WWE
# MEMORANDUM

**To:** Michael A. Thomas, P.E.
County Engineer, Boulder County Transportation Department
**Via Hand Delivery**

**From:** Wright Water Engineers, Inc.
Ian Paton, P.E., CPESC, CFM
T. Andrews Earles, Ph. D., P.E., D. WRE, CPESC

**Date:** January 20, 2011

**Re:** Summary of Findings – Fourmile Canyon Post-Fire Hydrology and Discussion of Conceptual Mitigation Measures

## INTRODUCTION

This memorandum was prepared by Wright Water Engineers, Inc. (WWE) to summarize the results of our analysis regarding the projected post-fire hydrology 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 (Smeins and Chambers, 2010) (see Figure 1).

In accordance with our scope of work, tasks completed to date and discussed in this memorandum include the following:

- WWE reviewed key documents and studies prepared by different federal agencies on the post-fire hydrology and potential for debris flows;
- WWE conducted field visits on November 17 and 28, and December 10, 2010 to inspect the burned areas of the watershed and areas that are prone to impacts from debris flow;
- WWE performed calculations and developed computer models to estimate the peak flow rates for a selected number of drainage basins that were identified as being most susceptible to debris flow in their current post-fire condition. WWE calculated clear water peak flow rates for storm events with recurrence intervals ranging from 2- to 100-years. Based on the clear water runoff calculations, estimates were also developed for the projected volumes of debris flows from the same basins for the 2-year event. The debris flow volume estimates were calculated for the purpose of comparison with debris flow volume estimates published in the United States Geological Survey (USGS) open file report (USGS, 2010). The USGS and WWE results, calculated using independent methods, were similar;

- WWE made calculations to assess the probabilities of different storm events occurring. These calculations were conducted in conjunction with an assessment of the projected hydrologic recovery of the watershed in the years after the fire. Together, the storm event probabilities and the hydrologic recovery of the watersheds can be used to assess the probability of specific flood events or debris flows;

- Locations were identified for conceptual measures to mitigate the anticipated debris flows of debris; and

- WWE participated in multiple meetings with personnel from Boulder County, USFS, USGS, and the City of Boulder to discuss the findings of this analysis.

## BACKGROUND INFORMATION

The following documents provider background information on prior studies conducted regarding the post-fire hydrology of the watershed.

- The Four Mile Emergency Stabilization Team (FEST) *Four Mile Emergency Stabilization Burned Area Report* (FEST, 2010).

- The BLM and USFS *Hydrology and Soil Specialist Report, Fourmile Canyon Fire, FUL0* (Smeins and Chambers, 2010)

- The United States Geological Survey (USGS) open file report on the *Probability and Volume of Potential Post-Wildfire Debris Flows in the 2010 Four Mile Burn Area, Boulder County, Colorado* (USGS, 2010).

In addition, post-fire peak flow rate data from other Colorado Front Range burn areas were also reviewed (Jarrett, 2010), as were precipitation data for the Fourmile Canyon area collected by the Urban Drainage and Flood Control District (UDFCD), and Geographic Information Systems (GIS) data of the burn area compiled by the USFS and provided to WWE by Boulder County.

The burn severity and slopes within the burned area are both important characteristics that affect the post-fire hydrology. Values for these parameters, as reported in Smeins and Chambers, 2010, are presented in Tables 1 and 2, respectively.

**Table 1. Burn Severity**

| Burn Severity | Acres | Percent of Burned Area |
|---|---|---|
| High | 684 | 11 % |
| Moderate | 3001 | 49 % |
| Low and Unburned | 2492 | 40 % |
| **Total** | **6177** | **100%** |

Source: Smeins and Chambers, 2010

**Table 2. Slopes Within the Burned Area**

| Slope | Percent of Burned Area |
|---|---|
| 0 – 10% | 6 % |
| 11 – 30% | 40 % |
| 31% + | 54 % |

Source: Smeins and Chambers, 2010

## METHODOLOGY

### Peak Flow Rate Estimates

Nine basins, as delineated by the USFS, were selected by WWE to be analyzed for peak flow rates and debris flows (see Figure 2). The basins analyzed were chosen based on their burn severity and increased susceptibility to debris flows and/or their potential for producing substantial volumes of debris flow. Burn severity, as determined by the FEST team, is shown on the figure from the FEST report (see Appendix A, Figure A-1). The probability of debris flow occurrence, as calculated by the USGS, is shown in Appendix B (Figure B-1) and the estimated debris flows volumes, for the 2-year, 1-hour storm event, are shown on Figure B-2. A list of the basins evaluated for this WWE analysis is provided in Table 3:

**Table 3. Drainage Basins Evaluated**

| Basin Number | Basin Name | Basin Size (acres) | Basin Size (square miles) |
|---|---|---|---|
| 0 | 4-mile Canyon Creek East | 290 | 0.45 |
| 3 | Sweet Home Gulch | 174 | 0.27 |
| 7 | Ingram Gulch | 286 | 0.45 |
| 10 | Emerson Gulch | 287 | 0.45 |
| 11 | Schoolhouse Gulch | 144 | 0.23 |
| 12 | Melvina Gulch | 129 | 0.20 |
| 16 | Unnamed Tributary 1 to Fourmile Creek West of Emerson | 109 | 0.17 |
| 18 | Nancy Mine Gulch | 85 | 0.13 |
| 23 | Short Cut & Sand Gulch | 483 | 0.75 |

Source: USFS and Boulder County

Estimates of peak flow rates and debris flows were calculated for drainage basins in their post-burn condition for the storm events listed in Table 4:

**Table 4. Storm Events Analyzed**

| Event | Precipitation Depth (inches) |
|---|---|
| 2-Year, 1-Hour | 0.9 |
| 10-Year, 1-Hour | 1.5 |
| 25-Year, 1-Hour | 1.7 |
| 100-Year, 1-Hour | 2.4 |

The precipitation depths in Table 4 are based on data published in the Urban Drainage and Flood Control District (UDFCD) Urban Drainage Criteria Manual, Volume 1, which are based on data published in NOAA Atlas, Volume III-Colorado. An exception is the 2-year, 1-hour event, for which the precipitation depth was derived from the value used in the USGS debris flow study.[1]

Storm events with a duration of one hour were selected for analysis because of the high intensity of these events and their potential for generating large peak flow rates, coupled with the relatively small size of the basins evaluated, which all have areas less than 1 square mile.

Predicted peak flow rates were calculated for the basins analyzed using a Curve Number loss method with the Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) computer model. HEC-HMS is a public domain model developed by the United States Army Corps of Engineers Hydrologic Engineering Center.

Selection of Curve Numbers for model input was based in part on values published by the Burned Area Emergency Response Team (BAER) for a range of burn conditions, taking into consideration the steepness of the slopes in the burn area (BAER, 2010), the soil type (primarily Hydrologic Soil Group D), and consultation with Dr. Robert Jarrett of the USGS. Curve Numbers used for the model are presented in Table 5:

**Table 5. Curve Numbers Used for HEC-HMS Model**

| Watershed Condition | Curve Number |
|---|---|
| Moderate Burn Severity | 89 |
| High Burn Severity | 96 |
| Moderate/High Burn Severity | 92 |

[1] The USGS open file report on the *Probability and Volume of Potential Post-Wildfire Debris Flows in the 2010 Four Mile Burn Area, Boulder County, Colorado* (Open-File Report 2010-1244 ) was originally published indicating that the one-hour event depth of 0.9 inches is for a 25-year event. This was later corrected to indicate that 0.9 inch, one hour storm is for a 2-year event.

The Curve Number of 92 for the combination of moderate and high burn severity is based on the general post-fire condition in the basins analyzed, with more area having moderate burn severity compared to high burn severity, as reflected in Table 1. Initial losses were estimated to be 0.2 times the watershed maximum retention after runoff begins, which is a standard adjustment in the model.

For pre-fire conditions, which are used to determine pre-fire baseline hydrologic conditions, the Curve Numbers for were estimated by determining the respective Curve Number values which were just below the value necessary to generate runoff from the 2-year, 1-hour rainfall event. Estimates of peak runoff rates from pre-fire conditions were used to determine the relative increases in runoff from pre-fire to post-fire.

For model input of rainfall data, a distribution of the one hour storm depths presented in Table 4 was derived from the peak one hour distribution used for the Colorado Urban Hydrograph Procedure (CUHP). For model input of lag time, the lag time value was calculated from slope data derived from topographic and basin geometry information for the basins.

### Debris Flow Estimates

For estimating debris flow volumes, since the model-generated projections for runoff are for clear water flow (i.e., no debris entrained), a bulking factor of 35 percent was added to the clear water flow values to estimate debris flow volumes. The bulking factor is based on typical values from the literature and past experiences with mud and debris flows in Colorado and New Mexico.

Debris flow volume estimates were calculated for the 2-year storm event only, for comparison purposes with the USGS study. The USGS study was also based on a 2-year, 1-hour event. The comparison is discussed in the Results section.

### Probability Calculations

For the storm events analyzed, the probability of each event occurring over the next ten years was calculated using the Binomial Theorem. The probability of occurrence over a ten year period was assessed since that is estimated to be roughly the time period necessary for the watershed to recover substantially, though not fully, in terms of hydrologic conditions.

## RESULTS

Results are presented below for projected post-fire peak flow rates, debris flow volumes, and probability of occurrence.

### Peak Flow Rates

Peak flow rate model estimates for the events analyzed are presented on Figures 3.1 through 3.4. For each storm event and for each basin analyzed, results are presented for both a moderate burn intensity condition and a high burn intensity condition to provide a range for bracketing the model results. In addition, the anticipated condition of the watershed (i.e., a combination of moderate and high burn intensity within each basin) is also presented.

WWE performed multiple reasonableness checks on peak flow rate predicted by the HEC-HMS model. These checks included simple Rational Formula calculations as well as comparison of peak runoff rates from actual runoff events where we were able to assign a frequency to the rainfall (one storm from Pajarito Canyon at Los Alamos and a second from Buffalo Creek). All reasonableness checks supported the numbers generated by the HEC-HMS model.

## Debris Flow Volumes

Estimates of debris flow volumes for the 2-year, 1-hour event are presented on Figure 5.1. Results from the USGS study area also presented on Figure 5.1 for comparison. Although the estimated volumes of debris flow were calculated using two independent methods, the results of the USGS study and WWE study compare favorably. The USGS debris flow estimates are based on an empirical formula derived from data collected from recently burned basins throughout the western United States as described in the USGS report (USGS, 2010). In contrast, as described above, the WWE debris flow estimates were calculated using a Curve Number-based model to calculate runoff volume with a bulking factor used to estimate the volume of debris flow.

For emergency management purposes, Figure 5.2 presents the quantity of sediment from the debris flow volumes shown in Figure 5.1, with horizontal lines across the graph that indicate the number of dump volume equivalents. The dump truck size used for Figure 5.2 is 13 cubic yards, which is the average size tandem dump truck that Boulder County Transportation Department officials have indicated would be used to remove sediment and debris from the burn area. It is noted that the entire volume of a debris flow will not necessarily need to be removed following a debris flow event. The fraction that needs to be removed will be site-specific.

## Probability of Occurrence

The probability of occurrence for a 2-year event within 10 years (the estimated period for hydrologic recovery of the watershed [WWE, 2003 and Earles e al. 2004]) is presented on Figure 6.1. A key point to note from Figure 6.1 is that a 2-year storm event is a virtual certainty to occur at least once within the next 10 years. There is roughly a 75 percent probability of a 2-year event occurring at least once in the next 2 years and roughly a 90 percent probability of a 2-year event occurring at least once in the next 4 years.

For the 10-year, 25-year and 100-year events, the probability of occurrence for each storm event is shown as a blue line on Figures 6.2 through 6.4, respectively.

Also shown on Figures 6.2 through 6.4 is a red line that indicates the estimated hydrologic recovery of the watershed, represented as the ratio of the peak flow rate in the post-fire condition by the peak flow rate in the pre-fire condition. The starting point for the hydrologic recovery line for each storm event is based on the ratio of post-fire versus pre-fire peak average unit flow rates calculated with the Curve Number loss method, as described previously. (Note: A similar hydrologic recovery line was not generated for the 2-year event because no pre-fire flow was predicted to occur, hence the ratio of post-fire to pre-fire flow would be essentially infinite.)

For Figures 6.2 through 6.4, the probability of a storm event occurring can be determined in conjunction with the hydrologic recovery of the watershed to assess the probability within the next 10 years of the occurrence of a particular post-fire peak flow rate multiplier.

## POTENTIAL MITIGATION MEASURES

Potential recommended locations of mitigation measures to collect or divert debris flows from the burn area were initially evaluated using model results and mapping of the basin topography. Locations were preliminarily identified, and then field verified where practical. Potential locations for both debris racks and debris barriers are shown on Figures 2.1 through 2.8. Further field analysis may indicate locations other than those shown in the report, or may reveal that what is shown in the report may not be feasible. This document is intended as an aid for further, more site-specific analysis and recommendations. Although WWE has identified potential locations for mitigation measures, this should not be construed to be a commitment from the County to construct these measures.

Suggested debris rack locations are sited to capture debris before it blocks culverts or covers roadways. Suggested debris flow barriers are sited to divert debris flow away from structures.

In all cases, the locations of debris racks or debris barriers shown on Figures 2.1 through 2.8 are schematic representations only and are not to scale. Debris racks should consist of heavy steel mesh or welded pipe that has been engineered for the site-specific conditions. Debris barriers should consist of anchored concrete blocks, compacted earthen berms or similar material that, again, has been engineered for the site-specific conditions. Other potential measures or structures may be considered as individual site conditions warrant.

## SUMMARY AND CONCLUSIONS

Regarding the probability of different storm events occurring, it is a virtual certainty that a 2-year event will occur at least once within the next 10 years. There is roughly a 75 percent probability of a 2-year event occurring at least once in the next 2 years and a 90 percent probability of a 2-year event occurring at least once in the next 4 years.

In the current post-fire condition, in those basins with moderate to high burn severity, peak flow rates are expected to increase substantially, particularly within the next two to three years. Post-fire peak flow rates are estimated to fall in the following ranges:

- For the 2-year, 1-hour event, in the pre-fire condition, negligible runoff is expected to have occurred. In the post-fire condition, the predicted unit rate of runoff for clear water flows ranges from approximately 0.5 to 0.8 cfs/acre.

- For the 10-year, 1-hour event, the predicted post-fire unit rate of runoff for clear water flows is estimated to range from approximately 1.25 to 2 cfs/acre. For the 100-year, 1-hour event, the estimated unit rate of runoff increases to as high as approximately 3.75 cfs/acre. (For reference, the basins evaluated and discussed in this memorandum range in size from 83 acres [Nancy Mine Gulch basin] to 483 acres [Short Cut and Sand Gulch basin], as shown in Table 3). For comparative purposes, the mean of the annual peak flow rates in Boulder Creek at USGS gage 06727000, located upstream from the confluence with Fourmile Creek (based on data collected from 1907 to 1995), is approximately 645 cfs.

Mitigation measures such as debris racks and debris barriers can be placed to protect culverts, roads and structures from debris flows during smaller events (i.e., potentially up to a 2-year event). However, it is important to recognize that larger events (e.g., larger than a 2-year event) will most likely overwhelm any measures intended to capture or divert debris flows. Therefore, a comprehensive warning and emergency preparedness system is essential.

The analysis described in this memorandum does not address potential impacts further downstream from the burn area (e.g., impacts along Boulder Creek).

## REFERENCES CITED

BAER, 2010. Burned Area Emergency Response Tools. Details of Curve Number Methods. Web link: http://forest.moscowfsl.wsu.edu/BAERTOOLS/ROADTRT/Peaklow/CN/supplement.html.

Earles et al., 2004. Los Alamos Forest Fire Impact Modeling. Journal of the American Water Resources Association. April.

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Jarrett, 2010. Front Range Post-Fire Flooding and Flood Hazards for Emergency Managers. (Presentation). USGS. Paleohydrology and Climate Change Project.

Smeins and Chambers, 2010. *Hydrology and Soil Specialist Report, Fourmile Canyon Fire, FUL0.* September 2010.

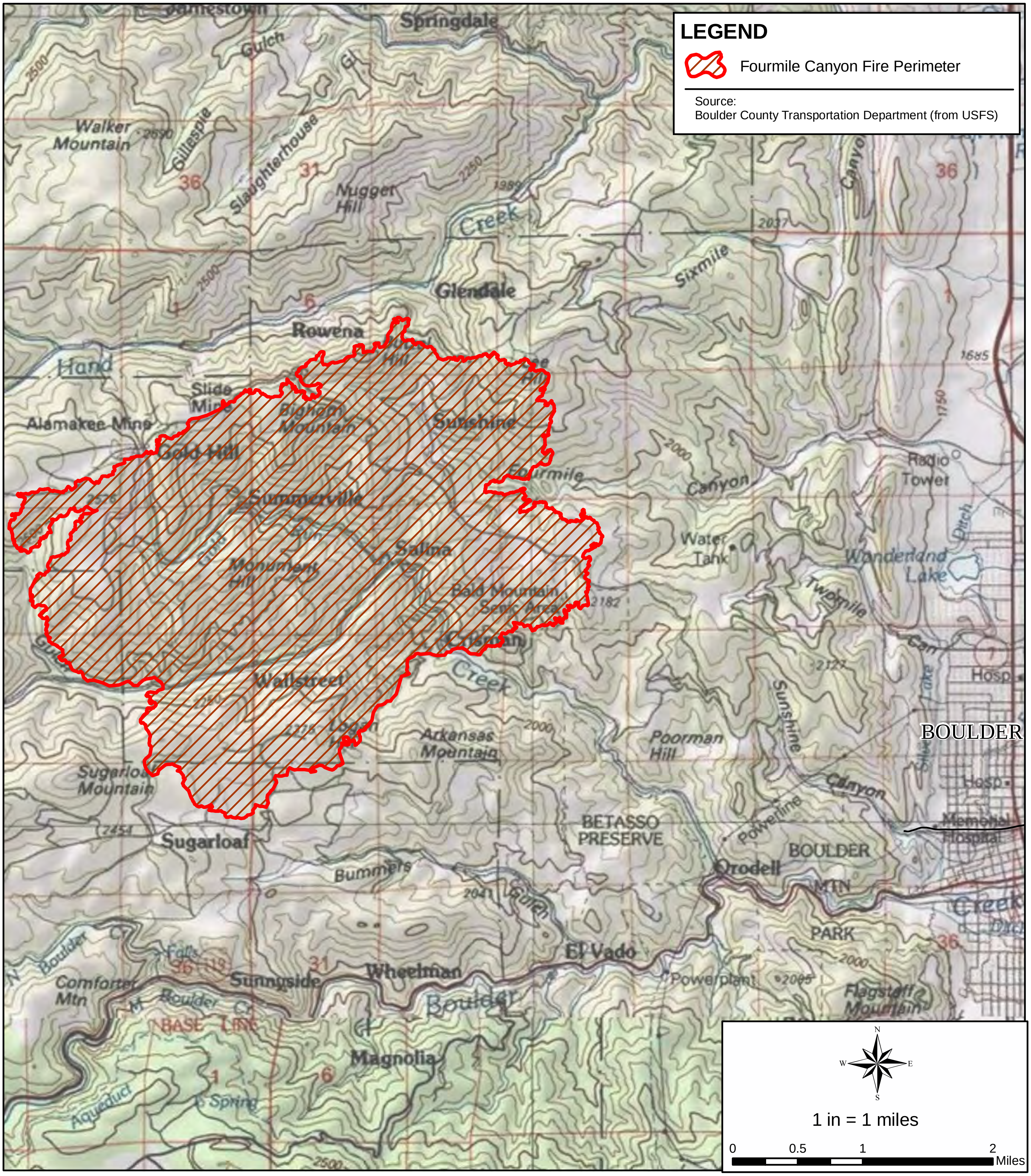
USGS, 2010. The United States Geological Survey (USGS) open file report on the *Probability and Volume of Potential Post-Wildfire Debris Flows in the 2010 Four Mile Burn Area, Boulder County, Colorado.* Open-File Report 2010-1244.

WWE, 2003. Compilation of Technical Research: Part 1: A Curve Number Approach to Evaluation of Post-Fire Subbasin Recovery Following the Cerro Grande Fire, Los Alamos, New Mexico. Part 2: Post-Burn Assessment of Hydrologic Conditions and Forest Recovery at the Three-Year Anniversary of the Cerro Grande Fire. Part 3: Summary of Mesa Verde 2000 Bircher Fire Basin Recovery in Morefield Canyon. September.

Attachment(s)

Figures 1, 2.0 to 2.8, 3.1 to 3.4, 4.1 to 4.4, 5.1 to 5.2, and 6.1 to 6.4
Appendix A, Figure A-1
Appendix B, Figure B-1 (Plate 1), Figure B-2 (Plate 2)

# Figures




Z:\Project Files\10\101-066\101-066.000\CAD-GIS\GIS\Figure1.mxd

Base Map: USGS Topographic Map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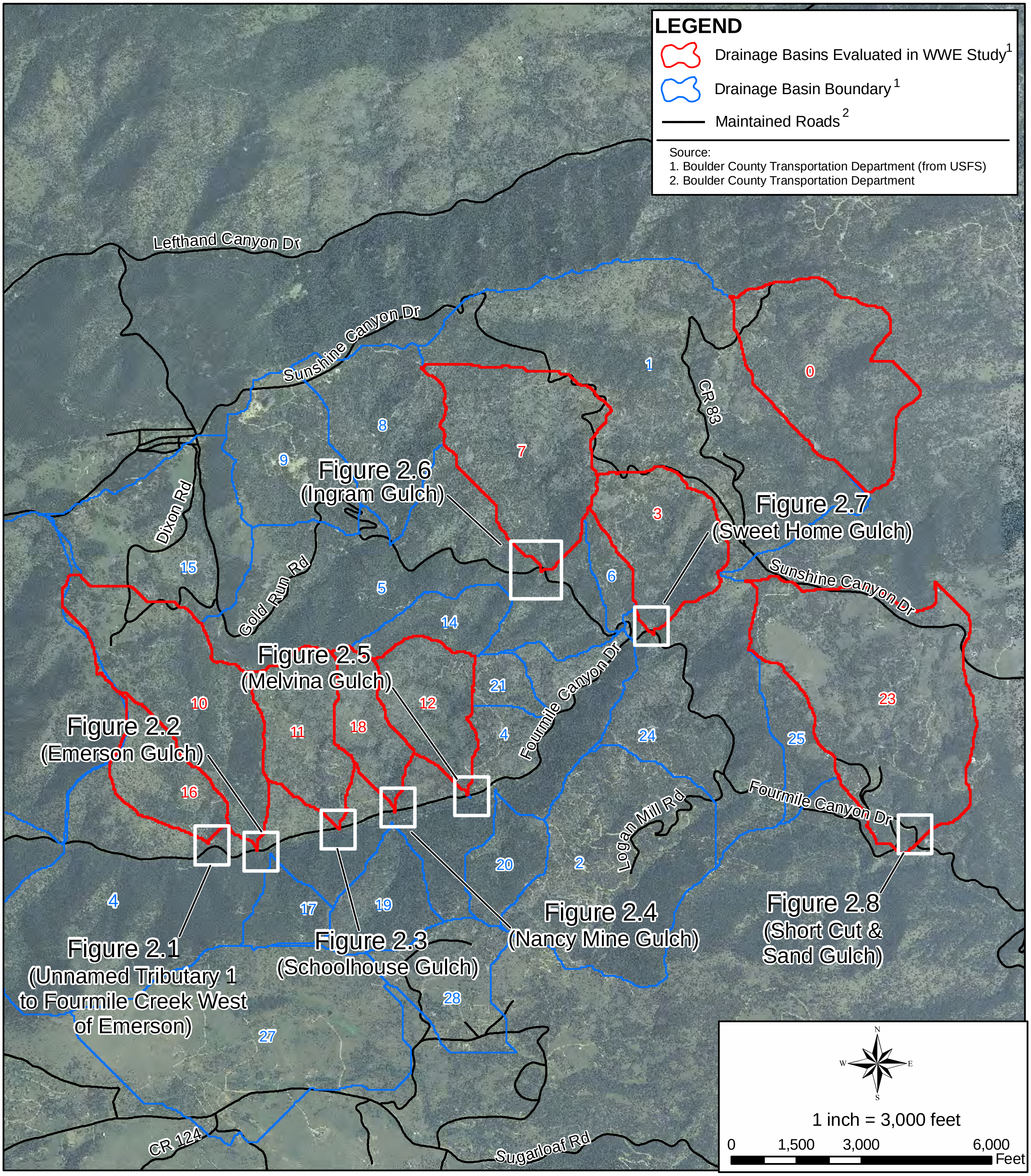
# 2010 Boulder Fourmile Canyon Fire Location Map

PROJECT NO.
101-066.000

FIGURE
1

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Base Map: USDA NAIP August 2009


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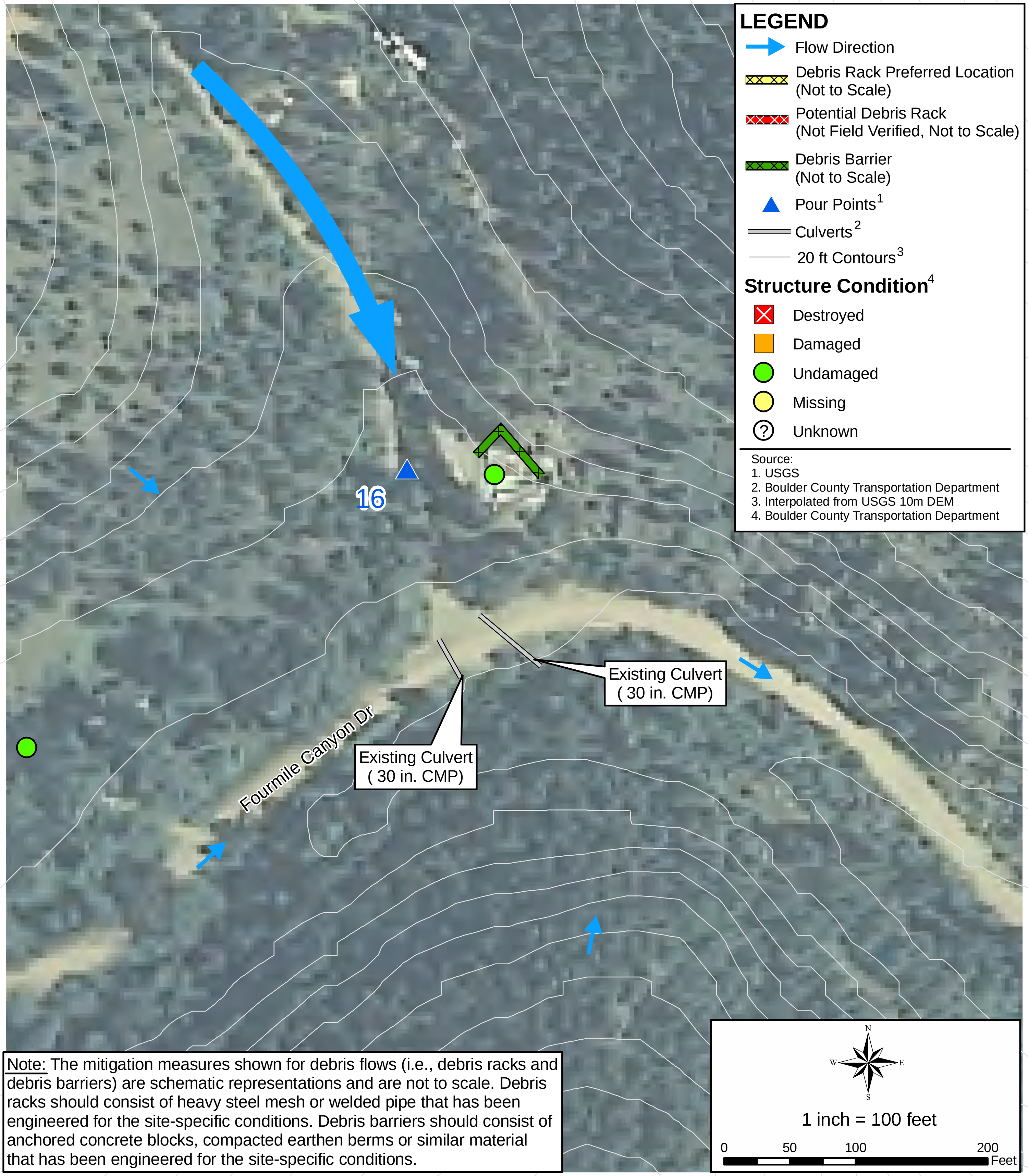
# 2010 Boulder Fourmile Canyon Fire
# DEBRIS CONTROL
## Index Map

PROJECT NO. 101-066.000

FIGURE 2.0




Note: The mitigation measures shown for debris flows (i.e., debris racks and debris barriers) are schematic representations and are not to scale. Debris racks should consist of heavy steel mesh or welded pipe that has been engineered for the site-specific conditions. Debris barriers should consist of anchored concrete blocks, compacted earthen berms or similar material that has been engineered for the site-specific conditions.

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Base Map: USDA NAIP August 2009


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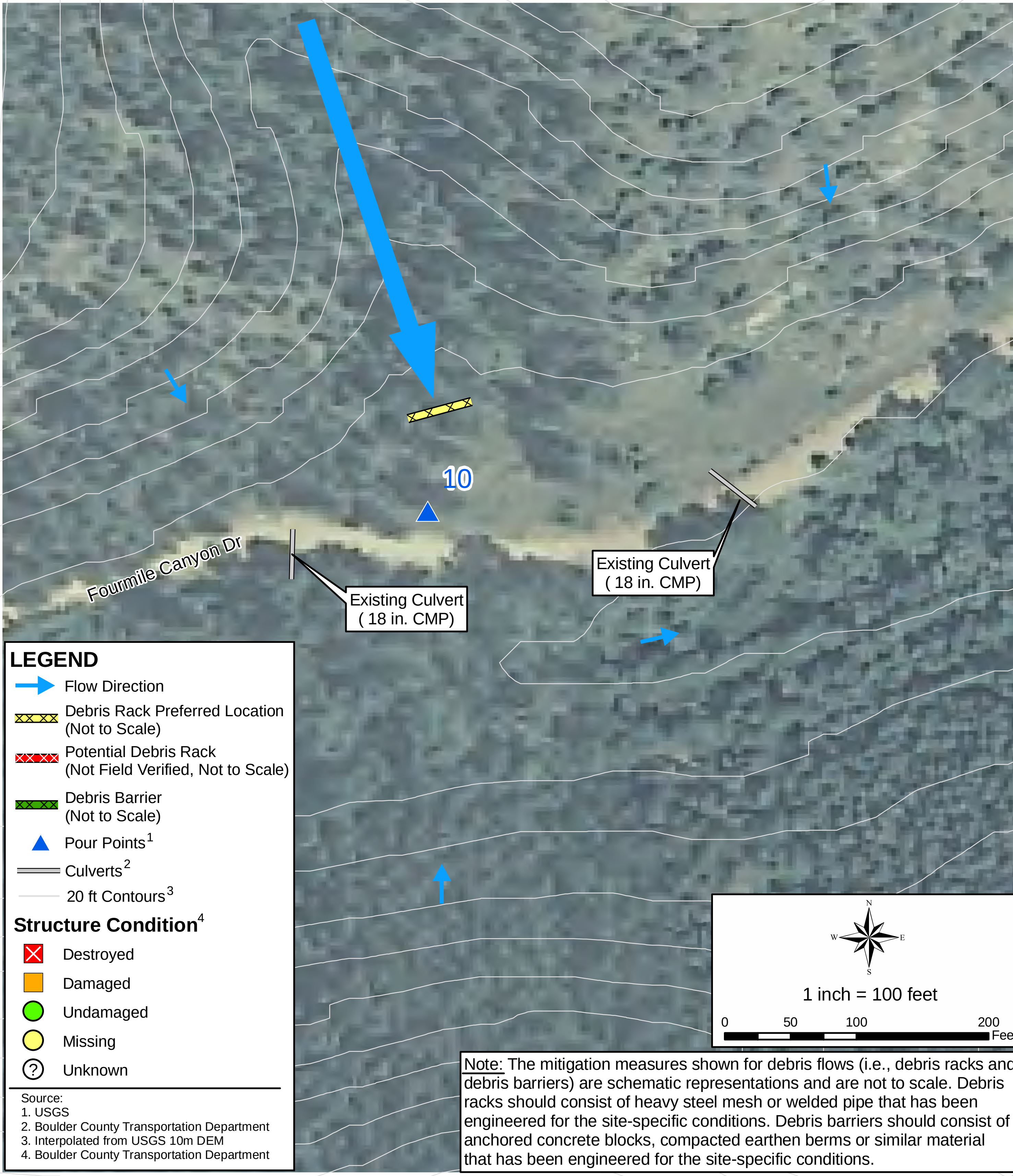
# 2010 Boulder Fourmile Canyon Fire
# DEBRIS CONTROL
## Pour Point 16
Unnamed Tributary 1 to Fourmile Creek West of Emerson

PROJECT NO. 101-066.000

FIGURE 2.1

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Base Map: USDA NAIP August 2009

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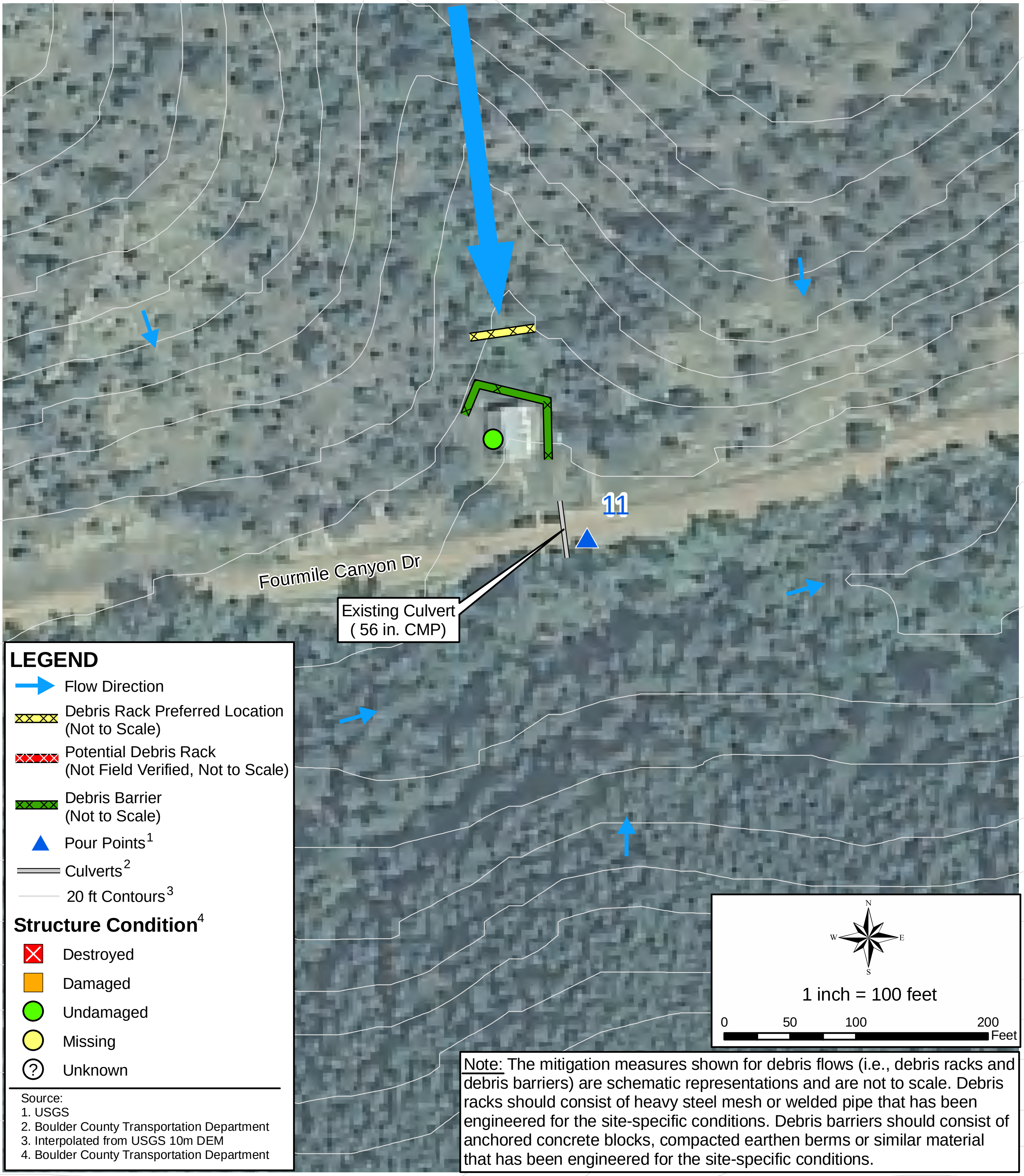
2010 Boulder Fourmile Canyon Fire
DEBRIS CONTROL
Pour Point 10
Emerson Gulch

PROJECT NO.
101-066.000

FIGURE
2.2




Note: The mitigation measures shown for debris flows (i.e., debris racks and debris barriers) are schematic representations and are not to scale. Debris racks should consist of heavy steel mesh or welded pipe that has been engineered for the site-specific conditions. Debris barriers should consist of anchored concrete blocks, compacted earthen berms or similar material that has been engineered for the site-specific conditions.

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2010 Boulder Fourmile Canyon Fire

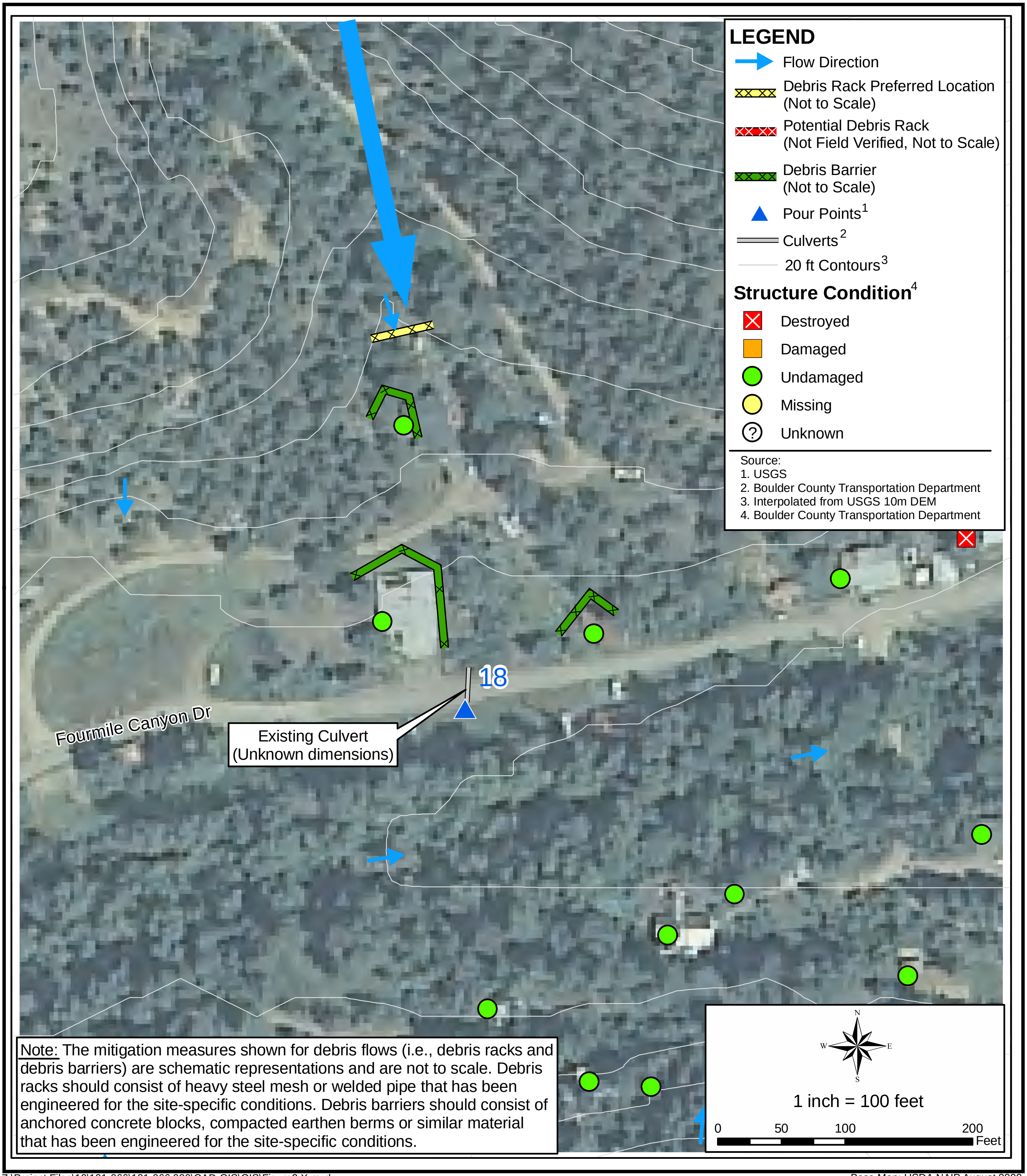
DEBRIS CONTROL

Pour Point 11

Schoolhouse Gulch

PROJECT NO. 101-066.000

FIGURE 2.3

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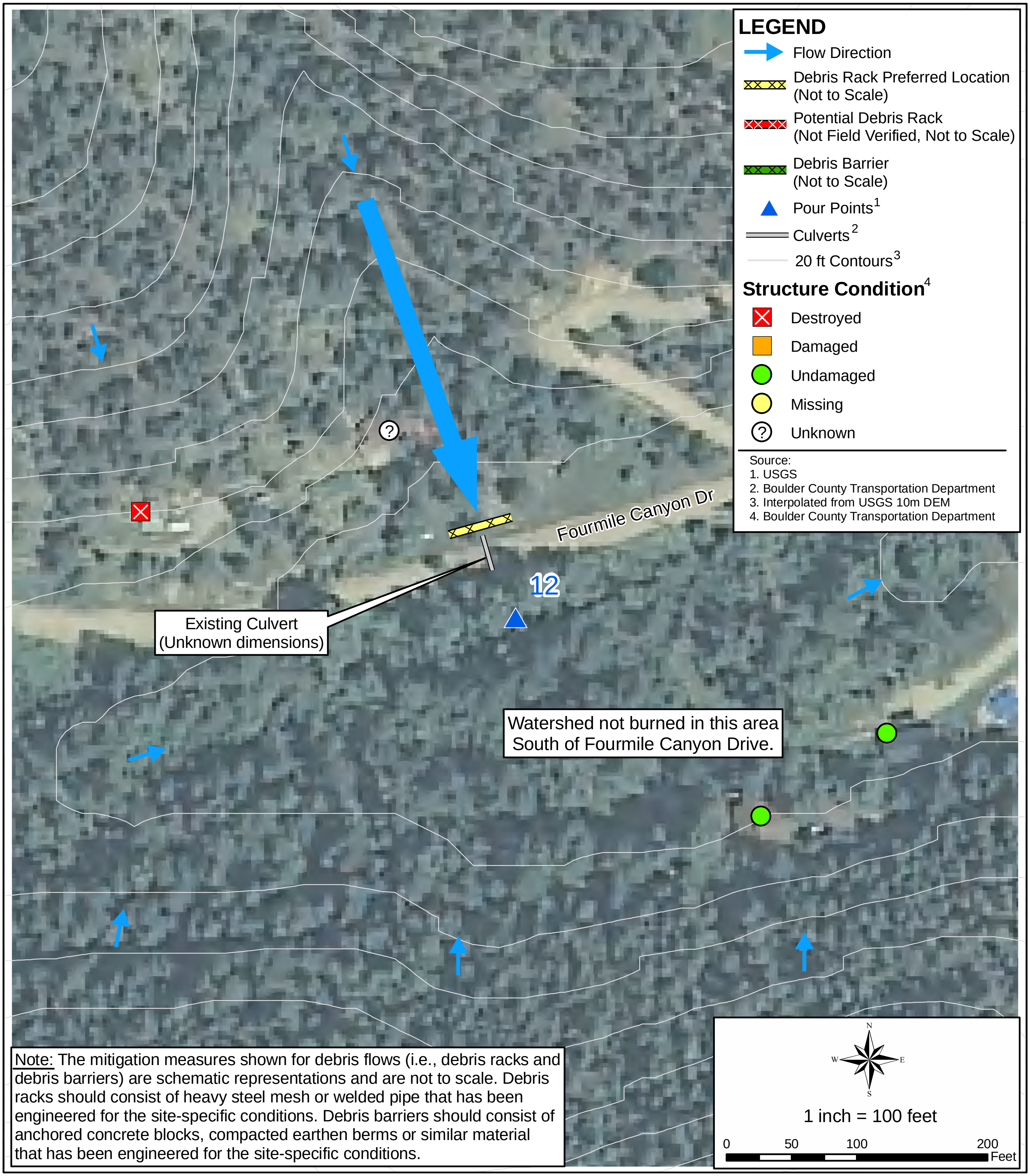
2010 Boulder Fourmile Canyon Fire
DEBRIS CONTROL
Pour Point 18
Nancy Mine Gulch

PROJECT NO.
101-066.000

FIGURE
2.4




Note: The mitigation measures shown for debris flows (i.e., debris racks and debris barriers) are schematic representations and are not to scale. Debris racks should consist of heavy steel mesh or welded pipe that has been engineered for the site-specific conditions. Debris barriers should consist of anchored concrete blocks, compacted earthen berms or similar material that has been engineered for the site-specific conditions.

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Base Map: USDA NAIP August 2009

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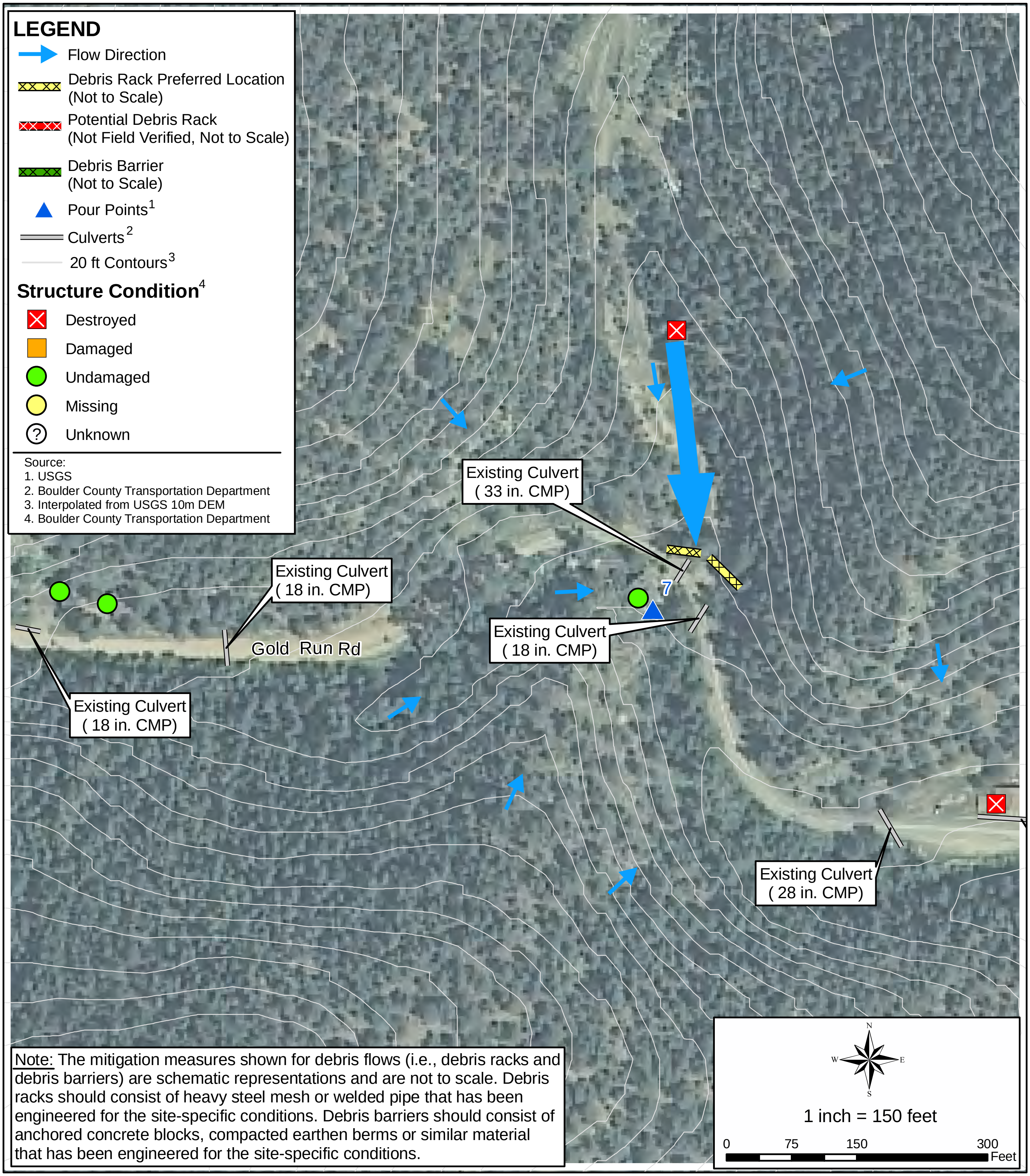
2010 Boulder Fourmile Canyon Fire
DEBRIS CONTROL
Pour Point 12
Melvina Gulch

PROJECT NO. 101-066.000

FIGURE 2.5

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2010 Boulder Fourmile Canyon Fire

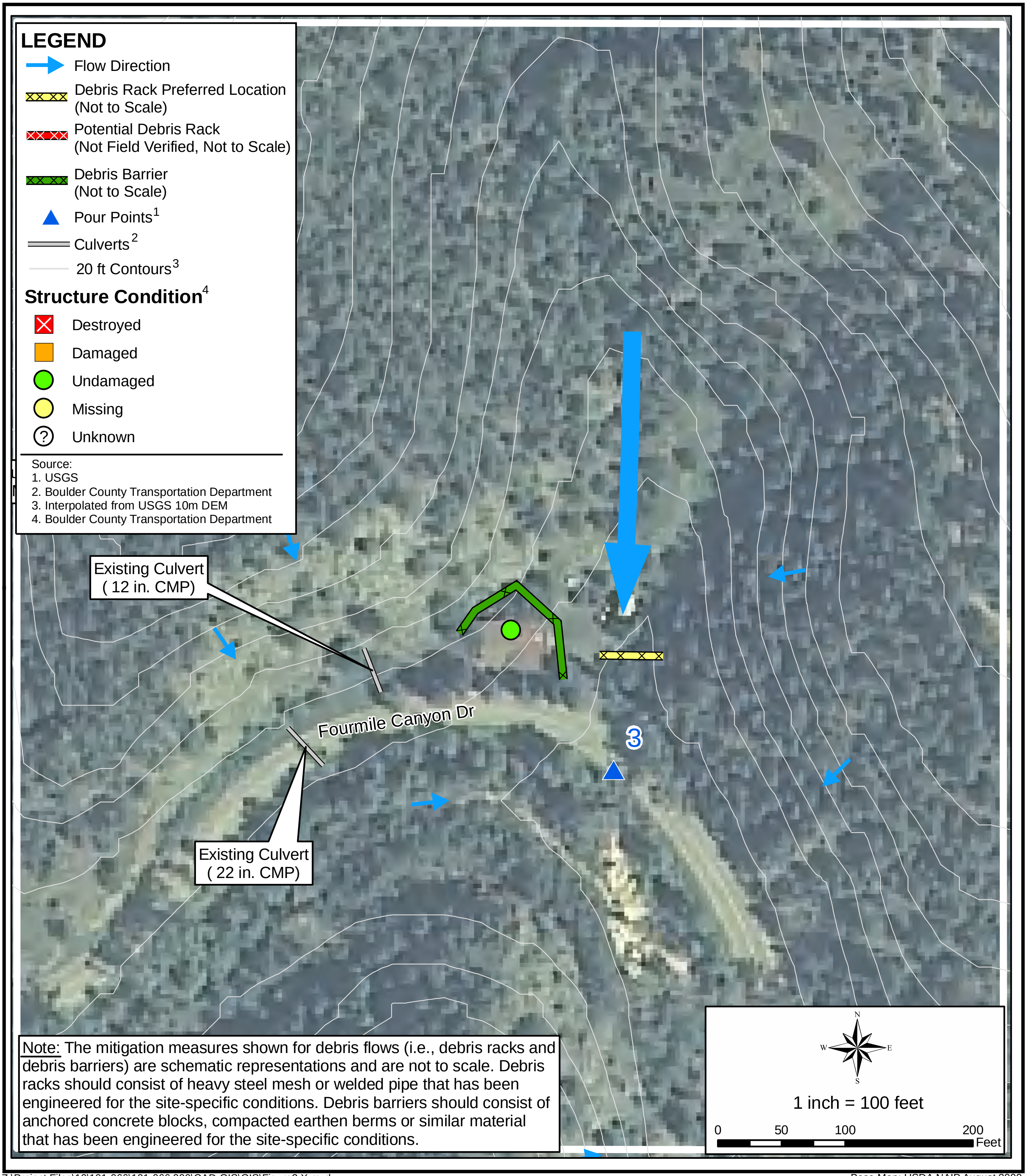
DEBRIS CONTROL

Pour Point 7

Ingram Gulch

PROJECT NO.
101-066.000

FIGURE
2.6

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2010 Boulder Fourmile Canyon Fire

DEBRIS CONTROL

Pour Point 3

Sweet Home Gulch

PROJECT NO. 101-066.000

FIGURE 2.7


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# 2010 Boulder Fourmile Canyon Fire
# DEBRIS CONTROL
## Pour Point 23
### Short Cut & Sand Gulch

PROJECT NO. 101-066.000

FIGURE 2.8

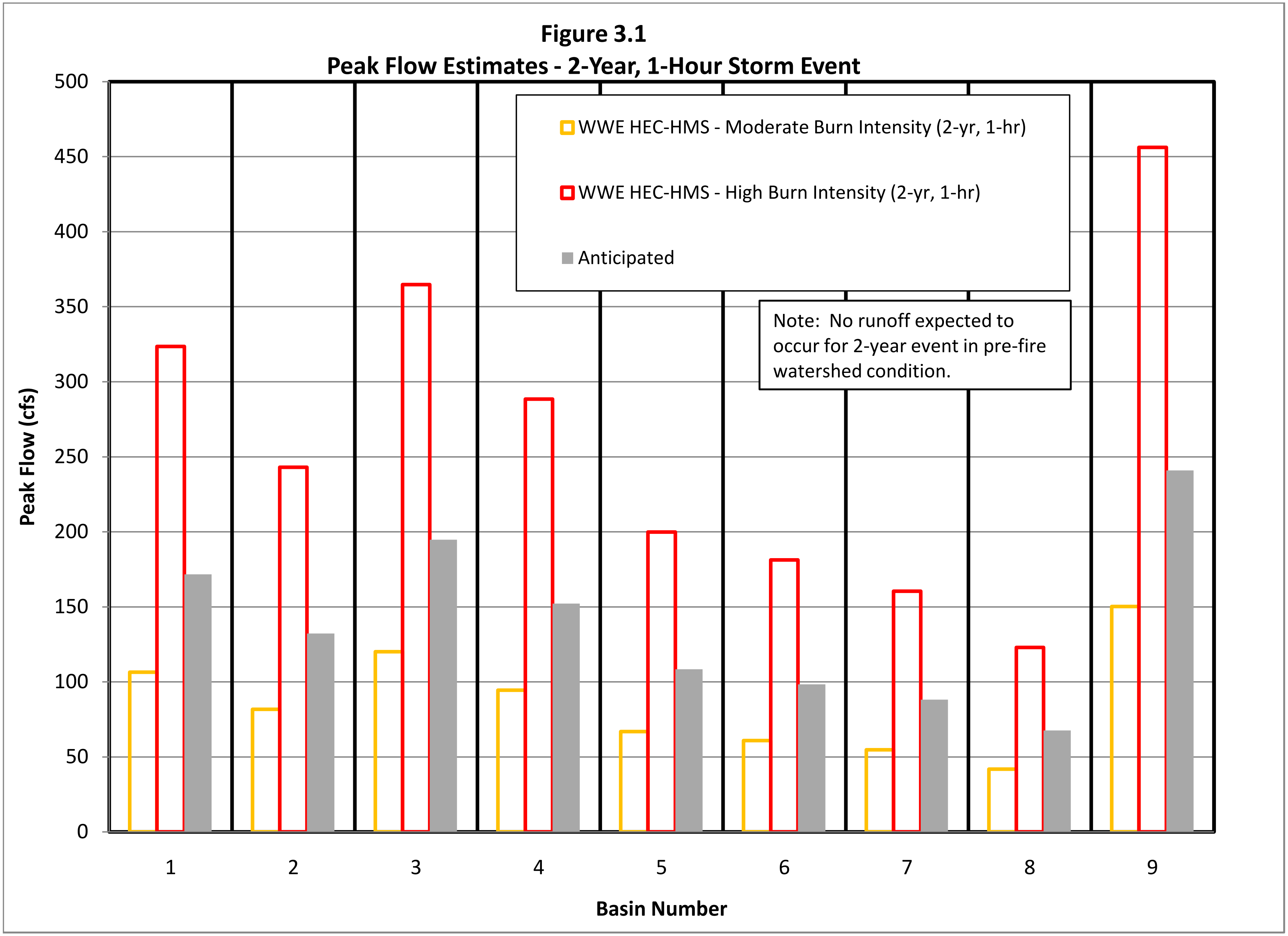


Figure 3.1
Peak Flow Estimates - 2-Year, 1-Hour Storm Event
WWE HEC-HMS - Moderate Burn Intensity (2-yr, 1-hr)
WWE HEC-HMS - High Burn Intensity (2-yr, 1-hr)
Anticipated
Note: No runoff expected to occur for 2-year event in pre-fire watershed condition.
Peak Flow (cfs)
0
50
100
150
200
250
300
350
400
450
500
1
2
3
4
5
6
7
8
9
Basin Number

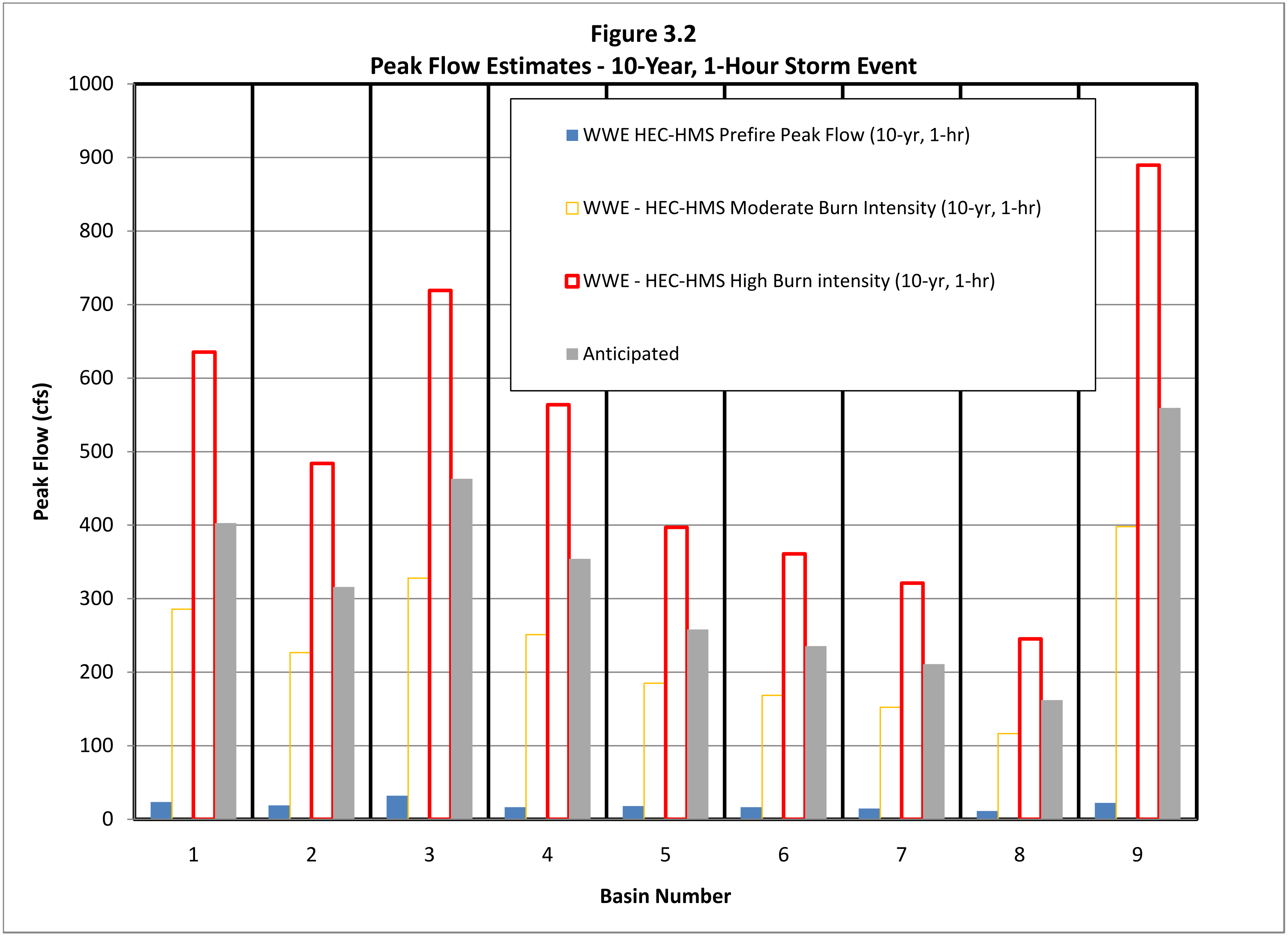


Figure 3.2
Peak Flow Estimates - 10-Year, 1-Hour Storm Event
WWE HEC-HMS Prefire Peak Flow (10-yr, 1-hr)
WWE - HEC-HMS Moderate Burn Intensity (10-yr, 1-hr)
WWE - HEC-HMS High Burn intensity (10-yr, 1-hr)
Anticipated
Peak Flow (cfs)
Basin Number
0
100
200
300
400
500
600
700
800
900
1000
1
2
3
4
5
6
7
8
9

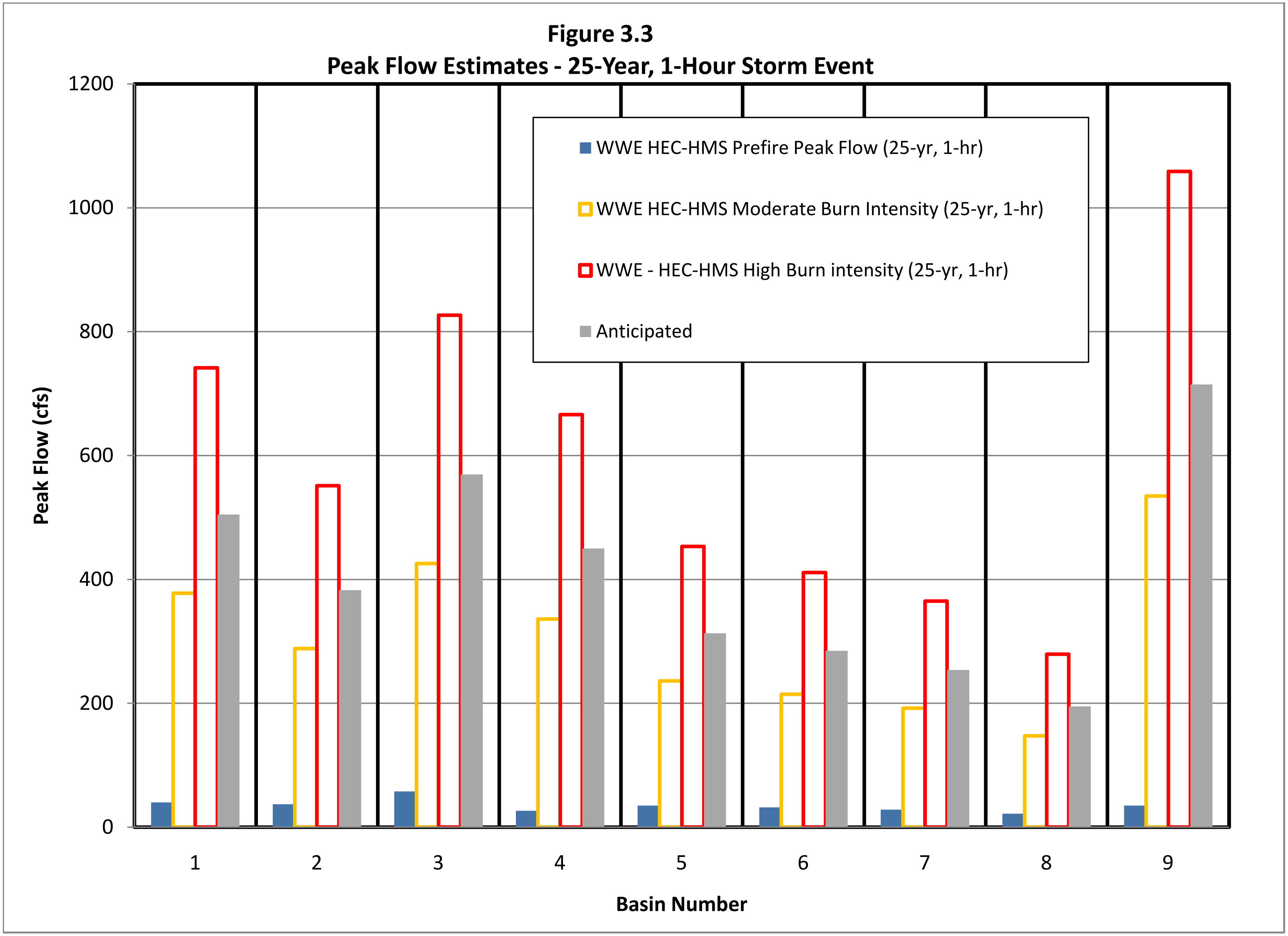


Figure 3.3
Peak Flow Estimates - 25-Year, 1-Hour Storm Event
Peak Flow (cfs)
0
200
400
600
800
1000
1200
1
2
3
4
5
6
7
8
9
Basin Number
WWE HEC-HMS Prefire Peak Flow (25-yr, 1-hr)
WWE HEC-HMS Moderate Burn Intensity (25-yr, 1-hr)
WWE - HEC-HMS High Burn intensity (25-yr, 1-hr)
Anticipated

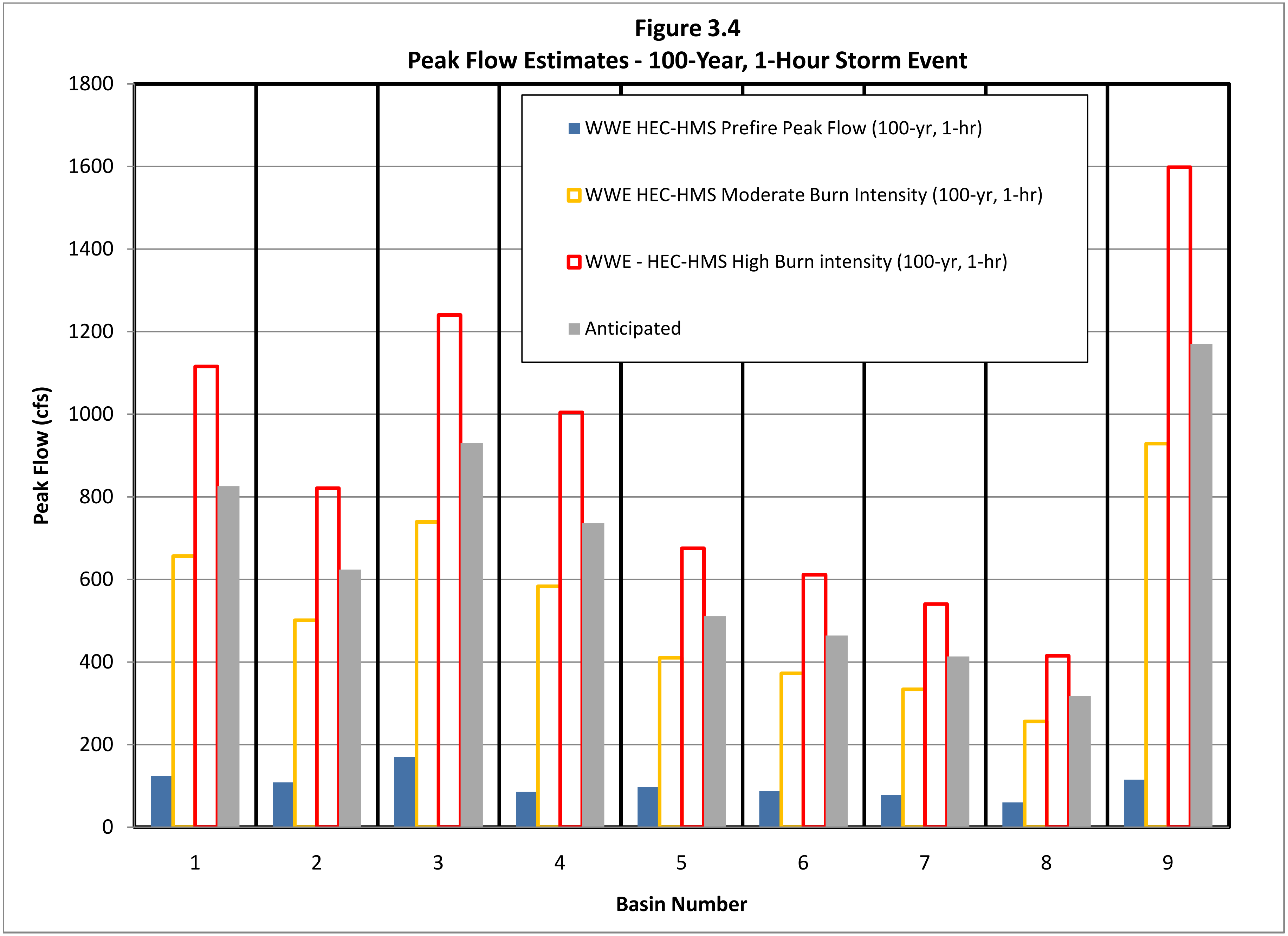


Figure 3.4
Peak Flow Estimates - 100-Year, 1-Hour Storm Event
Peak Flow (cfs)
0
200
400
600
800
1000
1200
1400
1600
1800
WWE HEC-HMS Prefire Peak Flow (100-yr, 1-hr)
WWE HEC-HMS Moderate Burn Intensity (100-yr, 1-hr)
WWE - HEC-HMS High Burn intensity (100-yr, 1-hr)
Anticipated
1
2
3
4
5
6
7
8
9
Basin Number

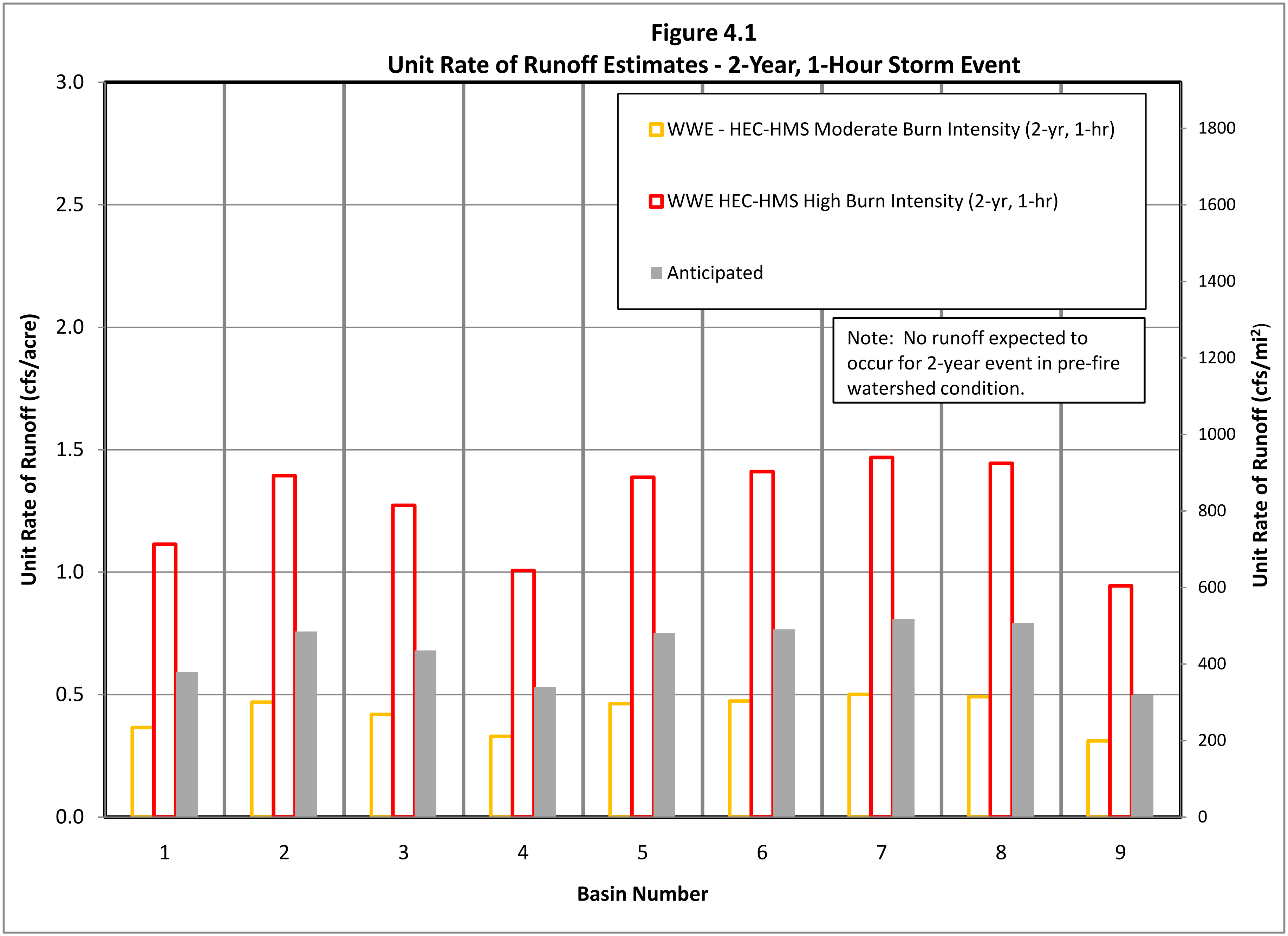


Figure 4.1
Unit Rate of Runoff Estimates - 2-Year, 1-Hour Storm Event
WWE - HEC-HMS Moderate Burn Intensity (2-yr, 1-hr)
WWE HEC-HMS High Burn Intensity (2-yr, 1-hr)
Anticipated
Note: No runoff expected to occur for 2-year event in pre-fire watershed condition.
Unit Rate of Runoff (cfs/acre)
Unit Rate of Runoff (cfs/mi²)
Basin Number
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1800
1600
1400
1200
1000
800
600
400
200
0
1
2
3
4
5
6
7
8
9

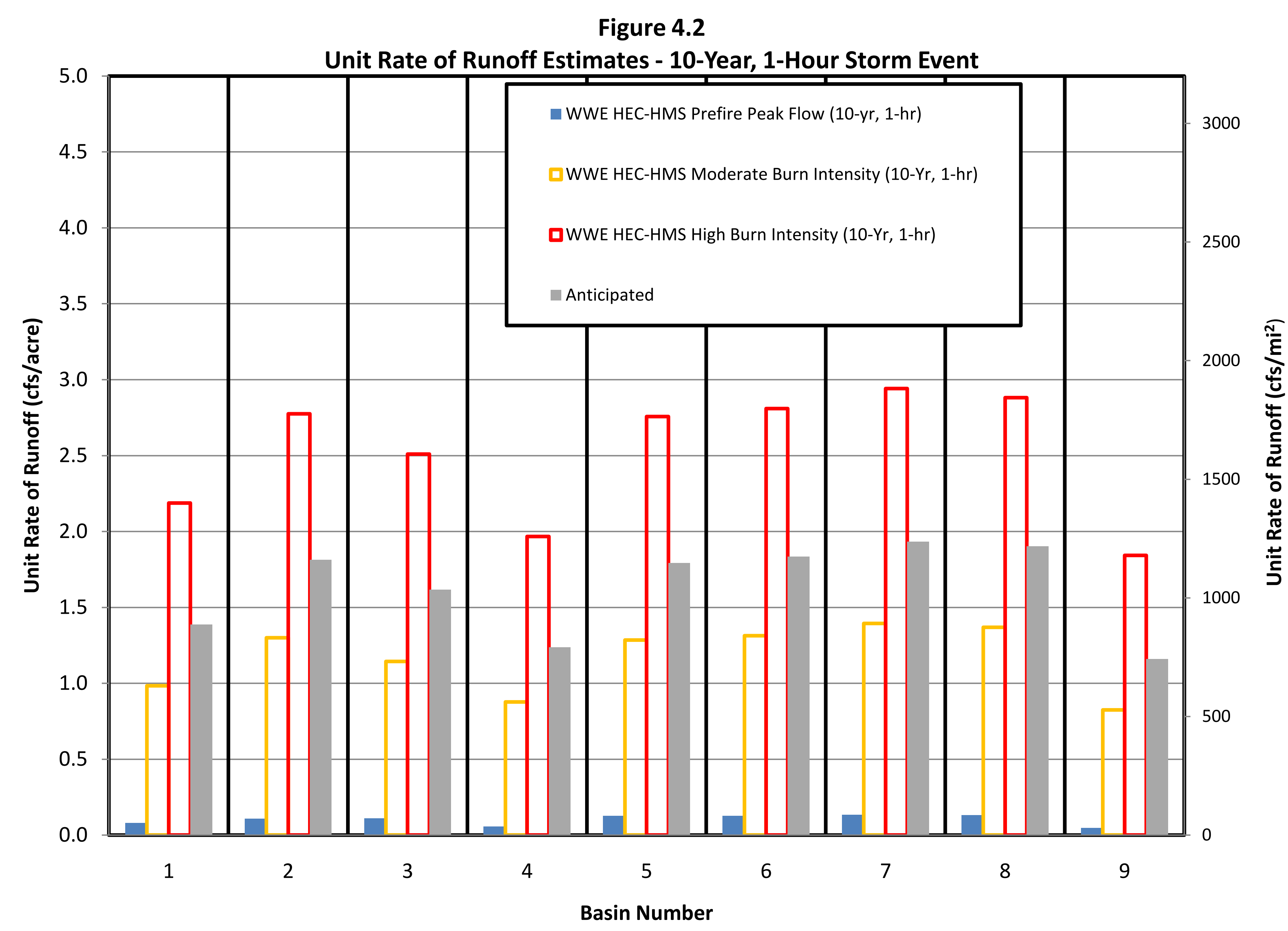


Figure 4.2
Unit Rate of Runoff Estimates - 10-Year, 1-Hour Storm Event
WWE HEC-HMS Prefire Peak Flow (10-yr, 1-hr)
WWE HEC-HMS Moderate Burn Intensity (10-Yr, 1-hr)
WWE HEC-HMS High Burn Intensity (10-Yr, 1-hr)
Anticipated
Unit Rate of Runoff (cfs/acre)
Unit Rate of Runoff (cfs/mi²)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
3000
2500
2000
1500
1000
500
0
1
2
3
4
5
6
7
8
9
Basin Number

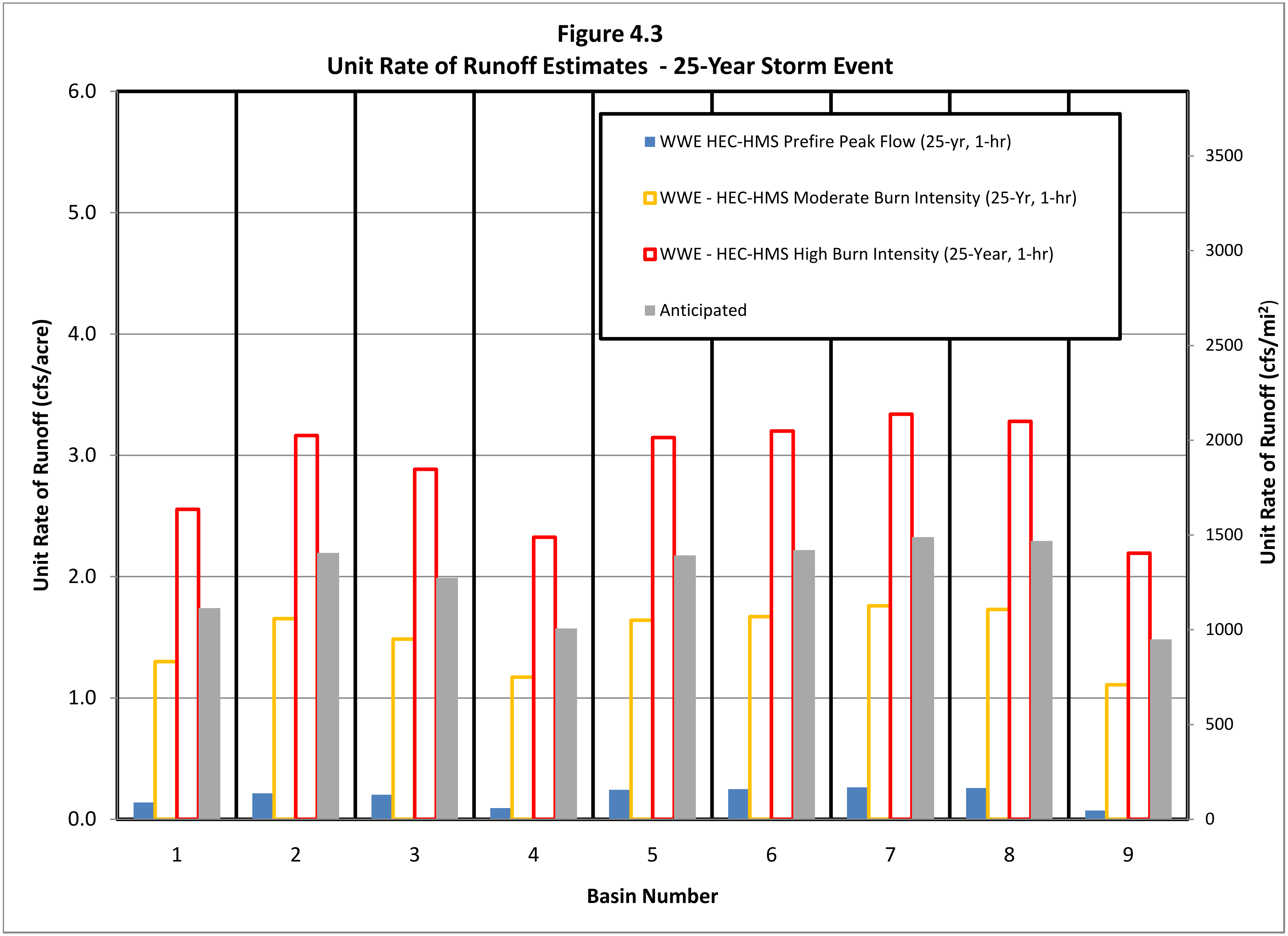


Figure 4.3
Unit Rate of Runoff Estimates - 25-Year Storm Event
WWE HEC-HMS Prefire Peak Flow (25-yr, 1-hr)
WWE - HEC-HMS Moderate Burn Intensity (25-Yr, 1-hr)
WWE - HEC-HMS High Burn Intensity (25-Year, 1-hr)
Anticipated
Unit Rate of Runoff (cfs/acre)
Unit Rate of Runoff (cfs/mi²)
Basin Number
6.0
5.0
4.0
3.0
2.0
1.0
0.0
3500
3000
2500
2000
1500
1000
500
0
1
2
3
4
5
6
7
8
9

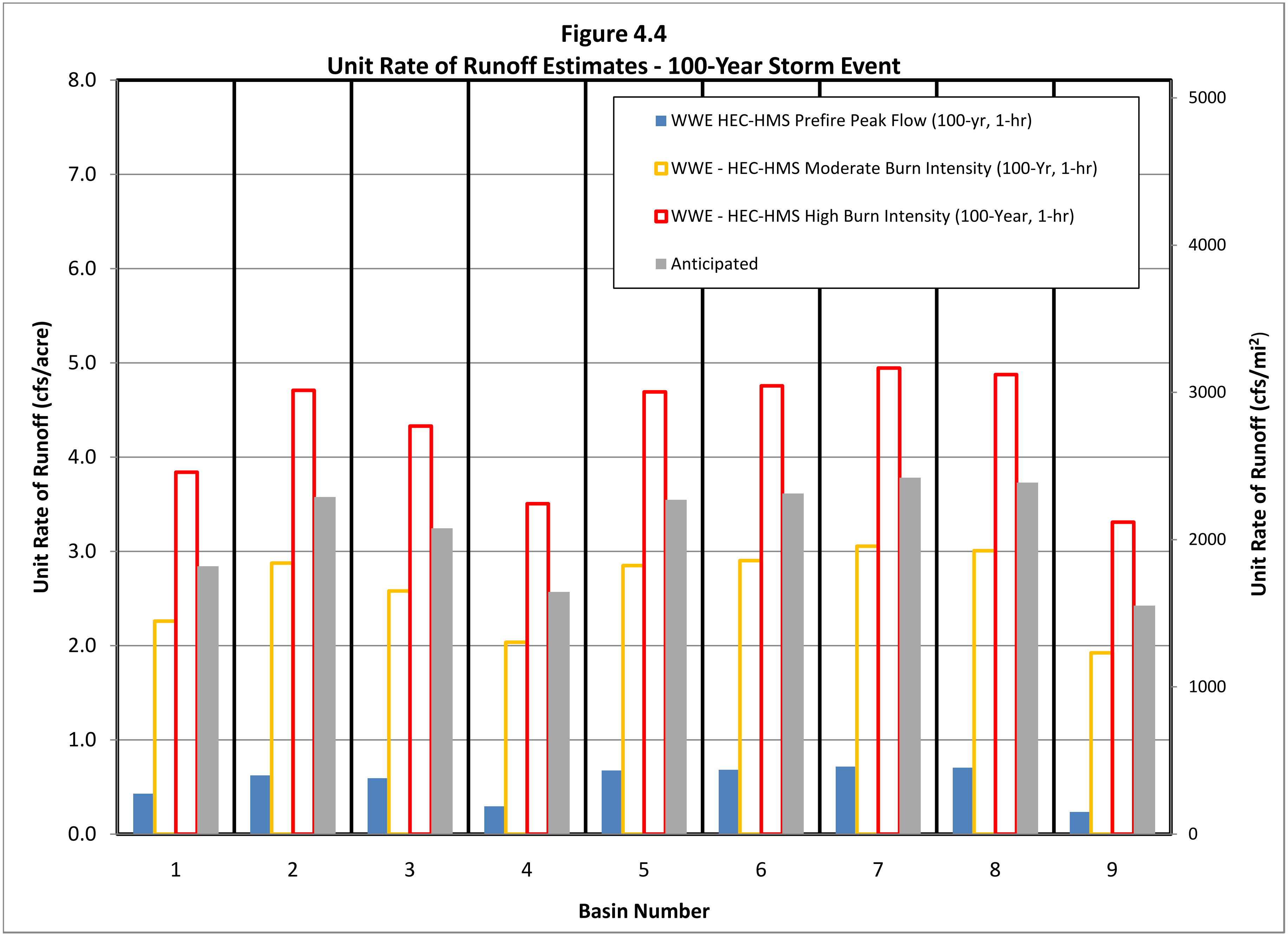


Figure 4.4
Unit Rate of Runoff Estimates - 100-Year Storm Event
WWE HEC-HMS Prefire Peak Flow (100-yr, 1-hr)
WWE - HEC-HMS Moderate Burn Intensity (100-Yr, 1-hr)
WWE - HEC-HMS High Burn Intensity (100-Year, 1-hr)
Anticipated
Unit Rate of Runoff (cfs/acre)
Unit Rate of Runoff (cfs/mi²)
Basin Number
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
5000
4000
3000
2000
1000
0
1
2
3
4
5
6
7
8
9

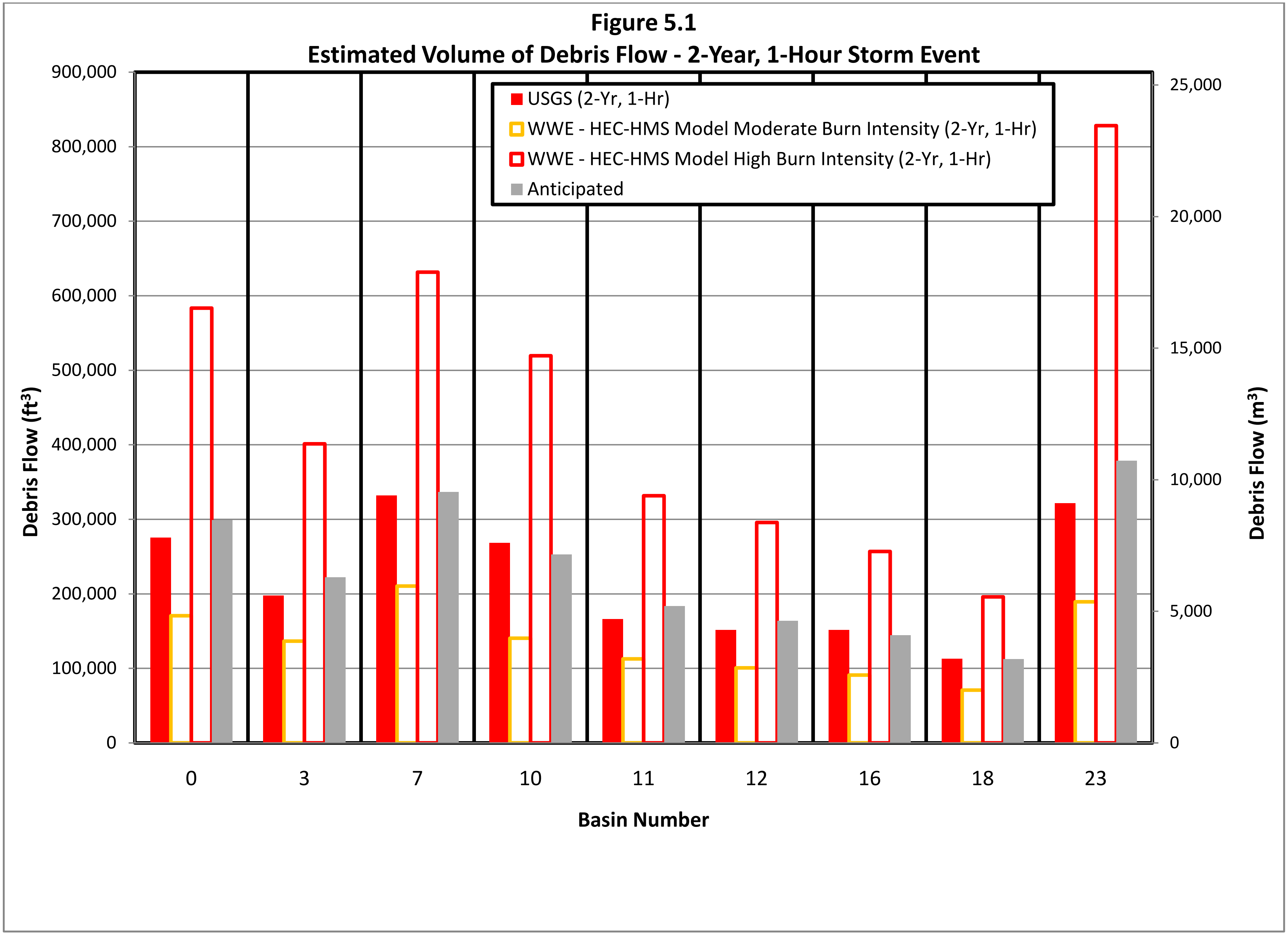


Figure 5.1
Estimated Volume of Debris Flow - 2-Year, 1-Hour Storm Event
USGS (2-Yr, 1-Hr)
WWE - HEC-HMS Model Moderate Burn Intensity (2-Yr, 1-Hr)
WWE - HEC-HMS Model High Burn Intensity (2-Yr, 1-Hr)
Anticipated
Debris Flow (ft³)
Debris Flow (m³)
Basin Number
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
25,000
20,000
15,000
10,000
5,000
0
0
3
7
10
11
12
16
18
23

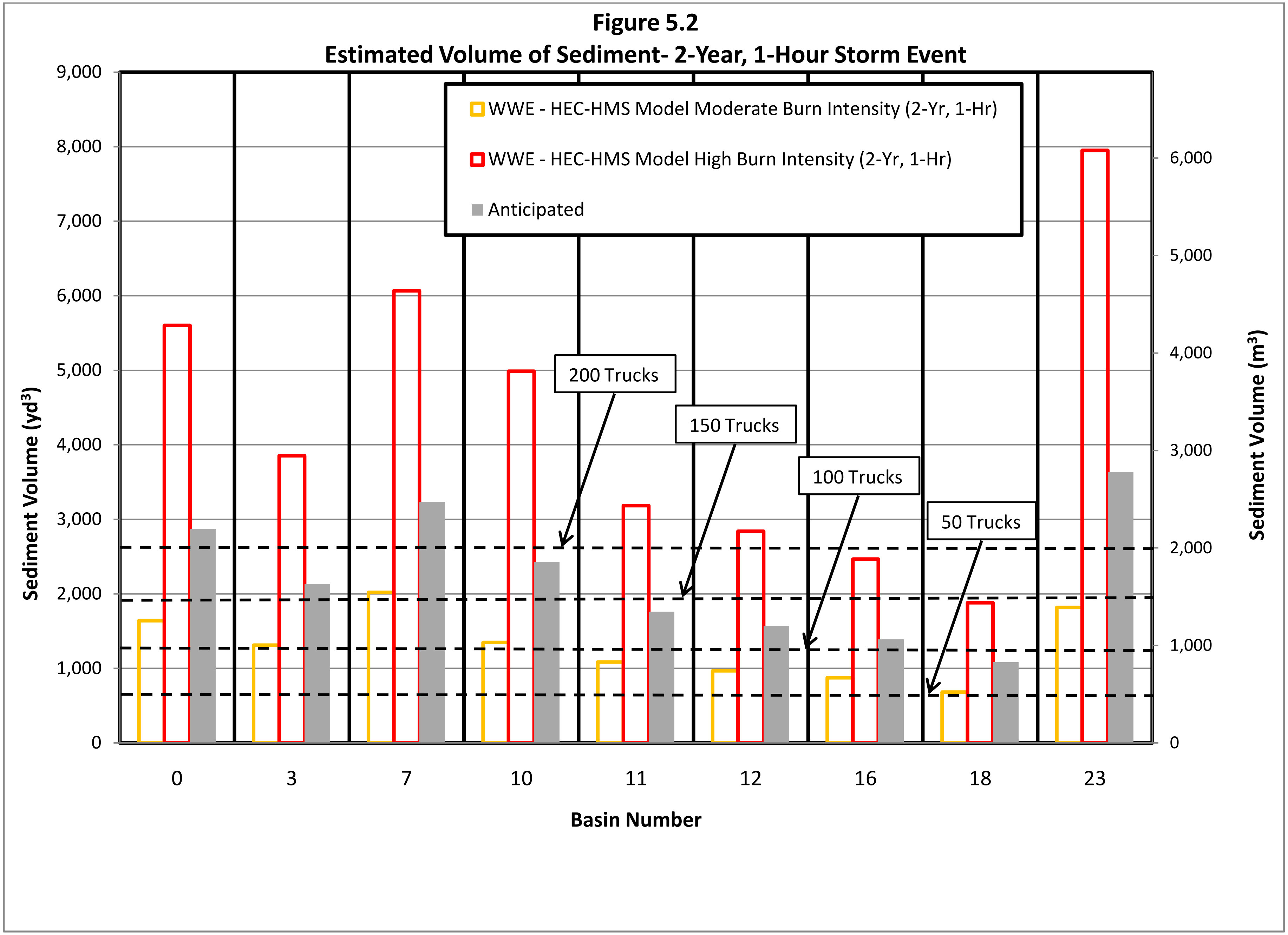


Figure 5.2
Estimated Volume of Sediment- 2-Year, 1-Hour Storm Event
WWE - HEC-HMS Model Moderate Burn Intensity (2-Yr, 1-Hr)
WWE - HEC-HMS Model High Burn Intensity (2-Yr, 1-Hr)
Anticipated
200 Trucks
150 Trucks
100 Trucks
50 Trucks
Sediment Volume (yd³)
Sediment Volume (m³)
Basin Number
0
3
7
10
11
12
16
18
23
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
6,000
5,000
4,000
3,000
2,000
1,000
0

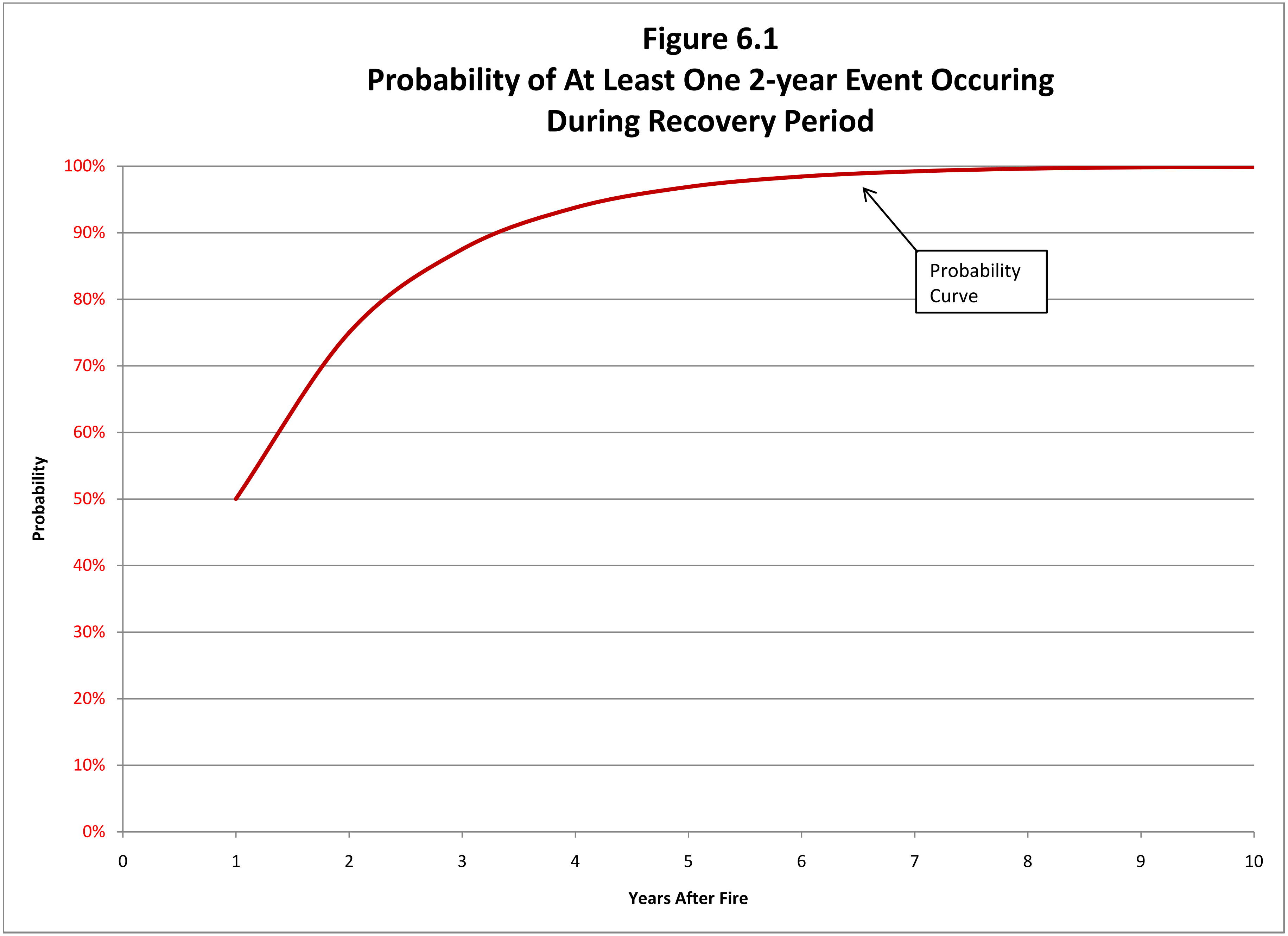


Figure 6.1
Probability of At Least One 2-year Event Occuring
During Recovery Period
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Probability
0
1
2
3
4
5
6
7
8
9
10
Years After Fire
Probability Curve

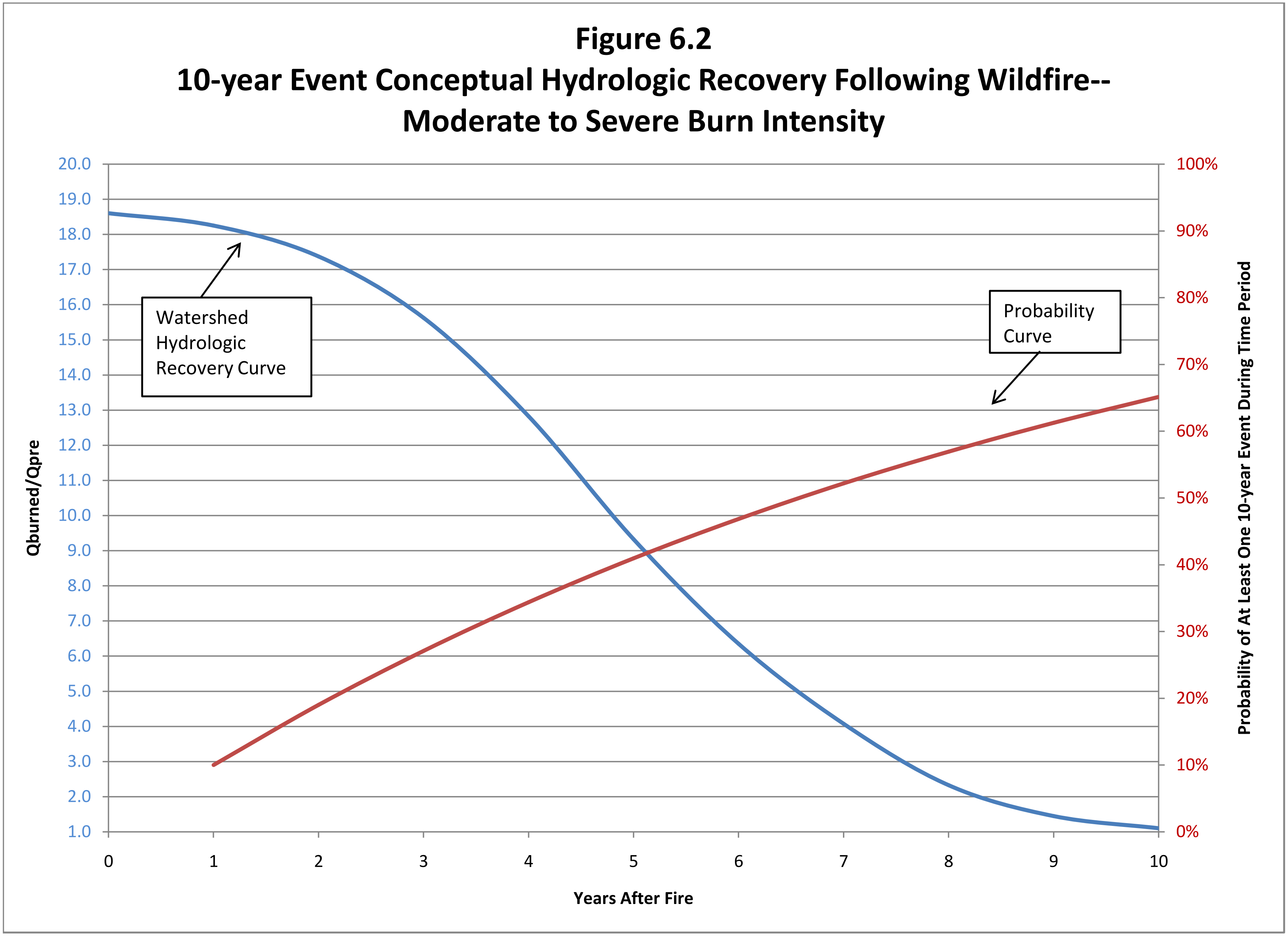


Figure 6.2
10-year Event Conceptual Hydrologic Recovery Following Wildfire--
Moderate to Severe Burn Intensity
Qburned/Qpre
20.0
19.0
18.0
17.0
16.0
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
Probability of At Least One 10-year Event During Time Period
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
1
2
3
4
5
6
7
8
9
10
Years After Fire
Watershed Hydrologic Recovery Curve
Probability Curve

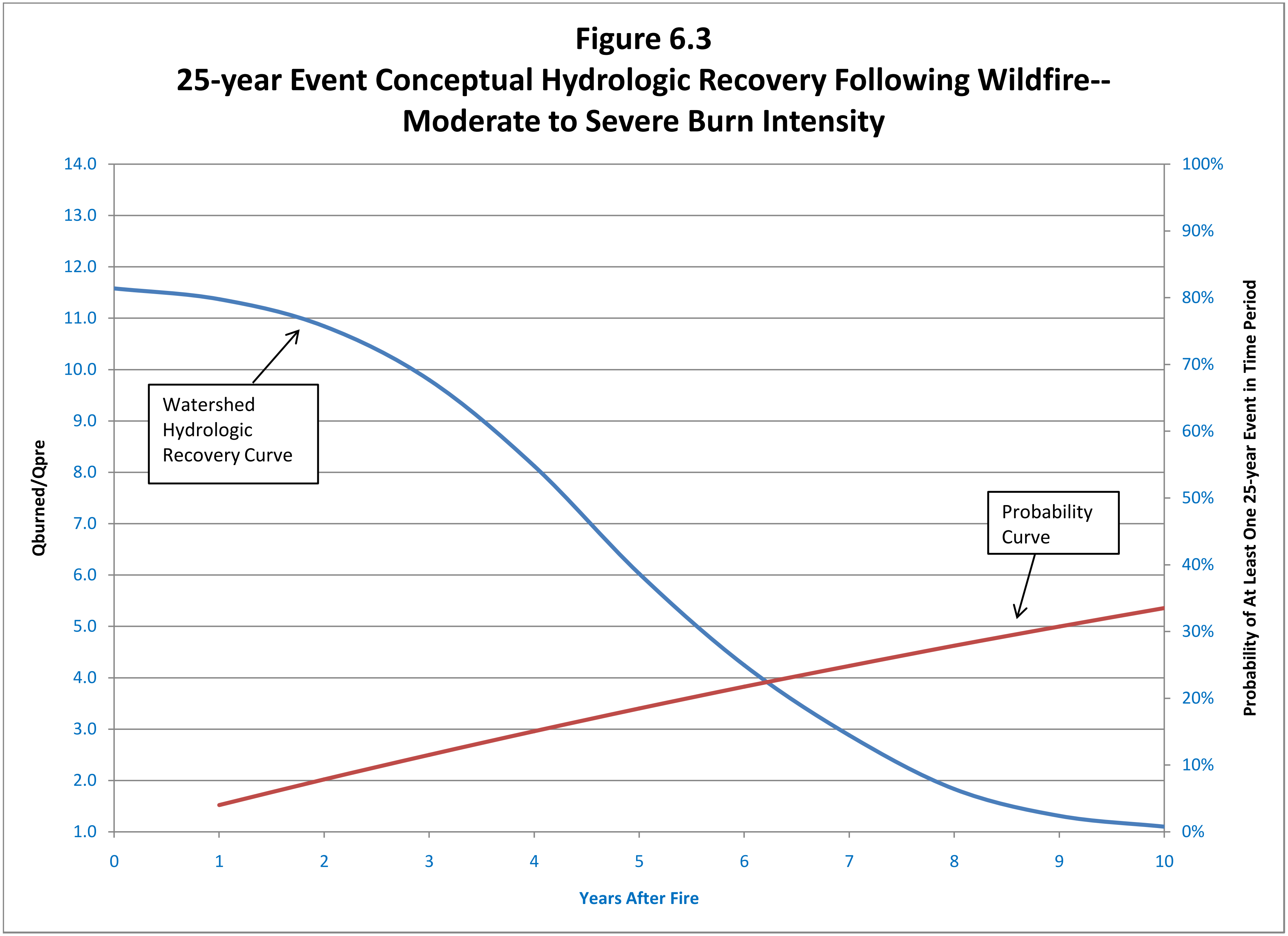
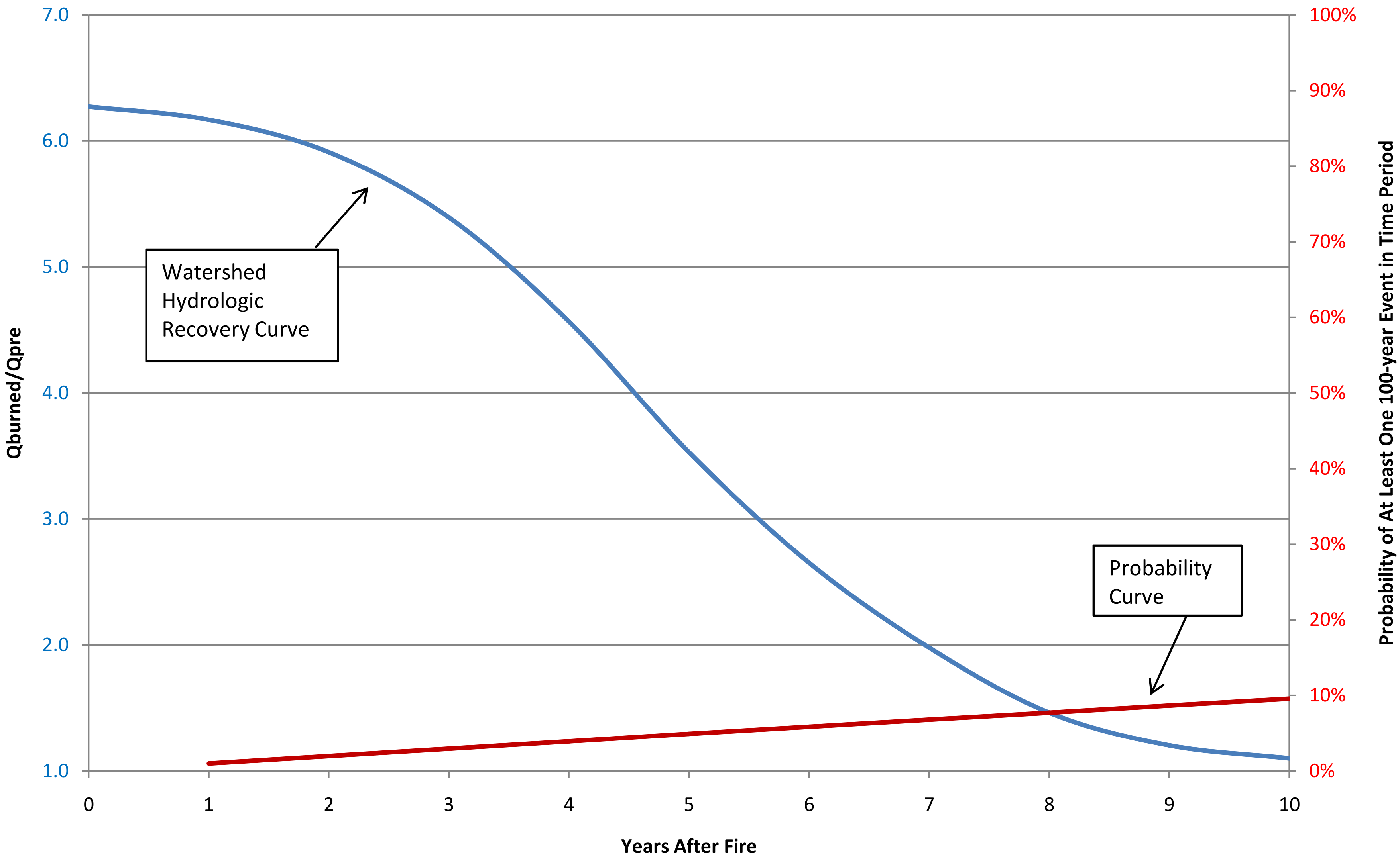


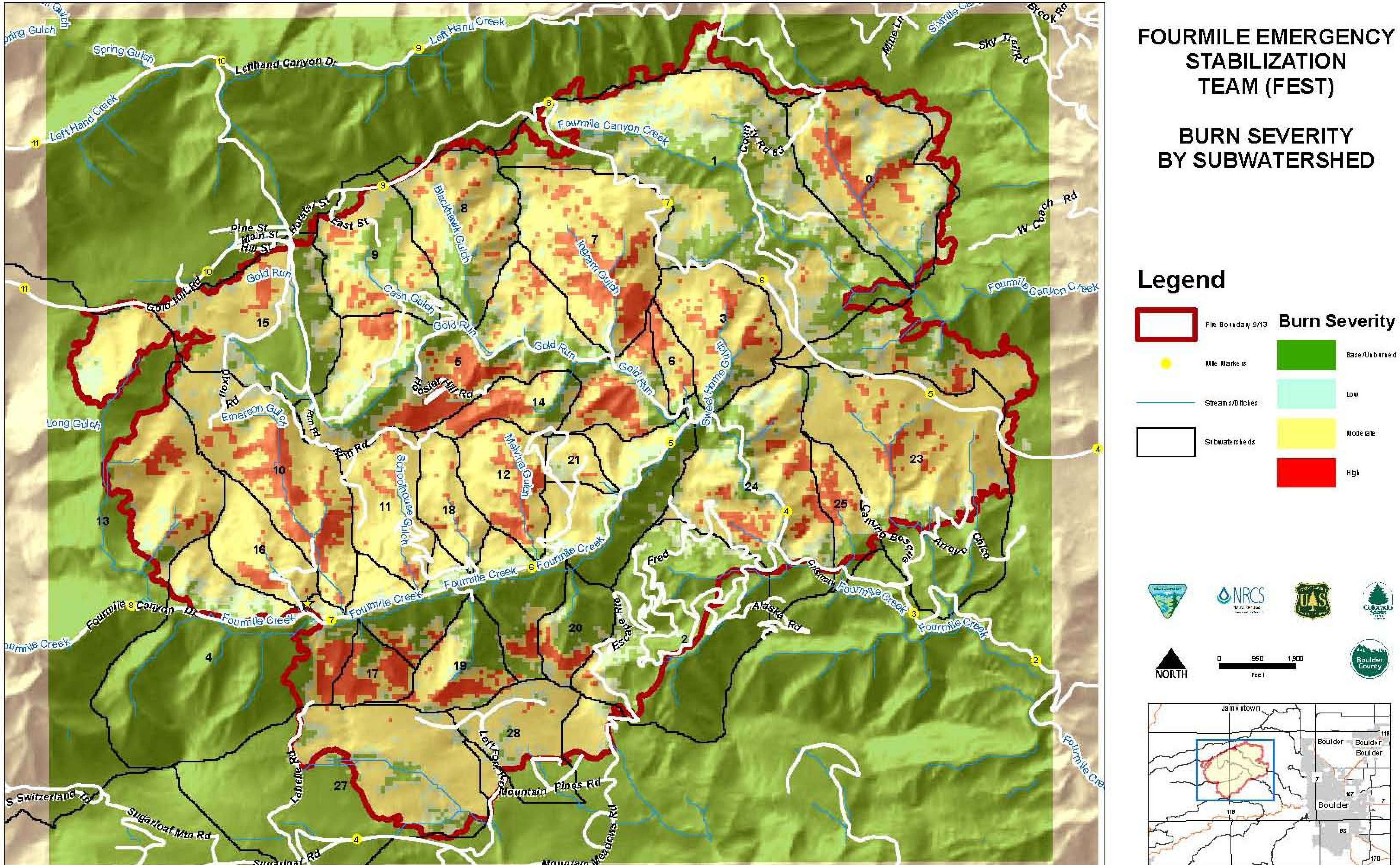
Figure 6.3
25-year Event Conceptual Hydrologic Recovery Following Wildfire--
Moderate to Severe Burn Intensity
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
Qburned/Qpre
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Probability of At Least One 25-year Event in Time Period
Watershed Hydrologic Recovery Curve
Probability Curve
0
1
2
3
4
5
6
7
8
9
10
Years After Fire

# Figure 6.4
## 100-year Event Conceptual Hydrologic Recovery Following Wildfire--Moderate to Severe Burn Intensity



# Appendix A
# (FEST Report Burn Severity Figure)

Appendix A-1.  FEST Burn Severity Map




This map is for illustrative purposes only. Boulder County Land Use Department makes no warranties regarding the accuracy, completeness, reliability, or suitability of these data. Boulder County Land Use Department disclaims any liability associated with the use or misuse of these data. In accessing and/or relying on these data, the user fully assumes any and all risk associated with this information.
Map Created by: MMM in Land Use 10/11/10

# Appendix B
# (USGS Report Figures)

U.S. Department of the Interior
U.S. Geological Survey

**OPEN FILE REPORT 2010-1244**
**Probability Map--PLATE 1**

Ruddy, B.C., Stevens, M.R., Verdin, K.L., and Elliott, J.G., 2010,
Probability and Volume of Potential Postwildfire Debris Flows
in the 2010 Fourmile Burn Area, Boulder County, Colorado

**Probability of a debris flow (percent) in response to a 25-year, 1-hour rainfall of 23 millimeters**

| BAER* Basin Number | Probability (percent) |
|---|---|
| 0 | 21 |
| 1 | 2 |
| 2 | <1 |
| 3 | 51 |
| 4 | 1 |
| 5 | 18 |
| 6 | 43 |
| 7 | 64 |
| 8 | 13 |
| 9 | 6 |
| 10 | 42 |
| 11 | 63 |
| 12 | 61 |
| 14 | 28 |
| 15 | 2 |
| 16 | 70 |
| 17 | 32 |
| 18 | 58 |
| 19 | 11 |
| 20 | 3 |
| 21 | 19 |
| 23 | 9 |
| 24 | 2 |
| 25 | 9 |
| 27 | <1 |
| 28 | 2 |


**The probability of a debris flow is estimated for a basin outlet (pour point) at the most downstream end of each drainage basin. Smaller subbasins within these delineated basins may have larger probabilities of a debris flow but they are not shown on this map.**

This work is preliminary and is subject to revision. It is being provided due to the need for timely "best science" information. The assessment is provided on the condition that neither the U.S. Geological Survey nor the United States Government may be held liable for any damages resulting from the authorized or unauthorized use of the assessment.

## Explanation

**Probability of a debris flow (percent) in response to a 2~~5~~-year, 1-hour rainfall of 23 millimeters** Should read 2-year

**BAER* basin pour point**
- 0 to 15
- 16 to 30
- 31 to 45
- 46 to 60
- 61 to 75

**Selected basins**
- 0 to 15
- 16 to 30
- 31 to 45
- 46 to 60
- 61 to 75

Stream
Road
Extent of burned area
BAER* basin delineation
Populated areas
High elevation points
23 BAER* basin number
103 Selected basin number

*Burned Area Emergency Rehabilitation

# Probability of Potential Postwildfire Debris Flows in the 2010 Fourmile Burn Area, Boulder County, Colorado

By
Barbara C. Ruddy, Michael R. Stevens, Kristine L. Verdin, and John G. Elliott
2010

Projection is NAD 1983 UTM Zone 13 North.

U.S. Department of the Interior
U.S. Geological Survey

OPEN FILE REPORT 2010-1244
Estimated Volumes Map--PLATE 2
Ruddy, B.C., Stevens, M.R., Verdin, K.L., and Elliott, J.G., 2010,
Probability and Volume of Potential Postwildfire Debris Flows
in the 2010 Fourmile Burn Area, Boulder County, Colorado

**Estimated volume of a debris flow (cubic meters) in response to a 25-year, 1-hour rainfall of 23 millimeters**

| BAER* Basin Number | Volume (cubic meters) |
|---|---|
| 0 | 7,800 |
| 1 | 11,800 |
| 2 | 6,600 |
| 3 | 5,600 |
| 4 | 161,400 |
| 5 | 43,500 |
| 6 | 1,500 |
| 7 | 9,400 |
| 8 | 5,600 |
| 9 | 4,500 |
| 10 | 7,600 |
| 11 | 4,700 |
| 12 | 4,300 |
| 13 | 51,800 |
| 14 | 2,800 |
| 15 | 3,500 |
| 16 | 4,300 |
| 17 | 2,200 |
| 18 | 3,200 |
| 19 | 3,300 |
| 20 | 2,500 |
| 21 | 1,400 |
| 23 | 9,100 |
| 24 | 368,000 |
| 25 | 1,900 |
| 27 | 3,600 |
| 28 | 160 |


**The volume of a debris flow is estimated for a basin outlet (pour point) at the most downstream end of each drainage basin.**

## Explanation

Estimated volume of a debris flow (cubic meters) in response to a 25-year, 1-hour rainfall of 23 millimeters [Should read 2-year]

**BAER* basin pour point**
- 156 to 1,000
- 1,001 to 2,000
- 2,001 to 3,000
- 3,001 to 5,000
- 5,001 to 368,000

**Selected basins**
- 50 to 1,000
- 1,001 to 2,000
- 2,001 to 3,000
- 3,001 to 5,000
- 5,001 to 6,700

- Stream
- Road
- Extent of burned area
- BAER* basin delineation
- Populated areas
- High elevation points
- 23 BAER* basin number
- 103 Selected basin number

*Burned Area Emergency Rehabilitation

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Projection is NAD 1983 UTM Zone 13 North.

# Estimated Volumes of Potential Postwildfire Debris Flows in the 2010 Fourmile Burn Area, Boulder County, Colorado

By
Barbara C. Ruddy, Michael R. Stevens, Kristine L. Verdin, and John G. Elliott
2010