CARSON RIVER WATERSHED

ALLUVIAL FAN INUNDATION MAPPING

March 2020

FLOODPLAIN MANAGEMENT SERVICES
SPECIAL STUDY

U.S. Army Corps of Engineers District
Walla Walla – Hydraulics Section
In Support of Sacramento District

Carson River Watershed Alluvial Fan Inundation Mapping

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1. **SCOPE**

In 2017 the U.S. Army Corps of Engineers Sacramento District mapped alluvial fans within the Carson River Watershed and assigned a qualitative risk to each fan as an aid to informing floodplain management decisions related to alluvial fans (Floyd et al 2017). The Carson Water Subconservancy District selected a subset of these fans for detailed analysis in the present study. The detailed analysis includes both geological mapping, included in a separate technical memorandum (Hunter and Floyd 2020), and hydraulic flood inundation mapping included in this document. The fans selected for detailed mapping are shown in Figure 1-1.

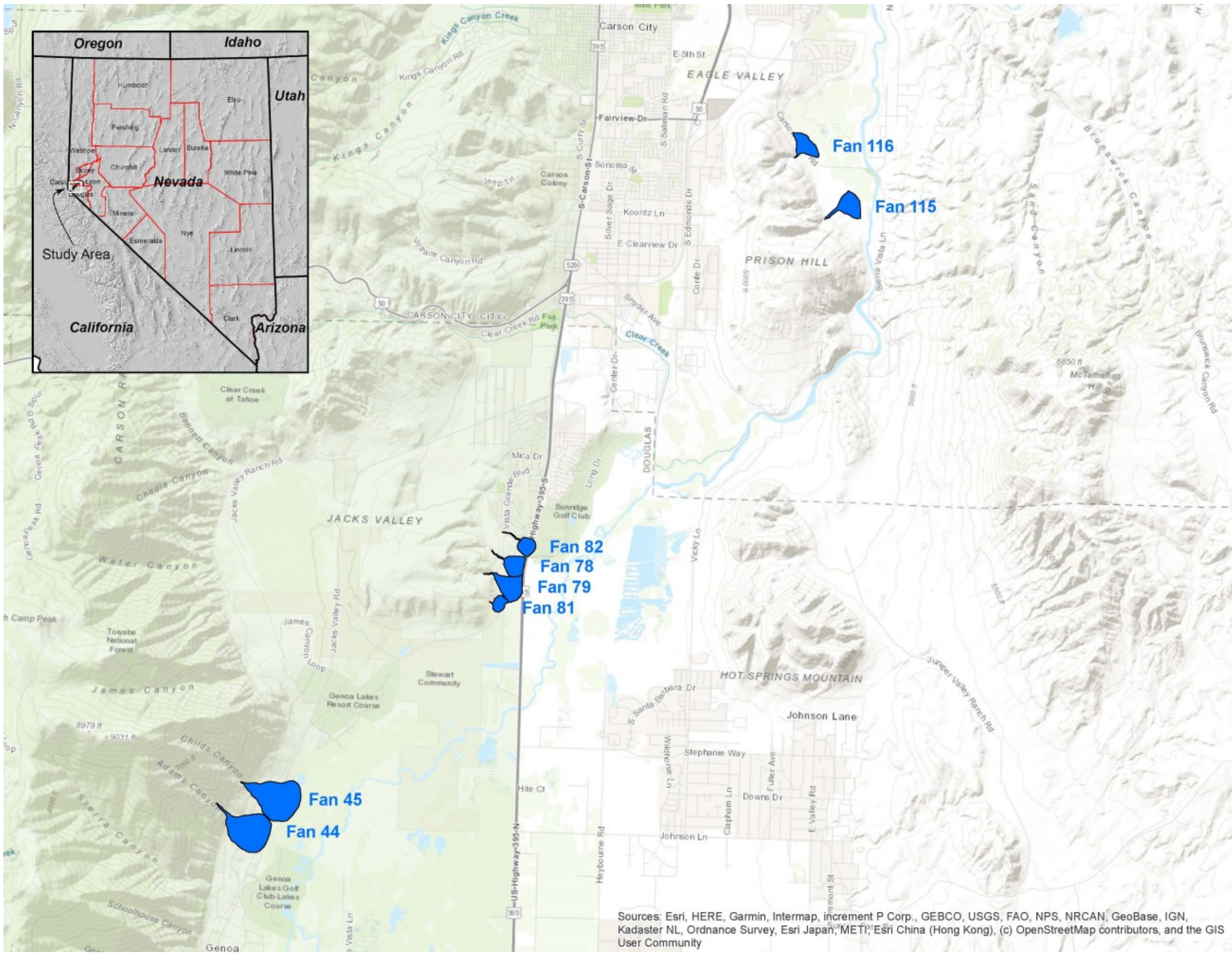


Figure 1-1. Alluvial fan locations

2. METHODOLOGY

The floodplain inundation mapping procedures used in this study generally reflect the 2016 Federal Emergency Management Agency (FEMA) guidance. In all cases, the 1-percent annual chance exceedance flood event (1/100 probability) is modeled. The guidance recommends mapping inactive and active areas of the alluvial fan using separate methodology. FEMA (2016) characterizes active alluvial fans as having "flow path uncertainty so great that this uncertainty cannot be set aside in realistic assessments of flood risk." Flow path uncertainty, due to migration and avulsion, are caused by sediment deposition and erosion, which can occur rapidly. A more detailed discussion about the causes of flow path migration and avulsion is provided in the geological assessment (Hunter and Floyd 2020).

In this study, *active* regions of the alluvial fans are modeled using the FEMA FAN program, which assumes a high level of flow path uncertainty (channel movement). However, active regions are also modeled using the Hydrologic Engineering Center's River Analysis System (HEC-RAS) to provided additional supplemental information that the FEMA FAN program cannot provide.

Inactive portions of the alluvial fan may also be subject to erosion and deposition, but the degree of flow path uncertainty is minimal compared to the active regions. In this study, inactive regions are modeled exclusively using an HEC-RAS 2-dimensional flow hydraulic model, which assumes flow path certainty (static channels).

Both FEMA FAN and HEC-RAS assume that the fluid being modeled is water. As a result, for fans where hyperconcentrated flow or debris flow are likely, additional qualitative assumptions have been made since these programs cannot model this type of flow.

2.1 FEMA FAN PROGRAM

The FEMA FAN program is intended for use on highly active fluvial-dominated (i.e. not debris flow dominated) conical alluvial fans with negligible urbanization. The FAN program relies on simple generic assumptions about alluvial fans. The primary assumption is that flow paths are allowed to move randomly beginning at the hydrologic apex. As a result, this program should only be applied to highly active portions of alluvial fans. While, in reality, flow paths may not be truly random (especially over short time scales), applying this assumption facilitates making conclusions about probability of inundation. Using a fixed relationship between depth and discharge (critical depth in a rectangular channel) the FAN program assumes that along any given contour the probability of inundation over the long term is the same at every location (i.e. random flow paths). Using these assumptions, the FAN program simply solves for the contour length that results in a probability of 1/100 for a given depth. For example, the 1 foot depth zone is the region between the 0.5 ft and 1.5 ft depth contours that result in a probability of 1/100. This procedure requires the program to use a range of flow rates (not just the 1-percent event), which it obtains by fitting user input flow data to a log-Pearson Type III flow frequency curve. This means that the 1-ft depth zone is not the area inundated during a 1-percent chance flood at a depth of 1 ft, but rather the area that has a probability of 1/100 of being inundated at a depth of 1 ft during any given year (or more precisely inundated with a depth between 0.5 ft and 1.5 ft). On the other hand, the depth maps produced by the HEC-RAS model (discussed in section 2.2) are the actual inundation depths that are expected during a 1-percent chance flood, assuming no channel movement. This distinction should be kept in mind when looking at the depth zones in section 3, especially when FAN results are combined with HEC-RAS results. For this study, the flow rates input into the FAN program were developed using WinTR-55, as discussed in section 2.3.

2.2 HEC-RAS TWO-DIMENSIONAL HYDRAULIC MODEL

HEC-RAS is a widely used hydraulic model that is capable of modeling the flow of water. For this study the 2-dimensional flow portion of HEC-RAS version 5.0.7 was used. HEC-RAS has not yet implemented sediment transport or debris flow for 2-dimensional flows (these features are under development). Therefore, this model assumes a static channel or terrain surface that does not erode or account for sediment deposition. HEC-RAS is capable of modeling velocity magnitudes, flow patterns, and flow depths using inflow flood hydrographs or direct rainfall runoff.

Alluvial fans are formed by sediment laden flows. Therefore, sediment is expected to be present during large events. When the minimum volumetric concentration of suspended fines is greater than 3-10% (depending on the grain-size distribution), the flow becomes hyperconcentrated (Pierson, 2005). Pierson also observed that fines-free flow mixtures can have much higher concentrations of sediment without becoming hyperconcentrated. When the flow is hyperconcentrated, the fluid properties, such as viscosity, deviate from the assumed fluid properties embedded in the 2-dimensional HEC-RAS model (version 5.0.7; future versions will have non-Newtonian capabilities). HEC-RAS is therefore not ideal for modeling 2-dimensional hyperconcentrated flows.

A bulking factor is sometimes applied to hydraulic models to account for additional flow volume due the presence of sediment. If the flow becomes hyperconcentrated when suspended fines exceed concentrations of 3-10%, then a bulking factor of more than 1.1 could imply hyperconcentrated flows and the model would not accurately represent the fluid motion. However, the sediment in this region is likely to be dominated by sand, which according to Pierson (2005) does not affect the fluid properties until it exceeds about 35% volumetric concentration. For this reason, a maximum bulking factor of 1.35 is used in this study. However, it should be noted that the presence of sand would also increase the Manning's n roughness, but adjustments were not made to n values since the model has not been calibrated to known depths.

Since the HEC-RAS model used in this study assumes a static terrain, the FEMA FAN program (section 2.1) was applied to active areas of the alluvial fan where flow path movement is likely. Unfortunately, neither the FEMA FAN program nor HEC-RAS are capable of modeling hyperconcentrated flow accurately. Flows with even higher sediment concentrations, such as debris flow or mud flow should not be modeled using the current versions of these programs, nor are the probabilities of such events easily identified. In cases where significant sediment concentrations are expected, qualitative assessments are made in this study.

Following is a list of key modeling parameters used in this study:

- Terrain resolution: ~ 1 ft for Indian Hills and ~1.9 ft for Prison Hill, derived from 2017 LIDAR point cloud discussed in the geology assessment (Hunter and Floyd 2020); note that buildings had been removed from the terrain.
- Model cell size: 4'x4' within the fan boundaries (may be larger beyond those extents)
- Manning's roughness n values vary by location (0.016 to 0.062)
- Inflow: 1-percent chance flood event hydrographs (see section 2.3) and direct rainfall
- Outflow boundary conditions: normal depth based on terrain slope
- Time step: adaptive, based on Courant number
- Computational equations: Full momentum (2-D Saint-Venant equations)
- All known culverts were modeled. Invert elevations were measured in the field relative to terrain surfaces, but were not surveyed (except for fans 44 and 45, which used design plan invert elevations). The depth of sediment in the culverts was based on observed depths at the time of modeling.
- Vertical Datum: NAVD88 feet; early hydrology work was completed in meters, prior to a requested change in the coordinate system
- Horizontal datum: NAD_1983_2011_StatePlane_Nevada_West_FIPS_2703_Ft_US; early hydrology work used NAD_1983_UTM_Zone_11N and LIDAR data were converted from this coordinate system into the state plan system cited above

Fans 44 and 45 were added to the study after the other fans had already been modeled. Low density sediment gravity flows (e.g., sandy mudflows and debris flows) are possible on these fans (see Hunter and Floyd 2020). HEC-RAS is not an appropriate model for this type of flow. For this reason a single HEC-RAS run was completed for these fans with a 1.35 sediment bulking factor, acknowledging that significantly more sediment is possible and could increase or alter the inundated foot print and increase the risk. Given the potential uncertainty, the single model run provided sufficient information to draw conclusions about the inundated area, making direct rainfall and blocked culverts alternatives unnecessary for fans 44 and 45.

2.3 HYDROLOGY

Gage data and water surface elevations of historic events were not available for any of the alluvial fans. As a result, an uncalibrated hydrologic model was utilized. The NRCS's (Natural Resources Conservation Service) WinTR-55 program was selected. This program uses the Curve Number Method (described in NEH-630 Ch. 9 and 10) to determine the amount of rainfall that runs off the watershed; the remaining rainfall is intercepted by plants, infiltrated into the ground, or stored in depressions. This method assumes that the ground is not frozen. The rainfall runoff is converted to a runoff hydrograph using the NRCS's dimensionless unit hydrograph and discrete convolution.

The watersheds studied are subject to both rainfall and snowmelt. For most events rainfall runoff is likely the dominant contributor to runoff, which justifies neglecting snowmelt. However, the watersheds draining to fans 44 and 45 originate at much higher elevations that would be associated with deeper snowpack. The uncertainty induced by sediment loads in fans 44 and 45 was assumed to be greater than the uncertainty in snowmelt contributions. As a result, snowmelt was neglected for all watersheds in this study.

The curve numbers were calculated in ArcGIS using hydrologic soil group and land use maps, with weighted areas. The percentage of ground cover was also calculated to determine the appropriate hydrologic condition. Table 2-1 shows the curve numbers for each watershed, alluvial fan, and rainfall area with runoff.

Table 2-1.

Location	Curve Number
Watershed 44	86
Watershed 45	86
Watershed 78	78
Watershed 79	82
Watershed 81	76
Watershed 82	81
Watershed 115	85
Watershed 116	86
78/82 rain area	73
79/78 rain area	75
81/79 rain area	76
Fan 115	72
Fan 116	75

Watershed boundaries were delineated in ArcGIS using the TauDEM toolbox. Watershed runoff was input as an inflow into the HEC-RAS models upstream of the hydrographic apex. In addition, direct rainfall was applied to alluvial fans 115 and 116 and to the rainfall areas in Table 2-1. Figure 2-1 shows the Indian Hills HEC-RAS region that did not have rainfall applied. This area had a composite curve number of 62, which would have resulted in relatively minor runoff (the majority infiltrating into the ground), but would have increased model runtime significantly due to small cell sizes.

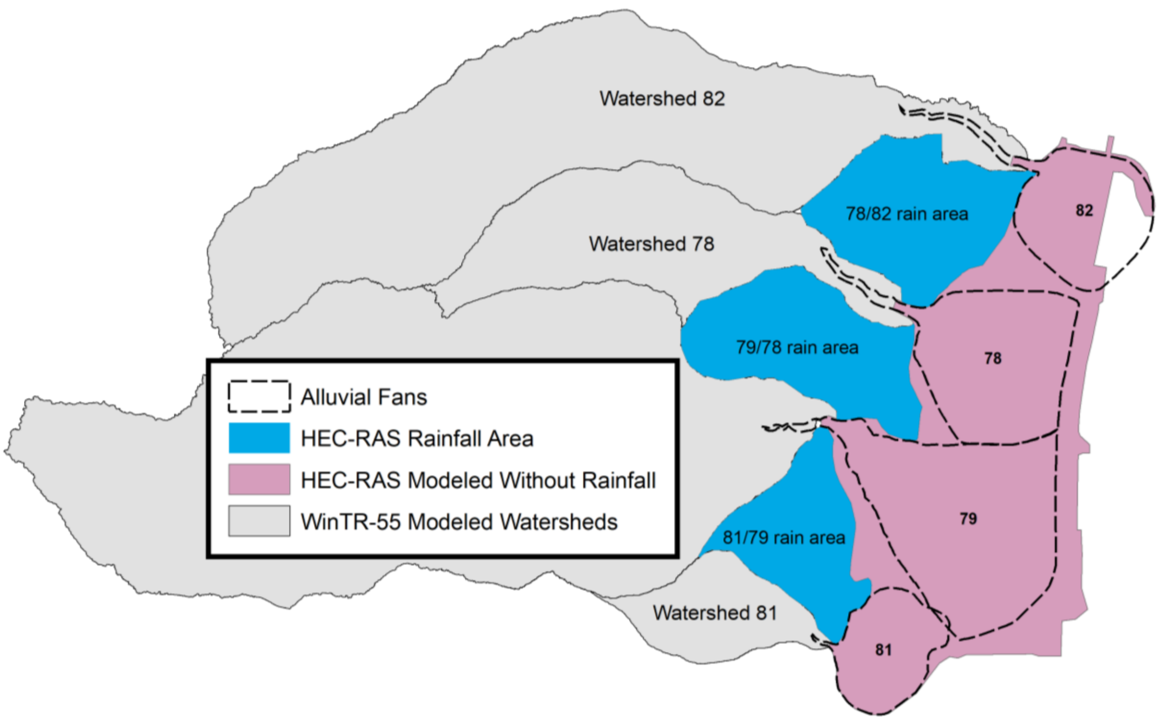


Figure 2-1. Indian Hills modeled areas

The Nevada West rainfall distribution was used in conjunction with the NOAA Atlas 14 gridded precipitation to create the 1-percent rainfall event. Partial duration series precipitation-frequency were used rather than annual duration to be consistent with what has historically been the practice of the NRCS (NEH-630 Ch. 4). The rainfall distribution was applied in WinTR-55 to generate runoff hydrographs.

For watershed 115 rainfall runoff was also applied to a separate HEC-RAS model of the watershed, which produced a hydrograph very similar to the WinTR-55 hydrograph, when calibrating to the WinTR-55 peak flow, demonstrating that the WinTR-55 methodology generates hydrograph shapes that are appropriate for these watersheds. The Manning's n value and cell size used in the watershed 115 HEC-RAS model were applied to the rainfall areas in Figure 2-1 to approximate runoff from those areas. Accuracy was not as important for the rainfall areas since the overall contribution to runoff was small compared to the watershed hydrographs.

The FEMA FAN program requires peak runoff for multiple recurrence intervals. The 24-hr rainfall in inches, along with the resulting peak runoff in cubic feet per second (cfs), are shown in Table 2-2.

Table 2-2. Precipitation and peak flow by annual exceedance probability, percent

	50%	**10%**	**4%**	**2%**	**1%**	50%	10%	4%	2%	1%
	24-hr Precipitation (in)					**Peak Flow (cfs)**				
Watershed 44	2.30	3.35	4.00	4.52	5.06	268	488	630	743	861
Watershed 45	2.17	3.16	3.77	4.26	4.76	239	444	576	679	790
Watershed 78	1.44	2.10	2.50	2.82	3.15	11	29	43	54	66
Watershed 79	1.45	2.10	2.51	2.82	3.15	47	124	179	224	274
Watershed 81	1.41	2.04	2.43	2.74	3.06	2	9	15	20	25
Watershed 82	1.46	2.12	2.53	2.85	3.18	21	59	86	108	132
Watershed 115	1.48	2.18	2.61	2.95	3.30	68	145	197	239	284
Watershed 116	1.45	2.13	2.55	2.88	3.22	51	108	147	179	212

HEC-RAS, on the other hand, requires a runoff hydrograph. The runoff hydrographs are plotted in Figure 2-2. The rainfall distributions were generated such that the rainfall probability is 1/100 for any duration between 5 min and 24 hrs (NEH-630 ch4). The time of concentration was computed using the SCS lag method. This method was selected because it compared favorably with the time of concentration computed using the full 2-dimensional HEC-RAS rainfall runoff model of watershed 115, which was representative of other watersheds in the study.

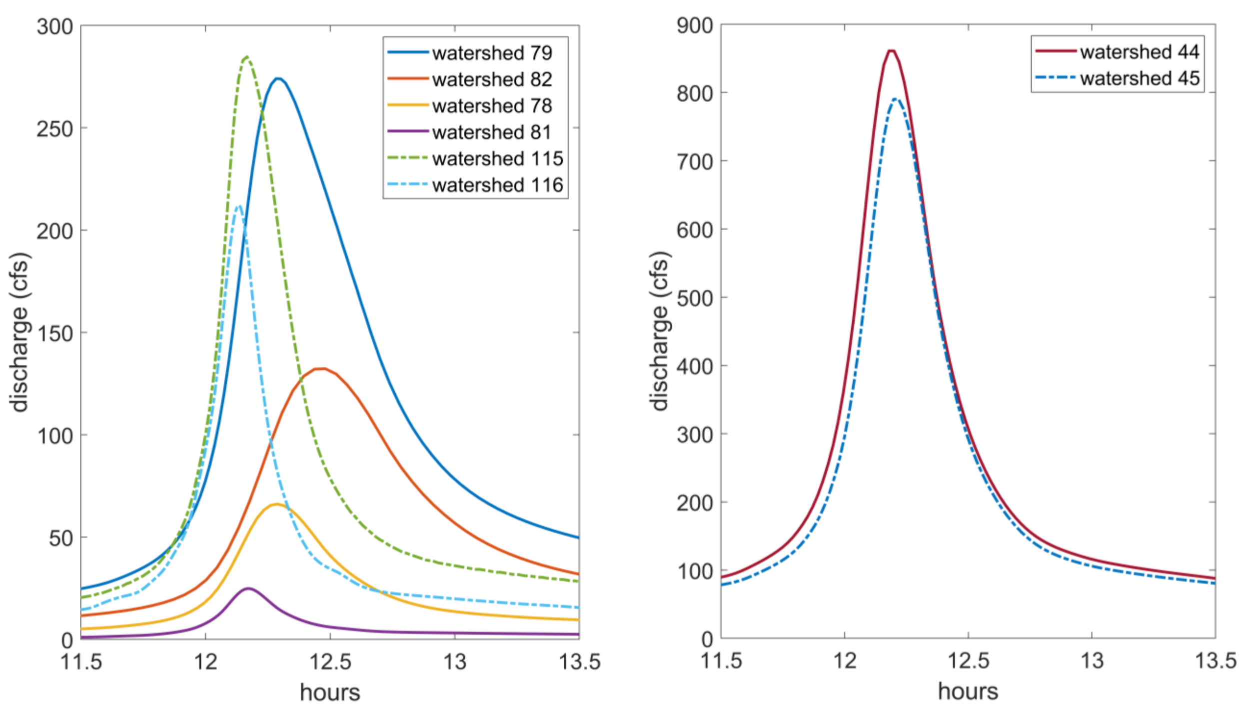


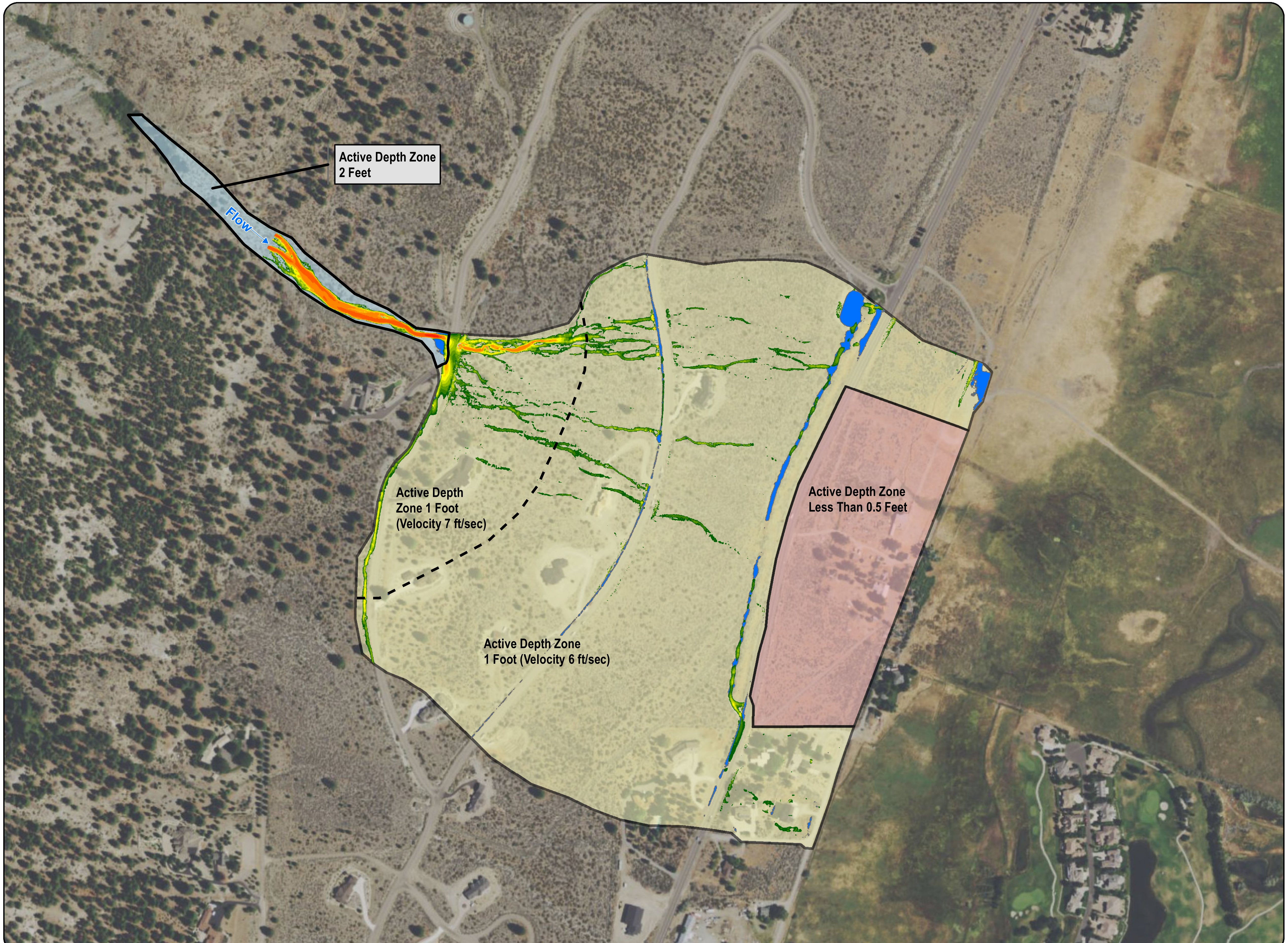
Figure 2-2. Runoff hydrographs

3. **INUNDATION MAPPING**

This inundation mapping section is divided into two parts: 3.1 Inundation Maps, and 3.2 HEC-RAS Model Output. Section 3.1 provides inundation maps that are similar to what one might expect from a FEMA study. Section 3.2 shows maps that have been output directly from the model to provide a broader picture of the modeling outcomes.

3.1 INUNDATION MAPS

FEMA (2016) recommends that the entire surface of an alluvial fan typically be designated at a minimum Zone X, for both active and inactive areas. However, the maps in this study only show Zone X (depth zones with shallow flow less than 0.5 ft) for areas of the alluvial fan that are either active or would be inundated without channel movement. All areas designated with a depth zone were either determined using the FEMA FAN program or by qualitative assessment of potential channel movement based on the HEC-RAS model results. When comparing depth zones to actual modeled depths, one must keep in mind that the FAN program is mapping the area that has a probability of 1/100 of being inundated, while the HEC-RAS model is mapping the inundated depth during a 1/100 probability event. Furthermore, the FAN program assumes that the flow is concentrated, which would be analogous to a portion of the flow path being blocked by sediment, forcing the majority of the flow in one direction. While this may be a conservative assumption in many locations, it will result in artificially lower depths (non-conservative) in areas where there are existing channels. For this reason, existing channels exceeding the specified depths are shown on the maps. Flow depths shown outside of the depth zones were generated strictly from the 2-dimensional HEC-RAS model. Depths less than 0.1 ft are not shown. Each inundation map is labeled by site number below (44, 45, 78, 79, 81, 82, 115, and 116).



Legend

Velocity Greater Than 6.5 Ft/Sec

- 6.5 - 7.5
- 7.5 - 8.5
- 8.5 - 9.5
- 9.5 - 10.5
- 10.5 - 11.5
- 11.5 - 12.5
- 12.5 - 13.5
- 13.5 - 15.5
- 15.5 - 20.5
- 20.5 - 30.5
- 30.5 - 40.62

Active Fan Depths (Feet)

- 1 Foot Zone
- 2 Foot Zone
- Less Than 0.5 Feet Zone
- Greater Than 1.5 Feet

- Velocity Zone Change
- Flow Direction

Notes:

Warning: Debris or mud flows are possible on this alluvial fan, which could result in much deeper flows than represented on this map.

Areas beyond the boundaries of the alluvial fan may also be subject to flooding, but are not shown in this map.

Carson River Watershed

Vicinity of Carson City, Nevada

Alluvial Fan Site 44

N

1 in = 0.08 miles

330 0 330 Feet

Meters 30 0 30

DATE	3/19/2020
DESIGNED	John Newton
DRAWN	Gary Slack
CHECKED	Tracy Schwarz

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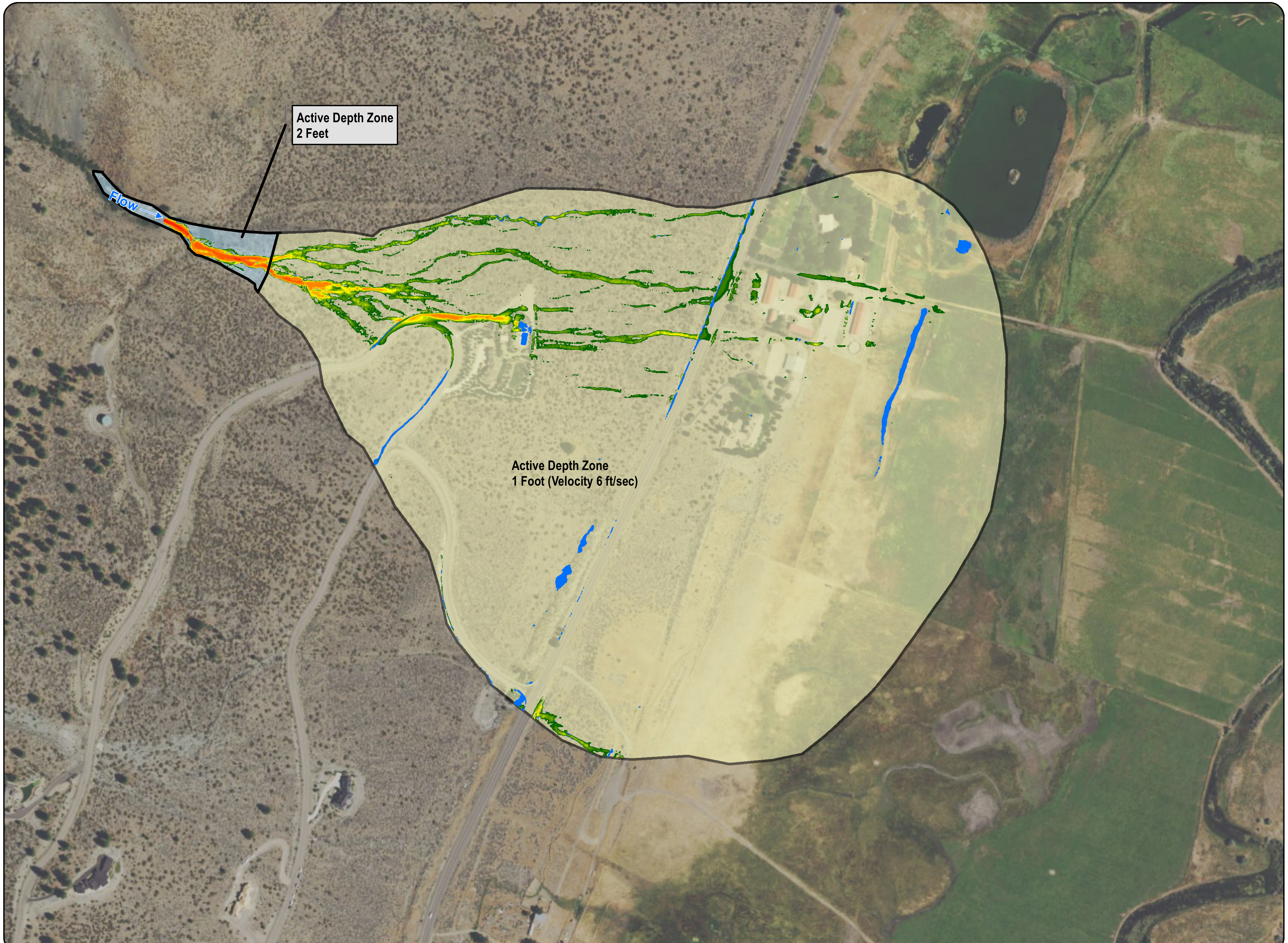
Northwest Division
Walla Walla District



Legend

Velocity Greater Than 6.5 Ft/Sec

- 6.5 - 7.5
- 7.5 - 8.5
- 8.5 - 9.5
- 9.5 - 10.5
- 10.5 - 11.5
- 11.5 - 12.5
- 12.5 - 13.5
- 13.5 - 15.5
- 15.5 - 20.5
- 20.5 - 26.5
- 26.5 - 33.91

Active Fan Depths (Feet)

- 1 Foot Zone
- 2 Foot Zone
- Greater then 1.5 Feet
- Flow Direction

Notes:

Warning: Debris or mud flows are possible on this alluvial fan, which could result in much deeper flows than represented on this map.

Areas beyond the boundaries of the alluvial fan may also be subject to flooding, but are not shown in this map.

Carson River Watershed

Vicinity of Carson City, Nevada

Alluvial Fan Site 45

N

1 in = 0.08 miles

330 0 330 Feet

30 0 30 Meters

DATE	3/19/2020
DESIGNED	John Newton
DRAWN	Gary Slack
CHECKED	Tracy Schwarz

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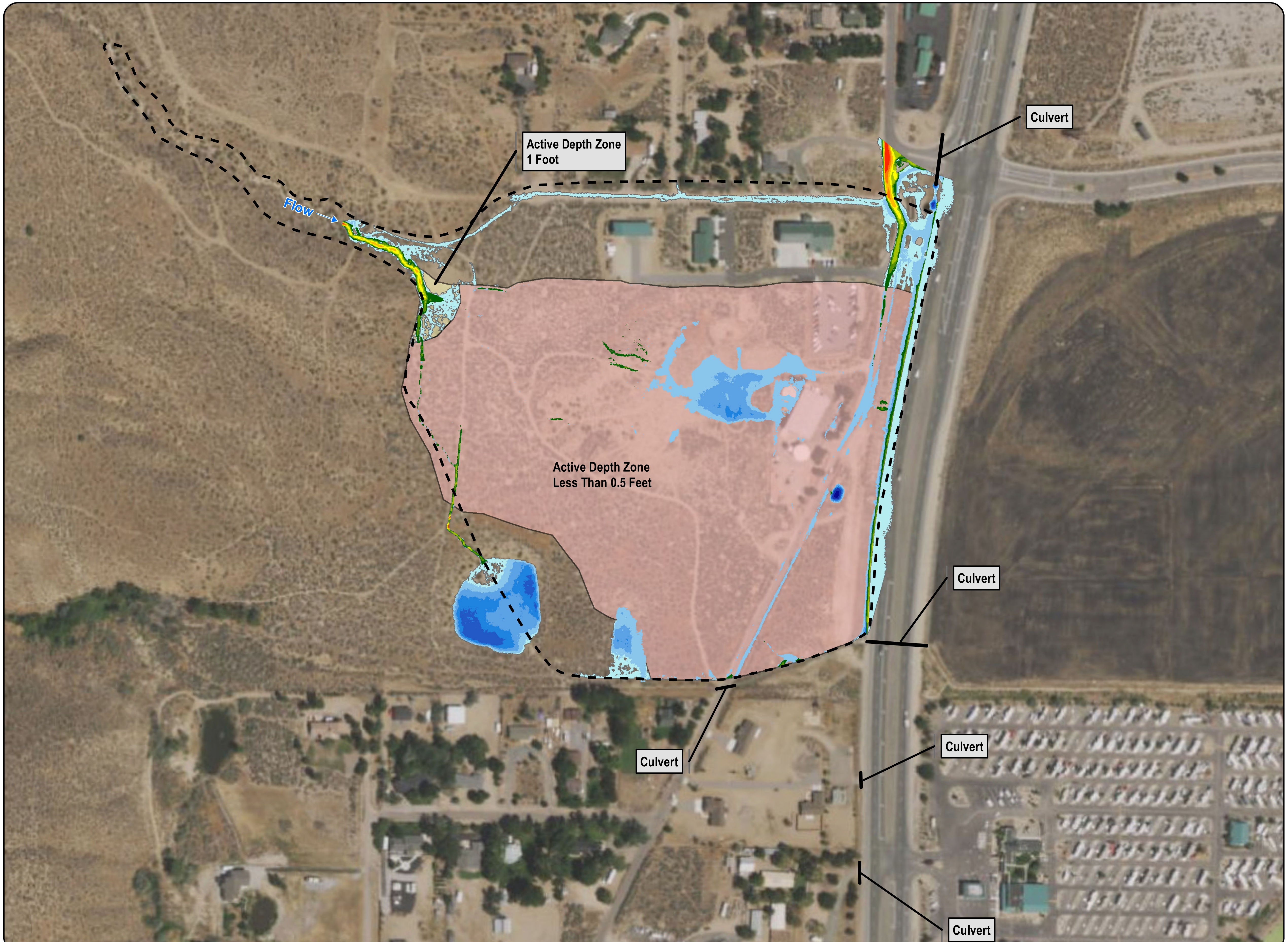
Northwest Division
Walla Walla District



Legend

Velocity Greater Than 3.5 Ft/Sec

- 3.5 - 4.5
- 4.5 - 5.5
- 5.5 - 6.5
- 6.5 - 7.5
- 7.5 - 8.5
- 8.5 - 9.5
- 9.5 - 10.82

Depth (Feet)

- 0.5 - 1.5
- 1.5 - 2.5
- 2.5 - 3.5
- 3.5 - 4.5
- 4.5 - 5.5
- 5.5 - 6.25

Inactive Fan Depths (Feet)

- 0.1 - 0.5

Active Fan Depths (Feet)

- 1 Foot Zone
- Less Than 0.5 Feet Zone

- Alluvial Fan Boundary
- Flow Direction

Carson River Watershed

Vicinity of Carson City, Nevada

Alluvial Fan Site 78

N

1 in = 0.05 miles

190 0 190 Feet

10 0 10 Meters

DATE	3/20/2020
DESIGNED	John Newton
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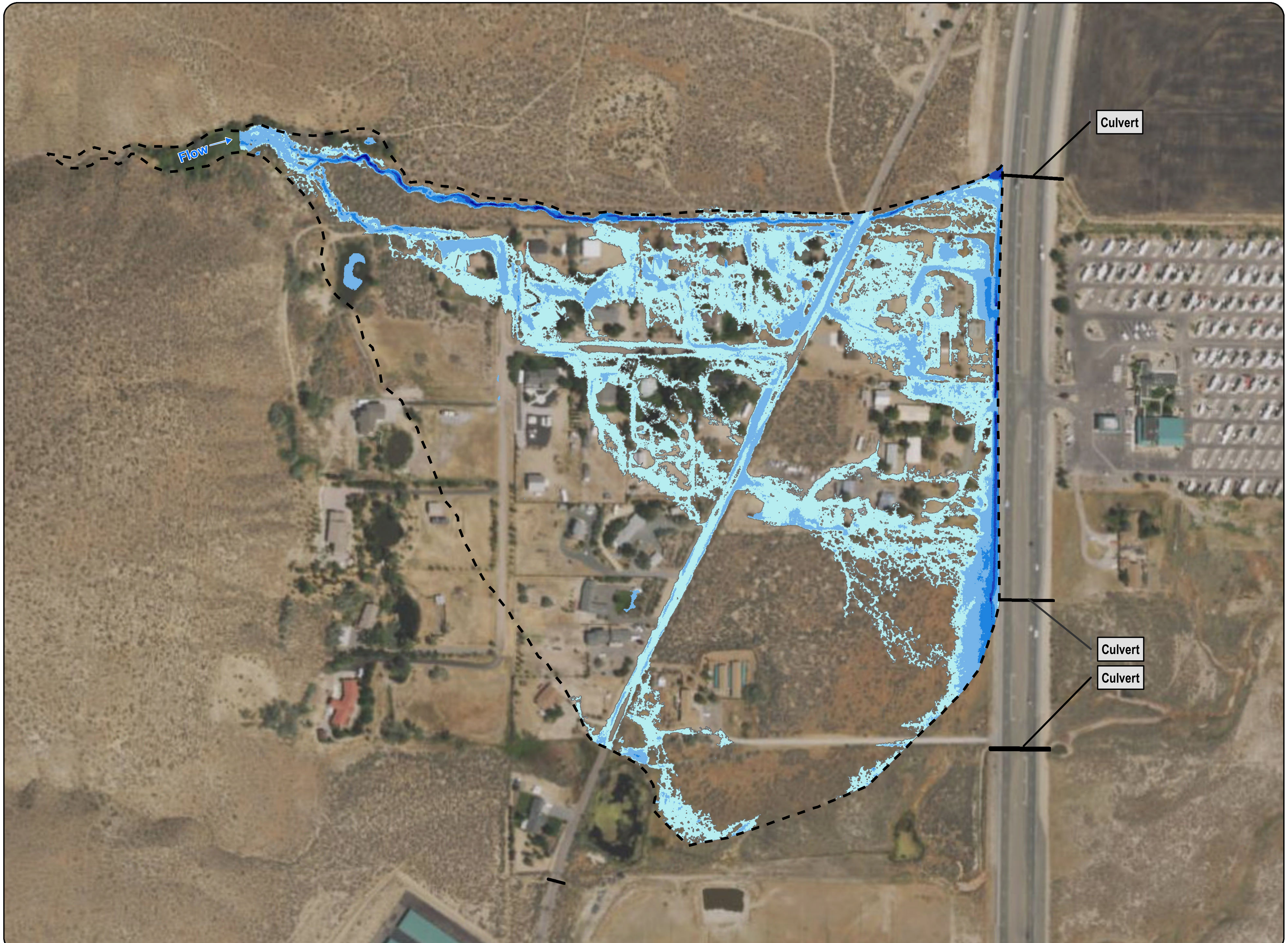
Walla Walla District



Legend

Inactive Fan Depth (Feet)

- 0.1 - 0.5
- 0.5 - 1.5
- 1.5 - 2.5
- 2.5 - 3.5
- 3.5 - 4.68

- Alluvial Fan Boundary
- Flow Direction

Notes:

Main channel velocity can exceed 12 ft/sec. Velocity is typically less than 2.5 ft/sec elsewhere, except for small isolated areas and roadside drainage, which can exceed 4.5 ft/sec.

There are no active fan areas.

Carson River Watershed

Vicinity of Carson City, Nevada

Alluvial Fan Site 79

N

1 in = 0.05 miles

190 0 190 Feet

10 0 10 Meters

DATE	3/19/2020
DESIGNED	John Newton
DRAWN	Gary Slack
CHECKED	Tracy Schwarz

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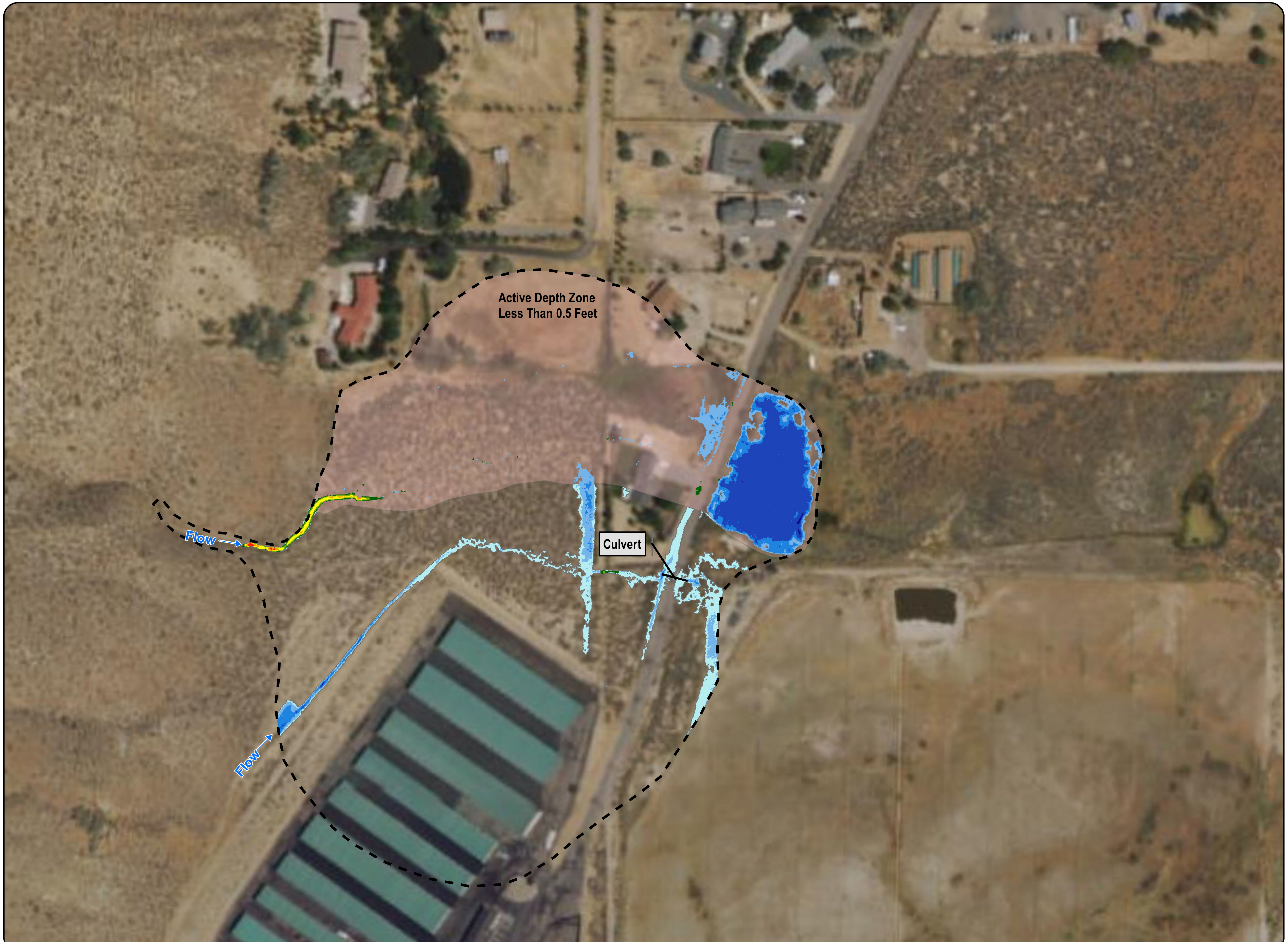
Northwest Division
Walla Walla District



Legend

Velocity Greater Than 3.5 Ft/Sec

- 3.5 - 4.5
- 4.5 - 5.5
- 5.5 - 6.5
- 6.5 - 7.5
- 7.5 - 8.82

Inactive Fan Depths (Feet)

- 0.1 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 2.56

Active Fan Depths (Feet)

- Less Than 0.5 Feet Zone

- Alluvial Fan Boundary
- Flow Direction

Carson River Watershed

Vicinity of Carson City, Nevada

Alluvial Fan Site 81

N

1 in = 0.03 miles

130 0 130 Feet

10 0 10 Meters

DATE	3/19/2020
DESIGNED	John Newton
DRAWN	Gary Slack
CHECKED	Tracy Schwarz

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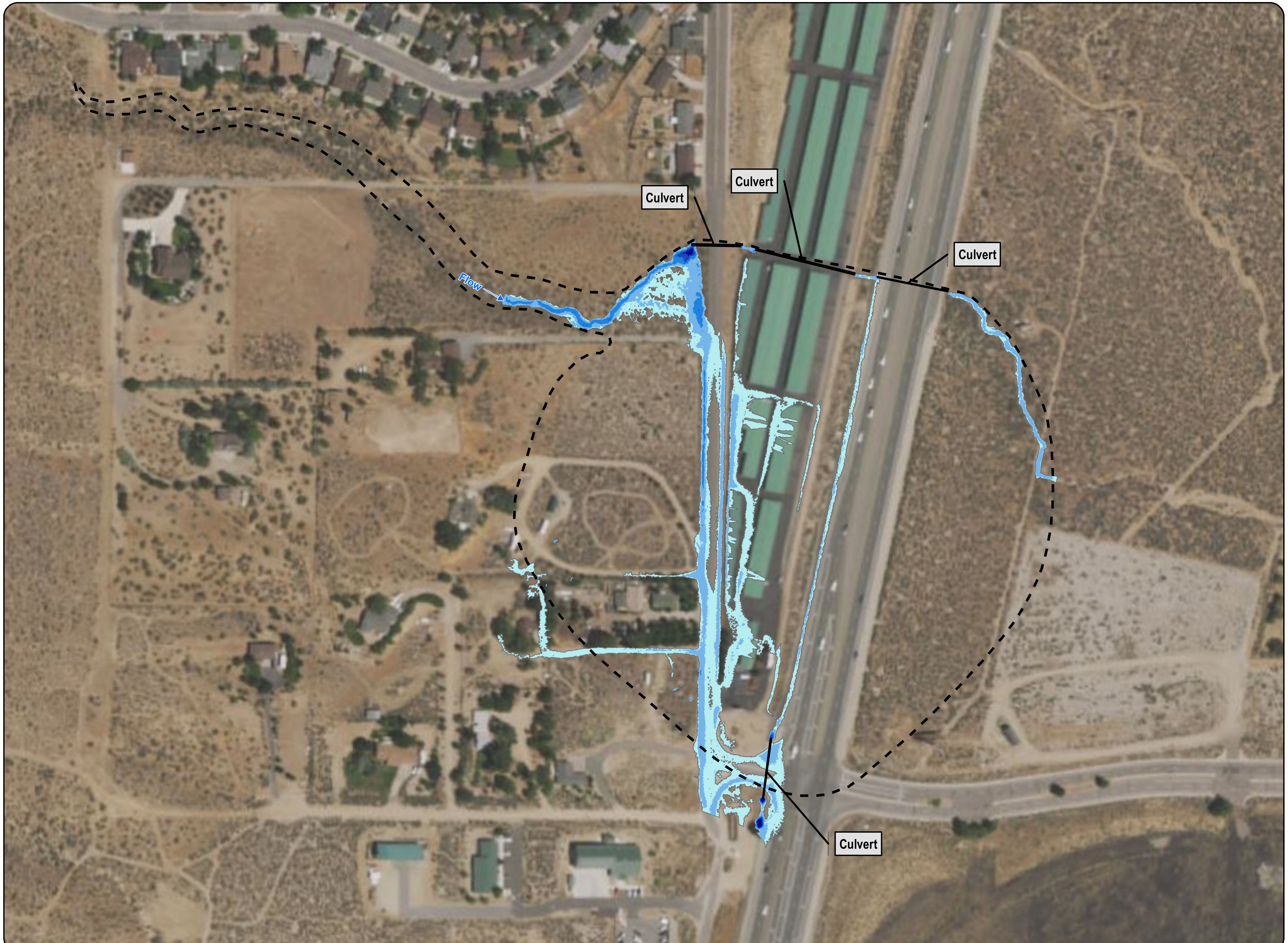
Walla Walla District



Legend

Inactive Fan Depths (Feet)

- 0.1 - 0.5
- 0.5 - 1.5
- 1.5 - 2.5
- 2.5 - 3.5
- 3.5 - 4.96
- Alluvial Fan Boundary
- Flow Direction

Note:

Roadside and main channel velocities exceed 12 ft/sec at some locations.

There are no active fan areas.

Carson River Watershed

Vicinity of Carson City, Nevada

Alluvial Fan Site 82

N

1 in = 0.04 miles

160 0 160 Feet

10 0 10 Meters

DATE	3/19/2020
DESIGNED	John Newton
DRAWN	Gary Slack
CHECKED	Tracy Schwarz

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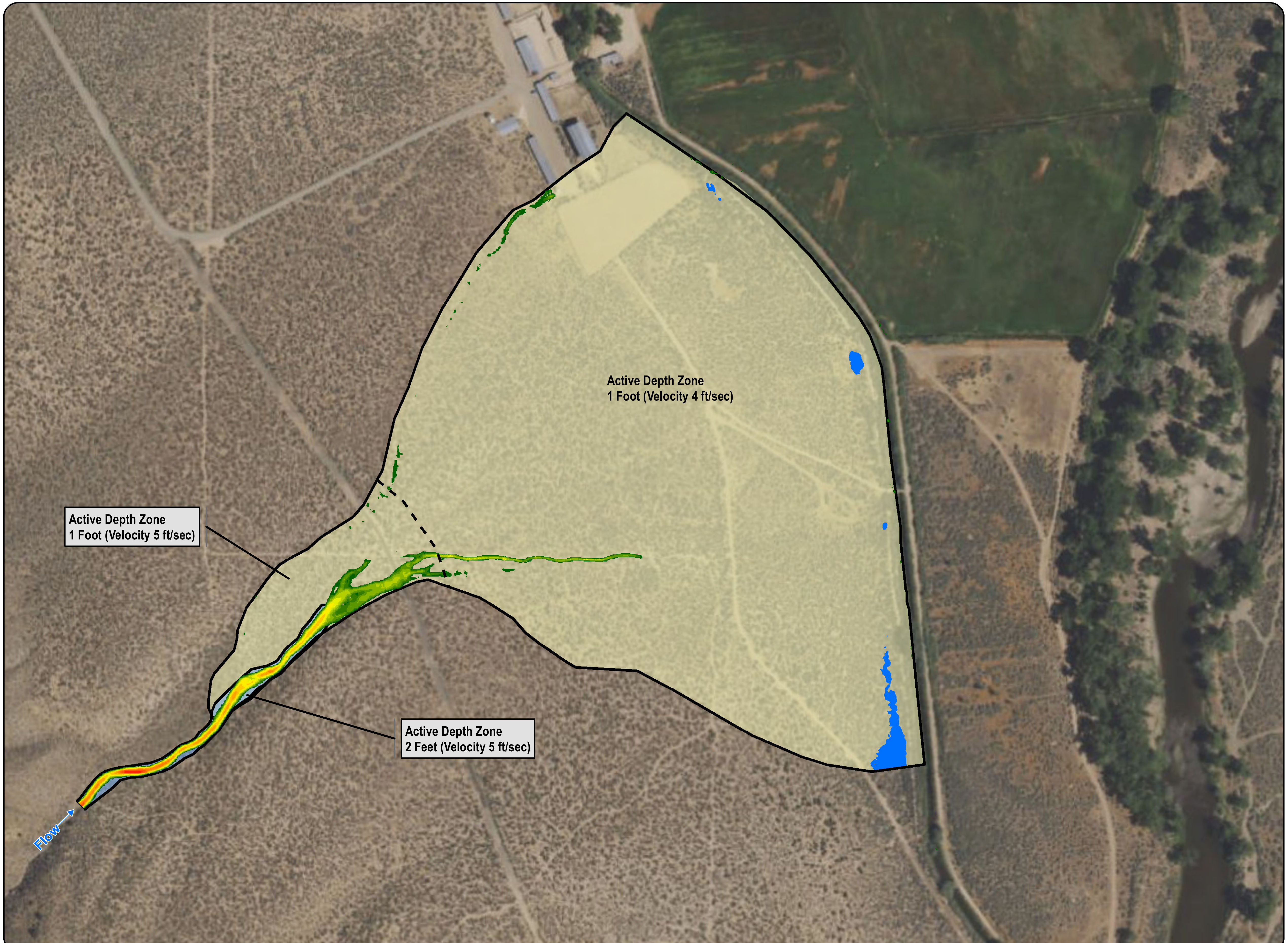
Walla Walla District



Legend

Velocity Greater Than 4.5 Ft/Sec

- 4.5 - 5.5
- 5.5 - 6.5
- 6.5 - 7.5
- 7.5 - 8.5
- 8.5 - 9.5
- 9.5 - 10.5
- 10.5 - 11.5
- 11.5 - 12.5
- 12.5 - 13.5
- 13.5 - 14.5
- 14.5 - 15.5
- 15.5 - 16.28

Active Fan Depths (Feet)

- 1 Foot Zone
- 2 Foot Zone
- Greater Than 1.5 Feet

- Velocity Zone Change
- Flow Direction

Carson River Watershed

Vicinity of Carson City, Nevada

Alluvial Fan Site 115

1 in = 0.05 miles

190 0 190 Feet

10 0 10 Meters

DATE	3/19/2020
DESIGNED	John Newton
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Northwest Division
Walla Walla District

Legend

Velocity Greater Than 4.5 Ft/Sec

- 4.5 - 5.5
- 5.5 - 6.5
- 6.5 - 7.5
- 7.5 - 8.5
- 8.5 - 9.5
- 9.5 - 10.5
- 10.5 - 11.47

Inactive Fan Depths (Feet)

- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 4.99

Active Fan Depths (Feet)

- 1 Foot Zone
- 2 Foot Zone

Flow Direction

Notes:

Velocity is not shown outside of the active zone. Main channel velocities can exceed 15 ft/sec, roadside drainage can exceed 5 ft/sec, and most other locations are typically below 2 ft/sec.

Carson River Watershed

Vicinity of Carson City, Nevada

Alluvial Fan Site 116

1 in = 0.05 miles

DATE	3/19/2020
DESIGNED	John Newton
DRAWN	Gary Slack
CHECKED	Tracy Schwarz

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Northwest Division
Walla Walla District

3.2 HEC-RAS MODEL OUTPUT

The maps in this section show the raw results of the 2-dimensional HEC-RAS modeling, assuming no channel bed movement and a 1-percent chance flood event. Depths less than 0.04 ft are not shown and rainfall induced depths less than 0.1 ft are not shown. Model boundaries are outlined and culverts are represented by black lines. See Figure 3-1 to Figure 3-10.

3.2.1 Fan 44 and 45

Debris flows are possible on these fans, but were not modeled. As such, these model results should not be used as-is for depth and velocity maps, because the risk is higher than it appears in the maps. Additional drainage to the south that could affect the ability for roadway flows to drain was not modeled; only the fans were modeled. Invert elevations were obtained from construction plans by adding 3.89 ft to convert from NGVD29 to NAVD88. Detention pond outlets were not modeled; instead only the culverts attached to the outlet structures were modeled since ponds will be full at the 1-percent chance flood event.

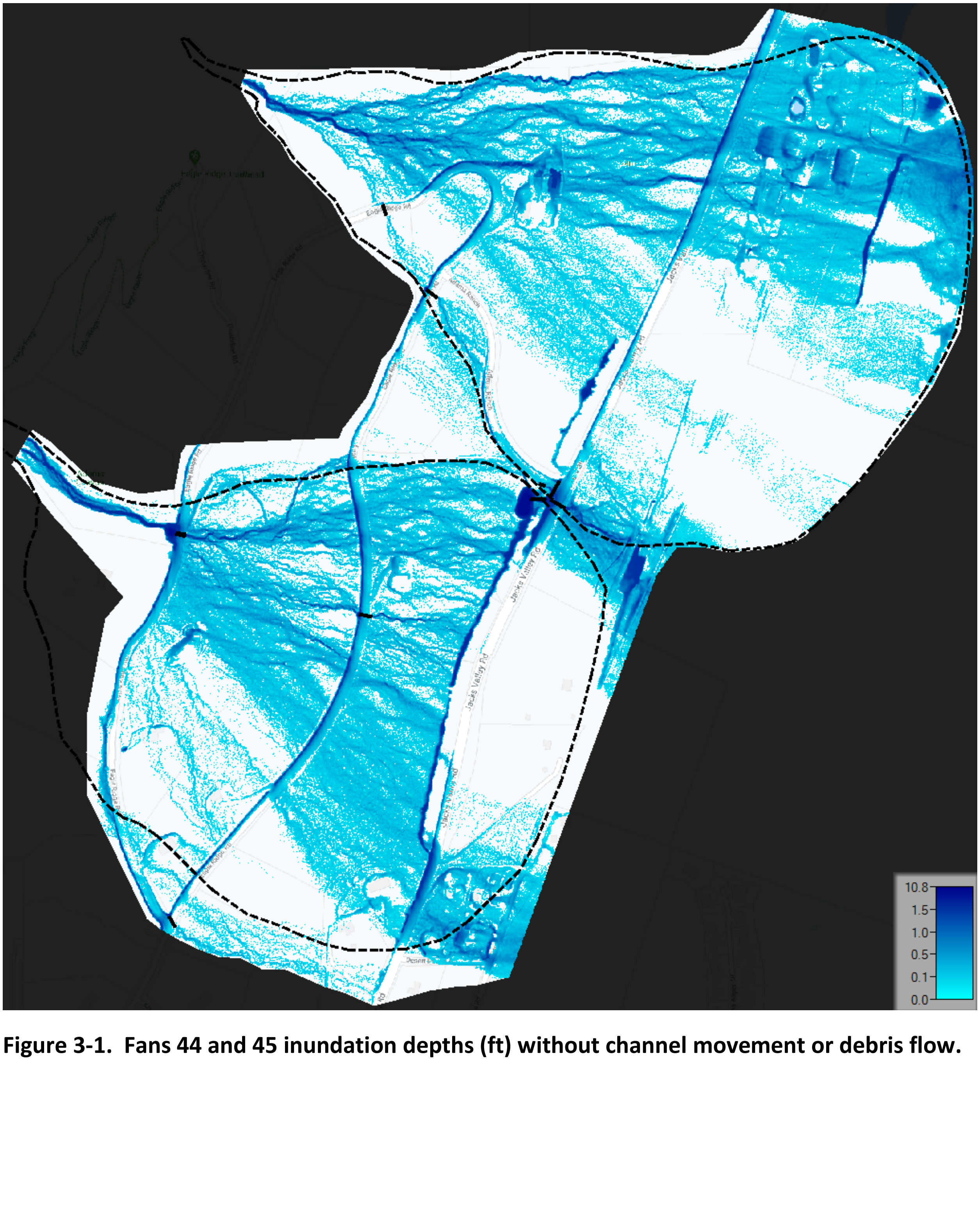

Figure 3-1. Fans 44 and 45 inundation depths (ft) without channel movement or debris flow.

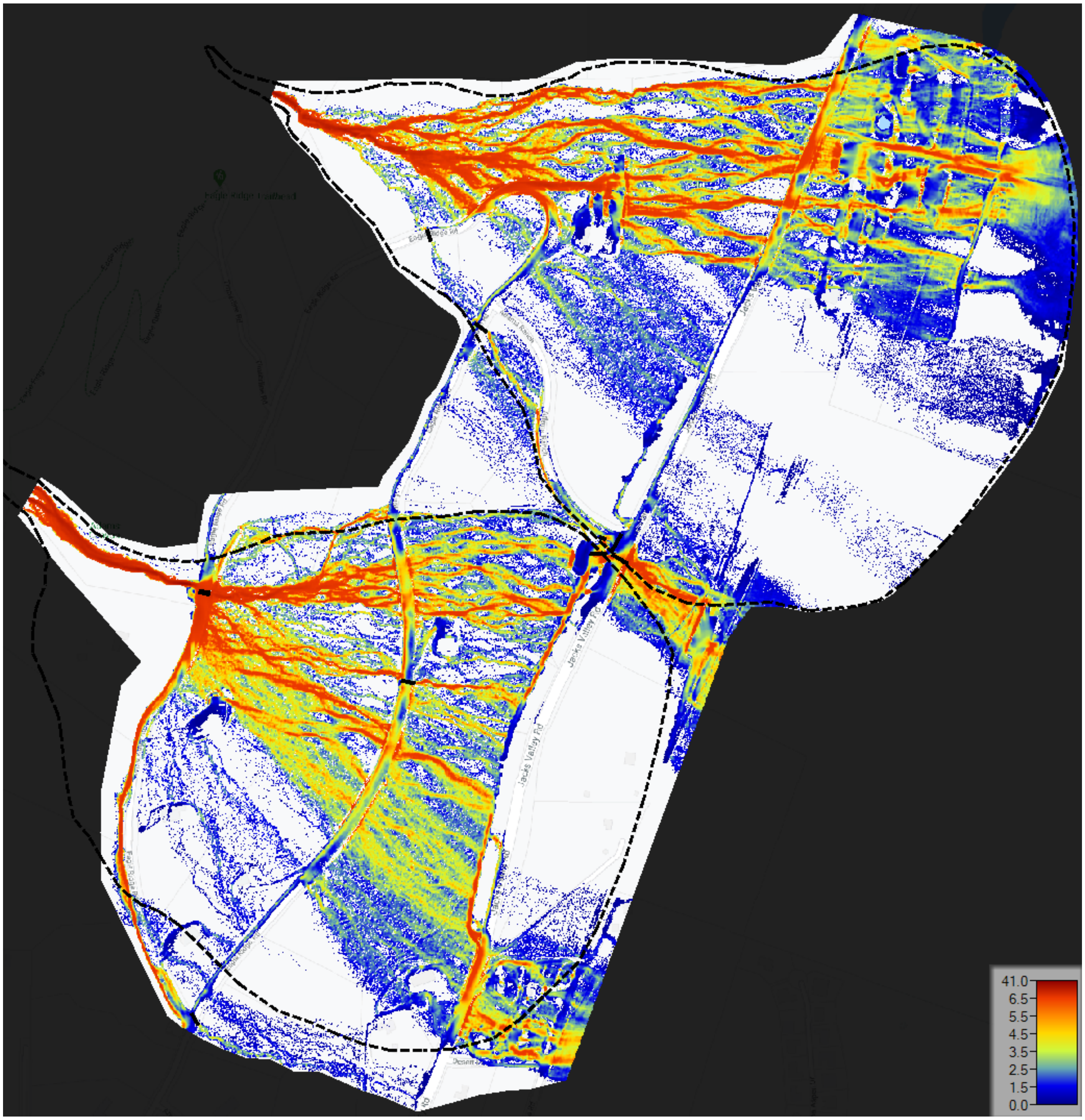

Figure 3-2. Fans 44 and 45 maximum velocity (ft/s) without channel movement or debris flow.

3.2.2 Fan 78, 79, 81, and 82 (Indian Hills)

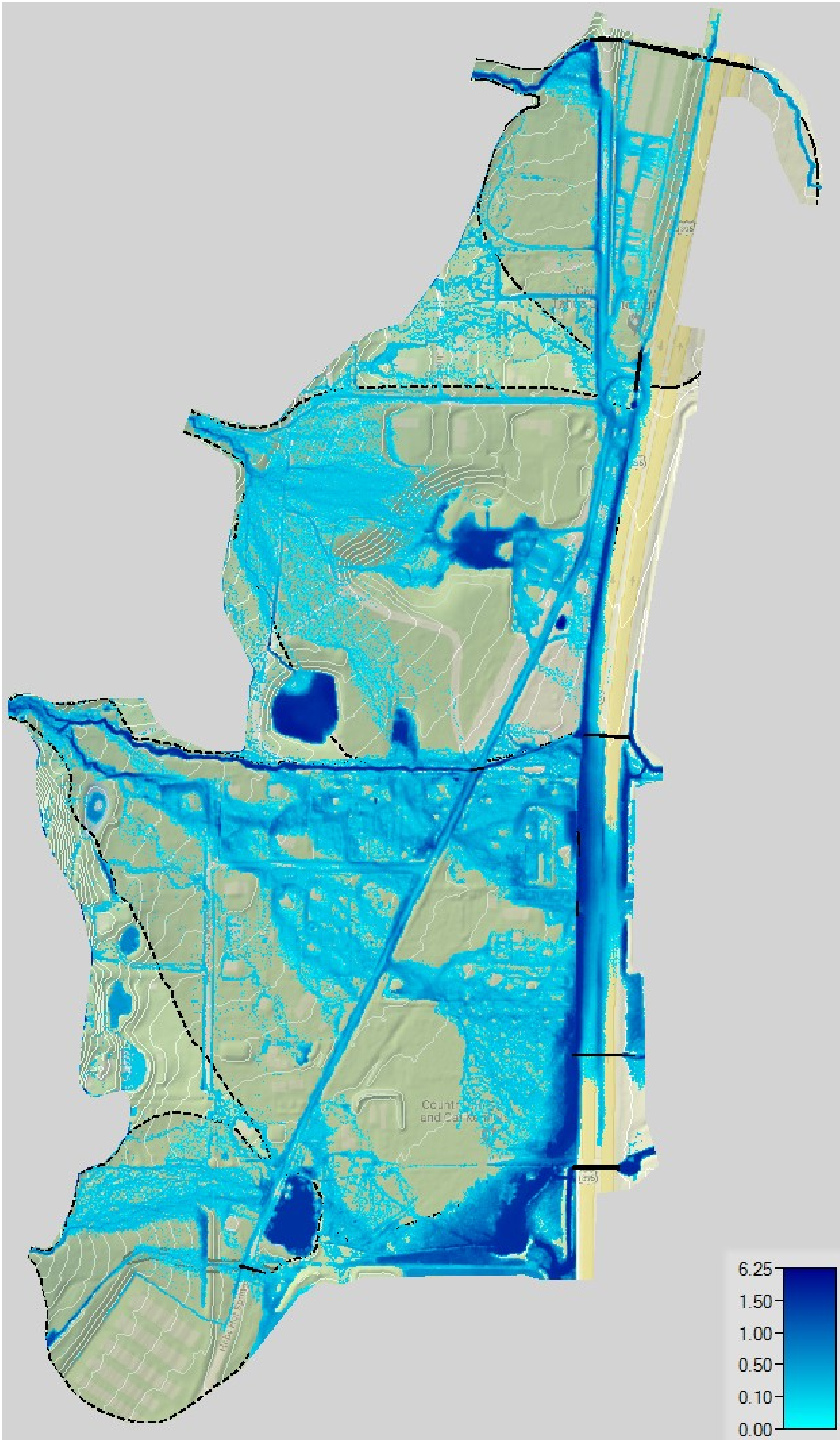

Figure 3-3. Fan 78, 79, 81, and 82 inundation depths (ft) without channel movement

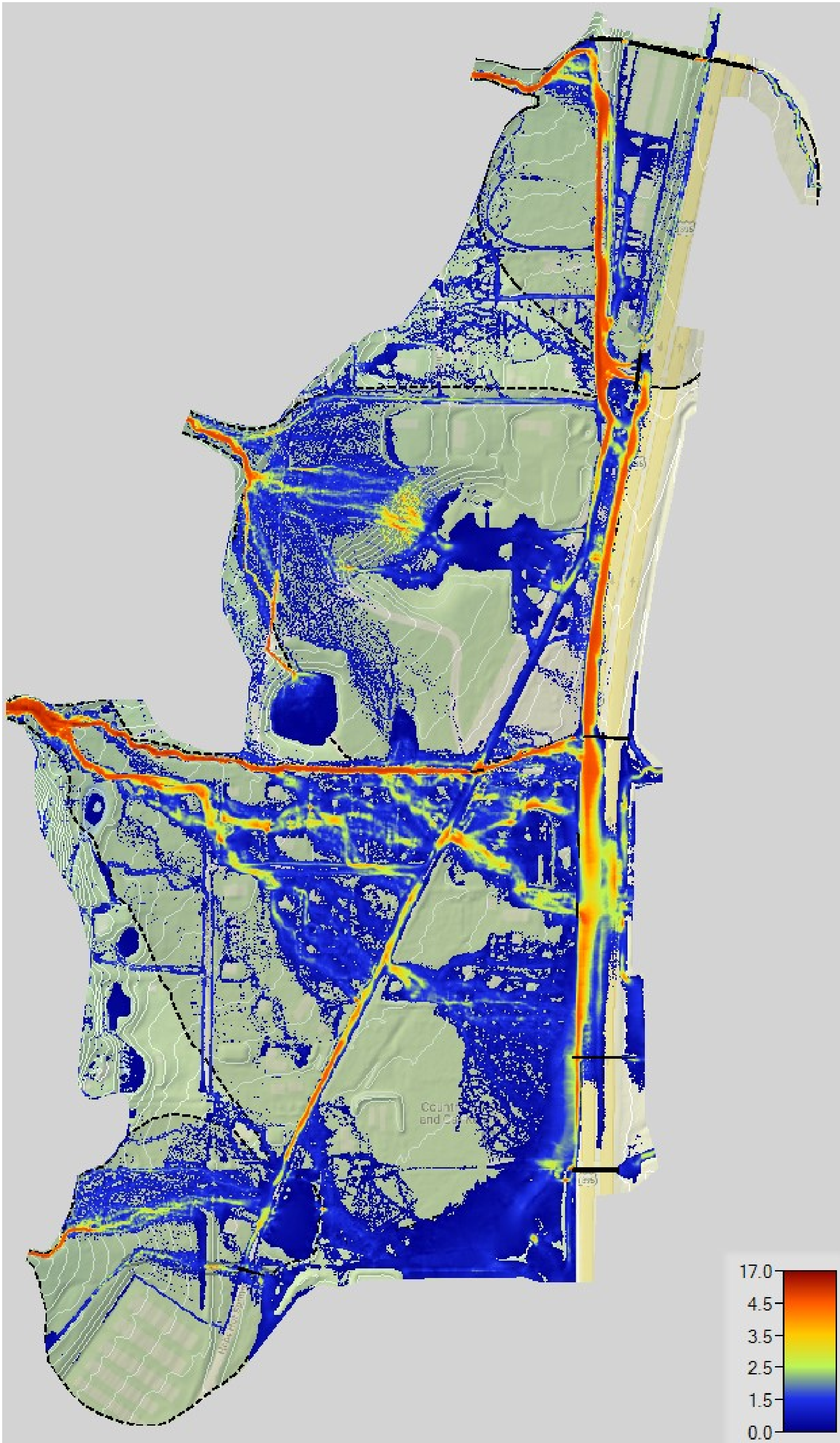

Figure 3-4. Fan 78, 79, 81, and 82 maximum velocity (ft/s) without channel movement

3.2.3 Fan 115

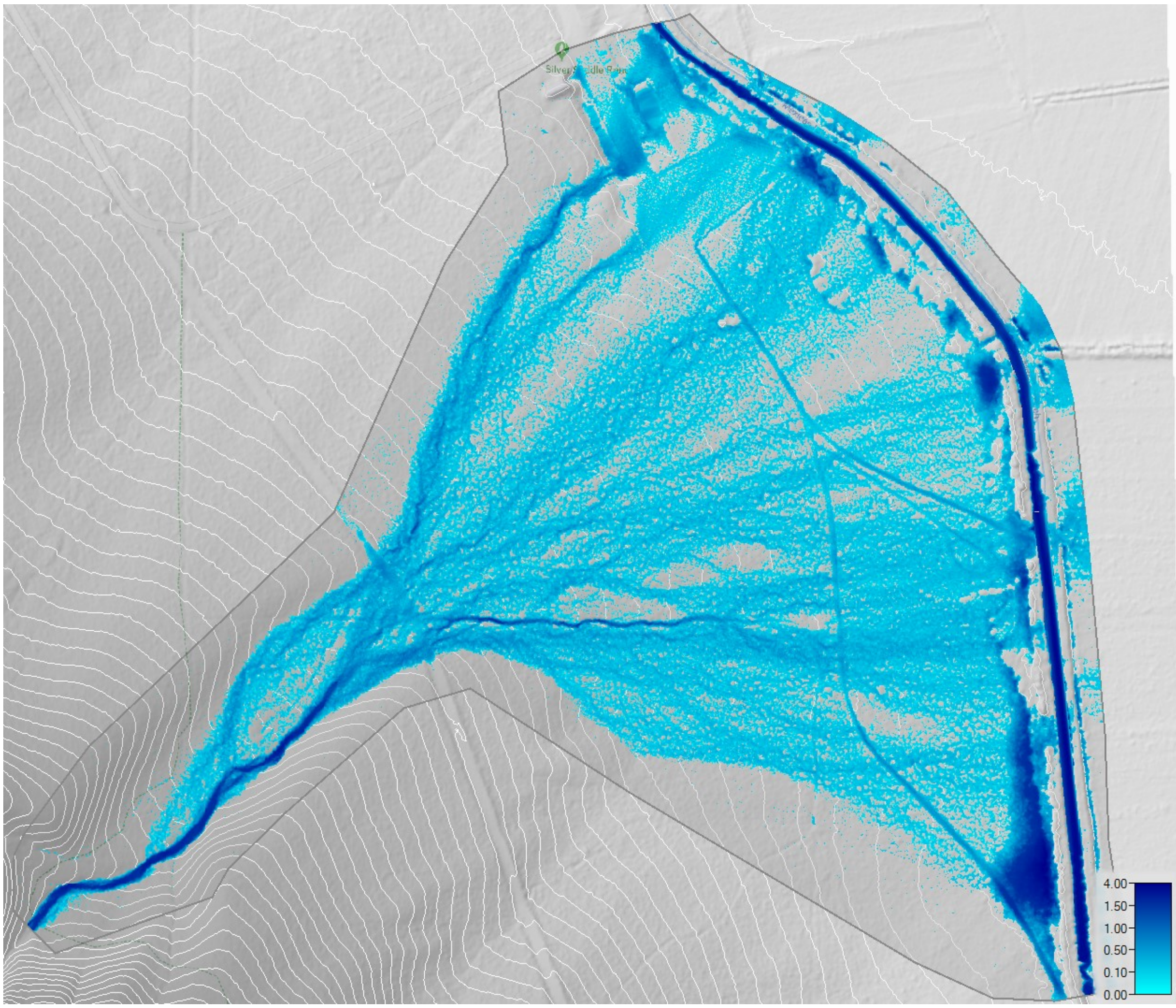

Figure 3-5. Fan 115 inundation depths (ft) without channel movement

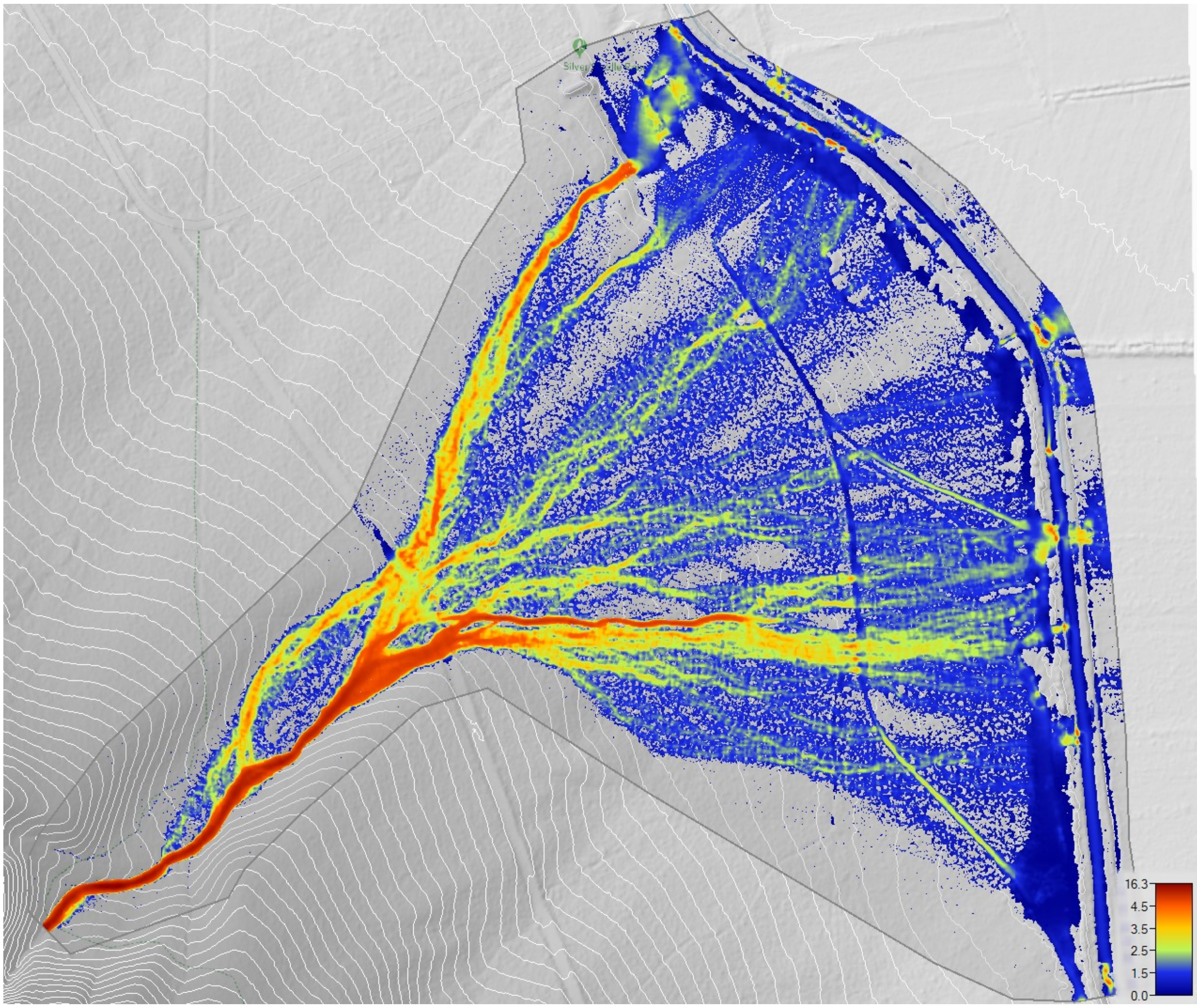

Figure 3-6. Fan 115 maximum velocity (ft/s) without channel movement

3.2.4 Fan 116

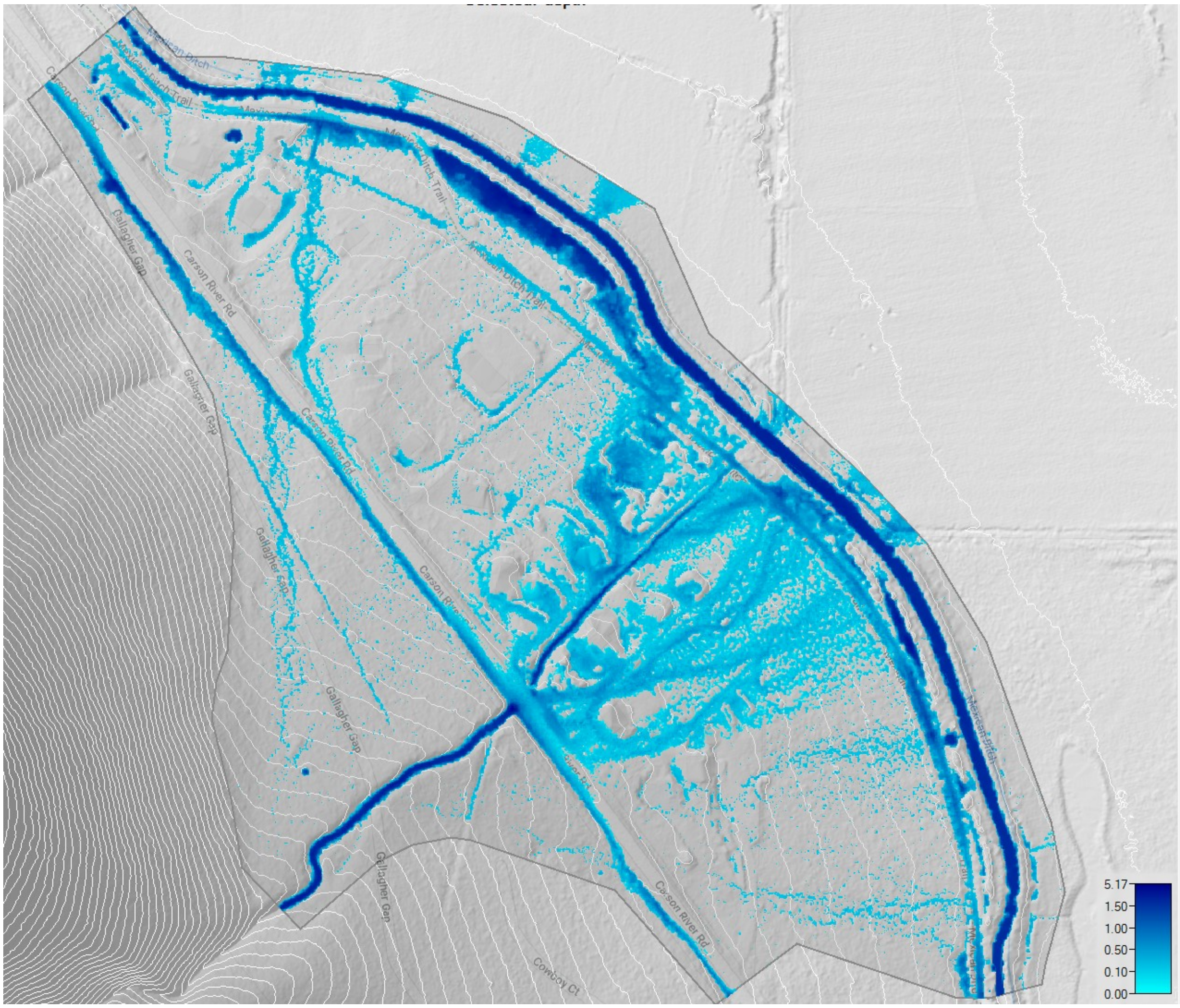

Figure 3-7. Fan 116 inundation depths (ft) without channel movement

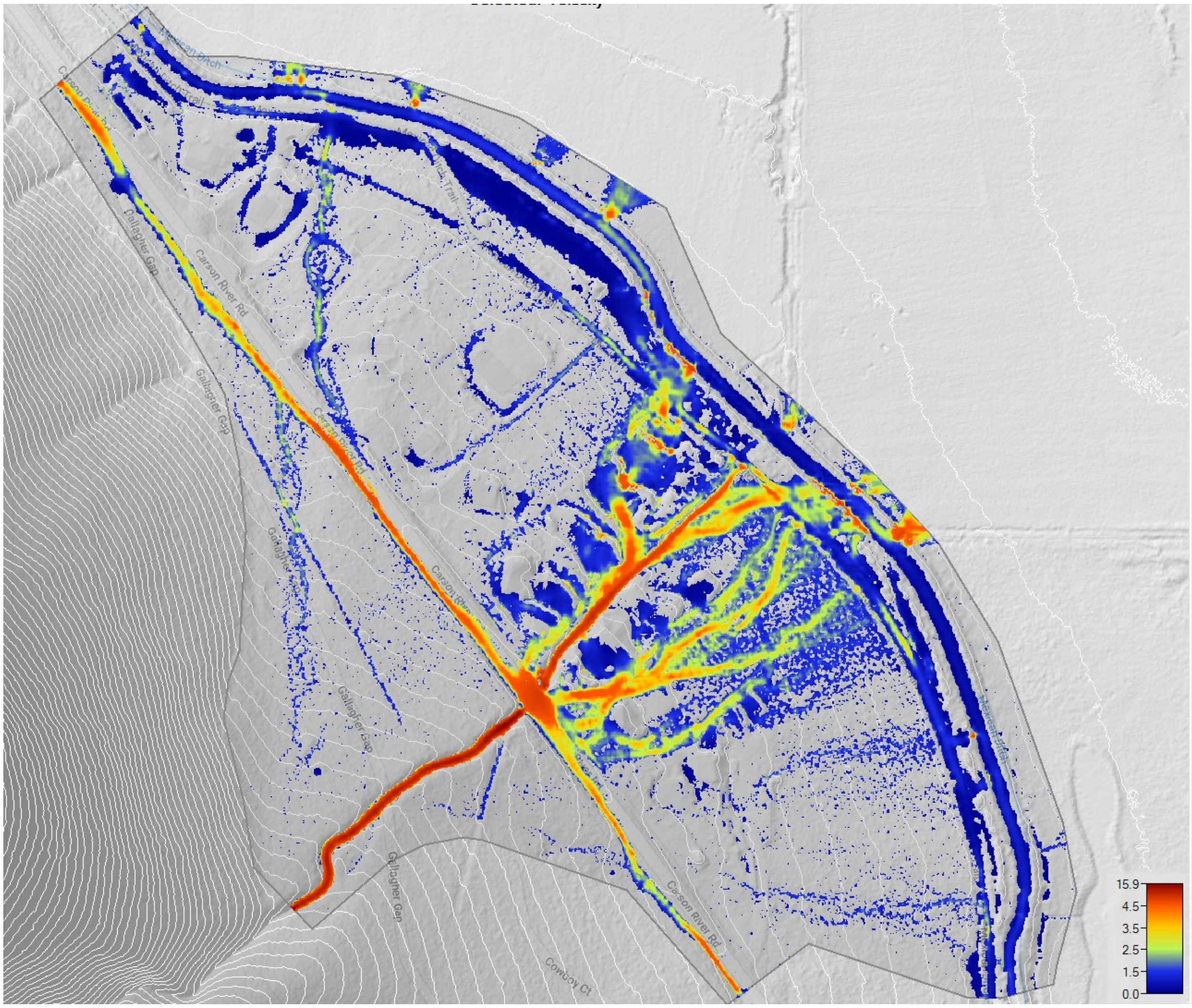

Figure 3-8. Fan 116 maximum velocity (ft/s) without channel movement

3.2.5 Effects of Blocked Culverts

This section shows model results where 95% (based on depth) of the culvert is filled in with sediment. Culverts are typically designed based on city or county regulations. It is common for cities to require that culverts are designed to handle the 10 yr or 25 yr event. When this is done, cities typically plan to pass larger events in the roadways. Most of the culverts in this study appear to have been designed to handle events much smaller than the 100 yr event. As a result, blocking the culverts does not have a big impact on the inundated areas, although it might for a smaller recurrence interval event.

3.2.5.1 Fan 116 blocked culvert

Figure 3-9 shows a comparison of inundated areas when blocking the culvert. Blocking the culvert resulted in only slight increases in depth upstream (not visible in Figure 3-9), but decreased depths and inundated area beyond the Mexican Ditch Trail. The velocity (not shown) increased by as much as 1 ft/s in the region where the roadway overtopped.

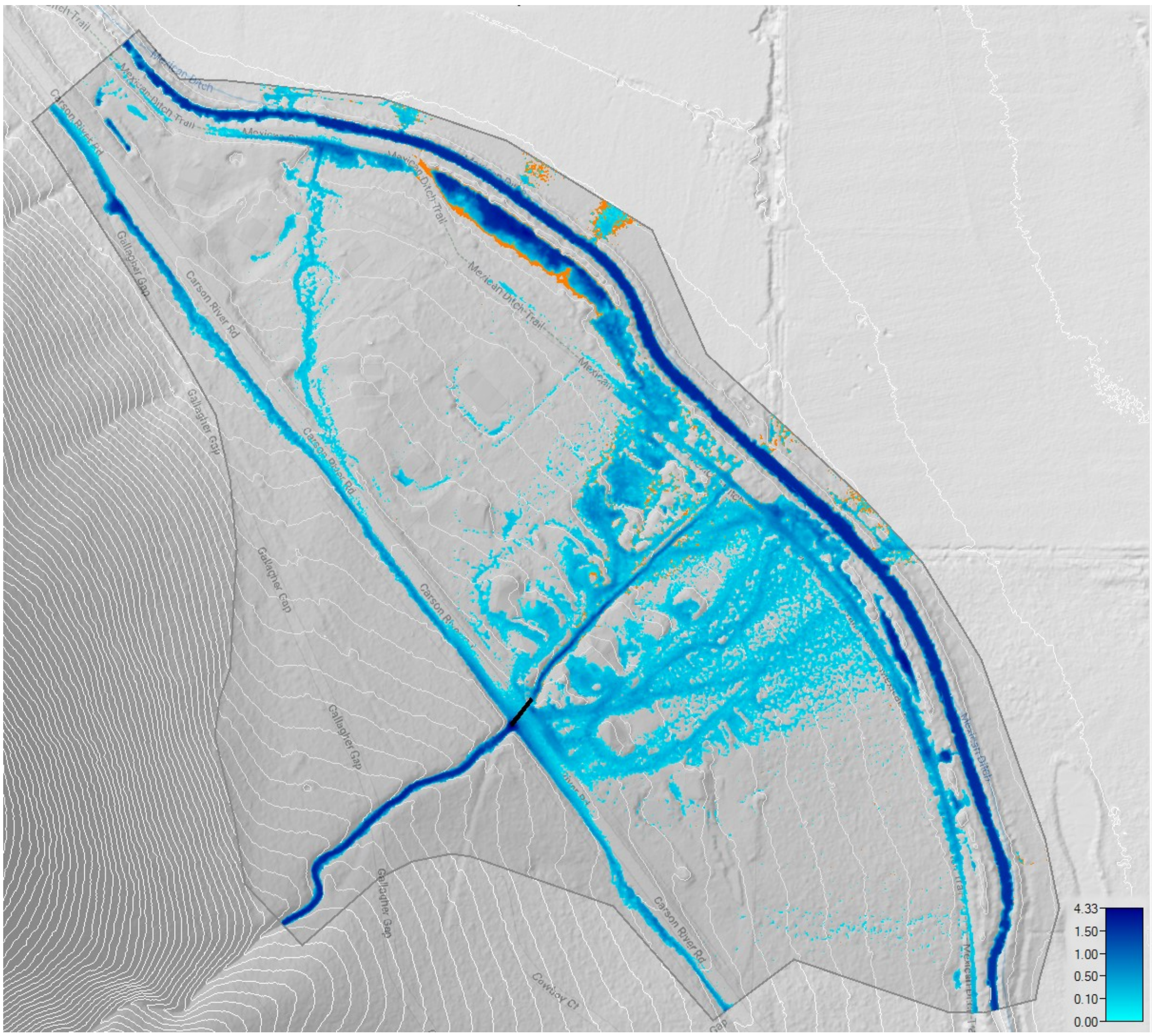

Figure 3-9. Fan 116 inundation depth (ft) for culvert modeled as-is (orange) compared to culvert 95% blocked (blue) with no channel movement or rainfall.

3.2.5.2 Indian Hills Fans 78, 79, 81, and 82 blocked culverts

Figure 3-10 shows the inundated area for the Indian Hills fans overlaid on top of the inundated area computed when all of the culverts were blocked at 95% depth. Blocking the culverts only resulted in minor increases in inundated area.

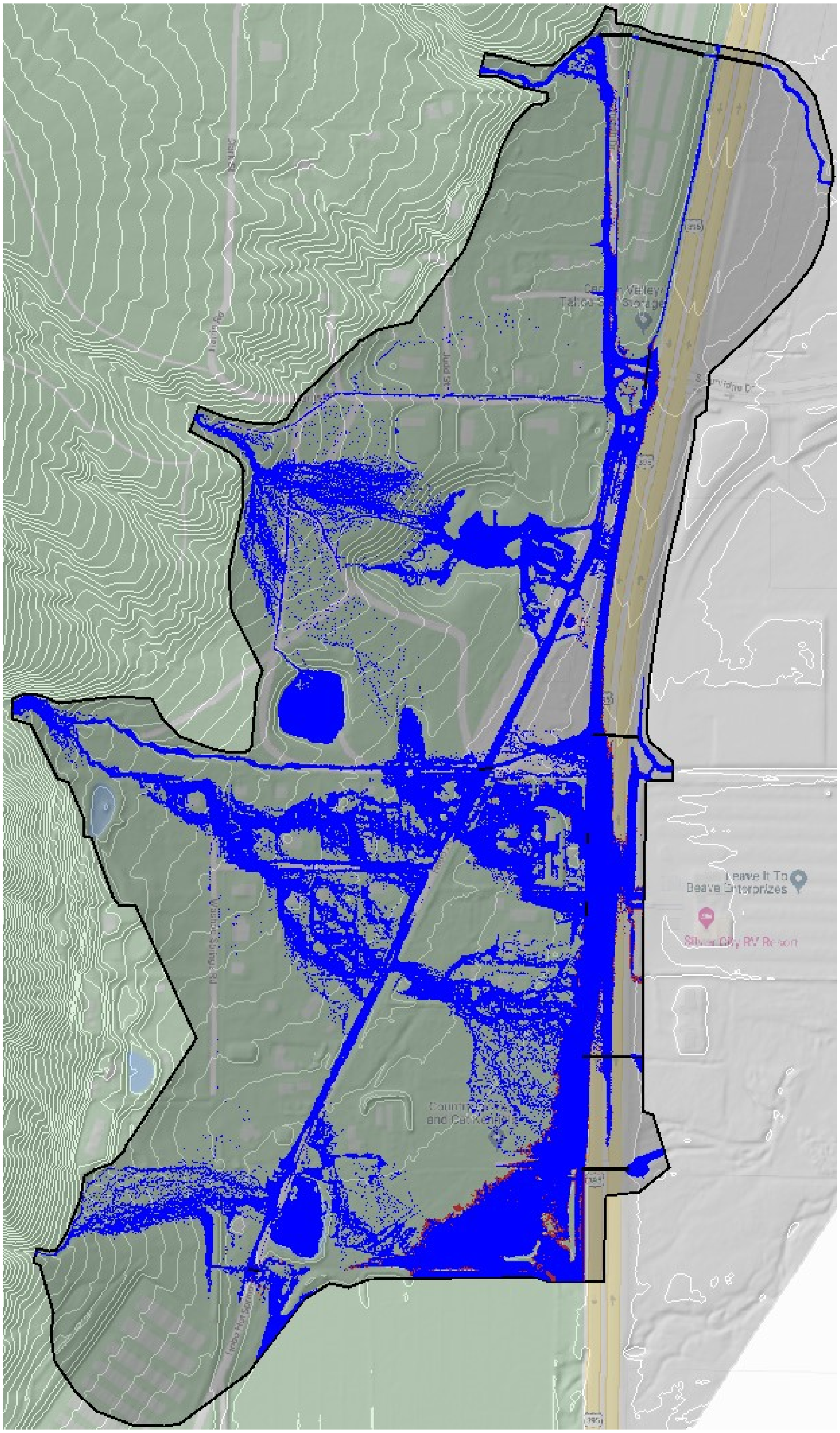

Figure 3-10. Indian Hills inundation area; red area results when culverts are 95% blocked

4. REFERENCES

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