Optimising Ecohydrological Protocols to Enhance Calcareous Wetland Rehabilitation in Abandoned Quarries

CIRCULATION PAPER

Prepared for The Ontario Aggregate Resources Corporation

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PREAMBLE

The aggregate extraction industry of Ontario faces numerous challenges once the extraction phase of a quarry operation has ceased. Societal and ecological concerns point towards a site restoration to a natural state as a preferred alternative to outright site abandonment. The objective of this research was to understand the ecohydrological conditions required for the establishment of a wetland type that will readily establish in shallow quarries and along deep quarry shorelines dominated by groundwater seepage: the calcareous fen. Over a three-year period (2005-2007) we evaluated the most cost-effective and efficient trajectory toward this restoration target.

BIODIVERSITY ENHANCEMENT THROUGH CALCAREOUS FEN CREATION

Calcareous fens are wetlands fed principally by groundwater rich in calcium and magnesium carbonate. These ecosystems exhibit very high species diversity, and serve as regional refugia for a number of rare plant taxa. Historically, calcareous fens have been subject to significant loss and degradation throughout North America and Europe due to groundwater extraction and/or diversion as well as nutrient enrichment from encroaching agricultural land use and atmospheric deposition. Because of their high biodiversity value these wetlands are now frequently targeted for protection and conservation. Additionally, the restoration of degraded calcareous fens is the focus of much research. Recent research has demonstrated the possibility of calcareous fen creation on sites without evidence of former fen presence; that is, the creation of calcareous fens on mineral substrate. This circulation paper follows on this concept by investigating the feasibility of creating a calcareous fen in a novel landscape setting: an abandoned dolomite quarry floor.

Many of Ontario's quarries are abandoned post-extraction because of groundwater seepage. While the presence of emerging groundwater makes wetland ecosystems logical rehabilitation targets, past restoration efforts have been largely ad hoc, with little scientific foundation. The lack of knowledge regarding appropriate water depth, substrate characteristics, and vegetation type, combined with limited resources has often led to the creation of open water/marsh-type ecosystems that have limited biodiversity and habitat value Where present, the calcium carbonate-rich groundwater seepages found in some quarries provide the perfect opportunity to investigate the calcareous fen wetland type as a low-cost, self-sustaining ecosystem that is more appropriate for the location, and a valuable societal and natural refuge.

SUITABLE POST-EXTRACTION SITES FOR CALCAREOUS FEN CREATION

Calcareous fens are ecosystems that have a relatively stable hydroperiod (seasonal extent of water table fluctuation). Standing water of 50 cm and water table drawdown below the ground surface represent extreme measures, and these events should be considered uncommon and short-lived. Thus, not all post-extraction quarry sites are amenable to this rehabilitation target. Ideal quarry sites will have relatively shallow standing water (< 2 m depth), with continued groundwater inputs to meet the added water and mineral demand of fen plant introduction. Sites where the extraction phase resulted in significantly deeper water levels should not be considered feasible for fen conversion. As a corollary, if the quarry walls are gently sloping it should be possible to create a fringing fen ecosystem surrounding the deeper central pool. Successful rehabilitation of post-extraction quarries to calcareous fens will only occur in regions with suitable calcareous bedrock, facilitating the appreciable calcium and magnesium carbonate levels in the emerging groundwater. Thus, sites situated on the Canadian Shield should definitely not be targeted for rehabilitation to calcareous fens. Additionally, there are areas in Ontario with sedimentary sandstone surficial bedrock, and quarries operating in these localities are not ideal candidates for calcareous fen creation. Lack of nearby natural calcareous fens should generally not be considered a sign of the unsuitability of a quarry for calcareous fen creation, as this may be due to a number of factors, including land-use alterations (farming, draining, urbanization) and the water table residing too deep in the natural landscape to support wetland development.

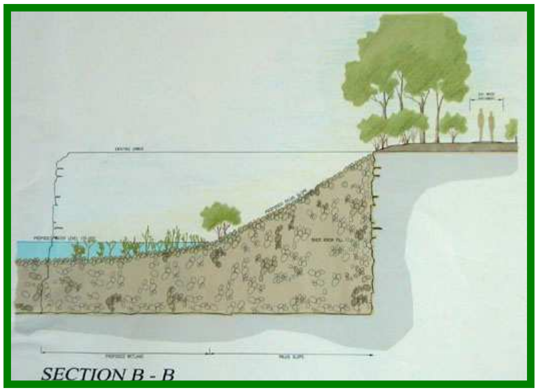
A PRELIMINARY ASSESSMENT OF THE FEASIBILITY OF CALCAREOUS FEN CREATION

Research was conducted at the Fletcher Creek Quarry and surrounding natural calcareous fens from 2005 to 2007. The Fletcher Creek Ecological Preserve is a 197 ha natural area in Puslinch Township owned by the Hamilton Conservation Authority (HCA). A large portion of the property is designated as a Provincially-significant Wetland, as well as an Environmentally Sensitive Area (ESA) in Wellington County. It contains a number of rare and unusual botanical species and serves an important role as a headwater source protection area. The quarry was ~3.5 ha in size with an irregular below-water extraction of ~ 0.8 ha that was between 4 and 6 meters in depth. The extraction operation was abandoned abruptly in the early 1930’s and no attempt was made to rehabilitate the site. Cliff faces up to 6 meters in height occurred around most of the site. The Fletcher Creek Quarry was rehabilitated in 2004 and early 2005 in three phases and provided an ideal opportunity to determine the optimal ecohydrological protocols for rehabilitation.

REHABILITATION OF QUARRY

Phase One

Phase one centered on removing and stock-piling topsoil, lowering the quarry walls, moving and shaping rock and upgrading the service road. The sidewalls were lowered using a hoe ram and backhoe, and trucks moved the shot rock to create the shape of a wetland.



Cross section diagram illustrating the before and after cliff wall rehabilitation.

Phase Two

In Phase two, the HCA, through the support of The Ontario Aggregate Resources Corporation (TOARC), completed the wetland rehabilitation by stabilizing the site and vegetation, replacing the overburden and topsoil that was stock-piled near the quarry, restoring the site with shrub and tree-plantings using plant material onsite and finishing the detailed wetland edge construction and building a wetland boardwalk to provide access for monitoring and scientific research.

Fletcher Creek quarry prior to site rehabilitation.

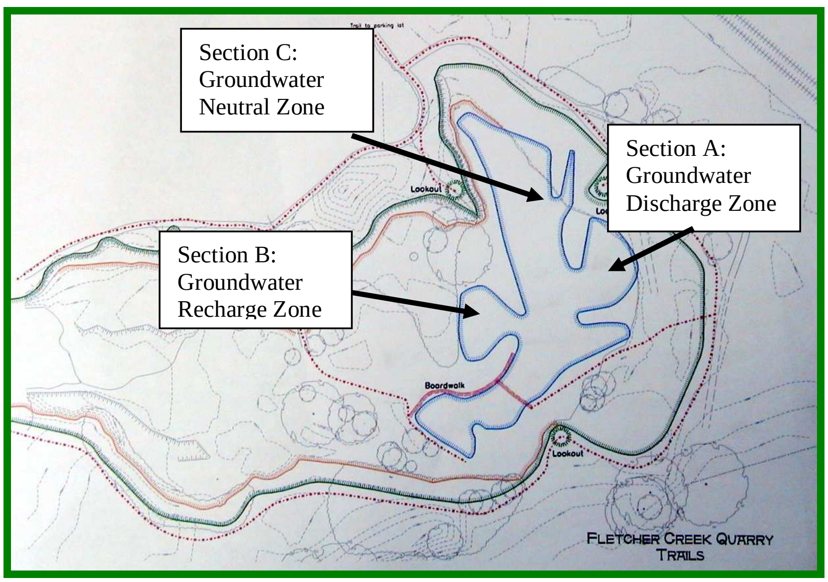
Fletcher Creek quarry after site rehabilitation.

Phase Three

Phase three concentrates on the provision of passive recreation and interpretive facilities to encourage uses such as nature walks, horse-back riding, photography, bird-watching, winter activities, etc.

Fletcher Creek Preserve Quarry Wetland (June, 2004)

During the rehabilitation three research areas were constructed: Section A: Groundwater discharge zone; Section B: Groundwater recharge zone; Section C: Groundwater neutral zones.



Quarry rehabilitation site indicating the three sections of experimentation.

FEN VEGETATION GROWTH ON THE QUARRY FLOOR

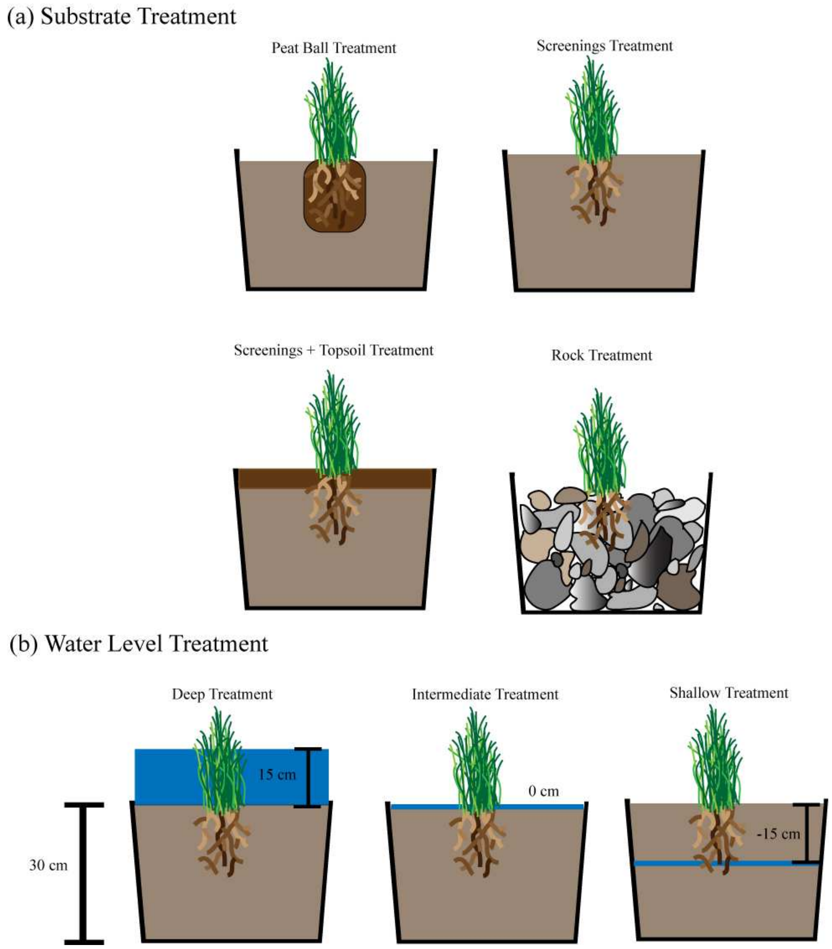
Phase One

In order to assess the optimum medium and water growing conditions of calcareous fen species a transplant experiment was initiated in May 2005 to assess species growth in a variety of substrate-water depth combinations. For this experiment, Section C of the quarry was used for its easy access, sloping ground surface, and its locality as neither a groundwater discharge nor recharge zone. Transplant material was excavated from the natural reference site to a depth of 30 cm and sub-sectioned at the quarry into 10-cm diameter plugs for transplant. As water sedge was the dominant vascular species in the portion of the natural site under study at that time an effort was made to select sections of the fen for removal that contained > 75 % water sedge. Where possible, further discrimination was made in the preparation of the small transplant plugs; that is, easily removable non-water sedge vegetation was separated from the plugs. Plugs were placed in 30 X 30 X 30 cm plastic garden bins with associated potting material.

The study design tested for the effects on plant survival and growth of two general parameters: 'substrate' and 'water depth'. Four substrate treatments were tested in the experiment, spanning a range of cost-alternatives to quarry rehabilitation. The first treatment consisted of inserting the intact plant-peat plug (Peat Ball Treatment) into stabilizing crushed limestone (screenings or fines). This represents the most expensive treatment option, as it requires procurement of a natural stock of plant-peat material from a calcareous fen in proximity to the rehabilitation project, with associated additional labour for extraction. It also destroys the integrity of the natural fen. On the other hand, this treatment was hypothesized to yield the greatest increase in biomass, as there is minimal disruption of the transplanted material.

The three remaining treatments each consisted of first washing-off the associated peat material from the roots of the plant plug to be inserted. The second treatment involved digging a little opening in a container filled with screenings, placing the plant roots in this cavity, and patting screenings around the plants for stabilization (Screenings Treatment). The third treatment followed this procedure, but also added a shallow, ~ 3 cm layer of topsoil on top of the screenings (Screenings + Topsoil Treatment). These two treatments provided an easy test of the effect of nutrient supply on plant growth: the screenings-only treatment representing little nutrient addition, the screenings + topsoil treatment representing abundant nutrient addition. Plant roots were placed in containers filled with coarse cobbles (random arrangement and size) for the fourth substrate treatment (Rock Treatment). This treatment represents the least costly implementation protocol with little physical manipulation of the rehabilitation site needed.

The effect of water level on aboveground biomass was tested through three depth treatments. Working with the natural slope of Section C of the quarry, transplant bins were arranged such that springtime water level was at 15 cm below ground level (Shallow Treatment), at the ground surface (Intermediate Treatment), and 15 cm above ground level (Deep Treatment). As the bins were 30 cm deep the first water level treatment consisted of half its potential rooting depth at the beginning of the growing season being unsaturated and aerobic. The intermediary water level treatment started its growing season with plant roots completely inundated, while the deep-water treatment was also subject to the lower portions of the aboveground biomass being inundated as well. The slope of the ground was modified so that within each treatment there was < 1.5 cm deviation from the above depths between replicates. The number of stems and inflorescences (flowers) were recorded in each of three year's of growth, and a final harvesting and weighing was performed in 2007 to compare aboveground biomass.



Phase Two

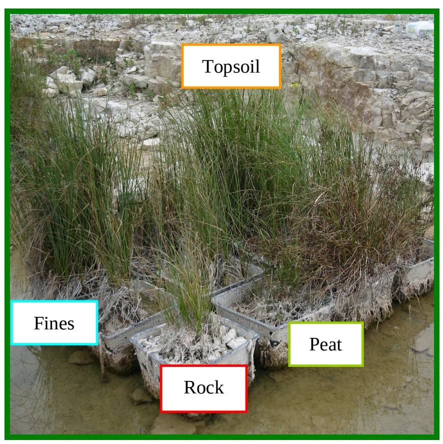
In early May 2006 another quarry transplant experiment was initiated. The goal of this portion of the project was to apply the preliminary information gathered from the mesocosm experiment to long-term site rehabilitation. That is, this experiment was not designed for harvesting the accumulated biomass, but rather was the first step at turning the Fletcher Creek Ecological Preserve Quarry into an open pool with a fringing calcareous fen ecosystem. The first two years' data can be found in the full version of this document.

NATURAL CALCAREOUS FEN SPECIES DIVERSITY

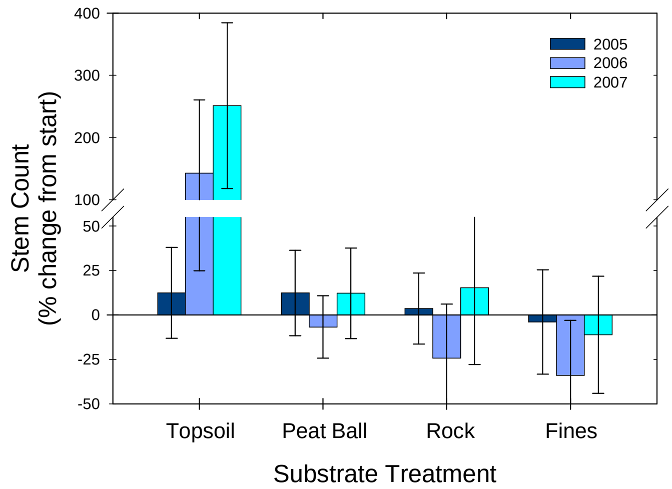
In order to determine the range of hydrologic conditions in which calcareous fen communities thrive an intensive monitoring effort was conducted at three natural reference calcareous fens. The foci of this monitoring campaign were to determine the hydrologic variability of the sites and how that variability contributes to vascular vegetation species diversity. The former objective aims at documenting the environmental settings capable of supporting calcareous fen communities; thereby identifying the breadth of conditions capable of potentially supporting a calcareous wetland community in an abandoned quarry. The latter objective seeks to determine the role those differing hydrological conditions on the species composition of calcareous fens. This portion of the research project generated a set of species most likely to succeed in a quarry rehabilitation project given that site's hydrologic variability. This list is provided at the end of this circulation paper. Full details on the species diversity at the natural calcareous fens and their hydrologic controls can be found in the full version of this report.

RESULTS OF PHASE ONE OF THE GROWTH EXPERIMENT

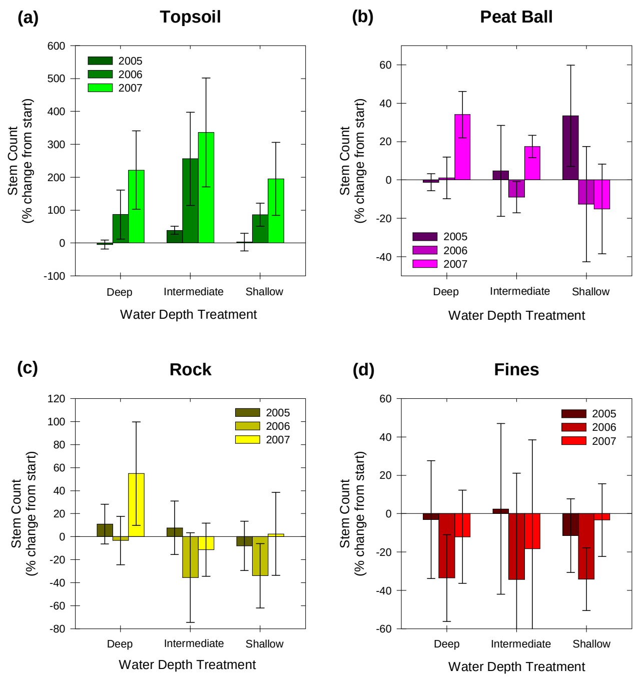
Many important findings on the growth of water sedge in abandoned quarries resulted from this research. The following represents the key results as they directly relate to the quarry rehabilitation process:



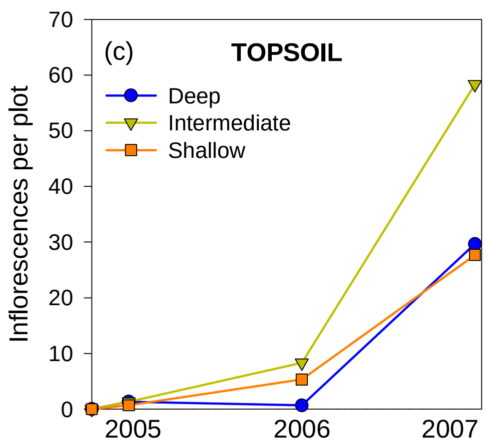
- Regardless of water depth treatment, water sedge growth, in terms of number of viable stems, was significantly greater when a thin layer of topsoil was added. At the end of three year's growth, water sedge stems in the topsoil treatments on average tripled in number. All other treatments did not experience a significant increase or decrease at the end of the experiment, though all replicates contained lush vegetation at the end of the experiment.

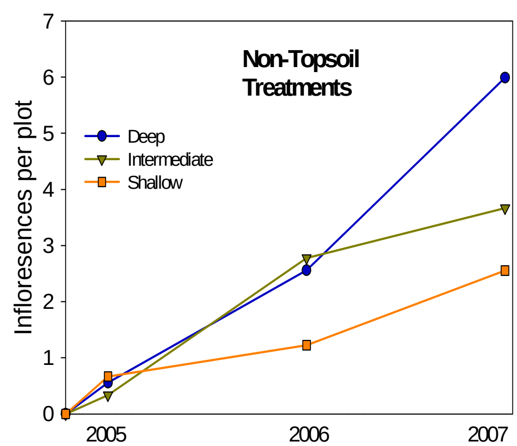


- Planting directly in the screenings material without topsoil proved to have the greatest negative impact on sedge growth, regardless of water depth.
- Planting in a springtime water level 15 cm below the ground (Shallow Treatment) was the poorest choice for water sedge stem growth, regardless of substrate type.
- The rock and peat-ball treatments experienced significant new stem growth in the last year of the experiment when planted with 15 cm of standing water in the springtime (Deep Treatment).

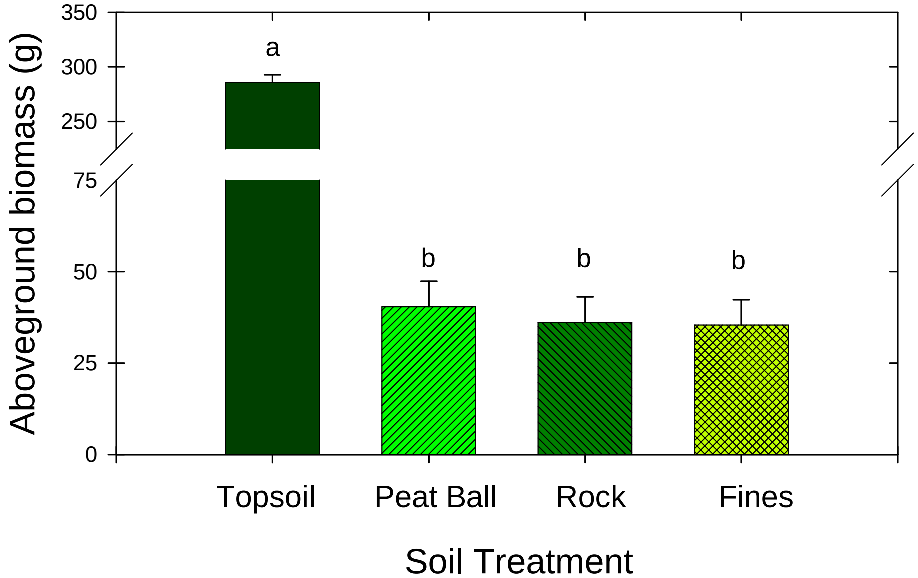


- The addition of nutrients, through topsoil application, significantly increased the number of inflorescences (flowers), regardless of water depth.
- The topsoil-amended treatments planted in the intermediate water levels yielded more flowers than the deep or shallow treatments, whereas in the other substrate treatments the number of flowers increased with increasing wetness.

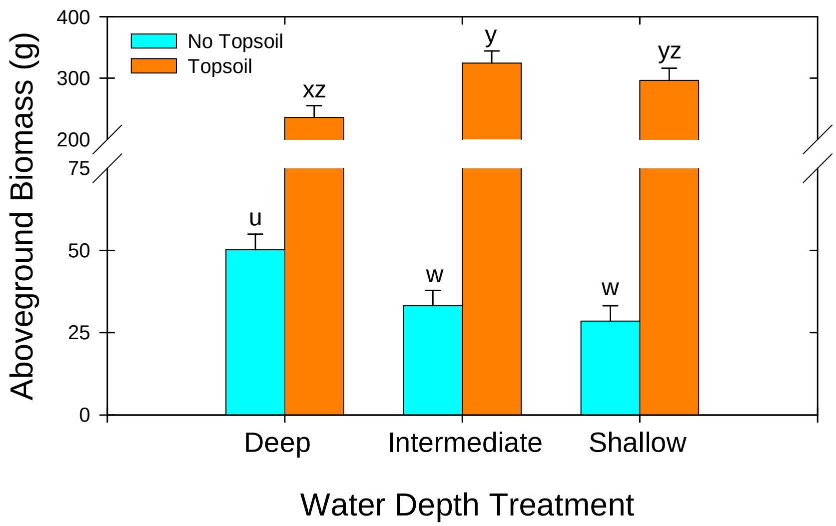




- The addition of a thin layer of topsoil increased aboveground biomass by 600 % relative to the other substrate treatments, regardless of water depth.



- When no topsoil was added, aboveground biomass increased with increasing wetness.
- When topsoil was added, aboveground biomass was greatest in the intermediate water level treatment.



- Field researchers observed fish eating portions of submerged sedge vegetation on more than one occasion in the qroundwater recharge zone. Fish were not observed eating the vegetation in areas of the rehabilitated quarry that were coated in organic matter (topsoil), particularly the groundwater discharge zone. It is hypothesized that the organic material precluded the possibility of fish spawning, drastically reducing their numbers, and thereby minimizing plant damage.

PROTOCOLS FOR CALCAREOUS FEN CREATION

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The following are recommendations derived from this research project and represent good first steps in enhancing the success of establishing fen species in quarry rehabilitation projects:

Preparing the site: (the planting medium)

- The quarry floor should be covered with a layer of cobble sized stone (or a size appropriate for the physical support of the plant stems) and material described as fine gravel or screenings should not be utilized. This layer of coarse aggregate should at a minimum be approximately 20 cm in depth.
- It is recommended that a small amount of topsoil (or other nutrient rich organic matter) be added to the surface of the coarse aggregate base for planting. The addition of topsoil led to significantly more stems, more flowers (infloresences) and more overall biomass than without the addition, often by a full order of magnitude.

Planting Conditions:

- Sites with at least 15 cm of standing water above the coarse aggregate on the quarry floor (at the beginning of the growing season) should be targeted. Sites having 30 cm of standing water are optimal providing the water level drops to the level of the quarry floor by the end of July.
- The quarry floor should be saturated for a minimum of 8 weeks at the start of the growing season.
- The water table should not drop more than 50 cm below the quarry floor by the end of the growing season.
- Maintaining standing water and/or a shallow water table enhances the de-gassing of CO_2 which facilitates calcium carbonate precipitation, a key component of calcareous fen sediment.
- Sites that are subject to early season water table drawdown are highly susceptible to invasive species such as buckthorn, common reed grass (*Phragmites australis*) and reed canary grass.
- Sites with standing water in excess of 40 cm for a majority of the growing season are highly susceptible to calcareous fen species mortality and may be subject to encroachment of cattails.
- Sites may benefit if fish can be excluded until plants are well established.

When to plant:

- For optimal growth in the first year it is recommended that planting fen vegetation be delayed until the water level drops to (or close to) approaches the surface of the coarse material applied above the quarry floor.
- Planting at this time (mid-July) reduces the anoxic-induced stress placed on the fen vegetation, ensuring maximal resource allocation to root and stem tissue

What to plant:

- Primary species for rehabilitation should include water sedge, tussock sedge, and yellow sedge.
- Secondary species for rehabilitation should include red-stemmed spikerush, beakrushes, tufted clubrush, wire and candle-lantern sedge.
- Plant material should not be harvested from natural fens as to preserve their ecological integrity. Planting material should be acquired from native plant nurseries that specialize in the collection, propagation and sale of locally appropriate species.

Recommended species for inclusion in quarry rehabilitation projects

	Latin Name	Common Name
Sedges		
	Carex aquatilis	Water Sedge
	Carex flava	Yellow Sedge
	Carex livida	Livid Sedge
	Carex stricta	Tussock Sedge
	Eleocharis erythropoda	Red-stemmed Spikerush
	Rhynchospora alba	White Beakrush
	Rhynchospora fusca	Brown Beakrush
	Scirpus cespitous	Tufted Clubrush
Grasses		
	Calamagrostis canadensis	Canada Blue Joint
	Muhlenbergia glomerata	Marsh Timothy
Herbs and Forbs		
	Galium trifidum	Small Bedstraw
	Lycopus uniflorus	Northern Bugleweed
	Lysimachia thyrsiflora	Tufted Loostrife
	Menyanthes trifoliata	Bogbean
	Solidago uliginosa	Bog Goldenrod
	Symphyotrichum boreale	Rush Aster
Shrubs		
	Salix pedicellaris	Bog Willow
	Salix petiolaris	Slender willow
Wetter Sites		
	Carex lasiocarpa	Wire Sedge
	Carex limosa	Candle Lantern Sedge
	Scirpus acutus	Hard-stemmed Bul Rush
	Scirpus validus	Soft-stemmed Bul Rush

Salix candida	Sage Willow
Drier Sites	
Carex interior	Inland Sedge
Carex lacustris	Lakebank Sedge
Symphyotrichum lanceolatum	Lance-leaved Aster