FROM **AGGREGATES** TO **AGRICULTURE**

THE ONTARIO AGGREGATE RESOURCES CORPORATION
TOARC

MAAP

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From Aggregates to Agriculture:

An Assessment of Farmland Rehabilitation in Ontario

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1.0 SUMMARY

In Ontario, agricultural rehabilitation is encouraged when aggregate extraction takes place on specialty or prime crop land under the Provincial Policy Statement (PPS) (OMMAH 2014). In fact, the PPS, delivered by Ontario's Ministry of Municipal Affairs and Planning (OMMAH) under the authority of the Planning Act, clearly states that "in prime agricultural areas, on prime agricultural land, extraction of mineral aggregate resources is permitted as an interim use provided that the site will be rehabilitated back to an agricultural condition" (Section 2.5.4.1, p. 28). This has become a contentious issue in Ontario, where information on whether these rehabilitation projects are successful is not available to the public or the aggregate producers.

Information on the current status of agricultural rehabilitation of aggregate pits and quarries in Ontario is minimal. No empirical, peer-reviewed literature exists in Ontario and very little is accessible from other provinces and international sources. Government documents focusing on this issue have not been published since 1982 and 1985 (MNRF, previously MNR). Publications, such as the State of the Aggregate Resources in Ontario Study (MNRF, 2009) and the Review of the Aggregate Resources Act (ARA) (Ontario 2013) have stated the need for more documentation and research regarding agricultural rehabilitation.

In response to these needs, this study reports on The Aggregates-to-Agriculture Database (ATAD), a comprehensive database developed by The Ontario Aggregate Resources Corporation (TOARC) to document occurrences of agricultural rehabilitation of aggregate extraction sites in Ontario. TOARC, as the sole trustee of the Aggregate Resources Trust, was created under authority of the Aggregate Resources Act to facilitate aggregate producers in balancing their impacts by compensating municipalities and carrying out research on aggregate resources management, including rehabilitation (TOARC 2015). The ATAD project further undertook to answer two questions: 1) to what extent has rehabilitation to agriculture occurred in Ontario, and 2) to what degree is agricultural productivity, crop quality and soil development on rehabilitated farmland as good as that on similar land that has not been disturbed.

To answer the question of how extensive rehabilitation of aggregate extraction sites to agricultural land usage is in Ontario, the ATAD was created with the goal of gathering, organizing and evaluating broad information on rehabilitated extraction sites presently used for agriculture (Phase 1 of the study). This included both surrendered extraction sites, which are sites that were licenced after 1990, legacy extraction sites, which are sites that were extracted from prior to 1990, and sites that have been progressively rehabilitated, which are sites where mined out areas are rehabilitated while extraction occurs on other parts of the site. To answer the question of how successfully such rehabilitated aggregate sites perform relative to farmland not impacted by extraction, 14 ATAD sites and paired controls on farmland which was not extracted were selected at random for extensive biological sampling and comparative analysis (Phase 2). Beyond determination of how extensive and how successful aggregates-to-agriculture rehabilitation has been in Ontario, a central goal of the analysis was to

evaluate patterns of success and failure with respect to potential best rehabilitation practices previously employed on study sites, including different tillage methods, fertilizer applications and cover-cropping strategies.

Phase 1 results indicated that approximately 15% of the post-extraction aggregate sites assessed in Southern Ontario supported agricultural after-uses, amounting to more than 1000 ha of land rehabilitated to agriculture across the province. Approximately 18,000 ha of rehabilitated land did not support agriculture. In total, 185 sites with agricultural after-uses were assessed, for which landowners were contacted and site visits were completed. Farmers were asked to rate the rehabilitated land on a scale of one (“1”) to ten (“10”), depending on whether they judged overall land quality to be equivalent (“10”) or highly inferior (“1”) to local farms untouched by extraction (“10”). Eight percent (8%) of the rehabilitated sites were rated as a 10, with an average rating of 6.2 amongst the 185 assessed sites. Farmers who used value-added management practices (cover crops, soil amendments) were more likely to rate the land higher than farmers who did not.

In Phase 2, 14 sites rehabilitated between 1980 and 2011 were assessed using soil, crop, and environmental sampling to determine objectively how similar rehabilitated extraction sites were to reference farmland, and the degree to which this depended on particular management practices. Six (6) of the 14 sites had differences in yield between the rehabilitated land and undisturbed land nearby, of which 3 were legacy sites and 3 were surrendered sites. Legacy sites with difference in yield were the most recently rehabilitated sites. However, the year of rehabilitation did not correlate well with yield differences for the surrendered sites. Stoniness was also a major factor, with 11 of the 14 sites showing significant differences in stoniness between undisturbed and rehabilitated land. Farmer ratings generally corresponded well with the measured yield estimates, with the legacy site ratings corresponding better than at surrendered sites.

Having information about agricultural rehabilitation in Ontario is important for the public and for aggregate producers. The results from this study show that agricultural rehabilitation has been going on continuously in Ontario since the 1970s, the quality of the rehabilitation (as measured by farmers’ ratings) is varied, and that there is room for improvement in rehabilitation techniques.

2.0 INTRODUCTION

Aggregates are one of the most important natural resources in Ontario - and one of the most controversial land use issues (Binstock and Carter-Whitney 2011). While environmental issues from aggregate extraction are minimal compared to other mineral and metal mining, the high-bulk, low-cost nature of aggregates makes mining close-to-market essential to keeping costs low (Drew et al. 2002; Poulin and Sinding 1996). Aggregates are used in all forms of construction and infrastructure therefore mining close-to-market means close to highly populated areas, causing an escalation in land use controversy (Binstock and Carter-Whitney 2011).

As population pressure increases in Southern Ontario, the public sees more of a need to protect areas of natural or cultural heritage from development. In Ontario this has included The Oak Ridges Moraine, Niagara Escarpment and Greenbelt protected areas (Binstock and Carter-Whitney 2011). However, these areas also have tended to have significant unexploited aggregate resources and become the last vestiges of close-to-market aggregate, causing increased tension between communities and aggregate producers (Binstock and Carter-Whitney 2011).

Government policy (PPS, 2005 and ARA, 1990) supports close-to-market extraction and considers aggregate extraction to be an interim land use, however, there is a lack of information on rehabilitation in Ontario, which increases the tension between government, industry and the public (MNRF 2009; ECO 2014). This is exacerbated by the poor track record that the aggregate industry has had in the past with rehabilitation and the lack of documentation (ECO 2005; McLellan 1985).

2.1 Agricultural Rehabilitation

Rehabilitation of aggregate extraction sites has been a requirement in Ontario since the Pits and Quarries Control Act was legislated in 1972 (Mackintosh and Hoffman, 1985). Rehabilitation, in this sense, usually refers to grading of slopes, re-spreading of the soil and re-vegetation of the site by seeding. Rehabilitation of land to pre-extraction land uses is encouraged, and since aggregate deposits often coincide with agricultural lands, rehabilitation to agriculture has been a relatively common practice in Ontario (Mackintosh and Mozuraitus, 1982). Agricultural rehabilitation, according to the Provincial Policy Statement, refers to the returning of a comparable amount of land to an agricultural capability of equal or similar quality prior to extraction (OMMAH 2014).

Interest in agricultural rehabilitation of aggregate extraction sites in Ontario has ebbed and flowed over the decades since 1970. In the 1970's an emphasis was placed on recreational uses for rehabilitated sites. Farmland preservation became an issue in the 1980's due to increasing urbanization and land use pressure, shifting interests towards agricultural rehabilitation (MNRF 2010). Since aggregate sites are often located in rural areas on agriculturally capable soils, rehabilitation to agriculture was seen as a positive and productive end-use (MNRF 2010). However, best management practices for agricultural rehabilitation were not known and there was little evidence of the success of these projects. During the 1980s two publications by the Ministry of Natural Resources and Forestry sought to address these issues and document rehabilitation methods and techniques suitable for agricultural lands (Table 1).

Table 1. Research on agricultural rehabilitation of aggregate extraction sites in Ontario.

Research	Author	Year
Agriculture and the Aggregate Industry	E.E. Mackintosh and E.J. Mozuraitus	1982
Rehabilitation of Sand and Gravel Pits for Fruit Production in Ontario	E.E. Mackintosh and M.K. Hoffman	1985

In the 1990's, interest in agriculture as a rehabilitation option diminished as sustainability of rare and sensitive ecosystems (e.g. alvars, tall grass prairies, fens etc.) came into the spotlight (MNRF 2010). Currently, a more balanced approach to rehabilitation is sought by many companies, where multiple land-uses are integrated. For example, agricultural land which integrates wildlife corridors will promote natural heritage as well as rural land-uses. This type of approach, along with an interest in agricultural land conservation has led to renewed interest in the techniques and planning required in agricultural rehabilitation of aggregate sites.

2.2 Past Research and Recommendations

Rehabilitation of aggregate extraction sites to agricultural land has not garnered as much attention by researchers as other types of mining rehabilitation activities. In fact, very few peer-reviewed articles exist on this topic in general, let alone with specific reference to Ontario. A number of studies in Ontario have included agricultural rehabilitation in larger overviews of aggregate rehabilitation, such as the State of the Aggregate Resources in Ontario Study (SAROS) (MNRF 2010) and the Ontario Stone Sand and Gravel Association (OSSGA) study of end-use (OSSGA 2013). Further, two government reports written in the 1980s focused more specifically on agricultural rehabilitation (see Table 1). The issue has garnered more interest in Europe, including a number of studies from Great Britain.

The SAROS report is a comprehensive review undertaken by the Ministry of Natural Resources and Forestry. One paper (Paper #6 Rehabilitation) focused on reviewing rehabilitation recommendations and practice. They assessed a list of the most recent surrendered licences (n=50) and progressive rehabilitation projects (n=50) at the time of the study. Within these sites 17 of the surrendered sites and 4 of the progressively rehabilitated sites had agricultural end-uses (MNRF 2010).

The OSSGA study of end-use took a more comprehensive approach to address the lack of general information on how aggregate extraction sites were being used after being surrendered. They assessed all surrendered aggregate licences within a specific area of Ontario, focusing on Protection Plan areas (Niagara Escarpment Plan, Greenbelt Plan, Lake Simcoe Protection Area and Oak Ridges Moraine) and the City of Ottawa (OSSGA 2013). They found that within these areas approximately 18% of the 568 sites surveyed had been rehabilitated to agriculture.

Existing recommendations regarding agricultural rehabilitation in Ontario come from the Aggregate Resources Act (1990) and its predecessor the Pits and Quarries Control Act (1971), as well as the research performed in 1982 by Mackintosh and Mozuraitus for the Ontario Ministry of Natural Resources and Forestry. The Act (1971, 1990) established a maximum slope steepness of 3:1 (measured as run over rise) for pits and the retaining of soil and subsoil on-site if agriculture was the planned after-use. Mackintosh and Mozuraitus (1982) looked at 63 aggregate extraction sites across Ontario that had been rehabilitated to agriculture. From their findings they suggested that 12 steps must be followed in order for agricultural rehabilitation to be successful (Table 2).

Table 2. Twelve steps to successful rehabilitation (Mackintosh and Mosuraitus 1985).

1	*Pre-Planning*
2	*Strip the topsoil, subsoil and overburden separately*
3	*Strip small areas at a time*
4	*Move soil materials under dry conditions*
5	*Rehabilitate progressively*
6	*Grade and contour the pit floor*
7	*Replace overburden, subsoil and topsoil in the correct sequence*

8	*Calculate volumes, depth, and areas to be covered carefully so as not to run out of soil material*
9	*Eliminate severe soil compaction*
10	*Create a post rehabilitation management plan*
11	*Use good agricultural practices*
12	*Be patient*

2.2.1 Pre-Planning

Pre-planning is particularly important in Ontario because changes to rehabilitation plans can be costly and complicated (MNRF 2010). Assessing the best after-uses for sites can be difficult, especially as science and society's demands change over time. For example, a property operating for more than 30 years may have originally been intended to return to agriculture; however, population growth or low soil capability for agriculture may cause a change to the after-use from agriculture to a better fit for the area (Trimble and Seibert 2002). This demonstrates that returning land to its prior use may not always be the best option. Considering the quality of the land prior to extraction is an important part of pre-planning. If the site is located on high quality agricultural land, agricultural rehabilitation should be considered as an after-use (Friedli et al. 1998).

2.2.2 Soil Handling

Soil quality can be defined as 'the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation' (Karlen and Andrews 2000). Handling of soil to move and stockpile during mining activities tends to have negative effects on soil quality, although research suggests that these effects can be minimized if soil is handled carefully.

Preserving the natural layers of topsoil and subsoil at a site is intrinsic to successful rehabilitation (Kaufmann et al. 2009b). Topsoil is the uppermost layer of soil that contains the greatest concentration of organic material and nutrients (Brady and Weil 1996). This layer is usually 15-30 cm in depth in agricultural soils where tillage has occurred (Mackintosh and Mozuraitus 1982). Subsoil is directly below the topsoil and can be up to 1 m in depth (Mackintosh and Mozuraitus 1982). This part of the soil can contain a significant amount of plant roots and tends to be very susceptible to compaction due to the presence of more clay and less organic matter (Mackintosh and Mozuraitus 1982). Mixing of topsoil and subsoil by inaccurate removal and storage can be detrimental at the time of rehabilitation because subsoil tends to dilute the nutrients and microbial activity in topsoil (Reeves et al. 2000). In a study on soil handling of agricultural rehabilitation in Britain, Reeves et al. (2000) found that soil mixing was likely to occur at most sites when soil was removed from a site because it is difficult to predict exact topsoil depth due to variability across a field. However, at the time of soil replacement most sites had only approximately 5% subsoil mixed with the topsoil (Reeves 2000).

Soil structure is particularly susceptible to damage when soil is being moved. Stahl (2002) states that soil structure, which can take hundreds of years to develop, is destroyed as soon as soil is moved. However, moving soil at low moisture content will minimize the damage to soil structure (Reeves et al. 2000). Storing soil in stockpiles also damages soil quality by increasing the bulk density, decreasing water holding capacity and reducing microbial activity (Stahl 2002). The consolidating effect of stockpiling depends on the soil texture, original density, moisture content, the height of the pile and the length of time soil is stored (Reeves 2000). Mackintosh and Mozuraitus (1982) suggest that soil should not be stored for more than 5 or 6 years, and current operations using progressive rehabilitation try to minimize this storage time by removing soil from a new extraction area and placing it directly onto an extracted area ready for rehabilitation. Minimizing the soil handling also decreases the risk to soil quality (Reeve 2000).

Re-applying a minimum of 15-20 cm of topsoil was deemed essential for agricultural crops, with a 1 m layer of soil material (topsoil + subsoil) over saturated zones to allow for drainage (Mackintosh and Mozuraitus 1982). Once reapplied, soils lack structure and are susceptible to erosion (Veenhof and McBride 1996). Kaufmann et al. (2009a) suggest that soils with poor aggregation are highly sensitive to compaction and water logging, which can lead to agricultural limitations. According to a number of European guidelines, soil can regain a level of structural integrity suitable for field crop production after 3 years if tillage and heavy trafficking are avoided (Kaufmann et al. 2009a). Soil ripping or deep tillage of subsoil can be used to alleviate compacted zones prior to reapplication of the topsoil (Reeve et al. 2000).

2.2.3 Post-Rehabilitation Management

A post-rehabilitation management plan is an important final step in the rehabilitation process. Most guidelines recommend planting a cover crop or grassland that requires minimal management and traffic while providing the soil with organic matter, aggregation and soil erosion control (Tobias 2008). Tobias (2008) suggests 5 years of this type of extensive management; however this figure is not based on scientific findings.

In summary, the effect of aggregate extraction on soil physical, chemical and biological properties can be severe. If not excavated, stored and managed properly, soil can become compacted, biologically inactive and unsuitable for agricultural after-use (Kaufmann et al. 2009a).

2.3 Room for Improvement

Rehabilitation of aggregate extraction sites has been a requirement in Ontario since 1971, however, the effectiveness and sufficiency of this rehabilitation is still being criticized by the public and experts alike (SAROS 2009). While there are strong examples of innovative rehabilitation across the province, the complicated and expensive nature of rehabilitation plan amendments has contributed to a general lack of creativity and flexibility in rehabilitation design – especially for small site owners/operators (SAROS 2009). The SAROS report engaged a diversity of stakeholders, all of whom agreed that rehabilitated land should be:

1. Compatible with surrounding land uses;
2. Returned back to its pre-extraction land use;
3. Useful; and
4. Left in a state as good as pre-extraction.

Based on these guidelines, agricultural rehabilitation may contribute significantly to aggregate site rehabilitation in Ontario. Unfortunately, there is no comprehensive information available as to where this rehabilitation is taking place, and if operators and farmers are following the existing recommendations.

In addition, many of the guidelines for agricultural rehabilitation are not based on scientific findings, but instead by stakeholder meetings (MNRF 2010). While this is important in a controversial industry, scientific backing of rehabilitation decisions could ease public mistrust. As well, an addition of science-based recommendations for rehabilitation in the ARA could also enhance industry decision-making on rehabilitation.

Therefore the primary goal of this study is to systematically collect, analyze and apply information about previous and ongoing agricultural rehabilitation in order to close the knowledge gap, promoting informed and productive rehabilitation decision-making within Ontario's aggregate production industry.

3.0 PHASE 1: COMPILATION OF AGGREGATES-TO-AGRICULTURE DATABASE

3.1 RESEARCH QUESTION AND OBJECTIVES

The research question and objectives for the first phase of the study were:

1. What is the extent of sites in Southern Ontario where land used for aggregate extraction has been returned to an agricultural use?
    a. Document the location and size of sand and gravel extraction sites in Southern Ontario that have been rehabilitated to agriculture;
    b. Contact producers and landowners to discuss extraction, rehabilitation, and current management practices;
    c. Survey sites by visiting locations and assessing a prescribed set of physical qualities.

3.2 METHODS

3.2.1 Database development

Lists of former aggregate sites were compiled for inclusion in this study. These included surrendered sites procured from the MNRF's Aggregate Licensing and Permitting System database (ALPS), legacy pits from TOARC's Management of Abandoned Aggregates Properties Program database (eMAAP), and wayside pits from the Ontario Ministry of Transportation (MTO). This resulted in a list of over 1,700 sites, across 32 counties in Southern Ontario. These sites are all of the documented locations where rehabilitation of aggregate extraction sites has occurred within the given area, and represents a variety of end-uses.

The type of end-use at each location was not known for the majority of the sites in the list. End-use information was collected by OSSGA in the 2010-2013 Study of Aggregate Site Rehabilitation in Ontario. This information was overlaid onto the master list for the Greater Toronto Area, City of Ottawa, Greenbelt Plan, Niagara Escarpment and Oak Ridges Moraine areas. Aggregate sites where progressive rehabilitation to agriculture occurred, or was occurring were added to the database of sites via calls from individual landowners and property managers as well as from information obtained from OSSGA's rehabilitation awards.

To enhance the amount of information, visits to MNRF district offices were undertaken in March and April 2013 and February 2014. Aggregate Inspector's surrendered licence files were viewed, and rehabilitation plans citing agriculture as the intended end-use of a site were noted and copied to assist in finding sites.

All sites were then examined using available aerial photography and satellite imagery. Although the imagery was somewhat outdated, conclusions on end use were possible for many sites where there was a clear indication of no agricultural activity (e.g. large ponds, forested areas, residential developments). Where aerial photography and satellite imagery did not provide enough detail, field verifications were completed.

3.2.2 Field Surveys

Sites where the end-use was unclear and sites that were verified as agricultural after-uses were mapped and visited by a field technician between May and November 2013. Sites east of Frontenac County were not visited in 2013 due to time and personnel constraints. Between April and November 2014 sites in Eastern Ontario and any outstanding sites across Southern Ontario that had not been completed in 2013 were visited (Figure 1). The study focused on Southern Ontario because it was anticipated that little agriculture production would be occurring in areas north of Renfrew, Peterborough and Simcoe Counties (OMAFRA 2015a). For each site where agriculture was confirmed or possible, research personnel attempted to contact landowners. Site surveys and landowner questionnaires were completed with the permission of the landowner.

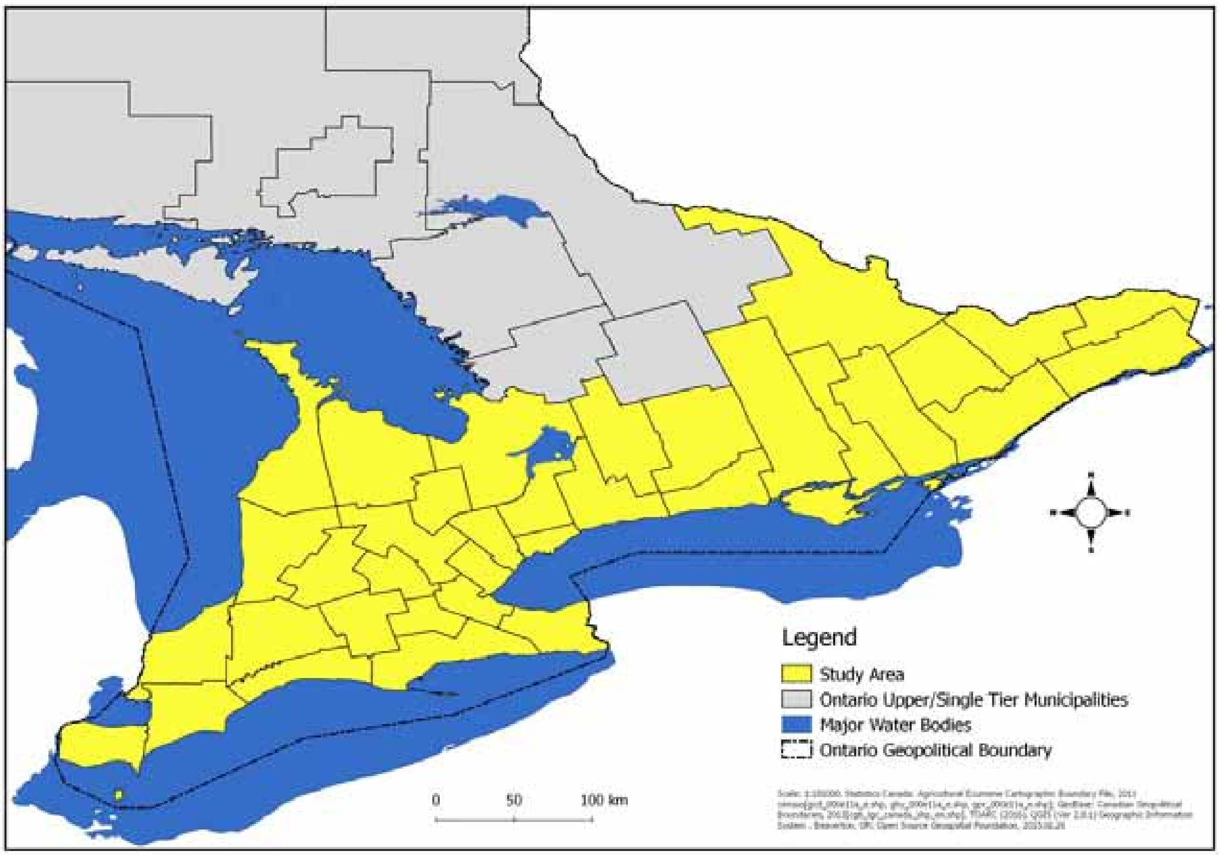


Figure 1. Map of the study area.

Surveys and questionnaires encompassed a range of information including: landowner contact information, site history (when known), rehabilitation techniques, current management practices, crop history, soil texture, stoniness, and surrounding land use. Crop type was split into 4 main categories: pasture, field crop, orchard and other.

3.2.3 Statistical Analysis

Where applicable, statistical analyses were performed on the data using the Past Software (v. 3.04) (Hammer 1999). No transformations were necessary for the data to meet the requirements for variance analysis (Bowley 2008). Arithmetic means were calculated and t-tests were used to test significant differences between means.

3.3 RESULTS AND DISCUSSION

3.3.1 General Results

The database resulted in a comprehensive list of more than 1,700 sites representing a range of end-uses across Southern Ontario which were systematically assessed between 2013 and 2014. This corresponded to a land area of approximately 24,000 ha. Land-use was confirmed to be non-agricultural at 59% of the sites and agricultural at 15% of the sites. A further 14% could not have the land-use confirmed, 9% had been amalgamated into active licences and 3% had other complications which limited the data, such as landowner refusal to participate in the survey or complete loss of knowledge regarding the extraction site (Figure 2).

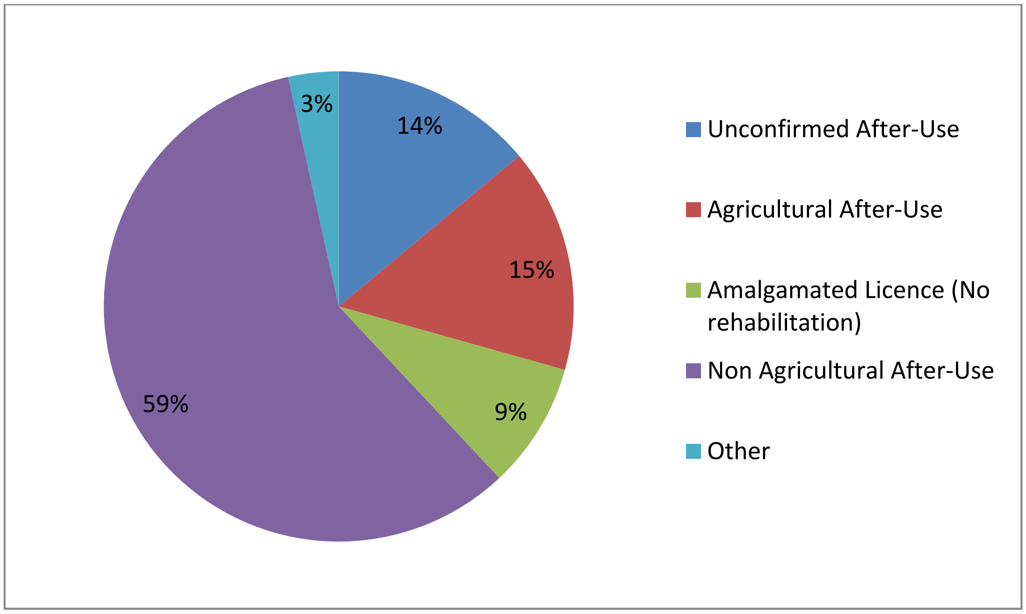


Figure 2. Status of post-extraction aggregate sites.

More than 1,000 of the 1,700 sites in the database (59%) did not experience rehabilitation to agricultural after-uses. This included sites that were confirmed in-office, using aerial imagery, and sites that were confirmed through visitation and conversation with landowners. An additional 153 sites had been amalgamated into active licences and were not rehabilitated. Non-agricultural sites corresponded to approximately 18,000 ha of land.

Sites labelled as 'unconfirmed end-use' included sites where landowner contact could not be established and which were not visible from public roadways. Sites classified as 'other' included 32 sites where information had been lost by landowners such that the pit could not be located, 10 sites where the landowners were not interested in participating in the study and 19 sites which were not visited due to time constraints. This corresponded to approximately 3,400 ha of land.

Analysis of the collected site data confirmed that 15% of rehabilitated sites in Southern Ontario, corresponding to approximately 2,500 ha of land, have been rehabilitated to agricultural after-uses. This was similar to OSSGA's findings in their Study of Aggregate Site Rehabilitation in Ontario, which found 18% of sites assessed to be used for agriculture.

These numbers represent the amount of sites documented in Ontario by the MNRF, MTO and MAAP. While these numbers are comprehensive given the sources, they are not necessarily all of the sites in

Ontario. For example, they do not include older, undocumented sites which would have had to be found through word-of-mouth or archives. With the time constraints on this project, it was not possible to collect information on these types of sites.

Site inventories and questionnaires were completed at a total of 185 sites confirmed as rehabilitated to agricultural after-uses. These were sites where farmers were successfully contacted and interviewed, and site visits to the rehabilitated land were conducted. An additional 87 sites were similarly confirmed, but classified as ‘partial’ inventories because site visits could not be completed and/or landowner questionnaires were never returned.

All of the sites inventoried were pits where sand or gravel extraction had occurred. Nearly half of these sites (46%) had experienced extraction and progressive rehabilitation as regulated under Ontario’s aggregate licensing program, while another 12% held wayside permits. A further 26% were legacy sites where extraction had occurred without a licence prior to 1990 and which were rehabilitated by the Management of Abandoned Aggregate Properties (MAAP) program. Information regarding the historical regulation of extraction operations (or lack thereof) could not be found for 16% of the sites investigated (i.e. status= ‘unknown’).The 185 sites with completed inventories comprised 1670.69 ha of land rehabilitated to agriculture in Southern Ontario. A further 839.97 ha of rehabilitated land corresponded to the 87 partial inventories where landowners were not successfully contacted for confirmation, and are considered ‘unconfirmed’ but likely rehabilitated to agricultural after-uses.

Analysis of the full set of completed site inventories for extraction sites rehabilitated to agriculture (185 sites) revealed that 58% of sites were used for production of field crops (including hay and annual row crops of corn, beans, small cereal grains) and hay (Figure 3), 36% were used as pasture, 2% supported apple or peach orchards, and 4% supported other agricultural uses including vegetable crops, vineyards, and fallow land. Four (4) sites supported multiple crop types – either field crop and orchard or field crop and pasture. In this study, hay is defined as areas of annual or perennial forage which were cut and collected and not grazed by livestock. Pasture is defined as any perennial forage that was predominately grazed by livestock and occasionally cut for hay. Permanent pasture often occurs in areas with physical constraints that do not allow for other agricultural uses (e.g. steep slopes, shallow soils, or stoniness).

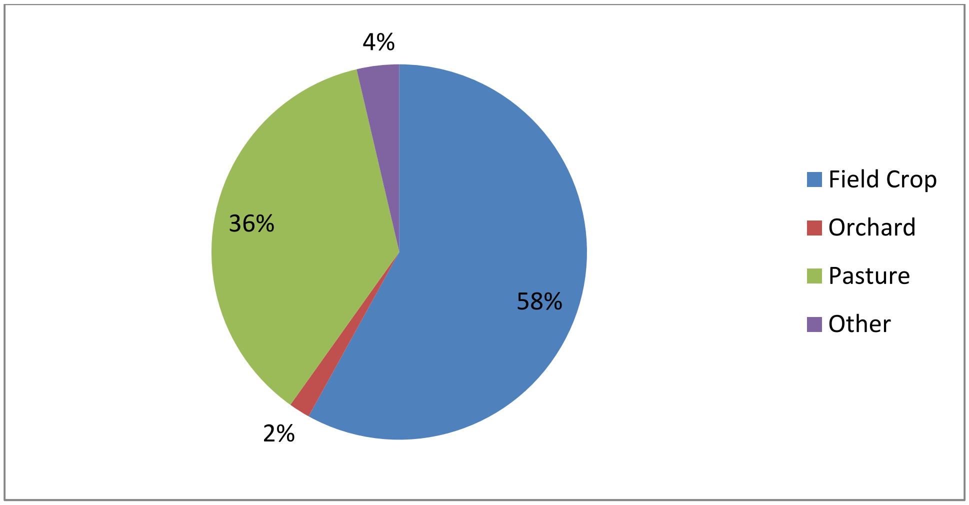


Figure 3. Types of agricultural after-uses of aggregate extraction sites.

Farmers were asked to rate rehabilitated land on a scale of 1-10, with a score of "1" indicating lands were only marginally suited for their current agricultural use and a score of "10" indicating that the rehabilitated land was fully equivalent to surrounding farmlands of similar usage which have never been impacted by aggregate extraction (Figure 4).

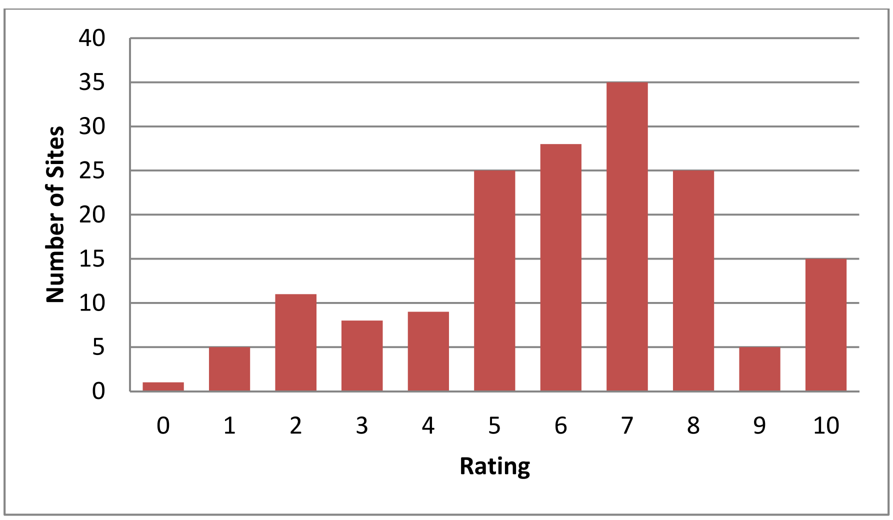


Figure 4. Number of agricultural rehabilitation sites rated from one ("1") to ten ("10") by farmers/landowners.

The mean rating of the rehabilitated land by farmers was 6.2, with 8% of sites rated as 10. More farmers rated the land above 5 (66%) then 5 or below (34%). Many of the farmers said that the rehabilitated land produced well in wet years, but does more poorly than the surrounding land in a dry year. Many farmers mentioned wet spots in their fields due to poor drainage. Some of the farmers were optimistic that the rehabilitated land was slowly improving over time. A few farmers were less positive, suggesting that the land had been irreparably damaged by poor rehabilitation.

3.3.2 Rehabilitation

The completed surveys showed sites that had been rehabilitated over a date range of 1960 to 2014 (Figure 5). The majority of the rehabilitation took place between 1990 and 2014, with 14 sites having been rehabilitated in the 1970s and 2 sites in the 1960s. Within the dataset, more agricultural rehabilitation projects were found which had taken place since the beginning of the 1990s than before 1980. This discrepancy may be due to the length of time since rehabilitation leading to changes in land-use or changes in landowners causing a loss of historical information. Also, data on recent aggregate extraction sites is more available, especially sites since the introduction of the ARA in 1990.

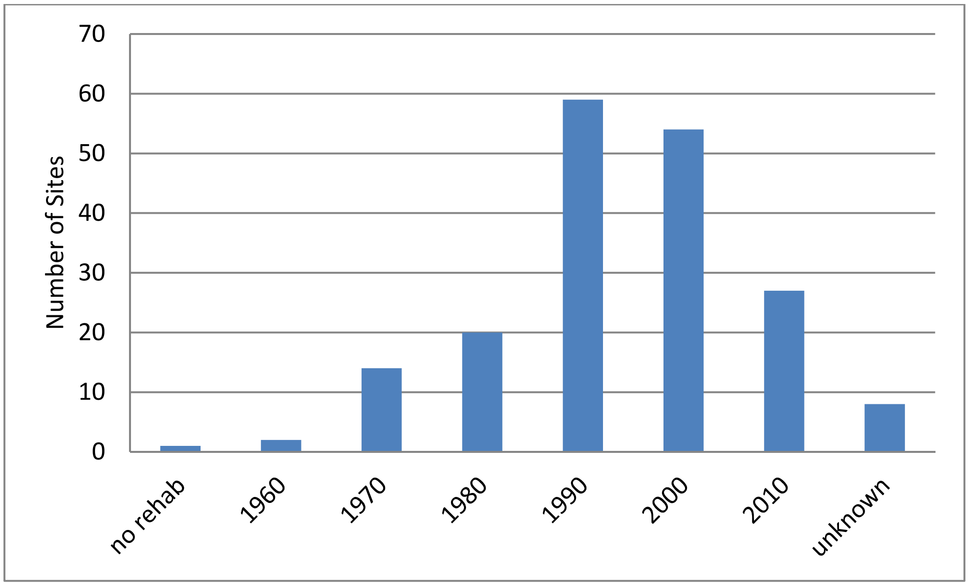


Figure 5. Number of sites rehabilitated to agriculture in each decade from 1960 to present.

There was also 1 site in the database that was being used for agriculture where no rehabilitation had taken place. This site had naturally revegetated to a meadow ecosystem and was being used to pasture cattle. Eight (8) additional sites were categorized as 'unknown'. These were sites with no site plan, where the owner of the land had changed since rehabilitation and the current landowner knew of the existence of an old site but did not know any specific history of the extraction.

Nearly one-third (31%) of the sites experiencing agricultural rehabilitation additionally supported non-agricultural after-uses on-site, from farmhouses and yards to industrial buildings, naturalized areas, and side slopes that were too steep for farm machinery.

3.3.3 Management Practices

Farmers were asked to describe the management practices they used on the land after rehabilitation was completed. These included the use of cover crops and soil amendments, tillage practices and fertilizer applications on the rehabilitated land.

3.3.3.1 Cover crops and soil amendments

Cover crops and soil amendments such as fertilizers and sources of organic matter (e.g. manure) are used for soil improvement (Teasdale 1996). Cover crops are grown for soil protection and improvement (i.e. rather than for the value of the crop itself) and soil amendments are used to improve the physical properties of the soil (Bulluck et al. 2002; Teasdale 1996). Cover crops were used by 90 of the farmers surveyed in this study and 40 farmers used soil amendments (Table 3).

Table 3. Percent of sites surveyed which used soil improvement and associated means.

Management Practice	% Yes	Mean	% No	Mean	% Unknown	Examples
Cover Crops	49	6.2	48	5.7*	3	Buckwheat, barley, alfalfa, clover, radish
Soil Amendments	22	6.4	74	5.6*	2	Manure, compost, biosolids

**indicated means across rows significantly different at p<0.01*

Cover crops have been shown to decrease soil erosion, increase soil organic matter content and have a positive effect on soil structure (Tobias, 2008). Spring use of cover crops can also provide weed suppression and can increase soil nutrients (Ebelhar et al. 1984). In this study, cover crops included planting buckwheat, barley or alfalfa directly after rehabilitation for plow-down, or under-seeding cereal crops with clover or tillage radish. Alfalfa and clover are two examples of leguminous cover crops, which improve soil structure as well as contribute significant amounts of nitrogen (N) to the soil for use by the next planted crop. Mean farmer ratings were higher in the surveys where cover crops had been used (6.2) then on rehabilitated land where cover crops had not been used (5.7) (Table 3).

Various amendments were added to the soil to improve its physical properties, including altering acidity (pH), increasing organic matter content, macro- and micro-nutrient concentrations, microbial activity, and water-holding capacity (Bulluck et al. 2002). The most common soil amendment used in this study of agricultural rehabilitation was barnyard manure or old hay. Mean farmer ratings were higher in the surveys where soil amendments had been used (6.4) than on rehabilitated land where they had not been used (5.6) (Table 3). Bulluck et al. (2002) looked at differences in soil physical and chemical parameters on farms using organic amendments or synthetic fertilizers and found that after two years significant soil improvements were seen on the farms using soil amendments. This may have been the reason why farmers who used these amendments consistently rated the land higher than farmers who did not.

3.3.3.2 Fertilizer

Most of the 185 sites surveyed used either commercially available fertilizer or manure to provide nutrients to the crops. Pasture sites were less likely to have commercial fertilizer applied than field crops (Table 4). Field crop sites were more likely to have commercial fertilizer applied than manure and pastures were more likely to receive manure. Pastures were also more likely to not receive fertilizer than field crop sites, with some farmers relying on grazing animals to provide enough fertilization.

Table 4. Percent of sites surveyed using fertilizer.

	Fertilizer (%)	Manure (%)	Both (%)	None (%)	Unknown (%)	Total (%)
Field Crop	23	14	12	5	9	63
Pasture	6	20	2	7	2	37

Bulluck et al. (2002) studied the differences in soil chemical and biological responses to organic or synthetic fertilizers. They found that microbial activity and levels of certain nutrients (Calcium (Ca), Magnesium (Mg)), cation exchange capacity (CEC), soil organic matter content and total carbon (C) was higher in soils where manure was applied as a fertilizer compared to soils where synthetic fertilizer was applied (Bulluck et al. 2002). Clark et al. (1998) found a similar result, where concentrations of C, phosphorus (P), potassium (K), Ca and Mg in soil were higher in manure-applied soils. Many of the farmers surveyed wished to apply manure to the rehabilitated land but did not have access to manure, or have enough manure, restricting their use of it and using commercially produced fertilizer instead.

3.3.3.3 Tillage Practices

Farmers at rehabilitated sites used a range of tillage practices based on preference and land type. Tillage was divided into 6 categories: conventional tillage, conservation tillage, no tillage, combination tillage, unknown and none (Table 5). Most pasture sites did not report any tillage because these sites are not worked yearly, however, many pastures are tilled and replanted every 5-10 years as they degrade. Field crop sites were fairly evenly spread between the tillage types.

Table 5. Tillage practices in field crop and pasture sites.

			Percent of Surveyed Sites	
Tillage Practice	**Definition (Walters and Jasa 2015)**	**Residue left on the soil surface**	**Field Crop (%)**	**Pasture (%)**
Conventional Tillage	Where the entire soil surface is disturbed by tillage (e.g. moldboard plow) and later disturbed again for seedbed preparation (e.g. harrow or disc).	<15%	13	0
Conservation Tillage	Tillage is reduced to only being disturbed for seedbed preparation (cultivator or chisel plow).	>30%	12	1
No Tillage	Soil is only disturbed to physically place seed in the soil.	100%	16	-
Combination Tillage	Use of more than one tillage system depending on the crop and the year.	variable	11	2
Unknown	Landowner was unsure of tillage practice used.	unknown	11	1
None	No form of tillage was used.	100%	-	33

Tillage increases trafficking on soil which can increase compaction of soils that are newly rehabilitated and lacking soil structure (Schaffer et al. 2007). No-till is often recommended for coarse textured soils to limit erosion, conserve soil water and increase soil organic matter (Doran 1980). No-till systems also tend to stay cool and wet longer in the spring, which can be a disadvantage in Northern climates where the growing season is relatively short (Doran 1980).

Tillage can be effective in managing weeds and incorporating fertilizer or manure into the soil (Doran 1980). Tillage also increases the rate at which soil organic matter is mineralized into usable forms for plants. This means that no-till systems have greater soil organic matter contents, but may require additional fertilizer (Ebelhar 1984). In general, no-till systems are thought to require greater inputs of herbicide and fertilizer than tillage systems, but over time have positive effects on the overall quality of the soil (Ebelhar 1984).

3.3.4 Physical Properties (soil types, slopes on site vs. surrounding and stoniness)

A number of physical characteristics were also observed and measured during the site visits. These included evidence of erosion and non-vegetated areas, percent ground cover by stones, slope height and slope steepness.

3.3.4.1 Erosion and Bare Areas

Areas devoid of vegetation were documented during the site visits (Table 6). These were divided into 7 categories: none, evidence of erosion, bare areas due to laneways, bare areas due to animals, areas with pooling water, other bare areas, and unknown. Approximately 75% of the sites surveyed had no evidence of erosion or bare areas.

Table 6. Percent of field crop and pasture sites surveyed with different types of erosion and bare areas.

		Percent of Surveyed Sites	
Type	**Example**	**Field Crop (%)**	**Pasture (%)**
None	No erosion or bare spots	51	24
Erosion	Rills and gullies	1	2
Laneways	Compacted areas due to vehicle traffic	2	0
Animal Effects	Areas where cattle dig or paths	0	4
Wet spots	Areas with water pooling	3	1
Bare areas	Areas too dry, coarsely textured, gravelly or compacted for plant growth	4	6
Unknown	Due to difficultly seeing into tall field crops	2	0

Approximately 85% of the field crop sites surveyed had no evidence of erosion or bare areas. Most of the bare areas within the 15% that had evidence of problems was due to wet spots or areas too gravelly or compacted for plant growth. Wet spots were usually due to drainage issues, with a number of farmers commenting that they were hoping to install a drainage tile to remove the wet area. Farmers with land that was too compacted or coarsely textured for plant growth suggested different methods to ameliorate this, including tillage, planting a deep-rooted cover crop or leaving the area fallow for a few years.

Within the pasture site surveyed, 63% had no evidence of erosion or bare areas and 37% did have evidence of erosion or bare areas. Pasture sites tended to be on more marginal land with less topsoil and steeper slopes, which leads to a greater susceptibility to bare areas and erosion. In addition, pasture areas are grazed by animals, which have significant impact on the land. Plant defoliation by grazing animals compounded by digging and preferential areas of trampling (cow paths) or laying (e.g. areas around shade or water troughs) can cause compaction and bare areas in pastures (Greenwood and McKenzie 2001).

3.3.4.2 Ground Cover by Stones

Stoniness can cause serious problems for agricultural production systems. Percent Ground Covered in Stones (GCS) was measured in 5 randomly selected 1 m x 1 m quadrats. In each quadrat the ground surface was visually inspected and a category of stoniness was assigned (<10% GCS, 10-25% GCS, 25-50% GCS, 50-75% GCS, 75-90% GCS, >90% GCS). The majority of the sites fell into the <10% GCS, 10-25 % GCS and 25-50 % GCS categories (Figure 6). Less than 10% of sites had stoniness cover greater than 50%.

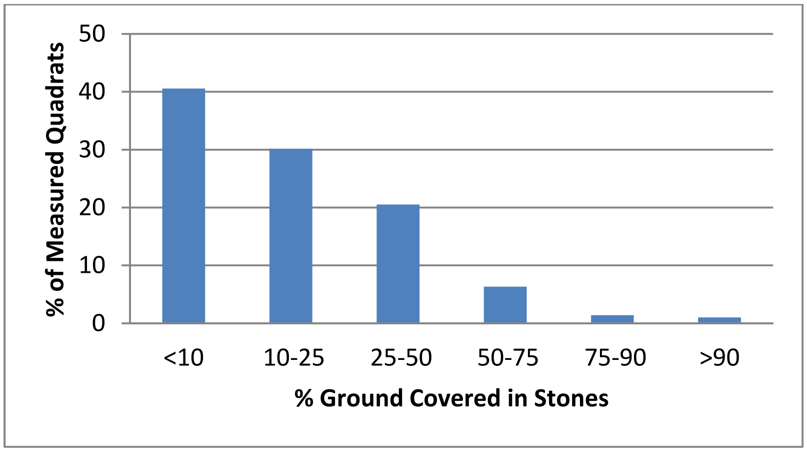


Figure 6. Percent of measured quadrats in each category of stoniness (%).

3.3.4.3 Slopes

Slopes were measured at the inventoried sites and recorded as run over rise (Table 7). The highest and steepest part of the site was recorded into categories of slope height and steepness. Slope height categories were <1 m, 1-4 m and >4 m and slope steepness categories were >1:1, 1:1, 2:1, 3:1 and <3:1 (measured as run over rise). Most of the field crop sites had slopes of <1 m in height and <3:1 slope steepness.

Table 7. Slope height and steepness at surveyed sites.

Slope Height	Slope steepness (run:rise)	Percent of sites	
		Field crop (%)	Pasture (%)
<1 m	**2:1**	2	
	3:1	0	1
	<3:1	26	7
1-4 m	**2:1**	6	3
	3:1	11	4
	<3:1	15	8
>4 m	**1:1**	0	1
	2:1	3	10
	3:1	2	2
	<3:1	2	1

Most of the sites with >4 m slopes were used for pasture and the sites with slopes <1 m were field crops. While steeper slopes exist on land that was being cropped, it would not have been possible to drive farm machinery on the steepest parts of the slopes. Many of these areas were left fallow, such as side slopes or a steep section in an otherwise flat field. Mackintosh and Mozuraitus (1982) stated that optimal relief for farmland was between 50:1 and 20:1.

3.4 CONCLUSIONS FOR PHASE 1

In Phase 1 of the Aggregates-to-Agriculture Study, more than 2,500 ha of land rehabilitated to agriculture was surveyed. The results show that rehabilitation of aggregate extraction sites in Ontario to agriculture has been occurring consistently since the 1970's, encompassing a large range of cropping systems, and differences in farmer satisfaction. The average rating out of 10 that farmers gave the rehabilitated land was 6.2, with 8% of farmers rating the land as 10. Farmers who used value-added management practices (cover crops, soil amendments) were more likely to rate the land higher than farmers who did not. Seventy-five (75%) percent of the sites showed no evidence of erosion.

The information from Phase 1 highlights the extent and frequency of agricultural rehabilitation in Southern Ontario, but does not address the issue of rehabilitation success in a quantitative manner. The farmer ratings were anecdotal data on rehabilitation success, however, the study was interested in taking this information a step further to measure quantitative success. Phase 2 aimed to fulfill this goal by measuring the differences between undisturbed and rehabilitated land and seeing how those related to the farmer ratings from Phase 1.

4.0 PHASE 2: COMPARATIVE ANALYSIS OF AGGREGATES TO AGRICULTURE SITES

4.1 RESEARCH QUESTION AND OBJECTIVES

The research question and objectives for the second phase of the research were:

1. Are aggregate extraction sites which have been rehabilitated to agricultural after-uses of equivalent productivity and overall quality to similar farmland which have not been impacted by extraction?
    a. Create a randomly selected list of study sites;
    b. Contact landowners and producers to collect information on pre-extraction conditions, extraction, rehabilitation, and current management;
    c. Measure and carry-out comprehensive comparative analysis of rehabilitated and reference farmland, with respect to crop yields, soil features and other critical environmental parameters.

4.2 METHODS

4.2.1 Site Descriptions

A list of sites rehabilitated to agriculture was compiled from the first phase of the study showing sites where landowners had been successfully contacted and that were being used for field crops. Sites identified as 'pasture' after-uses were removed. From this list, sites were randomly selected for Phase 2 of the study. Twenty (20) sites were originally chosen and landowners from these sites were contacted to determine the 2014 crop and to get approval for project participation. Six (6) sites were not included after this point due to lack of landowner interest and sites being converted from field crop to hay (or pasture) for the 2014 season. This left a total of 14 sites to be analyzed for Phase 2 of the research project.

The sites ranged in size and location across Southern Ontario from Bruce County in the west to Prince Edward County in the east with the majority of sites clustered in Huron, Bruce, Grey and Middlesex Counties. Figure 7 shows the distribution of the study sites.

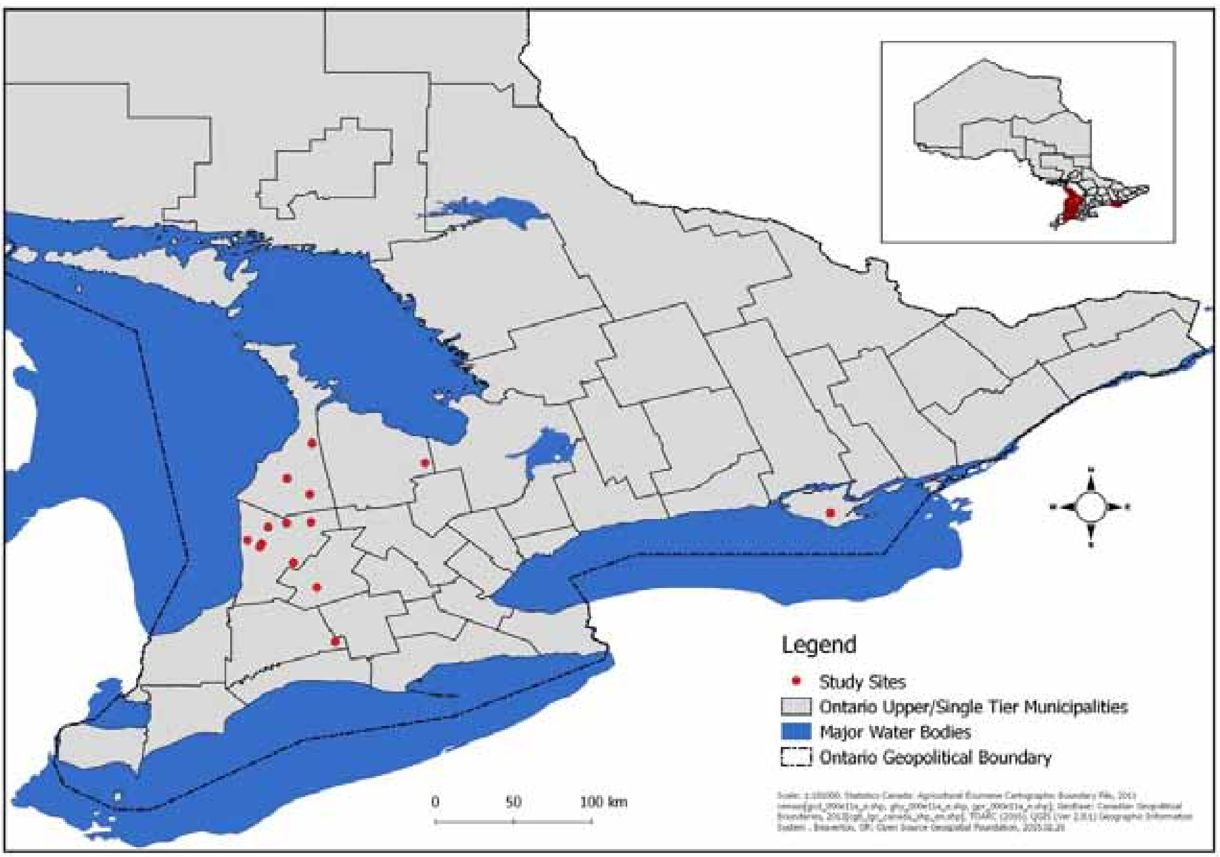


Figure 7. Map of study sites.

Four (4) of the chosen sites were producing winter wheat, four (4) were growing corn and six (6) were growing soybeans in 2014 (Table 8). Five (5) of the sites were legacy pits rehabilitated by the MAAP program between 2006 and 2011. The remaining nine (9) sites were licenced under the Aggregate Resources Act (from 1990) or the Pits and Quarries Control Act (from 1971). Rehabilitated areas ranged from less than 1 ha to 24.50 ha. Table 8 shows a number of management parameters that were noted at the study sites: use of fill during rehabilitation, installation of tile drainage in rehabilitated areas, type of fertilizer used by the farmer and type of tillage used at the site.

Table 8. Site list with general specifications and management practices.

Site	Status	Licenced	Rehabilitated	2014 Crop	Area (ha)	Fill	Tile	Fertilizer Type	Tillage
BRU-1	Surrendered	1950	1980	Soybean	12.70	Yes	No	I	No
BRU-2	Surrendered	1985	1998	Corn	4.38	No	No	I	Min
BRU-3	Legacy	unknown	2008	Corn	1.25	No	No	O+I	Mixed
GRE-4	Legacy	unknown	2006	Soybean	4.5	Yes	No	O	Min
HUR-5	Surrendered	1980	1994	Winter Wheat	4.00	No	Yes	I	No
HUR-6	Surrendered	1997	2007	Soybean	24.50	No	Yes	O+I	Conv
HUR-7	Legacy	unknown	2009	Winter Wheat	1.7	No	No	I	Conv
HUR-8	Surrendered	1993	2008	Corn	6.87	Yes	No	O	No
HUR-9	Legacy	unknown	2011	Soybean	3.1	No	No	I	No
HUR-10	Surrendered	1982	1982	Winter Wheat	8.75	No	Yes	O+I	Min
HUR-11	Surrendered	1992	1997	Winter Wheat	7.30	No	Yes	I	Min
MID-12	Surrendered	1995	2008	Soybean	2.25	No	No	O	Min
PER-13	Legacy	unknown	2006	Soybean	0.8	Yes	Yes	O	Mixed
PRI-14	Surrendered	1973	1993	Corn	8.10	No	No	O+I	Min

Where I = commercially produced fertilizer and O = manure; No = no-till, Min = minimum tillage, Mixed = mixed tillage practices, and Conv = conventional tillage.

See Appendix B for more detailed descriptions outlining rehabilitation and management at each of the sites.

4.2.2 Sampling Strategy

All sampling for this project was completed in 2014. The sampling took place in a pairwise manner in that the rehabilitated area of land was matched with a similar undisturbed area and both were sampled for comparison. In all cases in this study, the rehabilitated and the undisturbed area came from adjacent land that was owned by the same farmer and under the same management regime. Often, the areas were in the same field.

Pairwise sampling was used due to the difficulty in determining pre-existing conditions of sites that were extracted in the past. Since this phase of the project took place in 1 year, it was not possible to measure changes in the rehabilitated areas over time. The pairwise sampling of undisturbed areas nearby allows for a comparison, however, it cannot be assumed that the undisturbed area is representative of what the land may have been like before aggregate extraction. In many cases the extracted areas are glacial deposits of sand/gravel that may have different topographic and soil characteristics than the surrounding land features. In the course of this paper, it is important to understand that the undisturbed sites are merely a reference by which to compare the rehabilitated land, and not specifically what the land would have been like prior to extraction. Nevertheless, the adjacent sites were deemed the best comparison for this study.

4.2.3 Plant Sampling

Plant tissue samples were taken between July 21st and August 1st 2014 for the soybean and corn crops. These were sampled from at least 50 plants randomly collected across the sample area and composited. The top fully developed leaves of the soybeans were collected and mid-level leaves from the corn crops. One (1) sample from the rehabilitated area and 1 sample from the undisturbed area were submitted to SGS Agri-Food Laboratories in Guelph, Ontario for nutrient analysis of percent nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg) and calcium (Ca).

4.2.4 Yield Estimates

Yield estimates were determined as close to crop harvest as possible, ranging from July 2014 (winter wheat crops), to October and November 2014 (soybean and corn crops). Yield estimates involved counting grains or beans in lengths of crop rows at 10 random locations for each site, sampling seeds to dry and weigh, and calculating yield. In general yield was estimated using:

$$Yield = \left(\frac{number\ of\ plants}{length\ of\ row\ x\ row\ spacing}\right)\left(\frac{number\ of\ seeds}{plant}\right)(average\ grain\ weight)$$

Table 9 shows the specific yield estimating techniques used for individual crop types in this study.

Table 9. Parameters used in yield estimate equations for each crop species.

Crop	Length Along Crop Row Assessed	Number of Seeds	Weight	Reference
Winter Wheat	1 m	Number of grains per heads counted on 10 consecutive heads of grain.	100 seed count	Lyon and Klein (2007)
Soybean	1 m	Number of pods per plant for 10 consecutive plants + number of seeds per pod for random sample of pods.	100 seed count	Lee and Herbek (2005)
Grain Corn	5 m	Number of cobs per plant for all plants in length of row + number of seeds per cob for 3 cobs per row.	100 seed count	Nielsen (2014)

4.2.5 Soil sampling

Soil samples were collected in October and November 2014. This was after the winter wheat harvest, but the corn and soybean crops were still standing when the soil sampling was completed. Samples were collected from the top 20 cm layer of soil using a hand auger at 50 random locations across each sampling area. The soil was mixed in a bucket, large clods were broken up with a hand trowel and large root material was removed. A composite sample was collected from the bucket and submitted to SGS Agri-Food Laboratories to be analyzed for nutrients, organic matter content, cation exchange capacity and soil texture.

In addition, 5 intact 20 cm depth soil cores were also collected from each location, dried and weighed for a measure of soil bulk density (in g/cm^3) as per the method by Blake (1965).

4.2.6 Land Characteristics

General land characteristics were noted during the course of the sampling regime. Stone cover was assessed in the locations where yield estimates were performed, using a scale of 0% ground cover by stones to 100% ground cover by stones. Categorical information on slope height and steepness (reported as run over rise) was also noted.

4.2.7 Statistical Analysis

Statistical analyses were performed using the Past Software (v. 3.04) (Hammer 1999). No transformations were necessary for the data to meet the requirements for variance analysis (Bowley 2008). For the measured yield values, arithmetic means were calculated and pairwise t-tests were used to compare rehabilitated, undisturbed and Ontario average values. Univariate analysis of variance and t-tests were used to test significant differences in soil variables.

4.3 RESULTS AND DISCUSSION

4.3.1 General Information

4.3.1.1 Farm Management

Post-rehabilitation farm management is an important factor in rehabilitation success (Mackintosh and Mozuraitus 1982). Swiss guidelines suggest farmers use rehabilitated land as grassland for 5 years before starting to crop (Tobias et al. 2008). This lag time was implemented to allow the soil structure to redevelop and reduce problems associated with soil compaction (Schaffer et al. 2007). However, this management practice opposes the economic drivers of agriculture by not producing a saleable crop (Schaffer et al. 2007). Mackintosh and Mozuraitus (1982), who studied rehabilitation in Ontario, found that many farmers were choosing to grow corn or grain crops directly after rehabilitation.

To assess post-rehabilitation farm management, this study looked at on-farm usage of cover crops, type of fertilizer and tillage practices; correlating these practices to year of rehabilitation (Table 10).

Table 10. Farm management on rehabilitated sand and gravel extraction sites as shown by use of cover crops, type of fertilizer and tillage practice.

Site	Status	Rehabilitated	2014 Crop	Cover Crop	Fertilizer Type	Tillage
BRU-1	Surrendered	1980	Soybean		I	No
HUR-10	Surrendered	1982	Winter Wheat	yes	O+I	Min
PRI-14	Surrendered	1993	Corn	yes	O+I	Min
HUR-5	Surrendered	1994	Winter Wheat	no	I	No
HUR-11	Surrendered	1997	Winter Wheat	yes	I	Min
BRU-2	Surrendered	1998	Corn	yes	I	Min
GRE-4	Legacy	2006	Soybean	yes	O	Min
PER-13	Legacy	2006	Soybean	no	O	Mixed
HUR-6	Surrendered	2007	Soybean	no	O+I	Conv
BRU-3	Legacy	2008	Corn	no	O+I	Mixed
HUR-8	Surrendered	2008	Corn	no	O	No
MID-12	Surrendered	2008	Soybean		O	Min
HUR-7	Legacy	2009	Winter Wheat	no	I	Conv
HUR-9	Legacy	2011	Soybean	no	I	No

Where I = commercially produced fertilizer and O = manure; No = no-till, Min = minimum tillage, Mixed = mixed tillage practices, and Conv = conventional tillage.

Cover crop usage was less likely to have occurred on sites rehabilitated after 2006 than those rehabilitated between 1980 and 2006. Conventional tillage and mixed tillage practices were only seen after 2006.

The type of fertilizer was not strongly associated with year of rehabilitation. Additions of organic material in the form of manure has shown to improve the physical structure of soil, increasing soil organic matter content and providing soil nutrients for plant uptake (Richardson and Evans 1986). Eight (8) of the fourteen (14) study sites added organic material in this way.

4.3.2 Plant tissue

Green plant tissue was analyzed for nutrient content in study sites growing corn and soybeans in July and August 2014. All samples analyzed were above the critical levels as outlined by SGS Agri-Foods Lab for the parameters measured (Table 11). There were no significant differences for any parameters between the rehabilitated and undisturbed plant tissue.

Table 11. Means of plant tissue analysis in rehabilitated and undisturbed plots and showing critical levels; plant nutrient results recorded as percent.

	Corn			Soybeans		
	Rehabilitated	**Undisturbed**	**Critical Level**	**Rehabilitated**	**Undisturbed**	**Critical Level**
%N	3.238	3.403	2.500	5.100	5.162	4.000
%P	0.308	0.340	0.200	0.425	0.440	0.350
%K	2.043	1.985	1.200	2.225	2.202	2.000
%Mg	0.185	0.218	0.100	0.375	0.380	0.100
%Ca	0.555	0.528	0.200	1.270	1.097	0.500

4.3.3 Yield Estimates

4.3.3.1 Winter Wheat

Measured yields in the winter wheat plots ranged from 44.43 bu/acre to 101.07 bu/acre, while the Ontario average for 2014 winter wheat yields was 77.2 bu/acre (Table 12) (OMAFRA 2015b). The rehabilitated areas produced yield significantly lower ($p<0.01$) than the undisturbed areas and the Ontario average at 2 of the 4 sites in this study. At HUR-10 the mean value for the rehabilitated land did not differ significantly from the mean value for the undisturbed land or from the Ontario average.

Table 12. Mean winter wheat yields in bu/acre in rehabilitated, undisturbed and the Ontario average value for 2014 (OMAFRA 2015b).

Site	Status	Year of Rehabilitation	Rehabilitated	Undisturbed	Ontario Average
HUR-7	Legacy	2009	48.03a	98.13b	77.2c
HUR-11	Surrendered	1997	44.43a	80.84b	77.2b
HUR-5	Surrendered	1994	52.37a	69.10b	77.2b
HUR-10	Surrendered	1982	86.15ab	101.07a	77.2b

Mean values followed by the same letter across the rows are not significantly different at p=0.01

The site HUR-7 is a legacy pit that was rehabilitated by the MAAP program in 2009. This site had limited stockpiles of soil on site at the time of rehabilitation, therefore it was required that soil from a 15 m radius in the undisturbed field was stripped, mixed with the soil stockpiles and spread across the entire area to ensure sufficient topsoil dressing. This lack of stockpiled topsoil is a common occurrence on sites that pre-date the Pits and Quarries Control Act (1971) and makes rehabilitation to agriculture more difficult at these sites for the MAAP program. Mackintosh and Mozuraitus (1982) stated that the retaining of soil on site is perhaps the most important step in planning for agricultural rehabilitation. Since sites such as HUR-7 had no plan to return to agriculture, soil was sold or used elsewhere during operation of the site.

The other 3 sites which had winter wheat were licenced and had soil stockpiles left on site for rehabilitation. In the case of HUR-11 the pit floor was ripped, topsoil was replaced and the area was seeded to hay for a number of years before being put into an annual crop rotation. The difference between the rehabilitated and undisturbed area seen in the yield estimates for this site may be due to a difference in slope. The rehabilitated area had a 2-3 m high slope with a steepness of 3:1 while the undisturbed area slope was less than 1 m and <3:1.

4.3.3.2 Corn

Measured corn yields ranged from 90.58 bu/acre to 151.40 bu/acre (Table 13). The yield estimates of the rehabilitated land were significantly different ($p<0.01$) from the undisturbed land at 2 of the 4 sites growing corn. At 3 of the 4 sites the yields were estimated to be significantly below the 2014 Ontario average of 160.9 bu/acre (OMAFRA 2015b). The OMAFRA breakdown of yield estimates by county for 2013 indicate that corn yields in Huron county are generally higher (165.2 bu/acre) than in Bruce or Prince Edward counties (148.2 bu/acre and 142.7 bu/acre, respectively) (OMAFRA 2015b).

Table 13. Mean corn yields in bu/acre in rehabilitated, undisturbed and the Ontario average value for 2014 (OMAFRA 2015b).

Site	Status	Year of Rehabilitation	Rehabilitated	Undisturbed	Ontario Average
BRU-3	Legacy	2008	90.58a	115.73b	160.9c
HUR-8	Surrendered	2008	123.30a	140.00b	160.9c
BRU-2	Surrendered	1998	107.43a	122.14a	160.9b
PRI-14	Surrendered	1993	144.94a	151.40a	160.9a

Mean values followed by the same letter across the rows are not significantly different at p=0.01

The sites with significant differences between the rehabilitated and undisturbed sample locations were the most recently rehabilitated. The legacy pit BRU-3 yielded the poorest in both the rehabilitated and undisturbed areas. As this was a legacy site, limited amounts of soil were found for rehabilitation. The soil in the rehabilitated area had more stones and the resulting slopes were steeper than at the other sites producing corn. In addition, average grain corn yields for Bruce County are lower than average estimates from Huron County (OMAFRA 2015b). Stoniness levels were very high at HUR-8 which may have been the cause of the low yields compared to the undisturbed area and the Ontario average.

At the site PRI-14, there was no significant difference between the Ontario average, undisturbed and rehabilitated areas. This site was a sand esker that was removed, leaving a flat field with sandy soil and few stones. During rehabilitation a cover crop was used the first year, followed by 4 years planted to red clover hay. After this, the site was returned to an annual crop rotation.

The site BRU-2 yielded lower than the Ontario average but there was not a significant difference between the rehabilitated and undisturbed land. Gravel was removed at this site for 30 years, after which it was rehabilitated by ripping the pit surface, spreading stored topsoil and then planting a cover crop of barley. The site had a high but gentle slope with a 13:1 grade.

4.3.3.3 Soybeans

Soybean yield varied from 36.00 bu/acre to 78.66 bu/acre, while the Ontario average across counties was 45.5 bu/acre (Table 14). On sites where soybean yield was sampled, none of the rehabilitated areas differed significantly ($p<0.01$) from the 2014 Ontario average (OMAFRA 2015b). HUR-9, was the only site producing soybeans to have a significant difference between the rehabilitated and undisturbed areas. The undisturbed areas at 2 legacy sites (HUR-9 and PER-13) produced significantly above Ontario average yield. These sites are in a highly productive area of Ontario (Huron and Perth Counties) which generally produces higher soybean yields than where the other sites were located (Middlesex, Bruce and Grey Counties) (OMAFRA 2015b). The yield estimates used did not include a loss percentage which may have been the cause of high estimates.

Table 14. Mean soybean yields in bu/acre in rehabilitated, undisturbed and the Ontario average value for 2014 (OMAFRA 2015b).

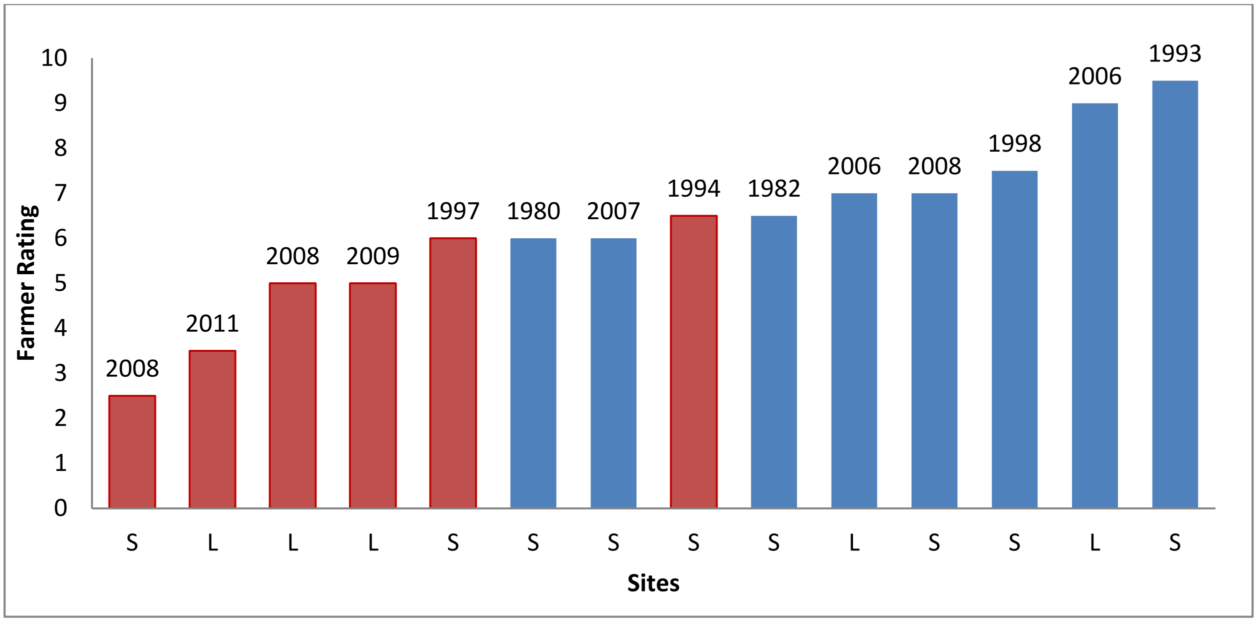
Site	Status	Year of Rehabilitation	Rehabilitated	Undisturbed	Ontario Average
MID-12	Surrendered	2008	60.20a	60.66a	45.5a
GRE-4	Legacy	2006	36.99a	48.47a	45.5a
BRU-1	Surrendered	1980	40.10a	42.73a	45.5a
HUR-6	Surrendered	2007	52.15ab	63.11a	45.5b
PER-13	Legacy	2006	64.81ab	78.66a	45.5b
HUR-9	Legacy	2011	47.94a	68.27b	45.5a

Mean values followed by the same letter across the rows are not significantly different at p=0.01

HUR-9, had significantly lower yield on the rehabilitated land versus the undisturbed land. This site is a legacy pit, and was the most recently rehabilitated site in the study. The farmer predicted that the yield would not be as good at this site but also said he had seen improvement in the yield every year since the rehabilitation.

4.3.3.4 Relating Yield to Farmer Ratings

During Phase 1 of the research, all farmers were asked to rate their rehabilitated land on an ordinal scale of one ('1') to ten ('10'), with 1 meaning that the farmer perceived the land to be unsuitable for agriculture and 10 indicating that the farmer thought the land produced crop yields as good as surrounding, undisturbed land. These ratings were then compared to the status, year of rehabilitation, crop species and yield estimates for the 14 sites in Phase 2 (Figure 8).



S= surrendered site; L= legacy site

Red bars= significant differences between the rehabilitated and undisturbed land; blue bars= no significant differences between the rehabilitated and undisturbed land (p<0.01)

Figure 8. Sites with significant differences (p<0.01) in yield measurements between rehabilitated and undisturbed sampling locations, shown with farmers ratings of the rehabilitated land and year of rehabilitation.

Farmer's ratings at legacy sites corresponded well with the measured yields. The ratings of 7 and 9 showed no difference (p<0.01) between the rehabilitated and undisturbed areas and the ratings of 5 and 3.5 showed differences. At surrendered sites, farmer ratings did not correlate as well with the yield estimates. Sites rated 6 and 6.5 appear in both the significant and not significant differences in measured yields.

In general, the soybeans performed better than the corn or winter wheat, on legacy and surrendered sites. This shows in the farmers ratings and the yield estimates. The only site with yield differences in a soybean crop was HUR-9, a legacy site that was the most recently rehabilitated of all the sites in this study.

4.3.4 Soil

4.3.4.1 Bulk Density

Compaction generally occurs in the course of extraction and rehabilitation of sand and gravel pits due to increased trafficking of soil and stockpiling (Reeve et al. 2000). Compaction has been cited as the most common limiting factor to agricultural production on rehabilitated mine sites (Shoeman 2001). Soil bulk density, often used as a measure of compaction, affects plant root growth in the range of 1.60 g/cm^3 to 1.69 g/cm^3, depending on soil texture (Table 15). At a soil bulk density of more than 1.80 g/cm^3 root growth in the soil is restricted at any soil texture.

Table 15. Soil bulk density (g/cm^3) values that affect and restrict root growth at different soil textures (NRCA 2001).

Texture	Bulk density that affects root growth	Bulk density that restricts root growth
Silt Loam	1.60	>1.75
Sandy Loam	1.63	>1.80
Loam	1.63	>1.80
Loamy Sand	1.69	>1.80

Mean soil bulk density values measured from the top 20 cm layer of soil at the sites in this study ranged from 0.982 g/cm^3 to 1.373 g/cm^3 (Figure 9). None of the measured values fell into the range of affecting or restricting root growth. Significant differences were seen between the rehabilitated and undisturbed sample locations at 2 of the sites in the research study.

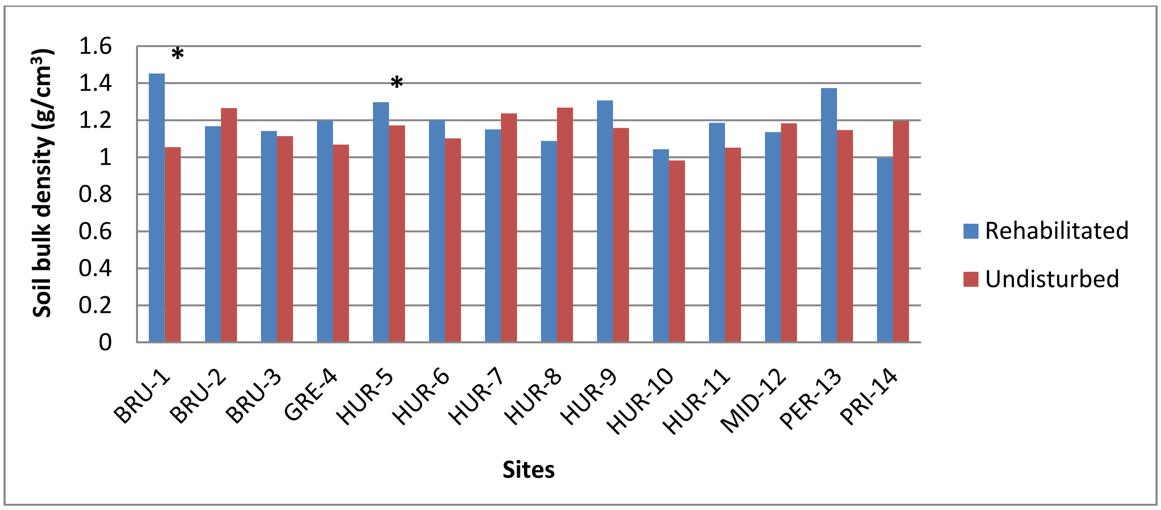


Figure 9. Mean soil bulk density (g/cm^3) in the top 20 cm layer of rehabilitated and undisturbed plots with (*) showing values with a significant difference ($p<0.01$).

Rehabilitated land had significantly higher soil bulk density at BRU-1 and HUR-5. Tobias et al. (2008) studied compaction in relation to different soil replacement methods and suggested that the problem of soil compaction in restored soils has lessened considerably since the early 1990s when awareness of this problem increased. Most of the sites in the current study were rehabilitated after 1990, which may be why compaction was not a limiting factor at any of the sites. Overtime, compaction is also alleviated by the re-establishment of normal biological activity in the soil increasing soil aggregation (Schaffer et al. 2007). Since many of the sites in this study were rehabilitated up to 25 years ago, compaction may be less problematic than at the time of rehabilitation.

4.3.4.2 Stoniness and Soil Texture

Stoniness can be a problem for plant growth and farming practices. Percent Ground Cover by Stones (GCS), as measured at 11 of the sites in this study, ranged from 16% to 85% on the rehabilitated land

and from 0.2% to 21% on the undisturbed land (Table 16). GCS was significantly higher in the rehabilitated land for all but 1 of the sites measured. The site, HUR-9, had an older aggregate extraction site in the area used as part of the undisturbed reference, unknown to the field technician until after sampling was completed.

Table 16. Soil texture and mean percent ground cover by stones in rehabilitated and undisturbed sample locations.

Site	Soil Texture		Ground cover by stones (%)	
	Rehabilitated	**Undisturbed**	**Rehabilitated**	**Undisturbed**
BRU-1	Loam	Silt Loam	32	0.2*
BRU-2	Loam	Silt Loam	85	0.8*
BRU-3	Sandy Loam	Loamy Sand	71	0.2*
GRE-4	Silt Loam	Silt Loam	35	0.2*
HUR-5	Loamy Sand	Sandy Loam	29	0.6*
HUR-6	Loam	Silt Loam	-	-
HUR-7	Loam	Silt Loam	74	8.2*
HUR-8	Sandy Loam	Sandy Loam	78	1.6*
HUR-9	Sandy Loam	Silt Loam	50	21
HUR-10	Loam	Loam	16	0.8*
HUR-11	Sandy Loam	Silt Loam	66	5.6*
MID-12	Loam	Sandy Loam	-	-
PER-13	Silt Loam	Silt Loam	-	-
PRI-14	Loam	Sandy Loam	63	5.4*

**indicates values significantly different at $p<0.01$*

In general, the percent sand in the bulk soil samples was greater in the rehabilitated land than in the undisturbed land. Texture differences due to importation of fill were not apparent at any of the sites.

4.3.4.3 Soil Chemical Characteristics

Bulk soil samples collected from the top 20 cm of soil were analyzed for a number of chemical characteristics which are good indicators of soil quality. These included pH, soil organic matter content, cation exchange capacity (CEC) and macronutrients (Table 17).

Table 17. Means of soil characteristics in rehabilitated and undisturbed sampling locations shown by type of crop.

Soil Characteristic	Crop Type	n	Rehabilitated	Undisturbed	p-value
pH		14	7.61	7.26	0.00097*
	Corn	4	7.55	6.98	0.13599
	Soybean	6	7.70	7.40	0.0234
	Winter Wheat	4	7.55	7.35	0.20098
Soil Organic Matter (%)		14	2.97	3.24	0.07031
	Corn	4	3.18	2.95	0.01822
	Soybean	6	2.88	3.38	0.005353*
	Winter Wheat	4	2.90	3.33	0.33456
Cation Exchange Capacity (MEQ/100g)		14	18.57	14.48	0.000366*
	Corn	4	17.05	11.58	0.03094
	Soybean	6	19.55	16.20	0.035111
	Winter Wheat	4	18.63	14.83	0.11298
Phosphorus (ppm)		14	49.64	35.79	0.042358
	Corn	4	28.25	27.25	0.84654
	Soybean	6	71.50	39.3	0.045339
	Winter Wheat	4	38.25	39.00	0.91686
Potassium (ppm)		14	127.00	125.86	0.93335
	Corn	4	94.00	62.50	0.12057
	Soybean	6	153.83	152.33	0.93361
	Winter Wheat	4	119.75	149.50	0.33003
Magnesium (ppm)		14	173.86	229.21	0.013794
	Corn	4	160.75	145.25	0.45235
	Soybean	6	188.33	284.67	0.018039
	Winter Wheat	4	165.25	230.00	0.10247
Calcium (ppm)		14	3118.5	2209.6	0.000244*
	Corn	4	2851.0	1797.3	0.027961
	Soybean	6	3275.2	2445.2	0.012711
	Winter Wheat	4	3151.0	2268.8	0.090598

**indicates values significantly different at $p<0.01$*

Soil pH in this study ranged from 6.38 in the undisturbed site at BRU-3 to 7.79 at the rehabilitated site at MID-12. This shows a range between slightly acid and mildly alkaline soils. There was generally a decrease in pH from the rehabilitated sampling locations to the undisturbed areas, with a significant decrease (p<0.01) in pH between the rehabilitated and the undisturbed areas overall. Uptake of plant nutrients is highly pH dependent, with nutrients changing solubility depending on the pH (Brady and Weil 1996). Soil organic matter also plays a large role in pH characteristics.

Cation exchange capacity and calcium were significantly (p<0.01) higher in the rehabilitated areas than in the undisturbed areas. Cation exchange capacity is a measure of a soils ability to hold onto positively charged nutrients (such as Mg, K, Na and Ca) and resist acidification (Hazelton and Murphy 2007). Soils with higher clay contents or higher organic matter content tend to have higher CEC (Brady and Weil 1996). The undisturbed land had a CEC of approximately 14 MEQ/100 g. This range of CEC is indicative of coarse to medium-textured soil that were formed on gravelly or sandy glacial deposits (CUCE 2007). The increase in CEC seen in the rehabilitated land may be the result of the increase in pH, since CEC is pH dependant (CUCE 2007).

4.3.5 Slopes

Slope height and steepness were estimated at the rehabilitated sites (Table 18). Slope height was categorized as <1 m, 1-4 m and >4 m and slope steepness as 2:1, 3:1 and <3:1. The height and steepness of the largest and steepest part of the rehabilitated site was recorded. No sites in the study had slopes greater than 4 m and 3:1 slopes. Most sites had slopes with <3:1 slopes.

Table 18. Slope height and steepness estimates shown with farmer ratings.

Site	Status	Year of Rehabilitation	Crop	Slope Steepness	Slope Height	Sig yield diff at 0.01	Farmer Rating
BRU-3	Legacy	2008	Corn	3:1	1-4	*	5
HUR-9	Legacy	2011	Soybean	<3:1	1-4	*	3.5
HUR-7	Legacy	2009	Winter Wheat	<3:1	1-4	*	5
PER-13	Legacy	2006	Soybean	<3:1	<1	-	7
GRE-4	Legacy	2006	Soybean	<3:1	<1	-	9
HUR-8	Surrendered	2008	Corn	3:1	1-4	*	2.5
HUR-11	Surrendered	1997	Winter Wheat	3:1	1-4	*	6
HUR-10	Surrendered	1982	Winter Wheat	3:1	1-4	-	6.5
BRU-1	Surrendered	1980	Soybean	<3:1	1-4	-	6
MID-12	Surrendered	2008	Soybean	<3:1	1-4	-	7
BRU-2	Surrendered	1998	Corn	<3:1	1-4	-	7.5
HUR-6	Surrendered	2007	Soybean	<3:1	<1	-	6
HUR-5	Surrendered	1994	Winter Wheat	<3:1	<1	*	6.5
PRI-14	Surrendered	1993	Corn	<3:1	<1	-	9.5

'' indicates yields significantly different at p<0.01 and '-' indicates yields not significantly different at p<0.01*

Lower and shallower slopes were seen at legacy sites that were rated higher by farmers and did not show yield differences between rehabilitated and undisturbed land. At surrendered sites there was not a strong correlation between farmer rating or yield and slope height and steepness.

4.4 CONCLUSIONS FOR PHASE 2

In Phase 2 of the Aggregates-to-Agriculture study, 5 legacy sites and 9 surrendered licences were assessed on 3 different aspects of overall farm quality: crop yield, crop nutritional quality, and physical features such as slopes, stoniness and soil quality. Six (6) of the 14 sites had differences in crop yield between the rehabilitated land and undisturbed land nearby, of which 3 were legacy sites and 3 were surrendered sites. The legacy sites which exhibited differences in yield were the most recently rehabilitated sites; however, year of rehabilitation did not correlate well with yield differences for the surrendered sites.

Every rehabilitated site in the study produced crops that were of equivalent nutritional quality to the reference farms. Eighty-six percent (86%) of rehabilitated sites showed no evidence of soil compaction relative to the undisturbed farms, and rehabilitated sites were indistinguishable from reference sites for almost every major soil variable likely to influence crop success. Statistically significant soil differences observed for the related variables of pH, calcium content and cation exchange capacity were all in a range that was unlikely to negatively impact crop yield. Stoniness estimates did show significant differences between the reference farms and the rehabilitated farms, with reference farms showing less than 5% stone cover on average and rehabilitated farms estimated at more than 50% stone cover on average.

The data presented here suggests that while legacy sites will continue to be a challenge for rehabilitation to agriculture when there is a lack of soil, progressively rehabilitated and legacy sites can have a high similarity to undisturbed sites in soil characteristics, crop quality and yield. Stoniness and slopes are two of the main challenges at rehabilitated sites, which likely influence plant-soil water relations and make farming more difficult.

5.0 CONCLUSIONS AND RECCOMENDATIONS FOR FURTHER RESEARCH

Agricultural rehabilitation of aggregate extraction sites continues to be a controversial land-use issue in Ontario, where population growth and the resulting infrastructure demands are seen to be at odds with Ontario's rural heritage and information on the frequency and success of such rehabilitation projects is limited. The accessibility of information goes a long way towards assuaging the frustrations of diverse stakeholder groups. The first objective of the study was to determine the extent of aggregate rehabilitation to agriculture in Ontario. More than 200 sites spread across Southern Ontario were identified during Phase 1, revealing that approximately 15% of aggregate site rehabilitation in Southern Ontario has resulted in agricultural land-uses. Within these sites, 58% were Field Crop, 36% were Pasture, 2% were Orchard and 4% were Other Agricultural Uses. This corresponded to a total of more than 1000 ha of land rehabilitated to agriculture in Ontario.

The second objective of the study was to determine the success of agricultural rehabilitation projects in Southern Ontario. This was more difficult to assess, with direct comparison of land pre- and post-extraction not possible due to the limited scope and timeline of the research. To measure success in

Phase 1 of the study farmers were asked to rate the land on a scale of one (“1”) to ten (“10”), with a mean rating of 6.2 for all the sites surveyed. These ratings, however, are subjective. Phase 2 of the study measured rehabilitation success on a smaller subset of sites by comparing yield on rehabilitated and undisturbed farmland. This quantitative approach allowed for a better estimate of rehabilitation success.

Fourteen (14) sites were assessed in Phase 2 of the study, focusing on crop yield, crop nutrition, and physical features. Yield measurements showed that 3 of 5 legacy sites and 3 of 9 surrendered sites had significantly lower crop yields on the rehabilitated land compared to the undisturbed land. Legacy pits are often a ‘worst case scenario’ for rehabilitation, with limited soil resources on site. The 40% of legacy sites that did not have significant differences indicates that farm management strategies can help ameliorate soils over time. Sixty-seven percent (67%) of surrendered sites in this study had no differences between the rehabilitated and undisturbed areas, showing that on site soil management and pre-planning are important for rehabilitation success.

Defining the differences that led some agricultural rehabilitation projects to be more successful than others was difficult in this study because of the multiple farmers, soils and management practices surveyed. A scientific study which examines specific management practices should be a priority to increase the success rate of future rehabilitation projects. This would include a detailed look at the before, during and after of a site. Also, soil storage methods should be examined to minimize the damaging effect of moving and storing soil.

From the anecdotal and quantitative evidence presented in this report, these best management practices are recommended:

- Soil removal in horizons, retention in berms and replacement should be done with extreme care;
- Stone picking should be performed at all sites showing increased stoniness at the time of rehabilitation;
- At sites with limited soil resources, add organic matter to the soil by adding manure, cover crops for plow-down or other sources of organic matter;
- Make drainage issues a priority, since poor drainage is difficult and expensive to correct post-rehabilitation.

In conclusion, 15% of aggregate extraction projects in Southern Ontario are eventually rehabilitated to agricultural land. The study suggests that while success rates are promising, there is room for improvement in agricultural rehabilitation of aggregate extraction sites in Southern Ontario. The evidence available from this study indicates that while more research is necessary to determine exact rehabilitation and management strategies to increase the success rate of agricultural rehabilitation, complete recovery of prime agricultural production after aggregate extraction is possible. Aggregate producers, government regulators and the general public should thus feel confident that aggregate resource development really can be an interim land use with minimal environmental impacts, even within Ontario's best farmlands if proper care is taken in the planning and rehabilitation of the land. This is in keeping with multiple government policies and generally supports the long-term sustainability and complementarity of both the agricultural and aggregate production industries.

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7.0 APPENDICES

Appendix A: Definitions

Course textured soil: the texture exhibited by sands, loamy sands and sandy loams (Brady and Weil 1996).

Critical levels: Refers to the level of a nutrient under which crop performance with be affected.

Fine textured soil: Consisting of or containing large quantities of the fine fractions, particularly of silt and clay sized particles. This includes clay loam, sandy clay loam, silty clay loam, sandy clay, silty clay, and clay textural classes (Brady and Weil 1996).

Legacy Pit or Quarry: A pit or quarry for which a licence or permit was never in force at any time after December 31, 1989 (MNRF 1990).

Progressive rehabilitation: Rehabilitation that is done sequentially, within a reasonable time, in accordance with the ARA, the regulations, the site plan and the conditions of the licence or permit during the period that aggregate is being excavated (MNRF 1990).

Surrendered Licence: An aggregate licence cancelled at the licensee's request, in which the annual licence fee payment and rehabilitation has been performed in accordance with the ARA, the regulations, the site plan and the conditions of the licence (MNRF 1990).

Appendix B: Phase 2 Site Descriptions

Site	Description
BRU-1	Part of a drumlin was removed from this site over a period from the 1950s to the early 1980s. The owner quit extracting when lower grade material was found and so part of the drumlin remains at the back of the property. An area of 7.17 ha was rehabilitated for agriculture in the late 1980s. The land slopes towards a wet spot in the field and has variable soil conditions. The area has been cropped with soybeans, cereals and corn in the last 5 years.
BRU-2	Extraction at this site began approximately 30 years ago with the removal of gravel from a hill on the site. An area of 5.710 ha was licensed. The rehabilitation took place in 1998 with ripping of the pit bottom and sloping to 13:1. Topsoil to a depth of 15 cm was then spread. After the rehabilitation, barley was planted as a cover crop. The following year the site was returned to the farmer's normal rotation of cereals, corn and beans.
BRU-3	A 1.25 ha legacy site was rehabilitated by the MAAP program in 2008. The site had steep, bare slopes that were rehabilitated to agricultural land. The site is in a corn, cereal, and soybean rotation.
GRE-4	This legacy pit was rehabilitated by the MAAP program in 2006. The site was 4.15 ha with slopes of 4-5 m and concrete, brush, and old machinery. It was located in the middle of an agricultural field and the owner was interested in returning it to an agricultural use. Very little topsoil was left on the site from the original extraction so the landowner brought in and spread topsoil after the MAAP program completed the re-sloping. The area was summer fallowed and stone picked for one year after rehabilitation followed by a green manure crop of canola. Dry cattle manure was also applied.
HUR-5	The site was an old sand pit, approximately 4 ha in size. It has a low spot running south east to north west that cannot be planted in wet years. It has been in a corn-soy-wheat rotation since rehabilitation in 1994.
HUR-6	This 24.50 ha site was progressively rehabilitated, with the final rehabilitation completed in 2007. Before extraction, the site was used as pasture land due to the large, steep slopes. With extraction and rehabilitation the slopes were reduced significantly and now the site is used for field crops.

Site	Description
HUR-7	This was a 1.7 ha legacy pit with significant steep slopes (average 3m with 2:1 steepness) which were devoid of vegetation, and a bare pit floor. It was rehabilitated by the MAAP program in 2009 and now used for field crops. The current crop rotation is corn, soybeans and wheat.
HUR-8	Approximately 6.87 ha of land was rehabilitated to agriculture in 2008. After extraction of an existing pit, the area was rehabilitated using fill from the nearby road construction. The land receives a fall application of manure every year since rehabilitation and is cropped in a rotation of corn and soybeans.
HUR-9	This legacy pit is attached at the lot line to an active license to the east. An area of 3.10 ha was rehabilitated by the MAAP program in 2011. The area was contoured using some rubble material on site and then covered with subsoil and 0.1 m of topsoil. A wet spot exists at the bottom of the pit area. The landowner has applied farmyard manure and planted wheat and soybeans in the subsequent years to build up the soil and increase production.
HUR-10	This site was licensed for approximately two years in the early 1980s. The license excavated an existing pit and removed a hill from the property, leaving a more contoured slope. The site was rehabilitated in 1982. The landowner has regularly applied manure to the field and has incorporated the area into a normal crop rotation including soybeans, small cereals and grain corn.
HUR-11	Approximately 7.30 ha was returned to agriculture after rehabilitation of this site in 1997. The pit floor was ripped and scarified to a depth of 0.5 m before topsoil was replaced to a depth of at least 0.1 m. The area was planted with barley seeded down to hay the first year after rehabilitation and was used for hay for a number of years before being put into rotation with soybeans, wheat, corn and hay.
MID-12	An area of approximately 6.90 ha was returned to agriculture in 2008. The extraction removed part of a hill that extended from the northwest towards the south east of the site. The sloping is less than 3:1. After rehabilitation the area was incorporated into the farms rotation of corn and soybeans.

Site	Description
PER-13	This legacy pit was a small wet area surrounded by some shrubby vegetation and 2:1 slopes. It was rehabilitated by the MAAP program in 2005. The wet area was filled with some rubble and foundation material from a nearby demolition and some clay was imported to the site. The slopes were contoured to be minimum steepness of 5:1. Wheat and soybeans have been cropped on the site since the rehabilitation.
PRI-14	The site was a sand esker that was removed leaving an almost flat field. The 8.10 ha site was licensed for 15 years and took 5 additional years to complete the rehabilitation. The site was cultivated during rehabilitation and a cover crop of oats and barley was planted, followed by red clover for hay. The area is now in a soybean, wheat, corn rotation.

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