Sea-To-Sky Aggregate Potential Mapping Project

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KEYWORDS: Aggregate, aggregate potential mapping, sand and gravel, Whistler, Squamish, Pemberton, Sea-To-Sky, inventory, database.

INTRODUCTION

The Sea-to-Sky region, north of Vancouver, British Columbia, is currently experiencing competing land use options which range from the development of scarce, but economically important aggregate resources to complete conservation and preservation of the natural resources. However, with the continued urban growth of communities such as the Villages of Whistler and Pemberton and the City of Squamish, coupled with a potentially successful bid for the 2010 Winter Olympics, pressure on the existing local aggregate reserves will eventually reach a critical stage. To address these concerns, the Ministry of Energy and Mines with funding assistance from the Corporate Resource Inventory Initiative (CRII), British Columbia Assets and Lands (BCAL), and Ministry of Transportation and Highways (MOTH), initiated a joint project to assess, at a reconnaissance level, the aggregate potential of the Sea-to-Sky corridor.

The Sea-to-Sky Aggregate Potential Map Project has four main objectives:

(1) Locate, compile and review all existing and readily available geological and geotechnical information housed within government, academia, and industry.

(2) Through fieldwork, identify and accurately record (using GPS and UTM grid references) the location of currently and previously active sand, gravel, and crushed stone aggregate extraction operations.

(3) Generate a Level III Aggregate Potential Map at a scale of 1:50,000 using surficial landform polygons as a base-map according to a methodology which most closely approximates provincial standards for this procedure (Bobrowsky *et al*., 1996a).

(4) Create a multi-layered comprehensive digital map and interactive database in a GIS format (ARCVIEW) that is readily accessible via the Internet to government, industry, and the public.

The Sea-to-Sky project is a regional reconnaissance study or "first approximation" which does not consider in detail the inherent properties of the material within a deposit. As defined elsewhere, the objective here is to generate Level III quality maps which provide, in a qualitative sense, the aggregate potential of distinct landforms (polygons) (*see* Table 1). The procedure adopted here places the reliability of the interpretations above Level IV and V maps, but below Level I and II maps. It is, therefore, the responsibility of the map user to not exceed the intended use of the product. Quality of aggregate, volume and grade estimates, for instance, require additional detailed study to that provided here.

The purpose of this paper is to provide a brief record of the activities undertaken thus far. Completion of the project and release of the data is anticipated for early 2001.

PREVIOUS AGGREGATE POTENTIAL STUDIES

In the last several years, the British Columbia Geological Survey Branch (GSB) has produced a number of Aggregate Resource Potential Maps. The current project follows the objectives and methodology established in the previous efforts. To date the following aggregate potential maps have been completed: Prince George region (Bobrowsky *et al*., 1996b); Okanagan region (Bobrowsky *et al.*, 1998) and Nanaimo Regional District (Massey *et al.*, 1998) (Figure 1) .

The Prince George pilot project consisted of five, 1:50 000 NTS map sheets (93G/10, 14, 15, 16 and 93H/2) in the shape of a cross centered over Prince George in north-central British Columbia. A digital map was produced from the exercise, which provided a means of evaluating the efficiency of the methods developed during the

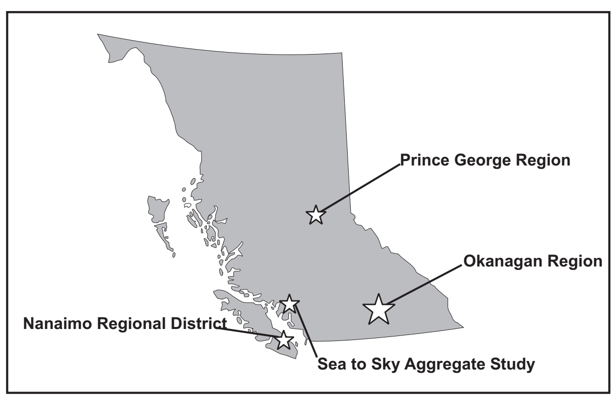

Figure 1. Locations of British Columbia Geological Survey Branch (GSB) aggregate potential mapping projects.

TABLE 1
SUMMARY OF DATA RELIABILITY, COST AND SUITABILITY OF LEVEL I TO LEVEL V AGGREGATE POTENTIAL MAPS IN BRITISH COLUMBIA

	I	II	III	IV	V
Map scales	1:100 to 1:10,000	1:10,000 to 1:50,000	1:50,000 to 1:100,000	1:100,000 to 1:250,000	1:250,000 to 1:500,000
Surficial (landform) data	yes	yes	yes	yes	yes
Field verification of polygons	yes	minimal	no	no	no
Air photo interpretation	new, detailed	new and pre-existing	as required	minimal	none
Water well data	yes	yes	yes	no	no
Use of existing geotech. data	yes	yes	minimal	no	no
Drilling and/or trenching	yes	minimal	no	no	no
New laboratory tests	yes	minimal	no	no	no
Literature research	detailed studies included	detailed studies included	regional studies	basic to regional studies	minimal
Verification of agg. pit locations	yes	yes	yes	minimal	no
Geo. mapping of agg. pits	yes	yes	yes	minimal	no
Product reliability	very high	high	moderate	low	very low
Avg. cost / map sheet	$50,000 +	$20,000 to $50,000	$10,000 to $25,000	$5,000 to $15,000	$1,000 to $10,000
Suitability of maps	site construction purposes	city planning to municipal planning	municipal to regional planning	broad regional planning	provincial planning

1995 Aggregate Forum (Bobrowsky *et al*., 1996a). Later, aggregate mapping for the Okanagan area included sixteen NTS 1:50,000 map sheets (82L/W and 82E/W) in the interior of British Columbia. The general area covers a rectangular section from Osoyoos on the Canada-US border, north to Salmon Arm. More recently, the Nanaimo Regional District study covered 9 NTS 1:50 000 map sheets (parts of 92C, B, F and G) on southeastern Vancouver Island. This last study area corresponds to the coastal section south of Duncan north to Qualicum Beach.

Dixon-Warren initiated aggregate potential mapping work on the Sea-to-Sky project in March, 2000, with the completion of NTS map sheets 92G/11 and 14,. Subsequent funding has extended the boundaries north defining the current Sea-to-Sky project.

AGGREGATE

Aggregate is defined as naturally occurring, hard construction material, such as sand, gravel, crushed stone or slag, which can be mixed with cementing material to form concrete and asphalt or can be used alone in road building, railroad ballast or other construction or manufacturing activities (Edwards *et al*., 1985). Aggregate is an essential commodity in urban and suburban areas and despite its relatively low unit value, it has become a major contributor to the economy.

Globally, the aggregate sector has experienced increasing pressure to manage this resource properly as accelerated urbanization has markedly increased consumption near large urban centers. Municipal expansion, alternate land uses, land sterilization, and public concern are some of the factors which have limited the availability of many traditional aggregate sources. Such factors, including the elevated cost of the product due to increased transportation distances, has created considerable concern about the aggregate industry's ability to supply aggregates to meet future demand. Initiatives such as the Sea-to-Sky Aggregate Potential Map Project provide the first step for ensuring the sustainable development of aggregate resources. The methodology used here provides a means for land planners to manage land areas which may be vital to continued development and maintenance of municipalities and their infrastructure.

Natural aggregate, such as sand and gravel, are the product of unique geological processes (Langer and Glanzman 1993). This generally restricts the location for potential aggregate deposits to those areas where specific environments of deposition either exist or existed. Understanding such processes and environments, has enabled aggregate geologists to predict those landforms which are most likely to contain aggregate.

LOCATION

The study area is located in southwestern British Columbia north of the Vancouver. The area is best described as a 10 kilometre wide corridor along the major transportation routes, delimited in the south by Daisy Lake and in the north by the head of the Lillooet River Valley near Salal Creek. Specifically, the corridor extends from Daisy Lake north to the town of Pemberton, and includes Callaghan Creek and Rutherford Creek. At Pemberton the corridor divides to encompass the Upper Lillooet River Valley as well as Birkenhead Lake and D'Arcy on the southern end of Anderson Lake. In total, the area examined here covers portions of NTS (1:50 000) map sheets 92J/2, 92J/3, 92J/6, 92J/7, 92J/8, 92J/9, 92J/10, 92J/11, 92J/12 (Figure 2). The communities of Whistler, Pemberton, Mt Currie, and D'Arcy all fall within the study boundaries.

PHYSIOGRAPHY

The study area is on the west coast of British Columbia some 40 kilometres north of Squamish (at the head of Howe Sound). This area is part of the "Coast Mountain" morpho-geological belt (summarized in Gabrielse *et al.*, 1991) with terrain typified by high, rugged mountains and deep glaciated valleys. The study area includes three biogeoclimatic zones, the Coastal Western Hemlock, the Mountain Hemlock, and the Alpine Tundra zones, each differentiated by elevation (Meidinger and Pojar, 1991). At lower elevations (sea-level to 900m), parts of the Coastal Western Hemlock zone predominate. This zone typically has cool summers and mild winters. The subalpine occurs within in the Mountain Hemlock zone, between 900 to 1800 metres asl. In this zone, climate is characterized by short, cool summers and long cool wet winters, with heavy snow cover for several months. The very high peaks occupy a relatively small portion of the study area and fall within the Alpine Tundra zone generally above 2250 metres asl. This zone is typically cold, windy, and snowy with short frost free periods.

GLACIAL HISTORY

Most unconsolidated deposits present in British Columbia owe their existence to the processes of glaciation and deglaciation. During the past few million years, the entire province has experienced a number of glacial and non-glacial cycles, the most recent of which (the Wisconsinan ca. 25,000 to 10,000 years BP) has had the greatest impact on aggregate accumulation and distribution.

As climate began to deteriorate some 25,000 years ago, ice previously restricted to the high alpine started to gradually expand. Valley glaciers advanced, eventually over topping inter-valley ridges and coalescing to form small mountain ice sheets (Davis and Mathews, 1944). Eventually glaciers spread across the interior plateaus and coastal lowland, covering most of the province and parts of the continental shelf, finally producing the Cordilleran Ice Sheet (Clague, 1986).

Minimal effort has been directed toward resolving the chronology of Quaternary events in the study area, but deglaciation can be inferred from work completed nearby at the head of Howe Sound and the Mamquam River Valley (Friele and Clague, personal communication, 2000). Apparently, glaciers had retreated from the Mamquam River Valley leaving it ice free and forested by about 14,000 yr BP. Deformed glaciolacustrine and diamicton deposits overlying unmodified glaciolacustrine sediments provide evidence for a glacial readvance about 13,500 yr. BP. A dated submerged end moraine at Porteau Cove marks the maximum extent of the readvance and further indicates that ice began to recede shortly after 12,800 yr BP. Ice continued to retreat up the Squamish River Valley as far as the confluence of the Cheakamus River by 11,800 yr BP. It is likely that the main trunk glaciers in the Cheakamus, Pemberton, and Birkenhead Valleys continued to decay throughout the Holocene by retreating into the high alpine, where remnant ice bodies persist today.

BEDROCK GEOLOGY

The rocks in this area can generally be divided into stratified and intrusive rocks and range in age from Upper Triassic to Recent. A number of faults and shear zones have locally stressed many of these rocks, as both brittle and ductile deformation can be observed at a number of outcrops.

Four groups are represented within the stratified division and include the Garibaldi, Gambier, Tyaughton, and Cadwallader groups (Journeay and Monger, 1994). The Garibaldi Group consists of Recent basalt to rhyodacite flows and pyroclastics, with minor sandstone, shale and conglomerate. The Gambier Group is Lower Cretaceous andesitic to dacitic tuff, breccia agglomerate, and andecite with argillite, conglomerate, lesser marble, greenstone and phyllite. A small sliver of the Upper Triassic Tyaughton Group occurs in the northeast and consists of shale, siltstone, sandstone, conglomerate and limestone. The Cadwallader Group includes the Hurley, Pioneer and possibly the Noel formations. This Upper Triassic group includes argillite, phyllite, sandstone, limestone, siltstone, conglomerate chert and mudstone, in addition to pillowed and massive tuff, with andesitic to basaltic flows and pyroclastics.

The intrusive rocks predominate in the area and are part of the Jurassic and/or Cretaceous Coast Plutonic Complex. These rocks include quartz monzanite, granodiorite, quartz diorite and dioritic complexes containing quartz diorite, amphibolite, greenstone and dike swarms.

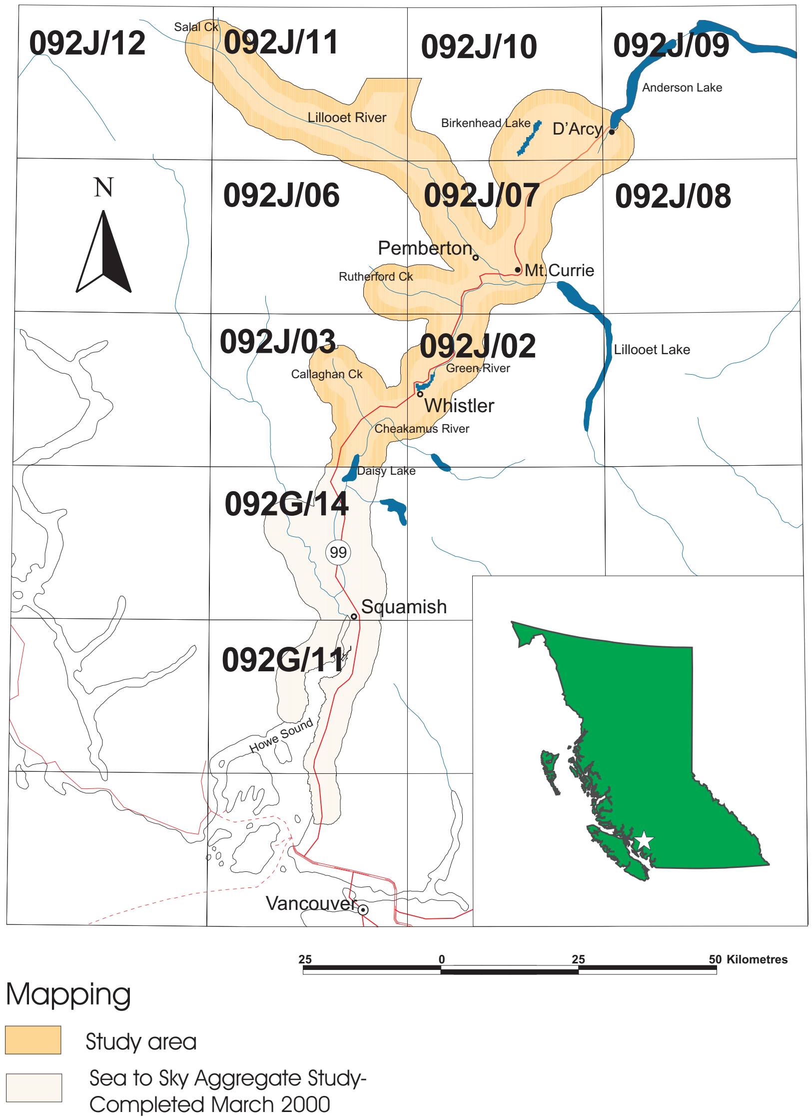

Figure 2. Sea-to-Sky Aggregate Potential Map Project is located directly north of the City of Vancouver and includes the communities of Whistler, Pemberton, D'Arcy, and Mt. Currie.

METHODOLOGY

The methodology for this study follows procedures and provincial standards established elsewhere (Bobrowsky *et al*., 1996a). The process consists of three parts and can be summarized as follows:

(1) data acquisition and compilation;

(2) fieldwork;

(3) polygon ranking.

Data from a number of sources must be located, compiled and evaluated to produce an integrated interpretive product. Information such as geotechnical reports, surficial and bedrock geology, water-well logs, drill reports, and consulting reports all contribute to better evaluating the surficial polygon data. Sources of this information include government, crown corporations, municipalities, and industry.

The following layers of data were compiled for this study:

- surficial material (primary and secondary)
- texture of surficial material (primary and secondary)
- landform expression (primary and secondary)
- quality and thickness of aggregate
- polygon area
- bedrock
- presence/absence of aggregate operations
- overburden thickness

The basemap was prepared from airphoto interpretation of surficial landforms, materials, and textures by J.M. Ryder & Associates Terrain Analysis Inc. following Howes and Kenk (1997) Terrain Classification System for British Columbia. This information was then digitized and the polygonal data then analyzed on a polygon-by-polygon basis for aggregate potential.

Fieldwork consisted of locating all active and inactive aggregate extraction operations including commercial pits as well as highway and logging (mainlines only) borrow pits (Figure 3). The pit descriptions include locations (verified and recorded using a hand held GPS unit), elevation, type of exposure, rough pit dimensions, number of sedimentary units present, clast size range, roundness range, sorting, estimate of size fraction percentages, estimate of clast lithology, bedding, imbrication, surficial material, texture, surface expression, and interpretation.

Once all available information is compiled, polygon attributes are assessed and assigned a numeric value (Table 2). Those attributes which are considered more relevant to aggregate potential (*e.g.* surficial material) are assigned a weighting factor to reflect the greater importance of this attribute. Individual values for the various layers of data are then incorporated into an algorithm that provides an overall value or ranking, for each polygon. Although the algorithms used change between the various studies primarily as a function of the available data, the concept and methodology has remained unchanged.

Those polygons, which are considered "undesirable" (ice, water, etc.), are identified and removed from the analysis. The frequency distribution of the final rank scores for the polygons is then evaluated and the distribution is divided into categories corresponding to primary, secondary, or tertiary aggregate potential.

Figure 3. Typical borrow pit used to facilitate logging road construction. Pits are generally small (~2000m^3) and exploit local material to reduce transportation distance (forest service road south of Birkenhead Lake).

RESULTS

The study encompasses an area of 2020 square kilometres (excluding work completed previously on NTS map sheets 92G/11 and 14), within which a total of 1467 surficial landform polygons were mapped (terrain mapping completed on contract with J. Ryder and Associates) (Figure 4). As noted earlier, such terrain polygons form the basis for categorizing aggregate potential. Polygon area ranges in size from 1.2 to 2225 hectares, which fur-

TABLE 2
EXAMPLE OF VALUES USED TO DETERMINE RANK FOR VARIOUS PARAMETERS. ATTRIBUTES ARE LISTED ON THE LEFT SIDE, AND THE PARAMETERS UNDER THE NUMERIC RANK VALUE
(THE PARAMETERS THAT ARE CONSIDERED MORE RELEVANT TO AGGREGATE POTENTIAL WILL RECEIVE A HIGHER RANK)

Ranking	5	4	3	2	1	0
Landform	Glaciofluvial	Fluvial	Ablation Till, Colluvium	Eolian, Moraine	Lacustrine Organic, Bedrock	Water
Texture	Gravel	Sandy Gravel	Boulders, Sandy Gravel, Silt	Silt, Clay, Sand, Gravel	Silt, Clay, Sand	Unknown
Area	>679 ha	398-679 ha	239-398 ha	132-239 ha	<132 ha	all water
Pit	N/A	N/A	N/A	N/A	Present	Absent
Overburden (from water wells)	0-3 ft (0-1 m)	4-6 ft (1-2 m)	7-16 ft (2-5 m)	17-33 ft (5-10 m)	>33 ft (>10 m)	Unknown
Thickness of gravel (from water wells)	>87 ft (>27 m)	56-87 ft (17-27 m)	34-55 ft (10-17 m)	16-33 ft (5-10 m)	0-15 ft (0-5 m)	Unknown
Volume (Pit)	>1 000 000 m^3	1 000 000 - 500 000 m^3	500 000 - 50 000 m^3	50 000 - 5 000 m^3	5 000 - 0 m^3	Unknown

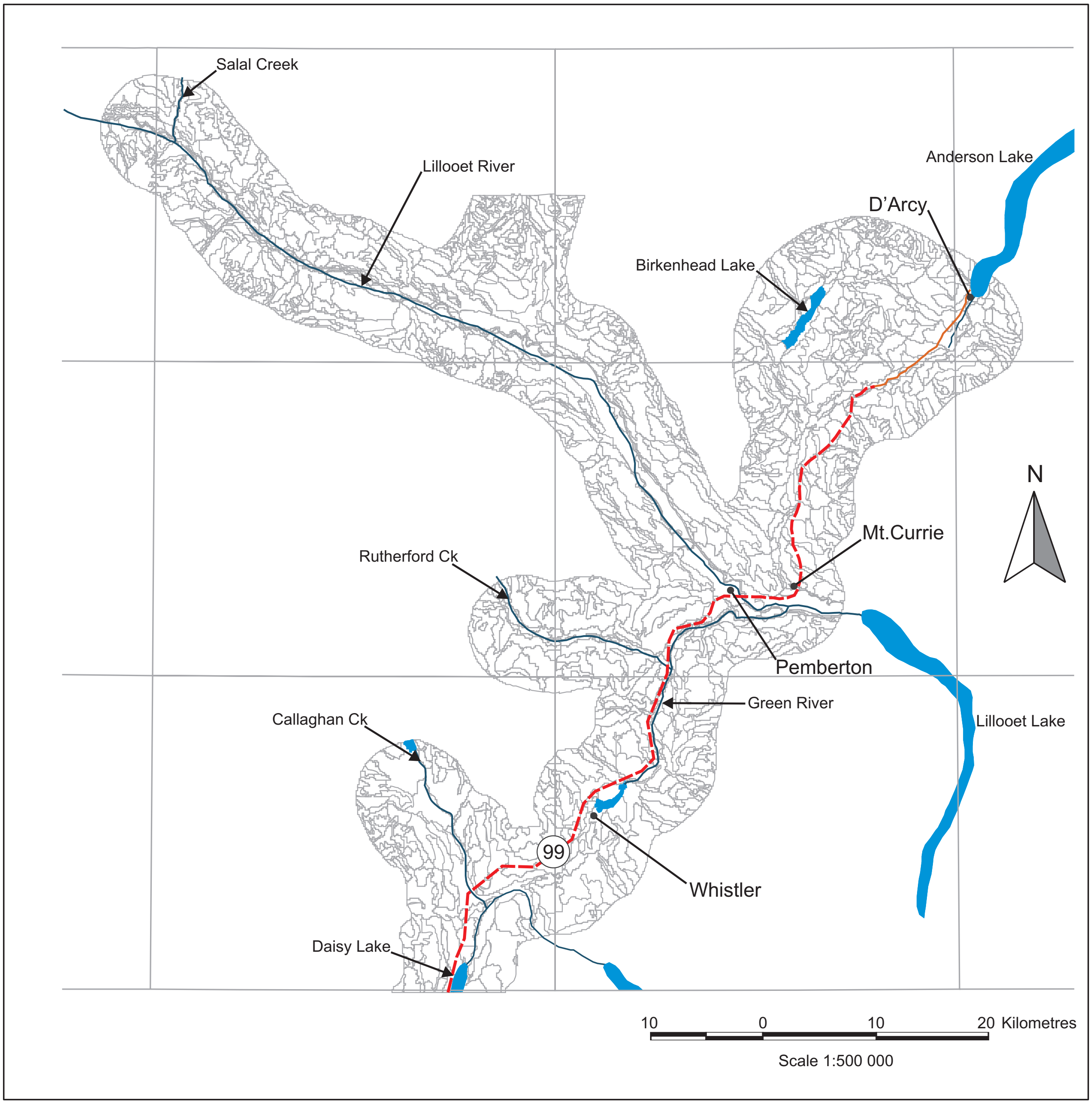

Figure 4. Polygon map produced for the Sea-to-Sky Aggregate Potential Map Project. Polygons delineate landforms of similar surficial material determined through airphoto interpretation.

ther defines the upper and lower theoretical limits for "area" as used in the aggregate algorithm. Similarly, 89 water-well records were obtained and described for the study (Figure 5). Well depths range from 8 to 145 metres, and are disproportionately distributed over the region, most occurring in valley bottoms and near transportation corridors. In addition to the water well information, 163 test pits and geotechnical drill holes were located from consultant or Ministry of Transportation and Highways reports (Figure 6). Test pits and drill holes ranged in depth from 1 to 37 metres. A further 56 drill logs were reviewed from the Ministry of Energy and Mines mineral assessment reports (ARIS). This information provided limited sedimentological data, though did provided a rough estimate of depth to bedrock. Finally, the distribution of active and inactive aggregate operations described in detail is shown in Figure 7. A total of 83 pits were visited of which 39, 32, and 12 were borrow, commercial, and miscellaneous operations, respectively.

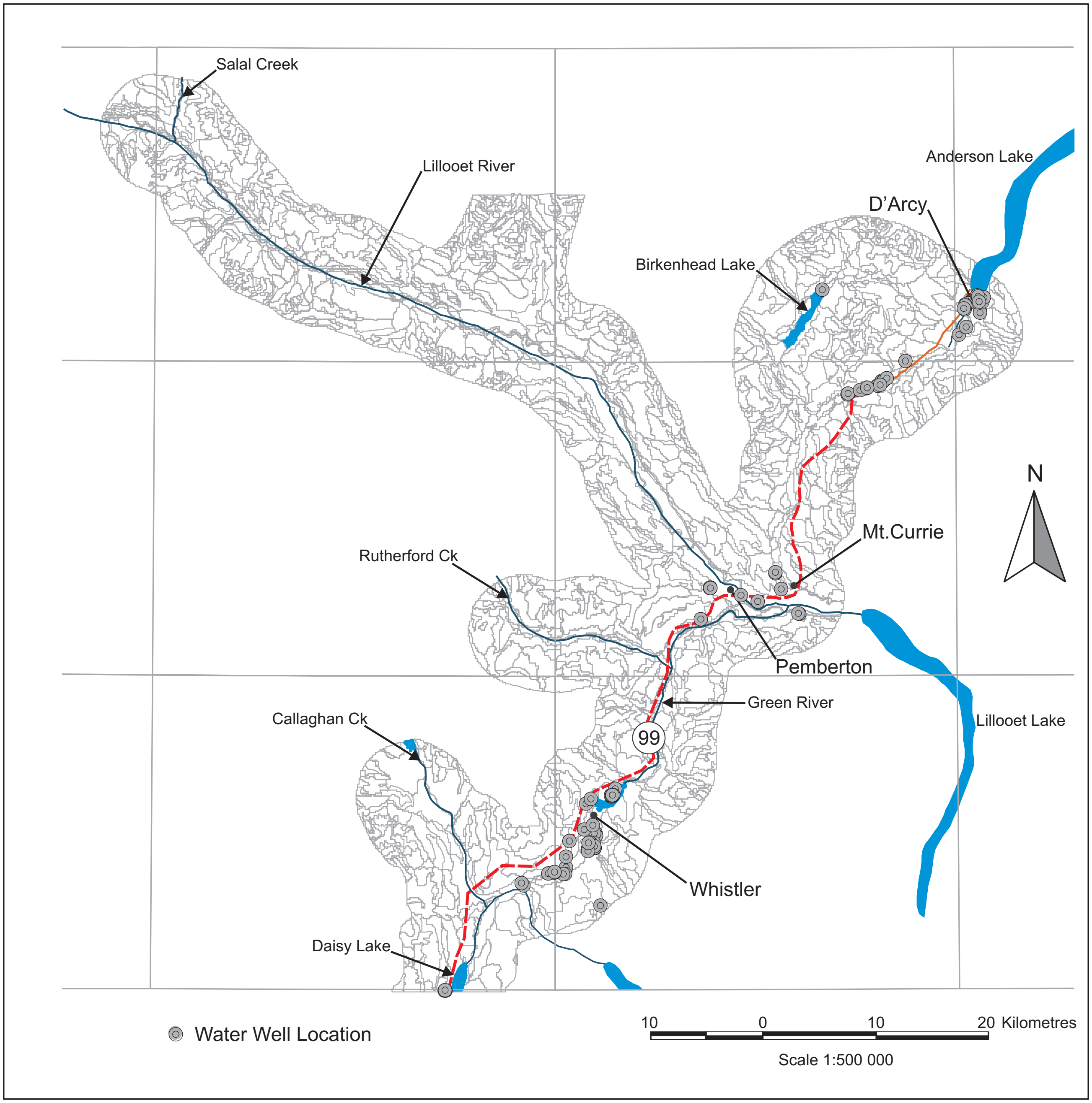

Figure 5. Water-well locations used to determine sedimentology and depth of overburden. Wells are generally concentrated around the communities of Whistler, Pemberton Mt. Currie and D'Arcy.

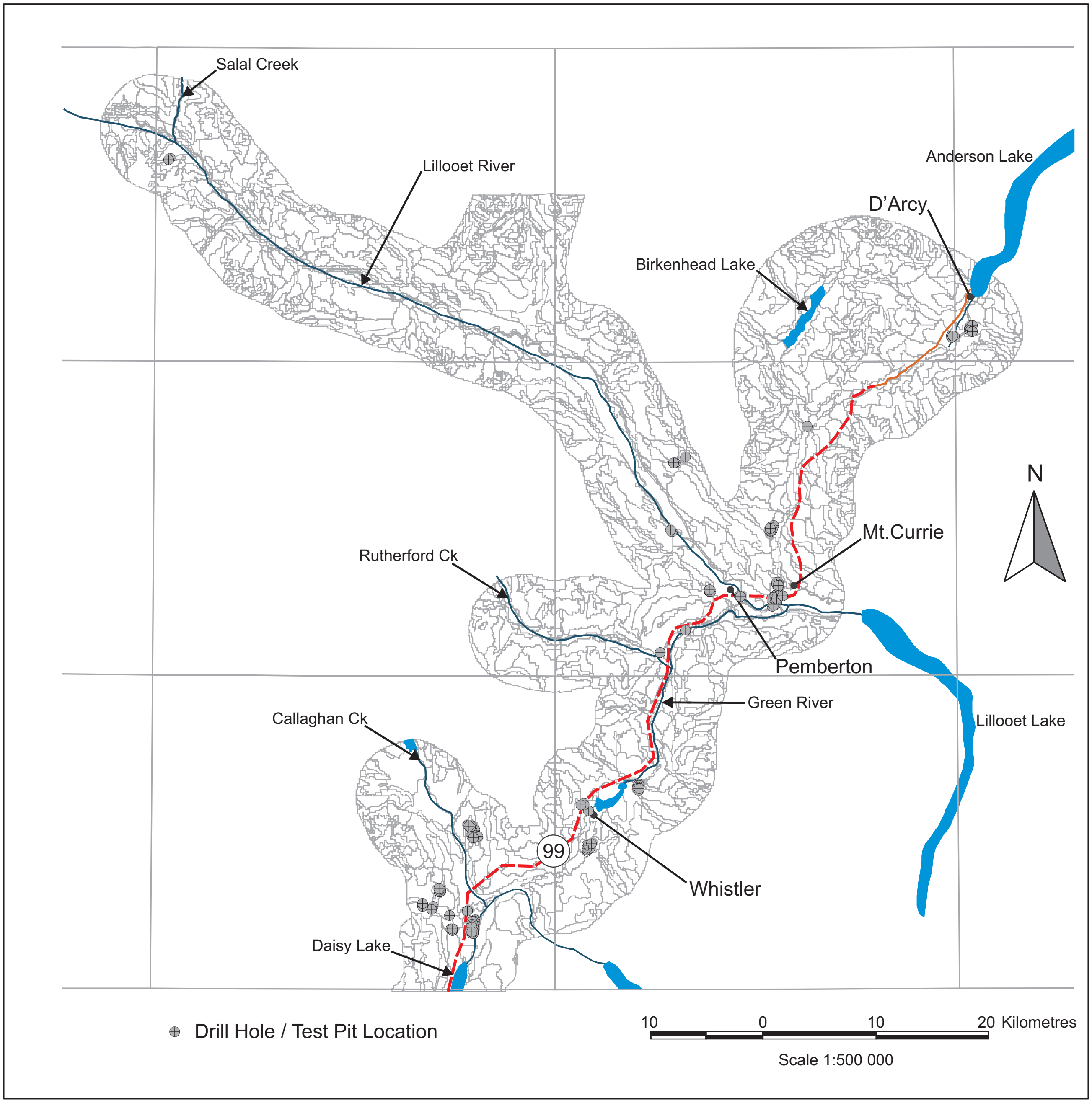

Figure 6. Drill hole and test pit locations from mineral assessment (ARIS), consultant, and MoTH reports. ARIS reports contain the results of mineral exploration programs and only provide minimal information on surficial sediments. The MOTH reports describe shallow test pits used to determine the suitability of sediments for aggregate. Consultant reports contain the most detail, although the distribution is restricted to a limited number of sites.

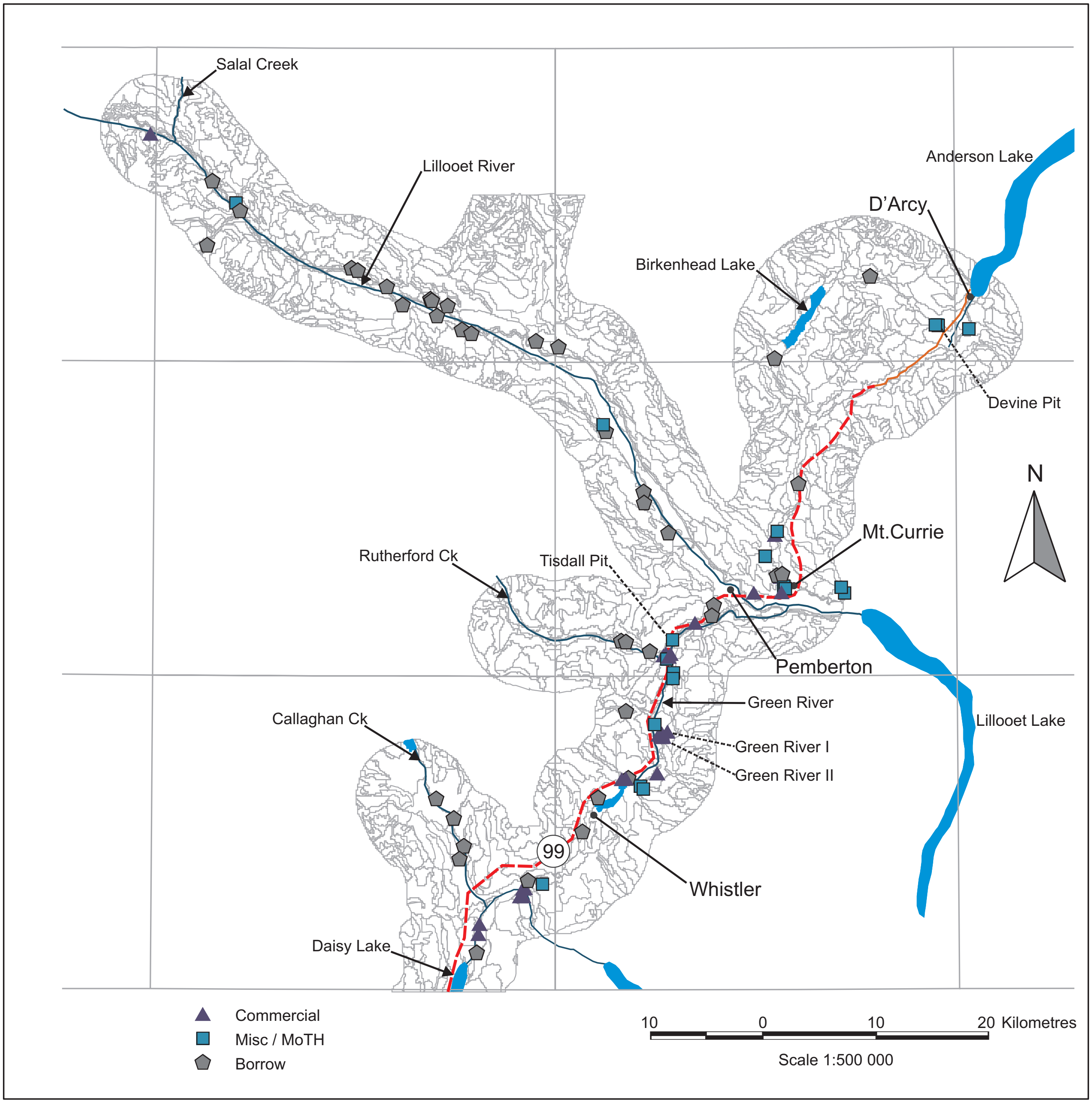

Figure 7. Active and inactive aggregate extraction operations including commercial, borrow, and other miscellaneous pits. Most commercial operations occur along Highway 99 as it is the major transportation route in the area. Borrow pits are more common on the logging roads, though MoTH have established some local borrow pits along the highway.

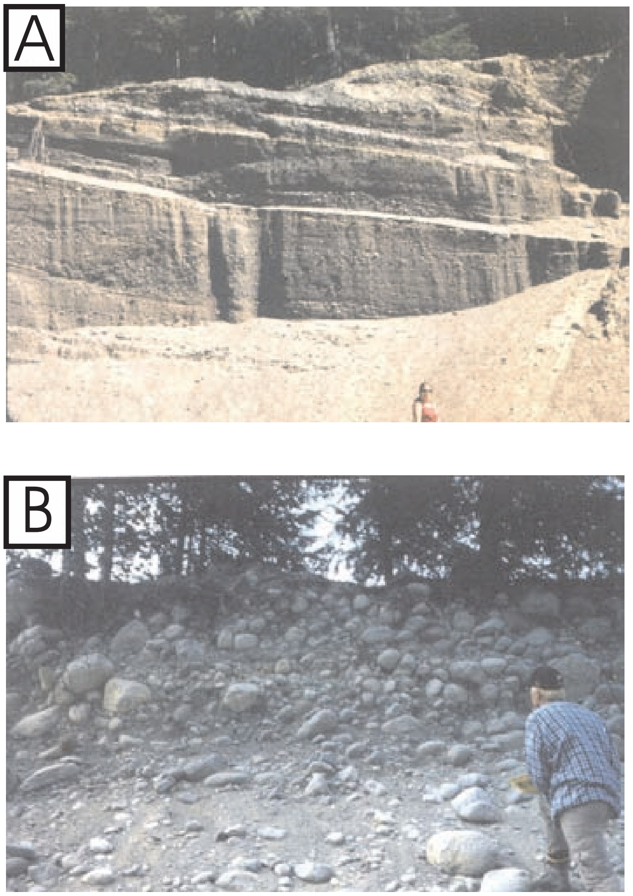

Photo 1. Examples of glaciofluvial deposits in the study area. “A” is from Devine Pit south of D’Arcy and consists of coarse sand and gravel beds dipping to the east. “B” is from the Tisdall Pit, north of Rutherford creek on Highway 99. Clasts range in size from sand to boulders and generally coarsen upwards (*see* Figure 7 for location).

Photo 2. Active mining of the colluvium along Lillooet Forest Service Road, in the upper Lillooet River Valley. Material here is being used to armor river banks (rip-rap) along reaches where erosion threatens the logging road. Other locations provide aggregate for road base and diking material.

As stated earlier, aggregate resources are restricted to specific locations where favorable geologic processes have deposited material. In this area, the dominant processes include fluvial, colluvial and glacial environments.

In general, the majority of active extraction operations in the study area are exploiting glaciofluvial and post-glacial fluvial deposits in the valley bottoms. During fieldwork, stranded glaciofluvial deposits were noted in terraces at elevations as high as 836 metres along some of the tributary valleys, however, for the most part, the larger deposits are commonly found in the major valley bottoms (average elevation: 200-600m). Typically the sediment is medium sand to large boulders, moderate to poorly-sorted, massive to moderately well-stratified (Figure 8). The dominant landforms are poorly to moderately-developed terraces, and fluvial and glaciofluvial floodplains and fans. One of the larger operations (Green River I and Green River II) (Figure 7) is currently working a combination of glaciofluvial, fluvial and lacustrine (well-sorted sand) material.

Many of the valleys contain over-steepened valley walls resulting from glacial scouring and erosion. Consequently, active colluvial processes such as rockslides, rockfalls, and debris flow activity are present. Along the base of the valley walls, some operations are removing this material for rip-rap and gravel, particularly for the construction of forest logging roads (Photo 2). Such deposits can generally be described as sand to very large boulders, moderately to poorly-sorted, massive to weakly-stratified, and very angular to subangular. Evidence for debris flow activity occurs on most steep mountain streams, and fresh debris flow scars are commonly visible.

Till is a sediment deposited directly from ice with very little, or no reworking by other processes. It is well known that the study area was glaciated during the Pleistocene and many of the landforms and bedrock features are the result of glacial activity. It is likely that much of the area was at one time covered with till, however significant portions of this material have subsequently been modified or eroded during the post-glacial period. A large portion of the till in the valley bottoms has been eroded by glacial melt waters and then buried by glaciofluvial and fluvial material. The occasional remnant, or isolated deposit of till is exposed particularly on eroded slopes or where road excavation has stripped overlying material. Despite relatively limited quantities, we observed a few operations developing sand-rich primary till as an aggregate source, but more commonly modified till (washed or colluviated till) seems to be preferred.

Table 3 summarizes the distribution of pits by the primary surficial material of the polygon in which the pits are located. An estimate of the area for the commercial operations ranges from 1800 to 53 240 square metres. Borrow pits are generally much smaller, ranging in areas from 136 to 3750 square metres. Material is generally moderate to poorly sorted and requires processing (*i.e.*

TABLE 3
SUMMARY OF PIT DISTRIBUTION BY THE PRIMARY SURFICIAL MATERIALOF THE POLYGON IN WHICH THE PIT IS LOCATED

	Commercial	Borrow	Misc.	Total
Colluvium	1	18	1	**20**
Fluvial	12	7	6	**25**
Glaciofluvial	9	3	2	**14**
Moraine	6	6	2	**14**
Rock	3	3	1	**7**
Undiff.	0	2	0	**2**
Volcanic	1	0	0	**1**
Total	**32**	**39**	**12**	**83**

washing, sorting, and/or crushing) before the aggregate becomes an acceptable product.

CONCLUSIONS

Most active aggregate extraction in the study area is exploiting fluvial and glaciofluvial deposits, though some operations are mining colluvium and to a lesser extent, till. Most operation occur along the major transportation routes in the valley bottoms where material is thickest and access easiest. Future operations are likely to follow this trend as existing infrastructure and shorter hauling distances dictate the economics of aggregate extraction.

ACKNOWLEDGEMENT

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