Appendix A-2: Inundation Map Documentation

FLOOD INUNDATION AREA

The dam-failure flood inundation mapping, provided in the Fisher Peak No. 1 Dam Emergency Action Plan (EAP), was prepared by W. W. Wheeler and Associates, Inc. (Wheeler) in June 2014. The purpose of this document is to summarize the methods and assumptions used to develop the inundation mapping. The flood inundation base mapping consists of 2014 aerial imagery available at http://services.arcgisonline.com as of June 2014. The flood inundation index map was prepared with the StreetMapUSA data layer (ESRI, 2005).

The inundation mapping for the failure of Fisher Peak No. 1 Dam was developed from a computer simulation of the dam failure and channel routing of the flood wave's travel through the stream channel downstream of the dam. The first step of the simulation was to prepare a reservoir routing model of the sunny day failure of Fisher Peak No. 1 Dam. This reservoir routing model was simulated with the U.S. Army Corps of Engineers (USACE) Flood Hydrograph Package, HEC-1 (USACE, 1998). Fisher Peak No. 1 Dam was modeled to fail with the water surface at the spillway crest elevation of 6266.4 feet, approximately 5 feet below the dam crest. This model was assumed to fail with no initial base flow in the downstream channel.

The second step of the analysis was to simulate the channel routing downstream of Fisher Peak No. 1 Dam of the breach hydrograph obtained from the HEC-1 model. The flood wave flows north through Trinidad for about 1.5 miles and into the Purgatoire River and continues in the Purgatoire approximately 4 miles downstream of Fisher Peak No. 1 Dam where the flood flows attenuates to less than 5,000 cfs. The channel routing of the breach hydrograph was simulated using the unsteady flow option in the USACE HEC-RAS River Analysis System computer model (USACE, 2010).

Downstream cross-sections used in Wheeler's HEC-RAS simulation model and flood inundation analyses were extracted from 5-foot contours provided by the City of Trinidad (Trinidad, 1991). The 5-foot contours were then used to develop a Triangulated Irregular Network (TIN) using ARCGIS. The developed TIN was then used to create the ground surface elevations used for the HEC-RAS hydraulic models. All of the cross-sections were extracted from the TIN surface using the HEC-GeoRAS ArcGIS extension developed by the USACE (USACE, 2011). A Manning's roughness value of 0.04 was used for the main channel and a value of 0.15 was used for the left and right overbank areas in the HEC-RAS model. Bridge modeling was included in the HEC-RAS model for significant bridge and culvert crossings. The bridge openings were measured by Wheeler with a hand-level and tape during the March 2014 site visit to the downstream floodplain. The bridges or culverts within the reach study that were significantly undersized for routing the dam breach discharges, were not included in the model because these smaller bridges were assumed to either be clogged with debris or wash out before the peak discharge reached these smaller bridges and culverts.

The sunny day failure peak breach discharge from Fisher Peak No. 1 Dam is 10,901 cfs. The sunny day breach inundation limits represent the assumed worst-case scenario for the limits of downstream flooding. The inundation mapping was terminated at approximately 4.1 miles downstream of Fisher Peak No. 1 Dam because the breach flood wave was less than 5,000 cfs which is the estimated threshold in which no habitable structures are threatened at flows up to 5,000 cfs (USBR, 2009).

BREACH PARAMETERS

The initial reservoir water surface for Fisher Peak No. 1 Dam was the water surface at the spillway. Other key dam breach parameters used in the dam failure simulation of Fisher Peak No. 1 Dam are shown in Table A-2.1.

TABLE A-2.1 - SUMMARY OF BREACH PARAMETERS
FISHER PEAK NO. 1 DAM EAP

Input	**Sunny DAY Dam Failure**
Breach Bottom Width (feet)	299
Breach Development Time (hours)	0.75
Breach Side Slopes	0.5
Breach Bottom Elevation	6186
Breach Initiation Water Elevation	6266.4
Dam Crest Elevation	6271.4
Initial Reservoir Water Elevation	6266.4

The breach bottom width of 299 feet was based on an average breach width of 340 feet (4 times the dam height of 85 feet) and breach formation side slopes. A sensitivity analysis was performed using a range of reasonable breach parameters to develop the breach bottom width using an erosion rate relationship defined by Von Thun and Gillette (1990) defined as the following:

Erosion Rate (ER) = Average Breach Width / Time of Failure

The range of erosion rates are defined by Von Thun and Gillette between the following:
ER = 200+4*Height (for easily eroded embankments) [521.6 ft/hr]
ER = 4*Height [321.6 ft/hr]

The erosion rate used was ER = 341.6 feet / 0.75hours = 455.5 feet/hour

This average breach width and failure time seemed realistic, providing a reasonably conservative peak discharge for the inundation mapping.

The dam breach parameters were chosen based on Wheeler's experience with other earth dam breach analyses and a review of several empirical breach relationships (FERC, 1991; MacDonald and Langridge-Monopolis, 1984; Froehlich, 1987; Fread, 1981). As part of the breach parameter selection process, a sensitivity analysis of a range of reasonable breach parameters was conducted and compared against erosion rate equations developed from historic dam failures (Von Thun and Gillette, 1990). This analysis indicated that the parameters listed above are appropriate.

RESULTS OF DAM FAILURE INUNDATION MAPPING

The results of the dam failure inundation analyses are illustrated on the flood inundation mapping of the EAP and summarized in Table A-2.2 and Table A-2.3. The inundation boundaries were developed using the HEC-GeoRAS extension to locate the intersection of the topographic surface and the maximum water surface elevation. The dam failure inundation information provided in this EAP should be used as a guideline of conservatively estimated dam failure flooding conditions. Actual conditions during an emergency at Fisher Peak No. 1 Dam may vary significantly from this information based on the actual conditions at the time of the emergency.

Flood wave travel times shown on the flood inundation maps and in Table A-2.2 are based on the assumption that Fisher Peak No. 1 Dam failure begins at time 0:00 (hours: minutes). The flood wave arrival time shown in the inundation summary below represents the approximate time after dam failure when the water surface elevation at each cross-section has risen two feet as a result of the dam-failure flood. The peak flood stage time shown represents the estimated time after Fisher Peak No. 1 Dam failure that the maximum expected flood depths are reached at each downstream cross-section.

TABLE A-2.2 – SUMMARY OF DOWNSTREAM ROUTING:
SUNNY-DAY-BREACH OF FISHER PEAK NO. 1 DAM
FISHER PEAK NO. 1 DAM EAP

Cross Section	Miles Downstream of the dam	Peak Flow (cfs)	Peak Water Surface Elevation (feet)	Peak River Stage (feet)	Flood Wave Arrival Time (hrs:min)	Time to Peak Flood Stage (hrs:min)
Fisher Peak No. 1 Dam	0.0	10,900	6,226	5	0:09	0:18
West Washington Ave.	0.9	10,831	6,086	10	0:12	0:22
West 4th Street	1.0	10,821	6,064	9	0:13	0:24
West 2nd Street	1.1	10,812	6,050	12	0:14	0:25
W. Cedar Street	1.7	10,185	5,993	10	0:23	0:32
N. Commercial Street	1.8	9,798	5,991	10	0:24	0:32
N. Linden Ave	2.3	9,450	5,970	9	0:28	0:36
160 Highway Bypass	3.4	7,403	5,943	6	0:40	0:56
Railroad Crossing	4.1	4,780	5,926	7	1:10	1:24

(1) Time t=0:00 starts at the initiation of the Fisher Peak No. 1 dam break

TABLE A-2.3 – SUMMARY OF KEY ROAD CROSSINGS
SUNNY-DAY-BREACH OF FISHER PEAK NO. 1 DAM
FISHER PEAK NO. 1 DAM EAP

Cross Section	Miles Downstream of the dam	Approximate Depth of Water over Road
West Washington Ave.	0.9	10(1)
West 4th Street	1.0	9(1)
West 2nd Street	1.1	12(1)
W. Cedar Street	1.7	N/A
N. Commercial Street	1.8	N/A
N. Linden Ave	2.3	N/A
160 Highway Bypass	3.4	N/A

(1) These bridges and culverts were assumed to be clogged for this analysis.

REFERENCES

1. City of Trinidad, 5-Foot Elevation Contour Data, (Trinidad, 1991), 1991.
2. Colorado Division of Water Resources, (CO DWR, 2007), *Rules and Regulations for Dam Safety and Dam Construction*, Denver, CO, January 2007.
3. Environmental Systems Research Institute (ESRI, 2005) *Street Map USA Data Layer*, April 1, 2005.
4. Federal Energy Regulatory Commission (FERC, 1991) *Engineering Guidelines for the Evaluation of Hydropower Projects*, April 1991.
5. Fread, D.L. (Fread, 1981) *Some Limitations of Dam-Breach Flood Routing Models*, Proceedings of the ASCE Fall Convention, St. Louis, Missouri, 1981.
6. Froehlich, David C. (Froehlich, 1987) *Embankment Dam Breach Parameters*, August 1987.
7. MacDonald, Thomas C. and Jennifer Langridge-Monopolis (MacDonald and Langridge-Monopolis, 1988) *Breaching Characteristics of Dam Failures*, May 1984.
8. United States Army Corps of Engineers, (USACE, 1998), *HEC-1 Flood Hydrograph Package,* Version 4.1, Davis, CA, June 1998.
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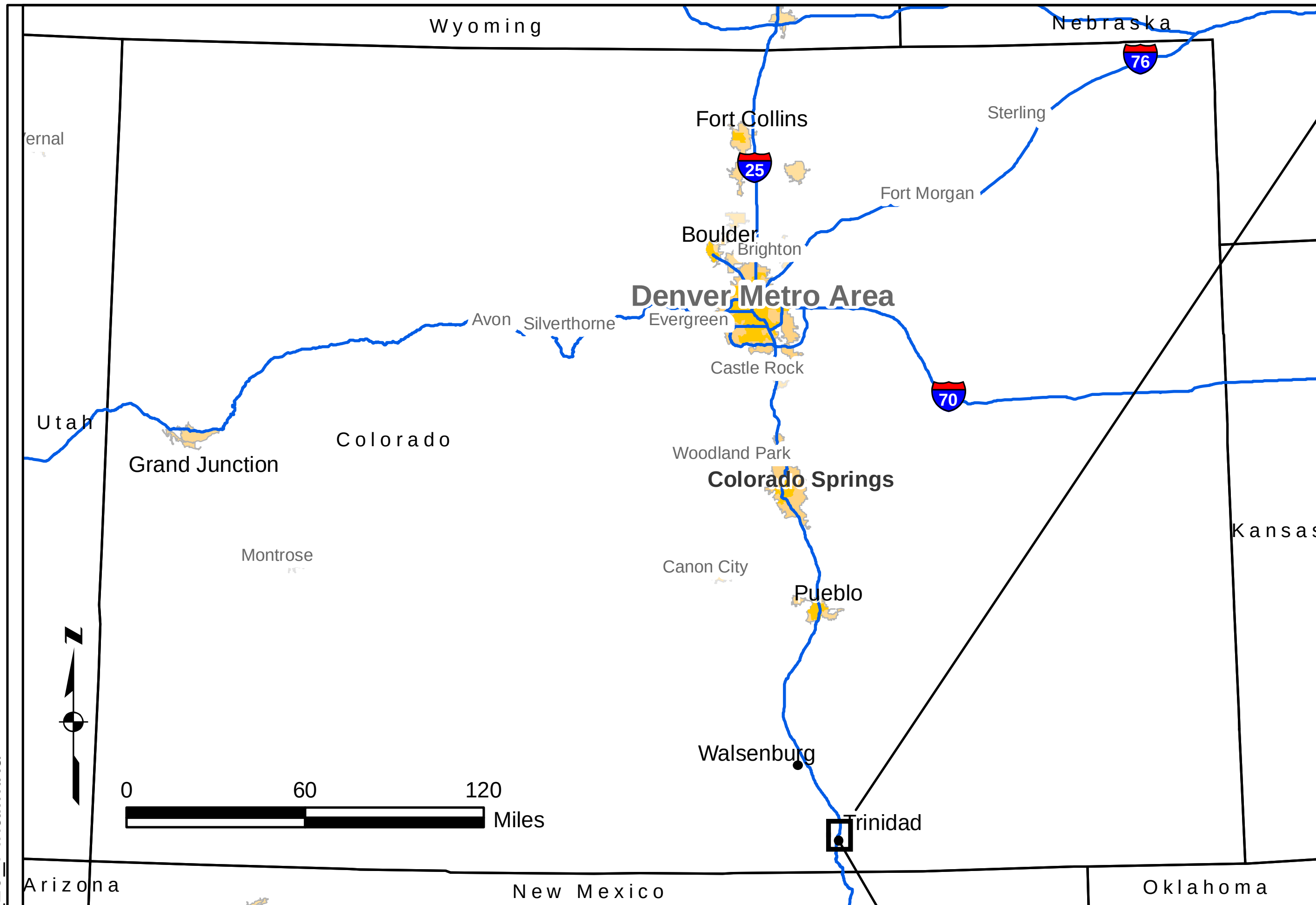
10. United States Army Corps of Engineers, Hydrologic Engineering Center, (USACE, 2010), *HEC-RAS, River Analysis Package,* Version 4.1.0, Davis, CA, January 2010.
11. United States Bureau of Reclamation, (USBR, 2009), Technical Report No. SRH-2009-33, *Hydraulic Modeling Results for the Purgatoire River and Trinidad Dam, Colorado,* October 2009.
12. United States Geologic Survey, (USGS, 2011), *National Elevation Dataset, Seamless Data Distribution System*, http://seamless.usgs.gov, 2011.
13. Von Thun, Lawrence and David R. Gillette, (Von Thun and Gillette, 1990), *Guidance on Breach Parameters,* March 13, 1990.



Location Map

Fisher Peak No. 1 Dam

DAMID 190104

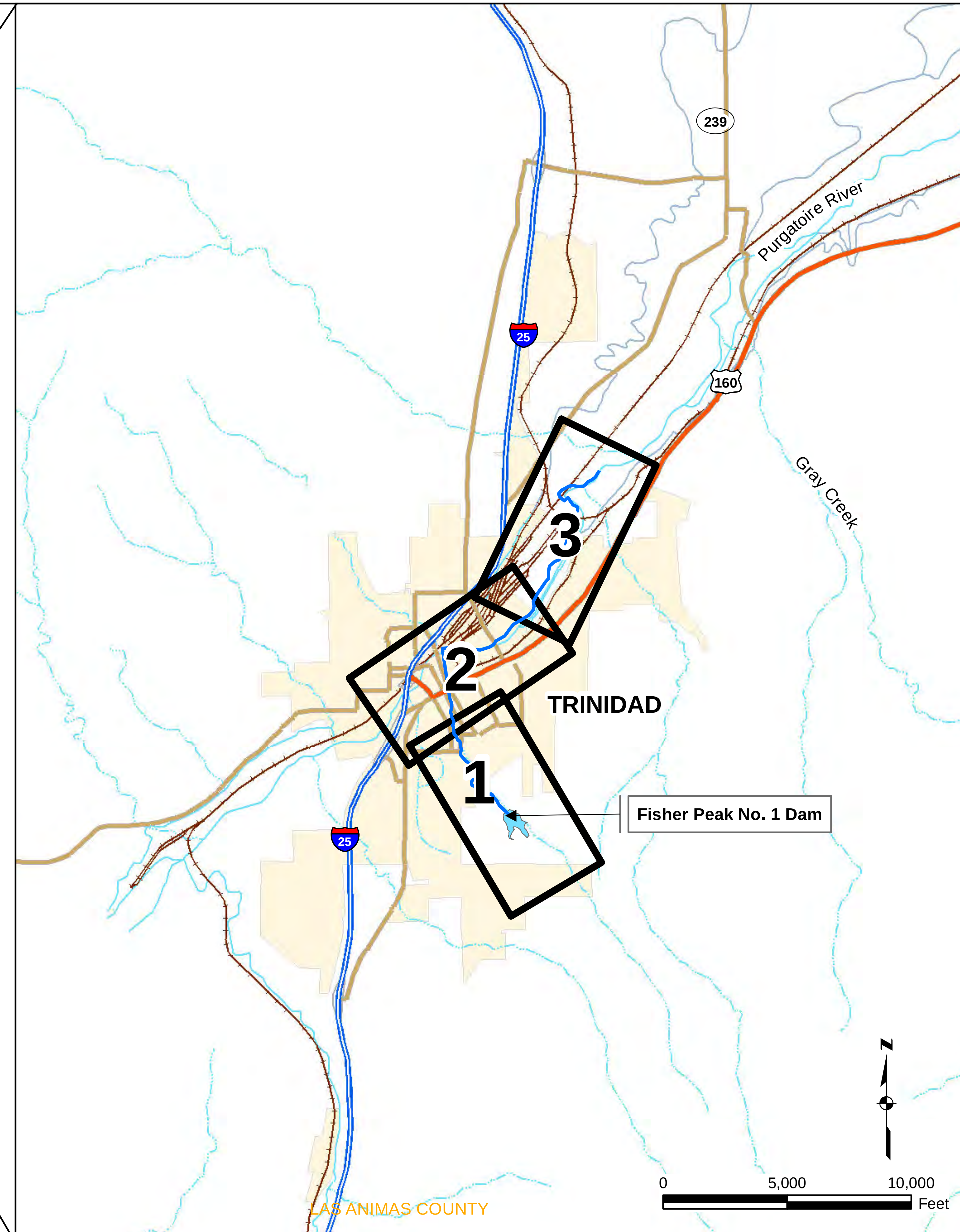
Emergency Action Plan

Dam Failure Flood Inundation Map Index

W. W. WHEELER & ASSOCIATES, INC.
Water Resources Engineers

Project No. 0673.04

June 2014



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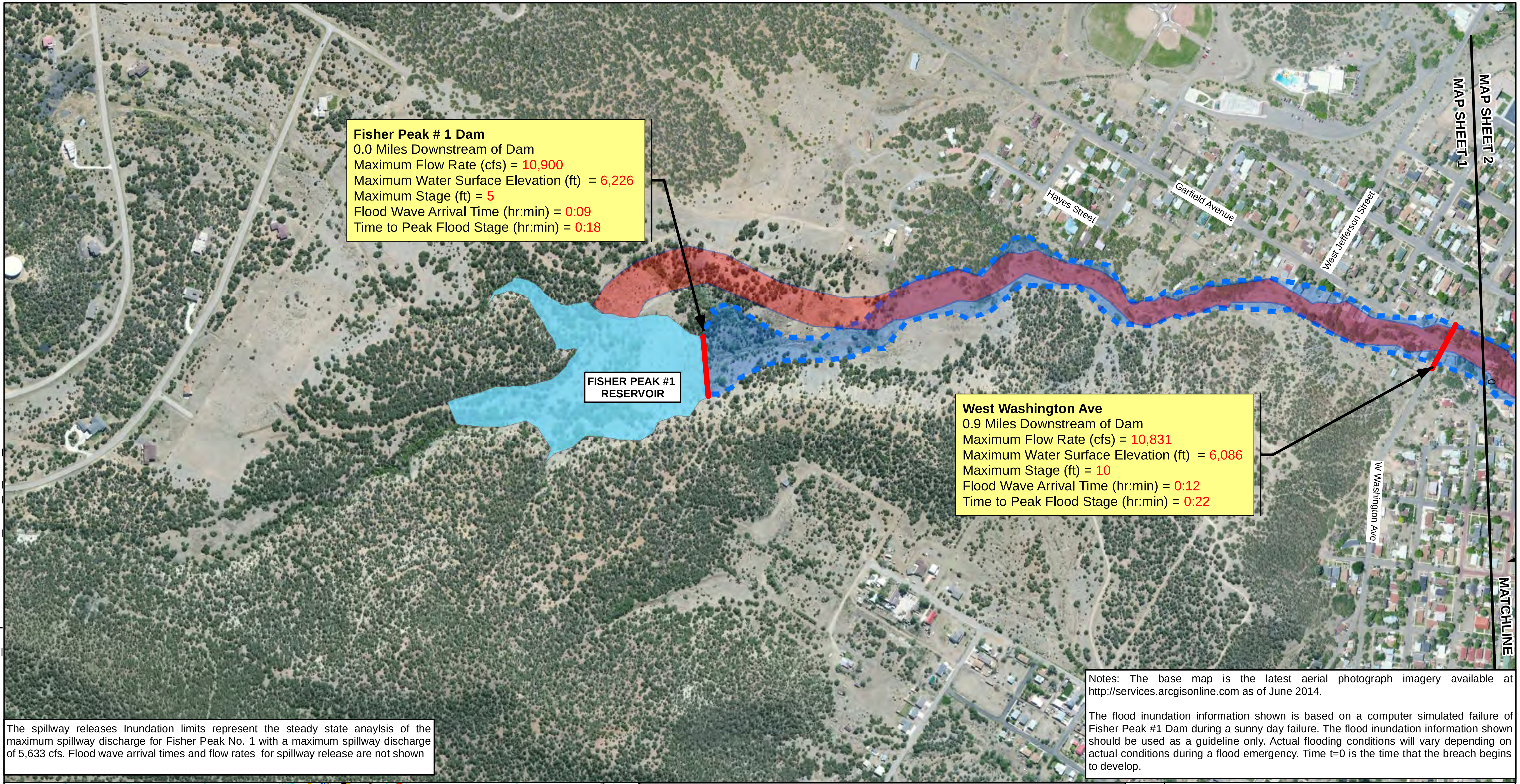
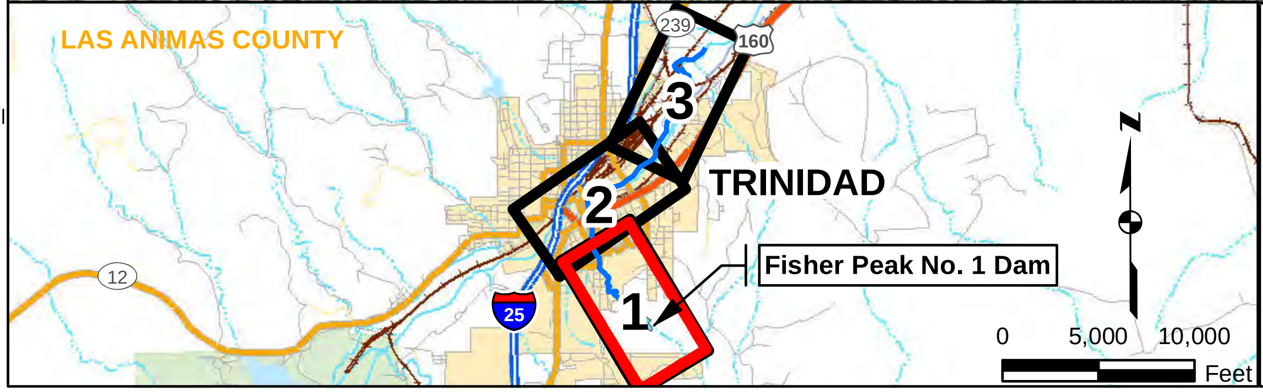


The spillway releases Inundation limits represent the steady state anaylsis of the maximum spillway discharge for Fisher Peak No. 1 with a maximum spillway discharge of 5,633 cfs. Flood wave arrival times and flow rates for spillway release are not shown

Notes: The base map is the latest aerial photograph imagery available at http://services.arcgisonline.com as of June 2014.

The flood inundation information shown is based on a computer simulated failure of Fisher Peak #1 Dam during a sunny day failure. The flood inundation information shown should be used as a guideline only. Actual flooding conditions will vary depending on actual conditions during a flood emergency. Time t=0 is the time that the breach begins to develop.



Flood Key

- Flood Inundation Limits (Sunny Day Breach)
- Maximum Spillway Releases Inundation Limits

0 250 500 Feet

JUNE 2014

W. W. WHEELER & ASSOCIATES, INC.
Water Resources Engineers

FISHER PEAK NO. 1
Emergency Action Plan
Dam Failure Flood Inundation Map

DAMID: 190104

MAP SHEET 1

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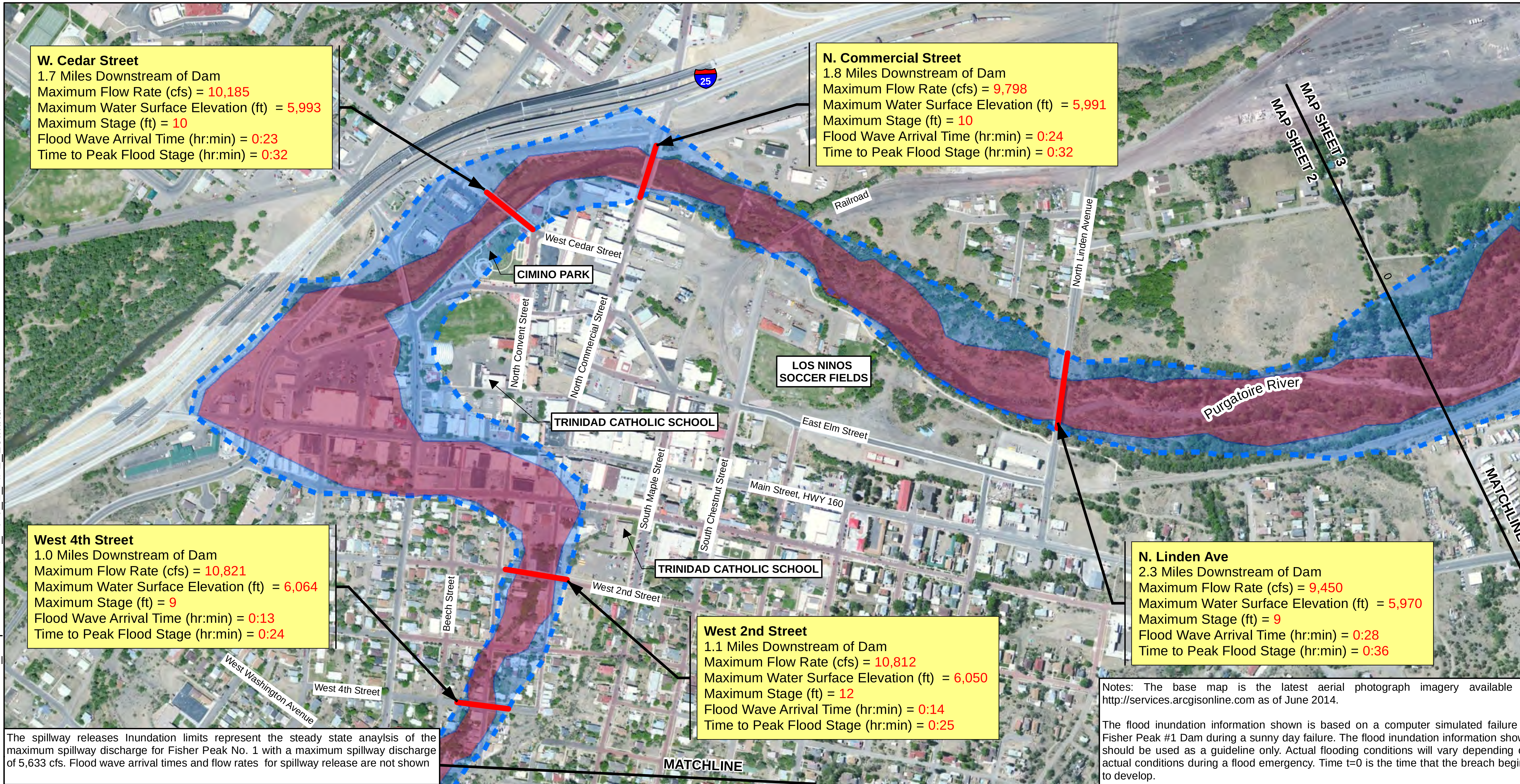

The spillway releases Inundation limits represent the steady state anaylsis of the maximum spillway discharge for Fisher Peak No. 1 with a maximum spillway discharge of 5,633 cfs. Flood wave arrival times and flow rates for spillway release are not shown

Notes: The base map is the latest aerial photograph imagery available at http://services.arcgisonline.com as of June 2014.

The flood inundation information shown is based on a computer simulated failure of Fisher Peak #1 Dam during a sunny day failure. The flood inundation information shown should be used as a guideline only. Actual flooding conditions will vary depending on actual conditions during a flood emergency. Time t=0 is the time that the breach begins to develop.

Flood Key

- Flood Inundation Limits (Sunny Day Breach)
- Maximum Spillway Releases Inundation Limits

N

0 250 500 Feet

JUNE 2014

W. W. WHEELER & ASSOCIATES, INC.
Water Resources Engineers

FISHER PEAK NO. 1
Emergency Action Plan
Dam Failure Flood Inundation Map

DAMID: 190104 | MAP SHEET 2

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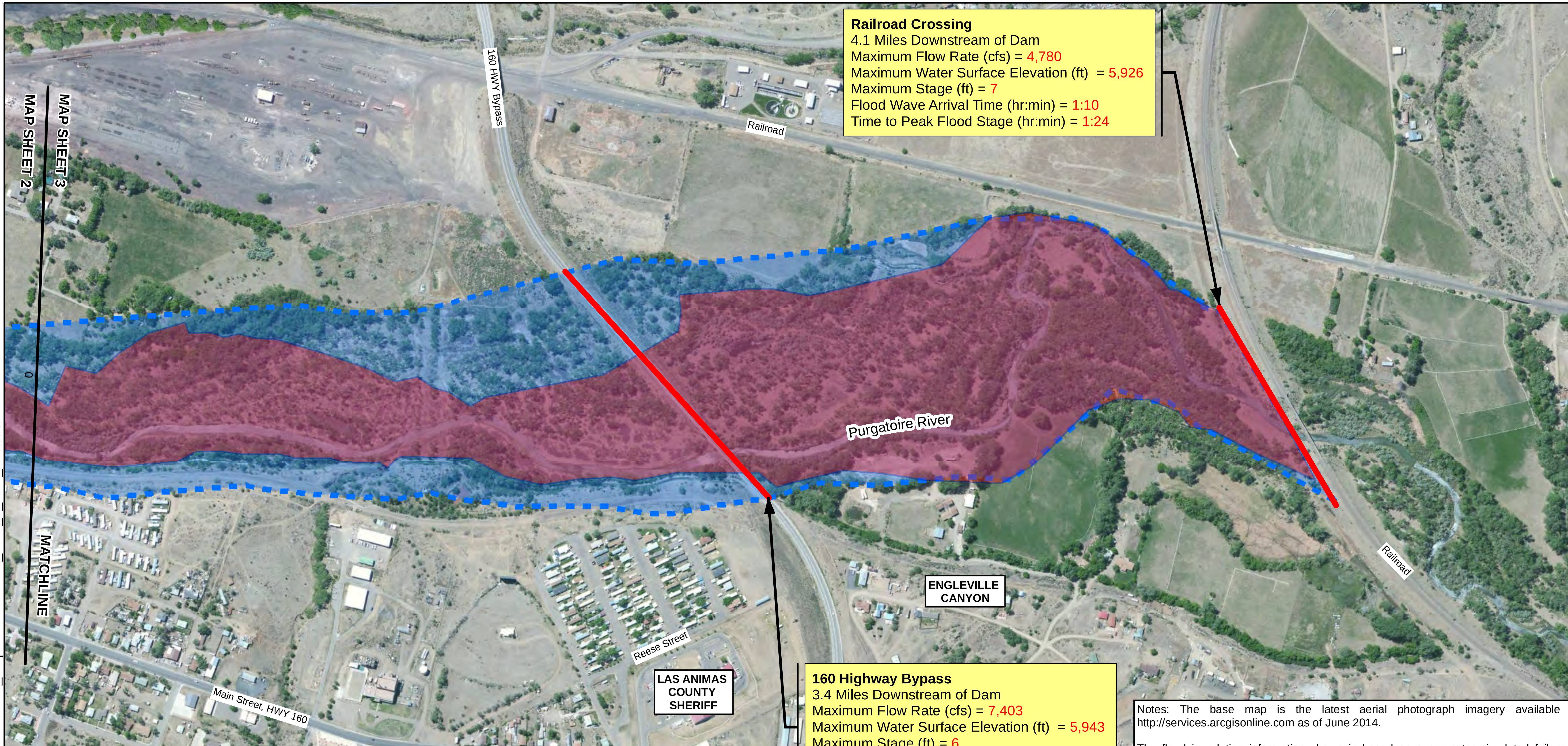
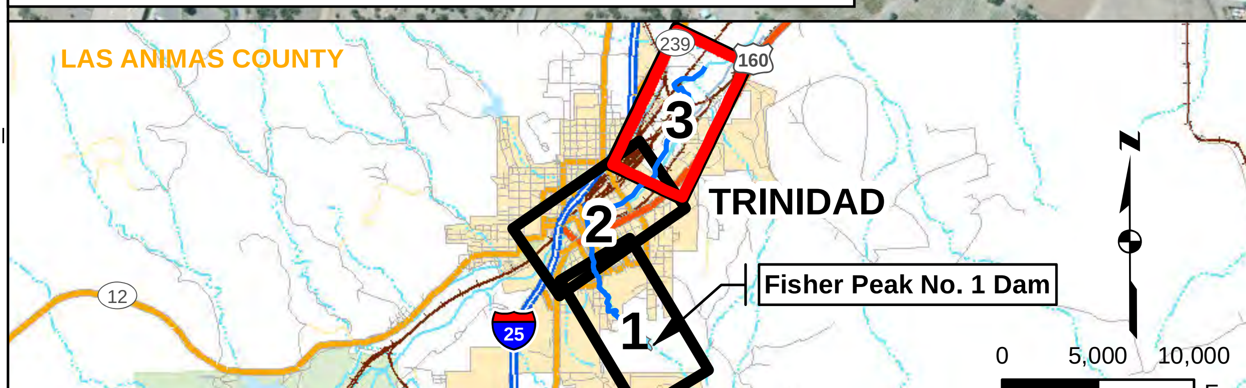


The spillway releases Inundation limits represent the steady state anaylsis of the maximum spillway discharge for Fisher Peak No. 1 with a maximum spillway discharge of 5,633 cfs. Flood wave arrival times and flow rates for spillway release are not shown

Notes: The base map is the latest aerial photograph imagery available at http://services.arcgisonline.com as of June 2014.

The flood inundation information shown is based on a computer simulated failure of Fisher Peak #1 Dam during a sunny day failure. The flood inundation information shown should be used as a guideline only. Actual flooding conditions will vary depending on actual conditions during a flood emergency. Time t=0 is the time that the breach begins to develop.



Flood Key

Flood Inundation Limits (Sunny Day Breach)

Maximum Spillway Releases Inundation Limits

0 250 500 Feet

JUNE 2014

W. W. WHEELER & ASSOCIATES, INC.
Water Resources Engineers

FISHER PEAK NO. 1
Emergency Action Plan
Dam Failure Flood Inundation Map

DAMID: 190104 | MAP SHEET 3

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Appendix A-2: Inundation Map Documentation

FLOOD INUNDATION AREA

The dam-failure flood inundation mapping, provided in the Fisher Peak No. 2 Dam Emergency Action Plan (EAP), was prepared by W. W. Wheeler and Associates, Inc. (Wheeler) in June 2014. The purpose of this document is to summarize the methods and assumptions used to develop the inundation mapping. The flood inundation base mapping consists of 2014 aerial imagery available at http://services.arcgisonline.com as of June 2014. The flood inundation index map was prepared with the StreetMapUSA data layer (ESRI, 2005).

The inundation mapping for the failure of Fisher Peak No. 2 Dam was developed from a computer simulation of the dam failure and channel routing of the flood wave's travel through the stream channel downstream of the dam. The first step of the simulation was to prepare a reservoir routing model of the sunny day failure of Fisher Peak No. 2 Dam. This reservoir routing model was simulated with the U.S. Army Corps of Engineers (USACE) Flood Hydrograph Package, HEC-1 (USACE, 1998). Fisher Peak No. 2 Dam was modeled to fail with the water surface at the spillway crest elevation of 6137.5 feet, approximately 5 feet below the dam crest. This model assumed no initial inflow in the downstream discharge channel.

The second step of the analysis was to simulate the channel routing downstream of Fisher Peak No. 2 Dam of the breach hydrograph obtained from the HEC-1 model. The flood wave flows north through Trinidad and into the Purgatoire River and continues in the Purgatoire approximately 3.4 miles downstream of Fisher Peak No. 2 Dam where the flood flows attenuates to less than 5,000 cfs. The channel routing of the breach hydrograph was simulated using the unsteady flow option in the USACE HEC-RAS River Analysis System computer model (USACE, 2010).

Downstream cross-sections used in Wheeler's HEC-RAS simulation model and flood inundation analyses were extracted from 5-foot contours provided by the City of Trinidad (Trinidad, 1991). The 5-foot contours were then used to develop a Triangular Irregular Network (TIN) using ArcGIS. The developed TIN was then used to create the ground surface elevations used for the HEC-RAS hydraulic models. All of the cross-sections were extracted from the TIN surface using the HEC-GeoRAS ArcGIS extension developed by the USACE (USACE, 2011). A Manning's roughness value of 0.04 was used for the main channel and a value of 0.15 was used for the left and right overbank areas in the HEC-RAS model. Bridge modeling was included in the HEC-RAS model for significant bridge and culvert crossings. The bridge openings were measured by Wheeler with a hand-level and tape during the March 2014 site visit to the downstream floodplain. The bridges or culverts within the reach study that were significantly undersized for routing the dam breach discharges, were not included in the model because these smaller bridges were assumed to either be clogged with debris or wash out before the peak discharge reached these smaller bridges and culverts.

The sunny day failure peak breach discharge from Fisher Peak No. 2 Dam is 5,006 cfs. The inundation mapping was terminated at approximately 3.4 miles downstream of Fisher Peak No. 2 Dam because the breach flood wave was less than 5,000 cfs which is the estimated threshold in which no habitable structures are threatened at flows up to 5,000 cfs (USBR, 2009). The flood inundation limits were extended beyond the USBR threshold to the edge of Trinidad to verify no issues in the model.

BREACH PARAMETERS

The initial reservoir water surface for Fisher Peak No. 2 Dam was the water surface at the spillway. Other key dam breach parameters used in the dam failure simulation of Fisher Peak No. 2 Dam are shown in Table A-2.1.

TABLE A-2.1 - SUMMARY OF BREACH PARAMETERS
FISHER PEAK NO. 2 DAM EAP

Input	Sunny Day Dam Failure
Breach Bottom Width (feet)	216
Breach Development Time (hours)	0.75
Breach Side Slopes	0.5
Breach Bottom Elevation	6080.8
Breach Initiation Water Elevation	6137.5
Dam Crest Elevation	6142.5
Initial Reservoir Water Elevation	6137.5

The breach bottom width of 216 feet was based on an average breach width of 248 feet (4 times the dam height 62 feet) and breach formation side slopes. A sensitivity analysis was performed using a range of reasonable breach parameters to develop the breach bottom width using an erosion rate relationship defined by Von Thun and Gillette (1990) defined as the following:

Erosion Rate (ER) = Average Breach Width / Time of Failure

The range of erosion rates are defined by Von Thun and Gillette between the following:
ER = 200+4*Height (for easily eroded embankments) [426.6 ft/hr]
ER = 4*Height [226.6 ft/hr]

The erosion rate used was ER = 246 feet / 0.75hours = 328.9 feet/hour

This average breach width and failure time seemed realistic, providing a reasonably conservative peak discharge for the inundation mapping.

The dam breach parameters were chosen based on Wheeler's experience with other earth dam breach analyses and a review of several empirical breach relationships (FERC, 1991; MacDonald and Langridge-Monopolis, 1984; Froehlich, 1987; Fread, 1981). As part of the breach parameter selection process, a sensitivity analysis of a range of reasonable breach parameters was conducted and compared against erosion rate equations developed from historic dam failures (Von Thun and Gillette, 1990). This analysis indicated that the parameters listed above are appropriate.

RESULTS OF DAM FAILURE INUNDATION MAPPING

The results of the dam failure inundation analyses are illustrated on the flood inundation mapping of the EAP and summarized in Table A-2.2 and Table A-2.3. The inundation boundaries were developed using the HEC-GeoRAS extension to locate the intersection of the topographic surface and the maximum water surface elevation. The dam failure inundation information provided in this EAP should be used as a guideline of conservatively estimated dam failure flooding conditions. Actual conditions during an emergency at Fisher Peak No. 2 Dam may vary significantly from this information based on the actual conditions at the time of the emergency.

Flood wave travel times shown on the flood inundation maps and in Table A-2.2 are based on the assumption that Fisher Peak No. 2 Dam failure begins at time 0:00 (hours: minutes). The flood wave arrival time shown in the inundation summary below represents the approximate time after dam failure when the water surface elevation at each cross-section has risen two feet as a result of the dam-failure flood. The peak flood stage time shown represents the estimated time after Fisher Peak No. 2 Dam failure that the maximum expected flood depths are reached at each downstream cross-section.

TABLE A-2.2 – SUMMARY OF DOWNSTREAM ROUTING:
SUNNY-DAY-BREACH OF FISHER PEAK NO. 2 DAM
FISHER PEAK NO. 2 DAM EAP

Cross Section	Miles Downstream of the dam	Peak Flow (cfs)	Peak Water Surface Elevation (feet)	Peak River Stage (feet)	Flood Wave Arrival Time (hrs:min)	Time to Peak Flood Stage (hrs:min)
Fisher Peak No. 2 Dam	0.0	5,006	6119	4	0:08	0:18
W. Jefferson Street	0.2	4,958	6074	4	0:15	0:20
E. 1st Street	0.6	4,937	6016	6	0:16	0:22
N. Animas Street	0.8	4,732	5992	6	0:18	0:26
W. Cedar Street	0.9	4,654	5990	6	0:20	0:28
N. Commercial Street	1.1	4,621	5988	5	0:22	0:29
N. Linden Ave	1.5	4,252	5968	5	0:26	0:32
160 Highway Bypass	2.6	3,289	5942	5	0:41	0:52
Railroad Crossing	3.4	2,769	5922	2	0:46	1:12

(1) Time t=0:00 starts at the initiation of the Fisher Peak No. 2 dam break

TABLE A-2.3 – SUMMARY OF KEY ROAD CROSSINGS
SUNNY-DAY-BREACH OF FISHER PEAK NO. 2 DAM
FISHER PEAK NO. 2 DAM EAP

Cross Section	Miles Downstream of the dam	Approximate Depth of Water over Road
W. Jefferson Street	0.2	4.0(1)
E. 1st Street	0.6	6.0(1)
N. Animas Street	0.8	N/A
W. Cedar Street	0.9	N/A
N. Commercial Street	1.1	N/A
N. Linden Ave	1.5	N/A
160 Highway Bypass	2.6	N/A

(1) These culverts were assumed to be undersized and clogged for this analysis.

REFERENCES

1. City of Trinidad, 5-Foot Elevation Contour Data, (Trinidad, 1991), 1991.
2. Colorado Division of Water Resources, (CO DWR, 2007), *Rules and Regulations for Dam Safety and Dam Construction*, Denver, CO, January 2007.
3. Environmental Systems Research Institute (ESRI, 2005) *Street Map USA Data Layer*, April 1, 2005.
4. Federal Energy Regulatory Commission (FERC, 1991) *Engineering Guidelines for the Evaluation of Hydropower Projects*, April 1991.
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6. Froehlich, David C. (Froehlich, 1987) *Embankment Dam Breach Parameters*, August 1987.
7. MacDonald, Thomas C. and Jennifer Langridge-Monopolis (MacDonald and Langridge-Monopolis, 1988) *Breaching Characteristics of Dam Failures*, May 1984.
8. United States Army Corps of Engineers, (USACE, 1998), *HEC-1 Flood Hydrograph Package,* Version 4.1, Davis, CA, June 1998.
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11. United States Bureau of Reclamation, (USBR, 2009), Technical Report No. SRH-2009-33, *Hydraulic Modeling Results for the Purgatoire River and Trinidad Dam, Colorado,* October 2009.
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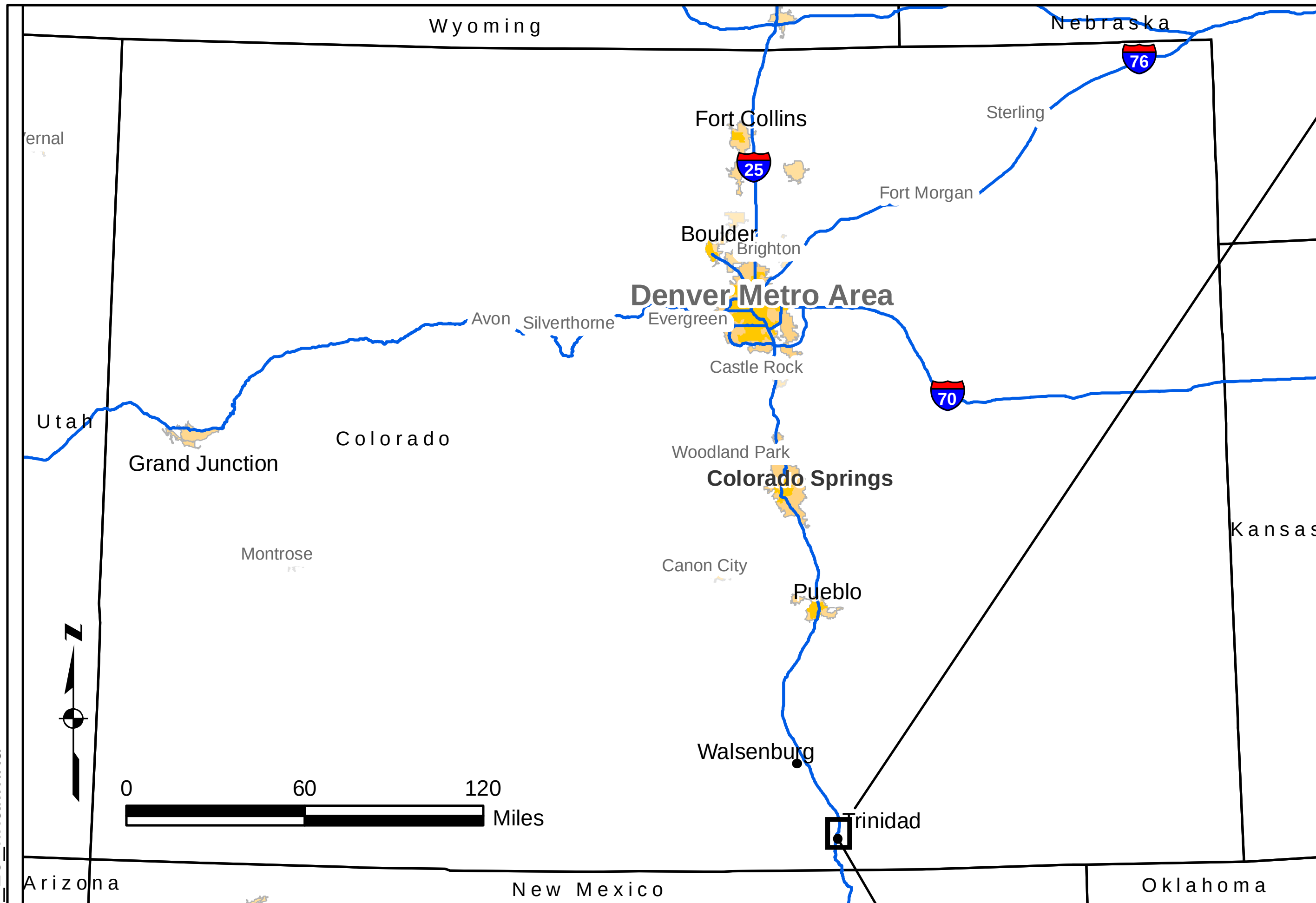
13. Von Thun, Lawrence and David R. Gillette, (Von Thun and Gillette, 1990), *Guidance on Breach Parameters,* March 13, 1990.



Location Map

Fisher Peak No. 2 Dam

DAMID 190105

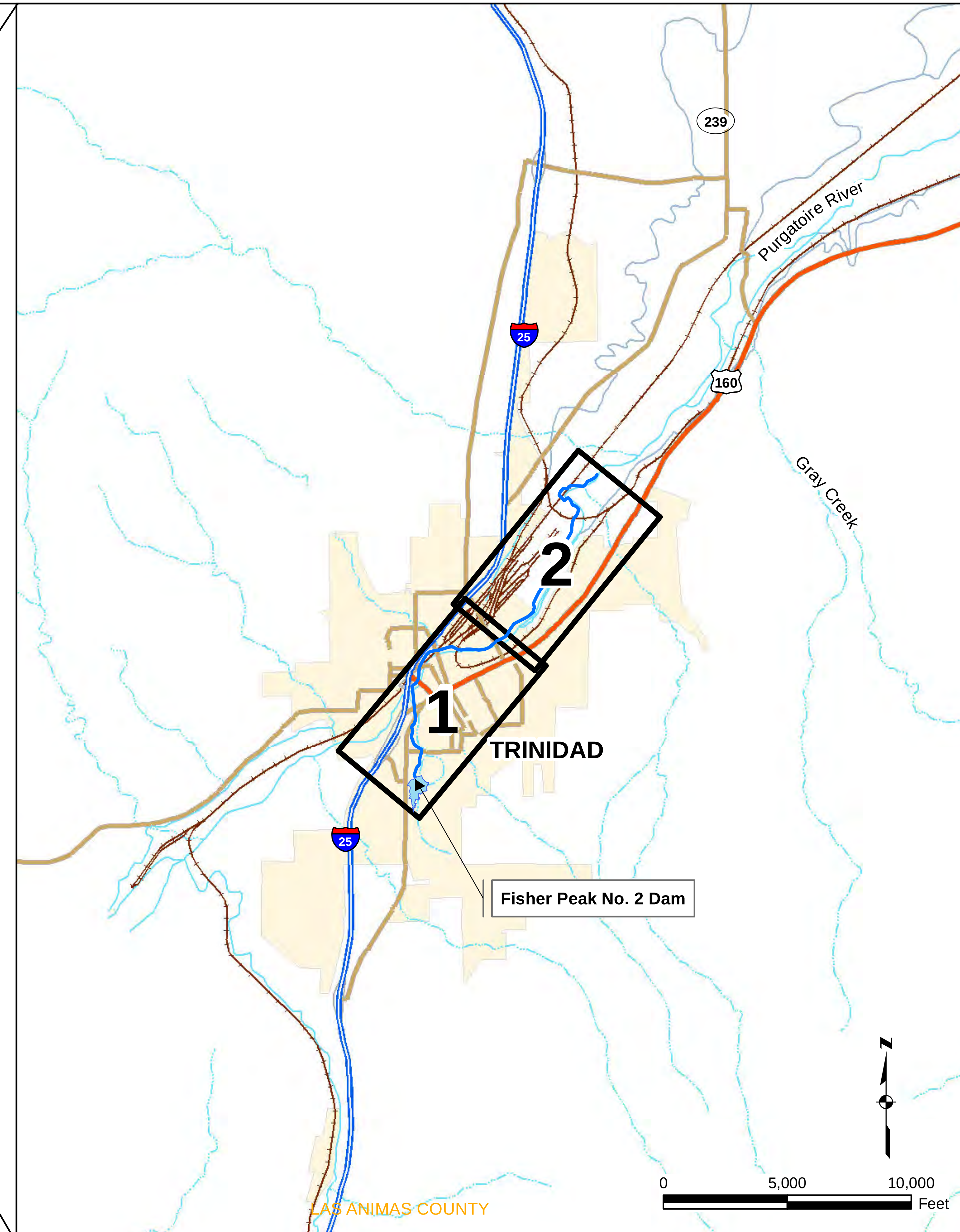
Emergency Action Plan

Dam Failure Flood Inundation Map Index

W. W. WHEELER & ASSOCIATES, INC.
Water Resources Engineers

Project No. 0673.04

June 2014



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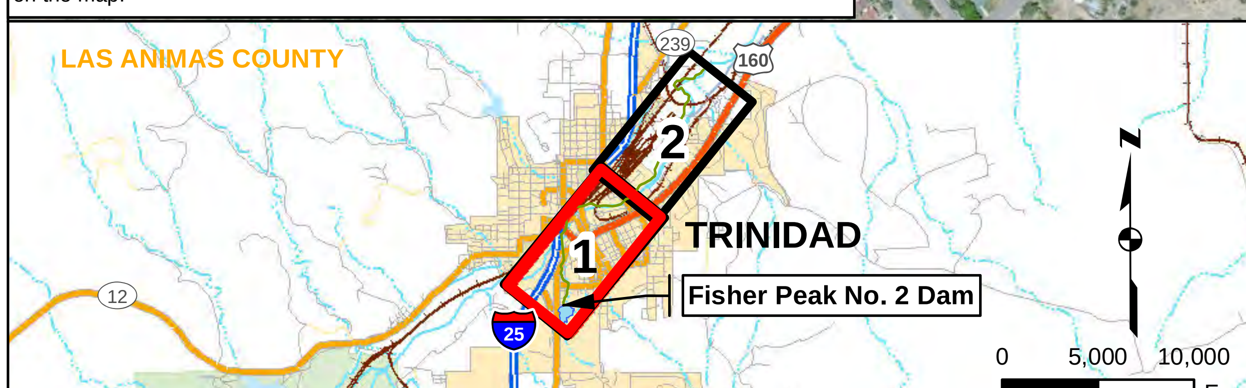
The spillway releases Inundation limits represent the steady state anaylsis of the maximum spillway discharge for Fisher Peak No. 2 with a maximum spillway discharge of 1,045 cfs. Flood wave arrival times and flow rates for spillway releases are not shown on the map.

Notes: The base map is the latest aerial photograph imagery available at http://services.arcgisonline.com as of June 2014.

The flood inundation information shown is based on a computer simulated failure of Fisher Peak #2 Dam during a sunny day failure. The flood inundation information shown should be used as a guideline only. Actual flooding conditions will vary depending on actual conditions during a flood emergency. Time t=0 is the time that the breach begins to develop.



Flood Key

- Flood Inundation Limits (Sunny Day Breach)
- Maximum Spillway Releases Inundation Limits

N

0 250 500 Feet

JUNE 2014

W. W. WHEELER & ASSOCIATES, INC.
Water Resources Engineers

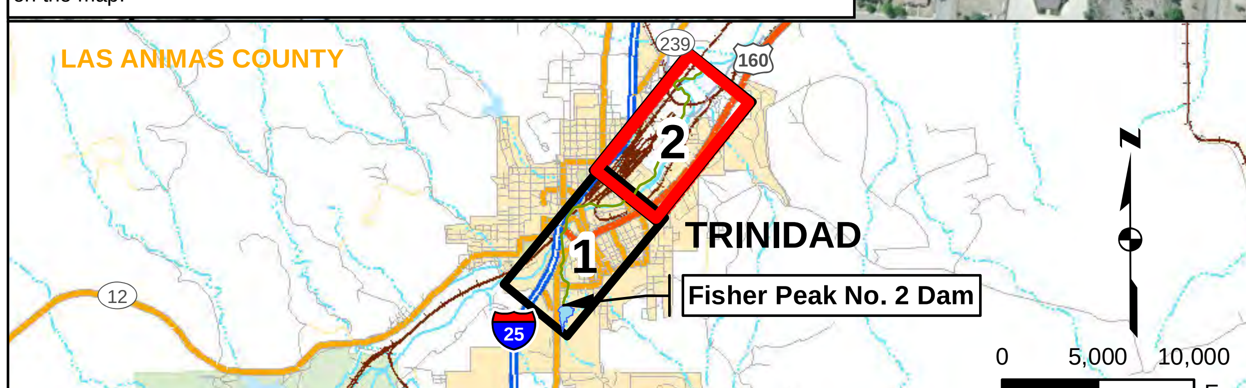
FISHER PEAK NO. 2
Emergency Action Plan
Dam Failure Flood Inundation Map

DAMID 190105	MAP SHEET 1

The spillway releases Inundation limits represent the steady state anaylsis of the maximum spillway discharge for Fisher Peak No. 2 with a maximum spillway discharge of 1,045 cfs. Flood wave arrival times and flow rates for spillway releases are not shown on the map.

Notes: The base map is the latest aerial photograph imagery available at http://services.arcgisonline.com as of June 2014.

The flood inundation information shown is based on a computer simulated failure of Fisher Peak #2 Dam during a sunny day failure. The flood inundation information shown should be used as a guideline only. Actual flooding conditions will vary depending on actual conditions during a flood emergency. Time t=0 is the time that the breach begins to develop.



Flood Key

- Flood Inundation Limits (Sunny Day Breach)
- Maximum Spillway Releases Inundation Limits

N

0 250 500 Feet

JUNE 2014

W. W. WHEELER & ASSOCIATES, INC.
Water Resources Engineers

FISHER PEAK NO. 2
Emergency Action Plan
Dam Failure Flood Inundation Map

DAMID 190105	MAP SHEET 2

Appendix A-2: Inundation Map Documentation

FLOOD INUNDATION AREA

The dam-failure flood inundation mapping, provided in the Pinon Canon Dam Emergency Action Plan (EAP), was prepared by W. W. Wheeler and Associates, Inc. (Wheeler) in June 2014. The purpose of this document is to summarize the methods and assumptions used to develop the inundation mapping. The flood inundation base mapping consists of 2014 aerial imagery available at http://services.arcgisonline.com as of June 2014. The flood inundation index map was prepared with the StreetMapUSA data layer (ESRI, 2005).

The inundation mapping for the failure of Pinon Canon Dam was developed from a computer simulation of the dam failure and channel routing of the flood wave's travel through the stream channel downstream of the dam. The first step of the simulation was to prepare a reservoir routing model of the sunny day failure of Pinon Canon Dam. This reservoir routing model was simulated with the U.S. Army Corps of Engineers (USACE) Flood Hydrograph Package, HEC-1 (USACE, 1998). Pinon Canon Dam was modeled to fail with the water surface at the spillway crest elevation of 6211.0 feet, approximately 12.5 feet below the dam crest. This model was assumed to fail with no initial base flow in the downstream channel

The second step of the analysis was to simulate the channel routing downstream of Pinon Canon Dam of the breach hydrograph obtained from the HEC-1 model. The flood wave flows southeast through the residential area in the northwest area of Trinidad and into the Purgatoire approximately1.4 miles downstream of Pion Canon Dam. After the flood wave flows into the Purgatoire River it flows approximately 6.8 miles where the flood flows attenuates to less than 5,000 cfs . The channel routing of the breach hydrograph was simulated using the unsteady flow option in the USACE HEC-RAS River Analysis System computer model (USACE, 2010).

Downstream cross-sections used in Wheeler's HEC-RAS simulation model and flood inundation analyses were extracted from 5-foot contours provided by the City of Trinidad (Trinidad, 1991). The 5-foot contours were then used to develop a Triangulated Irregular Network using ArcGIS. The developed TIN was then used to create the ground surface elevations used for the HEC-RAS hydraulic models. All of the cross-sections were extracted from the TIN surface using the HEC-GeoRAS ArcGIS extension developed by the USACE (USACE, 2011). A Manning's roughness value of 0.04 was used for the main channel and a value of 0.15 was used for the left and right overbank areas in the HEC-RAS model. Bridge modeling was included in the HEC-RAS model for significant bridge and culvert crossings. The bridge openings were measured by Wheeler with a hand-level and tape during the March 2014 site visit to the downstream floodplain. The bridges or culverts within the reach study that were significantly undersized for routing the dam breach discharges, were not included in the model because these smaller bridges would clog with debris or wash out before the peak discharge reached these smaller bridges and culverts.

The sunny day failure peak breach discharge from Pinon Canon Dam is 16,927 cfs. The sunny day breach inundation limits represent the assumed worst-case scenario for the limits of downstream flooding. The inundation mapping was terminated at approximately 8.2 mile downstream of Pinon Canon Dam because the breach flood wave was less than 5,000 cfs which is the estimated threshold in which no habitable structures are threatened at flows up to 5,000 cfs (USBR, 2009).

BREACH PARAMETERS

The initial reservoir water surface for Pinon Canon Dam was the water surface at the spillway. Other key dam breach parameters used in the dam failure simulation of Pinon Canon Dam are shown in Table A-2.1.

**TABLE A-2.1 - SUMMARY OF BREACH PARAMETERS
PINON CANON DAM EAP**

Input	Sunny Day Dam Failure
Breach Bottom Width (feet)	278
Breach Development Time (hours)	0.75
Breach Side Slopes	0.5
Breach Bottom Elevation	6144
Breach Initiation Water Elevation	6211.0
Dam Crest Elevation	6223.5
Initial Reservoir Water Elevation	6211.0

The breach bottom width of 278 feet was based on an average breach width of 318 feet (4 times the dam height of 79.5 feet) and breach formation side slopes. A sensitivity analysis was performed using a range of reasonable breach parameters to develop the breach bottom width using an erosion rate relationship defined by Von Thun and Gillette (1990) defined as the following:

Erosion Rate (ER) = Average Breach Width / Time of Failure

The range of erosion rates are defined by Von Thun and Gillette between the following:
ER = 200+4*Height (for easily eroded embankments) [468 ft/hr]
ER = 4*Height [318 ft/hr]

The erosion rate used was ER = 318 feet / 0.75hours = 424 ft/hr

This average breach width and failure time seemed realistic, providing a reasonably conservative peak discharge for the inundation mapping.

The dam breach parameters were chosen based on Wheeler's experience with other earth dam breach analyses and a review of several empirical breach relationships (FERC, 1991; MacDonald and Langridge-Monopolis, 1984; Froehlich, 1987; Fread, 1981). As part of the breach parameter selection process, a sensitivity analysis of a range of reasonable breach parameters was conducted and compared against erosion rate equations developed from historic dam failures (Von Thun and Gillette, 1990). This analysis indicated that the parameters listed above are appropriate.

RESULTS OF DAM FAILURE INUNDATION MAPPING

The results of the dam failure inundation analyses are illustrated on the flood inundation mapping of the EAP and summarized in Table A-2.2 and Table A-2.3. The inundation boundaries were developed using the HEC-GeoRAS extension to locate the intersection of the topographic surface and the maximum water surface elevation. The dam failure inundation information provided in this EAP should be used as a guideline of conservatively estimated dam failure flooding conditions. Actual conditions during an emergency at Pinon Canon Dam may vary significantly from this information based on the actual conditions at the time of the emergency.

Flood wave travel times shown on the flood inundation maps and in Table A-2.2 are based on the assumption that Pinon Canon Dam failure begins at time 0:00 (hours: minutes). The flood wave arrival time shown in the inundation summary below represents the approximate time after dam failure when the water surface elevation at each cross-section has risen two feet as a result of the dam-failure flood. The peak flood stage time shown represents the estimated time after Pinon Canon Dam failure that the maximum expected flood depths are reached at each downstream cross-section.

TABLE A-2.2 – SUMMARY OF DOWNSTREAM ROUTING:
SUNNY-DAY-BREACH OF PINON CANON DAM
PINON CANON DAM EAP

Cross Section	Miles Downstream of the dam	Peak Flow (cfs)	Peak Water Surface Elevation (feet)	Peak River Stage (feet)	Flood Wave Arrival Time (hrs:min)	Time to Peak Flood Stage (hrs:min)
Pinon Canon Dam	0.0	16,927	6157	12	0:09	0:24
Willow Street	0.6	16,790	6078	13	0:13	0:26
Prospect Road	0.7	16,639	6054	8	0:15	0:28
Nevada Street	1.0	16,498	6030	10	0:17	0:30
Entrance at Purgatoire River	1.4	16,409	5983	8	0:21	0:32
Linden Ave Bridge	1.7	15,297	5973	8	0:25	0:36
160 Highway Bypass	2.8	6,639	5943	6	0:47	0:54
Railroad Crossing	3.5	5,895	5926	6	1:04	1:32
County Road 75.1	6.0	5,304	5858	4	1:52	2;22
County Road 36	8.2	4,736	5750	5	3:04	3:45

(1) Time t=0:00 starts at the initiation of the Pinon Canon dam break

TABLE A-2.3 – SUMMARY OF KEY ROAD CROSSINGS
SUNNY-DAY-BREACH OF PINON CANON DAM
PINON CANON DAM EAP

Cross Section	Miles Downstream of the dam	Approximate Depth of Water over Road
Willow Street	0.0	13(1)
Prospect Road	0.7	8(1)
Nevada Street	1.0	10(1)
Linden Ave Bridge	1.7	N/A
160 Highway Bridge	2.8	N/A
Railroad Crossing	3.5	N/A
County Road 75.1	6.0	N/A
County Road 36	8.2	N/A

(1) These bridges and culverts were assumed to be clogged for this analysis

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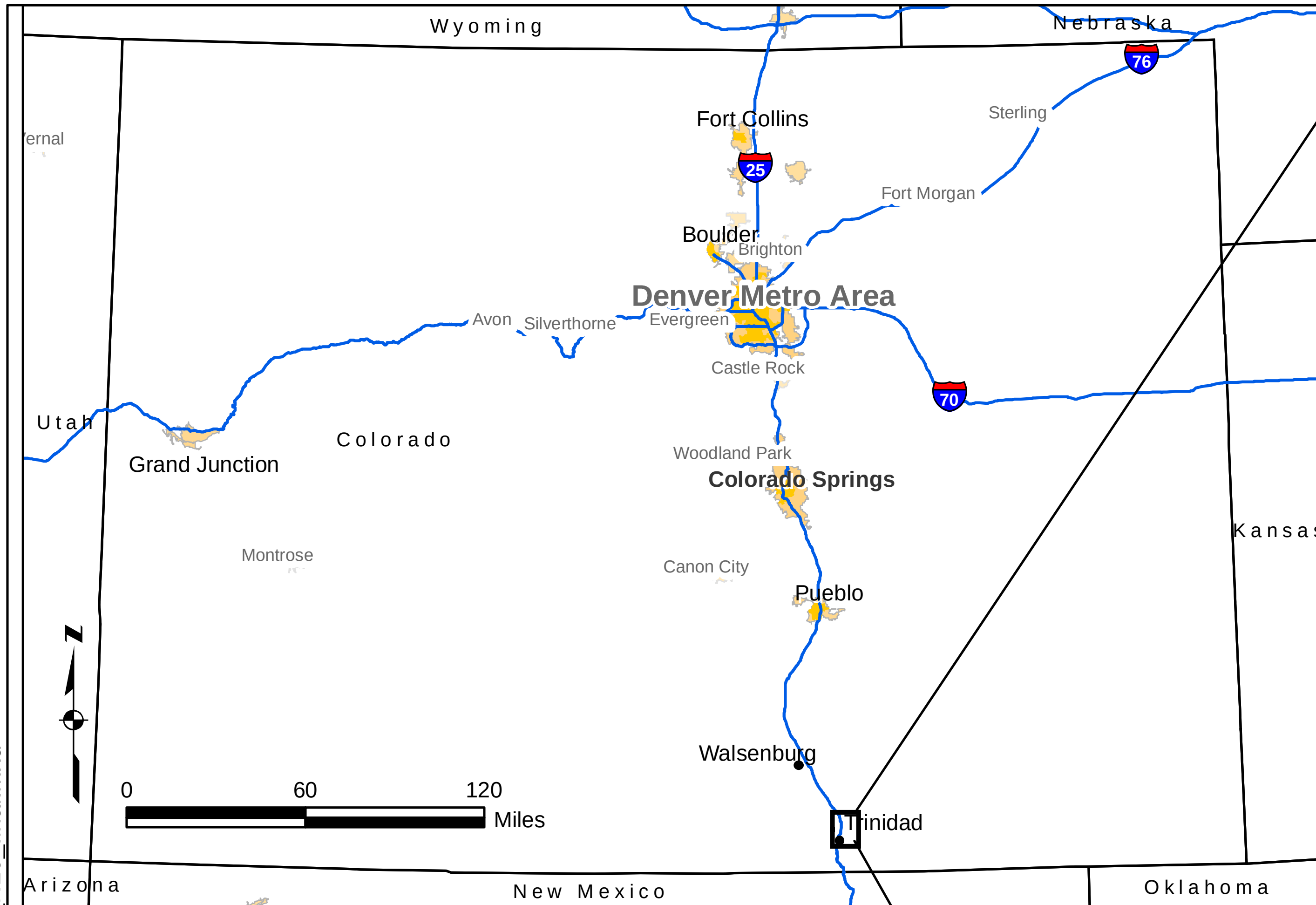
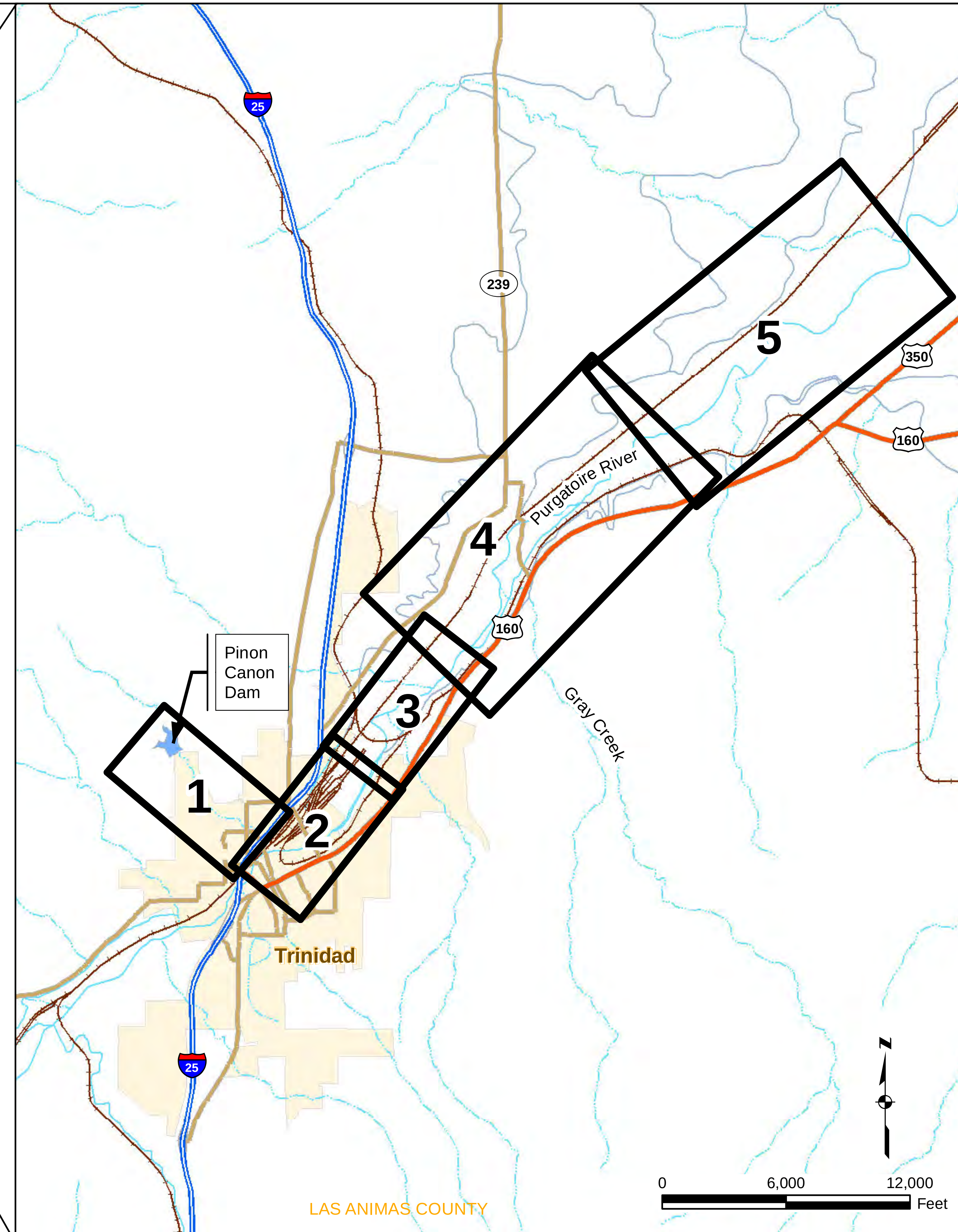


Location Map



Pinon Canon Dam

DAMID 190125

Emergency Action Plan

Dam Failure Flood Inundation Map Index

W. W. WHEELER & ASSOCIATES, INC.
Water Resources Engineers

Project No. 0673.04

June 2014

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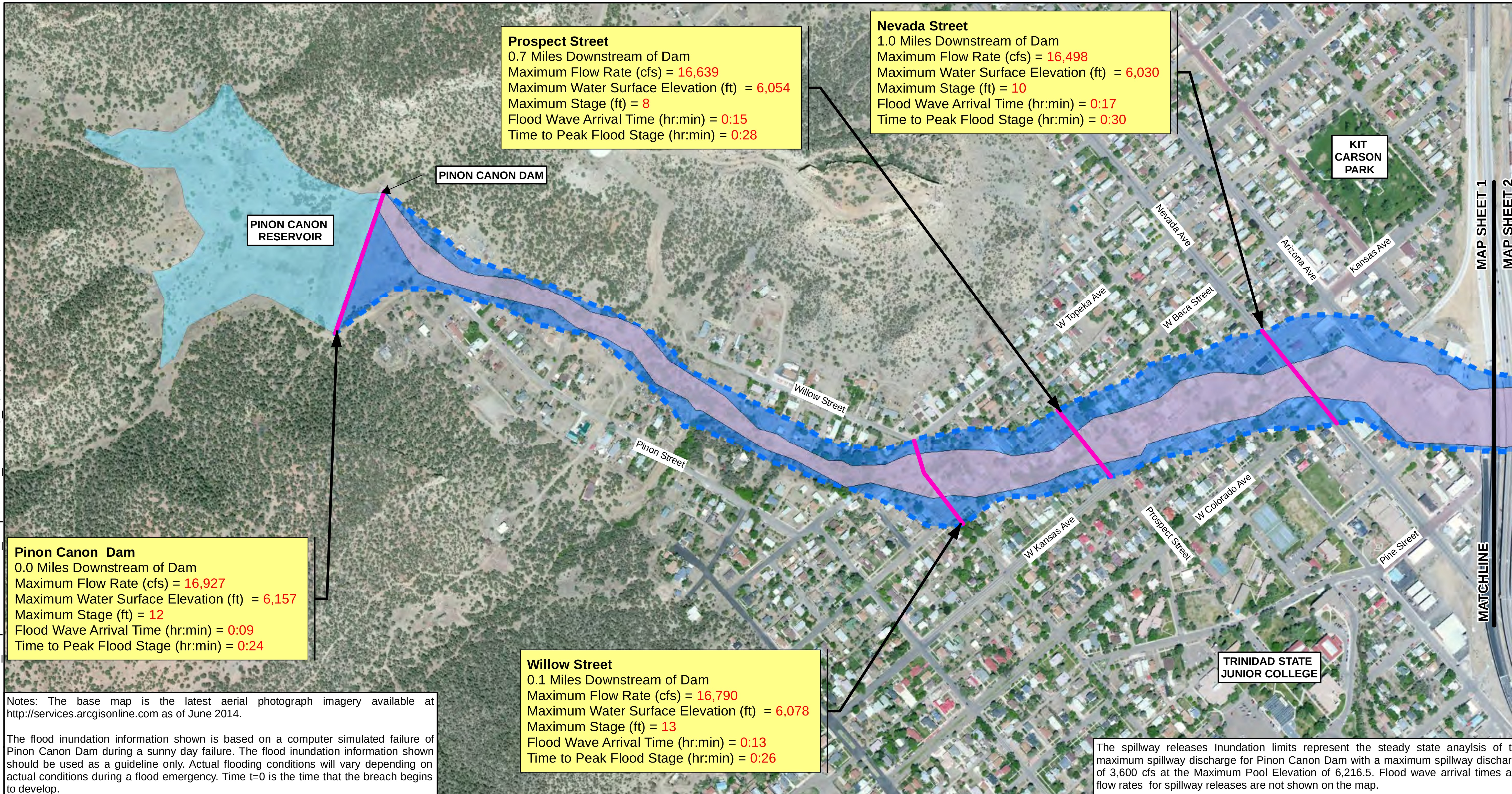


Prospect Street
0.7 Miles Downstream of Dam
Maximum Flow Rate (cfs) = 16,639
Maximum Water Surface Elevation (ft) = 6,054
Maximum Stage (ft) = 8
Flood Wave Arrival Time (hr:min) = 0:15
Time to Peak Flood Stage (hr:min) = 0:28

Nevada Street
1.0 Miles Downstream of Dam
Maximum Flow Rate (cfs) = 16,498
Maximum Water Surface Elevation (ft) = 6,030
Maximum Stage (ft) = 10
Flood Wave Arrival Time (hr:min) = 0:17
Time to Peak Flood Stage (hr:min) = 0:30

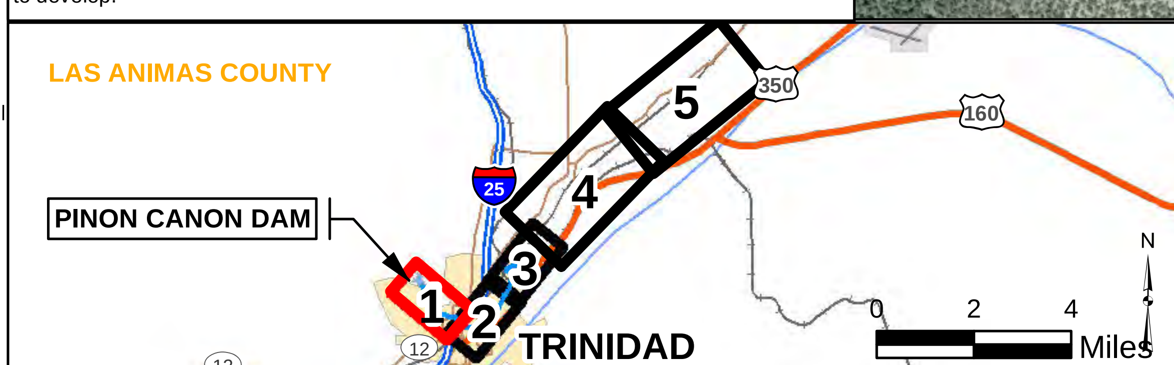
Pinon Canon Dam
0.0 Miles Downstream of Dam
Maximum Flow Rate (cfs) = 16,927
Maximum Water Surface Elevation (ft) = 6,157
Maximum Stage (ft) = 12
Flood Wave Arrival Time (hr:min) = 0:09
Time to Peak Flood Stage (hr:min) = 0:24

Willow Street
0.1 Miles Downstream of Dam
Maximum Flow Rate (cfs) = 16,790
Maximum Water Surface Elevation (ft) = 6,078
Maximum Stage (ft) = 13
Flood Wave Arrival Time (hr:min) = 0:13
Time to Peak Flood Stage (hr:min) = 0:26

Notes: The base map is the latest aerial photograph imagery available at http://services.arcgisonline.com as of June 2014.

The flood inundation information shown is based on a computer simulated failure of Pinon Canon Dam during a sunny day failure. The flood inundation information shown should be used as a guideline only. Actual flooding conditions will vary depending on actual conditions during a flood emergency. Time t=0 is the time that the breach begins to develop.

The spillway releases Inundation limits represent the steady state anaylsis of the maximum spillway discharge for Pinon Canon Dam with a maximum spillway discharge of 3,600 cfs at the Maximum Pool Elevation of 6,216.5. Flood wave arrival times and flow rates for spillway releases are not shown on the map.



Flood Key
Flood Inundation Limits (Sunny Day Breach)
Maximum spillway releases Inundation Limits

0 500 1,000 Feet

June 2014

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PINON CANON DAM
Emergency Action Plan
Dam Failure Flood Inundation Map

DAMID 190125 | MAP SHEET 1

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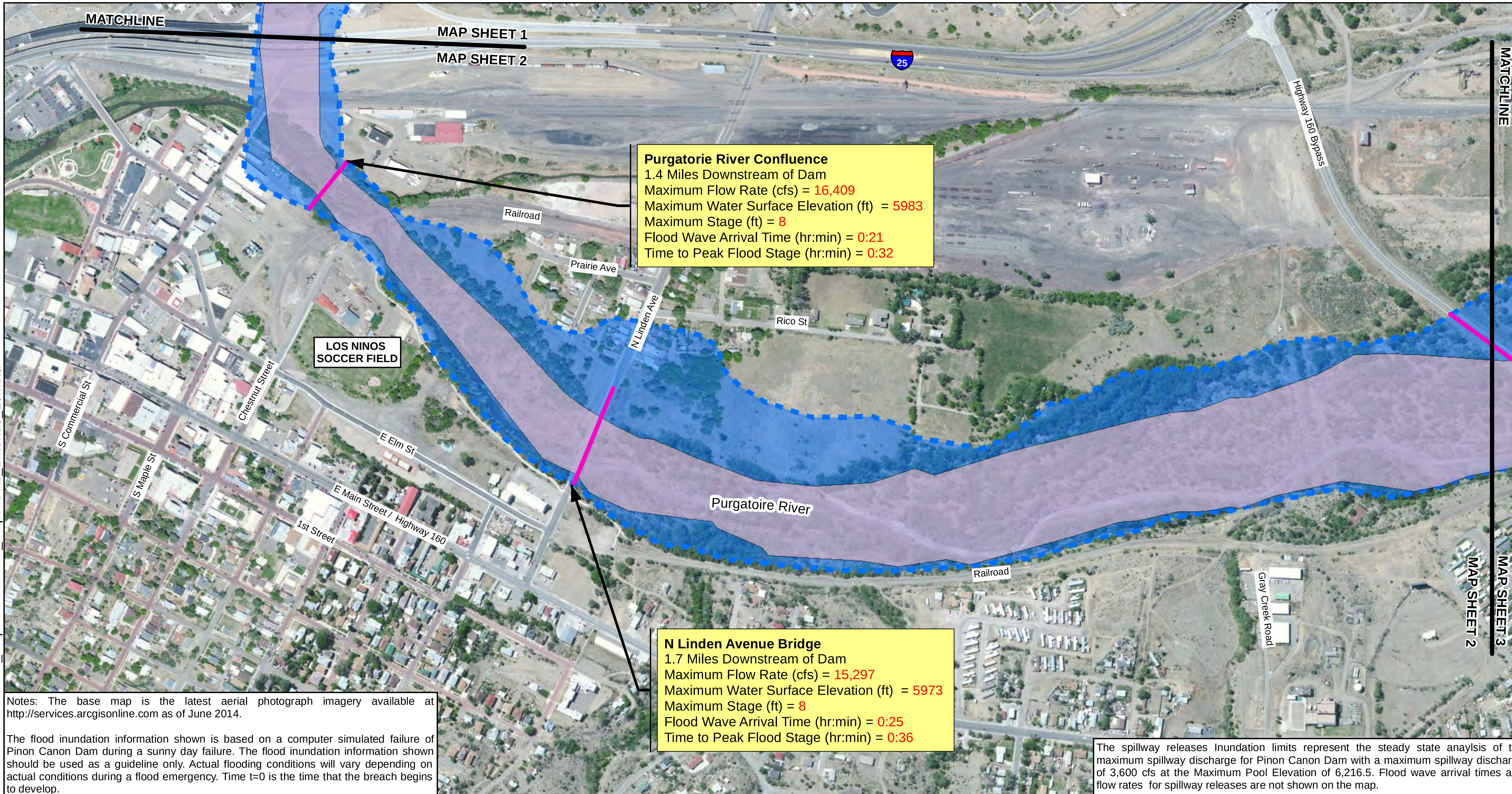

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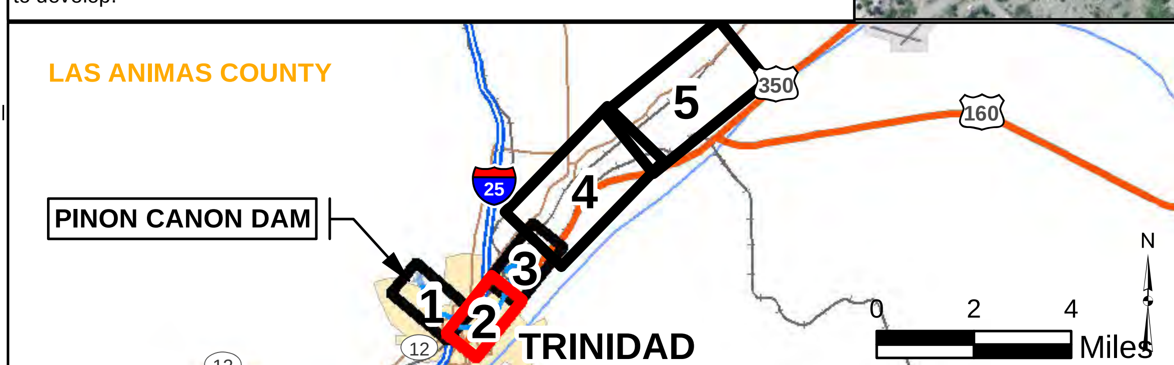

Flood Key

Flood Inundation Limits (Sunny Day Breach)

Maximum spillway releases Inundation Limits

0 500 1,000 Feet

June 2014

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PINON CANON DAM
Emergency Action Plan
Dam Failure Flood Inundation Map

DAMID 190125 | MAP SHEET 2

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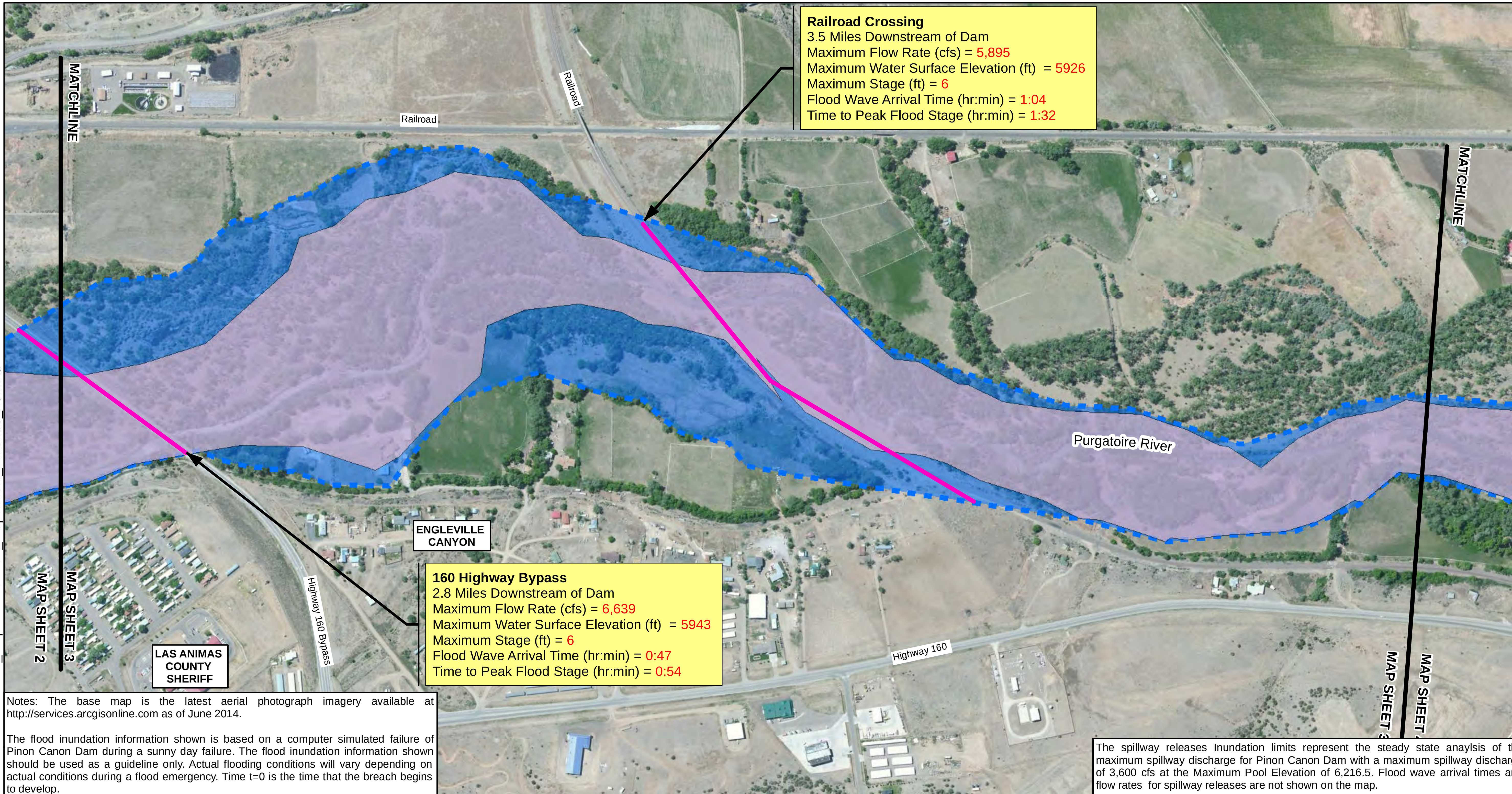

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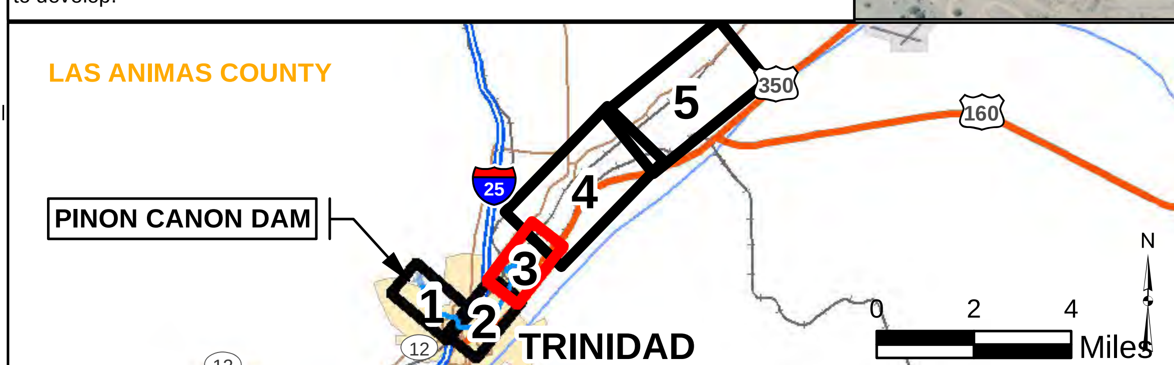

Flood Key

Flood Inundation Limits (Sunny Day Breach)

Maximum spillway releases Inundation Limits

0 500 1,000 Feet

June 2014

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PINON CANON DAM
Emergency Action Plan
Dam Failure Flood Inundation Map

DAMID 190125 | MAP SHEET 3

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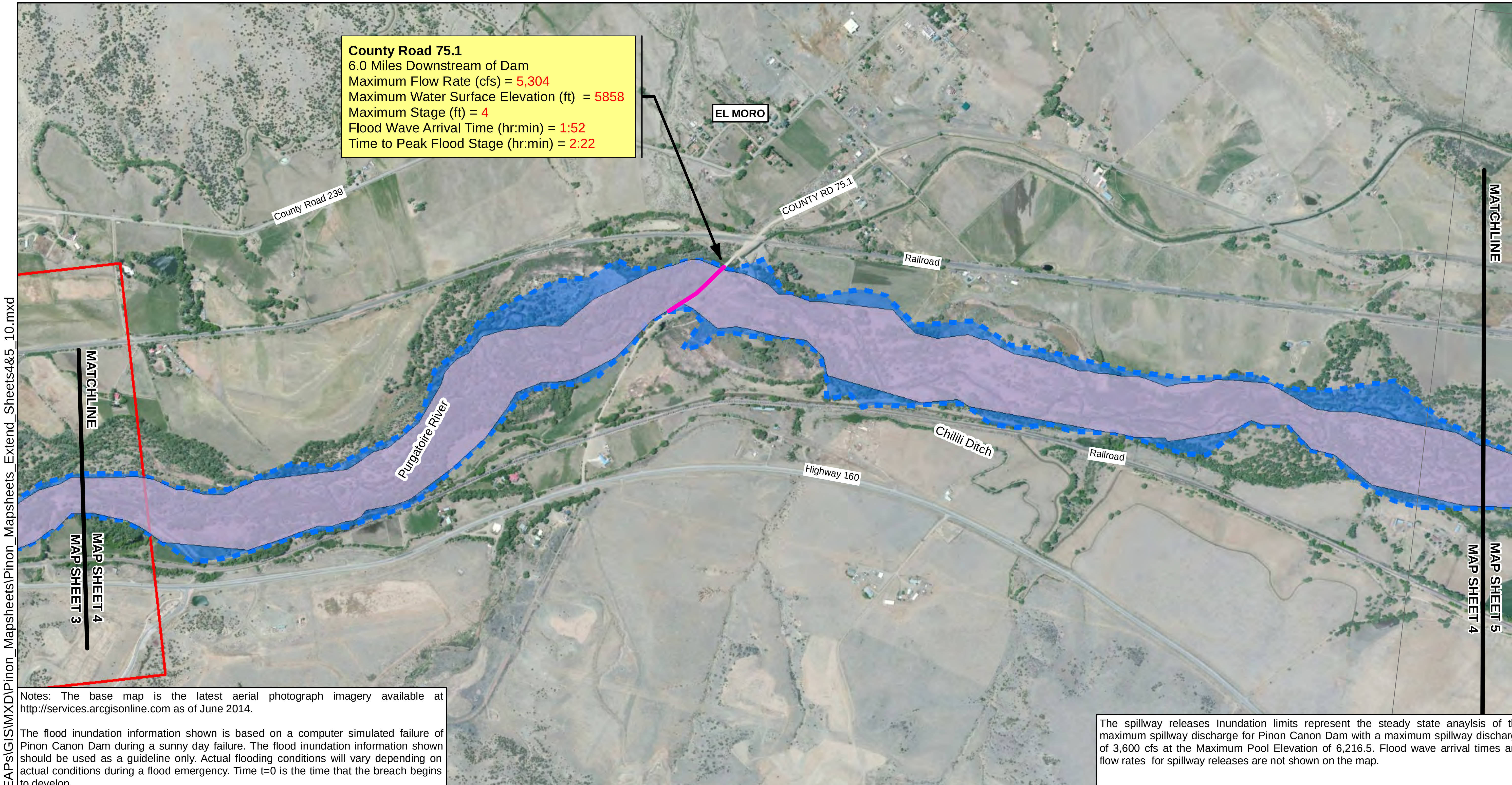

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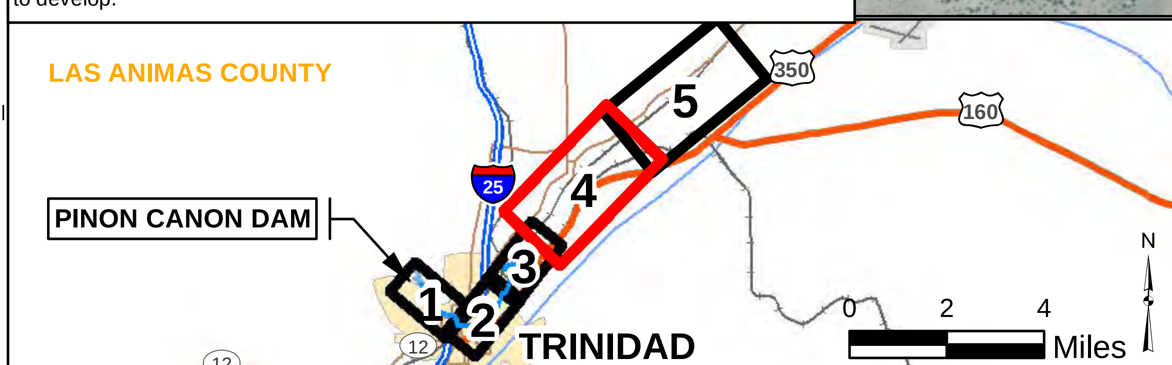

Flood Key

- Flood Inundation Limits (Sunny Day Breach)
- Maximum spillway releases Inundation Limits

0 1,000 2,000 Feet

June 2014

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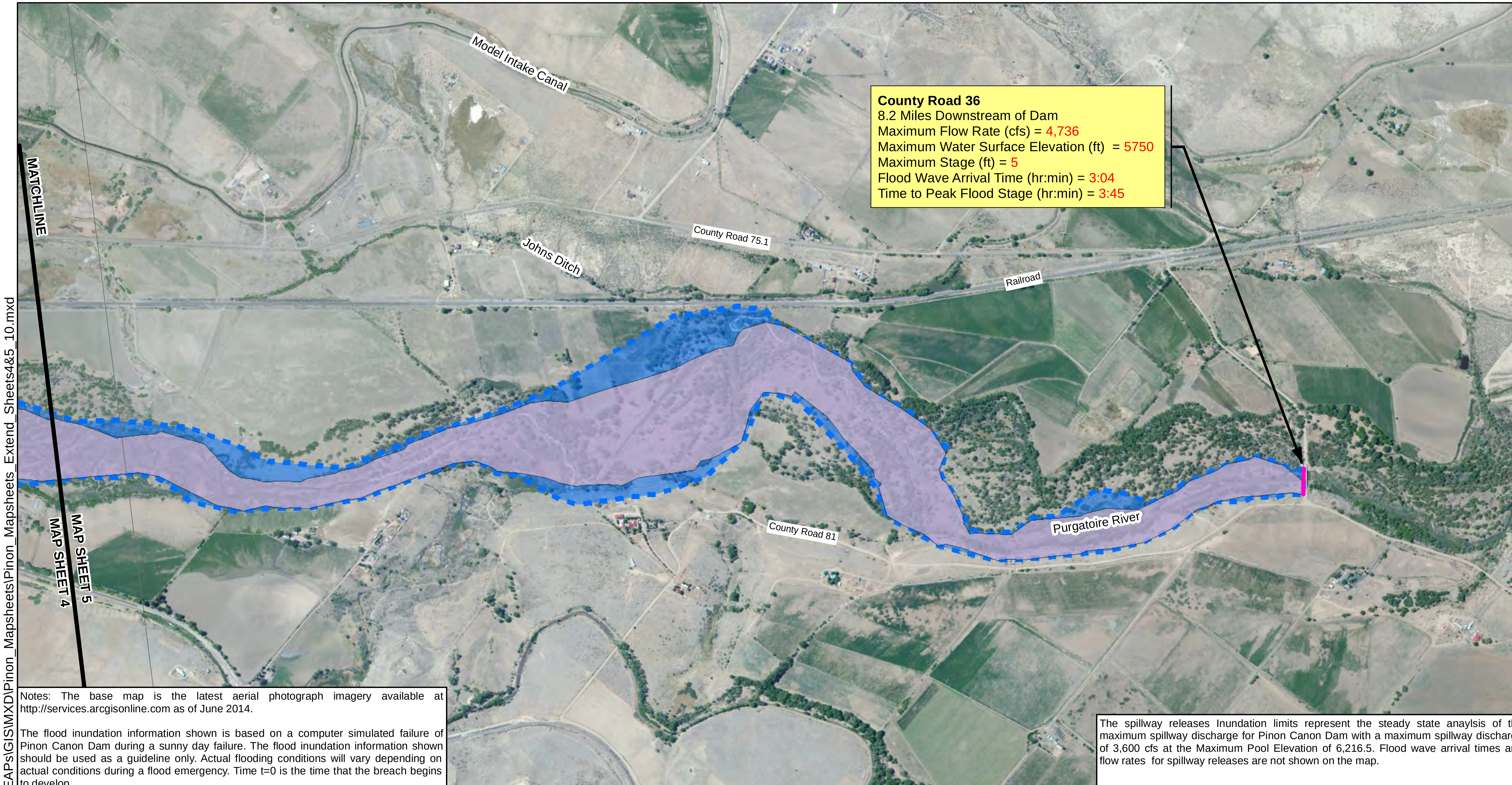
PINON CANON DAM
Emergency Action Plan
Dam Failure Flood Inundation Map

DAMID 190125

MAP SHEET 4



County Road 36
8.2 Miles Downstream of Dam
Maximum Flow Rate (cfs) = 4,736
Maximum Water Surface Elevation (ft) = 5750
Maximum Stage (ft) = 5
Flood Wave Arrival Time (hr:min) = 3:04
Time to Peak Flood Stage (hr:min) = 3:45

Notes: The base map is the latest aerial photograph imagery available at http://services.arcgisonline.com as of June 2014.

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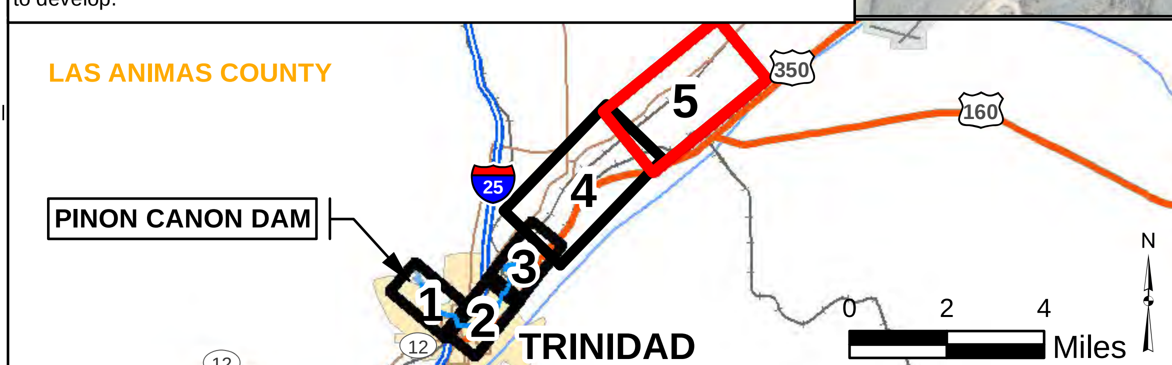

Flood Key

- Flood Inundation Limits (Sunny Day Breach)
- Maximum spillway releases Inundation Limits

0 1,000 2,000 Feet

June 2014

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PINON CANON DAM
Emergency Action Plan
Dam Failure Flood Inundation Map

DAMID 190125 | MAP SHEET 5

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