Donna Creek Washout-Flow—What Did We Learn?

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ABSTRACT

The 1992 Donna Creek washout-flow has the form of a large dendritic-shaped gully, 5 m deep at the headscarp with steep side walls extending up to 30 m deep. The gully covers a land area of approximately 4.5 ha, from which 422 500 m³ was eroded. The Donna Creek washout-flow was caused by changes made to the natural hillslope runoff. The changes were a direct result of water capture and routing along ditches of branch roads constructed for forest harvesting. These roads did not have sufficient cross-drains or culverts to permit water to cross the roads and return to natural drainage channels. The road capture and rerouting of runoff increased the drainage area to the site of the washout by 9.8 times. The hillslopes above Donna Creek experienced high rates of runoff on the days preceding the event (May 25–June 2, 1992). At peak flow, the volume of water delivered to the site was estimated at 0.23 m³/s, giving a daily total of about 20 000 m³ of water. The total volume of water delivered to the washout between May 23–June 2 was estimated at about 143 000 m³, a 7.3-fold or 730% increase over expected normal runoff. This excessive volume of water flowing over and into an area of a highly erodible glaciofluvial/glaciolacustrine terrace probably destabilized a steep spoon-shaped gully that opened a face for seepage and collapse of loose silts, sands, and gravels. Catastrophic seepage face erosion resulted in an avulsion of material. Debris flow surges rapidly transported material down an adjacent gully into Donna Creek. Large quantities of sediment entering Donna Creek, combined with high spring runoff, triggered a debris flood that transported debris 6 km down Donna Creek to Manson River.

INTRODUCTION

A large catastrophic washout-flow occurred on June 2, 1992, at Donna Creek, a major tributary of Manson River, about 75 km northwest of Mackenzie, B.C. (Figure 1). The landslide occurred in what appeared as a dry gravelly terrace, situated below a forested slope on which logging road subgrade had been constructed. In terms of cause, magnitude, and landslide process, the event is of particular interest to earth scientists. Moreover, the event also had significant implications for forest management in British Columbia:

• The washout-flow occurred just days prior to a scheduled release of 50 000 kokanee into Donna Creek. In June of the previous 3 years, 200 000
fingerling kokanee had been released into Donna Creek at the Manson Mainline road bridge. Kokanee were expected to return from Williston Lake to spawn in the fall of 1992 with the first major return in the fall of 1993. No records are available on actual kokanee returns for Manson River.

- The Forest Practices Code of British Columbia was enacted in 1995. In an attempt to prevent erosion and landslides, forest road regulations now require that drainage systems be built concurrently with subgrade construction, and that drainage systems be fully functional to accommodate surface and subsurface runoff.

- The forest licensee was charged under the Fisheries Act Section 35 (1) No person shall carry on any work or undertaking that results in the harmful alteration, disruption or destruction of fish habitat; and Section 36 (3) No person shall deposit or permit the deposit of a deleterious substance of any type in water frequented by fish. The offences were treated as indictable. A lengthy preliminary hearing took place through 1996–1997. Based on legal arguments, the charges did not proceed to trial in the Supreme Court of British Columbia.

This paper explores the causal factors and the landslide/erosion processes of the 1992 Donna Creek washout-flow.

**GENERAL CLIMATE AND HYDROLOGY**

Climate for the regional area is characterized by long, cold winters and cool, short summers. Total precipitation at lower elevations ranges from 400 to
700 mm. Winter precipitation is dominated by snow. Snow accumulations range from 400 to 1500 mm snow-water equivalent for Alken Lake at 1040 m above sea level (a.s.l.) and Pine Pass at 1430 m a.s.l., respectively. Streamflow for the region is dominated by spring snowmelt. Streams begin to rise with the onset of snowmelt in late March–early April, and rise rapidly with the contribution of mid- and higher elevation melt commencing in early May. Annual peak streamflow (peak runoff) occurs in late May–early June. Lower slopes in the immediate vicinity of the washout normally contribute to the early spring runoff. The land area that contributes water to the washout site is located at mid-elevations (1100–1450 m a.s.l.). Therefore, the main runoff from the hillslopes above the washout occurs during peak spring runoff generated for Donna Creek watershed.

**GENERAL GEOLOGY AND TERRAIN**

Surficial geology maps indicate an extensive glaciofluvial terrace along the lower slopes of Donna Creek valley (B.C. Ministry of Environment 1977; Plouffe 2000). The upper limit of the glaciofluvial terrace near the failure is at 1550 m. A glaciolacustrine terrace modified by erosion is shown between 900 and 1000 m elevation in the lower reaches of Donna Creek watershed. The maps indicate that the glaciolacustrine sediments extend upstream to the 1992 Donna Creek failure. The washout-flow is situated on a terrace located at mid-elevation on the east side of Donna Creek valley. Elevation of Donna Creek floodplain is 975 m and the hilltop above the washout is 1450 m. The landform rises steeply above the floodplain at 37° to 1050 m. The terrace surface slopes uphill in a series of short steep rises with an overall slope gradient of 10°. Visible within the erosion crater is a complex sequence of glaciofluvial sands and gravels overlying glaciolacustrine sands and silts. These sediments were deposited close to glacial ice. A thin discontinuous layer of compact glacial till covers mica schist bedrock (Ferri et al. 1988), which is exposed within the scarp. Moderately fine-textured morainal and colluvial materials mantle the surrounding slopes above the terrace. Figure 2 provides a schematic diagram of the relative positioning of these surficial materials.

![Diagram](image.png)

**Figure 2**  Schematic representation of the relative positioning of surficial materials. (Vertical exaggeration 2.5 x, stratigraphic boundaries are conceptual only.)
SITE DESCRIPTION

The crater eroded by the washout is a large dendritic gully, 5 m deep at the head scarp with steep side walls extending up to 30 m deep (Figure 3). The crater extends back 290 m from a deeply incised adjacent natural gully and covers a land area of approximately 4.5 ha, from which 422,500 m³ was eroded. Eroded material was rapidly transported by debris flow surges down the established gully across Donna Creek floodplain, a distance of 400 m. Destabilization of the gully side walls (40°) resulted in the addition of a few thousand cubic metres of material to the flows. Approximately 62,500 m³ of debris and sediment were deposited on the fan where the main gully empties onto the floodplain—few trees were left standing (Figure 4). A resultant

FIGURE 3 Crater eroded by the washout-flow. Note landform and roads on slope above.

FIGURE 4 Debris fan. Note few standing trees and 10 m high debris flow splash on trees.
debris flood down Donna Creek transported and deposited 360 000 m$^3$ of sediment and debris on the floodplain and behind logjams over 6 km toward Manson River (Figure 5).

Figure 5, a composite map of the washout-flow and hillslope, depicts topography, drainage basins, road locations, water flow directions, and site locations (1, 2, 3, 4, 5, and 6) referred to in the text.

**FOREST DEVELOPMENT**

The hillslope above the washout was forested, with the exception of road rights-of-way and roads constructed for timber harvesting. Construction of DC1000 branch road directly above the terrace started in 1988. Additional branch roads were constructed in January and February 1990 to access a proposed cutblock. Branch road DC1300 switchbacks up the slope to access the top of the proposed block. Further block access was obtained with mid-slope roads at lower and higher elevations, DC1310 and DC1320, respectively.

**DRAINAGE BASINS**

The established surface drainage on the hillslope above the Donna Creek washout occurs via four basins. The basins are poorly defined topographically on the steep uniform upper hillslopes, in contrast to deeply incised gullies cut through the glaciofluvial/glaciolacustrine landform, with

![Composite map—depicts topography, drainage basins (A–F), branch roads, water flow directions, and site locations (1–6) referred to in the text.](image-url)
outlets onto the Donna Creek valley flat. The basins designated as A, B, C, and D drain land areas of 39.3, 61.2, 49.5, and 24.4 ha, respectively. Basin E, a sub-basin of basin B, drains a land area of 5.8 ha. Basin E is important in that its catchment encompasses the 1992 washout and drains into the incised gully channel of basin B.

**DRAINAGE ALTERATION**

The construction of the DC1000 road dissected the natural drainage basins on the hillslope. A natural berm that formed the upper boundary for basin E was breached by a crawler tractor bladed “push-out” during or sometime after construction, to permit water to flow away from a low point on the road.

The DC1300 road contained four culverts (cross-drains) over a distance of approximately 2170 m. Two of the culverts were situated at lower elevations, along the road before the switchback at the DC1310 junction. Above the switchback, constructed drainage consisted of two culverts over a distance of approximately 1540 m. The steep road grade, running from 11.2 to 16.8% between the first and second switchback, contained no cross-drains (culverts, cross-ditches, or water bars) for approximately 700 m. DC1310 contained one culvert placed close to the junction of the DC1300 road. DC1320 contained no culverts or constructed cross-drains.

The construction of DC1300, DC1310, and DC1320 in 1990 altered the natural surface and subsurface drainage on the slope by collecting water along ditches and directing flow out of the natural drainage basins to new outlet locations 1, 2, 3, 4, and 5 above the washout site. Erosion along ditches and a sediment trail mark the path of water flow. This alteration of the hillslope drainage by the road network created a new drainage catchment area that covered approximately 56.9 ha (basin F). This expanded drainage into the washout represents a catchment increase of 9.8 times (56.9 ha/5.8 ha).

The major collection and channelization of water occurred along the DC1300 road above the second switchback, and further downhill along the steep section above the first switchback. Water flow eroded a deep channel in the ditch above the first switchback (Figure 6). This sediment filled the ditch and culvert at a low spot on the DC1310 road (location 2). Sediment-laden water flowed over the road, spilled out of the natural drainage channel below the road, and flowed overland down to the DC1000 road. Water and sediment exceeded the capacity of the drainage constructed along the DC1000 road (locations 3–5). Most water crossed the road via the bladed “push-out” onto the terrain directly above the washout (location 4, Figure 7). A sediment trail provides evidence of overland flow down to the terrace and crater head wall (Figure 8).

**SNOWMELT RUNOFF**

Air temperature and precipitation recorded for the area show consistently cool conditions (0–5°C) prior to May 15 with a significant drop in temperature on May 15 coupled with a large snowfall. A very rapid rise in tempera-
ture occurred on May 22, reaching an mean daily temperature of 17°C. An above-average snowpack, coupled with additional late May snow, followed by an increase in temperature, resulted in a rapid snowmelt in the elevation band of 1100–1500 m. Simulated snowmelt rates for the slopes above the failure indicate peak values of close to 4.5 cm per day (U.S. Army Corps of Engineers 1960). The entire area above the washout, combined by the altered road drainage into a single basin “F,” was contributing a high rate of water delivery—possibly at rates higher than a 50-year rainstorm event recorded in the spring of 1990.

The hillslope above Donna Creek experienced high rates of runoff from snowmelt from May 25 to June 2, 1992. Flows were determined using the

![Figure 6](image6.png)

**Figure 6** Ditch erosion above first switchback, location 2. Peak water flow was estimated at 0.31 m³/s.

![Figure 7](image7.png)

**Figure 7** Water delivered via the crawler tractor bladed “push-out” (location 4) is 0.23 m³/s—a daily total of about 20 000 m³/s.
Manning equation. Calculations for location 2 indicate a maximum flow of 0.31 m³/s. This value compares well to the simulated average daily value of 0.28 m³/s estimated for May 31, the date of the highest runoff at the site (total daily snowmelt and rainfall).

At peak flow, the volume of water delivered to the washout site via the push-out at location 4 was determined to be 0.23 m³/s—a daily total of about 20 000 m³ of water. This is equivalent to approximately 25 times the volume found in an average-size community swimming pool (800 m³; length 25 m, width 15 m, average depth 2.1 m). The total volume of water delivered to the area above basin E from May 23 to June 2 was about 193 000 m³. An estimated 74% flowed to the washout via the bladed “push-out” (location 4). This equals about 143 000 m³ or approximately 180 average-size community swimming pools over the 11 days. The estimated volume delivered to basin E was 7.3 times or 730% that received under natural conditions.

**EROSION PROCESS**

The event had a character typical of catastrophic seepage face erosion or washout that has been observed in glaciofluvial sands, silts, and gravels. For example, the grand campus washout of 1935 at UBC Vancouver (Williams 1966); Maryhill gravel pit washout, Coquitlam River valley (Allen 1957); gully-flow in deltaic sands and silts, Moise River, Quebec (Dredge and Thom 1976); caving erosion (Hungr and Smith 1985); gully erosion / caving erosion found in the Coquitlam River valley (Siebert 1987); and seepage-face erosion (Parker and Higgins 1990). Catastrophic seepage face erosion was also observed at Bowser River in 1995, a result of the diversion of a small stream by beaver onto a glaciofluvial terrace of sands and silts—no surface water flow reached the catastrophically formed gully.

A schematic representation of catastrophic seepage face erosion is presented in Figure 9. Under normal conditions, seepage exits the slope without...
causing erosion as the ground slope of the seepage face has adjusted to the highest recurrent seepage exit gradient and resulting seepage forces. A change in the discharge conditions results in an increase in seepage exit gradient above a critical value. (Seepage exit gradient is the slope of the piezometric surface adjacent to the drainage discharge point.) This increase in exit gradient may result from a rapid increase in groundwater discharge or sudden removal of material from the seepage face by a landslide or by running water. If the resultant erosion is of sufficient intensity, the retreating seepage face uncovers material with greater groundwater pressure, the exit gradient increases, and a continuing chain reaction results (Dr. O. Hungr, Univ. B.C., Earth and Ocean Science, Vancouver B.C., pers. comm., 1997).
EROSION DESCRIPTION

The large volume of surface water entering the site and the high infiltration rates of the gravelly sands permitted water to percolate through to depth. (The hydraulic conductivity measured for the glaciofluvial sands and gravels was $9.7 \times 10^{-3}$ and for the glaciolacustrine silts, $1 \times 10^{-4}$.) Thus, surface water added to the site greatly increased the amount of water delivered to water-bearing layers (aquifers) in the complexly bedded sands, silts, and gravels found within the terrace. Through-flow of the subsurface waters appears to have concentrated above fine-textured stratigraphic layers, and over impermeable layers of compact till and bedrock found in the site. Subsurface bedrock may also have helped to concentrate flows toward the failure outlet.

The substantial surface and subsurface flow directed toward location 6, a site of a small spoon-shaped depression on the terrace scarp, is assumed to have provided the trigger conditions. A rapid increase in seepage exit gradient resulted from a sudden increase in groundwater discharge or from the sudden removal of material from the seepage face by a landslide and/or running water. The removal of material on the scarp face uncovered material with greater groundwater pressure—generally confined, water-charged aquifers. The rapidly retreating seepage face then became the locus for caving failures and the convergence of surface and subsurface flow. At some point, the Donna Creek event reached a threshold where the erosional processes began to feed each other: headward advance, caving, collapse, and flow surges of liquefied material—hence, the sudden apparent avulsion of material that was first noticed on the morning of June 2, 1992. Debris flow surges rapidly transported a large volume of material from the site, down the adjacent gully channel, and down to Donna Creek. The excessive flow down the adjacent gully destabilized the steep gully side walls (slopes > 40°). Debris slides from these side walls entering the gully may have triggered debris flows or just added volume to the flow surges down the channel. Splash from flow surges is evident up to 5 m high along the gully side wall and 8 m high on the few trees left standing close to the apex of the fan. Large quantities of sediment and debris entering Donna Creek, combined with high spring runoff, triggered a debris flood (debris jam formation, breakage, and subsequent flow surges down the creek). Large volumes of sediment were deposited along the floodplain and temporarily stored behind logjams within the stream channel.

The description of the processes going on during this catastrophic event give rise to the question of what or how the event should be classified. The outcome is the formation of a large dendritic gully similar in shape and size to other gullies in the glaciofluvial/glaciolacustrine landform; hence, gully erosion or erosion by running water—a washout. Landslide processes are also involved: the collapse, dilation of material, and extremely rapid debris flow of liquefied material to Donna Creek; hence, flow or debris flow. The term “piping-flow” thus describes the overall complex landslide process.

Piping is a term commonly used to describe subterranean erosion (Parker and Higgins 1990). Terrain undergoing subsurface erosion often exhibits hollows or collapsed depressions aligned along routes of subsurface erosion. These features, combined with accompanying cave or pipe, are generally observed in arid climates in landforms composed of silt and clay. Piping is also used to describe soil pipes and/or water movement in forest soils in particular along root channels and along small erosion conduits in surficial
materials. Thus, piping is often a confusing or ambiguous term as related to landslides. On the other hand, piping may have been present in the landform before the event and active during the landslide process. Although, in non-cohesive materials this cannot be substantiated, in that features would not survive in sands, silts, and gravels as found at Donna Creek. More appropriately, catastrophic seepage face erosion describes the sudden change in the discharge conditions that result in an increase in seepage exit gradient, the subsequent convergence of surface and subsurface flow, retreating seepage face, caving, collapse, and debris flow surges.

GENERAL DISCUSSION

The catastrophic washout debris flow at Donna Creek serves well to emphasize a very basic concept in our knowledge of water source areas (drainage basins) and how roads modify water movement. A road constructed on a hillslope intersects many poorly defined micro-topographic drainage basins. If drainage is not adequately provided, the capture and redirection of surface and subsurface water in effect can expand the drainage area to an existing basin outlet. The subsequent increase in discharge into a different drainage basin (a result of an expanded drainage basin) can exceed the normal discharge of the channel or the ability of the site to disperse water, which may lead to slope failure. Water captured along forest roads is often directed off into the bush to disperse outside the natural drainage basin. The subsequent erosion is often not observed, in that erosion occurs out of sight from roads. Even though a site appears well drained, it may not handle an excessive increase in water. For example, well-drained sands and gravels of a glaciofluvial terrace overlying glaciolacustrine silts are highly erodible and subject to failure. Likewise, a kame terrace, composed of sands, silts, and gravel, situated on a hillside is highly erodible and subject to failure with the addition of excessive water.

Another important point emphasized by Donna Creek events ties closely to present requirements in the Forest Practices Code, Forest Road Regulations. Drainage basins are modified at the time of subgrade construction. As such, drainage systems must be installed and fully functional to accommodate surface and subsurface drainage runoff at the time of construction, and the drainage system must maintain surface drainage patterns as per B.C. Reg.106/98 Part 3.12 (1) (a) and Part 3.13 (1) (a) (Province of British Columbia 2000). If this practice had been implemented when roads were constructed in 1990 at Donna Creek, the washout-flow would not have occurred in June 1992. It is important to place adequate and functional drainage in a road subgrade at the time of construction.

The first reaction when we observe a large landslide or erosion event caused by an inappropriate practice on forest land is to find blame. However, it is important to step back and assess our involvement. We all travel forest roads for work and recreation access. How often do we see water captured and diverted long distances down a ditch, water flowing across a road in excess capacity for the drainage system, or the consequences of mass erosion? Often, these situations are observed but frequently the cause is not investigated or nothing is done to stop or correct the problem. In the Donna Creek situation, water capture and diversion by branch roads occurred during two
springs prior to the spring of 1992. It is hard to believe that no one observed or took action to correct drainage issues. In many respects, all of us working in the forest industry must take responsibility. We must observe, report, and correct drainage problems with roads to prevent serious erosion, landslides, and subsequent environmental degradation.

**SUMMARY**

The Donna Creek washout-flow was caused by changes made to the natural hillslope runoff. The changes were a direct result of water capture and routing along road ditches. These roads did not have sufficient cross-drains or culverts to permit water to cross the roads and flow into natural drainage channels. Excessive volumes of water were delivered onto highly erodible sands, silts, and gravel of a glaciofluvial/glaciolacustrine terrace at 730% that received under natural conditions. A rapid increase in seepage exit gradient resulted from the sudden increase in groundwater discharge, combined with a possible sudden removal of material at the terrace scarp by a landslide and/or running water. Catastrophic seepage face erosion describes the sudden change in the discharge conditions that result in rapidly retreating seepage face, caving, collapse, and debris flow surges of the June 1992 washout-flow. This catastrophic event at Donna Creek emphasizes a very basic concept in our knowledge of water source areas (drainage basins) and how roads can potentially modify water movement and cause destructive landslides.

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**LITERATURE CITED**


