Hydraulic Conductivity of Surface Soils Just South of Findlay Creek in Leitrim Wetland

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Introduction

For the construction of Findlay Creek Village the Tartan Development Company has modified significantly the north-east of the 1989 OMNR designated Provincially Significant Leitrim Wetland. Briefly, the modifications to the landscape include: 1. a berm to manage the surface water flow from the wetland core; 2. realignments and deepening of Findlay Creek to make the creek drainage consistent and compatible with the requirements for drainage within a housing development; 3. installation of a storm water management system to assure that storms do not cause damage and/or destruction in the housing development and 4. construction of houses on part of the actual wetland. As the Leitrim wetland is Provincially Significant (Ontario Ministry of Natural Resources) the housing development is supposed to be accomplished without resulting in any damaging impact on the wetland or Findlay Creek base flows. Numerous experts commented on the plans and the environmental assessment indicating there were insufficient hydrogeologic analyses including data collection and hydrologic modeling to anticipate the impacts of the housing developments which were planned and are now being implemented. The purpose of this investigation is to collect hydraulic conductivity data of the near surface soils along the development line, (deep within the actual wetland),in the north and east of the *protected* part of the wetland, as this area will be impacted first and most by development activity. While collecting such data it may be possible to ascertain if construction activities have already initiated changes to the hydrology of the *protected* part of the wetland.

Meaning of "*protected*" wetland

It is my understanding that the Provincial Policy Statement (2005) prohibits any development or alteration within the boundaries of the Leitrim wetland as evaluated and defined in 1989 (Figure 1, later in this report, shows the wetland boundaries). Historically, however, in the early 1990s a consultant for a developer put forward a proposal to protect what it described as the core of the wetland, leaving the balance of the wetland available for development and alteration. Current development proposals are predicated on protecting only this core. In this report, when I refer to the *protected* part or portion of the wetland I am referring to this core area.

Definition of Hydraulic Conductivity of soil in a saturated condition (*Ksat*)

Hydraulic conductivity of soil is a measure of how rapidly water moves through soil, either under an applied pressure or under the influence of gravity or both. Hydraulic conductivity is the soil's permeability to water and the name hydraulic conductivity is often interchanged with permeability. Hydraulic conductivity has been assigned the units of velocity, such as, cm per second or cm s^{-1}. When soil is fully saturated, i.e. nothing but water in the pore space, we use the term saturated hydraulic conductivity and in this report I use the symbol *Ksat*. In various soils one may encounter a very wide range in *Ksat*, for examples, *Ksat* for coarse sandy soil can be 0.01 cm s^{-1} and fine clayey soil can be as low as 0.00001 cm s^{-1}. *Ksat* is a key parameter of geologic material when making interpretation of hydrologic responses to pumping from wells or to installation of drainage systems. *Ksat* values for the soils and geologic strata within and around the *protected* part of the Leitrim wetland are critically important to assure that development activities are not and will not impact this *protected* part.

Methods of Measurement and Data Collection

Site locations:

A limited number of sites were chosen along the north and east boundary of the *protected* part of the wetland as this boundary will influence strongly how the wetland responds to any impact arising from the housing development activity to the north and east of the *protected* wetland. Figure 1 shows where the sites were chosen relative to the *protected* portion of the Provincially Significant wetland.

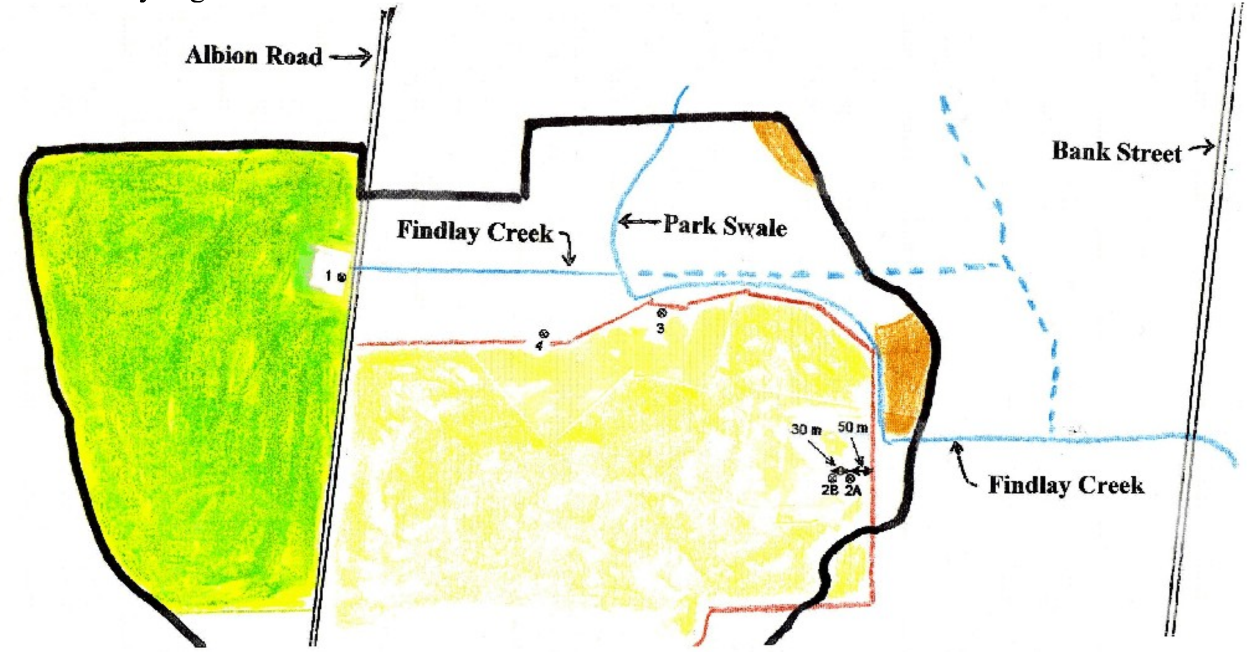

Figure 1. Northern part of the Leitrim Wetland. The numbered circled Xs indicate the approximate locations where soil was sampled and saturated hydraulic conductivity was measured.

Legend

— - OMB approved development line deep within the Leitrim Wetland.

▬ - OMNR's 1989 Provincially Significant Wetland boundary.

🟧 - Housing already constructed within the actual/scientific wetland boundary.

🟩 - Federally-owned portion of the reduced Provincially Significant Wetland.

- - - - Destroyed Findlay Creek channel and tributary channel.

🟨 - Protected, reduced part of the Provincially Significant Leitrim Wetland east of Albion Road

Measurement of Saturated Hydraulic Conductivity (*Ksat*):

Measurement of *Ksat* made use of two hand operated methods, the auger-hole method and the piezometer method (Topp, 2007a, b). In both methods the source of water and the hydraulic driving force are available from the usually existing high water table in the wetland. The auger-hole method is a field technique for measuring the *in-situ* saturated hydraulic conductivity, *Ksat*, of porous materials within the saturated zone (i.e. below the water table); and it is perhaps the most reliable and trusted means of obtaining *Ksat* values for the design of subsurface tile drainage systems. An alternative *in-situ* method for *Ksat* measurement in the saturated zone is the piezometer and it is widely used in hydrogeology for characterizing aquifer pumping characteristics.

The basic procedure for making an auger-hole measurement is: i) auger a hole that extends to at least 30 cm below the static water level; ii) allow the water in the auger hole to equilibrate to the static level; iii) add or remove water from the auger hole to initiate water flow into or out of the hole; iv) monitor the early-time change in water level in the auger hole as it re-equilibrates to the static level; and v) calculate *Ksat* from the measured rate of change of water level in the hole.

For the piezometer the procedure is the essentially the same as for the auger-hole. In piezometer measurements an open-ended pipe or casing is inserted into the hole (Figure 2). The pipe may extend to the bottom of the borehole, or it may terminate above the bottom leaving a cylindrical “piezometer cavity”. It is important that the pipe is sealed against the borehole wall so that leakage or short-circuit flow along the outside wall of the pipe is prevented. The principle of piezometer operation is the same as that for the auger-hole method; and consists of first allowing the water level in the piezometer pipe to equilibrate to the static or equilibrium water level, then quickly changing the water level in the pipe (usually by adding or removing water), and then monitoring the return of the water level back to the static level. The step-by-step procedures for both methods are described in Topp (2007a, b).

It was not possible to follow exactly the same procedure at all locations because the variations in soil and water table conditions necessitated adapting the general procedures described above to best accommodate the local conditions. All measurements were made from within hand-augered 10 cm diameter hole(s) at each site. The first measurement in each hole was made when the bottom of the hole was 30 to 35 cm below the equilibrium water table level. In those sites where the depth of peat was 30 cm or more below the water table we extended the first hole to the base of the peat for the initial measurement. This would give a single *Ksat* characteristic of the peat layer.

After completing measurements in the peat using the auger-hole method, a 15 cm diameter pipe was hammered into the peat and surrounding the previously augered 10 cm diameter hole (Figure 2). The purpose of this pipe was to seal off the direct flow of water from the peat into the hole so that flow into the 10 cm diameter hole next augered into the underlying mineral soil was flowing through the mineral soil. The measurements within the underlying mineral soil, with the peat thus isolated, were done by the piezometer method.

Water removal from the holes to initiate water flow was accomplished with a hand bailer having a rubber ball as foot valve seal. A bailer full of water could be filled and removed in about 20 s and, at most, two bailings were required to achieve satisfactory measurements. The rate of rise of water in the hole was determined using a standard tape measure modified with a small cylindrical float attached to the end of the tape. After water was bailed from the hole, the float-fitted end of the tape was dropped into the hole as it filled with water and a timer was used to record the rate of rise of the tape past a set marker (Figure 2).

(a) (b)

Figure 2: (a) Stand for securing measuring tape with tape as used in operation. (b) View from above showing float in pipe.

Results from Measurement

In the process of collecting saturated hydraulic conductivity data other substantiating data have also been obtained. These data results will be presented first. All data have been assembled and summarized in Table 1.

Water Table Depths:

The water table depths at most sites were within 10 cm of the soil surface, as expected in a wetland in July. At site 2, however, the water table was much deeper than we anticipated. At site 2A, 50 m west of the berm along the east side of the *protected* portion of the wetland the water table was at 85 cm below surface. At site 2B, 80 m west of the berm the water table was 64 cm below surface. Although the water table was relatively deep in the soil at site 2, there were surface pools of water which were apparently perched on slowly permeable layers at the interface between the peat and mineral subsoil. This kind of perched water pools has been observed at other wetland locations (David Lapen, personal communication).

Soil Layers, Depths and Types:

The soils at all sites were characteristic of wetland soil, the surface layers were organic soil (peat) of varying thicknesses, underlain by variable mineral soils. Proceeding from east to west, the peat depths were 15 to 20 cm (site 2), 65 to 70 cm (site 3), 75 to 85 cm (site 4) and approximately 20 cm just west of Albion Road (site 1) (Table 1). The underlying mineral soil varied from east to west both in type of soil and texture. At site 2A (the most easterly location) the mineral soil was a fine sandy glacial till from approximately 15 cm to 160 cm depth. At site 2B, however, the soil was different, fine sandy silt from 20 to 80 cm depth grading to fine sandy glacial till similar to that at site 2A. Site 2B was too rocky at 135 cm depth to prevent hand augering below this depth. At site 3A, the mineral soil was very fine sandy to silty material which lacked natural stability causing the augered holes to collapse which prevented going to depths below 100 cm. Site 3B, only about 10 m from 3A, had similar textured (very fine sandy to silty) soil which showed greater natural stability than at 3A. We were able to auger a hole to about 150 cm (the limit of our auger). At site 4A and 4B, the mineral soil was similar to that at 3B in both texture and stability. At site 4B, however, we were prevented from going deeper than about 130 cm because of rocks. At site 1, the mineral soil was very fine sandy to silty texture as at sites 3 and 4 but was grading to finer texture below 100 cm.

Table 1: Data collected at four sites in Leitrim Wetland.

Site	Peat Depth	Mineral Soil	Water Table Depth	Hole Depth	Method	*Ksat* x 10^3
	cm		cm	cm		cm s^{-1}
1	20	Very fine sand to sandy silt	10	65	AH	4.39
1			3.5	95	AH	1.00
1		As above, grading finer from 1m	3.5	135	AH	0.555
2A	17	Fine sandy till	84.5	121	AH	0.214
2A	17	Fine sandy till	84.5	162	AH	0.0827
2B	20	Fine sandy silt grading to fine sandy till at 80 cm with rock at 135 cm	63.5	125	AH	0.113
3A	**65**	**Very fine sandy to silty – mineral soil lacks stability**	**6.5**	**65**	**AH**	**31.6**
3A	65	As above	6	100	P	3.06
3B	**70**	**Very fine sandy to silty – soil more stable than at 3A**	**6.5**	**60.5**	**AH**	**183**
3B	70	As above for 3B	6.5	104.5	P	3.47
3B	70	As above for 3B	6.5	150	P	3.06
4A	**77**	**Very fine sandy to silty – soil was stable, similar to 3B**	**6.5**	**81**	**AH**	**29.7**
4A	77	As above for 4A	4	130	P	14.2
4B	**85**	**As above for 4A**	**4.5**	**92**	**AH**	**9.5**
4B	85	As above for 4A	5	125	P	21.1
4B	85	As above for 4A with rocks at 133 cm	4.5	130	P	5.12

Hydraulic Conductivity of the Peat

Only at sites 3 and 4 was water table depth in peat up to 30 cm – the minimum for the measurement method we were using. At site 1 the peat was not thick enough and at site 2 the water table was below the peat layer. Both conditions precluded measurement in the peat only. Thus, we have four measurements of the *Ksat* of intact peat. These four rows are in bold text in Table 1. These four show high variability with a range from 9.5 to 183 x 10^{-3} cm s^{-1}. The mean of these values is 35.7 x 10^{-3} cm s^{-1}, which is quite a high *Ksat* value but very reasonable for intact peat material. At site 1 the first measurement included peat in the material through which water was flowing and with a *Ksat* value of about half the lowest value in peat at sites 3 and 4 indicates that peat at site 1 was similar to that at sites 3 and 4 and with a similar *Ksat*. To give a feeling of how fast water can move through peat soil having *Ksat* of the mean value above (35.7 x 10^{-3} cm s^{-1}), suppose one could mark a small quantity of water and follow it for one hour. Under the influence of gravity alone the marked water would move 1.2 m or 4 feet vertically.

Hydraulic Conductivity of the underlying Mineral Soil

At site 2 the underlying mineral soil was of glacial origin as a fine sandy till. The mean *Ksat* was 0.126 x 10^{-3} cm s^{-1} and the three measurements going into this mean were of relative low variability (Table 1). Although the *Ksat* measured at site 2 was the lowest we encountered in this study, these values indicate a soil of moderate hydraulic conductivity by which water will move relatively quickly, for example, at about 0.5 cm or ¼ inch per hour under the influence of gravity.

The other three sites were underlain by very fine sand or silt indicating an original deposition from slowly moving water. From the *Ksat* values there appears to be a difference between site 1 with lower *Ksat* and sites 3 and 4 with the higher *Ksat*. At site 1 the mean *Ksat* was 1.35 x 10^{-3} cm s^{-1}. A mean value is not a realistic representation for this site as a trend to lower *Ksat* with depth is evident from Table 1. The *Ksat* at site 1 is 10 times or an order of magnitude higher than at site 2.

Sites 3 and 4 each showed *Ksat* which appeared different from the other, although the difference is not large for a parameter such as *Ksat*. The mean *Ksat* for site 3 was 3.19 x 10^{-3} cm s^{-1} and that for site 4 was 11.5 x 10^{-3} cm s^{-1}. Within each site the variability was low and there is no depth dependent trend as was observed at site 1. If we treat site 3 and 4 as not different from each other and calculate a mean *Ksat* for sites 3 & 4 we have a mean value of 6.07 x 10^{-3} cm s^{-1}. This *Ksat* is about 4 times that at site 1 and about 40 times that at site 2.

Thus at sites 3 & 4 a marked quantity of water flowing under the influence of gravity will move, on average, 22 cm or 9 inches each hour in the mineral soils underlying the peat.

Interpretation of the Findings in Relation to the Wetland Function

Impacts on the Water Table in the *Protected* Wetland

From site 2 at the eastern side, inside the *protected* part of the wetland, the data contain evidence that the water table within this *protected* wetland has already been affected by drainage to accommodate the neighbouring housing development. The water table below 80 cm deep at 50 m inside the *protected* part of the wetland on July 18 is most unusual. Water level observations at this location were made also on May 28 when the region of site 2 was under water, i.e. water table above surface. A month later, on June 29, the water level or the water table was at or near the soil surface. Thus a lowering of the water table by more than 80 cm in 21 days where surface flows have been prevented by the berm means that such large water loss would occur by evapotranspiration and downward drainage. Evapotranspiration losses occur through the soil surface via plants to the atmosphere and result in drying of the soil surface to a considerable extent. At the time of our measurements (July 18) the near surface soil was not dry and there were patches of water pools nearby our site, indicating that evapotranspiration was not a significant factor causing water loss from the area around site 2. Hence downward percolation appears to be the means of water removal from this eastern end *of the protected wetland area.* Further, site 2 is located in the lowest surface level found within the *protected* portion of the wetland and any negative impact such as a lowering of the water table will influence “upstream” of it more quickly and significantly than “downstream” locations.

Hydraulic Conductivity Implies Potential for Additional Negative Impact on the *Protected* Wetland.

Although the underlying mineral soil at sites 1, 3 and 4 appeared to be similar there were some differences in the hydrologic behaviour at each site. The *Ksat* values for site 1 appear to be lower than at site 3 and 4. Although a difference of factor of four in *Ksat* is not too large, it was not expected from visual examination. In 1979, my colleagues and I at Agriculture and Agri-Food Canada had made *Ksat* measurements in a similar soil (Piperville) using other methods. In that case we had variation of a factor of 10 at a single site and the magnitude of those values was between those found at site 1 and those at sites 3 and 4. This gives additional confidence in our current measurements.

Sites 3 and 4 which were midway along the northern boundary of the *protected part* of the wetland east of Albion Road had high *Ksat* to a depth of 1.5 m. From the soil map of the region the underlying mineral soil continues northward into the wetland area designated as part of the PSW by the OMNR in1989 and has similar hydrologic properties. When additional drainage and hydrology changes are made to lower the water in the region north of the *protected* wetland area to permit continued housing development, the *protected* wetland area will be drained very rapidly (within months) and initiate degradation in the *protected* wetland area. The wetland degradation will take the form of oxidation of the peat causing loss of peat but also unnecessary increases in green house gas emissions. Biologically the specific plants and wetland animals will also be impacted leading to changes in the ecological relationships. It difficult to estimate how far southward into the *protected* wetland these negative impacts would propagate without making use of additional hydrogeological knowledge within both the *protected* wetland and the planned housing development area. It is possible, however, to make inference from site 2 observations to indicate the potential impact is very extensive. For example, if the water table dropped to 80 cm deep at 50 m westward of the berm inside the eastern boundary (site 2) and to 65 cm deep at 80 m in a 3 week period in July as a result of drainage for development, it is reasonable to suggest that the impact of such drainage outside and to the northeast of the *protected* wetland has impacted well beyond 100 m inside the eastern boundary of the *protected* wetland area. The underlying mineral soil on the east side had the lowest hydraulic conductivity measured at the four sites. Applying these observations to sites 3 and 4 where we measured *Ksat* which is 40 times higher than at site 2, I suggest that drainage from south of site 3 and 4 inside the *protected* wetland will occur much more rapidly and would extend much further into the *protected area* of wetland. It is probable that the drainage would lead to a drop in water table which could occur twice as quickly and progress two to three times further into the wetland. The northern region of the *protected* wetland could be impacted rapidly and seriously by drainage to be done just north of the *protected* wetland boundary. This degradation of the wetland function could extend a considerable distance southward into the *protected* wetland.

The planned extension of housing development westward toward Albion Road will result in water table lowering west of Albion Road, resulting in strong probability of degradation of the wetland function in the *protected* wetland portion west of the Albion Road. This portion is federal crown land under jurisdiction of the Transport Canada.

Concluding Remarks

The saturated hydraulic conductivity *Ksat* of the upper 1.5 m of soil materials, both organic and the underlying mineral soils, was measured as moderate to high, indicating that water flow and loss of water can occur very quickly and extensively in these soils. The sites for measurement were located along the north and east boundary of the *protected* part of the wetland in close proximity to planned additional suburban developments. These data indicate the wetland function of the *protected* portion of the Leitrim wetland is extremely susceptible to adverse effects from any and all hydrologic activity in the proximity of the *protected* portion, such as to the north on which a drainage system is to be developed and which will lower the water table.

In the process of collecting *Ksat* data it was necessary to have water table data. At the most eastern sites, near where housing development has already been underway, we were extremely surprised to find that the water table was well below surface in mid-July and this condition had developed in a period of three weeks and extended 100 m or more into the eastern side of the *protected* part of the wetland. Such rapid and extensive drop in the water table resulted from the construction and drainage activity east of the *protected* part of the wetland. Very clearly this so-called "*protected*" part of the wetland has not been protected from the adverse impact of the construction and drainage taking place adjacent to the boundary of the *protected* part of this Provincially Significant Wetland. The wetland function has already experienced adverse effects. The probable adverse impact of additional development activity proceeding westward along the northern boundary of the *protected* portion of the wetland is considerably greater in both extent and degree because of the greater sensitivity to faster water loss from the more highly conductive or permeable soils found along the northern boundary.

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