Wetland Hydroperiod Guidance Document

November 2020

Executive Summary

The “hydroperiod” of a wetland refers to the seasonal pattern of water level fluctuation, both above and below the soil surface. The hydroperiod is a significant factor determining wetland ecological community type and habitat function. The water depth, duration of flooding, and degree of soil saturation in a wetland act as ecological filters, allowing some species to thrive while preventing others from colonizing an area. Many other factors contribute to wetland community composition but hydroperiod is generally understood to be the most important single factor influencing community composition and structure at a broad level (Leck & Brock 2000; Mitsch & Gosselink 2007; Barton *et al.* 2008; Raulings *et al.* 2010; Araya *et al.* 2011; Johnson *et al.* 2014; Chandler *et al.* 2017; Moore *et al.* 2017).

This document summarizes the current state of knowledge about the hydroperiods of healthy wetland communities found in the Toronto and Region Conservation Authority (TRCA) jurisdiction, and in southern Ontario more generally. The data presented here are drawn from monitoring sites within the watersheds of TRCA, Credit Valley Conservation, and Conservation Halton over the period 2012-2019; the intent is that this document be updated every 2-3 years as new data become available. Note that palustrine and isolated wetlands are represented in the data whereas riparian and coastal wetlands are not (as per Ontario Wetland Evaluation System hydrological classifications [OMNR, 2014]).

In defining a range of “normal” conditions for specific wetland communities, the intended uses of this information are:

1. To provide an indication of when a given wetland type could be impacted by a change in water level resulting from human activities. This could include adjacent land development or land cover change (e.g. urbanization), water taking, or discharge of effluent into a wetland.

2. To provide a range of target conditions for specific wetland types use in wetland restoration projects. This information could be used either to target a specific community for restoration or to predict ecological succession and the final state of a restored site based on water level monitoring.

3. To provide an indication of when a given wetland type could be impacted by a change in water level resulting from extreme weather events (e.g. drought, heat waves, or extreme seasonal precipitation) and/or climate change over the long term.

Recommendations for application of this information to decision making are provided in the “How to Apply the Summaries” section. There are a number of assumptions and limitations to the information presented in this document which readers should review before applying this information.

Toronto and Region Conservation Authority. 2020. Wetland Hydroperiod Guidance Document.

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1. BACKGROUND

Hydrology is arguably the most important factor determining wetland community structure, function, and composition (Leck & Brock 2000; Mitsch & Gosselink 2007; Barton *et al.* 2008; Raulings *et al.* 2010; Araya *et al.* 2011; Johnson et al. 2014; Chandler *et al.* 2017; Moore *et al.* 2017). Wetlands exist where land is seasonally flooded or where the water table is shallow, and are dominated by hydrophytic (water-loving) vegetation. Wetland plants have evolved special adaptations over millions of years to survive in these particular conditions, and many species (referred to as “obligate” wetland species) can live nowhere else. Many wildlife species also need wetland habitat to complete parts of their lifecycle, most notably amphibians but also some fish and birds.

Variations in wetland hydroperiod, or the seasonal pattern of water level fluctuation above and below the soil surface, create habitat niches for plants and wildlife species. Water depth and the degree of soil saturation act as important ecological filters, preventing obligate upland species from colonizing an area and limiting colonization by facultative (non-obligate) wetland species by imposing physical and biogeochemical constraints. The root zone anoxia (oxygen depletion) that develops under flooded stagnant conditions not only directly inhibits diffusion of oxygen into soils, and thus normal plant respiration, but also increases concentrations of certain elements and compounds to levels that are toxic to some upland plants. As a result, plants that can successfully exploit wetland environments have evolved a range of biological adaptations that allow them to survive in these harsh conditions, giving them a competitive advantage over other plant species.

The link between hydroperiod and wetland community type has been intuitively understood for some time. Wetland communities frequently occur in a predictable sequence along a gradient of saturation. For example, treed swamps tend to occur at the drier end of the gradient, adjacent to upland forest communities, while marshes, dominated by emergent vegetation such as cattails, have standing water for a longer period of the year. Shallow aquatic wetlands occur in areas where shallow water is present year-round and rarely, if ever, dry out. However, few studies have attempted to systematically describe the hydroperiods of different wetland communities common to southern Ontario (see Wheeler *et al.* 2004 for an example of systematic classification from the U.K.). While many studies have attempted to quantify wetland hydroperiods, comparison of these results is rendered difficult by the variety of different environments studied (different climates, species assemblages, salinity levels, soils, landscape settings, tidal patterns, etc.) and the lack of consistent hydroperiod metric definitions. For this reason, this document does not attempt to compare the data reported here against that reported in the literature; readers are referred to the literature cited at the end of this document for more information.

It is important to note that the wetlands described in this document are all associated with slowly moving or stagnant standing water (i.e. isolated and palustrine wetlands, as per the Ontario Wetland Evaluation System [OWES]) rather than with rivers (i.e. riparian wetlands). The two shallow aquatic wetlands are associated with small lakes slightly over the 8 ha size threshold for lacustrine systems, and so would technically be classified as lacustrine. In larger riparian and coastal systems, factors like sediment erosion and deposition, seiches and tides, and higher nutrient inputs tend to play a larger role in shaping wetland community structure than in isolated and palustrine wetlands, where water levels can be more directly correlated with community structure. Future studies and monitoring sites should focus on those types of wetlands not represented here to ensure that their range of tolerance to hydrological conditions is better understood.

Three different wetland classification systems are referred to in this document (OWES, Ontario ELC, and Canadian Wetland Classification System [CWCS]). The three systems are quite similar on the whole, with each recognizing Swamp, Marsh, Bog, and Fen as distinct wetland classes. The ELC and CWCS systems recognizing a further fifth class known as Shallow Water or Shallow Aquatic wetlands, consisting of areas where water <2 m depth is present all or most of the year, dominated by submergent or floating aquatic vegetation, and with <25% tree or shrub cover. In OWES these areas are considered to be a sub-class of Marsh, known as Open Marsh. The sub-classes within the three systems vary but they share the same overarching class structure and broadly similar definitions. OWES further classifies wetlands into four hydrological classes: Lacustrine, Riverine, Palustrine, and Isolated. Readers should consult these sources for further details on classification systems (OMNR, 2014; Lee *et al.*, 1998; NWWG, 1997).

2. PURPOSE

The purpose of this document is to summarize the current state of knowledge about the hydroperiods of healthy wetland communities found in the TRCA jurisdiction, and in southern Ontario more generally, based on long-term monitoring data collected from 19 wetlands. In defining a range of "normal" conditions for specific wetland communities, the intended uses of this information are:

1. To provide an indication of when a given wetland type could be impacted by a change in water level resulting from human activities. This could include adjacent land development or land use change (e.g. urbanization), water taking, or discharge of effluent into a wetland.
2. To provide a range of target conditions for specific wetland types for use in wetland restoration projects. This information could be used either to target a specific wetland community for restoration or to predict ecological succession and the final state of a restored site based on water level monitoring.
3. To provide an indication of when a given wetland type could be impacted by a change in water level resulting from extreme weather events (e.g. drought, heat waves, or extreme seasonal precipitation) and/or climate change over the long term.

This information will benefit planning ecologists who assess the likely impacts of land development and related activities (dewatering, effluent discharge, etc.) on adjacent wetlands. It can also benefit restoration ecologists and other users.

It is necessary to state the limitations of the data reported here: these data represent a preliminary characterization of hydroperiods within four broadly-defined wetland communities. The observed hydroperiod distributions represent the most likely ranges for healthy wetland communities belonging to a given type; however, it is not impossible that a healthy wetland could have a hydroperiod range differing somewhat from that reported here, particularly for Ecological Land Classification (ELC) codes (Lee et al., 1998) not represented within the existing data. Similarly, it is possible that human-induced changes to the water levels of a given wetland could result in ecological degradation while remaining completely within the bounds of the observed hydroperiod range for the corresponding wetland community type. Further limitations and assumptions are outlined in the following section. Additional guidance on interpretation is included in the “How to Apply the Summaries” section.

3. OVERVIEW OF DATA

The data used to produce the graphs and figures in this report was collected from 19 wetlands located across the watersheds of TRCA, Credit Valley Conservation (CVC), and Conservation Halton (CH). The locations of the monitoring sites are shown in Figure 1, while ELC codes are shown in Figure 2 along with the period of data coverage at each site. Water level data at each site was collected with a pressure transducer (water level logger) and a shallow well or piezometer situated near the center of the ecological unit.

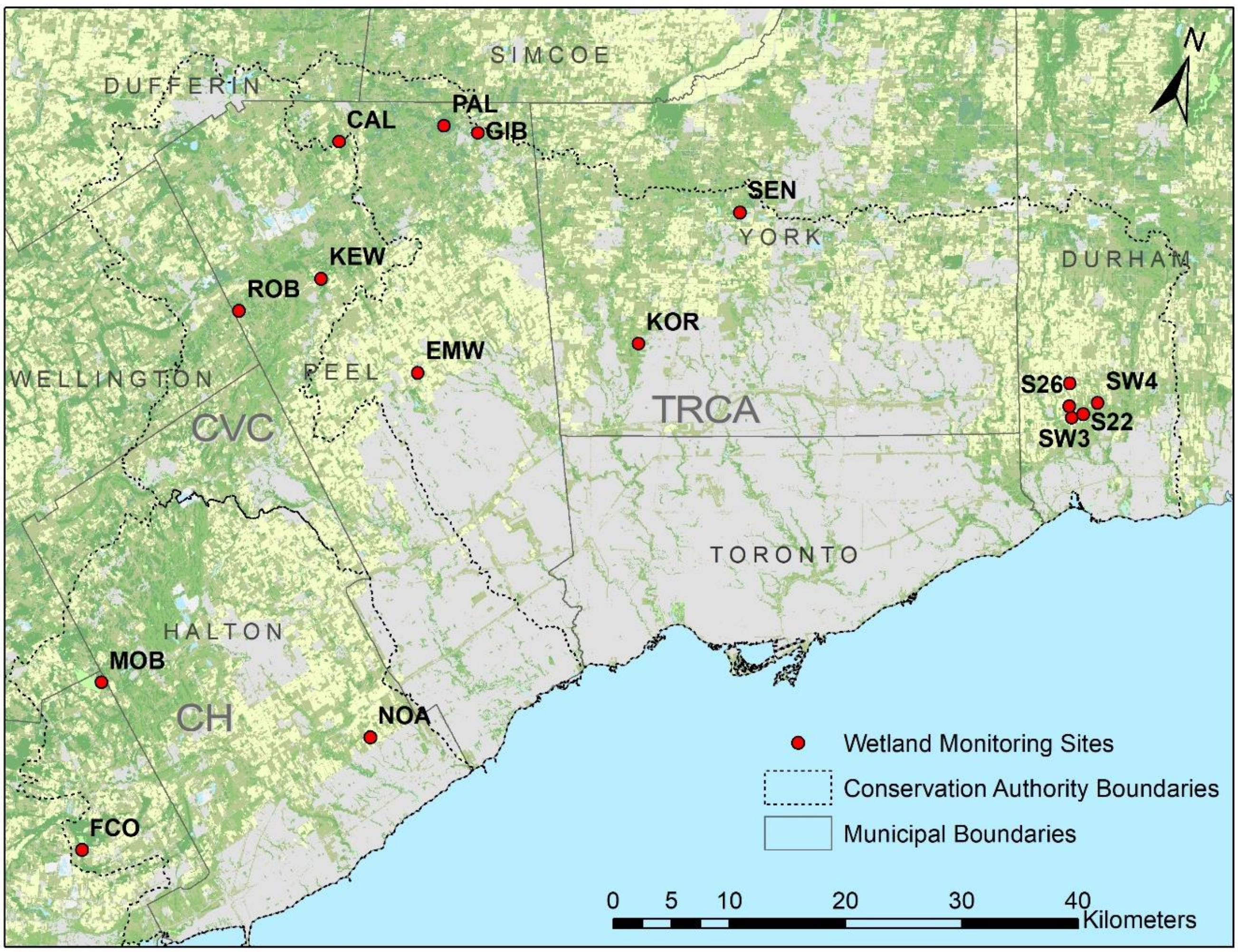


Figure 1: Wetland monitoring site locations

Site Code	Site Type	ELC Code	# Years Data	2013	2014	2015	2016	2017	2018	2019
EMW	SW	SWD3-3	3		■			■	■	
KEW-B	SW	SWD3-3	6	■	■	■	■	■	■	
MOB	SW	SWM1-1	6	■	■	■	■	■	■	
ROB	SW	SWD6-1	6	■	■	■	■	■	■	
S22-A	SW	SWD3-2	5			■	■	■	■	■
S26-A	SW	SWD3-2	3					■	■	■
SW1	SW	SWD6-2	2					■	■	
SW4	SW	SWD2-A	3					■	■	■
KEW-A	TH	SWTM3	6	■	■	■	■	■	■	
S22-B	TH	SWT2-4	6		■	■	■	■	■	■
S26-B	TH	SWT2-4	3		■			■		■
CAL	MA	MAS2-1A	1							■
FCO	MA	MAS2-2	6	■	■	■	■	■	■	
PAL	MA	MAS3-1A	1							■
KOR	MA	MAS2-1	5		■	■	■	■	■	
NOA	MA	MAS2-8	3	■	■	■				
SW3	MA	MAS2-8	3					■	■	■
GIB	SA	SAM1-A	2*							■
SEN	SA	SAM1-A	2*							■

Figure 2: Gantt chart showing number of complete years of data available at each site along with site type (SW=treed swamp; TH=thicket swamp; MA=marsh; SA=shallow aquatic) and ELC code (Lee et al., 1998). *Sites GIB and SEN include data through to November 2020.

The monitoring sites included here, which were selected for monitoring for a variety of different initial purposes, all share the following attributes:

- The wetlands are in a reference condition, meaning that the surrounding catchment land use and corresponding hydrology are believed to have been stable for a decade or longer based on historical aerial imagery. The ecology of the wetland could therefore be expected to be in equilibrium with the site's hydrology. Note that none of these wetlands are true reference sites, in that their surficial catchments have all been impacted to varying extents by human activities (e.g. agriculture, roads, forest management) but that they are nonetheless among the best examples of their respective community types in the Greater Toronto Area.

- The sites are headwater wetlands generally associated with stagnant or very slowly moving water and not with watercourses exceeding a first order stream (as per Strahler, 1957). Median catchment size is 21 ha.

The monitored wetlands are sorted into four type categories (marsh, treed swamp, thicket swamp, and shallow aquatic) based on the number of sites available, in order to differentiate sample populations at the coarsest level of community structure. Without a larger number of sites, it is not possible to group sites at a finer level of ecological detail; however, this does not exclude the possibility of ecologically meaningful differences in hydroperiod within each of the four type categories used here. Neither bogs nor fens are included as both are rare in the TRCA jurisdiction, comprising <1% of all wetlands by area; however, there is a large literature describing these wetland types (see e.g. Ingram, 1983).

Where three letter site codes are appended with "-A" or "-B", multiple distinct wetland communities have been monitored at a single large site (i.e. at a single point on the map in Figure 1).

Finally, for a calendar year of monitoring data to be included in these analyses, there must be fewer than 30 consecutive days of missing data and fewer than 60 days of missing data in total. The site also had to remain in a reference condition for that year (i.e. be unimpacted by any recent land use change, drainage change, or development within the catchment).

3.1 Assumptions and Limitations

The following assumptions and limitations are associated with the approach outlined here:

- Each wetland can be represented as a flat, homogeneous ecological unit with a single ground surface elevation (as per Figure 3). This assumption was determined to be appropriate for this analysis but may not be appropriate for some very large wetlands or wetlands occurring on sloped surfaces. Monitoring equipment is generally located as close as possible to the center of the ecological unit.

- Notwithstanding the assumption above, accurately determining the ground surface elevation in a wetland is not a trivial problem due to variable water levels, hummocks and depressions, and the presence of soft organic and muck soils. Ground surface elevation may be challenging to determine with the level of accuracy required here and should be regarded as a source of uncertainty.

- The general assumption throughout is that wetland hydroperiod is the dominant variable controlling vegetation community type and structure. This does not discount that other factors also interact to shape community structure and may even be dominant determinants of wetland community at some sites. Among these other factors are physical composition of the soil profile (partly reflected in the hydrology), water and soil chemistry, nutrient loading rate, seed bank, initial state along a path of ecological succession, and interactions between these factors.

- The link between hydroperiod and vegetation community can be challenging to resolve conclusively given that the species that may be best suited to conditions within a given wetland may not be present in the seed bank or in adjacent natural areas. Additionally, for tree species, the lag time between shifts in hydrological conditions and observable community response can be decades (Manzoni *et al.*, 2013).

- The various components of the water budget (precipitation, snowmelt, groundwater inflow, evapotranspiration, etc.) are not estimated here but could potentially be a relevant factor influencing wetland vegetation community structure. It is however noted that the hydroperiod, representing storage of water within the wetland, integrates all possible wetland hydrological inputs and outputs.

- The further the water level in a wetland falls below ground surface, the greater the difficulty of accurate comparisons between sites becomes. This is due to the interaction between soil properties, such as porosity and specific yield, and water level as measured in a well. Sites should be broadly comparable when the water level is in the shallow subsurface (less than about 50 cm below surface).

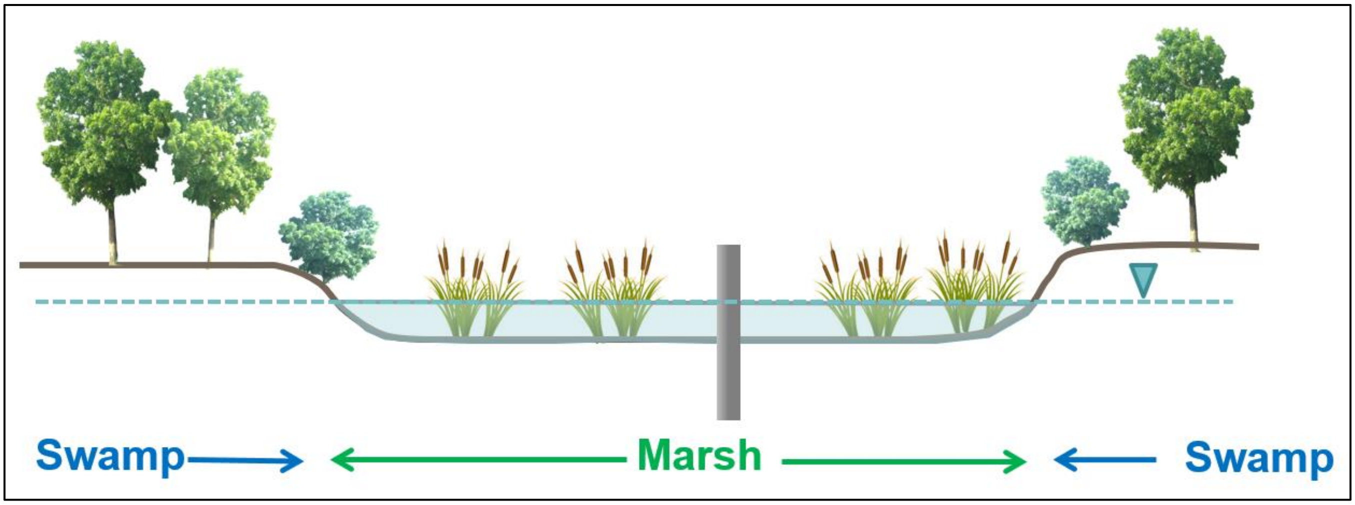


Figure 3: Representation of a wetland as a flat, homogeneous ecological unit with a single ground surface elevation. Multiple wetland community types are shown in this figure, with monitoring equipment at center.

- All the normal uncertainties and limits of precision with respect to data loggers and pressure transducers apply, including uncertainty introduced by barometric compensation of water level data. Correction of water levels using manual measurements on a seasonal basis can reduce the magnitude of potential error to within a few centimeters.

- Given the complexity of the dataset, with the specific years and number of years of data available varying from site to site, it was not possible to systematically control for “year” as a factor (in a statistical sense) without excluding a large proportion of the dataset. Therefore, the data for each site type has been lumped together to produce the graphs and statistics reported, under the assumption that the data taken together capture a representative range of conditions across time and space (i.e., climatically dry, wet, and normal years).

4. WETLAND HYDROPERIOD SUMMARIES

4.1 How to Read the Summaries

The following pages include summaries of hydroperiod characteristics for four different types of wetland common to southern Ontario. Although monitoring sites were all instrumented to be comparable with one another, these sites were set up over a period of several years by different agencies and for multiple different purposes, and so the number of sites in each category is not the same. For the shallow aquatic wetland type, the two sites were established in 2018 and there are only two years of data represented (January 2019 through November 2020). As such, the characteristics for this wetland type in particular should be considered preliminary and interpreted with caution.

Each page shows the range of water level conditions encountered within a given type of wetland, summarized as follows:

- In a wetland hydroperiod "ribbon diagram", showing the range of observed monthly-average water levels relative to average wetland ground elevation. Coloured bands correspond to the proportion of data falling within given percentile ranges. As the data used were highly non-normally distributed, percentile ranges are used in lieu of standard deviations, with the light green, yellow-orange, and percentile bands being equivalent to one, two, and three standard deviations, respectively, in terms of the proportion of the data they bound. A very similar method is used in CVC's Wetland Hydrological Assessment Method (2018).
    - The number of sites and the mean number of monitored years per site for each wetland type are shown in the legend.
    - The following terms are associated with the coloured bands: "most common" (dark green), "common" (light green), "uncommon" (yellow), and "rare" (red) conditions, respectively (after CVC, 2018).
- A table summarizing hydroperiod metrics for each wetland type. The metrics were determined using the Wetland Hydroperiod Analysis Tool (WHAT, v.1.2; TRCA, 2018). Further documentation on methods for determining these metrics is available in this document. Note that the maximum, minimum, and dry-out date metrics are calculated using a 10-day running average to capture general water level trends while reducing sensitivity to potential error in (hourly to daily) monitoring data resulting from barometric compensation, ice effects, and other random sources. The range representing the most common conditions (25th to 75th percentile, i.e. middle 50% of data) is shown alongside the average value. The table below provides an overview of the metrics and their estimated ecological significance.
    - The entire 25th to 75th percentile range should be considered as ideal ("most common") conditions for a given wetland type, at least for the ELC codes represented in the dataset, based on currently available data; see Appendix A for list of ELC codes.

Table 1: Overview of wetland hydroperiod metrics and estimated ecological significance

Parameter	Estimated ecological significance
Max. Water Level (10-day avg.)	Different plants may have water level tolerance thresholds related to pressure and oxygen diffusion within the water column (inhibiting aerobic respiration); fewer plant species may be able to thrive in wetlands of with longer/deeper periods of flooding (Mitsch & Gosselink, 2007) while habitat availability for fish and waterfowl may increase.
Max. Water Level Date	Timing of maximum water level conditions within the year may influence plant phenology and habitat provisioning for wildlife.
Min. Water Level (10-day avg.)	Some species (e.g. trees and shrubs) may require unsaturated conditions in the rooting zone for part of the year to survive, while drier, more broadly tolerable conditions may alter inter-species competition (e.g. with facultative upland plants). Also influences fish and wildlife habitat provisioning.
Min. Water Level Date	Timing of minimum water level conditions within the year may influence plant phenology and habitat provisioning for wildlife.
Dry-out Date (after April 1)	"Dry-out date" represents the first date after April 1 when the 10-day average water level falls below -0.05 m. -0.05 m is used instead of 0 m to indicate the point at which the surface of the soil begins to dry; at 0 m it is generally still saturated due to the capillary effect and pools of water may still be present. April 1 is used to capture the date within the growing season when conditions become dry, as wetlands will periodically have water levels below ground surface at the start of the calendar year in January. This metric relates to plant phenology and habitat provisioning, providing an indication of the periods during the year that a wetland is flooded vs. dry.
Total Duration of Inundation (Days)	Longer periods of flooding reduce oxygen diffusion into soils and thereby affect nutrient availability and increase concentrations of reduced elements and compounds, which can be toxic to some plants while providing a competitive advantage for others (Mitsch & Gosselink, 2007).
Days of Inundation > 0.25 m	Duration of water levels above 0.25 m depth; 0.25 m is an arbitrary benchmark but may correspond to a minimum value for certain ecological functions.
Days of Inundation > 0.50 m	Duration of "deep" water levels; 0.50 m is an arbitrary benchmark but may correspond to a minimum value for certain ecological functions.

4.2 How to Apply the Summaries

This section offers guidance on how to apply the wetland hydroperiod summaries presented in this document towards decision making. Guidance is divided into two subsections: 1) assessing impacts resulting from human-induced water level change; and 2) wetland restoration applications. Appropriate management actions to address observed or anticipated impacts will depend on the specific context of the site in question and are beyond the scope of this document.

It is almost never possible to identify precise thresholds of ecohydrological disturbance due to difficulties in assessing both what constitutes a loss of ecological function and the appropriate timescale on which to evaluate such a loss. The guidance here therefore uses a risk-based approach, whereby the projected risk of an impact increases as water levels deviate further from observed reference condition ranges. All projected impacts are based on expert ecological opinion and on anecdotal observations of sites where water level changes have led to shifts in wetland flora and/or fauna over time. An “impact” is defined here as an undesirable loss of ecological function, such as loss of entire flora or fauna community, or of habitat serving a particular species or group of species. An impact could also include a loss of other ecological functions, such as loss of organic / peat soils and associated carbon sequestration potential, or loss of hydrological storage for reducing peak outflows from a catchment.

While wetlands in the natural environment have a certain adaptive capacity to reach a new equilibrium state following hydrological disturbance, the fragmented nature of many rural and urbanizing landscapes in southern Ontario means that the wetland species that would normally be able to colonize or utilize altered habitat may not be able to do so. Reduced ecological connectivity between the natural areas within a fragmented landscape means that, for example, a population of amphibians that is lost when a wetland is impacted may be permanently extirpated from that area. In practice, hydrologically altered wetlands within an urban landscape often become simplified and degraded systems consisting of a few species, and are vulnerable to becoming dominated by invasive terrestrial or aquatic plants.

Note that very low water levels (e.g. periods when water levels drop >50 cm below ground surface) are difficult to measure with high accuracy and to compare among sites, as the properties of the soil profile (e.g. specific yield) and the geometry of the monitoring well become more important as water levels decline. Below this approximate threshold, monitoring data may not be comparable at the levels of accuracy required here.

4.2.1 Guidance for assessing impacts resulting from water level alteration

Table 2 outlines general principles for assessing the risk of impacts to a wetland, given a set of observed or predicted water levels for a particular wetland type (see definition of impact above). These principles assume that any impacts are due largely to changes in the water balance, and that water flowing into the wetland is not also carrying excessive loads of sediment, nutrients, pesticides, etc. These general principles may always be superseded by more detailed knowledge about a particular wetland or ecological function of interest.

Table 2: Hydroperiod ranges and associated risks of impact

Range of water level variation	Associated risk of impact
Within most common (dark green) range	Lowest possible risk of impacts; considered ideal conditions for wetland type and ELC codes represented.
Within common (light green) range	Low risk of impacts; within observed normal range of conditions for wetland type.
Within uncommon (yellow) range:	Impacts possible if water levels remain consistently towards either the upper or lower bounds of uncommon conditions for a period of months to years. Assessment of impacts must consider weather conditions – water levels within this range could be expected for very wet or very dry conditions (e.g. seasonal or annual precipitation and/or air temperature outside the 20th to 80th percentile range for the 30-year climate normal) but would otherwise suggest water level alteration. Community shift possible over the long term.
Within rare (red) range	High risk of impacts; if water levels remain within this range for any significant duration (e.g. months), impacts are likely. Water levels are at limits of observed record; greater concern if not explicable due to extreme weather events (e.g. drought). Impacts in this range may be irreversible if sustained for longer periods, and community shift is likely over the medium to long term.
Outside observed range	Very high risk of impacts; some impacts may be irreversible if sustained over a timescale of months. Possible to observe under natural / unaltered conditions only during climatic extremes. Community shift and degradation are extremely likely.

4.2.2 Guidance for wetland restoration applications

The second purpose of this document is to provide a range of target conditions for specific wetland types for use in wetland restoration projects. Two main ways of applying this document are envisioned:

a. To target a specific wetland community for restoration. Projected water levels would use either pre-restoration monitoring of water levels or modelling of wetland water storage using a simple water balance approach. The design of the wetland would consider the specific wetland type(s) of interest as well as other potentially desired ecological functions (e.g. reptile/amphibian overwintering). Parameters such as the location and elevation of water control structures (berms, weirs, etc.) would be adjusted to the geometry of the site in question, based on monitored or modelled water levels, to reflect the wetland type(s) of interest. In all cases, the dark green (most common) range reflects the best estimate for the target hydroperiod for each wetland type presented here.

b. To predict the ecological succession and final state of a restored site based on water level monitoring. In other words, using observed post-development water levels to predict the wetland vegetation that would ultimately be best suited to inhabiting a particular site. This could be used to evaluate if the species envisioned or planted at a site will be likely to survive and thrive there over the medium to long term.

For both applications a) and b), it is necessary to note that getting the right hydroperiod is a necessary but not a sufficient condition to ensure the establishment of a particular wetland vegetation community. Many other factors, such as soil texture and chemistry, organic matter content, water chemistry, nutrient loading rate, amount of direct sunlight, existing seed bank, and interactions with surrounding flora and fauna may play into the success or failure of a given vegetation community to establish itself. Certain conditions may only be necessary for the initial establishment of a given wetland type, while other conditions may be required in perpetuity. Finally, the range of possible hydroperiods for a given site may be limited by the prevailing soil and groundwater conditions, particularly for sites with high infiltration rates (e.g. sandy soils). Virtually all of the reference condition wetlands discussed here have either very low permeability soils (e.g. glacial tills) or moderate to strong upwards vertical hydraulic gradients (i.e. they are sites of groundwater discharge), based on monitoring data and field tests.

Treed Swamps

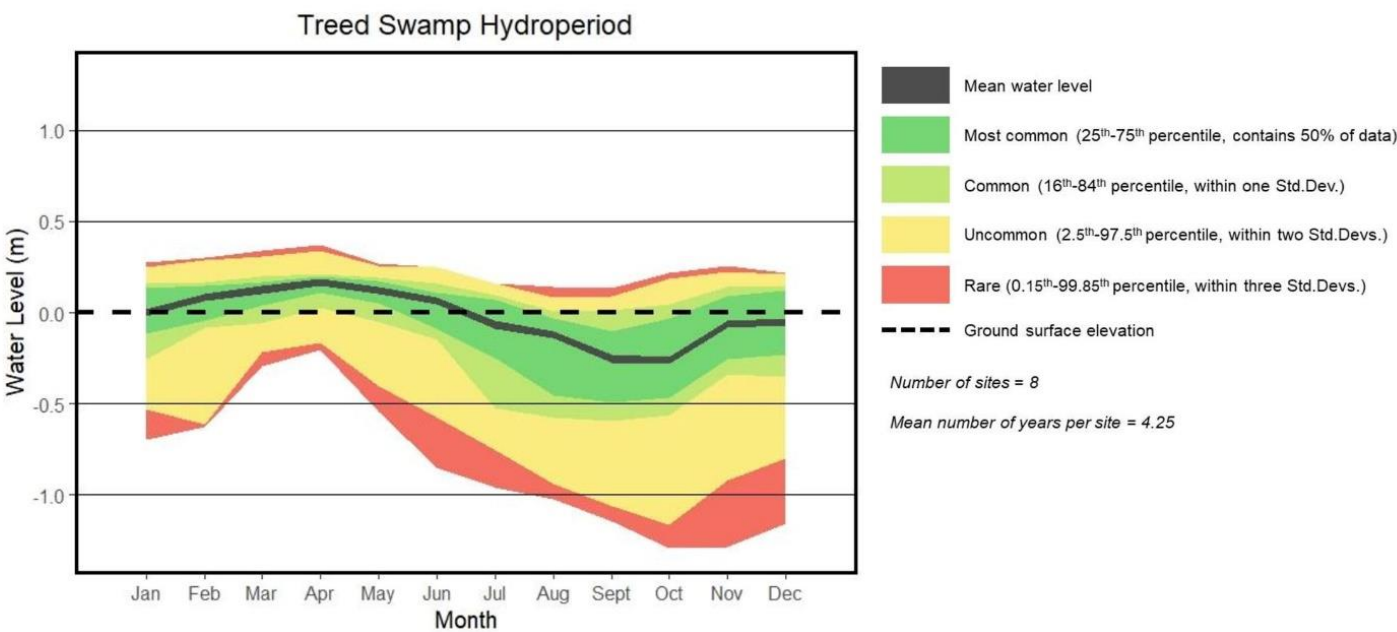
Image: A silver maple swamp in early spring with characteristic flooding.

Description: Treed swamps, one of the four wetland classes defined in the Ontario Wetland Evaluation System (OWES), are described as wooded wetlands with 25% cover or more of trees (OMNR, 2014). Vegetation cover may consist of coniferous and/or deciduous trees, tall shrubs, herbs, and mosses (OMNR, 2014). Treed swamps are characteristically flooded during spring, may remain waterlogged for large portions of the year, and do not commonly have deep peat accumulation (OMNR, 2014).

Treed swamps are distinguished from other wetland types by having the lowest maximum and minimum annual water levels (average values of 0.22 m and -0.48 m, respectively). Water levels tend to be above ground surface only during late winter and spring, roughly from January to June, but can occasionally be inundated for longer, and may periodically rise above ground surface following significant summer precipitation. Water levels >0.25 m in treed swamps are rarely observed except in isolated pools, and it is likely that sustained water levels exceeding this threshold would lead to die-back of dominant tree species. (This has been observed in a mixed hardwood swamp in Pickering Township where a water level increase to average annual maximums of ~0.45 m above local ground surface, believed to be caused by beaver activity, resulted in the death of most trees in the 14 ha stand).

As mature tree canopy is the defining feature of treed swamp wetlands, preventing dominant tree species from being drowned is the key to maintenance of these wetland communities, while also ensuring that the soil moisture regime prevents succession of tree species more typical of upland communities over time. Water levels tend to drop to lows of around 0.5 m below ground surface in early fall, but it is not clear if there is a lower threshold of tolerance for these communities. Shifts to drier, upland forest community types would likely be more gradual and occur through inter-species competition over a timescale of years to decades (e.g. Manzoni *et al.*, 2013), while impacts of drying to amphibians and other species utilizing vernal pools would be more immediate.

Note that the data shown here does not include any coniferous treed swamps; this must be regarded as a data gap.



Hydroperiod Summary Table

Parameter	Average Value	25th–75th Percentile Range
Max. Water Level (10-day avg.)	0.22 m	0.14 to 0.26 m
Max. Water Level Date	Apr 16	Mar 23 to May 4
Min. Water Level (10-day avg.)	-0.48 m	-0.67 to -0.32 m
Min. Water Level Date	Aug 28	Jul 18 to Oct 3
Dry-out Date (after April 1)	Jun 30	Jun 3 to Aug 6
Total Duration of Inundation (Days)	219	147 to 296
Days of Inundation > 0.25 m	2	0 to 15
Days of Inundation > 0.50 m	0	0

Thicket Swamps

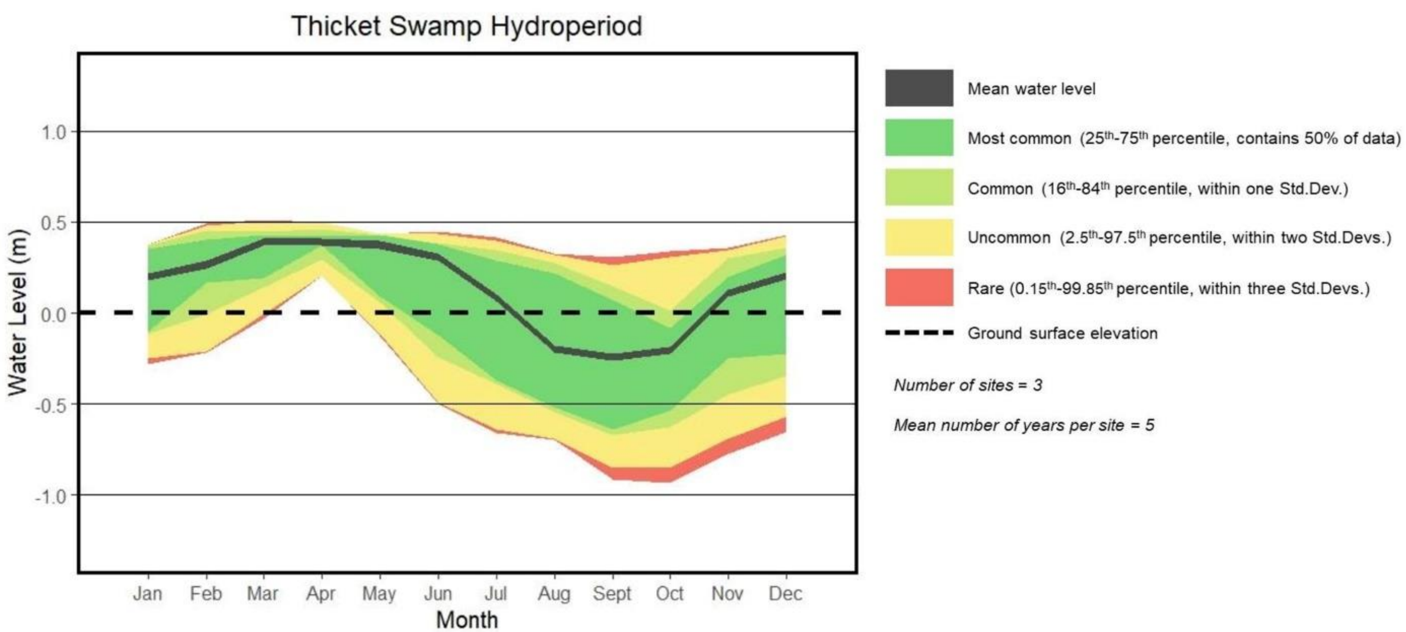
Image: A buttonbush thicket swamp in early summer.

Description: Thicket swamps are a sub-type of swamp described as wooded wetlands with 25% cover or more of shrubs (Lee et al., 1998; OMNR, 2014). They are distinguished from treed swamps by the predominance of shrub cover and have <25% tree cover. Thicket swamps are characterized by thick growths of tall shrubs such as willow species, red-osier dogwood, buttonbush and speckled alder (OMNR, 2014). They are recognized as a separate wetland sub-type in the Southern Ontario ELC system as well as in OWES.

The hydroperiod of thicket swamps is similar to that of treed swamps, the key difference being that maximum annual water levels tend to be about 0.25 m greater than that observed in treed swamps on the basis of available data (0.45 m vs 0.22 m). Higher water levels also tend to be sustained for much longer, with an average of 188 days above 0.25 m (compared to 2 days for treed swamps). This period of inundation >0.25 m is 45 days longer on average than for marsh communities. The total period of inundation over the year is also longer in thicket swamps relative to treed swamps by an average of 62 days. Observed minimum annual water levels do not differ greatly from treed swamps.

The small sample size (n=3) of wetlands in this community type limits the strength of the conclusions that can be drawn; monitoring of additional sites would be warranted. Anecdotally, this community type is often found within or adjacent to mature treed swamps in areas of deeper pooling water where sufficient sunlight reaches the thicket. It seems likely that thicket swamps require dry conditions for at least some part of the year to allow for survival of dominant shrub species.

Thicket swamps that experience increases in water levels, where either water levels exceed 0.5 m for extended periods or where the top of the soil profile is never dry, may drown over time, although this has not been observed directly.



Hydroperiod Summary Table

Parameter	Average Value	25th–75th Percentile Range
Max. Water Level (10-day avg.)	0.45 m	0.39 to 0.51 m
Max. Water Level Date	Apr 5	Mar 14 to Apr 13
Min. Water Level (10-day avg.)	-0.42 m	-0.67 to -0.22 m
Min. Water Level Date	Sep 11	Jul 26 to Oct 3
Dry-out Date (after April 1)	Jul 25	May 21 to Sep 23
Total Duration of Inundation (Days)	281	138 to 317
Days of Inundation > 0.25 m	188	24 to 212
Days of Inundation > 0.50 m	0.5	0 to 9

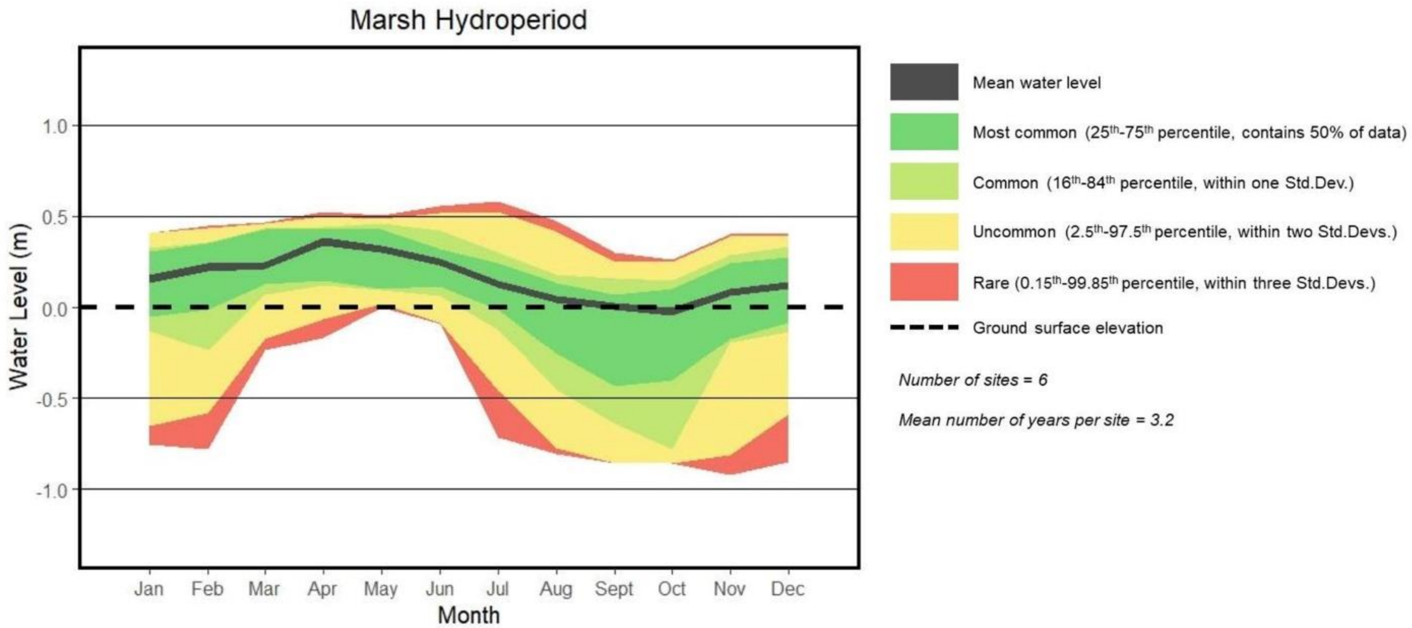
Marshes

Image: A large cattail marsh in late fall

Description: Marshes are wetlands where the predominant vegetation consists of emergent non-woody plants such as rushes, cattails, bulrushes, sedges, grasses and herbs (OMNR, 2014). Low shrubs such as sweet gale, red-osier dogwood, waterwillow, and winterberry may also occur, while tree and shrub cover remains ≤25% (Lee *et al.* 1998; OMNR, 2014). Whereas in the OWES system, wetlands dominated by submergent and floating vegetation are considered "open marshes", a sub-type of marsh, for the purposes of this document we distinguish these as a separate "Shallow Aquatic" class (as per ELC, CWCS). Note that all the sites represented here are considered "shallow marshes" under the ELC system, and no "meadow marshes" are represented.

The range of observed hydroperiods is fairly broad for marshes, as illustrated by the height of the coloured bands, despite the fact that 4 of 6 sites were dominated by broad-leaved cattail. The key feature of marsh hydroperiods may be the long duration of inundation, with sites remaining inundated all year in 26% of observed years (average of 301 days of inundation per year). This is the primary hydroperiod attribute distinguishing marshes from thicket swamps, while average maximum annual water levels were only marginally higher (0.47 m and 0.45 m for marshes and thicket swamps, respectively). It is not clear that hydroperiod alone can account for the differences in ecology between these two community types, and factors such as soils, nutrient input, shading, or initial condition may ultimately determine the path of ecological succession towards a marsh or a thicket swamp.

For marshes to persist requires conditions wet enough to preclude succession by tree and shrub species, while an upper water level threshold for emergent plants may exist around the highest observed water levels (0.6-0.7 m), though this is speculative. While marshes appeared to tolerate drier years without evidence of community shift, sustained drying is likely to lead to succession by trees and shrubs with increased opportunities for aggressive and invasive plant species to dominate. (This has been observed at a cattail marsh in Ajax, where altered drainage patterns shifted the hydroperiod such that the wetland was never inundated, and invasive *Phragmites australis* and buckthorn shrubs came to dominate.)



Hydroperiod Summary Table

Parameter	Average Value	25th–75th Percentile Range
Max. Water Level (10-day avg.)	0.47 m	0.34 to 0.54 m
Max. Water Level Date	Apr 5	Mar 19 to May 17
Min. Water Level (10-day avg.)	-0.17 m	-0.78 to -0.04 m
Min. Water Level Date	Aug 15	Mar 9 to Sep 5
Dry-out Date (after April 1)	Sep 14	Jul 16 to Dec 31*
Total Duration of Inundation (Days)	301	226 to 361
Days of Inundation > 0.25 m	143	34 to 193
Days of Inundation > 0.50 m	2	0 to 16

*Dec 31 dry-out date refers to a year in which the wetland is inundated for the entire year

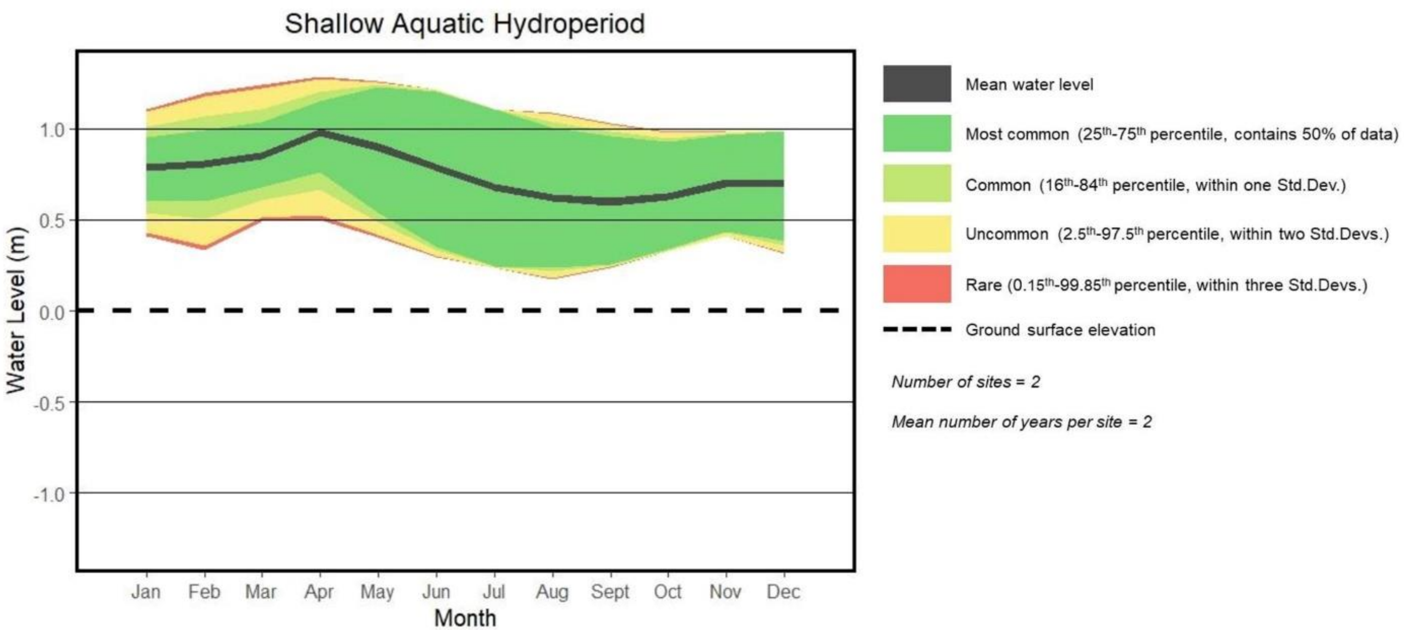
Shallow Aquatic Wetlands

Image: a water lily – bullhead lily mixed shallow aquatic wetland bordering a permanent lake.

Description: Shallow aquatic wetlands are a type of wetland occupying the ecotone between wetlands deep open-water aquatic systems. They are recognized as a distinct wetland type in the Southern Ontario ELC system and Canadian Wetland Classification System (NWWG, 1997), characterized by water < 2m deep present for all or most of the year with <25% of the surface occupied by standing emergent or woody plants. In OWES these wetlands are referred to as open-water marshes. Vegetation is dominated by submergent vegetation or floating aquatic plants. Shallow aquatic wetlands also play an important role in the lifecycle of a number of fish species, in particular as a refugia for fry and juvenile fish.

While data for the shallow aquatic wetland type is very limited, water levels clearly remain deep for much longer than other wetland types outlined here (>0.5 m for an average of 254 days). The maximum water level tolerance for shallow aquatic wetlands is understood to be 2 m depth (NWWG, 1997; Lee et al. 1998; OMNR, 2014), though this depth might exceed the tolerance for some shallow aquatic vegetation such as bullhead lily. Minimum water level is understood to be 0 m, with characteristic vegetation requiring constant inundation, though brief periods of exposed soil are likely tolerable. Sustained drying is almost certain to lead to loss of submergent vegetation and aquatic species, with eventual succession by emergents and shrubs.

Further monitoring of this wetland type is needed to establish better limits of tolerance. Note that the two wetlands represented are both classified as lacustrine (OWES definition) and are associated with lakes 10-15 ha area.



Hydroperiod Summary Table

Parameter	Average Value	25th–75th Percentile Range
Max. Water Level (10-day avg.)	1.07 m	0.84 to 1.25 m
Max. Water Level Date	Apr 21	Apr 14 to May 3
Min. Water Level (10-day avg.)	0.57 m	0.22 to 0.91 m
Min. Water Level Date	Aug 23	Jun 28 to Sep 11
Dry-out Date (after April 1)	N/A	Dry-out not observed
Total Duration of Inundation (Days)	365	365
Days of Inundation > 0.25 m	348	323 to 365
Days of Inundation > 0.50 m	254	115 to 365

Wetlands as Wildlife and Fish Habitat

In addition to providing habitat for unique plant species assemblages, wetlands play a critical role in the completion of lifecycles for many wildlife and fish species. Some birds and many amphibians rely on wetlands to complete part or all of their lifecycle. While it is beyond the scope of this document to relate hydroperiods to species' habitat requirements, consideration of the potential for impacts to wetland habitat provisioning functions is key to assessing the overall risk of water level alteration. For species requiring wetland or aquatic habitat, there should be at least some standing water at the times of year corresponding to important lifecycle to function as effective habitat. Some wetlands may function more effectively as amphibian habitat if they dry out annually to prevent establishment of fish species, though this will depend on the known or intended habitat functions of the wetland in question. Some resources are available to help planning ecologists and other decision-makers determine how to relate hydroperiod to habitat functions (see e.g. Amphibian Timing Chart, TRCA, 2014).

Image: A northern leopard frog in a marsh.

5. CONCLUSION AND FUTURE DIRECTIONS

This document presents long-term hydroperiod monitoring data collected from 19 wetlands in the Greater Toronto Area. These wetlands are some of the best examples of their respective community types in the region and are understood to have been in a reference condition for the duration of monitoring. The approach outlined here is intended to provide a template for future monitoring work and analyses at other sites.

The intent is to update this document every few years as more data becomes available. It is critical that any new data included be from sites that are representative of healthy wetlands within a given type, and that data be reliable, accurate, and collected from a representative location and elevation within the wetland. An approach to incorporating this data could be to collect 5 complete years of hydroperiod data at a given site and then to compare data and types among similar climate-years (see Appendix C). Further monitoring of Thicket Swamps, Shallow Aquatic Wetlands, and certain sub-types and ELC codes not represented in the current dataset is warranted. Future study should investigate riparian and/or coastal wetland hydroperiods. However, caution must be taken when comparing hydroperiods between headwater palustrine, isolated, or lacustrine wetlands, on the one hand, and wetlands associated with large rivers or open coastlines on the other; for the latter, processes operating on sub-daily timescales (e.g. peak flows, storm surges, erosion events) may be as ecologically important as annual or seasonal patterns of change.

One additional useful direction for future research would the study of sites that have become degraded due to altered hydrology. This is especially useful where baseline pre-disturbance monitoring data exist; in an ideal circumstance, both hydrology and ecology data would be available, and sites would remain intact enough that impacts could be attributed almost solely to altered water balance. Defining the limits of hydrological tolerance for different wetland communities requires more systematic documentation of the ecological response of wetlands to altered hydrology.

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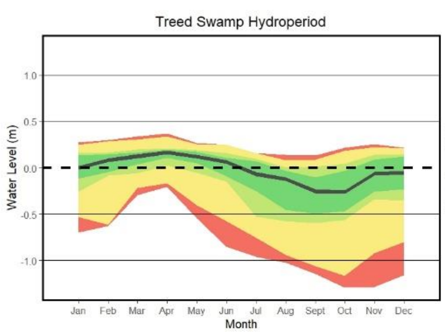
APPENDIX A: DETAILED MONITORING SITE ATTRIBUTES

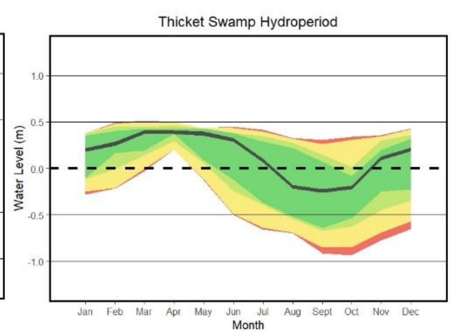
Site Code	Wetland Type	ELC Code	ELC Name	Wetland Size (ha)	Est. Catchment Size (ha)	Soil Texture (top 50 cm of profile)	Avg. Organic Matter (%)	Avg. Soil pH
EMW	Treed Swamp	SWD3-3	Swamp Maple Mineral Deciduous Swamp	2.2	26.9	Silty clay	5	5.0
KEW-B	Treed Swamp	SWD3-3	Swamp Maple Mineral Deciduous Swamp	1.6	Undefined	Very fine sandy loam	9	7.1
MOB	Treed Swamp	SWM1-1	White Cedar - Hardwood Mineral Mixed Swamp	4.5	No data	Silty clay/organic overlying silty sand	14	7.1
ROB	Treed Swamp	SWD6-1	Red Maple Organic Deciduous Swamp	5.5	No data	Organic (mesic)	79	6.1
S22-A	Treed Swamp	SWD3-2	Silver Maple Mineral Deciduous Swamp	0.5	6.7	Organic overlying clay loam	18	6.8
S26-A	Treed Swamp	SWD3-2	Silver Maple Mineral Deciduous Swamp	1.7	17	Silt loam to silty clay loam	17	7.2
SW1	Treed Swamp	SWD6-2	Silver Maple Organic Deciduous Swamp	2.8	21	Organic (fibric to mesic)	No data	No data
SW4	Treed Swamp	SWD2-A	White Ash Mineral Deciduous Swamp	2.3	27.1	Organic (mesic to humic) overlying sandy clay loam	35	7.0
KEW-A	Thicket Swamp	SWTM3	Willow Mineral Deciduous Thicket Swamp	1.3	Undefined	Very fine sandy loam	6	7.4
S22-B	Thicket Swamp	SWT2-4	Buttonbush Mineral Thicket Swamp	0.3	6.7	Silty clay loam overlying organic	24	6.7

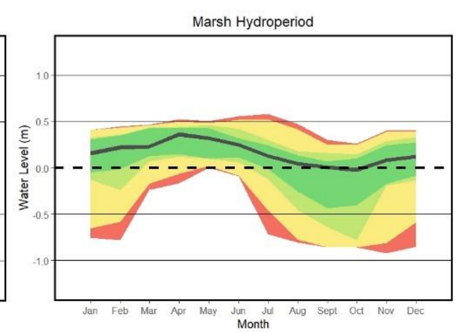
Site Code	Wetland Type	ELC Code	ELC Name	Wetland Size (ha)	Est. Catchment Size (ha)	Soil Texture (top 50 cm of profile)	Avg. Organic Matter (%)	Avg. Soil pH
S26-B	Thicket Swamp	SWT2-4	Buttonbush Mineral Thicket Swamp	0.2	17	Organic (mesic) over silty clay	28	6.9
CAL	Marsh	MAS2-1A	Broad-leaved Cattail Mineral Shallow Marsh	0.6	Undefined	No data	No data	No data
FCO	Marsh	MAS2-2	Bulrush Mineral Shallow Marsh	12.0	1,247	Clayey silt over silty sand	4	7.4
PAL	Marsh	MAS3-1A	Broad-leaved Cattail Organic Shallow Marsh	4.0	175	No data	No data	No data
KOR	Marsh	MAS2-1	Broad-leaved Cattail Mineral Shallow Marsh	0.2	15	Thin organic muck over silty clay	4	6.4
NOA	Marsh	MAS2-8	Rice Cut-grass Mineral Shallow Marsh	0.3	26	Silty clay to clayey silt	3	6.0
SW3	Marsh	MAS2-8	Rice Cut-grass Mineral Shallow Marsh	3.0	17.4	Clay loam over fine sandy loam	6	7.4
GIB	Shallow Aquatic	SAM1-A	Water Lily - Bullhead Lily Mixed Shallow Aquatic	4.8	No data	Organic muck bottom	No data	No data
SEN	Shallow Aquatic	SAM1-A	Water Lily - Bullhead Lily Mixed Shallow Aquatic	6.7	470	Organic muck bottom	No data	No data

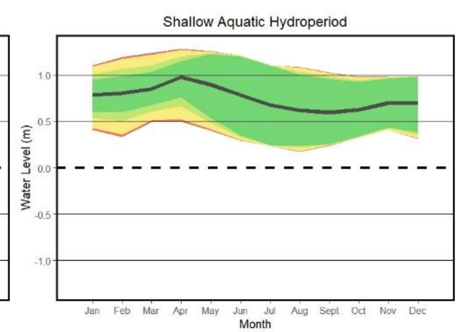
APPENDIX B: HYDROPERIOD SUMMARY COMPARISON TABLE FOR ALL WETLAND TYPES

	Treed Swamp		Thicket Swamp		Marsh		Shallow Aquatic	
Parameter	Average Value	25th– 75th %tile	Average Value	25th– 75th %tile	Average Value	25th– 75th %tile	Average Value	25th– 75th %tile
Max. Water Level (10-day avg.)	0.22 m	0.14 to 0.26 m	0.45 m	0.39 to 0.51 m	0.47 m	0.34 to 0.54 m	1.07 m	0.84 to 1.25 m
Max. Water Level Date	Apr 16	Mar 23 to May 4	Apr 5	Mar 14 to Apr 13	Apr 5	Mar 19 to May 17	Apr 21	Apr 14 to May 3
Min. Water Level (10-day avg.)	-0.48 m	-0.67 to -0.32 m	-0.42 m	-0.67 to -0.22 m	-0.17 m	-0.78 to -0.04 m	0.57 m	0.22 to 0.91 m
Min. Water Level Date	Aug 28	Jul 18 to Oct 3	Sep 11	Jul 26 to Oct 3	Aug 15	Mar 9 to Sep 5	Aug 23	Jun 28 to Sep 11
Dry-out Date (after April 1)	Jun 30	Jun 3 to Aug 6	Jul 25	May 21 to Sep 23	Sep 14	Jul 16 to Dec 31	N/A	Dry-out not observed
Total Duration of Inundation (Days)	219	147 to 296	281	138 to 317	301	226 to 361	365	365
Days of Inundation > 0.25 m	2	0 to 15	188	24 to 212	143	34 to 193	348	323 to 365
Days of Inundation > 0.50 m	0	0	0.5	0 to 9	2	0 to 16	254	115 to 365









APPENDIX C: CLIMATE-YEAR CLASSIFICATIONS

Climate-year classifications using IRI (2019) methodology on Toronto Pearson Airport climate station data using 1961-1990 baseline period. Pearson station is roughly in the geometric center of the monitoring sites and so provides a reasonable representation of annual averages for the region as a whole. Wet/Dry and Warm/Cool refer to data above the 80th percentile and below the 20th percentile respectively, while the adjective Record denotes values beyond the observed baseline maximum or minimum. (Data analysis from K. Bavrlic, CVC.)

Year	Precipitation	Air Temperature
2013	Wet	Record Warm
2014	Average	Average
2015	Average	Warm
2016	Dry	Record Warm
2017	Wet	Record Warm
2018	Wet	Warm
2019	Wet	Warm