Conservation of the endangered Small White Lady's Slipper in Manitoba, Canada – A Hydrogeological Approach

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ABSTRACT
The small white lady's-slipper, Cypripedium *candidum* is an endangered native terrestrial orchid, found at the northern limit of its range in Manitoba, Canada. Cypripedium *candidum* has specific site preferences, such that habitat destruction including alteration of hydrology is considered a primary threat to the orchid. Cypripedium *candidum* populations were examined in the context of their hydrogeological settings. Regionally, locations exhibited a preference for discharge margins of unconfined glacial sand aquifers. Field evidence of groundwater discharge as apparent at candidum sites. Monitoring at three locations found shallow water tables during the active growing period. Water samples exhibited high pH and were rich in calcium. The affected soil chemistry appeared to suppress competing species, allowing Cypripedium *candidum* to succeed. By understanding characteristic hydrogeological conditions, existing populations may be protected, locations of undiscovered populations may be predicted and habitat may be rehabilitated, thus assisting conservation efforts.

RÉSUMÉ
La petite sabot de Vénus blanche, Cypripedium *candidum*, est une orchidée terrestre indigène en voie de disparition, trouvée à la limite nord de son aire de répartition au Manitoba, Canada. Cypripedium candidum a des préférences spécifiques sur le site, de sorte que la destruction de l'habitat, y compris l'altération de l'hydrologie, est considérée comme une menace primaire pour l'orchidée. Les populations de Cypripedium *candidum* ont été examinées dans le contexte de leurs contextes hydrogéologiques. À l'échelle régionale, les emplacements présentaient une préférence pour les marges de décharge des aquifères de sable non confinés. L'évidence sur le terrain du rejet des eaux souterraines est apparente sur les sites candidum. La surveillance à trois endroits a permis de trouver des nappes phréatiques peu profondes pendant la période de croissance active. Les échantillons d'eau présentaient un pH élevé et étaient riches en calcium. La chimie du sol affectée semblait supprimer les espèces concurrentes, permettant à Cypripedium *candidum* de réussir. En comprenant les conditions hydrogéologiques caractéristiques, les populations existantes peuvent être protégées, l'emplacement des populations non découvertes peut être prédit et l'habitat peut être réhabilité, contribuant ainsi aux efforts de conservation.

1 INTRODUCTION

The small white lady's-slipper (Cypripedium *candidum*) is a perennial orchid species native to the eastern and central interior of North America. It is found in fifteen US states and in the provinces of Manitoba and Ontario, Canada. It reaches its northern extent in the province of Manitoba (FNA 2002). (Figure 1)

Cypripedium *candidum* grows 10-35cm high, averaging around 20cm. Plants occur as a single stem usually with a flower at the top, or a clump of stems. The flower is a small white pouch or "slipper" with faint pink-purple spots and veining, surrounded by yellow-green petals and sepals, streaked with purple. Flowering usually occurs in late May and early June. (Ames et al. 2016; Smith 2012).

This orchid's annual life cycle starts in May, when the stems flower buds emerge. These flower buds are easily frozen by late spring frosts during this time period, which may limit how far north this species can grow. Blooming takes place in late May and early June. Depending on weather conditions, the bloom period at a site may last one to two weeks. The seed pods set soon afterward and ripen by August and by September the plants are mostly withered.

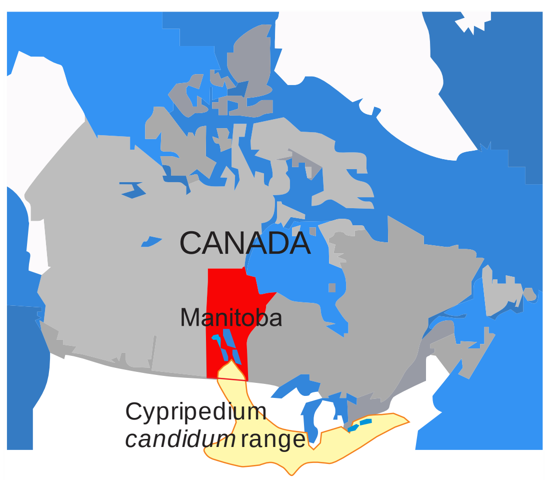

Figure 1. Range of Cypripedium *candidum* (after FNA, 2002).

Lady's slippers produce thousands or seeds which are transported by air and water up to 1500 km. Seeds contain no food energy and will germinate and grow only where specific types of mycorrhizal fungi and suitable site conditions exist. The plant embryo grows underground for the first 3 to 4 years, nourished by the fungi. Once emerged, the leaves produce energy through photosynthesis, but depending on site conditions, may take a decade or longer to reach flowering size (Curtis 1943). The association with mycorrhizal fungi allows established orchids to survive unfavourable environmental conditions (Smith 2012).

The small white lady's-slipper is listed as endangered by the government of Canada and by the provinces of Manitoba and Ontario. As a species, it is vulnerable at any given location throughout its range but is considered secure due to its wide distribution (COWSEWIC 1999).

There are 25 known separate populations in Canada: 18 in Manitoba and 7 in Ontario (Environment Canada 2014). Manitoba's populations are found in three distinct areas: the southeast tall grass prairie area, which has more than 50% of the plants, the Interlake aspen parkland area, and the western mixed-grass prairie area, particularly near the City of Brandon (CDC 2010).

2 HABITAT

Cypripedium *candidum* is shade intolerant and is one of only a few prairie orchid species. It is particular about site conditions and will not grow on land that has been cropped, intensely grazed or otherwise altered. Colonies of the plants are generally limited to undisturbed remnants of native prairie. These land parcels are typically orphaned from development by barriers, usually roads or fence lines, or may occur within the road allowances themselves (Smith 2012; CDC 2010).

In Ontario habitat is rich calcareous fens having high water table, organic soils and marl pools (Imre et al. 2005). In Manitoba, habitat consists of wet prairie grassland or prairie clearings in aspen woodland or fen. The land is generally gently undulating, often with low relief ridge and swale topography. The fens have a characteristic hummock and hollow relief, generally of about 30cm (CDC 2010). In Manitoba, roadside ditches are significant habitat, usually on the ditch shoulder near the fence line. Fourteen of Manitoba's eighteen populations have some portion occurring along roadsides, while eight populations are exclusively on roadsides (CDC 2010).

Cypripedium *candidum* requires a reliable supply of moisture during the growing season. As the plants prefer drained sandy soils, this moisture is generally provided by wicking of groundwater. (Imrie et al. 2005; Brownell 1981). Soils are moist to seasonally wet, and not flooded, though they may experience standing water briefly during spring melt. Soils are calcareous and alkaline, typically with pH of 7.0 to 8.5, having formed over glacial sediments which were derived from limestone and dolomite bedrock. Sediment types include glacial till, outwash, beach ridges, lake clays, or sedge peats. In Minnesota the orchids occasionally occur at drier sites where carbonate bedrock is very close to surface. (Smith 2012). While Cypripedium *candidum* and other Manitoba Cypripediums like moist conditions, wet conditions or elevated water table alone are not sufficient, as plants are not found in moist areas lacking active groundwater flow, such as marshes, swamps and floodplains.

The small white lady's-slipper does not compete well against more vigorous grasses or herbs. As such, a population's survival depends on the suppression of competitors. This is accomplished either through unfavourable ground, or through occasional disturbance, activities which may involve fires, grazing, trampling or mowing, which may be a threat in their own right. (Curtis 1946; CDC 2010).

Where it comes in contact with yellow lady's-slippers (Cypripedium *parviflorum*) hybrids are common and are designated as Cypripedium *andrewsii*. Hybridization has been reported at all sites in Manitoba (Foster and Hamel 2006). As hybrids are more vigorous, genetic dilution is considered a threat to the survival of the native species (Worley, 2009).

Threats to the plants are most often related to habitat change or loss. Loss may come as physical destruction through urban encroachment, tilling or excessive grazing or dredging of ditches. Habitat destruction may also occur indirectly through the alteration of hydrology. Nearby dams, drainage works, flooding or land use changes may alter the soil moisture regime, nutrient availability, or survival of mycorrhiza fungi in the soil.

3 HYDROGEOLOGICAL STUDY

This study investigates the geological, hydrogeological and hydrogeochemical factors influencing the distribution of Cypripedium *candidum* populations and site-specific habitats in Manitoba and how they are manifest in the natural environment.

The investigation has four components:

I. A field reconnaissance survey of locations of a variety of native orchids across Manitoba and parts of Saskatchewan and Minnesota over a period of six years (2011-2016). This involved visits to and observations of hundreds of orchid sites, and thousands of recordings of individual plant locations. The areas covered took in many ecosystems, including grassland, aspen parkland, boreal forest, mixed forest and a variety of wetlands. Many references in this paper about Cypripedium *candidum* and native Manitoba orchid habitat in general are based on personal observations made during field expeditions.
II. An office-based GIS mapping assessment of the regional distribution of the orchids relative mainly to geology, topography and hydrology.
III. Site visits to, and environmental assessments of selected Cypripedium *candidum* populations in Manitoba.
IV. Groundwater monitoring and sampling setups at three selected sites

Investigations led to development of a model of the characteristic hydrogeological influences on small white lady's slipper habitat.

3.1 Field Reconnaissance

During field reconnaissance, observations were made of site conditions at hundreds of growing locations of a variety of orchid species, the majority being Cypripedium *parviflorum* (yellow lady's-slipper) and Cypripedium *reginae* (showy lady's-slipper) and including, Cypripedium *candidum*. While many orchid species had common habitat preferences, Cypripedium *candidum* was more specific when it came to its position in the landscape, soils, aspect, moisture regime, natural state of habitat, associated companion plant species and need for suppression of competing plant species.

3.2 Regional Distribution in Manitoba

Locations of small white lady's-slipper colonies in Manitoba were plotted using ArcGIS™. Locations were compared to surface geology, soils and shallow aquifers, regional topography, drainage and cultural features.

Bedrock geology in Manitoba consists of Cretaceous shales in the southwest, a central band of Paleozoic carbonates, with Canadian Shield to the east and northeast. Surficial geology is dominated by thick glacial deposits from Pleistocene glaciation (Betcher et al. 1995).

During the late Wisconsinan glaciation, much of Manitoba was covered by Glacial Lake Agassiz. The former lake bed of Glacial Lake Agassiz, forms the clay soil plain of the Red River Valley, which is a central feature of southern Manitoba. Surrounding the Red River valley are an assemblage of coarser grained glacial deposits, including sandy moraines, beach ridges, fluvial deposits and large areas of deltaic deposits (Teller and Fenton 1980). Soils assume the texture of the glacial deposits beneath them. The widespread shallow sands constitute unconfined aquifers, often of considerable extent.

The glaciers which moved south across central Manitoba transported rock fragments primarily from the Canadian Shield and the Paleozoic carbonates. Glacial deposits in southern Manitoba are approximately 50% Shield rock and 50% carbonate (Teller and Fenton 1980). Many native orchid species including most Cypripediums favour soils rich in calcium carbonate. This is one reason why orchids proliferate in Manitoba more than elsewhere on the prairies (Ames et al, 2016).

Locations of Cypripedium *candidum* populations were compared to the texture of unconsolidated surficial geology and soils. Prominent coarse-textured glacial deposits include the extensive Sandilands upland complex of the southeast, which extends far into Minnesota, beach ridges surrounding former Lake Agassiz, deltaic features including the Portage sandhills, the Assiniboine delta aquifer and the Oak Lake aquifer, and glacial-fluvial deposits of the Brandon Hills.

Cypripedium *candidum* populations, which had been considered randomly distributed, correlated strongly to these particular features (Figure 2). The largest populations of Cypripedium *candidum*, which account for over 50% of all the plants in Manitoba are found within the Sandilands aquifer complex. The populations from the Interlake region between Lake Manitoba and Lake Winnipeg, correlated to beach ridge deposits which formed at the shoreline of Lake Agassiz. Western Manitoba populations were associated with the Portage Sandhills aquifer, the Oak Lake aquifer and the Brandon Hills (Spiritwood) aquifer (Figure 2).

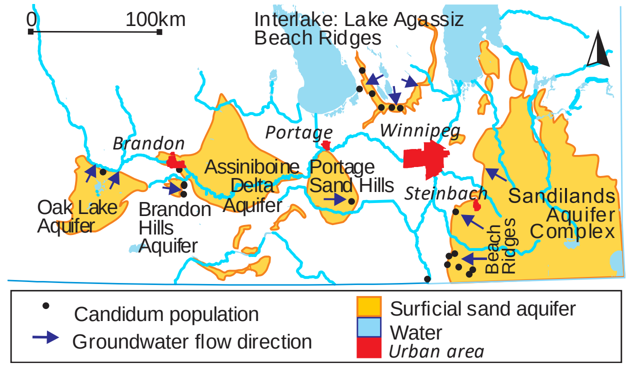

Figure 2. Location of Cypripedium *candidum* populations relative to surficial sand aquifers and groundwater flow.

When compared to topography, these same populations were found also to occur at the foot of regional uplands. They are found where the Sandilands and the Portage Sandhills transition to the Red River valley, the Interlake shoreline deposits descend to the Lake Manitoba Plain, and the Oak Lake aquifer to the Assiniboine River valley. Topographic relief is generally in the order of about 15 metres in most areas but is considerably more for the Sandilands.

The elevation differences and the coarse-textured substrate lead to development of active groundwater flow within the associated aquifers. The orchid populations strongly favour base-of-slope aquifer margin combinations. The thinning and pinching out of the aquifers at these locations intensifies groundwater discharge. Groundwater-fed wetlands of various sizes are found in all regions but are particularly expansive in the Sandilands area.

3.3 Site Assessments

Site visits were made to 10 different populations, representing the three regions: western, Interlake and Sandilands and all habitats, including fens, prairie swales and ditches. Sites were examined in the context of local topography, geology, cultural features and field manifestations of groundwater. Features encountered included springs or seeps, quick ground in the form of frost boils, flowing wells, shallow flow barriers, blocked drainages and nearby gravel pits. Vegetation was characteristically phreatophytic, commonly willow, poplar and swamp birch. The impoundment and subsequent seepage of shallow flow was important at all sites outside of the Brandon Hills, where contact springs prevailed. Site observations were used to develop generalized groundwater flow models. The general characteristics for these sites are summarized in Table 1.

Figure 3 shows cross sections through aquifer-hosted *candidum* populations in each of the three regions. Elevation and distance scales are different for each cross section.

Table 1: Site Characteristics and features

SITE NAME	SETTING	GROUNDWATER SETTING
Oak Lake	fen, ditch	Road and rail impoundment of defined drainage
Brandon City	swale, ditch	Springs/seep; quick ground; gravel pits
Brandon Hills East	swale, ditch	Springs/seep
Brandon Hills South	swale, ditch,	Springs/seep
Portage Sand Hills	ditch	Deep road cut
St Laurent	swale	Gravel pits; groundwater discharge to ditches
Argyle	swale	Wet prairie; Road impounded drainage
Woodlands	ditch	Spring discharge upslope; impounded drainage
Kleefeld	ditch	Quick ground, flowing wells, discharge sloughs; road impounded defined drainage
Tall Grass Prairie	swale	Low relief fen; some road impoundment

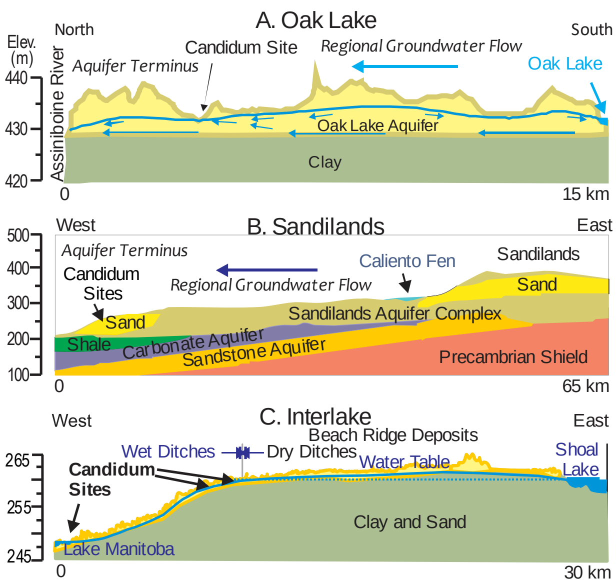

Figure 3. Geological Sections through Cypripedium *candidum* sites in A. Oak Lake (Western Manitoba); B. Sandilands; C. Interlake.

Cross section A is the Oak Lake aquifer between Oak Lake and the Assiniboine River valley, which is the outlet terminus of the aquifer. Regional flow is toward the Assiniboine valley and the local Cypripedium *candidum* population is located near the terminus of the aquifer in topographic low where active discharge is occurring.

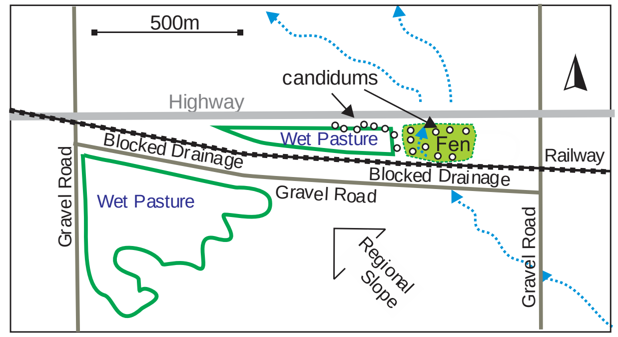

Figure 4. Cypripedium *candidum* locations relative to shallow drainage features on the Oak Lake Aquifer.

Orchids are generally absent in the Oak lake area in the central part of the aquifer, which is a complex of marsh lands, but are abundant near the terminus. Figure 4 is a plan view of the Oak Lake aquifer candidum population relative to groundwater seepage downslope of impounded poorly defined drainage.

The middle west-east cross section B is through the Sandilands aquifer complex. Regional groundwater flow discharges at the base of the main Sandilands upland as large areas of fens, notably the Caliento fen. The Cypripedium *candidum* populations are found near the western margin of the aquifer complex, where it pinches out against Red River valley clay. Cypripedium *candidum* grow in fens and wet prairie between beach ridges in this regional discharge zone. Orchids are generally absent farther west in the Red River valley. Figure 5 is a plan view of a monitored Sandilands candidum population, relative to impounded drainage and groundwater discharge features, including wetlands, a flowing well and seasonal quick ground (frost boils).

The bottom cross section C is of the Interlake area of Manitoba, depicting the topographic divide between the Shoal Lakes basin and Lake Manitoba. The Cypripedium *candidum* sites are found in beach ridge areas, notably at the elevation where the regional water table intercepts the land surface, defined by where baseflow begins in roadside ditches. Within the Shoal Lakes Basin, this point occurs at the level of the Shoal Lakes. While a variety of orchids are abundant at lower levels on the west side of the divide, they are scarce within the Shoal Lakes basin, and there are no known *candidum* populations east of the divide.

3.4 Site Monitoring

Three candidum populations near Winnipeg were selected for monitoring: one in the Sandilands, one in the Interlake and one in the west. All sites were in roadside ditches, which provided accessible as well as comparable and controlled settings. At each site, the location of each orchid plant was recorded using a hand-held GPS. Three species of orchids and one hybrid grew at the sites in varying numbers: Cypripedium *candidum*, Cypripedium *parviflorum*, the hybrid: Cypripedium *andrewsii* and Platanthera *aquilonis*.

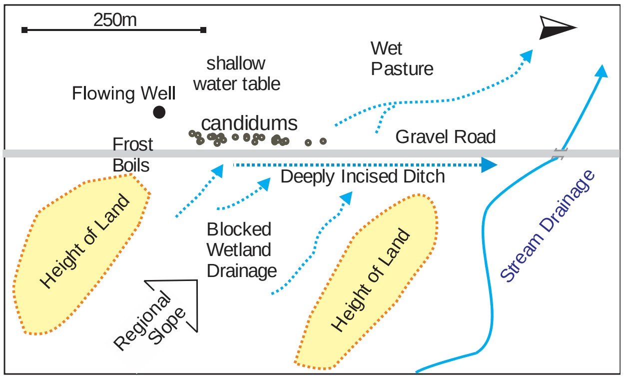

Figure 5. Locations of Cypripedium *candidum* at the Sandilands site, relative to shallow flow.

The Sandilands site was monitored from 2013 to 2016, the Interlake site from 2014-2016 and the western site from 2015-2016. Monitoring at each site consisted four or six two-inch pvc piezometers per site. The piezometers were completed at depths of 1 to 2 metres with the bottom 30 cm screened with 0.010 machine-slotted casing. Piezometers were positioned along the length of the ditches where *candidums* grew and where they did not.

The piezometers were installed using a soil auger and the geology of each hole was logged. The substrate was found to be silts and fine sands interspersed with gravel at the Interlake, sand and clay layers in the west and fractured sandy till in the Sandilands. Carbonate precipitation in the form of fine granules and occasional nodules was observed at all three locations. Reduced iron was observed lining the fractures at the Sandilands site.

Spot readings for water levels and conductivity were taken using an electric sounder at three to four-week intervals during the frost-free season from May to October. Water samples were collected from selected wells and analysed for major ions and trace metals.

The survey of the positioning of the orchids showed that the orchids were not randomly intermingled. Individual species would "stake out" preferred positions in the ditch. At the Interlake site, Cypripedium candidum formed groupings at the low end of the embankment, which were surrounded by a halo of the hybrid *andrewsii*, which were surrounded by Cypripedium *parviflorum*. Platanthera *aquilonis* was found near the *candidum*, but was off to one side, positioning itself lower on the embankment. This relative positioning was interpreted to indicate a subsurface condition, relating to moisture and/or soil chemistry, which favoured one species over another. At the surface, the *candidum* were located in areas where most other vegetation, particularly grasses struggled to grow. Cypripedium parviflorum was the least particular and had the broadest distribution along the ditch (Figure 6).

Monitoring showed a seasonal trend in shallow groundwater levels, which peaked in May and June and declined over the summer. While actual levels varied depending on the year, *candidum* thrived in areas where the average early-season water table was less than 0.2m from surface, dipping to 0.6m in late summer. In contrast, Cypripedium *parviflorum* favoured sites where the average water table averaged 1.0 m during the active growing season, dipping to 1.7 m in late summer. (Figure 7). Water availability is most critical during the active growing season, becoming less importing in late summer and fall as the plant ripens and enters dormancy. As a general observation, Cypripedium orchids in Manitoba have "good years" and "bad years". Peak years, signified by robust plants and numerous blooming stems involved good moisture levels during the previous and current active growing seasons, while the worst years involved poor moisture conditions during the previous and current season.

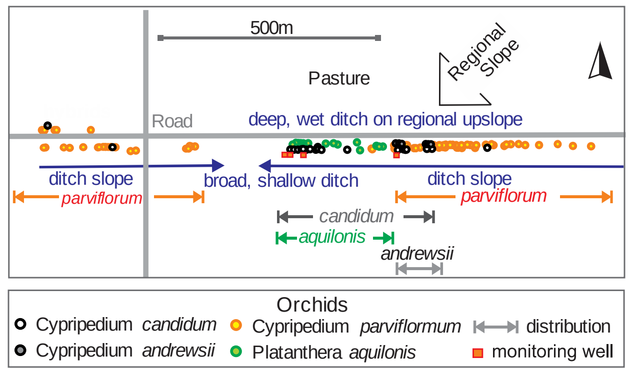

Figure 6. Hydrology and distribution of orchid species at a site in the Interlake region of Manitoba.

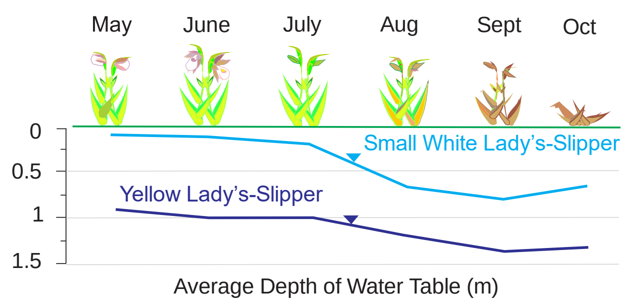

Figure 7. Seasonal change in average water table depth based on Sandilands and Interlake sites.

4 ORCHID HABITAT AND GROUNDWATER FLOW

Sites visited exhibited hydrological and hydrogeological conditions that fell into three general categories:

1. Road impoundments
2. Ridge and swale
3. Contact springs

4.1 Road Impoundments

Southern Manitoba, which is mainly agricultural, is surveyed into a network of "grid roads", which are roads or road allowances spaced one mile apart in the north-south and east-west directions, with drainage ditches on either side. This type of development has profoundly disrupted natural shallow drainage on the prairies.

In flat terrain, both ditches will drain and the tendency is for generally lowered water tables in naturally wet areas. On sloping lands, where roads are parallel to slope, ditches will flow freely. Roads perpendicular or oblique to slope form a barrier to natural drainage. Along these roads, upslope ditches will intercept surface and shallow subsurface drainage. To compensate for this, upslope ditches are often constructed or dredged deeper, out of necessity, to accommodate the water and to facilitate drainage. The impounded water must either drain laterally to natural slope via the ditch or flow under the road in line with slope via groundwater. Upslope ditches typically have ponded or sluggish flow and commonly contain stands of wetland vegetation in the form of cattails (Typha *sp*.).

Downslope ditches have a smaller capture area and tend to be drier, though they may periodically contain standing water. Generally neglected by drainage officials, these ditches often have broader sides, contain established grassy vegetation dotted with herbs. Both sides will tend to have phreatophyte vegetation, particularly willows, provided they are not kept mowed. (Figures 4,5,6)

Cypripedium *candidum* and often companion species of orchid, mainly Cypripedium *parviflorum* and Platanthera *aquilonis* will be found on the downslope ditch, but not on the upslope ditch (Figure 6). Orchids typically position themselves in a central position on the bank between the top and bottom of slope. Figure 8 shows the effect of the road barrier on shallow groundwater flow, typical of many orchid locations.

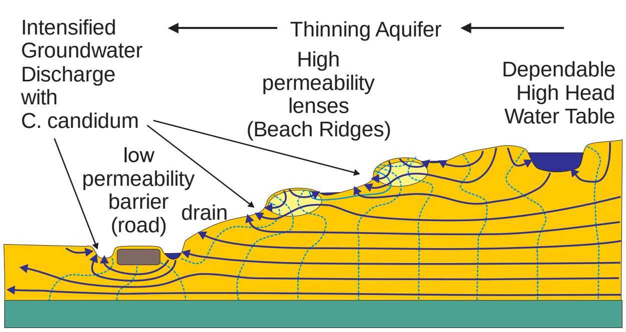

Figure 8. Hypothesized flow regime cross section for beach ridge and road barriers at *candidum* sites.

4.2 Ridge and Swale

Beach ridges that developed along the shoreline of glacial Lake Agassiz left behind a series of ridges and swales across the landscape, which are characteristically perpendicular to regional drainage. Consequently, they tend to form barrier to flow, and water retention on the upslope side. Because of they are sufficiently coarse-grained they will allow seepage through, which is discharged on the downslope side, with sufficient slope or driving force for flow. When resting on a less permeable layer, the lens shape of the beach ridges in cross section, cause distortions to the groundwater flow field which result in areas of concentrated discharge on the downslope side (Toth and Rakhit, 1988). (Figure 8)

Often this type of situation is accentuated by being imprinted on the discharge end of a larger scale groundwater discharge area, as evidenced by steady flow in drains, and expanses of wetland.

In nature, this is a typical natural habitat not only for Cypripedium *candidum*, but also for the endanger Platanthera *praeclara*, which are found growing in the swales between beach ridges (Gerla, et al, 2015). Sites in the Interlake and in the Sandilands in Manitoba characteristically have this type of habitat.

4.3 Contact Springs

Cypripedium candidum populations associated with contact springs are typical of the Brandon Hills area (Figure 9). The upland areas of the Brandon Hills are eroded remnants of the Spiritwood Buried valley deposits, which consist of mixed glacial and glaciofluvial deposits resting on clay (Toop, 2013). Near Brandon, three Cypripedium candidum populations are found in ditches, grassy swales, and broad, shallow fen type drainages surrounding a single hill (Figure 8). Fen areas are characteristically hummocky with mounds and holes on a scale of about 30 cm or less. These drainages may be simply moist swales or may have a sluggish central stream, with nearby contact springs and quick ground.

A common assumption for one site near Brandon has been that the orchids are associated with the stream hydrology. Less obvious is that the two sides of the stream are quite different. One side has no orchids whatsoever, while on the other side, orchids proliferate. The stream-side where the orchids proliferate is the base of the hill, and the orchids are positioned above the stream and a below a line of seepage springs situated in a pasture. At this site the fen is protected, but the springs and the source area for the springs is not. Should the source area succumb to proposed urban expansion, the protected area is unlikely to survive as orchid habitat.

Similarly, sites in Brandon Hills also appear to be associated with sluggish surface drainage, but on closer inspection they are also located beneath regions of springs or seeps.

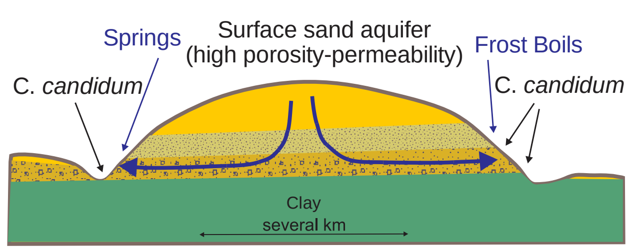

Figure 9. Hypothesized flow regime cross section for contact springs at *candidum* sites near Brandon.

5 GROUNDWATER CHEMISTRY

Water samples were collected from the Interlake and Sandilands monitoring sites. The water was generally Ca-

Mg-HCO_3 type water with total dissolved solids in a range of 275 to 725 mg/L, averaging 405 mg/L and very low sulphate and chloride. The pH range fell between 7.5 and 8.5, averaging 8.0. Measured alkalinity was in the range of 300 to 600 mg/L averaging 400 mg/L, while hardness was in the range of 270 to 670 mg/L, averaging 400 mg/L. Calcium carbonate precipitation had been observed within the soil zone in as granules and nodules.

One effect of the high pH and calcium-magnesium content is its effect on the availability of plant nutrients. Ideal soil pH is neutral, in the range of about 6.5 to 7.5. This is the optimal range for plant root growth. Most nutrients are readily accessible to plants within this range (Truog, 1946).

The greatest effect of high pH on nutrient availability is on the trace nutrients of manganese (Mn), iron (Fe), copper (Cu), Zinc (Zn) and Boron (Bo). These nutrients do not disappear from the system but are bound in various ways in the soil that make them inaccessible to plants. This may include adsorption onto clays and organic matter, or conversion to insoluble mineral forms (Truog, 1946; Appelo and Postma, 2005).

Major nutrients are also affected. Nitrogen is somewhat affected in terms of available forms. Phosphorus (P) or its form as phosphate (PO_4^{3-}) is the most affected major nutrient. Only inorganic P is available to plants. At pH from 2.5 to 7.3, $H_2PO_4^-$ is the main phosphate species, but above pH 7.3 HPO_4^{2-} dominates. This readily combines with calcium and magnesium and at higher pH forms increasingly insoluble minerals, such as apatite.

The high pH and consequent inaccessibility of plant nutrients, notably P likely accounts for the sparse vegetation, particularly for grasses at many *candidum* sites. The ability to take up nutrients at higher pH depends on the plant species. Most grasses, the main competitor to prairie orchids, will show declining vigour at pH higher than 7.5.

Orchids have a root association with mycorrhizal fungi, which is essential to their establishment and growth. The plants provide sugars to the fungi, while the fungi increase the ability of plants to access scarce or immobile nutrients, particularly phosphate. Phosphate, being relatively immobile is quickly depleted in the immediate root zone (Tinker and Nye, 2000). Roots are able to take up nutrients within a few millimetres of the root, but mycorrhizal fungi can expand this range to 15 cm and will transport the nutrient to the root interface (Smith and Read, 1997; Smith et al, 2003).

The orchid's root association with mycorrhizal fungi allows them to establish populations at sites unsuited to most other plants. This is of great importance to success, given Cypripedium *candidum*'s poor ability to survive direct competition.

6 DISCUSSION

Rather than occurring randomly, populations of Cypripedium orchids in southern Manitoba are organized in a predictable way, at multiple scales, through the influences of hydrogeology. On a regional scale the orchids show a clear preference for downslope discharge margins of major surficial sand aquifers, particularly in the presence of sufficient topography to drive regional groundwater flow. The association of the orchids with unconfined aquifer discharge, explains the otherwise puzzling regional distribution of the plants in southern Manitoba.

On an intermediate scale, on relatively undisturbed lands, suitable habitat was associated with gravel pits, flowing wells, springs, frost boils, wetlands and retention of water behind linear barriers. These were found in the context of local topography, ridges and swales or broad ditches.

At the local scale, suitable habitat might be recognized by observing suppressed vegetation and microtopography often in the order of about 30 cm occurring as sloping ditch embankments or as hummocks and hollows in fens. Calcium carbonate precipitation was also evident, indicating active discharge of carbonate-rich groundwater. The effect of groundwater discharge and the chemical processes taking place in the soil zone are likely important to the orchids and need to be better understood.

The hierarchy of scale also suggests that the nesting of flow systems may be of significance to orchid habitat, with overprinting of discharge occurring at regional, intermediate and local scales. Because of the habitat dependence on the larger landscape, protecting orchid growing sites alone is insufficient. The larger groundwater contribution area must also be considered in conservation strategies.

It is probable that ideal habitats for Cypripedium *candidum* are rare in nature. The species favours reliably moist groundwater-fed locations where other plants struggle to survive due to nutrient deficiencies. Fortunately, the land survey system in Manitoba has provided anthropogenic habitat. The zonation of species at individual sites shows that Cypripedium *candidum*, in its pure form can survive where *parviflorum* and *andrewsii* cannot, thus protecting the pure species from genetic mixing. It is probable that the plant could grow outside of these severe habitats, provided that competition is kept at bay. Certainly, the plant has been grown successfully under controlled conditions by orchid enthusiasts.

The general habitat preferences of Cypripedium *candidum* are shared with other orchid species. Platanthera *praeclara* an endangered species also colonizes ditches and was observed growing on the discharge side of a road-impoundment on the Tall Grass Prairie Preserve. Similar conservation principles may apply to more than one species.

Understanding hydrogeological characteristics of Cypripedium *candidum* habitat, may be applied to conservation efforts. This knowledge may be used to predict locations of currently undiscovered populations of the orchid. We may possibly identify suitable healthy habitat for plant colonisation, where populations currently do not exist but could. These sites become valuable during plant "rescue" efforts, when plants threatened by habitat destruction need to be relocated.

Degraded sites may be identified and rehabilitated. Cypripedium candidum was reported growing in

Saskatchewan in the 19th century and is considered extirpated in that province. The general location where it was noted has been degraded by heavy grazing. By identifying favourable sites for habitat rehabilitation, it may be possible that the orchid may be reintroduced and once again grace that province.

Finally, it may be possible to engineer orchid habitat. Most Cypripedium candidum populations in Manitoba are at least partially located in roadside ditches. These are locally anthropogenic in origin, though set within the broader natural system. It is important to recognise their function in controlling the local hydrogeology of adjacent orchid populations. In recent years, watershed managers, particularly in the Sandilands area, have build water retention structures to mitigate flooding. With sufficient understanding, it may one day be possible to incorporate orchid habitat into new engineering works.

7 REFERENCES

Ames, D.E., Bainard Acheson, P., Heshka, L., Joyce, R., Neufeld, J., Reeves, R., Reimer, E., Toop, D., and I. Ward. 2016. *Orchids of Manitoba: a Field Guide*, *Second Edition*. Native Orchid Conservation Inc. Winnipeg. 181pp.

Appelo, C.A.J. & Postma, D. 2005. *Geochemistry, Groundwater and Pollution, 2nd Edition*. CRC Press

Betcher, R., Grove, G. and C. Pupp. 1995. Groundwater in Manitoba: Hydrogeology, Quality Concerns, Management. NHRI Contribution No. CS-93017.

Brownell, V.R. 1981. COSEWIC status report on the small white Lady's-slipper Cypripedium candidum in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 63 pp. COSEWIC. 2010.

COSEWIC. 1999. Update: COSEWIC status report on the Small White Lady's-slipper Cypripedium candidum in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 20 pp.

Curtis, J.T. 1943. Germination and seedling development in five species of Cypripedium L. *American Journal of Botany* 30:199-206.

Curtis, J.T. 1946. Use of Mowing in Management of White Ladyslipper. *Journal of Wildlife Management* 10(4): 303-308.

Environment Canada. 2014. Recovery Strategy for the Small White Lady's-slipper (Cypripedium candidum) in Canada [Proposed]. Species at Risk Act Recovery Strategy Series. Environment Canada, Ottawa. 30 pp.

FNA (Flora of North America Editorial Committee). 2002. Flora of North America north of Mexico. Vol. 26. *Magnoliophyta: Liliidae: Liliales and Orchidales*. Oxford Univ. Press, New York. 723 pp.

Foster, C. and C. Hamel. 2006. Rare Species Surveys of the Manitoba Conservation Data Centre, 2005. MS Report 06-01. Manitoba Conservation Data Centre, Winnipeg, Manitoba. 43 pp.

Gerla, P., A. Aldous, L. Bach, C. Carlson, J. Gurrieri, E. Hoff, R. Johnson. 2015. Environmental Flows and Levels for Groundwater-Dependent Swale Wetlands of the Sheyenne National Grasslands, North Dakota. The Nature Conservancy and the USDA Forest Service. Portland, Oregon.

Imrie, A.L., R. Clavering, and C.L. Brodar. 2005. Small White Lady's-slipper: Impacts of Fen Succession. Ontario Parks, Southeastern Zone, Ministry of Natural Resources, Kingston.

MB CDC (Manitoba Conservation Data Centre). 2010. Manitoba CDC Element Occurrence Database. Wildlife and Ecosystem Protection Branch, Manitoba Conservation, Winnipeg, Manitoba.

Smith, W.R. 2012. *Native Orchids of Minnesota*. University of Minnesota Press. Minneapolis. 254pp.

Smith S.E., Smith F.A. and I. Jakobsen 2003. Mycorrhizal Fungi Can Dominate Phosphate Supply to Plants Irrespective of Growth Responses. *Plant Physiology* 133: 16-20.

Smith S.E. and D.J. Read 1997. *Mycorrhizal Symbiosis*. Academic Press, Cambridge

Teller, J.T and M. Fenton. 1980. Late Wisconsinan glacial stratigraphy and history of southeastern Manitoba. *Canadian Journal of Earth Sciences*, 1980, 17(1): 19-35

Tinker P.B. and Nye P.H. 2000. *Solute Movement in the Rhizosphere*. Oxford University Press, New York

Toop, D.C. 2013. Unconventional origins of the Spiritwood Buried Valley aquifer in Manitoba. *GAC-MAC Winnipeg 2013*. May 20-24, 2013. Winnipeg, Manitoba. Program with abstracts. Vol 36: 188.

Toth, J. and K. Rakhit, 1988. Exploration for reservoir quality rock bodies by mapping and simulation of potentiometric surface anomalies. *Canadian Society of Petroleum Geologists Bulletin*. 36, (4): 362-378.

Truog E (1946) Soil reaction influence on availability of plant nutrients. *Soil Science Society of America Proceedings* 11: 305-308

Worley, A.C., L. Sawich, H. Ghazvini, and B. A. Ford. 2009. Hybridization and introgression between a rare and a common Lady's slipper orchid, Cypripedium candidum and C. parviflorum (Orchidaceae). *Botany* 87: 1054-1065.

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