Burns Bog Ecosystem Review

Geology

Prepared for:
Delta Fraser Properties Partnerhip and
the Environmental Assessment Office
in support of the Burns Bog Ecosystem Review
Additional work on Publicly-owned lands conducted
for the Environmental Assessment Office in
Association with the Corporation of Delta

Submitted by:
AGRA Earth & Environmental Limited
Burnaby, BC

November 17, 1999
VE51007

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569244 British Columbia Limited
C/O ENKON Environmental
Unit 201, 2430 King George Highway
Surrey, British Columbia
V4P 1H8

Attention: Glenn Stewart

Ladies and/or Gentlemen:

RE:

Burns Bog Ecosystem Review Geology
Delta, British Columbia

We are pleased to submit six copies (five bound and one unbound) of our final report describing the findings of the Burns Bog Ecosystem Review, Geology at the above-referenced site with Additional Work on Delta-owned Lands Conducted for the Environmental Assessment Office in Association with the Corporation of Delta. The Terrain and Surficial Maps are provided in digital format as requested on the accompanying Compact Disc.

If you have any questions, please call the undersigned at (604) 294-3811. Thank you for the opportunity to be of service to the 569244 British Columbia Limited.

Yours truly,

AGRA Earth & Environmental Limited

John Lambert, P. Geo.
Project Manager

TABLE OF CONTENTS

EXECUTIVE SUMMARY *

1 Introduction *

1.1 Scope of Work *
1.2 Study Area *
1.3 Methods *

2 Location and Regional Setting *

3 Geological History *

3.1 Jurassic Period *
3.2 Cretaceous Period and Tertiary Period *
3.3 Quaternary Period *
3.4 Post Glacial *

4 Bedrock Geology *

5 Surficial Geology *

6 Stratigraphy *

6.1 Deltaic Sand Unit *
6.2 Silt Unit *
6.3 Peat Unit *

7 Effect of Geology on Hydrology *

8 Effect of Earthquakes on Bog *

9 Anthroprogenic Effects on Geologic Processes *

10 Maps *

10.1 Terrain Map *
10.2 Surficial Geology *

11 Conclusion *

12 Closing *

REFERENCES 16

LIST OF FIGURES

(Figures not available in electronic format,
please visit our satellite repositories to view a hard copy)

FIGURE 1 - Location Map
FIGURE 2 Geologic Time Scale and Subduction Zone
FIGURE 3 Past Sedimentary Environments
FIGURE 4 Evolution of the Fraser Lowland and Fraser Delta
FIGURE 5 Historical Stratigraphic Summary
FIGURE 6 Cross Section A-A’ (Looking North)
FIGURE 7 Cross Section B-B’ (Looking West)
FIGURE 8 Cross Section C-C’ (Looking West)

FIGURE 9 Study Area and Cross Section Locations

LIST OF MAPS

(Maps not available in electronic format,
please visit our satellite repositories to view a hard copy)

MAP 1 Terrain Map (in digital format on accompanying Compact Disc)
MAP 2 Surficial Geology Map (in digital format on accompanying Compact Disc)

EXECUTIVE SUMMARY

Geological history, geology, stratigraphy, and geological processes are described for Burns Bog and surrounding lands, and properties owned by the Corporation of Delta in the vicinity of Burns Bog. The report relied solely on information derived from a literature review, together with aerial photograph examination. No fieldwork was undertaken. Three geologic cross sections are provided. Two maps, at the scale of 1:10,000 were produced using a 1999 orthophoto, and aerial photograph stereo pairs. One map uses the British Columbia Terrain Mapping Classification System to delineate areas of distinct surficial materials, drainage, texture, and peat composition. The second map applies the surficial geology mapping of Armstrong and Hicock 1980, to Burns Bog and surrounding lands.

Geological history influencing Burns Bog and surrounding lands began during the Jurassic Period, 150 million years ago. Plate tectonics, episodes of mountain building, volcanic activity, glaciation, and changes in sea level provide the foundation and regional setting on which Burns Bog began to form approximately 5,000 years ago. The foundation on which Burns Bog has developed is made up of Late Cretaceous and Tertiary sedimentary rocks overlain by over 225 m of unconsolidated glacial outwash, till, marine sediments, and post glacial deltaic sediments. Crucial components of this foundation include the Fraser River, the Coast Mountains to the north, the Cascade and Chuckanut Mountains to the southeast, and the Strait of Georgia to the west.

During the Late Pleistocene and Holocene (40,000 years ago), a complex sequence of advances and retreats of the Cordilleran ice sheet and sea level fluctuations deposited the glacial outwash sediments, and marine sediments that underlie the Fraser River Delta and Burns Bog. By 8,000 years ago the Fraser River Delta was approaching the Burns Bog area, depositing the fine grained sediments, such as silts and clays, that are typical of the prodelta facies. The deltaic intertidal and wetlands environment resulted in the deposition of deltaic sand, overbank silt and organic deposits. Although the deposits have gradational contacts, they form three prominent stratigraphic units in the area of Burns Bog. The vertical and horizontal distribution of these units is illustrated on cross-sections presented in this report.

Data from geotechnical investigations for the construction of Highway 91 indicate the presence of a north south striking subsurface sand ridge feature under the east area of the bog, along the general alignment of Highway 91. The origin of this ridge is unknown. It is possibly a deltaic sand bar or island as it has had a significant effect on the deposition of the silt and organic units. Organic peat deposits thin across the subsurface sand ridge beneath the alignment of Highway 91. Between Highway 91 and Panorama Ridge the peat thickens to up to 10 m. These thick deposits may be due to prolonged wetland conditions that once occurred in a relatively stable environment created by the sand ridge feature and the

presence of Panorama Ridge.

The hydrology of Burns Bog is directly related to the stratigraphy of the area. The main likely sources of water to the bog are surface and subsurface drainage from the Newton Uplands and direct precipitation. Surface drainage from the Newton Uplands has been significantly reduced with the construction of the Northeast Interceptor drain. The hydrology within the bog itself has also been modified with the construction of numerous drainage channels, and the extensive peat harvesting that has altered the topography of the bog and also created a number of ponds.

Aquifers and artesian groundwater conditions are well documented to the south of Panorama Ridge and are associated with the Quadra Sand. The Quadra Sand aquifer may be connected to the deltaic sand unit beneath the Burns Bog, however, because existing subsurface information is limited to shallow depths, this relationship could not be substantiated.

1. INTRODUCTION

As part of the Burns Bog Ecosystem Review being undertaken on behalf of 569244 British Columbia Limited, AGRA Earth & Environmental was requested to conduct a geologic review of Burns Bog and surrounding lands. This report describes the geologic history, bedrock, surficial geology, stratigraphy, and geologic processes of Burns Bog (herein referred to as the bog) and the surrounding area. The work was subsequently extended to include a component of Delta owned lands in the Burns Bog area, as requested by the Environmental Assessment Office (EAO) in association with Corporation of Delta.

1.1 SCOPE OF WORK

The scope of work for this project as described in the Terms of Reference is as follows:

a. Review and summarize existing literature on the Lower Mainland and the bog’s geological processes.

b. Describe the bedrock, quaternary sediment and geological processes of the bog and surrounding lands.

c. Map the geological features, surficial materials, and dominant geological processes with special reference to those influencing hydrology, such as aquifers and old river channels.

d. Construct a stratigraphic profile (cross-section) of the bog area (maximum depth 30 m).

The scope was limited to literature review and did not include any field reconnaissance investigation or mapping.

1.2 STUDY AREA

For purposes of describing the geologic history and bedrock, the surrounding area encompasses the entire Fraser Lowland and adjacent mountains (Figure 1). For surficial geology mapping, stratigraphy, and cross sections, surrounding lands have been defined by the limits of the 1999 orthophoto coverage provided by ENKON Environmental Limited (Map 1). Lands owned by the Corporation of Delta, included as part of the study, comprise fifteen parcels of land located around the bog edges. Figure 9 presents the 1999 orthophoto coverage, the Fraser Delta Property, and the Corporation of Delta Lands.

1.3 METHODS

This report is based entirely on information taken from previous studies on Burns Bog and the geology of Southwestern British Columbia by industry, consultants, and researchers, as referenced. ENKON Environmental Limited provided several documents, reports and studies relating to Burns Bog and Delta Lands. The Greater Vancouver Regional District, Corporation of Delta, City of Vancouver, Ministry of Transportation and Highways, and the Ministry of Environment, Lands, and Parks were contacted for investigative reports and any other information they had available that would pertain to the geology review. In addition the University of British Columbia Library and Vancouver Public Library were searched for applicable information. A list of references available for the geology review is included at the end of this report. The subsurface stratigraphy presented is based primarily on geotechnical investigation reports prepared for various projects in the Burns Bog area by Piteau Associates (1983, 1994), Ministry of Transportation and Highways (DeBoer, 1982, 1983), Golder (1995), Dames and Moore (1974), and Terra Engineering Ltd (1999).

Two maps at the scale of 1:10,000 were produced using a 1999 orthophoto, and aerial photograph stereo pairs. One map uses the British Columbia Terrain Mapping Classification System to delineate different surficial materials, drainage, texture, and peat decomposition. The second map applies the surficial geology mapping of Armstrong and Hicock, 1980 to the 1:10,000 orthophoto.

2. LOCATION AND REGIONAL SETTING

Burns Bog is an organic deposit that covers an area of approximately 4,000 ha on the Fraser River Delta, immediately south of the South Arm of the Fraser River (Hebda and Biggs, 1981). The Fraser River Delta is located next to a geographic region referred to as the Fraser Lowland (Figure 1).

Armstrong (1984) describes the Fraser Lowland as a triangular shaped area of approximately 3,500 km^2 located in southwest corner of Canada and northwest corner of the United States (Figure 1). It is an area of low relief bordered by the Coast Mountains to the north, by the Cascade and Chuckanut Mountains to the southeast, and by the Strait of Georgia to the west. The adjacent mountain ranges have peaks in excess of 1,800 m and are dissected by deep U-shaped glacial valleys.

The Fraser River is the dominant geomorphological feature in the Fraser Lowland. The Fraser River has a catchment area of 234,000 km^2 and stretches a length of 2,800 km through British Columbia before it drains into the Strait of Georgia (Armstrong, 1984). The Fraser River transports a heavy load of sand, silt and clay, which is deposited to form the Fraser River Delta.

Burns Bog is an ombrotrophic domed bog that is approximately oval in shape. It measures about 9 km in the east-west direction and 5.5 km in the north-south direction (Piteau, 1994). The centre or top of the dome is 5 to 6 m above mean sea level, where as the lower periphery edges are only 1 to 2 m above mean sea level. The lands immediately surrounding the bog are generally of low relief, with the exception of the Newton Upland and Panorama Ridge to the east.

3. GEOLOGICAL HISTORY

The geological history of the West Coast can be traced back to the Jurassic Period. A geologic time scale is present for reference in Figure 2. The following sections, taken primarily from Armstrong et al. (1990) outline the present understanding of the events that produced the current geology of Southwestern British Columbia.

3.1 JURASSIC PERIOD

During the Jurassic Period (150 million years BP (before present) the ocean off the West Coast of North America looked very different than it does today. At that time, volcanic islands and shallow marine basins were present in the Fraser Lowland area (Stark, 1977) (Figure 3). This gave rise to the volcanic basalt, limestone, and sedimentary rocks that are now metamorphosed and uplifted in the Coast Mountains (Armstrong et al., 1990). It is believed that around this time, through tectonic activity, the oceanic Pacific plate collided, and subducted (Figure 2) under the continental plate of North America, bringing with it a land mass, now called Vancouver Island, from the southwest (Stark, 1977).

As the Pacific plate moved downward into the earth’s mantle, it melted, becoming magma, and then slowly rose up through the volcanic and sedimentary rock being deposited at the surface (Figure 2). During its slow ascent the magma cooled to form the plutonic rocks of the Coast Mountain Plutonic Complex. Parts of the older volcanic and sedimentary rocks that the magma intruded into were incorporated, heated, and deformed (metamorphism) resulting in metasedimentary and metavolcanic rocks. These metamorphosed rocks form the basement rocks in the western part of the Georgia Basin, and are left as remnants known as roof pendants and inclusions in the Coast Mountains. They are the only records of environmental conditions before the plutonic rocks formed. Some roof pendants in the Coast Mountain Range include metavolcanic (greenstone), metasedimentary, and minor amounts of crystalline limestone (marble) indicating environmental conditions with shallow marine basins, and volcanic activity.

3.2 CRETACEOUS PERIOD AND TERTIARY PERIOD

Throughout the Cretaceous and into the Tertiary, mountain building caused by the subduction of the Pacific plate under the North American plate produced uplift in the Coast Plutonic Complex. As the Coast Plutonic Complex was elevated above sea level it began to be eroded by rivers, which carried gravel, sand, mud, and plant debris into the Georgia Basin (Armstrong et al., 1990). These eroded sediments form the sedimentary rocks that underlie the unconsolidated sediments of the Fraser Lowland and Burns Bog. During this time, the Coast Mountains were only a series of low hills with a temperate humid climate (Armstrong et al., 1990). The eroded sediment was deposited in coalescing alluvial fans, and plains in the Georgia Basin, which continued to subside as more sediment was laid down (Figure 3). With the exception of coarse fan deposits, all the sediments would have been deposited horizontally, but subsequent tectonic activity has tilted them 8° to 12° towards the south (Armstrong et al., 1990).

Armstrong et al., 1990 indicated that the amount of uplift and erosion in this area resulted in the accumulation of up to 4,400 m of sediment. The sediment basin subsided at the same rate as the sediment was deposited. The surrounding hills in turn uplifted at the same rate as they were eroded. In this manner, a thick sequence of sediment was deposited.

The oldest rock in this sequence is a conglomerate of Upper Cretaceous age (65 million years BP) that rests directly on the basement of quartz diorite of the Coast Plutonic Complex (Armstrong et al., 1990). The youngest rocks are Miocene in age, but are buried deep beneath unconsolidated surficial deposits. Drill holes have penetrated shale, sandstone, and conglomerate with interbedded volcanic ash and coal.

Starting 20 million years BP, halfway though the Tertiary Period, Cascadian Volcanism began. Local volcanoes, Mt. Garibaldi, northeast of Squamish, and Mt. Baker, in Washington State both had major eruptions during the Late Quaternary time, but are now dormant. These volcanoes are only the most recent demonstration of volcanic forces in the area. There is evidence of three periods of volcanism collectively called Cascadian volcanism (Armstrong et al., 1990). Most Cascade volcanic rocks are mafic intrusive dykes and sills, andesites, and basaltic lava flows.

3.3 QUATERNARY PERIOD

Tectonic activity in the Jurassic and Cretaceous Periods configured the landmasses, and uplifted the mountain ranges seen in Southwestern British Columbia today. Episodes of glaciation and sea level changes were the dominant forces shaping and sculpting the landscape the during the Quaternary Period.

The stratigraphy in the Fraser Lowland was determined by a complex sequence of advances and retreats of the Cordilleran ice sheet and sea level fluctuations during the Late Pleistocene and Holocene Epochs of the Quaternary (40,000 years BP). Approximately 15,000 years BP, at the height of the last major glaciation (Fraser Glaciation), ice more than 1,500 m thick covered the Fraser Lowland and only the highest peaks of the nearby Coast Mountains projected through the ice (Clague, 1981, 1989). Figure 4 illustrates the geologic evolution of the Fraser Lowland and delta over the last 13,000 years.

As this maximum rapidly declined, glacial outwash sediments, including fluvial river and delta deposits, and ablation tills were deposited in front of the retreating ice. As low lying areas became ice free they were invaded by the sea, and subaqueous deltas, outwash fans, and channels were constructed as sediment laden waters were discharged from the wasting ice mass. Upland areas were left covered by thick deposits of glacial till.

During this glacial retreat, the present lower Fraser Valley was the site of a piedmont glacier that was entering the sea. Marine and glaciomarine sediments were deposited in the area, while tills, outwash, and ice contact deposits were on uplands. It was at this time that the Fraser River began to develop its position in the Fraser Lowland (DeBoer, 1983).

3.4 POST GLACIAL

The western Fraser Lowland was ice free by 11,000 years BP (Clague et al., 1997). By 8,000 years BP the Fraser River Delta was approaching the Burns Bog area, depositing the fine grained sediments, such as silts and clays, that are typical of the prodelta facies. As the delta continued to grow a complex sequence of deltaic silt, sand, and cross-bedded sand and gravel was deposited.

Burns Bog began developing in intertidal flats about 5,000 years BP. Sediments from the base (0-2m below sea level) of Burns Bog have yielded radiocarbon dates around 3,000 to 5,000 years BP (Hebda, 1977). Hebda, 1977 describes the development of Burns Bog based on plant material composition and developmental vegetation stages. Around 5,000 years BP, after initial colonization of the new emerged silty sand basal sequence, sedges (perhaps with some grasses), followed by shrubs such as <u>Myrica</u> and <u>Spiraea</u> and <u>Ledum</u> appeared and gave rise to sedge peat, heath peat, and wood peat. At approximately 3,000 years BP, <u>Sphagnum</u> appeared and produced sphagnum peat typical of a raised bog.

Piteau (1983) indicated that there is evidence to suggest that there were two large bogs (Lulu Island, and Burns Bog), one on each side of the present main channel of the Fraser River. An abandoned channel, comparable to the size of the present main channel, crossed eastern Lulu Island, from the vicinity of Annacis Island on the southeast to Mitchell Island on the northwest. This channel cut the Lulu Island into two parts. Blunden (1975, cited in Piteau, 1983) suggests that there may have originally been one large bog, while the Fraser River flowed north of Lulu Island along the present North Arm of the river. He suggests that the main channel is of recent origin, and became established when the river broke through the large bog some time after 2,500 years BP.

4. BEDROCK GEOLOGY

Bedrock outcrops in the lands surrounding Burns Bog are limited to the slopes of the Cascade and Coast Mountains, and isolated hills and creeks in the Fraser Lowland. In the immediate vicinity of Burns Bog, bedrock is buried deep below a thick sequence of unconsolidated Quaternary sediments. These include Pleistocene and Holocene glacial and post glacial deltaic and marine deposits. Figure 5 shows a generalized sequence of bedrock, surficial deposits and the time span of their formation in the Vancouver area. In Burns Bog bedrock is covered by a thick sequence of Quaternary (Ice Age) sediments, and up to 225 m of Post Glacial (Modern) sediments (Armstrong et al, 1990).

The Coast Mountains are made up of a group of rocks named the Coast Plutonic Complex that are primarily comprised of granite, granodiorite, quartz diorite, and dioritic complexes with gabbro and amphibolite. These rocks began to form 140 million years ago as deep magma slowly rose up through the earth’s crust cooling to form plutonic rocks, such as granite. The older volcanic and sedimentary rocks that the magma intruded into have been metamorphosed into gneiss, amphibolite, and greenstone.

The bedrock deep below Burns Bog is Late Cretaceous and Tertiary sedimentary rocks. This bedrock is about 70 million years old, and lies directly on the Coast Plutonic Complex basement rocks (Armstrong et al., 1990). It is exposed in several larger hills and low isolated mountains such as, Burnaby Mountain, Grant Hill, Silverdale Hill, and further east, Sumas Mountain. These rocks are mainly freshwater sedimentary rocks, conglomerates, feldspar rich sandstones, siltstones, and sandy shales that were deposited in the Georgia Basin by streams eroding the Coast Mountains. There are seams and lenses of coal interlayered with some of the finer grained sediments, having formed from plant debris which accumulated in bogs and swamps (Armstrong et al., 1990).

The Cascade Mountains are made up of volcanic and intrusive rocks, mainly basalt and andesite. These rocks formed by magmas intruding into the Tertiary sedimentary rocks of the Georgia Basin to form dykes and sills, or by lava cooling at the surface to form columnar jointed basalt. They are finer grained than the granitic plutonic rock of the Coast Mountains because the magma cooled faster and mineral crystals did not have time to grow large.

5. SURFICIAL GEOLOGY

The surficial deposits in Burns Bog and surrounding lands includes a thick sequence of post glacial deltaic sediments over glacial outwash, till and marine sediments. The organic peat of the bog caps these deltaic sediments.

Throughout the bog area there are organic peat deposits of varying degrees of decomposition. Towards the centre of the bog, peat is more fibrous, thicker, and less decomposed. With the exception of the eastern edge of the bog, in the Delta Nature Reserve, peat becomes thinner, and more decomposed toward the periphery. In the Delta Nature Reserve the peat is thick. Geotechnical data from construction of Highway 91 (DeBoer, 1982, 1983) show peat up to 10 m thick right adjacent to the Newton Upland. Peat mining activities have changed the elevation and the thickness of peat deposits, as well as drainage patterns within the bog. Areas that have been mined and are now inundated are delineated on the Terrain Map (Map 1). Several ponds have been created in the bog by hydraulic harvesting of peat. Further discussion of the formation and composition of the peat is presented in Section 6.3.

Deposits at, or near the surface in the vicinity of the bog, include fine overbank sand and silt, organic materials, glacially derived outwash sand and gravel, and glacial till.

Areas in the north, bordering the Fraser River, and a few smaller areas on the east and south, are covered by fine grained fluvial overbank silt and sand. Prior to the construction of flood control dykes, this material accumulated as a result of periodic flooding of the Fraser River. The accumulation of the overbank silt and sand has ceased since floods are prevented by the dyke structures. From soil mapping by Luttmerding, 1981, and soil field studies that AGRA conducted as part of the Burns Bog Ecosystem Review on Native Soils, no silty overbank sediments appear to extend into northern boundary of the bog. The actual southern limit of overbank sediments as mapped by Armstrong and Hicock, 1980 (Map 2) is difficult to confirm due to the extensive industrial development in the area.

The Newton Upland and Panorama Ridge form the eastern perimeter of the bog and are comprised of glacially derived fluvial sand and gravel, underlain by a dense lodgement till. Sand and gravel was deposited in braided river type environments that carried glacial meltwater and sediment from the ice front to the sea. Clague et al. (1996) indicate that there are landslides in the escarpment of the Newton Upland that borders the eastern edge of Burns Bog. Historic landslides have been recorded in this area. They were likely slow, retrogressive type slumps or ravelling in the uncemented sand and gravel. This type of instability appears to be common with this map unit on Armstrong and Hicocks' surficial geology map. One such landslide was evident on 1954 aerial photographs, in the area south of 64^{th} Avenue. Aerial photographs reveal that this slide has since been mined for sand and gravel.

6. STRATIGRAPHY

The stratigraphy in the Fraser Lowland was primarily determined by a complex sequence of advances and retreats of the Cordilleran ice sheet and sea level fluctuations during the Late Pleistocene and Holocene (40,000 years BP). As sedimentary environments changed from marine, glacial marine, glacial, fluvial, to terrestrial varying sediment packages were built up over one another to create the stratigraphy observed today.

The stratigraphy of the Burns Bog area is illustrated on three cross sections. The cross sections A-A' (W-E), and B-B' (S-N), and C-C' (S-N) (Figures 6 to 8) are based on previous work by Piteau (1983, 1994) related to hydrogeological studies of Burns Bog, and DeBoer, (1982, 1983), related to geotechnical investigations for the construction of Highway 91. Figure 9 illustrates the cross section locations. Borehole and geophysical data from other reports, such as Dames and Moore (1974), Golder Associates (1995), and Terra Engineering (1999), were also examined and compared to the cross sections, where applicable. The subsurface data available was mostly limited to depths ranging from 3 to 15 m and was obtained at sites located around the periphery of the bog in industrial, highway, or construction sites. The subsurface data reviewed revealed a stratigraphy that can be divided into three units with gradational contacts. The three units, from the base up are: deltaic sand, fine overbank silt deposits, and organic peat. Since the available data is limited in depth and is concentrated in a few areas of investigation, it does not provide broad coverage of the bog. It is not possible to interpret the degree of the interconnection between deeper stratigraphic units with any degree of certainty.

Each of the three units is described below.

6.1 DELTAIC SAND UNIT

Data from Piteau (1983, 1994) show the deltaic sand unit ranging in depths between 1 to 7 m below mean sea level, and having a thickness of 10 to 20 m. This unit provides the main aquifer in the area and is known to extend beneath all of the bog and northwards to the Richmond Landfill on Lulu Island (Piteau, 1994). Interlayered clayey silt and sand underlies the deltaic sand unit (Golder, 1995). This stratum is inferred to extend to depths of 34 m (Golder, 1995).

The Ministry of Transportation and Highways investigation in 1984 for Highway 91 (De Boers, 1982, 1983) revealed that the top of the deltaic sand unit underlying the silt and peat units varies in depth from between 5 to 10 m below the original ground level (-1 to 4 m elevation) along the present alignment of the Highway. A 1982 investigation of an earlier proposed alignment for the highway (location of Section C-C') revealed that the depth to the top of the sand unit was deeper (5 to 16 m depth, -2 to 8 m elevation) west of the present Highway alignment and south of the Nordel Interchange. Investigations for the connectors to 72nd Avenue and 84th Avenue show that the top of the sand unit falls deeply between the highway and Panorama Ridge to depths of between 20 and 30 m (-12 to 20 m elevation). The subsurface information provided by the Highway 91 investigations indicates that the Fc unit mapped by Armstrong in the northeast area of the bog, extends as a subsurface ridge feature beneath the general alignment of Highway 91.

Hebda (1977) also describes a subsurface mineral ridge that separates a shallow basin at the foot of the Panorama Ridge from the centre part of the bog.

6.2 SILT UNIT

Overbank deposits of silt, clayey silt, and organic silt, 0.8 to 5.5 m thick (in the vicinity of Vancouver City Landfill), overlie the deltaic sand and are likely continuous under the bog (Golder, 1995). This unit becomes sandier with depth and grades into the underlying deltaic sand unit. This unit daylights at the surface as recent overbank silt deposits near the shores of the Fraser River, as shown in cross section B-B' (Figure 7).

The thickness of the silt unit varies between 1 and 7 m west of the existing Highway 91 alignment. Along the subsurface ridge, the silt unit thins to approximately 2 to 3 m in thickness. In the basin area between Highway 91 and Panorama Ridge the silt unit is generally between 10 and 17 m in thickness. The subsurface data for the 72nd connector shows interbedded sand and silt horizons in the area west of Panorama Ridge. These deposits may represent deltaic and overbank sediments deposited by the Blake and Cougar Creeks that flow west from the Newton Upland. The sand lenses appear to interconnect with the deltaic sand unit that underlies Burns Bog.

6.3 PEAT UNIT

Organic peat deposits overlie the silt unit, and Piteau (1983, 1994) report that the peat varies in thickness from 1 m near the periphery of the bog to 5.6 m towards the centre. The three cross sections show this variation in peat thickness across the bog. In cross sections B-B', compression of the peat underneath the Vancouver City Landfill is evident.

The Highway 91 investigation data indicates that the peat generally varies in thickness from between 3 m and 9 m west of the existing highway alignment, between 3 and 4 m over the subsurface ridge along which the highway is constructed, and approximately 5 to 10 m thick to the east of the Highway and north of 72nd Avenue. This concurs with the findings of Hebda (1977), who also described a peat thickness of 5 m next to the Panorama Ridge, thinning to 3 m (as a mineral ridge) at 700 to 1,000 m west from the Panorama Ridge.

Golder (1995) and Piteau (1983, 1994) divide the peat unit into two distinct zones based on level of decomposition. The surface layer (acrotelm) is fibrous and less decomposed. Typically, the acrotelm is 0.3 to 1 m thick. The deeper layer (catotelm) is made up of a more decomposed material that is amorphous. At depth the peat often becomes more silty and grades into the underlying clayey silt.

Hebda (1977) differentiates peat based on plant material composition and developmental stage. Around 5,000 years BP, after initial colonization of the new emerged silty sand basal sequence, the bog went through three major stages of development, giving rise to three types of peat. First, sedges (perhaps with some grasses) occupied most of the bog, and produced a sedge type peat. Secondly, shrubs such as Myrica and Spiraea appeared, and soon after Ledum, to produce a woody peat and heath peat. Thirdly, at approximately 3,000 years BP this was replaced by Sphagnum to produce the sphagnum peat typical of a raised bog. Distribution of various peat types is outlined in the Native Soils component of the Burns Bog Ecosystem Review.

Hebda (1977) also notes the distinctness of bog evolution in the basin area located between the subsurface sand ridge and Panorama Ridge. Here, the Sphagnum phase only began recently, and the sedge phase was only transient. A swamp/marsh interval and a swampy shrub interval dominated this area, and Sphagnum did not become established until recently.

7. EFFECT OF GEOLOGY ON HYDROLOGY

Piteau (1994, 1983) describe Burns Bog as an elongated (east-west) orientated dome shaped ombrotrophic bog. By this definition the bog should obtain all its moisture from rainfall and not receive surface water runoff and groundwater recharge from adjacent uplands.

The presence of small deltaic fans at the base of Panorama Ridge in the vicinity of Blake and Cougar Creeks suggests that surface water may once have flowed onto the bog. An old map of the area (DeMill(e) and Paulik, 1997) also indicates that Cougar Creek once drained southwest from Panorama Ridge across the Bog. However, since the construction of the Northeast Interceptor Canal surface drainage is now diverted northwards around the Bog. Aerial photographs from the 1930s and 1940s show a small creek in the northwest corner of the bog (Map 2). In the past this creek flowed westward, draining the bog. Currently cranberry fields cover the area, and the creek is no longer evident

There is a possibility that water may also to reach the bog via groundwater flow from the Newton Uplands. For this to occur there needs to be a subsurface connection between aquifer formations in the upland area and the deltaic sands underlying the bog.

Piteau cite that Dayton and Knight (1993) report that the Municipality of Delta used to obtain some of its municipal water supply from two sets of artesian wells located within the Watershed Park near 64th

Avenue in Delta. These wells were between 73 and 85 m deep, and appear to have tapped the Quadra sand unit (PVa, b, c).

Although artesian wells are reported at the south end of Panorama Ridge in the Watershed Park, there has been uncertainty about whether artesian conditions continue northwards of 72nd Street. Artesian conditions north of 72nd Avenue may be absent because the PVa,b,c unit in this area is finer grained, silt and clay of marine and glaciomarine origin, that may not be hydraulically connected to the sandier PVa,b,c unit as in the Watershed Park area (Map 2). The absence could also be due to a lack of data north and west of Panorama Ridge. Some historical data was found during a search through the Ministry of Environment, Land, and Park Water Well Records Database. Two water well records were found in the area northwards of 72nd Avenue. These wells are drilled to a depth of 55 m, and are reported to have artesian flow, however one of the wells was abandoned in 1964 and is no longer in operation. At a depth of 55 m, the wells are sufficiently deep to be within the PVa,b,c (Quadra unit).

Piteau suggest that the Quadra sand unit is possibly hydraulically connected to the deltaic sand unit to the west beneath the bog, however, as illustrated by cross section A-A", the degree of interconnection is uncertain (Piteau, 1994). One possible but unproven connection could be the buried delta deposits at the foot of Blake and Cougar Creeks. If these creeks are connected to the Quadra Sand, groundwater may also be connected to the deltaic sands beneath the bog via the interfingering of the deltaic sand and the overlying overbank deposits.

Because silt and organic units of low permeability that overlie the deltaic sands, groundwater in the sand would be under confined conditions. Therefore, if groundwater within the deltaic sands was being supplied by water from the Newton Uplands, artesian flow conditions would be expected in wells located in the Bog. Data from wells drilled into the deltaic sand unit for landfill feasibility studies by Piteau (1983, 1992) demonstrate that this unit is under artesian pressures. This may be further evidence to suggest that there could be some connectivity. Hydrogeology of Burns Bog is discussed in more detail under a separate study that specifically addresses Hydrogeology.

8. EFFECT OF EARTHQUAKES ON BOG

Vancouver and adjoining regions lie within a zone of earthquake activity that rims the Pacific. Most epicentres occur in the Strait of Georgia, Puget Sound, and Vancouver Island, suggesting that there are active faults in these areas (Armstrong, 1984). If an earthquake is intense, the resulting vibrations may cause liquefaction (change of sediment from a solid to a quicksand-like liquid state) in areas underlain by saturated unconsolidated sand and silt deposits (Armstrong, 1984).

It is AGRA’s opinion that the effects of a large earthquake on Burns Bog, as currently developed, would not be catastrophic. If liquefaction of sand and silt occurred beneath the bog, there may be local upwelling, geysers or sand spouts in areas where the peat cover is thin. Liquefaction may also result in settlement as porewater pressures, built up during an earthquake dissipate.

9. ANTHROPROGENIC EFFECTS ON GEOLOGIC PROCESSESS

Over the past 100 years the Burns Bog area has undergone significant anthroprogenic alteration. As a result, natural geologic processes have been modified. One of the major changes as a result of human activities has been the alteration of natural drainage patterns and surface hydrology processes of the bog and surrounding lands.

The Northeast Interceptor Canal runs from 72nd Avenue north to the Fraser River. It was dug in 1917 along the Burlington Railway spur to divert flow from Blake and Cougar Creeks northwards to the Fraser River (Beak, 1982). Blake and Cougar Creeks historically flowed onto the bog. Cougar Creek is thought to have flowed south across the bog towards Big Slough as indicated on British Naval Charts from 1898 (DeMill(e) and Paulik, 1997). When Cougar Creek is in flood, it overflows from the Northeast Interceptor Canal and flows south along the railway ditch and through a culvert under the railway and sewer where is discharges into the old Cougar Creek course (DeMill(e) and Paulik, 1997).

Beak Consultants (1982) suggested that the bog received a significant portion of recharge from Panorama Ridge, which contributed to the maintenance of a high water table in the bog. After the Interceptor ditch was constructed surface runoff from Panorama Ridge was intercepted and the hydrology of the bog changed. This change resulted in a drop in the elevation of the water table that in turn caused the bog edges to slowly dry out in the successive years. As, a result the vegetation along the eastern edge of the bog has been observed to change from typical bog species to those typical of a coastal forest (Beak, 1982). However, as Hebda (personal communication) suggests, 1930s aerial photographs show forest growing in this area, and the area was logged during the 1970s, therefore it may be possible that this area has not been occupied by bog species for over one hundred years.

In World War II, there was a demand for magnesium for bombs. Peat played a vital part as a catalytic agent in the refining of magnesium (Burns, 1997). Therefore, Western Peat, a Canadian Company, began peat harvesting operations in the 1940s. Peat harvesting continued until the 1980s. The extraction of peat has had an impact on hydrology by creating ponds in the bog. Also, by changing the topographic profile and elevation of the peat, natural surface water flow directions were altered, and low points in the peat surface would collect precipitation and seepage. It should be noted, however, that peat is a renewable resource (DeMill(e), 1994). Vegetation in a cut over bog will recover in about 40 years; however, several hundred years would be required to replace the peat material that has been removed. Although the peat has now recovered in areas harvested in the 1940s to 1950s, drainage ditches and some ponds associated with deep harvesting are still present and affect the natural drainage of the bog.

In addition, ditches were constructed in order to transport water to and from different localities for purposes of agriculture, peat harvesting, road building, and construction. Drainage ditches and associated pump stations alter the natural hydrology of the bog.

Construction of dykes along River Road, on the northern boundary the bog, has altered natural periodic flooding of the bog. Dykes reduce the size and frequency of floods from the Fraser River. This has halted the cyclical deposition of fine grained river sediments onto the bog's northern boundary, and the natural building of levees on the river's edge.

10. MAPS

10.1TERRAIN MAP

A terrain map was produced at the scale of 1:10,000, using a 1999 orthophoto provided by ENKON Environmental Limited, and aerial photograph stereo pairs. Polygons were delineated based on different surficial materials, textures, geomorphology, and geologic processes. Polygons were also given a drainage classification. The mapping was based on the British Columbia Terrain Mapping Classification System. The 1:10,000 Terrain Map is included in digital format on the accompanying Compact Disc (CD).

10.2 SURFICIAL GEOLOGY

A surficial geology map of Burns Bog and surrounding lands was produced at the scale of 1:10,000, and was based primarily on the mapping done previously by Armstrong and Hicock, 1980. Armstrong and Hicock delineate polygons based upon lithostratigraphic position, and age of deposits.

Armstrong and Hicocks' map has been modified in the area near 72nd Avenue to include two small fluvial fan deposits, originating from the discharge of Cougar Creek and Blake Creek. These fan deposits are no longer accumulating because the creeks were diverted in 1917, and no are longer able to deposit sediment onto the bog. Silt to fine sand deposits were found at the surface, during native soils mapping, and so an appropriate polygon was added to the geology map. Geotechnical investigations for the construction of Highway 91 (DeBoer, 1982, 1983) also provided information to verify these fan deposits, and is explained in detail in Section 6. The 1:10,000 Surficial Geology Map is included in digital format on the accompanying Compact Disc (CD).

11. CONCLUSION

The geology, geologic history, stratigraphy, and geologic processes influencing hydrology were described by reviewing and summarizing the existing literature. Two maps, at the scale of 1:10,000, were produced using a 1999 orthophoto, and aerial photograph stereo pairs. One map uses the British Columbia Terrain Mapping Classification System to delineate different surficial materials, drainage, texture, and peat decomposition. The second map applies the surficial geology mapping of Armstrong and Hicock, (1980) to Burns Bog and surrounding lands. Armstrong and Hicocks' mapping was modified in the area near 72nd Avenue to include two small historical fluvial fan deposits, originating from the discharge of Cougar Creek and Blake Creek.

Geological history influencing Burns Bog and surrounding lands began during the Jurassic Period, 150 million years ago, as the oceanic Pacific plate collided, and subducted under the continental plate of North America. This tectonic activity created the uplift and Coast Mountains seen today in Southwestern British Columbia (Armstrong et al., 1990). The sediments eroded from the Coast Mountains form the Late Cretaceous and Tertiary sedimentary rocks that underlie the unconsolidated sediments of the Fraser Lowland and Burns Bog.

During the Late Pleistocene and Holocene (40,000 years BP) there were a complex sequence of advances and retreats of the Cordilleran ice sheet and sea level fluctuations. Approximately 15,000 years BP, at the height of the last major glaciation (Fraser Glaciation), ice more than 1,500 m thick covered the Fraser Lowland (Clague, 1981, 1989).

As this maximum rapidly declined, glacial outwash sediments, including fluvial river and delta deposits, and ablation tills were deposited in front of the retreating ice. As low lying areas became ice free they were invaded by the sea, and subaqueous deltas, outwash fans, and channels were constructed as sediment laden waters were discharged from the wasting ice mass. The western Fraser Lowland was ice free by 11,000 years BP (Clague et al., 1997). By 8,000 years BP the Fraser River Delta was approaching the Burns Bog area, depositing the fine grained sediments, such as silts and clays, that are typical of the prodelta facies.

Burns Bog began developing in intertidal flats about 5,000 years BP as rushes, cattails and sedges became established. Over the next 1,000 years, brackish marshes were replaced by wetlands dominated by sedges and grasses, and in this condition peat accumulated at a significant rate (Catherine Berris Associates, 1993).

The deltaic intertidal and wetlands environment resulted in the deposition of deltaic sands, overbank silts and organic deposits. Although the deposits have gradational contacts, they form three prominent stratigraphic units in the area of Burns Bog. The vertical and horizontal distribution of these units is illustrated on cross-sections presented in this report.

In general, the top of the deltaic sands are at an elevation of between 1 and 4 m beneath the Burns Bog, however, they form a north south striking subsurface ridge feature under the east area of the bog, along the general alignment of Highway 91. The origin of this ridge is unknown. It is possibly a deltaic sand bar or island as it has had a significant effect on the deposition of the silt and organic units.

The overbank silt deposits overlie the deltaic sands and generally vary between 1 m and 7 m in thickness across the bog. The deposits thicken toward the Fraser River and thin over the subsurface sand ridge feature. They also interfinger with the deltaic sands in the vicinity of 72nd Avenue, where they represent delta and overbank deposits of streams flowing from the Newton Uplands into the bog. Between the subsurface sand ridge and Panorama Ridge and north of this delta feature these deposits reach a thickness of up to approximately 17 m.

The organic deposits vary up between less than 1 m to 10 m in thickness across the bog. In general the peat forms an oval dome shaped deposit that is thickest in the central area of the bog and thins toward the margins. The peat also thins across the subsurface sand ridge beneath the alignment of Highway 91. Between Highway 91 and Panorama Ridge the peat thickens to up to 10 m. These thick deposits may be due to prolonged wetland conditions that once occurred in a relatively stable environment created by the sand ridge feature and the presence of Panorama Ridge.

The hydrology of Burns Bog is directly related to the stratigraphy of the area. The main likely sources of water to the bog are surface and subsurface drainage from the Newton Uplands and direct precipitation. Surface drainage from the Newton Uplands has been significantly reduced with the construction of the Northeast Interceptor drain. The hydrology within the bog itself has also been modified with the construction of numerous drainage channels, and the extensive peat harvesting that has altered the topography of the bog and also created a number of ponds.

Aquifers and artesian groundwater conditions are well documented to the south of Panorama Ridge and are associated with the Quadra Sand. The Quadra Sand aquifer may be connected to the deltaic sand unit beneath the Burns Bog, however, because existing subsurface information is limited to shallow depths, this relationship could not be substantiated.

12. CLOSING

We trust that the information provided in this report meets your requirements at this time. Should you have any questions or if we can be of further assistance, please do not hesitate to contact the undersigned at your convenience.

Yours truly,

AGRA Earth & Environmental Limited

Per:	Reviewed by:
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