VALLEY FLOOD MITIGATION MASTER PLAN — HYDROLOGIC AND HYDRAULIC ANALYSIS

PHASE I — EXISTING CONDITIONS AND TRAP CLUB IMPROVEMENTS

DRAFT TOPICAL REPORT RSI-2949

PREPARED FOR
Lewis and Clark County
Public Works Department
3402 Cooney Drive
Helena, MT 59602

MAY 2017

RESPEC

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1.0 INTRODUCTION

The Helena Valley, located in Lewis and Clark County just north of Helena, Montana, has historically suffered repeated widespread flood events, causing millions of dollars in damages and displacement costs. Following a large flood event in 2011, Lewis and Clark County embarked on a comprehensive flood mitigation planning effort. The "Valley Flood Mitigation Master Plan for the Helena Valley" (VFMMP, **Reference 1**) was prepared and finalized in April 2013. The document summarizes large scale flooding issues, with focus on Tenmile Creek and Silver Creek, and proposes conceptual-level solutions to manage floodwaters throughout the valley. The overarching goal outlined in the Master Plan is to convey and detain floodwaters in a controlled manner, to reduce the frequency and magnitude of flooding homes, businesses, and transportation corridors.

In 2012, Lewis and Clark County was successful in securing a flood mitigation grant from the Federal Emergency Management Agency (FEMA) through their Hazard Mitigation Grant Program (HMGP) to mitigate a portion of the overall flooding problem throughout the valley. The grant application proposed to formalize the "Trap Club" into a flood detention facility, in addition to upgrades to two culverts and grading of roadside ditches along North Montana Avenue, Sierra Road, and Interstate 15 (**Reference 2**).

In 2016, Lewis and Clark County contracted with RESPEC to implement flood mitigation projects outlined in the Master Plan. The first task (Task Order 1) was to develop a detailed hydrologic and hydraulic analysis for the two primary flooding sources in the Helena Valley: Tenmile Creek and Silver Creek, in addition to final design, permitting, and construction of the Trap Club project. The goal for the detailed hydrologic and hydraulic analysis is to better understand quantity, timing, and flow patterns throughout the Helena Valley, essential for planning, designing, and constructing flood control infrastructure. Additionally, the focus of the detailed study is to ensure infrastructure improvements do not adversely affect property owners within the planning area.

2.0 BACKGROUND INFORMATION

The Helena Valley area of Lewis and Clark County is primarily residential; however, the area also contains considerable commercial facilities, churches, and schools. The Helena Valley has a history of flooding problems with significant flood events in 1975, 1981, and 2011. Several properties and public infrastructure were flooded and suffered damages from these events. Flooding of lesser magnitude also occurred in 2014.

The flooding problem may be attributed to the lack of adequate conveyance infrastructure throughout the planning area. Both Tenmile Creek and Silver Creek leave the mountains and enter the Helena Valley on alluvial fans. Prior to settlement, Tenmile Creek migrated throughout the alluvial fan, regularly changing the location of its active channel and where it enters Lake Helena. Tenmile Creek likely combined with Silver Creek at one point in time prior to entering Lake Helena. As settlement and the industrial revolution occurred, Tenmile Creek was forced to remain in its present location through straightening, armoring, and berming, while residential, commercial, irrigation, and transportation infrastructure were developed.

Once Tenmile Creek reaches a defined flood stage near Green Meadow Drive, overbank flooding leaves its primary course and begins flowing northeast into the Helena Valley, never to return to the main channel. This flooding has historically been referred to as Tenmile Creek Overflow. The Silver Creek channel within the Helena Valley has been historically modified and provides limited flood flow capacity through developed areas. The ultimate fate for all Tenmile Creek Overflow waters is the D2 Drain Ditch, which also collects Silver Creek and discharges to Lake Helena.

Flooding in Helena Valley has been studied several times over the past five decades. Large flood events in 1975, 1981, and the most recent large event in 2011 all triggered flood mitigation investigations. In 1977, the Lewis and Clark County Commissioners and citizens passed resolutions to create a flood control advisory committee, tasked to develop favorable alternatives for flood control, and to create a flood control district to fund flood control projects.

A flood drainage study for Tenmile Creek was conducted by Morrison-Maierle and published in April, 1982 (**Reference 3**). That study developed a comprehensive flood drainage plan to reduce future flood losses in the Helena Valley area. Companion studies were also developed for Silver Creek, Eastgate Village/Treasure State Acres, Prickly Pear Creek, and Trout Creek.

In 2006, the United States Geologic Survey (USGS) completed a large scale flood insurance study of Tenmile Creek, the Tenmile Overflow that leaves the stream corridor and flows into the Helena Valley, and Silver Creek (**Reference 4**). The primary focus of that study was to update the FEMA Flood Insurance Rate Maps (FIRMs). The current effective FIRMs are based on results of that study.

During the 2011 flood, several neighborhoods, streets, and ditches were inundated. During the peak conditions, the berm separating North Montana Avenue from the Trap Club pit was breached and the pit allowed to fill. Immediate relief was recognized by adjacent properties. The disaster declaration following flooding in 2011 presented an opportunity to secure federal mitigation funding. Lewis and Clark County pursued a FEMA Hazard Mitigation Grant Program (HMGP) grant (**Reference 2)** to formalize the Trap Club pit into a flood detention facility to reduce future flood hazards and recurring damages.

In 2010, PBS&J contracted with Montana Department of Natural Resources and Conservation (DNRC) to conduct a flood re-study of Silver Creek (**Reference 5**). That study was also focused on updating the FEMA FIRM maps to current conditions.

The most recent effort published in April 2013 is the Flood Mitigation Master Plan for the Helena Valley, developed by Anderson Montgomery Consulting Engineers (**Reference 1**). That study sought to explore solutions to alleviate flooding impacts within the Tenmile Creek, Silver Creek, and Prickly Pear Creek drainages in Helena and East Helena. The plan contains conceptual level improvements to manage floodwaters throughout the Helena Valley.

The most notable flood event that inundated the entire project area occurred in May, 1981. This event exceeded a 500-year flood. Aerial imagery was acquired during this event which shows the residential area and school inundated (Figure 2). Another major flood event occurred in June 2011, a flood season that triggered a Presidential Disaster Declaration.

The repetitive nature of these studies is related to the complexity of the flooding problem. Current technological advancements in engineering hydrology and hydraulics, and new data has justified a restudy of flooding problems in the Helena Valley. This study develops detailed hydrologic and hydraulic analyses of Tenmile Creek Overflow and Silver Creek to aid master planning, and to support design, permitting, and construction of current and future flood mitigation projects.

3.0 DATA SOURCES

Several studies have occurred on Tenmile Creek and Silver Creek in the recent past. One priority for this study was to utilize previous modeling efforts and existing datasets to the maximum possible extent.

3.1 DIGITAL ELEVATION MODEL (DEM)

Two sources of digital elevation models were used in the development of the hydrologic and hydraulic analysis: a Bare Earth LiDAR DEM and a National Elevation Dataset (NED) 10M DEM.

3.1.1 LIDAR DIGITAL ELEVATION MODEL

In 2012, Lewis and Clark County contracted with Sanborn for the collection of Light Detection and Ranging (LiDAR) topographic mapping of the entire Helena Valley (**Reference 6**). The LiDAR was collected May 8th and May 9th, 2012 and processed to exceed the minimum accuracy specifications required by FEMA for detailed flood studies. LiDAR deliverables included a bare earth DEM, 2- foot contours, and a data summary report. The LiDAR data was collected with the following specifications:

Projection:	Montana State Plane HARN	<u>Units</u>
Datum:	Horizontal – NAD83	Meters
	Vertical – NAVD88, Geoid09	Meters

The LiDAR Bare Earth DEM (1.4 meter resolution) served as the primary topographic source for the study and was utilized to develop cross section geometry and the two dimensional domain within the hydraulic model. LiDAR was also utilized in the hydrologic analysis for basin delineation and flood flow routing.

3.1.2 NATIONAL ELEVATION DATASET (NED) 10M DIGITAL ELEVATION MODEL

Ten meter digital elevation models (10m DEM) for both the Tenmile Creek and Silver Creek watersheds were obtained through the Geospatial Data Gateway. Each 10m DEM tile was mosaicked into one seamless DEM. The 10m DEM provided a topographic model where LiDAR did not exist to facilitate basin delineation and flood routing within the hydrologic model.

3.2 FIELD SURVEY

A variety of field topographic survey was used in the development of the hydraulic analysis. Existing field survey datasets include:

- USGS field survey of Silver and Tenmile Creeks for 2006 FIS
- PBS&J field survey of Silver Creek and D2 Drain Ditch for 2010 FIS
- Robert Peccia and Associates field survey of Helena Valley in 2012

Additional field survey was collected by Robert Peccia and Associates for the hydraulic structures and road crossings within the D2 Drain Ditch, and areas known to have been changed since LiDAR acquisition in 2012. The additional survey areas were along McHugh Drive and Forestvale Road as a result of drainage improvements. All new survey collected by Robert Peccia and Associates was in October 2016 according to the following specifications.

Projection:	Montana State Plane	Units
Datum:	Horizontal – NAD83(2011)	International Feet
	Vertical – NAVD88, Geoid12A	US Feet

3.3 HYDRAULIC MODELS

The following existing hydraulic models were obtained and reviewed for potential use in this updated study:

- USGS HEC-RAS model for Tenmile Creek main channel (2006 FIS)
- PBS&J HEC-RAS model for Silver Creek and portions of D2 Drain Ditch (2010 FIS)
- RESPEC FEMA HMGP Scope Revision 2015 (**Reference 7**)

The PBS&J model for Silver Creek and portions of the D2 Drain Ditch was reviewed for its suitability in the updated study. The one-dimensional model was developed for regulatory purposes, and given the complex and multi-directional flowpaths in this area, was not used in the current Silver Creek study. Hydraulic structures within that model were used, where applicable, within the current study.

The USGS HEC-RAS model developed for the 2006 FIS for Tenmile Creek was also reviewed and is appropriate for use in the updated study. Substantial modifications were made to adapt the model to interface with the two-dimensional domain and update to current conditions.

4.0 HYDROLOGIC ANALYSIS

There are two primary sources of flooding in Helena Valley: Tenmile Creek and Silver Creek. Tenmile Creek spills from its left bank in the vicinity of Green Meadow Drive and McHugh Drive. Just upstream of this overbank flow divergence, Sevenmile Creek contributes a significant portion of the total drainage area to Tenmile. The Tenmile Creek Overflow travels through the Helena Valley prior to collecting along Interstate 15 and discharging into the D2 Drain Ditch. Silver Creek also enters the D2 Drain Ditch at Interstate 15. The D2 Drain ditch inevitably collects the majority of floodwaters in the Helena Valley and discharges into Lake Helena. A general overview of flooding sources, along with locations of USGS stream gages in the basins are shown in **Figure 4-1**.

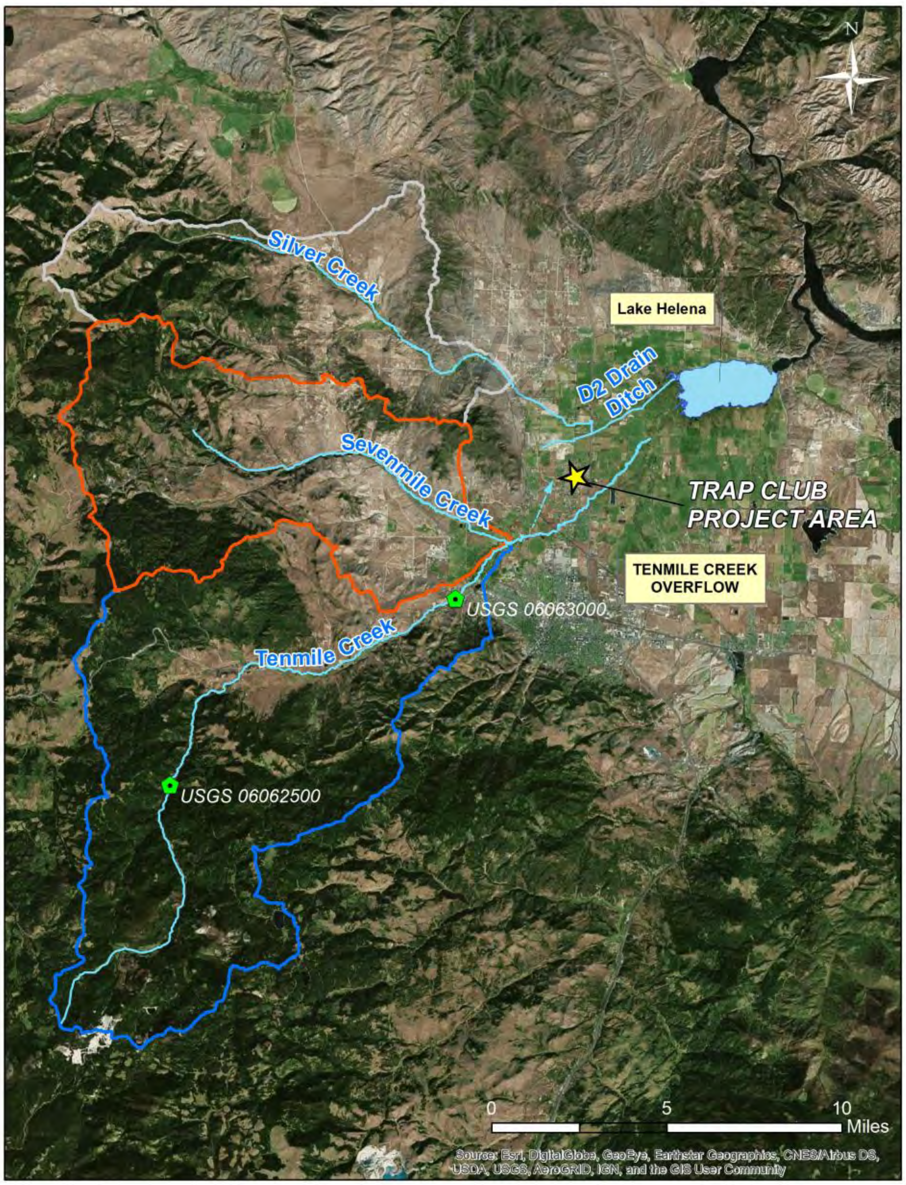

Figure 4-1. Hydrologic basins and USGS gage locations.

Several methods to calculate flood frequency for the variety of basins in the project area were explored including: stream gage flood frequency analysis, basin characteristics regression equations, and a rainfall-runoff analysis.

To understand the effectiveness of the Trap Club detention pond and to ensure proper operation of that facility, the complexities of the flow paths, the source of flood flows, and flood peak timing present the need to develop flood hydrographs for each flooding source.

4.1 FLOOD-FREQUENCY ANALYSIS, TENMILE CREEK

Two USGS stream gages with peak flow record exist on Tenmile Creek: USGS Gage 06062500 Tenmile Creek near Rimini, Montana and USGS 06063000 Tenmile Creek near Helena, Montana. The locations of these gages are shown on **Figure 4-1.** Flow from Sevenmile Creek watershed is not included in either gage and there is no known peak flow record that exists for Sevenmile Creek. Similarly, Silver Creek is not known to contain a peak flood record.

A log-Pearson Type III flood frequency analysis was completed for the two gaging stations on Tenmile Creek by USGS for development of their recently published Scientific Investigation Report (SIR) 2015-5019-F (**Reference 8**). Results from that analysis using data through water-year 2011 are presented in **Table 4-1**.

Table 4-1. Tenmile Creek Peak Flood Flow Frequency Results from SIR 2015-5019-F.

USGS Gage	Drainage Area (mi^2)	Peak Flow (cfs) Flood Frequency Results				
		10%	4%	2%	1%	0.2%
06062500 (Near Rimini)	33.0	452	721	1,030	1,460	3,320
06063000 (Near Helena)	98.7	631	968	1,340	1,860	3,980

The USGS SIR 2015-5019-F report outlines methods for transferring flood frequency results calculated at a stream gage to an ungaged location on the same stream using a ratio of drainage areas and a regional regression coefficient, according to the following equation from their report:

$$Q_{AEP,U} = Q_{AEP,G}\left(\frac{DA_U}{DA_G}\right)^{exp_{AEP}} \quad (6)$$

where

$Q_{AEP,G}$ is the AEP-percent peak flow for gaging station G, in cubic feet per second;

DA_U is the drainage area at ungaged site U, in square miles;

DA_G is the drainage area at gaging station G, in square miles; and

exp_{AEP} is the regression coefficient for an OLS regression relating the log of the AEP-percent peak flow to the log of the drainage area within each region (table 5).

Sevenmile Creek watershed enters Tenmile Creek downstream of USGS 06063000. Just below the confluence of Tenmile Creek and Sevenmile Creek, is the Tenmile Creek Overflow spill point, where flood frequency is desired just upstream of Green Meadow Drive. Peak flood frequency results from transfer of USGS 06063000 Tenmile Creek near Helena, Montana to the ungaged site just upstream of Green Meadow Drive are shown in **Table 4-2**.

Table 4-2. Flood Flows at Sevenmile/Tenmile Confluence from transfer of USGS Regression Analysis

Ungaged Site	Drainage Area (mi^2)	Peak Flow (cfs) Flood Frequency Results				
		10%	4%	2%	1%	0.2%
Tenmile Creek at Green Meadow Drive	161.4	915	1,359	1,842	2,510	5,173

The USGS SIR report suggests transferring flood frequency results at a gage to an ungaged location may yield reliable results when the ratio of ungaged-to-gaged drainage areas is between 0.5 and 1.5. Because the Sevenmile Creek watershed size is substantial, the drainage area ratio for transferring flood frequency results is 1.64. Results from the transfer may not yield reliable flow estimations because this ratio exceeds 1.5. Nonetheless, these results are useful for comparison purposes.

4.2 USGS REGRESSION EQUATIONS FOR UNGAGED LOCATIONS

Peak flow flood frequencies for Silver Creek and Tenmile Creek were calculated using USGS Basin Characteristics Regression Equations, as outlined in SIR 2015-5019-F. The USGS StreamStats Version 4 online tool was used to delineate the basins, calculate basin parameters, and generate flood frequency estimates with the regression equations (**Appendix A**). **Table 4-3** summarizes the peak flood frequency results for Silver Creek and Tenmile Creek where they cross Green Meadow Drive.

Table 4-3. Flood Frequency Flows for Silver and Tenmile Creeks Using StreamStats

Ungaged Site	Drainage Area (mi^2)	Peak Flow (cfs) Flood Frequency Results				
		10%	4%	2%	1%	0.2%
Silver Creek at Green Meadow Drive	46.7	437	720	982	1,300	2,280
Tenmile Creek at Green Meadow Drive	162.9	1,020	1,470	1,840	2,270	3,410

StreamStats reported the delineated basins to span into different hydrologic regions. The majority of both basins are located within the Southwest Region, with minor portions computed in the West Region. Areas in the West Region are assumed the result of different topographic data sources between the regional delineation and the project specific delineation. StreamStats provides results from equations developed for each region, as well as area-weighted results. The West Region specific results, and the area-weighted results were discarded.

4.3 RAINFALL-RUNOFF ANALYSIS

The proposed use of the Trap Club as a flood detention facility requires quantification of flood volumes and timing of peak flows from a runoff hydrograph to understand effectiveness and to properly operate the facility. Unfortunately, calculation of peak flood frequency from stream gage records or regression equations does not produce either time-series flow or flood volumes. Consequently, a rainfall-runoff model was developed for the Tenmile and Silver Creek watersheds using the U.S. Army Corps of Engineers' (USACE) HEC-HMS modeling program Version 4.2 (**Reference 9**). The HEC-HMS modeling program is a graphical user interface designed to simulate a precipitation-runoff response in urban or natural watersheds. The model accounts for user-specified meteorological data, a loss and transform method, and a reach routing method for multiple subbasins throughout each watershed.

The meteorological model for Tenmile and Silver Creeks was a 24-hour design storm to simulate the rainfall over the watershed. The SCS Runoff Curve Number Method was used to model potential losses. The transform method used was the Curve Number Method described in the National Engineering Handbook (**Reference 10**). The Muskingum-Cunge method was used to route the hydrograph through the watershed. Input parameters for each HEC-HMS model are presented and discussed, followed by results of the rainfall-runoff modeling.

The subbasins delineated for both Silver Creek and Tenmile Creek are shown in Figure 4-2. Each stream's crossing of Green Meadow Drive was taken as the outlet for each watershed. Therefore, the Sevenmile Creek basin is included in the Tenmile Creek model.

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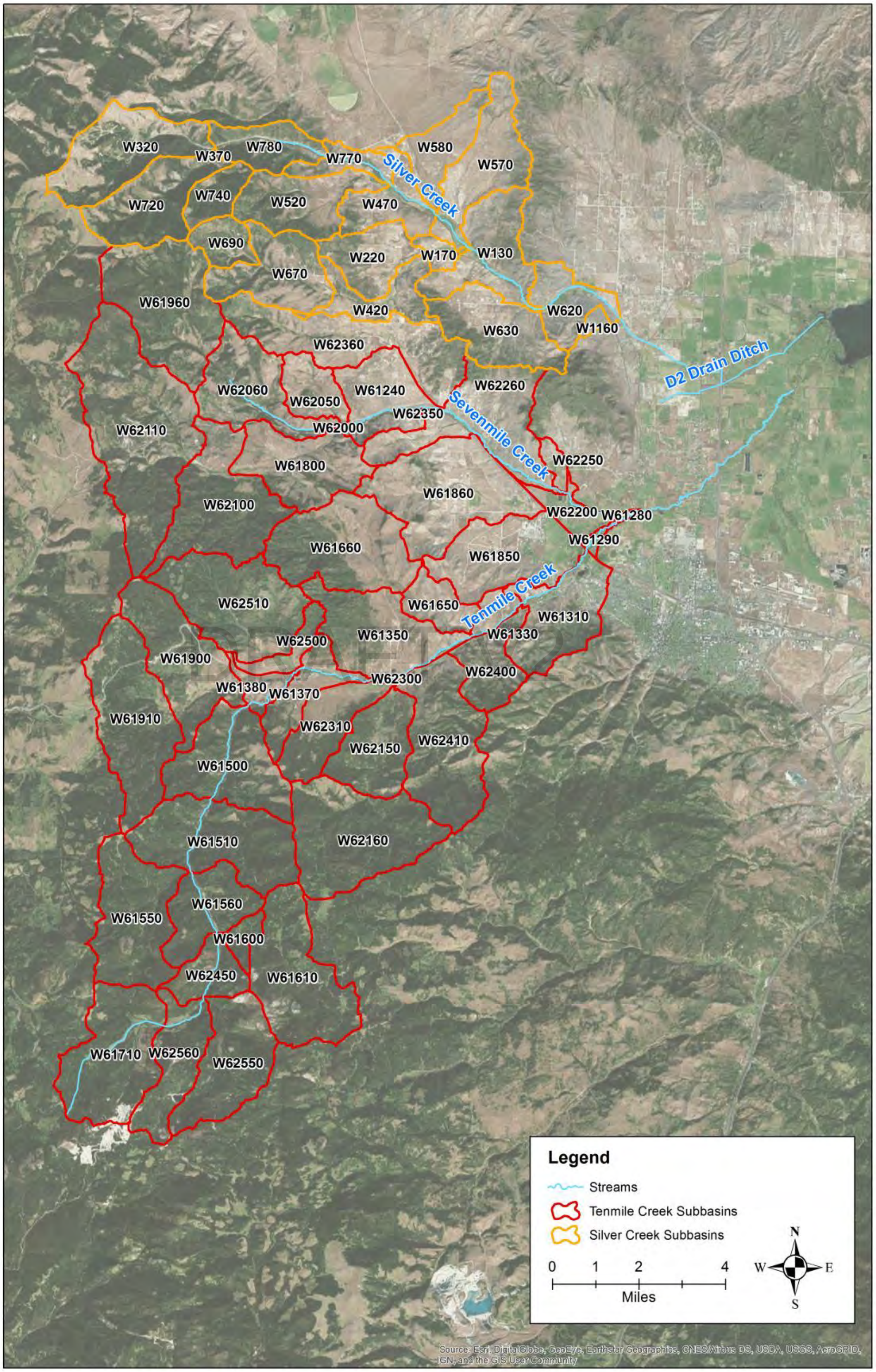

Figure 4-2. Basin delineation within HEC-HMS.

4.3.1 PRECIPITATION

Design storms were of a 24-hour distribution. Point precipitation depths for the 10-, 4-, 2-, and 1-percent-annual-chance storm events were taken from the isohyetal maps found in *NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States, Volume I – Montana* (**Reference 11**) for durations of 6 and 24 hours. All precipitation durations less than six hours were obtained using equations, figures and tables presented in *NOAA Atlas 2, Precipitation-Frequency Atlas of the Western United States, Volume I – Montana* and *Short Duration Rainfall Relations for the Western United States* (**Reference 12**). The 0.2-percent-annual-chance storm event precipitation values were extrapolated from a log-probability curve of the 10-, 4-, 2-, and 1-percent annual chance storm events. All point precipitation depths are displayed in **Table 4-4** for Silver Creek, and in **Table 4-5** for Tenmile Creek. All pertinent data used to determine the depths are included in **Appendix B**.

Table 4-4. Design storm rainfall depths (Silver Creek)

Duration	Point Rainfall Depth (in) for each Annual Exceedance Probability						
	50%	20%	10%	4%	2%	1%	0.2%
5 min	0.16	0.25	0.30	0.38	0.46	0.51	0.64
15 min	0.28	0.45	0.56	0.70	0.83	0.95	1.19
1 hr	0.41	0.65	0.81	1.01	1.19	1.37	1.70
2 hr	0.49	0.72	0.88	1.08	1.26	1.43	1.74
3 hr	0.55	0.79	0.94	1.14	1.31	1.49	1.82
6 hr	0.72	0.94	1.09	1.28	1.45	1.62	1.95
12 hr	0.95	1.25	1.45	1.71	1.95	2.17	2.60
24 hr	1.21	1.60	1.87	2.20	2.51	2.80	3.33

**0.2-percent-annual-chance precipitation depths were extrapolated from 50- to 1-percent-annual-chance depths.*

Table 4-5. Design storm rainfall depths (Tenmile Creek)

Duration	Point Rainfall Depth (in) for each Annual Exceedance Probability						
	50%	20%	10%	4%	2%	1%	0.2%
5 min	0.17	0.26	0.32	0.39	0.46	0.53	0.66
15 min	0.30	0.47	0.58	0.73	0.86	0.99	1.24
1 hr	0.44	0.69	0.85	1.06	1.25	1.44	1.80
2 hr	0.52	0.77	0.93	1.14	1.33	1.52	1.86
3 hr	0.60	0.84	1.00	1.21	1.40	1.58	1.95
6 hr	0.78	1.02	1.18	1.38	1.57	1.75	2.12
12 hr	1.04	1.35	1.57	1.83	2.09	2.32	2.80
24 hr	1.33	1.74	2.01	2.35	2.68	2.98	3.56

**0.2-percent-annual-chance precipitation depths were extrapolated from 50- to 1-percent-annual-chance depths.*

4.3.2 LOSS RATE

The SCS Curve Number Method was chosen to model potential runoff loss with respect to soil type and land use conditions. Soil and land use data were itemized for each subbasin.

Soils coverage was obtained in Soil Survey Geographic (SSURGO) format from the Natural Resources Conservation Service (NRCS) Geospatial Data Gateway (**Reference 13**). The hydrologic soil groups present in both watersheds are displayed in Figure 4-3. Small portions of both watersheds have undefined hydrologic soil groups in the SSURGO dataset. In order to provide a complete classification for the watershed, the undefined areas were conservatively assigned as hydrologic soil group D.

Land use data was also obtained from the NRCS Geospatial Data Gateway. Land use classifications are displayed in **Figure 4-4**. Shapefiles containing the soils and land use data were intersected and clipped to the watershed boundary using GIS. The resulting shapefile contained the land use associated to each soil type, along with the total area of each soil and land use combination. The NRCS *Urban Hydrology for Small Watersheds Technical Release 55* (**Reference 14**) was used to assign a set of curve numbers to each of the subbasins. When assigning curve numbers all areas were considered to be in good hydrologic condition with an antecedent moisture condition of two (AMCII). On-site evaluation and review of aerial imagery aided in assigning the most representative set of curve numbers to the different land use and vegetative cover types. The adopted land use curve numbers used for this study are shown in **Appendix B**.

Each subbasin's cumulative loss rate was determined by calculating an area weighted-average curve number value. Final weighted-average curve numbers for the subbasins are shown in **Appendix B**, as well as the calculations for the curve number method.

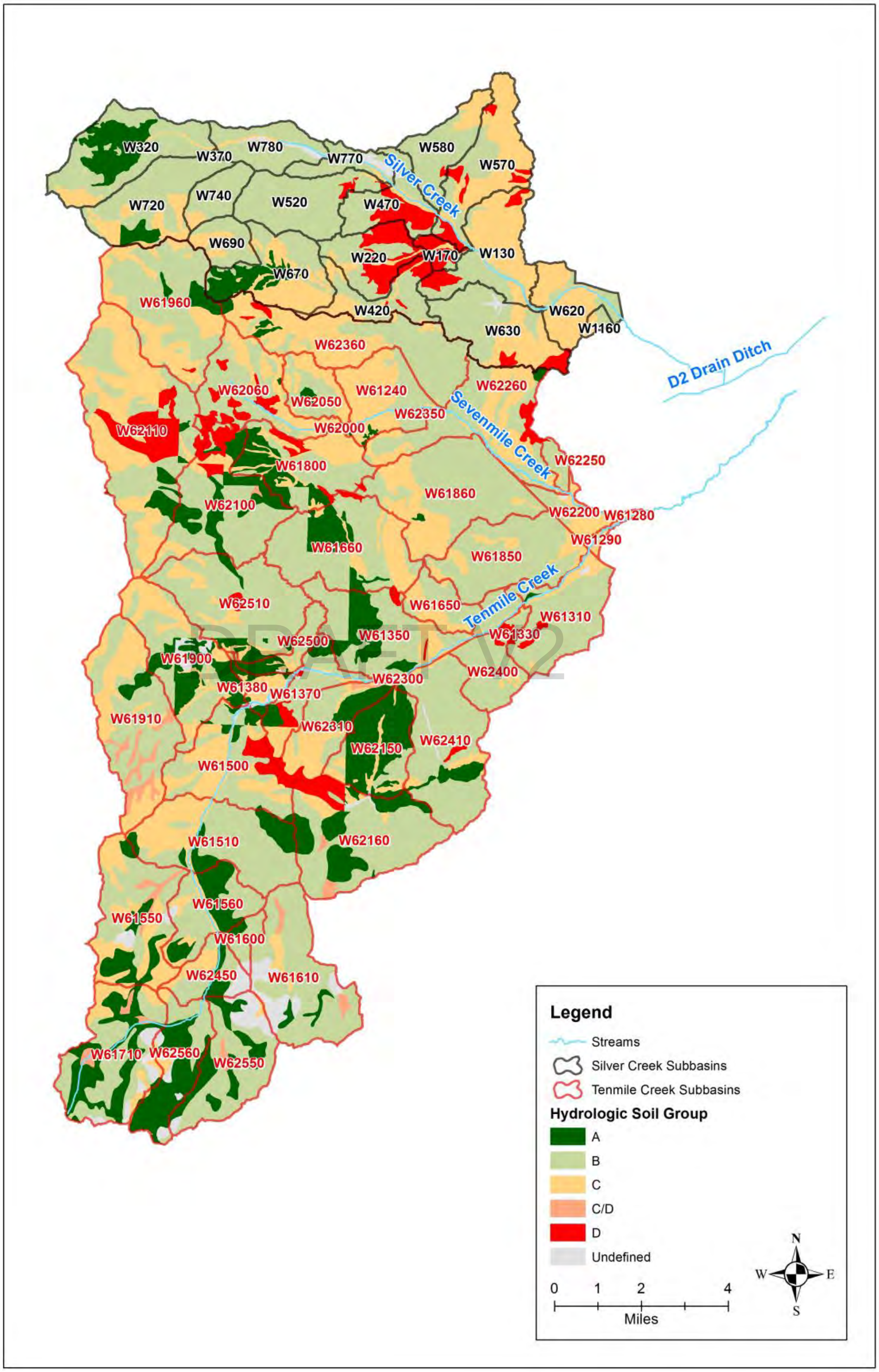

Figure 4-3. Hydrologic soil groups of the study area watershed.

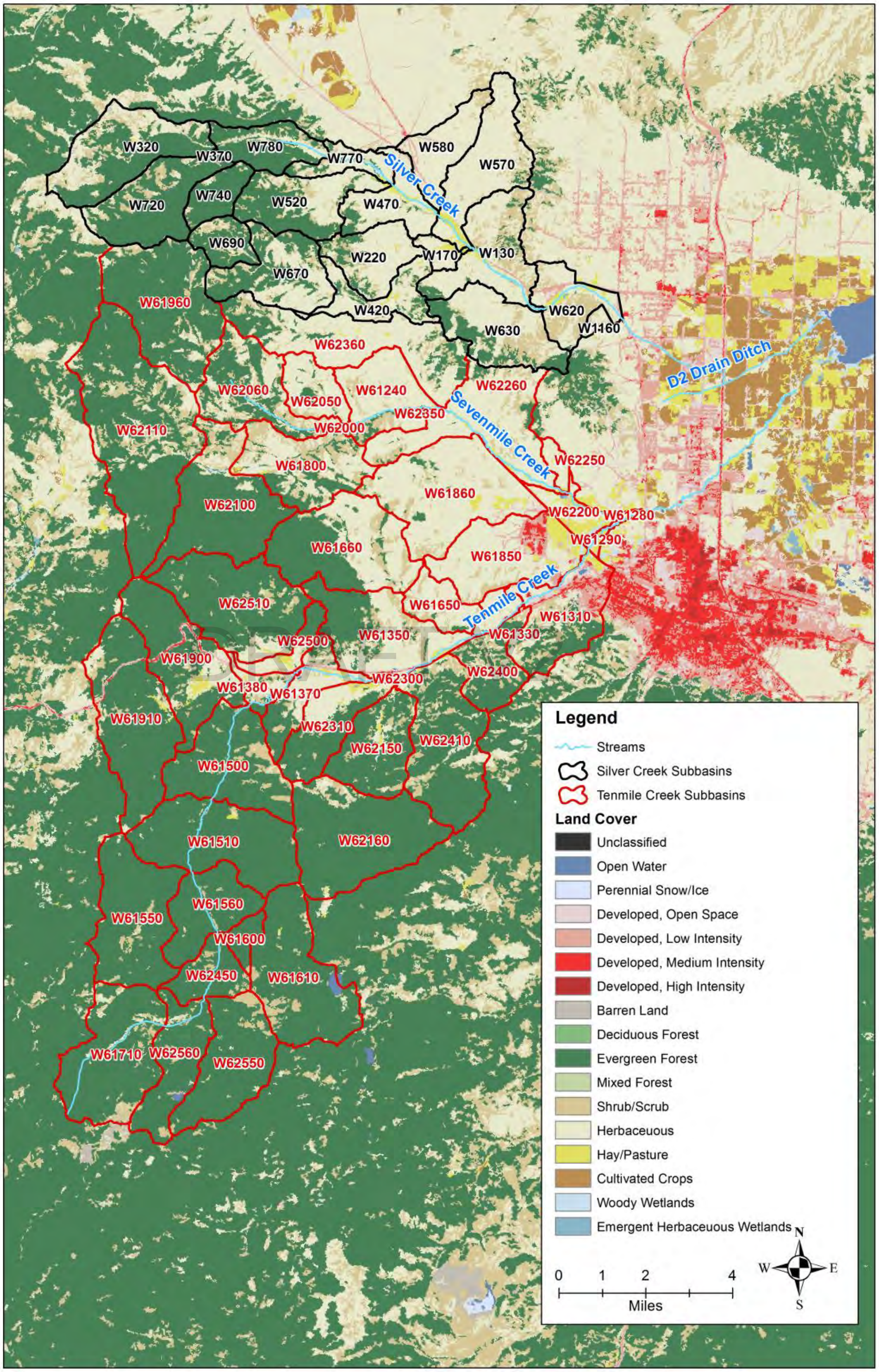

Figure 4-4. Land use types within the study area watershed.

4.3.3 TRANSFORM

The SCS Dimensionless Unit Hydrograph method requires the lag time to calculate runoff volume for the basin. Lag time was calculated using the Curve Number Lag Method using the following equation:

$$L = (l^{0.8}(S+1)^{0.7}) / 1900Y^{0.5}$$

where L equals the lag time in hours; l is the hydraulic length of the catchment in feet; Y represents the average watershed land slope in percent. Average watershed land slope is calculated with the equation:

$$Y = 100(CI)/A$$

where C is the sum of the length of the contour lines that pass through the watershed drainage area on the USGS quadrangle sheet in feet; I is the contour interval used on the quadrangle sheet in feet; and A is the drainage area of the basin, in square feet. The parameter S in the Lag equation is a storage term and is defined as:

$$S = (1000 / CN) - 10$$

in which CN represents the dimensionless curve number described in Section 4.3.2.

Both the hydraulic length of the catchment and the average watershed land slope were calculated using ArcGIS 10.4 with the LiDAR and 10-m DEM datasets, respectively. The path of the hydraulic length for each subbasin is shown in Figure 4-5. The slope tool within ArcGIS calculates slope for each cell of the DEM, from which an average is then obtained. In comparisons performed in previous studies, the average basin slope obtained through the ArcGIS slope tool compared well to the same parameter obtained by measuring contour lines. The method for calculating lag time and time of concentration was developed with topography from USGS quadrangle maps using the length of contour lines and contour interval within the basin. The topography shown on those maps is the same dataset as the USGS 10-m DEM. Therefore, the USGS 10-m DEM dataset was used for the average basin slope calculation to best align with how the method was developed.

HEC-HMS then uses the lag time parameter to internally calculate the time of concentration (t_c) for the watershed using the following equation:

$$t_c = L / 0.6$$

The results for Curve Number, hydraulic length, average watershed slope, lag time, and time of concentration are provided in **Appendix B**.

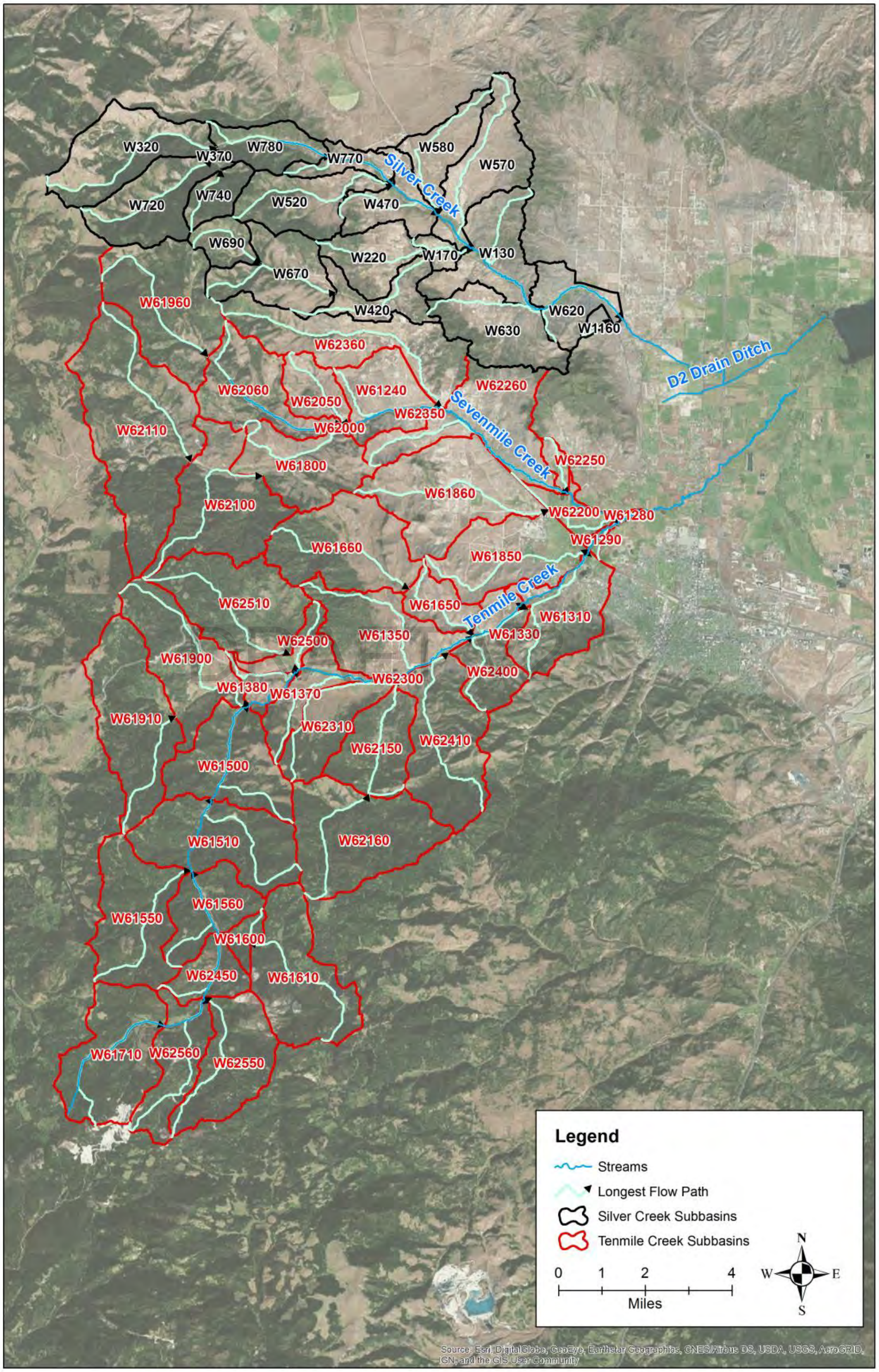

Figure 4-5. Longest flow paths (hydraulic length) within subbasins.

4.3.4 ROUTING

The Muskingum-Cunge method was used to route the runoff hydrograph through the watershed. This routine approximates the diffusion method, allowing the model to describe the physical nature of the basin and thus the attenuation potential. The HEC-HMS model allows the user to define an eight-point cross section to describe the channel and overbank geometries, roughness values, lengths and slopes for each reach. Routing reaches were delineated using ArcGIS 10.4. The eight-point channel cross sections, lengths and slopes were created for each reach using the best available topographic data for each subbasin. Manning's n roughness values were assigned based on site visits, aerial photography, literature values, and engineering judgment. Channel values varied throughout the simulated reaches from 0.040 – 0.050 to represent a meandering channel with stones and objects of variable form roughness. Manning's values of 0.040 – 0.12 were used in the overbanks to describe floodplains ranging from grasses to dense vegetation.

4.3.5 RESULTS

Because flood flow timing from each basin is desired, the timeframe for each model was set to January 1, 2017 at 0:00. Peak flow and time to peak results from the rainfall runoff analysis for select recurrence interval floods are provided in **Table 4-6**.

Table 4-6. Peak Flow and Time to Peak of various recurrence interval floods for Tenmile Creek and Silver Creek at Green Meadow Drive.

Event	Tenmile Creek		Silver Creek	
	Peak Flow (cfs)	Time to Peak (hrs)	Peak Flow (cfs)	Time to Peak (hrs)
0.2%	6,500	17.1	2,110	15.3
1%	2,980	18.2	1,030	15.8
2%	2,020	18.9	623	16.5
4%	1,270	18.1	377	16.4
10%	727	18.2	181	18.0

Figure 4-6 and **Figure 4-7** provide the rainfall runoff hydrographs for select recurrence interval floods for Tenmile Creek and Silver Creek, respectively, at Green Meadow Drive.

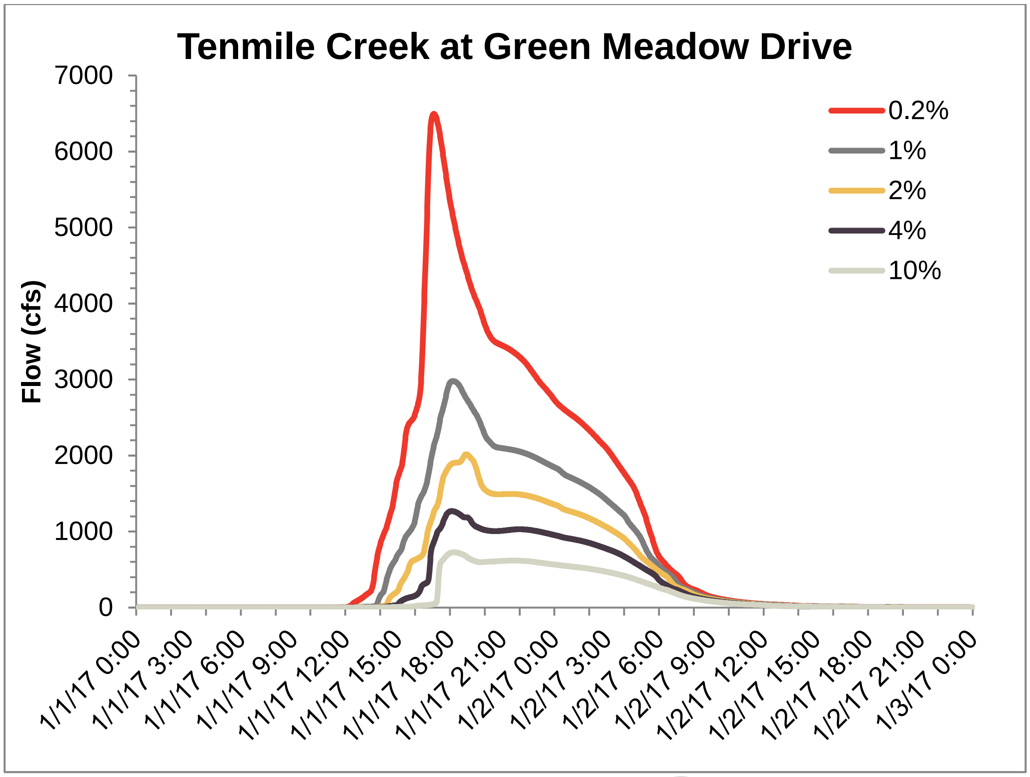

Figure 4-6. Tenmile Creek outlet hydrographs for select recurrence interval floods.

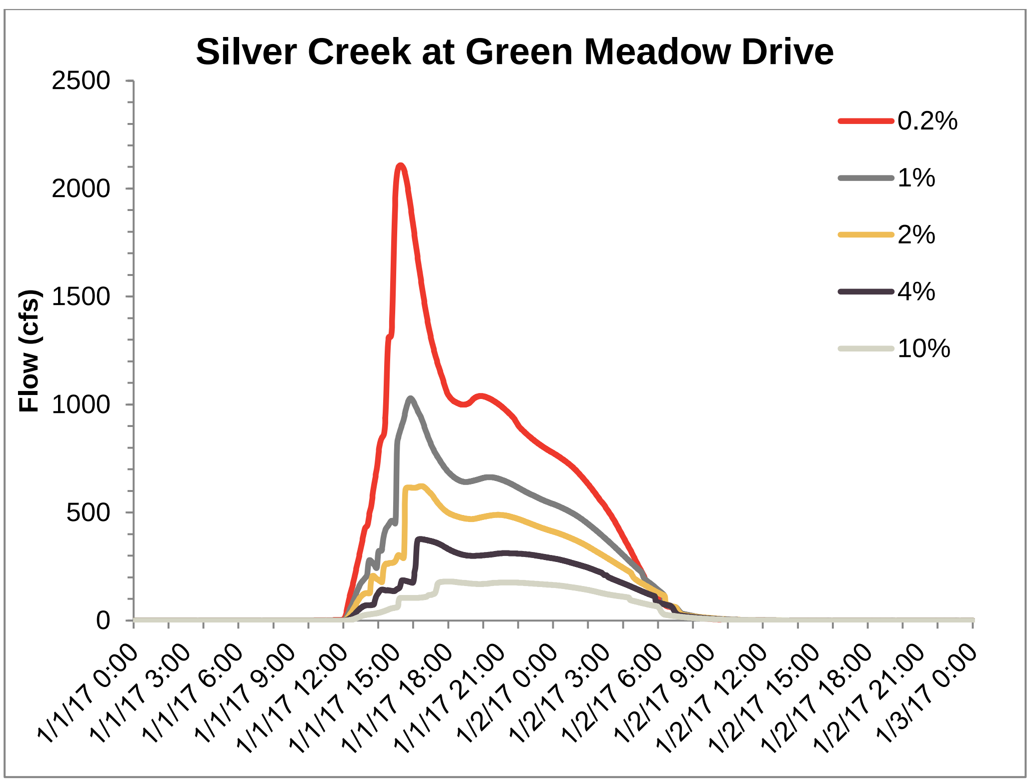

Figure 4-7. Silver Creek outlet hydrographs for select recurrence interval floods.

Initial results from the rainfall runoff model for Tenmile Creek were compared to previous studies and peak flows generated via other methodologies. It was determined that adjustments to basin parameters in the upper watershed were required to produce realistic results. The initial abstraction parameter was modified for each recurrence interval storm until peak flows resembled those from the USGS flood frequency results for USGS gage near Rimini (06062500) and the gage near Helena (06063000) as published in SIR 2015-5019-F.

Without gage data, the Silver Creek hydrographs cannot be verified for accuracy. However, no parameters were adjusted for the Silver Creek subbasins since no measured data exists for comparison.

4.4 DISCUSSION AND RECOMMENDED DISCHARGES

Tenmile Creek and Silver Creek have been studied several times throughout the last five decades. The primary limitation for development of flood frequency information for these basins may be attributed to lack of measured data to facilitate model development and calibration. Additionally, these basins appear to exhibit different flooding mechanisms, likely attributed to their dissimilar basin characteristics. Certainly, ample peak flow record exists on Tenmile Creek at two USGS gage locations. However, transfer of flood frequency results downstream of Sevenmile Creek is likely not reliable due to its significant contributing drainage area and differing basin characteristics. Inconveniently, the USGS gage near Helena was not operational during 2011 flooding; however, the USGS gage near Rimini was operational. This gage is high in the watershed though so less can be inferred of conditions lower in the basin. The most recent flooding in the Helena Valley occurred in March 2014, and flows were recorded on both gages. **Figure 4-8** shows the 2014 flow record for the USGS gage near Rimini (06062500) and the gage near Helena (06063000). Review of the flow record is worth consideration to illustrate the complexities in the watersheds.

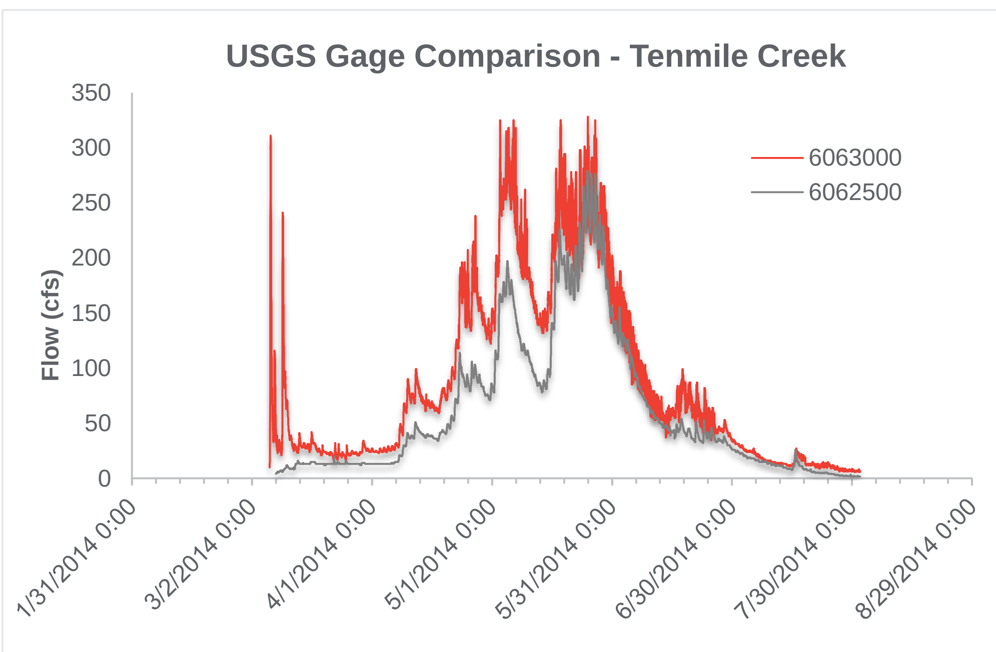

Figure 4-8. Tenmile Creek hydrographs at Rimini and Helena gages for 2014.

When the Helena Valley experienced flooding in March 2014, the Helena gage was exhibiting peaking conditions while the Rimini gage remained low-flow (not generating runoff). Early spring warm spells combined with rain are common in the Helena area and are phrased “Chinook” conditions. These conditions result in some snowmelt at lower elevations combined with rain on potentially frozen ground to produce flooding conditions. Interestingly, the peak at the Helena gage is a similar flowrate to what was measured for several occurrences in May during snowmelt runoff. No flooding was reported in May of 2014 yet the gage recorded similar peak flows to March flooding. This observation suggests Sevenmile Creek was contributing significant runoff during March that combined with flow from the lower Tenmile Creek watershed to cause flooding, yet flooding could not be deciphered from the Helena gage record.

Flooding from Tenmile Creek can be considered a “mixed population”, meaning flooding may result from snowmelt only, rain-on-snow events, or rainfall only events. When the conditions during the 2011 event are examined, a larger than normal snowpack accumulated throughout winter, and the cooler-than-normal spring. Late May and early June experienced notable rainfall on the snowpack, followed by rapid warming and more rain. As mentioned, the only streamflow record for this event is at the Rimini USGS gage that shows several diurnal peaks, with the true peak occurring on June 7^{th}.

Because flood volume and timing of basins are of interest, and the circumstances responsible for flooding in Helena Valley are complex, a standardized hydrograph generation approach may be the most appropriate to produce results that are relative to the characteristics of each basin and are useful for comparing peak flood timing and volume for design purposes.

The complexities of the mechanisms that generate flood flows into the Helena Valley may suggest a more robust and complex hydrologic model, such as a rain on snow or a continuous simulation model be developed. Continuous simulation or rain on snow event based models could provide more confidence in results if sufficient data is available for model construction and calibration. These models require significant additional data beyond what is available in these watersheds. Development of this type of model will require reaching beyond the watershed boundaries for limited data, in addition to developing and estimating additional data and parameters that have likely never been measured in these watersheds. They also require several assumptions that are usually sensitive and can produce inaccurate results without calibration to measured data. Without measured flow data for Sevenmile Creek, Tenmile Creek downstream of Sevenmile Creek, and for Silver Creek, there is not sufficient data to produce a reliable calibration. Introducing advanced complexity into the hydrologic analysis without data for calibration does not likely generate more reliable results.

Rainfall-runoff hydrographs have been developed for Tenmile and Silver Creek basins to supplement flood flow estimations of previous studies which have relied upon USGS regression equations, or transfer of gage analysis to below Sevenmile Creek confluence. **Table 4-7** and **Table 4-8** summarize the peak flows calculated for Tenmile Creek and Silver Creek, respectively, for the current study and past studies.

Table 4-7. Summary of discharges for Tenmile Creek at Green Meadow Drive

Source	10%-Annual-Chance	4%-Annual-Chance	2%-Annual-Chance	1%-Annual-Chance	0.2%-Annual-Chance
1982 FIS (Morrison-Maierle)	1,200	NA	2,535	3,365	6,700
2006 USGS Technical Support Data Notebook	1,200	NA	2,300	2,910	4,610
2017 USGS Basin Characteristics Regression	1,020	1,470	1,840	2,270	3,410
2017 Translation of Flood-Frequency Analysis of Gage Data (Helena, 06063000)	915	1,359	1,842	2,510	5,173
2017 HEC-HMS (HEC-HMS Element Tenmile Creek Outlet)	727	1,270	2,020	2,980	6,500

Table 4-8. Summary of discharges for Silver Creek at Green Meadow Drive

Source	10%-Annual-Chance	4%-Annual-Chance	2%-Annual-Chance	1%-Annual-Chance	0.2%-Annual-Chance
1982 FIS (Morrison-Maierle)	340	NA	560	660	910
2006 USGS Technical Support Data Notebook	177	NA	487	701	1,440
2017 USGS Basin Characteristics Regression	437	720	982	1,300	2,280
2017 HEC-HMS (HEC-HMS Element Silver Creek Outlet)	176	377	623	1,030	2,110

Comparison of the HEC-HMS 100-year peak flow (1,030 cfs) with 100-year flow estimations from USGS regression (1,300 cfs) indicates an acceptable level of agreement. Validation of Silver Creek runoff hydrographs at shorter return intervals should be completed in the future. Agreement between HEC-HMS flow (377 cfs) and USGS regression (720 cfs) at 25-year peak flows is much lower.

5.0 HYDRAULIC ANALYSIS

HEC-RAS version 5.0.3 (**Reference 15**) was used to model surface water hydraulics throughout the study area. A combination of one- and two-dimensional techniques was required to model the complex flow regimes. One-dimensional (1D) modeling is well-suited for calculating water surfaces within the channels of Tenmile Creek and the D2 Ditch, while two-dimensional (2D) modeling is best served to simulate sheet flow flooding across the urbanized areas of the Helena Valley. The following sections describe the existing conditions (EX) model. In addition to the EX model, the scope of this report is to simulate the proposed improvements outlined in the FEMA HMGP grant for the Trap Club Detention Pond. For this phase, those improvements serve as the proposed conditions (PC) model. The value of this approach is that the evolving analysis will be used to plan, design, permit, and implement future flood mitigation projects that ensure no adverse impacts are imposed upon existing landowners within the Helena Valley. Future improvements within the Helena Valley are anticipated and will be guided by the results of this analysis and the concepts proposed in the VFMMP. Once a mitigation project is implemented, the as-built condition will be incorporated into the current EX model. Then, planned improvements will be incorporated into the PC model and compared to EX to understand implications of the proposed project. Construction of the Phase I valley wide EX model is described in the following sections. It is important to note that during actual flood events, sandbagging efforts and culvert plugging are likely widespread across the valley and those conditions are not reflected in these simulations.

5.1 ONE DIMENSIONAL MODELING

One dimensional models were utilized for Tenmile Creek and the D2 Drain Ditch. Both one dimensional reaches were configured to interface with a two dimensional domain. Details of the one dimensional modeling construction (D2 Drain Ditch) and modifications (Tenmile Creek) are described.

5.1.1 MODEL EXTENTS

5.1.1.1 TENMILE CREEK

As mentioned, the USGS HEC-RAS model developed in 2006 for the current effective FEMA FIS was used as a base model for modification for the current study. The entire downstream portion of the model from confluence with Prickly Pear Creek to just upstream of the Tenmile Creek Overflow spill location was utilized. The model was truncated upstream from RAS River Station 36799.

5.1.1.2 D2 DRAIN DITCH

The one-dimensional portion of D2 Drain Ditch was modeled from its mouth at Lake Helena to just downstream of Interstate 15. The remaining portions of the D2 Drain Ditch upstream from the one dimensional extent were simulated in the two-dimensional domain.

5.1.2 BOUNDARY CONDITIONS

5.1.2.1 TENMILE CREEK

The 0.2%, 1%, 2%, 4%, and 10% annual chance event hydrographs from the HEC-HMS rainfall runoff analysis were input as the upstream boundary condition for the unsteady state simulation run. The downstream boundary condition was preserved from USGS which was set to Normal Depth with an assumed friction slope of .004.

5.1.2.2 D2 DRAIN DITCH

The D2 Drain Ditch was initially ran in an unsteady simulation as a downstream boundary condition to the two dimensional domain. As mentioned in the HEC-RAS 2D Modeling User Manual (**Reference 160**), a direct 2D to 1D connection has the highest degree of instability in HEC-RAS. The connection was configured for stable simulations but added considerable runtime. These results were compared to an identical simulation but where a rating curve was used as the downstream boundary condition to the 2D domain. Results were nearly identical so the direct connection was abandoned to improve model stability and decrease model run times. Therefore, the D2 Drain Ditch downstream of Interstate 15 remains as a steady state simulation of 10 profiles including: 10, 50, 100, 150, 200, 250, 500, 750, 1000, and 1500 cfs. The downstream boundary condition was set to Normal Depth with an assumed friction slope of .005 that was measured from the terrain slope.

5.1.3 CROSS SECTIONAL GEOMETRIES

5.1.3.1 TENMILE CREEK

All Tenmile Creek cross sectional geometries were preserved outside the vicinity of the Overflow location. The overbank geometries for all cross section upstream of RAS River Station 22616 (just downstream of Valley Forge Drive) were modified to reflect the best available LiDAR topography (collected in 2012). Channel bathymetry was preserved for these modified sections. Several cross sections were added and some existing sections realigned to reflect current conditions. All cross sections between McHugh and Green Meadow Drive were clipped to the extent of the highest terrain of the left overbank, to allow addition of lateral weirs and enable interface with the 2D domain. Ineffective flow stations were revised according to a 2:1 contraction ratio and a 1:1 contraction ratio and their elevations adjusted to the top of deck.

5.1.3.2 D2 DRAIN DITCH

All cross sections placed on D2 Drain ditch were new cross sections from field survey collected in October 2016. The cross sections were limited to the top of bank of the ditch. Once flow overtops the top of bank (in many locations a berm), flow spills from the main channel and flooding will likely occur. As mentioned, for this phase of modeling, the approach for D2 Drain Ditch is to understand its maximum capacity along its reach to Lake Helena, and to develop a rating curve for the 2D domain downstream boundary condition. Any proposed projects within the Helena Valley should be simulated to ensure discharges entering the D2 Drain Ditch do not increase and potentially adversely impact property owners downstream.

5.1.4 HYDRAULIC STRUCTURES

Several hydraulic structures are located throughout Tenmile Creek and D2 Drain Ditch modeled reaches. All structures on the Tenmile Creek reach were incorporated from the existing USGS RAS model. Structures along D2 Drain Ditch were surveyed by Robert Peccia and Associates in 2016 and incorporated into the analysis according to that survey. The naming convention for each crossing on D2 Drain Ditch was preserved from the VFMMP.

Table 5-1. Tenmile Creek Hydraulic Structures

River Station	Crossing	Type
34,005	-	Lateral Weir
33,129	Green Meadow	Bridge
33,005	-	Lateral Weir
28,405	-	Lateral Weir
28,333	McHugh	Bridge
27,955	-	Lateral Weir
23,272	N. Montana	Bridge
22,886	Valley Forge	Bridge
17,800	I-15 and Frontag	Bridge
8,953	Sierra	Bridge
6,874	Footbridge	Bridge
4,464	Private Crossing	Culvert

Table 5-2. D2 Drain Ditch Hydraulic Structures

River Station	Crossing	Type
12,909	Glass Drive 1	Culvert
12,672	Glass Drive 2	Culvert
11,709	Crossing F	Culvert
11,425	Crossing E	Culvert
9,944	Arrowhead Crossing	Culvert
8,031	Crossing D	Culvert
6,544	Crossing C	Culvert
6,084	Crossing B	Culvert
3,655	Crossing A	Culvert

5.1.5 ROUGHNESS COEFFICIENTS

The Manning's roughness values assigned within the hydraulic model were determined based on field observations, aerial photography, *Table 3-1* from the HEC-RAS Hydraulic Reference Manual (**Reference 17**), and Chow's *Open Channel Hydraulics* (**Reference 18**). The ranges of values selected are as follows:

	Main Channel	Overbank Area
Tenmile Creek	.035 - .050	.040 - .12
D2 Drain Ditch	.035- .050	.050

Roughness values were not modified from USGS values in the Tenmile Creek model. Both streams utilized single overbank/channel/overbank Manning's roughness values since, in general, changes in roughness characteristics were observed at a large scale.

5.1.6 AREAS OF NON-CONVEYANCE

It is apparent that the analyzed reach is comprised of multiple areas that are considered backwater or can be assumed to contain limited conveyance in the stream wise direction upon inspection of the inundation results. The Ineffective Flow Area method was implemented to correctly and conservatively calculate the total effective conveyance for each cross section for these areas. Cross sections bounding structures were also assigned areas of non-conveyance to force the one-dimensional steady state model to more accurately calculate the headloss due to flow contraction and expansion. The flow contraction and expansion areas were calculated using a 1:1 (stream wise: lateral) and a 2:1 ratio, respectively. The ratios of expansion and contraction were developed using the cross sectional velocities, the *HEC-RAS Hydraulic Reference Manual* (**Reference 17**)*,* and engineering judgment.

Several blocked obstructions were designated in the Tenmile Creek USGS model. Most obstructions were logical upon inspection of the terrain features; however, some obstruction were modified or removed to reflect current conditions since no documentation supporting the existing designations was located.

5.2 TWO DIMENSIONAL MODELING

The Tenmile Creek Overflow was modeled in two dimensions by USGS during the 2006 FIS update. The open source model FESWMS within the proprietary graphical user interface program SMS was used to develop the computational mesh, perform the calculations, and generate results. It was determined for this updated study that because of significant advancements in computer technology and software, it was appropriate to develop a new analysis within HEC-RAS 5.0.3.

5.2.1 TERRAIN

A terrain was constructed utilizing the 2012 LiDAR Bare Earth DEM as a base surface model. Field survey collected by Robert Peccia and Associates in 2012 and in 2016 was superimposed over the LiDAR where conditions were known to have changed, and where culverts were located. HEC-RAS 5.0.3 has the capability to simulate culvert hydraulics within the 2D domain. This capability requires the cell within the computational mesh to have an elevation lower than the culvert invert elevation. To accommodate this requirement, culvert invert points collected by field survey were buffered in ArcGIS by 4' to generate a polygon. The polygon was converted to raster and the surveyed elevations lowered by 0.25' and mosaicked over the terrain.

Traditional flood mapping for regulatory purposes often requires use of the bare earth surface. For this study, it was suspected that structures in flowpaths may be affecting flow direction, quantity, and velocity, so it was determined that structures should be incorporated into the terrain. Included within the 2012 LiDAR deliverable package was a polygon layer representing building footprints. This layer was attributed with an arbitrary 20' height, added to the terrain using raster math, and mosaicked over the terrain surface. It was determined that this approach will conserve flow volume, where as other approaches to simulate structures within the 2D domain (high roughness), may affect volume results.

5.2.2 COMPUTATIONAL PARAMETERS

One computational mesh was generated for the entire Helena Valley area generally located between Tenmile Creek for a southern and western boundary, Silver Creek for the northern boundary and Interstate 15 and North Montana Avenue for the eastern boundary. The computational mesh was generated in HEC-RAS 5.0.3 with a 25′ x 25′ cell spacing parameter. In addition to this spacing, breaklines were added for roadways that were elevated relative to the surrounding terrain. Breaklines were also added in major flowpaths and drainage channels. Most roadway breaklines utilized the same general mesh spacing; however, channel breaklines were reduced to a smaller spacing.

	Cell Spacing (ft)
Minimum Breakline	5
Maximum Breakline	45
General Mesh	25

The mesh cell size and computation time step are related factors for developing a 2D model. Early iterations of the model were course. As detail was added to the 2D domain, the cell spacing decreased to capture localized hydraulics, while decreasing the time step to target a Courant number of 1.

The diffusive wave option was utilized to perform all simulations with a time step of 1 second. To adequately capture runoff volume and peaking conditions, the computational time widow was established to ensure the rising limb of all hydrographs from Tenmile Creek and Silver Creek were represented in the analysis, and that ample time was provided to allow peak flows to travel through each system.

The computation time window was set to January 01, 2017 at 1200 to January 02, 2017 at 1200 for a 24 hour simulation. This timeframe references the hydrologic model, which begins January 01, 2017 at 0000. The hydraulic simulation begins 12 hours after rainfall begins, when appreciable flow enters the model domain, and ends 12 hours after rainfall stops in the watershed.

Most computation settings and tolerances were left at the RAS default with the exception of water surface tolerance and volume tolerance. Those settings were modified from the default 0.01 to 0.05 for both parameters.

5.2.3 BOUNDARY CONDITIONS

The 2D domain requires boundary conditions. The 2D domain adjoins the Tenmile Creek 1D model through lateral weirs which were placed along the spill crest adjacent to the channel. As the Tenmile Creek 1D reach experiences the increasing flow as a result of its hydrograph boundary condition, once the calculated water surface elevation in the main channel exceeds the lateral weir elevation (spill crest elevation), flow is passed from the 1D domain into the 2D domain. This flow exchange serves as the upstream boundary condition. HEC-RAS 5.0.3 allows selection of normal weir equation or use of the 2D flow equations to calculate flow transfer. This analysis evaluated both options. In general, it was observed that the 2D equations produced more flow into the 2D domain than when the weir equations were used. Furthermore, there was less head differential between the calculated 1D and 2D water surface elevations when the 2D equations were used. All lateral weirs utilized the 2D equations with the exception of 27955 that contains a culvert where the 2D equations cannot be used. For Silver Creek, the upstream boundary condition is the hydrograph results from the hydrologic model. As mentioned, timing for all boundary conditions is relative to the hydrologic model, with the intent to understand the timing of how flow moves through each system.

The downstream boundary condition for the 2D domain is the D2 Drain Ditch rating curve. This type of boundary condition was found to produce very similar results to those when D2 Drain Ditch was directly connected to the mesh. As mentioned, the direct connection was unstable, especially for large, infrequent flood events where Interstate 15 and Frontage Road are overtopped. For utilization of the rating curve, additional normal depth boundary lines were placed north and south of D2 Drain Ditch, to capture flow overtopping Interstate 15 and Frontage Road. The rating curve is shown on **Figure 5-1**.

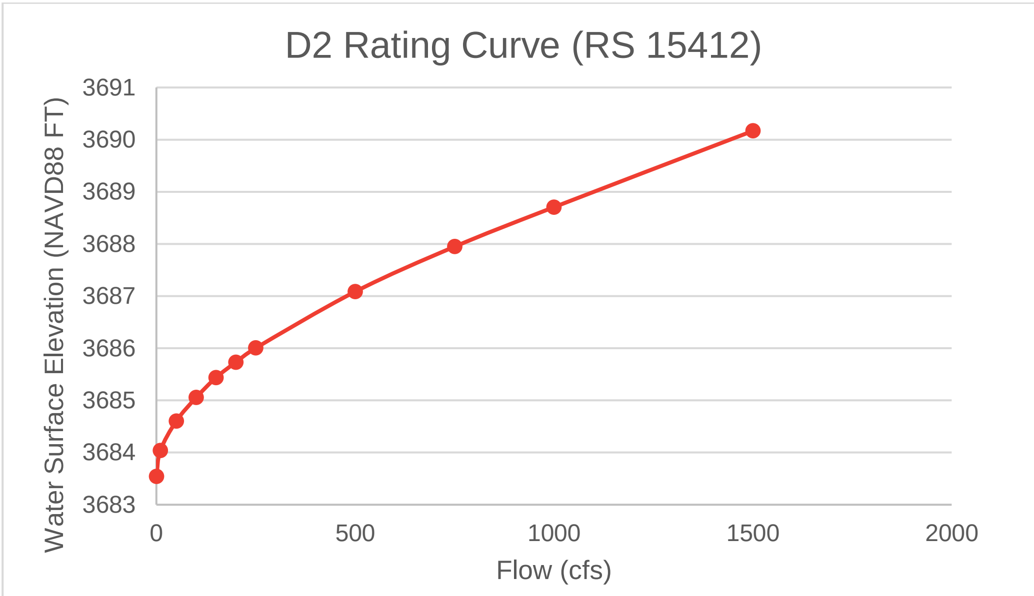

Figure 5-1. Primary downstream 2D boundary condition for frequent floods derived from River Station 15412.

5.2.4 HYDRAULIC STRUCTURES

The 2012 field survey conducted by Robert Peccia and Associates revealed hundreds of drainage culverts throughout the Helena Valley. The majority of culverts are small diameter and some are plugged. These culverts have an insignificant role conveying flood flows. However, larger diameter culverts exist and convey ditch flow through road embankments. It was determined all culverts with diameters less than 12" will not convey substantial flow nor affect flow direction. The majority of culverts 18" and larger were incorporated into the 2D domain through the Storage Area/2D Connection tool. In all cases, the 2D equations were used to calculate flow over the connection.

The Upper D2 Drain Ditch between Interstate 15 and its upstream origin was simulated within the 2D domain. It was unclear from inspection how and where sheet flow inputs would enter the upper reach of D2 Drain Ditch. These structures were incorporated using field survey collected by Robert Peccia and Associates in October 2016.

A total of 78 hydraulic structures (Storage Area/2D Connections) exist in the 2D domain. The connections act as breaklines in the computational mesh where cell spacing was varied to capture localized hydraulic conditions between culverts and the surrounding terrain. HEC-RAS 5.0.3 is currently limited in which cells interact with culverts in the connection. The cells interacting with the culvert must touch the connection line. To accommodate this limitation, lines were drawn along the top of embankment on the upstream side from the left, through two bends, and finish along the top of embankment on the downstream side. It is anticipated that future versions of RAS will allow input of culvert invert coordinates, rather than a station along an alignment, to associate these one-dimensional calculations with the 2D mesh computations. The final existing conditions (EX) model layout is shown in **Figure 5-2**.

RESPEC

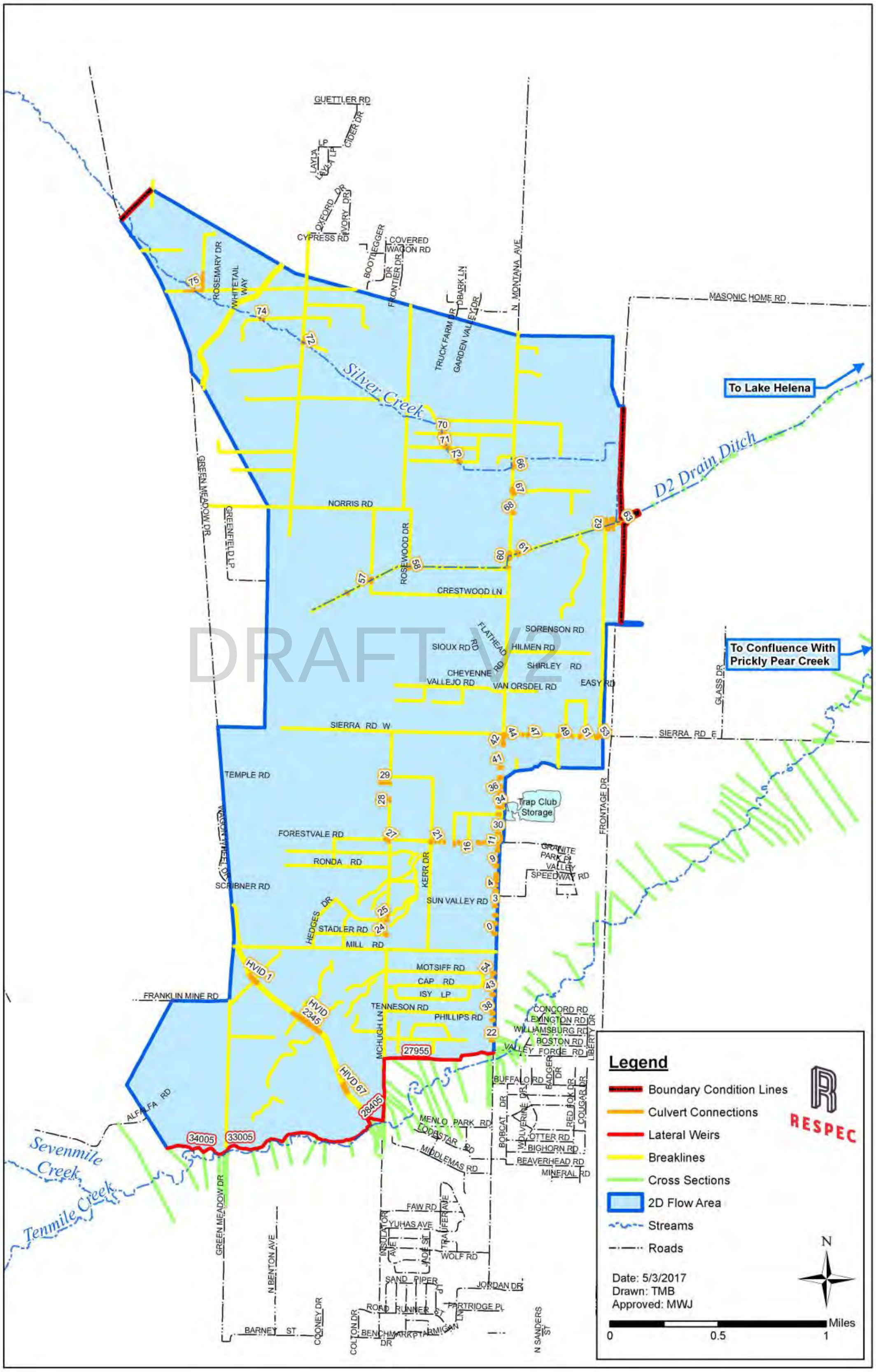

Figure 5-2. Final valley wide existing conditions (EX) model layout.

5.3 PROPOSED CONDITIONS – PHASE I: TRAP CLUB IMPROVEMENTS

The first project in the implementation of the VFMMP is to formalize the Trap Club as a flood detention facility and enhance nearby drainage infrastructure. In addition to formalizing the Trap Club as a flood detention facility, drainage improvements are also proposed. Enhanced drainage infrastructure includes an upsize of the culvert crossing under the Forestvale Drive and North Montana Avenue intersection, grading of the east ditch along North Montana Avenue and Sierra Road between Forestvale Drive and Interstate 15, an upsize of the culvert under Sierra Road at Interstate 15, and grading of the Interstate 15 ditch between Sierra Road and D2 Drain Ditch. This is the project awarded federal funding in 2012 as a result of the Presidential Disaster Declaration following 2011 flooding. It is important to note that the proposed changes are conceptual designs. The final design phase for Phase I will occur later and the model will be utilized to iterate and optimize the final design.

5.3.1 TRAP CLUB FLOOD DETENTION FACILITY

This work will include design, permitting, and construction of a flow diversion structure into the Trap Club gravel pit located just downstream of the Forestvale Road and North Montana Avenue intersection and sizing of a mobile pump system. In addition to the diversion structure to allow controlled inflow into the Trap Club pit, a mobile pump station will be sized to pump detained floodwaters from the Trap Club detention pond once floodwaters recede downstream. Because the theme of the simulation is to portray a worst case scenario, coincident flooding of Tenmile Creek and Silver Creek, the Trap Club pond was not incorporated into the hydraulic analysis. All flow and water surface elevation results assume the Trap Club pond is full and cannot accept additional flow. In an actual flood event, the Trap Club pond will be filled slowly while the flood peak enters the area, effectively reducing peak flow to downstream infrastructure. Additional modeling scenarios incorporating storage benefits are anticipated during final design of the Trap Club flood control facility.

5.3.2 CULVERT UPGRADES

Two culverts were proposed for upgrade in the FEMA HMGP grant application. The crossing under the Forestvale Drive and North Montana Avenue intersection is currently a 42″ diameter round culvert that will be increased to a 55″ x 88″ squash corrugated metal culvert.

The culvert under Sierra Road near Rossiter School and Interstate 15 will also be upsized. The existing culvert is a 36″ diameter round culver that will be increased to a 60″ diameter round culvert.

5.3.3 DITCH GRADING

A conceptual ditch geometry for the east ditch along North Montana Avenue between Forevestvale Drive and Sierra Road, the south ditch along Sierra Road between North Montana Avenue and Interstate 15, and the west ditch of Interstate 15 between Sierra Road and D2 Drain Ditch was graded into the existing terrain surface. The graded ditch contains a 20′ bottom width with 2:1 side slopes that daylight to the existing terrain.

The ditch profile along Sierra Road between North Montana Avenue and Interstate 15 is shallow. There is a large “hump” that pushes flow northward across Sierra and into the development to the north. The grading design substantially lowered the profile for positive drainage to the upgraded culvert under Sierra Road. Numerous additional culverts exist along Sierra that were not changed in this simulation.

The effectiveness of the ditch grading is limited by the capacity of the existing culverts and backwater continues to form and spill across Sierra Road. These culverts also need to be upsized to realize the maximum benefit of the ditch grading. This work will likely occur during the next phase of VFMMP implementation which will focus on D2 Drain Ditch capacity enhancements. Lastly, where the ditch profile was lowered along Sierra, the daylight slope encroaches on the Sierra Road prism. This grading was simulated to illustrate the fact that the large capacity ditch is significantly limited by the existing small diameter culverts. All ditch grading will be refined during final design of Phase I through model iterations and recognizing existing infrastructure constraints.

With the exception of the Trap Club storage area, all drainage enhancement elements from the conceptual design were superimposed over the existing conditions model to create the proposed conditions model. All conceptual design elements within the FEMA HMGP grant are shown in **Figure 5-3**.

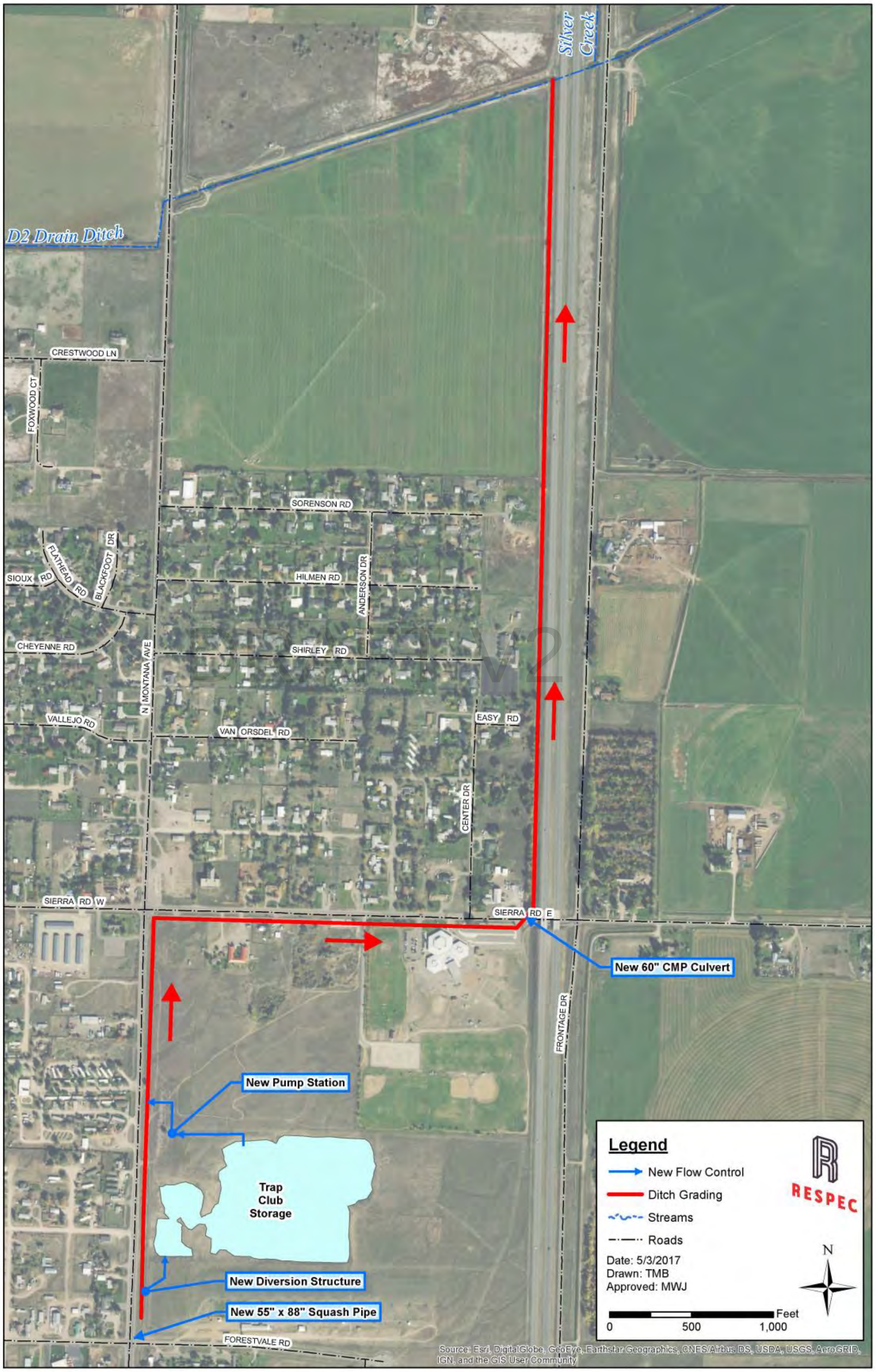

Figure 5-3. Conceptual design proposed in FEMA HMGP grant.

5.4 HYDRAULIC RESULTS

Since the 2011 flood triggered the disaster declaration and that event is generally considered to approximate a 25-year recurrence interval (4% annual chance) flood, those results are showcased and are targeted to maximize effectiveness of mitigation projects. Likely for the Helena Valley it is not feasible to design flood mitigation projects to the 500-year or even 100-year events. However, the 100-year event is of interest and it is anticipated mitigation activities will improve those existing flooding conditions. It is important to note that these results are not currently regulatory and inundation areas will differ from regulatory mapping.

5.4.1 INUNDATION MAPPING

Flood inundation maps were prepared to illustrate results from hydraulic modeling. The 4% annual chance flood event (25-year) and the 1% annual chance flood event (100-year) were determined to be the primary events of interest. Inundation maps were prepared in an index format and included in **Appendix C** for the 4% annual chance event, the 1% annual chance flood event, and the steady state maximum capacity results for lower D2 Drain Ditch.

5.4.2 AREAS OF INTEREST – PEAK FLOW

The profile tool in RASMapper was used to extract time-series flow for numerous locations within the 2D domain. Additionally, one dimensional results were reviewed. A summary of peak flows at the upstream extent of Tenmile Creek where flow leaves the system is provided in **Table 5-3**. It is important to note that because this is an unsteady state flow simulation, peak flow rates cannot be added to achieve continuity. Continuity is preserved in total volume moving through the system. Additionally, these peak flows represent major flowpaths. Minor flowpaths exist that were not included in these results.

Table 5-3. Tenmile Creek Overflow Existing Conditions Flow Results – Upstream.

Location of Peak Flow Results	4% Annual Chance Event (cfs)	1% Annual Chance Event (cfs)
Tenmile Creek Channel Upstream of Reach	1,270	2,980
Leaving Upstream of Green Meadow Drive	370	1,940
Leaving Upstream of HVID Canal	170	191
Leaving Upstream of McHugh Lane	104	172
Passing HVID 1 Culvert	118	787[1]
Passing HVID 2,3,4 and 5 Culverts	135	1,220[1]
Passing HVID 6 and 7 Culverts	50	54
Tenmile Creek Channel Downstream of N. Montana Ave	683	790

[1] *flow overtops HVID Canal embankment*

Within the Phase I project area (Trap Club), flows were measured at relevant locations for the existing conditions (EX), as well as the proposed conditions (PC) and are provided in **Table 5-4**.

Table 5-4. Tenmile Creek Overflow Flow Results - Phase I Project Area (Trap Club).

Location of Peak Flow Results	4% Annual Chance Event (cfs)		1% Annual Chance Event (cfs)	
	EX	PC	EX	PC
Through Forestvale Road and North Montana Ave Intersection	63	140	63	177
Across Sierra Road (West)	34	6	78	29
Across Sierra Road (East)	133	165	164	258
Through Sierra Road into Interstate 15 ditch	26	63	26	66

It is apparent from the calculated peak flows that the proposed conditions are impacting flow rates entering and leaving the project area. The flow in North Montana Ditch (east) adjacent to the Trap Club is similar for the 4% and 1% events, indicating the maximum capacity of the existing culvert and flow overtopping Forestvale Road rather than across North Montana Avenue. Peak flow across Sierra Road west and east are relative between North Montana Avenue and Interstate 15. A considerable amount of flow crosses Sierra Road west of North Montana Avenue that is not likely affected by the Phase I project and those results are not presented. Reductions of peak flows at Sierra Road (west) are reflected in the increased flows conveyed east prior to overtopping Sierra (east). Flow through Sierra Road represents the upgraded culvert near Rossiter School. An increase in peak flow is observed that reflects the increased capacity of the culvert. The flows are nearly identical between the 4% and 1% events because the pipe is at maximum capacity and excess flow is overtopping Sierra Road (east).

Peak flow results for Silver Creek and D2 Drain Ditch are of interest. No changes will occur in the Silver Creek model upstream of North Montana Avenue in and around the Sewell subdivision. However, changes are expected at the upstream size of North Montana Avenue where Tenmile Creek Overflow combines with Silver Creek flooding in addition to Interstate 15 where their flow also combines. Results for these areas are shown in **Table 5-5**.

Table 5-5. Silver Creek and D2 Drain Ditch Flow Results

Location of Peak Flow Results	4% Annual Chance Event (cfs)		1% Annual Chance Event (cfs)	
	EX	PC	EX	PC
Silver Creek Channel Upstream of Reach	377	n/a	1,030	n/a
Downstream of HVID Canal	376	n/a	929	n/a
Through Sewell subdivision	371	n/a	923	n/a
Through North Montana Ave Box Culvert (North)	53	n/a	94	n/a
Through North Montana Ave Box Culvert (South)	113	n/a	167	n/a
South to D2 Drain Ditch Upstream of North Montana Ave	192	n/a	635	n/a
D2 Drain Ditch Downstream of North Montana Ave	280	249	2,058[1]	2,040[1]
D2 Drain Ditch Downstream of Interstate 15/Frontage Road	522	522	1,822[2]	1,837[2]

[1] *flow overtops North Montana Avenue* [2] *flow overtops Interstate 15/Frontage Road*

Similar to Tenmile Creek, Silver Creek must pass through the narrow opening of the HVID Canal. However, unlike Tenmile Creek (except for overtopping events) the canal is not observed to provide substantial attenuation. Once Silver Creek passes through the HVID Canal opening, it spreads into sheet flow but stays somewhat unidirectional (unlike Tenmile Creek Overflow) until it reaches North Montana Avenue. Two 3′ x 10′ box culverts through North Montana Avenue provide some conveyance through the embankment near the Sewell subdivision; however, most of Silver Creek flooding turns south and into D2 Drain Ditch where it collects and attenuates. The D2 Drain Ditch downstream of North Montana Avenue shows reduced PC peak flow results when compared to the EX model for both events. This is explained by the culvert upsizing and ditch grading upstream that conveys additional flow east, as observed in the increased peak flows shown in **Table 5-4** for "through Forestvale Road" and across "Sierra Road (east)". These flow increases associated with the Trap Club project are attenuated upstream of Interstate 15 at the ponding area, and just downstream of Interstate 15 there is no change in peak flow observed for the 4% event and only a 0.8% increase for the 1% annual chance event. No change of peak flow for the 4% chance event can be attributed to the culvert at Interstate 15 building headwater but not overtopping. The 1% event overtops Interstate 15 and Frontage Road so the subtle increase in peak flow is attributed to appreciable storage being consumed by the Silver Creek peak arriving prior to the Tenmile Overflow peak and the increased peak associated with the Trap Club project translating through the overtopping flow.

Results from the steady state modeling of lower D2 Drain Ditch (downstream of Interstate 15 and Frontage Road) are summarized in **Table 5-6**.

Table 5-6. D2 Drain Ditch Downstream of Interstate 15 and Frontage Road - Steady Flow Max Capacity Results

River Station	Crossing	Max Capacity
12,909	Glass Drive 1	250
12,672	Glass Drive 2	450
11,709	Crossing F	200
11,425	Crossing E	250
9,944	Arrowhead Crossing	250
8,031	Crossing D	250
6,544	Crossing C	250
6,084	Crossing B	450
3,655	Crossing A	500

As mentioned, the steady state results reflect the maximum capacity of each crossing of lower D2 Drain Ditch. The ditch itself varies in capacity as well. Capacity improvements will focus on the crossings, in addition to gaps in the berm that intermittently lines both sides of the ditch.

Hydraulic modeling of this lower portion of the valley was limited to steady state modeling of the ditch only because flooding is implied once peak flows through Interstate 15 and Frontage Road exceed 200 cfs. Flooding likely begins at Glass Drive 1 and once flow is out of the banks, peak flows reduce substantially downstream. Enhanced modeling of the lower D2 Drain Ditch is anticipated during future mitigation phases to ensure no adverse impacts to landowners and to facilitate planning, design, permitting, and construction.

6.0 DISCUSSION AND RECOMMENDATIONS

This hydrologic and hydraulic analysis assumes coincident flooding of Tenmile Creek and Silver Creek resulting from a 24-hour duration design rain storm covering both basins. From both the hydrologic and hydraulic results it is apparent that flooding from Silver Creek occurs faster. The peak of each storm event hydrograph reaches Green Meadow Drive for Silver Creek earlier than does the peak for Tenmile Creek. That peak is conveyed without substantial attenuation through the Sewell subdivision until it arrives at North Montana Avenue.

Interstate 15 and Frontage Road are currently acting as large dams that buffer peak flows entering this area. North Montana Avenue is also acting as a large dam for all flows not crossing North Montana Avenue. This is illustrated in the inundation mapping where large ponded areas exist with nearly the same water surface elevation. These locations act as large storage areas that buffer peak flows.

It is important to note that the Trap Club Flood Detention facility was not considered in this "worst case scenario" analysis. During an actual flood event, the purpose of the facility will be to allow the pond to fill prior to arrival of the peak, effectively reducing peak flows downstream, where a decrease in peak flow in D2 Drain Ditch downstream of Interstate 15 would be realized. The 0.8% increase in peak associated with the Phase I project flow for the 1% event is within the cumulative error margin of the simulation. It is apparent upon inspection of the hydraulic results that the Phase I project likely has no impact on the flow conditions in the D2 Drain Ditch downstream of Interstate 15. However, there are appreciable changes to peak flows overtopping Sierra Road. It is also worth another mention that sandbagging and culvert plugging were not considered in these simulations, which may have an impact for amount of flow overtopping Sierra Road west of Interstate 15 ditch under the EX and PC conditions.

The modifications proposed in the conceptual design are observed to increase flows locally and the increased flows convey through the system until upstream of Interstate 15 where they are attenuated for both the 4% and 1% annual chance events. The following recommendations are provided based on the results of the simulations:

1. Infrastructure upgrades of D2 Drain Ditch at North Montana Avenue, Interstate 15, and Frontage Road crossings should be phased after infrastructure on lower D2 Drain Ditch is increased. Upgrades at these locations will result in loss of storage and may show considerable increased peak flows into lower D2 Drain Ditch. Currently, these crossings are essentially buffering lower D2 Drain Ditch landowners from infrastructure improvements upstream.

2. An expansion of the Phase I project including additional ditch grading and culvert upgrades along Forestvale Road and potentially another squash culvert should be considered through the Forestvale/North Montana intersection. This will allow additional conveyance into the Trap Club detention facility where the model is currently showing substantial overtopping of Forestvale Road west of North Montana Avenue.

3. The existing culverts along North Montana Avenue east ditch (downstream of Trap Club) and along Sierra Road between North Montana and Sierra Road continue to produce considerable backwater and overtopping of Sierra Road. Culvert upgrades should accompany the proposed ditch grading to realize maximum benefit from the grading work.

7.0 REFERENCES

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2. Atkins, Trap Club Emergency Detention Pond – Hazard Mitigation Grant Program Application Report, June 2012.

3. Morrison – Maierle, Inc., Lewis and Clark County Flood Drainage Study for Tenmile Creek, April 1982.

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11. National Oceanic and Atmospheric Administration (NOAA), Atlas 2, Volume I – Montana, Precipitation-Frequency Atlas of the Western United States, 1973.

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15. United States Army Corps of Engineers, Hydraulic Engineering Center – River Analysis System (HEC – RAS), Version 5.0.3, September 2016.

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18. Chow, Ven Te, Open Channel Hydraulics, McGraw-Hill Book Company, Inc. New York, 1959.

RESPEC

APPENDIX A

STREAMSTATS RESULTS

Tenmile Creek at GMD Streamstats

Region ID:

MT

Workspace ID:

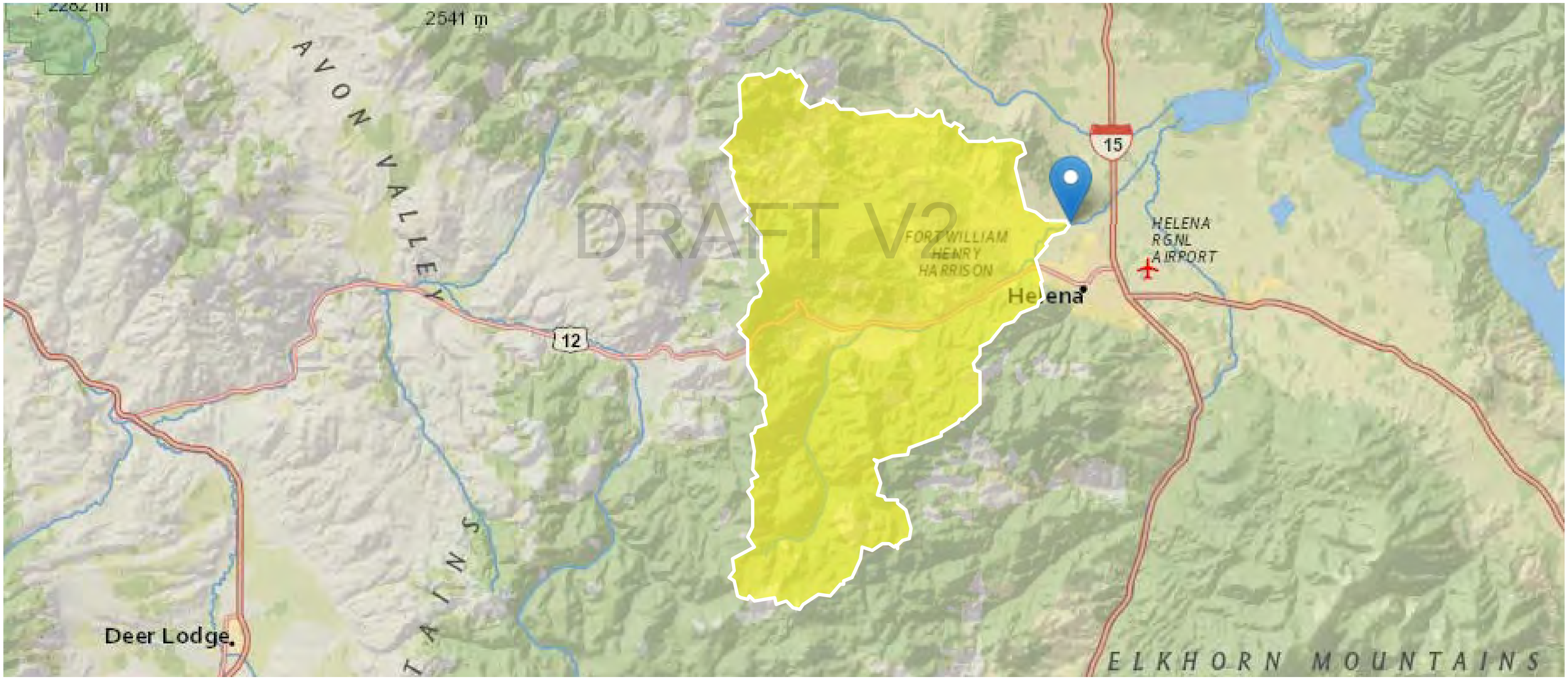
MT20170105091604520000

Clicked Point (Latitude, Longitude):

46.63179, -112.04765

Time:

2017-01-05 09:21:20 -0700



Basin Characteristics

Parameter Code	Parameter Description	Value	Unit
CONTDA	Area that contributes flow to a point on a stream (total drainage area minus non-contributing areas within basin)	162.9	square miles
EL6000	Percent of area above 6000 ft	26.2	percent
PRECIP	Mean Annual Precipitation	19.13	inches
FOREST	Percentage of area covered by forest	62.3	percent

Peak-Flow Statistics Parameters [83.94 Percent SW Region BasinC 2015 5019F]

Parameter Code	Parameter Description	Value	Min Limit	Max Limit
CONTDA	Contributing Drainage Area	162.9	0.42	2480
EL6000	Percent above 6000 ft	26.2	0	100

Peak-Flow Statistics Parameters [16.06 Percent W Region BasinC 2015 5019F]

Parameter Code	Parameter Description	Value	Min Limit	Max Limit
CONTDA	Contributing Drainage Area	162.9	0.6	2470
PRECIP	Mean Annual Precipitation	19.13	14.6	62.1
FOREST	Percent Forest	62.3	20.4	99.1

Peak-Flow Statistics Flow Report [83.94 Percent SW Region BasinC 2015 5019F]

Statistic	Value	Unit	Prediction Error (Percent)	Lower Prediction Interval	Upper Prediction Interval
1.5 Year Peak Flood	278	ft^3/s	117.8	59.4	1300
2 Year Peak Flood	389	ft^3/s	96	103	1470
2 33 Year Peak Flood	443	ft^3/s	90.1	124	1580

Statistic	Value	Unit	Prediction Error (Percent)	Lower Prediction Interval	Upper Prediction Interval
5 Year Peak Flood	730	ft^3/s	76.9	239	2230
10 Year Peak Flood	1020	ft^3/s	72.1	354	2970
25 Year Peak Flood	1470	ft^3/s	71.3	515	4210
50 Year Peak Flood	1840	ft^3/s	72	642	5280
100 Year Peak Flood	2270	ft^3/s	73.8	772	6650
200 Year Peak Flood	2720	ft^3/s	76.5	901	8240
500 Year Peak Flood	3410	ft^3/s	80.3	1080	10800

Peak-Flow Statistics Flow Report [16.06 Percent W Region BasinC 2015 5019F]

Statistic	Value	Unit	Prediction Error (Percent)	Lower Prediction Interval	Upper Prediction Interval
1.5 Year Peak Flood	236	ft^3/s	59.4	95	584
2 Year Peak Flood	317	ft^3/s	56.5	132	760
2 33 Year Peak Flood	358	ft^3/s	55.7	151	852
5 Year Peak Flood	560	ft^3/s	53.4	244	1280
10 Year Peak Flood	776	ft^3/s	52.8	341	1770
25 Year Peak Flood	1040	ft^3/s	53.2	455	2370
50 Year Peak Flood	1260	ft^3/s	54.2	543	2940
100 Year Peak Flood	1510	ft^3/s	56	636	3580
200 Year Peak Flood	1770	ft^3/s	58	727	4320
500 Year Peak Flood	2100	ft^3/s	61.4	824	5340

Peak-Flow Statistics Flow Report [Area-Averaged]

Statistic	Value	Unit

1.5 Year Peak Flood	271
2 Year Peak Flood	377
2 33 Year Peak Flood	429
5 Year Peak Flood	703
10 Year Peak Flood	985
25 Year Peak Flood	1400
50 Year Peak Flood	1750
100 Year Peak Flood	2140
200 Year Peak Flood	2570
500 Year Peak Flood	3200

Peak-Flow Statistics Citations

Sando, Roy, Sando, S.K., McCarthy, P.M., and Dutton, D.M.,2016, Methods for estimating peak-flow frequencies at ungaged sites in Montana based on data through water year 2011: U.S. Geological Survey Scientific Investigations Report 2015–5019–F, 30 p. (http://dx.doi.org/10.3133/sir20155019F)
Sando, Roy, Sando, S.K., McCarthy, P.M., and Dutton, D.M.,2016, Methods for estimating peak-flow frequencies at ungaged sites in Montana based on data through water year 2011: U.S. Geological Survey Scientific Investigations Report 2015–5019–F, 30 p. (http://dx.doi.org/10.3133/sir20155019F)

Silver Creek at GMD Streamstats

Region ID:

MT

Workspace ID:

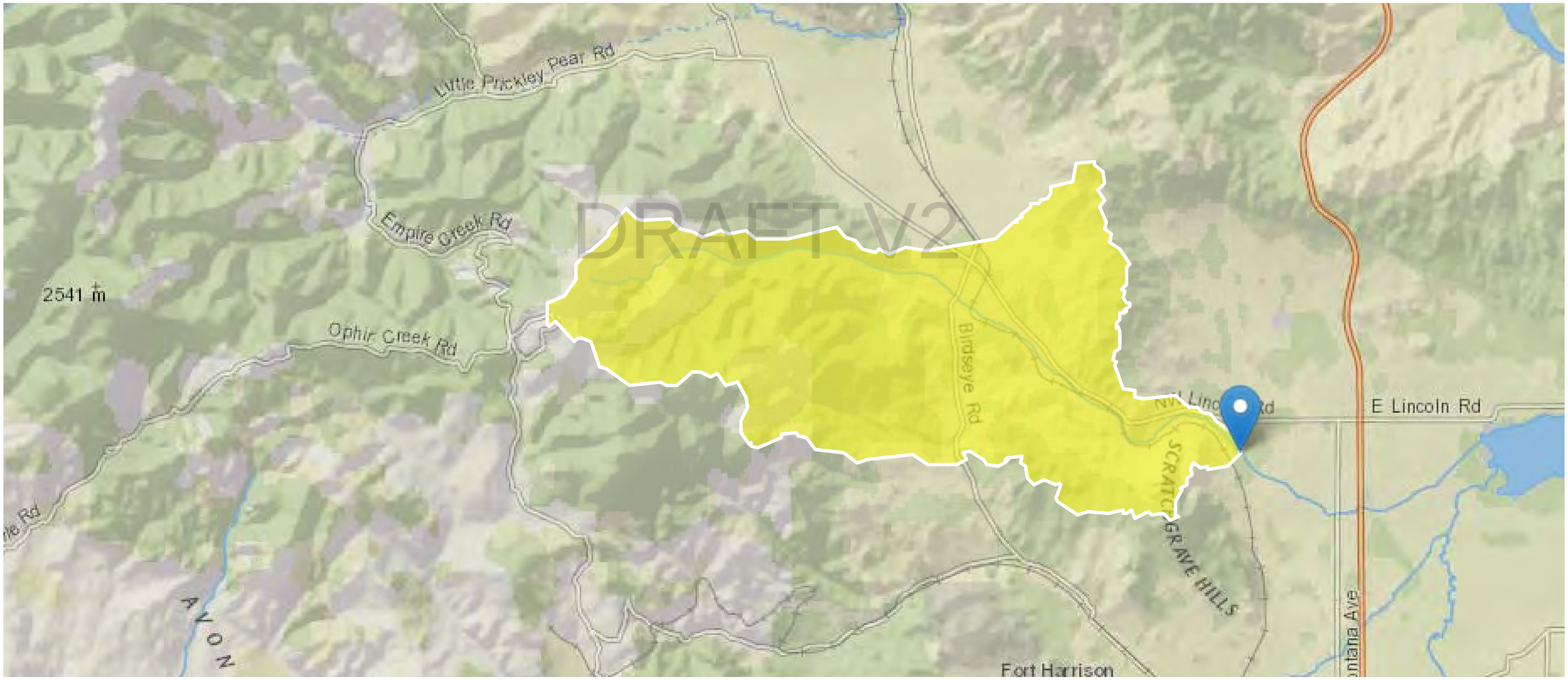
MT20170105092155123000

Clicked Point (Latitude, Longitude):

46.69529, -112.06113

Time:

2017-01-05 09:27:44 -0700



Basin Characteristics

Parameter Code	Parameter Description	Value	Unit
CONTDA	Area that contributes flow to a point on a stream (total drainage area minus non-contributing areas within basin)	46.7	square miles
EL6000	Percent of area above 6000 ft	11.1	percent
PRECIP	Mean Annual Precipitation	16.05	inches
FOREST	Percentage of area covered by forest	34.5	percent

Peak-Flow Statistics Parameters [98.38 Percent SW Region BasinC 2015 5019F]

Parameter Code	Parameter Description	Value	Min Limit	Max Limit
CONTDA	Contributing Drainage Area	46.7	0.42	2480
EL6000	Percent above 6000 ft	11.1	0	100

Peak-Flow Statistics Parameters [1.62 Percent W Region BasinC 2015 5019F]

Parameter Code	Parameter Description	Value	Min Limit	Max Limit
CONTDA	Contributing Drainage Area	46.7	0.6	2470
PRECIP	Mean Annual Precipitation	16.05	14.6	62.1
FOREST	Percent Forest	34.5	20.4	99.1

Peak-Flow Statistics Flow Report [98.38 Percent SW Region BasinC 2015 5019F]

Statistic	Value	Unit	Prediction Error (Percent)	Lower Prediction Interval	Upper Prediction Interval
1.5 Year Peak Flood	70.6	ft^3/s	117.8	15	333
2 Year Peak Flood	113	ft^3/s	96	29.5	429
2 33 Year Peak Flood	136	ft^3/s	90.1	37.9	489

Statistic	Value	Unit	Prediction Error (Percent)	Lower Prediction Interval	Upper Prediction Interval
5 Year Peak Flood	274	ft^3/s	76.9	88.7	845
10 Year Peak Flood	437	ft^3/s	72.1	149	1280
25 Year Peak Flood	720	ft^3/s	71.3	248	2090
50 Year Peak Flood	982	ft^3/s	72	337	2860
100 Year Peak Flood	1300	ft^3/s	73.8	436	3890
200 Year Peak Flood	1680	ft^3/s	76.5	544	5170
500 Year Peak Flood	2280	ft^3/s	80.3	705	7340

Peak-Flow Statistics Flow Report [1.62 Percent W Region BasinC 2015 5019F]

Statistic	Value	Unit	Prediction Error (Percent)	Lower Prediction Interval	Upper Prediction Interval
1.5 Year Peak Flood	76.8	ft^3/s	59.4	29.9	197
2 Year Peak Flood	111	ft^3/s	56.5	44.6	274
2 33 Year Peak Flood	128	ft^3/s	55.7	52.3	315
5 Year Peak Flood	222	ft^3/s	53.4	93.6	527
10 Year Peak Flood	328	ft^3/s	52.8	139	774
25 Year Peak Flood	470	ft^3/s	53.2	198	1110
50 Year Peak Flood	595	ft^3/s	54.2	246	1440
100 Year Peak Flood	737	ft^3/s	56	298	1830
200 Year Peak Flood	893	ft^3/s	58	350	2280
500 Year Peak Flood	1100	ft^3/s	61.4	411	2940

Peak-Flow Statistics Flow Report [Area-Averaged]

Statistic	Value	Unit

1.5 Year Peak Flood	70.7
2 Year Peak Flood	113
2 33 Year Peak Flood	136
5 Year Peak Flood	273
10 Year Peak Flood	436
25 Year Peak Flood	716
50 Year Peak Flood	976
100 Year Peak Flood	1290
200 Year Peak Flood	1660
500 Year Peak Flood	2260

Peak-Flow Statistics Citations

Sando, Roy, Sando, S.K., McCarthy, P.M., and Dutton, D.M.,2016, Methods for estimating peak-flow frequencies at ungaged sites in Montana based on data through water year 2011: U.S. Geological Survey Scientific Investigations Report 2015–5019–F, 30 p. (http://dx.doi.org/10.3133/sir20155019F)
Sando, Roy, Sando, S.K., McCarthy, P.M., and Dutton, D.M.,2016, Methods for estimating peak-flow frequencies at ungaged sites in Montana based on data through water year 2011: U.S. Geological Survey Scientific Investigations Report 2015–5019–F, 30 p. (http://dx.doi.org/10.3133/sir20155019F)

APPENDIX B

RAINFALL DEPTH CALCULATIONS AND HEC-HMS BASIN PARAMETERS

TENMILE CREEK BASIN PARAMETERS

Table B.1

Basin	Area (mi^2)	Composite CN	Hydraulic Length (ft)	Average Watershed Land Slope (%)	Lag (min)	Tc (min)
W61240	3.23	67.5	20,547	17.1	73.9	123.1
W61280	0.09	74.5	6,003	1.8	70.7	117.8
W61290	0.20	74.6	7,683	2.4	73.2	122.1
W61310	4.06	61.9	24,600	23.3	84.6	141.0
W61330	0.72	63.6	9,672	23.3	38.3	63.9
W61350	4.77	52.8	35,234	20.3	152.2	253.6
W61370	2.25	59.7	26,274	18.1	106.8	177.9
W61380	0.84	58.4	14,053	26.0	55.8	93.0
W61500	4.89	61.0	24,662	34.3	71.3	118.8
W61510	5.82	55.1	24,048	34.2	81.3	135.6
W61550	5.32	57.4	22,595	27.7	81.1	135.2
W61560	3.11	49.0	18,004	29.6	80.9	134.9
W61600	0.72	53.7	9,139	27.4	43.4	72.4
W61610	5.79	58.8	23,079	28.8	78.2	130.4
W61650	1.60	64.7	17,227	26.1	55.9	93.2
W61660	5.88	54.0	25,129	24.0	103.3	172.1
W61710	5.79	50.6	22,679	22.5	107.1	178.6
W61800	4.21	51.1	23,101	19.0	116.8	194.7
W61850	4.82	64.3	29,016	11.3	130.1	216.9
W61860	6.62	64.1	30,758	16.3	114.2	190.4
W61900	5.06	53.1	28,766	24.4	116.8	194.7
W61910	6.28	61.9	18,532	23.8	66.6	111.1
W61960	6.38	58.5	23,237	30.5	76.8	127.9
W62000	0.02	71.3	2,052	23.8	9.0	14.9
W62050	1.76	63.7	14,404	16.2	63.1	105.1
W62060	4.14	63.4	27,831	28.0	81.8	136.4
W62100	5.82	51.4	26,019	30.8	100.3	167.1
W62110	10.18	63.4	26,332	26.7	80.2	133.7
W62150	3.43	38.3	22,840	23.1	147.2	245.3
W62160	6.75	52.3	20,153	34.4	75.5	125.9
W62200	1.17	70.3	21,924	2.0	211.3	352.1

Basin	Area (mi^2)	Composite CN	Hydraulic Length (ft)	Average Watershed Land Slope (%)	Lag (min)	Tc (min)
W62250	0.49	63.3	9,895	6.8	72.7	121.2
W62260	5.62	65.6	41,248	13.9	150.7	251.2
W62300	0.00	74.0	250	3.3	4.1	6.9
W62310	2.90	57.3	26,752	19.5	111.1	185.1
W62350	0.00	61.6	589	5.0	9.3	15.5
W62360	6.04	64.8	42,102	14.9	150.4	250.7
W62400	2.29	57.1	22,253	34.1	72.8	121.3
W62410	5.84	53.8	29,174	33.0	99.8	166.3
W62450	1.81	56.6	15,247	40.1	50.3	83.8
W62500	1.07	43.4	11,608	19.8	80.5	134.2
W62510	5.93	54.5	26,643	27.2	100.6	167.7
W62550	4.45	51.6	22,765	28.8	92.6	154.3
W62560	3.26	43.9	24,984	26.2	127.6	212.6

SILVER CREEK BASIN PARAMETERS

Table B.2

Basin	Area (mi^2)	Composite CN	Hydraulic Length (ft)	Average Watershed Land Slope (%)	Lag (min)	Tc (min)
W570	4.02	70.9	31,957	10.3	123.8	206.4
W320	4.84	47.8	27,233	31.1	113.3	188.9
W370	0.07	56.8	2,501	37.7	12.1	20.2
W170	0.57	78.1	10,495	9.5	43.0	71.7
W620	2.31	69.0	19,958	18.5	66.7	111.2
W130	3.94	68.9	29,992	13.9	106.8	178.1
W220	2.51	69.8	16,239	11.6	69.8	116.3
W420	2.20	65.8	25,851	12.8	107.3	178.8
W470	2.36	68.3	17,181	8.4	89.3	148.8
W520	3.53	57.5	25,314	19.8	104.9	174.9
W770	1.21	65.4	17,212	12.1	80.6	134.4
W580	2.33	64.6	24,368	5.7	158.0	263.4
W630	3.88	64.5	18,790	16.5	75.8	126.3
W670	3.73	55.9	20,110	22.8	84.7	141.2
W690	1.33	59.1	11,976	34.9	41.6	69.4
W720	3.91	56.2	20,337	33.4	70.1	116.8
W740	1.37	56.6	9,639	29.3	40.7	67.8
W780	2.22	57.8	18,852	28.9	68.0	113.3
W1160	0.28	63.7	4,285	25.1	19.2	32.0

Precipitation Calculations
Tenmile Creek Watershed

Montana 46.5168°N 112.2438°W
Site-specific Estimates

	2YR	5YR	10YR	25YR	50YR	100YR	500YR
5 min	0.17	0.26	0.32	0.39	0.46	0.53	0.66
15 min	0.30	0.47	0.58	0.73	0.86	0.99	1.24
1 hr	0.44	0.69	0.85	1.06	1.25	1.44	1.80
2 hr	0.52	0.77	0.93	1.14	1.33	1.52	1.86
3 hr	0.60	0.84	1.00	1.21	1.40	1.58	1.95
6 hr	0.78	1.02	1.18	1.38	1.57	1.75	2.12
12 hr	1.04	1.35	1.57	1.83	2.09	2.32	2.80
24 hr	1.33	1.74	2.01	2.35	2.68	2.98	3.56

Values taken from NOAA Atlas 2, Online Precipitation Frequency Data Output Lat/Long Input

Values calculated using Equations 3 & 5 of *Precipitation-Frequency Atlas of the Western United States, Volume I - Montana - East of the divide calcs*

Values interpolated between 2YR and 100YR using Figure 6 of *Precipitation-Frequency Atlas of the Western United States, Volume I - Montana*

Values calculated using Equations 7 & 8 of *Precipitation-Frequency Atlas of the Western United States, Volume I*

Values interpolated using Figure 17 of *Precipitation-Frequency Atlas of the Western United States, Volume I - Montana*

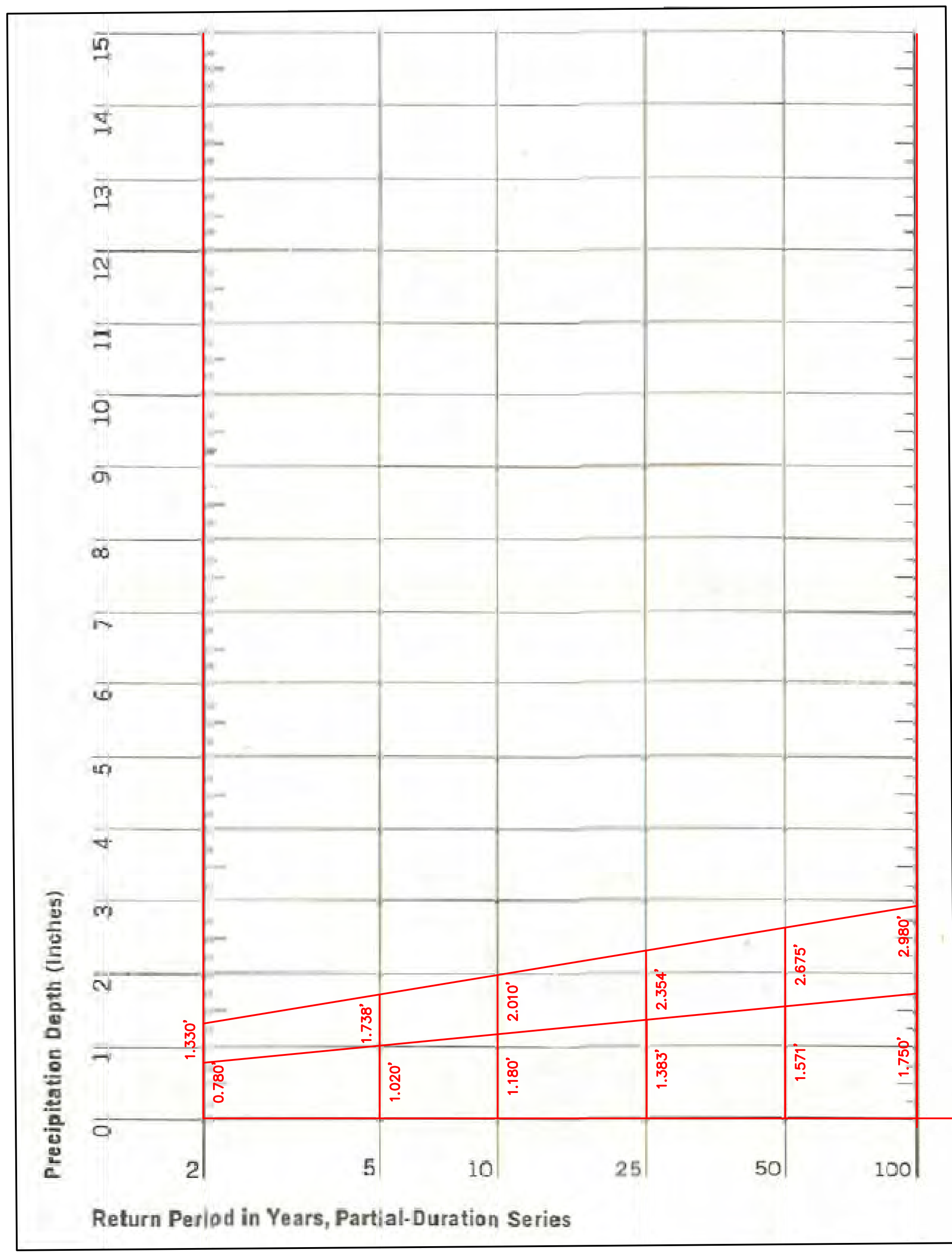
Values calculated using Table 11 of *Precipitation-Frequency Atlas of the Western United States, Volume I - Montana*

Values determined using ratios provided in *Short Duration Rainfall for the Western United States* (Arkell & Richards) - Front Face and High Plains North Region

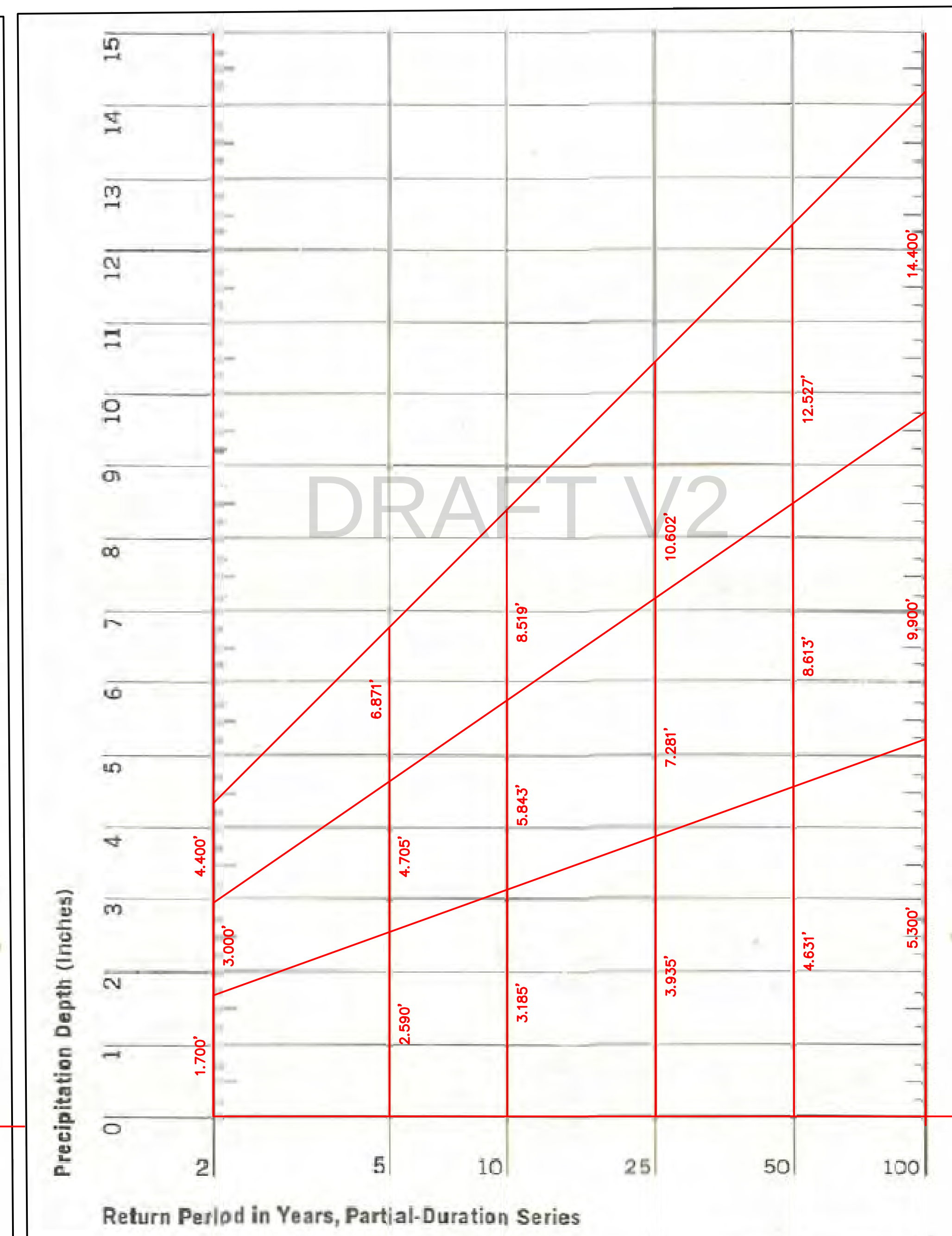
Extrapolated using normal-probability relationship

Tenmile Creek

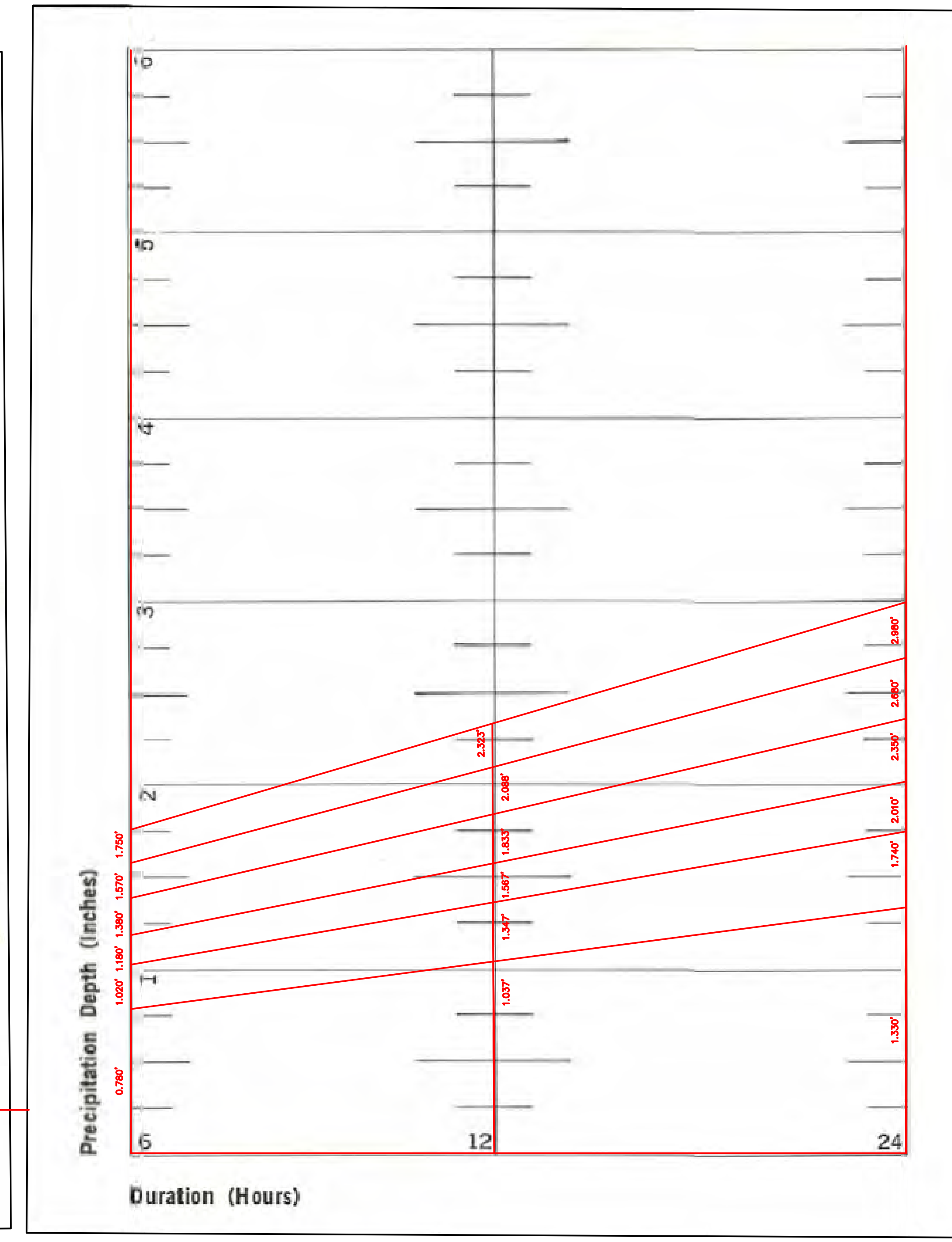
6 HR and 24 HR

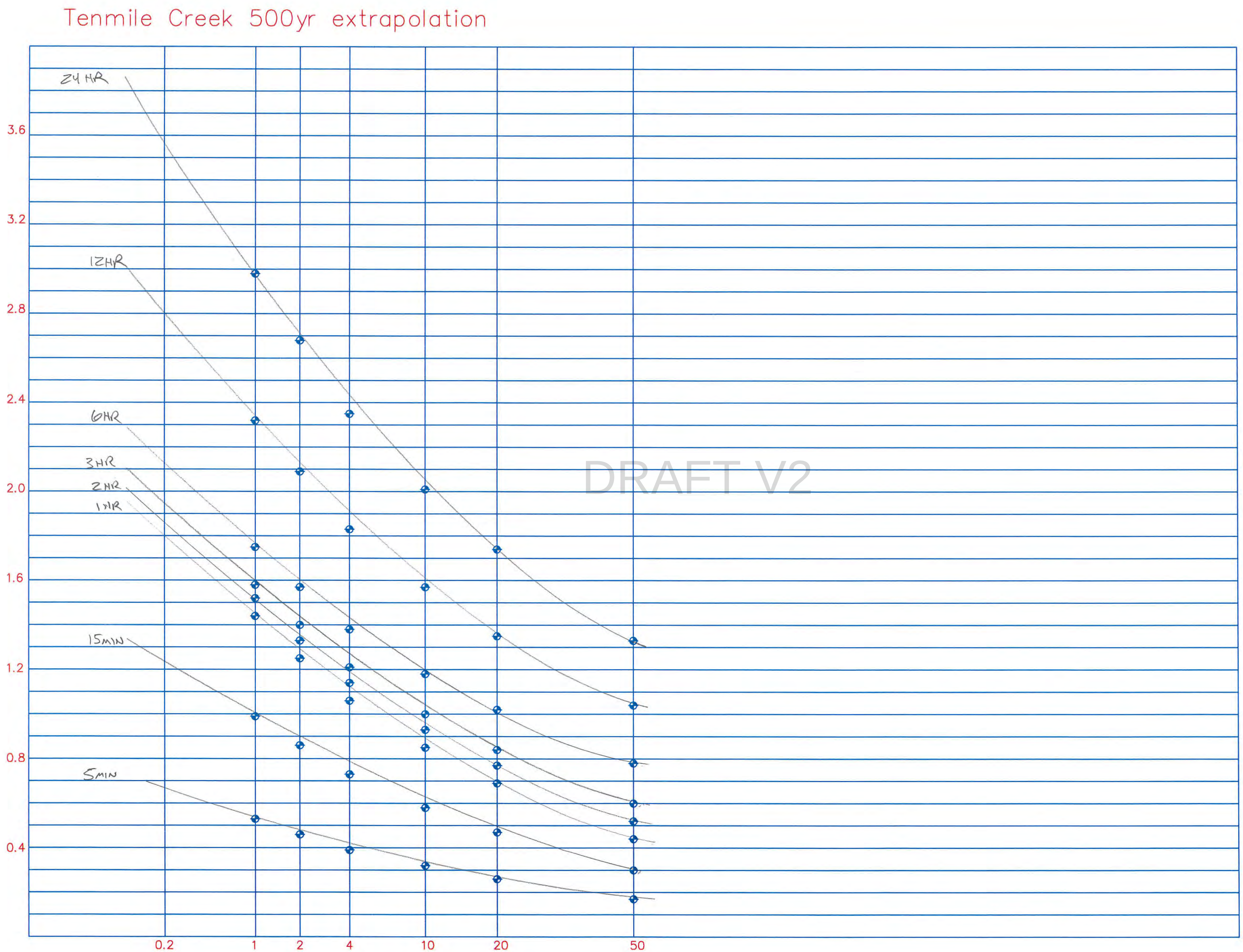


1 HR, 15 min, 5 min (values are factored by 10)



12 HR for 2yr, 5yr, 10yr, 25yr, 50yr, and 100yr




Tenmile Creek 500yr extrapolation
24 HR
12 HR
6HR
3HR
2HR
1HR
15MIN
5MIN
3.6
3.2
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0.2
1
2
4
10
20
50
DRAFT V2

Precipitation Calculations
Silver Creek Watershed

	2YR	5YR	10YR	25YR	50YR	100YR	500YR
5 min	0.16	0.25	0.30	0.38	0.46	0.51	0.64
15 min	0.28	0.45	0.56	0.70	0.83	0.95	1.19
1 hr	0.41	0.65	0.81	1.01	1.19	1.37	1.70
2 hr	0.49	0.72	0.88	1.08	1.26	1.43	1.74
3 hr	0.55	0.79	0.94	1.14	1.31	1.49	1.82
6 hr	0.72	0.94	1.09	1.28	1.45	1.62	1.95
12 hr	0.95	1.25	1.45	1.71	1.95	2.17	2.60
24 hr	1.21	1.60	1.87	2.20	2.51	2.80	3.33

Montana 46.7344°N 112.2299°W
Site-specific Estimates

Values taken from NOAA Atlas 2, Online Precipitation Frequency Data Output Lat/Long Input

Values calculated using Equations 3 & 5 of *Precipitation-Frequency Atlas of the Western United States, Volume I - Montana - East of the divide calcs*

Values interpolated between 2YR and 100YR using Figure 6 of *Precipitation-Frequency Atlas of the Western United States, Volume I - Montana*

Values calculated using Equations 7 & 8 of *Precipitation-Frequency Atlas of the Western United States, Volume I*

Values interpolated using Figure 17 of *Precipitation-Frequency Atlas of the Western United States, Volume I - Montana*

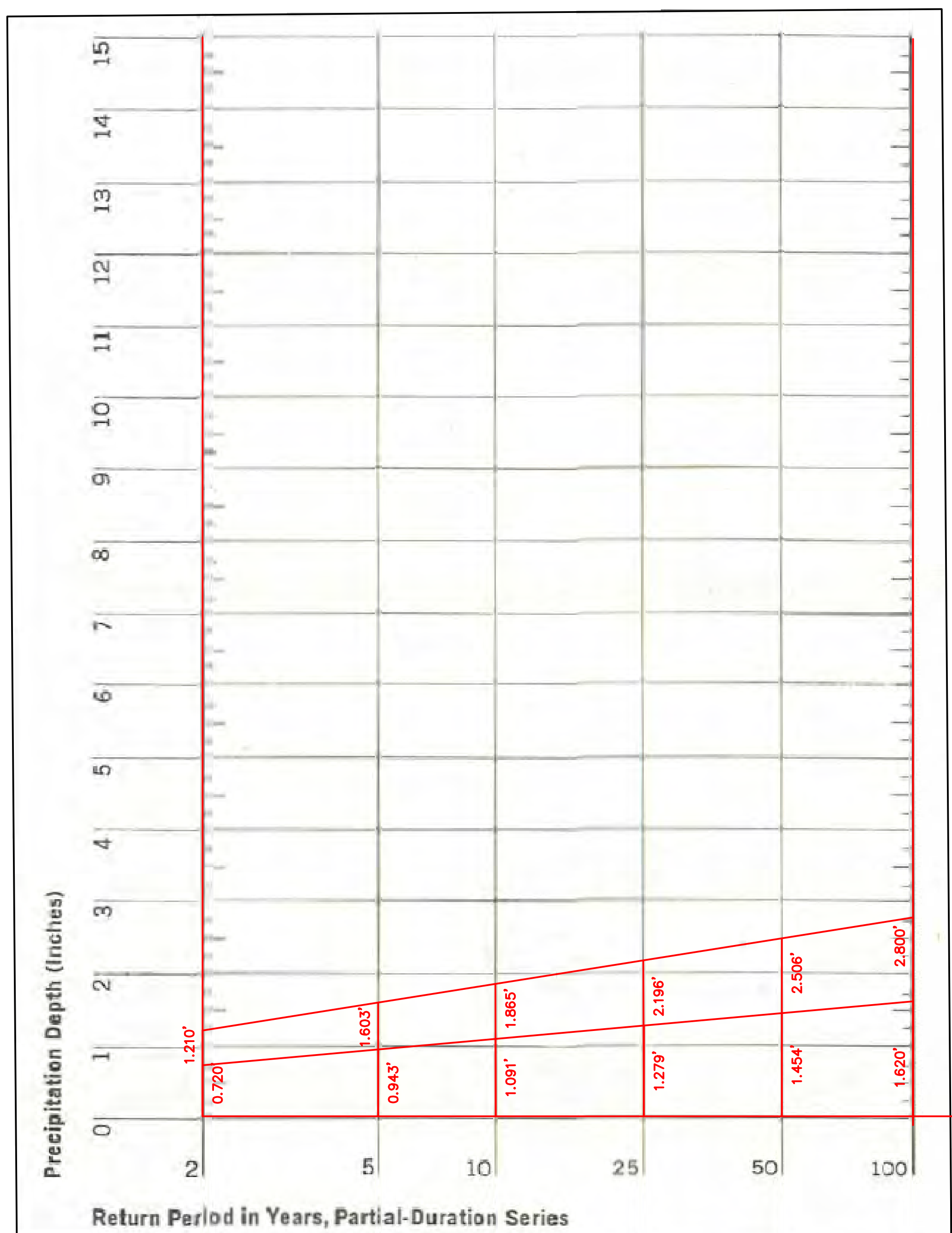
Values calculated using Table 11 of *Precipitation-Frequency Atlas of the Western United States, Volume I - Montana*

Values determined using ratios provided in *Short Duration Rainfall for the Western United States* (Arkell & Richards) - Front Face and High Plains North Region

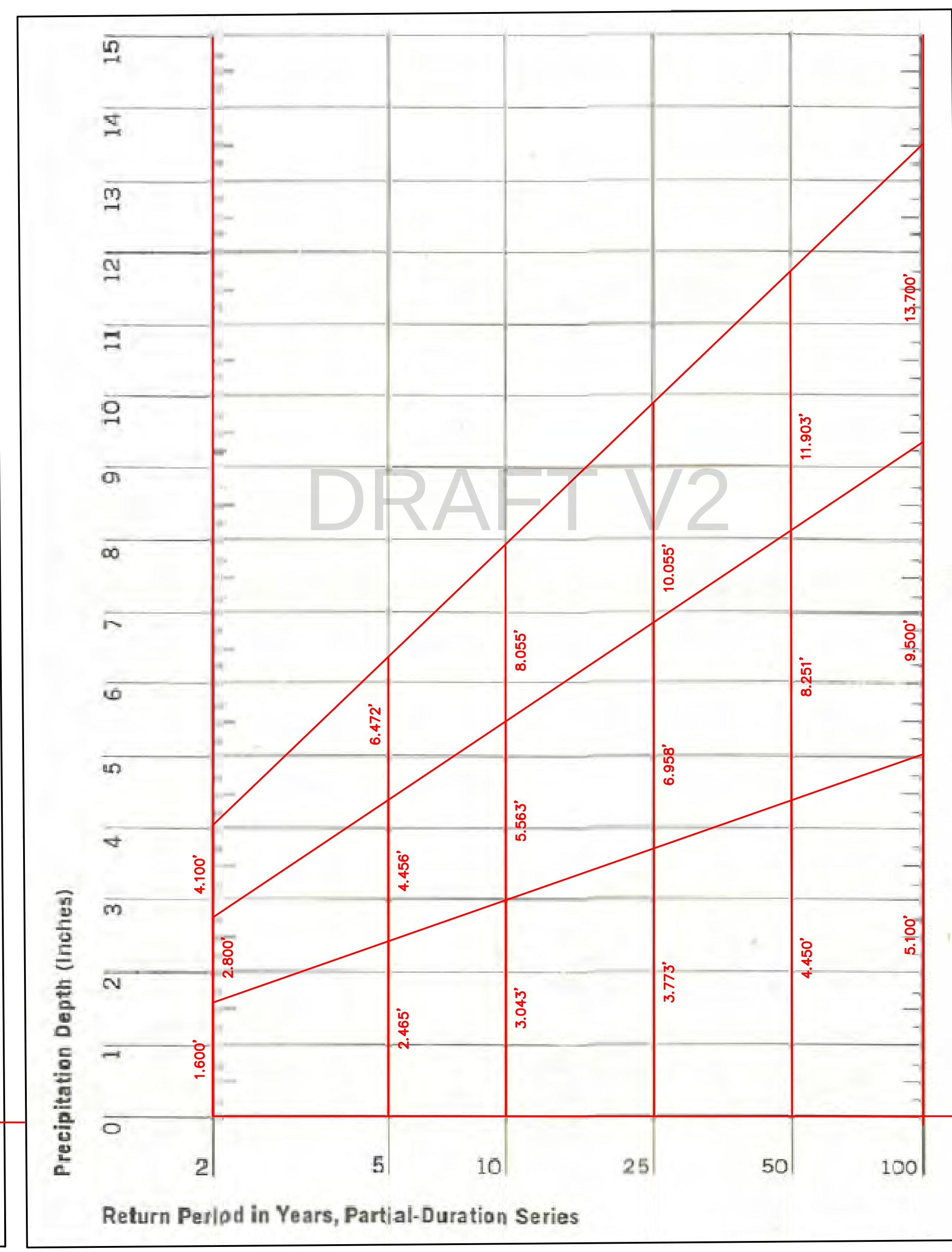
Extrapolated using normal-probability relationship

Silver Creek

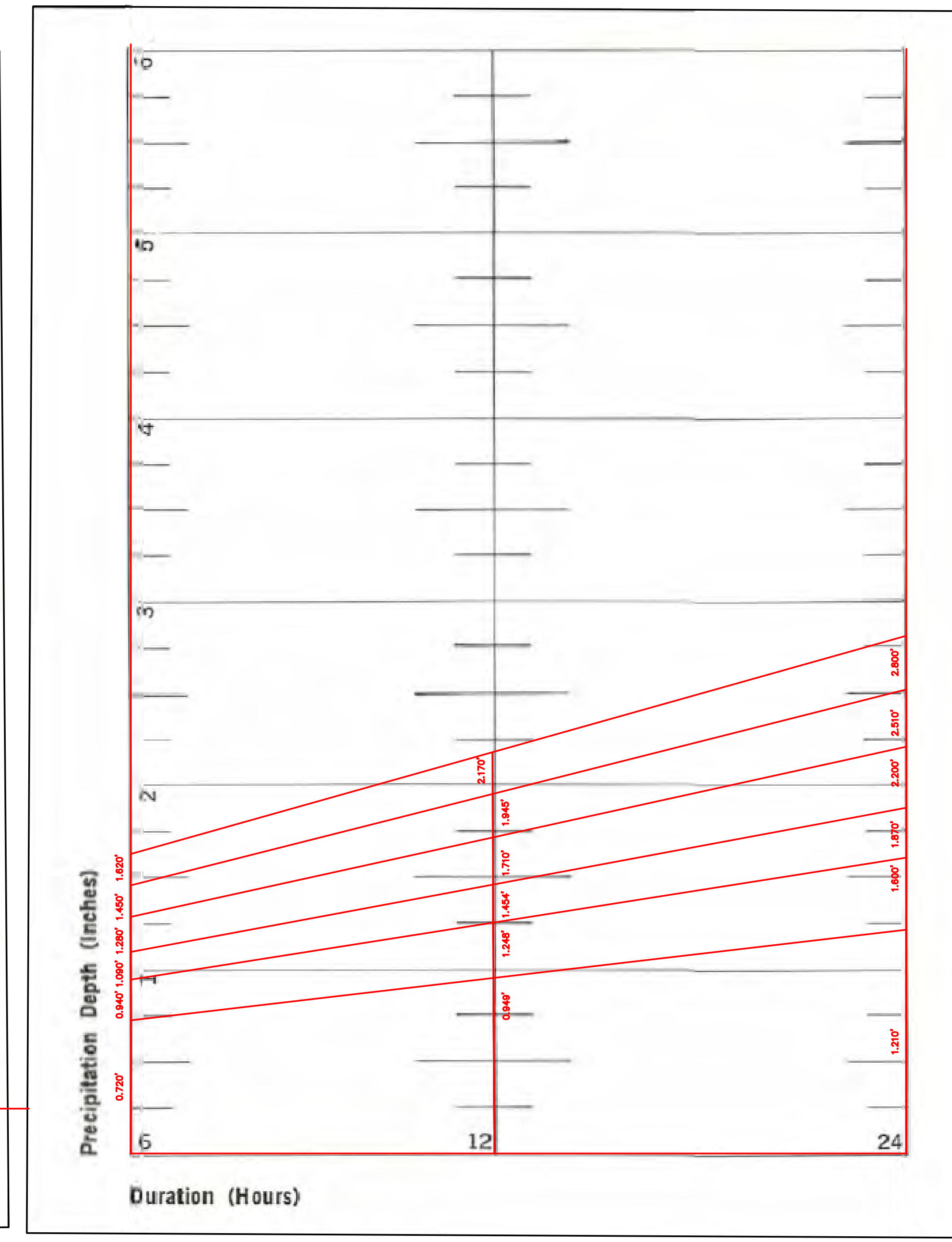
6 HR and 24 HR

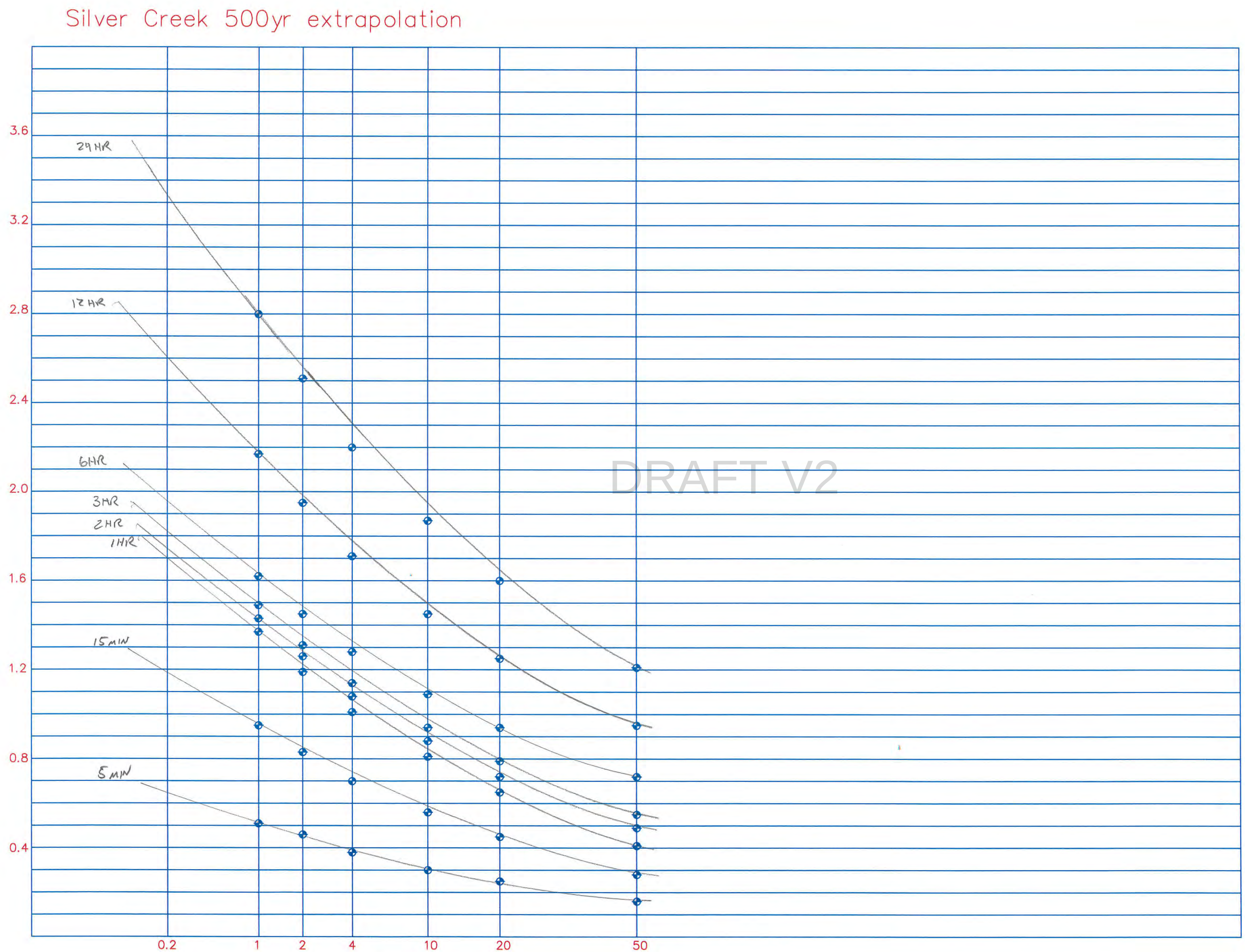


1 HR, 15 min, 5 min (values are factored by 10)



12 HR for 2yr, 5yr, 10yr, 25yr, 50yr, and 100yr




Silver Creek 500yr extrapolation
3.6
3.2
2.8
2.4
2.0
1.6
1.2
0.8
0.4
24 HR
12 HR
6HR
3HR
2HR
1HR
15MIN
5MIN
DRAFT V2
0.2
1
2
4
10
20
50

Land Use Category	Hydrologic Soil Group				Description	Assumption	Reference	Source
	A	B	C	D				
Shrub/Scrub	30	48	65	73	Shrub/Scrub	Good hydrologic conditions	Engineering Hydrology - Principles and Practices (Ponce)	NLCD
Barren Land	30	48	65	73	Mine Operations, Logged Areas, grasslands (assume same as shrub/scru	Good hydrologic conditions		
Deciduous Forest	30	55	70	77	Deciduous Forest	Good hydrologic conditions	Engineering Hydrology - Principles and Practices (Ponce)	
Evergreen Forest	30	55	70	77	Evergreen Forest	Good hydrologic conditions	Engineering Hydrology - Principles and Practices (Ponce)	
Mixed Forest	30	55	70	77	Mixed Forest	Good hydrologic conditions	Engineering Hydrology - Principles and Practices (Ponce)	
Developed, Open Space	39	61	74	80	Developed, Open Space	Lawns, parks, cemeteries with vegetation established	Engineering Hydrology - Principles and Practices (Ponce)	
Hay/Pasture	39	61	74	80	Hay/Pasture	Pasture, grassland or range for grazing - Good hydrologic conditions	Engineering Hydrology - Principles and Practices (Ponce)	
Herbaceuous		62	74	85	Herbaceous	Good hydrologic conditions	Engineering Hydrology - Principles and Practices (Ponce)	
Developed, Low Intensity	60	70	80	85	Developed, Low Intensity	1/2 acre lots - vegetation established	Engineering Hydrology - Principles and Practices (Ponce)	
Developed, Medium Intensity	61	75	83	87	Developed, Medium Intensity	1/4 acre lots - vegetation established	Engineering Hydrology - Principles and Practices (Ponce)	
Developed, High Intensity	77	85	90	92	Developed, High Intensity	Town houses	Engineering Hydrology - Principles and Practices (Ponce)	
Open Water	98	98	98	98	Open Water			
Cultivated Crops	58	72	81	85	Cultivated Crops	Close-seeded or broadcast legumes or rotation meadow straight row	Engineering Hydrology - Principles and Practices (Ponce)	
Emergent Herbaceuous Wetlands	78	78	78	78	Emergent Herbaceuous Wetlands		Michigan DEQ	
Woody Wetlands	78	78	78	78	Woody Wetlands		Michigan DEQ	

APPENDIX C

INUNDATION MAPS

SILVER CREEK BASIN PARAMETERS

Table B.2

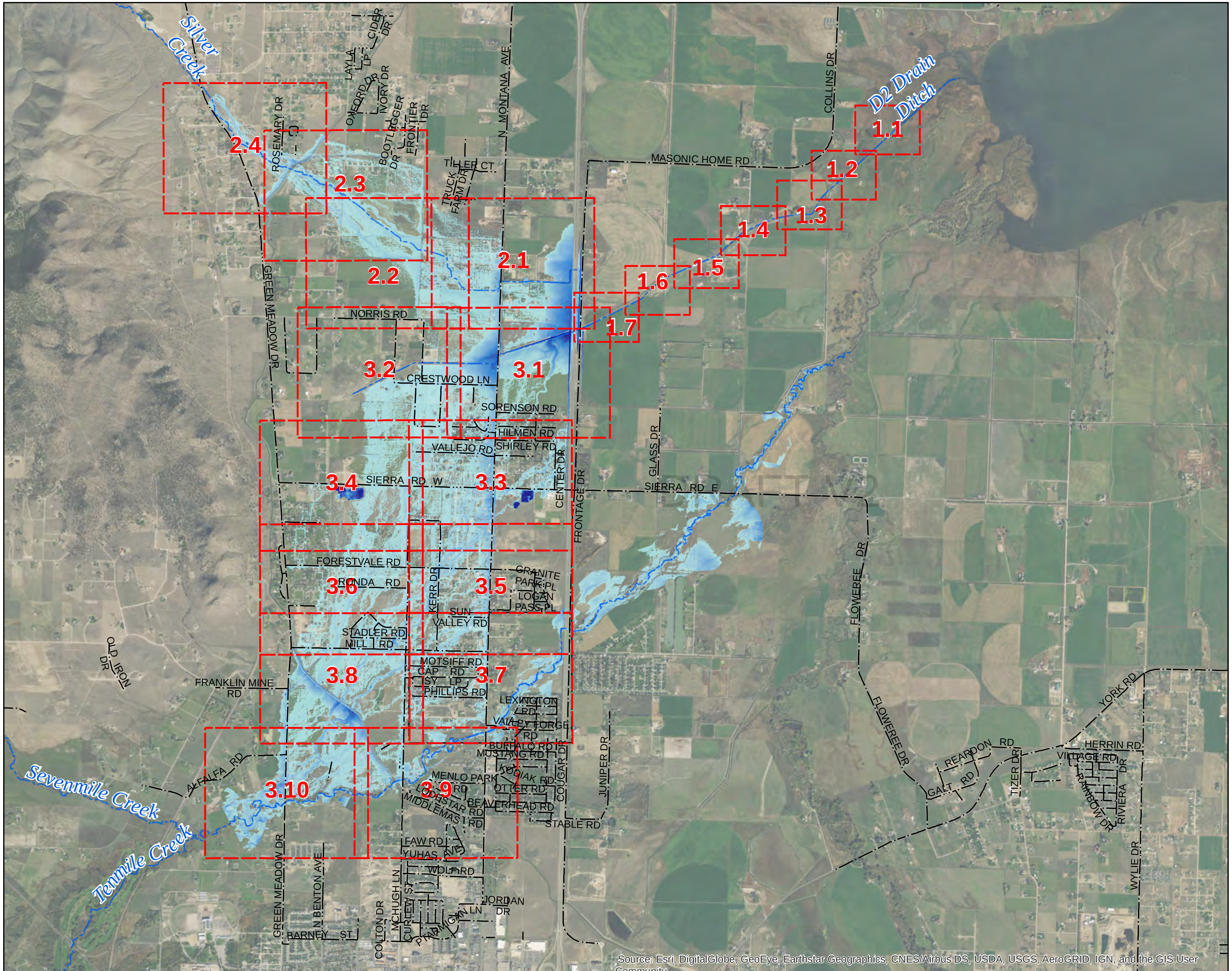
Basin	Area (mi²)	Composite CN	Hydraulic Length (ft)	Average Watershed Land Slope (%)	Lag (min)	Tc (min)
W570	4.02	70.9	31,957	10.3	123.8	206.4
W320	4.84	47.8	27,233	31.1	113.3	188.9
W370	0.07	56.8	2,501	37.7	12.1	20.2
W170	0.57	78.1	10,495	9.5	43.0	71.7
W620	2.31	69.0	19,958	18.5	66.7	111.2
W130	3.94	68.9	29,992	13.9	106.8	178.1
W220	2.51	69.8	16,239	11.6	69.8	116.3
W420	2.20	65.8	25,851	12.8	107.3	178.8
W470	2.36	68.3	17,181	8.4	89.3	148.8
W520	3.53	57.5	25,314	19.8	104.9	174.9
W770	1.21	65.4	17,212	12.1	80.6	134.4
W580	2.33	64.6	24,368	5.7	158.0	263.4
W630	3.88	64.5	18,790	16.5	75.8	126.3
W670	3.73	55.9	20,110	22.8	84.7	141.2
W690	1.33	59.1	11,976	34.9	41.6	69.4
W720	3.91	56.2	20,337	33.4	70.1	116.8
W740	1.37	56.6	9,639	29.3	40.7	67.8
W780	2.22	57.8	18,852	28.9	68.0	113.3
W1160	0.28	63.7	4,285	25.1	19.2	32.0

APPENDIX C

INUNDATION MAPS

VALLEY FLOOD MITIGATION
MASTER PLAN IMPLEMENTATION
FLOOD INUNDATION MAPPING INDEX

THIS FLOOD INUNDATION MAP IS FOR PLANNING PURPOSES ONLY AND IS NON-REGULATORY. THE CONDITIONS PORTRAYED ON THIS MAP REFLECT COINCIDENT FLOODING OF TENMILE CREEK AND SILVER CREEK, THE ACCURACY OF THE TOPOGRAPHIC DATA INPUT, AND THE LEVEL OF DETAIL WITHIN THE SUPPORTING HYDRAULIC MODEL. ACTUAL FLOOD CONDITIONS MAY DIFFER FROM THIS MAP.



Legend

Map Index

Select Roads

Streams

1% Annual Chance Flood

Depth (ft)

High : 18.5

Low : 0.001

Date: 5/1/2017
Drawn: MWJ
Base: ESRI World Imagery

Miles
0 0.5 1

N

RESPEC

VALLEY FLOOD MITIGATION MASTER PLAN IMPLEMENTATION FLOOD INUNDATION MAPPING

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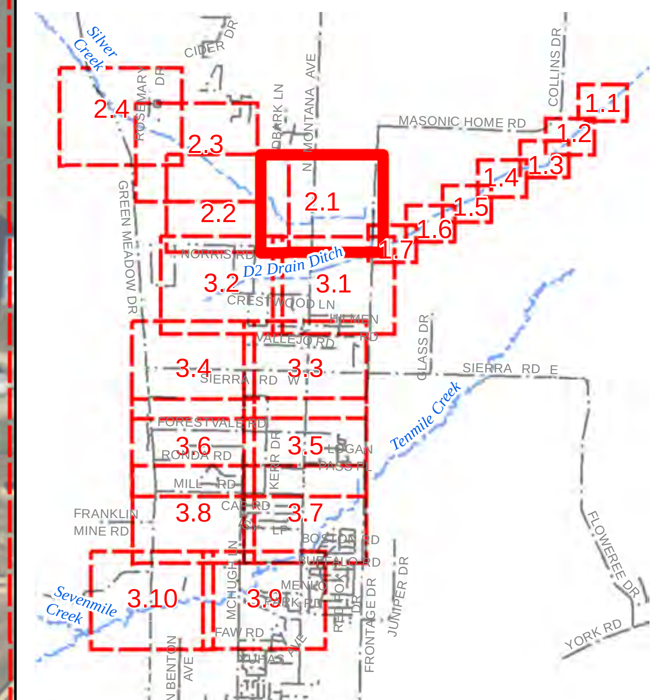


ARROWS INDICATE FLOW RESULTS (CFS) FOR THE EXISTING CONDITIONS (EX) AND PROPOSED CONDITIONS (PC) OF TRAP CLUB IMPROVEMENTS FOR THE 25-YR (25) AND 100-YR (100) COINCIDENT FLOOD EVENTS FOR TENMILE CREEK AND SILVER CREEK.

Legend

Map Index
FlowResults
Select Roads
Streams

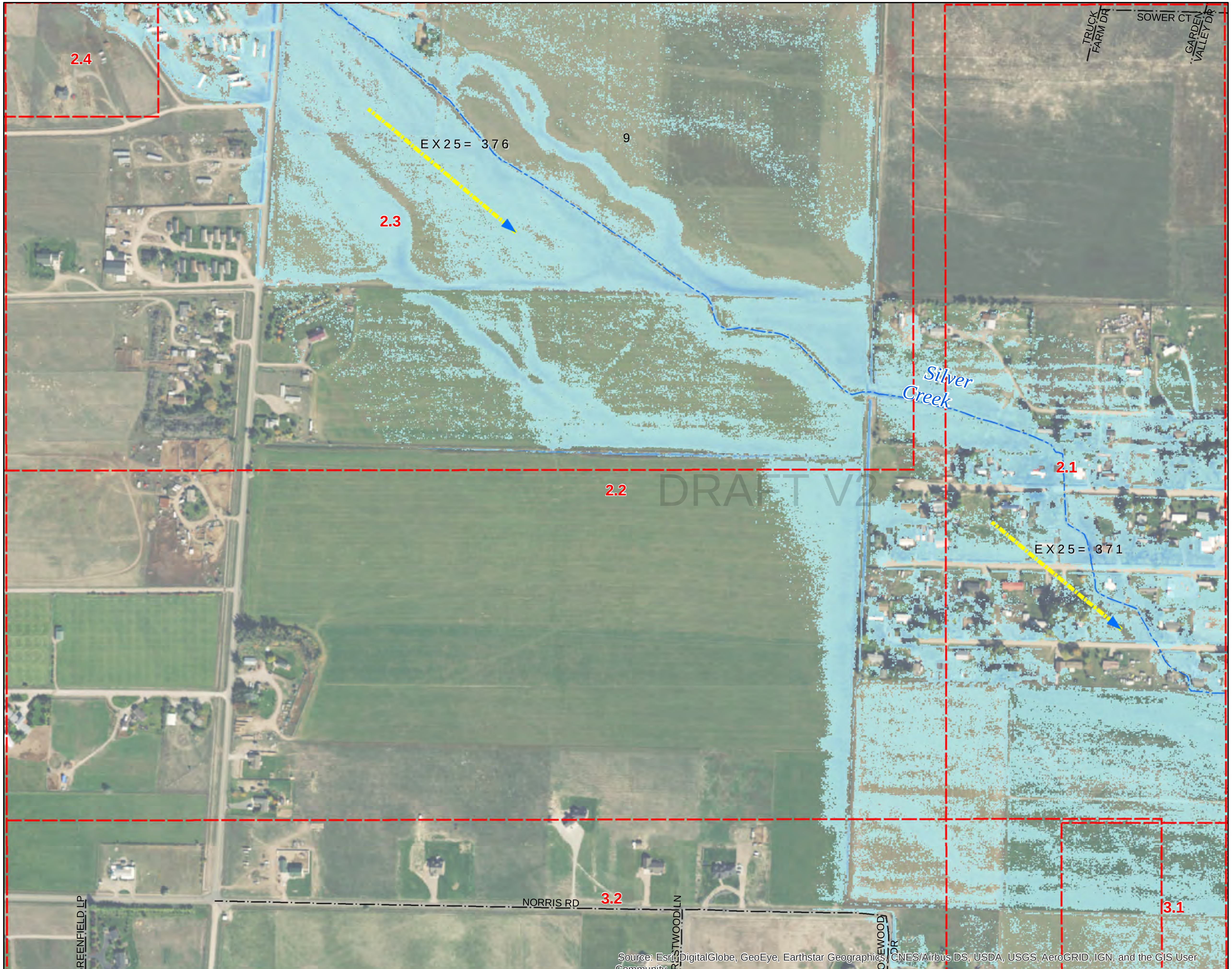
4% Annual Chance Flood Depth (ft)

High : 15.25
Low : 0.001

Date: 5/1/2017
Drawn: MWJ
Base: ESRI World Imagery

N

0 500 1,000 Feet



VALLEY FLOOD MITIGATION MASTER PLAN IMPLEMENTATION FLOOD INUNDATION MAPPING

FEMA

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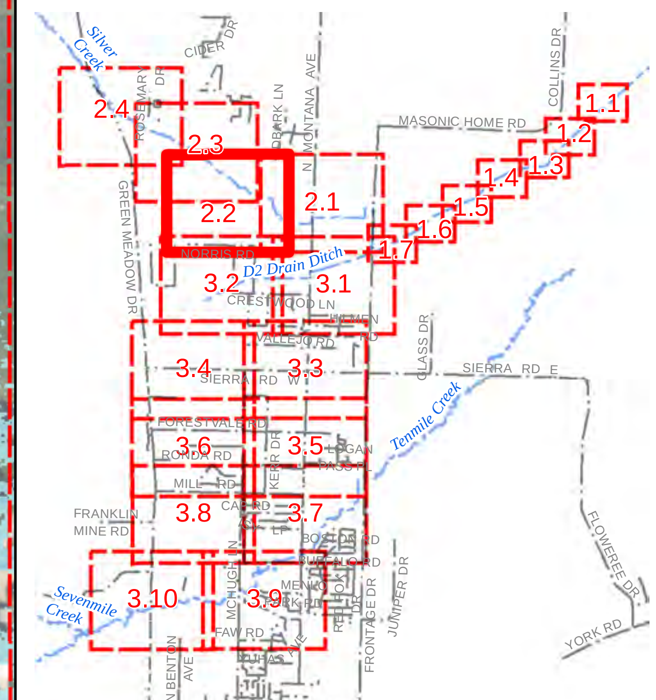

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Legend

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RESPEC

4% Annual Chance Flood

Depth (ft)

High : 15.25

Low : 0.001

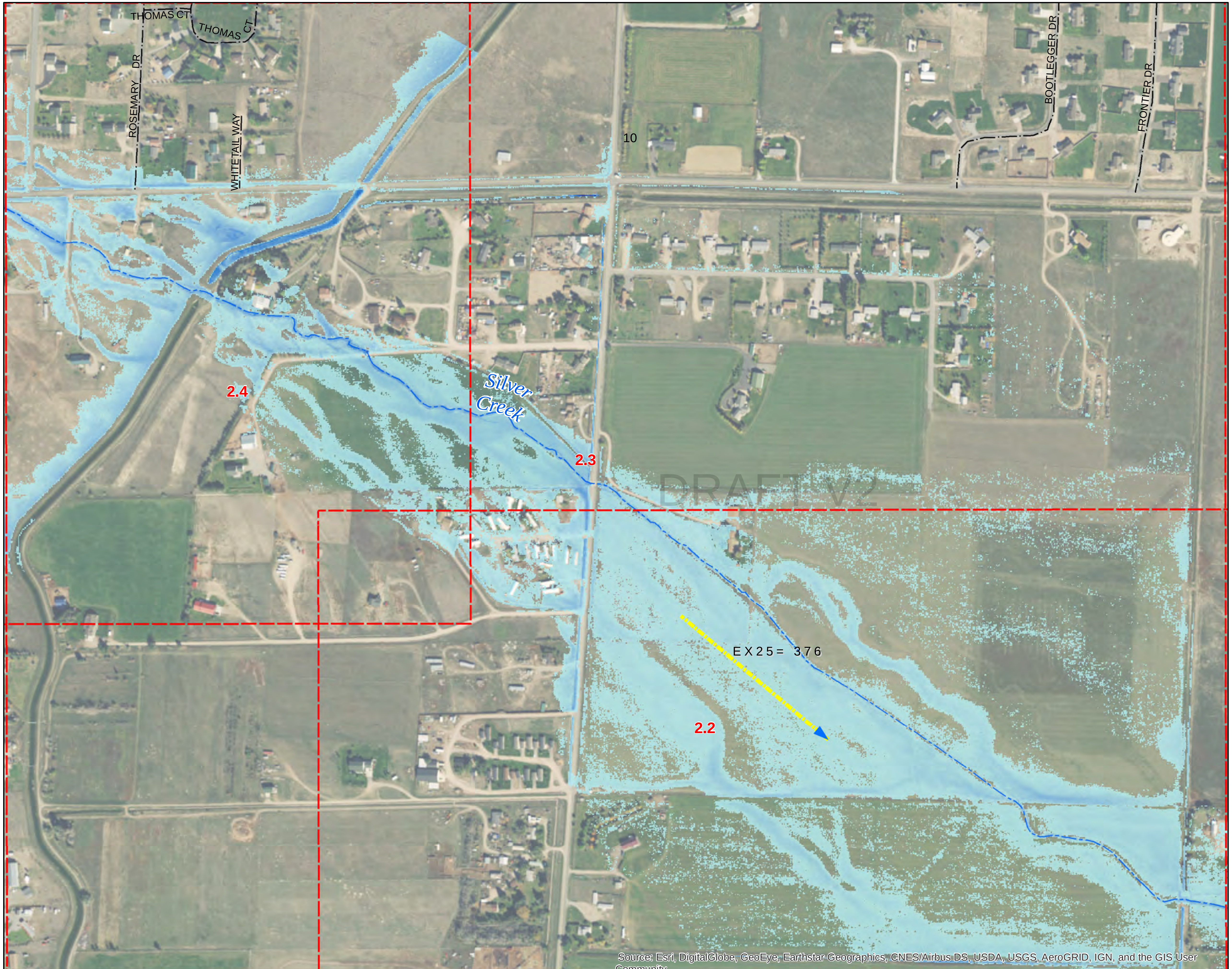
N

Date: 5/1/2017

Drawn: MWJ

Base: ESRI World Imagery

0 500 1,000 Feet



VALLEY FLOOD MITIGATION MASTER PLAN IMPLEMENTATION FLOOD INUNDATION MAPPING

MONTANA DISASTER & EMERGENCY SERVICES DES

FEMA

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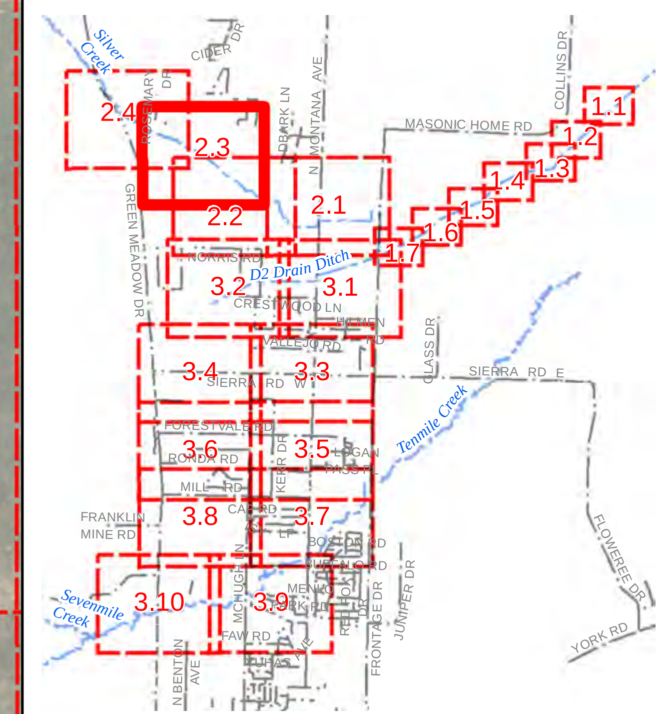

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Legend

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4% Annual Chance Flood

Depth (ft)

High : 15.25

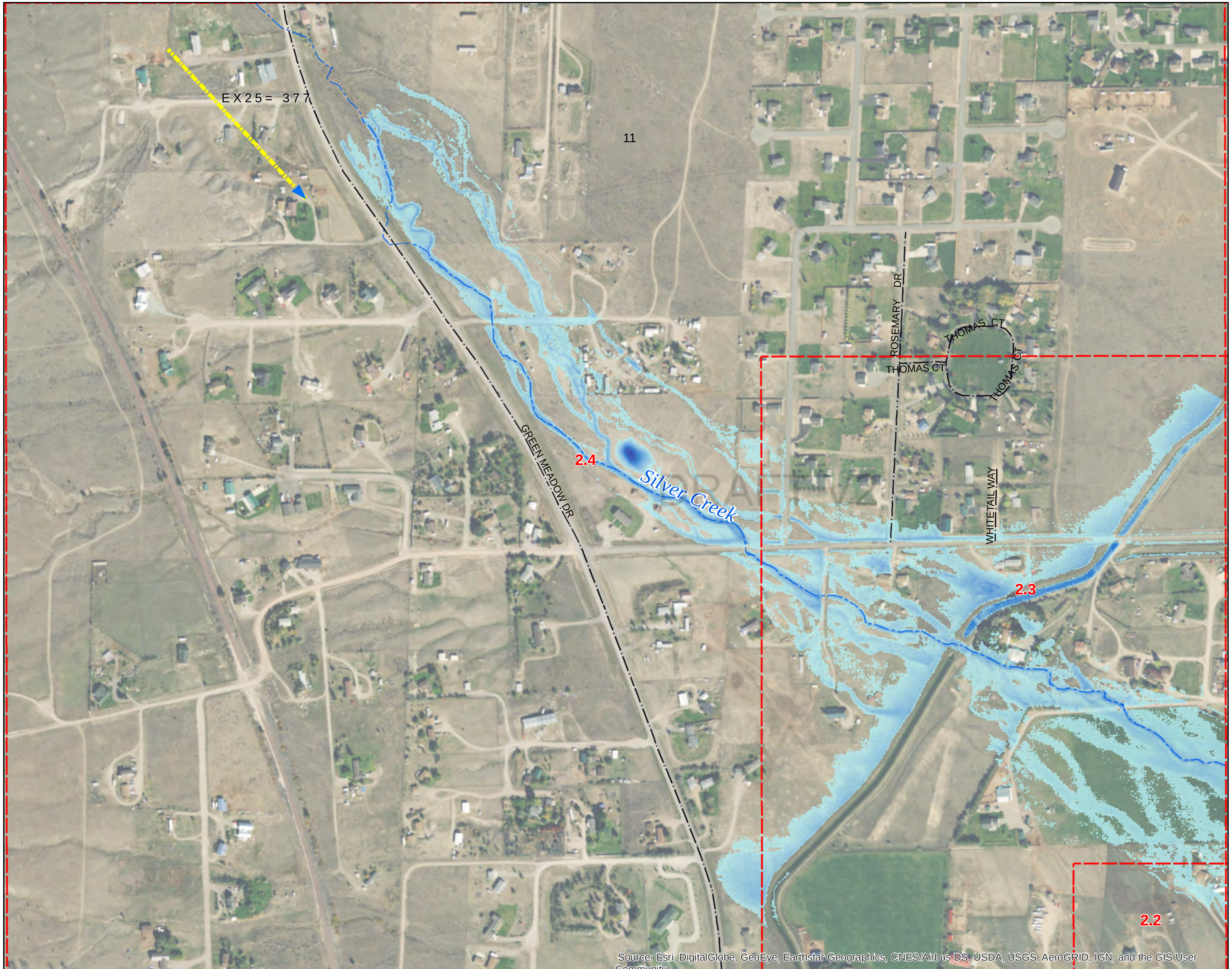
Low : 0.001

RESPEC

N

Date: 5/1/2017
Drawn: MWJ
Base: ESRI World Imagery

0 500 1,000 Feet



VALLEY FLOOD MITIGATION MASTER PLAN IMPLEMENTATION FLOOD INUNDATION MAPPING

DES FEMA

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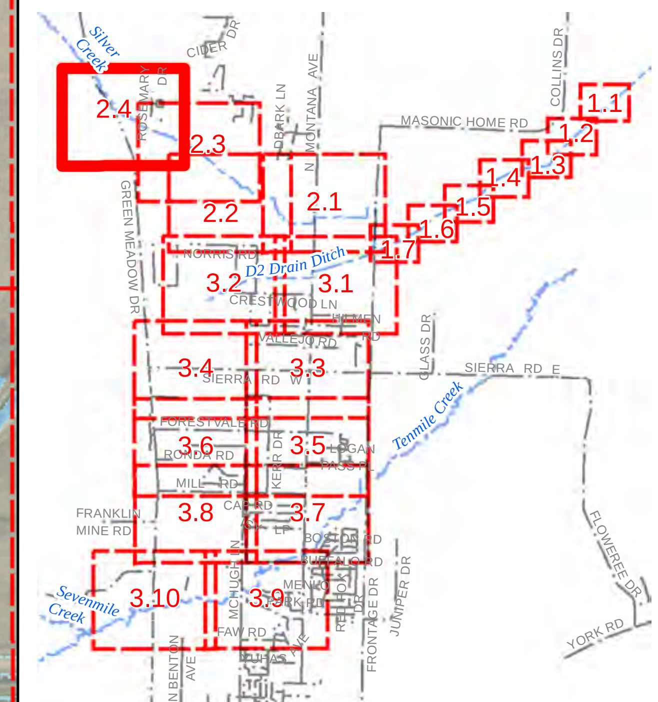

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4% Annual Chance Flood

Depth (ft)

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Date: 5/1/2017
Drawn: MWJ
Base: ESRI World Imagery

0 500 1,000 Feet

VALLEY FLOOD MITIGATION MASTER PLAN IMPLEMENTATION FLOOD INUNDATION MAPPING

MONTANA DISASTER & EMERGENCY SERVICES DES

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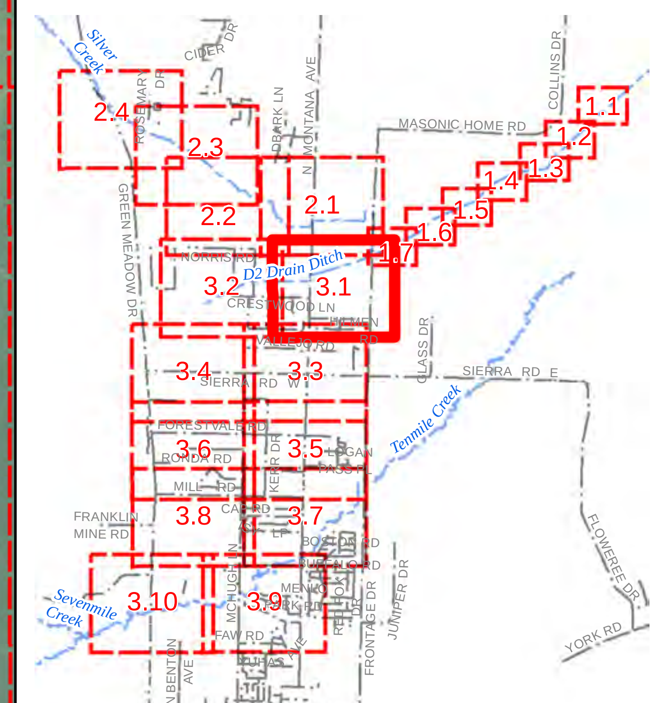

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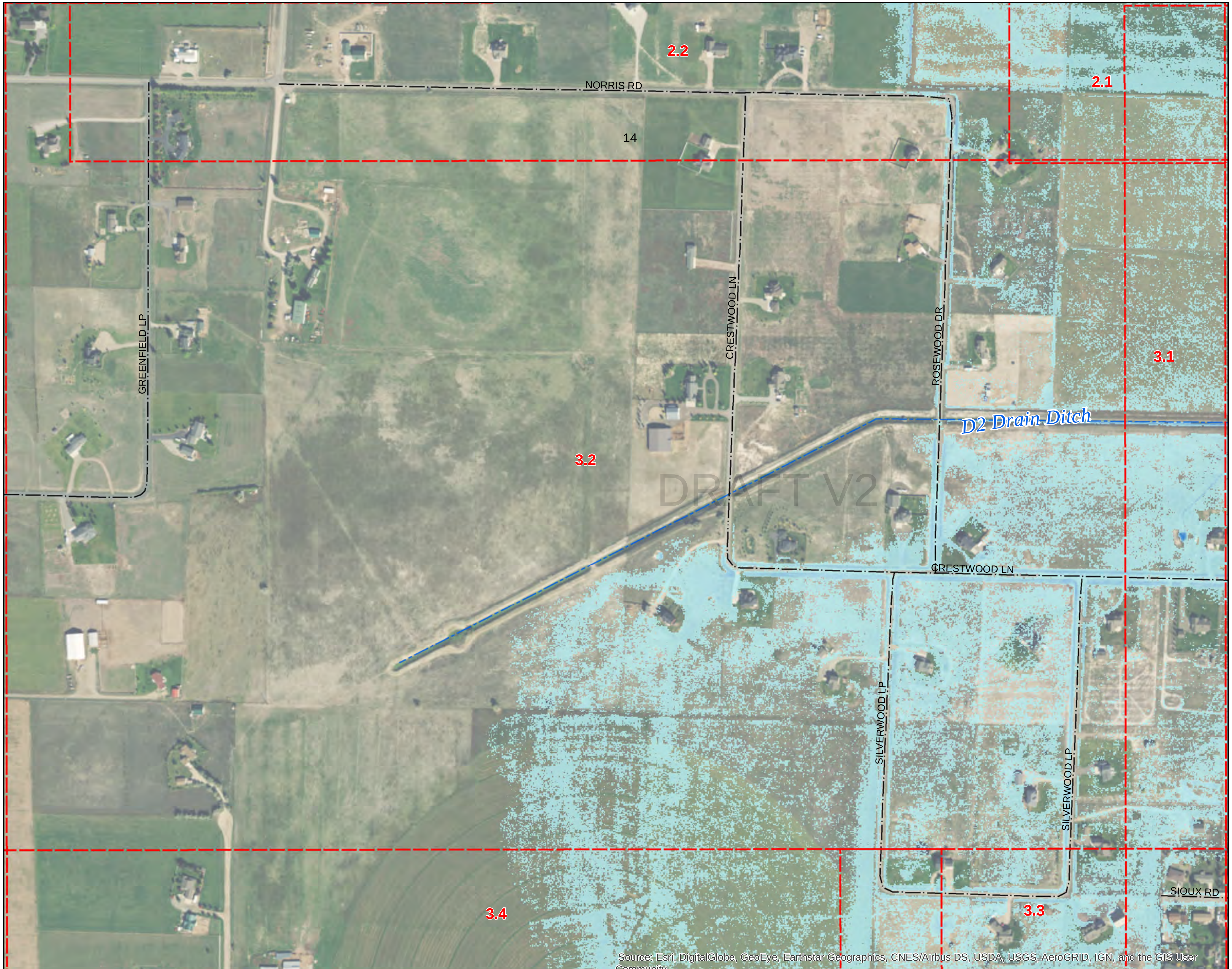
Date: 5/1/2017

Drawn: MWJ

Base: ESRI World Imagery

0 500 1,000 Feet



VALLEY FLOOD MITIGATION MASTER PLAN IMPLEMENTATION FLOOD INUNDATION MAPPING

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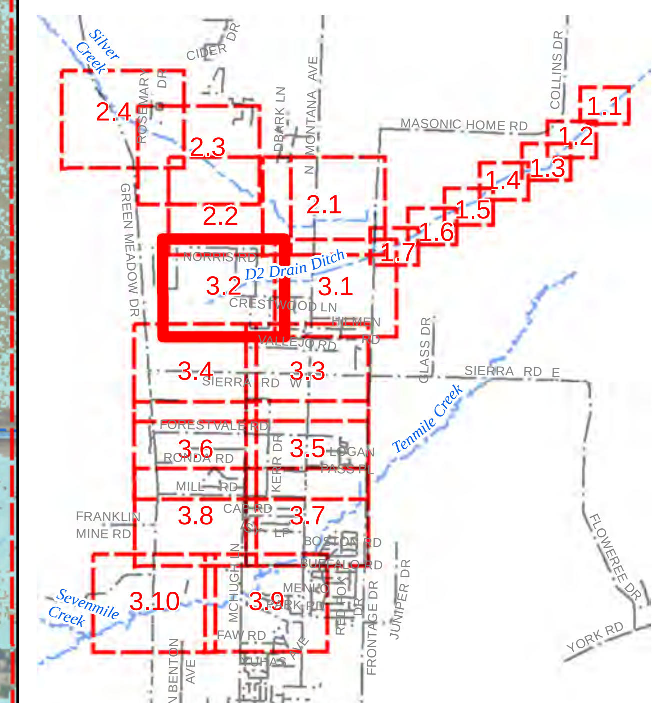

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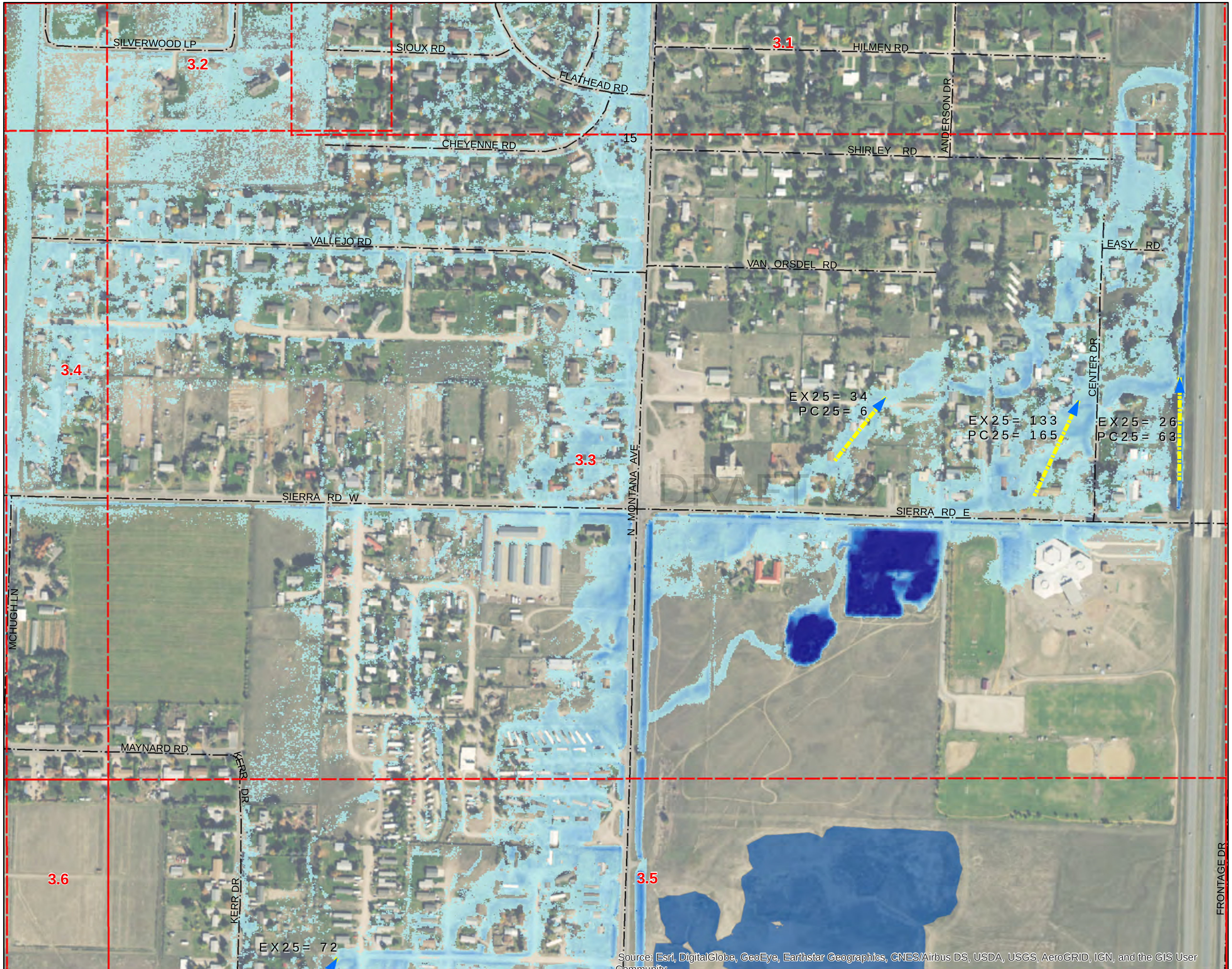
Date: 5/1/2017

Drawn: MWJ

Base: ESRI World Imagery

0 500 1,000 Feet



VALLEY FLOOD MITIGATION MASTER PLAN IMPLEMENTATION FLOOD INUNDATION MAPPING

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FEMA

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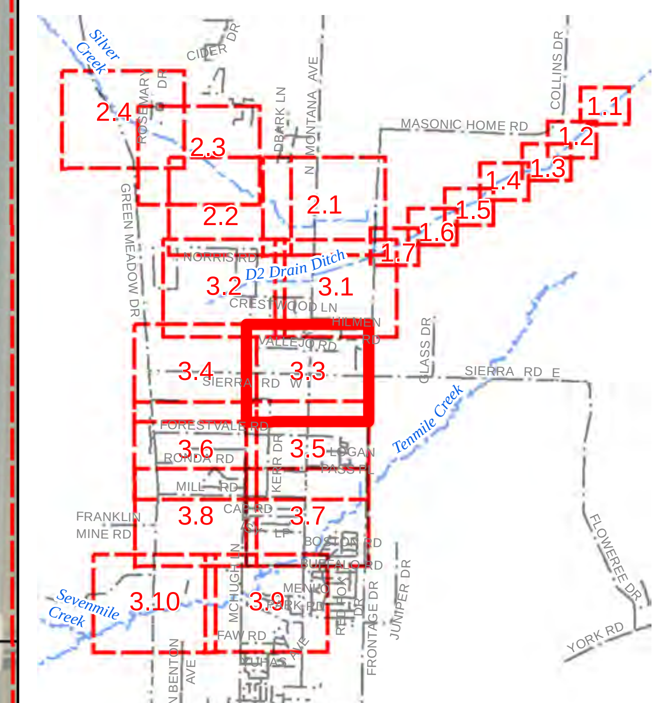

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RESPEC

4% Annual Chance Flood

Depth (ft)

High : 15.25

Low : 0.001

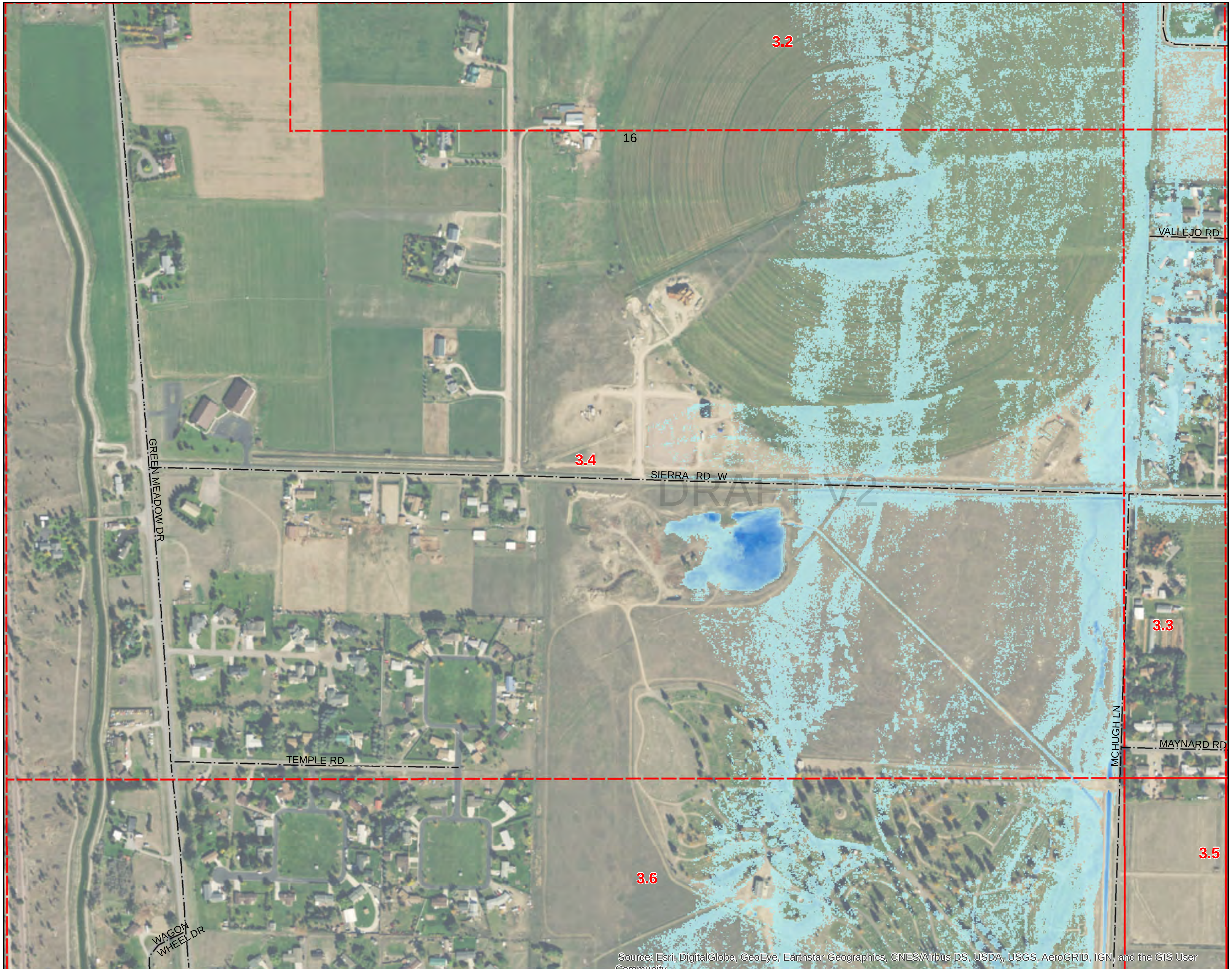
Date: 5/1/2017

Drawn: MWJ

Base: ESRI World Imagery

0 500 1,000 Feet

N



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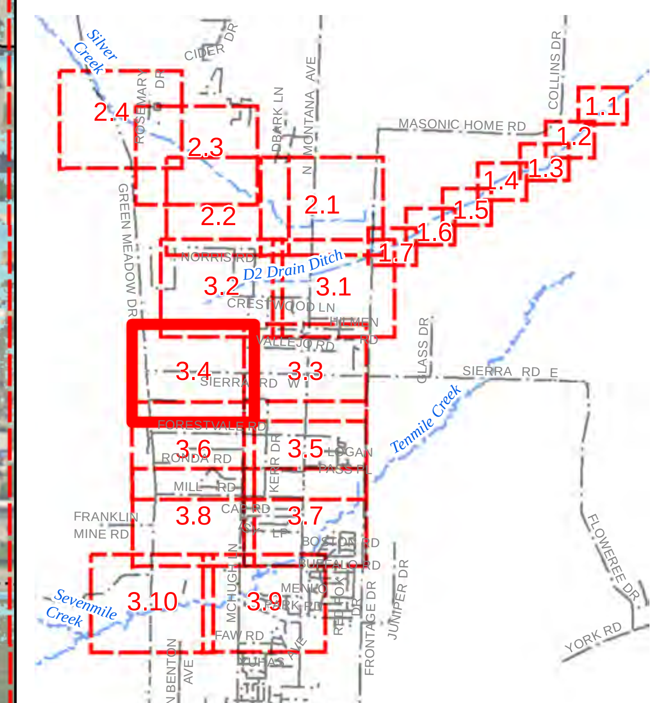

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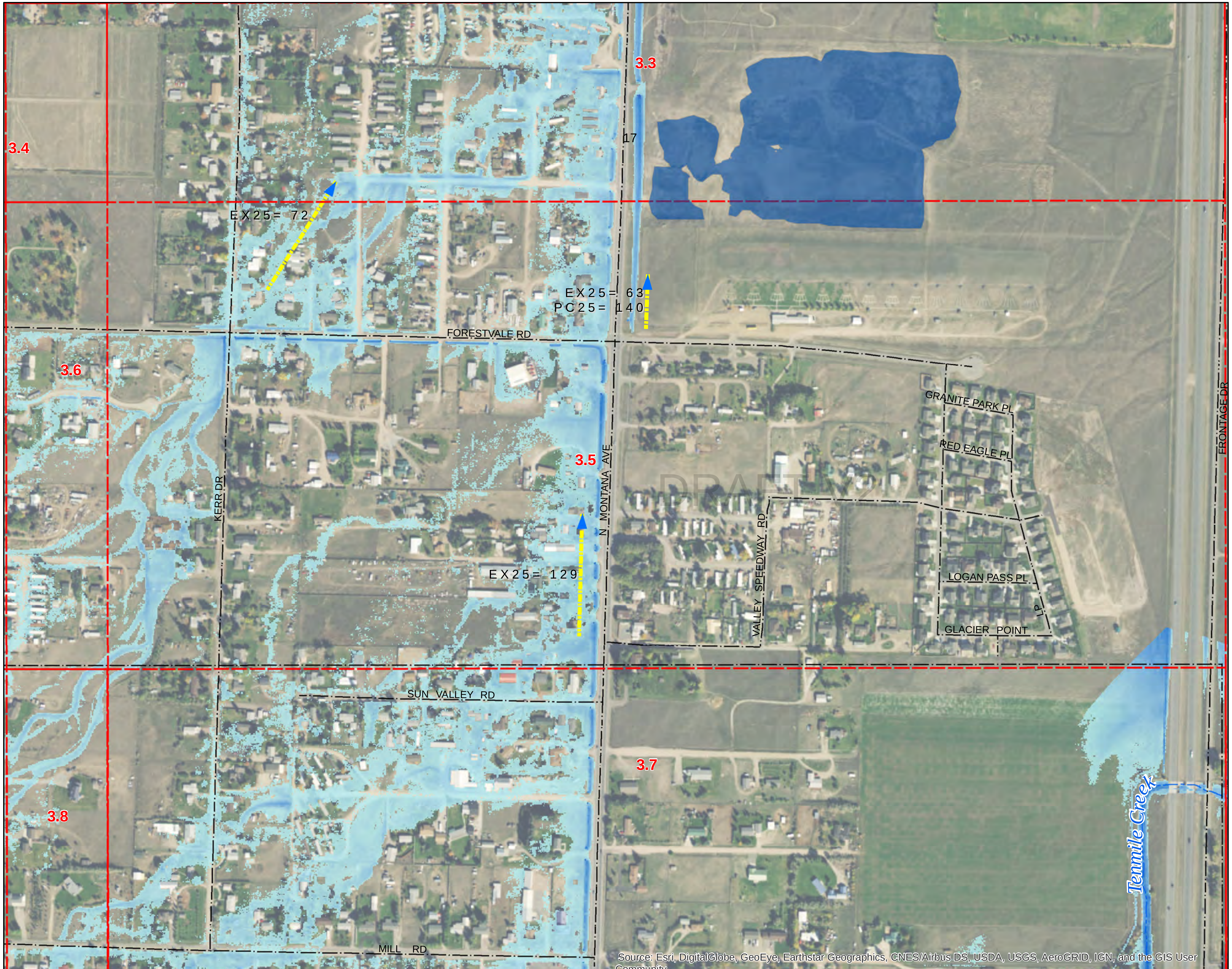
0 500 1,000 Feet



VALLEY FLOOD MITIGATION MASTER PLAN IMPLEMENTATION FLOOD INUNDATION MAPPING

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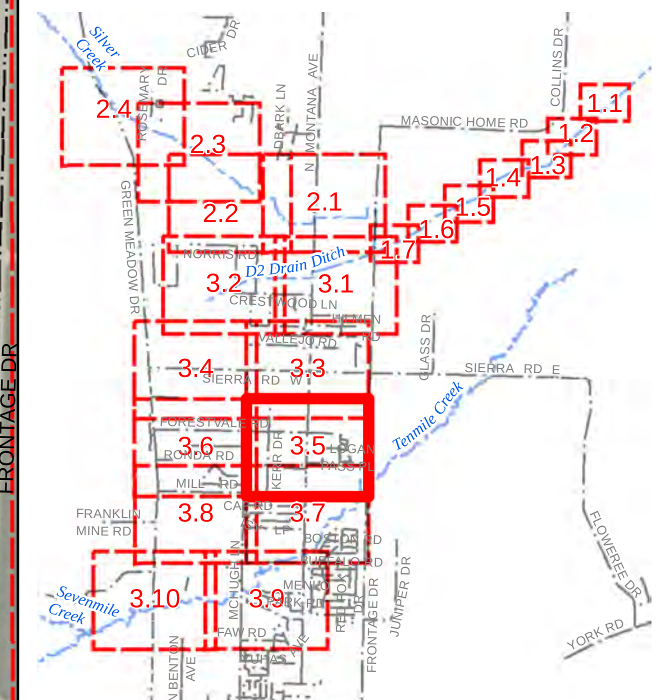

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Legend

- Map Index
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4% Annual Chance Flood

Depth (ft)

High : 15.25

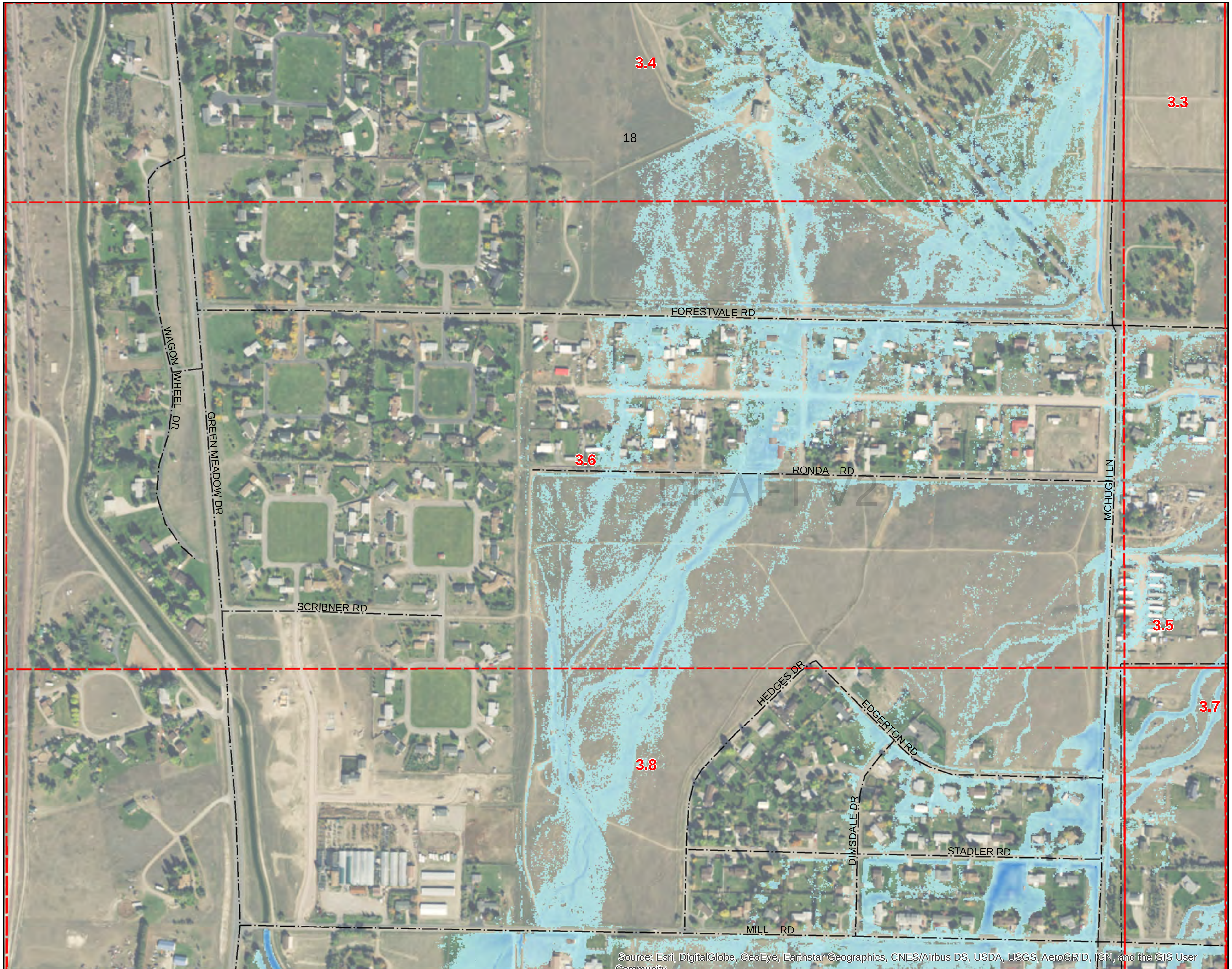
Low : 0.001

Date: 5/1/2017
Drawn: MWJ
Base: ESRI World Imagery

Feet: 0 · 500 · 1,000

N

RESPEC



VALLEY FLOOD MITIGATION MASTER PLAN IMPLEMENTATION FLOOD INUNDATION MAPPING

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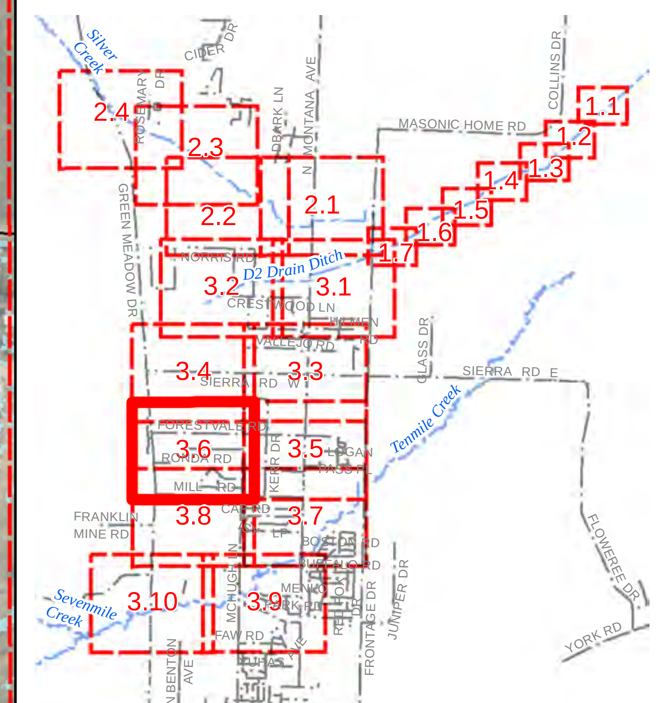

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Legend

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4% Annual Chance Flood

Depth (ft)

High : 15.25

Low : 0.001

Date: 5/1/2017

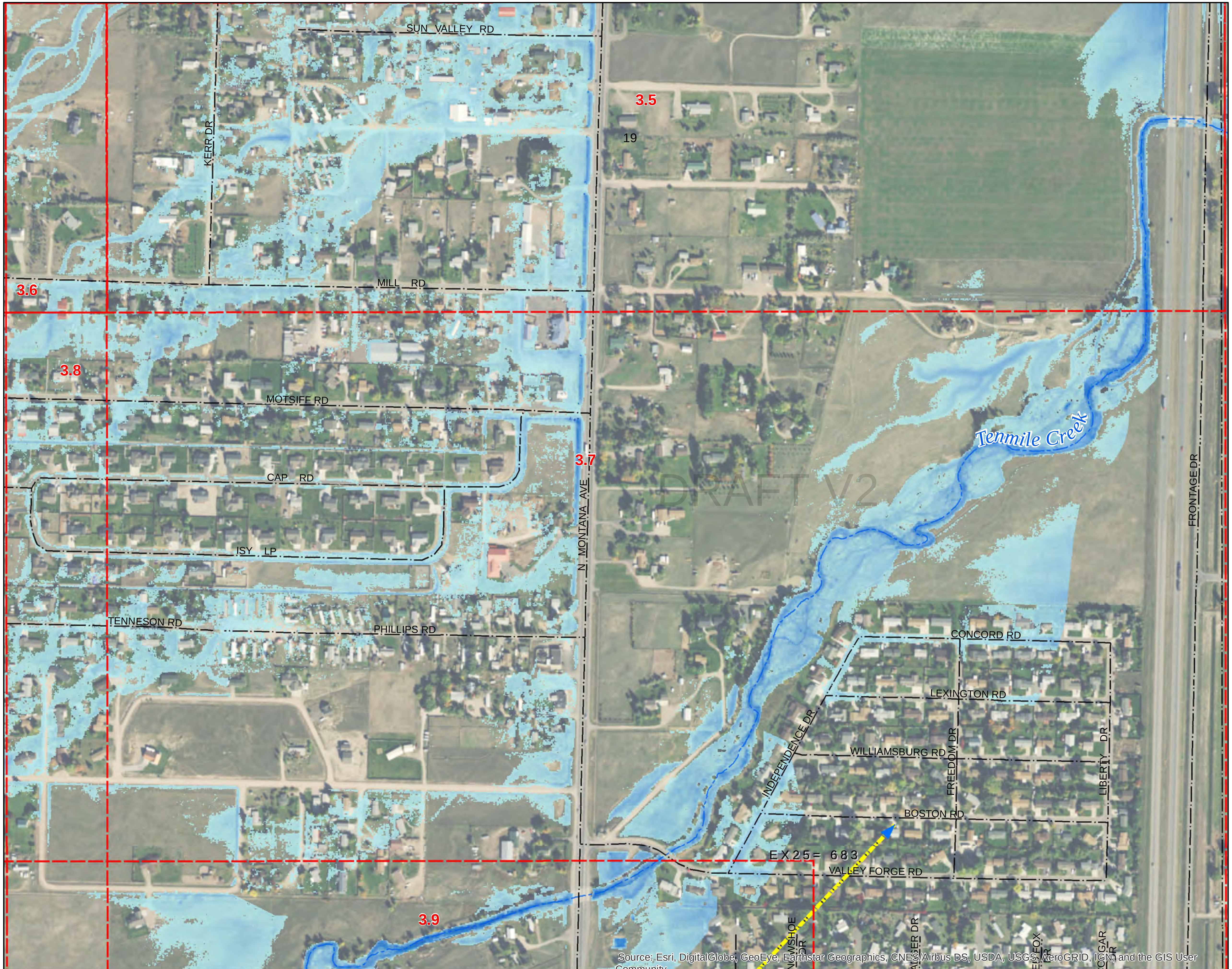
Drawn: MWJ

Base: ESRI World Imagery

N

0 500 1,000 Feet

VALLEY FLOOD MITIGATION MASTER PLAN IMPLEMENTATION FLOOD INUNDATION MAPPING



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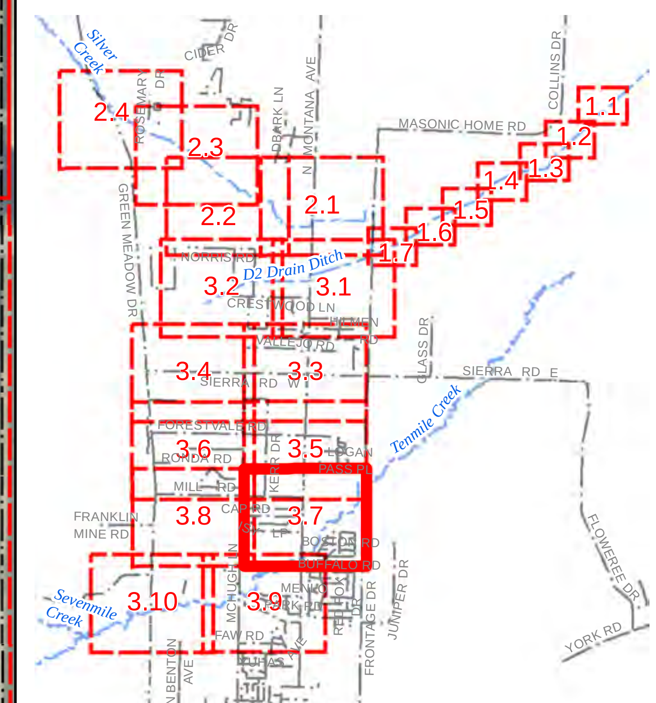

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Legend

- Map Index
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4% Annual Chance Flood

Depth (ft)

High : 15.25

Low : 0.001

Date: 5/1/2017
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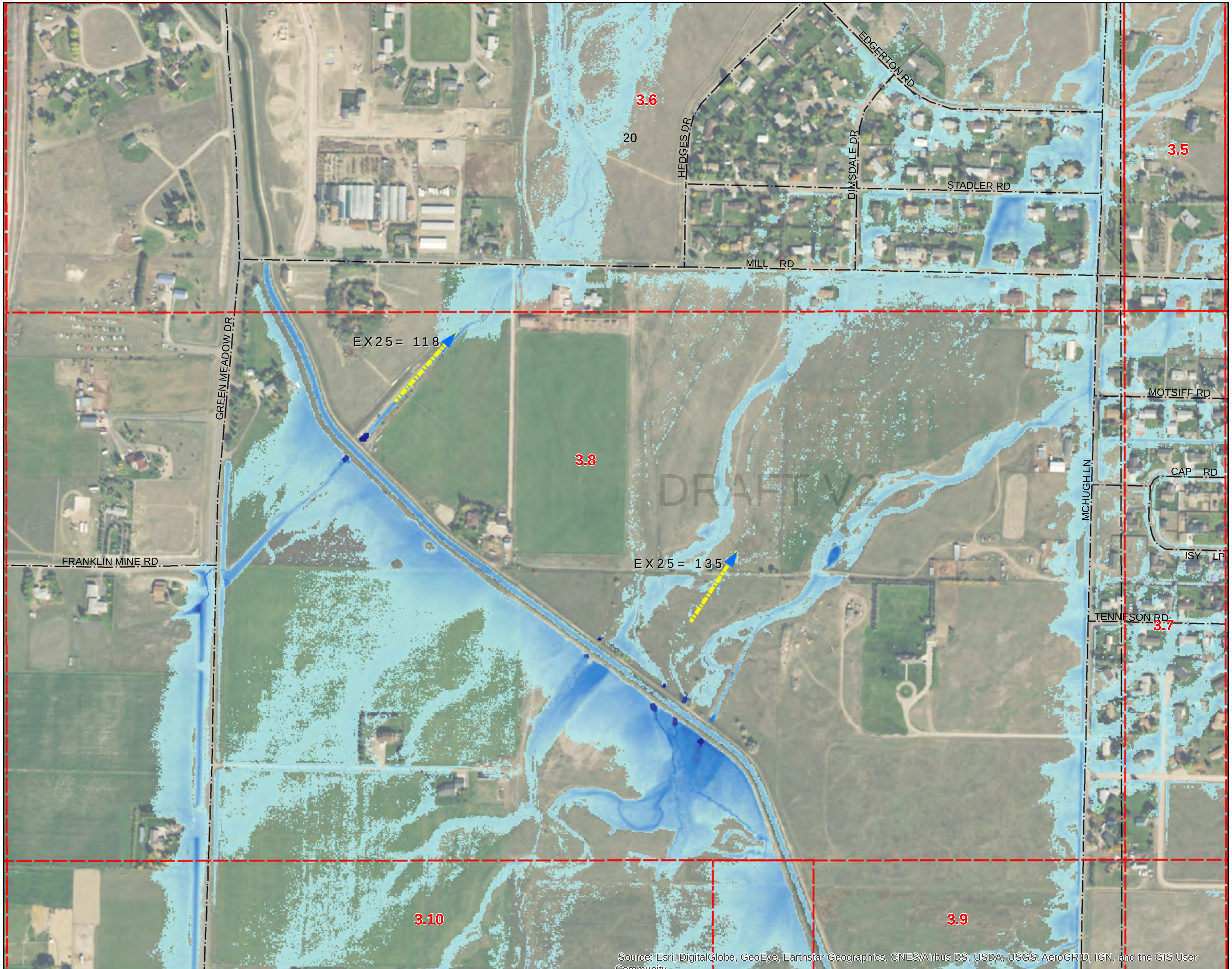
Base: ESRI World Imagery

0 500 1,000 Feet

N

RESPEC



VALLEY FLOOD MITIGATION MASTER PLAN IMPLEMENTATION FLOOD INUNDATION MAPPING

DES
FEMA

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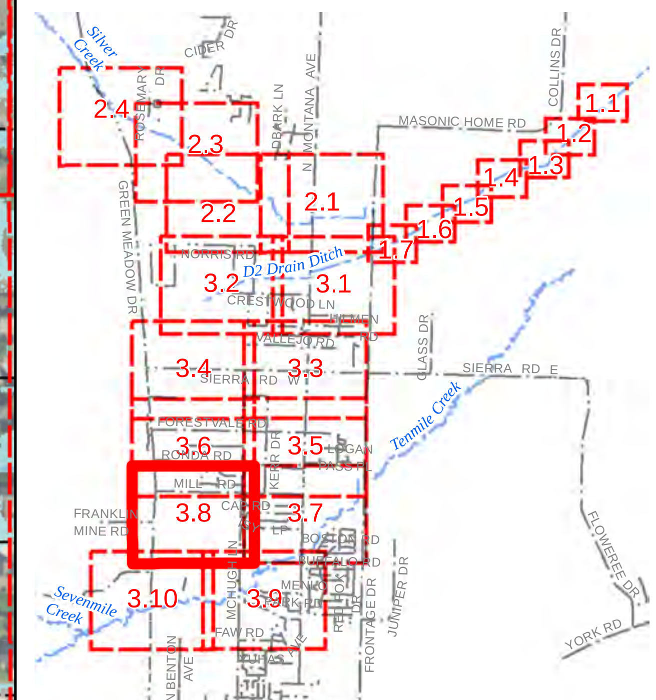

ARROWS INDICATE FLOW RESULTS (CFS) FOR THE EXISTING CONDITIONS (EX) AND PROPOSED CONDITIONS (PC) OF TRAP CLUB IMPROVEMENTS FOR THE 25-YR (25) AND 100-YR (100) COINCIDENT FLOOD EVENTS FOR TENMILE CREEK AND SILVER CREEK.

Legend

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RESPEC

4% Annual Chance Flood

Depth (ft)

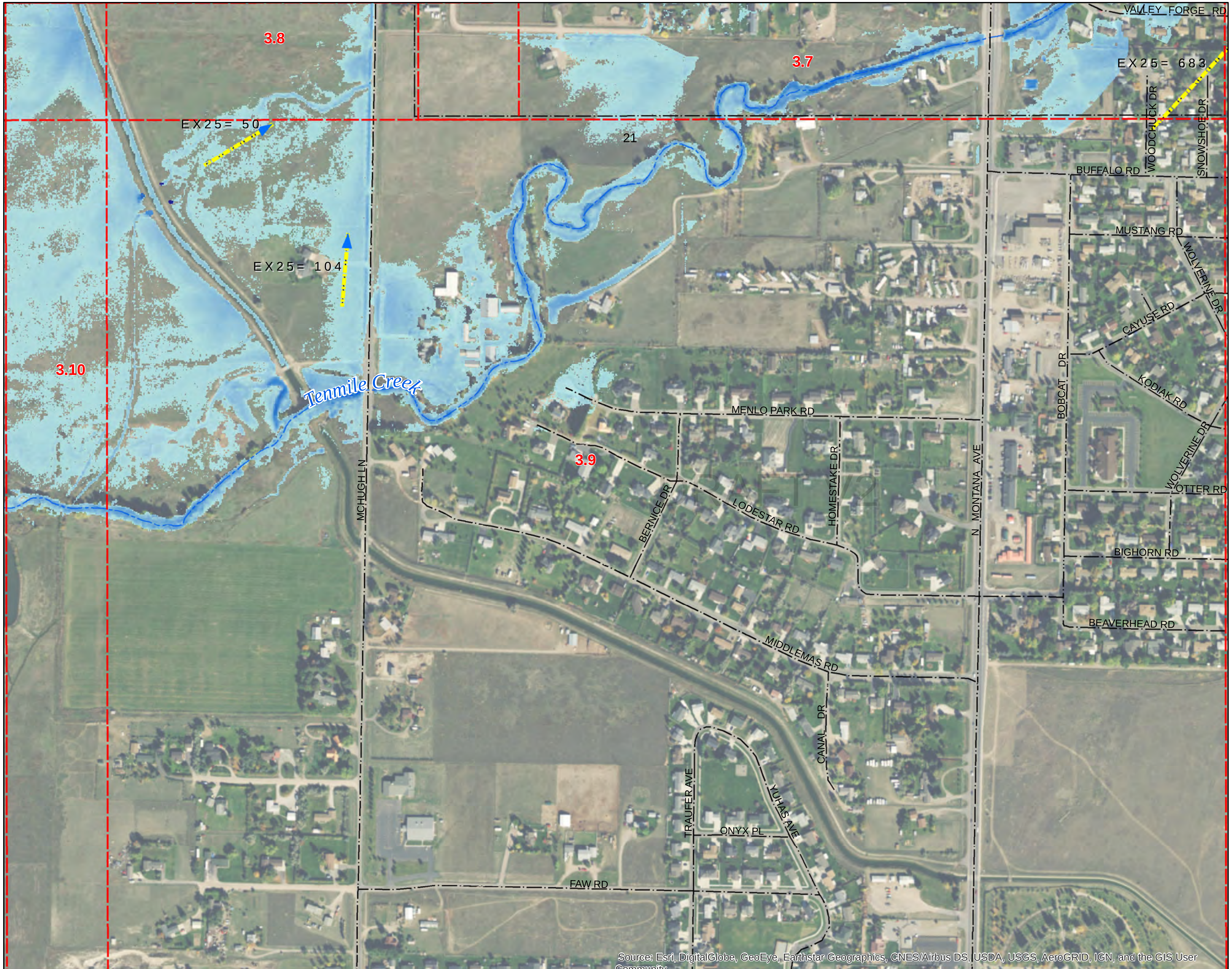
High : 15.25

Low : 0.001

N

Date: 5/1/2017
Drawn: MWJ
Base: ESRI World Imagery

0 500 1,000 Feet



VALLEY FLOOD MITIGATION MASTER PLAN IMPLEMENTATION FLOOD INUNDATION MAPPING

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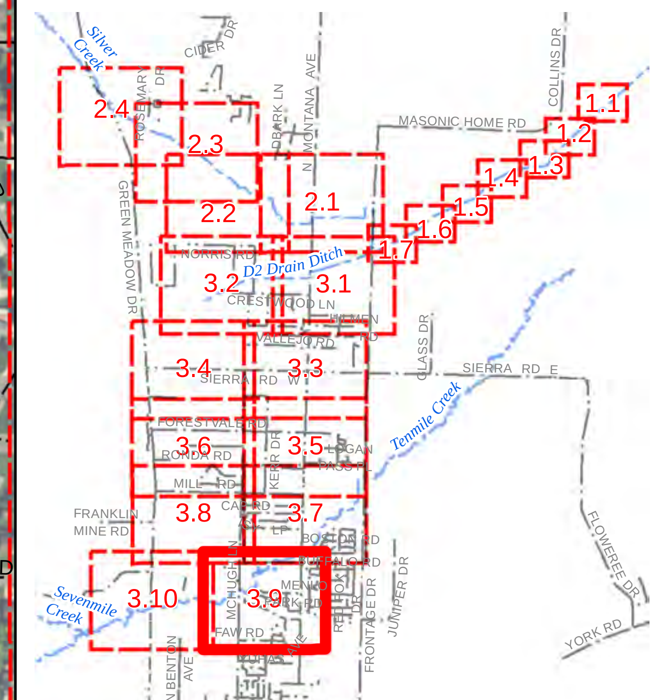

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VALLEY FLOOD MITIGATION
MASTER PLAN IMPLEMENTATION
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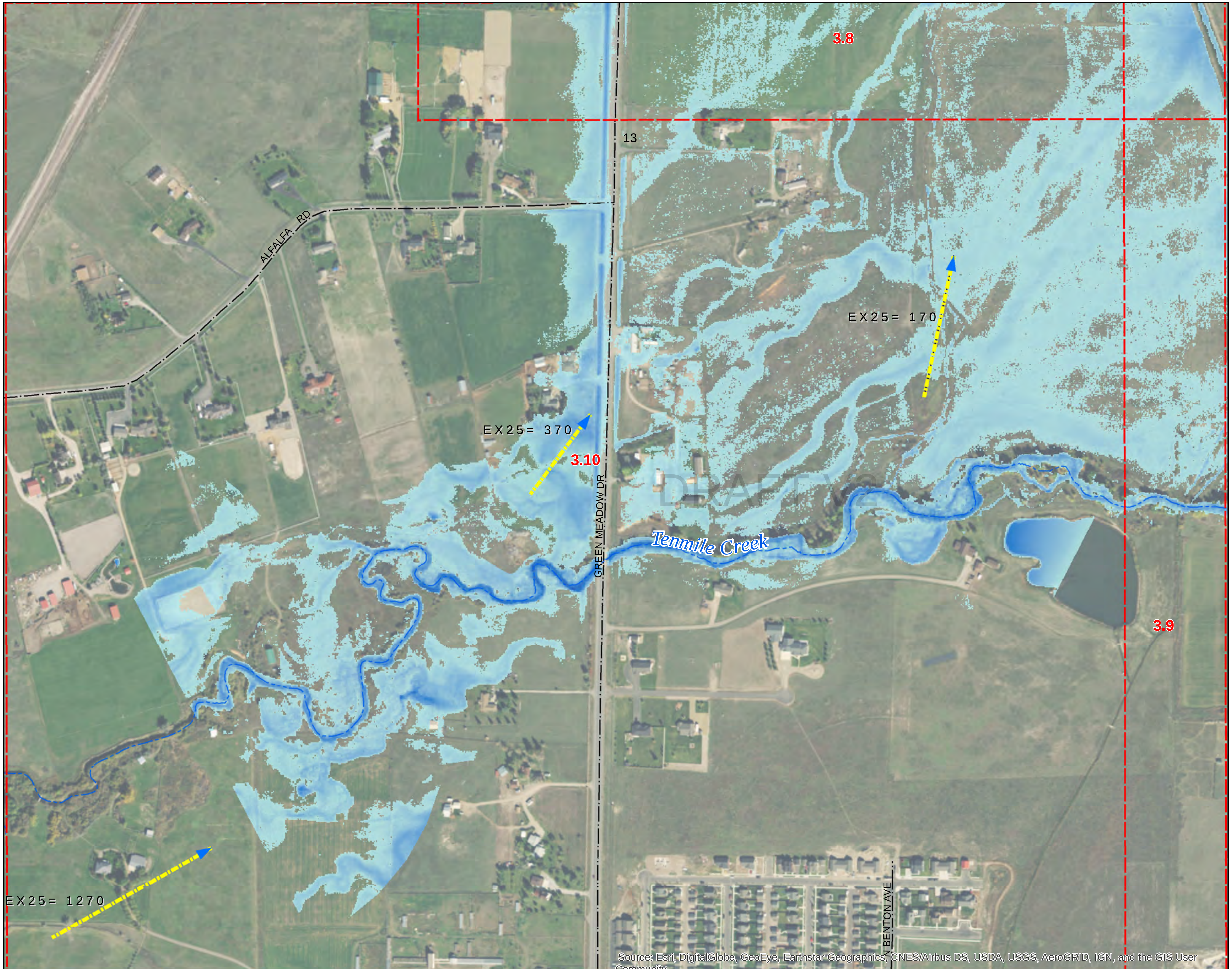

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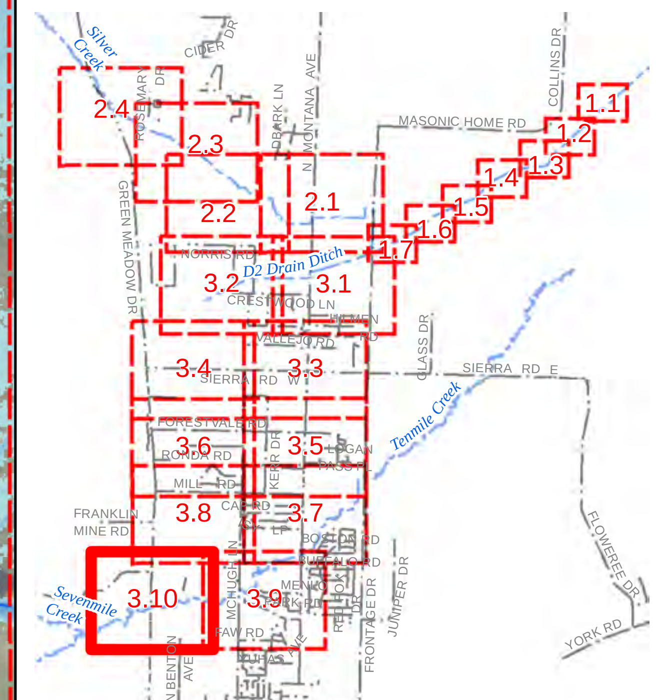

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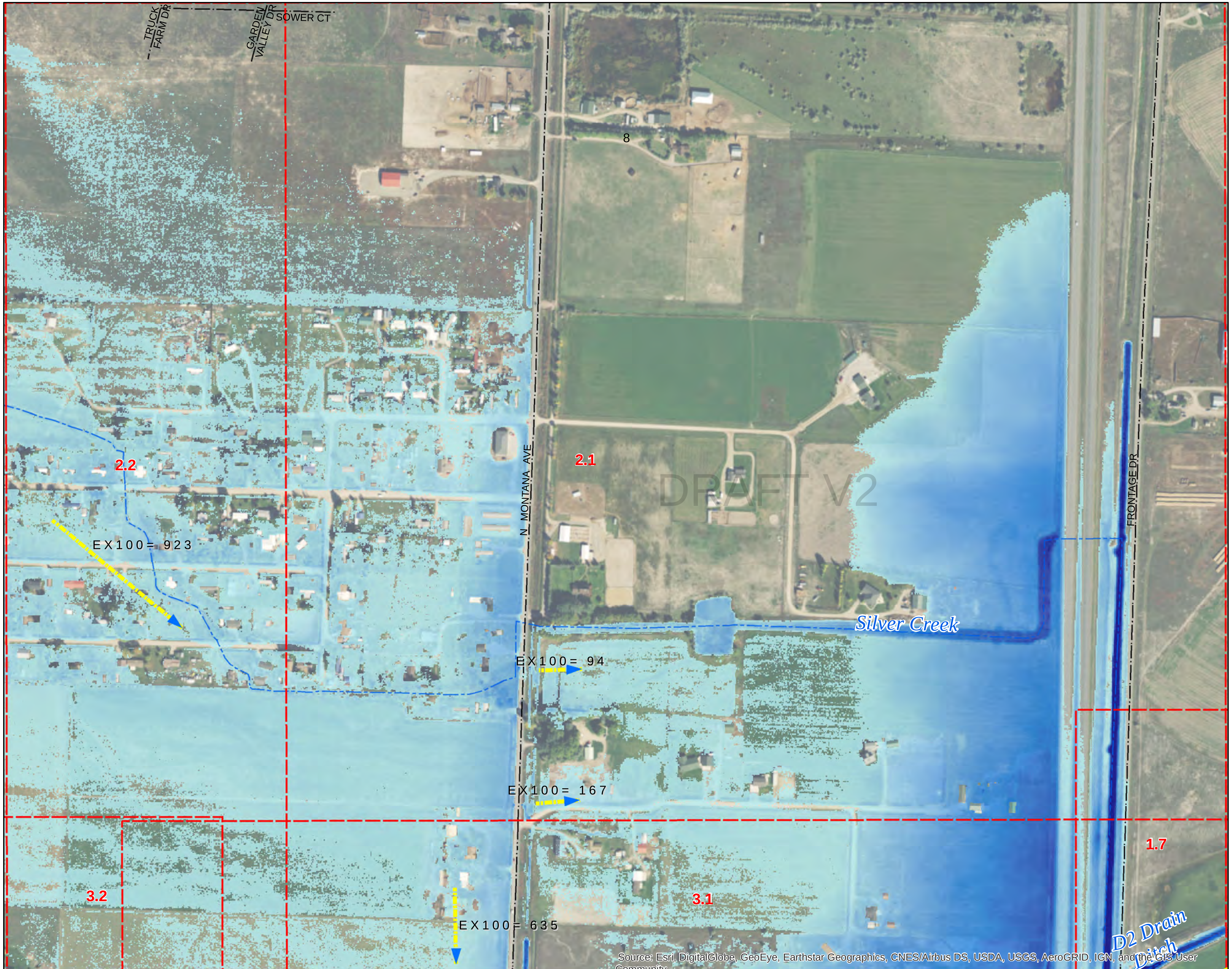

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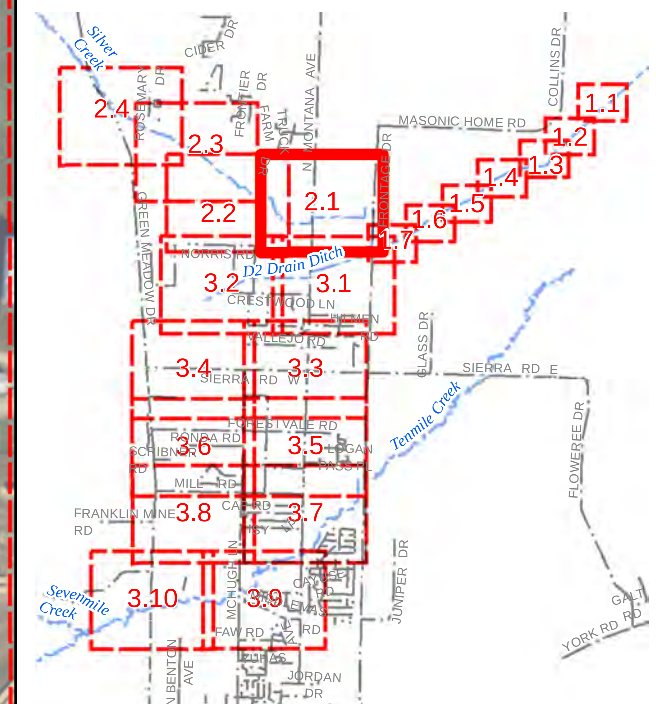

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Depth (ft)

High : 18.5

Low : 0.001

Date: 5/1/2017
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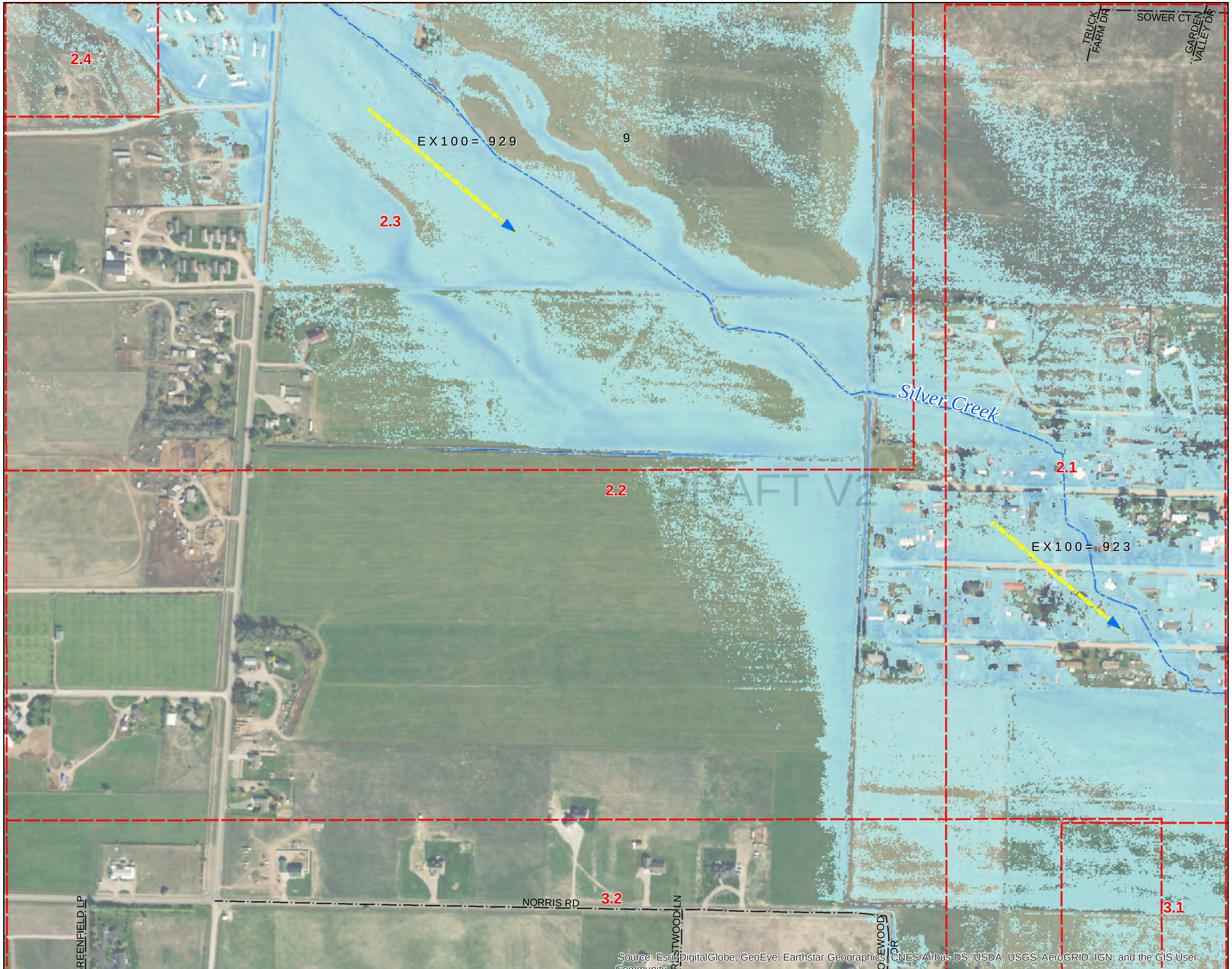
0 500 1,000 Feet

N



VALLEY FLOOD MITIGATION MASTER PLAN IMPLEMENTATION FLOOD INUNDATION MAPPING

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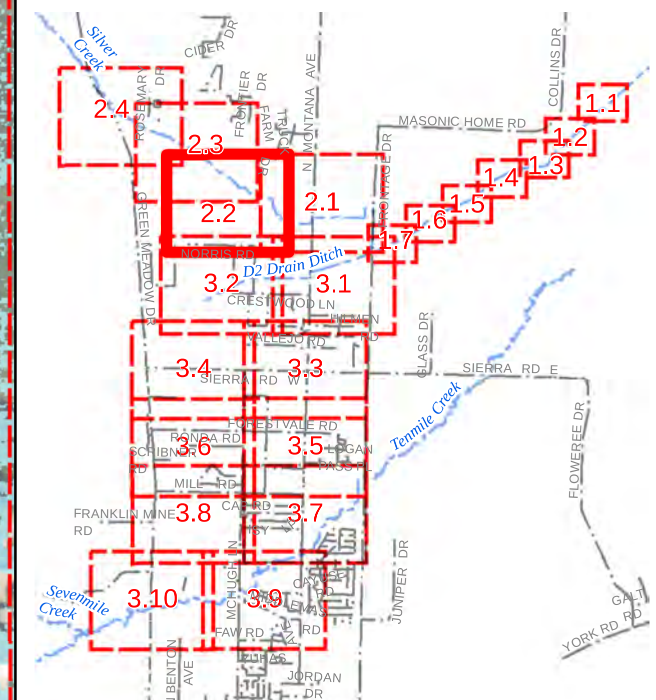

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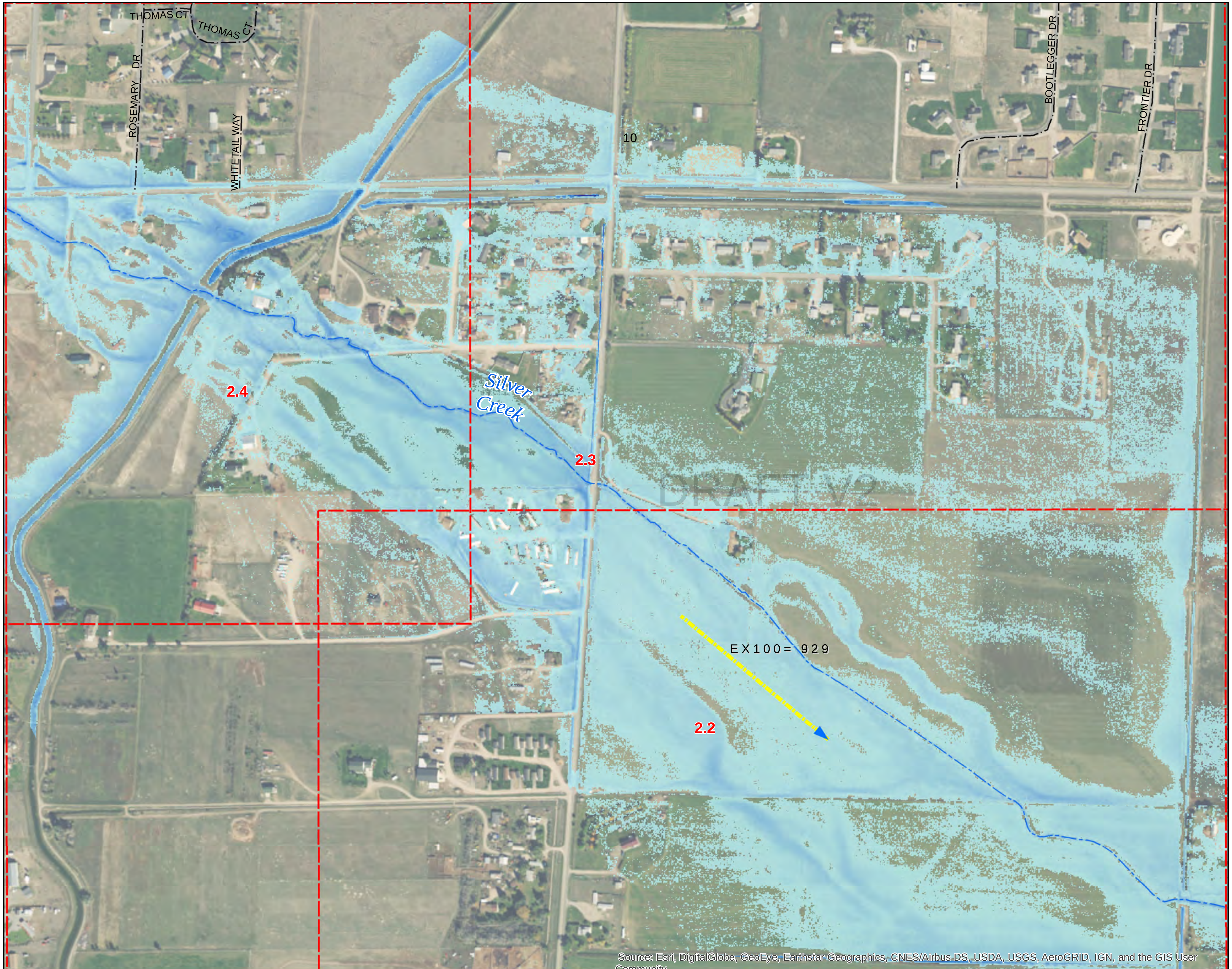

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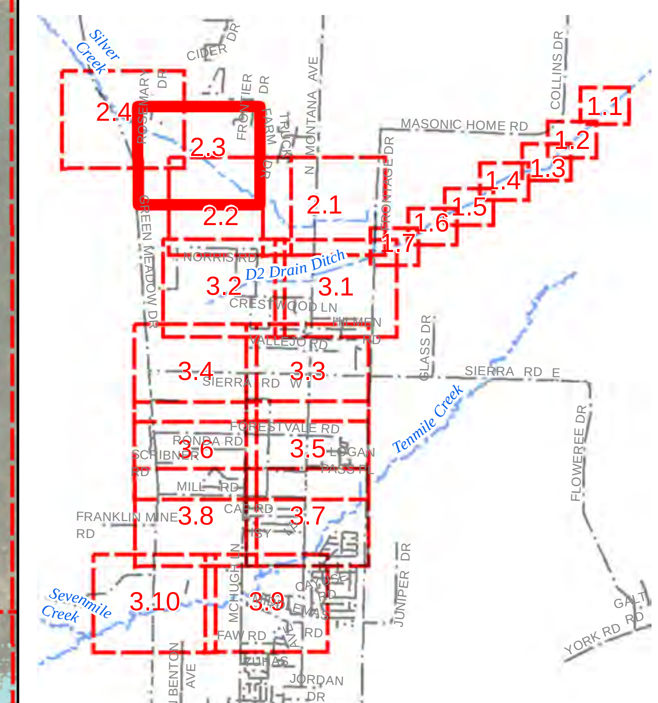

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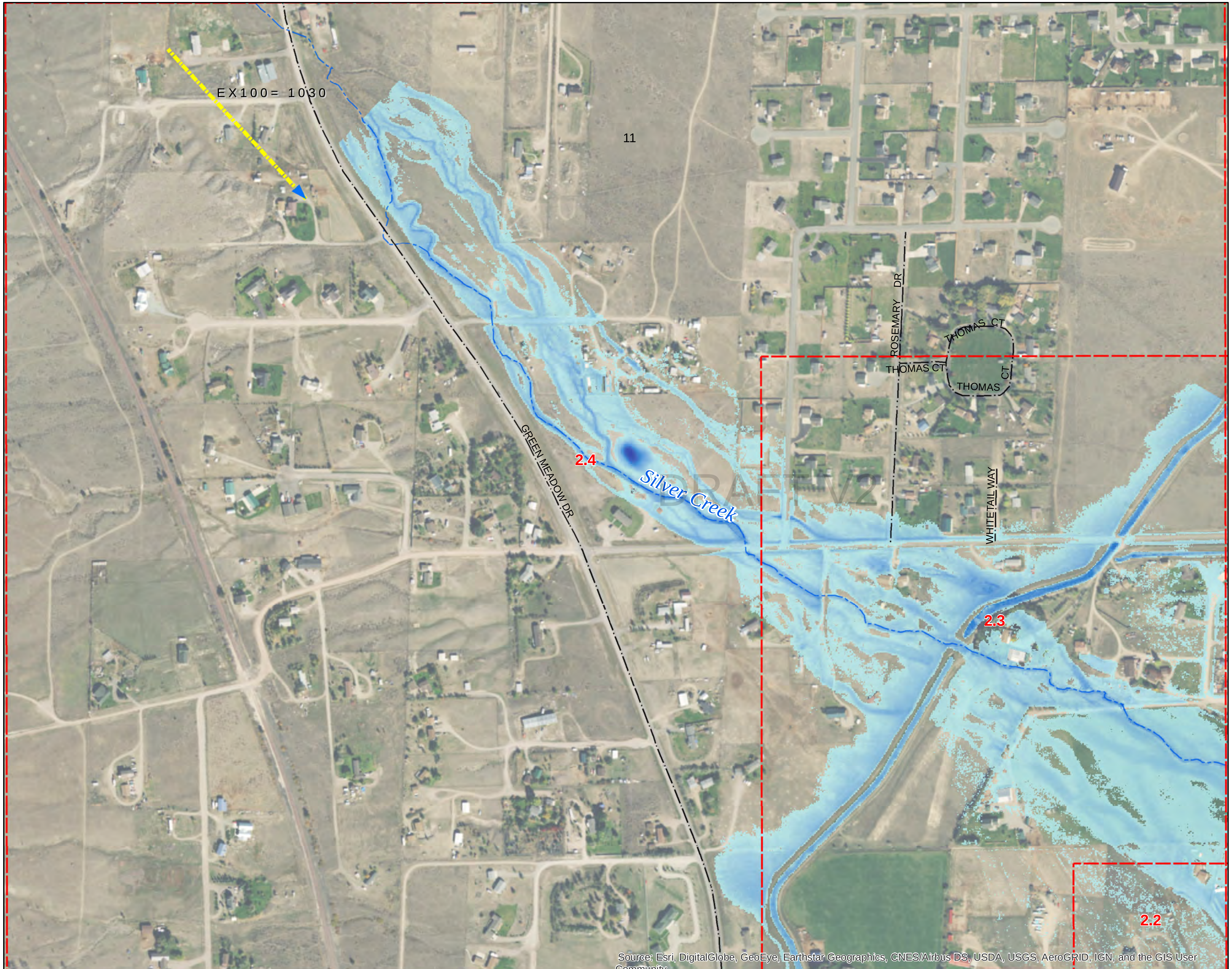

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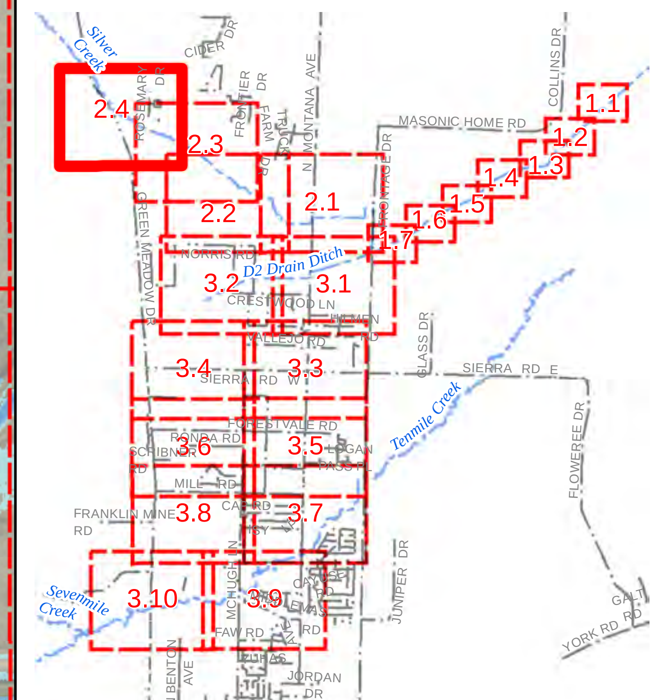

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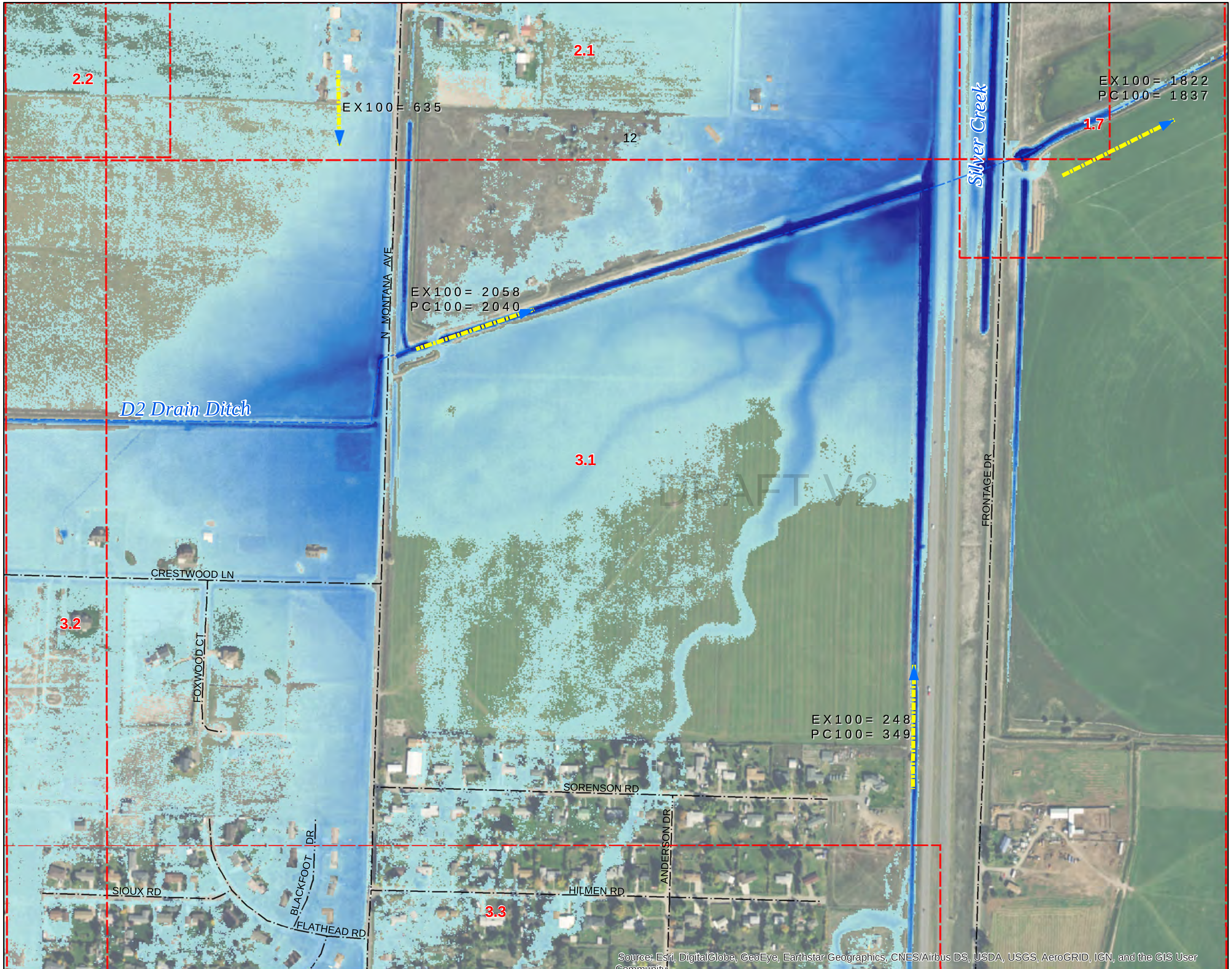

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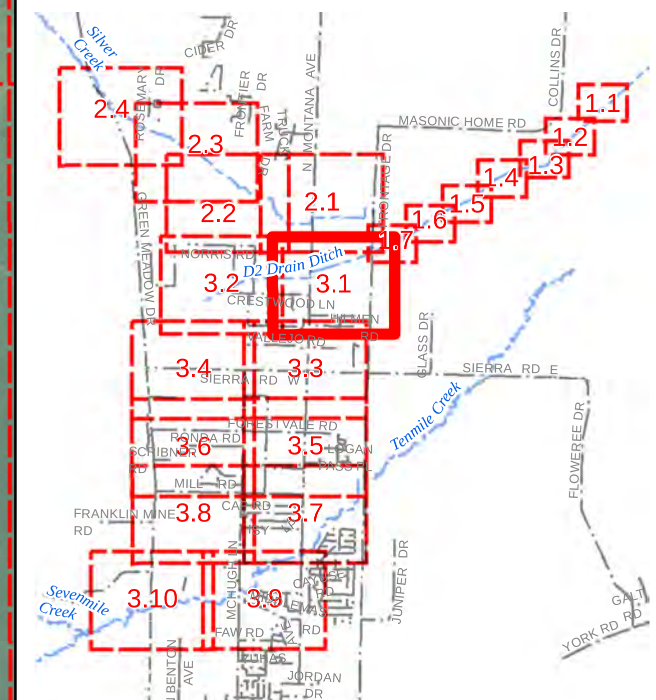

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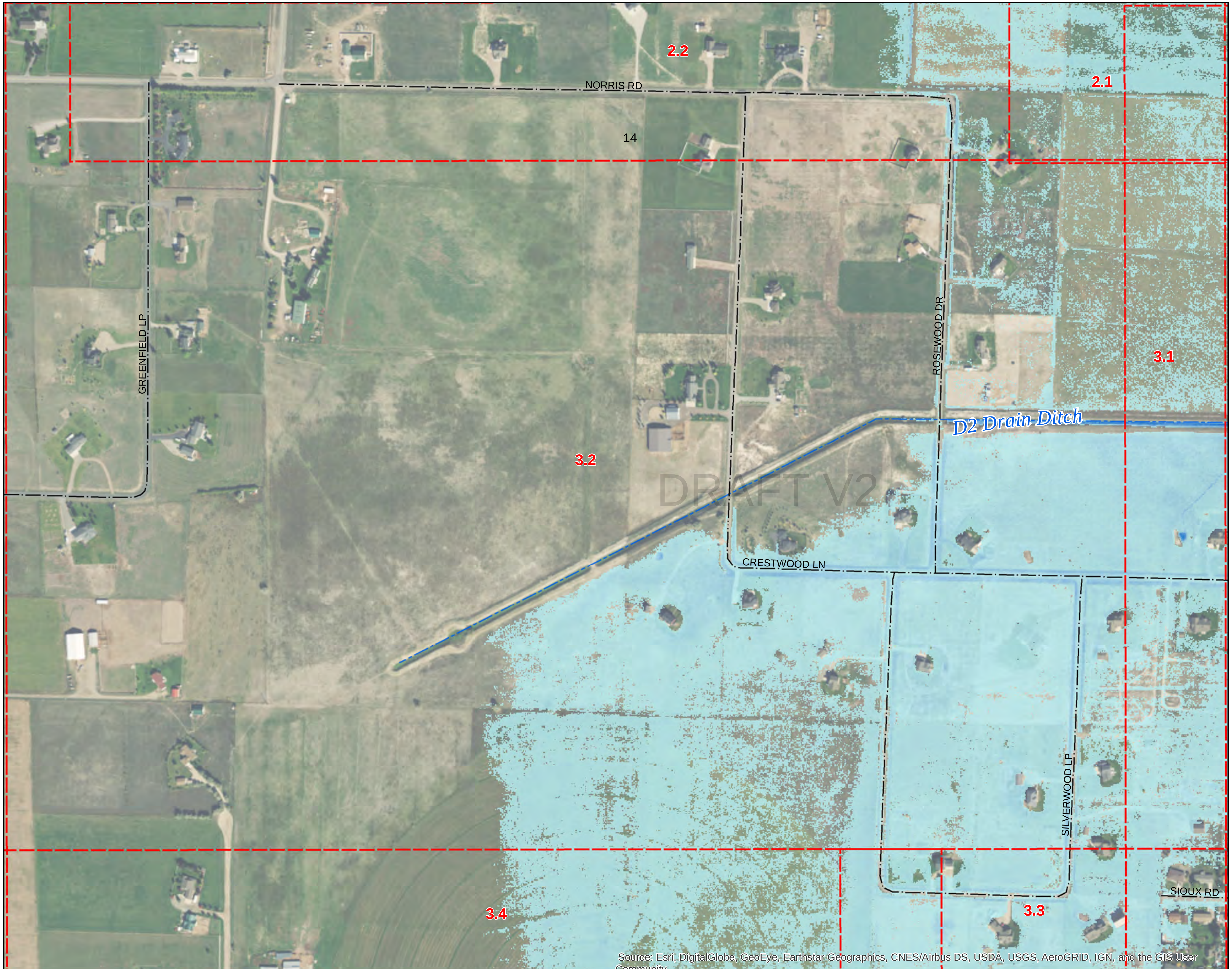

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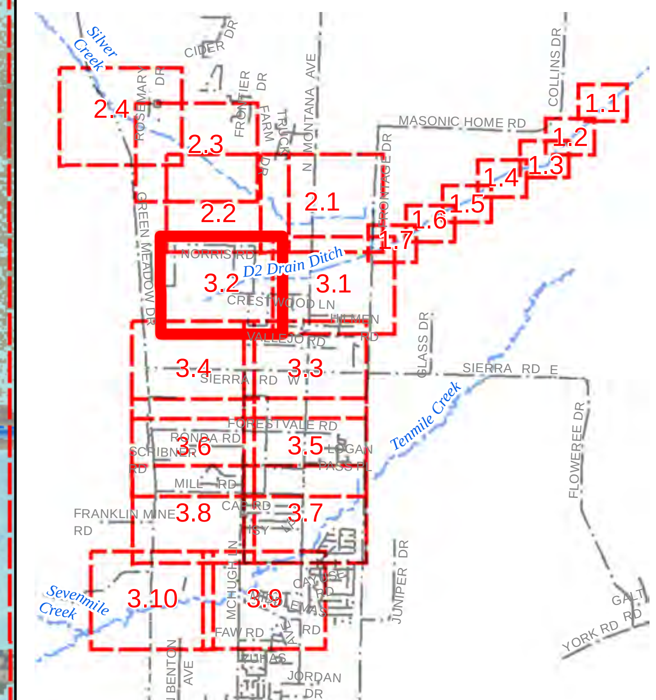

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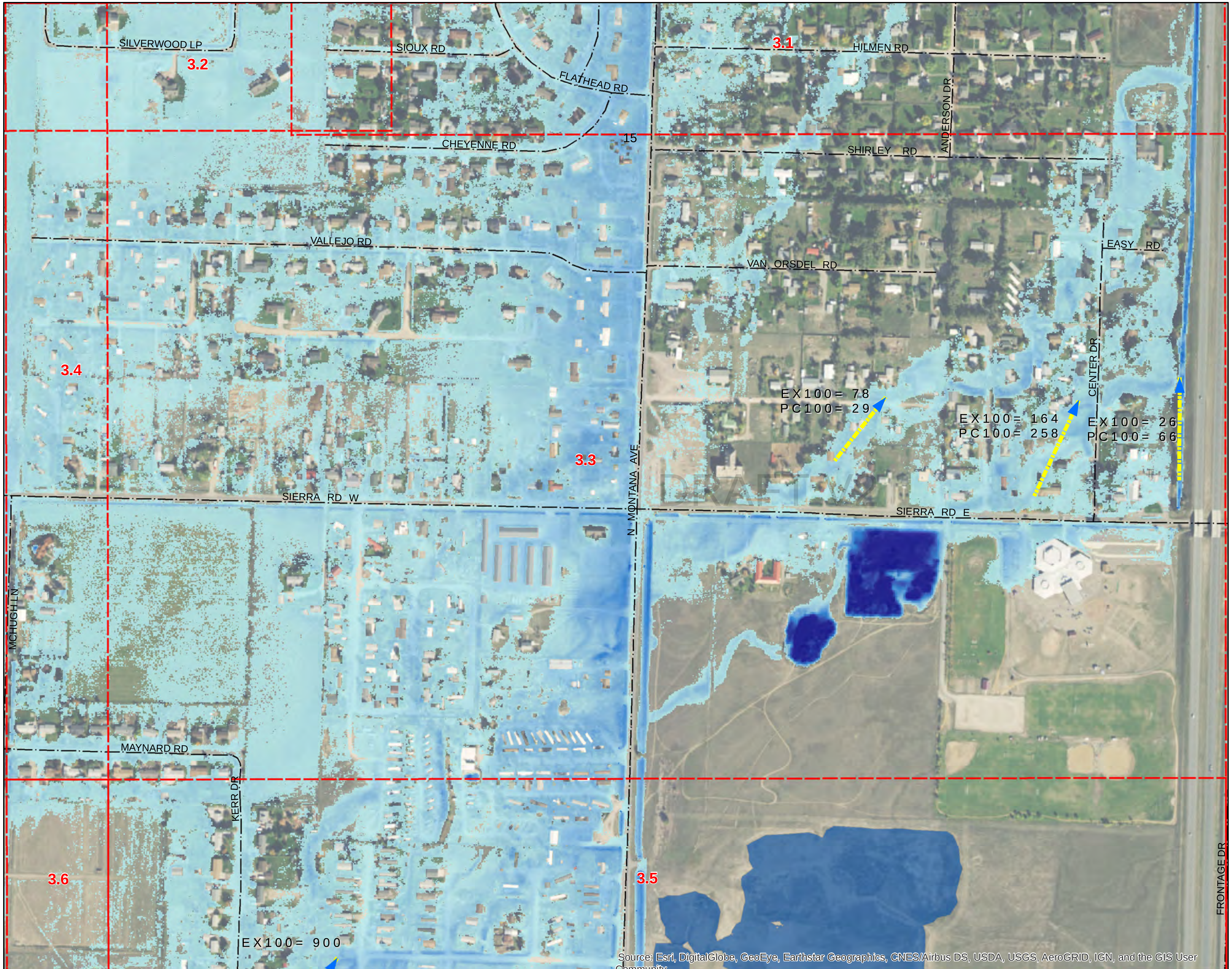

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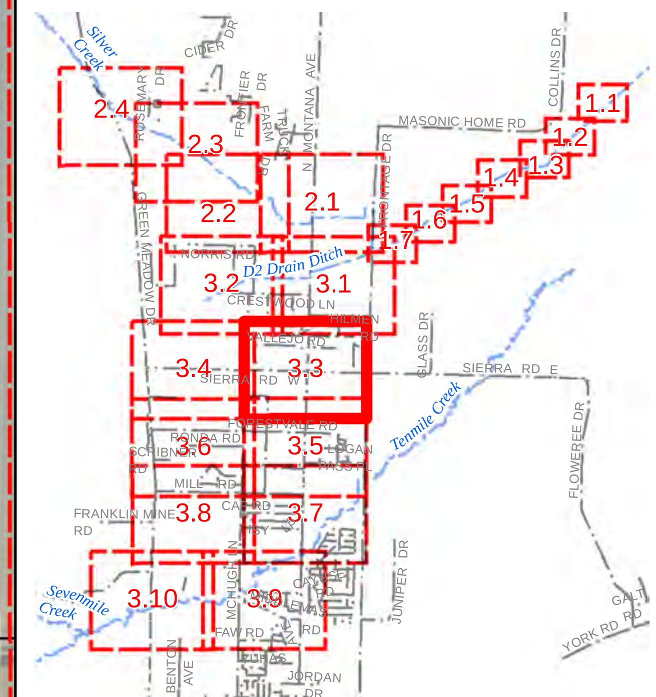

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Feet
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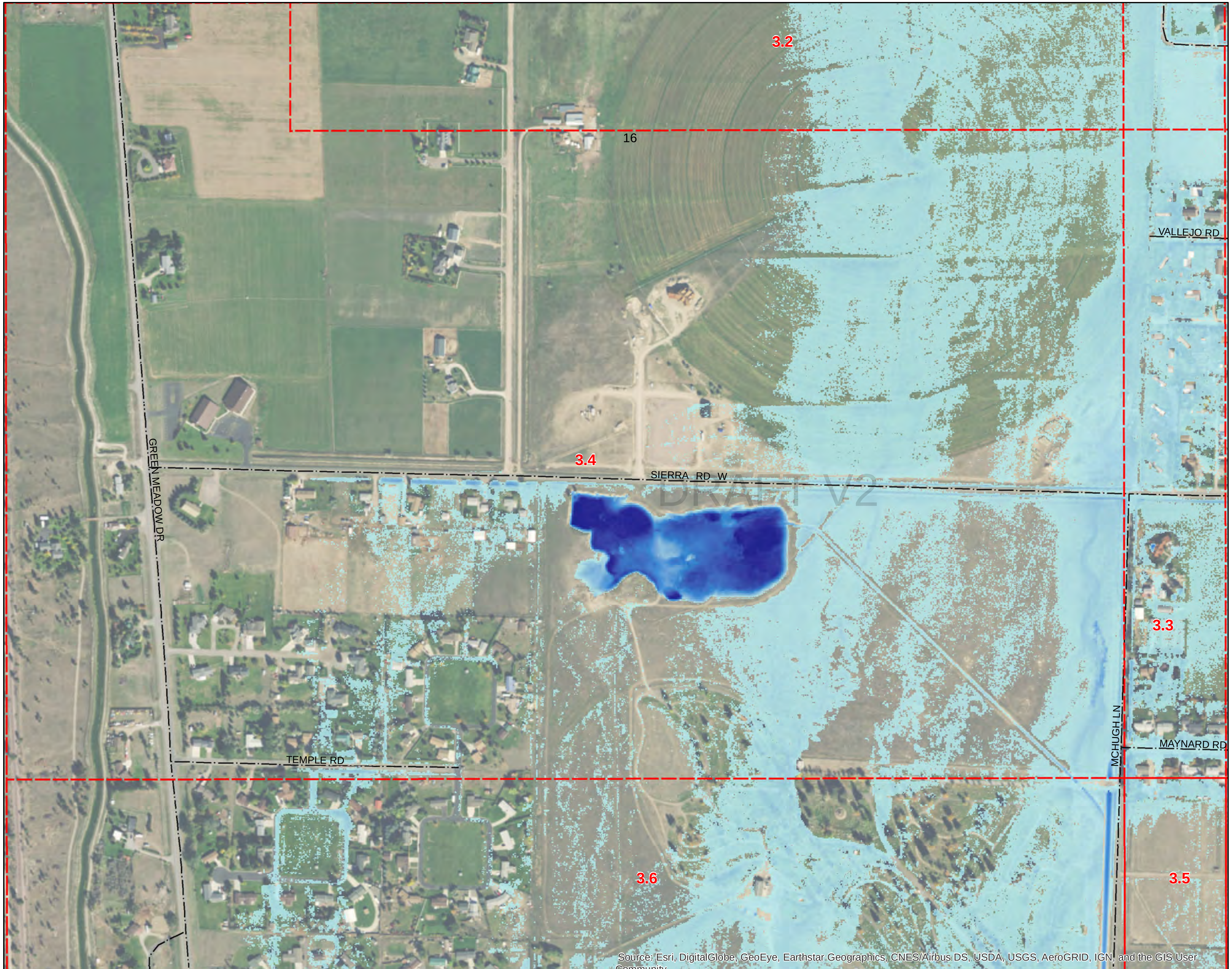
N

VALLEY FLOOD MITIGATION
MASTER PLAN IMPLEMENTATION
FLOOD INUNDATION MAPPING



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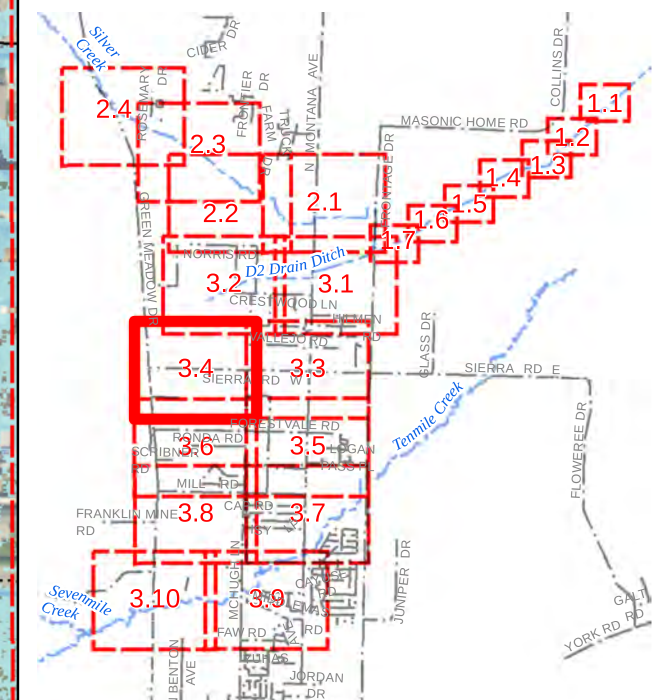

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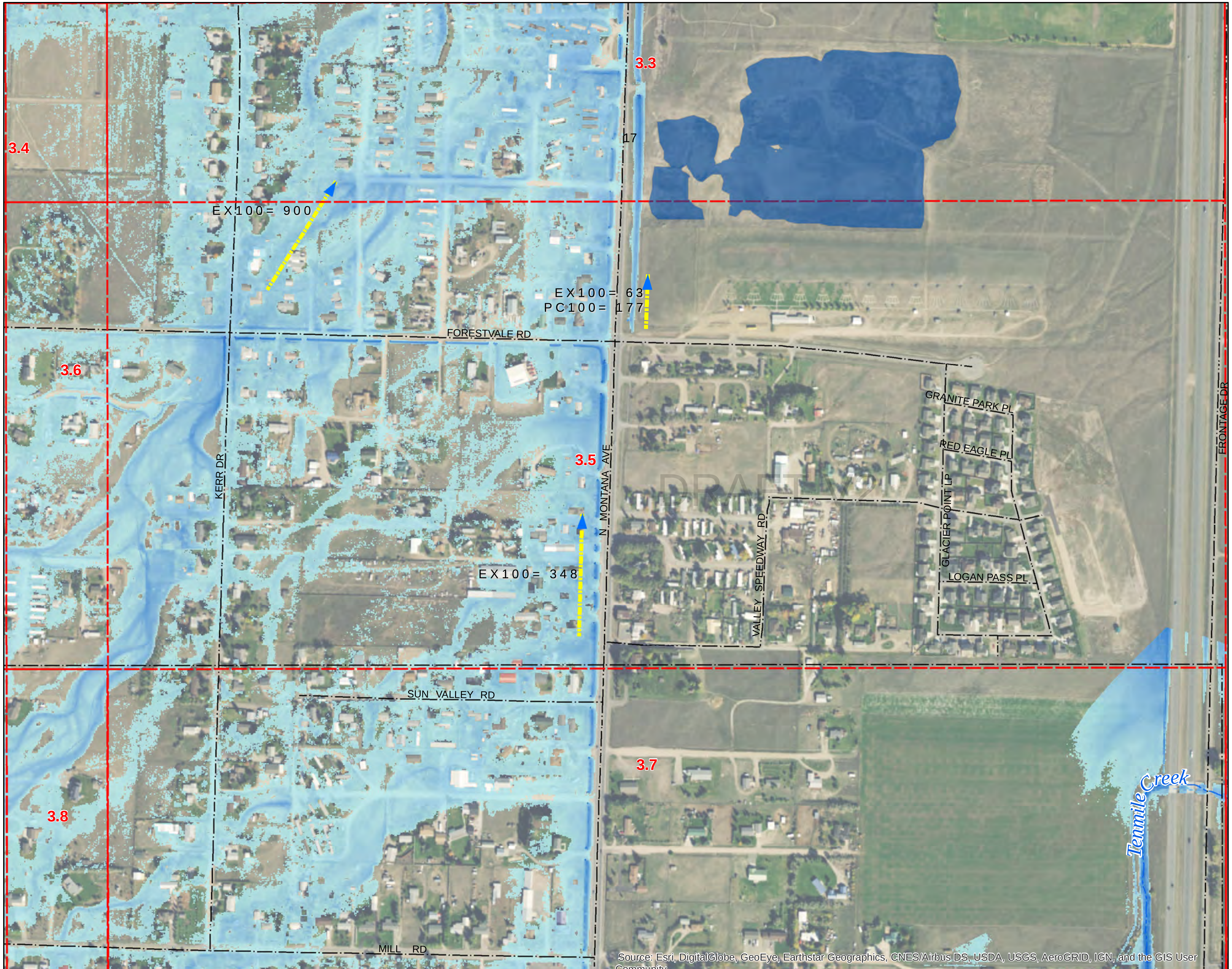

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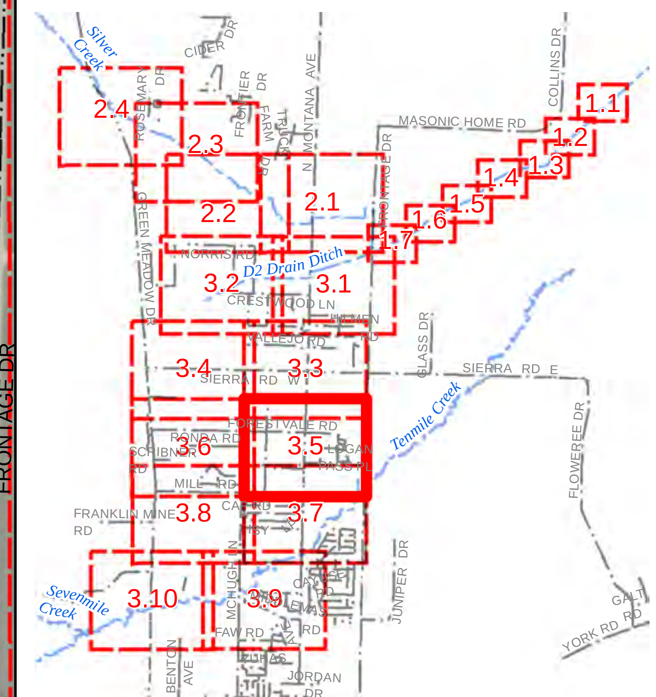

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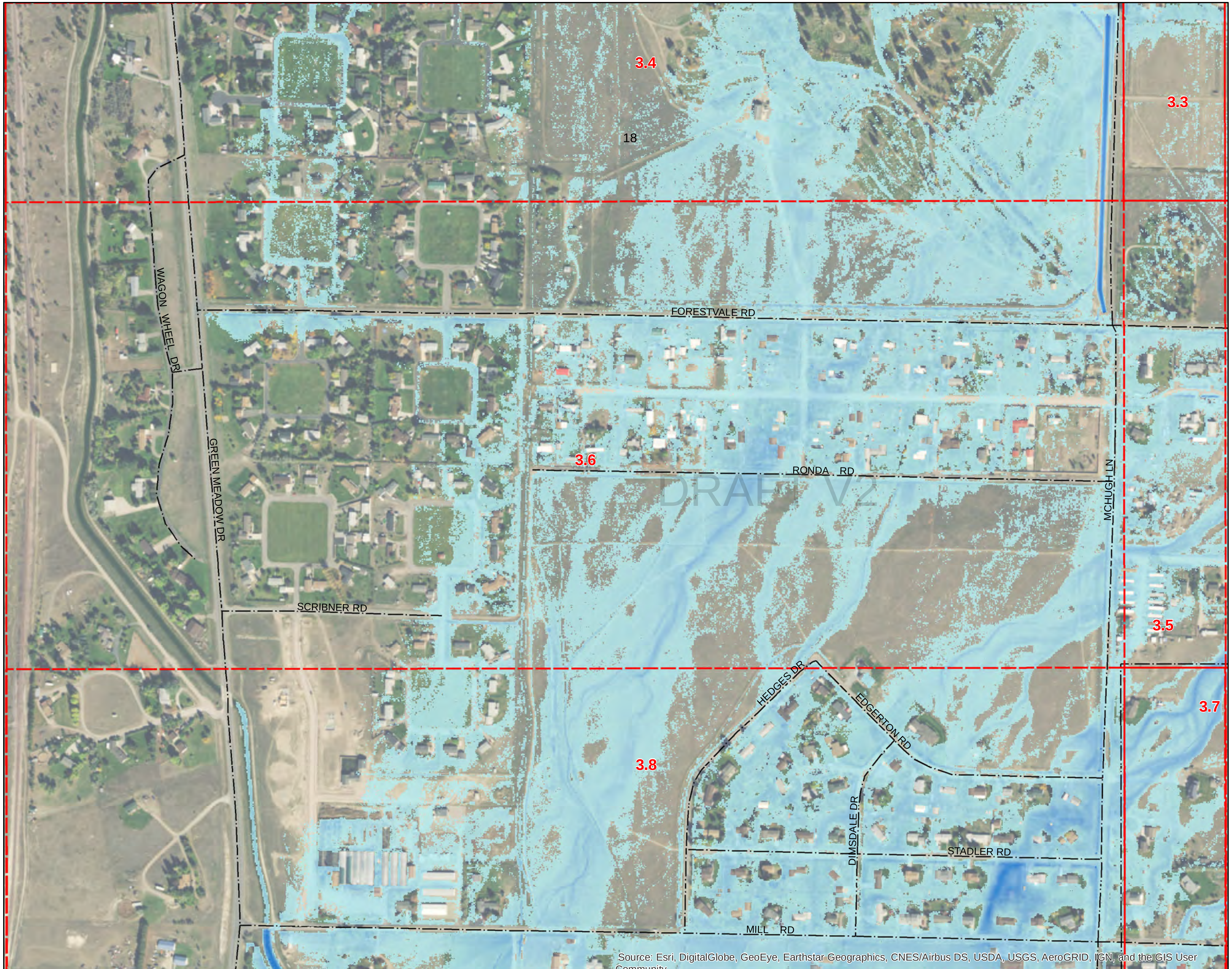

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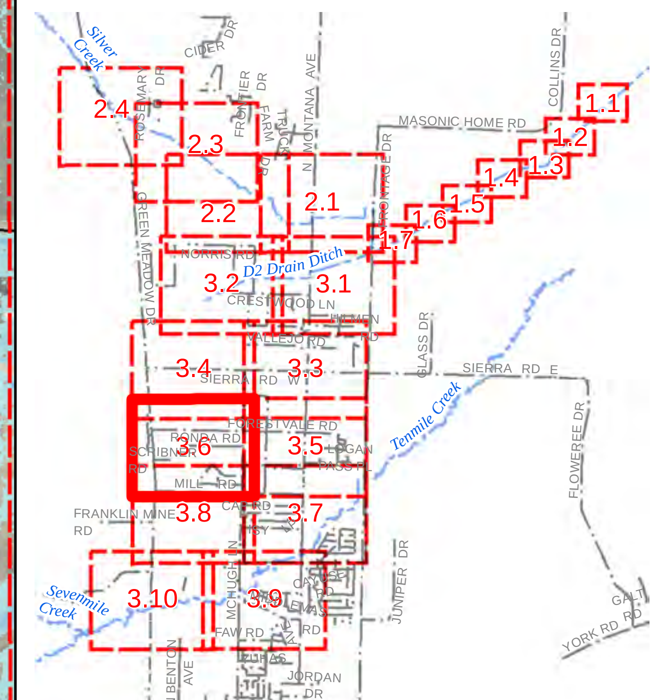

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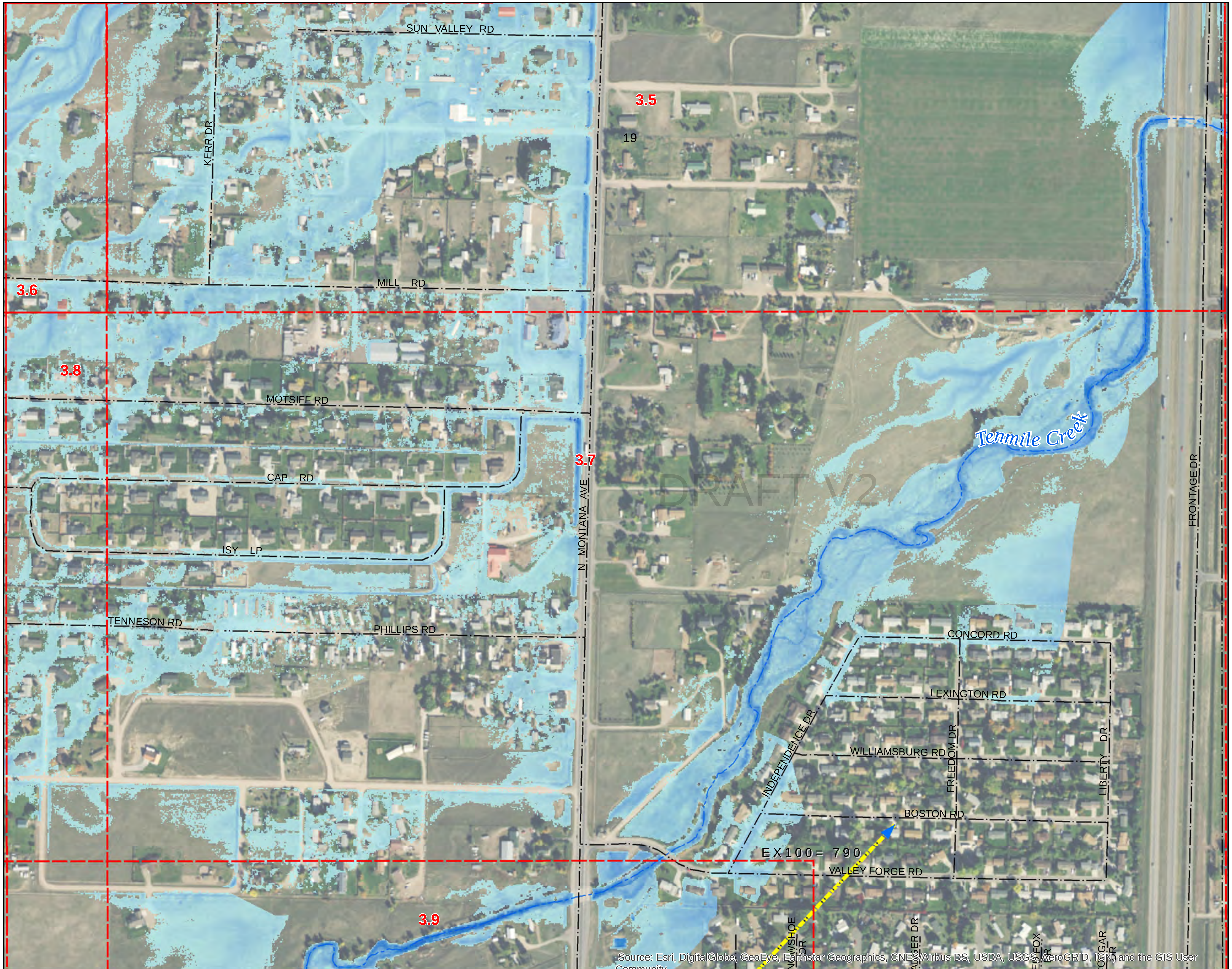

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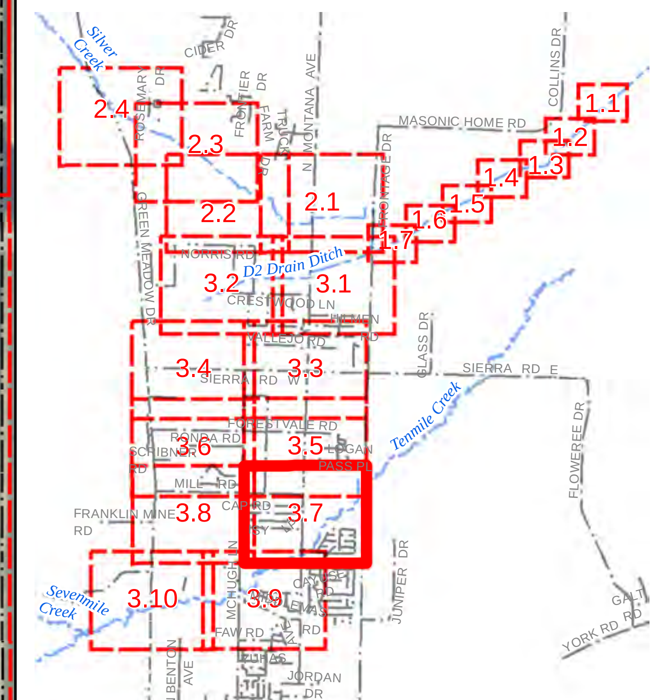

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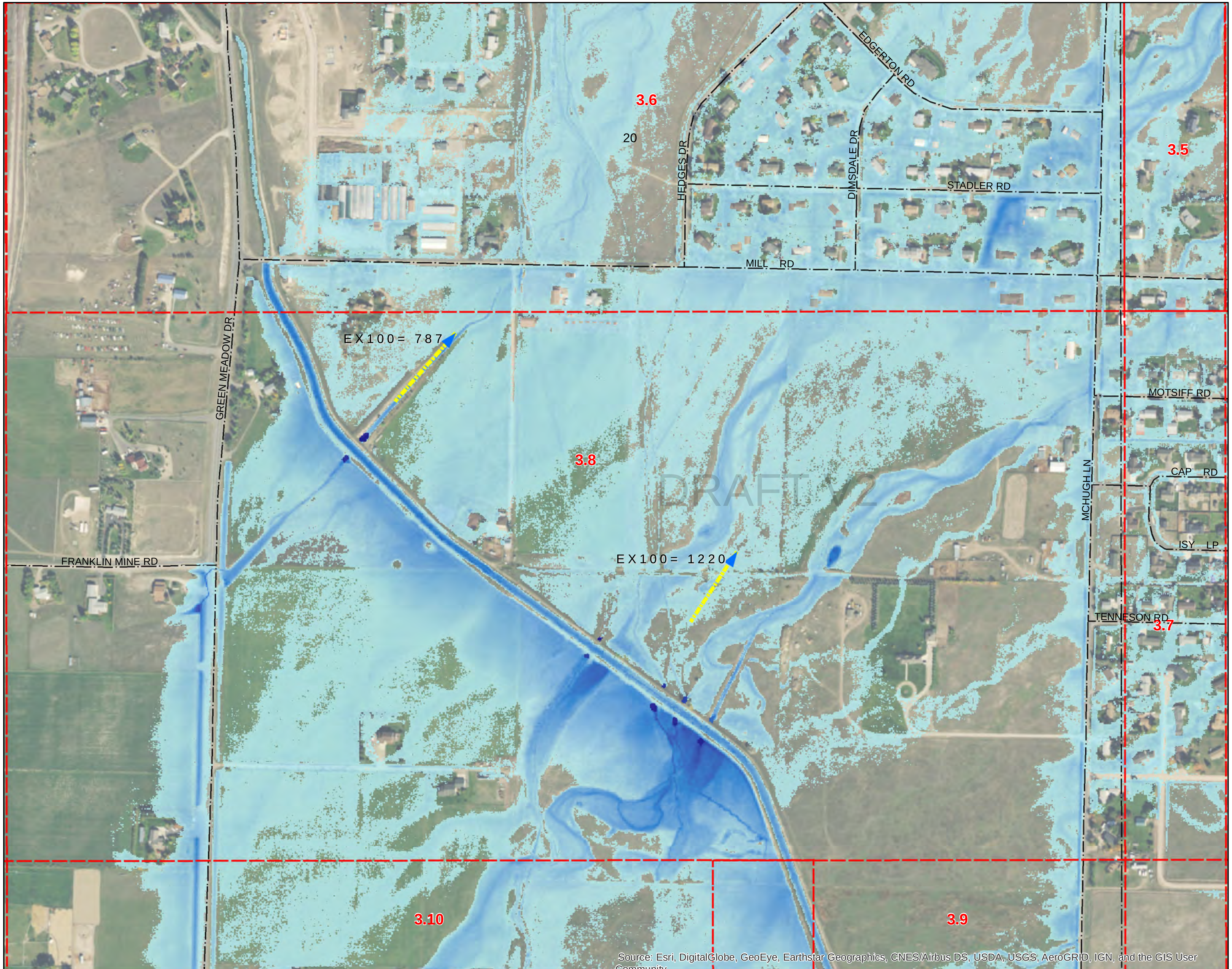

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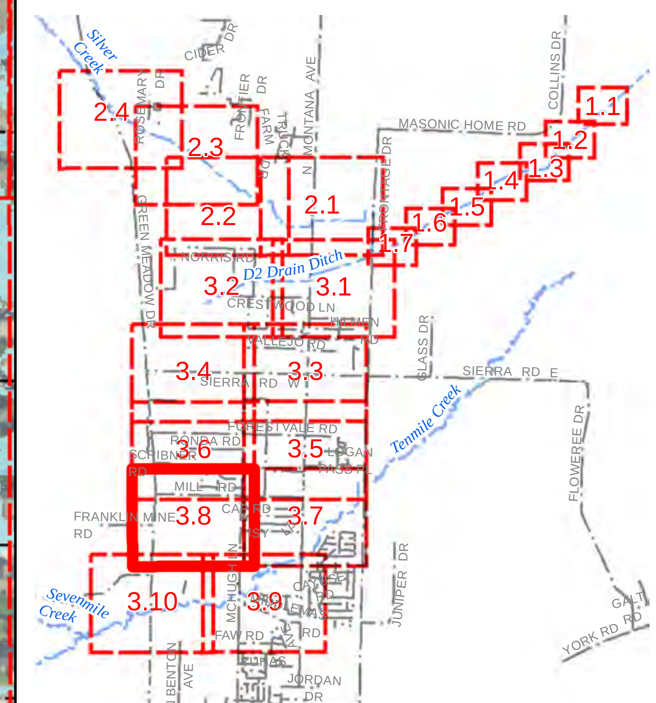

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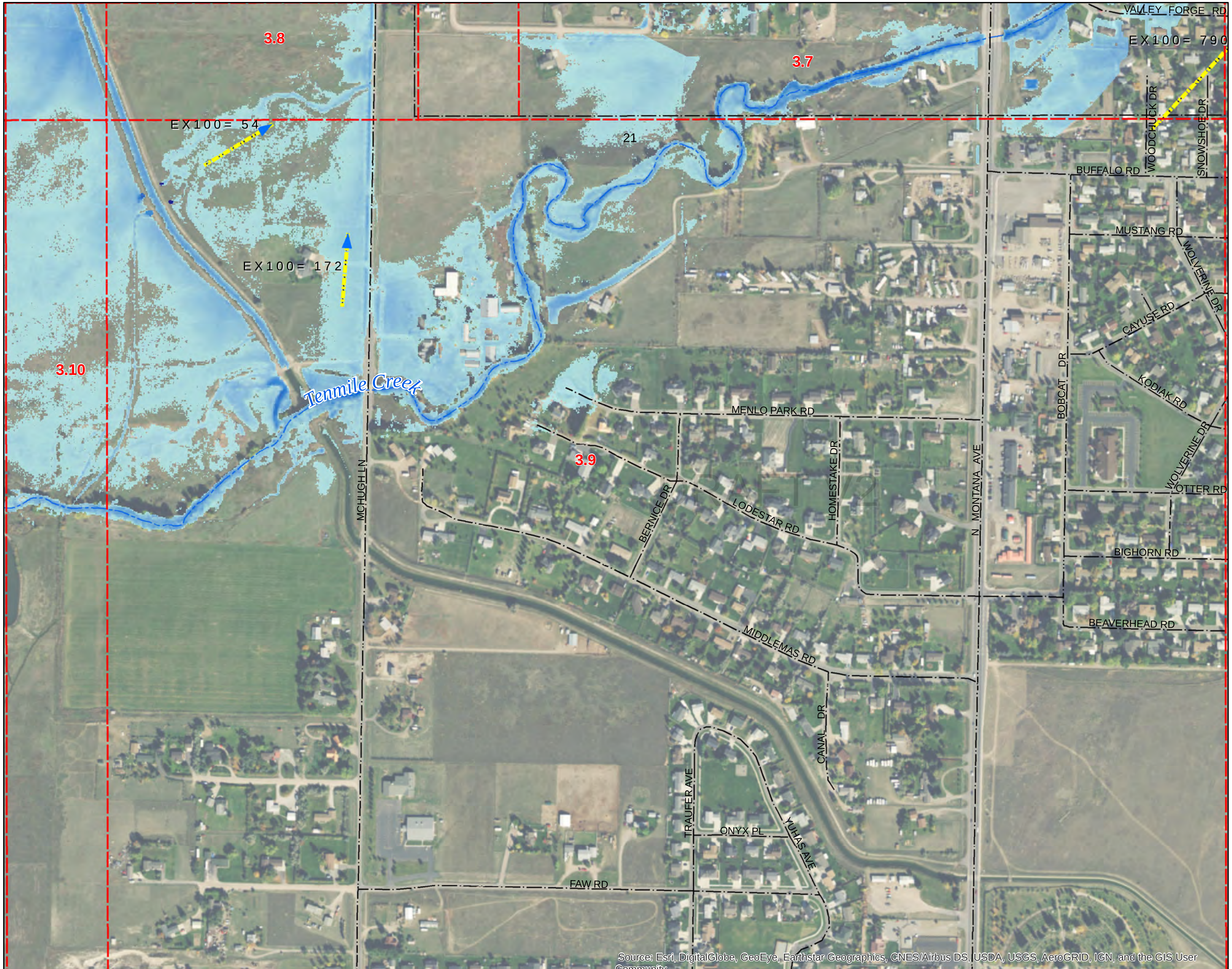

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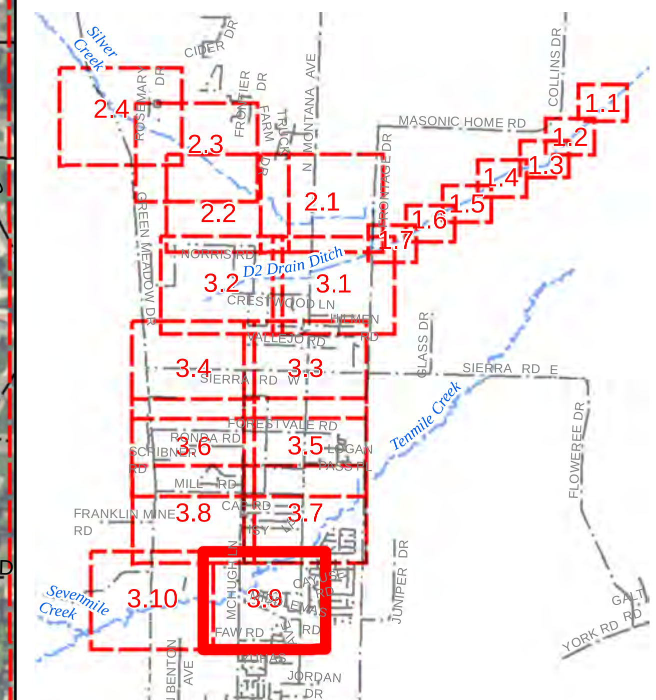

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Depth (ft)

High : 18.5

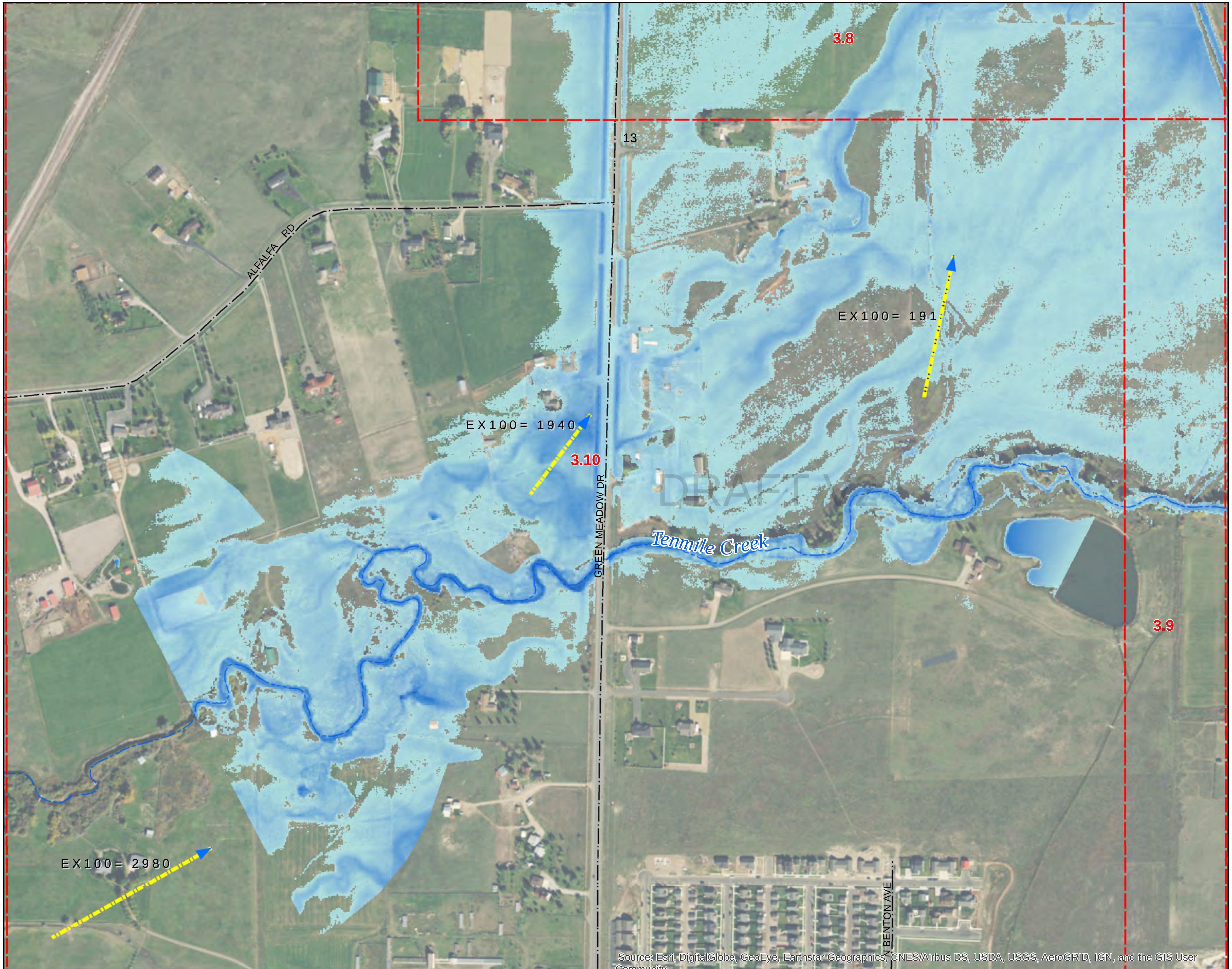
Low : 0.001

RESPEC

N

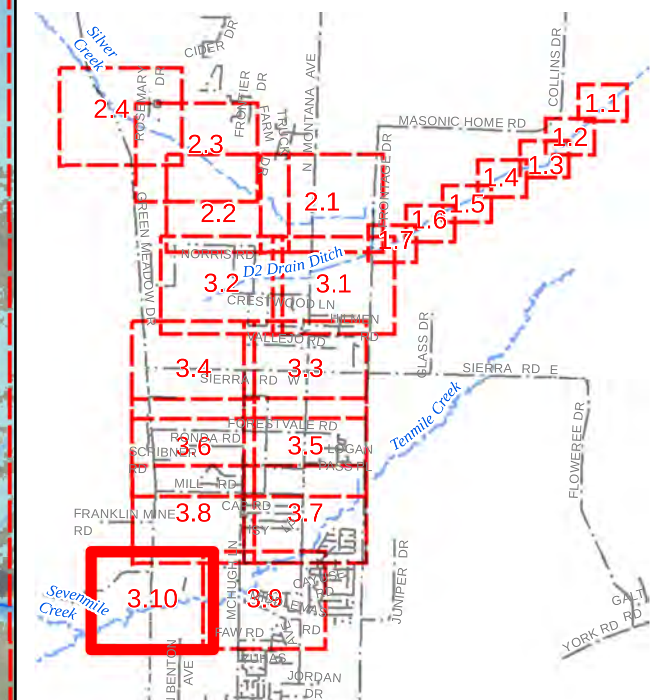
Date: 5/1/2017
Drawn: MWJ
Base: ESRI World Imagery

0 500 1,000 Feet



VALLEY FLOOD MITIGATION MASTER PLAN IMPLEMENTATION FLOOD INUNDATION MAPPING

THIS FLOOD INUNDATION MAP IS FOR PLANNING PURPOSES ONLY AND IS NON-REGULATORY. THE CONDITIONS PORTRAYED ON THIS MAP REFLECT COINCIDENT FLOODING OF TENMILE CREEK AND SILVER CREEK, THE ACCURACY OF THE TOPOGRAPHIC DATA INPUT, AND THE LEVEL OF DETAIL WITHIN THE SUPPORTING HYDRAULIC MODEL. ACTUAL FLOOD CONDITIONS MAY DIFFER FROM THIS MAP.



ARROWS INDICATE FLOW RESULTS (CFS) FOR THE EXISTING CONDITIONS (EX) AND PROPOSED CONDITIONS (PC) OF TRAP CLUB IMPROVEMENTS FOR THE 25-YR (25) AND 100-YR (100) COINCIDENT FLOOD EVENTS FOR TENMILE CREEK AND SILVER CREEK.

Legend

Map Index

FlowResults

Select Roads

Streams

1% Annual Chance Flood

Depth (ft)

High : 18.5

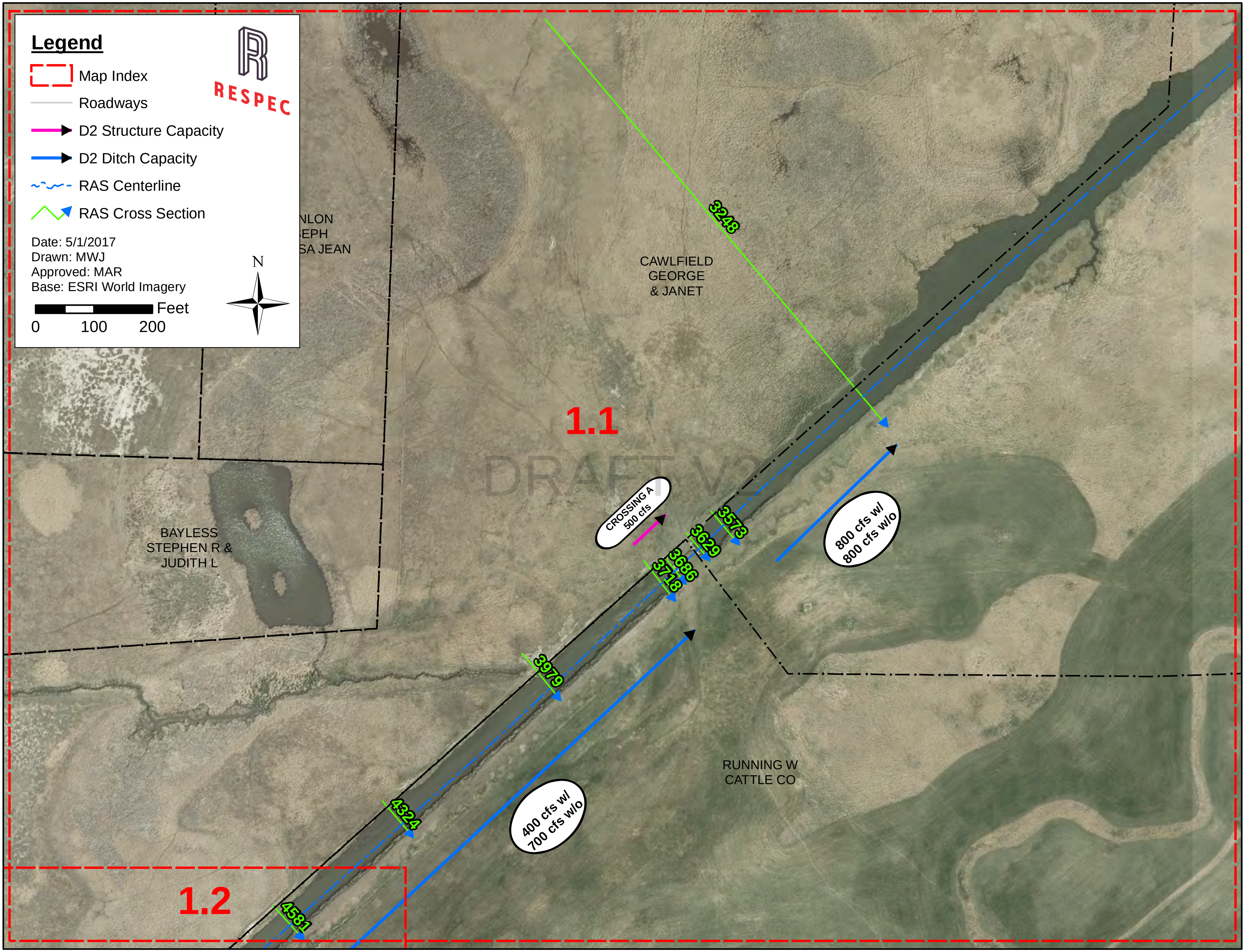
Low : 0.001

Date: 5/1/2017

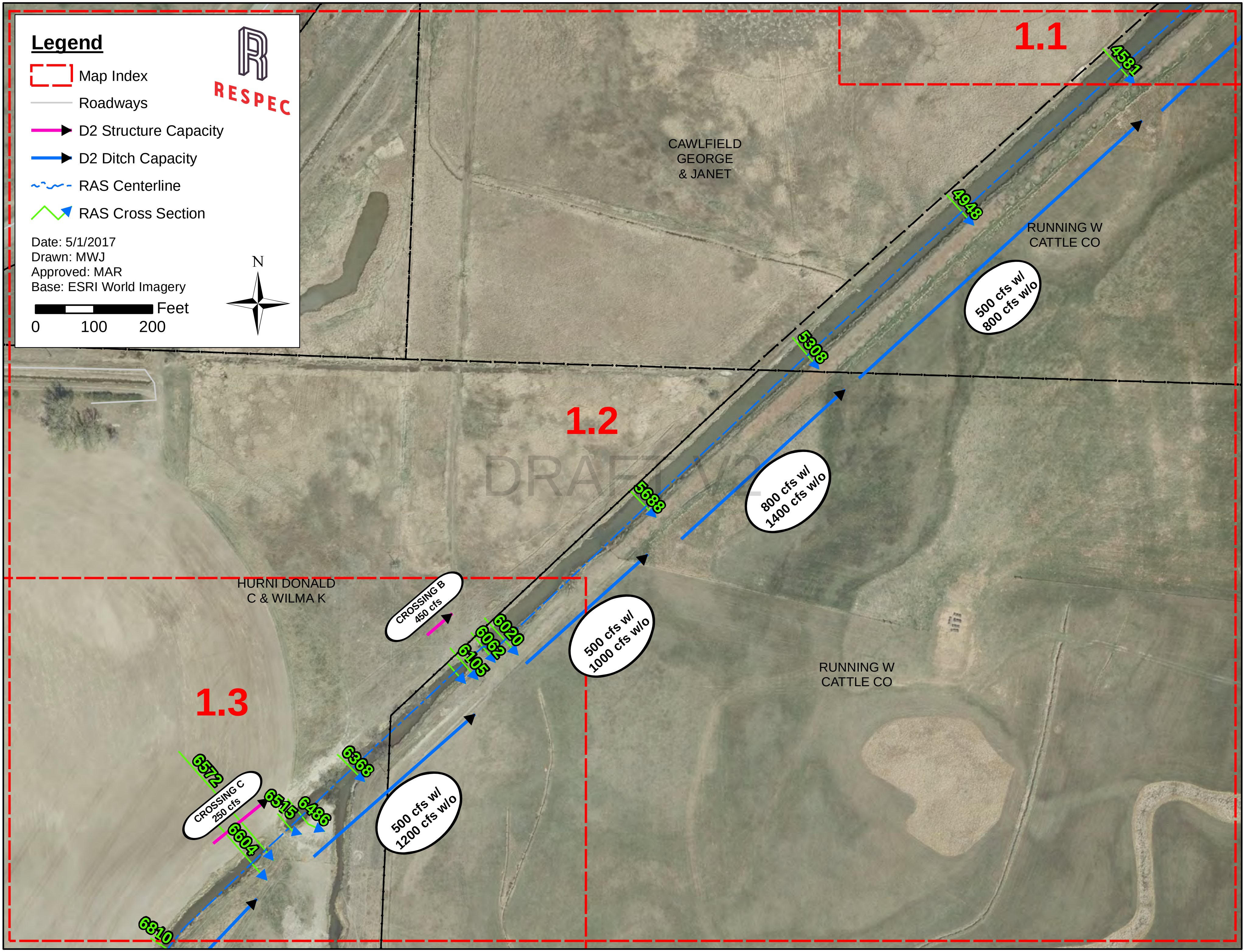
Drawn: MWJ

Base: ESRI World Imagery

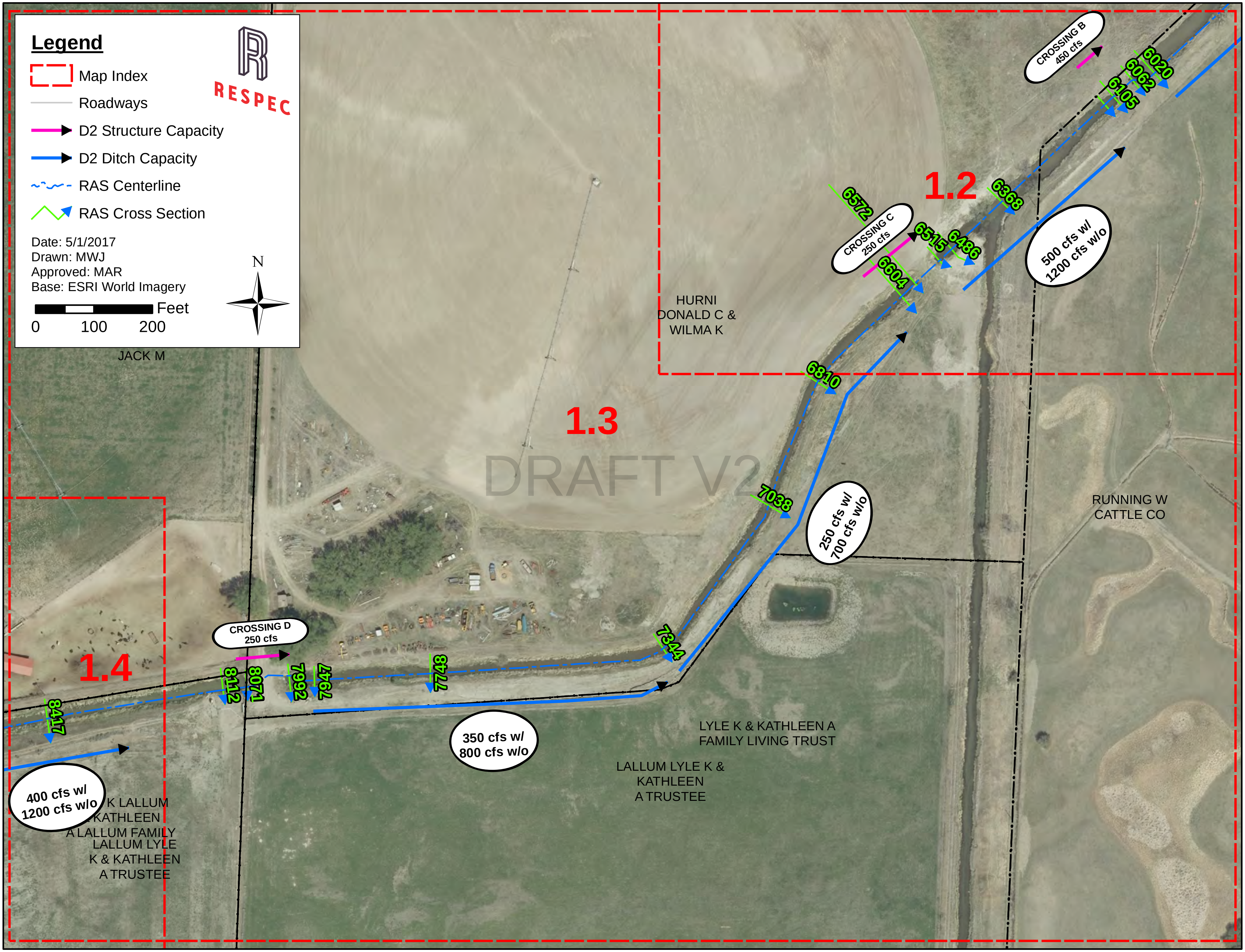
0 500 1,000 Feet



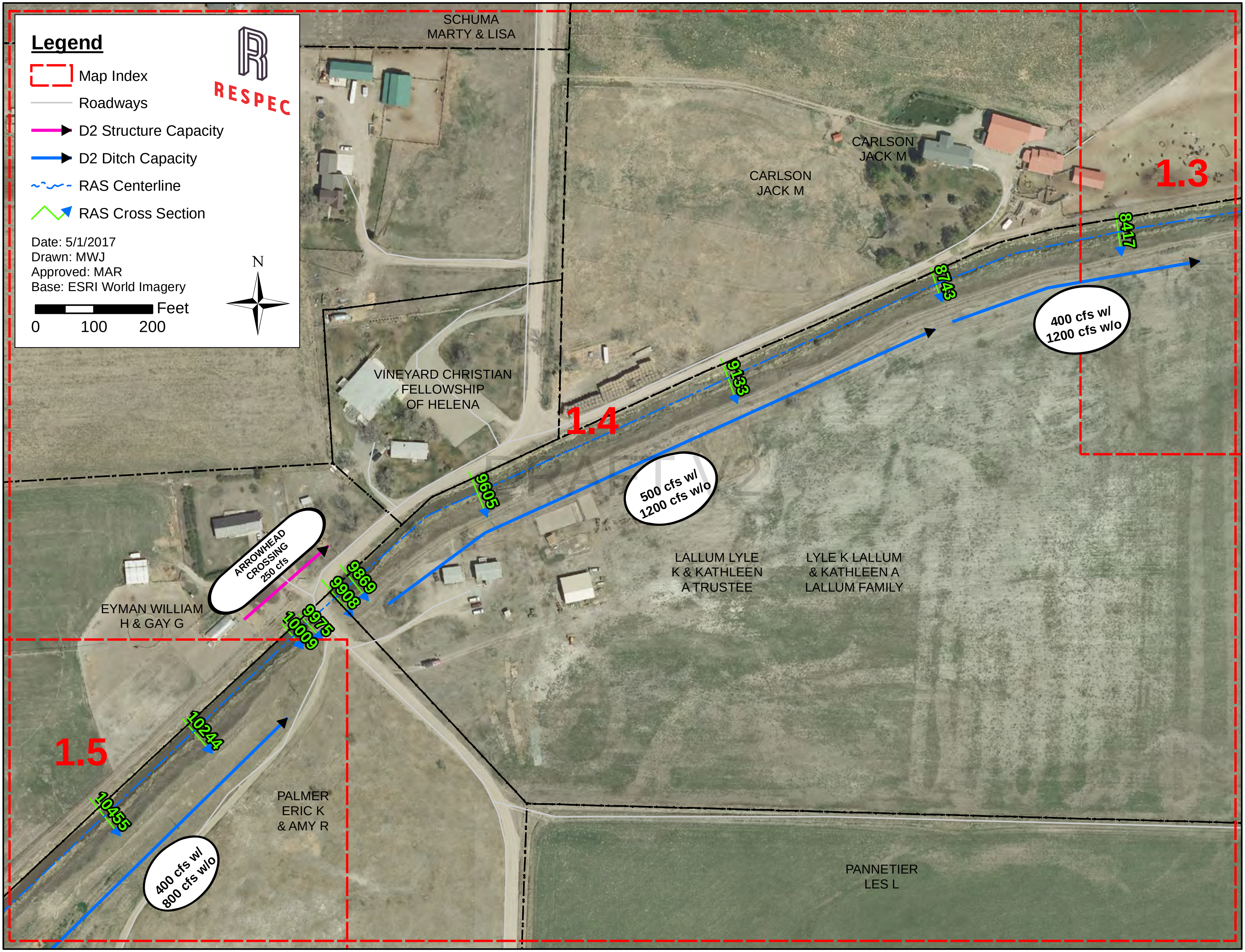
Legend
Map Index
Roadways
D2 Structure Capacity
D2 Ditch Capacity
RAS Centerline
RAS Cross Section
RESPEC
Date: 5/1/2017
Drawn: MWJ
Approved: MAR
Base: ESRI World Imagery
Feet
0
100
200
N
NLON
EPH
SA JEAN
CAWLFIELD
GEORGE
& JANET
BAYLESS
STEPHEN R &
JUDITH L
RUNNING W
CATTLE CO
1.1
1.2
DRAFT V2
CROSSING A
500 cfs
800 cfs w/
800 cfs w/o
400 cfs w/
700 cfs w/o
3248
3573
3629
3686
3718
3979
4324
4581



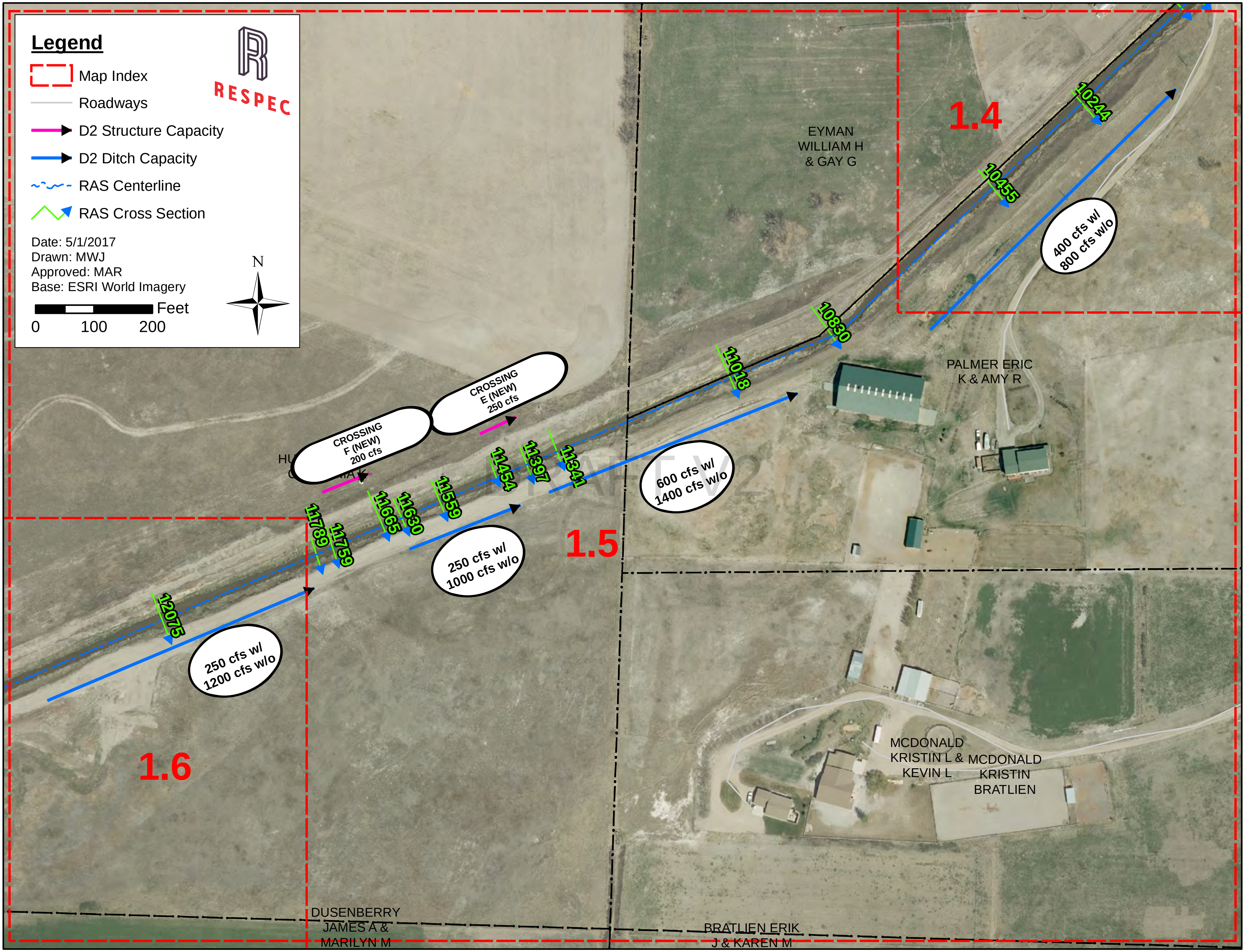
Legend
Map Index
Roadways
D2 Structure Capacity
D2 Ditch Capacity
RAS Centerline
RAS Cross Section
Date: 5/1/2017
Drawn: MWJ
Approved: MAR
Base: ESRI World Imagery
Feet
0
100
200
N
RESPEC
1.1
1.2
1.3
CAWLFIELD
GEORGE
& JANET
RUNNING W
CATTLE CO
HURNI DONALD
C & WILMA K
RUNNING W
CATTLE CO
DRAFT V2
4581
4948
5308
5688
6020
6062
6105
6368
6486
6515
6572
6604
6810
500 cfs w/
800 cfs w/o
800 cfs w/
1400 cfs w/o
500 cfs w/
1000 cfs w/o
500 cfs w/
1200 cfs w/o
CROSSING B
450 cfs
CROSSING C
250 cfs



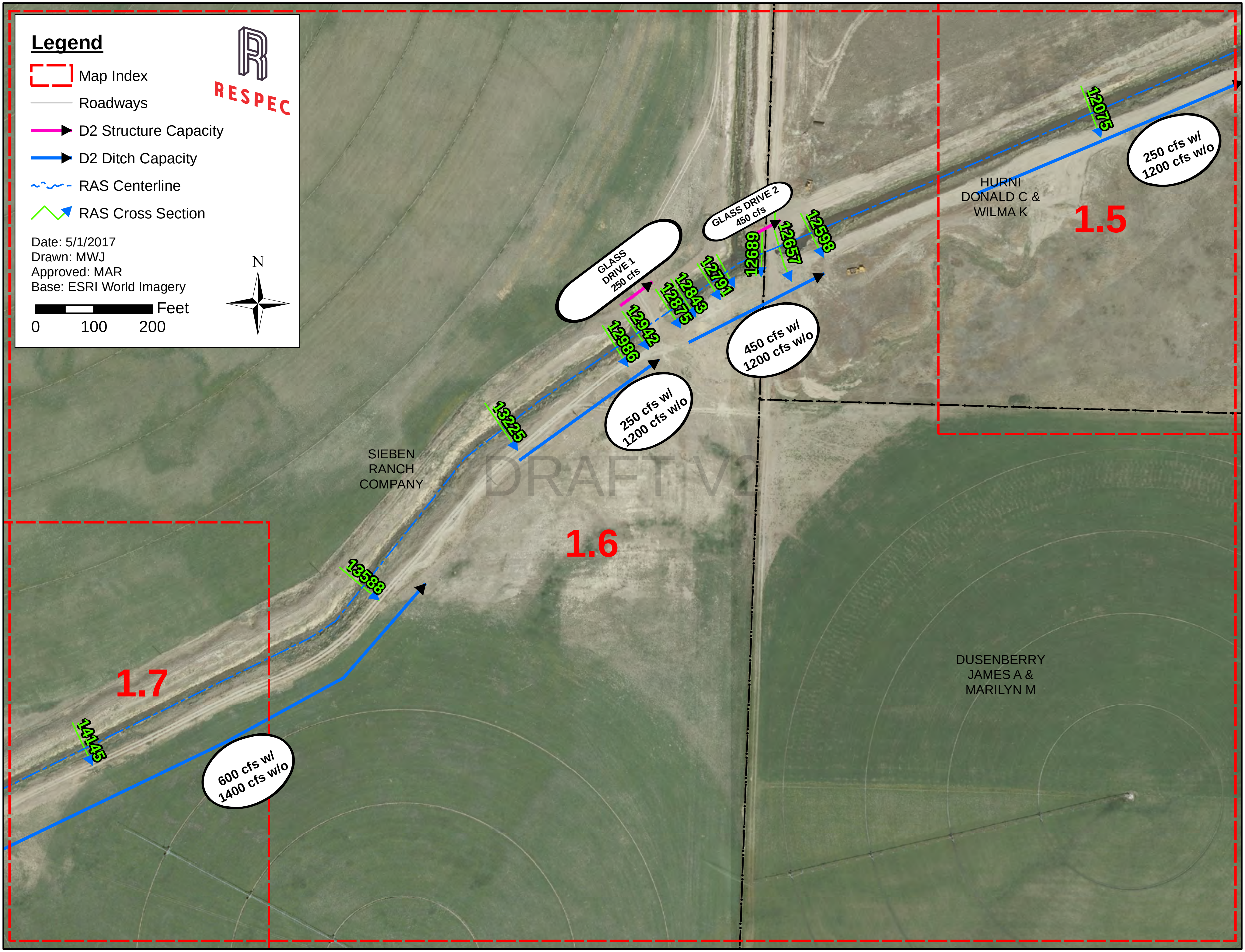
Legend
Map Index
Roadways
D2 Structure Capacity
D2 Ditch Capacity
RAS Centerline
RAS Cross Section
RESPEC
Date: 5/1/2017
Drawn: MWJ
Approved: MAR
Base: ESRI World Imagery
Feet
0
100
200
N
JACK M
1.2
1.3
1.4
DRAFT V2
CROSSING B 450 cfs
CROSSING C 250 cfs
CROSSING D 250 cfs
6020
6062
6105
6368
6486
6515
6572
6604
6810
7038
7344
7748
7947
7992
8071
8112
8417
500 cfs w/ 1200 cfs w/o
250 cfs w/ 700 cfs w/o
350 cfs w/ 800 cfs w/o
400 cfs w/ 1200 cfs w/o
HURNI DONALD C & WILMA K
RUNNING W CATTLE CO
LYLE K & KATHLEEN A FAMILY LIVING TRUST
LALLUM LYLE K & KATHLEEN A TRUSTEE
K LALLUM
KATHLEEN
A LALLUM FAMILY
LALLUM LYLE
K & KATHLEEN
A TRUSTEE

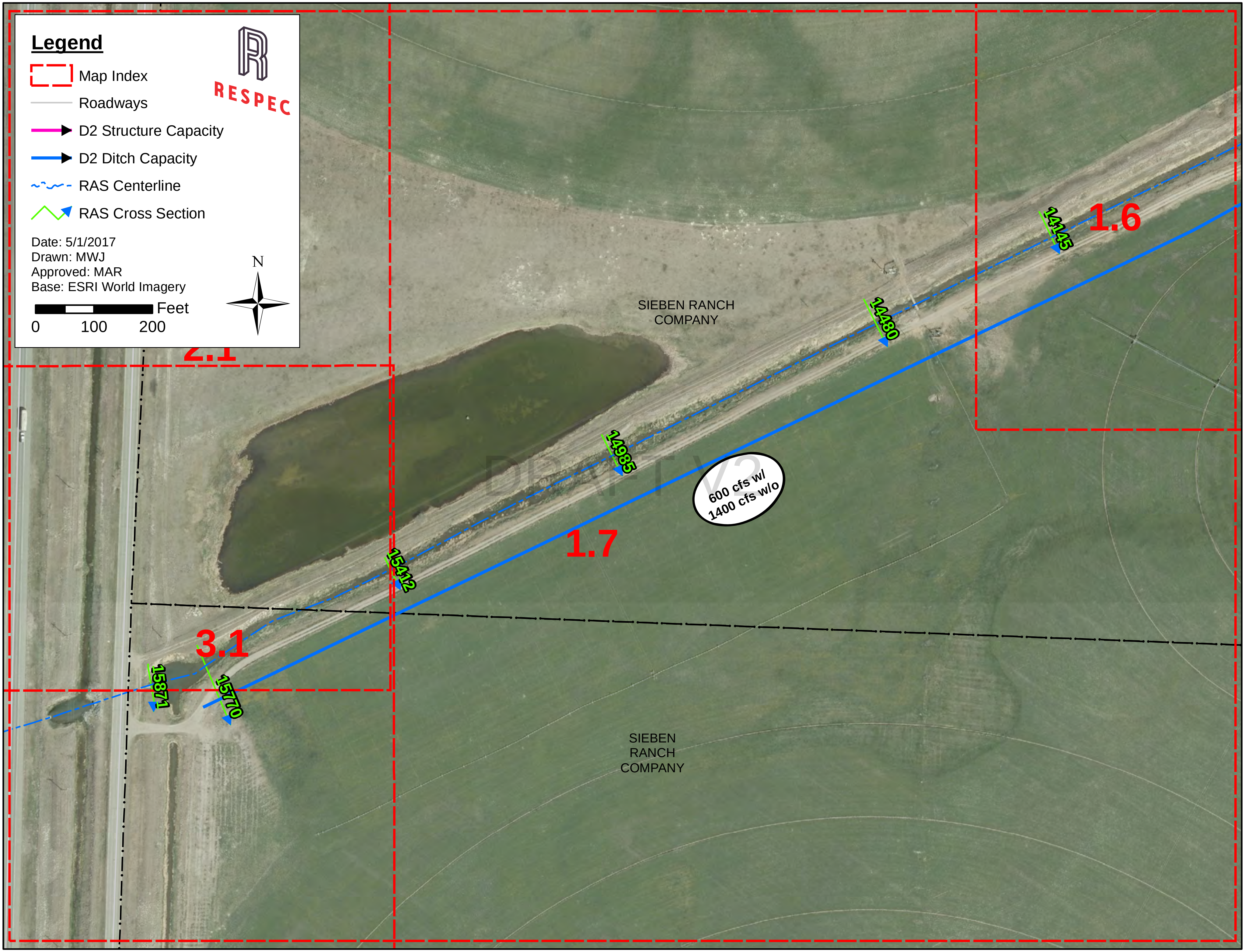


Legend
Map Index
Roadways
D2 Structure Capacity
D2 Ditch Capacity
RAS Centerline
RAS Cross Section
RESPEC
Date: 5/1/2017
Drawn: MWJ
Approved: MAR
Base: ESRI World Imagery
Feet
0 100 200
N
SCHUMA MARTY & LISA
CARLSON JACK M
CARLSON JACK M
1.3
8417
8743
400 cfs w/ 1200 cfs w/o
9133
VINEYARD CHRISTIAN FELLOWSHIP OF HELENA
1.4
9605
500 cfs w/ 1200 cfs w/o
DRAFT V2
ARROWHEAD CROSSING 250 cfs
9869
9908
9975
10009
EYMAN WILLIAM H & GAY G
LALLUM LYLE K & KATHLEEN A TRUSTEE
LYLE K LALLUM & KATHLEEN A LALLUM FAMILY
1.5
10244
10455
PALMER ERIC K & AMY R
400 cfs w/ 800 cfs w/o
PANNETIER LES L



Legend
Map Index
Roadways
D2 Structure Capacity
D2 Ditch Capacity
RAS Centerline
RAS Cross Section
Date: 5/1/2017
Drawn: MWJ
Approved: MAR
Base: ESRI World Imagery
Feet
0
100
200
N
RESPEC
1.4
1.5
1.6
EYMAN
WILLIAM H
& GAY G
PALMER ERIC
K & AMY R
10244
10455
10830
11018
11341
11397
11454
11559
11630
11665
11759
11789
12075
400 cfs w/
800 cfs w/o
600 cfs w/
1400 cfs w/o
250 cfs w/
1000 cfs w/o
250 cfs w/
1200 cfs w/o
CROSSING
E (NEW)
250 cfs
CROSSING
F (NEW)
200 cfs
MCDONALD
KRISTIN L &
KEVIN L
MCDONALD
KRISTIN
BRATLIEN
DUSENBERRY
JAMES A &
MARILYN M
BRATLIEN ERIK
J & KAREN M


Legend
Map Index
Roadways
D2 Structure Capacity
D2 Ditch Capacity
RAS Centerline
RAS Cross Section
Date: 5/1/2017
Drawn: MWJ
Approved: MAR
Base: ESRI World Imagery
Feet
0
100
200
N
RESPEC
GLASS DRIVE 1 250 cfs
GLASS DRIVE 2 450 cfs
250 cfs w/ 1200 cfs w/o
450 cfs w/ 1200 cfs w/o
250 cfs w/ 1200 cfs w/o
600 cfs w/ 1400 cfs w/o
12075
12598
12657
12689
12791
12843
12875
12942
12986
13225
13588
14145
HURNI DONALD C & WILMA K
SIEBEN RANCH COMPANY
DUSENBERRY JAMES A & MARILYN M
1.5
1.6
1.7
DRAFT V2



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Map Index
Roadways
D2 Structure Capacity
D2 Ditch Capacity
RAS Centerline
RAS Cross Section
Date: 5/1/2017
Drawn: MWJ
Approved: MAR
Base: ESRI World Imagery
Feet
0
100
200
N
RESPEC
2.1
3.1
1.7
1.6
SIEBEN RANCH COMPANY
SIEBEN RANCH COMPANY
600 cfs w/
1400 cfs w/o
DRAFT V2
15871
15770
15412
14985
14480
14145