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RESTORING THE NATURAL HYDROLOGY OF BURNS BOG, DELTA, BRITISH COLUMBIA – THE KEY TO THE BOG’S ECOLOGICAL RECOVERY

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ABSTRACT

Burns Bog is a globally unique raised ombrotrophic bog with radial drainage. Years of peat extraction and peripheral and internal draining, have greatly impacted natural hydrology and threatened the ecological integrity of the bog ecosystem. Acquired in 2004 through collaboration among governments the bog is now the focus of a major restoration effort, of which hydrology is a central piece. Two strategies that promote the recovery of the natural bog are the re-creation of natural hydrology, and the characterization and eventual re-establishment of the lagg zone. The restoration of bog hydrology involves retaining rainfall by reducing water losses out of the bog. The lagg is the essential peripheral drainage system of raised bogs. Key elements involve understanding the lagg's hydrology especially water table and flux, hydrochemistry and their relationship to ecosystem composition and structure.

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Introduction

Burns Bog is a raised bog ecosystem covering approximately 3,000 ha of the Fraser River Delta between the south arm of the Fraser River and Boundary Bay, British Columbia (Hebda et al. 2000) (Figure 1). In March 2004, over 2000 hectares of Burns Bog was purchased, through a partnership of four levels of government (Federal, Provincial, Regional and Municipal) to conserve its globally unique ecosystem. The bog area and ecosystem complex have been respectively reduced and degraded in the last century by agriculture, peat extraction and urban/industrial growth (Hebda et al. 2000). Delta Municipality, the Greater Vancouver Regional District and their partners have undertaken concerted efforts to maintain Burns Bog in perpetuity as a raised bog ecosystem.

Burns Bog is strictly ombrotrophic, thus all the water and ionic inputs derive solely from direct precipitation. The bog is unique on the basis of its chemistry (influenced by salt water through aerosol deposition), location on a large delta, flora, and large size. The Bog exhibits the typical characteristics of a raised bog ecosystem, including a peat mound raised above the marginal wetland surfaces, an internal water mound raised above the regional water table, acidic nutrient-poor water derived directly from precipitation, a two-layered peat deposit (acrotelm and catotelm), and widespread peatland communities dominated by *Sphagnum* and members of the Heather family (Ericaceae) (Hebda and Biggs 1981).

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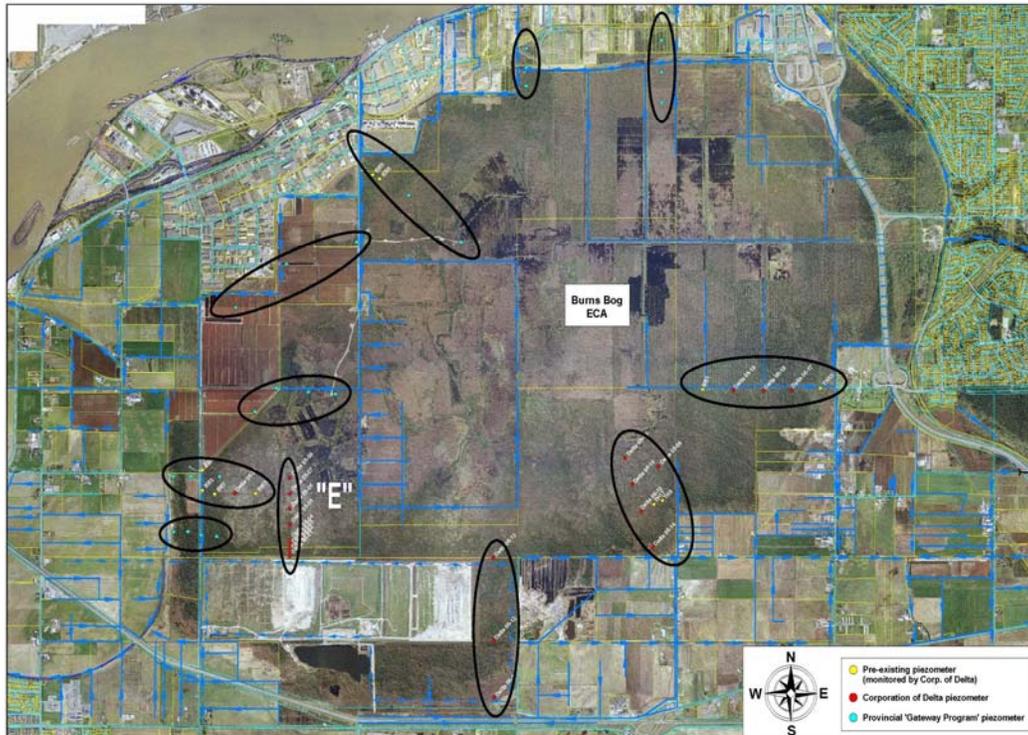


Figure 1. Burns Bog 2006. Blue lines and arrows indicate existing ditches and drainage directions. Red dots mark existing water level monitoring locations, and transects of sites are indicated by ovals. Note the transect labeled “E”, considered in detail in the text.

Burns Bog today is largely isolated from other natural areas by agricultural, residential and industrial development (Figure 1). Of the original bog area, 40% has been alienated by development. Human activities, especially peat mining, have disturbed the hydrology and ecosystems of more than half of the remaining bog area and these disturbances continue to affect the Bog today. Despite these disturbances, Burns Bog retains important ecological processes and continues to support distinctive bog communities. However, destruction of vegetation and the upper porous acrotelm layer over much of the surface, combined with the alteration of the hydrological regime and soil have impeded the peat-formation process. Without restoration of hydrology and plant communities the ecological integrity of the bog is at high risk (Hebda et al. 2000).

The Bog's hydrology is shaped by the water mound, fluctuating water levels in the acrotelm zone (top ca. 50 cm) shown schematically in Figure 2. The Bog's ecological viability is directly dependent on the extent and integrity of the water mound and the peat that encloses it. The upper porous acrotelm layer is vital to the persistence of the water mound and peat-forming communities dominated by *Sphagnum* mosses. Past activities have introduced an extensive system of ditches that greatly augment drainage, and currently only

29% of the Bog's original acrotelm and its dynamic water storage zone remains intact. Several of the ditches penetrate to the centre of the bog and rob the water mound extensively not just at the edges.

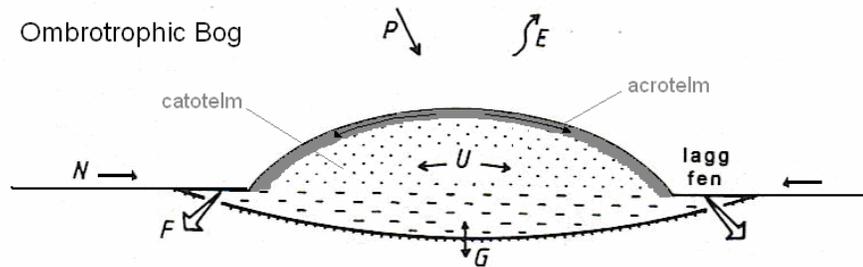


Figure 2. Morphology and hydrological relationships within an ombrotrophic bog. The thickness of the acrotelm is exaggerated in this view. Arrows indicate water fluxes: P, precipitation; N, surface water supply; U, lateral seepage in peat; E, evapotranspiration; F, surface water efflux; and G, exchange with deep groundwater (leakage) modified from Bragg (2002). The dashed area indicates the regional water table, and the dotted area the raised mound.

Calculation of the Bog's water balance suggests a surplus of about 200 mm of precipitation over evapotranspiration for an average year, and monthly water balance analysis for an average year shows that there is a moisture deficit from April to September (Hebda et al. 2000). The relatively low late summer water table, in the range of 27-39 cm below the lawn microtopographic surface, may explain why Burns Bog is near the climatic limits for raised bogs on the west coast of North America. The Bog's groundwater mound is sustained by: [a] a nearly impermeable base of clayey silt; [b] low hydraulic conductivity of the catotelm peat, i.e. impeded drainage restricting outflow of water; and [c] very low topographic gradient. Thus water falling on this raised mire can only flow laterally through the acrotelm by seepage which results in a water table highest (nearest to the surface) at the mire centre and an increased depth only towards margins.

Van Seters and Price (2001) indicated that without intervention, bogs previously affected by extraction do not recover over the long-term [> 25 years]. They suggest that blocking existing ditches may restore the basic hydrology and the water balance to the point that evapotranspiration is the greatest single output, but that the effectiveness of these measures varies according to the specific circumstances of the site. The Burns Bog Ecosystem Review (Hebda et al. 2000) suggested that increasing water levels within Burns Bog would be beneficial for the ecosystem leading to the recovery of peat-forming processes. They recommended maintaining higher water levels in and around Burns Bog providing that privately owned lands would not be flooded.

Maintaining and restoring the ecological integrity of Burns Bog's unique system depends upon successfully addressing the current and future hydrological impacts within and surrounding the bog. Three key hydrological problems have to be addressed; [1] excessive drainage, [2] loss of the natural lagg; and [3] conversion of peatland vegetation to coniferous forest with attendant increased interception and transpiration. In addition, the potential impacts of climate change need to be considered if this bog situated at the climatic limit for raised bogs is to be resilient to the changes that might occur in this century. In particular, it is necessary to consider the interrelationships of a slowly warming and drying climate with tree invasions into the centre of the bog, and with an increasing frequency of fires.

Excessive Drainage

Van Seters and Price (2001) demonstrated that harvested sites rarely return to functional ecosystems after abandonment because drainage and peat extraction lower the water table and expose relatively decomposed peat is hydrologically unsuitable for *Sphagnum* moss reestablishment. Establishment of *Sphagnum* is primarily related to maintaining a specific moisture regime that is acceptable to *Sphagnum* spore germination and early growth; pH and nutrients are also important factors for *Sphagnum* establishment (Rydin and Jeglum, 2006). Some natural regeneration of *Sphagnum* has occurred in isolated pockets on traditionally harvested (block-cut) sites for reasons that are poorly understood, but probably are related to maintenance of sufficient moisture during the summer drought. Augmented regeneration can be facilitated through *Sphagnum* "seeding" (Rocheport and Campeau 1997). Without suitable management (e.g. blocking ditches), affected areas are not expected to improve for a very long time.

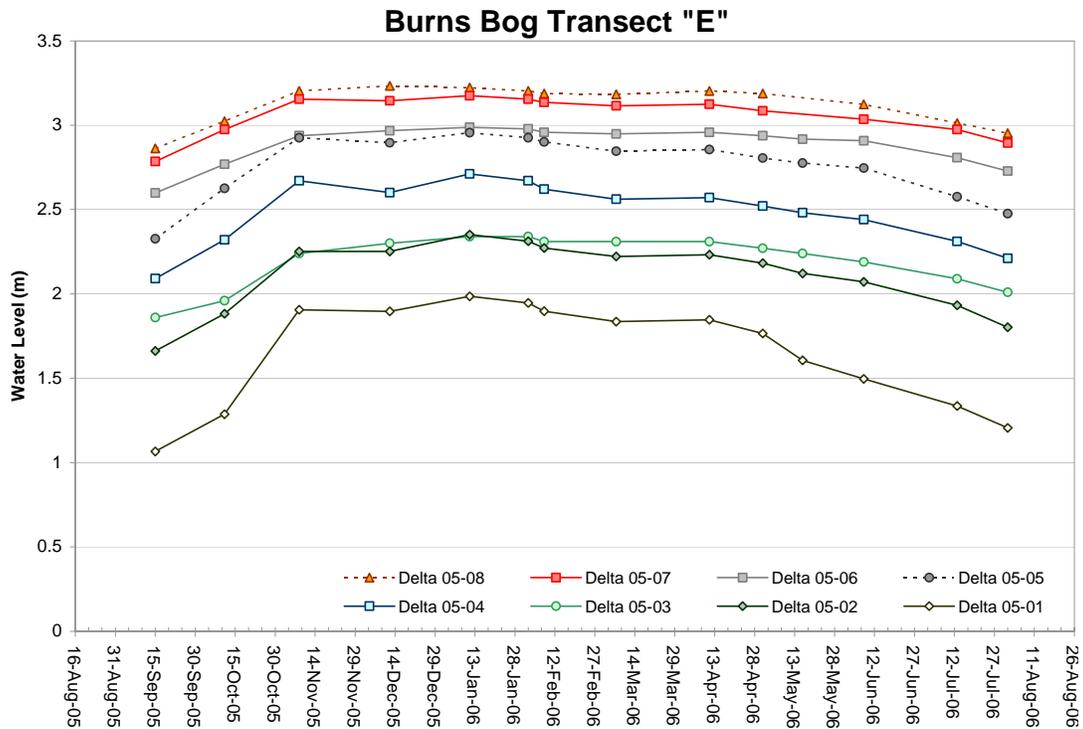


Figure 3 Seasonal and spatial variations in water levels along transect “E” of Burns Bog. The stations are ordered in relation to an axis along the radial flow pattern of the bog with Delta 05-08 being the innermost, and Delta 05-01 being near the bog margin within a few 10s of metres of a major peripheral drainage ditch system.

Stopping the uncontrolled drainage of the existing ditches is the first priority. A first level of ditch blocking has been started in the southeast corner of Burns Bog and water level and *Sphagnum* monitoring are being undertaken along transects to determine what water levels generate the “best” *Sphagnum* responses. Transect “E” shown in Figure 1 is located in one of the least altered areas of the bog and Figure 3 shows some results for measurements of water level in piezometers along the transect labeled “E” in Figure 1. The seasonal and spatial variation in water level along this transect are clearly shown. All stations in the transect show increases in water level during the winter rainy season. The seasonal variation is much greater at the outside margin of the bog [approximately a one metre change at Delta 05-01] than towards the interior of the bog [less than 0.5 m change at Delta 05-08]. Ecological response monitoring is being conducted to determine the growth responses of *Sphagnum* along the transect, and to assess the growth responses of *Sphagnum* and of lodgepole pines (*Pinus contorta*) in response to water table increases.

Long-term extensive monitoring is being conducted to determine the rate of recovery of the domed shape of the bog using a series of transects of subsurface water-level measuring devices from the edge to height of the dome. Water-level monitoring over the bog introduces particular challenges as standard procedures using fixed reference points must be adapted to relative references to accommodate the seasonal variation in height of the bog surface, changes in bog structure such as “mire breathing” or swelling of the bog with winter recharge, and to be able to detect the impact of hydrologic restoration on the structure of the bog surface and water mound. Several staff gauges and piezometers have been secured in subsurface mineral layer and surveyed to their absolute elevation. Others have been positioned in open ponds within the study area these permit measurement of absolute water table. The approach taken is to stratify observations with a focus on specific transects in bog watersheds areas to produce both a whole-bog data set while allowing detailed focus on selected watersheds to determine local ecological responses.

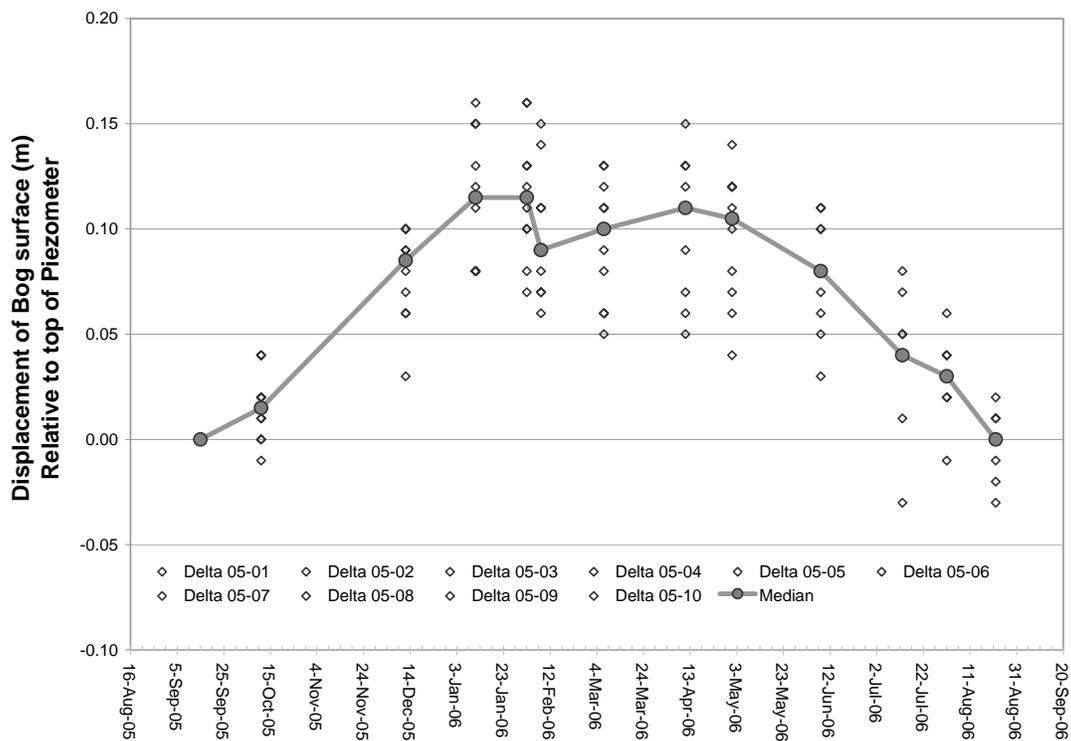


Figure 4. Median displacement (squares with solid line) of bog surface in meters, for 10 piezometers (open diamonds) as measured relative to the top of anchored piezometers. The average maximum displacement was 0.116 m. Maximum displacement values for individual piezometers ranged from 0.08 to .160 m.

Figure 4 illustrates the phenomenon of ‘mire breathing’, expansion and contraction of the peat in response to changes in water storage caused by varying inputs from precipitation (Hebda et al., 2000). Measurements were taken September 2005 through August 2006. Displacement was determined by calculating the change in piezometer pipe ‘stick-up’ (=height above the ground surface), using September 2005 ground elevation as a base datum. The ground elevation in August 2006 dropped below that of September 2005 at some piezometer locations, explaining why the last column on the chart has negative values. The piezometers are anchored into the Bog’s underlying silt layer; consequently the ‘top of piezometer’ elevation is fixed with respect geodetic datum. Mire breathing constitutes approximately 30% of the winter water storage in Burns Bog. The rapid rise of the surface following fall rains is notable in comparison the more gradual decline. The bog clearly retains large volumes of water in May and June well after the rainy season and even into the moisture deficit season in July.

Loss of Natural Lagg

Natural bogs are generally surrounded by a “lagg”. This lagg exists in the boundary between the bog and the surrounding area and represents a transition between the ombrotrophic bog and the minerotrophic areas adjacent. Hydrologically and hydrochemically it possesses attributes of both bog and adjacent lands but its hydrology is strongly influenced by the bog (especially in Burns Bog which is essentially on flat terrain). Thus a functioning lagg exhibits drastic changes over short lateral distances of hydrological, hydrochemical and ecological characteristics as mineral poor bog water mixes with mineral rich water from outside the bog. In Burns Bog, the existing lagg has been severely impacted and only in a few places does it exhibit the original natural form (Hebda et al. 2000).

For Burns Bog the restoration challenge is that of developing an effective plan that restores the water gradient; the chemistry gradient and the appropriate vegetation gradients that reflect natural transitions from bog to minerotrophic lagg communities for the biogeoclimatic region in which Burns Bog occurs. The challenge of re-creating the lagg is itself daunting, yet it must be met simultaneously with dealing with the bog-neighbour interface, particularly related to flooding. As we carefully block off the ditches and drains we must be prepared to work with adjacent landowners to ensure that actions to restore the bog hydrology do not interfere with the use of neighbouring lands or the ability to use road allowances. At present most existing flooding complaints are associated with beaver dams built on historic drainage ditches. The dams are extremely effective in not only raising the water level in the ditch but in raising it to the same elevation in the adjacent peat mass.

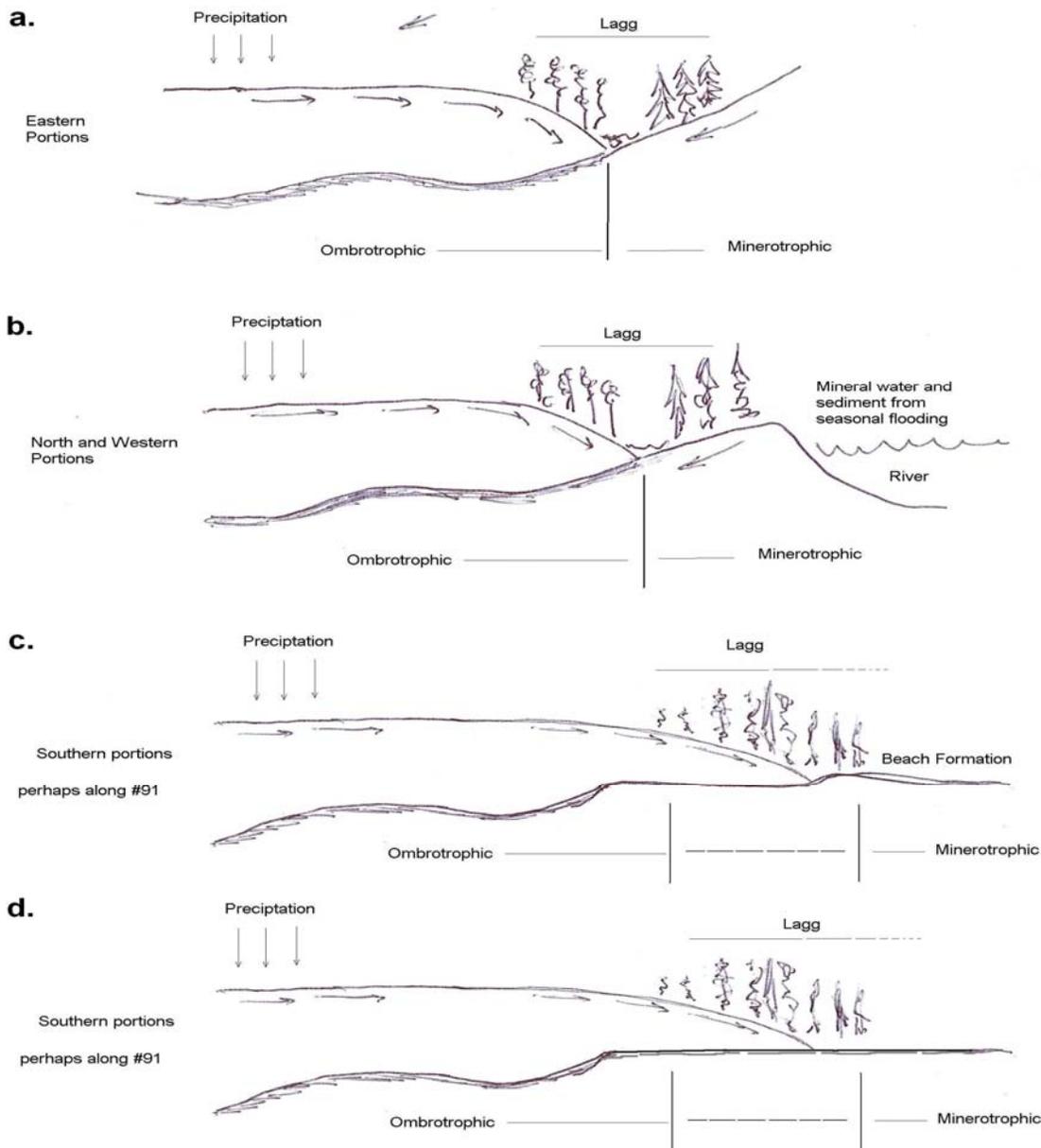


Figure 5. Conceptual structure of the pre-disturbance lagg in different portions of the Burns Bog perimeter; [a] Along the eastern boundary, the lagg was the transition between contributions from a mineral upland and those of the bog's peat upland; [b] Along the northern and western boundaries the lagg was the transition from the bog across the natural levee to the Fraser River and subject to periodic flooding and tidal fluctuations in the river ; [c and d] along the southern extent of the bog the width of the transition from the bog may have been 100s of metres in a zone of low ancient beaches [c] or flat deltaic terrain [d] dominated by natural discharge from the bog margin across a flat.. Modified from Damman (1986).

The lagg that originally surrounding Burns Bog is expected to have been diverse and complicated in structure (Hebda et al. 2000). At the eastern boundary, the lagg would have been structured as in many upland bogs, being the transition between the contributions from a mineral upland and those of the peat upland of the bog (Figure 5a). Along the northern and western boundaries the lagg was a transition from the bog to wet minerotrophic lagg and up onto the natural levee of the Fraser River (Figure 5b). Across the southern side of the bog the transition from the bog may have been significantly different as land forms such as ancient beaches may have contributed to lagg positioning (Figure 5c), or simply dominated by the natural seepage from the bog across a flat delta surface expanse (Figure 5d).

The process of restoring the lagg involves the re-creation of a relatively natural transition between bog and the minerotrophic surrounding area. The transition zone must function hydrologically creating a mixing zone for bog and non-bog water; allowing the chemical interactions of these two types of water to take place, and to allow the transition plant communities to become established. In particular it must buffer the nutrient poor acid water of the bog from cation-rich adjacent mineral lands. Without question the lagg restoration process will take a long time because the results must be suitable hydrologically, hydrochemically and ecologically. For example along portions of the bog margin the potential lagg zone is constrained sharply by human modifications (such as fill) and the original characteristics of a relatively gentle gradient are not feasible. Considerable experience will be needed to assess what lagg currently exists and to determine its characteristics. The challenge will be how to regenerate such attributes passively (natural succession), actively (restoration), or artificially (engineered structures). At present, it is unknown whether or not the natural attributes of a lagg can be engineered or artificially created, at the edge of the peat mass or elsewhere. Yet development pressures on adjacent lands pretty much guarantee that such artificial lagg will have to be constructed.

Conversion from Bog to Forest

Trees within the bog have the potential to enhance transpiration and remove water from the bog to the atmosphere. They also have the potential to increase interception compared to non-forest vegetation, a source of major water balance uncertainty in Burns Bog (Hebda et al. 2000). One of the specific impacts of the historical lowering of the water table, particularly along drainage ditches has been significant forest encroachment. Lodgepole pines, which in the undisturbed bog grew scarcely a metre or two high, were released into vigorous growth and new trees sprouted on disturbed peat surfaces. These changes have undoubtedly influenced the water balance.

One of the questions that is being assessed in the immediate future is whether or not raising the water table will as expected impede further forest encroachment and whether it will be followed by the reappearance of healthy plant community mosaics, with hummock, lawn, carpet, and mud bottom microtopographic phases. It is known that removal of trees can reduce water loss and raise water tables by reducing evapotranspiration and rainfall interception. Carefully planned and implemented thinning of forest on the bog margins could help to raise the water tables faster than ditch damming alone, and could support faster recovery of the natural pattern of *Sphagnum* species and community mosaics. Ecological restoration will be in part measured by the expansion of typical bog plant communities with associated species of vertebrate animals, invertebrates, fungi, and microorganisms. Restoration will also be measured by the control and decrease of fen species and other non-native species which have invaded along mineral-enriched road beds, ditches, and peat diggings.

Climate Change Effects

Climate change is expected to affect the pattern of temperature and precipitation of Burns Bog. Taylor and Langlois (2000) indicate that mean annual temperatures in the lower Fraser Valley will increase by 1°C by 2020 and by 4°C by the year 2100. Precipitation is expected to increase during winter months and decrease in the summer months in projections from both CGCM1 and HADCM2 general circulation models. More recent models [e.g. CGCM3 and HADCM3] continue to yield similar projections. Burns Bog depends upon rainfall for its entire annual supply of water, and it will be sensitive to changes in both timing and amounts of precipitation. The changes expected to occur this century suggest increased winter water supply and warmer drier summers with increased potential evaporation and transpiration. The re-establishment of a vigorous peat-forming processes and maintenance of the water levels in the bog will be crucial to the bog becoming resilient to projected climate changes. Specifically, the more winter precipitation that the bog mass retains the higher the water table will be in the summer dry months. Water storage is directly dependent in the water storage volume and capacity of the acrotelm which must be fully functional. A healthy acrotelm occurs only under an actively-growing *Sphagnum* complex. Thus restoration and recovery of peat-forming processes that depend upon the natural water mound of the bog must be encouraged to occur as soon as possible. This is the best insurance in the face of climate change.

Summary

Burns Bog is an important ecological feature of the lower Fraser Valley and is globally unique. All levels of government are committed to protecting the bog from further degradation and in long term restoration and maintenance of its natural attributes and ecological integrity. To achieve these goals, restoration of the natural hydrological processes is essential. Restoring the natural hydrological function of the entire bog will be complex, and remedial actions will need to be paralleled by hydrological and ecological monitoring, along with continuing appraisals of the efficacy of the actions to ensure that the goals are being achieved. Restoring the natural hydrology of the bog requires elimination of the augmented drainage provided by ditches, restoration of the lagg functions at the bog margins, and reduction in the increased evapotranspiration associated with the extensive encroachment of forest into the bog. The return of the appropriate hydrology will result in the restoration of natural bog plant communities and the desired ecological restoration of the entire bog. Restored ecological and hydrological function is essential if the bog is to be resilient to climate change.

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