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REPORT

Baltzers Bog Hydrological Study, Coldbrook, NS

NOVA SCOTIA DEPARTMENT OF ENVIRONMENT AND LABOUR

PROJECT NO. NSD19570

REPORT NO. NSD19570

REPORT TO	**Nova Scotia Department of Environment and Labour**
FOR	**Baltzers Bog Hydrological Study, Coldbrook, NS**

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EXECUTIVE SUMMARY

A hydrological assessment was conducted by Jacques Whitford Limited at the request of Nova Scotia Department of Environment and Labour with respect to the proposed expansion of the Mark-Lyn peat extraction operation at Coldbrook, NS. The purpose of the proposed work was to determine whether there is a hydraulic connection between the main drainage ditch on the site and Wood Lake, and whether water table control activity at the proposed project expansion could potentially impact water levels in Wood Lake.

Based on the work conducted to date, the following conclusions can be made:

- Baltzers Bog and Wood Lake are situated within a local groundwater recharge zone as evidenced by a down-ward hydraulic gradient.
- Wood Lake is extremely shallow (maximum 0.6 m) and has a maximum storage volume of only 3,134 m^3 based on conditions as of April 12, 2005. A peat layer underlies the lake, which would reduce flow rates from the lake to the ditch.
- Water levels in Wood Lake are perched about 0.5 m higher than water levels in the surrounding areas. Shallow water is moving away from the lake, through peat, and into the main drains at a low hydraulic gradient to the north, and at a slightly higher gradient to the east. Groundwater in the deeper sand aquifer is moving southeast towards the Cornwallis River.
- A minimal amount of water is lost from the lake due to the ditches.
- The ditch loses up to 58 % of its flow to the sand aquifer as it passes Wood Lake.
- Water is gained by the lake only by precipitation. Water is lost by evaporation and seepage through the lake bottom at approximately equal rates. Volumetric water balance calculations suggest that the lake levels could decline by more than 0.7 m during the summer months, essentially drying up the lake. Superimposed on this is a natural groundwater fluctuation of up to 3.0 m that would further contribute to the seasonal dewatering of the shallow lake.
- Historical aerial photos, measured water levels measured in April 2005, and the conceptual model suggest that Wood Lake water levels have dropped by approximately 1.5 m since peat extraction began 40 years ago.
- It is likely that further dewatering and removal of peat in close proximity to the lake (<50 metres) will further reduce water levels in the lake.

Removal of peat from the area north of the lake and south of the main east-west drainage ditch may increase the rate of annual water level decline in Wood Lake.

- Peat extraction north of the existing east-west drainage ditch is not expected to further impact water levels in Wood Lake. However, a gradient between the lake and the excavated areas will be present.

- If the main ditch were eliminated, and the runoff from north area peat cells were pumped into the peat south of the east-west drain, a positive effect on Wood Lake water levels may be realized possibly supporting water levels longer through the summer.

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1.0 INTRODUCTION

1.1 Background

On June 18, 2004 Mark-Lyn Limited (Mark-Lyn) submitted an environmental assessment registration document (EA) to Nova Scotia Department of Environment and Labour (NSEL) for a proposed soil/peat and aggregate operation on the South Bishop Road, at Coldbrook, Kings County, NS. The proposed project involves the extraction of peat from the area referred to as Baltzers Bog, and sand extraction from an adjacent sand deposit. The extracted sand and peat are intended for mixing at an off-site facility to produce various grades of soil used for landscaping and gardening.

In response to the EA document, the Minister of Environment and Labour issued a "more information decision" on July 13, 2004. Specifically, the Minister decided that insufficient information was provided to address public concerns related to the proposed undertaking. One key public concern related to the project is whether maintaining the on-site drainage ditches have had an impact on the adjacent Wood Lake, or will have an impact through the proposed expansion. Residents have suggested that drainage ditches on the project site have effectively been draining the lake for some time.

The proponent previously operated an approved peat harvesting operation on the site. This previous operation did not exceed 4 ha (10 acres) and therefore did not require an environmental assessment. The peat in the approved area has now been completely harvested by the proponent.

Mark-Lyn Construction Limited wishes to expand its soil-peat extraction operation at South Bishop Road, in Coldbrook, Kings County. The new extraction area will cover approximately 40 hectares adjacent to the existing area, which has become depleted. The production rate will be 19,114 m^3/yr (1.0 hectare per year) of peat, and 19,114 m^3/yr (0.6 hectares per year) of sand aggregate. Operation will be 10 hr/day six days per week (60 hr/wk) from May to October.

1.2 Purpose and Scope

The purpose of the proposed work is to determine whether there is a hydraulic connection between the main drainage ditch on the site and Wood Lake, and whether water table control activity at the proposed project expansion could potentially impact water levels in Wood Lake. The work objectives included:

- Conduct on-site investigations and monitoring to determine if a hydrological link exists between Wood Lake, and the existing drainage ditches maintained during previous operations on the site;
- Determine if the perimeter drainage ditches are contributing to the draining of Wood Lake;
- Determine if proposed expansion of operations could potentially result in the drainage of Wood Lake;
- Provide the results of the study in a report to the Minister of Environment and Labour; and
- Provide recommendations for mitigation of drainage impacts if warranted.

The field work scope carried out between April 12, 2005 and April 27, 2005 included:

- Site Reconnaissance;
- A survey of lake bathymetry for Wood Lake;
- Installation of 2 shallow manually-driven monitor wells;
- Installation of 6 monitor wells using a geotechnical drill;
- Hydraulic testing (slug tests) on three monitor wells;
- Elevation survey of water sources throughout the study area;
- Installation of a water level monitoring gauge in Wood Lake;
- Installation of two temporary flow monitoring stations in the main drainage ditch;
- Survey of all monitoring point elevations and locations; and
- Monitoring of water levels and flow rates over a one-week period.

1.3 Environmental Setting

1.3.1 Site Location and Land Use

The Mark-Lyn peat extraction site is located in the Village of Coldbrook, Nova Scotia, approximately 5 kilometres (km) west of the Town of Kentville (Figure 1, **Appendix A**). The site is bounded on the north by Highway 101, on the west by South Bishop Road, on the south by Shaw Resources Keddy Aggregate operations, and on the east by the Cornwallis River (Figure 2, **Appendix A**).

The existing peat operation is located in the west-central portion of the site. The proposed peat extraction areas are located in the northwest corner and northern portions of the site.

1.3.2 Climate

Climate data was compiled from the Kentville Meteorological Service of Canada (MSC) weather station for the years 1913 to 2005 (**Appendix B**). Climate normals for 1971-2000 are provided by MSC and are summarized in Table 1. Values used in the water balance calculations were calculated based on the complete historical data set (1913-2005) provided in **Appendix B**.

TABLE 1 Climate Normals (1971-2000) – Kentville, NS

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Daily Average (°C)	-5.5	-5.2	-0.9	4.9	10.9	16.1	19.4	18.9	14.3	9.0	3.8	-2.5	6.9
Daily Max(°C)	-1.19	-0.9	3.4	9.5	16.3	21.6	24.8	24.2	19.4	13.4	7.5	1.6	11.6
Daily Min (°C)	-9.78	-9.5	-5.2	0.4	5.4	10.5	14.0	13.5	9.2	4.5	0.1	-6.5	2.2
Extreme Max (°C)	17.0	15.6	23.0	26.7	32.5	35.0	36.1	37.8	32.8	28.3	22.5	18.3	-
Extreme Min (°C)	-30.6	-31.1	-27.8	-15	-6.7	-1.7	2.8	2.2	-3.3	-8.3	-16.1	-25.6	-
Rainfall (mm)	60.2	45.0	63.9	70.5	92.7	81.4	87.6	85.5	87.3	93.3	103.7	77.0	948
Snowfall (cm)	70.86	59.2	45.9	17.3	3.7	0	0	0	0	1.9	11.9	55	265.9
Precipitation (mm)	126.7	101.5	110.6	90.2	97.4	81.4	87.6	85.5	87.3	95.5	117.4	129.9	1210.9

Notes:
1. °C = degrees Celsius; mm = millimetres; cm = centimetres

1.3.3 Physiography and Drainage

Local ground elevations range from 19 to 25 m above sea level. The bog averages 22.5 m, Wood Lake averages 21 m and the sand ridges to the northeast and southwest are 30 m and 38 m high, respectively. No natural surface water courses are present on the site, which is believed to be a hydraulically isolated river meander zone. Drainage is generally to the east

and southeast towards the Cornwallis River. Most water entering the site as precipitation would be expected to infiltrate into the underlying sand and gravel aquifer; some would runoff in an easterly direction towards Wood Lake or move as groundwater underflow to the Cornwallis River through the permeable overburden or via the drainage system, and some would evaporate during the warmer months.

The area is topographically flat, which results in low hydraulic gradients and very slow surface water and groundwater flow velocity. Drainage is controlled by a series of drainage ditches that convey water from Baltzers Bog eastward past Wood Lake to the Cornwallis River. In September 2003, less than 0.3 metres of water was observed in Wood Lake, which is believed to be perched on poorly permeable materials above the sand and gravel deposits. Based on topography, it is suspected that Wood Lake is the remnant of an earlier larger lake that formed Baltzers Bog, and as such, is likely in direct hydraulic interaction with the bog.

Assuming direct hydraulic interaction with the shallow groundwater system, the water levels in this shallow lake would be expected to fluctuate seasonally. Three phenomena could affect water levels in Wood Lake. The role of drainage from the peat operation, evaporation from the lake surface and natural seasonal groundwater level fluctuations (caused by evaporation and groundwater base flow out of the local watershed) need to be addressed in order to confirm the degree of hydraulic interaction (if any) between the peat operation and Wood Lake.

1.3.4 Surficial Geology

An overview of the site surficial geology was presented in Appendix E of the EA submission (Terry W. Hennigar Water Consulting, 2004). That information is supplemented here with site-specific drilling information. The entire study area is underlain by ice-contact stratified sand, gravel, and silt deposits of Quaternary age. These deposits may be in excess of 20 metres deep in this area. The morphology of Cornwallis River (Figure 1, **Appendix A**) also suggests that there could be buried river channel deposits at depth where the river possibly passed through the bog area in the past. The interpreted stratigraphy is shown in cross-section on Figure 4, **Appendix A,** and is discussed in Section 3.2.3. Drilling indicates that the site is underlain by alternating deposits of loose to compact reddish brown silty sand, sand, and gravel layers with variable percentage of silt fraction.

1.3.5 Bedrock Geology

Bedrock underlying this site is reddish-brown sandstone and shale of the Triassic-aged Wolfville Formation. No bedrock outcrops are present, and

the bedrock unit is not expected to be a factor in the hydraulic interaction between Wood Lake and the surrounding water courses or drainage features.

1.3.6 Hydrogeology

Baltzers Bog is overlain by highly permeable Cornwallis, Herbert and Truro soil types developed on 24 to 30 m of Quaternary aged sand and gravel deposits that are underlain by reddish-brown sandstone and shale of the Triassic-aged Wolfville Sandstone. Baltzers Bog is located within a local groundwater recharge area, possibly within a meander cut-off of the Cornwallis River. The bog and Wood Lake are perched on poorly permeable materials above more permeable sand and gravel deposits. No site-specific water level data is available; however, water levels in both the peat deposits and Wood Lake would be expected to fluctuate both seasonally and with individual rainfall events.

A hydrograph for NSDEL Monitor Well 001 in Coldbrook indicates a typical average annual water fluctuation of up to 3 metres per year in the sand and gravel units (MacIntosh, 1984).

Table 2 summarizes the hydraulic properties of the sand and gravel aquifers throughout Kings County based on 26 pumping tests of screened water supply wells (NSDEL Pumping Test Inventory 2002).

TABLE 2 Summary of Pumping Test Data For Quaternary Sand and Gravel Wells in Kings County

	Depth (m)	Diam (mm)	Casing (m)	Test Hours	WL (m)	T (m^2/d)	Q/s (m^2/d)	K (cm/s)
Min	13.7	100.0	7.2	6.0	0.1	74	35.0	9.1×10^{-3}
Max	50.0	508.0	45.0	168.0	22.5	5967	1409.0	2.3
Average	28.8	202.1	23.2	80.1	7.2	808	422.9	2.7×10^{-1}
Geomean	26.8	190.1	20.9	68.4	5.2	368	250.1	1.1×10^{-1}
Median	27.7	203.0	23.8	72.0	6.2	358	238.8	1.1×10^{-1}
St. Dev	10.9	81.4	10.2	41.9	5.3	1286	426.9	4.8×10^{-1}
N	26	24	25	26	26	26	23	26

Source: NSDEL Pumping Test inventory (1966-2002)
Notes: m – meters; mm – millimeters; cm – centimeters; s – sec; T – Transmissivity; Q – well yield; K – Hydraulic Conductivity
Average – arithmetic mean; Geomean – geometric mean;
St.Dev – standard deviation; N – number samples

1.3.7 Water Supply

Residents in the Coldbrook area and the unserviced western areas of Kentville are supplied by individual drilled (and occasionally dug) wells. Drilled wells may be completed in either overburden (open casing or screen points) or the underlying sandstone bedrock. No water supply wells are known to be present on the Mark Lyn site. A well log for the adjacent Shaw sand quarrying operation was located in the NSDEL Well Log Database. The Shaw well is a 42.7 m (140') drilled well completed in sandstone bedrock with 40.8 m (134') of casing. The overburden consists of 37.8 m (124') of sand and gravel, overlying shale and sandstone bedrock. The Shaw well is reported to produce 37.9 L/min (10 gpm) with a static water level of 11.9 m (39'). The nearest residences with water wells occur along South Bishop Road, immediately west and up-gradient of the study area. A typical domestic well completion is illustrated on the cross-section (Figure 4, **Appendix A**). Overburden in the vicinity of South Bishop Road is reported to consist of 5 m of silty sand, overlying soft shale and sandstone. While numerous residential wells are known to occur east of the Cornwallis River, none are indicated between Baltzers Bog and the Cornwallis River (Figure 1, **Appendix A**). In consideration of the minor (< 3 m) water table changes at this site, no drilled residential wells are expected to be at risk.

2.0 FIELD PROGRAM

2.1 Site Reconnaissance

A senior hydrogeologist and senior ecologist met with Mr. Scott Lister, Regional Hydrogeologist, NSDEL on April 8, 2005. The objectives of the project were discussed, and a reconnaissance of the study area was made. An inspection of the peat operation, the drainage ditches, and Wood Lake was made, and preliminary locations for surface water and groundwater monitoring points were determined.

At the time of the site inspection, the following observations were noted:

- The Lake level was near its seasonal high, with several perimeter trails being under water.
- The main drainage ditch was flowing at a slow velocity and extended approximately 550 m from the existing peat operation, eastward through the proposed peat operation, then south via the main outfall drain located east of Wood Lake (Figure 2, **Appendix A**).

- Several smaller ditches were noted that drained to the main ditch. These ditches exhibited very minor flow.
- The main ditch is situated 10 to 30 m east of Wood Lake. The ditch is situated between two berms comprised of fill derived from the original excavation and past clean-outs.
- The main ditch appeared to be free of encumbrances on April 8, 2005.

2.2 Hydrologic Survey

A preliminary survey of surface water levels was conducted to determine the flow directions and surface water elevations within the excavated peat area. This involved direct elevation survey of open water sources throughout the excavated areas by determining the elevation of a temporary stake then measuring the depth to the apparent water level. The objective was to determine horizontal flow gradients throughout the area.

2.3 Wood Lake Bathymetry

There was little or no information respecting the actual depth, storage capacity and morphology of Wood Lake. The storage capacity of Wood Lake was determined through an investigation of the area and depth of the lake. The current spatial extent of Wood Lake was determined using a Global Positioning System (GPS) survey of the shore line and/or obvious high water mark using a Sokkia differential GPS device. A detailed bathymetric survey of the lake bottom was conducted using manual probes along predetermined transects. Using this information and the water level gauge, a map of the lake bottom topography was prepared (Figure 3, **Appendix A**), and a lake storage volume was calculated.

2.4 Wood Lake Water Level Gauge

A water level gauge was installed on Wood Lake, and was used to monitor water level changes. This gauge consists of a fiberglass post with an aluminum gauge which can be read from the shoreline indicating inches of water. The post was driven into the bottom sediments at the deepest portion of Wood Lake, so that monitoring may be continued throughout the summer months. Once the water level drops below the lake bottom, a monitor well (MW2) installed into the lake sediments can be used to measure water levels. The lake gauge and MW2 locations are shown on Figures 2 and 3, **Appendix A**.

2.5 Drainage Ditch Flow Measurements

Flow measurements were obtained at two locations (STA-3 and STA-4) over the monitoring period at the locations shown on Figure 2, **Appendix A.** Flow station STA-3 located upstream of Wood Lake consisted of a temporary 200 millimetre (8") diameter culvert placed across the drainage ditch. This was necessary as the flow in the ditch was too low for the flow monitoring equipment. Flow station STA-4 consisted of the concrete culvert located at the Shaw sand pit access road, down-gradient of Wood Lake. The culvert was cleaned out so that accurate measurements could be taken. Cross-sectional areas were calculated and average flow velocities were measured using a GlobalWater Open Channel Flow Meter. During periods of high flow, the cross-sectional area of the ditch at STA-3 was calculated and measured using traditional stream gauging techniques. The objective of the two flow stations was to determine water gain or loss in the main ditch as it passed east of Wood Lake. Two additional drainage ditch measurements were made in the vicinity of the active peat operation (STA-1 and STA-2, Figure 2, **Appendix A**)

2.6 Monitor Well Installation

Two types of groundwater monitoring devices were installed to assess groundwater flow pathways at the site. Due to the density of the sand material it was not possible to install manually driven wells with the exception of MW2 and MW3. These monitor wells were screened across the shallow water table, and are used to determine the horizontal hydraulic gradient between the drainage ditch and Wood Lake. The shallow monitor wells consist of 12 mm diameter PVC screens, and were installed manually as follows:

- Push or hammer a pilot hole to required depth or to refusal using a steel rod and driving device;
- Remove the drive rod;
- Insert slotted screen into pilot hole, and push to desired depth leaving about 0.3 m of stick-up;
- Install a 51 mm PVC protector to stabilize the monitor well;
- Pump several litres of water from the monitor well to clear slots and render well hydraulically efficient;
- Note water level recovery rate (infers relative hydraulic conductivity), if possible;

- Measure water level from top of casing, and measure casing stick-up above grade or water table;
- Install a vented PVC cap; and
- Clearly label each monitor well.

Six piezometers were installed in the sand and gravel overburden to an approximate depth of 10 to 12 m using a track-mounted geotechnical drilling rig equipped for hollow-stem auger drilling. These wells are intended to provide additional information on vertical hydraulic gradient, stratigraphy and hydraulic properties in the area. Approval was obtained from the adjacent Shaw sand and gravel operation for access to the ditch area of the site. Care was taken to minimize vegetation damage around the drill sites. The well locations are shown on Figures 2 and 3, **Appendix A**. The deep wells were aligned along a proposed east-west geologic cross-section to provide stratigraphy and to assess vertical hydraulic gradients (Figure 4, **Appendix A**).

Samples of overburden materials were recovered for lithology and hydraulic conductivity classification. Monitor wells consisting of 51 mm diameter Schedule 40 PVC flush threaded pipe with 1.5 to 3.0 m of No. 10 slot Schedule 40 PVC screen were installed at each location. The screened interval was isolated from shallower zones with bentonite chips or bentonite grout. Drilling services were provided by Boart Longyear Inc, under the direction of a Jacques Whitford technologist. Drilling and monitor well installation was completed on April 15 and 19, 2005.

The soil samples were inspected at the Jacques Whitford lab, and detailed borehole logs showing stratigraphy, water level and as-built monitor well completion were prepared. A summary of the well construction details are provided in Table 3. Copies of monitor well records are included in **Appendix C**.

TABLE 3 Monitor Well Construction Details

Monitor Well	Unit	Total Depth of Hole (m)	Elevation [1]		Sand Pack Zone		Bentonite Seal	
			Top of PVC Casing (m ASL)	Ground Surface (m ASL)	From (mbg)	To (mbg)	From (mbg)	To (mbg)
MW1	Silty sand	3.1	21.3	20.8	0.9	3.1	0.3	0.9
MW2	Fine sand	0.8	21.6	20.9	0.1	0.8	0.0	0.1
MW3	Fine sand	0.9	21.2	20.5	0.0	0.9	-	-
MW4S	Sand/gravel	4.5	24.8	24.0	2.4	4.5	1.5	2.4
MW4D	Sand	12.5	24.8	24.0	9.1	12.5	1.0	9.1
MW5	Coarse silty sand	12.2	23.4	22.9	9.1	12.2	6.1	9.1
MW6S	Silty sand	3.1	21.7	21.2	0.9	3.1	0.2	0.9
MW6D	Silty sand	10.0	21.9	21.3	8.0	10.0	5.0	8.0

Notes: 1. mbg = metres below grade

2.7 Hydraulic Testing

Each completed monitoring well was developed by pumping until hydraulically acceptable for subsequent hydraulic testing and monitoring.

Hydraulic response tests (e.g., slug tests) were performed on each of the three piezometers. This was accomplished by introducing a solid cylinder (slug) of known volume, and then monitoring the rate of water level fall (Falling Head test) or water level rise (Rising Head test) after the slug was introduced or removed from the borehole. The results were interpreted by a hydrogeologist using AquiferTest Version 3.5 (Waterloo Hydrogeologic, 2003), a software program for interpretation of groundwater hydraulic testing data. Estimates of hydraulic conductivity (the volume of groundwater that could flow through a unit area of porous media under a unit decline in water level) were determined for each screened zone. Hydraulic testing results are contained in **Appendix D**.

2.8 Surveying

An elevation survey was conducted over the entire subject area. A level transit was employed to determine the top of casing and/or water elevations of all monitoring wells, the lake gauge, several points along the main drainage ditches, lake shore perimeter, and any open water areas throughout the wetlands. An elevation for Cornwallis River at its closest point and areas outside the study area were determined from best available mapping, for preparation of geologic cross-sections. Coordinates for each monitoring point were determined using a high precision Sokkia GPS unit. When found, local property markers, and an existing on-site monitor well were also surveyed into the grid for future reference.

2.9 Monitoring

Water level and flow measurements were conducted on four occasions over the approximate 10 day period available for this assessment, including all monitor wells, the lake gauge, surface water points and the stream flow stations. A technician from the Jacques Whitford Kentville office visited the site to collect water level measurements for all monitoring points as many times as practical within the 1.5 week available monitoring period; one major rainfall event (about 21 mm) on April 20, 2005 was included.

3.0 ASSESSMENT

3.1 Baltzers Bog and Wood Lake Hydrology

3.1.1 Drainage Patterns

The presence of Baltzers Bog is likely the result of water stored within a fluvial cut-off channel or isolated basin underlain by lower permeability sediments. Due to the shallow water table depth and expected seasonal water level variation (i.e. in the order of 3 metres based on local hydrographs), the formation of peat deposits was favoured. The hydrology of Baltzers Bog and Wood Lake has undergone changes in the past 50 years.

3.1.1.1 Undeveloped Land (Pre – 1967)

Aerial photos (1931, 1945, 1955) indicate that the land was undeveloped prior to 1955 with the exception some clearing of vegetation. Peat elevations in Baltzers Bog average about 22.5 m ASL. Given that the formation of peat occurs within the shallow water table, it is probable that the original elevation of Wood Lake was close to 22.5 m ASL during this time, compared to the approximately 21 m ASL on April 20, 2005. Wood Lake is likely a remnant of a larger surface body that diminished in size with the formation of the peat bog. The lake is surrounded by peat bog on the north, west and south, and is found to be underlain by up to 0.4 m of peat on the east side (MW2).

Prior to construction of the perimeter drains and subsequent deep drainage ditch, water levels in the lake were likely controlled by evaporation, surface water flow at low topographic points in the basin and groundwater discharge. Water gained by Wood Lake from rainfall and runoff from surrounding areas, was lost by the lake primarily through evapotranspiration, exfiltration to the underlying sand aquifer through the lake bottom, and through direct runoff to a suspected outfall at the southeast corner to Cornwallis River. The low lying terrain between the sand hills at the extreme southeast corner of the lake was likely the historical outfall prior to 1955 (Figure 2, **Appendix A**). This inferred drainage pathway contains the present drainage ditch outfall.

3.1.1.2 Present On-site Drainage System

A perimeter drainage ditch that appears to drain to the south of Wood Lake is visible on the 1967 aerial photo. Sections of this perimeter ditch were located on the site during the present field program averaging about 1.5 m in depth relative to the surrounding terrain. No ditches were noted to be flowing directly from Wood Lake into the drainage network. A more recent and deeper drainage ditch presently runs in an east-west direction down the center of Baltzers Bog, and follows in a north to south direction east of Wood Lake (Figure 2, **Appendix A**). The surface water elevation in this main ditch was approximately 1.5 m lower than the elevation of Wood Lake on April 20, 2005. Minimal flow was observed in the main drainage ditch during the investigation. Measured flows are summarized in Table 4 along the main drainage ditch.

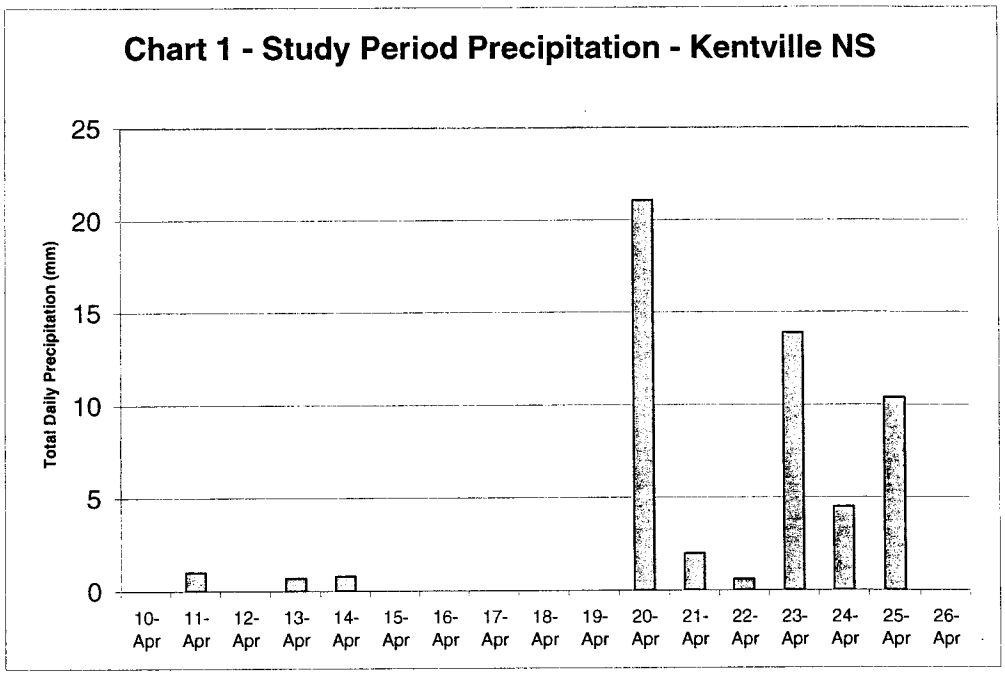
TABLE 4 Summary of Measured Surface Water Flows, April 20

Station ID	Location	Date	Measurement Method	Measured Flow (m^3/day)[1]
STA-1	Excavated area of peat	12-Apr-04	12-Apr-04	127.2
STA-2	Excavated area of peat	12-Apr-04	12-Apr-04	132.9
STA-3 (installed April 20/05)	Drainage ditch upstream of Wood Lake	20-Apr-04	20-Apr-04	242.0
		25-Apr-05	25-Apr-05	186.7
		27-Apr-05	27-Apr-05	88.7
STA-4	Drainage ditch downstream of Wood Lake	12-Apr-04	12-Apr-04	55.3
		20-Apr-04	20-Apr-04	118.0
		22-Apr-05	22-Apr-05	75.8
		25-Apr-05	25-Apr-05	183.4
		27-Apr-05	27-Apr-05	69.4

Notes:
1. m^3/day = cubic metres per day

Three major precipitation events (>10 millimetres) occurred during the study period on April 20, 23, and 25, 2005. The daily precipitation totals recorded at the nearby Kentville weather station are shown on Chart 1.

The main drainage ditch that drains the excavated area and passes around Wood Lake is primarily ponded water, with little discernable flow. On April 12, 2005, flow entering the main drainage ditch at STA-2 was approximately 133 m^3/day, while the outflow measured down stream of Wood Lake at STA-4 on the adjacent Shaw property was only 55 m^3/day. This 59 % decline in flow indicates that surface water is being lost from the ditch to the underlying sand aquifer as it passes Wood Lake. A 3.3 % to 58 % reduction in discharge is also noted between STA-3 and STA-4 on April 20, 25, and



27, 2005. Outflow is being lost to the groundwater along the length of the drainage ditch. No flow from the ditch into Wood Lake is expected, since water levels in the Lake are consistently higher than levels in the ditch. This indicates that the ditch is not receiving significant groundwater inflows from Wood Lake.

3.1.2 Wood Lake Bathymetry

Figure 3, **Appendix A** illustrates the bottom topography of Wood Lake. The contours each represent a 0.1 m of water depth. The lake has a surface area of 1.65 hectares, and was shallow (<0.6 m or <2 feet) on April 12, 2005, which could be expected to represent the maximum annual depth of water after the annual spring melt period.

Based on the bathymetric survey conducted on April 12, 2005, the maximum depth of water encountered was 0.56 m with an average depth of 0.19 m. The total storage of water on April 12, 2005 was calculated to be approximately 3,134m^3. This does not account for water held in storage in the peat. Peat thickness at location MW2 located in the lake footprint, was approximately 0.4 m, which could represent an additional 3,300 m^3 of water storage assuming a peat porosity of 50%.

Based on the lake bathymetry, it is apparent that summer evaporation alone (est. 559 mm) could almost dry up the lake during an extended period without rain, leaving a few small ponds in the middle north portion of the lake. This is consistent with anecdotal reports.

3.2 Hydrogeology

3.2.1 Groundwater Elevations and Flow Directions

Groundwater elevations measured on April 20, 22, 25, and 27, 2005 are summarized on Table 5. Water levels in the shallow piezometers (MW2, 3, 6S) ranged from 0.9 m below ground to +0.1 m above grade, averaging 0.8 m. Water levels in the deeper piezometers set in the sand aquifer ranged from 1.9 m (MW1) to 4.9 m (MW4D), averaging 3.8 m below ground.

TABLE 5 Summary of Groundwater Elevations

Location	Groundwater Elevations							
	20-Apr-05		22-apr-05		25-Apr-05		27-Apr-05	
	mbg	m ASL	mbg	m ASL	mbg	m ASL	mbg	m ASL
MW1	1.94	18.83	1.96	18.81	1.94	18.83	1.98	18.79
MW2	-0.07	20.95	-0.12	21.00	-0.12	21.00	-0.11	20.99
MW3	0.58	19.93	0.45	20.06	0.41	20.10	na	na
MW4S	dry	Dry	4.47	19.54	4.47	19.54	dry	dry
MW4D	4.90	19.11	4.57	19.44	4.99	19.02	4.65	19.36
MW5	4.23	18.68	4.25	18.66	4.23	18.68	4.26	18.65
MW6S	0.92	20.29	0.87	20.34	0.83	20.38	0.88	20.33
MW6D	2.12	19.19	2.13	19.17	2.11	19.20	2.14	19.17

Notes:

1. m ASL = metres above sea level; mbg = metres below grade

Groundwater flow directions for the sand and gravel units (i.e. deeper deposits) are indicated on Figure 5, **Appendix A.** Shallow groundwater flow directions are presented on Figure 6, **Appendix A.** The deep groundwater flows toward the Cornwallis River to the south and southeast at an average horizontal gradient of approximately 0.5 % across the site.

Shallow groundwater flow using the open water elevations (WP), shallow drive points, and ditch and lake measurements are shown on Figure 6, **Appendix A.** The shallow groundwater flows away from the excavation area and Wood Lake northwards towards the main drain at a low hydraulic gradient of about 1%. An approximate 5 % gradient is indicated between Wood Lake and the main drain east of the lake. It is clear from the shallow water levels that water levels in Wood Lake are presently higher than the surrounding groundwater table. This implies a potential for water to flow from Wood Lake radially towards the surrounding drains through the remaining peat areas.

On April 25, 2005, vertical hydraulic gradients were both downward at monitor well pair MW4S/D and MW6S/D at values of 7% and 17% respectively (mean 12 %). These values indicate that the Baltzers Bog area, including Wood Lake is situated in a recharge area for the deeper sand and gravel aquifer.

3.2.2 Hydraulic Properties

Measured values of hydraulic conductivity (K) from slug testing conducted on four monitor wells are summarized in Table 6. The measured values are several orders of magnitude lower than values observed in sand and gravel well pump tests as outlined in Table 2, Section 1.3.6. This is likely due to the presence of river alluvium, and higher percentages of silt in the sand matrix in the vicinity of the bog, in comparison to the coarse sand and gravel deposits that the screened production wells would have been completed in.

Hydraulic conductivity values in MW4D were two orders of magnitude lower than the average values observed in the other wells. This lower K is the likely cause of the existence of Baltzers Bog, as surface water would not rapidly drain into the underlying sandy silt unit. The material in this area likely contains a higher degree of silt fraction than the other areas, despite the presence of a coarse sand fraction. This unit does not appear to exist below Wood Lake; however, the deposition of silt and decaying organic matter on the lake bottom would act to decrease the K value potentially one or two orders of magnitude directly below the lake.

Monitor well MW5 exhibited a very fast response (>90% in 11 seconds) consistent with coarse sand. A K value in the order of 5×10^{-2} centimetres per second (cm/s) similar to the pump test mean is estimated for this well.

TABLE 6 Summary of Hydraulic Testing

Monitor Well ID	Test Method	Analysis Method	Hydraulic Conductivity (cm/s)	Average Hydraulic Conductivity (cm/s)
MW4D	Falling Head	Bouwer & Rice	1.78×10^{-5}	2.2×10^{-5}
MW4D	Rising Head	Bouwer & Rice	2.70×10^{-5}	
MW5	Falling Head	Bouwer & Rice	5.00×10^{-2}	5.0×10^{-2}
MW5	Rising Head	Bouwer & Rice	5.00×10^{-2}	
MW6S	Falling Head	Bouwer & Rice	2.45×10^{-3}	3.1×10^{-3}
MW6S	Rising Head	Bouwer & Rice	3.80×10^{-3}	
MW6D	Falling Head	Bouwer & Rice	1.45×10^{-3}	1.4×10^{-3}
MW6D	Falling Head	Bouwer & Rice	1.23×10^{-3}	
MW6D	Rising Head	Bouwer & Rice	1.40×10^{-3}	
MW6D	Rising Head	Bouwer & Rice	1.57×10^{-3}	
Average				**1.5×10^{-3}**
Geomean				**1.5×10^{-4}**
Geomean (near lake)				**6.0×10^{-3}**

Notes:
1. cm/s = centimetres per second
2. Analysis using Waterloo Hydrogeologic AquiferTest Version 3.5

A wide range of K (2.2×10^{-5} to 5.0×10^{-2} cm/s) is indicated from the field slug testing. A geometric mean K in the order of 6.0×10^{-3} cm/s is suggested in the vicinity of the ditch east of Wood Lake. The shallow sand is slightly more permeable than the deep sand at MW6

3.2.3 Conceptual Hydrogeological Model

A conceptual hydrogeological model was developed for the Baltzers Bog study area based on historical data and the data collected during the current field program. An east-west cross-section of the site is presented in Figure 4, **Appendix A** with further detail in the vicinity of the lake and drainage ditch provided in Figure 4A, **Appendix A.**

The cross-section shows a perched water table in Baltzers Bog overlying a deeper water table in the sand and gravel aquifer. Strong downward gradients of 7% to 17% indicate that Baltzers Bog and Wood Lake are recharge areas for the deeper sand and gravel aquifer. Surface water in the drainage ditch also appears to be in a perched condition, and is also likely losing water to the underlying aquifer.

3.3 Water Balance

A general water budget was prepared for this site to the limit of available data. Climate normals from the nearby Kentville Research Station (1913 to 2005) were used to assess the mean monthly and mean annual precipitation. Estimates of potential evapotranspiration were generated using this data and the Thornthwaite (1931) method. Calculations for potential evapotranspiration are presented in Table E.1, **Appendix E.**

A water budget mass balance approach was used to estimate the amount of surface water run-off in 2004 and to compare this amount to previous year's data. Calculated values are presented in Table 7 and in Table E.2, **Appendix E.** Water is added to the system through precipitation, and water is lost through evapotranspiration, surface runoff, soil moisture storage, and infiltration into the ground. Assuming that all the water that infiltrates into the ground to a depth below the water table recharges the underlying groundwater (and therefore reappears in the stream flow as base flow), a simplified water budget for the area can be written as:

$$\mathbf{P_i - ET_i - (R_{S\,i} + GW_{R\,i} + SMS_i) = 0} \qquad \text{Equation [1]}$$

where: P_i = Precipitation in month *i*, mm

ET_i = Evapotranspiration in month *i*, mm

$R_{S\,i}$ = Surface Runoff in month *i*, mm

$GW_{R\,i}$ = Groundwater Recharge in month *i*, mm

SMS_i = Soil Moisture Storage in month *i*, mm

Although changes in soil moisture storage will occur, over longer periods of time the changes in soil moisture storage are expected to be negligible compared to runoff and evaporation. As a result, Equation [1] may be re-written as:

$$\mathbf{R_{S\,i} = P_i - ET_i - GW_{R\,i}} \qquad \text{Equation [2]}$$

This equation was used to estimate the amount of surface water run-off in 2004 on a monthly basis and compare this amount to estimates for the mean climate data (1913-2005). In order to complete the water budget analysis, the following generalizations were used:

- Given that the site is located in Nova Scotia, and that mean monthly temperatures in December to March are less than zero degrees Celsius, it was assumed that precipitation which occurred during these months was held in storage within a snow pack, to be released during the spring melt period.

- If monthly groundwater outflow and evapotranspiration levels were greater than the monthly precipitation amounts, surface water run-off was assumed to be zero.

- Groundwater recharge in any one month could not be less than zero (*i.e.*, no negative values).

- The Thornthwaite (1931) equation for estimating the potential evapotranspiration (i.e., the amount of evapotranspiration that would occur if sufficient water were present) was used to estimate the term "ET_i" in Equation [2].

- In months where the mean monthly temperature was less than 0 °C, the potential evapotranspiration was assumed to be zero.

- The groundwater recharge was broken into two components to identify groundwater being lost to the drainage ditch and groundwater lost to the deeper sand and gravel aquifer.

- The Wood Lake watershed is limited to the surface area of the lake.

TABLE 7 Estimated Maximum Water Losses from Wood Lake (Area 16,512 m^2)

	2004		1913-2005	
	Mean (mm)	Percent of P	Mean (mm)	Percent of P
Annual Precipitation	889	-	1092	100.0
Evapotranspiration	607	68.3	559	51.2
Direct Surface Water Runoff to Drainage System (Winter only)	304*	34.3	427*	39.1
Groundwater Recharge into Lake	Negligible	Negligible	Negligible	Negligible
Discharge from Lake to Main Drainage Ditch on east	73	8.2	73	6.6
Discharge from Lake to North Drainage Ditch	14.6	1.6	14.6	1.3
Groundwater Discharge to the Cornwallis River (Total Runoff)	646	72.7	646	59.1

Notes:
1. mm = millimetres; P = precipitation
2. Values are "maximum" annual potential water losses over lake area
3. *this assumes water will overflow the sides of lake (likely in winter) but this is not the case, as the regional water table has already been lowered by previous dewatering activities.

Water balances were calculated for each month. Table 7 summarizes the mean annual total water balance for Wood Lake Watershed. Based on the above assumptions, and calculations shown in Table E.2, **Appendix E**, the potential direct runoff (in this case, groundwater recharge) from Wood Lake watershed is expected to be in the order of 646 mm/year, or 59.1 % of the mean annual precipitation (P).

Evapotranspiration calculations suggest that up to 559 mm/year or 51.2 % of P could naturally be lost from the lake surface from April to November. Evaporation values for a shallow water body would be greater than calculated potential evapotranspiration values; therefore, using evapotranspiration values will be conservative. Using the Wood Lake bathymetric data, this would result in most of the lake (> 90% of storage) being lost to evaporation alone, resulting in a diminished water surface area (See Figure 3, **Appendix A**).

An estimated 171 mm (e.g., 90 d x 1.9 mm/d recharge through lake bottom) of groundwater outflow from Wood Lake to the sand aquifer over an extended drought period of 90 days could result in over 90 % of the lake storage being depleted. Only some of this exfiltration is to the drainage ditch (about 8.2 % of P or 11.3 % of the maximum potential exfiltration), with the remainder moving under the drainage ditch through the sand aquifer to the Cornwallis River (see Section 3.4).

3.3.1 Comparison of 2004 Precipitation Levels With Long Term Means

The summer mean monthly rainfalls for the past few years were compared with the long term climate normals, to determine if seasonal rainfall trends are responsible for observed low water levels in the lake reported in September of 2004 (EA report). No discernible trends were observed in the precipitation data based on a preliminary assessment.

The year 2004 was reported to be a dry year with 889 mm of precipitation compared to the 92 year mean of 1092 mm. With the exception of October and November, all months were drier in 2004 than long term normals (**Appendix E**). Assuming 607 mm (68.3% of P) of evapotranspiration, the lake could almost completely dry up by the end of the summer of 2004. The combined effects of groundwater outfall and evapotranspiration during a dry year would likely dewater the entire lake.

3.4 Interactions Between Wood Lake, Baltzers Bog and Drainage Ditch

Factors affecting interaction between Wood Lake and the main drainage ditch include the hydraulic properties of the lake bottom and geologic materials between the lake and the ditch, hydraulic head difference, and proximity of the ditch to the lake.

3.4.1 Drainage Ditch

Cross-sections (Figure 4 and 4A, **Appendix A**) indicate that there is an approximate 1.5 m difference between the lake surface and water levels in the drainage ditch. This implies some potential for drainage between the lake and the ditch. The lower water table level at MW5 east of the ditch compared to MW6D west of the ditch near the lake further implies that groundwater is moving beneath this ditch, and possibly out of the ditch, towards the Cornwallis River. This suggests that if water is leaving Wood Lake, it is only partially intercepted by the drainage ditch, and that some discharge would occur towards Cornwallis River whether or not the ditch was present.

The conceptual cross-section (Figure 4 and 4A, **Appendix A**) and the measured shallow water level in the drainage system and the peat areas show that the lake and the peat area are hydraulically connected. Water levels in the remaining peat are slightly lower than the lake level by approximately 0.5 m on April 20, 2005. Prior to inception of the drainage system, water levels would have averaged 1.0 to 1.5 metres higher (22.0 to 22.5 m ASL) than the lake. Water levels in Wood Lake (21.0 m) and the surrounding peat areas (WP1 and WP4, 20.5 m ASL and 20.4 m ASL respectively) are approximately the same. Water levels in the main drainage ditch range from 19.6 m ASL (extreme west end WP2) to 19.3 m ASL (extreme east end) at WP6, with a gradient of 0.03% over almost 1,000 metres of drainage ditch.

Groundwater modeling and detailed analytical solutions are beyond the scope of this investigation. To estimate the component of this maximum potential groundwater flow that drains from the lake into the main drainage ditch, a simple approximation was made using the one-dimensional Dupuit-Forcheimer flow equation (Equation [3]) for unconfined conditions (Freeze and Cherry, 1979). Calculations are presented in Table E.3, **Appendix E**.

$$Q = K/2 * ((h_l^2 - h_0^2)/L),$$ where Equation [3]

Q = inflow rate to ditch in cubic metres per day

K = hydraulic conductivity in m/day

h_l = height of water above the base of the aquifer, end of flow system in metres

h_0 = height of water above the base of the aquifer, initial in metres

L = length of the flow system

Assuming an average K of 2.2 x 10^{-5} cm/s, and a ditch length of 200 m, and the distance between Wood Lake and the main drainage ditch of 20 metres, the potential flow rate into the ditch is 3.6 m^3/day which represents only 0.2 mm per day of water level decline. A similar calculation of outflow towards the north and west sides of the lake to drainage ditches indicates a smaller (0.7 m^3/day or 0.04 mm/day of surface water decline). The likelihood of fine-grained materials on the lake bottom accounts for the presence of the lake in the first place. If these lower K (likely in the order of 2 x 10^{-5} cm/s as indicated in MW4D) were not present, the perched lake could not exist. Several simulations were made using the various K values indicated in the slug testing; only the lowest values of K simulate observed conditions (e.g., the lake would drain rapidly with sand type K values).

The drainage ditch exhibited an average flow rate of 100 m^3/day during the study period, representative of runoff from the peat operation, and drainage from the shallow aquifer along the ditch. The estimated contribution from Wood Lake via groundwater discharge to the east ditch is minimal (< 4 %). Furthermore, the ditch was found to be losing water as it passes Wood Lake.

3.4.2 Losses Through Lake Bottom

Maximum potential groundwater flow out of Wood Lake can be approximated using a version of Darcy's Equation (Equation [4]) is described below. Calculations are presented in Table E.3, **Appendix E**.

Q = KiA, where Equation [4]

Q = groundwater flow in cubic metres per day;

I = vertical hydraulic gradient (m/m);

A = area through which the water is moving (i.e. lake area)

Groundwater losses through the bottom of the lake are also considered to be small. Assuming a lake area of 16,512 m^2, an average K of 2.2 x 10^{-5} cm/s, and a maximum vertical hydraulic gradient of 0.1, an infiltration of 32 m^3/day (1.9 mm per day water level decline) is estimated for Wood Lake.

3.4.3 Interaction With Remaining Bog

It is apparent from this assessment that the peat extraction operations in Baltzers Bog have affected water levels in the lake by approximately 1.5 m over 40 plus years. The lake surface is perched above the surrounding shallow groundwater levels, and is likely similar to water levels residing within the non-extracted peat areas. The drainage network has lowered groundwater levels to about 0.5 m or more below the current lake surface elevation, which is below the present lake bottom. We suspect that water level differences between the lake and the peat would be similar or reversed during drier portions of the year. Water levels in Wood Lake are buffered somewhat from lower water levels in the mined areas by the intervening peat deposits, which would tend to hold groundwater at a slightly higher level, and consequently reduce the rate of exfiltration through the sand units from Wood Lake.

Extracting the peat between the east-west ditch and Wood Lake is expected to further lower water levels in the lake, possibly to a point below the bottom of the lake. It is noted that an approximate 0.4 m peat layer exists below some portions of the lake. As the peat extraction face advances closer to the Lake, it is expected that water from the lake will flow north towards the excavation and drainage ditches at a higher rate than at present.

3.5 Mitigative Opportunities

Some opportunity exists to mitigate impacts from further peat extraction. If the peat extraction is kept north of the east-west ditch, less water level impact might occur in the vicinity of the lake, in consideration that the east ditch exhibits minor to negligible impact on the lake water levels.

If the present drainage method is replaced with a "wet" peat extraction technique, less water level impact should occur. For example, some peat operations isolate cells with cutoff walls, dewater one cell at a time, and leave the larger area saturated.

If the main ditch were eliminated, and the runoff from north area peat cells were actively pumped into the peat south of the east-west drain, a positive effect on Wood Lake water levels may be realized (i.e., eliminate the drain outfall, and allow runoff to migrate through the intervening peat deposits

towards and through Wood Lake, possibly supporting water levels longer through the summer).

After cessation of peat operations, it is uncertain how much the water table might recover. The current excavated area west of Wood Lake is excavated to the sand surface. Water accumulating here would be expected to recharge into the underlying sand aquifer at a higher rate compared to the pre-extraction situation.

4.0 CONCLUSIONS

Based on the work conducted to date, the following conclusions can be made:

- Baltzers Bog and Wood Lake are situated within a local groundwater recharge zone as evidenced by a down-ward hydraulic gradient.
- The main input to Wood Lake is through precipitation; there are no surface water inputs and groundwater inputs are negligible.
- Wood Lake is extremely shallow, with an average depth of 0.19 m on April 12, 2005, covers an area of 1.65 hectares, and has a maximum storage volume of only 3,134 m^3.
- Water levels in Wood Lake are about 0.5 m higher than surface water, groundwater and ditch water levels in the surrounding areas. Shallow groundwater is moving away from the lake, through peat, and into the main drains at a low hydraulic gradient to the north, and at a slightly higher gradient to the east. Groundwater in the deeper sand aquifer is moving southeast towards the Cornwallis River.
- The presence of the drainage ditch contributes indirectly to the rate of lake water decline by lowering the water level in the peat zone; however, calculations suggest that direct water movement between the lake and the drainage ditch is small. In fact the ditch loses between 3 % and 58 % of its flow as it passes Wood Lake. This lost ditch water infiltrates to groundwater and moves east to the Cornwallis River. Some discharge would occur towards the Cornwallis River whether or not the ditch was present.
- The primary mechanisms of outflow from the lake is through evaporation and groundwater outflow through the bottom of the lake at approximately equal rates. Evapotranspiration and groundwater outflow volume calculations suggest that the lake levels could decline seasonally by 1.2 m, essentially drying up the lake. Expected seasonal water table fluctuations of an additional 3.0 m or more will further exacerbate lake level decline.

- Most of the pond water is lost to evaporation alone (55%) or >90% of storage; a minimal amount of water (6.5%) is lost to the ditches. The combined effects of groundwater outfall and evaporation during a dry year would likely dewater the lake.

- Historical aerial photos, current water levels and the conceptual model suggest that Wood Lake water levels have dropped by approximately 1.5 m since peat extraction began. The lowered water level in Wood Lake is likely caused by a combination of historical peat extraction and associated dewatering drains and natural seasonal groundwater fluctuations.

- At the present range of lake water levels, no overland outfall occurs from Wood Lake. The original lake outfall at the southeast corner is now a natural dam, with no overland discharge occurring from the lake.

- Since Wood Lake water levels are higher than surrounding surface and groundwater levels, it is likely that further dewatering and removal of peat in close proximity to the lake (<50 metres) will further reduce water levels. In general, removal of peat from the area north of the lake and south of the main east-west drainage ditch will increase the hydraulic gradients away from the lake and may increase the rate of annual water level decline in Wood Lake.

- Pending further monitoring of water levels between the main drainage ditch and Wood Lake, peat extraction north of the existing east-west drainage ditch is not expected to further impact water levels in Wood Lake.

5.0 CLOSURE

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The conclusions and recommendations presented in this report are based upon work undertaken by trained professional and technical staff, in accordance with generally accepted engineering and scientific practices, current at the time the work was performed, and represent the best judgement of Jacques Whitford based on the existing data obtained. Due to the nature of the work and the limited scope of work completed, Jacques Whitford cannot warrant against undiscovered environmental liabilities. Conclusions and recommendations presented in this report should not be

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This report was prepared by Denis Parent, B.E.S., C.E.T., and David S. MacFarlane, M.Sc., P.Geo., and peer review was provided by David V. Fanning, P.Geol. Manager Southwest Nova Scotia Region.

Yours very truly,

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