Chapter 7 – Mudflow Analysis

7.0 Introduction

This chapter provides information on the potential and magnitude of mud floods and mudflows that may develop in Aspen due to rainfall events, snowmelt, or rain on snow events. This chapter also provides guidance on the design process for sites at risk for mudflows, including the allowable mud deposition and mitigation techniques.

Mudflows are very viscous, hyper-concentrated sediment flows, whose fluid properties change dramatically as they flow down alluvial fans or steep channels. The behavior of the mudflow is a function of the fluid matrix properties (i.e. density, viscosity, and yield stress), channel geometry, slope, and roughness. Viscosity is in turn a function of the type of sediment (clay or silt), the sediment concentration, and the water temperature. Mudflows have high sediment concentrations and high yield stresses, which may produce laminar flow [1]. Smaller rain events (i.e. 10-year or 25-year storm event) are more likely to cause mudflows than larger events such as the 100-year flood. Usually, the peak concentration of sediment during a mudflow event is about 45%, and the average sediment concentration is between 20% and 35%.

The probability that a mudflow event will occur in Aspen is relatively high. Geologic maps published by the U.S. Geological Survey show large areas on Aspen Mountain directly above the City that are defined as potentially unstable, and mudflows have historically occurred in and near the City.

7.1 Mudflow Analysis in Storm Drainage Master Plan

The FLO-2D Model was applied as a part of the Surface Drainage Master Plan developed in 2001 (WRC Engineering 2001) (Master Plan). The model was used to estimate the amount of runoff expected to occur during a rain event and the expected depth of flow, water and sediment. WRC developed a delineation of mudflow hazard areas (mudflow plain) in the downtown portion of the City and evaluated alternatives for reducing and/or managing mudflow hazards including drains and channels, cutoff walls, diversion of mudflows to abandoned mines and regulation of development in the mudflow plain. It is notable that the WRC analysis focused only on the downtown portion of the City—mudflows have the potential to occur in other parts of the City, especially in areas that are on or adjacent to steep slopes.

Based on economic analysis, the preferred alternative in the Master Plan was to regulate development within the mudflow plain by requiring modeling of the effects of development on the mudflow plain. When model results show that development activities will result in adverse impacts to nearby properties (i.e. a rise in the mudflow elevation), mitigation/refinement of project design is required to keep post-development mudflow elevations at or below pre-project levels to the maximum extent practicable.

7.2 Applicability

This chapter applies to all new development and redevelopment within the City of Aspen that lies in red, blue or yellow mudflow zones or other areas at risk for mudflow as determined by the City Engineer. The red zone are areas comprised of slopes greater than 30%. The blue mudflow zone includes areas on or within 200 feet of a slope greater than 30% defined on the City of Aspen slope map (can be located in the City GIS or Engineering departments) as seen in Figures 7.1 a - f. The yellow mudflow zone are those areas south of Durant that are located within the 2-ft mudflow depth on the 100-yr mudplain map in the Master Plan as shown in Figure 7.1.

[1] Mud floods are similar to mudflows, but they are less viscous, more turbulent and contain less sediment than mudflows (they behave more like “clear water” flood flows).

- Red or Blue mudflow zones – For development projects that will modify existing grades or create additional obstructions (buildings, roads, etc.) in red or blue mudflow zones, the applicant must provide an analysis of the 100-year mudflow event to demonstrate that the proposed development will manage mudflow impacts to his/her site and neighboring site to the maximum extent practicable, providing appropriate safety from mudflow impacts that are physically and economically feasible. Factors that will be considered in determining the "maximum extent practicable" for each site include mudflow depth, proximity to steep slopes, soil characteristics, slumping and earth movement, possible mudflow obstructions, potential mudflow paths, integrity/strength of the existing or proposed on-site structure(s) and neighboring structures, proposed mitigation techniques (both structural and non-structural),and economic reasonability and feasibility.

- Yellow mudflow zones – For areas located in the yellow mudflow zone or other areas as determined by the City Engineer, requirements of this chapter will be identified by the City Engineering Department on a case-by-case basis considering factors including mudflow depth in a 100-year event, presence or close proximity of steep slopes (typically >15 or 20 percent) on-site or up- or down-gradient of a development, soil characteristics, history of past mudflows, slumping and earth movement, and other factors.

Mudflow analysis is not required if the applicant can demonstrate that the potential area of blockage (i.e. length, width and height) of a proposed structure below the corresponding mudflow elevation from **Figure 7.1** will remain unchanged. However, impacts from mudflow must still be managed to the maximum extent practicable.

7.3 FLO-2D Overview

FLO-2D is a two-dimensional, finite difference flood routing model, which uses a kinematic wave or diffusive wave equation to estimate overland flow. In addition to modeling water-only flow, the program also models hyper-concentrated sediment flow. The following general description of the FLO-2D model has been adapted from the Master Plan and the FLO-2D Users Manual (O'Brien 2007).

FLO-2D requires a representation of the topography of the study area. This is accomplished by establishing a network of nodes and assigning x-y coordinates and elevations to each node. The nodes must be placed in a rectangular grid with equal spacing between nodes. Decreasing the node spacing increases the number of nodes and decreases the length of time step used in the model. Both factors increase the model's run time.

One of the unique features of the FLO-2D model is its ability to simulate flow problems associated with flow obstructions or loss of flood storage. Area reduction factors (ARFs) and width reduction factors (WRFs) are coefficients that modify the individual grid element surface area storage and flow width. ARFs can be used to reduce the flood volume storage on grid elements due to buildings or topography. WRFs can be assigned to any of the eight flow directions in a grid element and can partially or completely obstruct flow paths in all eight directions simulating floodwalls, buildings or berms.

Flow in the model is generated by simulating rainfall on each node in the study area or by inputting a runoff hydrograph at select nodes (see **Chapter 3** for developing hydrographs). Rainfall and inflow hydrographs cannot be used simultaneously. The amount and direction of overland flow is calculated in eight directions – directly forward and backward, to each side, and in the four diagonal directions.

Mudflows are modeled using inflow hydrographs. The input data contains the hydrograph data, flow versus time, the concentration of sediment conveyed by the flow, and concentration by volume versus time. FLO-2D routes the hyper-concentrated flows, tracking the sediment volumes through the system. Changing sediment concentration, dilution effects, and the remobilization of deposits are simulated at each node. Mudflow cessation and deposition can be predicted by the model. Sediment concentration governs the movement of the fluid matrix.

The model also accounts for the initial rainfall abstractions and infiltration. Infiltration is estimated for each node using the Green-Ampt equation. The flow area and storage volume associated with each node can be reduced to represent buildings. Streets can also be modeled to increase the conveyance through these nodes.

Results generated by the FLO-2D model include outflow hydrographs at designated nodes, maximum flow depths and velocities, and a summary of the total inflow, outflow, storage, and losses within the study area.

Additional documentation related to FLO-2D can be found on the website http://www.flo-2d.com/ and in the Master Plan in the mudflow section (http://www.aspenpitkin.com/pdfs/depts/43/1963-20.pdf).

7.4 Requirements for New Development and Redevelopment

Mudflow analysis for new development and redevelopment shall be conducted by a Professional Engineer with past experience with mudflow analysis, preferably with past experience using FLO-2D. FLO-2D is the preferred method for mudflow analysis. However, the City is willing to accept other models or analyses that are based on the following factors:

- Type and quality of soils
- Evidence of groundwater or surface water problems
- Depth and quality of any fill
- Slope of the site and adjacent sites
- Weight that proposed structure will impose on slopes

For areas falling within the delineated mudflow plain, as established in the Surface Drainage Master Plan (Master Plan), where mudflow depths are greater than 2 foot, modeling analysis should follow the steps below. Mudflow analysis using modeling methods may also be required for other mudflow hazard areas not shown in the Master Plan at the discretion of the City Engineering Department.

The following steps are recommended and preferred for mudflow analysis:

1. <u>Obtain current official FLO-2D model files from the City of Aspen</u>. The model files developed by WRC as a part of the Master Plan, including modifications for development projects within the mudflow plain approved by the City since the Master Plan, define the “official” mudflow model for the City of Aspen. Model files reflecting effects of streets and buildings shall be used. Model files can be obtained from the City Stormwater Manager. The City also will provide hard copy and/or electronic model results from the most recent approved application to accompany the electronic model files.

2. <u>Create a duplicate of the official model</u>. The user should first run model files from the City’s official model on their own system without making any changes to the input files. Results should be compared with previous results to confirm that the model is running properly on the user’s system. Any differences should be resolved to obtain agreement between model runs on a user’s computer and previous model runs. Minor differences (< 0.1 ft) may be acceptable and may arise from using different versions of the software.

3. <u>Refine grid</u>. To model a proposed development, a maximum grid spacing of 50 feet is required, as recommended in the Master Plan. If new properties need to be assigned to a node or nodes due to the refined grid, the properties of the nodes from the coarser grid should be retained for the finer grid unless more detailed information is available for the finer grid. The user should run the model with the refined grid for pre-project conditions (i.e. existing structures without modification for proposed development). This model run will establish baseline mud/water surface elevations.

4. Modify geometry input. To accurately model a proposed project the user must adjust area and width reduction factors for nodes where the proposed development is located. Other than adjustments to geometric parameters to accurately reflect the proposed development, model input values in the official model should not be altered by the user.

5. Compare predicted mud/water surface elevations with pre-project (baseline) conditions. Once the model has been run using the modified geometry to reflect the proposed development, mud/water surface outputs should be compared at nodes for pre- and post-project conditions. A rise in the mud/water surface elevation from the pre- to post-project conditions is allowable only if it affects just the property of the proposed project and the proposed project is designed for hydrostatic and dynamic forces of the mudflow.

6. Evaluate static and dynamic mudflow forces and identify potential mitigation measures. Static forces due to the mudflow can be calculated based on the density of the mudflow and the mudflow depth. The static force of the mudflow must be computed as hydrostatic pressure based on the full depth of the mudflow, as determined by the model, using 1.5 times of the hydrostatic force of water (1.5 x 62.4 lbs/ft^3 = 93.6 lbs/ft^3).

   Even more significant than static forces, dynamic forces associated with mudflows have the potential to cause structural damage—according to FEMA floodplain training literature, water moving at 10 miles per hour exerts the same pressure on a structure as wind gusts at 270 miles per hour. The forces from a mudflow, with even greater density than water, are even more significant. A number of empirical formulas for calculating the dynamic forces of mudflows are available. Based on review of applicable equations, the following is recommended for calculation of mudflow dynamic forces in Aspen:

   $$P = \frac{9(62.4)H^2}{2}$$

   Where:

   P = Dynamic Force (lbs/ft)
   H = Depth of Mudflow (ft)

   The dynamic force is assumed to act at a height of one-third of the mudflow depth. A safety factor of 1.5 must be applied to both the static and dynamic forces. The developer/engineer must consult with the City before beginning the mudflow protection analysis to confirm the proper application of this section.

   Typical mitigation measures include elevating finished floor elevations of buildings above the mudflow plain elevation (plus freeboard), construction of retaining walls to stabilize steep slopes, and construction of diversion channels and/or deflection walls.

7. Prepare submittals to City. Required submittals include a tabular comparison of mud/water surface elevations at all nodes, revised mudflow plain mapping (e.g. update of mudflow depth map in Master Plan), and electronic copies of all model input and output files.

Once the City reviews and approves mudflow modeling for a proposed project, the model submitted will become the new “official” model that will be used for future proposed developments within the mudflow plain.

7.5 References

O’Brien J.S. FLO-2D Users Manual, Version 2007.06. June 2007.

WRC Engineering, Inc., Storm Drainage Master Plan for The City of Aspen, Colorado, November 2001.

Federal Emergency Management Agency, Department of Homeland Security, United States Code of Federal Regulations, Title 44 – Emergency Management and Assistance, Part 60 – Criteria for Land Management and Use, 60.4 and Subpart C.

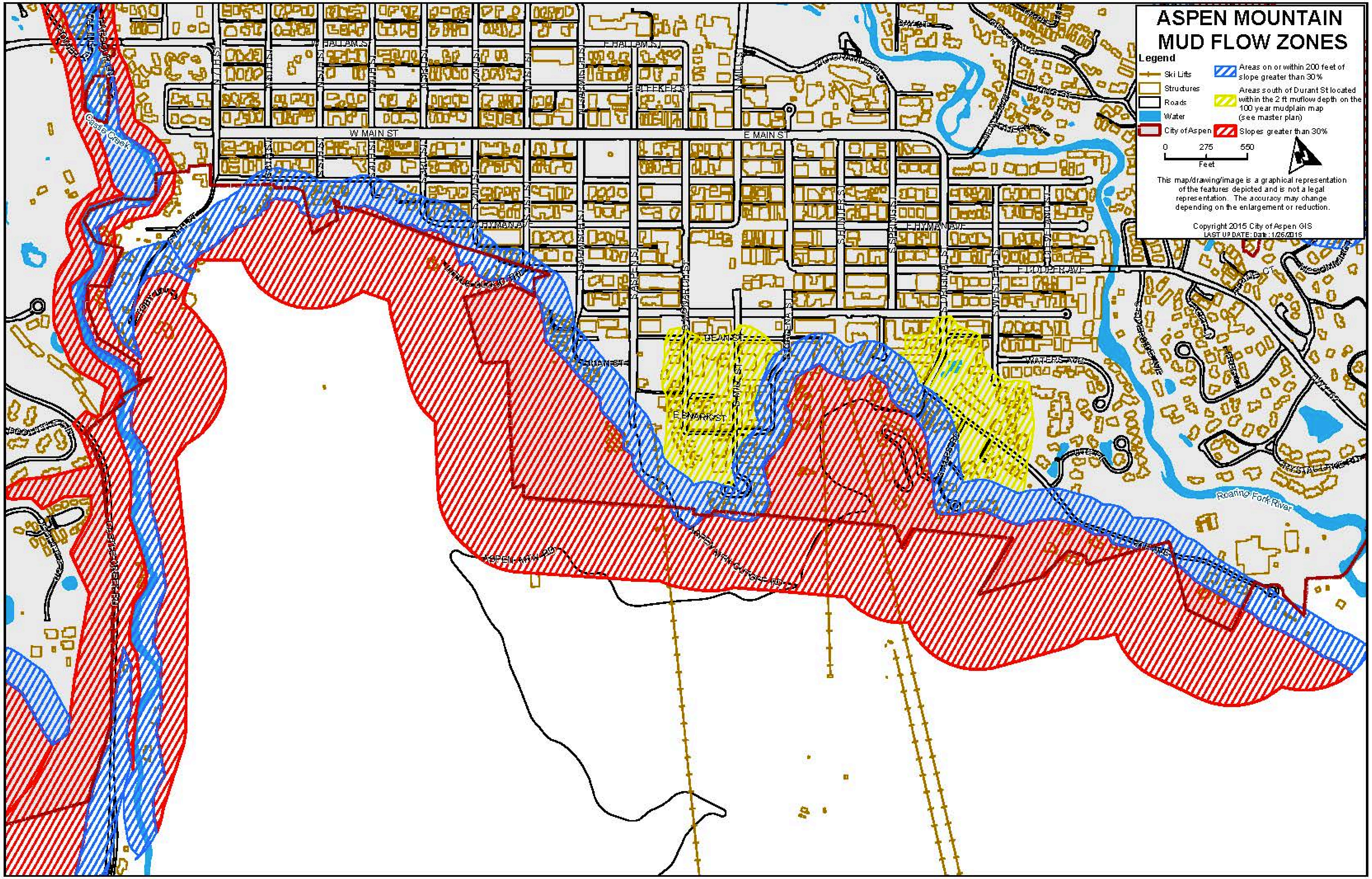

Figure 7.1 a – Aspen Mountain Mudflow Zones

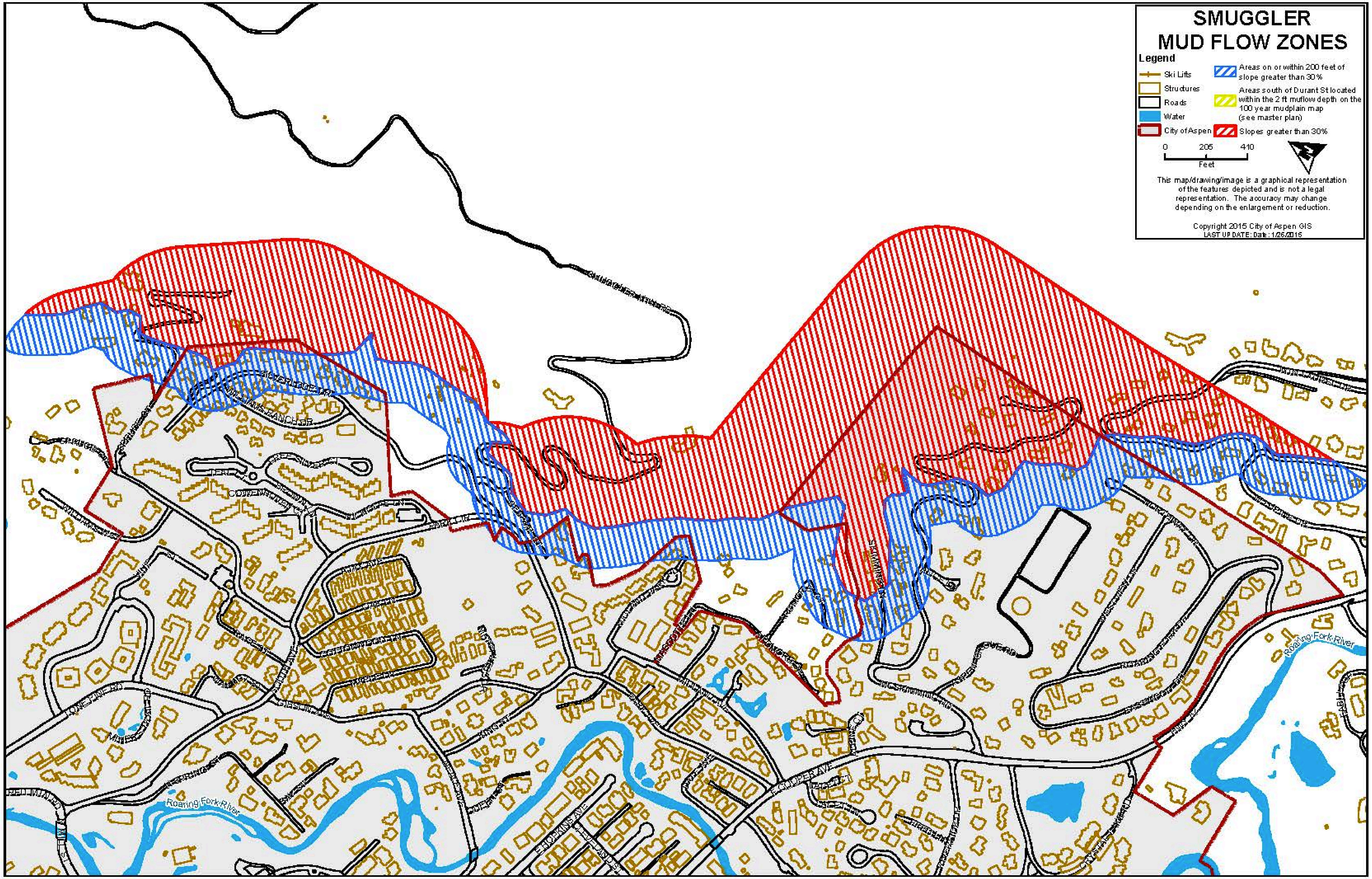

Figure 7.1 b – Smuggler Mountain Mudflow Zones

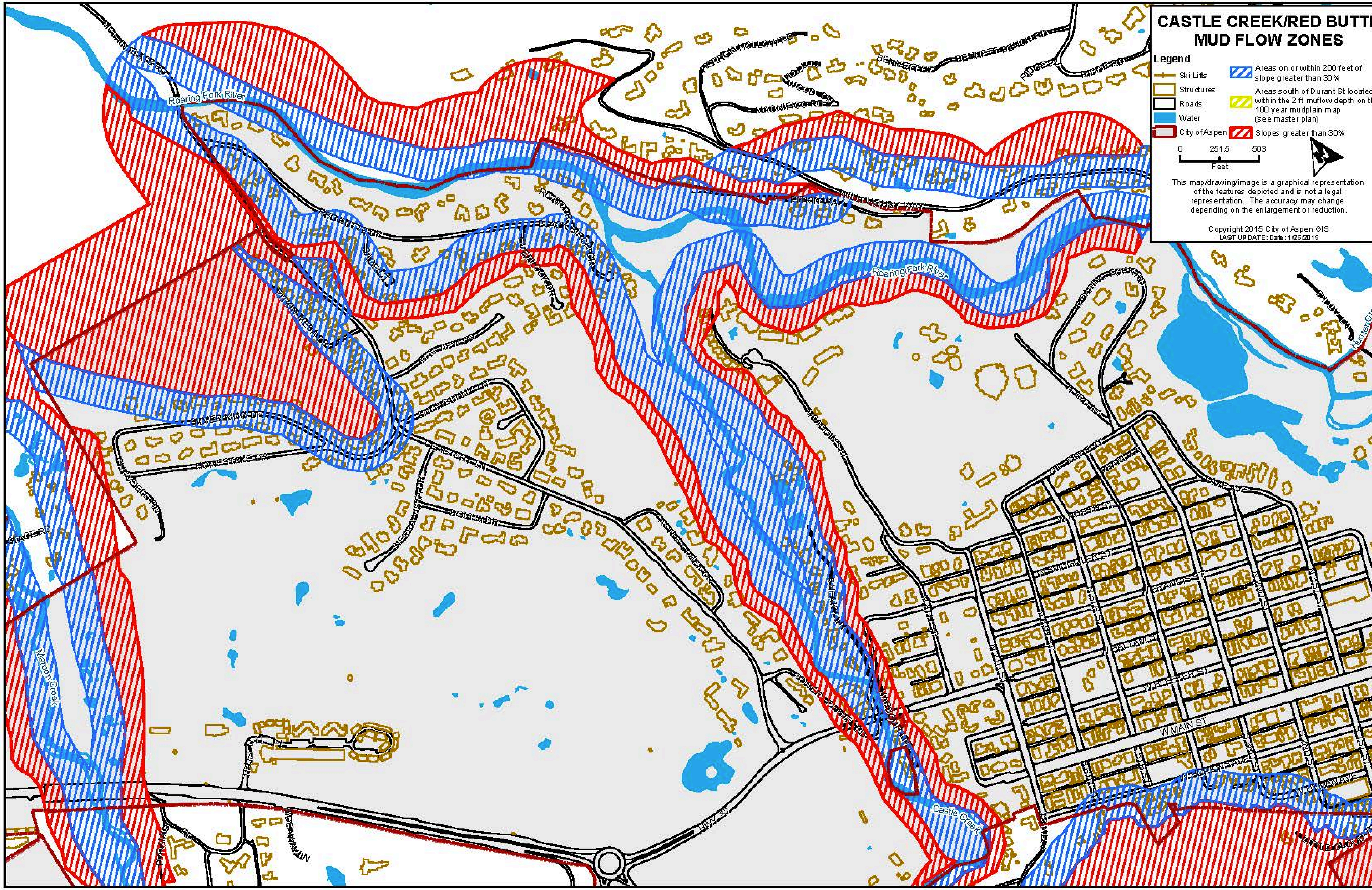

Figure 7.1 c – Castle Creek/Red Butte Mudflow Zones

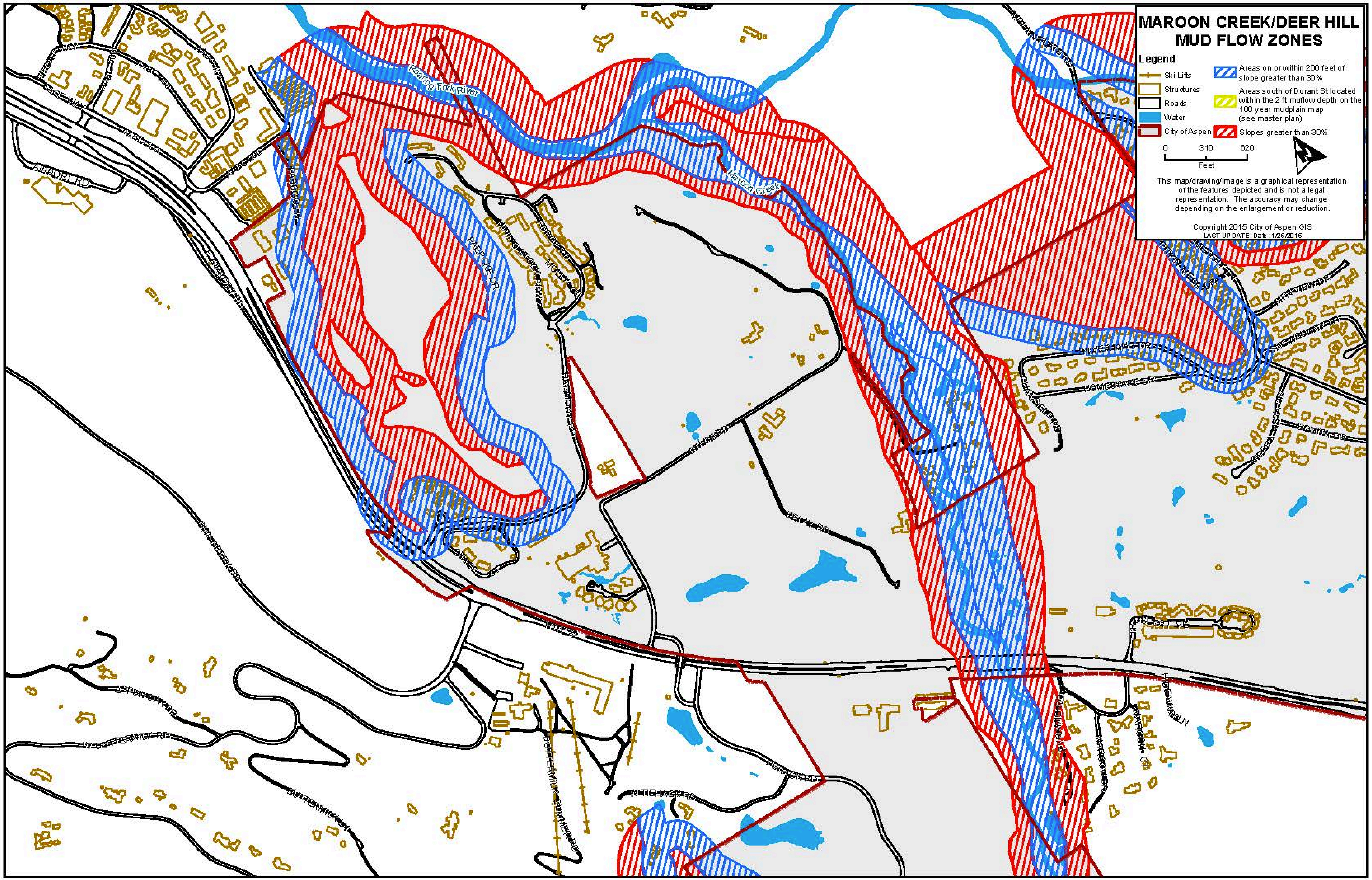

Figure 7.1 d – Maroon Creek/Deer Hill Mudflow Zones

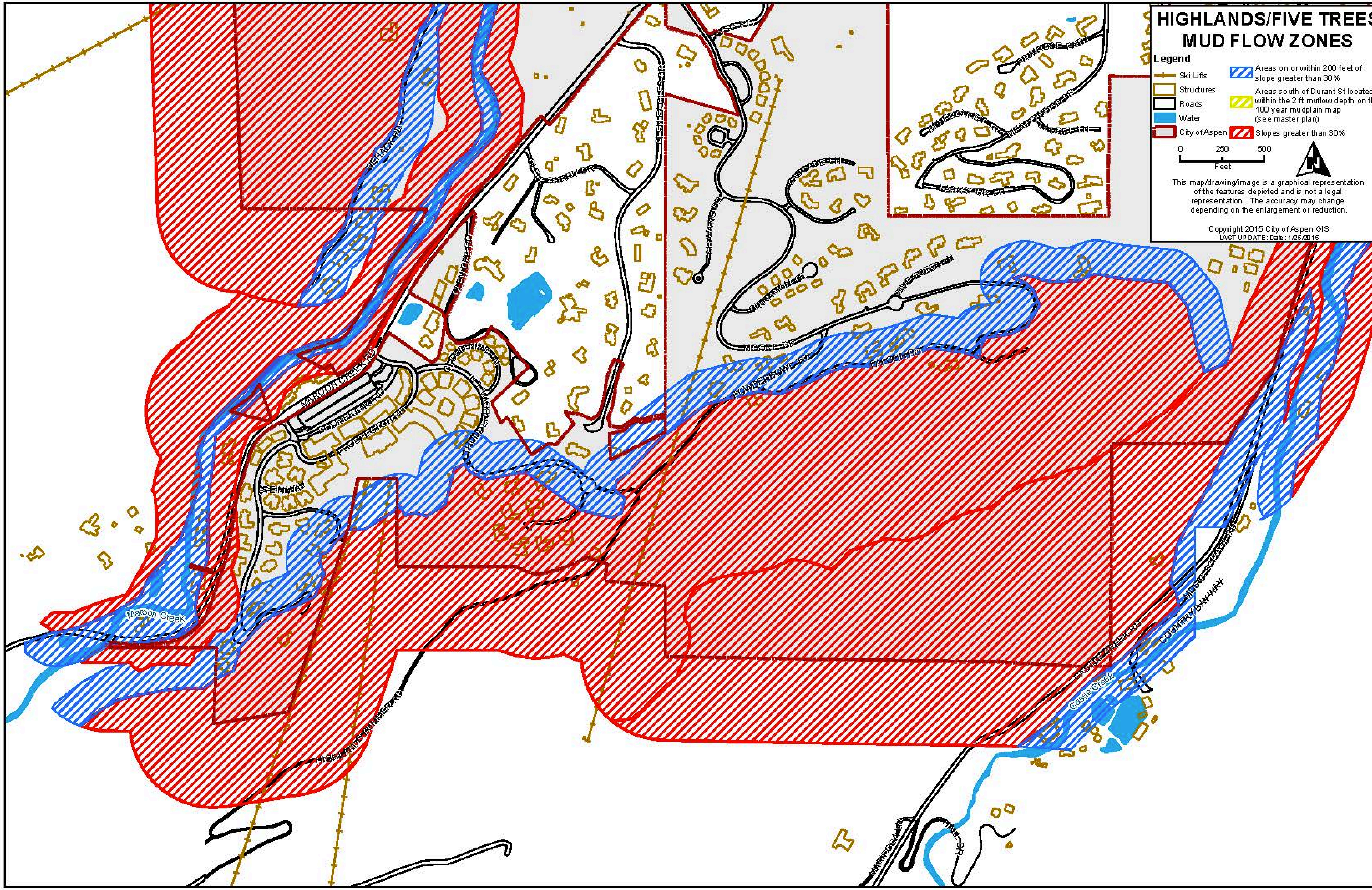

Figure 7.1 e – Highlands/Five Trees Mudflow Zones

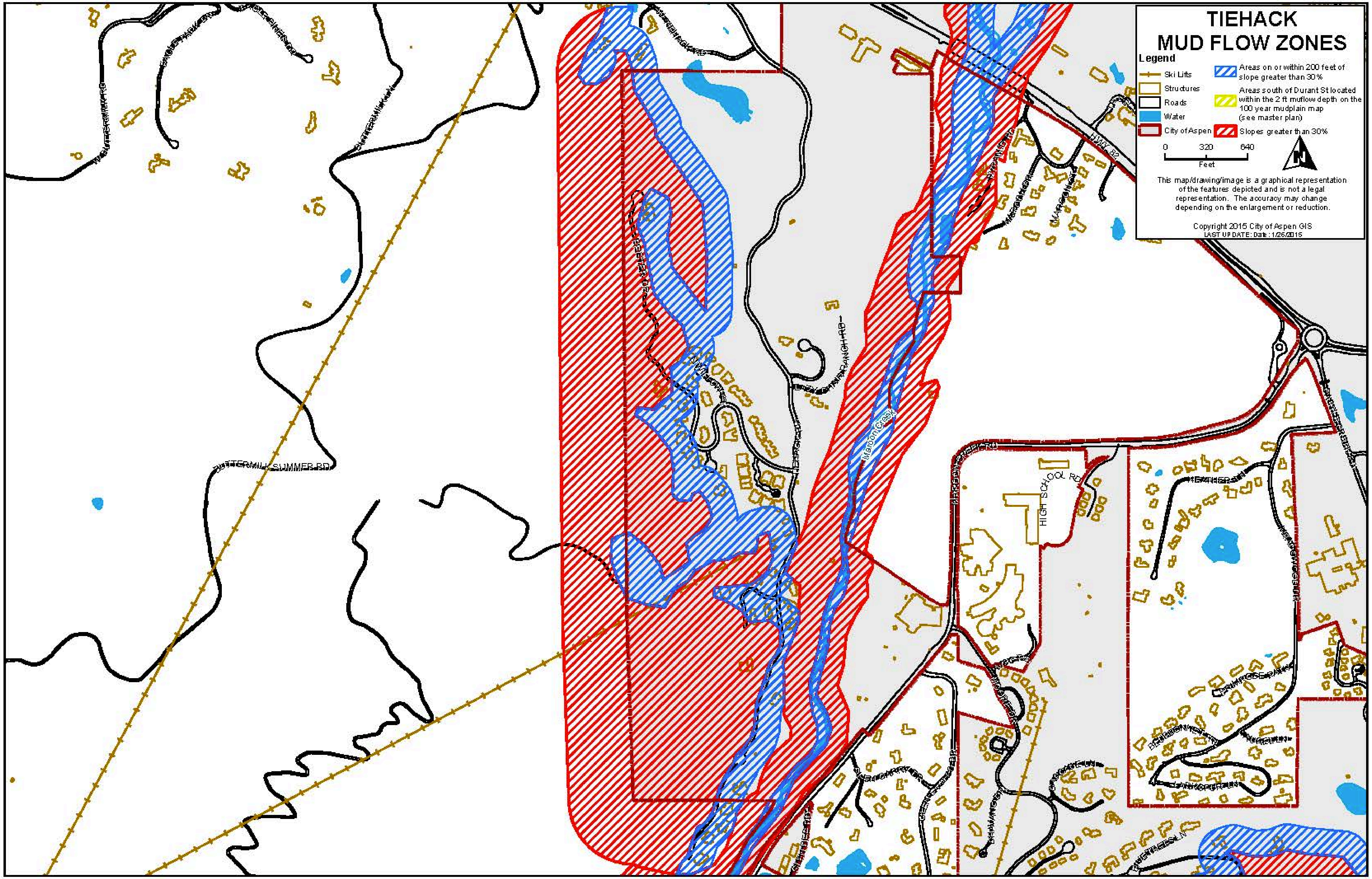

Figure 7.1 f – Tiehack Mudflow Zones