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DEBRIS FLOW AND FLOOD REVIEW
PROPOSED HAYMEADOW DEVELOPMENT
BRUSH CREEK ROAD
EAGLE, COLORADO

JOB NO. 113 097A

JUNE 12, 2013

PREPARED FOR:

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PURPOSE AND SCOPE OF STUDY

This report presents the findings of a debris flow and flood (hyperconcentrated flow) review for the proposed Haymeadow Development, Eagle, Colorado. The Haymeadow property is located in the Brush Creek valley about one mile southeast of the Eagle town center as shown on Figure 1. The purpose of the review was to assess the potential hyperconcentrated flow risk and to develop geotechnical information for the design of the project stormwater management plan. This study is part of our scope of services described in our April 10, 2013 proposal to Abrika Properties, LLC.

Information presented in this report is based on further analysis of our previous study at the project site (Hepworth-Pawlak Geotechnical, 1998 and 2006). In addition, a field reconnaissance of the property was made on May 7, 2013. This study includes a geomorphologic analysis of the tributary drainage basins that are potential sources of future hyperconcentrated flows, assessment of the potential hyperconcentrated flow risk and development of geotechnical information that may be used in design of stormwater management facilities for hyperconcentrated flows. This report summarizes the information developed by this study, describes our evaluations and presents our findings.

SUMMARY OF FINDINGS

The tributary drainage basins and associated fans shown on Figure 2 along the northern part of the Haymeadow property are geologically active and are the potential sites of future debris flows and floods (hyperconcentrated flows). Historic hyperconcentrated flows in the region have been triggered by infrequent, unusually intense thunderstorms. Without long term observations it is not possible to estimate statistical recurrence times for hyperconcentrated flows at the Haymeadow property with a high level of confidence. The statistical recurrence time for a major hyperconcentrated flow from the large and medium-size drainage basins is likely 100 years and probably longer. The statistical recurrence time for a major hyperconcentrated flow from the small drainage basins is likely between 50 and 100 years. A major hyperconcentrated flow from any of the tributary basins should not present a large risk to human life but a major flow has the potential for property and structure damage. If the risk is not acceptable to the owner or government regulatory agencies, then mitigation to reduce the potential risk should be considered.

PROPOSED DEVELOPMENT

At the time of this report, development planning was in the initial stages and preliminary grading and stormwater management plans were not yet available. It is our understanding that the 600 acre property will be a residential development with a mix of medium and high density, single family lots. The development will also include parks, civic sites and open space.

PROJECT SITE CONDITIONS

The property is located about one mile southeast of the Eagle town center on the north side of Brush Creek, see Figure 1. The Brush Creek valley floor in this area is nearly level with a longitudinal slope that is typically less than 3 percent down to the northwest. In the northern part of the property the valley floor abruptly transitions to steep hillsides where slopegrades are in the range of 25 to 100 percent.

Brush Creek is a primary tributary to the Eagle River that is located about one mile to the northwest of the project site. The creek is a moderate size, perennial stream with a drainage basin that covers about 150 square miles and heads in the Sawatch Range to the southeast. Several tributaries to Brush Creek cross through the property. These tributary drainage basins only support ephemeral streams with surface flow following periods of heavy rainfall. At the time of this study, the property was still an operating ranch. Most of the valley floor is flood irrigated hay fields and pasture. Outside the irrigated areas, vegetation consists of sage and other brush with some juniper and pinon trees. Willows and cottonwood trees are common along Brush Creek.

GENERAL CHARACTER OF DEBRIS FLOWS AND FLOODS

The drainages shown on Figure 2 adjacent to the north side of the Haymeadow property have the potential to produce debris flows and floods (hyperconcentrated flows).

Hyperconcentrated flows differ from clear water flows by their higher sediment content as described by O'Brien and Julien (1985). Because of the high sediment concentrations, hyperconcentrated flows can differ considerably from clear water flows and mitigation measures appropriate for clear water flows are not always appropriate for mitigation of hyperconcentrated flows. Clear water flows usually have sediment concentrations by volume (Cv) of less than 20 percent. Hyperconcentrated flows with sediment concentrations between Cv 20 and Cv 45 percent are referred to as *debris floods* and hyperconcentrated flows with sediment concentration between Cv 45 and Cv 65 percent are referred to as *debris flows* (O'Brien and Julien, 1985). In addition to water, soil and rocks, hyperconcentrated flows incorporate brush, logs and other organic debris.

The study by Coe and Others (2003) shows that Meltons's number can be used to assess the hyperconcentrated flow type and the relatively frequency of the flows. Melton's number is an index of basin roughness:

$$M = R / (A)^{0.5}$$

Where M is Melton's number, R is basin relief and A is the basin area. Basins with Melton's numbers of less than around 0.35 usually only produce debris floods and basins with Melton's numbers greater than around 0.35 usually produce both debris flows and floods (Coe and Others 2003). Basins with large Melton's numbers produce hyperconcentrated flows more frequently than basins with small Melton's numbers.

CHARACTER OF DRAINAGE BASINS AND ASSOCIATED FANS

Stormwater runoff from the tributary drainages along the north side of the Haymeadow property discharges on to fans where the basins transition to the Brush Creek valley floor. The fan sediments are mostly debris flow and flood (hyperconcentrated flow) deposits. For this review we have divided the tributary drainage basins into three groups based on basin surface area and other geomorphologic characteristics. The tributary basins and associated fans are shown on Figure 2. Figures 3 and 4 show the details of the small basins and fans.

LARGE SIZE BASINS

Information pertaining to the four large size tributary basins is presented in Table 1. These basins have surface areas between about 90 and 240 acres. The basin slopes along the longest flow line between the fan head and highest elevation in the basins vary between 0.11 and 0.25 feet per feet, and the basins have Melton's numbers between 0.20 and 0.23. The Melton's numbers indicate that the four larger basins will likely only produce debris floods and not debris flows. Regional soil surveys show that the large basins at the site have soils that are mostly in Hydrologic Group C with some Group B soils (National Resources Conservation Service, 2008). Hillside slopes that are steeper than 30 percent in the four larger basins cover between about 17 and 77 percent of the total basin surface area.

The fans below the four larger tributary basins cover most of the main Brush Creek valley floor on the north side of the creek. The fans have narrow, long fingers that extend well into the hillsides to the north. The fans have surface areas between about 25 and 100 acres and the fan area to basin area ratios (A_f / A_b) are between 0.29 and 0.70. The fans have gentle longitudinal slopes. Average fan slopes are between 0.04 and 0.06 feet per foot.

MEDIUM SIZE BASINS

Information pertaining to the four medium size tributary basins is presented in Table 1. These basins have surface areas between about 6 and 80 acres. The basin slopes along the longest flow line between the fan head and highest elevation in the basin vary between 0.28 and 0.35 feet per feet, and the basins have Melton's numbers between 0.35 and 0.40. The Melton's numbers indicate that the four medium size basins will likely only produce debris floods but debris flows could occur in the basins with the higher Melton's numbers. Regional soil surveys show that the medium size basins at the site have soils that are mostly in Hydrologic Group C with some Group B soils (National Resources Conservation Service, 2008). Hillside slopes steeper than 30 percent in the four medium size basins cover between about 79 and 91 percent of the total basin surface area.

The fans below the four medium size tributary basins cover much of the main Brush Creek valley floor on the north side of the creek. The fans have narrow, long fingers that extend well into the hillsides to the north. The fans have surface areas between about 8 and 50 acres and the fan area to basin area ratios (A_f / A_b) are between 0.49 and 1.32. The fans have gentle longitudinal slopes. Average fan slopes are between 0.05 and 0.08 feet per foot.

SMALL SIZE BASINS

Information pertaining to the sixty-four small tributary basins is presented in Table 2. These basins have surface areas between about 0.2 and 8 acres. The basin slopes along the longest flow line between the fan head and highest elevation in the basin vary between 0.13 and 0.48 feet per feet. Most of the small basins (95 percent) have slopes greater than 0.2 feet per feet. Ninety-four percent of the small basins have Melton's numbers greater than 0.35 which indicates that both debris flows and debris floods should be expected from nearly all of the small basins. Regional soil surveys show that the small basins at the site have soils that are mostly in Hydrologic Group C (National Resources Conservation Service, 2008). Eighty percent of the small basins have hillside slopes greater than 30 percent over the total basin area.

The fans below the small basins do not extend more than about 800 feet down slope of the fan heads and eighty percent of the fans are less than 300 feet long. Seventy percent of the small fans have average fan slopes greater than 0.15 feet per feet. The fans have surface areas between about 0.1 and 2 acres and the fan area to basin area ratios (A_f / A_b) are between 0.04 and 2.2.

DEBRIS FLOW AND FLOOD RECURRENCE AND RISK

The fans in the project area are largely the product of sediments deposited by debris flows and floods (hyperconcentrated flows) that have repeatedly occurred in post-glacial times, during about the past 15,000 years. The fans are still active and should be considered sites of future hyperconcentrated flows. Regional soils studies by the National Resources Conservation Service (2008) indicate that a weakly developed A/Bw/Bk pedogenetic soil profile is commonly present on the fans. This indicates that hyperconcentrated flows that add new sediments to the fan surface are infrequent. However, without long term observations it is not possible to estimate statistical recurrence times for hyperconcentrated flows with a high level of confidence. Based on the Melton's numbers (M), in our opinion major hyperconcentrated flows from the large drainage basins (M = 0.21± 0.01) likely have a statistical recurrence time of 100 years and probably longer. Major hyperconcentrated flows from the medium size basins (M = 0.38 ± 0.02) likely also have a statistical recurrence times of 100 years and probably longer. Major hyperconcentrated flows from the small basins (M = 0.56 ± 0.2) likely have statistical recurrence times between about 50 and 100 years. A major hyperconcentrated flow from all of the tributary basins should not present a large risk to human life but a major flow has the potential for property and structure damage. The damage could result from erosion, dynamic flow impact loads, and the deposition of mud and debris. If these risks are not acceptable to the owner or government regulatory agencies, then mitigation to reduce the potential risk should be considered.

DEBRIS FLOW AND FLOOD DESIGN INFORMATION

Design information that may be used for evaluating debris flow and flood (hyperconcentrated flow) mitigation are presented in this section of the report. We expect that additional geotechnical design information will be required for the design of specific mitigation facilities when the type and location of the facilities have been determined.

DESIGN RAINFALL

Historic debris flows and floods (hyperconcentrated flow) in western Colorado with a similar geologic setting as the project site have been triggered by runoff from unusually intense thunderstorms. In our opinion, a reasonable design rainfall for mitigation design is the 100-yr, 1-hour thunderstorm. The National Oceanographic and Atmospheric Administration (2013) estimates that the 100-year, 1-hour rainfall in the project area is 1.18 inches.

FLOW SEDIMENTS CHARACTER

Since the existing fan deposits are sediments from past debris flows and floods (hyperconcentrated flows), the sediment character of future hyperconcentrated flows will be similar to the existing fan deposits. Our previous laboratory tests (Hepworth-Pawlak Geotechnical, 1998) and laboratory test information from the National Resources Conservation Service (2008) indicate that the large and medium size drainage basins have produced hyperconcentrated flows that contained about 10 percent gravel to small boulder-size rocks in a predominantly silt loam matrix and to a lesser extent a sandy clay loam matrix. The minus 200 size sieve fraction of the flow matrix is typically 74 ± 19 percent with clay (less than 0.002 mm in size) content between 20 and 30 percent. The small drainage basins have produced hyperconcentrated flows that contained about 10 percent gravel to small boulder-size rocks in a silt loam matrix. The minus 200 size sieve fraction of the flow matrix is typically 84 ± 12 percent with a clay (less than 0.002 mm) content between 20 and 30 percent.

DEBRIS FLOW VOLUMES

The design debris flow volumes for the large and medium size basins are presented in Table 1 and the design volumes for the small basins are presented in Table 2. The design debris volumes are based on the empirical debris volume model developed by Cannon and Others (2010). The design volumes are the amount of debris that is expected at the fan heads and some deposition of debris should occur between the fan heads and the proposed development area. Estimates of the debris volumes deposited above the development or mitigation facilities cannot be made until the location of these facilities has been determined. Input variable used in the volume model are: (1) drainage basin areas with slopes steeper than 30 percent; (2) percent basin area burned by wildfire; and (3) rainfall depth. The volume estimates in Tables 1 and 2 are for the non-burned vegetation condition and the 1-hour, 100-year rainfall of 1.18 inches.

FLOW DEPTH AND VELOCITY

Design hyperconcentrated flow depths and velocities for the fans down slope of the tributary basins are presented in Table 3. The depths and velocities are for unchannelized sheet and rill flow. The values presented in Table 3 are based on the laminar-viscous flow model proposed by Hunger and Others (1984). Additional flow dynamics information may be needed for mitigation design when the type and location of the mitigation facilities have been determined. The additional information may include dynamic impact pressure, static deposition pressure and flow run-up heights.

LIMITATIONS

This study was conducted according to generally accepted geotechnical engineering principles and practices in this area, at this time. We make no warranty either express or implied. Information submitted in this report are based on our previous studies at the project site, topographic map and aerial photograph interpretations, and published numerical models. This report has been prepared exclusively for our client to provide information of hyperconcentrated flow risk assessment and preliminary mitigation design. If the hyperconcentrated flow risk is not acceptable and hyperconcentrated flow mitigation is incorporated in the stormwater management plan, we should consult with the designers to determine if the proposed mitigation is consistent with the information presented in this report. We expect that additional geotechnical design information will be required for the design of specific mitigation facilities. We are not responsible for technical interpretations by others of our information.

Respectfully Submitted,

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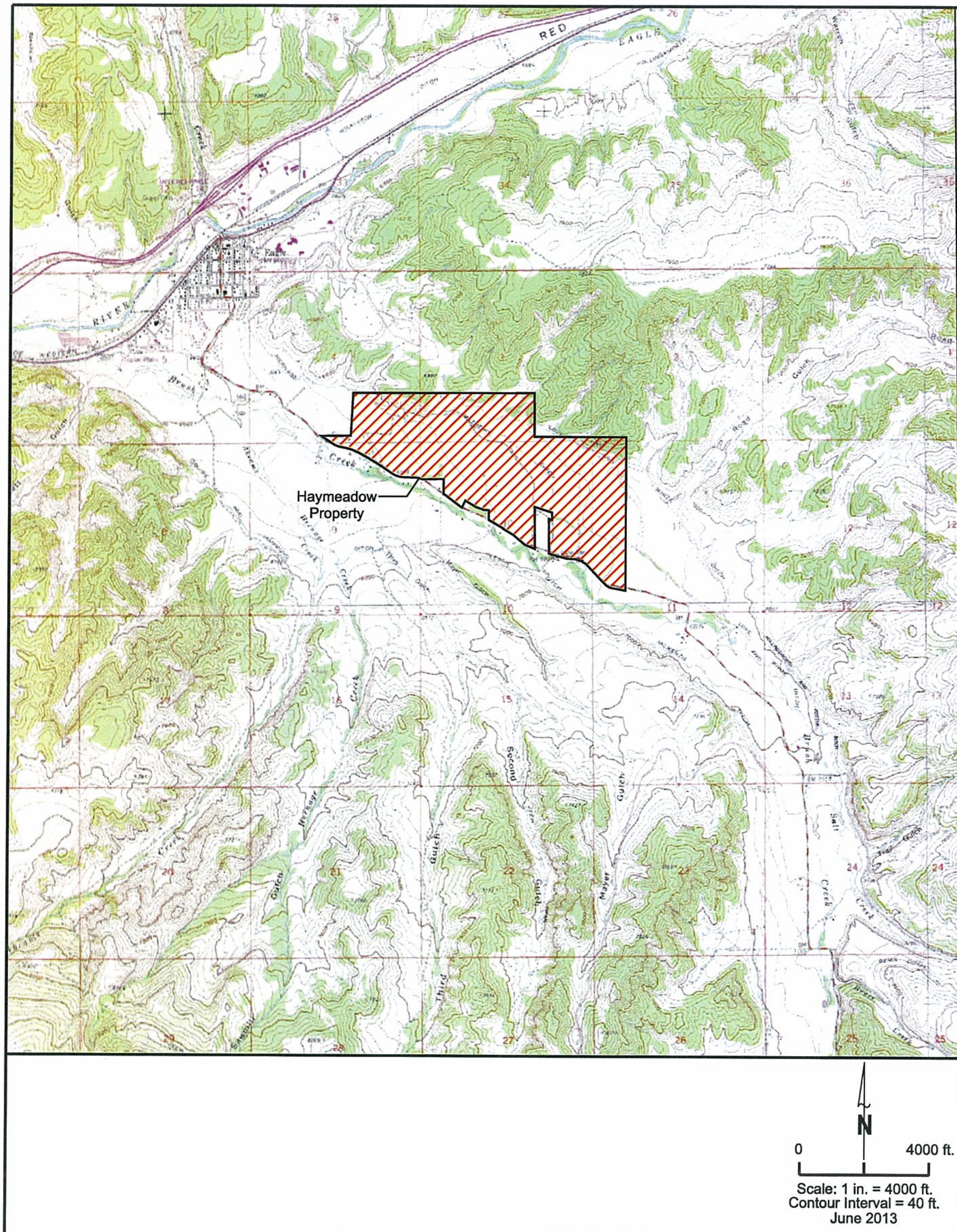
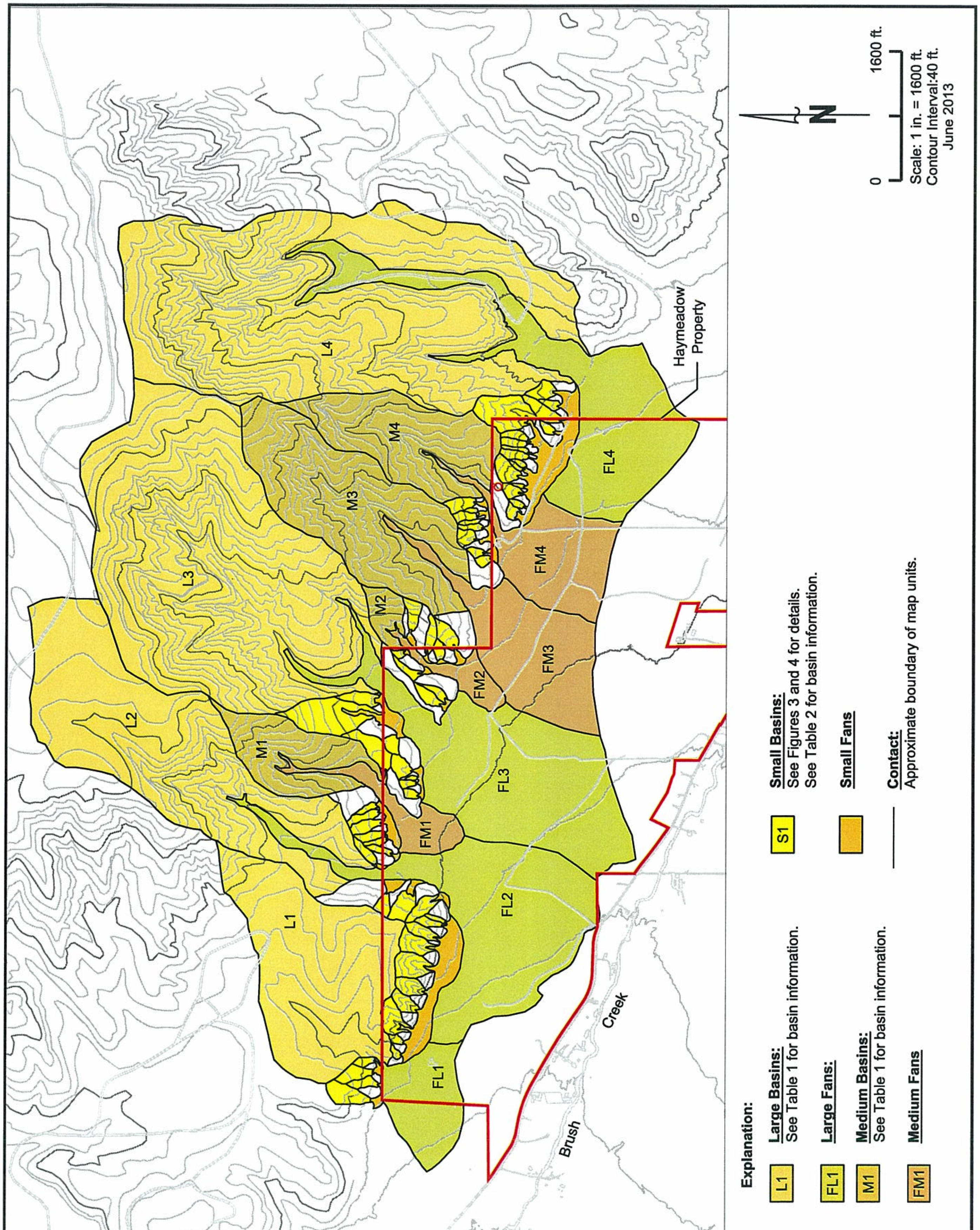
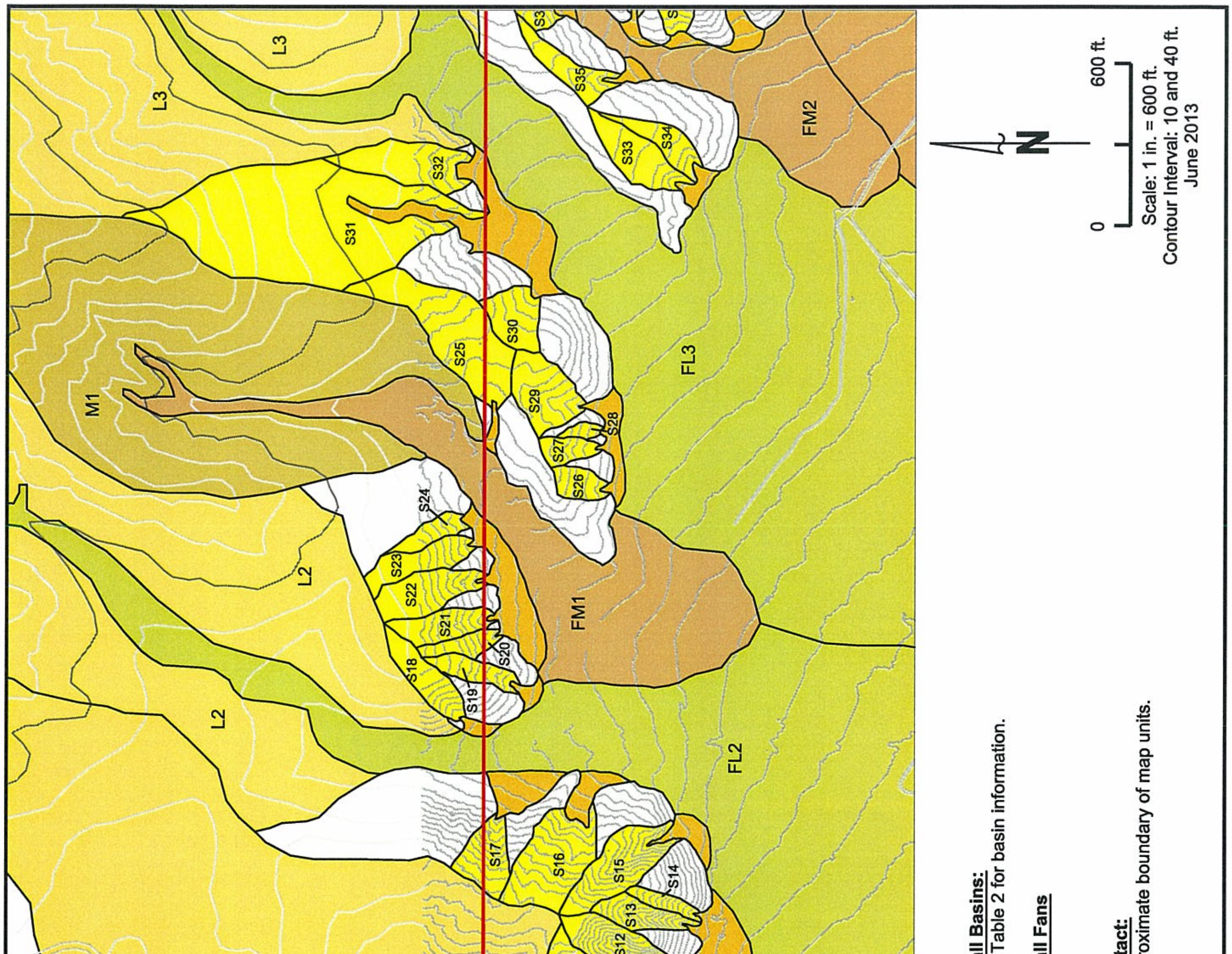


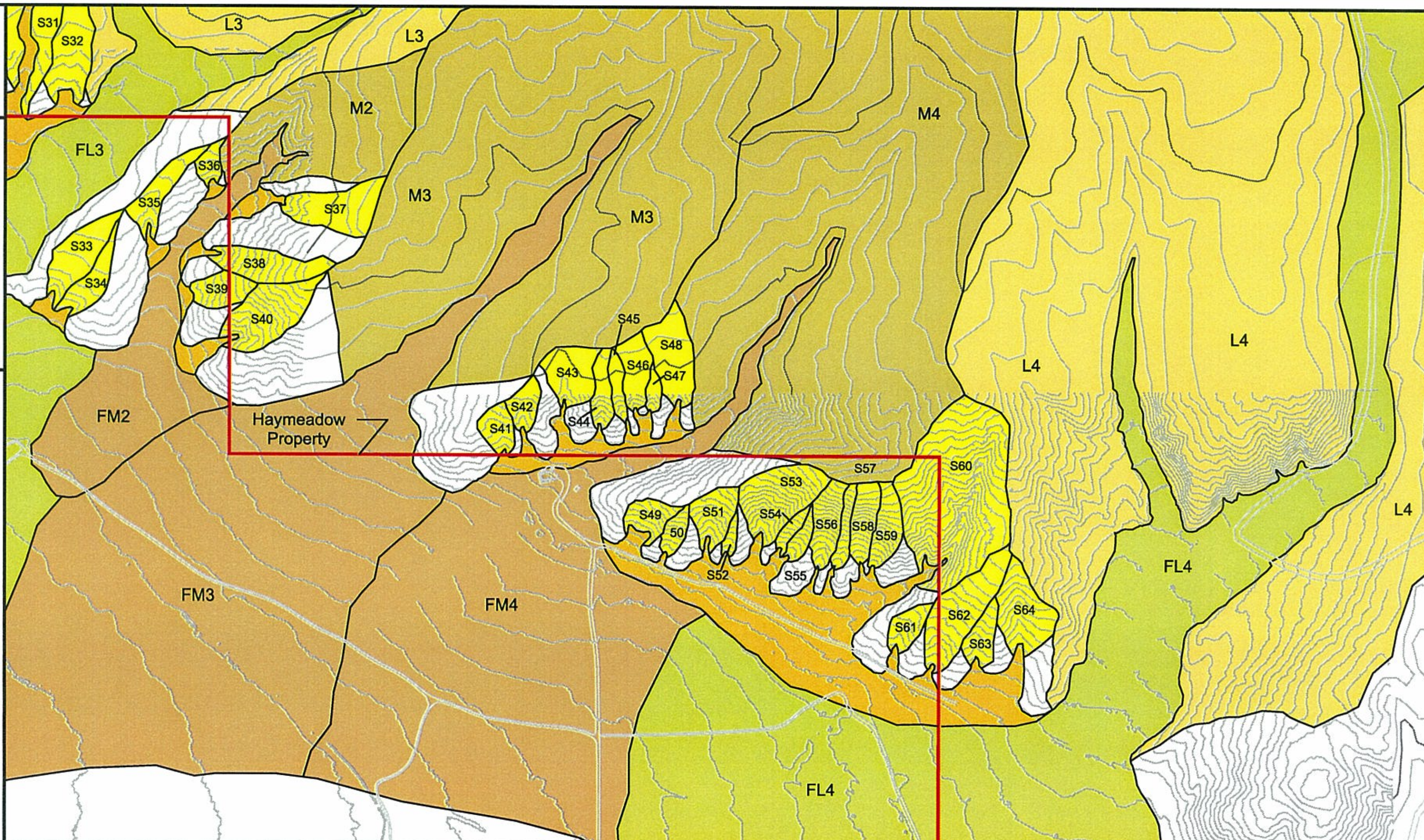
113 097A	HP Geotech HEPWORTH-PAWLAK GEOTECHNICAL	Haymeadow Development Project Site Location	Figure 1



113 097A	HP Geotech HEPWORTH-PAWLAK GEOTECHNICAL	Haymeadow Development Large and Medium Tributary Drainage Basins and Associated Fans	Figure 2



113 097A	HP Geotech HEPWORTH-PAWLAK GEOTECHNICAL	Haymeadow Development Small Tributary Drainage Basins and Associated Fans Western - Area	Figure 3



Explanation:

L1	**Large Basins:** See Table 1 for basin information.
FL1	**Large Fans:**
M1	**Medium Basins:** See Table 1 for basin information.
FM1	**Medium Fans**
S1	**Small Basins:** See Table 2 for basin information.
(orange swatch)	**Small Fans**
———	**Contact:** Approximate boundary of map units.

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Haymeadow Development
Small Tributary Drainage Basins and Associated Fans Eastern - Area

Figure 4

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Table 1

Large and Medium Size Tributary Drainage Basin Information

Job No. 113 097A
June 2013

Basin Number	Basin Area	Basin Slope	Basin Melton's Number	Percent `Basin Area Steeper than 30 Percent	Design Debris Volume
L1	90.1 ac	0.11 ft/ft	0.22	17 %	1330 yd^3
L2	129.1 ac	0.13 ft/ft	0.21	38 %	2700 yd^3
L3	222.8 ac	0.18 ft/ft	0.23	77 %	5660 yd^3
L4	244.1 ac	0.25 ft/ft	0.20	77 %	6010 yd^3
M1	28.4 ac	0.35 ft/ft	0.36	82 %	1720 yd^3
M2	6.3 ac	0.31 ft/ft	0.40	91 %	730 yd^3
M3	81.5 ac	0.29 ft/ft	0.35	89 %	3390 yd^3
M4	47.6 ac	0.28 ft/ft	0.39	79 %	2280 yd^3

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Table 2

Small Size Tributary Drainage Basin Information

Job No. 113 097A
May 2013

Basin Number	Basin Area	Basin Slope	Basin Melton's Number	Percent `Basin Area Steeper than 30 Percent	Design Debris Volume
S1	2.4 ac	0.19 ft/ft	0.37	100%	442 yd^3
S2	0.8 ac	0.27 ft/ft	0.57	100%	237 yd^3
S3	1.4 ac	0.20 ft/ft	0.39	100%	328 yd^3
S4	0.5 ac	0.22 ft/ft	0.42	100%	182 yd^3
S5	0.3 ac	0.26 ft/ft	0.43	100%	130 yd^3
S6	0.3 ac	0.21 ft/ft	0.39	100%	145 yd^3
S7	2.2 ac	0.36 ft/ft	0.49	100%	424 yd^3
S8	1.3 ac	0.45 ft/ft	0.75	100%	307 yd^3
S9	1.5 ac	0.43 ft/ft	0.66	100%	336 yd^3
S10	2.7 ac	0.40 ft/ft	0.43	100%	474 yd^3
S11	2.0 ac	0.26 ft/ft	0.40	100%	398 yd^3
S12	1.2 ac	0.32 ft/ft	0.59	100%	291 yd^3
S13	0.6 ac	0.38 ft/ft	0.81	100%	208 yd^3
S14	0.3 ac	0.40 ft/ft	0.92	100%	133 yd^3
S15	1.5 ac	0.25 ft/ft	0.41	100%	333 yd^3
S16	1.9 ac	0.20 ft/ft	0.31	100%	385 yd^3
S17	0.9 ac	0.31 ft/ft	0.40	100%	248 yd^3
S18	0.8 ac	0.24 ft/ft	0.56	100%	241 yd^3
S19	0.5 ac	0.25 ft/ft	0.58	100%	182 yd^3
S20	0.4 ac	0.29 ft/ft	0.66	100%	157 yd^3
S21	0.8 ac	0.27 ft/ft	0.59	100%	227 yd^3
S22	1.1 ac	0.25 ft/ft	0.45	100%	283 yd^3
S23	0.8 ac	0.22 ft/ft	0.46	100%	242 yd^3
S24	0.4 ac	0.29 ft/ft	0.72	100%	160 yd^3
S25	2.7 ac	0.15 ft/ft	0.36	15%	153 yd^3
S26	0.4 ac	0.24 ft/ft	0.36	86%	148 yd^3
S27	0.4 ac	0.19 ft/ft	0.34	54%	105 yd^3
S28	0.1 ac	0.29 ft/ft	0.60	88%	79 yd^3
S29	1.2 ac	0.14 ft/ft	0.24	40%	170 yd^3
S30	0.8 ac	0.19 ft/ft	0.26	15%	78 yd^3
S31	8.2 ac	0.28 ft/ft	0.40	30%	441 yd^3
S32	1.4 ac	0.21 ft/ft	0.44	61%	242 yd^3
S33	1.0 ac	0.12 ft/ft	0.25	22%	109 yd^3
S34	0.6 ac	0.13 ft/ft	0.32	29%	97 yd^3
S35	0.7 ac	0.15 ft/ft	0.35	25%	98 yd^3
S36	0.3 ac	0.25 ft/ft	0.44	100%	126 yd^3
S37	1.3 ac	0.33 ft/ft	0.66	100%	309 yd^3
S38	1.0 ac	0.32 ft/ft	0.71	100%	274 yd^3
S39	0.6 ac	0.26 ft/ft	0.42	100%	198 yd^3

Table 2

Small SizeTributary Drainage Basin Information

Job No. 113 097A
June 2013

Basin Number	Basin Area	Basin Slope	Basin Melton's Number	Percent `Basin Area Steeper than 30 Percent	Design Debris Volume
S40	1.6 ac	0.33 ft/ft	0.57	100%	341 yd^3
S41	0.5 ac	0.29 ft/ft	0.41	100%	171 yd^3
S42	0.4 ac	0.32 ft/ft	0.50	100%	160 yd^3
S43	1.0 ac	0.28 ft/ft	0.44	100%	253 yd^3
S44	0.5 ac	0.35 ft/ft	0.75	100%	169 yd^3
S45	0.3 ac	0.34 ft/ft	0.85	100%	130 yd^3
S46	0.7 ac	0.35 ft/ft	0.64	100%	207 yd^3
S47	0.2 ac	0.31 ft/ft	0.64	100%	99 yd^3
S48	1.2 ac	0.30 ft/ft	0.56	100%	295 yd^3
S49	0.6 ac	0.34 ft/ft	0.42	100%	180 yd^3
S50	0.3 ac	0.35 ft/ft	0.63	100%	133 yd^3
S51	0.8 ac	0.34 ft/ft	0.49	100%	222 yd^3
S52	0.2 ac	0.41 ft/ft	0.91	100%	85 yd^3
S53	1.6 ac	0.42 ft/ft	0.58	100%	350 yd^3
S54	0.2 ac	0.48 ft/ft	1.05	100%	107 yd^3
S55	0.3 ac	0.43 ft/ft	0.96	100%	119 yd^3
S56	0.8 ac	0.45 ft/ft	0.88	100%	227 yd^3
S57	0.4 ac	0.46 ft/ft	1.31	100%	142 yd^3
S58	0.7 ac	0.48 ft/ft	0.93	100%	206 yd^3
S59	0.7 ac	0.44 ft/ft	0.91	100%	211 yd^3
S60	6.0 ac	0.28 ft/ft	0.41	100%	757 yd^3
S61	0.5 ac	0.28 ft/ft	0.46	100%	164 yd^3
S62	1.7 ac	0.22 ft/ft	0.48	100%	359 yd^3
S63	0.5 ac	0.30 ft/ft	0.53	100%	177 yd^3
S64	1.3 ac	0.26 ft/ft	0.40	100%	305 yd^3

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Table 3

Design Flow Depths and Velocities on Fans

Job No. 113 097A
June 2013

Drainage Basin	Flow Type	Max. Flow Depth	Max. Flow Velocity
Large-Size Basins	Debris Flood	1.5 ft.	6 fps
Medium-Size Basins	Debris Flood	1.0 ft.	5 fps
	Debris Flow	4.0 ft.	2 fps
Small-Size Basins	Debris Flood	1.0 ft.	2 fps
	Debris Flow	2.0 ft.	1 fps