rationale:

Decision band H integrates the results of decision bands D through G into an overall assessment score for relative risk to property, infrastructure, and public saftety.

Applying Decision Band scores

Decision band scores consistently in the medium-high range of decision bands A and B (risk to aquatic and riparian ecosystems of wood removal), and in the low range of decision bands C to G suggest options of no action, monitoring, stabilization, or signage (Figure 2). Scores in the low range of decision bands A and B and the medium-high range of the other decision bands suggest options of remedial pruning, closing the reach or moving the wood (Figure 2). Table 1 provides further information on the implications of choosing one of the options within the oval in Figure 2.

Table 1. Implications of individual options in Figure 2

No action	• can help to ensure continued beneficial habitat effects of wood • low risk to recreational users
Monitor	• can help to ensure continued beneficial habitat effects of wood • facilitates evaluating how interactions among discharge, sediment and wood influence habitat through time • recreational moderate-high risk wood in a low use or high-skill reach • recreational low risk wood in a high use reach
Stabilization	• can help to ensure continued beneficial habitat effects of wood • can reduce risks to infrastructure • to reduce recreational risk of unstable pieces moving to high-risk locations after assessment • reduce recreational risk by using natural stabilization techniques such as burial rather than cables and ropes
Signage/Outreach	• can reduce risks to recreational users; inform recreational users of new wood & educate recreational users to avoid public protest
Remedial pruning	• can reduce risks to recreational users by reducing snagging potential & making avoidance easier • may reduce beneficial effects to habitat
Close reach	• can help to ensure continued beneficial habitat effects of wood • can reduce risks to recreational users
Move wood	• may reduce beneficial habitat effects of wood • can reduce risks to infrastructure & recreational users for moderate-high risk wood in moderate-high use areas

V. Concluding Remarks

Figure 2 provides an overview of the sequence of steps that we suggest for assessing the benefits and risks posed by wood in stream channels and on floodplains. This sequence starts with the relatively short Checklist for Initial Assessment of Wood (Tool 1), followed by the Large Wood Structure Stability Analysis (Tool 2), the Decision Bands (Tool 3), and/or the Multi-Criterion Decision Analysis (Tool 4). We suggest that any decision to retain wood should be coupled with ongoing monitoring. Monitoring can be used to re-evaluate wood benefits and risks if conditions at a site, such as bed elevation or channel cross-sectional, change as part of the natural dynamics of a river. Monitoring can also be a key component of ongoing refinement of risk assessment. The procedures outlined in this report should be implemented by experienced, interdisciplinary teams. The weights that we suggest in the decision bands can also be adjusted based on stakeholder preferences.

The procedures outlined in this report represent a more nuanced approach to managing wood in river systems than automatically removing all wood. However, managers in some regions of the country are being more proactive than simply considering retaining naturally recruited instream wood. Managers in the U.S. Pacific Northwest, in particular, are now actively adding individual wood pieces and engineered logjams to channels because of the recognized physical and ecological benefits of wood. Jones et al. (2014) review some of these restoration projects and the success of the projects in achieving desired restoration of fish habitat.

An example of a large engineered logjam built by the Washington State Department of Transportation on the bank of the Hoh River along U.S. Highway 101.

Photo from Herrera Environmental Consultants, Inc (http://www.fhwa.dot.gov/publications/publicroads/06jan/05.cfm)

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VIII. Appendix: Definitions

bankfull channel: bankfull can be defined as the portion of the channel that contains relatively frequent floods occurring every 1-2 years, or as the portion of the channel below the inflection point at the top of the bank – above bankfull, flow moves beyond the channel and into the floodplain

biomass: the mass of living organisms within an area

channel morphology: the cross-sectional shape, downstream slope, bedforms (e.g., pools, riffles, steps, dunes), and planform (e.g., straight, meandering, braided) of a channel

debris: word sometimes used to refer to instream wood

floodplain: floodplain can be defined based on flood recurrence interval (e.g., 100-year floodplain), or as the portion of the valley bottom that would be inundated relatively frequently (every 1-2 years) under a natural flow regime

floodplain wood: large wood outside of the channel but within the floodplain

foot entrapment: when someone's foot becomes entrapped on the bottom of a shallow stream and the current pushes the person over, such that the individual can no longer stand or extract themselves without help; this usually occurs when someone is trying to stand or wade in shallow, swift moving water.

habitat heterogeneity: variation in physical environmental features (e.g., water depth, flow velocity, substrate) within an area

hyporheic: the portion of unconfined, near-stream aquifers where stream water is present; can also be defined as a flow-through subsurface region containing flowpaths that originate and terminate at the stream

instream wood: large wood that is at least partially within the bankfull channel

large wood: typically defined as wood pieces greater than 10 cm in diameter and 1 m in length
lateral migration: lateral movement of a channel, either via gradual erosion of one bank, or via abrupt shifting (avulsion) across the valley bottom during a flood

LWD: large woody debris, sometimes used to refer to instream wood

longitudinal: the downstream direction

macroinvertebrates: an invertebrate large enough to be seen without a microscopic; in streams, these are typically the juvenile stage of insects such as mayflies or caddisflies, and are typically bottom-dwellers (benthic)

multi-thread channels: a channel planform that includes multiple flow paths; these can shift laterally relatively rapidly between unvegetated bars (braided channel) or individual sub-channels can be more persistent features with forested islands between them (anastomosing channel)

natural flow regime: the hydrograph that would occur in the absence of human alteration of flow via dams, diversions, groundwater withdrawal, construction of levees, etc

organic matter: composed of organic compounds that have come from once-living organisms and their waste products in the environment (e.g., leaves, twigs, pine needles, frass)

periphyton: a community of algae, bacteria, microbes and fine detritus that is attached to cobbles and wood in the streambed

reach: any length of stream of interest for a particular study or concern; a reach is often defined as some multiple of the width of the channel at bankfull

riparian: the valley bottom outside of the channel, typically similar to the floodplain, but characterized by hydrophilic (water-loving) plants tolerant of inundation and mechanical damage during floods

risk: the probability of something happening multiplied by the resulting cost or benefit if it does

species richness: the number of different species represented in an ecological community

stability: the presence or absence of changes in channel morphology, flow regime, biomass, habitat heterogeneity, and other characteristics of rivers is highly dependent on the timespan being considered – what might appear to be a substantial change and evidence of instability when considered over relatively short time intervals, may appear as part of regular fluctuations within a generally stable state when considered over longer time periods

strainer: an obstacle in the river that is porous, such that items or people pushed up against it by the current cannot pass or swim through

uncertainty: limited knowledge makes it impossible to exactly describe the existing state, a future outcome, or more than one possible outcome

APPENDIX G

GUIDANCE FOR HYDROLOGIC AND HYDRAULIC ANALYSES

COLORADO
Colorado Water Conservation Board
Department of Natural Resources

1313 Sherman Street, Room 721
Denver, CO 80203

Memorandum

To: Matthew Buddie, CFM MSB
National Flood Insurance Program Specialist, FEMA Region VIII
From: Jamie Prochno, PE, CFM JCP
Community Assistance Program Coordinator
Date: September 21, 2014

Subject: Guidance for Hydrologic and Hydraulic Analyses

BACKGROUND

The September 2013 floods caused widespread damage to many communities along Colorado's Front Range. The amount of rainfall, over 15" in some areas, and steep topography resulted in major erosion, deposition, and relocation of several rivers and streams in the affected area. Therefore, many of the mapped Special Flood Hazard Areas (SFHAs) on effective Flood Insurance Rate Maps (FIRMs) no longer reflect current conditions. As communities begin permanent recovery work, the Colorado Water Conservation Board (CWCB) recognizes the need to provide guidance to local officials, property owners, and contractors for projects where the SFHA and current conditions no longer match. The purpose of this document is to help guide recovery efforts and ensure communities stay in compliance with minimum requirements of the National Flood Insurance Program (NFIP). Scenarios not described here should be discussed with the FEMA Region VIII Office or the CWCB.

It is the community's responsibility to manage all development occurring in the SFHA. Communities must ensure all local, State, and Federal permits are received, including a local floodplain development permit, and specific requirements are met before the project commences. In instances where there is a conflict between local, State, or Federal requirements the more restrictive regulation shall prevail.

The requirement to conduct a hydrologic and hydraulic analysis for proposed development in floodways is outlined in Title 44 of the Code of Federal Regulations, Section 60.3(d)(3). Pursuant to NFIP regulations, an analysis is required to show that proposed projects in the floodway will not cause any increase in Base Flood Elevations (BFE), which is referred to as a no-rise analysis. Section 60.3(d)(4) states that encroachments into the floodway may cause an increase in BFEs, provided that the community first applies for and receives a Conditional Letter of Map Revision (CLOMR). The CWCB Rules and Regulations for Regulatory Floodplains in Colorado, Rule 8(B) includes a higher standard than 44 CFR 60.3(c)(10) and stipulates that a CLOMR is required when a proposed project will increase BFEs more than 0.5 foot on a waterway with BFEs for which a regulatory floodway has not been computed. The requirements for submitting new technical data to FEMA are contained in 44 CFR 65.3 and require a community to submit technical or scientific data, in the form of a Letter of Map Revision (LOMR), to FEMA within six months of project completion when BFEs have increased or decreased as the result of a physical change to the floodplain.

POLICY GUIDANCE

The following guidance applies to projects that are located within a regulatory floodway or in a floodplain with BFEs where a floodway has not been defined; and therefore, may require a no-rise analysis, CLOMR or LOMR.

Restoring to Effective Conditions

Channels may be restored to effective conditions without further analysis. Effective condition is considered the modeled condition reflected in the effective Flood Insurance Study, including floodplain and floodway boundaries, base flood elevations, flows, and channel geometry. The project must adhere to any other federal, state or local regulations and permit requirements.

Projects that were properly designed, permitted, and constructed prior to the flood may be replaced in-kind without further analysis so long as the conveyance equals that of the original structure. The project must adhere to any other federal, state or local regulations and permit requirements. Reduction in conveyance as a result of sedimentation may require channel modification. Changes in structure design or channel modification must go through the normal review process which may include a no-rise analysis, CLOMR, and LOMR.

Stream Crossings and Restoration Projects

Where current and effective conditions do not match and the community does not intend to return the channel to effective conditions, hydrologic and hydraulic analysis will be required for proposed projects. A no-rise analysis must show that the proposed project does not increase water surface elevations of the base flood. A no-rise analysis may be defined as:

- The proposed conditions model shows no increase in water surface elevations compared to the existing conditions models; or
- The proposed conditions model shows no increase in water surface elevations compared to the pre-flood conditions model.

Additional engineering will be required to determine existing conditions in areas where the channel has migrated. Existing conditions should not reflect any man-made temporary work such as temporary crossings, bridges, culverts, hydraulic structures, or other developments that have been constructed since the flood. Structures present before the flood may be included in the existing conditions model even if they were washed out as a result of the flood. Pre-flood conditions may only be used for the no-rise analysis if sufficient data exists to determine the channel geometry and structures that were present prior to the flood.

CLOMR Requirements

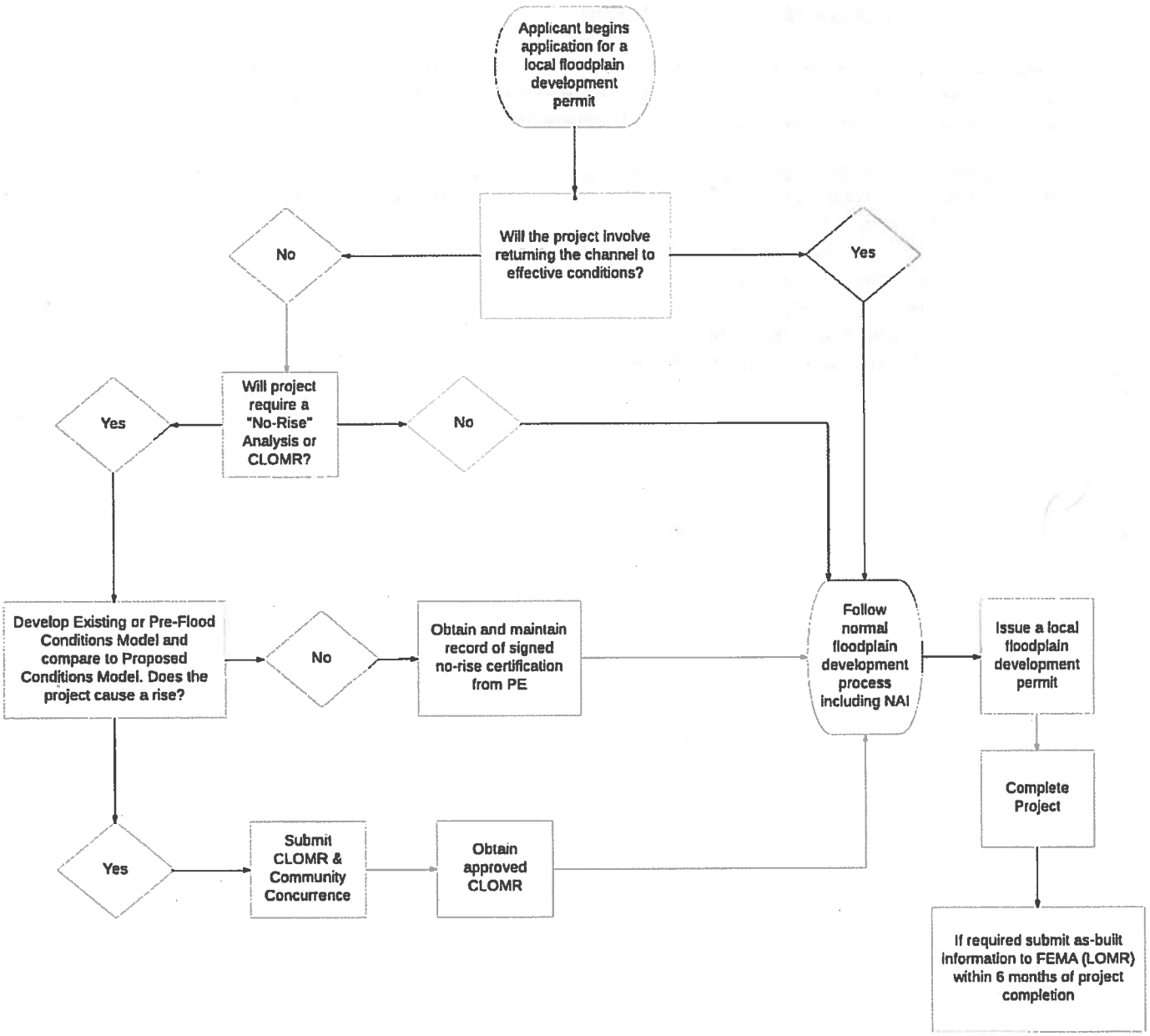
A CLOMR may be required when proposed conditions show increases in water surface elevations of the base flood compared to existing conditions. If the project is located in a floodway, a CLOMR is required if a no-rise analysis cannot be completed according to the guidance outlined above. If the project is located in a floodplain with BFEs and no floodway, a CLOMR is required if the project causes more than 0.5 foot of increase in water surface elevations. For CLOMRs, the standard MT-2 process must be followed.

LOMR Requirements

A LOMR must be submitted within six months of completion for all projects when the proposed conditions model shows an increase or decrease in BFEs compared to the effective model. The standard MT-2

process must be followed, including as-built information showing post-project conditions. It is the community's responsibility to ensure all information is submitted to FEMA in a timely manner.

The following flow chart illustrates a simplified representation of the process for floodplain permitting:



RECOMMENDED PRACTICES

CWCB encourages communities to look holistically at projects and ensure the effects of one project will not negatively impact others. In the event potential adverse impacts are identified, the local jurisdiction should be prepared to take steps to minimize and mitigate the impacts. The Association of State Floodplain Managers refers to this principal as "No Adverse Impact" (NAI). NAI should be a lens in which local officials, property owners, and contractors look at every project. Additional information on NAI can be found at http://www.floods.org/index.asp?menuID=460.

Local floodplain development permits should also be considered outside of the effective SFHA where projects are now subject to flood damage as a result of channel migration. This determination must be made by the local floodplain administrator using Best Available Data.

CWCB encourages communities to ensure that proposed projects within rivers and floodplains are aligned with community, regional and watershed plans. Projects should also consider multiple objectives, which may include:

- Restoring stream channels,
- Providing habitat for aquatic and terrestrial species,
- Restoring riparian areas,
- Reducing erosion,
- Reducing flood hazards, or
- Increasing the capacity to utilize water.