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Flow Modeling and Damage Estimates for the Argonaut Mine Dam Failure Study

Prepared by:
RTI and CDM Smith

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1. Introduction

The objective of Argonaut Mine Dam Failure Study is to model, assess, and map damages as a result of a potential failure of the Eastwood Multiple Arch Dam ("Argonaut Dam"). Potential risks associated with Argonaut Dam failure are described in **Appendix A**. We used the FLO-2D model to simulate dam failure and create downstream mud flow inundation footprints for three flow scenarios (three inundation maps), followed by the use of the HAZUS model to estimate potential losses within each inundation map modeled by the FLO-2D. The three scenarios represent dry, average, and wet conditions of dam failure. Potential life-loss associated with the dam failure is an overriding concern compared to economic damages and losses, however, the HAZUS model does not account for such losses, and therefore potential life-loss as a result of dam failure is not included in the study.

Argonaut Mine site is a former gold mine tailings disposal area located along Argonaut Lane and Hoffman Street in the City of Jackson, California. It consists of the Argonaut Mine and Mill Area and the Argonaut Mine Tailings Disposal Area. The Mine and Mill are located approximately one-half mile north of the Tailings Disposal Area. In the Tailings Disposal Area, the tailings are contained by three dams; upper earthen tailings dam, lower earthen tailings dam, and the concrete Argonaut Dam (**Figure 1-1**).

The Argonaut Dam was built in 1916 and has been filled with sediment from runoff from mine tailings piles. The total volume of tailings in the impoundment behind the dam is approximately 165,000 cubic yards, or 247,500 tons. The estimated volume of freestanding water impounded behind the dam when it overtops is 2.8 acre-feet, or nearly 1.0 million gallons. The purpose of this report is to describe data collection, modeling methods, assumptions, and results, including inundation maps obtained via the FLO-2D modeling and the total loss tables and maps obtained via the HAZUS modeling. It is expected that subsequent to the client and project team review of this report, the total damage costs may be revised based on comments received. To date, no investigation of mitigation measures has been requested.

***Disclaimer**: The findings and conclusions in this report have not been formally disseminated by the EPA and should not be construed to represent any Agency determination or policy.*

In this report, inundation maps generated from the FLO-2D model are intended to be used as input data for the HAZUS model, which estimates approximate costs due to the losses resulted from the Argonaut Dam failure (and not to delineate exact inundation boundaries after dam failure). If the actual sediment property parameters for the study area are much different from those assumed in the model, it is possible that the actual inundation maps for mudflow would vary from the simulations generated in this study.

The Draft maps and tables generated from HAZUS model are the most sensitive and preliminary information shared to date. The HAZUS model estimates approximate costs due to the losses resulting from failure of the subject dam using unit cost estimates provided within the software. It is expected that additional damage costs (e.g., mud cleanup costs, costs due to highway closure, infrastructure repair, etc.) could be calculated upon receipt of more accurate site-specific information (e.g., mud clean-up cost per unit volume, estimated number of one-way traffic trips per day) from local stakeholders (e.g., City of Jackson, County of Amador, Caltrans, etc.).

This report and its appendices are a preliminary document for EPA use only and should not be cited or quoted without written permission from EPA. Further, this document is not intended to be used for any work performed by outside parties. Outside use of these findings should include independent verification of study results.

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Source: ESRI World Imagery, World Street Map

Figure 1-1

Site Features Map
Argonaut Mine Tailings Pile
Jackson, California

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2. Hydrology Modeling Using HEC HMS

HEC-HMS, developed by USACE Hydraulic Engineering Center, was used to simulate the rainfall - runoff process of the watershed. The model provides hydrograph inputs for the watershed areas tributary to the study area modeled by FLO-2D. The modeling methods, approaches, and data used to develop the HEC-HMS model are described in the following sections.

2.1 Watershed Delineation

Topographic data are required to delineate subbasin boundaries and reaches for the HEC-HMS model. In this study, topographic data for the HEC-HMS model were obtained from the USGS National Elevation Dataset (NED) having 1/3 arc-second resolution (approximately 30 feet on the ground).

The watershed area for the HEC-HMS model is approximately 121 acres and is subdivided into 4 subbasins ranging in size from 20.7 acre to 49.8 acres. ArcHydro tools of the ArcGIS were used to delineate the watershed subbasins and stream reaches. Figure 2-1 displays the subbasin and stream reach delineation.

2.2 Rainfall and Design Storm

The design storm rainfall depths were obtained from NOAA's National Weather Service Precipitation Frequency Data Server (PFDS) (http://hdsc.nws.noaa.gov/hdsc/pfds/). The gauge closest to the study area is Sutter Hill CDF (ID# 04-8713). The NOAA's precipitation frequency estimate data at Sutter Hill CDF are included in Appendix B. In this study, the flood hydrographs for 2-year and 100-year, 24-hour duration storm events were selected for the average and wet flow conditions, respectively. Table 2-1 presents the rainfall depths of these two storm events, which are obtained from the NOAA's precipitation frequency estimate data at Sutter Hill CDF (**Appendix B).**

Table 2-1 Rainfall Depths (in inches)

	Recurrence Interval (years)	
Duration	**2**	**100**
5-min	0.165	0.449
10-min	0.236	0.643
15-min	0.286	0.778
30-min	0.401	1.09
60-min	0.535	1.46
2-hr	0.760	1.72
3-hr	0.925	1.97
6-hr	1.33	2.63
12-hr	1.86	3.81
24-hr	2.66	5.79

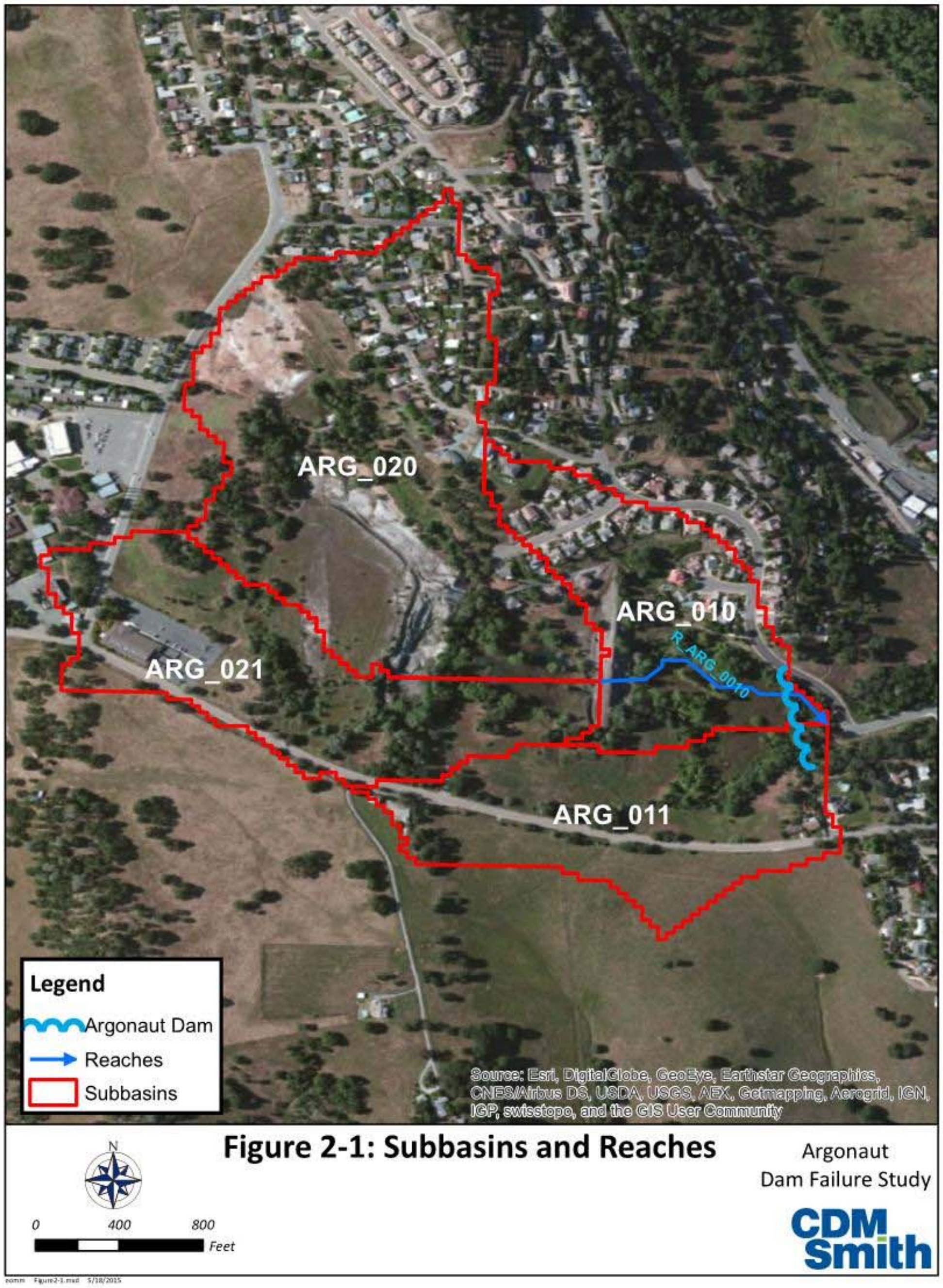

Figure 2-1: Subbasins and Reaches

2.3 Temporal Distribution of Rainfall

The rainfall distribution was developed using the HEC-HMS Frequency Storm "built-in" feature. It was assumed that peak intensity of the rainfall occurs at 50 percent of the rainfall; i.e., intensity position set at 50 percent in the Frequency Storm. Figure 2-2 presents the rainfall hyetograph for the 100-year, 24-hour duration storm event.

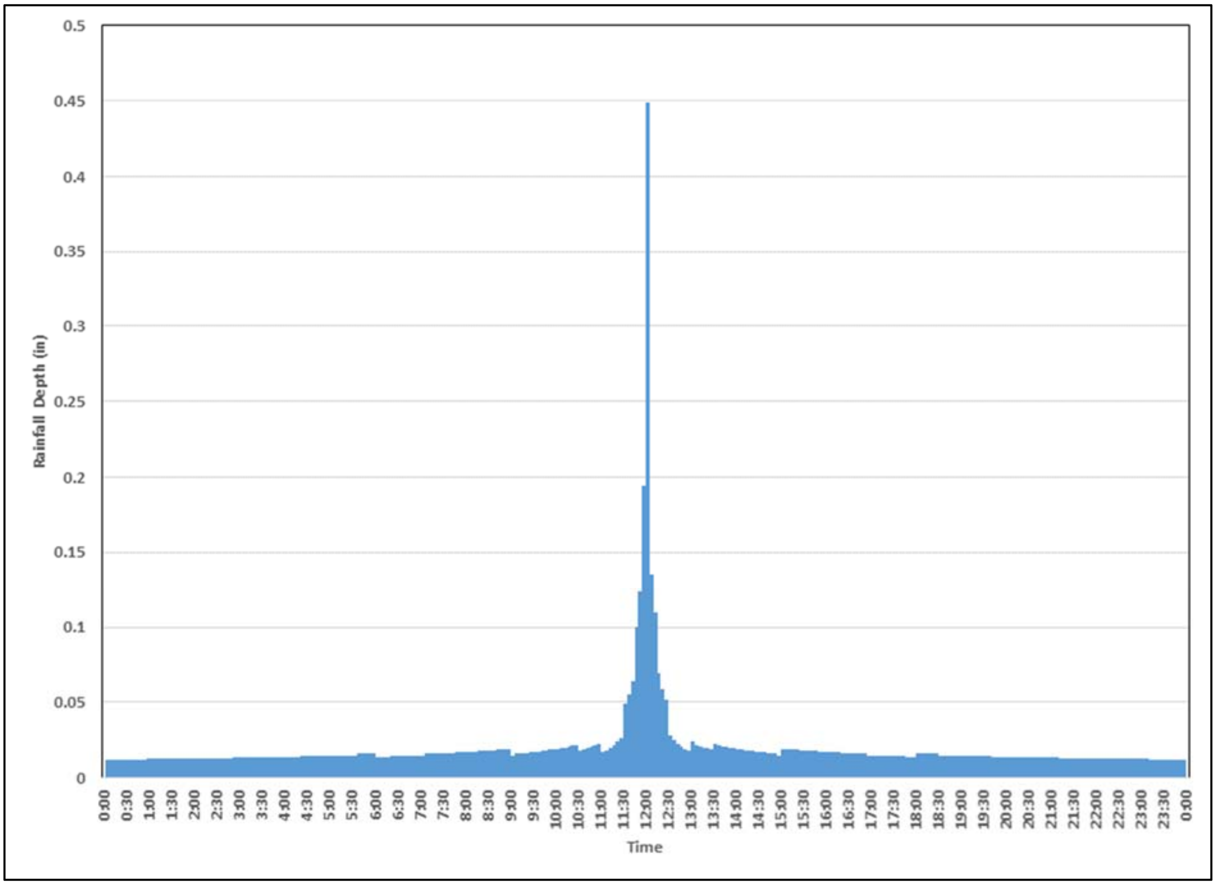

Figure 2-2 Temporal Distribution of 100-yr 24-hr Rainfall

2.4 Subbasin Transform

In the HEC-HMS model, the transform method describes how the excess precipitation (runoff) reaches at the low point of each subbasin. In this study, the Snyder Unit Hydrograph method, which shapes the runoff based on an input of lag time, is used. Lag time is defined as the time between the centroid of the rainfall hyetograph and the peak flow of the resulting hydrograph.

Lag time was calculated using the following equation provided in Sacramento City/County Drainage Manual – Hydrology Standards ("Sacramento Drainage Manual", 1996). This equation was originally developed by Snyder (1938) and later revised by USACE and U.S. Bureau of Reclamation (USBR).

$$T_l = 1560 \cdot n \left(\frac{LL_c}{S^{0.5}}\right)^{0.33}$$

Where:

T_l = Lag Time (minutes);

L = subbasin flow path length from the edge of the subbasin to the outlet (miles);

L_c = flow length from the centroid of the subbasin to the outlet (miles);

S = slope of the subbasin along the flow path length (ft/mile); and

n = Manning's roughness coefficient of the subbasin

The subbasin Manning's roughness coefficients were estimated using Table 7-1 of the Sacramento Drainage Manual (1996). **Table 2-2** presents the estimated lag times per subbasin, and the parameters used in the estimation.

Table 2-2 Subbasin Lag Times

Subbasin	L (mi)	L_c (mi)	s (ft/mi)	n	Lag (min)	Lag (hr)
ARG_010	0.3711	0.1759	642.1446	0.093	20.29	0.34
ARG_011	0.3678	0.1674	455.9097	0.115	26.04	0.43
ARG_020	0.5767	0.2843	276.0670	0.096	32.62	0.54
ARG_021	0.5055	0.2993	248.2851	0.115	38.72	0.65

2.5 Hydrograph Shape – Peaking Factor

In the HEC-HMS model, the Snyder Unit Hydrograph allows for the use of peaking factors, which generally will vary from 0.4 in flatter areas to 0.8 in mountainous areas. Peaking factors are used to increase peaks in mountainous areas and flatten the hydrograph shapes in the relatively flat subbasins. In this study, peaking factor of 0.8 was selected for all four subbasins, considering steepness of the watershed.

2.6 Infiltration Loss

In this study, it was assumed that the dam watershed area is already fully saturated; therefore, no rainfall infiltration loss was estimated in the model.

2.7 Reach Routing

Only one reach exists in the study watershed. Muskingum-Cunge was selected as the routing method for the reach in the HEC-HMS model. Length and slope were determined from the ArcGIS and topography data. Manning's roughness value was estimated using Table 7-5 of the Sacramento Drainage Manual (1996). **Table 2-3** presents the reach routing parameters.

Table 2-3 Reach Routing Parameters

Reach	L (ft)	s (ft/ft)	n	Shape	Side Slope (xH:1v)
R_ARG_0100	1044.4	0.0977	0.05	Triangle	20

2.8 Model Results

The HEC-HMS model was run for the 2-year and 100-year, 24-hour duration storm events. Figure 2-3 presents the 2-year and 100-year hydrographs generated at the outlet of the watershed (Argonaut Dam). The 2-year and 100-year peak discharges at the outlet of the watershed (Argonaut Dam) are 68.6 and 209.9 cfs, respectively. Uncertainties and limitations of the modeling are described in **Appendix A**.

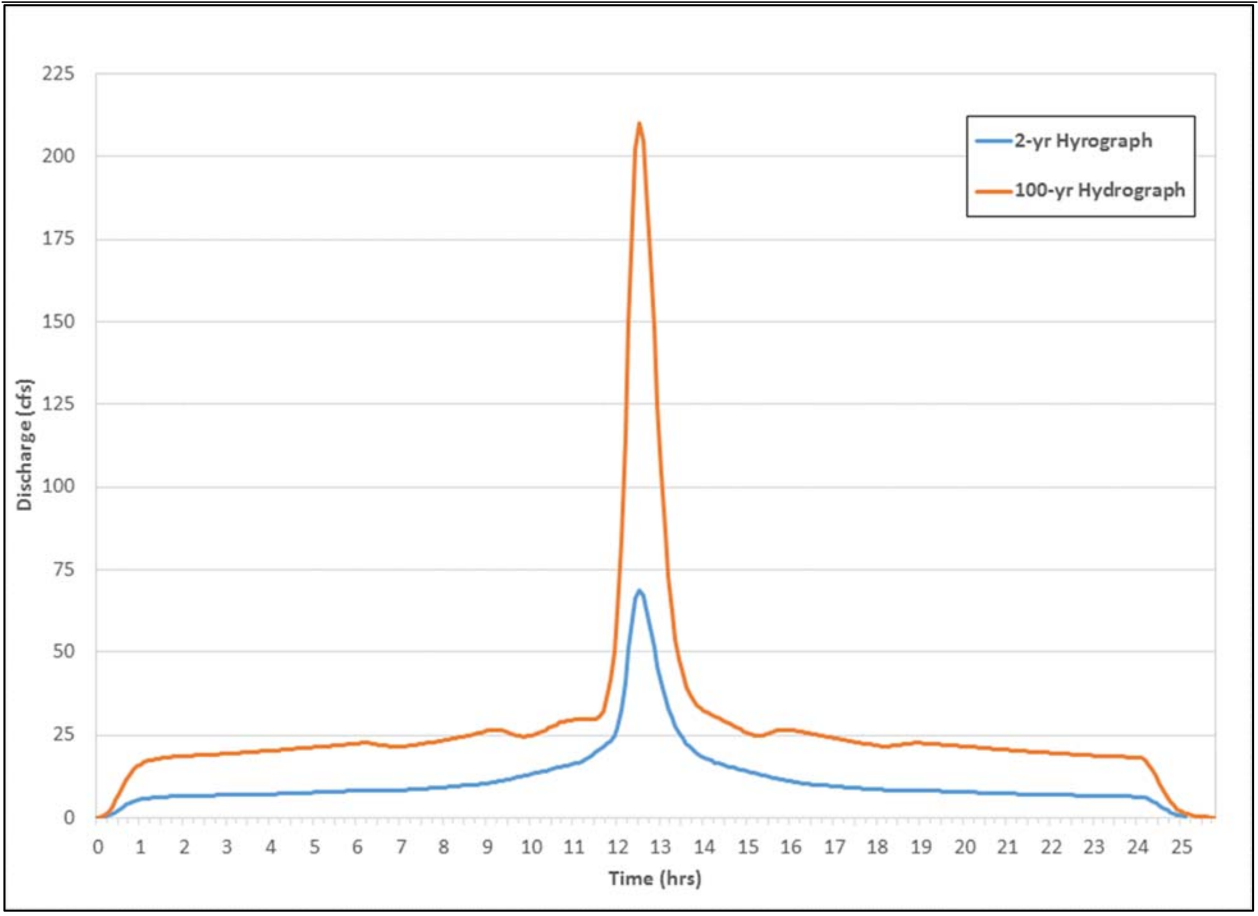

Figure 2-3 2-yr and 100-yr Hydrographs at Argonaut Dam

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3. FLO-2D Modeling

The dam failure modeling and downstream mudflow routing for the inundation area mapping were performed using the FLO-2D (version 2009) computer model. FLO-2D, developed by FLO-2D Software, Inc., is a 2-D computer model that routes a flood hydrograph over a system of square grid elements. The modeling methods, approaches, and data used to develop the FLO-2D model are described in the following sections.

3.1 FLO-2D Model Capabilities and Theory

FLO-2D is a tool for delineating flood hazards, regulating floodplain zoning or designing flood mitigation. The model simulates not only river overbank flows, but also unconventional flooding problems such as unconfined flows over complex alluvial fan topography, split channel flows, mud/debris flows, and urban flooding. FLO-2D is on FEMA's list of approved hydraulic models for both riverine and unconfined alluvial fan flood studies.

FLO-2D is a simple volume conservation model. It moves the flood volume around on a series of grid elements (tiles) for overland flow or through stream segments for channel routing. Flood wave progression over the flow domain is controlled by topography and resistance to flow. Flood routing in two dimensions is accomplished through a numerical integration of the equations of motion and the conservation of fluid volume for either a water flood or a hyper-concentrated sediment flow.

The governing equations consist of the continuity equation and the equation of motion (dynamic wave momentum equation):

Continuity Equation

$$\frac{\partial h}{\partial t} + \frac{\partial hV}{\partial x} = i$$

Momentum Equation

$$S_f = S_o - \frac{\partial h}{\partial x} - \frac{V}{g}\frac{\partial V}{\partial x} - \frac{V}{g}\frac{\partial V}{\partial x} - \frac{1}{g}\frac{\partial V}{\partial t}$$

Where:

h = flow depth

V = depth-averaged velocity

i = excess rainfall intensity

g = gravitational acceleration

S_f = friction slope based on Manning's equation

S_o = bed slope

The equations of motion in FLO-2D are defined as a quasi two-dimensional. The momentum equation is solved by computing the average flow velocity across a grid element boundary one direction at a time.

There are eight potential flow directions (see Figure 3-1); i.e., the four compass directions (north, east, south and west) and the four diagonal directions (northeast, southeast, southwest and northwest). Each velocity computation is essentially one-dimensional in nature and is solved independently of the other seven directions.

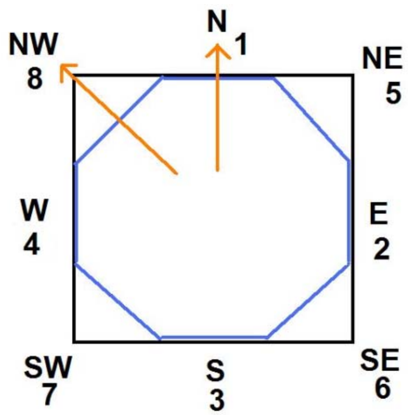

Figure 3-1 Eight Flow Directions of a Grid Element of the FLO-2D Model

3.2 Topographic Data

Like the HEC-HMS model, topographic data for the FLO-2D model were obtained from the USGS National Elevation Dataset (NED) having 1/3 arc-second resolution (approximately 30 feet on the ground). Therefore, considering that the accuracy of the generated inundation maps are limited to the resolution of the topographic data used for the model, topographic features less than 30 feet cannot be presented correctly in the inundation maps.

3.3 Manning's Roughness Coefficients

Manning's roughness coefficients were selected based on an aerial photograph. Various areas within the study area were delineated, and then the following roughness coefficients were selected for those delineated areas:

- Road: n = 0.016
- Channel (Jackson Creek): n = 0.040
- Low vegetation: n = 0.040
- Residential area: n = 0.130
- Medium tree cover: n = 0.090
- Dense tree cover: n = 0.115.

3.4 Estimate of the Volume of Tailings

The total volume of the tailings within the dam impoundment was estimated by Superfund Technical Assessment and Response Team (START), based on aerial survey contours and soil boring data generated in the 2008 site investigation. This volume includes tailings between the toe of the Lower Earthen Tailings Dam and Argonaut Dam, approximately 165,000 cubic yards (START, 2014). In this study, it was assumed that this entire volume would flow downstream after dam failure.

3.5 Modeling Scenarios

FLO-2D model was run for three flow scenarios (dry, average, and wet flow conditions) for mudflow condition (i.e., three inundation maps generated). The dry, average, and wet flow conditions are defined as follows:

- **Dry Flow Condition**: It is assumed that the dam fails in the absence of precipitation (e.g., due to pressure from the dam impoundment, impacts due to earthquake, etc.). The dam impoundment is assumed to be fully saturated.

- **Average Flow Condition**: It is assumed that the dam fails during a 2-year storm event. The dam impoundment is assumed to be fully saturated and a 2-year hydrograph is added into the model. The total volume of the 2-year hydrograph is 26.8 acre-feet. The dam fails at the peak of the 2-year hydrograph. During a storm event in April 2006, it was investigated that water circumvented Argonaut Dam to the south and also poured over the top of dam (**Figure 3-2**). Per the historical precipitation data at Sutter Hill CDF, the total rainfall depth from April 2, 2006 through April 4, 2006 (during 4 days) was 5.14 inches. In the NOAA's precipitation frequency estimate data at Sutter Hill CDF (**Appendix B**), it falls under the rainfall depths between 2-year and 5-year return interval.

- **Wet Flow Condition**: It is assumed that the dam fails during a 100-year storm event. The dam impoundment is assumed to be fully saturated and a 100-year hydrograph is added into the model. The total volume of the 100-year hydrograph is 58.4 acre-feet. The dam fails at the peak of the 100-year hydrograph.

3.6 Dam Failure Modeling Procedures

In the FLO-2D model, failure of the Argonaut Dam was modeled following the procedures listed below:

- Assign the grid elements on the topographic data to create the grid system. A grid element size of 50 feet was selected, considering the resolution of the topographic data (approximately 30 feet). **Figure 3-3** presents the grid element system with the outflow grid elements used in the model. The outflow grid elements are located at the downstream end of the study area. The outflow grid elements discharge any inflow off the grid system without effecting the water surface elevation.

Figure 3-2 Runoff Flowing over the Tip of Argonaut Dam (April 4, 2006)

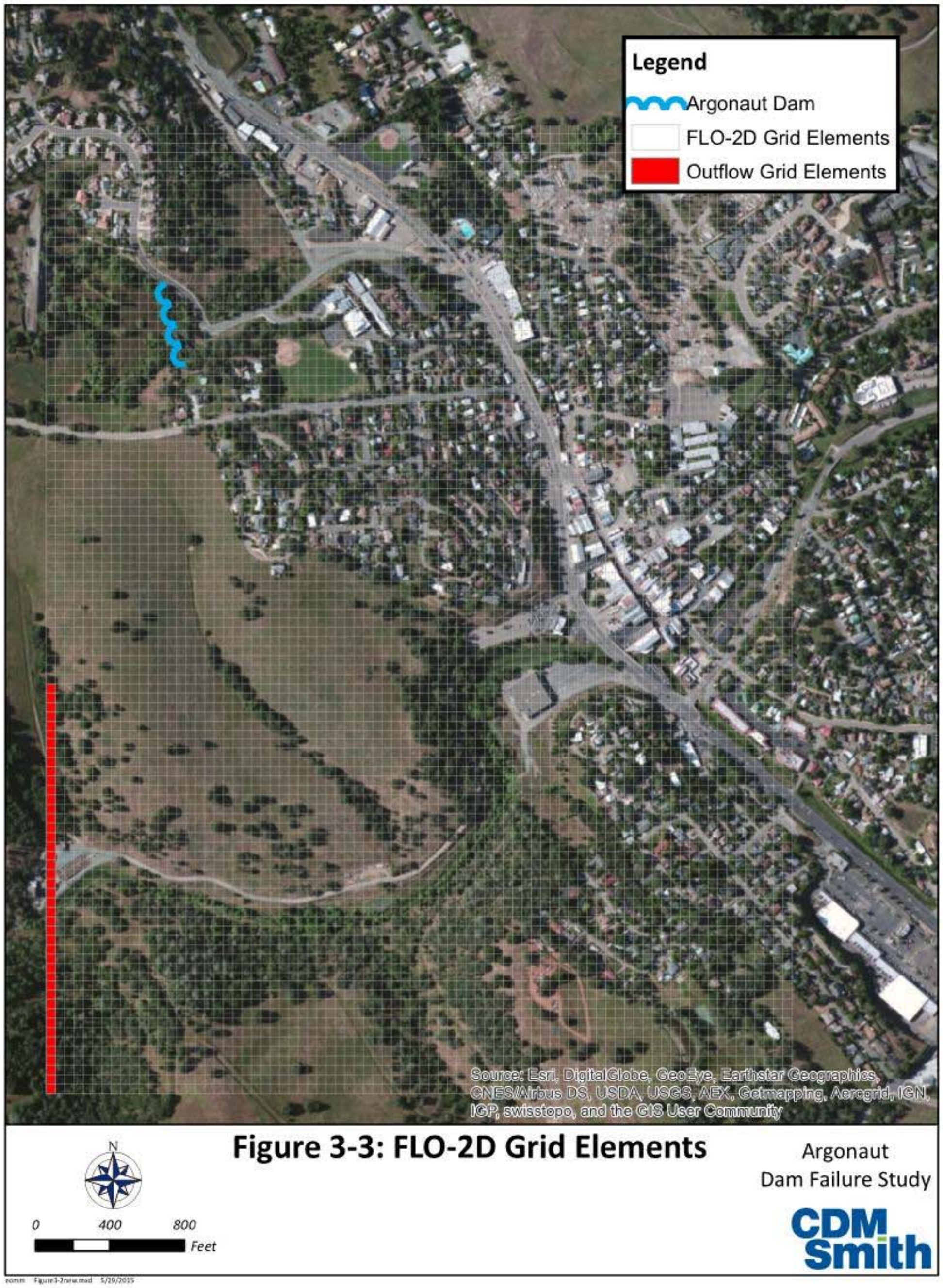

Figure 3-3: FLO-2D Grid Elements

- Lower topographic data within the dam impoundment area to contain the total volume of the tailings (165,000 cubic yards) without overtopping the dam.
- Assume that the lowered dam impoundment area will be filled with a water-sediment mixture (i.e., mudflow) before the dam failure starts (i.e., during a warm-up period). This is not a part of the actual dam failure simulation. The assumption was made to make sure that the volume of the mud within the dam impoundment is the same as the estimated one. Based on the assumption, a mudflow hydrograph having the same volume as the total volume of the tailings (165,000 cubic yards) is located at the upstream end of the dam impoundment (refer to **Section 3.6.1** for the details about the mudflow hydrograph).
- Model Argonaut Dam by levees. In the FLO-2D model, the levee breach failure can be modeled by specifying several parameters related the levees (refer to **Section 3.6.2** for the details about the levee breach failure).
- Assign input parameters for the mudflow simulation of the FLO-2D (refer to **Section 3.6.3** for the details about the input parameters of the mudflow simulation).
- Start each model run only with the mudflow hydrograph. In the case of the dry flow condition, the dam failure starts at the end of the mudflow hydrograph. In the case of the average and wet conditions, the storm hydrograph starts at the end of the mudflow hydrograph, and the dam failure starts at the peak of the storm hydrograph.

3.6.1 Synthesizing a Mudflow Hydrograph

The volume of the mixture of water and sediment in a mudflow can be determined by multiplying the water volume by the bulking factor (BF). The bulking factor is defined as:

$$BF = \frac{1}{1 - C_v}$$

Where:

C_v = sediment concentration by volume

The sediment concentration by volume is defined as:

$$C_v = \frac{V_s}{V_w + V_s}$$

Where:

V_w = volume of water

V_s = volume of sediment

The sediment concentration by volume of the tailing was estimated from the USACE's geotechnical report (USACE, 2015(2)), where the average void ratio (e) of tailings samples behind the Argonaut Dam is measured as 1.15. The void ratio (e) can be converted into porosity (φ):

$$prosity\ (\varphi) = \frac{V_v}{V_v + V_s} = \frac{e}{1 + e} = \frac{1.15}{1 + 1.15} = 0.535$$

where

V_v = volume of void space

Assuming that the dam impoundment is fully saturated (i.e., $V_v = V_w$),

$$C_v = 1 - \varphi = 1 - 0.535 = 0.465$$

For C_v =0.465,

$$BF = \frac{1}{1 - 0.465} = 1.869$$

Then, the water volume of the fully saturated tailings (165,000 cubic yards) within the dam impoundment is:

$$V_w = \frac{165{,}000\ yd^3}{1.869} = \frac{4{,}455{,}000\ ft^3}{1.869} = 2{,}383{,}628\ ft^3$$

Assuming that the duration of the mudflow hydrograph is 4 hours and its shape is rectangular (i.e., constant discharge during the duration), the discharge of the hydrograph is:

$$Q = \frac{2{,}383{,}628\ ft^3}{4 \times 3600\ sec} == 165.53\ ft^3/\sec\ (cfs)$$

The 4-hour duration was determined based on initial modeling results showing that at least 4 hours are required so that the lowered impoundment area can be relatively evenly filled with the mudflow.

In the mudflow simulation of the FLO-2D model, the sediment concentration by volume also needs to be specified for the input hydrographs. **Figure 3-4** presents the water hydrograph and sediment concentration by volume of the mudflow hydrograph used in the model. As described in this section, in the mudflow simulation, the total volume of the water hydrograph is increased by the bulking factor (1.869). When the constant sediment concentration by volume (0.465) is applied to the water hydrograph, the total volume of the mudflow hydrograph becomes the same as the total volume of the tailings (165,000 cubic yards).

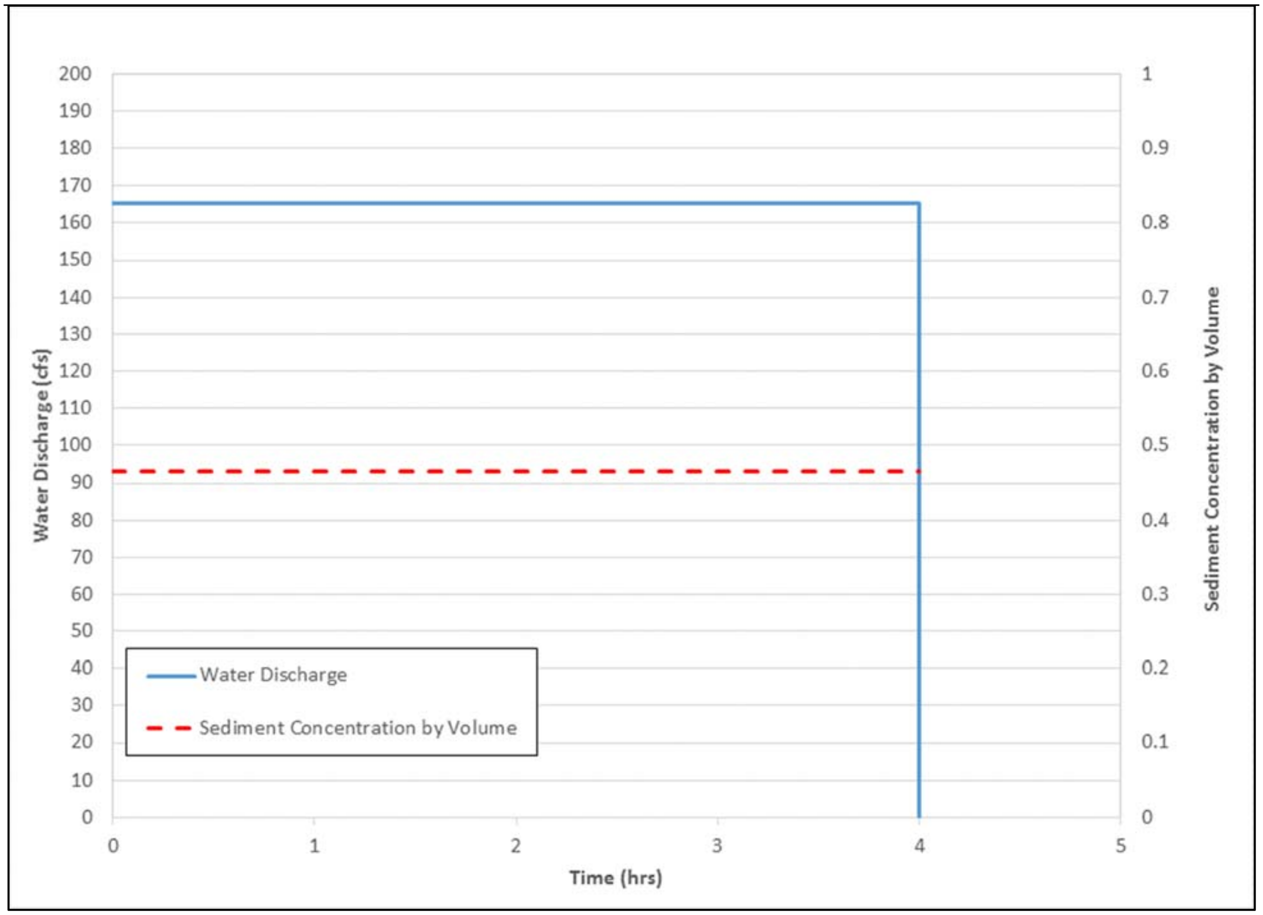

Figure 3-4 Water Hydrograph and Sediment Concentration by Volume of the Mudflow Hydrograph

3.6.2 Levee Breach Failure

In the FLO-2D model, the Argonaut dam was modeled by levees. The levees were set at the grid elements located along the Argonaut Dam (eight grid elements). In the FLO-2D model, the levee breach failure can be modeled by specifying the following parameters; elevation of prescribed failure (ft), duration (hrs) for failure after failure level is exceeded, initial levee breach width (ft), vertical rate of levee breach opening (ft/hr), and horizontal rate of levee breach opening (ft/hr). These parameters were set based on the assumption that the dam structure fails totally and abruptly at the end of the mudflow hydrograph (dry flow condition) or at the peak of the storm hydrograph (average and wet flow conditions). Therefore, levee breach failure parameters of the model were set as follows:

- Elevation of prescribed failure (ft): At this elevation, the levee starts to fail. At all levees, it was set at 1,368 ft, so that the dam could start to fail at the end of the mudflow hydrograph.
- Duration for failure after failure level is exceeded (hrs): The failure of the levee will be delayed for this duration, after the water surface elevation reaches at the prescribed failure elevation. At all levees, it was set at the time to the peak of the storm hydrograph; i.e., 12.5 hours for both average and wet flow conditions, so that the dam could start to fail at the peak of the storm hydrograph.
- Vertical rate of levee breach opening (ft/hr): Progressive levee failure is simulated by this rate. At all levees, it was set at 1,000 ft/hr, based on the assumption that the dam fails totally and abruptly.
- Initial levee breach width (ft): This is the width of the levee breach at the beginning of the failure. At all levees, it was set at the total width of the levee, which means that all the levees located along the

Argonaut Dam alignment would start to be lowered across the whole length of the dam at the same time at the beginning of the failure.

- Horizontal rate of levee breach opening (ft/hr): It was set at 0 ft/hr, to keep the initial levee breach width during the simulation.

3.3.3 Mudflow Simulation

The fluid characteristics of the mudflow are much different from the clear-water. Mudflows are non-homogeneous, non-Newtonian, and transient flood events whose fluid properties change significantly as they flow down steep watershed channels or across alluvial fans. FLO-2D routes mudflows as a fluid continuum by predicting viscous fluid motion as function of sediment concentration. Therefore, in the FLO-2D model, the following input parameters are required; sediment concentration by volume, coefficients used to calculate viscosity and yield stress, resistance parameter for laminar flow, and sediment specific gravity. These parameters are obtained or estimated as follows:

- Sediment concentration by volume: As described in Section 3.6.1, the sediment concentration by volume was estimated as 0.465 based on the USACE's geotechnical report (USACE, 2015(2)), where the average void ratio of tailings samples behind the Argonaut Dam is measured as 1.15.

- Coefficients used to calculate viscosity and yield stress: The viscosity and yield stress are calculated using empirical relationships which are functions of the sediment concentration by volume. The coefficients of the relationships are empirically determined by laboratory experiment (O'Brien and Julien, 1988). Because in most cases, the coefficients to define the relationships are not readily available, it is recommended to use the coefficients provided in Table 3 of FLO-2D Simulating Mudflow Guidelines (FLO-2D, 2008; **Appendix C**). Also, per the Guidelines, to simulate a viscous mudflow, it is recommended that the Glenwood 4 viscosity and yield stress coefficients are assigned. **Table 3-1** presents the Glenwood 4 viscosity and yield stress coefficients, which were selected for the mudflow simulation of this study.

Table 3-1 Yield Stress and Viscosity Coefficients (FLO-2D, 2008)

Source	Viscosity: $\eta = \alpha e^{\beta C_v}$		Yield Stress: $\tau_y = \alpha e^{\beta C_v}$	
	α	β	α	β
Glenwood 4	0.00172	29.5	0.000602	33.1

- Resistance parameter for laminar flow (K): Recommended resistance parameters for laminar flow are provided in Table 2 of FLO-2D Simulating Mudflow Guidelines (FLO-2D, 2008; **Appendix C**). The table shows that K for concrete/asphalt ranges from 24 to 108. Considering that per initial modeling results, most of the mudflow resulting from the dam failure flows through the roads including Sutter Street and Highway 49 and their neighboring parking lots, 100 was selected for the resistance parameter in the mudflow simulation.

- Sediment specific gravity: 2.65 was selected, which is the specific gravity of quartz particles.

As described above, input parameters required for the mudflow simulation were estimated based on the data and recommended values from USACE's geotechnical report (USACE, 2015(2)) and FLO FLO-2D Simulating Mudflow Guidelines (FLO-2D, 2008). However, if the sediment property parameters used in the model are much different from the actual parameters within the study area, it is possible that the actual inundation maps for mudflow would vary from the simulations generated in this study..

4. Inundation Maps from FLO-2D Modelings

The FLO-2D model was run for the following three scenarios:

- Mudflow and Dry Flow Condition
- Mudflow and Average Flow Condition
- Mudflow and Wet Flow Condition

In these simulations, it was assumed that the total volume of the tailings consists of water and sediment mixture.

For each of three scenarios, two types of inundation maps were generated:

- **Maximum Inundation Depth Maps** (Figures 1a, 2a, and 3a of **Appendix D**): Presents maximum inundation depths by color.
- **0.1-foot Inundation Boundary Maps** (Figures 1b, 2b, and 3b of **Appendix D**): Presents the inundation boundary of the area within which the maximum depth is greater than 0.1 foot.

For each scenario, the maps together present the following:

- **Mudflow – Dry Flow Condition** (Figures 1a and 1b of **Appendix D**): The maximum total inundation area from the Argonaut Dam to the downstream end of the modeling boundary is 42.3 acres. The maximum inundation depth on Highway 49 is 13 feet, which occurs near True Value hardware store. The maximum total length of inundation along Highway 49 is approximately 0.46 miles.
- **Mudflow – Average Flow Condition** (Figures 2a and 2b of **Appendix D**): The maximum total inundation area from the Argonaut Dam to the downstream end of the modeling boundary is 50.9 acres. The maximum inundation depth on Highway 49 is 15 feet, which occurs near True Value hardware store. The maximum total length of inundation along Highway 49 is approximately 0.51 miles.
- **Mudflow – Wet Flow Condition** (Figures 3a and 3b of **Appendix D**): The maximum total inundation area from the Argonaut Dam to the downstream end of the modeling boundary is 54.3 acres. The maximum inundation depth on Highway 49 is 15 feet, which occurs near True Value hardware store. The maximum total length of inundation along Highway 49 is approximately 0.51 miles.

For a comparison, the FLO-2D model was run for the following three clear water scenarios:

- Clear Water and Dry Flow Condition
- Clear Water and Average Flow Condition
- Clear Water and Dry Flow Condition

In the clear water simulations, it was assumed that the total volume of the tailings (165,000 cubic yards) consists of clear water only. Outputs from the clear water simulations are included in **Appendix E**.

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5. FLO-2D Modeling Summary and Conclusions

Table 5-1 summarizes the results from the FLO-2D modeling. The maximum total inundation area could be up to 54 acres, and the maximum inundation depth on Highway 49 could reach up to 15 feet.

Table 5-1 Summary of the FLO-2D Modeling

Scenarios	Max Total Inundation Area (acres)	Max Depth on HWY 49 (feet)	Max Inundation Length along HWY 49 (miles)	Location of Max Depth On HWY 49
Mudflow – Dry Flow Condition	42.3	13	0.46	near True Value hardware store
Mudflow – Average Flow Condition	50.9	15	0.51	near True Value hardware store
Mudflow – Wet Flow Condition	54.3	15	0.51	near True Value hardware store

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6. HAZUS Modeling

FEMA's HAZUS model was used to estimate potential losses within each inundation map modeled by the FLO-2D. HAZUS is a nationally applicable standardized methodology that contains models for estimating potential losses from earthquakes, floods, and hurricanes. HAZUS uses GIS technology to estimate physical, economic, and social impacts of disasters.

6.1 Inundation Model of the HAZUS

For this study, the Inundation Model of the HAZUS Induced Damage Models was selected to assess potential inundation losses due to dam failure. This model provides the methods for assessing inundation loss potential due to dam and levee failure, tsunami and seiche. For each of these hazards, various levels of results can be obtained according to the complexity of the evaluation, data requirements, and the use of expert assistance to perform the assessment (FEMA, 2015).

In the Inundation Model due to dam and levee failure, the inundation boundary maps are used as input data to evaluate the population and economic values in the affected area, which are estimated per each of the census blocks within the area.

For the inundation maps modeled by the FLO-2D, the Inundation Model predicted the following potential losses:

- Building Loss
- Content Loss
- Inventory Loss
- Relocation Cost
- Income Loss
- Rental Income Loss
- Wage Loss
- Total Vehicle Loss

For the mudflow conditions, the total loss was increased after estimating additional loss due to the mudflow compared to the clear-water as described below.

6.2 Estimate of Additional Loss Due to the Mudflow

In the Inundation Model of the HAZUS, depth-damage curves are used to estimate the potential losses, which exist only for flood water (i.e., clear-water). However, considering that the pressure on buildings due to the mudflow is greater than that due to the clear-water, at a minimum the loss related to the buildings (i.e., Building Loss) should be increased.

In the FLO-2D model, to estimate the maximum impact force on the structures, impact pressure (P_i) on a grid element is calculated using the following equation (FLO-2D, 2008):

$$P_i = k\rho_f V^2$$

where

k = coefficient (1.28 for water for both English and SI units),

ρ_f = flow density, and

V = maximum velocity regardless of direction

To consider additional impact force on the building structures, the ratio of the mudflow impact pressure to the clear-water was estimated. Considering that the maximum velocity of the mudflow is already considered in the FLO-2D model and then in inundation maps, the ratio can be calculated as the ratio of the coefficient (k) and flow density (ρ) only:

$$\text{Impact Pressure Ratio} = \frac{k_m \rho_{fm}}{k_w \rho_{fw}}$$

where

k_m = coefficient for mudflow,

k_w = coefficient for water,

ρ_{fm} = mudflow density, and

ρ_{fw} = water density

k_m is calculated as (FLO-2D, 2009; Deng, 1996):

$$k_m = 1.261e^{C_w}$$

where

C_w = sediment concentration by weight (0.697; estimated from USACE's geotechnical report (Jan, 2015))

Therefore,

$$k_m = 1.261e^{0.697} = 2.53$$

ρ_{fm} is calculated as (Julien, 1998):

$$\rho_{fm} = \rho_s(1 - P_o) + \rho_w P_o$$

where

ρ_s = density of solid particles (2,650 kg/m^3),

ρ_w = density of water (1,000 kg/m^3), and

P_o = porosity (0.535; estimated from USACE's geotechnical report (USACE, 2015(2))

Therefore,

$$\rho_{fm} = 2{,}650(1 - 0.535) + 1{,}000 \times 0.535 = 1{,}767 \text{ kg/m}^3$$

Then,

$$\text{Impact Pressure Ratio} = \frac{2.53 \times 1{,}767}{1.28 \times 1{,}000} = 3.5$$

Therefore, for the mudflow conditions, the Building Loss obtained from the Inundation Model is multiplied by the Impact Pressure Ratio of 3.5, and then, the total loss was calculated as the sum of this increased Building Loss and the other loss types listed above.

7. Maps and Tablesfrom HAZUS

HAZUS model was run for three inundation maps obtained from the FLO-2D modeling.

For each of three scenarios, two types of outputs were generated:

- Total Losses by Census Block Map: Presents estimated total losses of each census block within the inundation boundary (Figures 1c, 2c, and 3c of **Appendix D**).
- Potential Loss Summary Table: Summarizes estimated potential losses within the inundation boundary (Tables 1, 2, and 3 of **Appendix F**).

For a comparison, the HAZUS model was run for the three clear water scenarios. Outputs from the clear water simulations are included in **Appendices E and G**.

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8. Total Losses Estimated from HAZUS

Table 8-1 summarizes the results from the HAZUS modeling. The total losses range from $18 million up to $34 million.

The HAZUS model estimates approximate costs due to the losses resulting from failure of the subject dam using depth-damage curves provided within the software. It is expected that additional damage costs would be calculated upon receipt of more accurate site-specific information listed in the following section from local stakeholders (e.g., City of Jackson, County of Amador, Caltrans, etc.).

Table 8-1 Summary of the HAZUS Modeling

Scenarios	Total Loss ($)	Building Loss ($)	Content Loss ($)	Inventory Loss ($)	Relocation Cost ($)	Income Loss ($)	Rental Income Loss ($)	Wage Loss ($)	Total Vehicle Loss ($)
Mudflow - Dry Flow	**17,806,622**	10,027,500	5,718,000	84,000	1,000	3,000	0	48,000	1,925,122
Mudflow - Average Flow	**28,924,427**	16,597,000	9,194,000	133,000	1,000	7,000	1,000	76,000	2,915,427
Mudflow - Wet Flow	**34,239,709**	19,607,000	11,004,000	163,000	2,000	10,000	1,000	93,000	3,359,709

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9. Additional Damage Costs to be Considered

The following damage costs may need to be included in the total loss, in addition to the losses predicted by the HAZUS:

- **Clean-up cost for the mud accumulated on Highway 49**: It is expected that the information required to estimate the mud clean-up cost can be provided by the City of Jackson, County of Amador, or California Department of Transportation (Caltrans). Using the obtained information and total volume of the mud accumulated on the highway estimated from the FLO-2D, the mud clean-up cost can be calculated.

- **Cost due to road closure**: To estimate the cost due to the highway closure, the following information needs to be obtained: total days of the closure of Highway 49 due to the mud clean-up work, the estimated number of one-way traffic trips per day, additional time per one-way trip due to the road closure, number of additional miles, etc.

- **Additional damages or losses**: Other damages can be predicted by the project team and stake holders, such as cost of damages to natural resources and tourism, emergency response costs, any utilities or infrastructure other than the roads and buildings that would need to be repaired, or potential school closures.

9.1 Estimate of Additional Damage Costs

The project team is in the process of collecting the information required to estimate the additional damage costs. **Table 9-1** presents a summary of the additional damage costs currently estimated for mudflow-wet flow condition, based on the information provided to date by local and federal agencies; these costs are estimated at approximately $86 million. Therefore, considering that the total loss cost from the HAZUS model for the mudflow-wet flow condition is 34 million dollars, the total damage/loss cost due to the Argonaut Dam failure could be estimated at over $120 million.

Table 9-1 Additional Damage Costs for Mudflow-Wed Flow Condition

Damages		Estimated Cost ($)	Data Source
Clean-up of mud accumulated on HWY 49	Mud clean-up work	1,185,000	Caltrans
	Repair or replacement of the highway	2,595,000	
Cost due to road closure	Basis of estimated cost (via Caltrans): - Duration of road closure due to mud clean-up: 25 days - Duration of road closure due to construction of the highway: 15 days - Additional distance due to road closure: 50 miles - Additional time due to road closure: 1.25 hours - Number of one-way traffic trips: 9,350 (Caltrans, 2014) - Refer to **Appendix H** for the damage cost calculation	24,605,000	Caltrans
Habitat Restoration	Basis of estimated cost: - Complete re-vegetation and recovery of aquatic habitat (completely denuded after removal of mud and contamination) - Small geographic scale and overall replacement of vegetation/creek bed, based on past ‘intensive’ riparian projects in urban settings - USFWS estimated $1M - $1.5M for the restoration of 1.2 miles of Jackson Creek, which was determined based on the FLO-2D modeling extent. However, it is likely that the mudflow continues to flow down to Lake Amador, 7 miles downstream, and then, the restoration cost needs to be increased; 7/1.2 x $1.5M ≈ $8.8M	8,800,000	U.S. Fish & Wildlife Service (USFWS)
Damages to Natural Resources	Per Natural Resources Damage Assessment and Restoration (NRDAR) principles, secondary restoration required as compensation to the public for the lost natural resources over time: - The responsible parties would be required to provide an additional ~1.0 stream mile of restoration (based on presumed overall injuries to “natural resource services” provided by the Creek) - Estimate of $500,000/stream mile for typical riparian habitat “improvement” project	500,000	U.S. Fish & Wildlife Service (USFWS)
Hazardous waste clean-up, transportation, and disposal	- 250,000 tons x $100/ton	25,000,000	EPA
Damages to tourism	- Annual income generated from tourism in Amador County is approximately $46M (Visit California, 2015) - If we assume tourism would be fully impacted over a 6-month period due to cleanup and restoration work, the economic loss of income from tourism in Amador County would be approximately $23 million	23,000,000	Visit California
Emergency Response	Information/data not received yet		City of Jackson / Amador County
Damage/Loss to utilities and infrastructure	Information/data not received yet		City of Jackson / Amador County
Losses to the local economy	Information/data not received yet		City of Jackson / Amador County
Damage/loss to historical buildings	Information/data not received yet		City of Jackson / Amador County
Cost due to closure of government services	Information/data not received yet		City of Jackson / Amador County
Cost due to closure of schools	Information/data not received yet		Amador County Unified School District
Total:	**$85,685,000**		various

10. References

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Appendix A: Potential Risks Associated with Argonaut Dam Failure/Uncertainties and Limitations of the Modeling

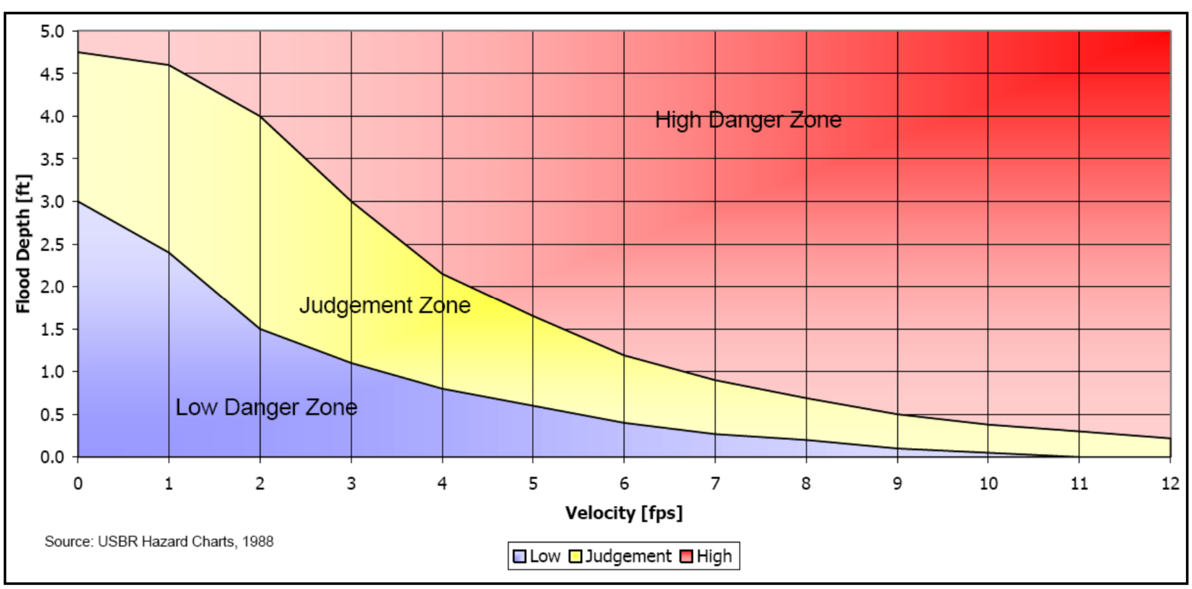
Potential Risks Associated with Argonaut Dam Failure

- In 2013-2014, the U.S. Environmental Protection Agency (USEPA) and Army Corps of Engineers (USACE) conducted studies of the dam integrity and material behind the Argonaut Dam (USACE, 2015(1)). In 2014, they concluded that the Argonaut Dam is structurally unstable and subject to failure and release of the tailings materials (USEPA, 2014). Also, they found that lower earthen tailings dam was to be marginally stable with regards to slope stability. The materials that comprise the lower earthen tailings dam were found to be stronger with regards to shear strength than the tailings slimes behind the dam.

- This report provides modeling estimates of the flooding and mudflow damages that would result from the failure of Argonaut Dam. However, if there was massive loss of tailings in the Argonaut Dam impoundment, it could undermine and destabilize the lower earthen tailings dam causing a release of up to 345,000 cubic yards of tailings in the middle slimes impoundment.

- Potential life-loss associated with the dam failure is an overriding concern compared to economic damages and losses, however, the HAZUS model does not account for such losses, and therefore potential life-loss as a result of dam failure is not included in the study. For reference, the U.S. Bureau of Reclamation (USBR) identified the flood hazard for pedestrians as a combination of depth and velocity (*Downstream Hazard Classification Guidelines* - ACER Technical Memorandum No. 11, 1988) as follows:

Flood Hazard for Pedestrians



- Above figure presents depth-velocity-flood danger level relationship for adults. An adult is considered any human over 5 feet tall and weighing over 120 pounds.
- Low Danger Zone: Almost any size adult is not seriously threatened by flood water.
- Judgement Zone: Danger level is based upon engineering judgement.
- High Danger Zone: Almost any size adult is in danger from flood water.
- After defining the above three zones, the number of the people located in each zone needs to be estimated. Subsequently, if possible (or necessary), the impacted population would need to be assigned a value in order to be included in the total damage cost.

Uncertainties and Limitations of the Modeling (HEC-HMS, FLO-2D and HAZUS)

Conservative Inundation Boundaries

The inundation boundaries can be considered conservative for the following reasons:

- Because this study was focused on the failure of the Argonaut Dam due to an instability or flooding of the dam structure, the HEC-HMS modeling was limited to the watershed of Argonaut Dam. If the discharges from the north of the city and upstream of Jackson Creek were considered in the mudflow simulation using the FLO-2D, the area of the inundation would be larger than the current modeling results. Therefore, the inundation boundaries generated in this study can be considered conservative in terms of the inundation area.
- The damming of the stream channel with mud and debris was not considered. Blockage of the channel (Jackson Creek) would cause the mudflow and flood waters to spread laterally throughout the town.
- The inundation maps only show approximately one-third of Main Street would be inundated (**Figure A-1**). However, per the field investigation, invert elevations along Main Street are lower than those along Highway 49 parallel to it. In that case, the inundation boundary should have been connected through Main Street. As described in Section 3.2 of the report, topographic data for the FLO-2D model were obtained from the USGS NED having 1/3-arc-second resolution (approximately 30 feet on the ground), and then, based on it, a grid element size of 50 feet was selected for the modeling. Therefore, considering that the size of the grid elements is 50 feet, the inundation boundary near Main Street cannot be delineated in sufficient detail to be connected through the street, because elevations of the grid elements located along Main Street are higher than the actual invert elevations along the street. For a better delineation of the inundation boundary, topographic data with a higher resolution is required.

- The modeling did not consider potential failures of the upper and lower earthen tailings dams. In 2014, the USACE found that lower earthen tailings dam was marginally stable with regards to slope stability. However, there was concern that the earthen dam could be undermined and destabilized, if there was a massive loss of tailings in the concrete dam basin. The USACE did not conduct a geotechnical investigation of the upper earthen tailings dam and slimes impoundment, because it was not considered a high risk for failure.

HEC-HMS Model

Some of input parameters of the HEC-HMS model were determined based on the following assumptions:

- Manning's n Roughness Coefficients of **Table 2-2**: Considering that areas of the subbasins are relatively small, instead of using a weighted average of n values, a single n value representing each subbasin was selected from Table 7-1 of the Sacramento Drainage Manual (1996), and used in the HEC-HMS model. Due to relatively small subbasin areas and lengths, the impact of the n values on the lag times seems to be very minor.
- Peaking Factor of **Section 2.5**: In this study, peaking factor of 0.8 was selected for all four subbasins, considering steepness of the watershed. FLO-2D is a volume conservation flood routing model. The model is more focused on the total volume of the hydrograph rather than the peak discharge. Therefore, even though the peaking factors of the hydrographs were estimated based on the steepness of the watershed rather than calibration or regional studies, considering that the total volumes of the hydrographs are the same regardless of the peaking factors, impact of the peaking factors on the FLO-2D modeling results seems to be very minor.
- Watershed Delineation of **Section 2.1**: **Figure 2-1** shows that boundaries of downstream subbasins are delineated a couple of hundred feet across the dam. Because the remaining capacity of the dam is very small (2.8 ac-ft), the dam is easily overtopped during most storm events. Also, a basin is located immediately downstream of the dam. Therefore, considering these factors, we located the outlet of the dam watershed at a location where the outlet of the basin is located.

FLO-2D Model

FLO-2D model were developed based on the following assumptions:

- The FLO-2D model was developed based on the assumption that the geometry data developed based on 1) topographic data (USGS National Elevation Dataset (NED) having 1/3-arc-second resolution); and 2) Manning's n roughness coefficients defined for the various surface types are sufficient for the purpose of this study. Therefore, Area Reduction Factor (ARF), Width Reduction Factor (WRF), and Street Segment options of the FLO-2D were not used in the model, which require more detailed information of the study area and refinement of the input data.

- As described in the report, the viscosity and yield stress are calculated using empirical relationships, and the coefficients of the relationships are empirically determined by laboratory experiment. Practically, it is not possible to obtain those coefficients specific to the study area, therefore using the coefficients provided in Table 3 of FLO-2D Mudflow Simulation Guidelines is a suitable way to obtain those values. Because the Guidelines recommend using the Glenwood 4 viscosity and yield stress coefficients of the table to simulate a viscous mudflow, those were selected for the mudflow simulation of this study. Therefore, using those coefficients can be considered as the only option for the viscous mudflow simulation recommended by FLO-2D.

HAZUS Model

- The tables of **Appendix F** include "Total Tons of Debris" and "Displaced Persons", but they are not included in the total loss calculation. No detailed explanation regarding these values is provided in the HAZUS reference manuals.

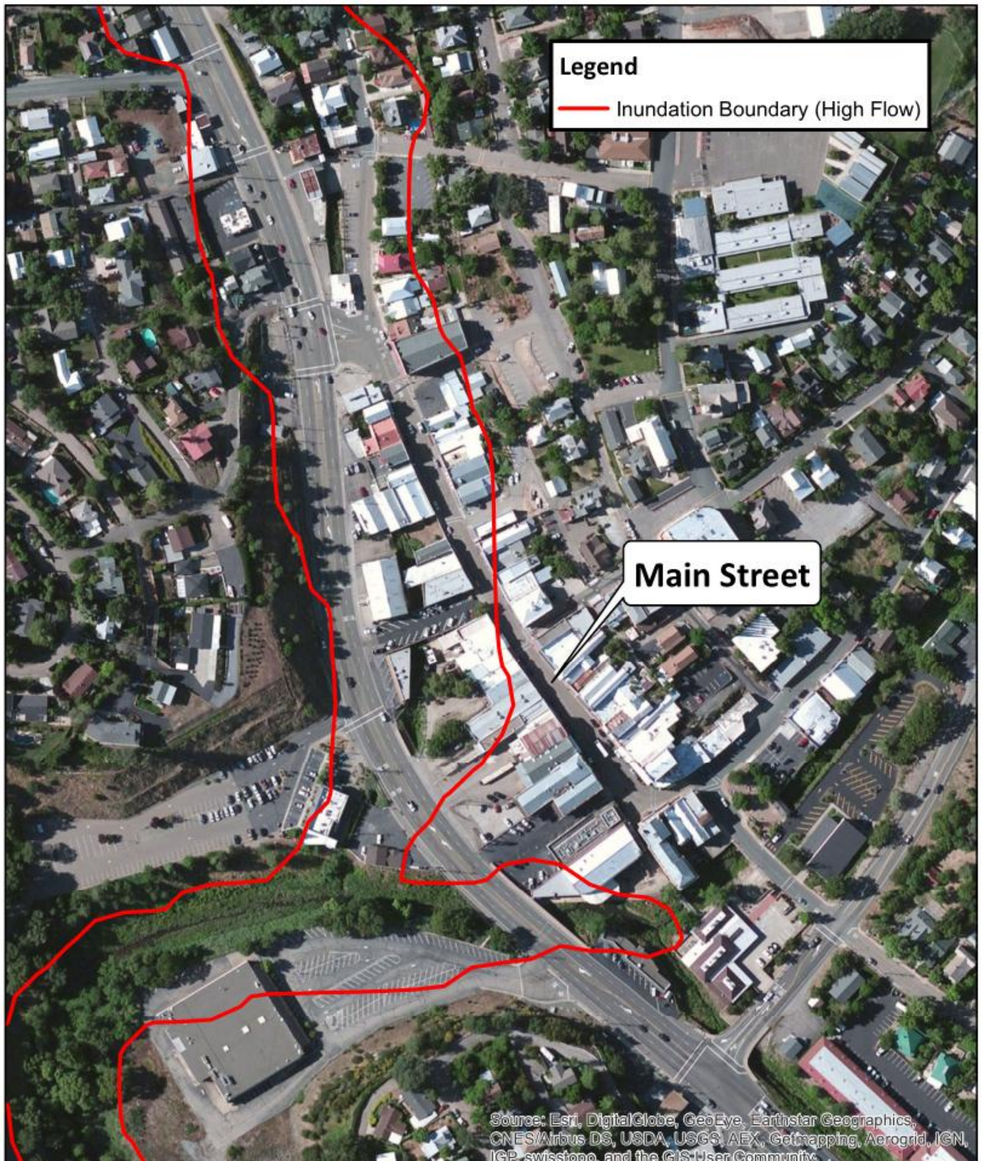


Figure A-1: Inundation Boundary near Main Street

N

0 400 800 Feet

Argonaut
Dam Failure Study

CDM Smith

NOAA Atlas 14, Volume 6, Version 2SUTTER HILL CDF
Station ID: 04-8713
Location name: Sutter Creek, California, US*
Latitude: 38.3772°, Longitude: -120.8008°
Elevation:
Elevation (station metadata): 1586ft*
* source: Google Maps

POINT PRECIPITATION FREQUENCY ESTIMATES

Sanja Perica, Sarah Dietz, Sarah Heim, Lillian Hiner, Kazungu Maitaria, Deborah Martin, Sandra Pavlovic, Ishani Roy, Carl Trypaluk, Dale Unruh, Fenglin Yan, Michael Yekta, Tan Zhao, Geoffrey Bonnin, Daniel Brewer, Li-Chuan Chen, Tye Parzybok, John Yarchoan

NOAA, National Weather Service, Silver Spring, Maryland

PF_tabular | PF_graphical | Maps_&_aerials

PF tabular

PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.135 (0.119-0.154)	0.165 (0.145-0.189)	0.210 (0.185-0.242)	0.252 (0.219-0.293)	0.318 (0.264-0.387)	0.375 (0.303-0.470)	0.449 (0.351-0.581)	0.574 (0.432-0.770)	0.785 (0.560-1.11)	0.991 (0.675-1.47)
10-min	0.193 (0.170-0.221)	0.236 (0.209-0.271)	0.302 (0.265-0.347)	0.362 (0.314-0.421)	0.456 (0.378-0.554)	0.538 (0.434-0.674)	0.643 (0.502-0.832)	0.822 (0.619-1.10)	1.13 (0.802-1.60)	1.42 (0.967-2.11)
15-min	0.233 (0.206-0.267)	0.286 (0.252-0.327)	0.365 (0.321-0.419)	0.438 (0.380-0.509)	0.551 (0.457-0.670)	0.651 (0.525-0.815)	0.778 (0.608-1.01)	0.995 (0.748-1.34)	1.36 (0.970-1.93)	1.72 (1.17-2.55)
30-min	0.327 (0.289-0.374)	0.401 (0.353-0.459)	0.511 (0.449-0.588)	0.613 (0.533-0.713)	0.772 (0.641-0.939)	0.912 (0.736-1.14)	1.09 (0.851-1.41)	1.39 (1.05-1.87)	1.91 (1.36-2.71)	2.41 (1.64-3.57)
60-min	0.437 (0.386-0.499)	0.535 (0.472-0.612)	0.682 (0.599-0.784)	0.818 (0.711-0.951)	1.03 (0.855-1.25)	1.22 (0.982-1.52)	1.46 (1.14-1.88)	1.86 (1.40-2.50)	2.55 (1.81-3.61)	3.21 (2.19-4.76)
2-hr	0.640 (0.566-0.732)	0.760 (0.670-0.870)	0.932 (0.819-1.07)	1.09 (0.943-1.26)	1.32 (1.09-1.60)	1.51 (1.22-1.89)	1.72 (1.34-2.23)	1.96 (1.47-2.63)	2.57 (1.83-3.65)	3.24 (2.21-4.81)
3-hr	0.786 (0.694-0.899)	0.925 (0.816-1.06)	1.12 (0.986-1.29)	1.29 (1.12-1.50)	1.54 (1.28-1.88)	1.75 (1.41-2.19)	1.97 (1.54-2.55)	2.21 (1.66-2.97)	2.60 (1.85-3.68)	3.28 (2.23-4.86)
6-hr	1.13 (0.998-1.29)	1.33 (1.17-1.52)	1.59 (1.40-1.83)	1.82 (1.58-2.11)	2.13 (1.77-2.59)	2.37 (1.92-2.97)	2.63 (2.06-3.40)	2.90 (2.18-3.90)	3.28 (2.34-4.65)	3.59 (2.44-5.32)
12-hr	1.53 (1.36-1.75)	1.86 (1.64-2.13)	2.29 (2.01-2.63)	2.63 (2.29-3.06)	3.10 (2.57-3.77)	3.45 (2.79-4.32)	3.81 (2.97-4.92)	4.17 (3.14-5.60)	4.66 (3.32-6.60)	5.03 (3.43-7.46)
24-hr	2.09 (1.90-2.34)	2.66 (2.42-2.99)	3.39 (3.07-3.81)	3.96 (3.55-4.49)	4.70 (4.08-5.53)	5.25 (4.46-6.32)	5.79 (4.79-7.15)	6.33 (5.09-8.05)	7.04 (5.41-9.34)	7.57 (5.61-10.4)
2-day	2.76 (2.51-3.09)	3.54 (3.22-3.98)	4.52 (4.09-5.09)	5.28 (4.74-5.99)	6.26 (5.43-7.36)	6.98 (5.92-8.39)	7.68 (6.35-9.48)	8.37 (6.72-10.6)	9.27 (7.12-12.3)	9.93 (7.36-13.7)
3-day	3.27 (2.97-3.67)	4.20 (3.81-4.71)	5.35 (4.85-6.02)	6.24 (5.60-7.08)	7.38 (6.40-8.68)	8.21 (6.96-9.87)	9.01 (7.45-11.1)	9.80 (7.87-12.5)	10.8 (8.31-14.4)	11.6 (8.57-15.9)
4-day	3.63 (3.31-4.07)	4.67 (4.25-5.25)	5.95 (5.39-6.70)	6.92 (6.22-7.87)	8.17 (7.09-9.61)	9.07 (7.69-10.9)	9.93 (8.21-12.3)	10.8 (8.65-13.7)	11.8 (9.11-15.7)	12.6 (9.36-17.4)
7-day	4.45 (4.05-4.99)	5.74 (5.22-6.45)	7.28 (6.60-8.20)	8.44 (7.59-9.59)	9.89 (8.58-11.6)	10.9 (9.25-13.1)	11.9 (9.81-14.6)	12.8 (10.3-16.2)	13.9 (10.7-18.5)	14.7 (10.9-20.3)
10-day	5.09 (4.63-5.71)	6.57 (5.97-7.38)	8.32 (7.54-9.37)	9.62 (8.64-10.9)	11.2 (9.73-13.2)	12.3 (10.5-14.8)	13.4 (11.0-16.5)	14.3 (11.5-18.2)	15.5 (11.9-20.6)	16.4 (12.1-22.5)
20-day	6.91 (6.29-7.75)	8.95 (8.13-10.0)	11.3 (10.2-12.7)	13.0 (11.7-14.8)	15.1 (13.1-17.8)	16.5 (14.0-19.9)	17.8 (14.7-22.0)	19.0 (15.3-24.2)	20.5 (15.7-27.2)	21.5 (15.9-29.5)
30-day	8.37 (7.61-9.38)	10.8 (9.82-12.1)	13.6 (12.3-15.3)	15.6 (14.1-17.8)	18.1 (15.7-21.3)	19.7 (16.7-23.7)	21.2 (17.5-26.2)	22.6 (18.1-28.7)	24.2 (18.6-32.2)	25.4 (18.8-34.9)
45-day	10.4 (9.42-11.6)	13.3 (12.1-14.9)	16.7 (15.1-18.8)	19.1 (17.1-21.7)	21.9 (19.0-25.8)	23.9 (20.2-28.7)	25.6 (21.2-31.6)	27.2 (21.8-34.6)	29.1 (22.4-38.6)	30.4 (22.5-41.8)
60-day	12.1 (11.0-13.5)	15.4 (14.0-17.3)	19.1 (17.3-21.5)	21.8 (19.6-24.8)	25.0 (21.7-29.4)	27.2 (23.0-32.7)	29.1 (24.0-35.9)	30.8 (24.8-39.2)	32.9 (25.3-43.7)	34.3 (25.5-47.3)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

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PF graphical

Table 2 Resistance Parameters for Laminar Flow[1]	
Surface	Range of K
Concrete/asphalt	24 -108
Bare sand	30 - 120
Graded surface	90 - 400
Bare clay - loam soil, eroded	100 - 500
Sparse vegetation	1,000 - 4,000
Short prairie grass	3,000 - 10,000
Bluegrass sod	7,000 - 50,000

[1] Woolhiser (1975)

Table 3. Yield Stress and Viscosity as a Function of Sediment Concentration				
Source	$\eta = \alpha e^{\beta Cv}$		$\tau_y = \alpha e^{\beta Cv}$	
	α	β	α	β
Field Data				
Aspen Pit 1	0.181	25.7	0.0360	22.1
Aspen Pit 2	2.72	10.4	0.0538	14.5
Aspen Natural Soil	0.152	18.7	0.00136	28.4
Aspen Mine Fill	0.0473	21.1	0.128	12.0
Aspen Watershed	0.0383	19.6	0.000495	27.1
Aspen Mine Source Area	0.291	14.3	0.000201	33.1
Glenwood 1	0.0345	20.1	0.00283	23.0
Glenwood 2	0.0765	16.9	0.0648	6.20
Glenwood 3	0.000707	29.8	0.00632	19.9
Glenwood 4	0.00172	29.5	0.000602	33.1
Relationships Available from the Literature				
Iida (1938)*	-	-	0.0000373	36.6
Dai et al. (1980)	2.60	17.48	0.00750	14.39
Kang and Zhang (1980)	1.75	7.82	0.0405	8.29
Qian et al. (1980)	0.00136	21.2	-	-
	0.050	15.48	-	-
Chien and Ma (1958)	0.0588	19.1-32.7	-	-
Fei (1981)	0.166	25.6	-	-
	0.00470	22.2	-	-

*See O'Brien (1986) for the references.

Conversion: Shear Stress: 1 Pascal (PA) = 10 dynes/cm^2
Viscosity: 1 PAs = 10 dynes-sec/cm^2 = 10 poises

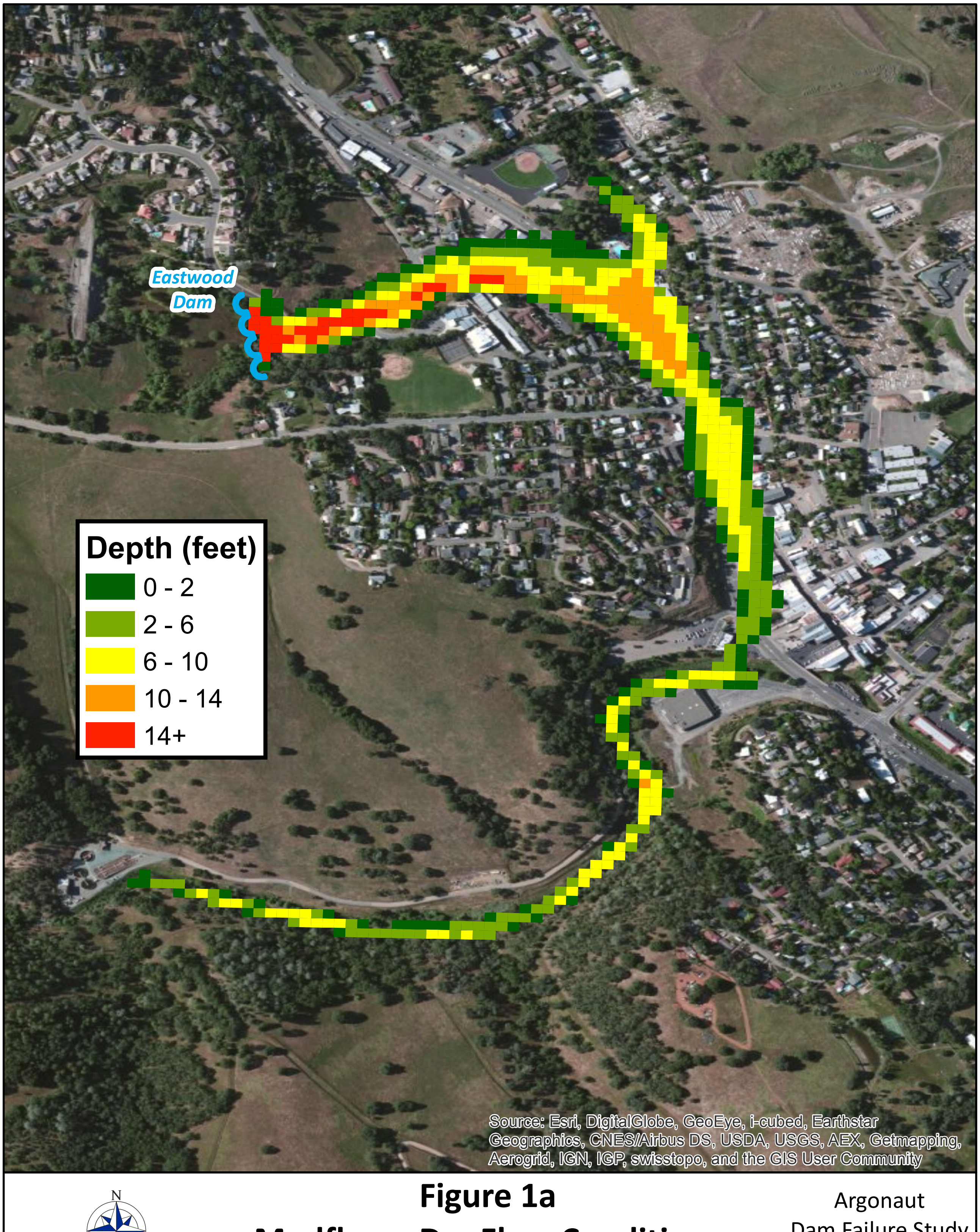

Figure 1a
Mudflow - Dry Flow Conditions
Maximum Depth

Argonaut
Dam Failure Study

CDM Smith

thielentr Argonaut_Mudflow_Dry_Depth.mxd 3/27/2015

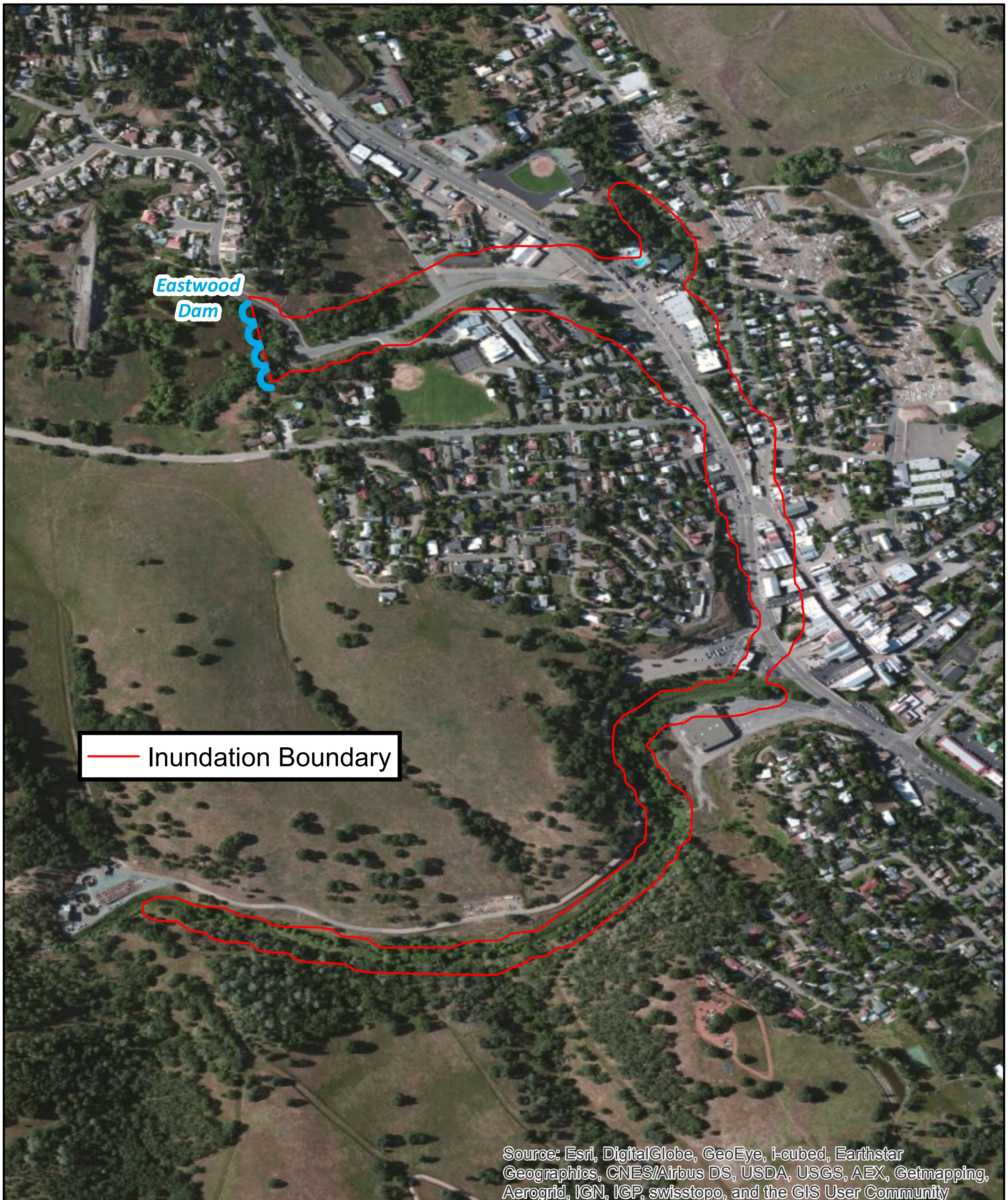

Figure 1b

Mudflow - Dry Flow Conditions

0.1 Ft Depth Inundation Boundary

Argonaut
Dam Failure Study

CDM Smith

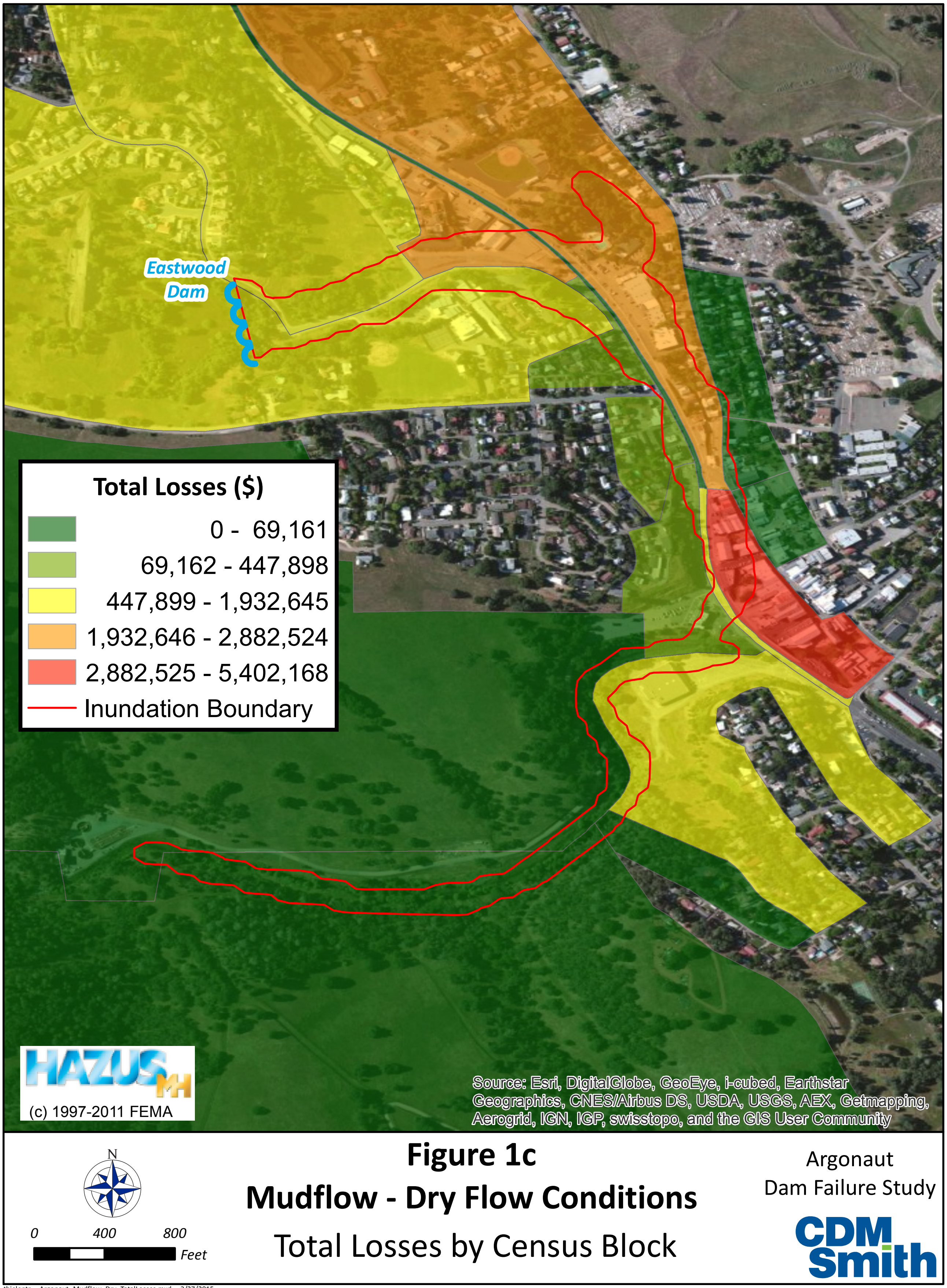

Figure 1c

Mudflow - Dry Flow Conditions

Total Losses by Census Block

Argonaut
Dam Failure Study

CDM Smith

thielentr Argonaut_Mudflow_Dry_TotalLosses.mxd 3/27/2015

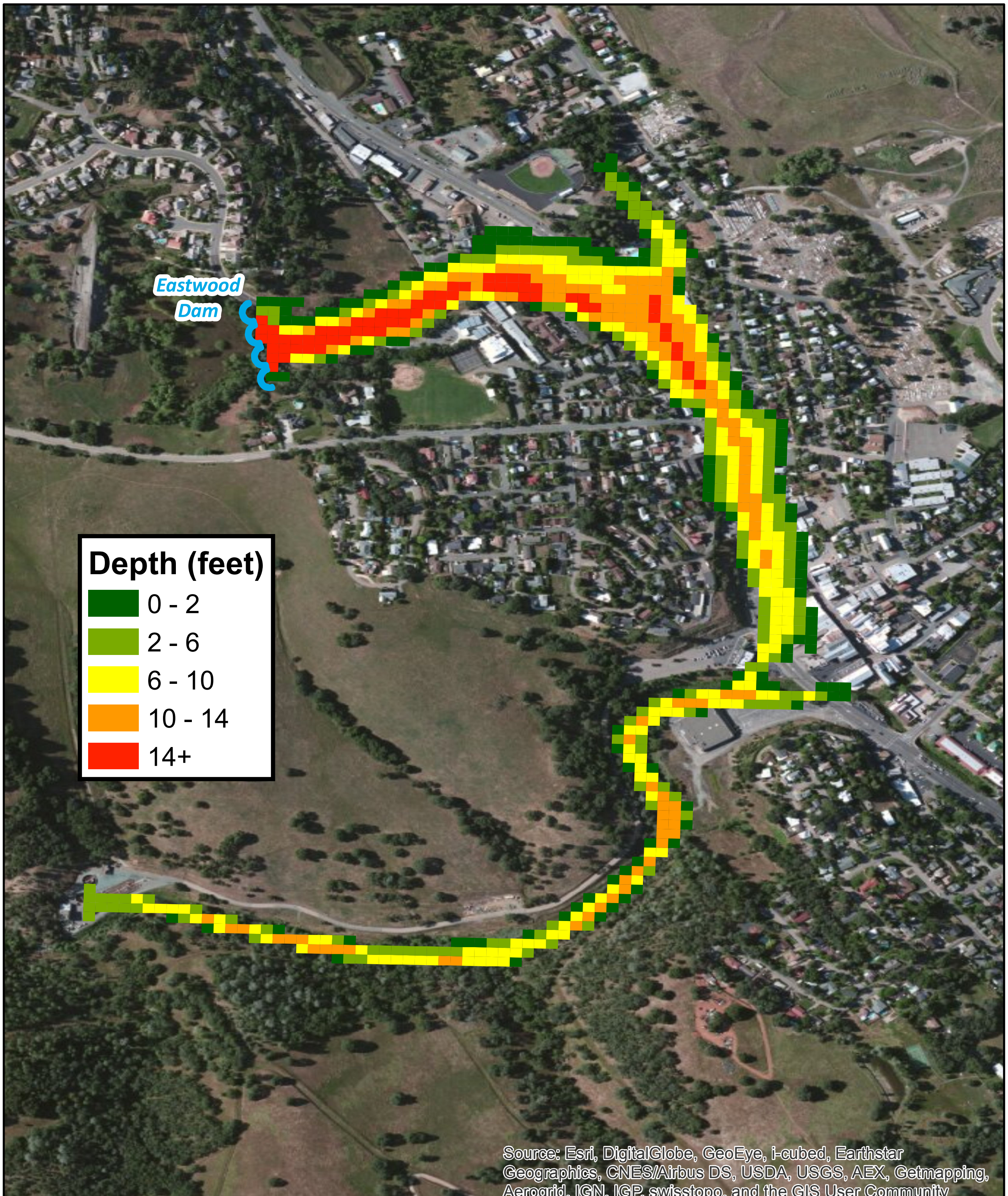

Figure 2a
Mudflow - Average Flow Conditions
Maximum Depth

Argonaut
Dam Failure Study

CDM Smith

thielentr Argonaut_Mudflow_Avg_Depth.mxd 3/27/2015

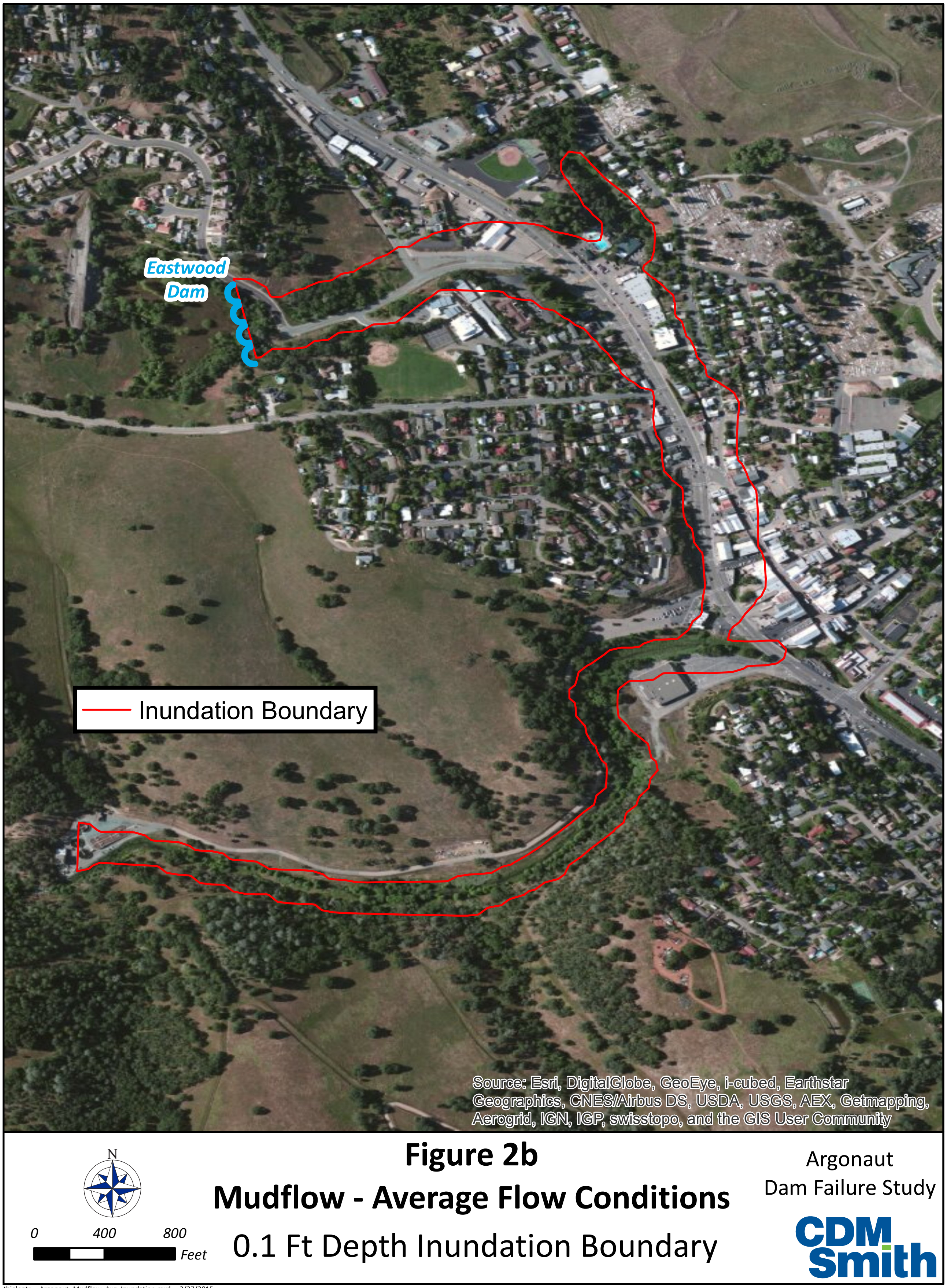

Figure 2b

Mudflow - Average Flow Conditions

0.1 Ft Depth Inundation Boundary

Argonaut
Dam Failure Study

CDM Smith

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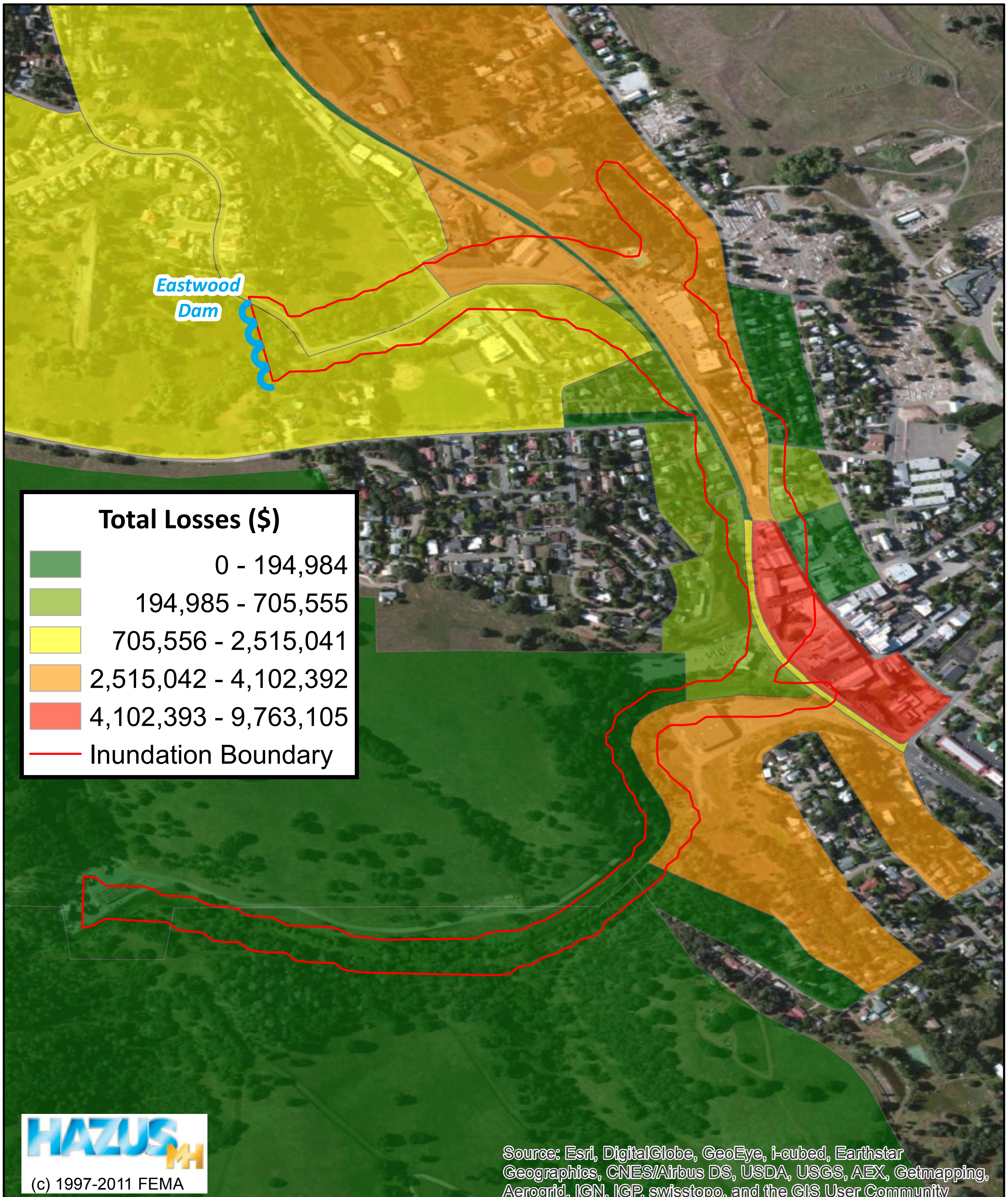


Figure 2c

Mudflow - Average Flow Conditions

Total Losses by Census Block

Argonaut
Dam Failure Study

CDM Smith

thielentr Argonaut_Mudflow_Average_TotalLosses.mxd 3/27/2015

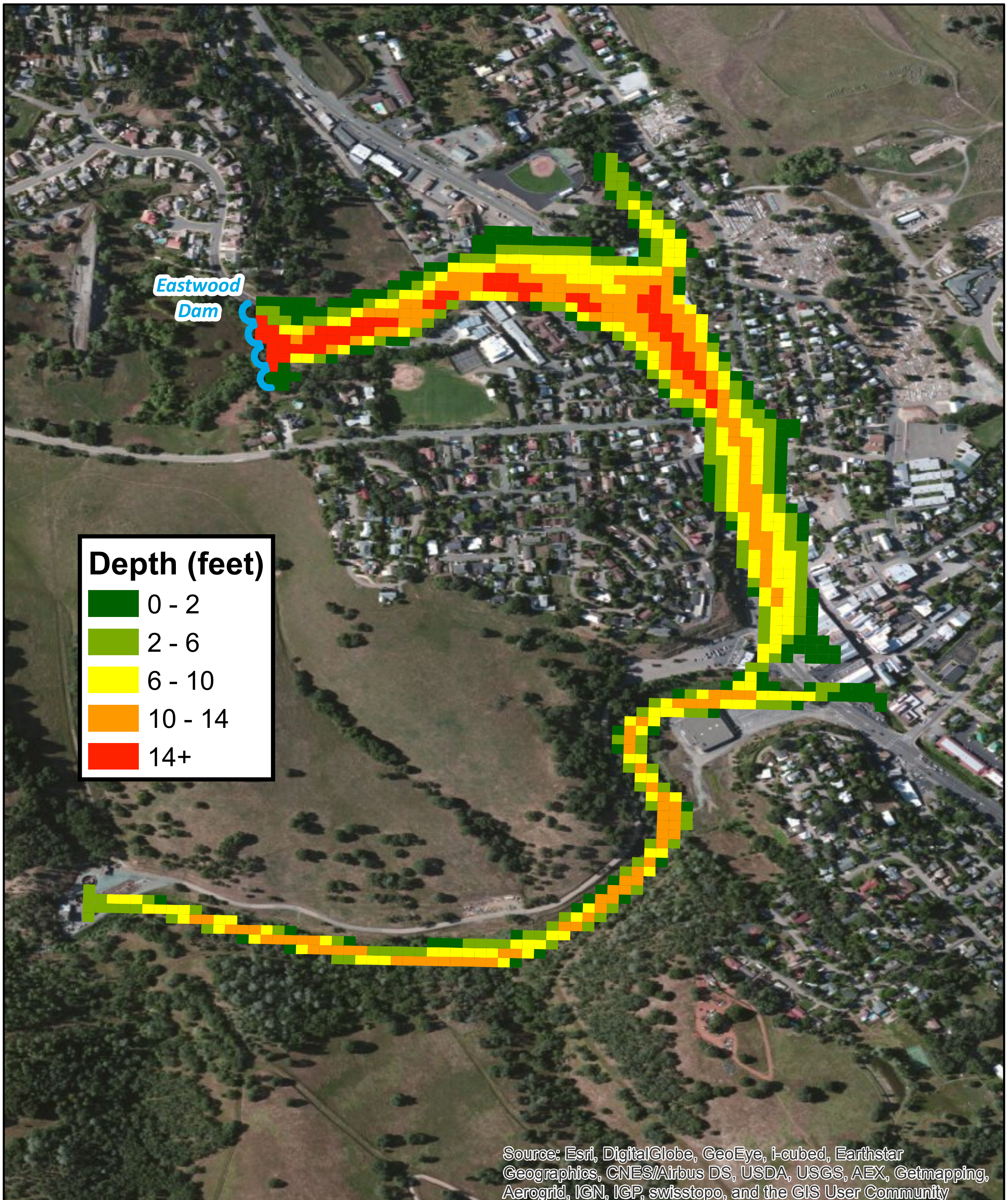


Figure 3a
Mudflow - Wet Flow Conditions
Maximum Depth

Argonaut
Dam Failure Study

CDM Smith

thielentr Argonaut_Mudflow_Wet_Depth.mxd 3/27/2015

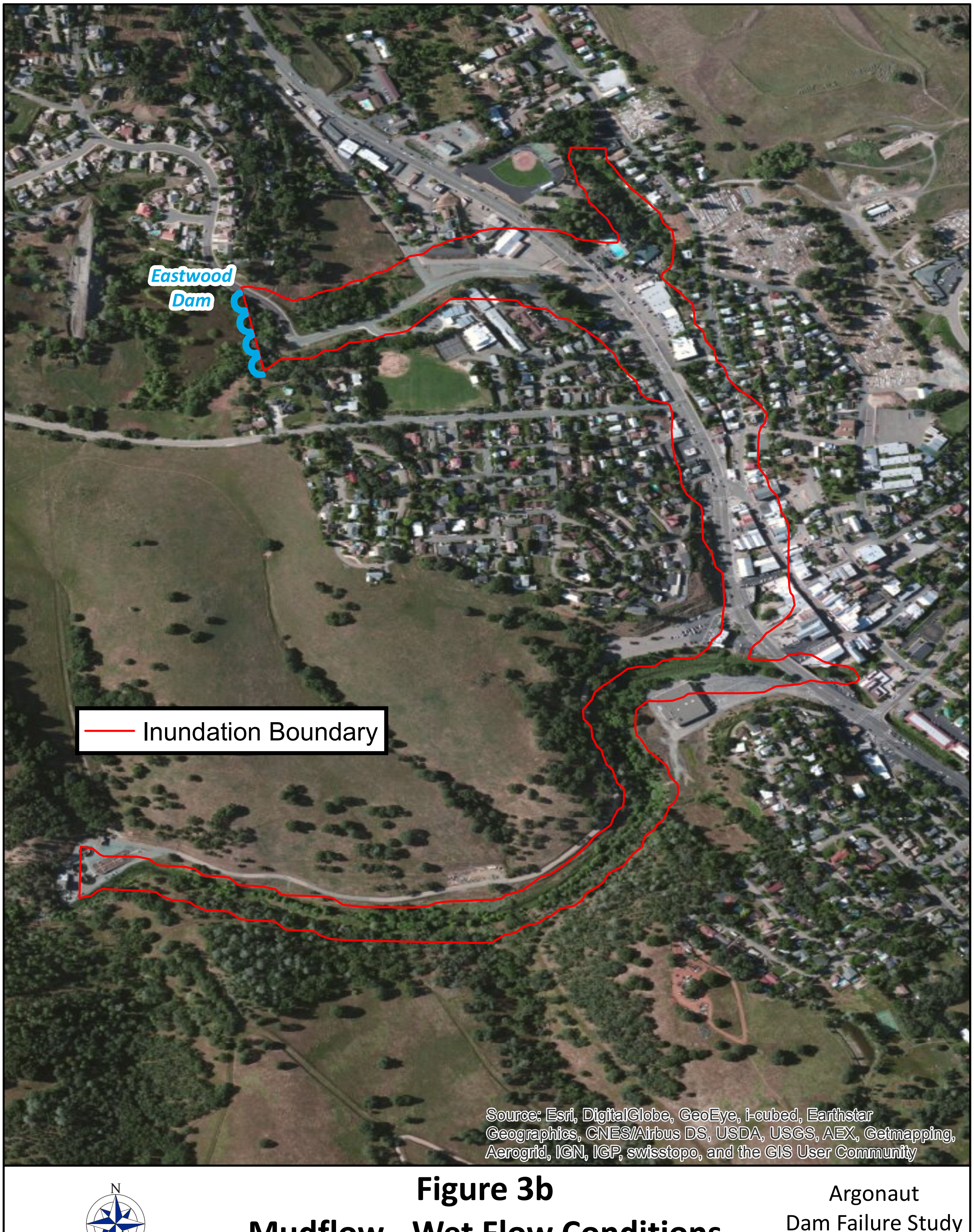


Figure 3b

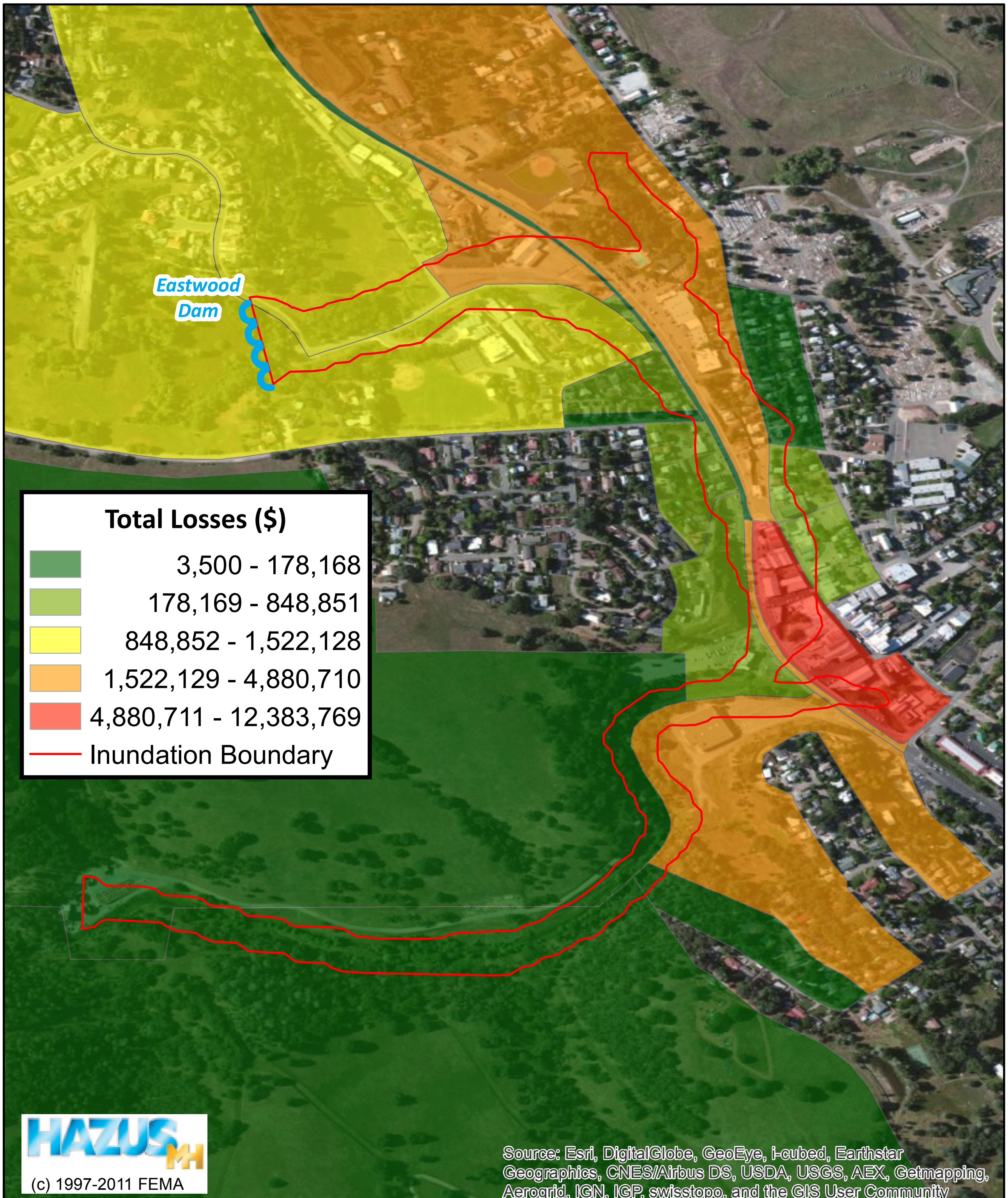
Mudflow - Wet Flow Conditions

0.1 Ft Depth Inundation Boundary

Argonaut Dam Failure Study

CDM Smith

thielentr Argonaut_Mudflow_Wet_Inundation.mxd 3/27/2015



N

0 400 800 Feet

Figure 3c

Mudflow - Wet Flow Conditions

Total Losses by Census Block

Argonaut
Dam Failure Study

CDM Smith

thielentr Argonaut_Mudflow_Wet_TotalLosses.mxd 3/27/2015

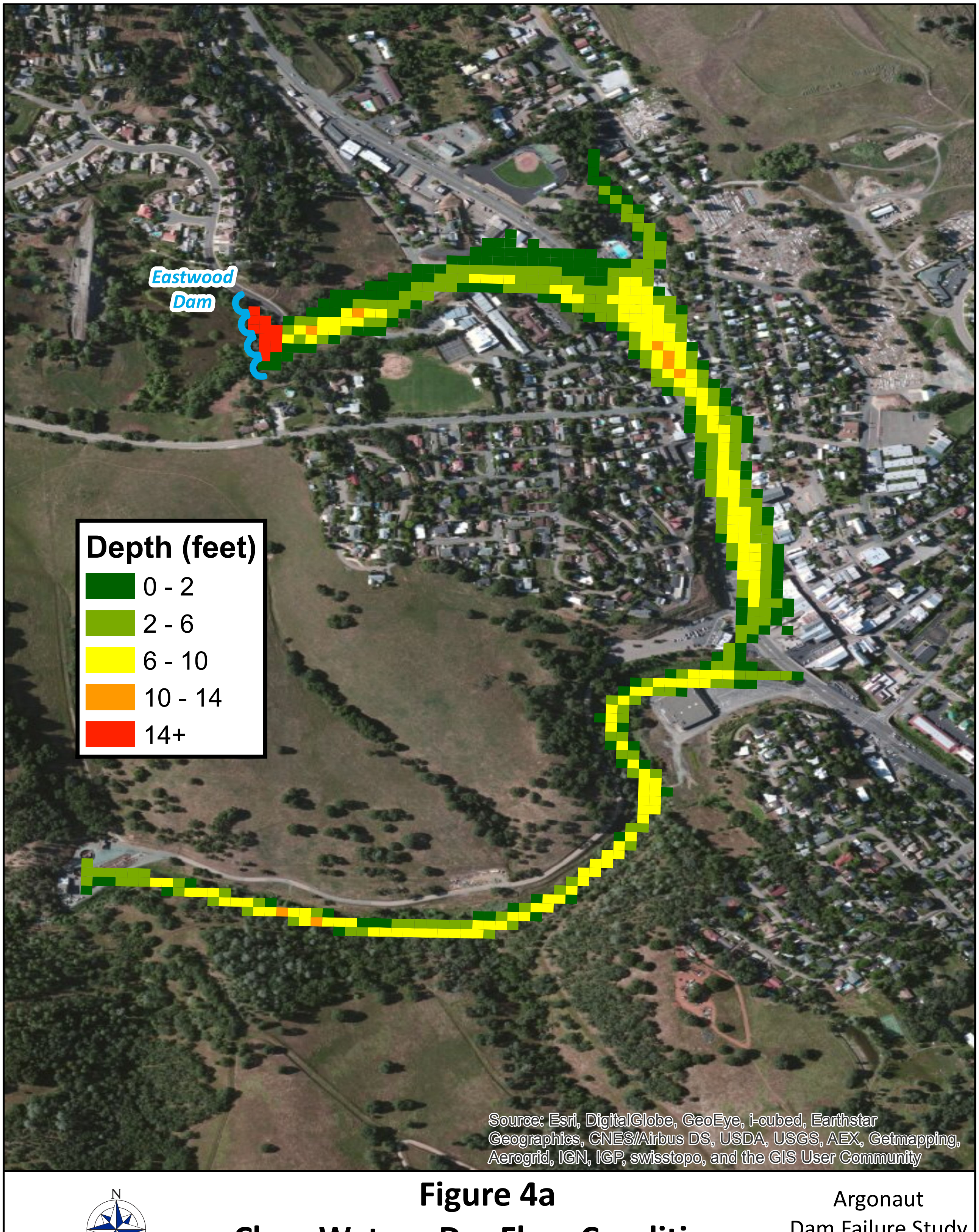


Figure 4a

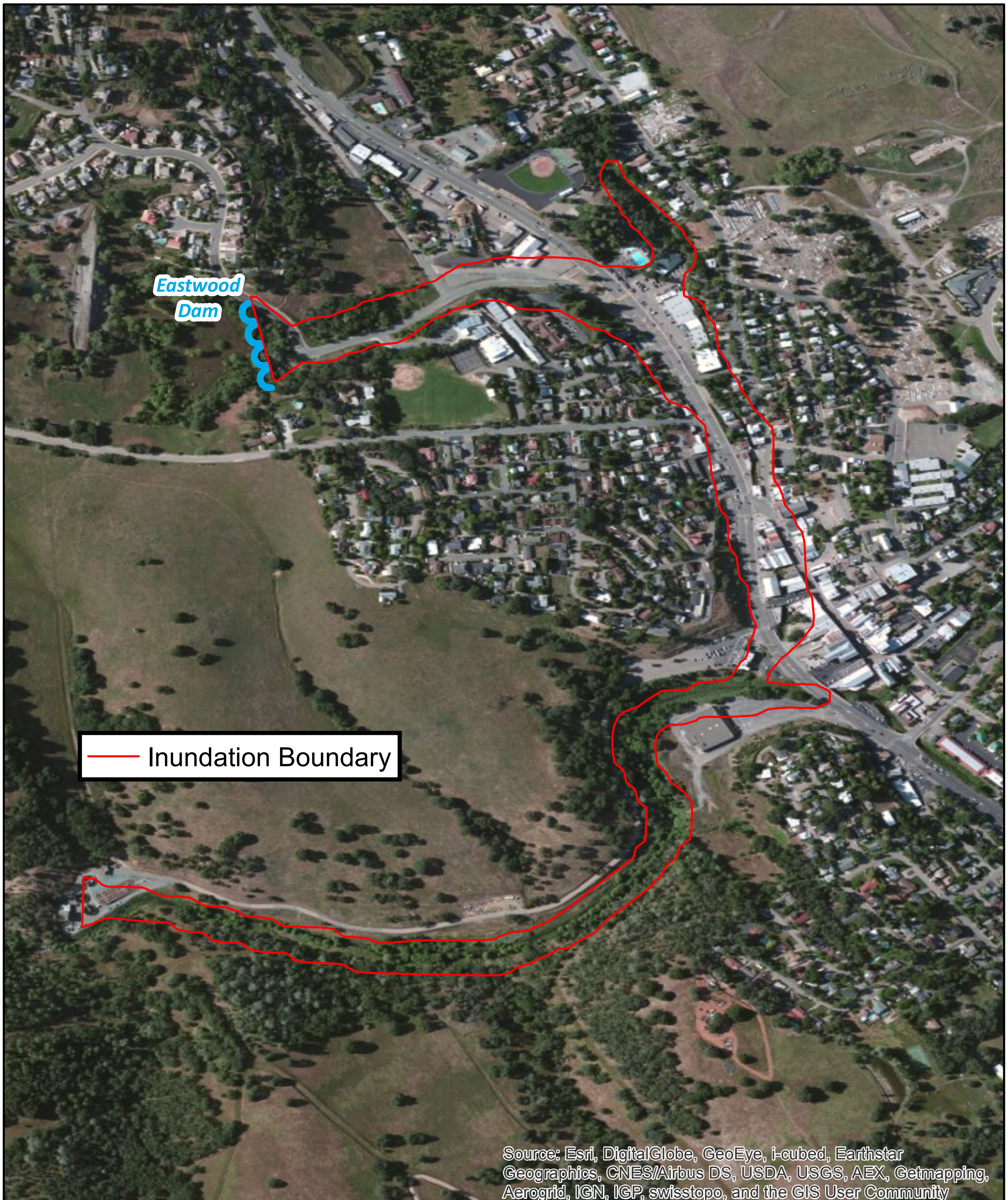
Clear Water - Dry Flow Conditions

Maximum Depth

Argonaut
Dam Failure Study

CDM Smith

thielentr Argonaut_Clearwater_Dry_Depth.mxd 3/27/2015



N

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Figure 4b

Clear Water - Dry Flow Conditions

0.1 Ft Depth Inundation Boundary

Argonaut
Dam Failure Study

CDM Smith

thielentr Argonaut_Clearwater_Dry_Inundation.mxd 3/27/2015

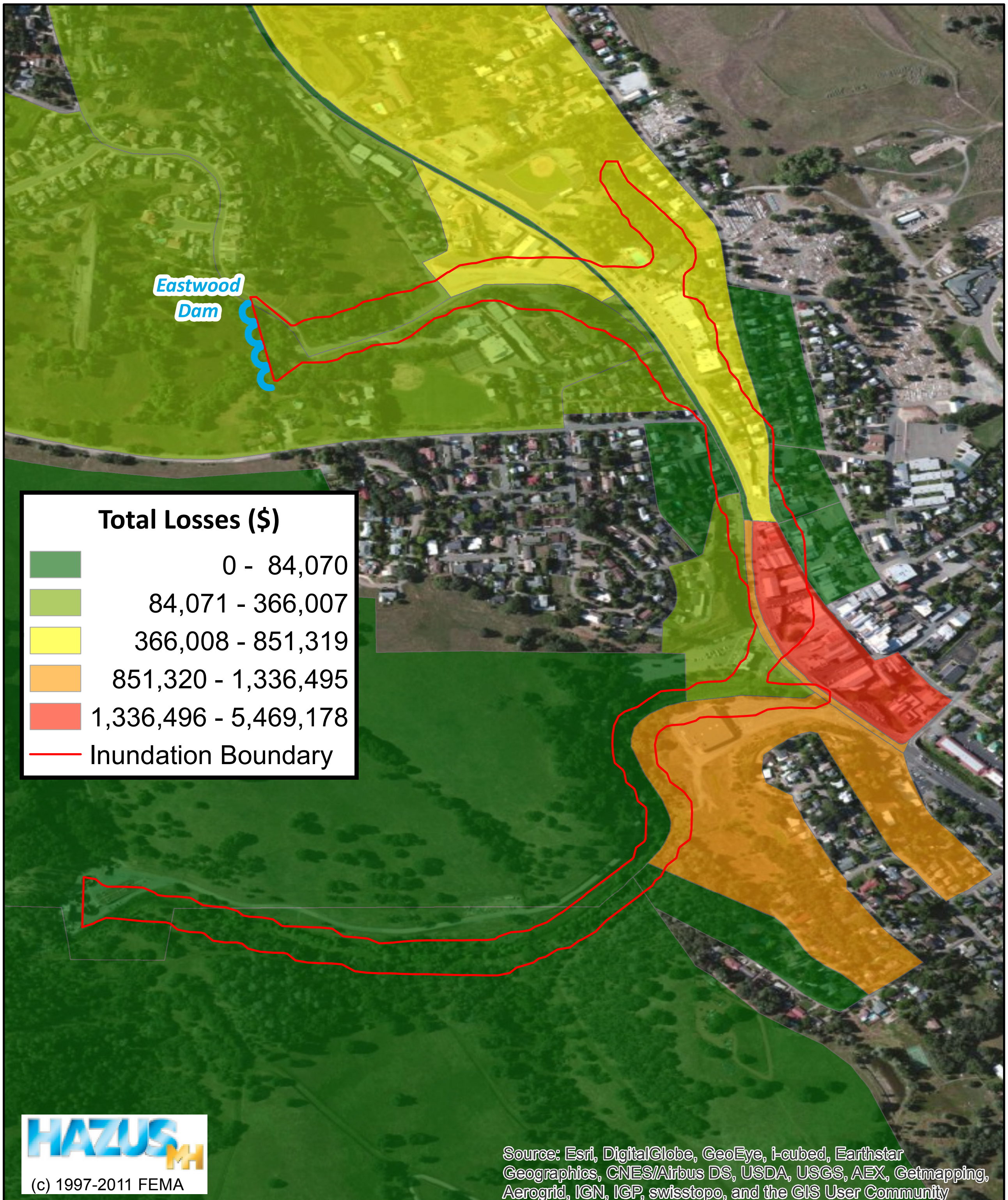

Figure 4c

Clear Water - Dry Flow Conditions

Total Losses by Census Block

Argonaut
Dam Failure Study

CDM Smith

thielentr Argonaut_Clearwater_Dry_TotalLosses.mxd 3/27/2015

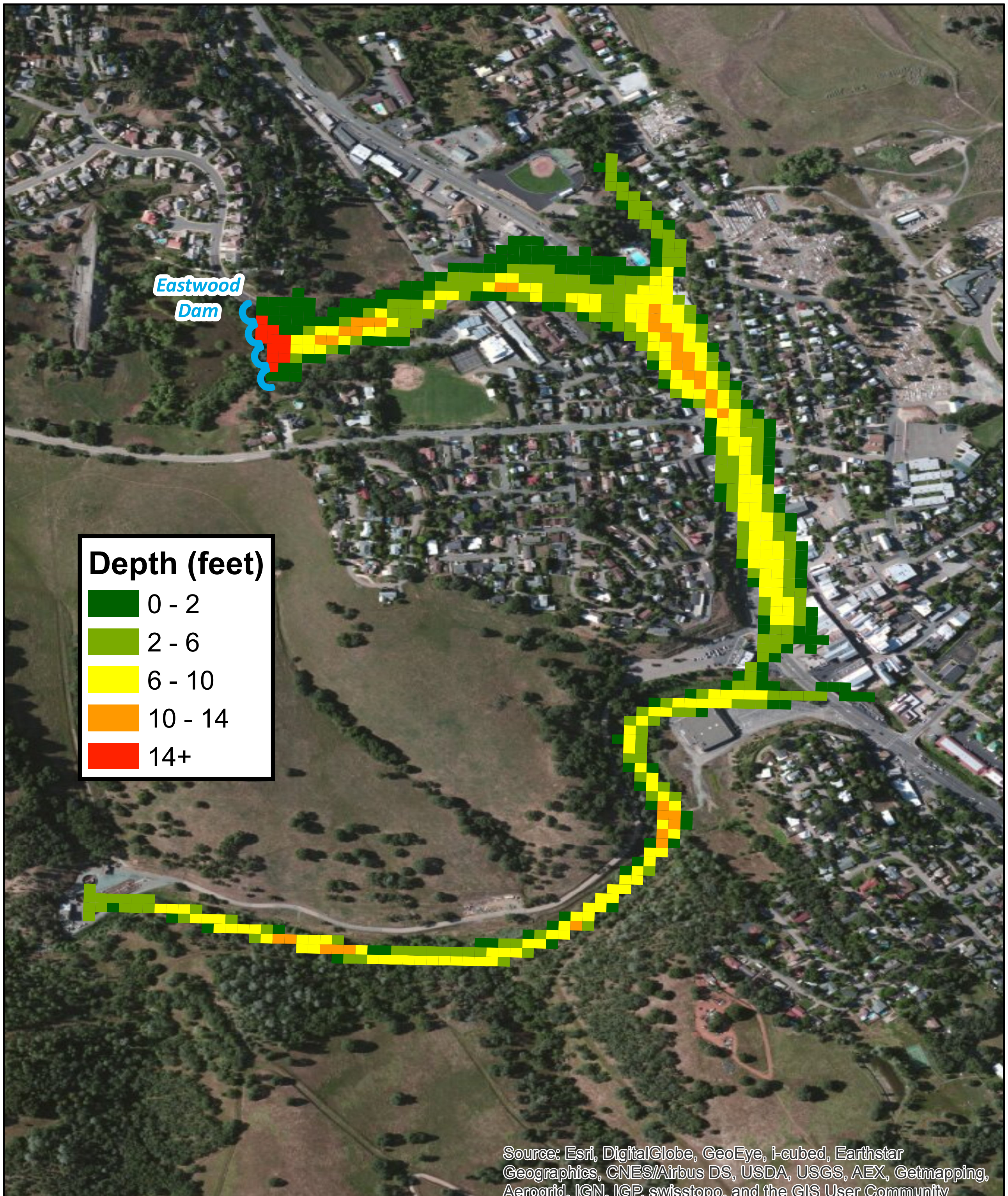

Figure 5a

Clear Water - Average Flow Conditions

Maximum Depth

Argonaut Dam Failure Study

CDM Smith

thielentr Argonaut_Clearwater_Avg_Depth.mxd 3/27/2015

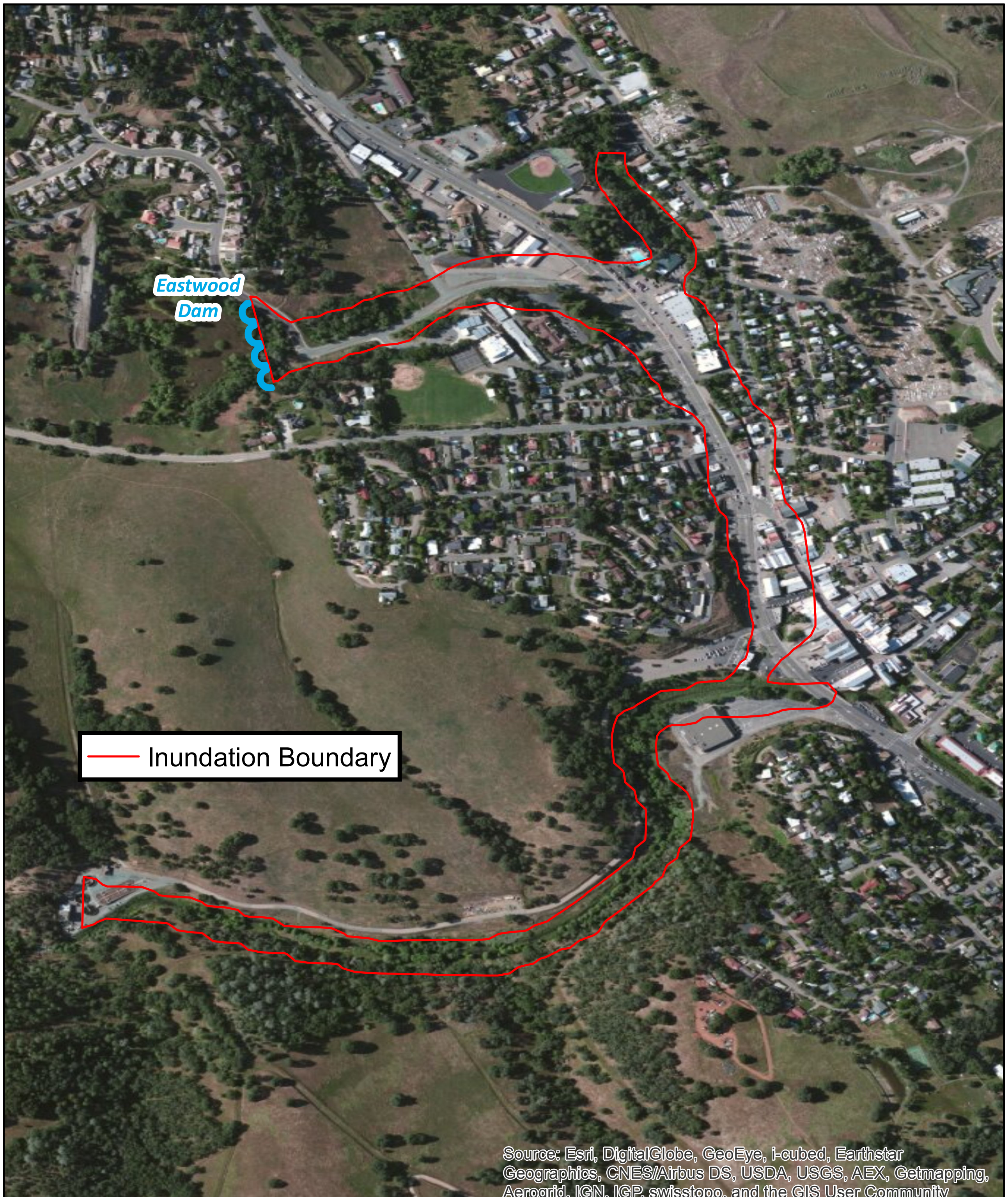

Figure 5b

Clear Water - Average Flow Conditions

0.1 Ft Depth Inundation Boundary

Argonaut
Dam Failure Study

CDM Smith

thielentr Argonaut_Clearwater_Avg_Inundation.mxd 3/27/2015

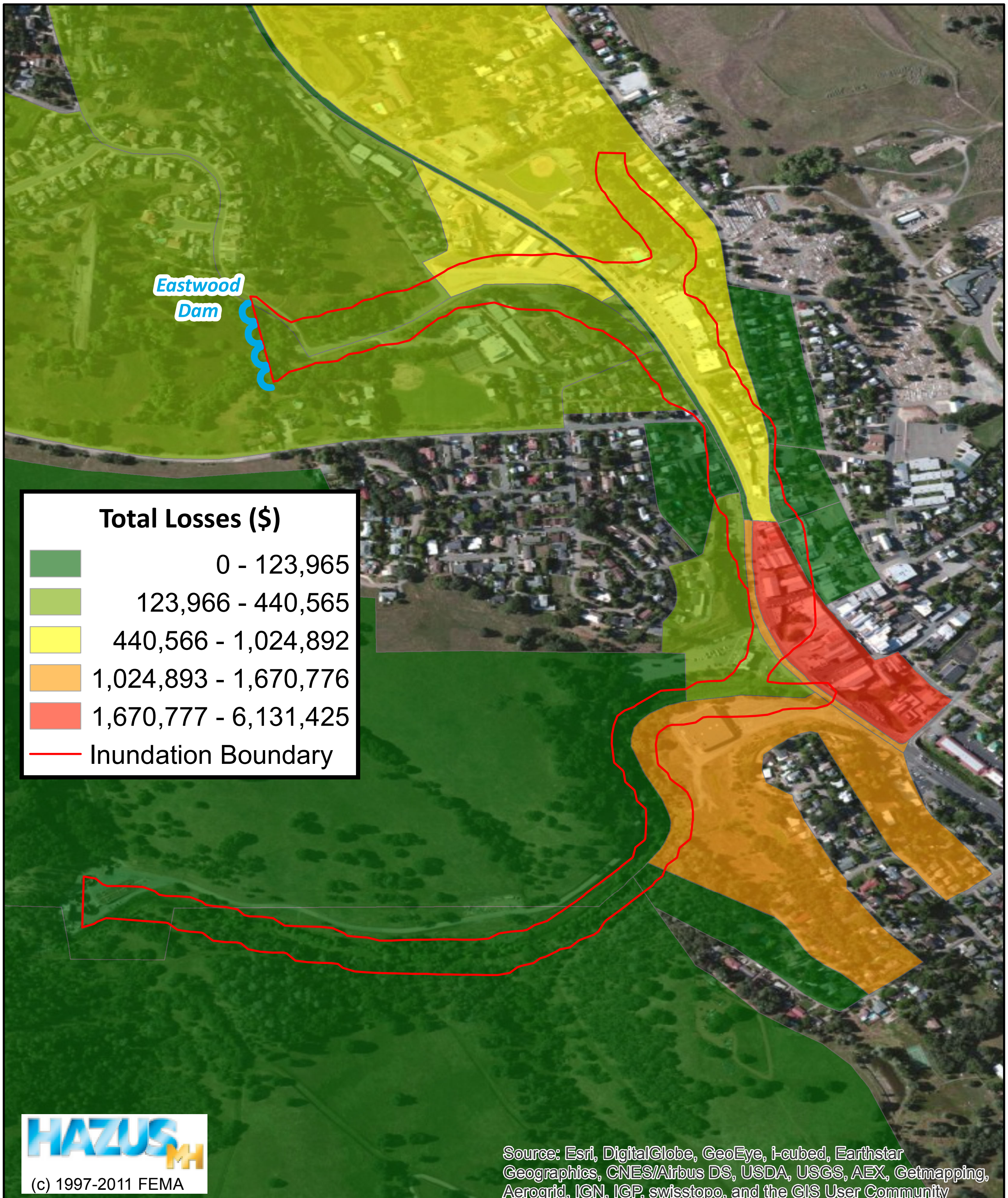

Figure 5c

Clear Water - Average Flow Conditions

Total Losses by Census Block

Argonaut Dam Failure Study

CDM Smith

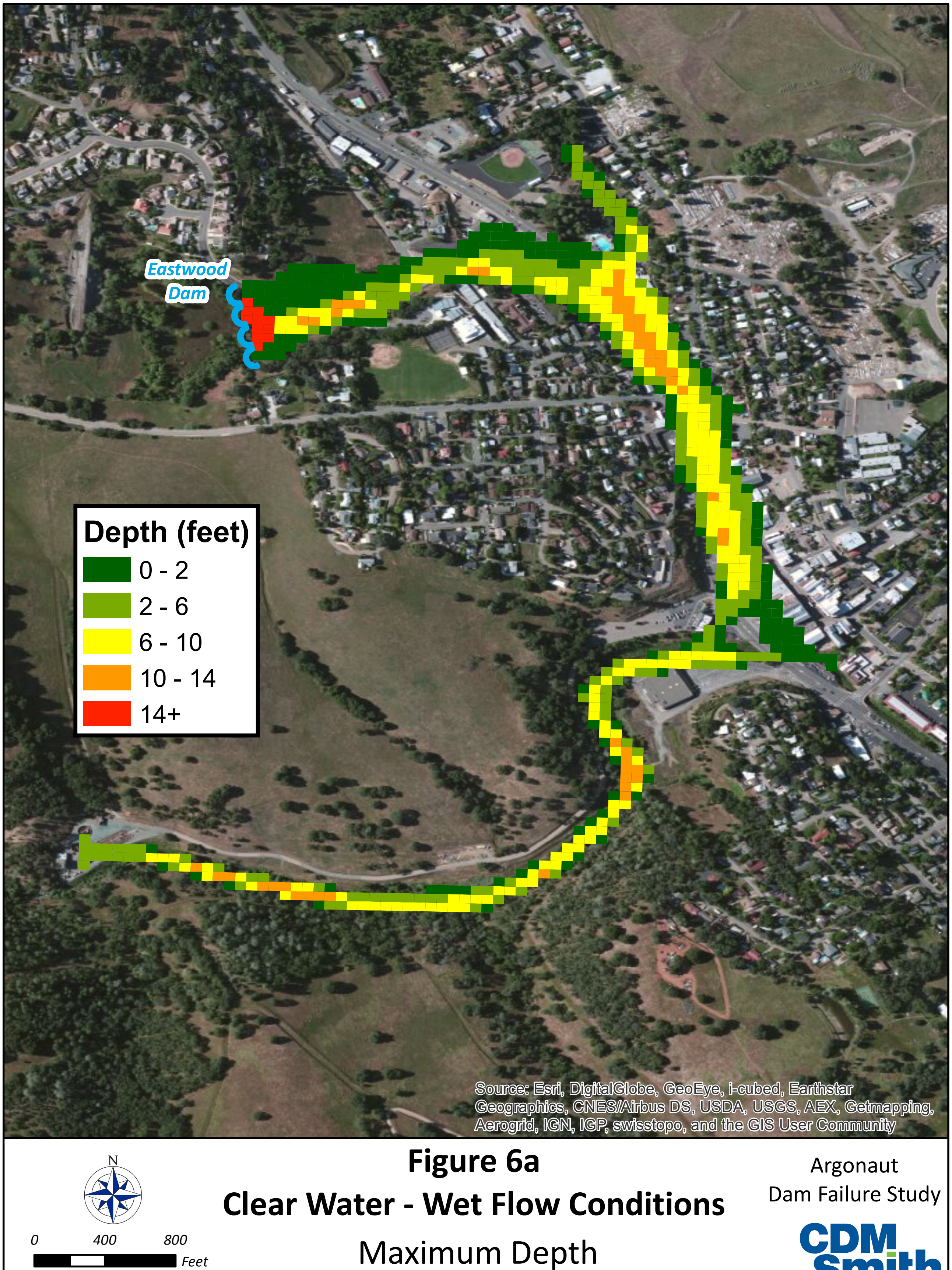

Figure 6a

Clear Water - Wet Flow Conditions

Maximum Depth

Argonaut
Dam Failure Study

CDM Smith

thielentr Argonaut_Clearwater_Wet_Depth.mxd 3/27/2015

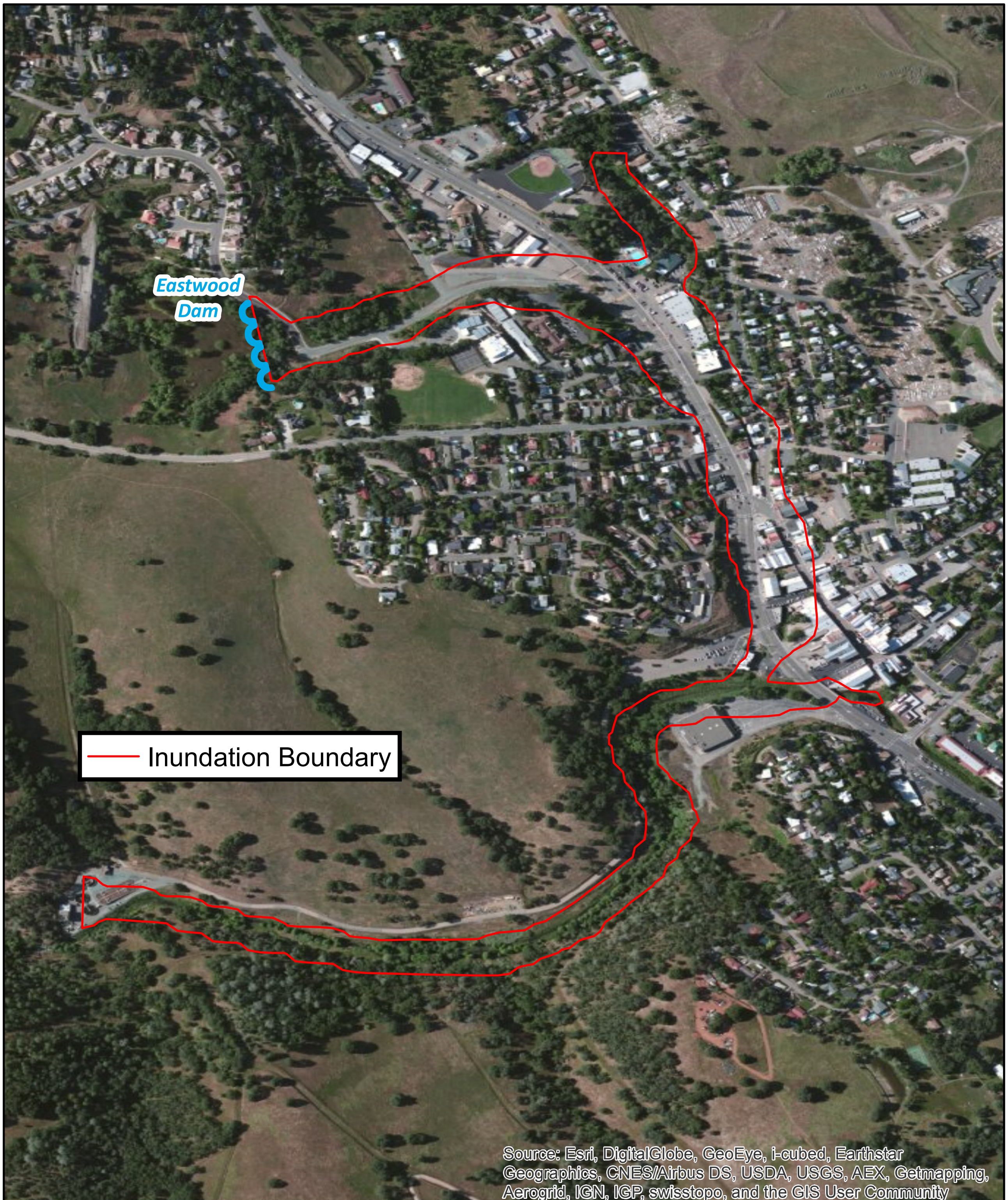

Figure 6b

Clear Water - Wet Flow Conditions

0.1 Ft Depth Inundation Boundary

Argonaut
Dam Failure Study

CDM Smith

ThielenTR Argonaut_Clearwater_Wet_Inundation.mxd 3/31/2015

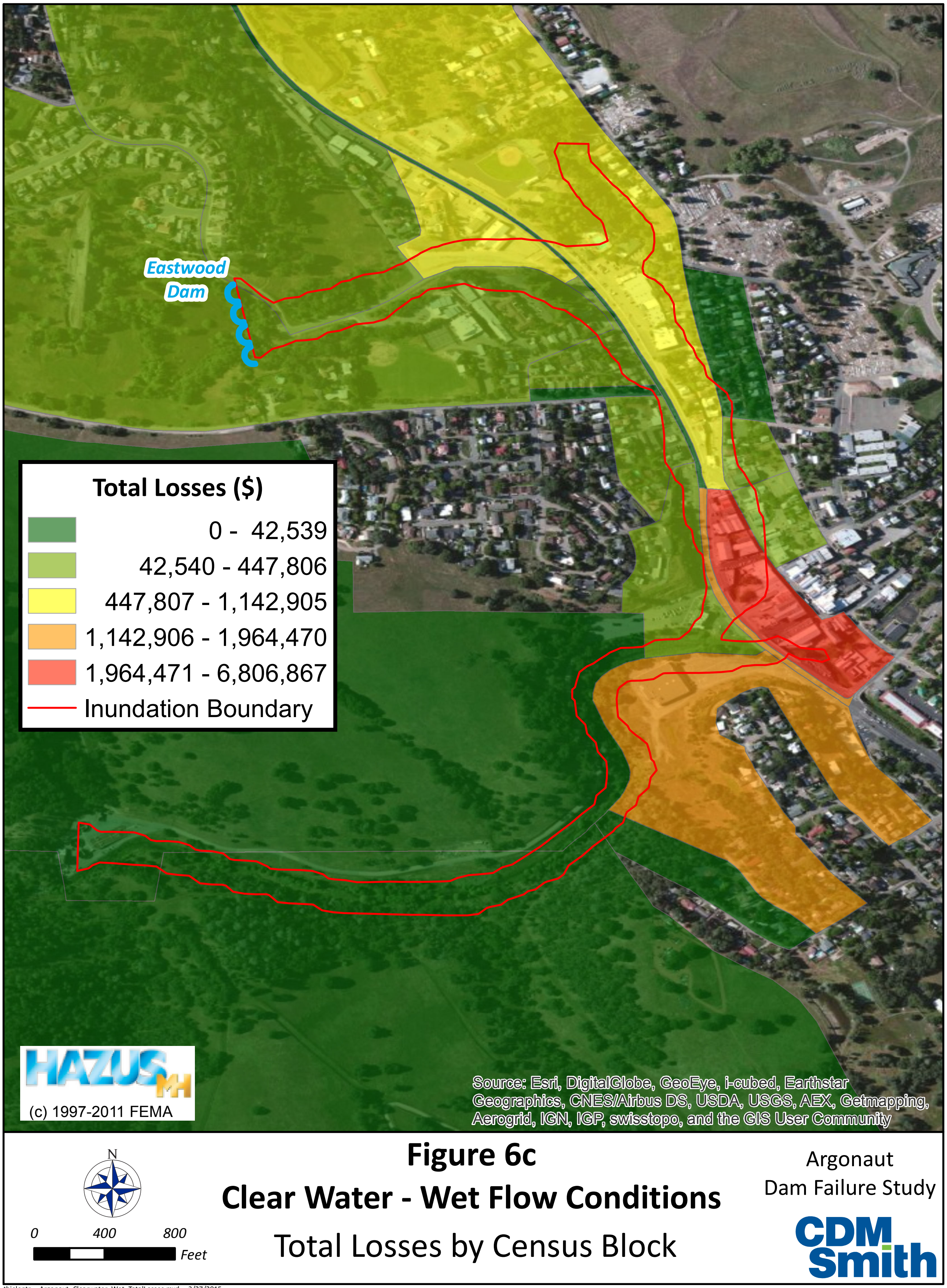

Figure 6c

Clear Water - Wet Flow Conditions

Total Losses by Census Block

Argonaut
Dam Failure Study

CDM Smith

thielentr Argonaut_Clearwater_Wet_TotalLosses.mxd 3/27/2015

Table 1: Mudflow - Dry Flow Condition - Potential Loss Summary Table

OBJECTID	CensusBloc	TotalLoss	BuildingLoss	ContentsLoss	InventoryLoss	RelocationCost	IncomeLoss	RentalIncomeLoss	WageLoss	TotalVehicleLoss	TotalTons - Debris*	DisplacedPersons*
1	060050004012008	**$1,131,771**	$544,000	$462,000	$2,000	$0	$0	$0	$0	$123,771	62	10
2	060050003041007	**$669,148**	$258,000	$311,000	$2,000	$0	$0	$0	$9,000	$89,148	47	7
3	060050005003023	**$155,411**	$35,000	$75,000	$2,000	$0	$0	$0	$0	$43,411	0	1
4	060050005003008	**$205**	$0	$0	$0	$0	$0	$0	$0	$205	0	0
152	060050005003005	**$0**	$0	$0	$0	$0	$0	$0	$0	$0	0	0
303	060050005003024	**$1,097,645**	$334,000	$638,000	$2,000	$0	$0	$0	$2,000	$121,645	6	5
304	060050005003000	**$167,524**	$98,000	$60,000	$0	$0	$0	$0	$0	$9,524	7	5
305	060050003041012	**$687,095**	$186,000	$395,000	$1,000	$0	$0	$0	$3,000	$102,095	24	4
306	060050005003037	**$3,471**	$2,000	$1,000	$0	$0	$0	$0	$0	$471	0	1
307	060050004012014	**$1,946**	$0	$0	$0	$0	$0	$0	$0	$1,946	0	3
308	060050004012030	**$0**	$0	$0	$0	$0	$0	$0	$0	$0	0	1
804	060050003041019	**$205,398**	$97,000	$91,000	$0	$0	$0	$0	$0	$17,398	9	5
805	060050004012012	**$3,662,168**	$696,000	$2,153,000	$34,000	$1,000	$3,000	$0	$29,000	$746,168	28	8
806	060050003041014	**$1,807,524**	$430,000	$931,000	$30,000	$0	$0	$0	$0	$416,524	32	8
807	060050004012031	**$1,008,154**	$176,000	$581,000	$11,000	$0	$0	$0	$5,000	$235,154	0	0
808	060050004012010	**$46,661**	$9,000	$20,000	$0	$0	$0	$0	$0	$17,661	0	0
809	060050004012015	**$0**	$0	$0	$0	$0	$0	$0	$0	$0	0	2
		$10,644,122	$2,865,000	$5,718,000	$84,000	$1,000	$3,000	$0	$48,000	$1,925,122	217	60

*Not included in the total

Factored Losses (3.5 factor applied to Building Loss)

OBJECTID	CensusBloc	TotalLoss	BuildingLoss	ContentsLoss	InventoryLoss	RelocationCost	IncomeLoss	RentalIncomeLoss	WageLoss	TotalVehicleLoss	TotalTons - Debris*	DisplacedPersons*
1	060050004012008	**$2,491,771**	$1,904,000	$462,000	$2,000	$0	$0	$0	$0	$123,771	62	10
2	060050003041007	**$1,314,148**	$903,000	$311,000	$2,000	$0	$0	$0	$9,000	$89,148	47	7
3	060050005003023	**$242,911**	$122,500	$75,000	$2,000	$0	$0	$0	$0	$43,411	0	1
4	060050005003008	**$205**	$0	$0	$0	$0	$0	$0	$0	$205	0	0
152	060050005003005	**$0**	$0	$0	$0	$0	$0	$0	$0	$0	0	0
303	060050005003024	**$1,932,645**	$1,169,000	$638,000	$2,000	$0	$0	$0	$2,000	$121,645	6	5
304	060050005003000	**$412,524**	$343,000	$60,000	$0	$0	$0	$0	$0	$9,524	7	5
305	060050003041012	**$1,152,095**	$651,000	$395,000	$1,000	$0	$0	$0	$3,000	$102,095	24	4
306	060050005003037	**$8,471**	$7,000	$1,000	$0	$0	$0	$0	$0	$471	0	1
307	060050004012014	**$1,946**	$0	$0	$0	$0	$0	$0	$0	$1,946	0	3
308	060050004012030	**$0**	$0	$0	$0	$0	$0	$0	$0	$0	0	1
804	060050003041019	**$447,898**	$339,500	$91,000	$0	$0	$0	$0	$0	$17,398	9	5
805	060050004012012	**$5,402,168**	$2,436,000	$2,153,000	$34,000	$1,000	$3,000	$0	$29,000	$746,168	28	8
806	060050003041014	**$2,882,524**	$1,505,000	$931,000	$30,000	$0	$0	$0	$0	$416,524	32	8
807	060050004012031	**$1,448,154**	$616,000	$581,000	$11,000	$0	$0	$0	$5,000	$235,154	0	0
808	060050004012010	**$69,161**	$31,500	$20,000	$0	$0	$0	$0	$0	$17,661	0	0
809	060050004012015	**$0**	$0	$0	$0	$0	$0	$0	$0	$0	0	2
		$17,806,622	$10,027,500	$5,718,000	$84,000	$1,000	$3,000	$0	$48,000	$1,925,122	217	60

*Not included in the total

Table 2: Mudflow - Average Flow Condition - Potential Loss Summary Table

OBJECTID	CensusBloc	TotalLoss	BuildingLoss	ContentsLoss	InventoryLoss	RelocationCost	IncomeLoss	RentalIncomeLoss	WageLoss	TotalVehicleLoss	TotalTons - Debris*	DisplacedPersons*
1	060050004012008	**$1,394,256**	$679,000	$566,000	$3,000	$0	$0	$0	$0	$146,256	100	11
2	060050003041007	**$784,868**	$316,000	$358,000	$2,000	$0	$0	$0	$9,000	$99,868	59	8
3	060050003041018	**$0**	$0	$0	$0	$0	$0	$0	$0	$0	0	1
4	060050005003023	**$259,870**	$64,000	$124,000	$4,000	$0	$0	$0	$0	$67,870	0	1
5	060050005003008	**$1,291**	$1,000	$0	$0	$0	$0	$0	$0	$291	0	0
152	060050005003005	**$1,000**	$1,000	$0	$0	$0	$0	$0	$0	$0	0	0
303	060050005003024	**$2,317,553**	$699,000	$1,390,000	$3,000	$0	$1,000	$0	$4,000	$220,553	17	6
304	060050005003000	**$288,055**	$167,000	$105,000	$0	$0	$0	$0	$0	$16,055	11	6
305	060050003041012	**$849,470**	$257,000	$467,000	$2,000	$0	$0	$0	$4,000	$119,470	50	4
306	060050005003037	**$10,584**	$7,000	$3,000	$0	$0	$0	$0	$0	$584	0	1
307	060050004012014	**$221,544**	$42,000	$127,000	$2,000	$0	$1,000	$0	$0	$49,544	2	7
308	060050004012030	**$132,484**	$25,000	$81,000	$1,000	$0	$0	$0	$0	$25,484	1	4
804	060050003041019	**$251,349**	$121,000	$110,000	$0	$0	$0	$0	$0	$20,349	13	5
805	060050004012015	**$218**	$0	$0	$0	$0	$0	$0	$0	$218	0	5
806	060050004012012	**$6,365,605**	$1,359,000	$3,655,000	$59,000	$1,000	$5,000	$1,000	$49,000	$1,236,605	60	11
807	060050003041014	**$2,459,892**	$657,000	$1,216,000	$38,000	$0	$0	$0	$2,000	$546,892	93	9
808	060050004012031	**$1,677,541**	$335,000	$968,000	$19,000	$0	$0	$0	$8,000	$347,541	0	0
809	060050004012010	**$53,847**	$12,000	$24,000	$0	$0	$0	$0	$0	$17,847	0	0
		$17,069,427	$4,742,000	$9,194,000	$133,000	$1,000	$7,000	$1,000	$76,000	$2,915,427	408	79

*Not included in the total

Factored Losses (3.5 factor applied to Building Loss)

OBJECTID	CensusBloc	TotalLoss	BuildingLoss	ContentsLoss	InventoryLoss	RelocationCost	IncomeLoss	RentalIncomeLoss	WageLoss	TotalVehicleLoss	TotalTons - Debris*	DisplacedPersons*
1	060050004012008	**$3,091,756**	$2,376,500	$566,000	$3,000	$0	$0	$0	$0	$146,256	100	11
2	060050003041007	**$1,574,868**	$1,106,000	$358,000	$2,000	$0	$0	$0	$9,000	$99,868	59	8
3	060050003041018	**$0**	$0	$0	$0	$0	$0	$0	$0	$0	0	1
4	060050005003023	**$419,870**	$224,000	$124,000	$4,000	$0	$0	$0	$0	$67,870	0	1
5	060050005003008	**$3,791**	$3,500	$0	$0	$0	$0	$0	$0	$291	0	0
152	060050005003005	**$3,500**	$3,500	$0	$0	$0	$0	$0	$0	$0	0	0
303	060050005003024	**$4,065,053**	$2,446,500	$1,390,000	$3,000	$0	$1,000	$0	$4,000	$220,553	17	6
304	060050005003000	**$705,555**	$584,500	$105,000	$0	$0	$0	$0	$0	$16,055	11	6
305	060050003041012	**$1,491,970**	$899,500	$467,000	$2,000	$0	$0	$0	$4,000	$119,470	50	4
306	060050005003037	**$28,084**	$24,500	$3,000	$0	$0	$0	$0	$0	$584	0	1
307	060050004012014	**$326,544**	$147,000	$127,000	$2,000	$0	$1,000	$0	$0	$49,544	2	7
308	060050004012030	**$194,984**	$87,500	$81,000	$1,000	$0	$0	$0	$0	$25,484	1	4
804	060050003041019	**$553,849**	$423,500	$110,000	$0	$0	$0	$0	$0	$20,349	13	5
805	060050004012015	**$218**	$0	$0	$0	$0	$0	$0	$0	$218	0	5
806	060050004012012	**$9,763,105**	$4,756,500	$3,655,000	$59,000	$1,000	$5,000	$1,000	$49,000	$1,236,605	60	11
807	060050003041014	**$4,102,392**	$2,299,500	$1,216,000	$38,000	$0	$0	$0	$2,000	$546,892	93	9
808	060050004012031	**$2,515,041**	$1,172,500	$968,000	$19,000	$0	$0	$0	$8,000	$347,541	0	0
809	060050004012010	**$83,847**	$42,000	$24,000	$0	$0	$0	$0	$0	$17,847	0	0
		$28,924,427	$16,597,000	$9,194,000	$133,000	$1,000	$7,000	$1,000	$76,000	$2,915,427	408	79

*Not included in the total

Table 3: Mudflow - Wet Flow Condition - Potential Loss Summary Table

OBJECTID	CensusBloc	TotalLoss	BuildingLoss	ContentsLoss	InventoryLoss	RelocationCost	IncomeLoss	RentalIncomeLoss	WageLoss	TotalVehicleLoss	TotalTons - Debris*	DisplacedPersons*
1	060050004012008	**$1,541,365**	$752,000	$625,000	$3,000	$0	$0	$0	$0	161365	124	12
2	060050003041007	**$764,628**	$303,000	$351,000	$2,000	$0	$0	$0	$10,000	98628	54	8
3	060050003041018	**$105,668**	$29,000	$58,000	$2,000	$0	$0	$0	$0	16668	1	3
4	060050005003023	**$283,253**	$72,000	$134,000	$4,000	$0	$0	$0	$0	73253	0	1
5	060050005003008	**$2,330**	$2,000	$0	$0	$0	$0	$0	$0	330	0	0
152	060050005003005	**$1,000**	$1,000	$0	$0	$0	$0	$0	$0	0	0	0
303	060050005003024	**$2,800,710**	$832,000	$1,709,000	$5,000	$0	$1,000	$0	$5,000	248710	24	6
304	060050005003000	**$323,718**	$188,000	$118,000	$0	$0	$0	$0	$0	17718	13	6
305	060050003041012	**$831,804**	$244,000	$462,000	$2,000	$0	$0	$0	$4,000	119804	45	5
306	060050005003037	**$11,584**	$7,000	$4,000	$0	$0	$0	$0	$0	584	0	1
307	060050004012014	**$368,213**	$73,000	$197,000	$3,000	$0	$1,000	$0	$1,000	93213	4	8
308	060050004012030	**$541,351**	$123,000	$336,000	$10,000	$0	$0	$0	$0	72351	6	5
804	060050003041019	**$291,167**	$140,000	$128,000	$0	$0	$0	$0	$0	23167	19	6
805	060050004012015	**$19,172**	$11,000	$6,000	$0	$0	$0	$0	$0	2172	1	7
806	060050004012012	**$7,936,269**	$1,779,000	$4,547,000	$72,000	$2,000	$7,000	$1,000	$63,000	1465269	85	14
807	060050003041014	**$2,426,303**	$635,000	$1,210,000	$38,000	$0	$0	$0	$2,000	541303	74	9
808	060050004012031	**$1,931,629**	$399,000	$1,095,000	$22,000	$0	$1,000	$0	$8,000	406629	0	0
809	060050004012010	**$54,543**	$12,000	$24,000	$0	$0	$0	$0	$0	18543	0	0
		$20,234,709	$5,602,000	$11,004,000	$163,000	$2,000	$10,000	$1,000	$93,000	3359709	451	91

*Not included in the total

Factored Losses (3.5 factor applied to Building Loss)

OBJECTID	CensusBloc	TotalLoss	BuildingLoss	ContentsLoss	InventoryLoss	RelocationCost	IncomeLoss	RentalIncomeLoss	WageLoss	TotalVehicleLoss	TotalTons - Debris*	DisplacedPersons*
1	060050004012008	**$3,421,365**	$2,632,000	$625,000	$3,000	$0	$0	$0	$0	161365	124	12
2	060050003041007	**$1,522,128**	$1,060,500	$351,000	$2,000	$0	$0	$0	$10,000	98628	54	8
3	060050003041018	**$178,168**	$101,500	$58,000	$2,000	$0	$0	$0	$0	16668	1	3
4	060050005003023	**$463,253**	$252,000	$134,000	$4,000	$0	$0	$0	$0	73253	0	1
5	060050005003008	**$7,330**	$7,000	$0	$0	$0	$0	$0	$0	330	0	0
152	060050005003005	**$3,500**	$3,500	$0	$0	$0	$0	$0	$0	0	0	0
303	060050005003024	**$4,880,710**	$2,912,000	$1,709,000	$5,000	$0	$1,000	$0	$5,000	248710	24	6
304	060050005003000	**$793,718**	$658,000	$118,000	$0	$0	$0	$0	$0	17718	13	6
305	060050003041012	**$1,441,804**	$854,000	$462,000	$2,000	$0	$0	$0	$4,000	119804	45	5
306	060050005003037	**$29,084**	$24,500	$4,000	$0	$0	$0	$0	$0	584	0	1
307	060050004012014	**$550,713**	$255,500	$197,000	$3,000	$0	$1,000	$0	$1,000	93213	4	8
308	060050004012030	**$848,851**	$430,500	$336,000	$10,000	$0	$0	$0	$0	72351	6	5
804	060050003041019	**$641,167**	$490,000	$128,000	$0	$0	$0	$0	$0	23167	19	6
805	060050004012015	**$46,672**	$38,500	$6,000	$0	$0	$0	$0	$0	2172	1	7
806	060050004012012	**$12,383,769**	$6,226,500	$4,547,000	$72,000	$2,000	$7,000	$1,000	$63,000	1465269	85	14
807	060050003041014	**$4,013,803**	$2,222,500	$1,210,000	$38,000	$0	$0	$0	$2,000	541303	74	9
808	060050004012031	**$2,929,129**	$1,396,500	$1,095,000	$22,000	$0	$1,000	$0	$8,000	406629	0	0
809	060050004012010	**$84,543**	$42,000	$24,000	$0	$0	$0	$0	$0	18543	0	0
		$34,239,709	$19,607,000	$11,004,000	$163,000	$2,000	$10,000	$1,000	$93,000	3359709	451	91

*Not included in the total

Table 4: Clear Water - Dry Flow Condition - Potential Loss Summary Table

OBJECTID	CensusBloc	TotalLoss	BuildingLoss	ContentsLoss	InventoryLoss	RelocationCost	IncomeLoss	RentalIncomeLoss	WageLoss	TotalVehicleLoss	TotalTons - Debris*	DisplacedPersons*
805	060050004012012	**$5,469,178**	$1,103,000	$3,205,000	$51,000	$1,000	$3,000	$1,000	$41,000	$1,064,178	45	10
303	060050005003024	**$1,336,495**	$408,000	$772,000	$3,000	$0	$1,000	$0	$3,000	$149,495	8	5
807	060050004012031	**$1,324,799**	$241,000	$782,000	$16,000	$0	$0	$0	$6,000	$279,799	0	0
1	060050004012008	**$851,319**	$401,000	$349,000	$1,000	$0	$0	$0	$0	$100,319	30	9
806	060050003041014	**$659,566**	$140,000	$372,000	$12,000	$0	$0	$0	$0	$135,566	6	6
305	060050003041012	**$366,007**	$77,000	$224,000	$0	$0	$0	$0	$2,000	$63,007	5	4
2	060050003041007	**$356,009**	$119,000	$173,000	$1,000	$0	$0	$0	$6,000	$57,009	10	7
804	060050003041019	**$149,650**	$69,000	$65,000	$0	$0	$0	$0	$0	$15,650	5	4
3	060050005003023	**$164,667**	$38,000	$79,000	$2,000	$0	$0	$0	$0	$45,667	0	1
304	060050005003000	**$84,070**	$50,000	$29,000	$0	$0	$0	$0	$0	$5,070	4	3
308	060050004012030	**$50,587**	$11,000	$36,000	$0	$0	$0	$0	$0	$3,587	1	2
307	060050004012014	**$33,862**	$6,000	$24,000	$0	$0	$0	$0	$0	$3,862	1	3
808	060050004012010	**$35,239**	$4,000	$16,000	$0	$0	$0	$0	$0	$15,239	0	0
306	060050005003037	**$3,387**	$2,000	$1,000	$0	$0	$0	$0	$0	$387	0	1
4	060050005003008	**$247**	$0	$0	$0	$0	$0	$0	$0	$247	0	0
152	060050005003005	**$0**	$0	$0	$0	$0	$0	$0	$0	$0	0	0
809	060050004012015	**$0**	$0	$0	$0	$0	$0	$0	$0	$0	0	1
	Total	**$10,885,082**	$2,669,000	$6,127,000	$86,000	$1,000	$4,000	$1,000	$58,000	$1,939,082	116	56

*Not included in the total

Table 5: Clear Water - Average Flow Condition - Potential Loss Summary Table

OBJECTID	CensusBloc	TotalLoss	BuildingLoss	ContentsLoss	InventoryLoss	RelocationCost	IncomeLoss	RentalIncomeLoss	WageLoss	TotalVehicleLoss	TotalTons - Debris*	DisplacedPersons*
805	060050004012012	**$6,131,425**	$1,278,000	$3,563,000	$57,000	$1,000	$5,000	$1,000	$50,000	$1,176,425	56	11
303	060050005003024	**$1,670,776**	$524,000	$959,000	$3,000	$0	$1,000	$0	$3,000	$180,776	9	6
807	060050004012031	**$1,517,357**	$285,000	$888,000	$18,000	$0	$0	$0	$7,000	$319,357	0	0
1	060050004012008	**$1,024,892**	$486,000	$421,000	$1,000	$0	$0	$0	$0	$116,892	38	10
806	060050003041014	**$869,406**	$184,000	$484,000	$15,000	$0	$0	$0	$0	$186,406	8	7
305	060050003041012	**$440,565**	$99,000	$267,000	$0	$0	$0	$0	$2,000	$72,565	6	4
2	060050003041007	**$429,699**	$149,000	$208,000	$1,000	$0	$0	$0	$7,000	$64,699	15	8
804	060050003041019	**$193,101**	$90,000	$85,000	$0	$0	$0	$0	$0	$18,101	6	5
3	060050005003023	**$192,870**	$45,000	$91,000	$4,000	$0	$0	$0	$0	$52,870	0	1
304	060050005003000	**$123,965**	$73,000	$44,000	$0	$0	$0	$0	$0	$6,965	6	4
308	060050004012030	**$88,651**	$16,000	$59,000	$1,000	$0	$0	$0	$0	$12,651	1	4
307	060050004012014	**$84,187**	$19,000	$56,000	$0	$0	$0	$0	$0	$9,187	1	4
808	060050004012010	**$39,146**	$5,000	$18,000	$0	$0	$0	$0	$0	$16,146	0	0
306	060050005003037	**$7,584**	$5,000	$2,000	$0	$0	$0	$0	$0	$584	0	1
152	060050005003005	**$1,000**	$1,000	$0	$0	$0	$0	$0	$0	$0	0	0
4	060050005003008	**$267**	$0	$0	$0	$0	$0	$0	$0	$267	0	0
809	060050004012015	**$0**	$0	$0	$0	$0	$0	$0	$0	$0	0	2
		$12,814,892	$3,259,000	$7,145,000	$100,000	$1,000	$6,000	$1,000	$69,000	$2,233,892	146	67

*Not included in the total

Table 6: Clear Water - Wet Flow Condition - Potential Loss Summary Table

OBJECTID	CensusBloc	TotalLoss	BuildingLoss	ContentsLoss	InventoryLoss	RelocationCost	IncomeLoss	RentalIncomeLoss	WageLoss	TotalVehicleLoss	TotalTons - Debris*	DisplacedPersons*
1	060050004012008	**$1,142,905**	$542,000	$472,000	$2,000	$0	$0	$0	$0	$126,905	49	10
2	060050003041007	**$431,676**	$149,000	$208,000	$1,000	$0	$0	$0	$9,000	$64,676	15	9
3	060050003041018	**$0**	$0	$0	$0	$0	$0	$0	$0	$0	0	1
4	060050005003023	**$209,495**	$50,000	$99,000	$4,000	$0	$0	$0	$0	$56,495	0	1
5	060050005003008	**$285**	$0	$0	$0	$0	$0	$0	$0	$285	0	0
152	060050005003005	**$1,000**	$1,000	$0	$0	$0	$0	$0	$0	$0	0	0
303	060050005003024	**$1,964,470**	$601,000	$1,153,000	$3,000	$0	$1,000	$0	$3,000	$203,470	14	6
304	060050005003000	**$154,793**	$91,000	$55,000	$0	$0	$0	$0	$0	$8,793	7	4
305	060050003041012	**$447,806**	$100,000	$272,000	$0	$0	$0	$0	$2,000	$73,806	6	4
306	060050005003037	**$8,584**	$5,000	$3,000	$0	$0	$0	$0	$0	$584	0	1
307	060050004012014	**$157,255**	$31,000	$102,000	$1,000	$0	$0	$0	$0	$23,255	2	4
308	060050004012030	**$258,514**	$62,000	$171,000	$4,000	$0	$0	$0	$0	$21,514	3	4
804	060050003041019	**$210,966**	$100,000	$92,000	$0	$0	$0	$0	$0	$18,966	7	5
805	060050004012015	**$0**	$0	$0	$0	$0	$0	$0	$0	$0	0	3
806	060050004012012	**$6,806,867**	$1,446,000	$3,932,000	$63,000	$3,000	$8,000	$1,000	$64,000	$1,289,867	64	15
807	060050003041014	**$863,819**	$182,000	$482,000	$15,000	$0	$0	$0	$0	$184,819	8	7
808	060050004012031	**$1,618,374**	$313,000	$940,000	$19,000	$0	$0	$0	$8,000	$338,374	0	0
809	060050004012010	**$42,539**	$8,000	$18,000	$0	$0	$0	$0	$0	$16,539	0	0
		$14,319,349	$3,681,000	$7,999,000	$112,000	$3,000	$9,000	$1,000	$86,000	$2,428,349	176	74

*Not included in the total

Cost Due to Closure of Highway 49

Value of Roadway Loss of Function	$	29.63	[$/vehicle/hour]
Number of One-way Trips		9,350	[one-way trips]
Cost per Mile	$	0.58	[$/mile]
Mile Detour		50.0	[miles]
Detour Duration		1.25	[hours]
Total Value of Service per Day	$	615,113.00	[$/day]
Total Days of Closure		40	[day]
Total Value of Service during Closure	**$**	**24,604,520.00**	[$]