Agriculture and the Aggregate Industry

Industrial Mineral Background Paper 3

Ministry of Natural Resources
Ontario

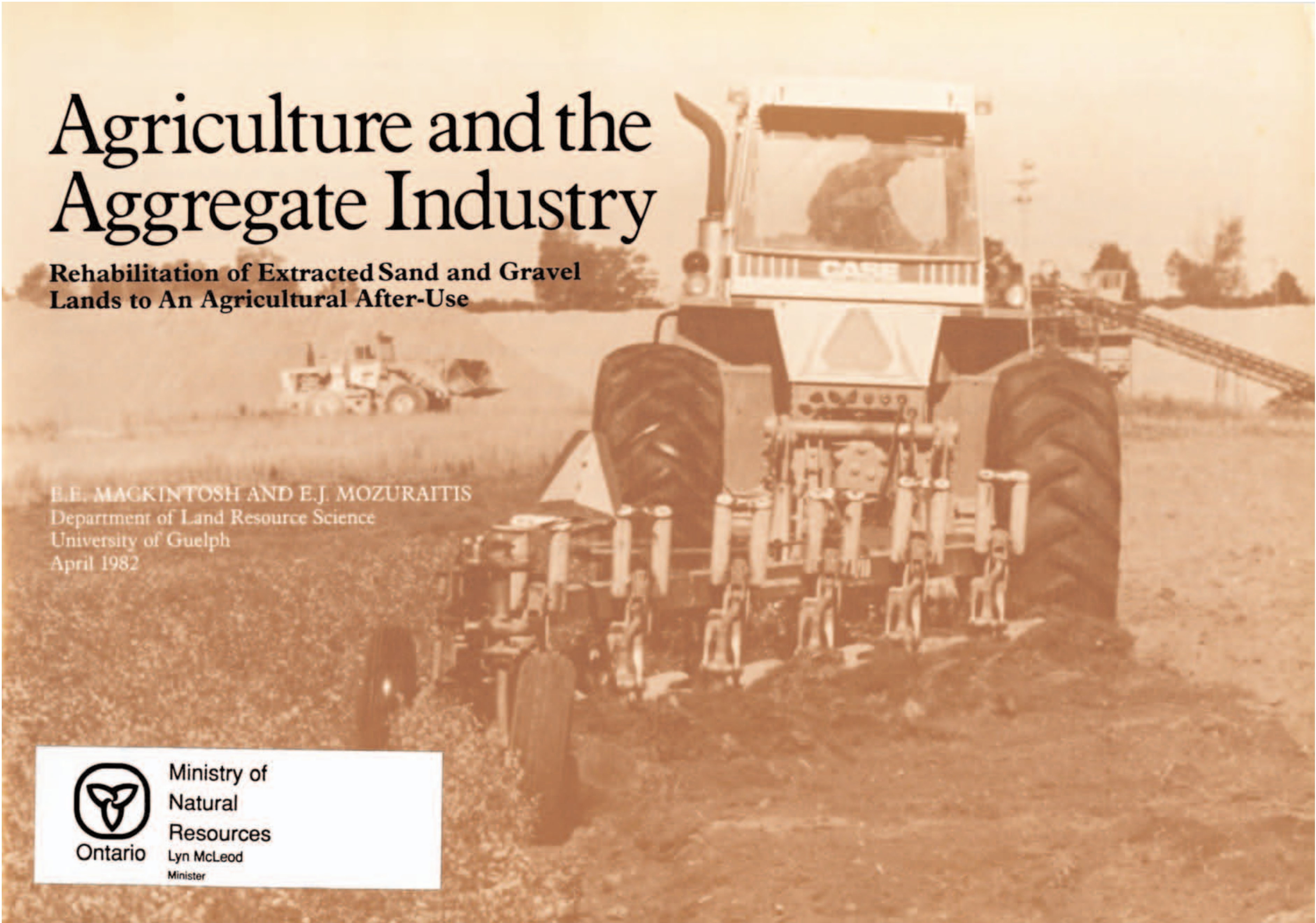
INDUSTRIAL MINERAL BACKGROUND PAPER 3

Parts of this publication may be quoted if credit is given to the Ontario Ministry of Natural Resources, Mineral Resources Branch. It is recommended that reference to this report be made in the following form:

Mackintosh, E.E. and E.J. Mozuraitus
1982: Agriculture and the Aggregate Industry: Rehabilitation of Extracted Sand and Gravel Lands to An Agricultural After-Use; Ontario Ministry of Natural Resources, Mineral Resources Branch, Industrial Mineral Background Paper 3 (IMBP 3), 44pp.

ISSN 0228-7811
ISBN 0-7743-7129-3

(cover photograph courtesy of TCG Materials Ltd.)



Agriculture and the Aggregate Industry

Rehabilitation of Extracted Sand and Gravel Lands to An Agricultural After-Use

E.E. MACKINTOSH AND E.J. MOZURAITIS
Department of Land Resource Science
University of Guelph
April 1982

Ministry of Natural Resources
Ontario
Lyn McLeod
Minister

Contents

Background

The increased competition and pressures on rural lands during the past decade has made the general public more aware of the need for wise management and stewardship of our agriculture lands. In response to this pressure, it is increasingly common for members of the aggregate industry to restore extracted sand and gravel lands to agricultural production. Considerable progress has been made in site reclamation to recreational land uses[4,11] such as playgrounds, parks, conservation areas and residential sites since passage of the Pits and Quarries Control Act[8]. However, there is a lack of available information on the best procedures to use in rehabilitating for an agriculture after-use.

Preliminary evidence[6] also suggests that there is considerable overlap between high quality aggregate lands and high quality agriculture lands. The source material for both industries are derived from glacial material overlying sedimentary bedrock formed during the Pleistocene glaciation, between 7,000 and 16,000 years ago. Deposits consist of outwash plains, outwash channels, kames, eskers and glacial lake deposits. Several of these deposits, outwash plains for example, represent a primary source for sand and gravel; and as well, they form the parent material for prime agricultural soils.

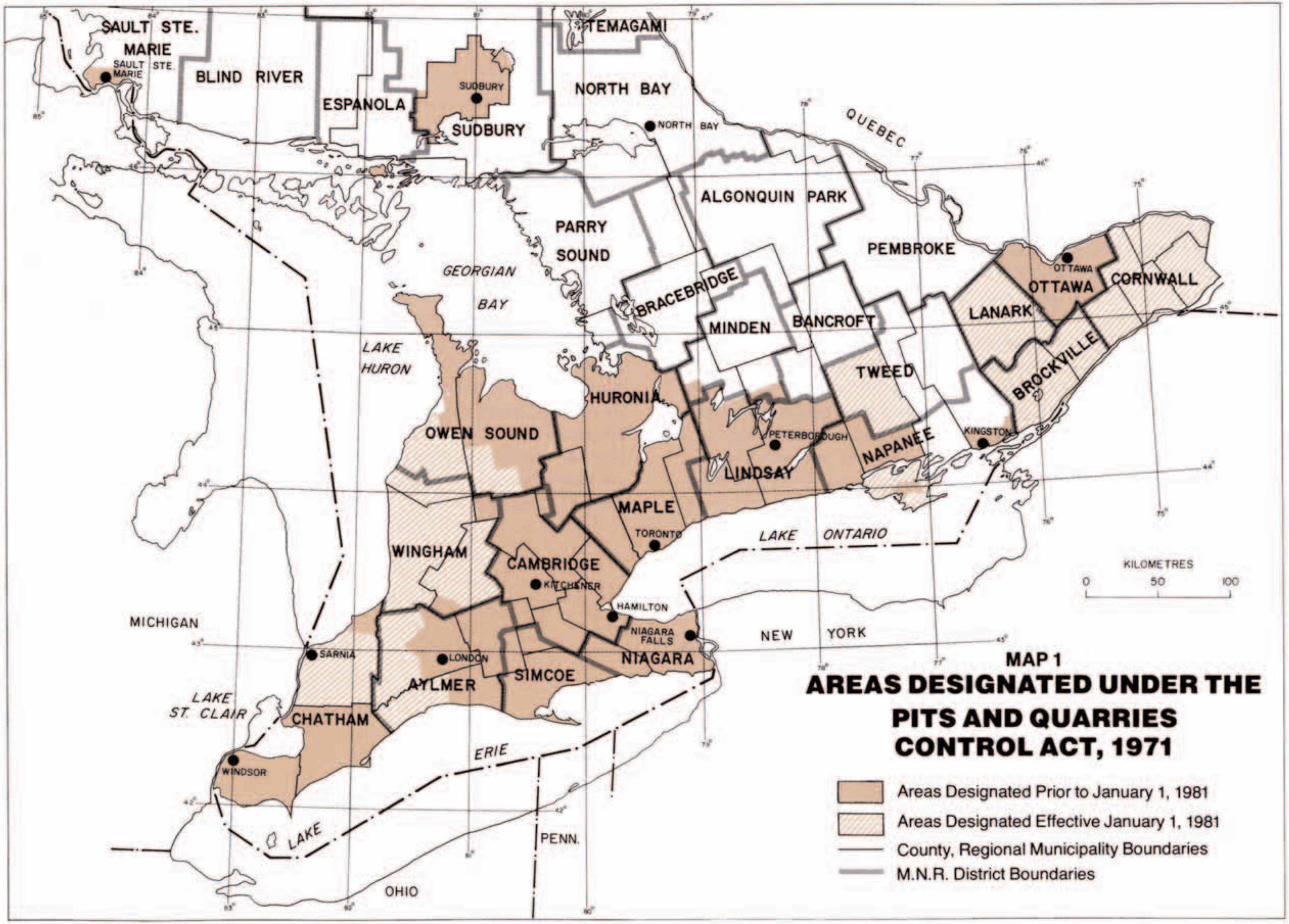
As a result of 1) the forecasted demands for sand and gravel; 2) government policy on preservation of agricultural lands as set out in the Food Land Guidelines[10]; and 3) the fact that most of southern Ontario is now designated under the Pits and Quarries Control Act[8] (Map 1), conflict between the aggregate and agricultural industries is inevitable. Rationalizing competing demands between these land-uses will become increasingly important in the future and the concept of land reclamation may present one alternative solution to the problem.

In view of the foregoing, the Industrial Minerals Section, Ontario Ministry of Natural Resources, funded a two year research contract with the Department of Land Resource Science, University of Guelph, to investigate various issues related to the rehabilitation of agricultural lands. Details of the study are reported elsewhere.

Planning for Agriculture and the Food Land Guidelines

The Food Land Guidelines[10] is a policy statement of the Government of Ontario on planning for agriculture. The policy document describes how to identify and inventory agricultural resource lands, establishes priority ratings on these lands in terms of their value to agriculture as a basis for allocating lands within a municipality, and develops land use designations and supporting policies for official plans.

Two different classes of lands are identified as being important for continuing agriculture production: those lands classed as arable croplands (Classes 1-4 inclusive) in the Canada Land Inventory[5], soil capability classification for agriculture; and those lands designated as specialty crop areas. The former lands are described in Appendix 4. Specialty crop lands depend on a combination of climate and/or soil conditions which supply the specific needs of certain crops such as tree fruits and vegetables. The Niagara Region (tree fruits), the Holland Marsh (vegetables), and the Norfolk sand plains (tobacco) are examples of specialty crop areas. They are limited in extent, and produce crops which otherwise would not be available locally.



MAP 1
AREAS DESIGNATED UNDER THE PITS AND QUARRIES CONTROL ACT, 1971

In addition to identifying those lands important to maintaining a viable agriculture industry, the 'Food Land Guidelines' also addresses the issue of sorting out competing demands for land. Specifically, it addresses the critical issue of maintaining agriculture lands within the rural-urban fringe zone where the tendency is for lands to lay idle or vacant until construction occurs. Of crucial importance to the aggregate industry is the recognition in the guidelines that the conflict between the competing demands of the aggregate and agriculture industries for land need not be severe. The reasoning behind this statement is the recognition that extractive areas can be rehabilitated for agriculture purposes in many instances. Thus, the concept of interim land use or sequential land use is well established in developing planning policy for agriculture lands. Recognition of this fact is also evident in many other areas such as the strip-mine coal areas of Canada and the United States, the Rhein brown coal areas of Germany, and the aggregate mines of Great Britain.

This area is predominately Class 1 and 2 soils for agriculture. The objective of rehabilitation should be to restore the land to an equivalent pre-extracted productivity level.

These lands are Class 5 and 6 for agriculture due to slope limitations. If desired, lands of this nature could be upgraded to a higher capability class by a proper rehabilitation program.

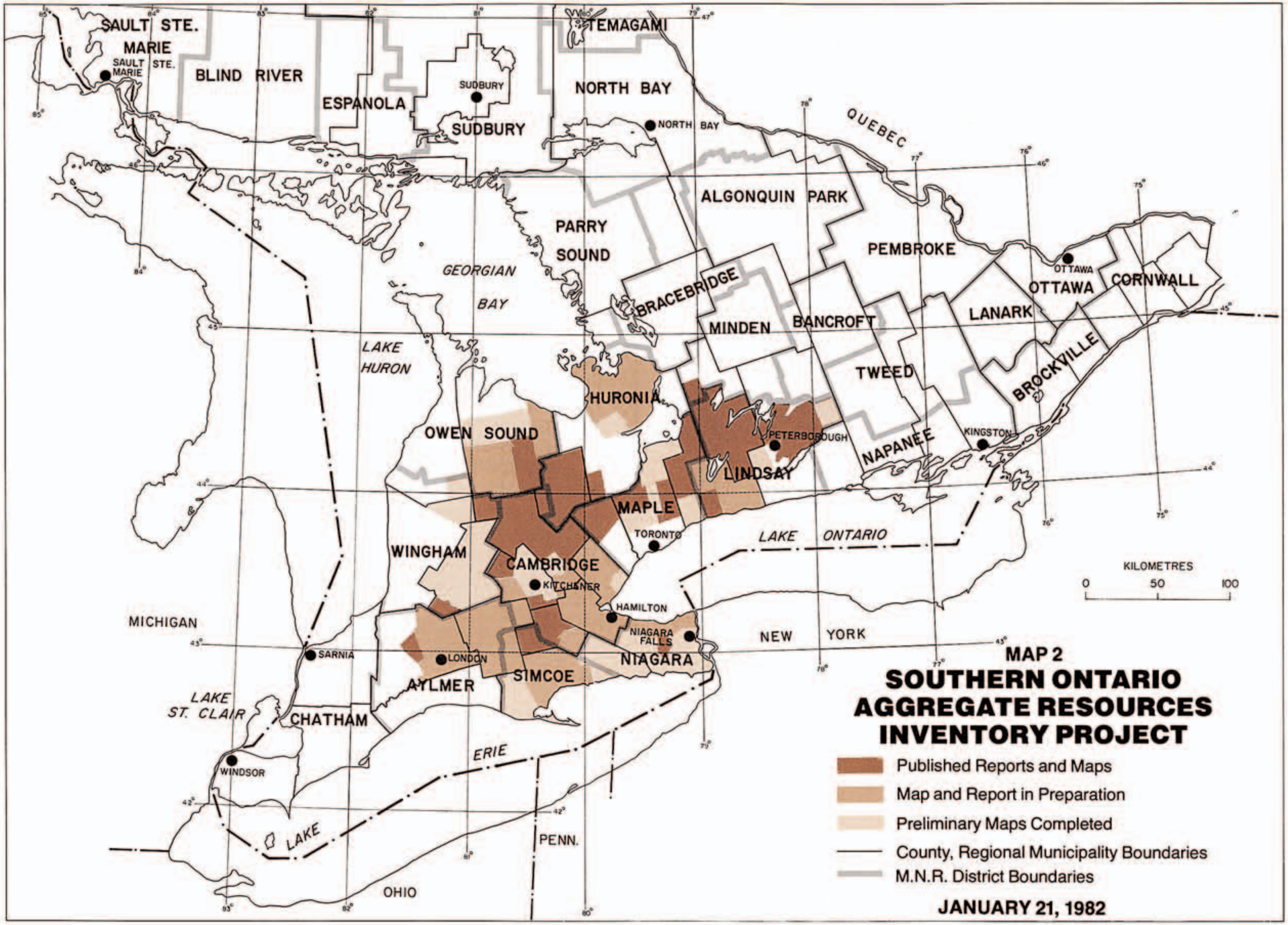
Coincidence of Prime Aggregate and Prime Agricultural Lands

Until recently it has been difficult to obtain an accurate estimate of the area of prime agriculture lands that were underlain by commercial deposits of sand and gravel. The Aggregate Resources Inventory Program (ARIP; Map 2), sponsored by the Ontario Geological Survey, Ministry of Natural Resources, now makes this comparison possible.

The purpose of the A.R.I.P. is to provide the basic geological information required to include potential mineral aggregate resource areas in planning strategies and official plans. Comprehensive planning and resources management strategies are required to make the most efficient use of available resources for the future. The aim of the reports is to assist decision-makers in protecting the public well-being by ensuring that an adequate supply of mineral aggregate remains available for future use.

The program rates all deposits as being of primary, secondary or tertiary economic importance to the sand and gravel industry. An A.R.I.P. report is published by township and includes a 1:50,000 scale map showing the distribution of the deposits. To obtain a measure of overlap between prime aggregate and agriculture lands, A.R.I.P. maps were simply overlain onto the 1:50,000 scale soil capability for agriculture maps[5, 7] and the area of coincidence measured (Table 1). This information has been recorded by township, but is summarized here according to Ministry of Natural Resources Districts (Map 1; Appendix 1) as hectares of prime agriculture lands (Soil Capability for Agriculture Classes 1-3) overlying primary, secondary and tertiary aggregate deposits.

The most economically viable land to extract for sand and gravel are the primary deposits. Many large scale commercial operations are located in primary deposits, and to a lesser extent secondary deposits, whereas smaller operations and wayside pits are often found in secondary and tertiary deposits. The main area for concern between the two industries will obviously focus on lands designated as primary aggregate reserves and as well some secondary deposits. This overlap will inevitably lead to conflict which can be reduced and/or avoided by the implementation of sound rehabilitation programs. Although there are large areas of tertiary deposits it is doubtful if significant amounts of extraction will occur on these lands; hence, the potential for conflict with agriculture should be minimal.



MAP 2
SOUTHERN ONTARIO AGGREGATE RESOURCES INVENTORY PROJECT

Table 1. The Area of Prime Agriculture Lands Overlying Primary, Secondary and Tertiary Aggregate Deposits in Southern Ontario.

O.M.N.R. District	Type of Aggregate Deposits					
	Primary		Secondary		Tertiary	
	Hectare*	Per cent**	Hectare	Per cent	Hectare	Per cent
Aylmer	6,812.6	1.0	21,259.6	3.2	53,000.2	8.0
Brockville	30.2	0.1	3,161.6	2.9	12,204.9	11.2
Cambridge	31,449.2	6.2	23,355.1	4.6	69,314.2	13.7
Carlton Place	167.3	0.1	2,248.3	1.3	9,891.5	5.6
Chatham	3,343.0	0.5	3,182.3	0.5	63,592.1	9.8
Cornwall	0.0	0.0	3,795.4	1.1	21,007.1	6.3
Huronia	11,388.8	3.5	12,307.4	3.8	92,194.8	28.7
Lindsay	3,018.7	0.9	20,797.3	6.0	49,693.1	14.4
Maple	11,693.6	4.4	16,368.0	6.1	26,624.0	9.7
Napanee	210.6	0.1	4,148.2	1.5	7,000.2	2.4
Niagara	1,083.6	0.4	2,418.6	1.0	11,595.3	4.8
Owen Sound	14,267.7	3.7	17,512.8	4.5	20,171.2	5.2
Simcoe	3,662.3	2.3	941.2	0.6	30,950.7	19.5
Tweed	183.8	0.5	1,984.8	5.9	211.0	0.6
Wingham	4,331.3	0.8	33,321.1	5.8	19,449.3	3.4
TOTAL	91,678.5	—	167,269.9	—	485,582.9	—

* The total area in hectares of aggregate deposit underlying classes 1-3 lands by O.M.N.R. District.

** The per cent of the total area of Soil Capability Classes 1-3 within each O.M.N.R. District that is underlain by different types of aggregate deposits.

An Evaluation of Agricultural Rehabilitation in Ontario

To assess the state of the art in agricultural rehabilitation of extracted sand and gravel lands, a study was carried out in 1980 to inventory and evaluate reclaimed sites located throughout southern Ontario. The principal objectives were:

- to provide an inventory of sites rehabilitated to an agriculture after-use
- to evaluate the success of the rehabilitation procedures
- to determine the major problems encountered during and subsequent to rehabilitation.

The study has been reported in full, and provided a basis for the recommended rehabilitation procedures discussed in detail in subsequent sections of this publication. A summary is given below.

Study Method

The study was carried out in the Ontario Ministry of Natural Resources (O.M.N.R.) Administrative Districts located throughout southern Ontario (Map 1; Appendix 1). Sample sites were chosen from a list compiled by O.M.N.R. of sand and gravel producers reporting agricultural rehabilitation. After an initial investigation, sixty-three sites (Map 3; Appendix 2) were chosen for study on the basis of: location within the study region; sand and gravel was extracted rather than clay or stone; and the after-use was genuinely agriculture.

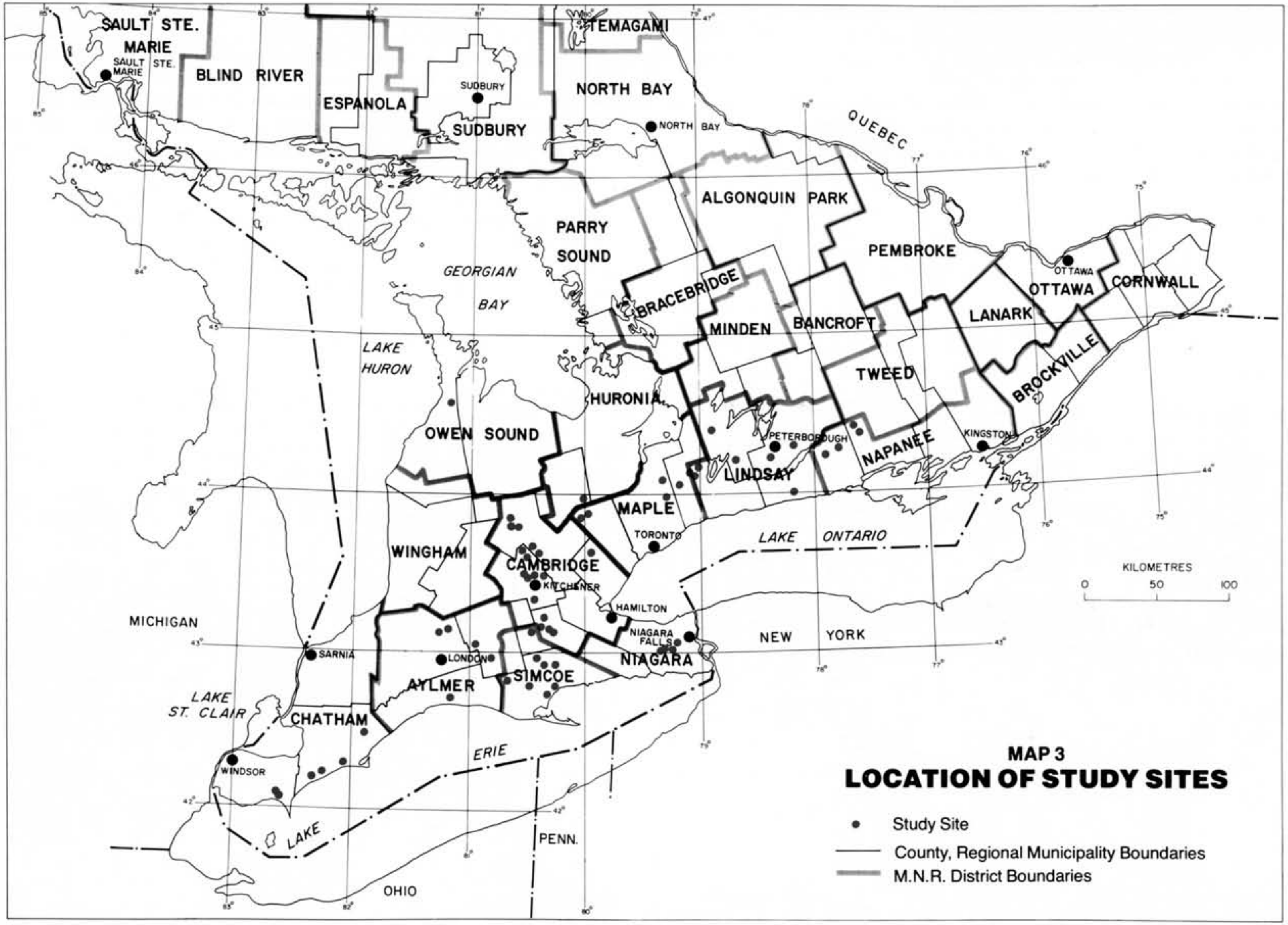
Standardized field sheets were developed and information recorded during onsite inspections included slope, drainage, surface stoniness, depth of soil replaced including topsoil and/or subsoil, composition of the soil replaced, extent of soil compaction, soil fertility, vegetative cover, and a rating for soil capability for agriculture.

A questionnaire was also designed to aid in establishing a history of conditions during rehabilitation for each site, and the post rehabilitation management program. The questionnaire was completed by interviewing personnel from the respective companies or local area farmers who were directly involved in the post rehabilitation management programs.

The Extent and Success of Agricultural Rehabilitation

Most examples of site restoration to an agriculture after-use in southern Ontario are small in size; indeed, approximately 70 per cent are less than three hectares in area and only two sites include more than ten hectares. A complete range of agricultural crops are grown on the properties including grain corn, soybeans, tobacco, coarse grains, forages (grasses and legumes), and tree fruits (apples and sour cherries).

To obtain some measure of the success of the restoration programs, the rehabilitated soil capability class was compared to the pre-extraction capability class obtained from the 1:50,000, C.L.I. maps. Because the majority of sites are less than three hectares in size, there is potential for considerable error in this analysis. The minimum area shown on the original county soil surveys which are the basis for the 1:50,000 C.L.I. maps is about ten hectares which means that many of the rehabilitated sites



MAP 3
LOCATION OF STUDY SITES

could be a higher or lower capability class than shown. In spite of these limitations, if one uses pre- and post-extractive soil capability class as the criterion for success, 60-70 per cent of the sites studied can be considered as successful in their rehabilitation programs. Considering the lack of guidelines available to the industry on rehabilitation to agriculture, the success rate is remarkably good and presents an optimistic outlook for rehabilitation programs in the future.

Problems Encountered in Rehabilitation

A problem common to many rehabilitated sites and certainly one that is characteristic of abandoned pits is the absence of topsoil, and in many instances subsoil, for site reclamation. Mixing of topsoil and subsoil was also a common limitation. Prior to there being requirements for site rehabilitation, topsoil and subsoil were often sold as an additional source of revenue and were not available for restoration purposes in pits prior to 1971. Consequently, reclamation of most older pits to an agriculture use could involve costly purchase of topsoil and/or subsoil. Indeed, costs could be so high as to prohibit reclamation for agriculture and an alternative land use should be sought. At a minimum, 15 to 20 cm (6-8 inches) of topsoil is required for optimum restoration conditions.

Poor drainage (excessive wetness) was a problem encountered on several reclaimed sites. It originates from one of several conditions: extracting down to water table levels or below ground water levels; extracting down to underlying impermeable layers of silty or clayey materials which could create saturated water conditions; and/or failure to design outlets for surface runoff from the site.

From an agriculture standpoint, a minimum of one meter of combined topsoil and subsoil overlying a zone saturated with water is desirable for

Rehabilitation of a sand and gravel pit for Sour Cherry production
(courtesy TCG Materials Limited, Fonthill Pit).

Following several years under forages, it is possible to grow common field crops successfully. Corn field on the rehabilitated Wooddisse Wayside Pit, Maryborough Township.

adequate plant growth during the growing season.

A number of other problems were also observed but these were related to detailed rehabilitation measures that arise from inexperience of the operators in reclamation procedures and can be readily corrected. Some of these include excessive stoniness, subsequent cropping programs, compacted pit floors and inadequate treatment of applied topsoil and subsoil to ameliorate compaction problems.

Many soils overlying sand and gravel deposits are stony by nature. As well, some mixing of topsoil/subsoil with the underlying sand and gravel deposit during stripping operations may also increase the stone content. Consequently, a post reclamation management program will often involve a stone picking operation.

One of the most common failures encountered in the post rehabilitation management programs was concerned with crop choice. There was a definite tendency toward growing corn or other grain crops immediately following site rehabilitation. The preferred crops are forages which should include a deep rooted legume such as alfalfa. These crops add organic matter back into the soil to build up natural soil fertility levels and improve soil structure. As well, deep rooted legumes also tend to reduce soil compaction which is one of the more common limitations noted on many properties.

If soil compaction is too severe, deep tillage operations using agricultural subsoilers or related equipment may be required to ameliorate the problem.

Costs of Agricultural Rehabilitation

Under the new regulations of the Pits and Quarries Control Act an operator is required to pay 8¢ per tonne of material removed in the

Rehabilitation of a Sand and Gravel Pit for Agriculture - Northumberland County. Before (left) and After (right)

Crop of Alfalfa - The light grey patches are a result of lack of topsoil and excessive droughtiness. Where the availability of adequate topsoil and/or subsoil is a problem serious consideration should be given to permanent pasture or some alternative non-agricultural land use.

previous calendar year as a security deposit to ensure future rehabilitation of the site. The maximum security deposit paid in is $3,000 per hectare for each hectare requiring rehabilitation or where progressive rehabilitation is being practiced, the security deposit may be reduced to a minimum of $1,000 per hectare.

Using the O.M.N.R. rehabilitation claims reports for the Cambridge District the cost of rehabilitation to agriculture ranged from $1,712.21 to $13,710.68 per hectare. On a metric tonnage basis, the average cost of the successfully rehabilitated sites was 4.6¢ per tonne, ranging from 3.5 to 5.5¢ per tonne. These costs included all necessary earth moving, trimming, grass seeding and mulching, and the initial planting of grass and legumes, together with chemicals and fertilizers.

Using the information presented here, it appears as though the 8¢ per tonne security deposit is adequate to ensure successful rehabilitation to an agriculture after-use. Further, once a portion of a pit is depleted, it no longer brings the operator any returns while in its unrestored state. Unless sold, which is highly unlikely, it is to the producer's advantage to rehabilitate in conjunction with extraction.

Progressive rehabilitation is less costly at this stage since the necessary equipment is readily available and most of the soil is handled only once. The minimum amount of security deposit required will be lower as the amount of land still requiring rehabilitation is reduced. This in effect increases the amount of money that is reimbursed from the fund to the producer and lowers his production costs.

Conclusions

The overall success of sites rehabilitated to an agricultural after-use offers encouragement and optimism for rehabilitation as one solution to the obvious future conflict between prime aggregate and prime agriculture lands. Successful examples of rehabilitation provide an excellent demonstration of what can be achieved with good planning and careful practices.

In spite of the success with which a wide range of agricultural crops have been grown on rehabilitated sand and gravel lands, there is a need for improved practices. Of critical importance is the need for pre-planning to ensure successful completion of the restoration operation. In particular, this study demonstrated an obvious need to strip and retain all topsoil and subsoil from a site; to pay closer attention to the depth of extraction in relation to water table levels; and, the need for developing a well planned, post rehabilitation management program.

An improvement in the type and quality of information available for development of sound rehabilitation plans would also be helpful. Subsequent sections of this publication are intended to supply some of this information, by clarifying techniques available to operators and by providing an assessment of the types of information required to design a suitable rehabilitation program.

Soil Characteristics Affecting Plant Growth

The term soil, as used here, is defined as a medium for the growth of plants which furnishes the plant with an anchor for its roots as well as nutrients, water, and oxygen for growth and reproduction. The main characteristics of soil that can be used to assess its value for agricultural crops, including fruits and vegetables are:

- soil texture
- soil structure
- soil compaction
- available soil water storage
- soil drainage
- stoniness
- soil depth
- relief

Topsoil/Subsoil/Overburden

Three distinctive zones of soil are recognized in the rehabilitation of sand and gravel lands: topsoil, subsoil, and overburden (Figure 1). Topsoil and subsoil are the most important layers for plant growth and where possible, should be stripped separately from the overburden. The terms are defined as follows:

Topsoil: This is the uppermost zone of the soil and is recognized by the darker color caused by the accumulation of organic matter. On arable, agriculture lands, it is normally restricted to the depth of cultivation which is about 15 to 30 cm (Table 2).

The key component of topsoil is organic matter. It promotes the development of good soil structure and improves soil strength characteristics, both of which are critical for a soil to withstand the mechanical pressures from agricultural machinery. As well, organic matter improves the water holding capacity of the soil and supplies nutrients for plant growth.

Table 2: The Relationship of topsoil/subsoil/overburden to Soil Horizons.

Type of Layer	Corresponding Soil Horizon*,[3]
Topsoil	Ap and Ah
Subsoil	all A horizon material below the Ap/Ah all B horizons upper C horizons
Overburden	lower C and II C horizons

*terminology used in county soil survey reports.

Subsoil: This is the zone immediately beneath the topsoil and may extend to a depth of one metre or more (Table 2). Under natural conditions, the subsoil is often well structured, and contains numerous plant roots. Indeed, during summer drought periods, plants may obtain much of their moisture requirements from this zone.

The subsoil is low in organic matter and often contains an accumulation of clay-sized particles. If exposed to mechanical pressures caused by heavy machinery, the subsoil will readily compact causing a reduction in water movement and root penetration. This effectively reduces the volume of soil available for plant growth and unless corrected, yield levels will fall off significantly.

Overburden: The term 'overburden' is restricted to all material lying between the subsoil and the workable sand and gravel deposit. Many sand and gravel deposits in Ontario do not contain overburden material. Engineers often use the term to refer to materials lying above the workable deposit, including topsoil and subsoil. However, the term is used here in the more restricted sense. Often the material below the subsoil is undesirable for agronomic purposes and it should be handled separately in the stripping and restoration process. If the overburden is of good quality it can be used as a source of subsoil, but its suitability will have to be determined on an individual site basis.

Soil Texture

Soil texture is usually described by words such as loam, sand loam, or silty clay which can be assessed qualitatively by hand in the field. The chemical and physical properties of soils are closely related to soil texture. For instance, soils with high sand and gravel contents are porous, hold little water and drain well. In contrast, a high clay content is a major factor contributing to swelling, shrinking, stickness, water retention, and often poor drainage in soils.

Soil texture is not altered by normal agriculture practices and should not be confused with soil structure which can readily be altered by mechanical forces.

Soil Structure

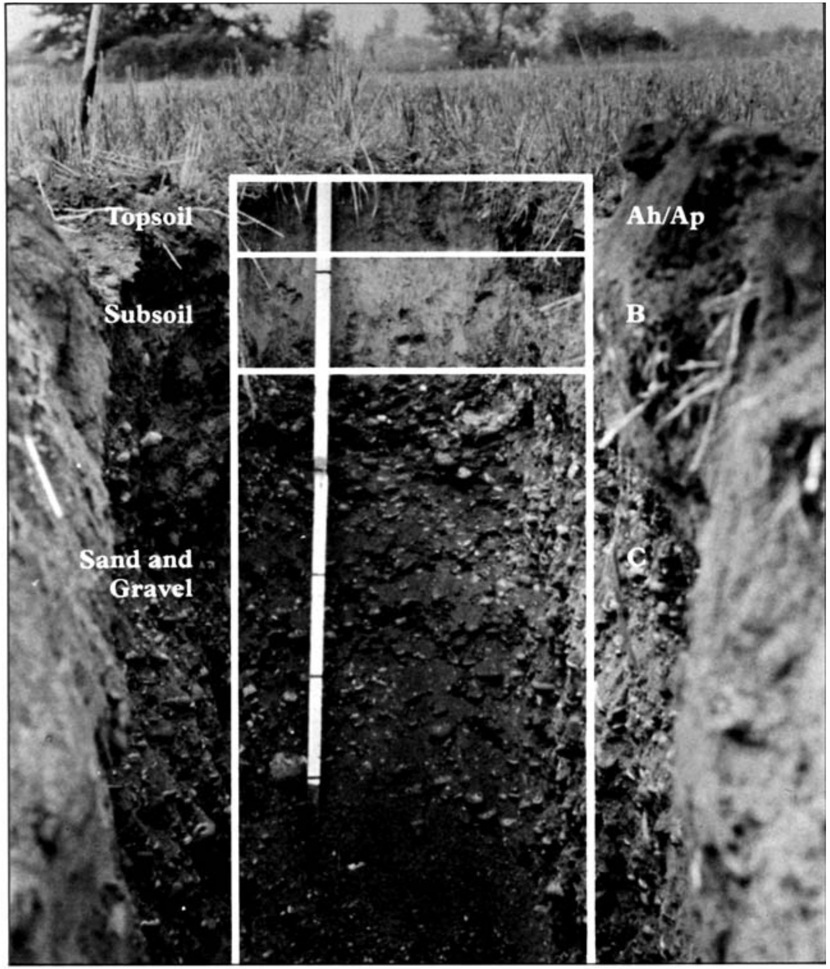
While soil texture refers to the size and amount of mineral particles, soil structure refers to the physical arrangement of mineral and organic particles into granules, peds or clods of different sizes and shapes. Because the individual soil particles do not pack closely together to form the maximum density possible, these granules contain pores and channels which fill with air and water. In a normal soil, 50 to 60 percent of the soil volume consists of these voids which provide openings for air and water movement and root entry. The roots of most agriculture crops will not grow in soils when the amount of pore space falls below 35 to 40 percent.

The main agents responsible for binding the individual soil particles together are clay, decomposed organic materials, iron and aluminum oxides, and plant roots. The most important of these agents is organic matter which is why the preservation of topsoil is so important in a land rehabilitation program.

Cultural practices modify soil structure. For example, the growth of most forage crops promotes the development of good soil structure. In contrast, mechanical operations may destroy soil structure and cause soil compaction. In extreme conditions, compaction may be so severe as to form hard, indurated pans that restrict entry of both roots and water.

The formal terms for the description of soil structure are given in the Ontario Institute of Pedology publication 'Field Manual for Describing Soils'[1].

Figure 1 - Soil Horizons (Topsoil and subsoil should be stripped and stored separately for rehabilitation purposes. Many sand and gravel deposits in southern Ontario do not contain an overburden layer).



Soil Compaction

The degree of soil compaction determines both the size and amount of soil pores. Bulk density is used to describe the degree of compaction of a soil. It is a measure of the weight of dry soil per unit volume expressed as grams per cubic centimetre (g/cm^3). Under field conditions, values for sandy soils are 1.4 to 1.6 g/cm^3; other soils 1.2 to 1.4 g/cm^3; and compacted soils up to 1.7 to 2.2 g/cm^3. Bulk densities of 2.0 g/cm^3 are not uncommon on pit floors due to heavy vehicular traffic, and compare with 1.2 to 1.3 g/cm^3 in the more loosely spread soils. It is generally agreed that root penetration of most crops is severely restricted at densities of 1.6 g/cm^3 and greater. Consequently, it is important to maintain bulk density at low levels in order to promote optimum conditions for plant growth (Figure 2).

Available Soil Water Storage

This is one of the most important characteristics of a soil for plant growth. It is a measure of the amount of water that crops can extract from the soil and is directly related to soil texture. The available soil water storage on a volumetric basis can vary as follows:

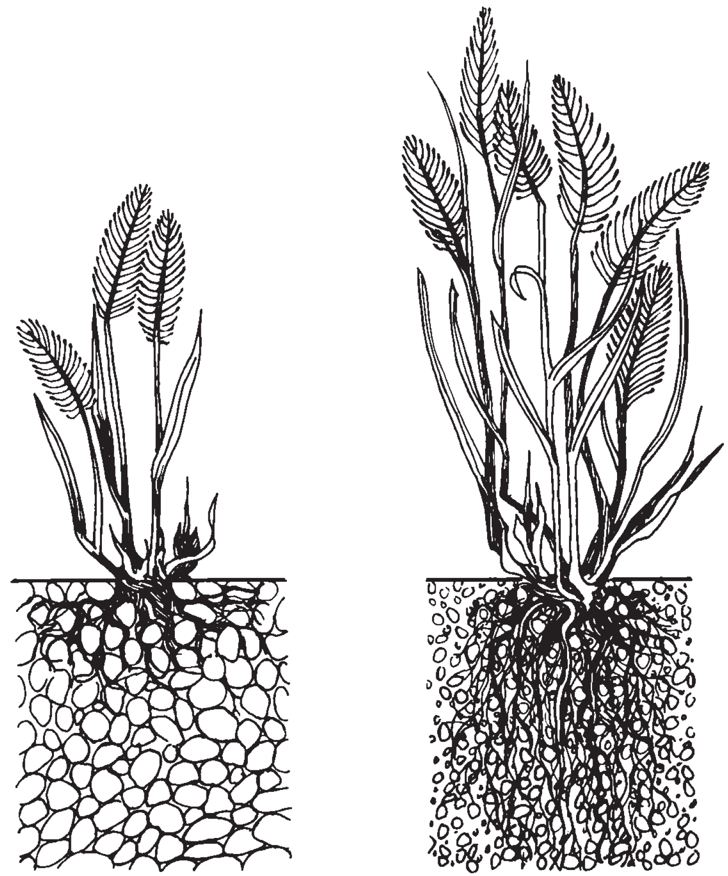
clay - 5%	sandy loam - 12%
clay loam - 10%	sand - 4%
silt loam - 18%	

Two points are evident from this. Firstly, soils vary considerably in their ability to supply water to plants. As an example, coarse textured gravelly soils often contain less than 1 cm of available water holding capacity per 30 cm of soil depth. Secondly, this means that plant roots must be able to penetrate up to a metre or more into the soil to obtain adequate soil moisture reserves, although the majority of plant roots are located within 15-25 cm of the soil surface.

Soil Drainage

When water fills all of the spaces or pores between the soil particles, the soil is said to be saturated. If this situation persists over a long period of time air movement is restricted and the soils may become devoid of oxygen, i.e. anaerobic. Plant roots require oxygen to function properly and their growth is severely restricted under anaerobic conditions.

Figure 2 - Schematic diagram illustrating root penetration and soil aeration (Root penetration and soil aeration are severely restricted in compacted soils (left). Roots will not normally penetrate soils with a bulk density greater than 1.6 - 1.7 g/cm^3. In porous, well structured soils (right) root penetration and soil aeration are not limiting plant growth).



Soils may become saturated with water for a number of reasons. Excess water that fills the soil pores normally moves vertically downward in a soil and its rate of movement is determined by soil texture and structure. Any marked change in soil texture or structure can impede this downward movement of water and cause saturation and/or horizontal movement of water to occur. Compacted layers created by heavy equipment or the presence of hard pan also cause similar problems.

The level of the underlying water table can also cause soil wetness. In low lying areas the level of the water table is often within the plant-root zone which effectively reduces soil depth.

The duration of time which excess water remains within the plant-root zone is used as criteria to determine the soil drainage class. As one progresses from well through imperfectly, poorly and very poorly drained soils, the duration of time a soil remains saturated increases. Under field conditions, soil drainage class is assessed visually by such things as soil color.

Most agricultural crops grown on poorly or very poorly drained soils require artificial drainage in the form of open ditches or tile drains to survive.

Stoniness

Stoniness is a common problem associated with soils overlying sand and gravel deposits. The presence of stones has two effects on agricultural land. Firstly, in mechanized farming practices, the presence of an excessive amount of stones hinders cultivation, seedbed preparation, and at times, may cause damage to farm equipment. Secondly, as the stone content increases, the volume of soil available from which the plant roots can extract water and nutrients decreases.

A post rehabilitation management program will therefore, often contain a stone removal program. The quality of some lands can be improved by stone picking operations.

Excessive stoniness restricts mechanized farming and reduces crop yields
(Courtesy TCG Materials Limited)

Soil Depth

In the production of agricultural crops, this usually refers to the effective depth of soil which permits entry of plant roots to sustain their growth. Root growth can be restricted by compacted layers of soil, bedrock, indurated pans caused by cementing agents such as iron and aluminum oxides, silica and calcium carbonate, waterlogged conditions, toxic chemicals or by consolidated subsoils.

The following definitions are commonly used in Ontario soil surveys with respect to rooting zones overlying bedrock:

- very shallow	- less than 20 cm
- shallow	- 20-50 cm
- moderately deep	- 50-100 cm
- deep	- greater than 100 cm

A decrease in soil depth reduces the effective volume from which plants can extract plant nutrients and soil water.

Relief

The principal components of relief are elevation, slope and exposure or direction of slope. The primary influence of relief is through its effects upon water drainage, runoff and erosion. Secondary effects are associated with variations in exposure to sun and wind, and air drainage.

It is important that the rehabilitated land surface be graded to ensure adequate drainage of water. A gradient (or slope) of 2-5 per cent is desirable for proper development of microdrainage channels for surface runoff and drainage. As well, the original pit floor should be reshaped by grading so as to prevent development of closed drainage depressions and provide for adequate subsurface drainage.

Site Planning: Assessing the Feasibility of Rehabilitating to an Agriculture After-Use

Of all the recommendations presented herein, the most crucial factors in determining the overall success of a rehabilitation program are adequate pre-planning and the need for progressive rehabilitation. The primary objective is to ensure orderly extraction and restoration according to a comprehensive plan developed prior to initiation of extraction. Pre-planning for agriculture rehabilitation will determine the feasibility of restoration to an agriculture use and provide a set of guidelines to ensure the final plan is in accordance with that goal. Strict supervision of each phase is an essential component of a successful rehabilitation program.

One of the most common problems encountered when determining the feasibility of rehabilitating extracted sand and gravel lands for agricultural production (before extraction is started) is the lack of adequate baseline information. This information should include documentation of:

- surrounding land uses
- surface drainage pattern
- depth to watertable
- hydrogeology of site
- depth of extraction
- stratigraphy of the site
- composition of substratum immediately beneath the pit floor
- topsoil, subsoil and overburden, its distribution and thickness
- composition of the topsoil, subsoil and overburden
- soil capability for agriculture rating
- crop yields

Information on the stratigraphy and hydrology of a site can be obtained from a hydrogeological investigation, while much of the remainder is available from surficial geology information and routine soil surveys. In all cases, a detailed site investigation is required as the general purpose surficial geology and county soil survey maps do not contain sufficient detail to allow for proper site planning.

Surrounding Land Uses

All site plans should include documentation of surrounding land uses. Sand and gravel operations often occur in agricultural areas and it is desirable, therefore, to rehabilitate these operations to an agriculture after-use. In many instances however, aggregate extraction occurs on the immediate urban fringe or in proximity to an urban area and rehabilitation for an agriculture after-use may not be compatible with surrounding land uses. As well, restoration of the original surface uses may or may not be physically or economically possible as a result of extraction procedures. Alternatives may have to be considered that do not involve the original land use.

Where aggregate extraction is carried out on productive farmland and restoration to an agriculture after-use is desirable, the primary objective should be restoration to equally productive farmland.

Geohydrology, Depth to Water Table and Depth of Extraction

Information on surface drainage, depth to water table, and the movement of ground water should be assessed for each site. An appraisal of the effects of the extraction program on surrounding site drainage is then possible.

If the goal of rehabilitation is to return the land to agriculture, the 'rule of thumb' is that approximately one metre of soil material should be left over the mean high water table level, otherwise fill and/or drainage is required. Where extraction occurs below the water table, backfill of adequate quality must be available to meet this requirement or alternatively, appropriate drainage outlets must be identified whereby it is also possible to design a drainage system to lower water table levels and dispense with the need for fill material. Both of these latter solutions can be extremely costly and a detailed cost analysis should be undertaken prior to entertaining either option. As well, a detailed assessment of the impact of lowering water levels on surrounding land uses is required.

Stratigraphy of the Site

A detailed stratigraphic report of a future sand and gravel extraction site is required to determine: the exact composition and value of the deposit; the contours of the pit floor; and, the composition of materials below the pit floor. The latter two points are required in devising a scheme for progressive rehabilitation. This information is required for locating the knobs, ridges and/or depressions on the pit floor in order to determine the amount of land levelling during progressive rehabilitation. Also, the composition of the pit floor is an important component in the development of the rehabilitation plan. For example, if the pit floor lies on impermeable or compressible silty and clayey material, severe soil compaction will occur, soil drainage will be impeded, and a perched water table condition causing excessive wetness will result.

Depth and Distribution of Surface Material

Information on the distribution and depth of topsoil, subsoil and overburden is required to develop a rehabilitation plan.

The depths of topsoil and subsoil should be mapped in detail for the entire site. This information is used in preparation of the stripping program, the amount of material to be stockpiled, and finally, the soil conditions that will form the basis for development of the post rehabilitation management program. It is important to obtain information on the variation in thickness of these layers so that all the material available can be carefully stripped and fully utilized during rehabilitation.

Composition of Surface Material

In addition to collecting information on the depth and distribution of surface material (topsoil, subsoil and overburden), its composition must also be known. In particular, stoniness and soil texture are two important considerations since it may be possible to improve the capability class by rehabilitation. Contouring of the pit floor can remove slope limitations, whereas stone picking can overcome limitations due to stoniness.

Soil Capability for Agriculture

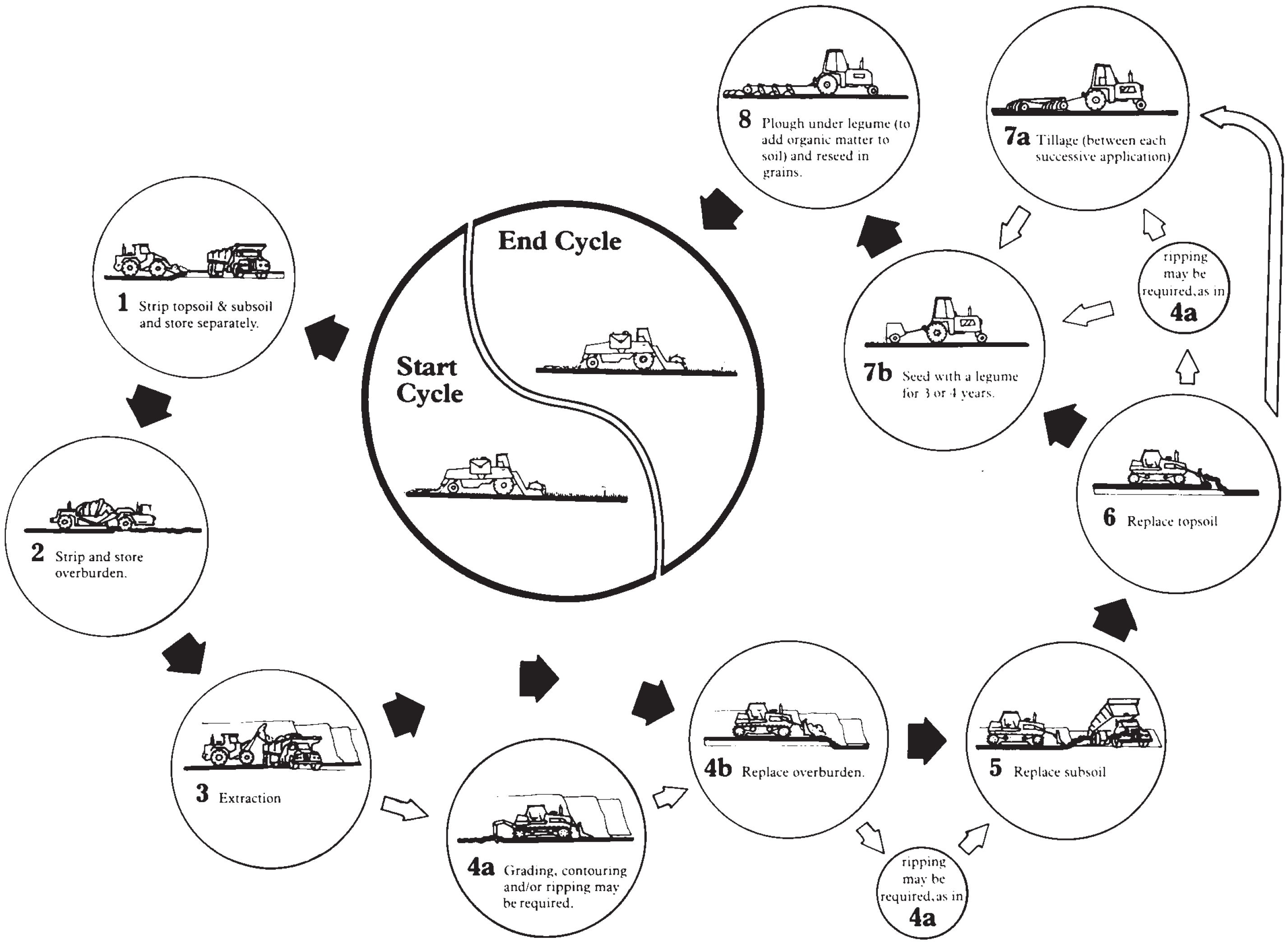
The site should be rated according to the 'soil capability classification for agriculture' prior to extraction. This serves as a benchmark against which to compare the success of the rehabilitation program in areas where adequate yield information is not available.

Steps to Successful Rehabilitation – The Recipé

Steps to successful restoration of agriculture lands can be summarized as follows (Figure 3):

1. Pre-planning.
   It is vital to know, in advance, what has to be done, but the plan should allow for modifications if these become necessary.
2. Strip the topsoil, subsoil, and overburden separately.
   The materials must be handled and stored separately. Do not intermix topsoil with other soil material.
3. Strip small areas at a time.
   Stripping off ground cover exposes the soil to increased erosion and sediment loss. Only strip small areas that can be extracted within a reasonable time.
4. Move soil materials under dry conditions.
   Soils are more easily damaged when wet and should be moved mainly during the drier months of June through September inclusive.
5. Rehabilitate progressively.
   Topsoil may deteriorate in storage i.e. berms, or may be lost. Progressive rehabilitation allows for direct movement of soil and prevents these harmful effects as well as reducing the cost of earth moving.
6. Grade and contour the pit floor.
   There must be an overall plan for draining the land including a drainage outlet for surface water runoff. Slopes between 2 and 5 per cent are desirable for agriculture purposes.
7. Replace overburden (if any), subsoil and topsoil in the correct sequence.
   There should be about one metre of topsoil/subsoil/overburden overlying ground water levels to provide for adequate plant growth.
8. Calculate volumes, depth and areas to be covered carefully.
   A common problem encountered is insufficient soil to finish restoration.
9. Eliminate severe soil compaction.
   Severe soil compaction can be avoided by moving soil materials when dry and by using lighter equipment. Where severe soil compaction has occurred, it may be necessary to undertake deep ripping (subsoiling) in conjunction with the reapplication of topsoil/subsoil/overburden.
10. A post rehabilitation management program is critical for success.
    A period of at least five years is required to restore the soils to their original pre-extracted productivity levels. The choice of crops is crucial and emphasis should be placed on increasing soil fertility and improving structure by use of legumes.
11. Use good agriculture practices.
    A local area farmer should be retained for undertaking agricultural operations. Strict control of choice of crops, deep tillage and fertilization should be exercised by the operator.
12. Be patient.
    Successful restoration is a slow process. Any attempt to shortcut the procedures outlined will only increase the opportunity for failure.

Figure 3 - Schematic diagram illustrating the different stages in rehabilitation for agricultural uses.



Pre-planning

The key component of a successful rehabilitation program is **site planning.** This involves the planning and programing of extraction activities and after-use design in advance of any extraction. Under the licensing of the Pits and Quarries Control Act, a site plan must be filed and should consist of three distinct parts:

- existing features
- operational plan
- rehabilitation plan

The value of the site plan is that it guides the direction and manner of excavation and rehabilitation so that the operator can plan the most efficient use of machinery and manpower. A lot of unnecessary work and expenses such as double handling of topsoil and overburden material can be avoided if a detailed site plan is used.

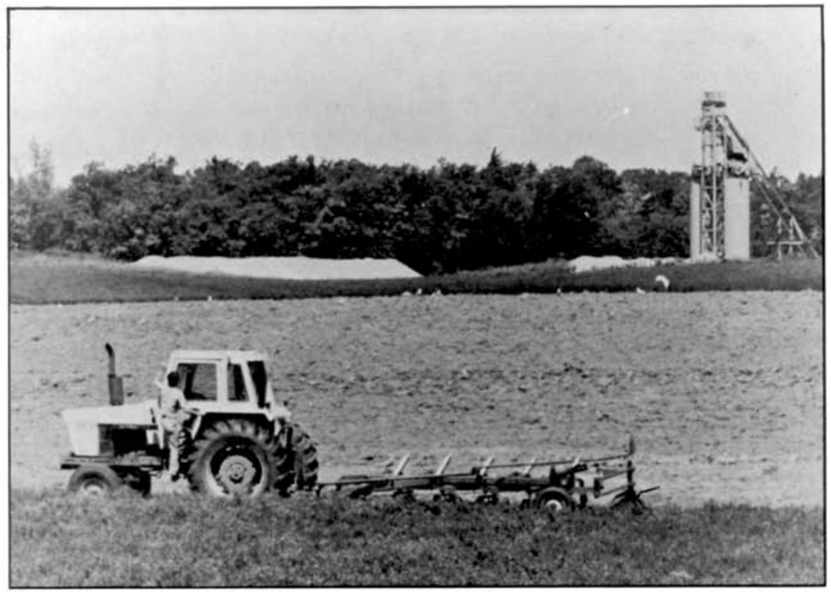
Because the requirements for rehabilitation of land to an agricultural after-use are more demanding than for many other land uses, it is of even greater importance to have completed an adequate assessment of the feasibility of agriculture rehabilitation, together with a proposed plan of action.

Stripping and Stockpiling

The topsoil, subsoil and overburden should be stripped and stockpiled separately. Much of the subsoil and/or overburden is required for constructing screening berms. Cost of earth moving can be significantly reduced by progressive rehabilitation during this phase of the operation.

A detailed soil map should be prepared for each site showing the depth of the various soil layers. These measurements are then used to develop a stripping plan. Topsoil can be identified by its dark colour and every

Progressive rehabilitation reduces cost and also reduces the length of time a site is taken out of agriculture production *(courtesy TCG Materials Limited).*



precaution should be taken to maximize the amounts of topsoil removed without diluting it significantly with material from lower horizons, i.e. subsoil.

Saving topsoil is critical to the overall success of rehabilitation. Its high content of organic matter, natural high fertility and water holding characteristics makes it an ideal material for plant growth. The quality of topsoil may deteriorate during storage; the exact nature of the changes is not well understood but there are shifts in soil fungal dominants and mycorrhizae and the loss of other micro-organisms. However, micro-organisms can remain dormant for several years without adverse affects. Interference with root development or changes that could effect the cycling of plant nutrients such as carbon, nitrogen and phosphorus seem to be only temporary in nature. As a general rule however, topsoil should not be stored for more than about four to five years. The need to stockpile topsoil can be almost eliminated through progressive rehabilitation. This also avoids double handling of the materials which reduces cost as well as maintaining a high quality topsoil.

The volume of topsoil should be estimated and then used to determine the amount returned during progressive rehabilitation. **A common failure in the reapplication program is the overgenerous spreading of topsoil and subsoil in the beginning which results in a deficiency of materials on the final area to be rehabilitated.** The soil materials should be spread when dry, which restricts earth movement in most years to the months of June to September. Heavy earth scraping equipment should be avoided in reapplying the various soil layers as it causes excessive soil compaction. Ideally, the soil material should be reapplied using wide tracked crawler bulldozers. Rubber tired equipment should be avoided when possible. As a general 'rule of thumb' the less the amount of equipment moving over the site the better from the standpoint of soil compaction. Thus, reapplication of 15-25 cm of topsoil in one operation is preferable. The depth of topsoil reapplied is determined by the quantity available and no benefits seem to be evident from having more than 70 to 100 cm of topsoil.

Progressive Rehabilitation

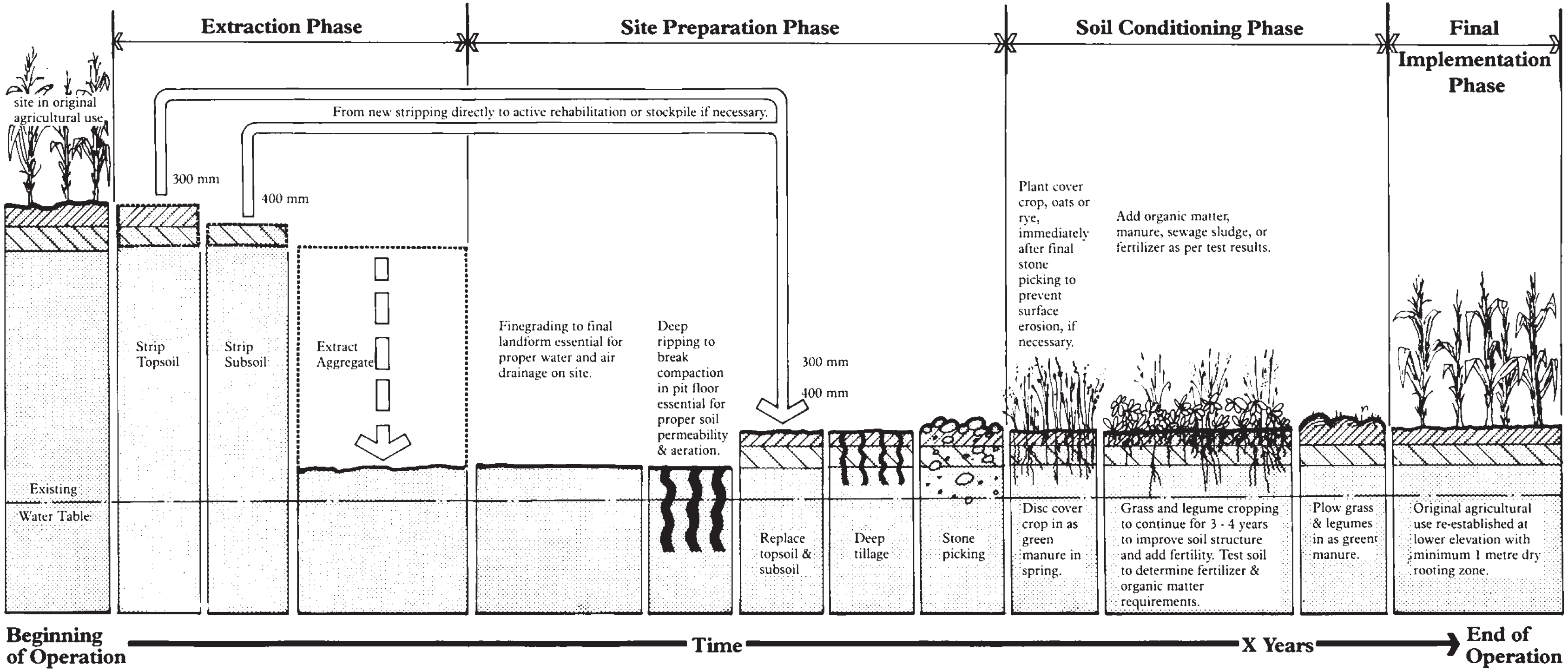
Closely related to the need for pre-planning is the idea of **progressive rehabilitation.** Progressive rehabilitation refers to rehabilitation done sequentially during the period that sand and gravel is being excavated (Figure 4). It is encouraged for a variety of reasons. Firstly, it reduces both time and cost of rehabilitation, secondly it keeps visual conflict with the surrounding landscape to an absolute minimum, and thirdly it reduces the amount of time that agriculture lands are withdrawn from production.

Development of a detailed site rehabilitation plan in the pre-extraction phase, coupled with progressive rehabilitation are two key components in ensuring a successful restoration program.

Grading and Recontouring the Pit Floor

Pit floors in sand and gravel operations are quite often uneven and severely compacted due to heavy vehicular traffic. To restore these lands to agricultural production the slopes of the pit floors should preferably be in the range of 2-5 per cent. The grading program should be directed toward reconstituting slopes acceptable for agricultural production as well as ensuring provision for adequate surface water drainage. The recontouring should eliminate small pockets of closed drainage systems or depressional areas where water tends to accumulate and results in a water-logged

Figure 4 - Progressive rehabilitation sequence for restoration to an agricultural after-use.



condition. It is critical to identify and design an outlet for surface runoff from the site.

The size and shape of the tracts of farmland is another surface feature that must be controlled. This will require careful planning and accurate grading for reshaping the pit floor to provide for large, regularly shaped fields on the post-extracted landscape.

Closely related to surface form are the back slopes of the pits. These commonly have 3:1 or 2:1 slopes (Figure 5) which are excessive from the standpoint of mechanized farming and cattle grazing. For agriculture purposes, slopes in the range of 6:1 to 10:1 are generally satisfactory, although grading backslopes to this level may not be feasible in relation to size of the pit or for economic reasons.

During the recontouring phase much of the pit floor may have been disturbed by regrading. This tends to break up compacted areas of the pit floor and it may reduce the area requiring ripping. Close inspection of the pit floor is needed on a site by site basis to determine whether or not ripping is required.

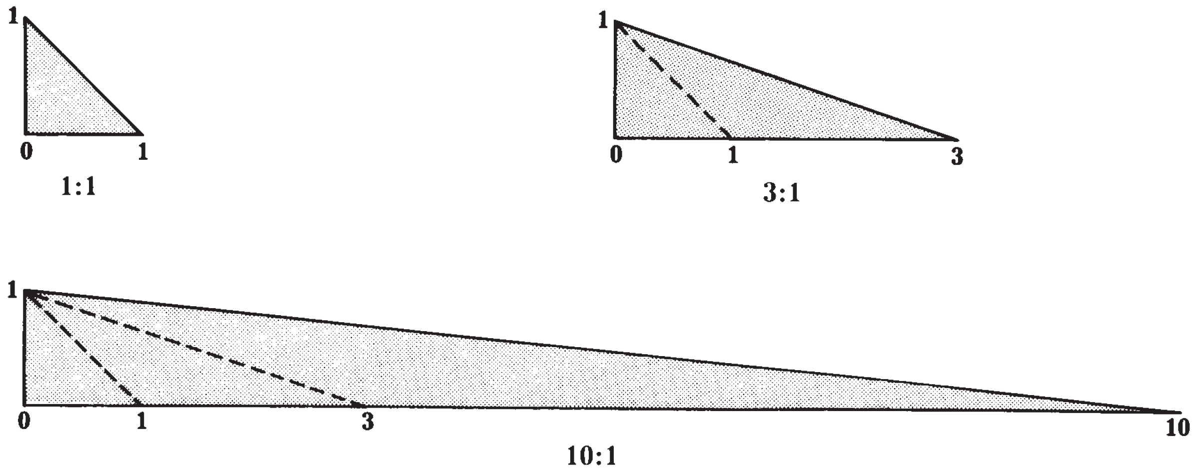
Problems with High Water Table Levels

Where extraction of sand and gravel occurs down to the water table level, or below the water table, special precautions are required in order to rehabilitate the site to an agricultural after-use and costs incurred may make such an after-use impractical. To ensure adequate conditions for plant growth, a minimum of one metre of topsoil/subsoil is required over the mean high water table levels. This can be achieved using a number of alternative methods. The most obvious solution is to restrict mining to those layers approximately one-half to one meter above the mean high water table level. This is not always practical for economic reason.

Steep slopes are unsuitable for mechanized farming; can lead to serious erosion problems; and should be seeded with a cover crop
(from Coates & Scott, 1979, photo no. 21)

Replacement of topsoil is critical for successful rehabilitation to agriculture
(from Coates & Scott, 1979, photo no. 22)

Figure 5 - Slope Gradients[4].



1:1 slope - the maximum final pit or quarry slope allowed under Section 8.1, 8.2 Ont. Reg. 378, Pits and Quarries Control Act.

3:1 slope - generally considered to be the maximum gradient for safe side hill vehicle travel, for effective surface erosion control and for safe pedestrian access up and down slope.

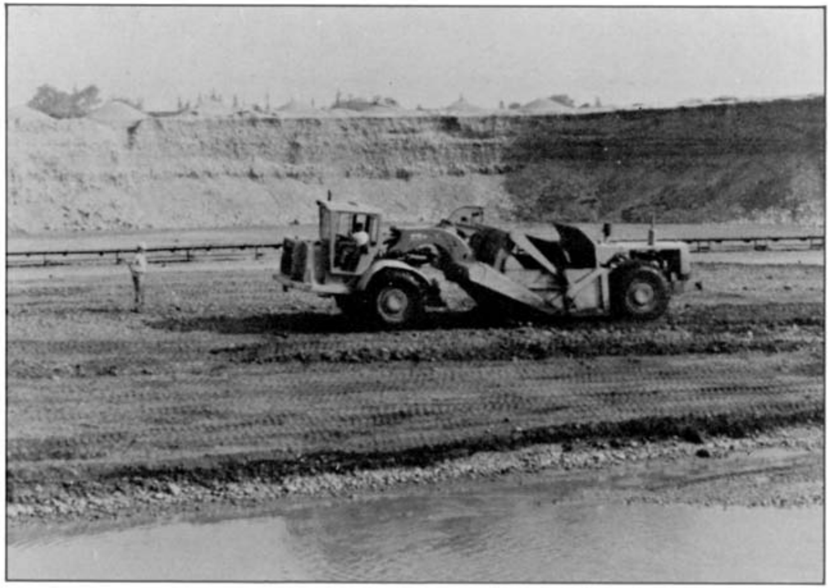
10:1 slope - slopes in the range of 3:1 to 10:1 are generally satisfactory for forestry, recreation and some agricultural uses.

(after Coates & Scott, 1979, p5.)

Provided adequate outlets can be identified, an interceptor drain, together with a tile drainage system, could be installed to lower the water table levels. However, a full assessment of the impact of lowering water table levels on surrounding land uses is required prior to adopting this option. Lastly, inert fill material could be imported to fill in the excavation. In the latter instance, extreme caution must be exercised in the choice of fill materials. This procedure has gained wide acceptance in Great Britain, but as yet, has received little support in Ontario.

Eliminating Severe Soil Compaction During Reapplication

The stripping and reapplication of topsoil/subsoil/overburden is usually carried out using heavy earth moving equipment such as motorized earth scrapers, front-end loaders, or bulldozers. Such equipment tends to compact soil, particularly if the soil is wet. In practice, this restricts stripping, stockpiling and reapplication activities to the drier months of June to September inclusive.



Heavy earth-moving equipment causes severe soil compaction and should not be used for reapplication of topsoil, subsoil or overburden. This earth mover can exert pressures greater than 5 kg/cm^2 when fully loaded.

Pit floors may be compacted as a result of constant use by heavy equipment during extraction operations. Moreover, each step during the reapplication of the soil can cause soil compaction by movement of heavy equipment. Compacted layers can restrict root penetration and water movement which could result in water-logged conditions. Crop yields are reduced significantly under these conditions and remedial measures are required to overcome the problem. Remedial measures consist of ripping the compacted layers with subsoilers, or where possible, deep tillage cultivators. Subsoil operations should be conducted with the ripper shanks about one metre apart and run on a diagonal pattern. A tillage operation may be required between each successive application of soil material.

Compaction can only be avoided completely by working under dry conditions and using alternative types of earth moving equipment, which exert pressures less than 1-2 kg/cm^2. This can be accomplished by utilizing wide tracked crawler tractors. Use of rubber tired equipment for grading and reapplication of materials should be avoided when possible.

Choice of Crops

There is a tendency amongst operators to grow corn or other general field crops immediately following restoration. This is an unfortunate choice of crops and should be discouraged as an agriculture practice.

One of the best ways of breaking up compacted layers and at the same time improving soil structure and general soil fertility is by devising a cropping program (Appendix 5) that initially includes a leguminous crop such as alfalfa, or legume/grass mixtures. Alfalfa is preferred because its deep growing taproots aid in breaking up compacted layers, it adds organic matter and nitrogen to the soil and it improves soil structure. A suggested cropping sequence is shown in Table 3. The forage crop should be grown and cut regularly for at least three to four years, after which a grain crop may, if desired, be planted in rotation with a legume/forage crop.

Where poor drainage becomes a problem, birdsfoot trefoil should be substituted for alfalfa. Alfalfa should only be seeded on areas where the mean winter water table level is about one meter below the soil surface. Under droughty conditions an alfalfa/bromegrass mixture can replace

A major problem in land rehabilitation is soil compaction. Mechanical ripping using an agriculture subsoiler (above), deep tillage cultivator or crawler tractor (below) is required to ameliorate adverse soil compaction problems
(bottom photograph courtesy of Crothers, Caterpillar Dealers, Concord)

Leguminous crops such as alfalfa are important in ameliorating soil compaction and also improve general soil fertility levels
(courtesy TCG Materials Limited).

Table 3 - A suggested cropping sequence for a post rehabilitation management plan.*

Time Frame	Cropping Program	Comments
year 1	seed cover crop such as oats or rye	control of soil erosion
years 1-4	seed legume or legume/ grass mixture	preferrably alfalfa to improve general soil conditions
year 5+	tree fruits; speciality crops, row crops, or coarse grains grown in rotation with legume/grass mixtures	

* see Appendix 5 and 6 for details.

alfalfa alone and seeding should commence prior to May 15th in southern Ontario. Bromegrass or timothy can be grown in conjunction with birdsfoot trefoil on poorly drained sites.

Immediately following final grading and tillage of a site, it should be seeded to a cover crop. The principal objective of cover crops is the control of surface soil erosion. On steep back slopes, i.e. 5:1 or greater, hydroseeding with a straw mulch may be required. Oats or rye are suitable cover crops to use while establishing a legume/grass cover. Winter wheat and other similar overwintering crops should not be used in this capacity.

For many existing pits, particularly those operated prior to implementation of the Pits and Quarries Control Act, it is not possible to rehabilitate for arable crop production. In these instances, consideration should be given to establishing permanent pasture using primarily drought resistent grass mixtures.

The application of manure as a solid waste (above) or liquid slurry (below) improves soil structure and general soil fertility levels and is a recommended practice on rehabilitated lands
(Courtesy R. Sheard, Department of Land Resource Science).

Post Rehabilitation Management

The amount of time required to restore rehabilitated land to pre-extracted productivity levels will depend on how well each stage of the program is carried out. The final and often neglected stage in a restoration program is the post rehabilitation management plan. **The purpose of this phase of the program is to build up organic matter levels, improve soil structure and re-establish the network of pores and voids by which the soil drains.** The post rehabilitation management program should be directed toward cultivation practices, cropping programs and other soil management practices concerned with restoring soil productivity.

i) Cultivation: It may consist of ripping compacted layers, followed by deep tillage and stone picking. An agricultural subsoiler may be used to break up compacted layers, but in some instances, only short-term relief will be achieved from subsoiling as reconsolidation of the compacted layers will occur after a few years.

ii) Building up organic matter levels: In addition to growing legume/grass mixtures, liberal applications of manure or sewage sludge are beneficial in building up organic matter levels, improving soil structure and general soil fertility levels.

iii) Fertilization: Prior to seeding crops, samples should be taken for a soil test analyses (Appendix 3) to determine the type and rates of fertilizer application. Nitrogen fertilization is not required for legume establishment. Phosphorus additions will be required and since most soils overlying sand and gravel deposits are coarse textured, potash deficiencies are a common occurrence.

iv) Time duration: A sound post rehabilitation management program is crucial to the long term success of agriculture rehabilitation. The primary objective of the program is still restoration of soil structure and not yield levels. In this respect it is critical that the aggregate company maintain control over the site for a minimum of eight years following rehabilitation to ensure adherence to the post rehabilitation plan. During this period, it may be desirable for the company to enter into a leasing agreement with a local area farmer to undertake the various farm related operations.

Other studies in North America and Europe have clearly demonstrated that forage yields on reclaimed land can be comparable to that of nearby undisturbed lands within about four years. Row crops such as corn and soyabean are being successfully grown on reclaimed lands but yields are commonly lower for a longer period. Row crops perform much better after a few years of grass-legume production. Little yield information is available for crops in Ontario due to the early stages of development in land rehabilitation.

v) Monitoring: The site should be monitored for several years following rehabilitation to check for signs of subsidence, compaction and poor drainage. If micro-depressions occur in the field due to subsidence, some additional land leveling, infilling, or surface drainage may be required. Where compacted layers are found, they should be broken up by tillage or subsoiling. The subsoiler should be used when the ground is dry to maximize benefits.

The cropping program may have to be adjusted to accommodate any adverse changes noted during the monitoring phase.

Summary

Due to the considerable overlap between high quality sand and gravel lands and high quality agricultural lands there will be continued conflict and competition for lands in the future. One alternative solution to this dilemma is the implementation of a sequential land use program wherein aggregate extraction is viewed as an interim land use followed by rehabilitation to agriculture. This concept is receiving wide spread acceptance throughout the coal mining areas of western Canada and the United States as well as abroad in such countries as Germany and Great Britain.

A review of sites rehabilitated to an agricultural after-use in southern Ontario indicates a high level of success considering the lack of guidelines available to the industry on rehabilitation to agriculture. As greater emphasis is placed on pre-planning and progressive rehabilitation the success of rehabilitation programs can also be expected to improve. In conjunction with this, implementation of sound agronomic practices will ultimately lead to further improvements. Those practices outlined here should be considered as an essential component of any program directed towards rehabilitation for agriculture. Undoubtedly, these practices will be modified and improved upon as new technologies are introduced and as additional data becomes available from future research efforts.

Acknowledgements

This publication is the result of a two year contract between the University of Guelph (Department of Land Resource Science) and the Ontario Ministry of Natural Resources (Industrial Minerals Section). The study was directed by one of the authors, E.E. Mackintosh, with the able assistance of E. Mozuraitis, Research Associate, Wendy Worthy, Graduate Research Assistant, E.G. Woodley, Computer Technologist and help from summer students, S.E. Johnston and S.G. Putz. The considerable assistance of numerous aggregate producers (Appendix 2) and personnel from the Ministry of Natural Resources is gratefully acknowledged. We would particularly like to thank R.A. Cline, Horticultural Research Institute of Ontario, Vineland Station and J.E. Winch, Department of Crop Science, University of Guelph for review and constructive comments on the crop selection guide, and S. Lowe, TCG Materials Limited, B. van den Broek, Ministry of Agriculture and Food, and T. Presant, Canada Department of Agriculture for reviewing the manuscript.

Appendix 1

Ministry of Natural Resources District Offices.

Aylmer District
Box 340
353 Talbot Street West
Aylmer, Ontario
N5H 3R2
(519) 773-9241

Brockville District
101 Water St. West
Brockville, Ontario
K6V 5Y8
(613) 342-8524

Cambridge District
Box 2186
Beaverdale Road
Cambridge, Ontario
N3C 2W1
(519) 658-9356

Carleton Place District *
10 Findlay Avenue
Carleton Place, Ontario
K7C 3Z6
(613) 836-1237

* formerly the Districts of Lanark and Ottawa (Maps 1, 2 and 3)

Chatham District
Box 1168
435 Grand Ave. West
Chatham, Ontario
N7M 5L8
(591) 354-7340

Cornwall District
Box 1749
113 Amelia St.
Cornwall, Ontario
K6H 5V7
(613) 933-1774

Huronia District
Midhurst, Ontario
L0L 1X0
(705) 728-2900

Lindsay District
322 Kent St. West
Lindsay, Ontario
K9V 2Z7
(705) 324-6121

Maple District
Maple, Ontario
L0J 1E0
(416) 832-2761

Napanee District
1 Richmond Blvd.
Napanee, Ontario
K7R 3S3
(613) 354-2173

Niagara District
Box 1070
Highway No. 20
Fonthill, Ontario
L0S 1E0
(416) 892-2656

Owen Sound District
611 Ninth Ave. East
Owen Sound, Ontario
N4K 3E4
(519) 376-3860

Sault Ste. Marie District
Box 130, 69 Church St.
Sault Ste. Marie, Ontario
P6A 5L5
(705) 949-1231

Simcoe District
645 Norfolk Street North
Simcoe, Ontario
N3Y 3R2
(519) 426-7650

Sudbury District
Box 3500, Stn. A
Sudbury, Ontario
P3A 4S2
(705) 522-7823

Tweed District
Metcalfe St.
Tweed, Ontario
K0K 3J0
(613) 478-2330

Wingham District
R.R. No. 5
Wingham, Ontario
N0G 2W0
(519) 357-3131

Appendix 2

An inventory of existing sites rehabilitated for agriculture – List of Operators.*

1. Len Goodwin Excavating Ltd.
2. TCG Materials Ltd.
3. Angelstone Ltd.
4. Premier Concrete Products Ltd. (Div. of Lake Ontario Cement Ltd.)
5. Standard Aggregates (Div. of Standard Industries Ltd.)
6. Cox Construction Ltd.
7. James Murray Construction Ltd.
8. Mann Construction Ltd.
9. Township of Woolwich
10. Regional Municipality of Waterloo
11. Preston Sand and Gravel Co. Ltd.
12. J.C. Duff Ltd.
13. Township of Brantford
14. Steed and Evans Ltd.
15. King Paving and Materials (Div. of Flintkote Co. of Can. Ltd.)
16. Nichols Gravel Supply Ltd.
17. Regional Municipality of Haldimand - Norfolk
18. Town of Delhi
19. City of Nanticoke
20. Harold Peper & Sons Ltd.
21. D.B. Kelly Construction Co. Ltd.
22. Jack Jones Trucking Ltd.
23. Southwind Development Co. Ltd.
24. Shelton Brothers Ltd.
25. V.W. Ruckle Ltd.
26. Matthews Group Ltd.
27. Shouldice Cement Products Ltd.
28. V.W. Ruckle Ltd.
29. Frank Pigeon and Sons Ltd.;
30. County of Kent
31. Huron Construction Ltd.
32. Doey Gravel and Construction Ltd.
33. Green and Ross Paving and Excavation Ltd.
34. James Sabiston Ltd.
35. Harden and King Construction Ltd.
36. Township of Scugog
37. Beaverdale Construction Ltd.
38. Dagmar Construction Ltd.
39. Dick Reed Excavating Ltd.
40. P.J. Sullivan
41. County of Northumberland
42. Beaverdale Construction Ltd.
43. R.H. Thompson
44. Dibblee Construction Co. Ltd.

see Map 3 for locations.

Appendix 3

Sources of Information.

1. County soil survey reports and related information
   - The Ontario Government Bookstore
     Main Floor, 880 Bay St.
     Toronto, Ontario
     M7A 1N8

   or Mail Order
     Ministry of Government Services
     Publication Services Section
     5th Floor, 880 Bay St.
     Toronto, Ontario
     M7A 1N8

   - Ontario Institute of Pedology
     University of Guelph
     Guelph, Ontario
     N1G 2W1
2. Surficial geology, aggregate resource inventory papers and aerial photographs
   - Ontario Ministry of Natural Resources
     Public Service Centre
     Room 1640, Whitney Block
     Queen's Park
     99 Wellesley St. W.
     Toronto, Ontario
     M7A 1W3

Appendix 3

Sources of Information cont'd.

3. Soil capability for agriculture maps (1:50,000 series)
   - Graphic Arts Service
     Information Branch
     Ontario Ministry of Agriculture and Food
     Johnston Hall, Room 28
     University of Guelph
     Guelph, Ontario
     N1G 2W1
4. Soil test information
   - Soil Testing Laboratory
     Department of Land Resource Science
     University of Guelph
     Guelph, Ontario
     N1G 2W1
5. Information on local agriculture conditions can be obtained from the Extension Branch, Ontario Ministry of Agriculture and Foods' County and/or District Agricultural Representative Offices and from the Soils and Crops Branch, Ontario Ministry of Agriculture and Foods' County and/or District extension specialists in field crops, horticulture crops, seeds and weeds control, and pest control.

Appendix 4

A summary of soil capability classes for agriculture.

Class I	Land has no significant limitations for a wide range of crops. The soils are deep, well drained and occur on level or nearly level topography. There are no serious hazards or limitations, and under good management are often the most productive soils for many farm crops.
Class II	Land has moderate limitations that may restrict the range of crops which may be grown successfully. The limitations on land use are moderate and could include one or more of the following: imperfect drainage, rolling topography, moderate erosion and stoniness.
Class III	Land has moderately severe limitations that restrict the range of crops or the land may require special management practices to sustain productivity. The limitations are more severe than in Class II and may affect timing and ease of tillage, planting and harvesting, as well as the range of crops that may be grown successfully.
Class IV	Land is subject to severe limitations that restrict the range of crops. Generally, the soil is too susceptible to erosion, too stony or too poorly drained to be cultivated on a regular basis.
Class V	The limitations are severe and normally prevent the use of land for the sustained production of annual field crops. Class V land is unsuitable for cultivation of general field crops but with special intensive management (land clearing, erosion and water control) could be used for forage production or developed as grazing areas.
Class VI	Land is capable of producing perennial forage crops and should be kept in a permanent vegetative cover. The limitations include steep slopes, severe erosion, shallow soil over bedrock or other features that make cultivation generally impractical.
Class VII	Land is not considered suitable for agriculture and includes rockland, quarries and areas virtually devoid of soil.

Appendix 5

Crop Selection Guide

Common Name *Botanical Name*	Drainage[1]				Texture[1]			pH Range	Persistence	Seeding Rate	Climatic Range (Corn Heat Units) (Appendix 6)	Planting Time
	Rapid	Good	Imperfect	Poor	Sandy	Loamy	Clayey					
Legumes												
Alfalfa *Medicago sativa*	*	**	*	–	**	**	**	6.5-8.0	3-4 yrs. S. Ont. 2-3 yrs. N. Ont.	13 kg/ha	All areas	Early spring
Birdsfoot Trefoil *Lotus corniculatus*	*	**	**	*	*	**	**	5.5-7.5	Long term	11 kg/ha	All areas	Early spring
Alsike Clover *Trifolium hybridum*	*	*	**	**	*	**	**	5.5-7.5	2-3 years	11 kg/ha	All areas	Early spring
Red Clover *Trifolium pratense*	*	**	**	*	*	**	**	6.0-7.5	1-2 yrs. S. Ont. 2-3 yrs. N. Ont.	11 kg/ha	All areas	Early spring
Sweet Clover *Melilotus alba*	*	**	**	**	–	**	**	6.5-8.0	2 years	11 kg/ha	All areas	Early spring
White Clover (Ladino type) *Trifolium repens*	–	**	**	*	–	**	**	6.0-7.5	1-2 years	2-4 kg/ha	All areas	Early spring
Crownvetch *Coronilla varia*	*	**	*	–	*	**	*	5.5-7.5	Long term	15-18 kg/ha	All areas	Early spring
Soybean *Glycine max*	–	**	*	–	–	**	*	6.0-7.5	1 season	100 kg/ha (17 cm rows) 70 kg/ha (34 cm & wider rows)	2500+	May 15-30

[1] *The following mean:*
** – *recommended*
* – *will tolerate*
– – *not recommended*

Appendix 5

Cont'd.

Common Name *Botanical Name*	**Drainage[1]** Rapid	Good	Imperfect	Poor	**Texture[1]** Sandy	Loamy	Clayey	**pH Range**	**Persistence**	**Seeding Rate**	**Climatic Range (Corn Heat Units) (Appendix 6)**	**Planting Time**
Grasses												
Bromegrass *Bromus inermis*	*	**	**	*	**	**	**	not pH sensitive	Long term	11 kg/ha	All areas	Early spring
Tall Fescue *Festuca arundinecea*	*	**	**	**	*	**	**	not pH sensitive	Long term	14 kg/ha	All areas	Early spring
Orchard Grass *Dactylis glomerata*	**	**	*	_	*	**	*	not pH sensitive	Long term	9 kg/ha	All areas	Early spring
Timothy *Phleum pratense*	*	**	**	*	*	**	**	not pH sensitive	Long term	9 kg/ha	All areas	Early spring
Reed Canary grass *Phalaris arundinacea*	*	*	**	**	_	**	**	not pH sensitive	Long term	9 kg/ha	All areas	Early spring
Perennial Ryegrass *Lolium perenne*	*	**	**	*	**	**	**	not pH sensitive	Short term	1-3 kg/ha	All areas	Early spring

Appendix 5

Cont'd.

Common Name ***Botanical Name***	**Drainage[1]** Rapid	 Good	 Imperfect	 Poor	**Texture[1]** Sandy	 Loamy	 Clayey	**pH Range**	**Persistence**	**Seeding Rate**	**Climatic Range (Corn Heat Units) (Appendix 6)**	**Planting Time**
Spring Grains												
Spring Barley *Hordeum vulgare*	_	**	*	_	*	**	**	6.0-8.0	1 season	110 kg/ha	All areas	Early spring
Corn *Zea mays*	_	**	*	_	**	**	**	6.0-8.0	1 season	11-22 kg/ha	2300-2500 2500-2700 2700-2900 2900-3100 3100-3300 3300-3700	May 20-25 May 18-20 May 16-18 May 14-16 May 12-14 May 10-12
Oats *Avena sativa*	_	**	*	*	*	**	**	6.0-8.0	1 season	75 kg/ha	All areas	Early spring
Winter Grains												
Winter barley *Hordeum vulgare*	*	**	*	_	*	**	**	6.0-8.0	1 season	110 kg/ha	2700-2900 2900-3300 3300-3700	Aug. 26-Sept. 5 Sept. 5-15 Sept. 15-25
Winter rye *Secale cereale*	*	**	*	*	**	**	**	6.0-8.0	1 season	95 kg/ha (small seed) 160 kg/ha (large seed)	2300 & less 2300-2700 2700-2900 2900-3300 3300-3700	mid-August Sept. 1-5 Sept. 5-15 Sept. 15-25 Sept. 25-Oct. 10
Winter wheat *Triticum aestivum*	*	**	*	_	*	**	**	6.0-8.0	1 season	130 kg/ha	2300-2700 2700-2900 2900-3300 3300-3700	Sept. 1-5 Sept. 5-15 Sept. 15-25 Sept. 25-Oct. 10

Appendix 5

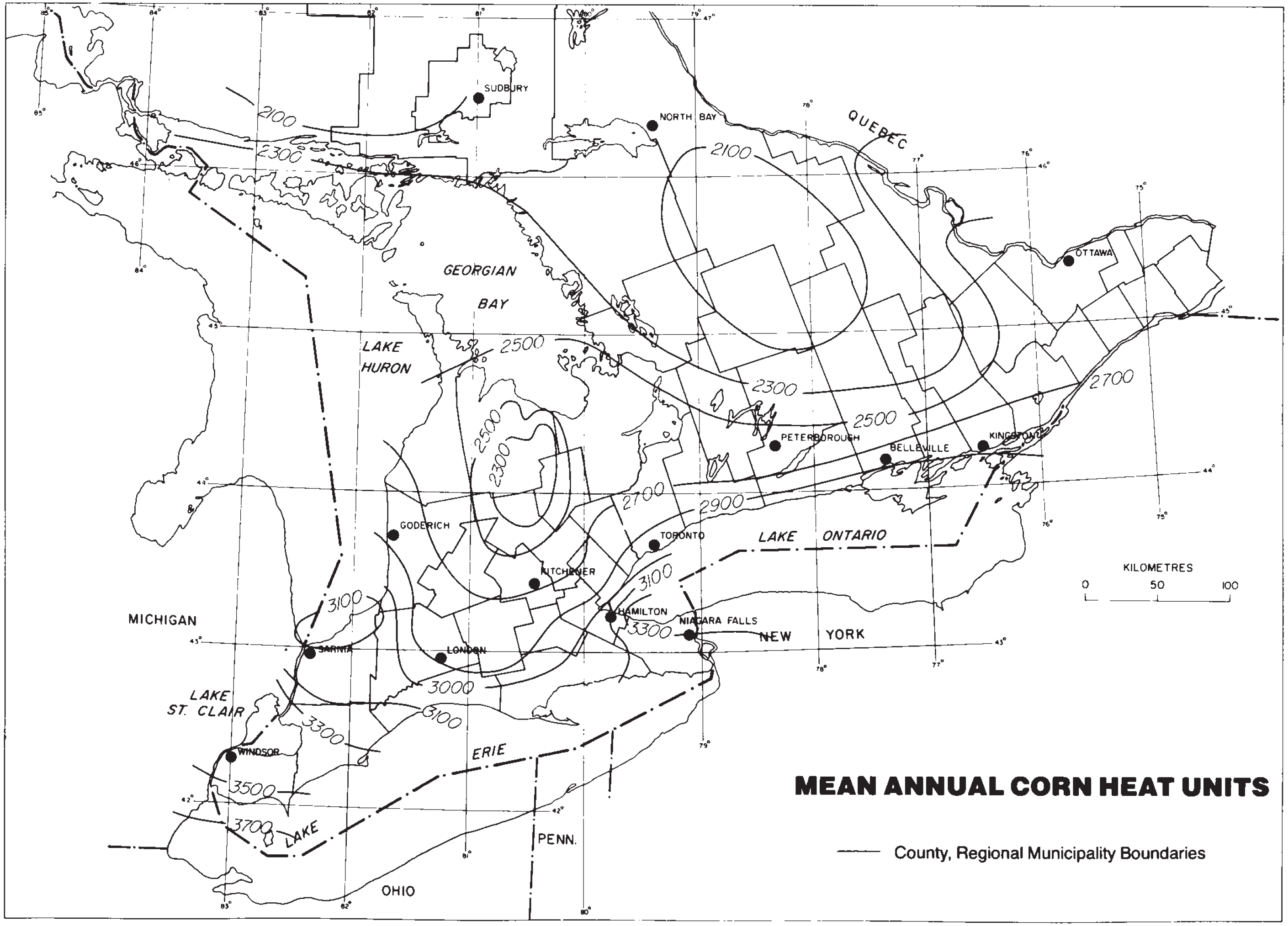
Cont'd.

Common Name *Botanical Name*	Drainage[1]				Texture[1]			pH Range	Persistence	Seeding Rate	Climatic Range (Corn Heat Units) (Appendix 6)	Planting Time
	Rapid	Good	Imperfect	Poor	Sandy	Loamy	Clayey					
Orchard Crops†												
Apple *Malus domestica Borth*	*	**	*	–	**	**	*	5.5-7.0	will depend on location & variety	depends on rootstock		Early spring
Apricot *Prunus armeniaca*	*	**	–	–	**	**	–	5.5-7.0	10-15 years	250-500/ha		Early spring
Sweet cherry *Prunus avium*	*	**	–	–	**	*	–	5.5-7.0	30-35 years	200-400/ha		Early spring
Tart cherry *Prunus cerasus*	*	**	–	–	**	*	–	5.5-7.0	25-30 years	250-500/ha		Early spring
Grape *Vitis labrusca*	*	**	*	–	**	**	**	5.5-7.0	15-50 years	1000-1800/ha		Early spring
Peach *Prunus persica*	*	**	–	–	**	*	–	5.5-7.0	10-15 years	300-600/ha		Early spring
Pear *Pyrus cummunis*	*	**	*	–	**	**	*	5.5-7.0	20-40 years	250-500/ha		Early spring
Plum *Prunus domestica*	*	**	*	–	**	**	*	5.5-7.0	20-25 years	250-500/ha		Early spring

† *check with local O.M.A.F. extension specialist for climatic requirements.*

Appendix 6

Mean Annual Corn Heat Units[2]



Selected References

References Cited

1. BELISLE, J. (ed.). 1980. Field Manual for Describing Soils. Ontario Institute of Pedology.
2. BROWN, D.M., G.A. MCKAY and L.J. CHAPMAN. 1968. The Climate of Southern Ontario. Department of Transport. Climatological Studies Number 5.
3. CANADA SOIL SURVEY COMMITTEE. 1978. The Canadian System of Soil Classification. Canada Department of Agriculture Publication No. 1646.
4. COATES, W.E. and O.R. SCOTT. 1979. A Study of Pit and Quarry Rehabilitation in Southern Ontario. Ontario Geological Survey Miscellaneous Paper 83.
5. DEPARTMENT OF REGIONAL ECONOMIC EXPANSION. 1969. Soil Capability Classification for Agriculture. The Canada Land Inventory Report No. 2.
6. HOFFMAN, D.W. 1974. Trends in Land Use in Ontario. In 'Ontario Aggregate Industry: Problems and Potentials'. Conference Summary. University of Guelph.
7. HOFFMAN, D.W. and H.F. NOBLE. 1975. Acreages of Soil Capability Classes for Agriculture in Ontario. ARDA Report No. 8.
8. PROVINCE OF ONTARIO. 1972. The Pits and Quarries Control Act, 1971. Revised Statutes of Ontario, 1980, Chapter 378. Toronto, Canada.
9. PROVINCE OF ONTARIO. 1978. The Topsoil Preservation Act, 1977. Revised Statutes of Ontario, 1977, Chapter 49. Toronto, Canada.
10. PROVINCE OF ONTARIO. 1978. Food Land Guidelines. A Policy Statement of the Government of Ontario on Planning for Agriculture.
11. YUNDT, S.E. and D.B. AUGAITIS. 1979. From Pits to Playgrounds. Aggregate Extraction and Pit Rehabilitation in Toronto - an Historical Review, Ontario Ministry of Natural Resources.

Additional Reading

ALBERTA SOILS ADVISORY COMMITTEE. 1981. Proposed Soil Quality Criteria in Relation to Disturbance and Reclamation. Alberta Agriculture.

BRADSHAW, A.D. and M.J. CHADWICK. 1980. The Restoration of Land. The Ecology and Reclamation of Derelict and Degraded Land. University of California Press, Los Angeles.

LAND CONSERVATION and RECLAMATION COUNCIL. 1977. Guidelines for the Reclamation of Land in Alberta. Alberta Environment.

LOWE, S.B. 1979. Trees and Shrubs for the Improvement and Rehabilitation of Pits and Quarries in Ontario. Ontario Ministry of Natural Resources.

MARSHALL, I.B. 1980. The Ecology and Reclamation of Lands Disturbed by Mining: A Selected Bibliography of Canadian References. Lands Directorate Working Paper No. 1. Environment Canada.

McRAE, S.G. 1979. The Agricultural Restoration of Sand and Gravel Quarries in Great Britain. Reclamation Review, Vol. 2, pp. 133-141.

MERRITT, W.A. and R. BROOKSBANK. 1980. Towards an Effect Prediction Model of Compaction and Rutting Resulting from Construction Activities on Agricultural Lands. Ontario Hydro Report No. 80312.

SCHALLER, F.W. and P. SUTTON (Editors). 1978. Reclamation of Drastically Disturbed Lands. American Society of Agronomy, Inc.

SCHIECHTL, H. 1980. Bioengineering for Land Reclamation and Conservation. The University of Alberta Press.

SINGLETON, P.C. and S.E. WILLIAMS. 1979. Effects of Long Term Storage on the Fertility and Biological Activity of Topsoil. Institute of Energy and Environment, University of Wyoming.

WEBBER, L.R. 1975. Ontario Soils - Physical, Chemical and Biological Properties and Soil Management Practices. Ontario Ministry of Agriculture and Food Publication 492.

Notes

Industrial Mineral Background Papers

1. Peat, Marwick and Partners and M.M. Dillon
1980: Mineral Aggregate Transportation Study: Final Report; Ontario Ministry of Natural Resources, Mineral Resources Branch, Industrial Mineral Background Paper 1 (IMBP 1), 133 pp.

2. Minnes, D.G.
1982: Ontario Industrial Minerals; Ontario Ministry of Natural Resources, Mineral Resources Branch, Industrial Mineral Background Paper 2 (IMBP 2), 55pp.

3. Mackintosh, E.E. and E.J. Mozuraitus
1982: Agriculture and the Aggregate Industry: Rehabilitation of Extracted Sand and Gravel Lands to An Agricultural After-Use; Ontario Ministry of Natural Resources, Mineral Resources Branch, Industrial Mineral Background Paper 3 (IMBP 3), 44pp.

Publications of the Ontario Ministry of Natural Resources, Mineral Resources Group and price list may be obtained from:

Public Service Centre
Ministry of Natural Resources
Room 1640, Whitney Block
Toronto, Ontario
M7A 1W3

and

The Ontario Government Bookstore
880 Bay Street
Toronto, Ontario
M7A 1N8

Orders for publications should be accompanied by cheque or money order, payable to the Treasurer of Ontario.


5006