FLOODPLAIN MANAGEMENT
ON ALLUVIAL FANS

Report

to

MINISTRY OF ENVIRONMENT
WATER MANAGEMENT BRANCH

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August 15, 1983
File: 15-33-1

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SYNOPSIS

Floodplain management on alluvial fans presents a number of unique problems. The purpose of this report is to provide a basis for assessing the hazard of flooding on alluvial fans in order to make recommendations for land development of alluvial fans.

The report consists of four main sections. The first describes alluvial fans and processes involved in their formation. The second discusses data which should be collected in order to assess an alluvial fan. The third describes a procedure for systematically evaluating the hazard of flood damage on an alluvial fan and the fourth section gives examples of application of this procedure to five alluvial fans representative of conditions throughout British Columbia.

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1. INTRODUCTION

This report summarizes the results of a study entitled Floodplain Management on Alluvial Fans. The terms of reference are contained in a request for a proposal accompanying a letter dated August 25, 1982 from the Water Management Branch of the Ministry of Environment (Appendix A). The proposal submitted by Thurber Consultants by letter dated September 14, 1982 was accepted and authorization for the study was provided in Contract dated November 1, 1982.

The professional team for the study comprises H.W. Nasmith, P. Eng., Dr. Rolf Kellerhals, P. Eng., and Dr. June Ryder. Mr. W.W.K. Smyth, P. Eng., Senior Hydraulic Engineer, Water Management Branch, Ministry of Environment has provided assistance and guidance to the study team with respect to Ministry requirements.

1.1 Background

Since 1974 the Ministry of Environment has administered The British Columbia Floodplain Development Control Program with the objective of identifying flood risk areas and providing recommendations on the management of floodplain lands. For the purposes of this program, floodplains have been defined arbitrarily as areas subject to flooding by the "Designated Flood". This flood has a statistical frequency of once every 200 years. A freeboard allowance of (usually) 0.6 metres is added to produce the elevations which form the floodplain boundary and safe building elevation. The probability levels vary from province to province but the B.C. range is within the range of values adopted elsewhere in Canada. In carrying out its responsibilities the Ministry reviews subdivisions, official regional, settlement and community plans and zoning bylaws.

Since 1974 numerous detailed hydrological and engineering studies have been carried out to delineate and map the floodplain for areas susceptible to flooding which may be developed for residential and commercial use throughout the province.

As discussed in later sections of this report flooding and flood hazards on alluvial fans differ in several significant ways from flooding on normal river floodplains. As a result, the well established procedures for delineating floodplains along rivers and lakes are not applicable on alluvial fans and the criteria for developments on alluvial fans cannot be stated in analogy with those for floodplains.

1.2 Objective and Scope

As stated in the terms of reference the purpose of the study is to:

- evolve and codify the general principles for analysis of alluvial fans with respect to determining their suitability for development.
- translate the results of analysis into actual conditions for consent to development.
- apply the above developed principles to specific cases.

2. DESCRIPTION OF ALLUVIAL FANS

2.1 Definition

An alluvial fan** is an accumulation of sediment that has been deposited where a stream changes from a confined channel with relatively steep gradient in a canyon or gully to an unconfined channel with relatively gentle gradient on a lowland or plain. The stream channel (stream bed) becomes broader and shallower as its gradient decreases.

An "active" alluvial fan is a fan upon which sediment is accumulating (ie. net accumulation) under present day conditions. An "inactive" alluvial fan was built during the past before some change in conditions put an end to sediment deposition.

** The term "alluvial fan" is used here in its broadest sense to include features variously referred to as "debris flow fans", "alluvial cones", some "colluvial fans", and others.

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Geometry: The surface of an alluvial fan is a sector of a cone. (See Fig. 1 for fan geometry and terminology used here). It normally has a perceptible gradient (at least 2° or 3%) from apex to toe. Longitudinal profiles may be straight or concave, but cross profiles (at 90° to any longitudinal profile) are always convex. The angle subtended by the sector of the cone at the fan apex may reach 180° or more, but it is rarely less than 30°.

Coalescing fans may be present where two or more closely adjacent creeks flow out onto a plain.

Identification: On a topographic map, an ideal alluvial fan appears as a series of arcuate and concentric contour lines that are convex downslope (Fig. 2), provided of course, that the total range of elevation of the fan is several times greater than the contour interval. (On 1:50 000 N.T.S. map sheets with 100' contour interval many small fans are marked by a single, smoothly bulging contour.) A concave break of slope is commonly but not always present along the stream channel at the fan apex.

Dimensions: Alluvial fans range in size from miniature landforms a few metres across, such as those seen at the foot of new road cuts after heavy rainstorms, to major landforms with a radius of several kilometres and a vertical elevation range of two or three hundred metres.

Stream behaviour: On alluvial fans where sediment accummulation is occurring at the present time ("active fans") the position of the stream channel is not fixed: streams shift their position frequently and abruptly. Thus sediment deposition and erosion by rapidly flowing water are the chief hazards to settlement on fans. Inundation by standing or slow-flowing water, such as occurs along floodplains and shorelines, takes place only under abnormal circumstances.

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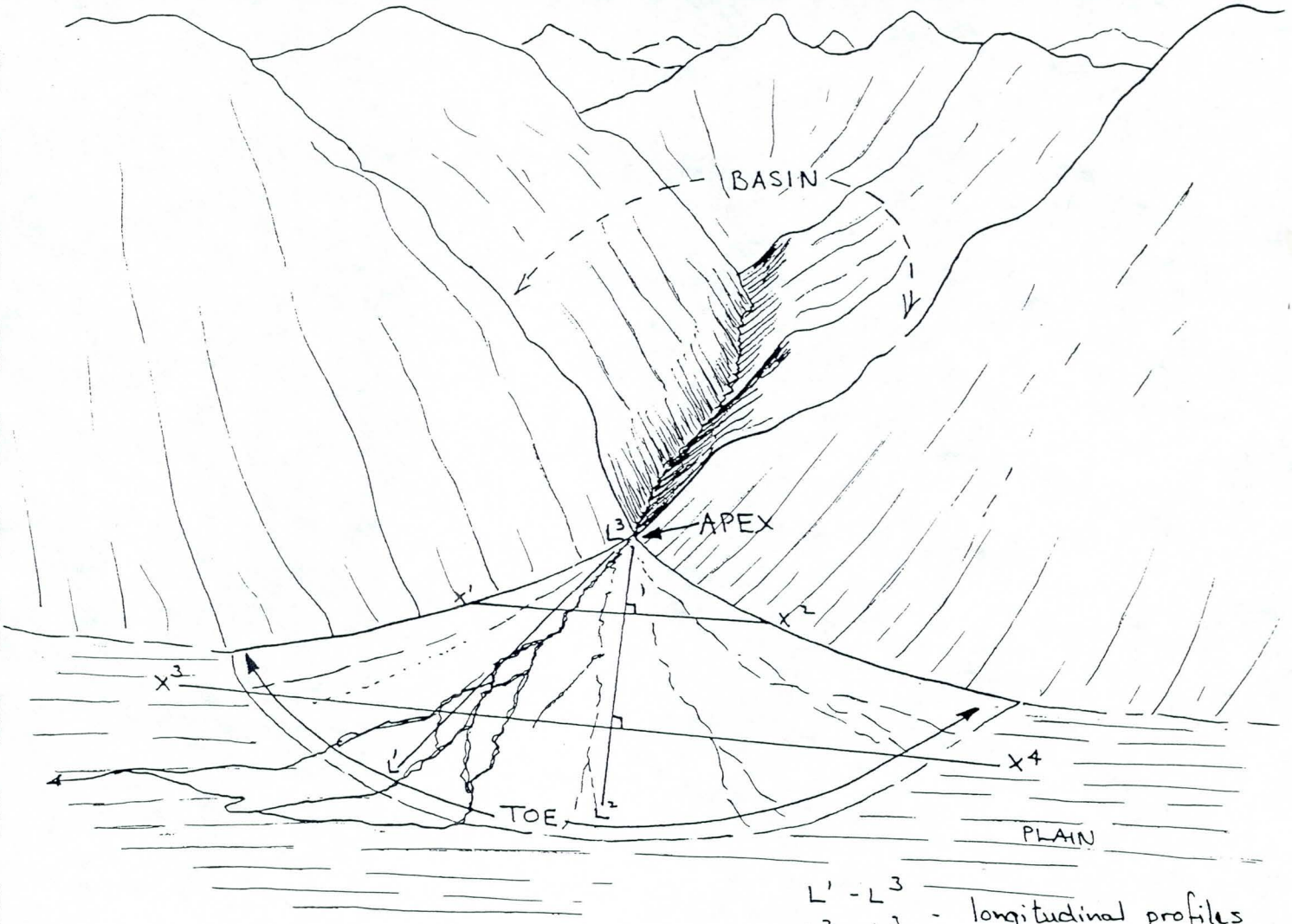
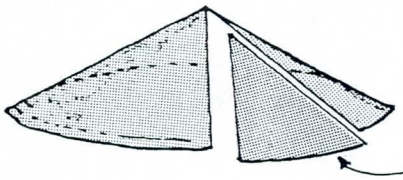


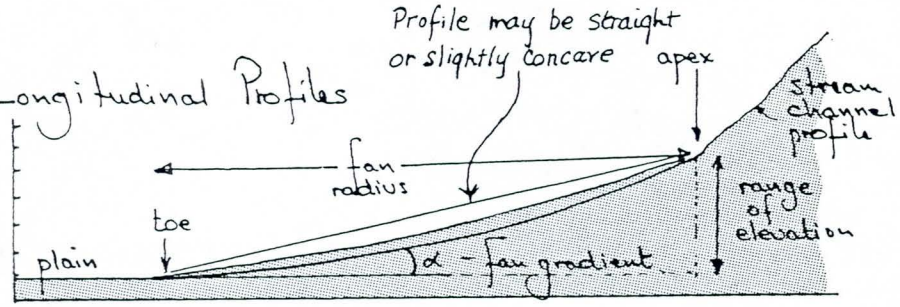
$L^1 - L^3$
$L^2 - L^3$ - longitudinal profiles

$X^1 - X^2$
$X^3 - X^4$ cross profiles

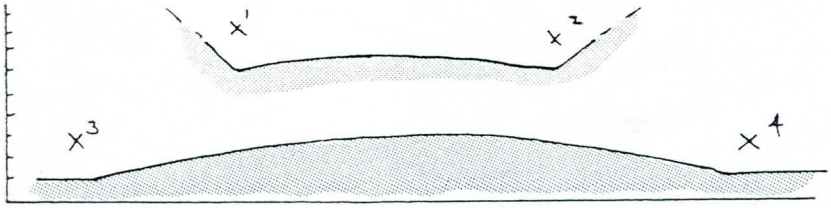


Sector of a Cone

Typical Longitudinal Profiles



Cross Profiles (from sketch above)



MORPHOLOGY AND TERMINOLOGY
FOR TYPICAL "ACTIVE FAN"

FIGURE 1

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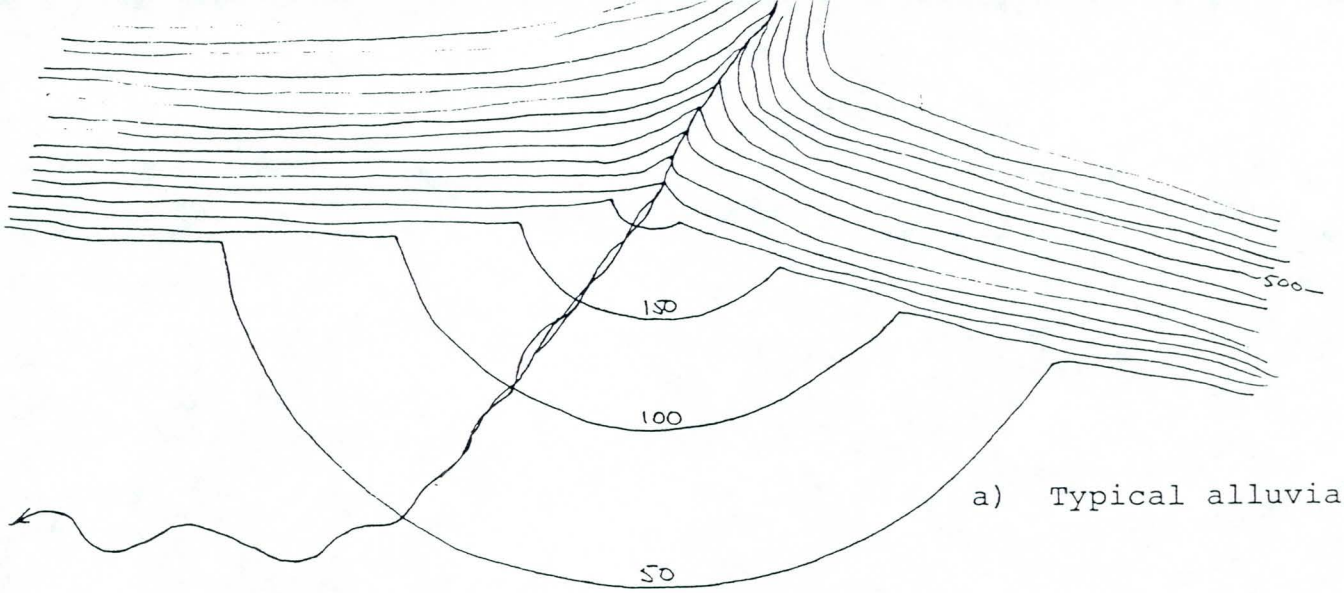
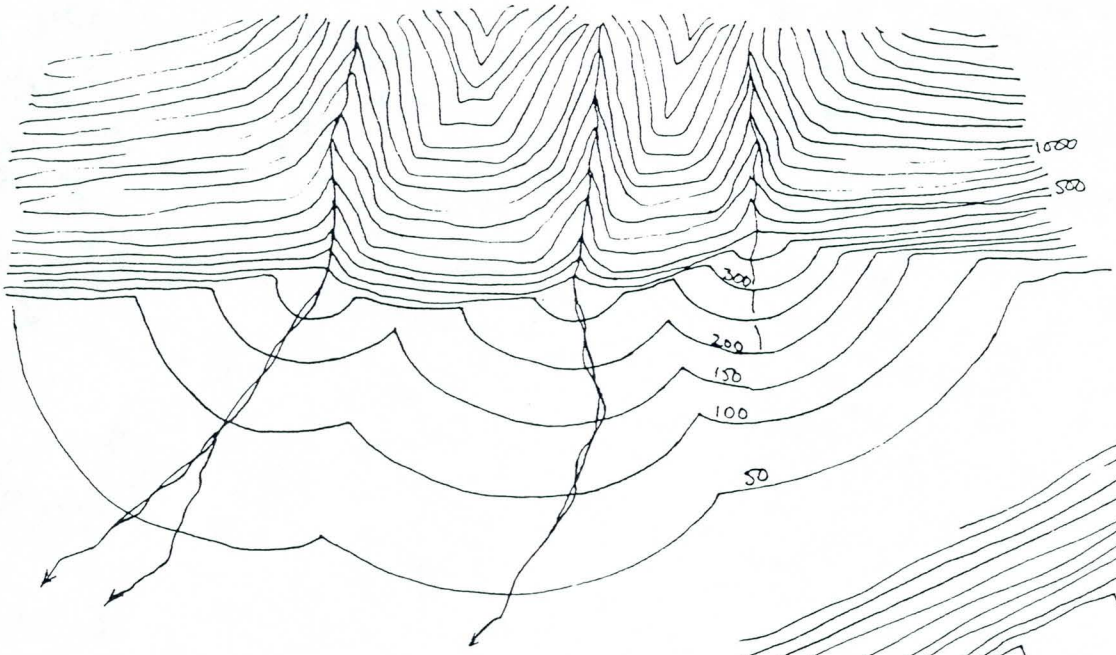
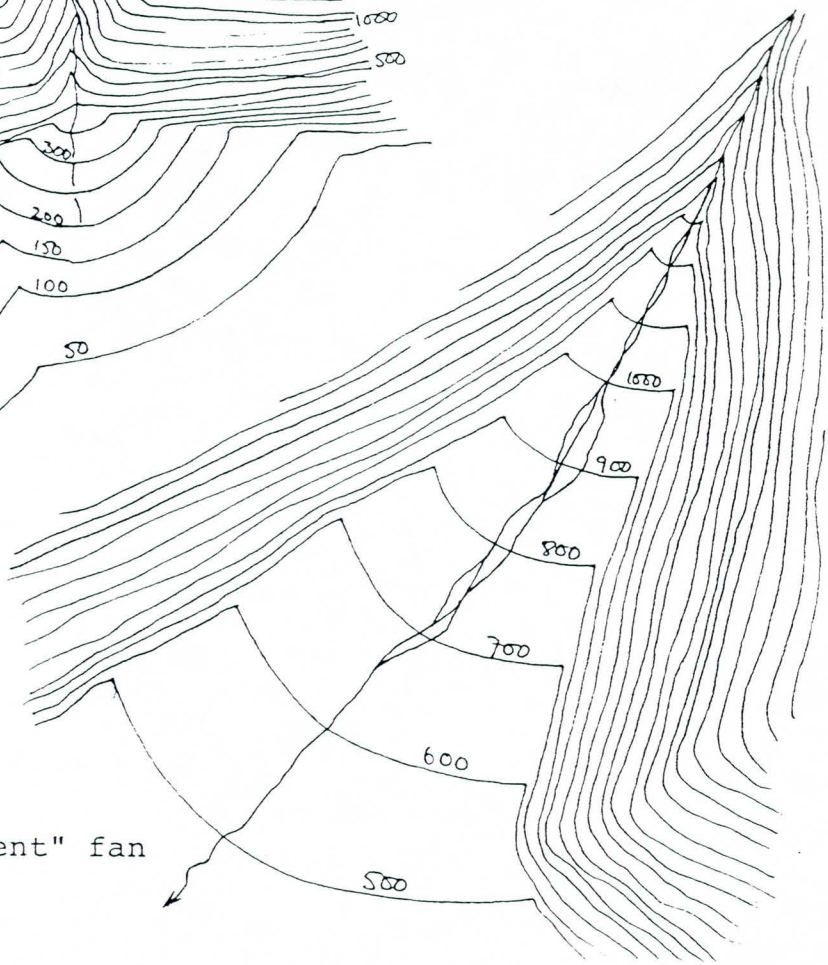


a) Typical alluvial fan



b) Coalescing alluvial fans



c) Narrow "embayment" fan

ALLUVIAL FANS ON TOPOGRAPHIC MAPS

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FIGURE 2

2.2 Process of Alluvial Fan Formation and Related Characteristics of the Fan Surface

There are three ways in which sediment is transported to and deposited upon alluvial fans: fluvial (stream) processes, debris flows (including mudflows), and debris torrents. Many, possibly most, fans result from more than one mode of deposition, however, for descriptive purposes, it is useful to consider them separately.

2.2.1 Fluvial Deposition

Streams and rivers transport material in solution (dissolved load), in suspension (clay, silt and fine sand), and as bedload (sand and gravel). It is this latter component that accummulates on fluvial fans. Bedload material consists of the sand to boulder sized materials that are normally visible along the bed and banks of a stream at low water. During floods, these large particles are moved along the stream bed, rolling or bouncing, due to the tractive force exerted by the flowing water. The magnitude of the tractive force is proportional to the velocity of the stream, and this in turn depends upon the depth of the water and its downstream gradient. Consequently, when the water becomes shallower and the gradient lessens as the stream emerges from a canyon and spreads out onto a plain, some bedload material can no longer be carried forward and begins to accumulate within the stream channel. Larger particles (cobbles and boulders) are deposited first near the fan apex, and successively smaller particles (pebbles, sand) are deposited further down the fan.

As a result of bedload deposition, gravel bars (islands) tend to form in the stream channel, the water splits to flow around them, and thus a braided channel pattern is formed. At low water, only one channel may be occupied by the stream, but during floods several channels may be active and a large part of the fan may be occupied by flowing water. Continued accumulation of gravel raises the stream bed above adjacent parts of the fan surface. Consequently the stream needs to shift its course from time to time

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to older, relatively low parts of the fan. The new course is not necessarily adjacent to the older one; a stream may shift abruptly from one side of a fan to the other without even temporarily occupying an intermediate position. Abrupt channel shifts to new positions are common on fans and are called "avulsions". Thus areas of a fan that are remote from the present channel and have not had any sediment accumulation for many years may suddenly be inundated by flowing water during a flood.

Active and abandoned channels on fluvial fans, particularly steep channels in coarse gravels, may be bounded by natural lévees. These are dyke-like features that extend along the main channel banks and consist of piled-up boulders that became stranded on the edges of the channel during flood. Range of relief between crest of a lévee and floor of a former channel pool may be as much as 3 or 4 metres. Thus a fluvial fan, particularly where it is relatively steep and bouldery near its apex, may have pronounced surface relief.

2.2.2 Debris Flow and Mudflow Deposition

A debris flow is a mixture of water and sediment that is of such a viscosity that it flows rapidly down steep, and confined channels, but slows and spreads laterally, like molasses, on level or gently sloping ground. Debris flows normally contain a high proportion of fine particles (silt and clay), but also include coarser rock fragments ranging up to blocks as big as automobiles. Logs and smaller pieces of wood may also be included. Mudflows consist almost entirely of fine particles. In British Columbia they are much less common than debris flows, generally occuring only in areas of thick lacustrine and marine Quaternary sediments, and they will not be further discussed here.

Debris flows are initiated when either weathered rock material or glacial drift of suitable texture becomes saturated, loses internal cohesion, and flows down slope. Flows may originate from small landslides on valleysides, from collapse of undercut stream

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banks, and from debris that accummulates in the stream channel itself during dry weather. Flows most commonly occur when the ground is saturated (but not frozen or snow covered) as a result of either prolonged heavy rainfall or sudden extremely heavy rainfall, or both.

A debris flow generally assumes a tongue-like or lobate form as it spreads and comes to rest on a fan. Excess water escapes from the saturated debris and drains down slope where it may deposit sheets of silt and sand, or it may become concentrated into stream channels. Water flow also usually follows a debris flow down the main stream channel. This flowing water cuts into the debris flow and reworks and sorts parts of the debris flow material. Thus shallow channels floored by fluvial sands and gravels are formed across the debris flow deposit and the more distal parts of the fan.

Where the central part of a debris tongue continues to flow after its margins have become stationary, or where a debris flow follows and partially spills over the banks of an old channel, debris flow lévees are formed. Some debris flow lobes survive intact, commonly surrounded by a semicircle of 'bulldozed' boulders.

Lévees and lobes provide a certain amount of local relief on the surface of debris flow fan. Relatively viscous flows tend to produce thicker debris flow layers and greater surface relief.

2.2.3 Debris Torrents

Debris torrents are intermediate in character between stream floods and debris flows. In other words, they may be considered either as a very wet variety of debris flow or as a stream flood with a high sediment concentration. They differ from debris flows in that: 1) they contain little fine material (silt, clay), and consequently the flowing mass is less cohesive and less viscous, 2) the depositional zone does not normally spread out over the gentle slopes of a fan: debris torrents tend to come to rest close to the break of slope at the fan apex.

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Debris torrents are generated in steep terrain under conditions of extreme rainfall and stream discharge. They are generally triggered by slides of debris entering a stream channel, and then they mobilize more debris as the ensuing slurry moves downstream. The volume of debris carried onto a fan by a debris torrent may be several orders of magnitude greater than the slide which triggered the event. Temporary blockage of a stream channel by a debris slide may result in an extremely high instantaneous discharge as the dam collapses and this can provide the erosive capacity to initiate a debris torrent downstream. Debris torrents may travel down a stream channel for several kilometres before terminating on a fan.

Debris torrent deposits typically consist of chaotic and heterogeneous masses of rock fragments including very large fragments and vegetation debris. Boulder lévees may be formed. Because the torrents are mobile only in steep, well defined channels, deposition occurs rapidly at and close to the fan apex, and this results in unpredictable channel diversions and construction of relatively steep fans.

2.2.4 General comments

The process(es) of deposition that takes place on an alluvial fan is determined by the characteristics of its basin and by local hydrologic conditions. The most relevant basin parameters are:

- sediment availability and type
- steepness of the valley side slopes
- vegetation cover
- extent and degree of disturbance by mining, logging or natural landslides.

The most relevant hydrologic parameters are:

- maximum runoff rate
- processes which influence runoff rate e.g. snowmelt, rainfall, glacier melt, and condensation snowmelt during rainstorms.

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A few generalizations can be made. Fluvial fans are typically associated with relatively large basins with permanently flowing streams. Stream gradients above the fan tend to be relatively low and the fans tend to be relatively large. Debris flows fans are typically associated with comparatively small and steep basins with ephemeral creeks (flowing only as a result of heavy rain or snowmelt): a supply of fine textured debris (e.g. from till or weathered shale) also promotes debris flows. These fans are relatively steep. Debris torrent fans occur at the foot of steep basins, commonly hanging valleys, in the Coast and Cascade Mountains. Fans are relatively steep.

As mentioned above, fans are commonly constructed by more than one process of deposition. Although historic records of major floods and debris flows are short compared to the frequency with which significant events occur, information about the processes responsible for a particular fan can be gained by examining exposed fan deposits, (e.g. in road cuts), by reviewing drill logs, and by careful examination of the fan surface in the field and on air photos. Many fans consist of alternating layers of debris flow deposits and fluvial deposits and it is, in fact, unusual to find materials of only one genetic type.

2.3 Development of Soil and Vegetation on Alluvial Fans

Growth of plants and soil development commences as soon as a fan surface, or any part of fan surface, becomes free from disturbance. In general, vegetation growth is more apparent and occurs faster than obvious soil development. Consequently the relative ages of various parts of a fan surface can be defined on the basis of vegetation types and areal patterns. For example, willows and alders may have colonized a recently abandoned channel, whilst conifers occupy stable intermediate areas. Trees can be dated by ring counts, and where a single generation stand exists, absolute dating of old channels and debris flows may be achieved. However, in general it is not appropriate to use the presence of mature vegetation

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as an indicator of a permanently stable (i.e. 'inactive') fan surface (or part of a fan) since the length of time to maturity of conifers in many parts of the Province is less than the specified frequency (200 years) of significant floods. Mature vegetation may in fact indicate a relatively 'low' area on a fan that is 'due' to be occupied shortly by the stream channel, precisely because it has not been occupied for some time.

Soil development on fans is a slow process - a mature soil may indicate a greater age of fan surface than a mature forest, but unfortunately, absolute age can not normally be determined from soil characteristics.

2.4 Geological History of Alluvial Fans

It is useful to consider the geological history of alluvial fans since this provides a context within which fan characteristics (see 2.5) can be readily explained and understood.

Alluvial fans that exist in the present landscape, ("active" fans and "inactive" fans of various types, see 2.5) postdate the most recent general glaciation of British Columbia (Fraser Glaciation). Development of fans commenced during deglaciation, about 13,000 to 10,000 years ago, as soon as suitable sites were uncovered by receding ice. Fans and other valley-floor depositional features, such as outwash plains, deltas, and lake sediments, were built up rapidly at this time because an abundant supply of sediment - glacial drift on valleysides - was available to creeks and rivers and there was little vegetation initially.

Sites for fan development were provided chiefly by outwash plains, kame terraces, till plains, and glacial (ice-dammed) lake and ocean shorelines where fans were superimposed upon deltas. However, some of these sites were temporary: recession of ice from kame terraces, lowering of lake levels due to melting ice dams, and an apparent lowering of sea level due to isostatic rebound of the land, brought about lowering

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of local base levels and steepening of gradient along many creeks. This in turn resulted in erosion, downcutting and dissection of many late-glacial alluvial fans (see 2.5 d,f, and g).

During postglacial time, alluvial fans have been constructed upon floodplains, upon deltas along modern lake and ocean shorelines, upon lacustrine plains, and in shallow depressions in drift or bedrock. Erosion and downcutting along many major rivers has again resulted in lowering of local base levels, and left former floodplains as terraces with superimposed fans. These fans are commonly partially or totally dissected (2.5 d & f). Where fan deposition alternated with fan dissection at intervals dictated by terrace development, fans with telescope structure may have formed (2.5 g).

One of the contributing causes to the post-glacial entrenchment of major rivers has been a gradual decline in the availability of sediment for transportation, and hence a tendency of rivers to pick up sediment from their beds and thus cut downward. This effect is also apparent on some fans. Where the elevation of the lower end of a tributary creek is fixed by a floodplain or lake (i.e. a local base level), entrenchment of the creek cannot occur at the fan toe but it may take place further upstream. Thus a fan-head trench may be formed (2.5.2 d). A similar effect could also result from increased peak flows of the fan's creek.

Deposition of fluvial sediments, debris flows, and debris torrents continues either regularly or sporadically upon many alluvial fans at the present time. Other fans may be inactive features even though they have undergone no degradation.

Layers of ancient volcanic ash (tephra) are present in some alluvial fans (as well as in some other depositional landforms such as talus slopes). Commonly occurring volcanic ash beds have been dated and traced back to their source volcanoes. Thus they provide a useful indication of the age and possible rates of accumulation of fan sediments. Three ash units are widespread in southern British Columbia.

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TABLE

Volcanic Ash Layer	Source	Age* (Yrs B.P.)	Typical Appearance
Mazama	Crater Lake Oregon	6600	white silt, 1-10cm thick
St.Helen's "Y"	Mt.St.Helen's	3200	white silt, 1-5cm thick
Bridge Rvr.	Meager Mt. (Pemberton)	2400	white, ranges from silt to pumice pebbles, 1 cm to over 1 m thick.

Ash layers are relatively easy to recognize in the field, but lab analysis is generally required for specific identification.

2.5 Morphological Classification of Alluvial Fans

The overall morphology (ie. topography or shape) of an alluvial fan is a result of its geological history and processes of formation. Fan morphology can be interpreted to indicate whether or not a fan is likely to be "active".

Fans can be classified morphologically from air photo interpretation, from analysis of topographic maps of suitable scale and contour interval, or from brief field inspection.

* B.P. = before present

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Classification

a) Steep fan

Definition: the longitudinal gradient of the upper one-third of the fan is between 10° and 25° (17 and 47%); the stream channel is on the fan surface or incised to only a shallow depth [see d) below]; the fan generally resembles those of Figures 1 and 2 but is comparatively steep.

Interpretation: the fan is probably active; the dominant depositional process is either debris flow (most likely if the fan has a relatively small, steep basin and no permanently flowing stream) or debris torrent (most likely if the fan has a relatively large basin in humid mountains and a permanent stream).

b) Moderately steep fan

Definition: the longitudinal gradient of the upper one-third of the fan is between 5 and 10° (9 and 17%); the stream channel is on the fan surface or incised to only a shallow depth [see d) below]; the fan generally resembles those illustrated in Figures 1 and 2.

Interpretation: the fan is probably active; it is likely that either debris torrents or debris flows are deposited on the upper part of the fan, but that flowing water effectively modifies the fan surface.

c) Gently sloping fan

Definition: the longitudinal gradient of the fan is less than 5° (9%); the stream channel is on the fan surface or incised to only a shallow depth [see d) below]; the fan generally resembles those in Figures 1 and 2.

Interpretation: the fan is probably active; it is likely that fluvial processes govern sediment deposition and fan surface characteristics.

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d) Dissected fan

Definition: the stream is entrenched into the fan surface for the entire distance between apex and toe; the depth of the gully that is occupied by the stream is sufficiently great that no overflow of water or sediment onto the fan surface will occur during flood; see Figure 3; fan may have any gradient (2 to 25°).

Interpretation: fan surface is inactive and free of flood hazard.

e) Fan with fan-head trench

Definition: the stream is entrenched below the fan surface near the fan apex but emerges onto the fan surface before it reaches the fan toe; fan may have any gradient between 2 and 25°.

Interpretation: the upper part of the fan may be inactive (depending upon the depth of the fan-head trench) while the lower part of the fan may be active (Figure 4). The intersection point is the apex of the (probably) active part of the fan. Fan-head trenches occur on fans where fluvial processes are important: the gradient criteria of b) and c) above can be used to assess the likelihood of other depositional processes.

f) Fan with fan-toe trench

Definition: the stream is on the surface of the upper part of the fan, but becomes entrenched before it reaches the fan toe; fan may have any gradient between 2 and 25°; Figure 5.

Interpretation: the whole fan could be considered active because if the stream on the upper fan were to shift its position, then a new stream course anywhere on the lower fan could result. However, if the fan-toe trench is a fairly major feature, and if no old abandoned fan-toe trenches exist elsewhere on the fan, then the stream has likely been stable for a great

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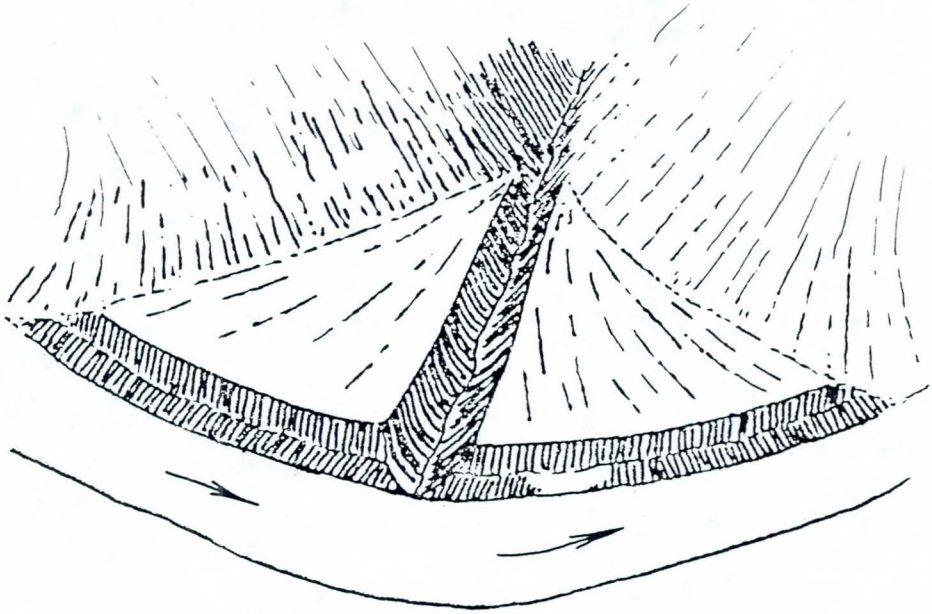
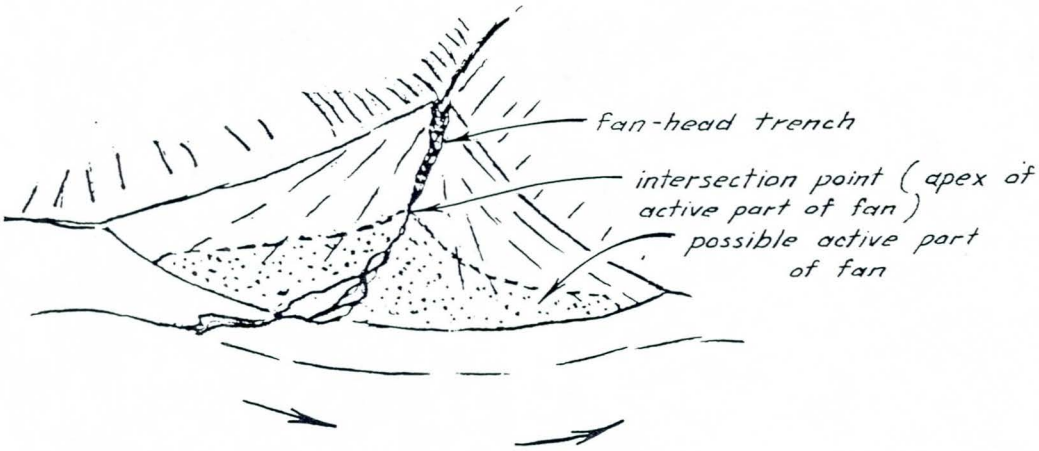


DISSECTED FAN

Block diagram of a dissected fan. The remaining fan surface is inactive if the gully is deep enough to contain the stream under all possible conditions of flood and blockage. Fan dissection occurred due to entrenchment of the major river.

FIGURE 3



FAN WITH FAN-HEAD TRENCH

Block diagram of a fan with a fan-head trench. Diagram indicates how the fan may have active and inactive zones. Stream incision probably occurred in response to either decreasing sediment supply or increasing stream discharge.

FIGURE 4

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length of time. It will probably remain so for as long as the present conditions of water and sediment supply remain undisturbed.

g) Telescope-structure fan

Definition: a fan with one or more surfaces inset below an older, higher fan surface (Figure 6).

Interpretation: the lowest fan surface may be active if the stream is not entrenched; the higher surfaces are inactive.

2.6 Alluvial Fans Distinguished From Similar Landforms

2.6.1 Definitions

Talus cones (sometimes called alluvial cones) are accumulations of rockfall debris. Cone gradients are typically steeper than 30° and longitudinal profiles are straight above a basal concavity. Debris consists of angular particles that are roughly size sorted, with fine material near the apex and coarse material (generally large angular boulders) at the toe of the cone.

Avalanche cones are constructed by accumulation of debris transported and deposited by snow avalanches. Cone gradients are generally less than 30° and longitudinal profiles are commonly highly concave, although some are almost straight. Debris consists of angular rock fragments, which show little systemmatic size variation downslope, and wood debris. Avalanche cones can be recognized by their location at the lower end of avalanche chutes (topographically constricted avalanche tracks - funnels or gullies), the presence of avalanche tracks upon them, and the presence of lingering snowbanks near cone apices in spring and early summer. (Avalanche tracks, the paths repeatedly followed by snow avalanches; are marked by strips of immature vegetation (deciduous shrubs or young trees, and young coniferous trees) and damaged trees. The bright green colour of avalanche track vegetation contrasts strongly with adjacent dark green

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zones of mature coniferous forest, and thus tracks below timberline are easily recognized when viewed either in the field or on air photos.

Avalanche hazards, although they may affect all or part of a fan are a problem separate from hazards due to active fan building processes. They are not considered in this report. Procedures for evaluating avalanche hazards have been developed by the British Columbia Ministry of Highways and the National Research Council of Canada.

Floodplains - Although alluvial (fluvial) fans are themselves a particular kind of floodplain, it is obviously necessary to distinguish between fans and (other) floodplains for the purposes of this project. Because some floodplains, like fans have braided channels and are subject to the same hazards as fans, the best way to differentiate them is by the rather arbitrary geometric criterion mentioned earlier: regular arcuate and concentric contours characterize a fan. (Figs 1 & 2)

2.6.2 Discussion

Although typical talus cones and avalanche cones are clearly distinguished from alluvial fans by their characteristics described above, intermediate forms do occur. For example, a fan/cone may be constucted by both debris flows and rockfall; its characteristics will reflect the combined processes, in particular its gradient will be steeper than that of a 'normal' debris flow fan but less than that of a talus slope. Accordingly, it is proposed that again an arbitary criterion be applied: that alluvial (debris flow) fans are characterized by gradients of less than 25°.

Fans or cones that show avalanche tracks should not be classified only as alluvial fans, (even though their toes may well carry the scars of shifting channels), because it is most likely that snow avalanches represent the greatest hazard to human settlement on such sites.

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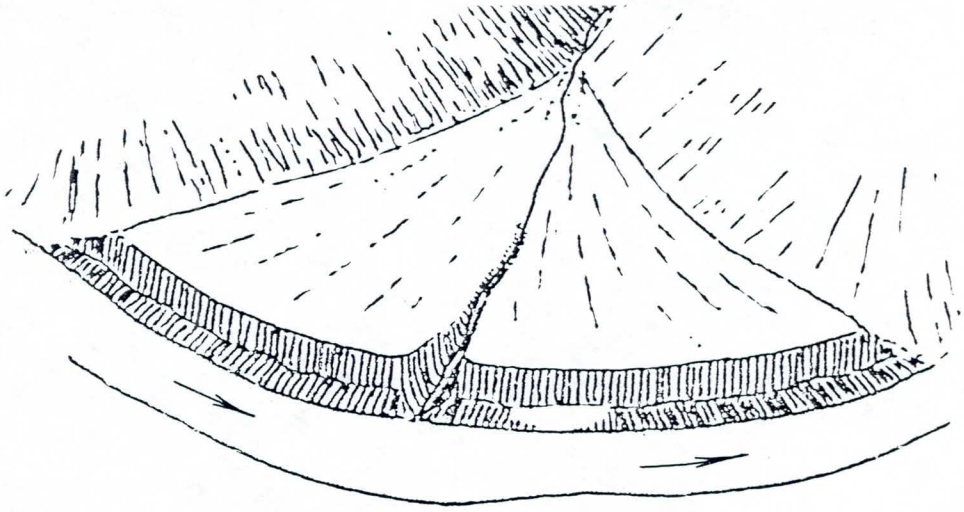
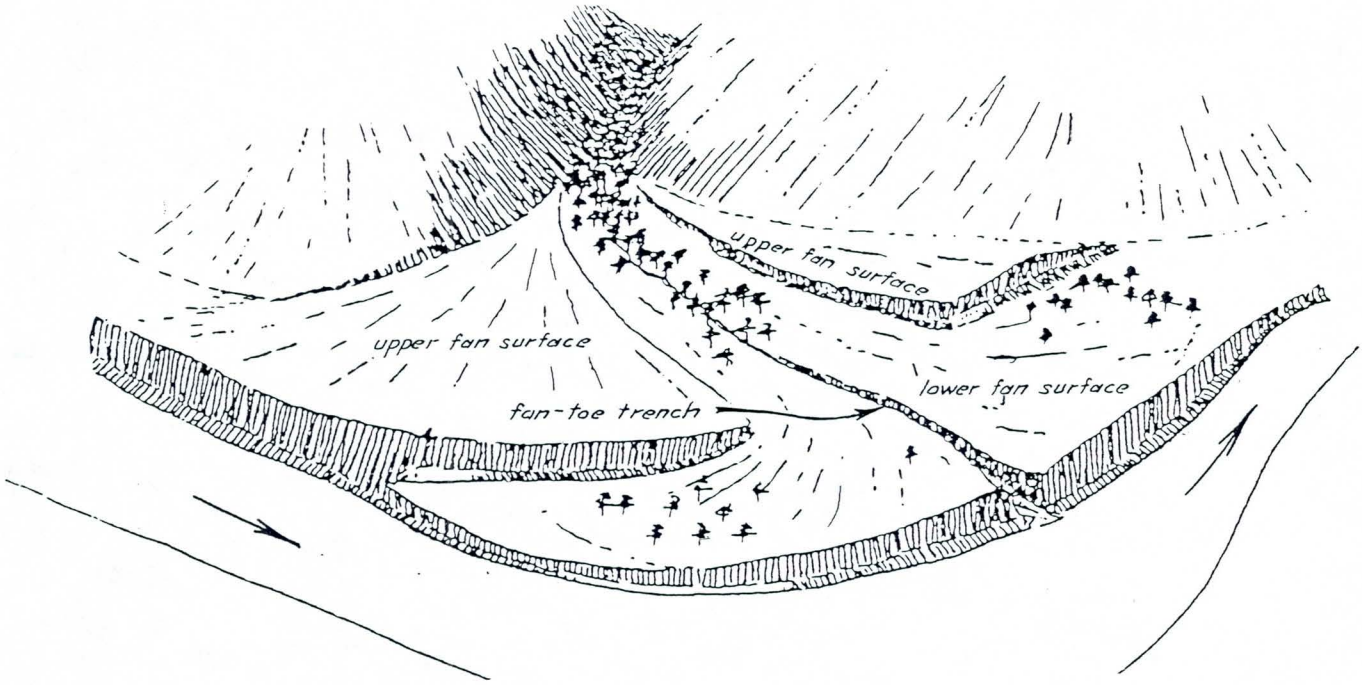


FAN WITH FAN-TOE TRENCH

Block diagram of fan with toe-fan trench. Stream incision is occurring due to entrenchment of major river.

FIGURE 5



TELESCOPE STRUCTURE FAN

Block diagram of telescope structure fan. In this case a fan-toe trench has formed in the lower of the two fan surfaces, but the lowest surface of some telescope structure fans may be active. Fans like this form where a major river is shifting, from side to side on its floodplain, and periodically trimming back the toe of a tributary fan.

FIGURE 6

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2.7 Alluvial Fans on Terrain Maps

Alluvial fans and similar features are normally indicated on terrain maps issued by the British Columbia Ministry of Environment, and on surficial geology maps published by the Geological Survey of Canada. Fans dominated by fluvial processes are normally shown as fluvial or alluvial fans (symbols commonly used are Ff, gFf, $F^{A}f$ etc.). Fans dominated by debris flows are shown as colluvial fans (e.g. Cf, dCf, gCf), but so also are some other features such as talus cones (Cf, rCa, aCa, Cc) and avalanche cones (Cf-A). Consequently these maps provide only partial information about the distribtion of "alluvial fans" as defined in this report.

3. DATA AND BASIC STUDIES REQUIRED FOR EVALUATION OF ALLUVIAL FANS

The following sections discuss the sources of information which are required for an evaluation of the flooding hazard on an alluvial fan. The amount of information collected will depend on the importance of the study and the availability of funds, e.g. the cost of a large scale topographic or orthophoto plan may not be justified for a fan where only a few widely scattered residences are planned. However such detailed mapping is probably essential where closely spaced housing developments are proposed or underway.

3.1 1:50,000 Scale NTS Topographic Maps

In general the contour interval is too coarse for identifications of all but the largest fans. The maps are useful for determining the drainage area above the fan and for getting a general indication of the character of the watershed. A rough profile of the entire stream from the toe of the fan to its headwaters should be drawn from NTS maps.

3.2 Vertical Air Photographs

Vertical air photographs are available for most areas of the province from the Resource Surveys and Mapping Branch of the Ministry of Environment. Photographs taken at different times and to different scales are available. In addition several private commercial survey organizations have extensive photo coverage taken for special projects (mining, highways, railways, transmission lines, pipelines, etc.)

A study of vertical air photos using terrain analysis techniques to produce a terrain map is an essential part of evaluation of an alluvial fan. The ELUC classification should be refined to give greater attention to minor topographic detail particularly the delineation of abandoned stream channels (see Appendix A).

3.3 Large Scale Topographic or Orthophoto Maps

Large scale maps are very useful in providing quantitative information about the micro-relief of the fan surface which is generally needed to differentiate between various degrees of hazard. These maps are prepared on a scales of about 1:5,000 with contours at one metre intervals. The presence of trees or brush on the fan and the availability of vertical control limits the reliability of the contour locations but when this mapping is available, it is often very useful and for concentrated housing development, it may be worthwhile to have these maps specially prepared.

In situations where large scale mapping is not available or justified, a few carefully located transects across the fan combined with a profile along the stream will provide valuable confirmation of the air photo interpretation by indicating the degree of incision of active or abandoned channels and by quantifying differences in elevation between various fan surfaces.

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3.4 Hydrology

A detailed review of the hydrology of the stream should be carried out at an early stage of the study. This would include a review of the relevant stream records if they are available, or a review of the records of nearby streams and the dates and character of observed floods. A review of published regional flood studies should be made and an estimate made of the existing channel capacity. This hydrologic study will assist in interpreting information from eyewitness accounts and other sources of historical information.

3.5 Historical Information

Conclusions from the previous studies (Sections 3.1 to 3.4) can often be confirmed and amplified with historical information from a wide variety of sources. These include the files of various government agencies, newspaper files and interviews with long-time residents. The objective of assembling historical information is to establish the frequency and severity of past flooding problems and if possible to identify the process responsible (e.g. fluvial sedimentation, debris flows, ice jams, etc.).

3.6 Field Observations

Air photo interpretations and details of topographic features should be confirmed by field traverses. Evidence of the effects of floods on vegetation along stream channels, evidence of recent flows of water along dry channels, and other characteristics of the fan surface such as the age of vegetation in old channels and degree of soil development should be examined. In the watershed, evidence of slides and erosion which contribute heavy loads of sediment to the stream should be examined. The character of the channel of the stream both on the fan and in the watershed should be examined.

In effect the field work involves detective work to collect evidence from a variety of observations which will confirm or modify conclusions from the

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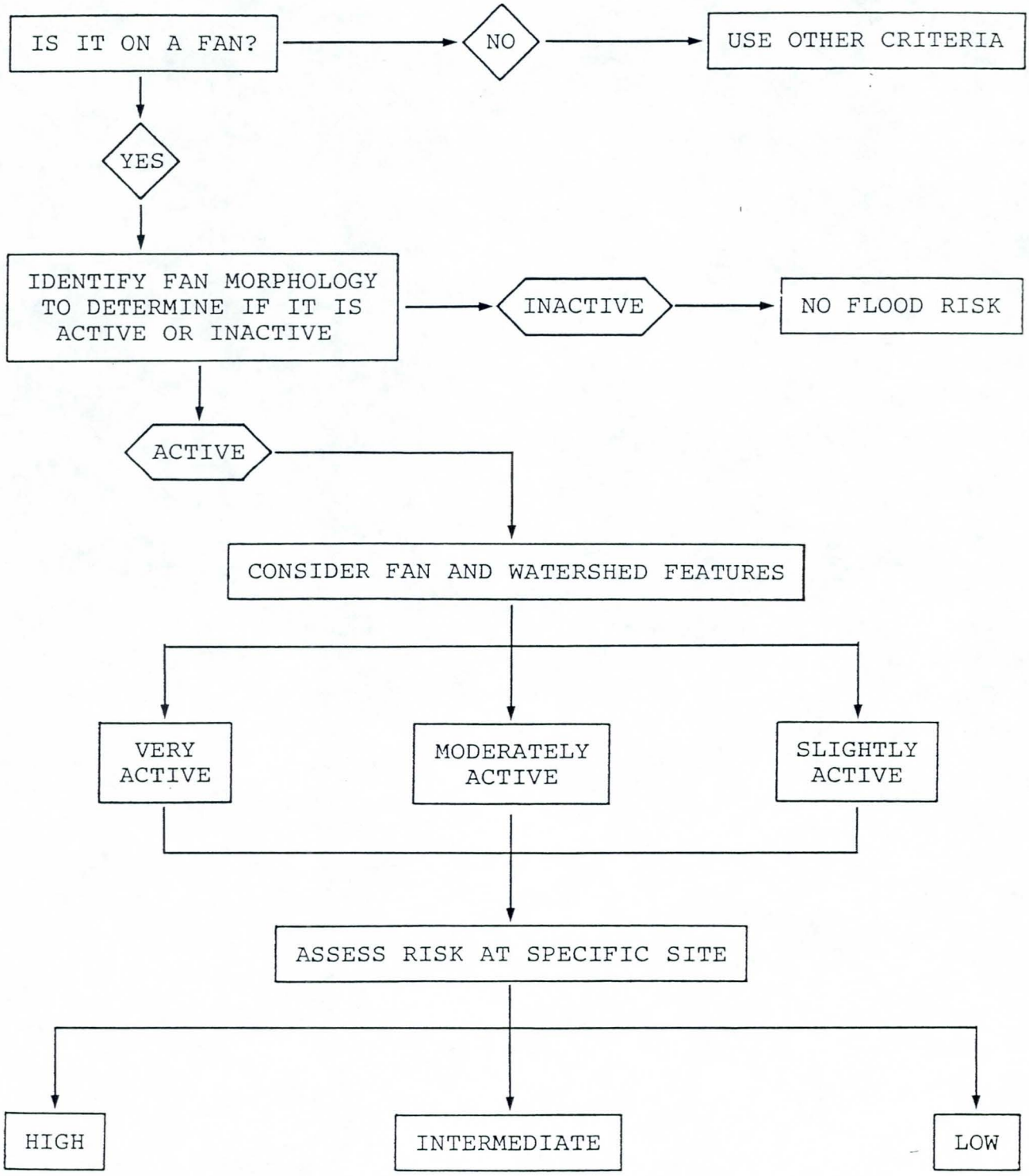

SEQUENCE OF STEPS IN ASSESSING
FLOOD RISK ON AN ALLUVIAL FAN

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FIGURE 7

previous studies. In some cases, it may be desirable to call on the expertise of specialists in various fields (soil science, ecology, geomorphology, etc.).

4. EVALUATION OF RISK OF DAMAGE BY FLOODING ON AN ALLUVIAL FAN

At the outset it should be recognized that for most sites on an alluvial fan there is some risk of flood damage. Because of the difficulty of predicting the behaviour of streams on alluvial fans it is almost impossible to obtain a quantitative evaluation of risk comparable to the 200 year flood risk for a floodplain site.

On a floodplain, damage is principally by inundation and the risk is the same over wide areas of the floodplain where the ground surface is below the flood level. By contrast the flood damage on an alluvial fan is from erosion and deposition by running water by debris flows and debris torrents. The damage may have a very erratic pattern as the stream shifts its channel.

Figure 7 shows a step-by-step sequence for assessing the risk of damage from flooding for a specific building site on an alluvial fan. The sequence consists of first determining if the site is on an alluvial fan. If it is not, then other criteria for evaluating risk need to be used.

The next step is to decide if it is an active or inactive fan. For purposes of this study, an active fan is considered to be a fan where natural processes are continuing to deposit sediment on the fan surface. The present stream channel is considered to be part of the fan surface unless it is incised. An inactive fan is one where no deposition is occurring on the fan surface usually because the channel is incised and the stream is able to carry sediment from the watershed above the fan to a depositional site beyond the limits of the fan. If the fan is inactive there is essentially no risk.

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For an active fan some evaluation of how active it is is required. An active fan may be very active, moderately active or only slightly active. The degree of activity depends on the amount, frequency, location and process of sediment deposition.

Finally, on any active fan the risk of flooding is not uniform over the whole fan, but varies according to the location on the fan and may be strongly affected by minor topographic features.

The topics to be addressed are discussed in more detail in the following paragraphs.

4.1 Is the Site on an Alluvial Fan?

The identification of an alluvial fan is discussed in Section 2.1 and illustrated in Figs. 1 and 2. The most important criterion is the topographic form which is a sector of a cone and is characterized by convex contours. If the topography is complex and not clearly identified as an alluvial fan then the risk of flood damage must be assessed on some other basis.

4.2 Is the Alluvial Fan Active?

An active fan is one which is being built up by the addition of fresh sediment. A dissected fan (2.5 d and Figure 3) is inactive, and any sediment that arrives at the fan apex is carried to the toe without being deposited on the fan surface. Certain areas of fans with fan-head trenches (2.5 e and Figure 4) or fan-toe trenches (2.5 f and Figure 5) may be inactive while other parts are active. The lowest fan surface of a telescope-structure fan (2.5 g and Figure 6) may be active.

The distinction between an active and inactive fan is based primarily on the topographic relation between the stream channel and the fan surface. If the channel is incised so that the stream cannot overflow its banks or break out of its channel then the fan may be considered to be inactive and the risk of damage by flooding is minimal.

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It is difficult to assess the depth to which a creek must be incised (eg. depth of the fan-head trench) before the adjacent fan surface can be considered to be inactive. Even if the trench or gully occupied by the creek is large enough (from hydrologic considerations) to contain the maximum flood, allowance still has to be made for possible temporary blockage. This may occur due to log jams, pile-ups of boulders, and local slumping of undercut stream banks, which may also include trees toppling into the creek and other causes. Blockage or overflow may also happen if a debris flow or debris torrent comes to rest in the gully. If the incised creek has developed a floodplain, or in other words, if the gully has a flat floor (outside of the channel itself), then overflow onto the fan surface is less likely to occur. A close examination of the incised zone of the creek and the stream channel at and above the fan apex should be made with regard to all possible blockage mechanisms. The capacity of the gully can then be reassessed.

4.3 How Active is the Fan?

Given that the fan is active (i.e. it is not incised) the degree of activity depends principally on the volume and character of the sediment which is transported to the apex of the fan, and how it is distributed over the fan. This cannot be directly measured but must be inferred from observation of the characteristics of the watershed and of the fan itself.

Very active fans will be found where the upstream watershed:

- provides a stream with an abundant supply of unconsolidated, medium to coarse granular sediment or loose rock; steep slopes of loose debris may extend down to the stream channel
- provides fine textured material suitable for transformation into mud flows or debris flows (e.g. certain types of weathered bedrock, till, lacustrine and marine silts and clays)

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- is characterized by landslides, eroding stream banks and slopes disturbed by road building, logging etc.

- has steep stream gradients and steep valley sides.
- is subject to flash floods - i.e. the time for concentration of flood runoff is short and there is a very large difference between low flows and high flows.

Streams which have glaciers in their headwaters tend to build very active fluvial fans because they have an abundant source of sediment which is not stabilized by vegetation, and at the same time have extreme variation in flow between periods when the source is frozen and when warm rain is falling on the snow and ice.

On the fan itself various lines of evidence suggest a high level of activity.

- numerous secondary and abandoned channels.
- reports of changes in channels and flooding.
- recent channel shifts indicated by vegetation.
- evidence of recent debris flows, particularly near the fan apex, including debris caught up in vegetation, mud or damage on tree trunks, fresh looking boulders, levées and lobes, lack of mature soil and immature vegetation.
- evidence of recent debris torrents, particularly near fan apex, including fresh looking boulders, vegetation debris, damaged trees (but still standing), damaged or washed-out structures such as culverts, immature vegetation.
- a high watertable outside the stream channel suggests that the channel is being built up by deposition of the bed load.
- a high ratio of the area of active braided channel to the area of the fan itself together with evidence of channel shifting is evidence of very active fan-building processes.
- a tendency for stream flow to sink into the ground accelerates build up of the bed and consequent tendency to shift channels.

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The least active fans will be found where the upstream watershed is.

- well vegetated with no evidence of abundant sediment sources.
- the steam gradient is low and the channel is stable.
- the difference between maximum and minimum flow is minimum - e.g. where lakes tend to even out flood flows.

On the least active fans the evidence tends to be negative.

- a stable channel with well vegetated banks.
- a channel slightly incised though not so deeply incised as to justify a conclusion that the fan is inactive.
- stratigraphic evidence in the form of a volcanic ash at shallow depth (i.e. 1 m) indicating a very slow build-up of the fan.
- mature soil development and uniform cover of vegetation.
- veneer of wind-blown silt and sand.

Evidence for a very active fan will probably be easily recognized and unambiguous. The evidence for moderate and slight activity may be more ambiguous and difficult to interpret. Judgement and experience will be required in an assessment.

It should be noted that some of the changes in a watershed that are due to human activities such as logging or road building by inappropriate methods, can increase the amount of sediment that is supplied to a stream. This sediment may then take several years or even decades to move down the stream it may eventually "reactivate" a formerly inactive or only slightly active fan.

4.4 Site Specific Risk of Flooding

On any fan whether it is very active, moderately active or slightly active the risk of flooding is not uniform over the whole fan.

In general the highest risk is in the upper 1/3 of the fan unless the stream is significantly entrenched at the head of the fan (see Fig. 4 and Section 2.5 e). The risk is particularly high where the stream gradient above the apex of the fan is very steep and changes abruptly to a flatter gradient so that there is a tendency to deposit sediment at the apex of the fan. The risk is also greatest at the apex of the fan where sediment is transported to the fan by debris flows or debris torrents.

The risk of flooding is intermediate in the middle third of the fan and in general is lowest in the lower third of the fan. The exception for this last statement is again where a fan-head trench exists (Fig. 4 and Section 2.5 e). In this case deposition and channel shifts may occur along the stream where it crosses the lowest part of the fan.

Superimposed on this general variation of risk over the surface of the fan is a detailed variation of risk related to proximity to the stream channel, and to temporary or abandoned channels. The highest risk is adjacent to the exisiting stream channel, in abandoned channels and in any depressions on the fan surface (i.e. where contours on a large scale map may bulge toward the fan apex). The risk diminishes away from the channels on higher ground (i.e. where contours bulge toward the fan toe) and is lowest on any minor topographic high which is situated so as to divert a stream or mudflow around it.

Risk is also relatively great at sites that are in a direct line downslope from any sharp bends in the stream channel, particularly if the stream is in any way constricted at that bend. During a flood streams may divert along roads, trails, transmission line clearings or any smooth areas. Walls, road and railway embankments, buildings, ditches and other minor topographic features can also influence the course of a sudden stream diversion or the route taken by a debris flow.

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The site specific evaluation of risk applies only to specific building sites and requires a detailed field examination. Such an evaluation of risk would not be applicable if any significant amount of road building or site grading was to be done to prepare an area for subdivision for a number of building sites.

5. MITIGATION OF RISK

Although some risk of flood damage will always remain for houses built on an active alluvial fan mitigation measures can be used to reduce the risk to an acceptable level for parts of the fan.

The first method is by zoning and building site selection. The most hazardous areas of the fan can be zoned for uses which do not require permanent occupancy and building sites can be chosen which are away from the channels on local topographic highs. This procedure is applicable only to low density developments involving a few houses.

For more extensive subdivision developments the general zoning of hazardous areas for nonoccupancy uses can be applied but the road building and site grading for housing should be designed to provide protection from channel shifting and erosion. In order to do this, provision must be made for ample alternative channel routes and continued observation and if necessary maintenance of the channel.

The most difficult problems arise when substantial development has already occurred on an active fan. Often the stream has been confined or diverted to an unstable channel from which it may break out during a severe storm. Resolution of this hazard may require such engineering features as sediment traps, diversion dykes and drop structures. This sort of problem justifies thorough engineering evaluation and may require an expensive solution.

6. EXAMPLES

In order to test the procedure and principles for evaluating flooding hazards on alluvial fans which have been outlined in the preceding sections, the team carried out an office study of five alluvial fans. The results of the office study are summarized in the following sections. They are described to illustrate the recommended procedures for evaluation of alluvial fans and illustrate the range of problems which are encountered in British Columbia.

Following the preparation of this report in draft form the senior author (Nasmith) visited three of the fans, Simms/Hillier Creek, Lemon Creek and Duhamel Creek accompanied by the local representative of the Water Management Branch. Observations and recommendations for action have been added to the discussion of these three examples. In some cases the field studies modified the assessment from office studies and point out the need for field studies to follow office studies before decisions can be made regarding development on alluvial fans.

6.1 Simms Hillier Creek

6.1.1 Background*

This fan is located on the north side of the Eagle River valley about 8 km east of Sicamous. On the 1:50,000 NTS map (82 L 15, Malakwa) the creek is not named and the fan is too small to be indicated by contours at 100 foot intervals. The fan (but not the watershed) is shown on orthophoto floodplain mapping of the Eagle River (sheets 3&4, scale 1:5000, contour interval 1 metre). The bulk of the fan is forested and the contours do not appear to accurately delineate the surface of the fan. Vertical air photographs taken in 1969 and 1975 at two different scales* were used

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* Lists of photographs, maps and other reference material are contained in Appendix B.

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for the present study. Limited development has occurred on the fan to date but a request to subdivide has recently been received.

6.1.2 Evaluation

Is it a fan? Yes. The typical fan shape can be identified by examination of the vertical air photos. The fan is too small to be delineated by 100 ft contours on the 1:50,000 map and the 1 metre contours on the air photo mapping appear confused by the forest cover.

Is the fan active? The stream channel appears to be only slightly below the general surface of the fan, and therefore the fan must be considered potentially active. The fan appears to have a moderately steep gradient (a quick field check will confirm this), suggesting that some process in addition to fluvial deposition has been involved in fan building. There is no evidence of recent channel shifts and the channel follows a relatively steep straight path across the fan.

How active is the fan? Examination of the watershed on air photos reveals evidence of old logging and minor instability. The stream channel is steep immediately above the fan as indicated both from air photos and the 1:50,000 map, indicating a potential for debris flow. Examination of air photos of the fan shows what appears to be a uniform stand of coniferous trees and no clear indication of old abandoned channels. The fan has not pushed the Eagle River to the opposite side of the valley or caused any apparent change in the character of the river where the creek enters, suggesting that rapid growth of the fan has not occurred recently and that very little sediment is being transported across the fan and deposited in the Eagle River.

On the basis of the office study of maps and air photos, the fan appears to be only slightly active unless the effects of logging in the watershed destablize it.

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6.1.3 Hydrology

The hydrology of Simms and Hillier Creek was discussed with Paul Doyle in the field. Hillier Creek is a small creek with a poorly defined natural channel and development on the fan would require establishment of a creek channel. Since it is a small creek the channel could be constructed to dimensions adequate for anticipated flow. Simms Creek is a substantial stream but except near the apex where it is confined by a low dyke the channel appears to have adequate capacity for anticipated floods. If the dyke is strengthened and unless the channel is blocked by debris there should be no flood hazard.

6.1.4 Field Observations

The fans of Simms and Hillier Creeks were examined on July 13 in the company of Mr. Paul Doyle of the Water Management Branch in the Kamloops office.

The file dealing with Water Management Branch experience and applications was not available so that no historical data regarding the fans was available.

The fan of Simms Creek has been disturbed by development in the last few years. Payne Road and Solsqua Road in places are located in what appear to be old stream channels. Houses located near the apex of the fan appear to have been built within the past ten years. A portion of the fan near the apex has been used as a stockpile site for crushed gravel and a small knoll near the apex appears to have been removed.

The stream channel is straight with coarse natural and imported riprap along the banks and shows no conspicuous evidence of erosion above the bridge on Solsqua Road.

Over the surface of the fan there are a number of dry stream channels which appear to have formed where overland flow was concentrated into a channel.

The material at the apex of the fan where it can be seen in the banks and in the stream channel consists of coarse angular gravel and boulders strongly suggestive of debris torrent or debris flow deposition.

Typical

There is no evidence of a recent debris torrent but this hazard has occurred in the past and may occur in the future. If debris is deposited at the apex of the fan, the creek may be diverted anywhere on the fan. The greatest hazard exists above Solsqua Road where deposition of debris would be greatest. Below Solsqua Road the stream might occupy a new channel but some floodproofing could be achieved by avoiding existing dry channels and raising the buildings well above the surrounding ground.

Hillier Creek is relatively small and flows in a poorly defined channel. It has built an alluvial fan over glacial deposits which are being worked as a source of gravel. Logging activity and road building has increased the sediment load of sand and fine gravel and this is being deposited near the mouth of the creek.

6.1.5 Conclusions

In general further development on the fan above Solsqua Road should not be allowed due to the risk of debris flows or debris torrents. Below Solsqua Road the lots should be 1/2 hectare or larger and buildings should have a standard setback from both the present channel and dry abandoned channels. The buildings should also be protected by being raised between 0.6 and 1.5 metres above the surrounding ground.

Development on the Hillier Creek fan should not proceed until the creek has been established in an adequate channel. Houses should be set back from the channel 15 metres and raised between 0.6 and 1.5 metres above the level of the surrounding ground.

A site specific evaluation should be made for each lot.

6.2 Duhamel Creek

6.2.1 Background

Duhamel Creek drains into the north side of the West Arm of Kootenay Lake about 8 km east of Nelson. The creek has built a clearly defined fan which can be recognized on the 1:50,000 NTS map (82 F). Vertical air photos taken at three different scales were used for the study. Extensive development has already taken place on the fan and numerous requests for subdivisions have been received.

6.2.2 Evaluation

Is it a fan? Yes. The typical fan shape can be identified on the 1:50,000 NTS map and on the vertical air photos.

Is the fan active? Although at first sight this appears to be a 2-level telescope-structure fan, closer examination of the air photos shows that the "upper surface" does not have a fan shape (i.e. convex cross profile is lacking) and it is in fact a glaciofluvial terrace.

Over the main portion of the true fan the stream is only incised a shallow amount and this portion must be considered active. However the surface of the fan to the east is two to three metres higher than the main portion and this part of the fan is no longer active.

On the map 82 F NW (Slocan) in Soils of the Nelson Area, Resource Analysis Branch, Bulletin 20, 1980 by J.R. Jungen, the Duhamel Creek fan is shown as part of a composite unit which includes the fan and part of the adjacent glaciofluvial terrace.

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How active is the active portion of the fan? Examination of the watershed on the air photos reveals the slopes above the creek have extensive terraces of glacial drift which have been gullied and there are extensive avalanche tracks and possibly debris flow tracks into the creek. There is therefore a moderate supply of sediment being brought to the creek above the fan. A road has been pushed into the watershed suggesting that logging or mining may take place in the future with the possibility of further increasing the sediment load. The main stem of the stream in the watershed basin has a relatively flat gradient. The transportation of sediment from the basin to the fan is therefore principally by fluvial processes which will slowly remove the sediment from the basin to the fan. There is some evidence of log jams in the basin.

Examination of the fan on the air photos indicates a portion of the fan surface which is 2 to 3 metres (estimated) above the rest of the fan surface. The creek is eroding glaciofluvial terraces just below the apex of the fan and this provides a further source of sediment on the fan. The creek is crossed by several roads and there are numerous abandoned channels across the fan although development of roads, and housing obscures the details of these old channels. The stream appears to divide about halfway down the fan and there appears to be some sort of control structure which has the potential for a log jam and diversion. There is some evidence of a recent change in the relative discharge down the two distributaries inasmuch as what appears to be the smaller distributory has the larger arrowhead delta where it enters the lake.

The points where the roads cross the creek are potential diversion points and the roads themselves may act to control the flow of the creek after being diverted. It is difficult to predict where the diverted creek would flow.

On the basis of the office study it appears that the fan is moderately active to very active.

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6.2.3 Hydrology

No detailed study of the hydrology of Duhamel Creek has been made although some records were collected in the early 1920s during the irrigation season. However the files of the Water Management Branch in Nelson show that flooding or blockage of the channel occurred in 1948, 1969, 1971, 1972, 1974 and 1975. It is clear that the present channel capacity is less than the flood stage which occurs every few years. A comprehensive hydrological analysis would be required if engineered flood protection was to be built.

6.2.4 Field Observations

The fan of Duhamel Creek was examined on July 11, 1983 in the company of Mr. D.C. Boyer of the Water Management Branch in the Nelson office.

The field observations confirmed the presence of an area of the fan amounting to about the most easterly one third of the fan which is raised above the active area of the fan and which can be considered inactive and free from flooding hazard.

The scar at the apex of the fan proved to be a borrow area not a slide which nevertheless is contributing sediment to the stream.

There is evidence of a high watertable adjacent to the stream downstream from the highway and indication that in places the stream channel is above the surrounding ground.

Examination of cuts along the road in the watershed above the fan indicate abundant source of bouldery gravelly sand which is being carried into the stream channel.

THURBER

6.2.5. Conclusions

Physical and historical evidence clearly indicates that the active portion of Duhamel Creek fan is actively aggrading and will continue to do so. No further development should be permitted on the active portion of the fan. Extensive engineering work would be required to protect new developments and significant expenditures for maintenance of the creek channels will continue to be required.

Approximately one third of the fan at the eastern edge is inactive and not subject to flooding and development on this portion of the fan can be permitted.

6.3 Lemon Creek

6.3.1 Background

Lemon Creek flows into the Slocan River about five kilometres south of Slocan Lake. The watershed and fan of the Creek are shown on 1:50,000 NTS map. 82 F 11. The fan is crossed by provincial highway 6 and by the Canadian Pacific Railway Line. The encroachment of the Lemon Creek fan into the Slocan River has caused flooding along the Slocan upstream from the junction with Lemon Creek. A study of the flood problem was prepared for the Water Investigations branch by Northwest Hydraulic Consultants Ltd. in January 1975. Vertical air photographs taken in July 1969 were used for the present study. The Northwest study indicates that photographs taken in 1939, 1952, 1965 and 1974 are available.

6.3.2 Evaluation

Is it a fan? Yes. The typical fan shape is recognizable on the 1:50,000 NTS map and can be clearly seen on the vertical air photos.

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Is the fan active? Yes. The creek channel is not incised into the fan and from the highway crossing downstream is a braided channel. It is a gently sloping fan probably dominated by fluvial processes.

How active is the fan? Examination of the watershed on the air photos indicates an abundant supply of sediment to Lemon Creek. There are numerous debris flow tracks, talus slopes and landslides and many small slides where the river is undercutting the valley sides. A logging road has been pushed into the watershed and logging and road construction may add to the sediment carried to the fan. At least one slide appears to have been triggered by road construction. Sediment is transported to the fan by fluvial processes, not debris flows or debris torrents.

The fact that the fan has forced the Slocan River to the opposite side of the valley indicates that the sediment is deposited at the edge of the fan faster than the Slocan River can remove it.

Examination of the vertical air photographs reveals numerous scars on the fan surface which indicate past channels. Some of them appear to have been formed before construction of the railway. The scale of the photographs is not adequate to indicate the micro relief. One or more surveyed transects could be made to measure the micro-relief.

On the basis of the office study of maps and photographs and review of the report by Northwest Hydraulic Consultants the fan of Lemon Creek appears to be moderately active. There is a very active zone along the channel of the creek. The highway and railway crossings constrain shifting of the channel at these points. The railway and highway embankments may act as dykes to protect certain areas from encroachment by the stream. In general the whole fan appears to be potentially subject to flooding.

6.3.3 Hydrology

The study by Northwest Hydraulic Consultants presents a flood frequency curve for Lemon Creek which can be used to assess the probability of the channel capacity being exceeded.

6.3.4 Field Observations

The fan of Lemon Creek was examined on July 11 in the company of Ken Gorsline of the Water Management Branch in Nelson.

No detailed topographic mapping of the fan is available but the overall slope of the fan is relatively flat and it appears that the fan is not subject to debris torrents or debris flows.

Several dry abandoned channels can be identified on the surface of the fan and they might be temporarily occupied if part or all of the flow of Lemon Creek were diverted by a log jam. The presence of the railway and highway bridges however will probably ensure that the creek is kept in its present channel.

The stream channel between the highway and railway bridges is eroding its banks and there are a number of overflow channels which are only occupied at flood stage. The stream occupies or threatens to occupy a zone on each side of the main channel from the highway bridge to the Slocan River.

The channel is aggrading in the vicinity of the CPR bridge. Records in the Water Management Branch files indicate that channelization has been undertaken every three or four years.

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6.3.5 Conclusions

No development should be allowed within a zone about 300 metres wide which includes the main channel and flood channels of Lemon Creek from the highway bridge to the junction with the Slocan River. This zone will allow some shifting of the creek channel and ultimately could be backed by properly constructed dykes.

No development should be allowed on the fan upstream from Highway No 6.

Elsewhere on the fan habitable buildings should be set back 15 metres from dry channels and should be raised between 0.6 and 1.5 metres above the surrounding ground. A site specific evaluation should be made for each lot.

6.4 Nusatsum River

6.4.1 Background

The Nusatsum River joins the Bella Coola River from the south about 4 km east of Hagensborg. The fan and watershed of the Nusatsum River are shown on 1:50,000 NTS map 93 D 8. For this study low level air photographs were used and a large scale topographic plan (1:6000 with 1 m contours) was available.

6.4.2 Evaluation

Is it a fan? Yes. The contours on the 1:50,000 map are not sufficient to show the characteristic fan topography which however can be clearly identified on the detailed map and the vertical air photographs.

Is the fan active? The detailed topographic plan does not cover the entire fan but it is clear that the braided channel is not incised significantly in the fan. The fan is clearly active. The sediment is transported and deposited on the fan by fluvial processes. It is a gently sloping fan in an embayment.

How active is the fan? The following features indicate that the fan is very active. The Nusatsum River has pushed the Bella Coola River to the opposite site of the valley and deposition of sediment is modifying the character of the Bella Coola upstream from the junction. The basin of the Nusatsum provides abundant sediment both from outwash from glaciers and from landslides, debris torrents and erosion of older glacial terraces. On the fan itself the high ratio of the area of active braided channel to the area of the fan together with evidence of channel shifting clearly indicates a very active fan building process.

6.4.3 Hydrology

The character of the braided stream channel is indicative of large fluctuations in river flow. A study of the hydrology of the river is required for any engineering design of flood protection works.

6.4.4 Field Examination

Field examination could be made to confirm features indicated from a study of air photos.

6.4.5 Conclusions

The fan building processes are very active and without significant engineering protection all sites on the fan would be considered high risk. No development should be approved.

6.5 Port Alice

6.5.1 Background

Port Alice townsite was damaged by debris flows and flooding in 1973 and 1975 and extensive studies and protective works were implemented. The evaluation reported here is on the basis of information which would have been available prior to development of the townsite. The site of Port Alice (Rumble Beach) is shown on 1:50,000 NST 92 L/G (Alice Lake). Vertical

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air photos taken after the development were available and a detailed topographic plan on a scale of 1" = 400' with 25' contours was available.

6.5.2 Evaluation

Is it a fan? Yes. The contours on the 1:50,000 map are suggestive of a fan and the air photos and detailed topographic plan confirm this. The fan is unusual in that it is large to relative to the size of the watershed. This fact, plus the moderately steep gradient, suggests debris flows or torrents as the chief agent of deposition.

Is it active? The creek channels prior to development of the townsite do not appear to have been incised and therefore the fan would be considered active. The creeks appear to be intermittent and during periods of low flow the water sinks into the ground before reaching the inlet. This tendency to lose water to the ground makes the channel particularly susceptible to channel shifting.

How active is the fan? The key to evaluating the activity of this fan is the recognition of the significance of debris flows in bringing sediment to the apex of the fan from where it is distributed over the fan surface by normal fluvial process. You would be suspicious that normal fluvial processes are not the whole story if you consider that a relatively large fan is located downstream from a small watershed. The creek channels in the watershed leading to the apex of the fan are extremely steep (more than 30°) and thus are capable of generating debris torrents or debris flows. And finally a field examination should have identified an exposure in the creek channel near the fan apex of intermingled wood, cobbles and silt as debris flow deposit.

On the basis of information available before development of the townsite the fan would be classified as no more than moderately active but the significance of debris flows should be recognized.

The disturbance of the watershed by logging and road construction made the likelihood of a debris flow much greater than it would be in an undisturbed watershed.

RISK AT A SPECIFIC SITE

After the damage in 1973 and 1975 an engineering study was made utilizing models and a system of dykes was constructed to protect the developed area of the townsite. If the study had been conducted prior to development of the town the configuration of the protective works would probably have been different than what was built to protect an existing community. The area required for the town occupied almost the entire fan and where this sort of development of a fan is proposed a comprehensive engineering study of the fan is essential.

If only a few houses were proposed the protection could be achieved by restricting the upper 1/3 of the fan for no habitable buildings and siting buildings in the rest of the fan either on local topographic highs or providing appropriate flood proofing requirements in recognition of the tendency of the creeks to shift channel anywhere on the fan.

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APPENDIX A

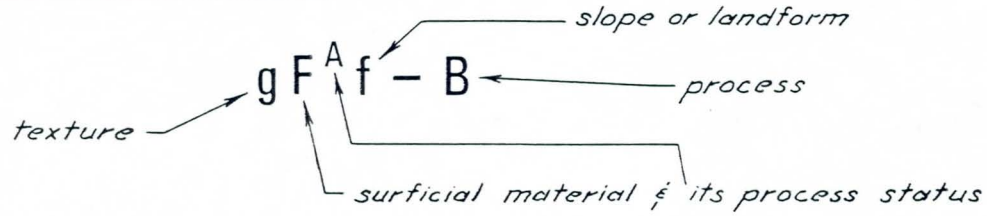
Terrain Mapping of Fans and Their Basins

Terrain Classification Systems for Details Mapping of Alluvial Fans

The mapping scheme that is outlined below has been compiled from the Terrain Classification System (E.L.U.C. Secretariat, 1976) and a revised version of the Terrain Classification System that is currently in preparation. A few extra symbols have been included. The scheme that is outlined here should be used only for detailed and large scale mapping of alluvial fans. Additional symbols from the original Terrain Classification System can be used if necessary.

This system allows a fan to be subdivided into aerial units (terrain units), each of which is described by a terrain unit symbol (see below). On-site symbols are then added to indicate the locations of significant features on the fan surface. Readers are referred to the original publication (E.L.U.C. Secretariat 1976, or 3rd printing of same, 1978) for a thorough description of the system.

Terrain Unit Symbol



Surficial Material Symbols

The first step in mapping a fan is to subdivide it according to its surficial material and process status (i.e. its degree of activity).

	F^I	Fluvial material; inactive
Use either:	F	Fluvial material; active deposition
or:	F^V, F^M, F^S	fluvial material; very active moderately active, slightly active deposition
	C	debris flow (colluvial) material, with superscripts for process status as defined above
	T	debris torrent material, with superscripts for process status as defined above

Note: Process status can be defined more precisely (i.e. in terms of recurrance intervals) if sufficient information is available.

Texture Symbols

g	gravel	a mixture of several particle sizes
b	boulders	
k	cobbles	definitions according to Wentworth scheme - see E.L.U.C. Secretariat, (1976).
p	pebbles	
s	sand	
$	silt	
c	clay	

Note: These symbols can be used singly or in combination, e.g. sg = sandy gravel; alternatively, the symbols of the Unified Soil Classification Scheme can be used.

Landform (Surface Expression) Symbols

e	0 - 2°	slope symbols - should be applied to fan surface(s) only; class boundaries can be adjusted if necessary
n	2 - 5°	
x	5 - 10°	
y	10 - 17°	
z	17 - 25°	

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Additional Landform Symbols for use on complex fans:

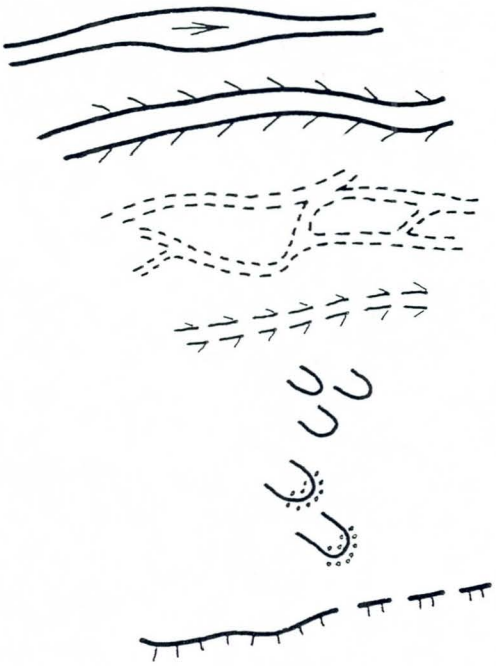
s	scarp
t	terrace
f	fan (no slope gradient specified)
p	plain: 2°
v	veneer: a layer 1 m thick
j	gentle slope: 2 - 10°
m	moderate slope: 10 - 35°

Process Symbols

-B	braiding channel (active)
-E	old, abandoned channels
$-R_d$	debris flows
$-R_t$	debris torrents
-V	gullying

Note: These symbols are used where some process(es) in addition to the one that deposited the surficial material is operating.

On-Site Symbols



active channel or channel zone

channel with levées

dry channels: fresh, old

dry channels with levées

debris flow lobes

debris flow lobes with boulders

scarp slope: well defined, poorly defined

∘ ∘ ∘ ∘ ∘ ∘ ∘ ∘ ∘	boulders
✳	groundwater close to surface; seepage
✳→	spring
⊙ 24	observation site

Examples of Terrain Unit Symbols

bg $F^{M}x$ - E	a moderately active part of a fan, consisting of bouldery gravel, with a longitudinal gradient of 6-10°, and many old channels
$bT^{A}y$	a steep and bouldery part of a fan where debris torrents are deposited; it is active, but the degree of activity cannot be specified.
g$$C^{S}y$ - B	fan constructed chiefly by debris flows, but with shallow channels where debris flow material is reworked by streams

Terrain Classification System of Mapping of Watershed Areas of Alluvial Fans

The revised edition of the Terrain Classification System (E.L.U.C. Secretariat, 1976) that will be issued by the B.C. Ministry of Environment (Resource Surveys and Mapping Branch) contains several features that can be usefully applied to the mapping of fan basins. For large scale mapping, mass movement processes that supply sediment to streams can be differentiated (e.g. debris flows, debris torrents, slumps, etc.). They can be mapped either generally within a terrain unit by use of terrain unit symbols, or more specifically by use of on-site symbols. On-site symbols can be used to show slide scars

(sediment sources), the paths followed by the various types of flows and slides, and their state of activity. Surficial materials, texture, and landforms, and stratigraphic information can be included on a basin map if necessary, or only sediment sources and mass movement processes can be shown.

Terrain maps of a fan basin from air photos taken several years apart will allow comparisons of basin conditions and identification of any changes in sediment supply to the stream.

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APPENDIX B

Reference Material Used in Evaluation of Examples of Alluvial Fans

Simms/Hillier Creek Fan

Air Photos	Date	Scale
BC 5353 - 209 to 212	Aug. 1 & 2, 1969	40 chains
BC 5353 - 218/219	Aug. 1 & 2, 1969	40 chains
BC 81027 - 169 to 171	July 25, 1981	1:20,000

1:50,000 map 82L/15 Malakwa

Ortho photo map: Floodplain Mapping - Eagle River Jan. 1979 Scale 1:5000, sheets 3 & 4

Duhamel Creek Fan

Air Photos	Date	Scale
BC 7108 - 213 to 215	Aug. 31, 1968	20 chains
BC 7109 - 26 to 30	Sept. 4, 1968	20 chains
BC 7111 - 12 to 15	Sept. 4, 1968	20 chains
BC 81028 - 260 to 263	June 25, 1981	1:6000
BC 82031 - 200 to 203	Aug. 23, 1982	1:20,000

1:50,000 map - Kokanee Peak

Lemon Creek Fan

Air Photos	Date	Scale
BC 5352 - 179 to 181	July 31, 1969	40 chains
BC 5356 - 64/65	July 28 & 31, 1969	40 chains
BC 5356 - 88 to 90	July 28 & 31, 1969	40 chains

1:50,000 NTS map 82F/11 Kokanee Peak

Report - Slocan River - Lemon Creek, Investigation of Flood and Bank Erosion Problems - by Northwest Hydraulic Consultants Ltd. for Water Investigations Branch, January 1975.

Nusatsum River

Air Photos	Date	Scale
BC 80146 - 38 to 50	Dec. 18, 1980	1:12,000
BC 80146 - 92 to 100	Dec. 18, 1980	1:12,000
BC 80146 - 123 to 131	Dec. 18, 1980	1:12,000
BC 80146 - 132 to 140	Dec. 18, 1980	1:12,000

1:50,000 NTS Map 93 D7 - Bella Coola and 93 D8 Stuie

1:6000 mapping - Bella Coola (Ext to M 247), project 80-152T

Port Alice (Rumble Beach)

Air Photos	Date	Scale
BC 5567 - 005 to 009	Jan. 3, 1974	
BC 5567 - 021 to 023	Jan. 3, 1974	
BC 5695 - 244 to 248	Nov. 19, 1975	

1:50,000 NTS 92 L/6 Alice Lake

- Report on Debris Flows at Rumble Beach/Port Alice - by Thurber Consultants Ltd. for Water Resources Service, Ministry of Environment, February 1976.

- Report on Dykes to Protect Port Alice/Rumble Beach from debris flows - by Thurbe Consultants Ltd. for Water Resources Service, Ministry of Environment, July 1976 (includes maps on scale of 1"=400')

- Paper - Design of Dykes to Protect Against Debris Flows at Port Alice, British Columbia - H.W. Nasmith and A.G. Mercer in Canadian Geotechnical Journal, vol. 16, 1979, pp. 748-757.

General References

Miles, M.J. and Kellerhals, R., 1981 Some Engineering Aspects of Debris Torrents; in Proceedings, Fifth Canadian Hydrotechnical Conference, Canadian Society of Civil Engineering, Fredericton, N.B. pp. 395-420.

Rachocki, A., 1981 Alluvial Fans, pub. John Wiley & Sons, Toronto.

Ryder, J.M., 1971 Some Aspects of the Morphometry of Paraglacial Alluvial Fans in South Central British Columbia. Canadian Journal of Earth Sciences V.8, pp. 1252-1264.

MINISTRY OF ENVIRONMENT

PROVINCE OF BRITISH COLUMBIA

Terms of Reference
For a Study Entitled

"FLOODPLAIN MANAGEMENT ON ALLUVIAL FANS"

Background

In discharging its responsibilities under Sec. 82(1) of the Land Title Act the Ministry of Environment is required to regulate the development of land in flood-prone areas. This may take the form of prohibiting development entirely or the establishment of specific conditions for consent to development. These conditions become registered as covenants against the properties concerned.

On alluvial fans the rules and data employed for usual hydrologic flooding do not apply and it becomes a difficult problem to determine what reasonable, fair and prudent conditions for consent should be established.

Objectives and Scope

The purpose of the study is to:

1. Evolve and codify the general principles for analysis of alluvial fans with respect to determining their suitability for development.

   Since it is expected that these principles will be applied to many fans throughout the Province, it is important that they be straight-forward in application and require a minimum of expense.

2. Translate the results of analysis into actual conditions for consent to development.

3. Apply the above developed principles to specific cases, namely:

   a) Duhamel Creek fan near Nelson
   b) Ross Creek fan, Shuswap Lake area
   c) Brash Creek and Ashton Creek fans near Enderby
   d) Lemon Creek Fan

The number of specific cases investigated may be expanded or contracted to fit budgetary constraints.

Contact Person

During the course of the study, the contact person for the Province will be Mr. Kennedy Smyth, P. Eng., at Victoria, telephone 387-6402.

Mr. Smyth will receive brief monthly written progress reports from the consultant and will provide guidance as required and all reasonable

assistance to the study.

When the report has reached draft stage, two copies shall be submitted to Mr. Smyth for review and discussion with the consultant.

Contract

The consultant selected will be required to enter into a fee-for-service contract with the Province, based on the Terms of Reference.

Completion Date

The time for completion of the sudy should not exceed six (6) months from the date of commencement. However, allowance will be made if adverse weather conditions affect fieldwork. The consultant should indicate his schedule at the time of submission of his proposal.

Report Copies

1) Two copies of the draft stage report as described above.

2) Ten copies of the final report.

Study Cost

The consultant will be expected to ensure that the total cost of the work to the Province will not exceed $ 22,000.

Consultant Proposal

Two (2) copies of the consultants' proposal, based upon, but not necessarily limited to, the foregoing stated objectives, will be received by Mr. P. M. Brady, Director, Water Management Branch, Ministry of Environment, 765 Broughton Street, Victoria, B. C., V8V 1X5, Attention Mr. Kennedy Smyth, up to 4:00 pm. on September 15, 1982.

The proposal should include information on the staff proposed for the study and the fee structure applicable to them.

Hjalmar W. Hjalmarson, P.E.
Consulting Hydrologist
HC75 Box 3558
Camp Verde, AZ 86322
(520) 567-6755

9/23/95

Mr. Dave Smith, P.E., M.E.
Thurber Engineering, Ltd.
Vancouver, B.C, Canada V6G 2T3

Dear Dave,

Thank you for the report on floodplain management of alluvial fans. As reported, the report is excellent and useful for my study of alluvial fan flooding in the arid southwestern U.S.

I sincerely would like to return your favor. Please do not hesitate to ask if I might be of service.

Best Regards,

Winn Hjalmarson

☒ THURBER ENGINEERING LTD.
☐ THURBER ENVIRONMENTAL CONSULTANTS LTD.
☐ THURBER CONSULTANTS LTD.

Suite 200, 1445 West Georgia St.
VANCOUVER, B.C. V6G 2T3
Phone: (604) 684-4384
Fax: (604) 684-5124

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NOTICE OF TRANSMITTAL

DATE: Sept 5, 1995

TO: Mr. W. Hjalmarson
HC 75 Box 3558
CAMP VERDE, Arizona USA 86322

ATTENTION:

REFERENCE: Alluvial Fan Mgt

YOUR FILE:

OUR FILE: 7-1-5

THE FOLLOWING ITEMS:

Copy of our 1983 report.

THE ABOVE ITEMS ARE:

☐ FOR YOUR APPROVAL
☒ AS REQUESTED
☐ FOR YOUR COMMENT
☐ FOR YOUR RECORDS
☐ FOR YOUR INFORMATION
☐ FOR CONSTRUCTION

ITEMS WERE:

☒ MAILED
☐ UNDER SEPARATE COVER
☐ PICKED UP
☐ DELIVERED IN PERSON
☒ BY MESSENGER
☐ DELIVERED BY HAND

REMARKS:

Regards

COPIES OF ☐ ITEMS ABOVE ☐ TRANSMITTAL ONLY

SENT TO:

BY: DSmith (DAVE SMITH)

TG-NOT MAR/90