QUARRIES IN THE PRAIRIE LANDSCAPE

PROJECT MANAGEMENT FOR THE DEVELOPMENT AND REHABILITATION OF CRUSHED LIMESTONE QUARRIES



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by D. James Paterson

A Practicum submitted in Partial Fulfillment
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DONALD JAMES PATERSON

A practicum submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF LANDSCAPE ARCHITECTURE

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ABSTRACT

Limestone quarrying for the production of crushed stone is an essential industry within southern Manitoba, as it provides the construction industry with much of its mineral aggregate needs. The construction industry requires a reliable and economical supply of crushed limestone products to provide the roads, houses, and industries that modern society demands. The Winnipeg region is rich in limestone bedrock resources, but many potential sources are being sterilized for numerous reasons.

Crushed limestone is a high-bulk, low-value product that necessitates surface mining and short-haul distances for the individual operations to remain economically viable. Consequently, large quarry operations are located close to their Winnipeg markets in regions of often conflicting land uses. Noise, dust, vibration, and public safety are common problems with existing operations, while abandoned quarries are often left in an unacceptable condition. Despite the recognized need for their products, the current public attitude towards the crushed limestone industry focuses upon the severe social and environmental impacts that such operations can cause.

The study explores the "aggregate dilemma" in depth, and concludes that the crushed limestone producers will have to improve their public image. A project management planning process is proposed for the resolution of many of the social and environmental issues concerning the industry. Project management of limestone quarries including planned site development, comprehensive management, and creative rehabilitation may provide exciting economic and land use opportunities in the future. Technical information is provided as an information base for future rehabilitation activities.

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INTRODUCTION

1.1 Background

Limestone quarrying for the production of crushed stone is an essential industry within southern Manitoba, as it provides the construction industry with much of its mineral aggregate requirements. Mineral aggregates, including sand, gravel, and crushed limestone, are high-bulk, low-value products that necessitate surface mining and short-haul distances for the industries to remain economically viable. With the assurance of continued urban expansion and the further depletion of nearby sources of sand and gravel aggregates, all levels of government have recognized the need to conserve and protect the limestone resources we have and to plan for continued quarrying operations.

Despite such acknowledgement, valuable reserves of limestone bedrock continue to be sterilized through the processes of urban sprawl, rural development, and municipal controls. A number of municipalities have derived some benefits from barring or regulating crushed limestone quarries within their jurisdiction, but that is not the sole rationale behind such imposed restraint. The current attitude toward the crushed limestone industry focuses upon the severe social and environmental impacts that such operations can cause. Municipal councils foresee the problems of noise, vibration, dust, and public safety, along with the question of what to do with the quarry after it is depleted. Indeed, the problem of public safety and liability is an ongoing issue that the quarry operators have yet to come to terms with. In short, as one quarry operator so aptly stated, "everyone wants doorsteps, but no one wants the industry on their doorsteps".

In several instances, the crushed limestone operators have been their own worst public relations representatives. The industry contends that it is simply attempting to provide a product which the public demands. But operators are all too slowly realizing that it can no longer be "business as usual". Increased public resentment and

government regulation make that impossible. The current public image of the limestone industry, although tarnished, need not be irreparable. However, the industry needs to change its attitude and the operators must be convinced that they will have to modify present quarrying practices if they are to be recognized as good corporate citizens.

The solution to the social problem can be realized through careful planning of each quarry site, followed by a thoughtful site development and operations planning program. With the initiation of a thoroughly planned and creatively progressive rehabilitation program, environmental impacts can be lessened, and the site can be developed to provide for safe and specific future land uses. Ideally, limestone operations could provide opportunities for large-scale landforms designed for real economic benefits in the future.

Traditionally, quarry site development and rehabilitation has been solely the domain of mining engineers. The future growth and development of the crushed limestone industry will be increasingly determined and directed by the input from planners, landscape architects, government agencies and their personnel.

Simply stated then, the issue that will be addressed throughout this study will be: how can the crushed limestone operation be incorporated harmoniously into the land use cycle?

The issue involves:

1) eliminating undue social problems, while
2) allowing for efficient quarry operations, and
3) the realization of future rehabilitation goals and objectives.

1.2 Purpose

The purpose of this practicum is to provide the essential information for initiating a project management program designed specifically for crushed limestone operations. This study provides

guidelines for the site development, operations planning, and progressive rehabilitation of quarry operations within the Winnipeg region.

The author has recognized that many of the readers may not be familiar with the crushed limestone industry. Consequently, the study has been structured as an information manual which:

1) initially outlines the scope of the issues
2) proposes a project management process for the resolution of many of those issues.
3) synthesizes pertinent background and technical information into an easily retrievable form.

1.3 Objectives

In the context of the stated purpose, the objectives of this study are:

1) To introduce the reader to the crushed limestone industry. Background information will be provided on both the industry and the resource itself.

2) To discuss the "aggregate dilemma" confronting the crushed limestone industry and the ways in which varying levels of government are attempting to handle the situation.

3) To outline the social and environmental issues involved with the crushed limestone industry.

4) To provide objectives and guidelines that may be utilized to control or eliminate many of the problems previously identified. These objectives and guidelines will focus upon the following:
   a) site development, which includes aspects of site analysis and site planning.

b) operations planning

c) progressive rehabilitation of the site for the purpose of improved public safety and rehabilitation of a site based upon a previously defined land use.

5) To provide valuable technical and rehabilitation guidelines, including a discussion on selection and techniques of revegetation. Vegetation species lists will also be provided for reference for the vegetation requirements of specific areas.

1.4 Study Format

The study has been organized into three parts. Part One deals with the overall context of the issues. The second is directed specifically at the description of a project management process. The third part provides pertinent background and technical information.

Part I (Sections 1, 2, 3) will introduce the reader to the mineral aggregate industry, and the many issues involved with crushed limestone quarrying in southern Manitoba. The intent and detail of Manitoba's legislative requirements for rehabilitation will be reviewed, and selected municipal responses to the crushed limestone quarry dilemma will be outlined.

An overview of the problems of current operating and rehabilitation practices will provide the basis for the study. The main focus of the practicum is a discussion of the objectives and advantages of using a project management program directed specifically for the development and rehabilitation of crushed limestone quarries. A proposed conceptual model that incorporates the main features of this approach will be introduced here.

Part II (Sections 4-9) outlines and describes the phases, stages, and components of the proposed conceptual model provided in Part I. Objectives and guidelines for the preparation of site development, rehabilitation, and post mining plans are furnished throughout.

Part III (Sections 10-14) provides essential background information, technical site development and rehabilitation guidelines, and specific vegetation species lists as an information base for further study in this field.

Part 1
Quarries and the Landscape



THE INDUSTRY AND THE ISSUES

2.1 The Aggregate Industry

An uninterrupted and economical supply of mineral aggregate is essential if the construction industry is to continue to provide the roads, houses, and commercial and industrial development that modern society demands. Mineral aggregates, including sand, gravel, and crushed rock, are the raw materials utilized in the production of cement and asphalt, road metal, railway ballast, as well as any number of specialized products. The mineral aggregate industry is not only one of the largest industries in North America, it also remains one of the fastest growing industries within the primary sector of our economy.[1]

Despite these facts, the huge dimensions and the relative importance of the mineral aggregate industry continue to be underestimated by society. The value of production for mineral aggregates in 1979 was approximately $800 million, while the industry directly employed over 3,500 people.[2] That same year, approximately 385 million tonnes of mineral aggregate were excavated, as compared to 33 million tonnes of coal (1 tonne = 1.1023 tons).[3] Despite the perceived enormity of the coal-producing industry, the mineral aggregate industry is massive in comparison.

Manitoba utilizes approximately 13.6 million tonnes of mineral aggregate annually. See TABLE 1. A proportional breakdown of the various uses of these products in Manitoba is shown in TABLE 2. There are abundant sources of sand, gravel, and crushed limestone within the Winnipeg region. Approximately 2.7 million tonnes of sand and gravel

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1 A.G., McLellan, "The Aggregate Dilemma"; The Conservation Council of Ontario Bulletin, Oct. 1975, p. 12.

2 Mining in Canada Facts and Figures (The Mining Association of Canada, 1980), pp. 18 and 36.

3 Ibid, p. 36.

TABLE 1

CONSUMPTION OF MINERAL AGGREGATE IN MANITOBA AND THE WINNIPEG REGION

CONSUMPTION OF AGGREGATE
WINNIPEG REGION 1973
(000 tons)

	Winnipeg Region	Revised Manitoba Total	Winnipeg Region Percent of Province
Residential			
Sand & Gravel	869.9	974.7	89.2
Limestone	168.1	191.3	87.9
Total	1038.0	1166.0	89.0
Non-Residential			
Sand & Gravel	843.1	963.1	87.5
Limestone	83.9	100.9	83.2
Total	927.0	1064.0	87.1
Road Construction			
Sand & Gravel	2331.2	9218.0	25.3
Limestone	599.1	599.1	100.0
Total	2930.3	9817.1	29.9
Other Engineering			
Sand & Gravel	1296.8	2346.7	55.3
Limestone	80.0	138.3	57.8
Total	1376.8	2485.0	55.4
Total Construction			
Sand & Gravel	5341.0	13,502.5	39.6
Limestone	931.1	1,029.6	90.4
Total	6272.1	14,532.1	43.2

Source: U.M.A. Group, Aggregate Resources of the Winnipeg Region; Manitoba Mineral Resources Division, 1976

TABLE 2

PROPORTIONAL BREAKDOWN OF THE VARIOUS USES OF MINERAL AGGREGATE IN MANITOBA

SAND AND GRAVEL ALLOCATION DATA, 1973
(000 tons)
MANITOBA

Use	Statistics Canada	Revised	Percent Adjustment	Winnipeg Region
Road construction	6,747	8,669	28.5	2,025
Ice control	79	14	(82.2)	13
Concrete aggregate	1,843	2,241	21.6	1,952
Asphalt aggregate	550	535	(2.7)	242
Railroad ballast	776	928	19.6	66
Mortar sand	153	26	(83.0)	15
Mine fill	67	—	—	—
Other fill	1,618	1,113	(31.2)	952
Other uses	13	2	(84.6)	1
Total allocated	11,846	13,528	14.0	5,266
Total production	13,700	14,449	5.5	5,353
Percent allocated	86.5	93.6	—	98.4

LIMESTONE ALLOCATION DATA, 1973
(000 tons)
MANITOBA

Use	Statistics Canada*	Revised	Percent Adjustment
Rubble & riprap	2.8	—	—
Concrete aggregate	35.0	35.0	nil
Asphalt aggregate	75.0	75.0	nil
Road metal	239.9	518.6	116.2
Railroad ballast	—	24.7	—
Canadian cement & lime plants	—	724.3	—
Other uses	237.6	—	—
Total	590.3*	1,377.6	133.3

Source: U.M.A. Group, Aggregate Resources of the Winnipeg Region; Manitoba Mineral Resources Division, 1976

are produced from the Bird's Hill area, while roughly 0.9 million tonnes of crushed limestone are produced in the municipality of Rockwood.[4] See FIGURE 1.

2.1.1 The Limestone Industry

Used alone or as component parts, limestone and one of its constituents, lime, have a large number of uses in various industrial and chemical processes. See TABLE 3. Limestone has been processed into an almost unlimited range of sizes and specifications, from a product as fine as powder to the huge eight-ton pieces of armour stone which are produced for shoreline protection along southern Ontario lakes. Vast quantities of limestone are required in the manufacture of such necessitites as asphalt shingles, sugar refining, and steel production. Should a continuous and economical suppply of these basic materials be interrupted, it would affect us all detrimentally.

The use of limestone (including dolomite) to produce crushed stone is one of the more basic uses of the product. In its processed state, crushed limestone is loose, easily handled, and depending on its specified use, can be composed of a wide range of grain sizes. Therefore, the product can be readily compacted while retaining good internal drainage characteristics, making it a preferred and stable material for fills and as a base course for pavements or building structures.[5] Crushed stone is often used as fill because of its high bulk and relatively low cost.[6]

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[4] Personal communication with B. Bailey and C. Jones, Mineral Resources Division personnel, May 1982.

[5] Personal communication with R. Glassford, B. Bailey, Mineral Resources Division personnel, February 1982.

[6] The National Research Council, Surface Mining of Non-Coal Materials (National Academy of Sciences 1980), p. 15.

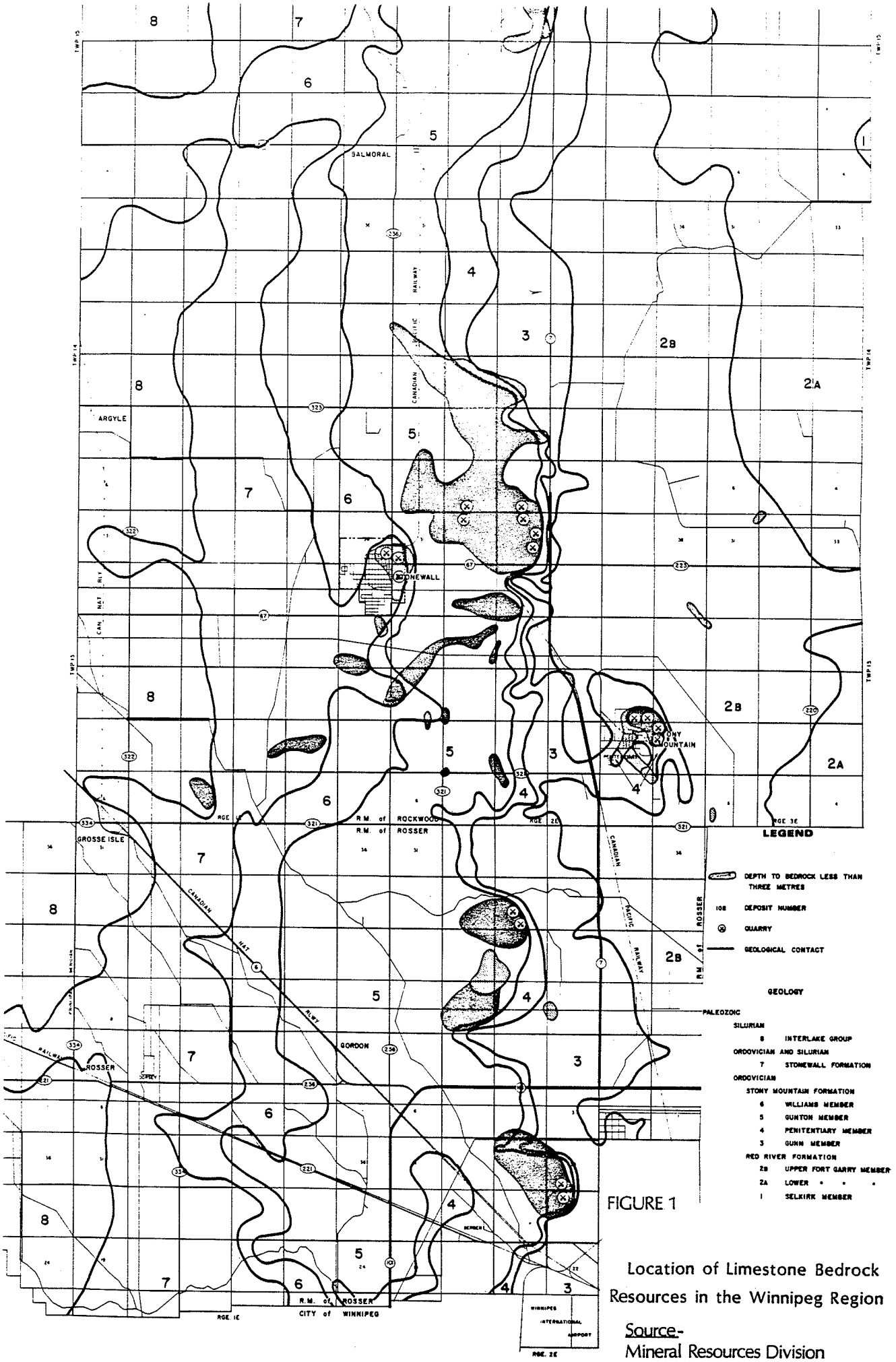

FIGURE 1

Location of Limestone Bedrock Resources in the Winnipeg Region

Source:-
Mineral Resources Division

TABLE 3

THE USES OF LIMESTONE AND LIME

Uses of limestone

Use	Remarks	Specifications
Fluxstone for pig iron	In blast furnaces; removes mainly Al and Si, also Mn and S	Less than 3% non-carbonate impurities; maximum of 0.1% S, 0.02% P; lump size, 8 inch to 1 inch range; fines not usable
Flux for iron sinters	Pulverized limestone mixed with iron fines, powdered coke, to form agglomerates	Both high-calcium and dolomitic limestones can be used
Open hearth furnace and foundry use	Limestone, being replaced in part by quicklime	As for pig iron, except maximum of 1.5 to 2% SiO_2
Nonferrous metals refining processes	Flux in refining Cu, Pb, Zn, and Sb; also low grade bauxite for alumina	Usually high-calcium limestone used; specifications as for pig iron
Glass; fluxing and conditioning of melt	Used either in limestone or lime form, dependent on quality of glass	Both high-calcium and dolomitic types are used; uniformity in composition important; generally less than 0.06% FeO; SiO_2 plus Al_2O_3 less than 3%
Pulp and paper	Limestone used in sulphite process, reacted with SO_2 to form calcium bisulphite	Minimum 95 to 97% $CaCO_3$; must be in large fragment size
Portland cement	Limestone main ingredient, mixed with clay, silica, and iron to comply with specific limits of composition	Must be low in magnesia; maximum of 5% $MgCO_3$, preferred 3% $MgCO_3$; SiO_2 less than 1.3%; Al_2O_3 less than 3.7%
Filter beds	To aid in purification of sewage plant and other effluents; also used in acid neutralization	Sound, fine-grained stone preferred
Agricultural limestone	Used principally in eastern United States and Canada	Crushed to -0.1 inch; chert undesirable
Mineral feed	High-calcium limestone	98 to 98.5% $CaCO_3$; finely pulverized
Poultry grit	Either limestone or dolomite can be used	Purity unimportant; uniform size, ¼-inch ± ⅛-inch
Building stone	Soundness, bedding, colour, fracture, and appearance are important	No pyrite; any composition from limestone to dolomite
Aggregate, coarse and fine	Angular form in concrete considered to give better set than sand and gravel	Any sound carbonate; chert or clay undesirable
Other construction uses	Road stone, railroad ballast, rip rap, roofing granules	Various specifications

Uses of lime

Use	Remarks	Specifications
Steel manufacture	As a flux; promotes removal of P, Si, and S	Generally high-calcium lime, low in MgO, SiO_2 and S
Nonferrous processes	In magnesia-from-seawater processes; in neutralization of acid leaching solutions from uranium mills; in flotation of some Zn, Ni, and Pb ores; in cyanidation process of gold milling; in Bayer process for Al_2O_3	Various specifications
Pulp and paper	Lime used in sulphate process in Kraft paper plants, to regenerate caustic soda; calcium carbonate recovered, calcined in plant kilns; also used in soda process. Used in some sulphite processes for pulp and paper	High-calcium lime, 92.5% CaO, less than 2.5% MgO, less than 3% combined SiO_2, Fe_2O_3 and Al_2O_3; dolomitic lime used in some sulphite process plants
Chemicals	Soda ash, bicarbonate of soda, and caustic soda by the Solvay process; calcium carbide for acetylene process; calcium chloride	High-calcium lime; for calcium carbide, less than 0.02% P
Sugar refining	Sucrose extracted from sugar beets is treated with lime to remove phosphatic materials and organic acids	Pulverized quicklime from on-site kilns; CO_2 required in processing; less than 1.5% SiO_2 + insolubles, and less than 1% $MgCO_3$ in the limestone
Water treatment	Combined with soda ash in the lime-soda softening process; also used in purification processes	Mainly high-calcium lime
Sewage and waste	Added to neutralize acidity, and thus to promote biological oxidation processes; also used in chemical treatment of sewage and wastes from a variety of industrial plants	Mainly high-calcium lime; dolomitic lime may be used in acid neutralization
Sand-lime brick and cellular blocks	Formed in autoclaves from a mixture of sand and lime; lightweight cellular concrete blocks are produced from special mixtures	High-calcium lime; either hydrated lime or pulverized quicklime
Soil stabilization	Lime reacts with clay minerals to reduce plasticity, and acts as a cementing agent; used extensively in road construction	Laboratory testing of specific soil required to determine whether high-calcium or dolomitic lime is more effective (see Wicks and Whitehead (1965) for application to Manitoba soils)
Miscellaneous uses	Soil liming; bituminous paving; plaster and stucco; insecticides; bleaches; paints; tanning	Variable with use

Source: Bannatyne, B., High Calcium Limestone Deposits of Manitoba; Mineral Resources Division, Publication 75-1, 1975

Crushed stone and sand and gravel are virtually interchangeable in the market, but all three have their individual virtues that allow operators from all three products to coexist and to produce for the same market.[7] Crushed stone, due to its sharp angles, provides a better binding surface for road base or railway ballast than does round stone or gravel.[8] To give you some idea of the amounts of these products that are required for construction projects, as much as 1,000,000 tonnes of mineral aggregate may be required for the construction of 16 kilometers of roadway.[9]

Mineral aggregate resources within the Winnipeg region have historically been important and fairly extensive land users. In 1975, 2,466 hectares of land were used as pits and quarries.[10] Between 1945 and 1975, the land area disrupted by pits and quarries in the Winnipeg region increased by 1,685 Ha - an over 200 percent increase (1 Ha = 2.5 acres).[11]

By utilizing the current estimate on the volume of crushed limestone produced annually, we can visually relate the amount of impact that limestone quarrying has on the landscape. Assuming 0.9 million tonnes are produced at 2.7 tonnes/cubic meter of solid stone, there are 0.3 million cubic meters of stone excavated each year. This may be graphically visualized as excavating approximately eight regulation-sized football fields (including end zones) annually, to a depth of six meters. These figures do not include the huge volumes of

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7 Ibid.

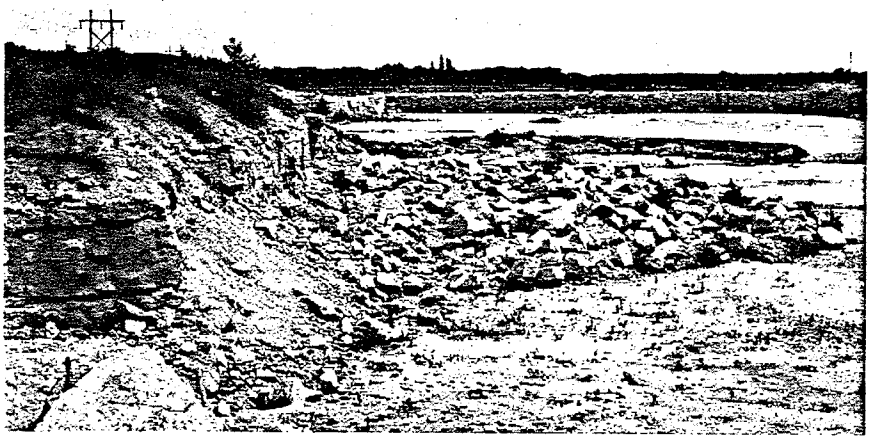
8 P. Large, Sand and Gravel in Manitoba, Mineral Resources Division Education Series, No. 78/1 (Winnipeg : Manitoba Department of Mines, 1978), p. 3.

9 British Sand and Gravel Association, Gravel Pits and... ; (London: S.A.G.A.), p. 6.

10 N. Ward, Land Use Programs in Canada:Manitoba; (Environment Canada, 1977), p. 124.

11 Ibid.







The Crushed Limestone Industry has historically been an important and fairly extensive land user.

overburden removed prior to quarrying, or the volumes of unsuitable low-quality rock removed. These figures may still seem relatively unimpressive, but consider that there are only a handful of crushed limestone producers and that they all quarry within a comparatively small region.

2.1.2 Industry Location Factors

Limestone bedrock resources within the Winnipeg region are geographically widespread. However, extraction is clearly limited by economic, geological, and social factors. All mineral aggregate products are bulky, heavy, and relatively low-cost commodities, which can stand very little increase in hauling distance from extraction site to consumer without a prohibitive increase in the cost of the delivered product. It has been estimated that transport costs by truck are approximately 30 to 40 percent of the price of a ton of aggregate produced in Bird's Hill and delivered just nineteen kilometers to Winnipeg.[12] Therefore, existing sources of mineral aggregates are invariably located in close proximity to their urban markets.

This transportation cost factor is especially important when we analyze the competitive relationship between the limestone producers and the sand and gravel producers. Although the industries are similar, and many of their products can be directly substituted for one another, production costs for sand and gravel are lower. Stockpile costs are approximately 50 percent less for sand and gravel products than for their counterpart limestone aggregate products.[13] To compete, the crushed limestone producers must be located closer to their market and take advantage of the reduced costs of transport.

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[12] The U.M.A. Group, Aggregate Resources of the Winnipeg Region (Manitoba Department of Mines, 1976), p. 49.

[13] Personal communication with B. Bailey and C. Jones, Mineral Resources Division personnel, May 1982.

Limestone bedrock resources within the Winnipeg region would be virtually infinite, except for the restrictive costs of production. The stripping ratio of a surface mining operation refers to the number of units of unpayable material (i.e. topsoil, subsoil, and overburden) that must be removed in order to quarry one unit of payable material (i.e. limestone or dolomite bedrock).[14] The current economically viable stripping ratio for crushed stone operations is approximately one to two; that is, if three meters of overburden must be stripped, then there must be six meters of bedrock suitable for crushed limestone available.[15] There are only a limited number of potential locations that possess such favorable stripping ratios.

Suitable sources of limestone bedrock are also determined by the quality of stone which may be won from the site. Different bedrock geological units vary widely in their relative physical attributes, and only certain limestone strata are suitable for application as crushed stone.

Without a large and economical supply of mineral aggregate, consumer costs and taxes would rise due to increased construction costs. For instance, the state of New York lost thirty million dollars per year due to increased building costs from the sterilized mineral aggregate resources lost to urban development.[16] In light of this fact and with the continued depletion of nearby sources of sand and gravel, it would seem logical that there should be a corresponding desire to conserve and protect sources of limestone aggregate and to plan for their continued operation. However, sterilization of valuable limestone bedrock reserves continues through the processes of urban sprawl, rural

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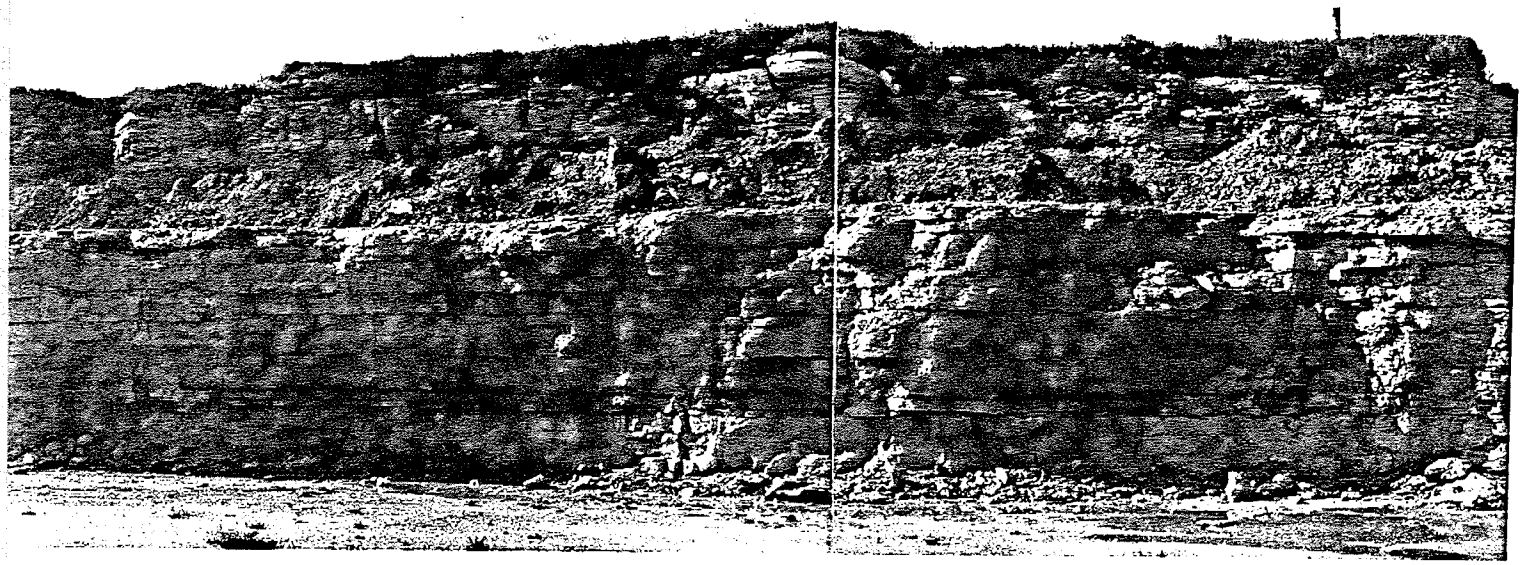
14 U.S.D.A. Forest Service, User Guide to Engineering; (General Technical Report INT-70, 1979), p. 27.

15 Personal communication with R. Glassford, Mineral Resources Division personnel, February 1982.

16 D.L. Keyes, Land Development and the Natural Environment : Estimating Impacts (New York, 1976), p.128.







The Winnipeg region is rich in limestone bedrock resources that are especially important due to favorable stripping ratios and high quality limestone.

development, and municipal controls. One must examine all the issues prior to formulating any valid conclusions.

2.2 The Aggregate Dilemma

Because of the direct relationship between limestone aggregate source and urban market, the crushed limestone producers have had to deal with increasing conflicts and pressures. Limestone producers are often in direct competition for property with other land users, many of which have equal or greater short-term benefits accruing to them. For example, rural residential developments provide a far greater short-term benefit for a municipality as they pay substantially higher property tax assessments. Currently, limestone quarry operations provide no direct financial benefits for the municipality in question. With increasing demands for all types of private and public development, the problems of securing suitable future limestone deposits within easy reach of the market will not only continue, but will likely worsen.

Economic and technological limitations imposed upon the industry require both surface mining and quarry extraction techniques. Limestone quarry operations in close proximity to an expanding urban population account for numerous social conflicts. Bill Coates, a landscape consultant for the Aggregate Producers Association of Ontario, has listed six major nuisance factors that have been brought forward in opposition to these surface mining operations. Although these are examples from southern Ontario, all are relevant to the situation within the Winnipeg region:

1) increased truck traffic
2) increased noise
3) increased vibration
4) increased dust levels
5) unsightly site appearance
6) increased physical danger.[17]

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[17] W. Coates, "Can Surface Mining be Compatible with Urbanization? (A paper presented to the Canadian Institute of Mining and Metallurgy, 1975), p.2.

I believe a seventh negative social impact can be added (as a consequence of all of the above):

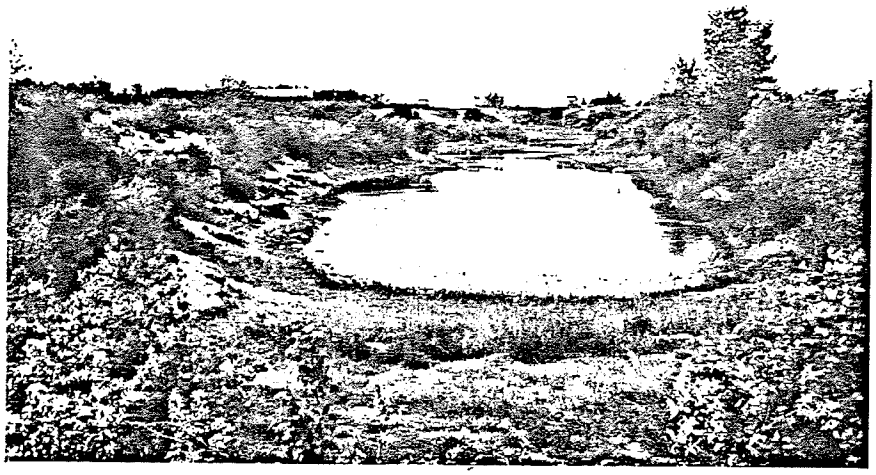
7) lower property values on the periphery of the operations.

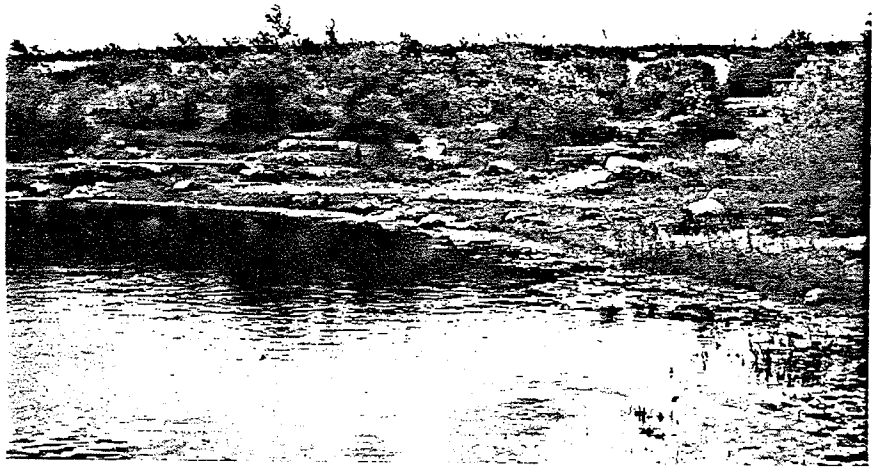
In short, we can see the dilemma with which the limestone aggregate industry is faced. There is an overall public demand for their goods, which in turn causes social conflicts. The very products that the crushed limestone producer provides will be utilized in the highways, homes, and industries that further aggravate the future growth of the crushed limestone industry.

Another contentious issue involved is the consequence of the excavations--the quarry itself. Exhausted quarries have been perceived as areas of exploitation and dereliction. Abandoned limestone quarries pose a threat to public safety, become unauthorized dumping grounds, and remain for decades essentially void of any vegetative restoration.

These unwanted legacies of the crushed limestone industry are not only a detriment for the municipality in question, but also for the existing and future crushed limestone operators. Limestone quarrying is supposed to be an interim land use, but left unrehabilitated, quarries can provide few if any future land use possibilities. Unused and undesired, abandoned limestone quarries will remain as negative symbols of an industry which is presently suffering from reduced production and increasing government regulation.

The crushed limestone industry is currently suffering from a public image problem. If prevailing trends are an indication, the negative image of limestone quarrying will become a serious one with which the industry must cope. The producers argue that they are providing essential products for which there is public demand. The public meanwhile, has become more politically aware, sophisticated, and concerned than ever before. Compounding this, the public has a contemporary interest in physical ecology and environmental topics, and is now raising those issues by organizing citizen groups and becoming







Left unrehabilitated, abandoned quarries are slow to revegetate themselves. Shown is Little Mountain Quarry which ceased operations in 1906.

more involved in municpal zoning and planning matters. With the government cast as both arbitrator and guardian of the land in question, there is no doubt that conflicts will result in the increased legislative sterilization of limestone resources, through the processes of intensified monitoring and regulation of the limestone aggregate producer.

Clearly, there is an economic justification for the government to conserve and protect both the existing and future bedrock resources, and provide for the continued operations of the crushed limestone industry. Equally as clear is the need to protect society from the negative social and environmental impacts that the industry can inflict.

2.2.1 The Government Response

In Manitoba, the aggregate dilemma is being confronted by several different pieces of legislation and government agencies. These can be summarized as follows:

1) **Resource Identification**

The Provincial Mineral Resources Division has initiated a survey program to identify the locations, quality, and overburden thickness of potential limestone bedrock quarrying within the Winnipeg region (specifically within the municipality of Rockwood). This survey has been combined with demand projections for crushed limestone to provide a basis for evaluating the need to protect specific reserves from future development. This information is vital to provincial and municipal planning officials for consideration in the formation of municipal development plans and is of particular interest in the approval of land subdivision proposals.

2) **Rehabilitation Regulations Under the Mines Act**

The Quarrying Minerals Regulation (Manitoba Regulation 226/76) passed pursuant to the Mines Act, was enacted specifically to deal with surface mineral extraction operations (except metallic minerals). The major focus of the regulation is to establish controls to achieve safe operation and rehabilitation of pits and quarries, and in doing so, places most of the onus on pit and quarry operators to comply with the regulations. The objectives are basically: to minimize hazards to public safety, to protect the environment, to optimize the productivity of the post mining landscape, and to utilize efficiently the available resources.

This regulation requires every owner of a commercial quarry or a commercial quarry lease to submit a "plan of rehabilitation" to be updated on a three-year basis:

> Upon depletion of the quarry, or prior to suspension of production for a period not exceeding twelve months, the owner must "rehabilitate" the landscape in accordance with the submitted plan.[19]

Unless otherwise approved, rehabilitation under the regulation must consist of:

a) the removal of vegetative cover and overburden in advance of the working face at a minimum distance of twice the height of the working face;
b) upon depletion, the sloping of the quarry walls no steeper than 45 degrees;
c) the distribution of overburden over the surface of the sloped quarry walls and the quarry floor;
d) planting of vegetation appropriate to the environment of the commercial quarry on the surfaces covered by overburden;

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[19] B.A. Bailey, "A Guide to Comprehensive Rehabilitation Planning of Pit Mining Regions," Practicum Department of Landscape Architecture 1981 p. 12.

e) the contouring of quarry walls standing below water level to minimize danger to the public;
f) disposing of all debris, refuse, scrap or inflammable liquids in an approved manner;
g) any other activities of a similar nature to any of those described in clauses (a) to (f).[20]

The relative effectiveness of this regulation to date has been quite disappointing, especially from the point of view of limestone quarry operations compliance. Few operators have submitted adequate site plans or proposals for progressive or future rehabilitation, let alone shown any interest in actually performing the suggested techniques of rehabilitation.

3) **Municipal Controls on Mining Activity**

The objectives of the Planning and Municipal Acts of Manitoba are basically to allocate authority to the local area municipal governments under the guidance of provincial policy and guidelines. Provincial Land Use Policy 13 states that "economically valuable aggregate and quarry mineral deposits should be protected from surface land uses that would interfere with their ongoing and future exploitation." However, a municipal council can still utilize the powers granted to it under the Planning and Municipal Acts to prohibit the establishment of new operations and to regulate existing quarries within the council's boundaries. The R.M. of Rosser, for example, has a number of potentially valuable aggregate deposits available within its boundaries, but has acted against the establishment of quarries there. Due to a limestone quarry's inherent social nuisance factors while providing very little tax return to the municipalities in question, legislative sterilization of mineral aggregate reserves (through revoking quarry proposals or imposing strict industry controls with municipal by-laws) is becoming increasingly a serious issue for industry and government alike.

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20 Manitoba Quarry Minerals Regulation 226/76, Being a Regulation Under the Mines Act Governing the Disposition of Crown Minerals and the Rehabilitation of Commercial Quarries, p. 593.

In summary, it is obvious that the provincial government through its regulating agency, the Mineral Resources Division, does realize the importance of the conservation, management, and exploitation of mineral aggregate deposits. However, it has been somewhat ineffective in the actual achievement of that goal. It is clear that municipal and provincial officials have not been presented with enough information from which to establish criteria suitable for the assessment of both existing and proposed pit and quarry operations. Moreover, the series of overlapping legislation regarding the mineral aggregate industry does not seem to satisfy either the needs of the industry or public sentiment.

2.2.2 Current Rehabilitation Practice

Manitoba Regulation 226/76 requires that the owner of a commercial quarry submit a rehabilitation plan which illustrates rehabilitation as mining progresses and when the mining is completed. Although the regulation is well intended, I see a fundamental problem with it from the outset.

Since quarry operations may be active for upwards of forty years, the future land use of the site is almost never known, and the quarry owner is often uncommitted towards the objectives of rehabilitation. Consequently, submitted rehabilitation plans are frequently vague and provide little information or inaccurate information.

Rehabilitation is conducted on company time with company money, people, and equipment. Often the decisions are "ad hoc" and result in on-site design with the operator directing a bulldozer during slack times. This practice may provide for faster and cheaper decisions which can be carried out during slow periods. The operator is also not required to provide immediate design costs to a consultant.

However, the results of such practice may lead to hasty, ill-conceived decisions which can produce more work and problems in the long run. Furthermore, documentation of rehabilitation techniques, both

good and bad, will be non-existent or inaccurate. Consequently, current rehabilitation practices will continue to exist, and new and better techniques will not be found.

Rehabilitation that is conducted at the termination of a quarry operation is likely only to meet the minimum legal requirements. These provincial requirements may be bolstered by stricter municipal requisites, however, the R.M. of Rockwood has not yet elected to do so.

One of the provincial requirements calls for quarry walls not to exceed a 1:1 or 45 degree slope. These slopes are often unsafe (they are very steep to traverse), unuseable (except for a few uses such as rock climbing), and unstable. If these slopes are formed by backfilling over the vertical quarry face, the resulting slopes may be more unstable than the existing quarry face. Furthermore, the character and quality of the exposed quarry face would be replaced by a derelict and unattractive slope condition that is often no better than the condition it is aimed at improving.

If current rehabilitation techniques continue, quarry operations will remain obtrusive to the surrounding neighbourhood; the often impromptu and ill-advised rehabilitation techniques will remain as evidence of previous operations; and the public image of the crushed limestone industry will progressively worsen.

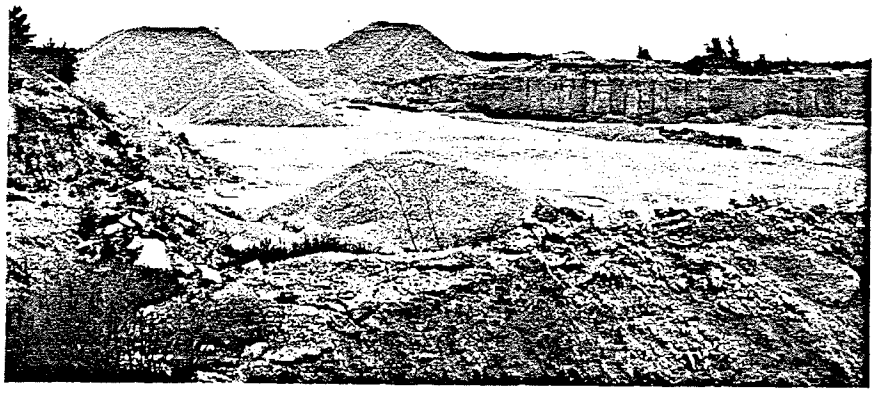
THE OPPORTUNITY

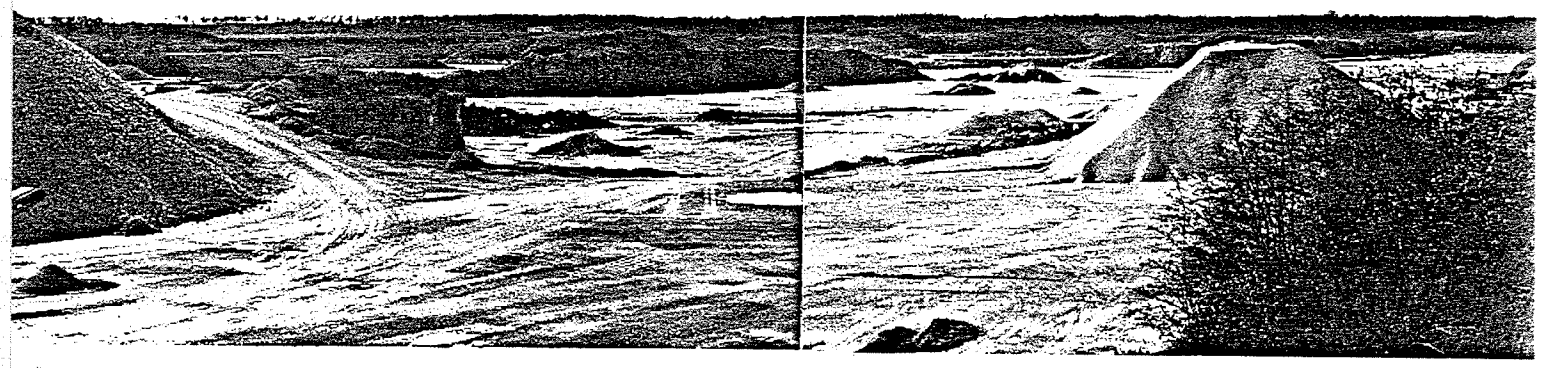
3.1 Potential Discovered

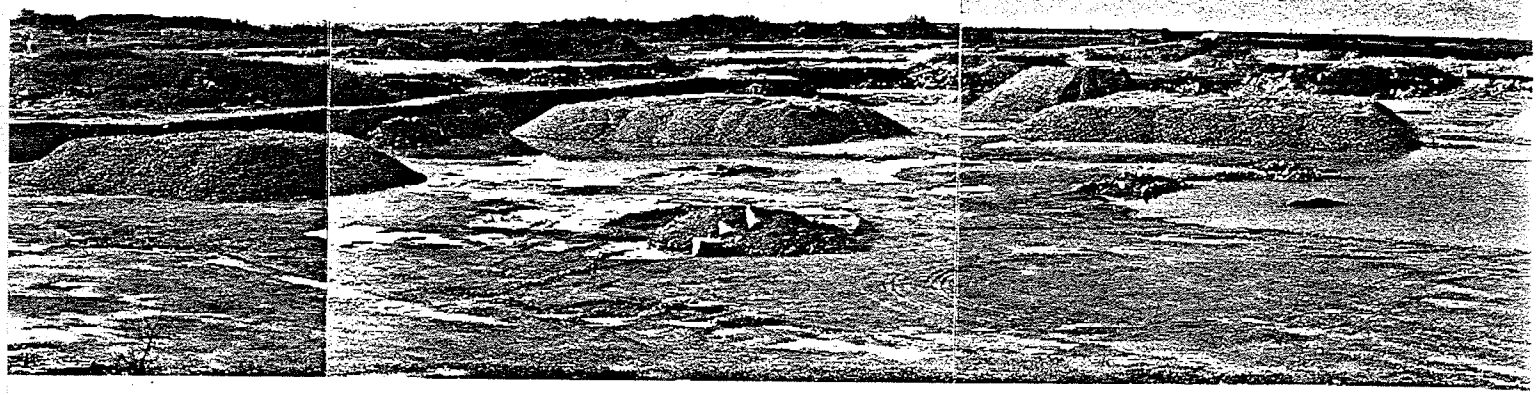
The potential benefits to be derived from limestone quarrying can be immense. The limestone industry utilizes large earth-moving machinery and techniques to create immense quarries sunk deep into the surrounding topography. To provide for such large-scale modification of the prairie landscape would not normally be possible were it not for the value of the rock extracted. Through creative utilization of these quarries, and the huge volumes of previously stripped overburden and earth, vast land shaping opportunities can be designed for future social and economic benefit.

Crushed limestone operations are in close proximity to the source of a permanent and expanding population in Winnipeg. Consequently, the number of potential uses for rehabilitated quarries is large and progressively increasing. Considering the relatively low cost of the land in the quarrying region, there are untold possibilities for land speculation and development opportunities. With the addition of existing technology, quarry operations are now capable of excavating below the water table, which can only add to the number of potential land uses and opportunities that currently exist.

This enormous potential may be wasted, unless site planning and progressive rehabilitation planning and management techniques are incorporated into the mining process. Virtually all of the social impacts caused by the quarry operation can be controlled or eliminated with the incorporation of proper site planning techniques. Operations planning can provide for the efficient working of a site, by ensuring that soil, overburden, stockpiling, and processing locations, do not interfere with future quarry operations. Combined with progressive rehabilitation planning, reduced operational costs can be achieved by eliminating the need to handle overburden more than once. This practice also serves to reduce the amount of vertical quarry faces on the site.







The cumulative impact caused by limestone quarry operations can be substantial. Opportunities for future land uses may be lost without comprehensive site management.

This alone could lessen the liability concerns of the operator by improving public safety. Progressive rehabilitation also reduces the need for large capital outlay at the termination of quarry operations as rehabilitation is almost complete and the land is in more saleable condition.

Planning, engineering, and design consultants for the crushed limestone producers may provide further benefits for the industry. The volumes of reports, drawings, and details that document how the client's money is to be spent allow for easy examination of the processes we plan to incorporate. This written knowledge may also encourage new, improved, safer, and possibly cost-saving techniques to be used.

3.2 The Project Management Planning Process

Project Management is a service that may be utilized to provide for the continued planning, design, and management of a quarry operation - from its inception to the realization of a future land use. Limestone quarries and their operations are obviously subject to constant and radical changes over time. Sir Geoffrey Jellicoe once described a limestone quarry as a gigantic piece of serendipic sculpture, always in movement:

> The role of the landscape designer is primarily to recognize that such a sense of sculpture really exists, and thereafter to act as guide, philosopher and friend in its growth.[21]

FIGURE 2 provides an example of a Project Management Planning Process as applied to a limestone quarry operation. The project management approach is not a linear process and neither is the given example precise for all crushed limestone quarry applications. However, by providing an example of an entire planning process, it serves as a basis for the description of the individual components.

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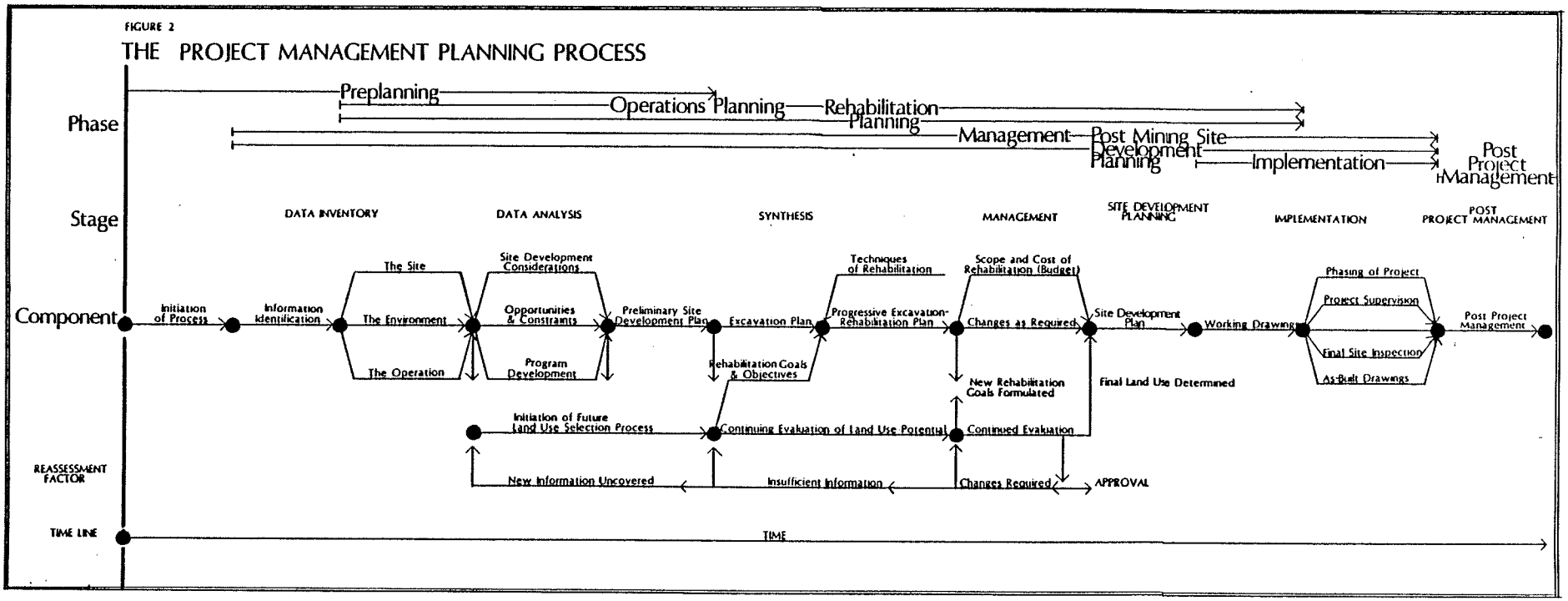
[21] Sir Geoffrey Jellicoe, Hope Works, Derbyshire : A Progress Report on a Landscape Plan 1943 - 1993 (Kent : Westerham press, Blue Circle Industries Limited, 1980), p. 27.

FIGURE 2

THE PROJECT MANAGEMENT PLANNING PROCESS



Simplified to its basic components, the project management planning process is not much different than a typical technical approach to design solutions.

Typical Design Solution Model

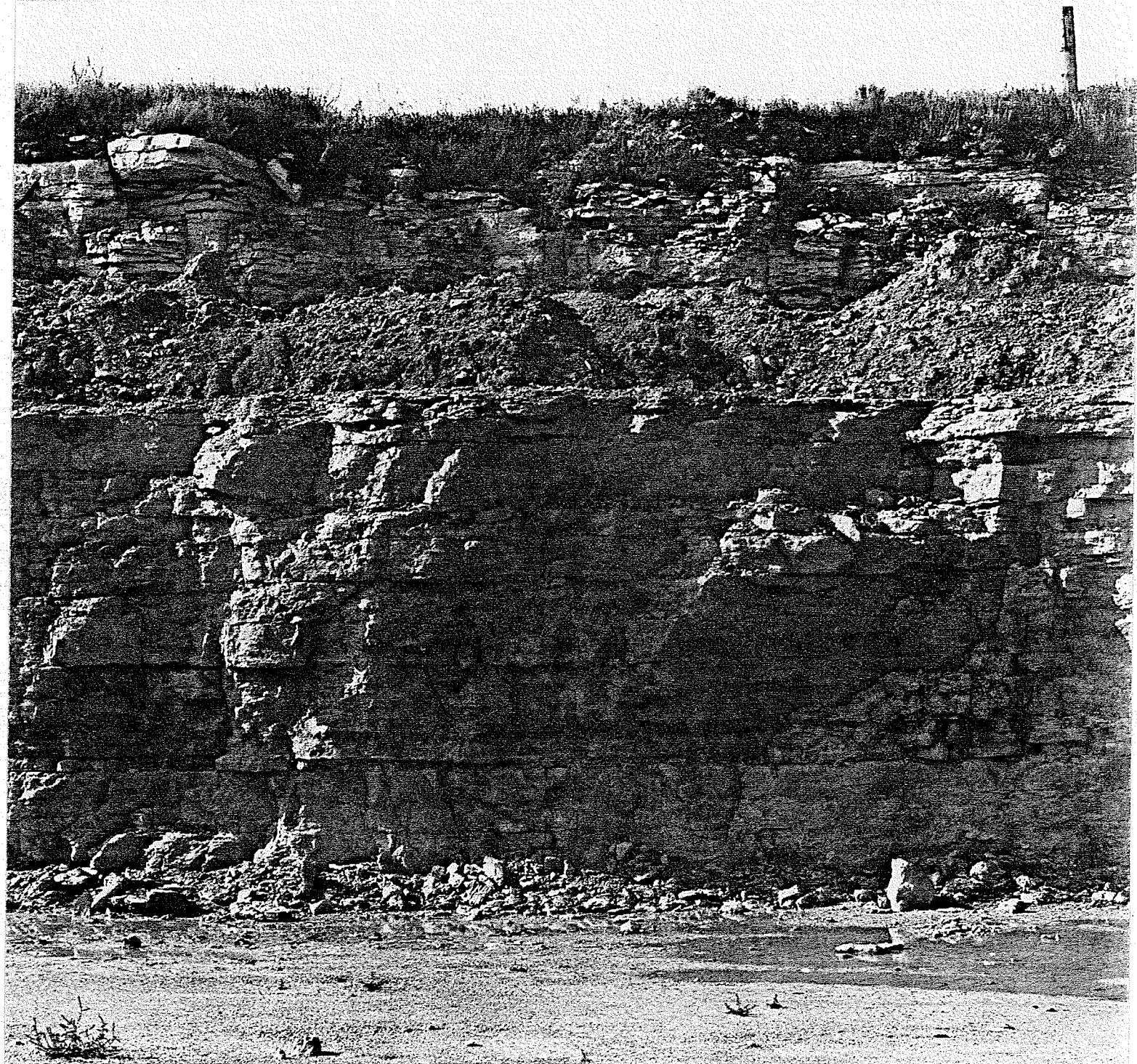
1. Definition of the issues and problems, preliminary goal formulation, and identification of the data required.
2. Data Inventory
3. Data Analysis.....Opportunities and Constraints.
4. Design Synthesis.....Preliminary Design
5. On-going Interplay and Re-evaluation
6. Final Design

It has been recognized that throughout the lifespan of a limestone operation, quarry technology may improve, future land use decision may alter radically, or unforseen social or environmental impacts may occur. The project management process is flexible enough to incorporate such changes and apply them towards the formulation of new development and rehabilitation goals.

Quarry operations may remain active for forty or more years, in which time the actors may have changed several times. Indeed, several different mine operators or several different landscape or engineering consultants may be involved throughout the lifespan of a quarry.

Existing quarry operations are also in varying stages of development, in which case some of the components of the project management scheme would not be required. The point of this discussion is that, although the principal actors and components may change, the concept of project management can still be applied to achieve the goal of rehabilitation to a future land use.

Part 2
The Project Management Planning Process



PREPLANNING

4.1 Purpose

Careful planning should always be the initial step in any technical problem solving process. The preplanning phase of the proposed project management process involves the following:

1) Issue or Problem Definition (Preliminary Goal Identification) - involves a statement of what services you have been hired to provide.
2) Data Inventory - involves the identification and collection of information required.
3) Data Analysis - involves the systematic review and analysis of the information to determine the assets, liabilities, and dominant characteristics of the study area.[1]

4.2 **Issue or Problem Definition** (Preliminary Goal Identification)

In light of the potential opportunities which have been presented, and the government requirements stipulated in Manitoba Regulation 226/76, the following planned objectives should be basic to any crushed limestone quarry operation:

1) to provide for the efficient working and excavation of the available limestone bedrock.
2) to provide for the minimum disturbance to the neighbourhood throughout the operating life of the quarry.
3) to provide for the regular evolution of the quarry throughout its lifetime towards a beneficial after-use.

4.3 Data Inventory

The data inventory stage requires the gathering of all information that may influence planning and development decisions concerning the project. In short, the data inventory provides the background

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[1] K. Schellie, Sand and Gravel: A Transitional Land Use, (National Sand and Gravel Association), p. 123.

information pertaining to the site, the operations which are to take place upon it, and the social context into which these operations will have to fit.

The information pertaining to the site and environment can be recorded in a series of drawings which identify the location and types of features to be considered. (The Mineral Resources Division recommends a working scale of 1 inch to 200 feet for larger quarries.)

A suggested list of information which may be required is provided in TABLE 4. FIGURE 3 provides an example of a base map for a hypothetical crushed limestone quarry operation. SECTION 13.3 will provide the reader with knowledge of the "typical" quarry operation.

4.4 Data Analysis

There are two aspects to the data analysis stage. One focus must involve the human purpose for the site (i.e. crushed limestone quarrying), while the other focus must analyze the site as an ongoing system. One must then determine how the quarry operation will affect both the existing site conditions and the future changes or dynamic nature of the site:

> Site and objectives cannot be studied independently but only in relation to each other - the purposes indicating what aspects of the site are relevant, the site analysis influencing the goals that are possible or desirable, and the budget defining what can be done.[2]

Three important components of the site analysis stage involve site development considerations, the formulation of opportunities and constraints, and the generation of the site development program.

TABLE 4

EXAMPLES OF PLANNING DATA REQUIRED FOR THE DATA INVENTORY

The Site

Surface Data

Location
Boundary survey
Easements and right-of-way
Acreage
Access
Surface drainage
Existing wooded areas
Views into the site

Sub-Surface Data

Depth of topsoil, subsoil, overburden
Topsoil and subsoil characteristics
Quality of bedrock
Depth to groundwater

The Environment

Existing land uses
Proposed land uses
Municipal servicing of site
Legislative controls
- Provincial
- Municipal

Climatic data (i.e. prevailing winds)

The Operation

Method of extraction
Rate of extraction
Excavating pattern
Processing plant & stockpile requirements
Office requirements
Additional site requirements (i.e. concrete or asphalt batch plant requirements)

Sources: Schellie, K. Sand and Gravel: A Transitional Land Use (Silver Springs: National Sand Gravel Association), p. 120.
Coates, W. "Social Ecology of Surface Mining" Paper submitted to the Canadian Institute of Mining and Metallurgy, Ottawa: 1972, p. 4.
Bauer, A. A Guide to Site Development and Rehabilitation of Pits and Quarries (Toronto: Ontario Department of Mines, 1973), p. 2.

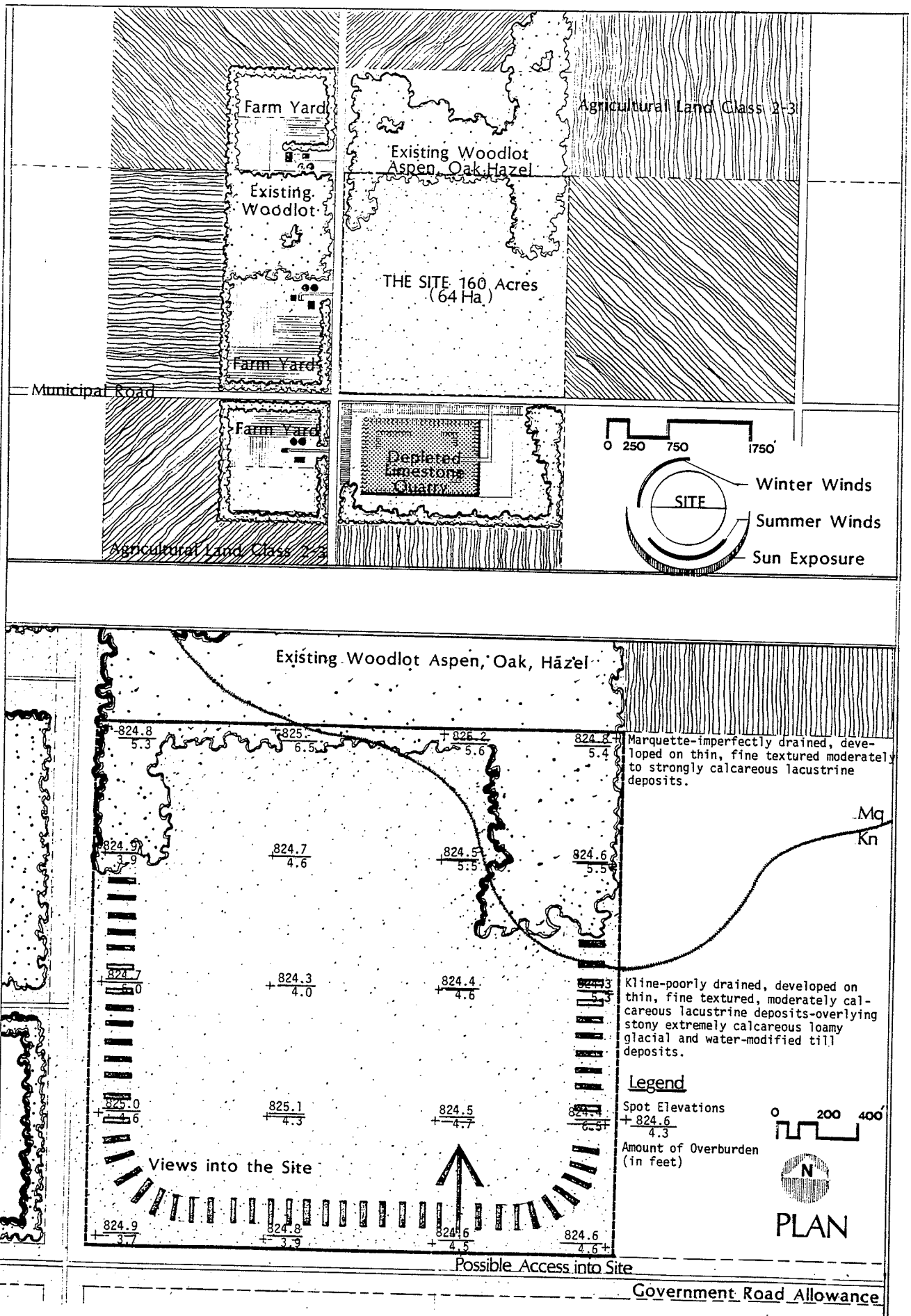

FIGURE 3 QUARRY SITE ANALYSIS PLAN

4.4.1 Site Development Considerations

In order to identify some of the potential conflicts a proposed operation may have upon its surrounding neighbourhood, one must become familiar with typical social impacts attributed to limestone quarry operations. SECTION 14.1 provides some useful background information in this regard. Basic site design criteria can then be developed and incorporated into the site development plan to control or eliminate the negative operational effects of any quarry operation.

4.4.2 Opportunities and Constraints

Every site offers its own unique potential and limitations for development. Through analysis of the data collected in the inventory stage, a number of specific development opportunities and constraints may be identified. This information will be critical in the formulation of the site development and operations plans, while also having implications on the future land use opportunities for the site. Examples of possible opportunities and constraints are provided in TABLE 5.

4.4.3 Program Development

The development of a detailed program is required prior to the design of the initial site development plan. The program may furnish a quantitative schedule of required berming and stockpile areas, activity settings to be provided, their linkages, and the resources to be devoted to them. An example of an activity setting may include the necessary processing plant and stockpile requirements of a proposed quarry operation.

The program will be prepared with the client, reviewed by him, and modified as the project management program proceeds. TABLE 6 provides examples of program information that may be developed.

TABLE 5

OPPORTUNITIES AND CONSTRAINTS WHICH MAY AFFECT SITE DEVELOPMENT

Opportunities	Constraints
Existing trees on the perifery of the site may be utilized for screening purposes.	Residential area on the west side of the operation.
Large buffer area to the north of the site (i.e. may not require berming along site boundary).	Depth to water table.
	Depth to poor quality rock (i.e. Gunn member).
Neighbouring limestone quarry on east side of operation (no need to berm between the adjoining properties). May quarry straight through to property limits.	Lack of fill (overburden and waste rock) to provide rehabilitation of entire site.
	Type of equipment available in the operation (i.e. no caterpillar tractor).

TABLE 6

EXAMPLES OF PROGRAM INFORMATION

1) Berming and Stockpile Requirements
   This may include a) estimates of volumes of soil and overburden on the site.
   b) approximate lengths, heights, and volumes, of material required for berming.
2) Activity Setting Space Allocations
   This may include a) a written account of exactly what activity is to take place within them.
   b) adequate size and shape requirements.
3) Linkages Between Activity Settings
   This may include a) access to and from activity settings.
4) Estimated Costs Involved
   This may include a) estimates of site clearing and stockpiling.
   b) estimates of berms or fencing.
   c) estimates for seeding and maintenance of berms.

All of the site analysis data will be continually sifted, organized, and developed into a concise form that must be able to accept new information. The site analysis stage will become an evolutionary process upon which a continuing design process can be based.

OPERATIONS PLANNING

5.1 Purpose

Operations planning is defined here as being the process of determining the initial development of the site and the continued phasing of the extractive operation within the site. Consequently, the operations planning stage is also separated into two distinct but related components--the preliminary site development, and excavation planning.

5.1.1 Preliminary Site Development Planning

The preliminary site development plan will provide a layout or design for the organized physical alteration of the land to accommodate the particular operational activities and features required.[3] Although subject to varying degrees of modification as the extraction continues, the initial plan should at least provide a guide to the operator for:

1) the efficient placement of facilities and materials (including topsoil, subsoil, and overburden).
2) the minimization of off-site impacts attributed to the operations.
3) the improvement of the appearance of the site both during and after operations.

Since the preliminary site development plan should provide the operator with the information required to "open up" his quarry site, the plan may include the information listed in TABLE 7. FIGURE 4 provides an example of a site development plan.

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[3] See Schellie, p. 122; Lynch, p. 4; A. Bauer, A Guide to the Site Development and Rehabilitation of Pits and Quarries (Ontario Department of Mines, 1970), p. 2; and S.M. Haywood, Quarries and the Landscape (The British Quarrying and Slag Federation Ltd., 1974) p. 23.

TABLE 7

PRELIMINARY SITE DEVELOPMENT PLAN REQUIRED INFORMATION

Site Boundaries

- All site boundaries and easements or right-of-ways (i.e. the 33 meter government road allowance on municipal roads).
- Required government setbacks for pits and quarries.

Site Elements (including locations for:)

- Access into the site.
- Quarry office and truck scale.
- Employee and truck parking.
- Processing and stockpiling areas.
- Any other site facilities required initially.
  - batch plant (asphalt or concrete)
  - explosives building
  - equipment storage
  - equipment service building
- Indicate existing screening (masses of vegetation).
- Indicate required screening.
  - berms
  - security fencing
- Indicate the initial area to be quarried.
- Indicate any required drainage diversions.

Sources:

Schellie, K. Sand and Gravel Operations: A Transitional Land Use (Silver Springs: National Sand and Gravel Association), p. 124.

Bauer, A. A Guide to Site Development and Rehabilitation of Pits and Quarries. (Toronto: Ontario Department of Mines, 1970) p. 5.

Haywood, S.M. Quarries and the Landscape. (Croydon: British Quarrying and Slag Federation, 1974), p. 39.

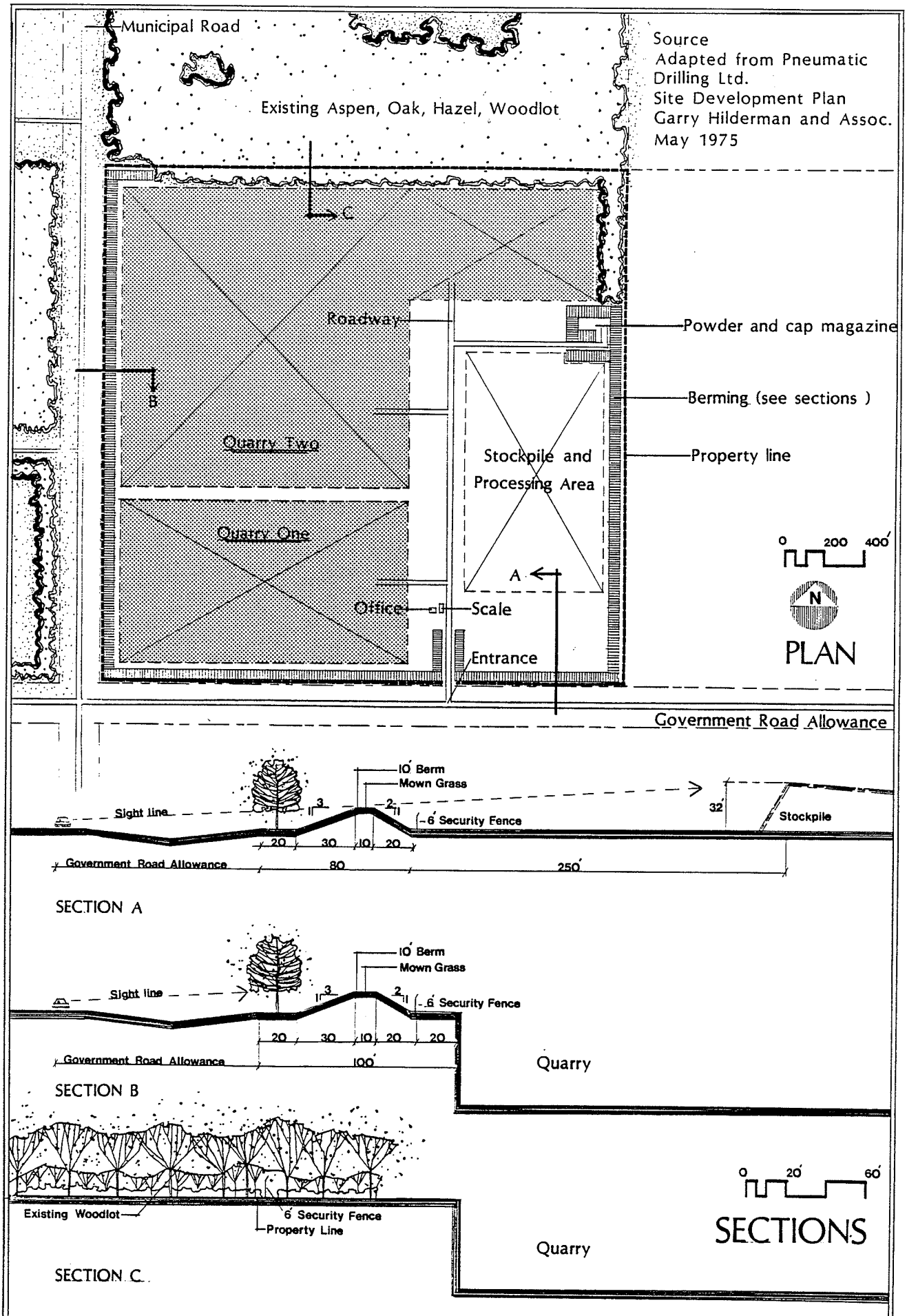

FIGURE 4

QUARRY SITE DEVELOPMENT PLAN

A well conceived and well-executed quarry site development will help to establish a positive intent and do much to dispel fears that performance will not match promise.[4]

5.1.2 Excavation Planning

Excavation planning can be defined as the process which determines the phasing of the actual quarry operation as it proceeds throughout the site. The initiation of an excavation planning process may provide a guide to the operator for:

1) the effective exploitation of the bedrock within the site.
2) the efficient use of the operations manpower and machinery.

In some cases, an efficient and rational plan of extraction may not be sufficient. Quarry operations which were once considered acceptable may, in the course of a few years, become offensive to surrounding land uses. In an effort to minimize public opposition, extraction plans should be adopted with both existing and future surrounding land uses in mind. The progression of the quarry operations should then be arranged to move the extraction areas away from sensitive land uses as quickly as possible.[5]

The excavation sequence should therefore be influenced and determined by:

1) the preliminary site development plan.
2) the amount and type of aggregate required (specifications of the aggregate required). See SECTION 13.2
3) efficient quarry operational procedures.
4) existing and future surrounding land uses.

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[4] Haywood, p. 42.

[5] W. Coates, "Operations and Rehabilitation Planning" (A paper presented to the Aggregate Producers Association of Ontario, Toronto, 1974), p. 3.

FUTURE LAND USE SELECTION

6.1 Purpose

The ongoing evaluation of future land use opportunities is required to guide both the determination of the long-term development goals and the short-term progressive rehabilitation objectives of the site. Without this direction, the progressive extraction and rehabilitation of the site may create unsuitable or unusable areas of land which may destroy future land use opportunities.

The determination of the future land use of a site should be based from the outset on geotechnical and resource economic considerations (ie. trade-offs--would the land be worth more by not quarrying the last ten percent of the site?). Ideally, the future land use of the site should be selected prior to the extraction planning stage of the program. The extraction / progressive rehabilitation program could then be directed specifically towards the goal of developing the land for the selected purpose. This is rarely possible however, as the relative length of the quarry operation often precludes the selection of a definite post-mining land use. Throughout the lifespan of an operation there is the possibility of considerable change in quarry technology, the regional setting, and society's demands and needs.

6.2 The Selection Process

There are three basic determinants which influence criteria to develop future land use potentials for a quarry site. They are:

1) location and need determinants
2) landform determinants
3) scope and cost of improvements determinants

TABLE 8 provides a guide to many of the aspects of a quarry site and operation, which should be analyzed to determine future land use potential.

TABLE 8

LAND USE SELECTION DETERMINANTS

1. Location and Need Determinants

Physical

- proximity of the site to an urban area
- proximity of the site to transportation
- proximity of site to utilities
- proximity to other sites of competing or supplementary uses
- possible expandibility of site

Cultural

- surrounding land uses (conflicts)
- zoning regulations and future land use policy (municipal)

2. Landform Determinants

- size of site
- site character
- prescence of safety hazards
- slope (aspect and gradients)
- soil quality
- ground water table
- drainage

3. Scope and Cost of Improvements Determinants

- amounts of material available for backfill (i.e. overburden and waste rock)
- engineering and ecology feasibility
- cost and type of regrading
- costs of revegetation
- site facility and utility costs
- degree of commitment or permanence of the land use (i.e. pasture land requires a low density of commitment, while rural residential requires a high degree of commitment).

Sources:

Schellie, K., Sand and Gravel: A Transitional Land Use; National Sand and Gravel Association, pg. 38

Coates, W. E.,'Operations and Rehabilitation Planning', a Paper presented to Rehabilitation Seminar, Toronto, 1974

Bauer, A., A Guide to Site Development and Rehabilitation of Pits and Quarries; Ontario Department of Mines Industrial Minerals Report 33, 1970, pg. 24

There is no specific formula to determine a definitive future land use. However, through analysis of the inter-relationships between the land use selection determinants, several highly-feasible specific future uses may be identified.

The location and need determinants may actually restrict the feasibility of certain land uses. For example, if there are several existing golf courses in the immediate area, and there is no specified need or demand for any additional facilities, another golf course would have a low priority for development in the foreseeable future.

The landform determinants will basically affect the character and form of the development. Certain quarry characteristics will suggest possibilities for specific types of after-use activities while severely reducing the possibility of others. For example, if the quarry site is scheduled to remain a dry operation (i.e. above the water table), there is no need to consider water-based activities (until such a time as the quarry operator decides to excavate below the water table). See SECTION 15 for a discussion on the typical post-mining quarry form.

Meanwhile, the scope and cost determinants may limit the feasibility and/or quality of the future land uses. For example, limited amounts of material suitable for backfilling and shaping may severely limit the future land use potentials for the site. The real land use opportunities are based upon how the quarry features and land shaping materials (overburden and waste rock) are utilized.

Not unlike the rest of the project management program, the process of future land use selection must be flexible, evolutionary, and one that permits re-evaluation at any stage.

PROGRESSIVE REHABILITATION PLANNING

7.1 Purpose

Progressive or planned rehabilitation is rehabilitation that is conducted concurrently with the quarry extraction operation. The Provincial Mines Act and its regulations do not specifically require progressive rehabilitation during operations. However, there are certain incentives for the quarry operator to undertake such a program. Because excavation and progressive rehabilitation objectives are pre-determined, the possible benefits to the quarry operator are many:

1) Equipment and manpower may be utilized more effectively.
2) Safety hazards may decrease.
3) Misplacements of overburden and waste materials may be reduced.
4) Overburden may only have to be handled once.
5) Available fill material (overburden and waste rock) can be utilized more effectively.
6) Much of the rehabilitation will be completed before the operation is completed (no large cash outlays must be made to "fix up" the site and the land is a more saleable condition.
7) The amount of useable land may be increased.
8) If the future land use is previously determined, the quarry operation can be directed to improve the character or nature of the specified after-use.

The progressive rehabilitation program and its techniques will be determined by the following:

Determinants	Effects
1. the characteristics of the quarry operation (the extraction plan)	- determine the phasing and timing of the progressive rehabilitation
2. the quarry rehabilitation goals	- help to identify requirements or objectives of the progressive rehabilitation program.

3. the quarry landform determinants
   - help to identify the feasibility and techniques of progressive rehabilitation.
4. the operations equipment

When combined, analyzed, and co-ordinated, these factors will help to determine the most efficient method to develop the maximum potential of the site.

7.2 Rehabilitation Goals and Objectives

Rehabilitation goals are determined by future land uses selected for the site. Goal statements define the long-range aims of the progressive rehabilitation program within the context of the site and operational features. The desired rehabilitated condition can be described in terms of three broad long-range qualitative goals or categories. They are as follows:

1) Establishment of environments which do not require continued intensive inputs (i.e. high maintenance requirements) to maintain an ecologically stable landscape (i.e. no erosion and vegetation which will re-establish itself).
2) Establishment of soils and landscapes amenable to agricultural production on a sustained basis.
3) Construction of landscapes suitable for and committed to such uses as housing, industry, or commerce.[6]

Frequently, the future land use selection process will not provide us with a well-defined future land use when we are formulating rehabilitation goals:

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[6] National Research Council, Surface Mining: Soil, Coal, and Society (National Academy Press, 1981), p. 162.

> In the absence of a well-defined land use decision, the establishment of an ecologically stable, desirable, and productive self-sustaining community leaves the widest range of options for future use.[7]

These broad long-range rehabilitation goals are often not definite enough to provide guidance for the short-range objectives of the progressive rehabilitation of the site. Consequently, performance objectives must be formulated to direct the rehabilitation earthwork (including backfilling and grading) and revegetation of the site.

Performance objectives can be described in terms of their legal, functional, or aesthetic purposes, and must be determined for both the progressive earthwork and revegetation programs for the site.

1) Legal performance objectives are those that are stipulated by the Provincial Mines Act and its regulations. For reasons previously stated, operators may wish to rehabilitate their sites far beyond the extent of the legal requirements.

2) Functional performance objectives basically provide for the disposition of overburden and soil combined with a program of site preparation and revegetation to establish safe, usable, and ecologically stable sites.

3) Aesthetic performance objectives can determine the character and quality of the rehabilitated site. Creative utilization of quarry features (ie. quarry faces) overburden, and innovative planting techniques may provide opportunities for additional and potentially dramatic future land uses for quarry sites.

TABLES 9 and 10 provide a list of examples of performance objectives for earthworks and revegetation programs.

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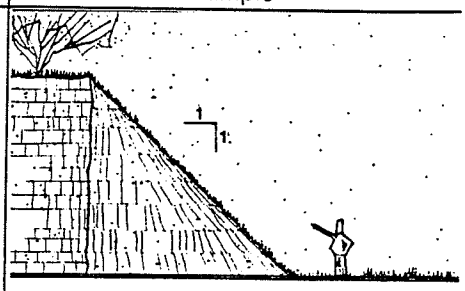
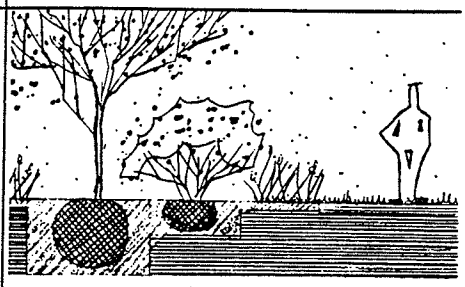
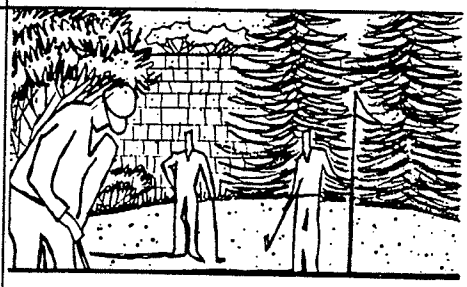
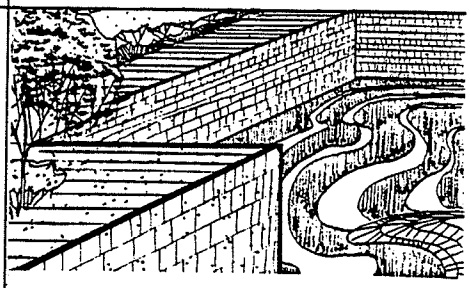
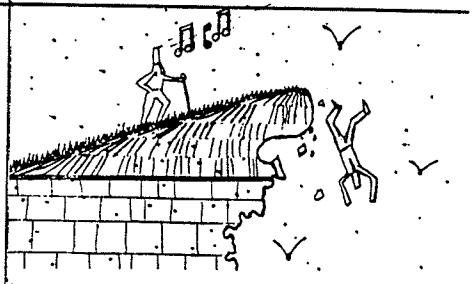
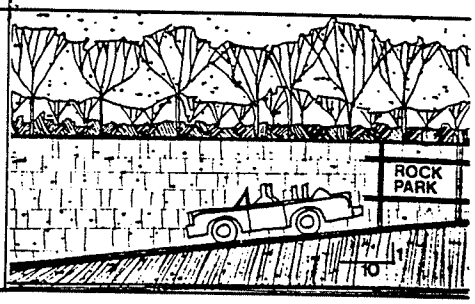
[7] Ibid.

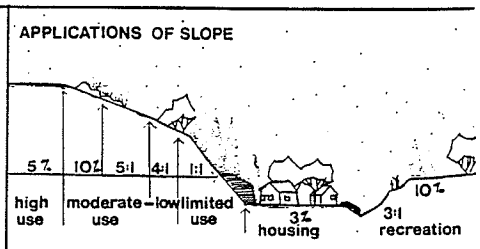
Table 9

EXAMPLES OF PERFORMANCE OBJECTIVES FOR EARTHWORKS

Type of Objective	Objective / Requirements or Comments	Example
LEGAL	Objective - to meet the legal requirements of the Manitoba Mines Act and its regulations. Requirements - upon depletion of site, the sloping of all quarry walls to 45 or 1:1	
FUNCTIONAL Quarry Floors	Objective - to cover bare sterile bedrock with a friable rooting medium or enough material to accomodate buried services such as sewers and waterlines. Requirements - i.e. 30 to 60 cm. of soil is required for grass, while a minimum of 1.3 meters of soil is required for large trees.	
	Objective - to provide relatively flat open areas to accomodate a maximum amount of potential after-use. Requirements - i.e. an 18 hole regulation golf course requires a minimum of 150 acres of relatively flat land. - a par 3, 18 hole golf course requires from 40 to 60 acres. - a golf driving range may require 10 to 15 acres.	
	Objective - Due to the bowl effect of quarries, suitable land must be provided for either temporary or permanent water drainage basins. Comment - i.e. approximately 2.4 hectares (6 acres) of the quarry floor in the Standard Quarry Operation is either temporarily or permanently covered by surface drained water.	
Quarry Faces	Objective - to improve safety aspects of the site by reducing dangers within the quarry. Requirements - the removal of vegetative cover and overburden from the top of quarry faces to provide advance warning of possible dangers.	
	Objective - to provide access to the quarry floor. Requirements - i.e. a 10% or 10:1 slope is the maximum gradient for most public road and street designs. - an 8% or 12.5:1 slope is the maximum gradient for wheelchairs, bikes, and walkways.	

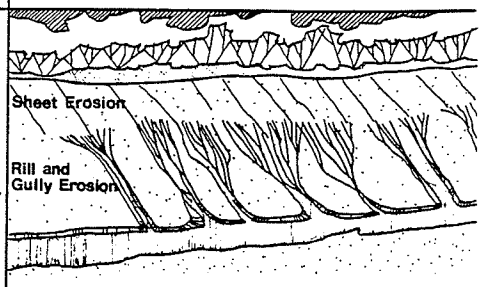
Objective - to provide slopes for different land uses.

Requirements - Ski slopes may require slopes from 5 - 25%.
- Toboggan runs may require slopes ranging from 5 - 15%.



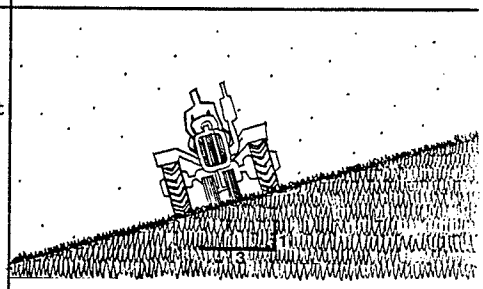
Objective - to provide slopes which are physically stable (i.e. erosion and slope failure are minimized).

Requirements - i.e. physically stable slopes are determined by factors including slope gradient, slope length, and the type of fill material the slope is composed of. Generally however, a 33% slope is considered to be stable under most conditions.



Objective - to provide for suitable maintenance of slopes.

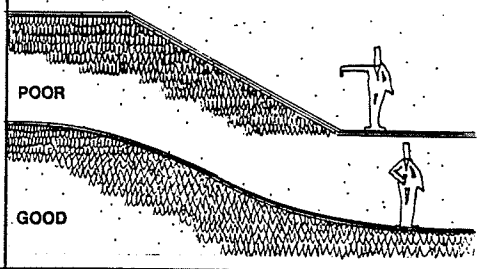
Requirements - i.e. a 33% slope is the maximum gradient for tractor mowing of grassed areas.
- a 50% slope is the maximum gradient for planted slopes (ground cover, shrubs).



AESTHETIC

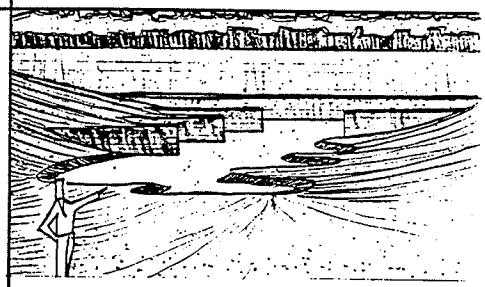
Objective - to provide grades which meet the surrounding landform as smoothly and naturally as possible.

Comments - Slopes should not break abruptly from existing conditions, but rather, should form gentle transitional slopes between existing and post-mining conditions.



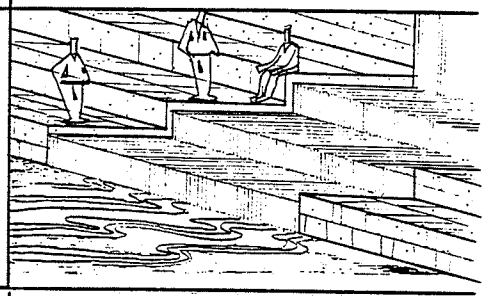
Objective - to provide for variations in slope conditions, ranging from shallow to steep, to vertical rock faces.

Comments - Many sections of the vertical face may remain stable without rehabilitation techniques required. These conditions may be dramatic, novel, and aesthetic features, within any future land use for the site.



Objective - to provide creative features within the quarry site.

Comments - Limestone bedrock may be terraced to provide creative features in quarry rock faces.
- creative use of water drainage areas may provide for opportunities to utilize water features within the quarry site.

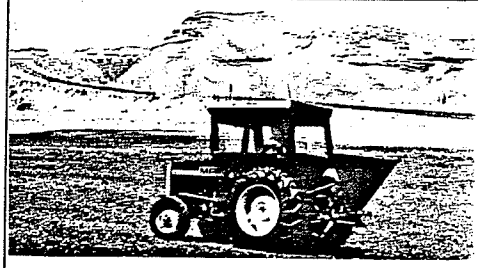
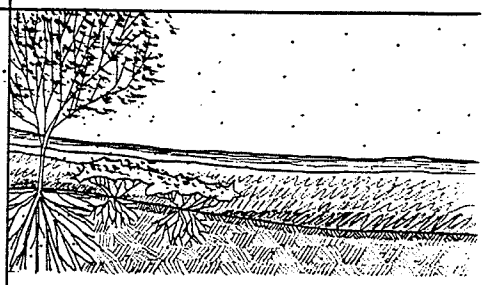
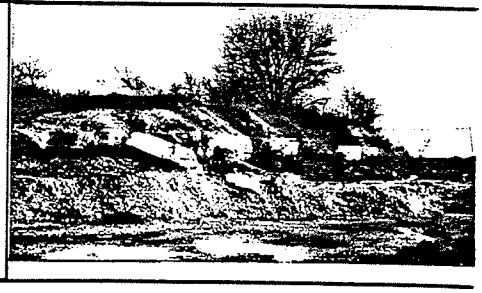


SOURCES

- Coates, W. E., and Scott, O. R., A Study of Pit and Quarry Rehabilitation in Southern Ontario; Ontario Geological Survey, Miscellaneous Paper 83, 1979, pg. 4
- Assorted readings and personal observations.

Table 10

EXAMPLES OF PERFORMANCE OBJECTIVES FOR REVEGETATION

Type of Objective	Objective / Requirements or Comments	Example
LEGAL	Objective - to meet the legal requirements of the Manitoba Mines Act and its Regulations. Requirements - upon depletion of site, the planting of vegetation appropriate to the environment of the commercial quarry on the surfaces covered by overburden.	
FUNCTIONAL	Objective - to establish a vegetative cover that provides erosion and weed protection. Requirements - i.e. dense rhizomatous sod building plants such as Kentucky Bluegrass, Poa pratensis crowd out most weed species and provide complete coverage of the soil surface. - deeply rooted plants, such as Crested Wheatgrass, Agropyron cristatum serve as soil stabilizers on steep slopes.	
	Objective - to establish a vegetative cover that will enhance the physical properties of the soil. Requirements - i.e. leguminous cover crops, such as Alfalfa, Medicago sativa have the ability to fix atmospheric nitrogen and transform it into a soluble form for plant growth. - deep and abundantly rooted plants, such as Creeping Red Fescue, Festuca rubra have the ability to improve soil structure and aeration of the soil.	
	Objective - to provide a vegetative cover which is native or adapted to the site so that the plant material is able to persist and reproduce. Requirements - i.e. trees, such as Balsam Poplar, Populus balsamifera, have been found volunteering and reproducing themselves in depleted limestone quarries. - shrubs, such as Amur Maple, Acer ginnala are subject to lime induced chlorosis, which would severely restrict their ability to persist and reproduce.	
	Objective - to provide a vegetative cover which can be utilized for wildlife habitat and forage. Requirements - i.e. thicket forming shrubs, such as Silverberry, Elaeagnus commutata provide suitable habitat for many species of birds. - perennial grasses, such as Timothy, Phleum pratense offer excellent forage for deer and livestock.	
AESTHETIC	Objective - to cover bare earth and rock to reduce the visual contrast between the quarry site and the surrounding landscape. Comments - i.e. the region in which the majority of limestone quarrying is done is typically an agrarian medium-sized mixed farm type of environment. There are also many existing aspen-bur oak woodlots in the area. Any attempt to visually blend the quarry environment into the surrounding landscape should take these features into account.	

7.3 The Progressive Extraction-Rehabilitation Plan

This plan is the basis for any rehabilitation activities or techniques that may be conducted concurrent with the quarrying operation. It may be formulated subsequent to the determination of the operations plan and the rehabilitation goals and objectives for the quarry site. The progressive extraction-rehabilitation plan may then be utilized as an integral part of the crushed limestone quarrying procedure.

The plan may be designed to provide for concurrent stripping of overburden in advance of extraction. The overburden and waste rock generated from quarrying can then be utilized to backfill quarry faces or to cover quarry floors progressively. In this way, safety hazards may be minimized, circulation will be improved, site features (i.e. quarry walls, slopes, and floor) will conform to the proposed after-use for the site, and the post-mining utilization of the site will be realized much sooner than could be realized otherwise.[8] See FIGURE 5.

Unless the future land use of the site is known, and rehabilitation goals and objectives are firmly established, the progressive extraction-rehabilitation plan need not be overly detailed or specific. A very general plan that provides the quarry manager with an indication of desired effects or conditions is much more valid at this stage of the operation. Examples of information that may be included are provided in FIGURE 6.

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[8] Schellie, p. 163.

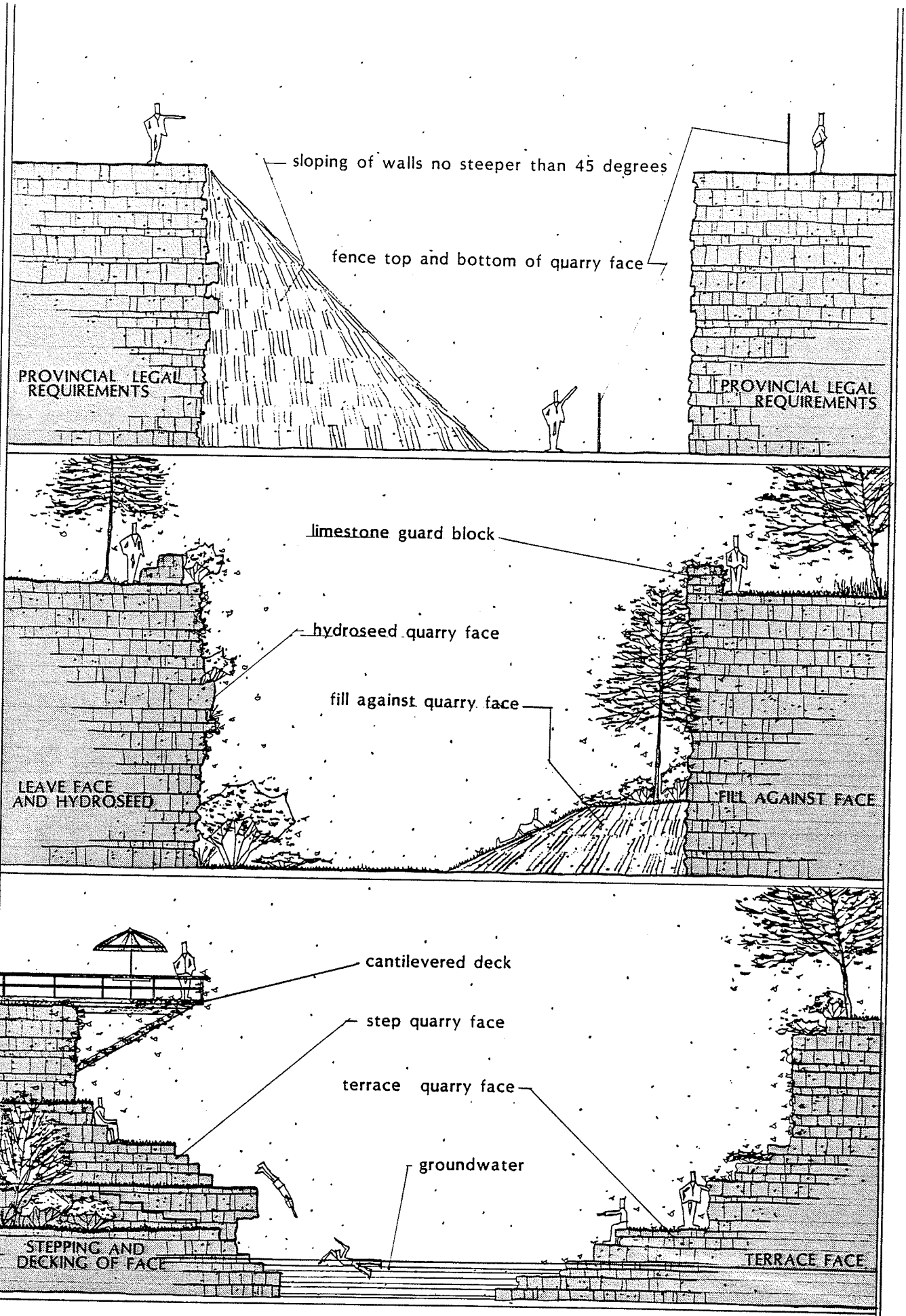

FIGURE 5 Examples of Quarry Face Treatments

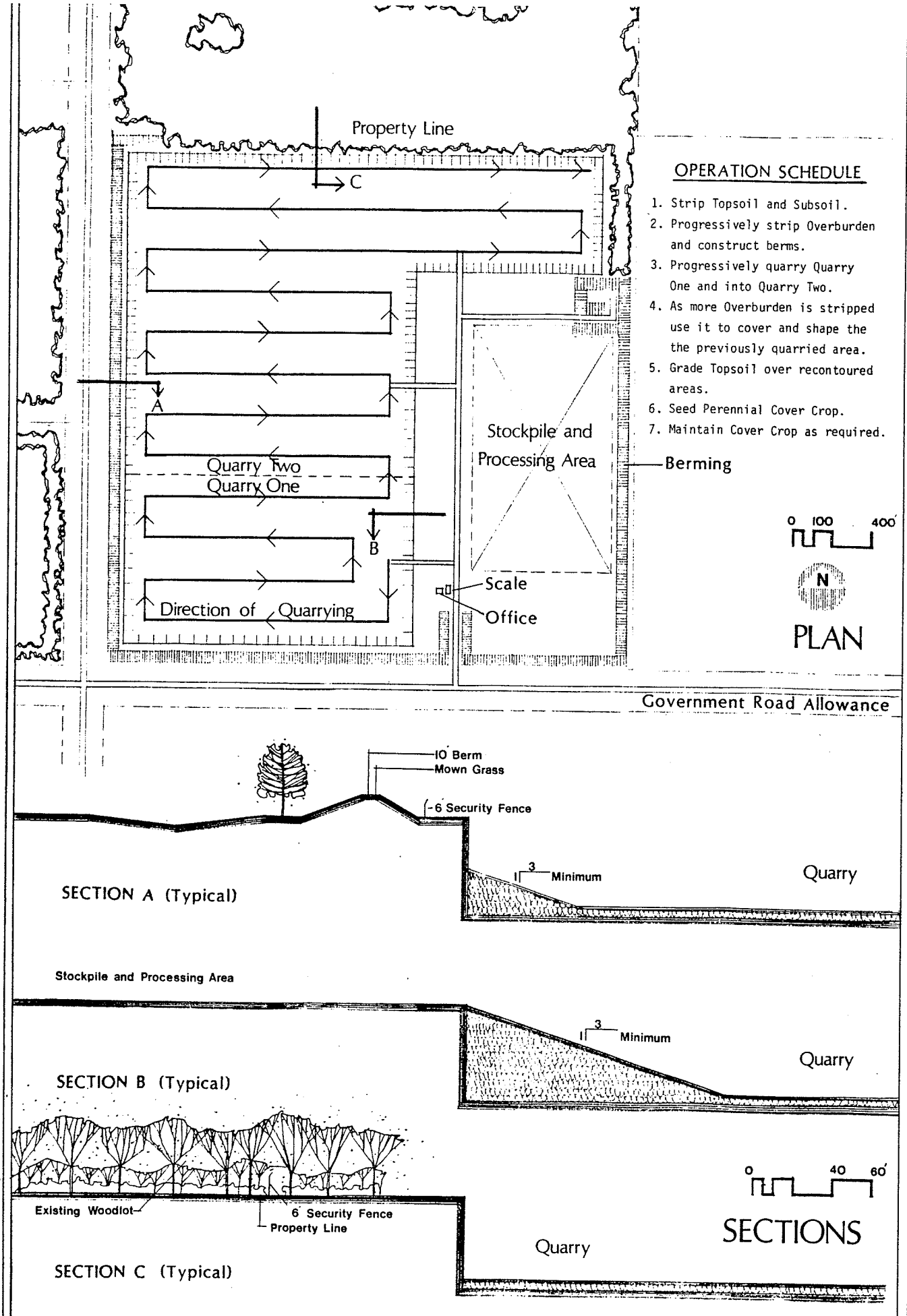

FIGURE 6 PROGRESSIVE EXTRACTION-REHABILITATION PLAN

MANAGEMENT AND POST MINING SITE DEVELOPMENT

8.1 Purpose

The purpose of this section is to provide an outline of the management and post mining site development phases of the project management program. Management refers to the ongoing control or direction that quarry operators may receive from various specialists. Their services may range from simple annual reassessments of the quarry operation to the formulation of comprehensive management programs. Such extensive programs can provide the quarry manager with progressive evaluations of the site opportunities and constraints.

Post mining site development refers to the planning, designing, implementing, and maintaining of the future land use determined for the site. At the minimum, rehabilitation must achieve the legal requirements of the Mines Act and its regulations. Further site development may provide for future land use opportunities, such as unique housing or recreation facilities.

8.2 Management

Considering the length and nature of crushed limestone quarrying, ongoing project management is a critical (although often neglected) practice. Any management program should emphasize the need for landscape maintenance. Regular painting of structures, repair of fences, weeding and mowing of berms, and maintenance of trees and shrubs is required to preserve a positive public image.

It is necessary that the quarry manager is advised and assisted by the various specialists routinely if the requirements of the progressive extraction-rehabilitation plan are to result in practical reality on the ground.[9]

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[9] D. Thomas and P. Gawn, The Practise of Site Treatment (1978; rpt. London: Institute of Quarrying), p. 5.

The very nature of the progressive extraction-rehabilitation plan is one that requires constant re-evaluation and amendment. The Mineral Resources Division has recognized this need for revision by requiring that quarry operators submit a current rehabilitation plan every three years for reassessment. Consequently, the project management planning process must include intervals of reappraisal to accommodate changes over time resulting from refinement of the data base, shifts in goal priority, and correction of inaccuracies:

> Managing the design process means maintaining the flow of information, coordinating the work of all the actors, keeping the design open to all who are vitally concerned, choosing the best design strategy; and encouraging a cyclic return to the original problem without allowing the cycling to become a closed trap from which recommendations never emerge.[10]

8.3 Post Mining Site Development Planning

The post mining site development phase is actually initiated from the outset and incorporates all of the planning phases previously described. Once the future land use for the site has been positively determined, the detailed design of the site development plan may begin. This plan should therefore represent the culmination of the rehabilitation and design effort.

Prior to the final design, a program, budget, and design and construction schedule should be developed similar to that required for the preliminary quarry site development plan. Once established, a schematic site design may be prepared within the framework of the site, the amounts of fill available for land-forming, the operational characteristics, and the proposed budget. The schematic site design involves the transfer of accumulated data and development goals into design terms.[11] See FIGURE 7.

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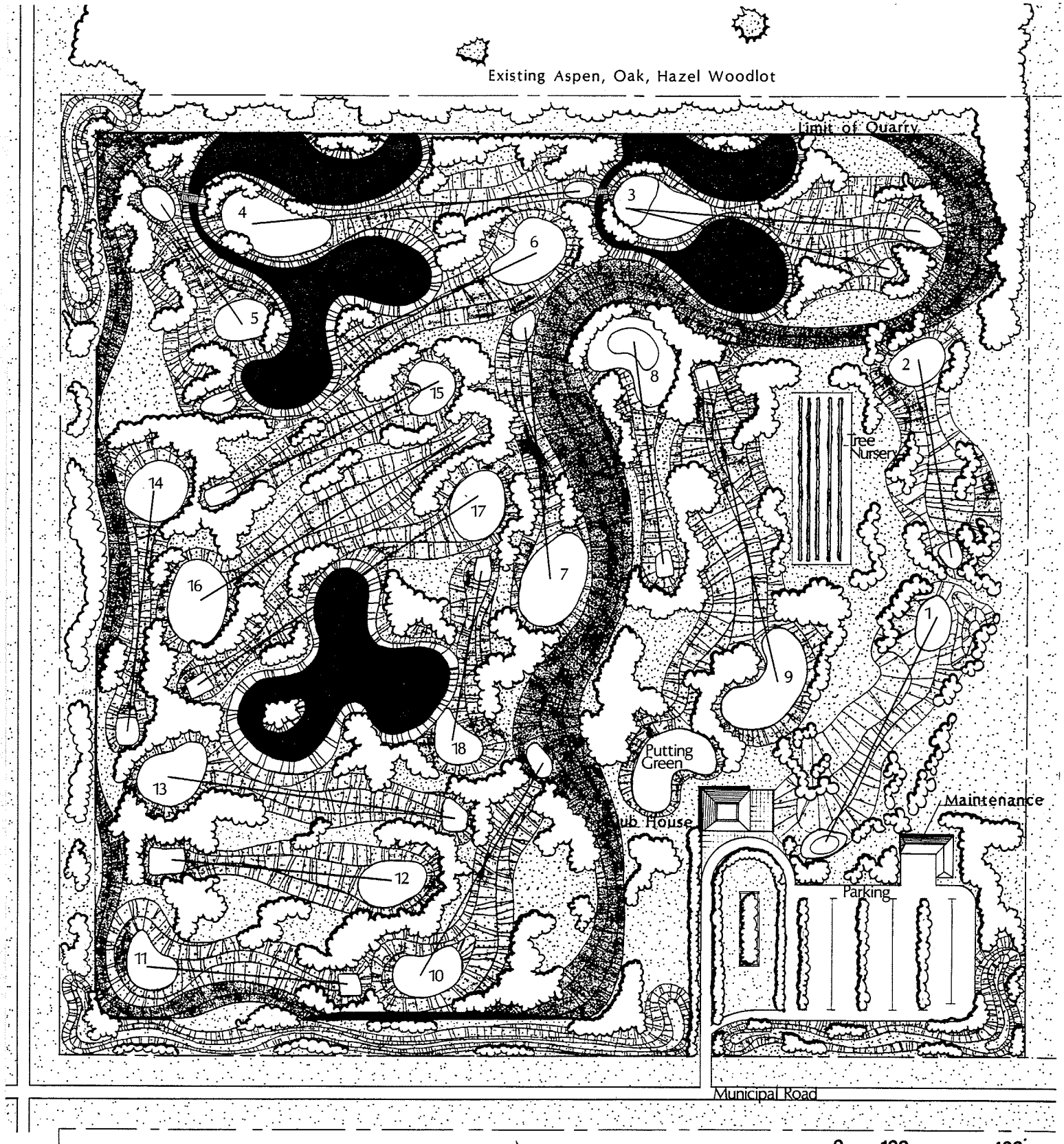
[10] Lynch, p. 264.

[11] Schellie, p. 124.



Limestone Golf and Country Club

FIGURE 7 POST MINING SITE DEVELOPMENT PLAN

The schematic post mining site development plan should graphically illustrate such aspects as:

1) the overall ground form (contours), including water and underwater levels where required and proposed surface water drainage.
2) structures, utility locations, activity locations, circulation patterns including new positions and levels for roads, footpaths, and water courses (including landscape treatment of these elements).
3) location, quantities, and types of plant materials required for rehabilitation.
4) the treatment of the quarry floor, embankments, and cliff faces.[12] The schematic site development plan may then provide for a rough estimate of the cost of the proposed site design.

8.4 Implementation

As soon as the schematic site development plan and its rough budget have been approved, the implementation phase of the project management program can begin. This phase may involve developing the schematic design plan in its technical dimensions and details (i.e. working drawings), planning and scheduling the construction activites, and project supervision of the work on site. Depending upon the scope and budget of the rehabilitation work, several contracting firms may be involved in the project at the same time.

Working drawings are the technical drawings that enable the site development plan to be constructed as designed. Working drawings for quarry rehabilitation normally should include the following:

1) The Grading Plan shows the final ground elevations and contours of the site for the purposes of: making the site more suitable for its intended land use; ensuring adequate surface drainage (to avoid erosion); accommodating structures, foot paths, roads, and utilities.

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[12] Lynch, p. 256.

2) The Layout Plan includes the location of all buildings, roads, hard surface areas, utilities, and the location and nature of details.
3) The Planting Plan includes the location of trees, shrubs, planting beds, and areas to be seeded, sodded, or requiring special treatment. Plant types, quantities, and sizes should be indicated on this plan.
4) The Detail Drawings are required to explain the construction of many of the site details, including paving, walls, signs, outdoor furniture, and any other special planting or design details.[13]

If the rehabilitation scheme is large and detailed enough to require the services of several contracting firms, working drawings will be accompanied by bid procedures, the general and special conditions of work, and the technical specifications for the construction to be accomplished.[14]

Planning and scheduling of the separate construction activities and on-site supervision by the project manager will ensure a more efficient and successful development of the rehabilitation and construction project. Construction supervision may be necessary, not only to ensure compliance by the contractors, but also to make detailed adjustments as unexpected problems or opportunities arise.[15]

8.5 Post Project Management

The purpose of post project management is to ensure that the completed site development achieves the designed intentions or maturity in the most economical manner possible. Considering the large capital outlay in the design and construction phases of the project management process, costs of a maintenance program should become a requisite expense within the entire project.

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[13] Schellie, p. 124; Lynch, p. 256; and Landscape and Site Development (Ottawa: Department of Public Works Canada, 1977)
[14] Lynch, p. 256.

[15] Ibid, p. 257.

Post project management may require the following:

1) the formulation of a project management or maintenance schedule.
2) periodic site inspections to ensure that guarantees are honored and replacement of plant material is satisfactory.
3) the provision of directions or suggestions for the improvement of the ongoing project management program.

CONCLUSION

Modern society requires an economical supply of mineral aggregate products produced by the crushed limestone industry. However, that same society will no longer tolerate the detrimental social and environmental impacts that the quarrying of limestone can cause. Consequently, the continued development and expansion of the crushed limestone industry within southern Manitoba offers a unique dilemma for the quarry manager, municipal official, and all others concerned. See FIGURE 8.

To date, most quarry operators have refused to recognize the need to improve their poor public image. The consequence of this lack of foresight will surely induce increased monitoring and regulation of quarry operations by municipalities and government agencies. It is the author's contention that if the crushed limestone producers were to attempt to improve their public image, the advantage of such action would provide future benefits for all concerned.

The Project Management Planning Program discussed here is presented as a guide to site development and the rehabilitation of crushed limestone quarries. The intent of such a program is to provide possible resolutions to many of the issues and problems inherent in the crushed limestone industry. Upon implementation, this planning process might also provide several benefits, which are summarized as follows:

Benefits for the Quarry Manager

1) An overall planning program provides a more functional, efficient, and better-looking quarry operation.
2) The site development plan takes better advantage of the natural existing screening opportunities afforded by the site.
3) It provides the quarry operation with a more efficient stripping and stockpiling plan.
4) It provides an incentive for progressive rehabilitation to take place concurrent with extraction operations.

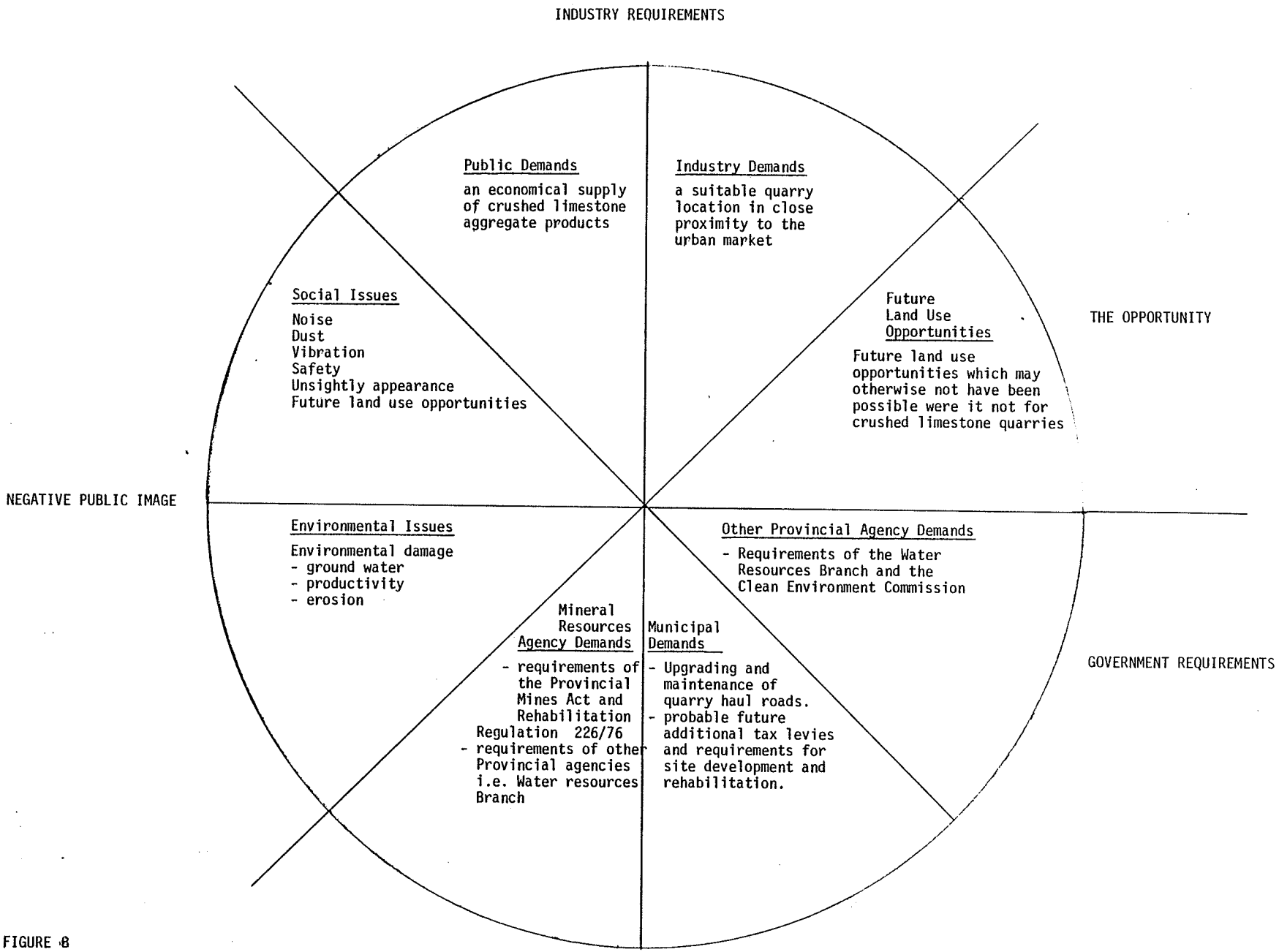

FIGURE 8

THE CRUSHED LIMESTONE INDUSTRY DILEMMA

5) With an overall development plan, the three year rehabilitation plan submissions are much easier to produce, they are more accurate, and recommendations from government agencies and private consultants can be more useful to the quarry manager.
6) It may provide for reduced rehabilitation costs at the termination of the operation, while immediately providing the manager with more saleable land.
7) Future submissions by limestone quarry operators would be more readily welcomed by the municipality in question.

Benefits for the Municipality

1) Frustrations in attempting to monitor or regulate quarry operations are reduced.
2) The rehabilitated quarries can provide sources of new land use opportunities, and possibly new sources of revenue.

Benefits to the Government Agencies

1) The job of monitoring and enforcement of Provincial Acts, Orders, and Regulations would be much improved.
2) Rehabilitation plans submitted by the quarry operators would be more accurate and useful for reappraisal purposes.

Benefits for Society

1) Society will still receive the mineral aggregate products that are required, but from a more attractive, efficient operation.
2) There is the possibility of remodelling the landscape into large-scale landforms of real future and economic benefit.

As has been outlined, there are several existing and future benefits to be derived for all parties involved from the continued and properly planned development and expansion of the crushed limestone industry in southern Manitoba:

> ...only by acceptance on behalf of all parties of the need for such a total commitment by the industry and society, will the largely unnecessary ills of the past fade in the memory, to be replaced by an image of an industry making a positive contribution to society's requirements and the continuing evolution of the landscape.[16]

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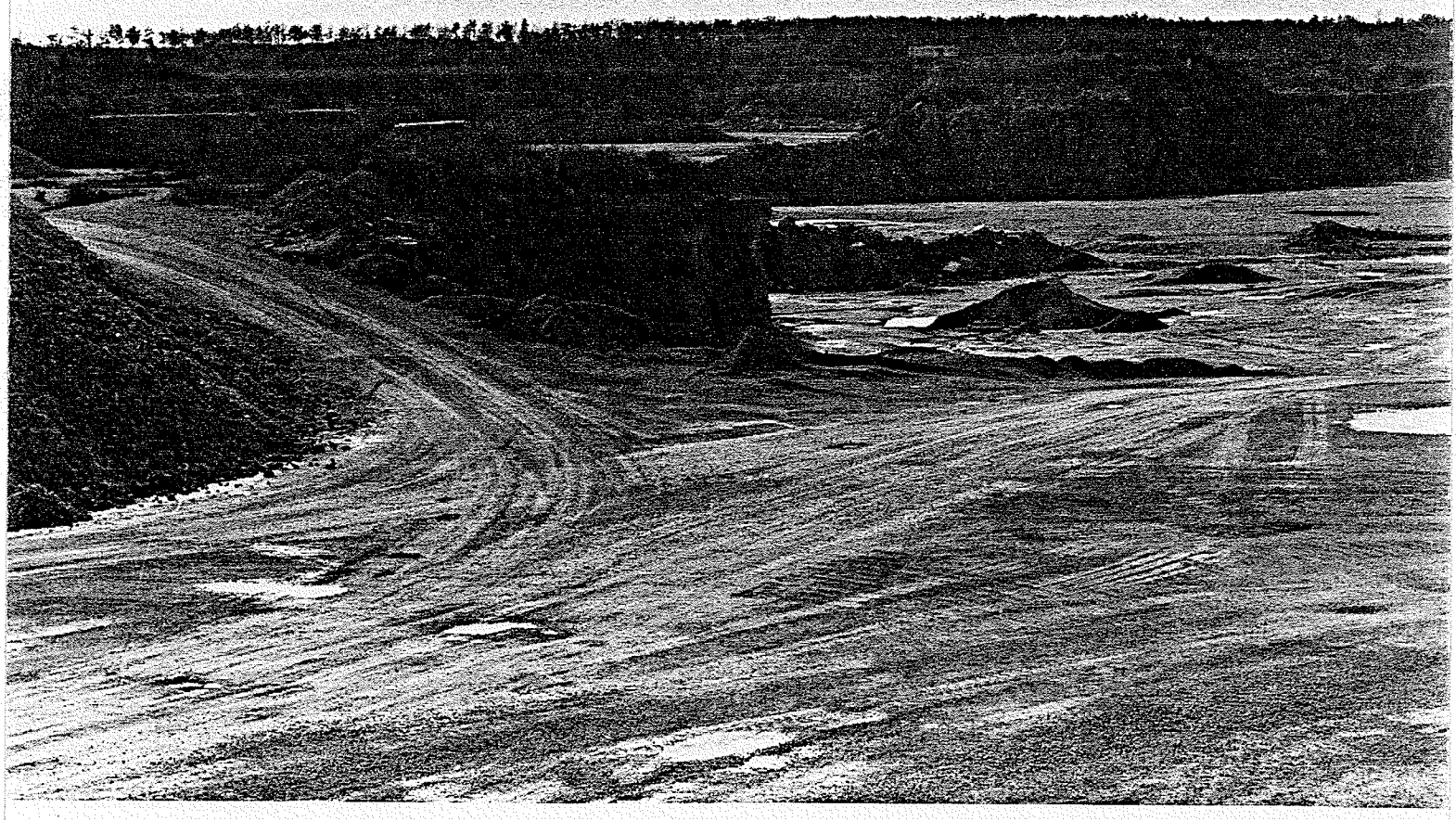
16 Thomas and Gawn, p. 7.

Part 3
Background and Technical Information



THE RESOURCE, IT'S CLASSIFICATION AND EXTRACTION

10.1 Purpose

The purpose of this section is to provide the reader with essential background information on the geologic origins of the limestone resource in southern Manitoba, the classification of crushed limestone products, and the typical crushed limestone quarry operation.

10.2 The Resource

10.2.1 Formation of Limestone Bedrock

The important limestone bedrock deposits we are exploiting in southern Manitoba are those that belong to the Ordovician and Silurian systems which occured during the Palaeozoic era some 320 to 440 million years ago.[1] Through an analysis of the marine life that was deposited, we know that between Ordovician and Silurian times the Interlake area was part of a large, generally shallow and warm, marine depositional basin. A series of carbonate-based sediments were laid down during this period directly over the pre-existing Precambrian bedrock. These carbonate based sediments consisted of calcareous shales and argillaceous (limestone containing impurities that represent a large proportion of the rock) and crystalline limestones, many of which were subsequently dolomitized to varying degrees.[2]

Calcium and magnesium (the main components of limestone and dolomite) were released when the pre-existing rock was weathered over vast periods of time. The calcium and magnesium salts were carried in solution and diffused throughout the great sea which once engulfed the Interlake area. These dissolved lime salts were subsequently removed from the shallow water by two agencies; organic activity and chemical processes.[3]

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[1] J.F. Davies et al., Geology and Mineral Resources of Manitoba (Manitoba Department of Mines and Natural Resources, 1962), p. 133.

[2] J. MacLaren, Mineral Aggregate Study of the Southern Interlake Region (Winnipeg, Manitoba Department of Miners, 1980), Volume I, p.50.

[3] M.F. Goudge, Canadian Limestones for Building Purposes (Canada Department of Mines, 133), p. 5.

The organic activity was created by the incredible numbers of tiny carbonate-shelled creatures that had the ability to extract lime salts from the water. Upon death, these minute shells fell to the sea floor in great deposits augmented by larger shelled creatures and also the material extracted from sea water by the corals.[4]

Chemical precipitation was the other agency which removed the dissolved salts from solution. This occured when the water was unable to hold the lime salts in solution due to causes such as changes in water temperature or composition. The lime salts crystallized out as extremely small crystals and sank to the ocean floor.[5]

The accumulation of these shells, corals, and crystals formed a loose mass of solids and ooze. This mass was subsequently consolidated into limestone by a number of factors which may have acted singly or in combination. The primary limestone-forming agency was probably the growth of cementing crystals of calcite or dolomite throughout the mass.[6] This cementation was caused by the weight of either the material itself or the beds of other material deposited on top. The tremendous pressure due to earth movements also played an important role in the consolidation of these limestone deposits.

10.2.2 Surficial Geology

The surficial or quaternary geology of the Rockwood area has developed as a relatively recent event in terms of the geological time scale. Several separate Ice Ages combined to rework the bedrock formations laid millions of years ago. However, we are only very knowledgeable of the most recent of the great Ice Ages; the Wisconsin

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[4] Ibid., p. 5.

[5] Ibid., p. 5.

[6] M.F. Goudge, Limestones of Canada; Their Occurrence and Characteristics (Canada Department of Mines and Resources, 1944), Part V, p. 2.

Glaciation, whjich occured approximately 22,000 years ago.[7] The Wisconsin Glaciation, and the subsequent Pro-Glacial Lake Agassiz, are the main contributors to the existing surficial geology, as they served to destroy much of the evidence of the previous Ice Ages.

As the Kewatin and Patrician Ice Sheets (Wisconsin Glaciation) retreated northward, the broken rock material held within them was deposited as outwash plains and moraines. Material was dropped on the land or in shallow water, forming a layer of unsorted drift or boulders, sand, silt, and clay.[8]

As the ice sheets blocked the northward drainage flow, and the height of the surrounding land blocked other drainage outlets, the vast Pro-Glacial Lake Agassiz formed over virtually all of southern Manitoba. The Rockwood area was overlaid by lacustrine clays which were deposited at the bottom of the Agassiz Basin. During the waning stages of the glacial lake, shallow water over the Interlake region caused wave action which in turn reworked some of the previously deposited sediments.[9] As a result, the depth to the carbonate bedrock varies widely in the Rockwood area, ranging from depths of one meter to in excess of sixty meters.[10]

10.3 Classification and Use of Limestone

Limestones depart more or less widely from their theoretical composition of calcite, which is pure limestone (calcite = calcium carbonate = $CaCO_3$). The majority of the limestone bedrock utilized within Manitoba varies between its theoretically pure form ($CaCO_3$) and

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[7] The U.M.A. Group, Aggregate Resources of the Winnipeg Region (Winnipeg: Manitoba Department of Mines, 1976), p. 31.

[8] Davies, p. 151.

[9] U.M.A. Group, p. 33.

[10] W. Michalyna, W. Gardiner, and G. Podolsky, Soils of the Winnipeg Region Study Area (Winnipeg: Municipal Planning Branch, 1975), p. 3.

that of dolomite ($MgCO_3$). Dolomite and limestone are so similar, they are often found in adjacent beds or intermixed with one another.

High quality limestone (or dolomite) bedrock is pure white. The wide range in colors in the bedrock (colors may range from greys, to golds, to rust) is due to weathering and impurities. As impurities increase in these rocks, they become more clayey, shaley, or sandy.[11] See TABLE 11 for some of the physical characteristics of limestone and dolomite.

In order that excavated limestone meet the many specifications demanded, the aggregate must be processed. Crushed limestone is classified and sold on the basis of particle size and quality of stone. The particle size of crushed stone is determined using a recognized system of screens or sieves to separate the material into different sizes. The size of the holes in each sieve is commonly expressed in terms of inches or millimeters (i.e. 3/4" sieve or 19 mm. sieve), or in terms of a mesh (i.e. a 200 mesh screen has 200 equal-sized holes within every square inch; equal to a 75 micrometer sieve).[12] Specifications for different products require that crushed limestone conform to certain uniform sizes and proportionate mixtures of sizes. For example, the Province of Manitoba Highways Department requires that crushed limestone for use in highway base courses, must contain the following mixture of sizes:

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[11] E. C. Eckel, Cements, Limes, and Plasters (New York: John Wiley and Sons Inc., 1922), p. 93.

[12] P. Large, Sand and Gravel in Manitoba Manitoba Mineral Resources Division Education Series 78/, (Winnipeg, 1978), p. 7, and Keeping Pace with the 80's. (Downsview, Ontario: Aggregate Producers Association of Ontario, 1982), p. 84.

Manitoba Highways Aggregate Grading Specifications[13]

100% of the material passing through a 1" screen
40-70% of the material passing through a No. 4 screen
10-30% of the material passing through a No. 40 screen
5-50% of the material passing through a No. 200 screen

The nominal size referred to is the smallest screen size through which 100% of the material may pass (i.e. in the previous case, 1" or 2.5 cm) would be the nominal size of the product).[14]

The quality of the stone may also be utilized in the classification of crushed limestone because impurities reduce the engineering properties of the stone. Many specifications limit the permissible amounts of deleterious substances in aggregates. TABLE 12 lists the various limestone bedrock strata that are quarried in the Rockwood region and rates their suitability for use as construction aggregate. Suitability depends on physical properties plus the capability of the rock to withstand stresses placed upon it when it is used as a construction material. Currently, the majority of quarries are exploiting the Gunton Member of the Stony Mountain Formation.

The relative quality of the bedrock strata can be tested through specific tests outlined by the American Standards Association (A.S.A.), the Canadian Standards Association (C.S.A.) or the American Railway Engineering Association (A.R.E.A.). If the product's use is not critical, varying grades or qualities of crushed stone may be mixed (termed "benefication") so that the relative lifespan of a quarry's quality rock reserve can be lengthened.[15]

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[13] Manitoba Highways Grading Specifications.

[14] Keeping Pace with the 80's, p. 83.

[15] Personal communication with C. Jones, Mineral Resources Division personnel, May, 1982.

TABLE 11

PHYSICAL CHARACTERISTICS OF LIMESTONE AND DOLOMITE

Calcite (Pure Limestone)	Lime	CaO	56%
	Carbon dioxide	CO_2	44%
	Calcium carbonate	$CaCO_3$	100%
Dolomite (Pure Dolomite)	Carbon dioxide	CO_2	48%
	Lime	CaO	30%
	Magnesia	MgO	22%
	Dolomite		100%

Sources: Eckel, Cements, Limes and Plasters; John Wiley and Sons Inc. 1922.

Messervey, Limestone and Dolomite in Nova Scotia; Nova Scotia Dept. of Public Works and Mines, Halifax, 1927, pg. 9

	tons/yd^3	kg/m^3	yd^3/ton	m^3/kg. x 1000
Compact Limestone (solid rock)	1.9-2.1	2550-2800	.48-.52	.36-.39

Source: McGregor, The Drilling of Rock; CR Books, London, 1976, pg. 197

	lbs./$ft.^3$	% of wear	hardness	toughness
Limestone	165	5.0	14.1	9
Dolomite	170	5.5	14.9	9
Granite	167	4.3	18.3	11

Weight of Material

Material	Wt. 1 yd. = 27 cubic ft.
Cement (Portland	2538
Dolomite (crushed fine)	2565
Dolomite (broken lump)	2565
Gravel (dry loose)	2970
Gravel (dry packed)	3051
Gravel (wet packed)	3240
Limestone (run of crusher)	2565
Limestone (fines out)	2700
Limestone (1 1/2" or 2" grade)	2295
Limestone (above 2" grade)	2160
Sand (dry loose)	2565
Sand (wet packed)	3240

Source: Nichols, Moving the Earth; North Castle Books, Greenwich 1976, pgs. 3-6

TABLE 12

SUITABILITY OF BEDROCK FOR AGGREGATE PRODUCTION

Formation	Member or Unit	Rock Type	Potential Aggregate Quality	Uses
Interlake Group			High	
Stonewall		dolomite	High	
Stony Mountain	Williams	dolomite	Low	
	Gunton	dolomite	High	crushed stone
	Penitentiary	dolomite	Medium	crushed stone
	Gunn	calcareous shale-thin limestone interbeds	Low	
Red River	Fort Garry (upper)	dolomite and limestone	Medium High	crushed stone, high-calcium limestone
	Fort Garry (lower)	dolomite	Medium	crushed stone
	Selkirk	dolomitic limestone	Low	Tyndal Stone
	Cat Head	dolomite to dolomitic limestone		crushed stone, rubble, rip rap
	Dog Head	dolomitic limestone		
Winnipeg		koolnitic shale and quartzose sandstone		

Sources: MacLaren, J., Mineral Aggregate Study of the Southern Interlake Region, Vol. 1, Winnipeg 1980, pg. 7

Bannatyne, B., High Calcium Limestone Deposits of Manitoba; Mineral Resources Division, Winnipeg 1975, pg. 19

10.4 Crushed Stone Quarry Operations

To contribute effectively to the solution of the "aggregate dilemma", and to gain acceptance by the mining industry, the reader must be knowledgeable and fluent in quarry operations and development, and in the procession of mined shapes upon the land.[16] It is the purpose of this section to introduce and discuss the operations involved in quarrying for the limestone which is suitable for crushing for building aggregate.

To relate the steps involved in a crushed limestone operation adequately, I will utilize the example of a typical existing quarry. Although crushed limestone operations naturally will vary depending upon the site, the scale of the operation, and the type of equipment involved, there are several basic steps which are common and often necessary practise. I am utilizing the Standard Quarry operation, which is probably the largest of all quarries within the Winnipeg region, and as such, contains all the essential elements of the existing quarries. In all probability, this example will be similar to any future operations.

Standard Limestone Quarries is a large, long-established operation located five kilometers northeast of Stonewall. The quarry was opened in 1961 and currently produces 400,000 tonnes of limestone aggregate per year.[17]

The initial steps involved with every mineral aggregate operation are basic and essentially universal in application. See TABLE 13.

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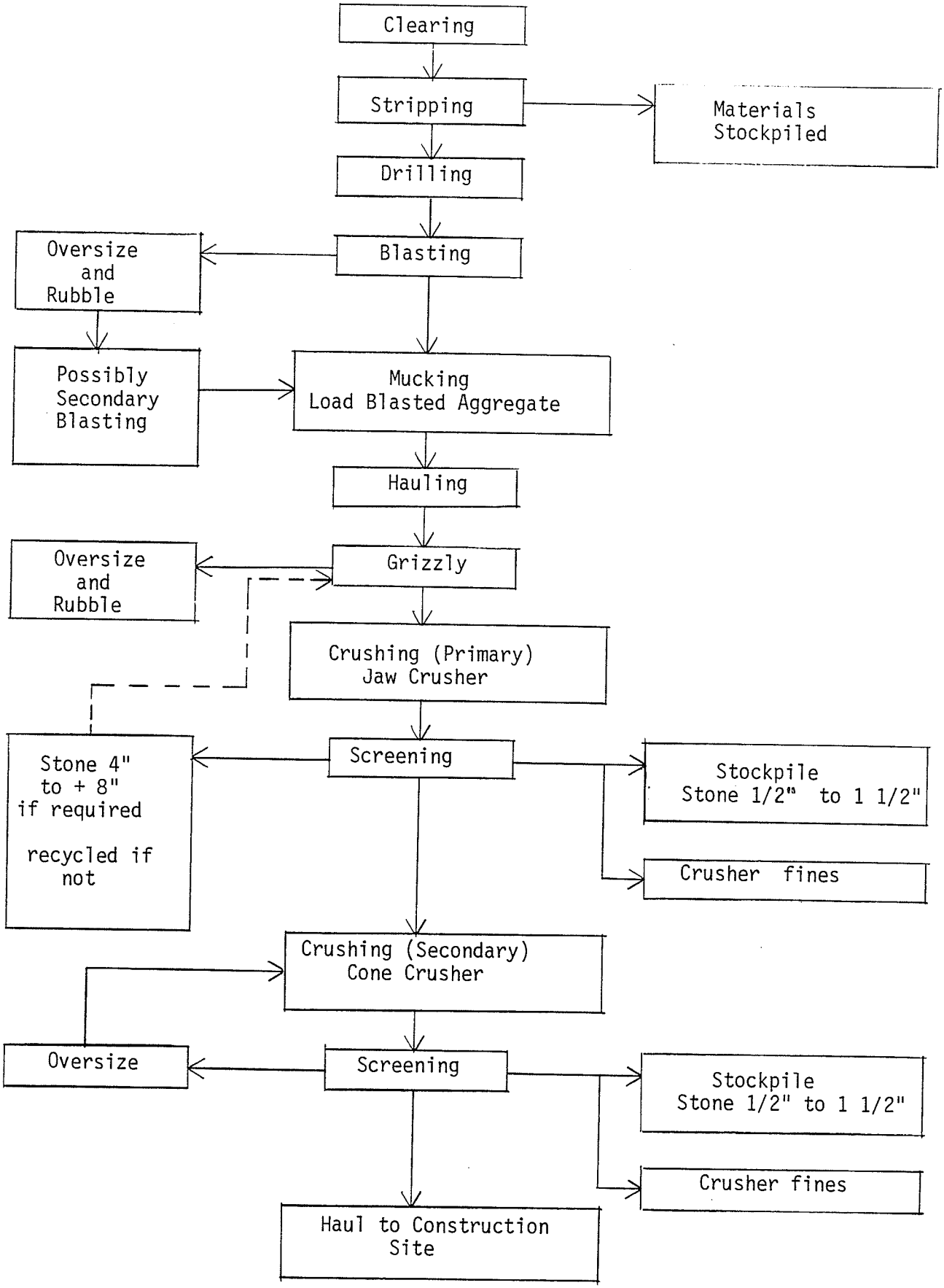
[16] Creating Land for Tomorrow, American Society of Landscape Architects LATIS Series (Washington: E.D.A.W. Inc. (A.S.L.A.), 1978), p. 6.

[17] J. MacKay, "Environmental Control Report," (Winnipeg, 1979), Manitoba Clean Environment Commission, File 1874, p. 3.

TABLE 13



FLOW DIAGRAM OF A CRUSHED LIMESTONE QUARRY OPERATION

These are as follows:

1) Clearing involves the removal and disposal of any and all vegetation or structures that are located within the limits of the proposed excavation. Typically, the terrain is cleared by a front-end loader or bulldozer to remove existing stands of oak and aspen, shelter belt plantings, or native pasture. Grubbing is the term applied specifically to the removal of tree stumps and trash litter. The cleared material is either hauled away, burned, or more commonly buried in the subsequent formation of earth berms on the periphery of the site.

2) Stripping involves the removal of the overburden and/or topsoil overlying the bedrock of the proposed excavation site. The topsoil layer is generally the biologically productive zone containing the plant nutrients and organic material necessary for vegetative growth. Overburden may be defined as that portion of earth material overlying the bedrock up to, but not including, the topsoil. Typically, overburden is stripped from the excavation site and utilized in the formation of earthen berms on the periphery of the property.

In very few areas will the bedrock ever be accessible prior to clearing and stripping. Locations of outcrops of limestone bedrock were the sites of the earliest quarrying activities (i.e. Stonewall, Stony Mountain), and despite the proximity of the bedrock to the ground surface, some clearing and stripping were required.

In principle, topsoil should be stripped separately from the overburden. However, the typical situation in Rockwood is that both topsoil and overburden are stripped together, as much of the overburden (glacial drift) is virtually as fertile as the topsoils above them.[19]

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[19] Personal communication with R. Glassford, Mineral Resources Division Chief Mining Engineer, February 1982.

Further, topsoil may be so poor as to be practically indistinguishable from the immediate overburden below. Current stripping procedure at Standard Quarries is that both overburden and topsoil are stripped by the firm's front-end loader.[20]

The removal of the overburden from a site involves a large expense prior to the actual operation. In the case of a large operation, all of the overburden could be removed prior to bedrock excavation. Since most quarries expand very slowly, the usual case is for stripping and extraction to be carried out throughout the life of the quarry. The stripping costs will be affected by the type and amount of material removed, the distance the material is hauled, and the efficiency of the operation.[21] At Standard Quarry, the overburden varies from 1.5 to 2 meters. Occasionally, between layers in the bedrock strata, softer more friable shale and sandstone deposits may be encountered, which must also be removed and stored or stockpiled.

Within Rockwood, there are three typical methods for removing overburden from the site. These are:

A) Front-end Loader
   - usually a five metre bucket loader which is utilized in the quarry operation.
   - usually strip at slack times or at the beginning of the season.

B) Caterpillar Tractor
   - usually rented on a contract basis.
   - usually utilized to strip the entire site or enough land to quarry for one year.

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20 Ibid.

21 Nichols, pp. 10-11.

C) Belly Dump Scraper (larger operations)

- usually rented on a contract basis.
- usually removes all overburden and dumps it to create berms on the periphery of the site.
- excellent for stripping the topsoil layer. Also enables the separation of the topsoil from the overburden.[22]

If there are more than 1.5 meters of overburden, then the operator will usually contract a belly dump scraper.[23] This is due to the relative inefficiency of a front-end loader to handle this type of work.

Provincial regulations require that overburden be stripped in advance of the working face at least twice the height of the quarry face. Typically, we find even in smaller operations that it is economically advantageous to strip much larger areas of overburden when equipment is available.[24]

3) Excavation: The basic processes involved in excavation of limestone are very similar and are utilized widely in Manitoba. They are drilling, blasting, and mucking.[25]

A) Drilling: The process of quarrying requires that stone be removed from its parent bedrock. By drilling bedrock using pneumatic drills, an explosive charge can be laid to break the stone from the bedrock strata. Pneumatic rock drills are also called percussive, as the bedrock is fragmented by repetitive impaction.[26] The commonly utilized rock drill is called an "air track" which consists of a compressed air drill mounted on a small crawler or tracked unit.

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[22] Personal communication with R. Glassford, February 1982.

[23] Ibid.

[24] Bailey, p. 20.

[25] D. P. Krynine and W. R. Judd, Principles of Engineering Geology and Geotechnics (New York: McGraw-Hill, 1975), Chapter 8; B. Carson, General Excavation Methods (New York: McGraw-Hill, 1961); and U.M.A. Group.

[26] McGregor, p. 41.

Steel drill rods with specially shaped tips or bits are forced into the rock to form a series of vertical holes along a straight line parallel to the quarry face. The diameter, spacing, amount of explosive charge, and the height of the bench or working face, are factors influencing the output of excavated rock from the quarry face.[27] Typically, the quarry operators drill approximately 6.35 cm holes, with 2-2.6 meter spacings between holes, and a six meter bench height.[28]

B) Blasting: Quarry blasting is the most efficient method of shattering rock in its bed, and it is conducted to produce sizes of stone capable of being picked up by a front-end loader. Generally, the material blown will be consistent in structure, for, as a seam runs out, another portion of the quarry may have to be opened up.

Typically, a line of holes is fired parallel to the face and if the spacing is correct, the holes mutually interact with each other to form a new flat face.[29] In a well engineered blast, the majority of the rock will be broken less by explosive force than it will be afterwards by slumping under the pull of gravity.[30] Depending upon the operation and the relative success of the blast, there are either one or two blasting stages. Primary blasting is the process previously explained. This is conducted using an ammonium nitrate (fertilizer) and fuel oil mix. The amount of explosive charge varies greatly between operations, but most quarries primary blast twice a day.[31] Secondary blasting may be necessary if the pieces of rock are too big for the front-end loader or crusher. Black powder is used in secondary blasting.

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27 Krynine and Judd, p. 310.

28 Personal communication with R. Glassford, Mineral Resources Division personnel, February 1982; and Various "Environmental Control Reports" (Winnipeg: Clean Environment Commission, 1979).

29 McGregor, p. 200.

30 Nichols, p. 9-38.

31 Various "Environmental Control Reports: (Winnipeg: Clean Environment Commission, 1979).

Limestone operators basically work one long face. While mucking up one blast, they are drilling and setting explosives on another portion of the face. In theory, if the operators are working efficiently, the new portion of the face will be ready to blast immediately after mucking the preceeding blast.[32]

C) Mucking: Mucking is the process of removing the blasted stone from the quarry floor. Crushed limestone operations typically use a front-end loader with a five meter bucket for this operation.[33] Depending upon the scale of the operation, the loader is used to dig and load the "muck", and sometimes even to haul the stone to the portable processing unit.

4) Processing Plants: The majority of crushed stone operations utilize a portable processing plant to process the rock into the various specifications required. Although every operation may own a different unit, the basic steps are almost universal in application.

A) Grizzly: The grizzly is generally a primary screen with fairly coarse openings that may serve up to three basic purposes:

a) It serves as a dump point for blasted rock.
b) It reduces the load to the primary crusher in that material too large for the crusher is rejected and material not requiring primary crushing may be bypassed to the secondary unit.
c) It controls the feed-rate into the primary crusher to prevent jamming and yet provide for optimum efficiency of the crusher.

B) Primary Crusher: Rock crushers reduce rocks to smaller and more uniform sizes. Primary crushers are usually jaw crushers which work run-of-pit and produce a coarse product of from 1.3 to 2 cm.[34]

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[32] Personal communication with R. Glassford, Mineral Resources Division personnel, February 1982.

[33] Ibid.

[34] Personal communication with R. Glassford, Mineral Resources Division, February 1982.

> A jaw crusher consists of an immovable and a movable jaw lined with wear resistant lining plates. The movable jaw rotates about a horizontal axis in a pendulum action and crushes the stone material by striking the immovable jaw.[35]

C) Screening: Screening of the primary crusher-run material is conducted prior to secondary crushing for purposes similar to those of using a grizzly. Specification-sized product will be screened out; intermediate pieces will be passed onto the secondary crusher, while oversize pieces are sent back to the primary crusher.

Screens may be welded bars, sheet steel, rubber, or wire cloth, with round, square, slot, or octagonal holes. In order for separation of the products, movement must take place. There are different screens, variously relying on gravity flow, rotating, shaking or vibrating, or raking to separate the various products.[36]

D) Secondary Crusher: Crushed stone operations within the Winnipeg region typically use secondary crushers of the Cone or Gyratory type. These crushers utilize a conical crushing member which moves in a small circle around a vertical axis inside a fixed bowl or mantle. Rock is fed into the top of the bowl, falls between the cone and the mantle, and is crushed as the opening narrows with the movement of the cone.[37] When the product specification is critical, cone crushers are capable of producing a finer, more uniform product than the jaw crushers can. Screening is done immediately after secondary processing in exactly the same fashion as between primary and secondary processing.

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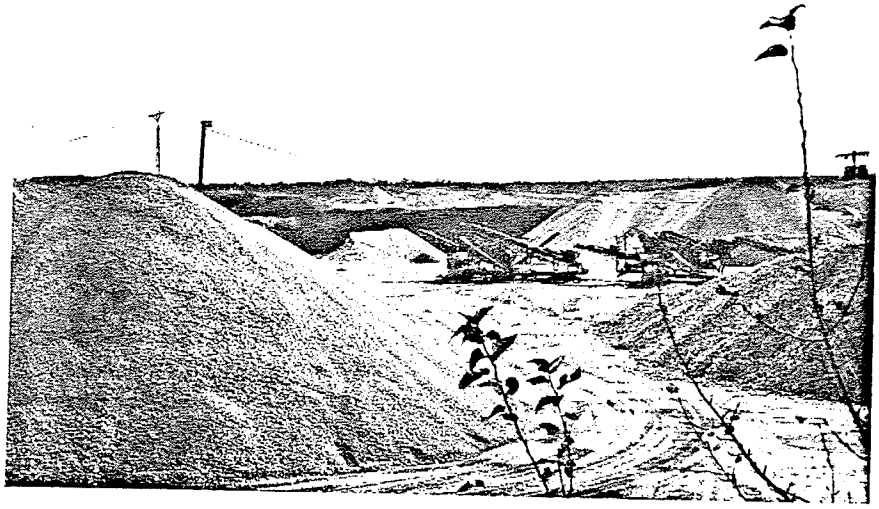
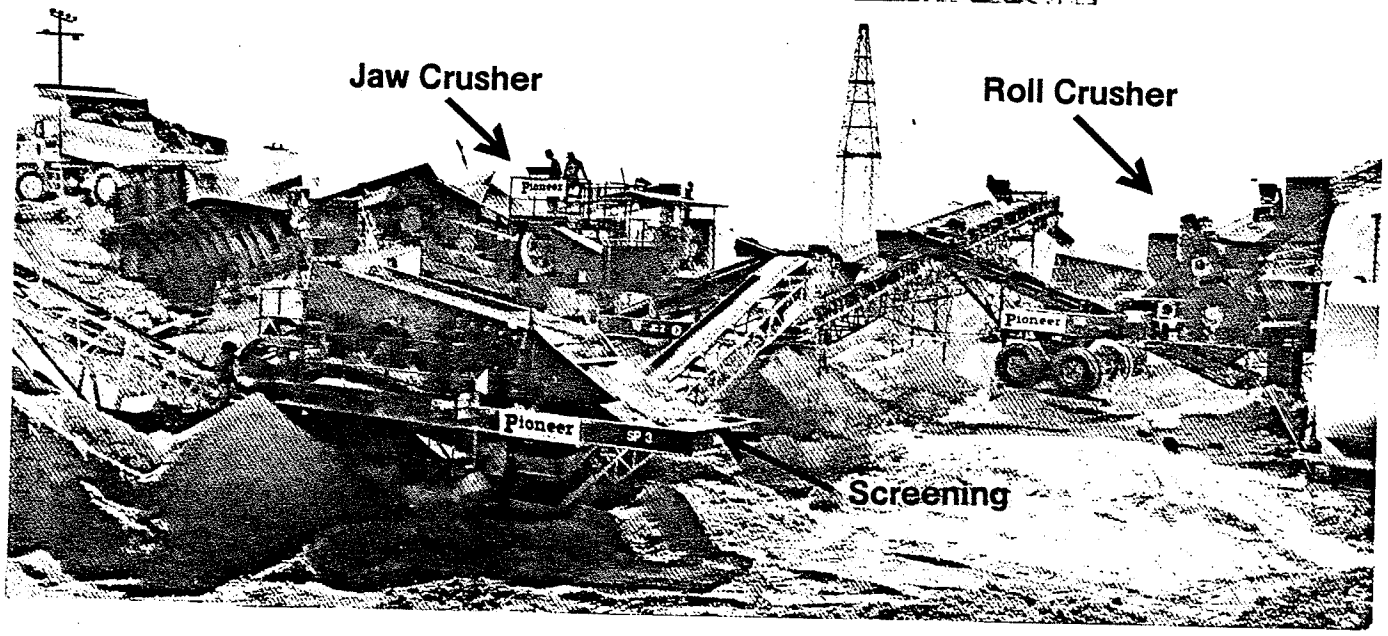
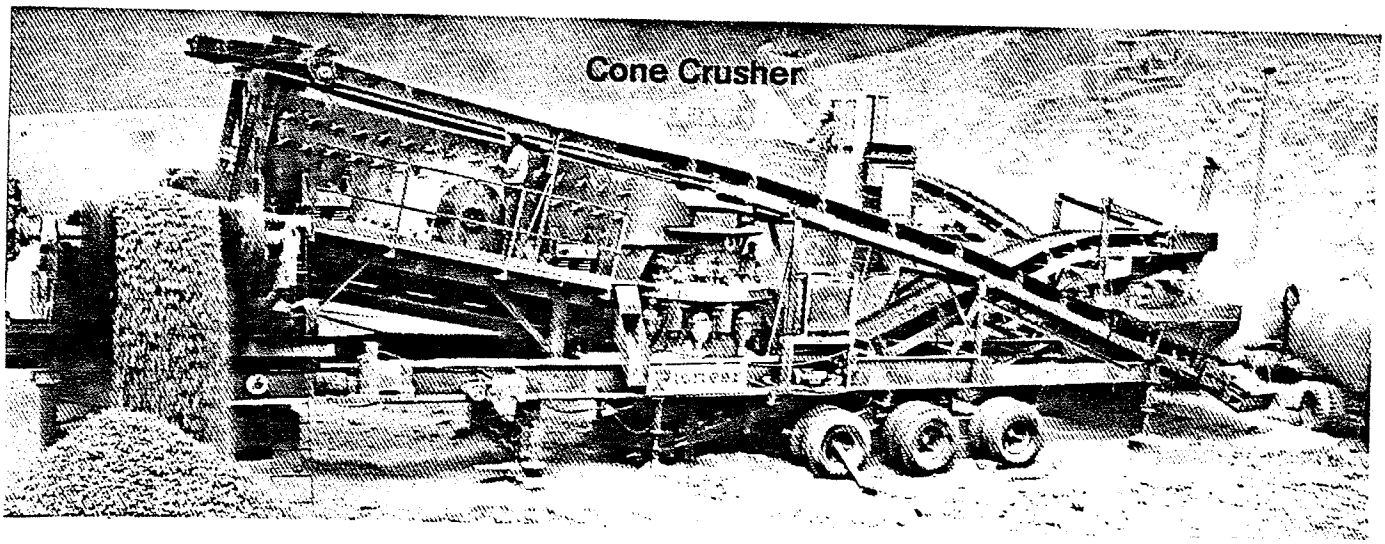
[35] Krynine and Judd, p. 315.

[36] Nichols, p. 21-73.

[37] Ibid. p. 21-83.







Examples of processing plants required by crushed limestone operations.

Source: Pioneer Product Catalogues.

SITE DEVELOPMENT CONSIDERATIONS

11.1 Analysis of Socially Objectionable Impact Features

11.1.1 Purpose

Limestone quarry operations generate several socially objectionable impacts which may adversely affect surrounding land uses and users. By analyzing the typical limestone operation in terms of its essential elements and activities, it is possible to pinpoint certain sources of negative effects. Five major socially undesirable impacts can be attributed to crushed limestone quarrying within the Rockwood municipality:

1) Increased noise levels
2) Increased vibration levels
3) Increased dust levels
4) Increased safety hazards
5) Unattractive site appearance

It is the purpose of this section of the study to examine these potentially objectionable features of limestone quarrying, and to attempt to quantify and estimate the impact on the surrounding neighbourhood. This information is essential to the consulting planner engineer or landscape architect because it provides criteria on which site planning and design decisions can be based. Since limestone extraction occurs primarily in the months from April to November, the problems of noise, vibration, and dust emissions during the winter months will not be considered.

11.1.2 Impact from Noise

Noise can produce adverse effects on people's health, comfort, and enjoyment, and is currently regarded as a source of environmental pollution. Some of the non-auditory effects of noise pollution are:

TABLE 14

FLOW DIAGRAM OF OBJECTIONABLE IMPACT FEATURES

Noise, Dust, and Vibration Impacts from Crushed Limestone Aggregate Quarries

Operation	Emissions from Operation		
	Noise	Dust	Vibration
1. Stripping & stock-piling of soil & overburden for use in future rehabil-itation.	noise from mobile equipment (graders, scrapers, loaders, caterpillars, etc.)	particulates (dust) from stripping and stockpiling.	
2. Drilling of holes for explosives. loading of explos-ives.	noise from compressor and rockdrills.	particulates from drilling rock.	
3. Detonation of explosives	airborn blast over-pressure noise.	particulates from blast (dust to flyrock size).	groundborne vibration from blast.
4. Mucking & hauling of broken rock to crusher.	noise from mobile equipment (loaders, trucks)	particulates from materials handling,particulates raised from quarry floor by trucks.	
5. Crushing	noise from crusher	particulates from crushers.	
6. Conveyors & screening	noise from conveyors and screening.	particulates from conveyors and screens.	
7. Stockpiling on site	noise by mobile equipment from materials handling.	particulates wind entrained from stockpiles and materials handling.	
8. Hauling to construction site.	noise from trucks	particulates vehicle raised from roadways, and wind entrained from uncovered trucks.	

Source: J.W. MacKay, Head, Noise Pollution Control InterDepartmental Memo, April 19, 1979

Psychological Effects - annoyance
- decreased mental and work performance
- stress

Physiological Effects - decreased sleep
- increased pulse rate
- increased blood pressure
- increased muscle tension

In the municipality of Rockwood, noise generated from limestone quarry operations may not only cause adverse effects on people, but also on livestock and wildlife, which are highly sensitive to loud sounds. It is clear that before land use decisions can be made with respect to existing or future limestone quarries, we must be able to estimate the existing and potential impact of noise pollution from these operations.

Noise is produced by virtually all of the operations utilized within a crushed limestone quarry. High-speed drilling, blasting, mucking, processing, and hauling of limestone all produce varying sound amplitudes (measured in decibels - dBs) and sound frequencies (measured in cycles per second or hertz - Hz). See TABLE 14 for a step-by-step analysis of noise-producing operations involved in limestone quarrying.

The apparent loudness of a sound is dependent upon the sound's amplitude and frequency. In order to determine the loudness of sounds for land use planning and legal decisions, the A-weighted or dBA scale is often used. This scale combines sound amplitudes and frequencies and correlate them with the level of noise or annoyance people attribute to various types of sound.

According to evidence produced at the Clean Environment Commission Hearings,[38] the following site-specific quarry operations cause most annoyance:

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[38] Clean Environment Commission Public Hearings into Limestone Quarry Operations in the R. M. of Rockwood, 1981.

Most Disturbing	Impulse	1) Blasting
	Steady	2) Drilling (compressor & rockdrill)
	Steady	3) Processing Plants (crusher, etc.)
Least Disturbing	Steady	4) Mobile Machinery (loader, trucks)

Considerable sound is also generated by trucks hauling the finished product. This mobile source of noise disturbance can actually have the most impact, since the producers may haul from stockpile during the winter months.

Blasting is the most disturbing noise generated, as it is a loud impulse noise which can cause people, livestock, and wildlife to be startled. TABLE 15 shows typical sound pressure levels of quarry operations, compared with typical sound pressure levels utilized in land use planning decisions and Clean Environment Commission Orders.

The knowledge of a few basic properties of sound is essential for land use planning and site design decisions:[39]

1) Sound generally decreases with distance. See TABLE 16
2) Sound may be reinforced or reduced due to winds. Reinforcement of sound occurs downwind. Reduction of sound occurs upwind.
3) Sound may be refracted due to temperature gradients within the earth's atmosphere (thermal inversions). See FIGURES 9 and 10.

The following impacts from noise emanating from mineral aggregate operations should help to quantify some of the effects on the surrounding neighbourhood:

- Past 150 meters from the boundary of the operations, people were not able to distinguish the pit machinery noise from the ambient noise of the neighbourhood.[40]
- Complaints regarding blasting have been registered up to 3.2 kms from the source of the blast.[41]

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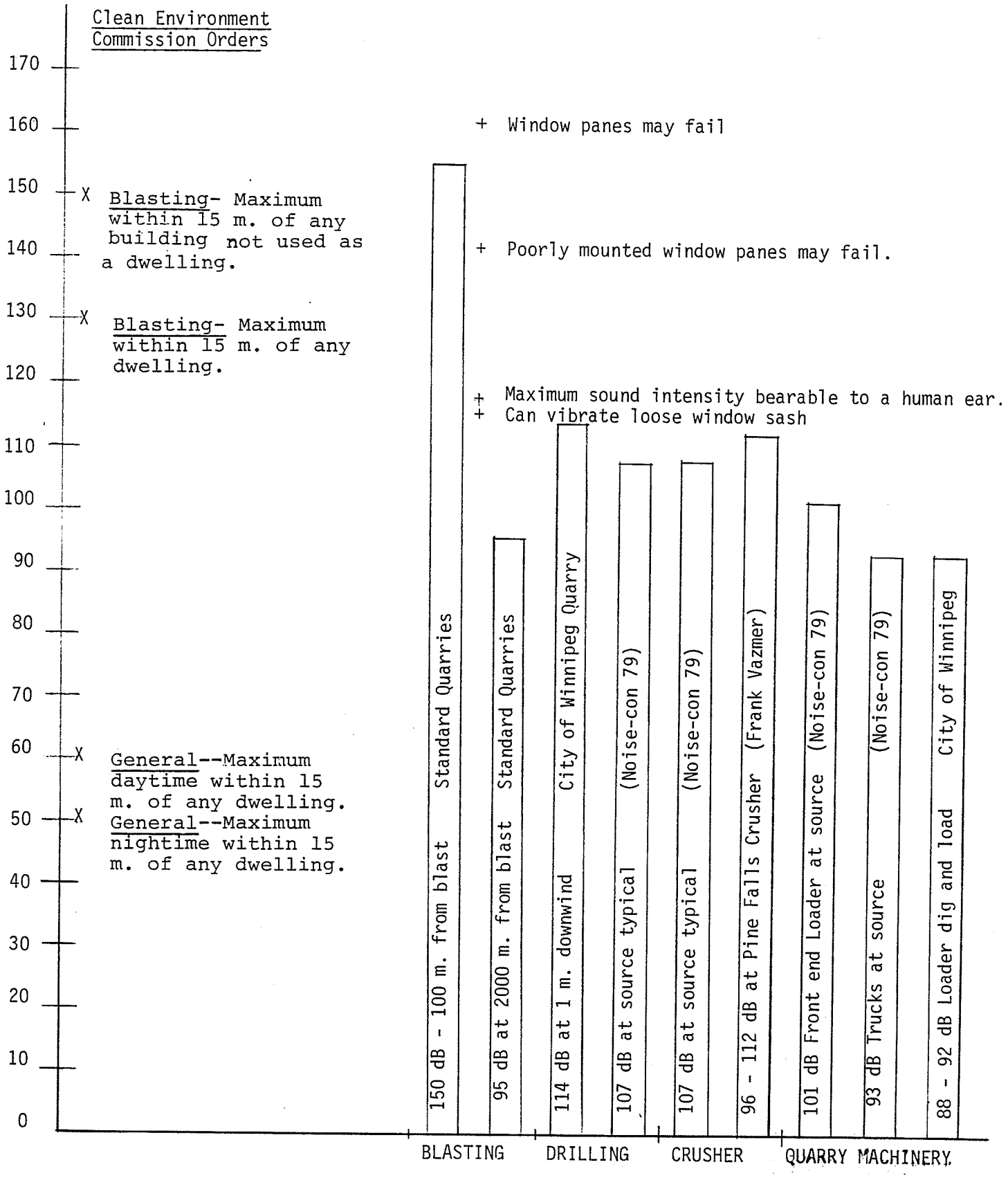
[39] See M. J. Crocker and J. A. Price, Noise and Noise Control (CRC Press, 1975) I, for a complete discussion of the properties of sound.

[40] Schellie, p. 23.

[41] Clean Environment Commission Hearings on Quarries in the Rockwood Area (Winnipeg, 1981) IV, p. 81.

TABLE 15

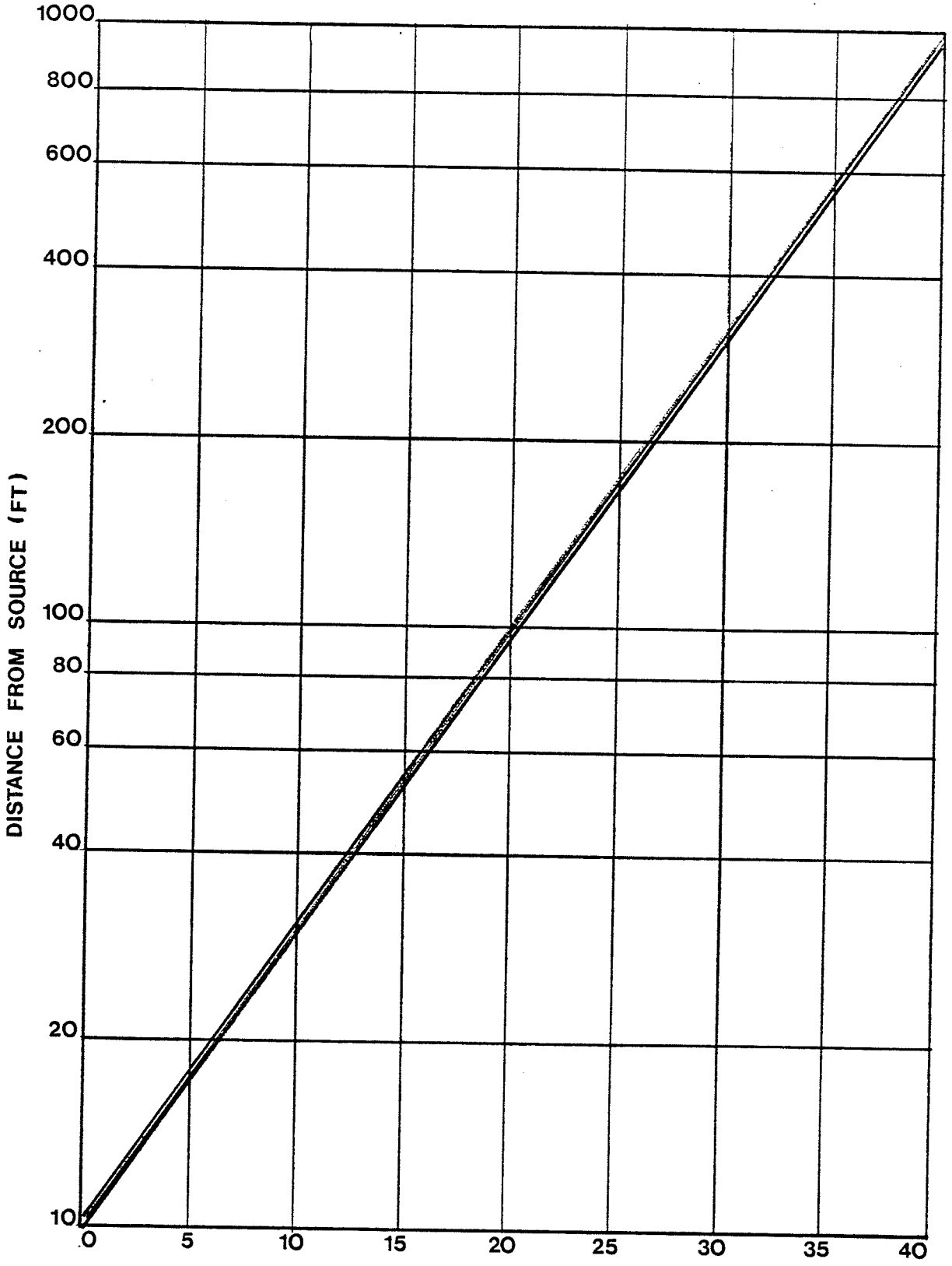
TYPICAL SOUND PRESSURE LEVELS OF QUARRY OPERATIONS



Source: F. Vazmer, Mineral Resources Division personnel

TABLE 16

SOUND REDUCTION DUE TO DISTANCE

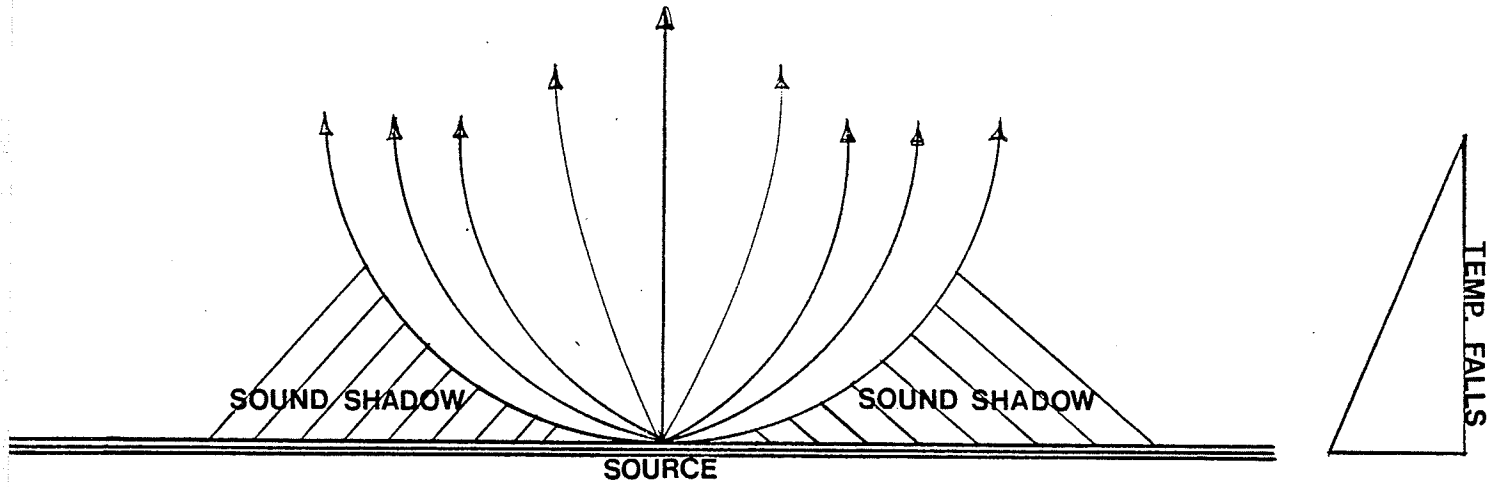


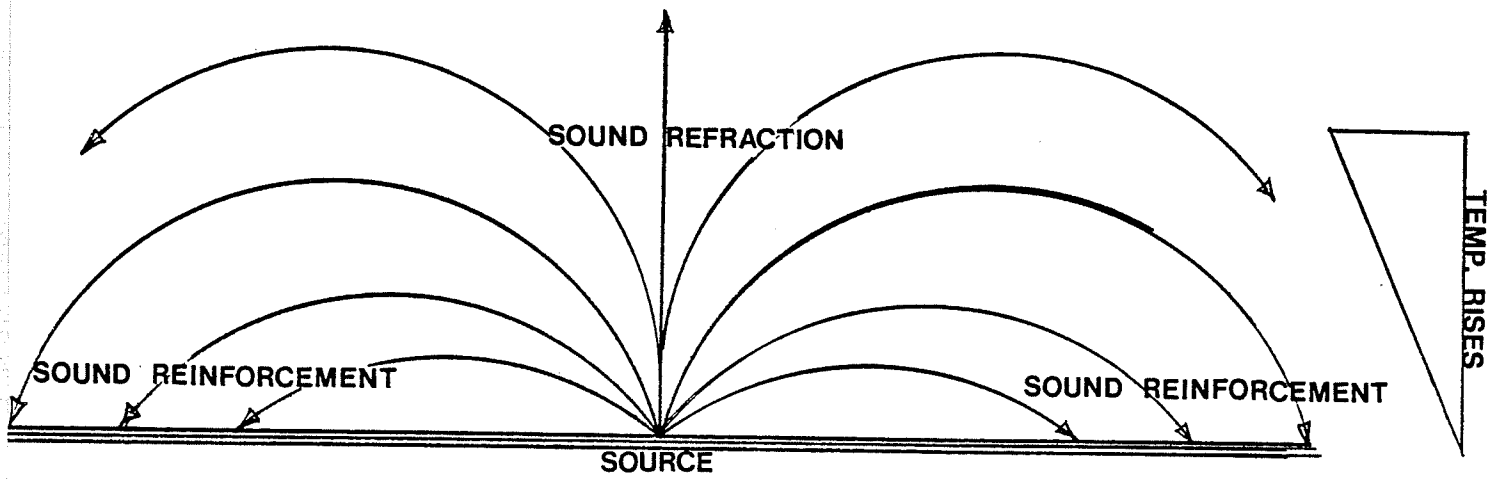
Inverse Square Law - By doubling the distance between a point source of noise and the receiver of noise in an open sound field, the sound pressure level may be decreased by 6 dB. (Crocker 1975).

Source: Robinette, G. O., Plants, People, and the Environmental Quality; U.S. Dept. of the Interior, 1972

FIGURES 9 + 10

EFFECTS OF TEMPERATURE GRADIENTS ON SOUND





Temperature gradients in the earth's atmosphere can also cause refraction of sound. Given perfect conditions, the refraction pattern for temperature gradients is symetrical about a vertical line from the source. Provided no wind, shadow may be eliminated (upwind) or enhanced (downwind).

Source: Crocker, M. J., Price, J. A., Noise and Noise Control; CRC Press, 1975

11.1.3 Impact from Vibration

Ground vibration caused by production blasting is a problem inherent in quarry operations. Both air blasts and ground vibrations are transmitted by energy from an explosion which is not spent in shattering rock from its bed. Ground waves or vibrations are set up in the rock at the blast source and move away from this point at varying velocities. People and animals are highly sensitive to ground motion, and vibrations constitute the principal source of both actual and imagined damage to buildings in the vicinity of the blast.[42]

Structural damage may be caused as a foundation tries to move or change shape with the earth in which it is embedded. The inertia in the rest of the building results in a stress between the building and its foundation.[43]

Ground vibrations are determined by a physical measurement of the earth's movement caused by a blast. A logarithmic reduction of ground motion is experienced with an increase in distance away from the blast.[44] Current Clean Environment Commission Orders require that soil-borne vibrations may not exceed:

1) 12 mm/sec. peak particle velocity recorded at any building (off the property) maintained as a dwelling.
2) 50 mm/sec. peak particle velocity * recorded at any building for use other than a dwelling.[45]

   * similar values are caused by stomping on a floor.[46]

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[42] Nichols, p. 9-41.

[43] Ibid.

[44] Personal communication with L. Bilton, Mineral Resources Division Mines Inspector, February 1982.

[45] An Order of the Clean Environment Commission Under the Clean Environment Act, Number 855, October, 1979.

[46] Nichols

According to recent measurements, there is no reason to believe quarry blasting in Rockwood could ever be of the magnitude to damage structures. Standard Quarries blasts were measured at one complainant's residence at approximately 6 mm/second, well within the prescribed limits.[47] However, research has indicated that the average person can feel vibration levels from .1 to 1 percent of the level necessary to damage structures.[48]

At a vibration level of 25 mm/sec, twenty percent of families will complain. At 10 mm/sec, eight percent will complain of noise, and at 2.5 mm/sec, one percent will complain.[49]

Vibration levels caused by blasting within the Rockwood municipality will continue to be a negative psychological impact on neighbouring people, livestock, and wildlife.

11.1.4 Impact from Dust

The ambient atmosphere contains a wide mixture of suspended dust from various sources. Limestone quarrying may be a substantial contributor. Increased dust levels can cause negative impacts upon the immediate neighbourhood, by increasing the severity of dust storms (eye strain), causing increased cleaning of indoor offices and homes, increased washing of automobiles, and an increased need to paint outdoor structures. Particulates may also restrict plant growth by blocking light.

Blowing dust may be emitted from all phases of a quarry operation, but the most significant sources of dust are:

1) Blasting.
2) Vehicle raised dust from roads.

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47 J. W. MacKay, "Environmental Control Reports" (Winnipeg: Standard Limestone Quarries, 1979), p. 3.

48 Clean Environment Commission Hearings on Quarries in the R. M. of Rockwood (Winnipeg, 1981) IV, p. 81.

49 R. Dick and D. Siskind, "Keep your Blasting under Control" Coal Age (November 1979), pg. 108.

3) Wind entrained dust from stockpiles.
4) Fugitive dust from uncovered moving vehicles.[50]

Processing of crushed stone is one of the two most significant sources of emitted dust. Research in the U.S. shows that 75 percent of the dust from an operation is emitted from crushers.[51]

An estimate of particulate emissions across Canada shows that sand and gravel operations were the source of 264,000 tonnes of dust per year, second only to forest fires (325,000 tonnes annually)[52] Sand and gravel pits may contribute up to .06 kg. of particulate emissions per tonne of material mined.[53] Applying these figures to the limestone industry, approximately twenty-seven tonnes of dust could be emitted annually from quarries in the Rockwood area.

Particulates from sand and gravel operations typically include fine dust (1 micron to 1 mm. in diameter) and fine sand (20 to 200 microns in diameter).[54] The following impacts from dust emissions from mineral aggregate operations should help to quantify some of the effects on the surrounding neighbourhood:

1) The heaviest of dust particles fall within a .8 km. radius of the activating source.[55]
2) Wind may carry dust particles 1.2 km. away from the quarry site.[56]
3) Excessive dust can be produced with a wind up to .46 kms. from a quarry.[57]

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[50] Op. cit. p. 85.

[51] G. R. Shelley and Associates Villeneuve Area Gravel Development and Reclamation Study (Edmonton, 1977), p. 68.

[52] G. R. Shelly and Associates, p. 67.

[53] Ibid. p. 68.

[54] Ibid. p. 67.

[55] Schellie, p. 139.

[56] Clean Environment Hearings, III, p. 14.

[57] Ibid.

11.1.5 Impacts on Public Safety

Pits and quarries can be attractive nuisances for people, particularly if a portion of the property is under water. Fences, signs, and the establishment of berms around these sites have helped to keep the rate of accidents low, but accidents at both abandoned and working pits and quarries will continue to occur.[58] Inadvertent access to an active quarry site can present the dangers of vertical drops and explosives blasting. Increased and rapidly moving truck traffic will also be prime concerns to people neighbouring limestone quarry operations.

A current and critical topic for the limestone quarry operator is the issue of liability. The Mineral Resources Division has indicated that the quarry operator is in a precarious position when is comes to public safety in terms of liability. In short, in the event of an accident within a quarry, the individual operator cannot be protected sufficiently from the possibility of costly legal action. As the population expands in the area of the crushed limestone quarries, the issue of liability is bound to become an even greater concern of the individual operator.

11.1.6 Unattractive Site Appearance

Crushed limestone quarry operations are typically an unsightly instrusion on what is basically a pleasant rural environment. The Stonewall area is characterized by small mixed farm operations with many fine natural woodlots. The limestone operations have interrupted the serenity of the scene with their uninviting entrance ways, their cluttered plant office areas, and unfortunate berming techniques.

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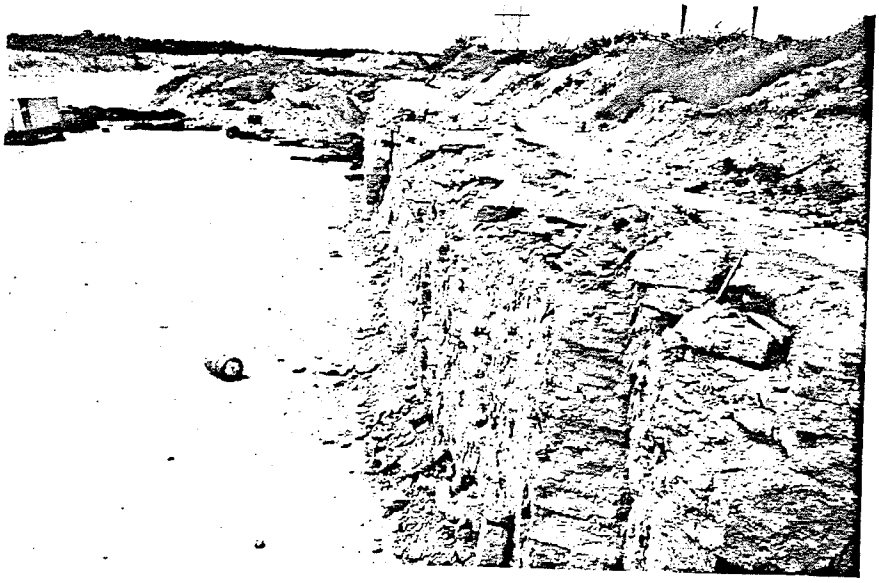
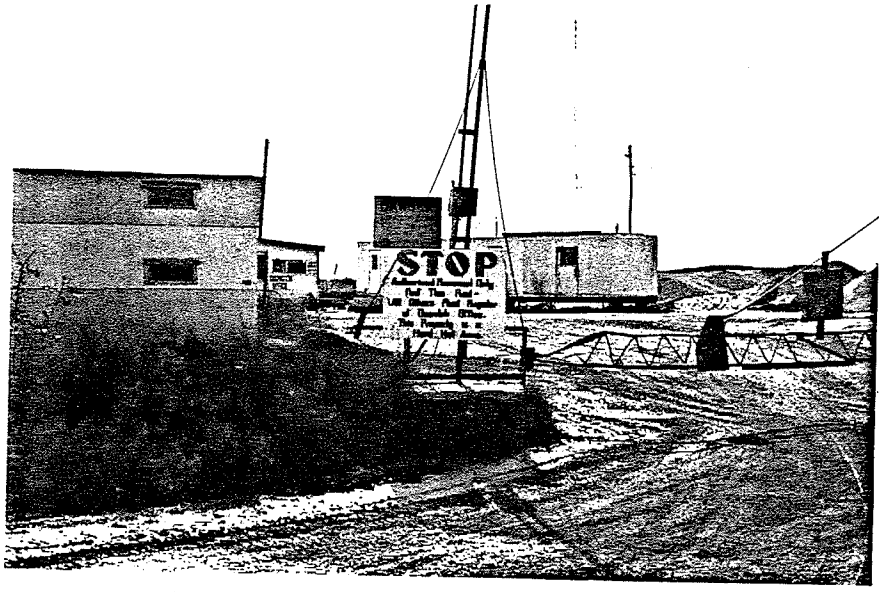
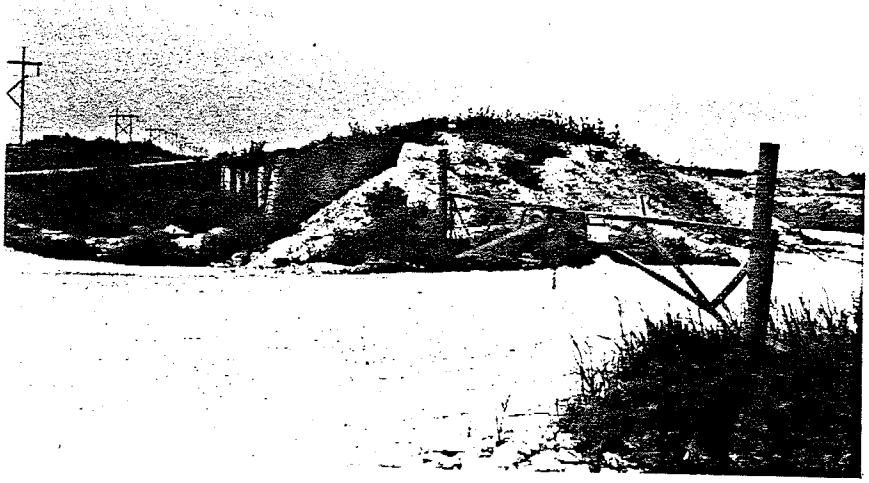
58 National Research Council, Surface Mining of Non-Coal Minerals (National Academy of Sciences, 1980), p. 29.







Social concerns of public safety and unattractive site appearance are illustrated in these photos.

Because their offices are frequently housed in trailers, and their processing plants and batch plants are portable, these operations look to be transient in the landscape. Berming around the site is typically conducted for reasons of convenience. The berms serve as on-site disposal areas for the overburden, subsoil, and topsoil that must be stripped prior to excavation. Consequently, the berms are never graded to achieve smooth slopes, and they are never revegetated, causing them to be erosion prone and a source of weed problems. Many of the operations are located in and about existing woodlots, but few producers have taken advantage of the natural screening possibilities afforded by the site.

QUARRY LANDFORM DETERMINANTS

12.1 Post Mining Quarry Form

12.1.1 Purpose

The post mining quarry form of an operation has implications on the future land use potentials of any given site. The purpose of this section is to introduce the reader to many of the variables which may determine the post mining quarry form.

Despite the obvious similarities between quarry production and quarry forms within the Stonewall area, each operation and its resulting landform will be unique unto itself. Sir Geoffrey Jellicoe describes quarry form as being a gigantic piece of serendipic sculpture always in movement. There are no blueprints for optimum quarry development because there is no exact knowledge of what quality of rock is going to be encountered from day to day. Pockets of impurities found within the excavation may cause extreme variations in the ultimate form of the quarry. However, several landscape features in post operations quarry form are typical and essential elements that must be analyzed within any rehabilitation project. Post mining quarry features to be considered include:

1) Size of Quarry
2) Shape
3) Depth
4) Floors
5) Walls
6) Essential Operational Features
7) Surface Drainage Areas

12.1.2 Size

The surficial area encompassed by the quarry will be of differing sizes dependent upon the following variables:

a) the operations's property limits.
b) the internal setback requirements placed upon the operations.
c) the amount of land covered by overburden which is uneconomical to move (the current stripping ratio is approximately 1:2. If one unit of overburden must be removed then two units of limestone must be made accessible.
d) the area required to stockpile overburden upon the site.
e) the area required to process and stockpile crushed stone products. Sometimes this area is established within an excavated portion of the quarry.

Obviously there is no standard size for a limestone operation but the newer and larger quarry operations seem to range from approximately 40 to 64 hectares (1/4 section)[59]

Internal setbacks are on-site, undisturbed restricted zones which prevent limestone extraction or related operations from having a potentially disturbing or damaging effect on adjacent property or utility.[60] Internal setbacks are established either through policy or regulation by municipal and provincial authorities.

The amount of land covered by overburden which is within a quarry site and is uneconomical to move (i.e. unfavorable stripping ratio) is probably negligible for most operations existing today. These sites have been exploited essentially because of their favorable stripping ratios (i.e. bedrock at or near the surface). However, future operations may be faced with areas with unfavorable stripping ratios within a portion of their property.

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[59] This is based upon personal observations of the sizes of several quarries within the R.M. of Rockwood. Standard, Winnipeg, and General Stone Products operations range within these sizes.

[60] Shelly and Associates, p. 164.

The amount of area required to stockpile overburden is a larger factor than many would estimate. Given a 64 ha site, with an average of one meter of overburden, approximately 650,000 cubic meters of overburden must be stripped and stockpiled within the site. (1.5 - 1.8 meters of overburden was stripped at General Stone Quarries.)[61] Consider, moreover, a possible swell factor of from twenty to forty percent and the magnitude of the overburden problem is made even more immense.[62] (These values will be reduced to ten to twenty-five percent if compacted by machinery.)

The area required to process and stockpile crushed stone may or may not be a factor to consider in quarry form. For example, the Stonewall Limestone Quarry utilizes approximately thirty percent of the site (20 ha) reserved for processing and stockpiling requirements. Many operations utilize portions of the quarry floor to process and stockpile the various crushed stone products, but typically some of the site is not excavated due to these requirements.

12.1.2 Shape

The shape of exhausted quarries will obviously be dependent upon the property boundaries, but typical operating shapes are square (General Stone Quarry), rectangular (Standard Quarry), and L-shaped (City of Winnipeg Quarry). These geometric shapes are efficient forms for limestone quarrying operations.

12.1.4 Depth

The depth of an exhausted limestone quarry will be determined by the quality of the stone and the depth of the water table. Low quality argillaceous limestone cannot be quarried economically due to its

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[61] B. Bannatyne "Industrial Mineral Geologist's File" (Winnipeg, Mineral Resources Division).

[62] Nichols, p. 3-6. (Swell factor for good Common Earth).

unsuitability as a mineral aggregate. However, as high quality limestone reserves become depleted, benefication of limestone mixtures may be utilized. This may result in further exploitation of lower quality limestones which may further lower the depth of these quarries.

In current practice, once the water table is encountered during operations, the depth of the excavation will be curtailed at that level. Quarrying beneath the water table requires modified excavation techniques (dewatering and special explosives), and because of concerns that the groundwater may be polluted, the continued monitoring by the Water Resources Division. Quarry depths currently range from a depth of a few meters (first bench level) to an average of fifteen meters within the bedrock. Depths to twenty meters have been excavated in the City of Winnipeg Stony Mountain quarry.[63]

12.1.5 Floors

The floor of an exhausted quarry is typically very flat since the excavation occurs down to the top of an underlying geological formation or bedding plane. The crushed stone operations are currently exploiting the Gunton and Penitentiary members, while the underlying Gunn member is of much lower quality. (Although the City of Winnipeg seems to be excavating some, it is mainly argillaceous limestone and shale.) Larger quarries all exhibit substantial relief on the quarry floor due to stockpile areas of reject and oversize material, and areas that have not been quarried due to lower quality deposits being encountered.

12.1.6 Walls

Quarry walls are either very steep to vertical, or are collapsed and uneven due to softer rock falling down over the face of the wall. These faces may be the full depth of the quarry (11 - 15 meters) or the

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[63] B. Bannatyne.

depth of one of the operations' "lifts". Some operators work the entire depth of the face in one operation (lift), while others may work two or more lifts to achieve that depth.

These walls will weather to varying degrees and colors (owing to the quality of the rock and varying degrees of impurities), and can be dramatic features for any future landscape development.

12.1.7 Essential Operational Features

These features are basically the office site, entrance requirements to the site and the quarry floor, processing plant and asphalt or concrete batch plant locations, and stockpile areas. As was mentioned earlier, these features can occupy a substantial portion of any quarry site. Individual differences will accrue to each operation, so site specific analysis of these features is suggested.

12.1.8 Surface Drainage Areas

Due to the sheer size of quarry floors, and the nonexistent surficial drainage occuring upon them, water ponding is common in lower areas of the site. Settlement of dust and crusher fines serves to make the floor virtually impervious to water percolation into the underlying bedrock fissures. Many ponds occur periodically throughout the season, but several gather enough water to become permanent features within the quarry environment. Permanent groundwater lakes are a common feature in Eastern Canadian limestone quarry operations, and there is no reason that groundwater lakes could not be created within the study region.

ENVIRONMENTAL IMPACTS FROM QUARRYING

13.1 Purpose

Limestone quarrying may have adverse effects on soil productivity depending on the mining and rehabilitation methods used at the site, and the extent to which these methods alter the physical and chemical characteristics of the soil. It is the purpose of this Section to outline many of the environmental impacts that may occur as a result of typical mining and rehabilitation techniques. This knowledge may then be utilized for the following purposes:

1) to develop new techniques of materials (overburden and soil) handling, storage, and reconstruction in order to limit detrimental impacts.
2) to develop thorough site preparation techniques which offset the detrimental impacts of damaging mining and rehabilitation practises.

Prior to the discussion on environmental impacts caused by limestone quarrying, the reader must first become knowledgeable about the nature of the soil.

13.2 Nature of the Soil

Soils are formed through an intricate process in which they evolve from their geological parent material through the action of soil-forming processes (i.e. weathering, erosion, leaching), which are controlled by environmental parameters or soil-forming factors. These factors include:

1) the climate, or the temperature and moisture in the soil.
2) the biota (plant and animal life), which modify the soil, climate, add organic matter, and later decompose organic matter.
3) the parent material, which contributes the soil minerals which in turn affect the texture, the water retention capacity, and the mineral reserve.

4) the position of the soil in relation to topography.
5) the age, or the length of time during which the soil has been under the influence of soil-forming processes.
6) In the case of cultivated soils, man has modified the soils through agricultural practises.[64]

The variations in the relative importance or dominance of one or more of the soil-forming processes results in such developments as the addition or removal of organic matter, translocation of clays, or chemical and physical alterations in the soil. These processes result in the formation of soil horizons.[65] Soil horizons differ from one another in such properties as color, texture, structure, and chemical and biological activities.

The form of soil horizons can easily be observed in the field by the soil profile--a vertical section of the soil cut through its horizons and on into the parent material.

(See FIGURE 11 for a generalized soil profile description) Soil profiles may be utilized as indicators of soil properties. However, it is the function, not the form of the soil horizons that is important.[66]

Most soils have three master horizons identified as A, B, and C or for the purposes of discussion in terms of surface mining and rehabilitation, topsoil, subsoil, and overburden.

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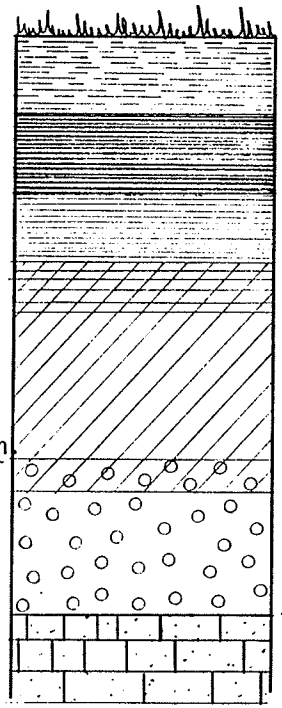
64 Ehrlich, Poyser, Pratt, and Ellis Report of a Reconnaissance Soil Survey of Winnipeg and Morris Map Sheet Areas, Manitoba Soils Reports, No. 5 (Winnipeg, 1976).

65 For a complete discussion of soil-forming factors, see Watson, Parker, and Polster, Manual of Species Suitability for Reclamation in Alberta (Alberta Land Conservation and Reclamation Council, 1980), pp. 11-14; and Manitoba Soils and their Management (Manitoba Department of Agriculture), pp. 21-23.

66 National Research Council, Surface Mining, Soil, Coal, and Society (Washington, National Academy Press, 1981), p. 87.

FIGURE 11

DIAGRAM OF A HYPOTHETICAL SOIL PROFILE



Solum

L,F,H

Organic debris lodged on soil developed under forest,usually absent on grassland soils

A

Horizon of maximum biological activity and maximum eluviation (removal of materials dissolved or suspended in water or both)

B

Horizon of illuviation (accumulation of suspended material from A),or of maximum clay accumulation,or of blocky or prismatic structure,or both.

C

The soil parent material (limestone bedrock)

L loose leaves and organic debris largely undecomposed
F organic debris,partly decomposed or matted
H well decomposed organic matter,original structures undiscernible

A_1 A dark coloured horizon with a high content of organic matter mixed with mineral matter

A_2 A lighter coloured horizon of maximum eluviation (clay,iron,and humus may be leached from this zone.

Transitional Zone between A and B horizon

B Horizon of maximum illuviation; silicate clays,minerals,and iron from A horizon accumulate here.

Transitional Zone between B and C horizon

C Unaltered or slightly altered parent material,usually an accumulation of calcium carbonate and other soluble salts (i.e. magnesium carbonate), sometimes high bulk density

Consolidated bedrock

Sources: 1. Manitoba Department of Agriculture, Manitoba Soils and Their Management; pg. 18

2. National Research Council, Surface Mining, Soil, Coal, and Society; National Academy Press, 1981, pg. 87

Topsoil (A horizon) is the uppermost (surface soil), typically dark-colored zone of the soil that receives the maximum effect of biological activity and leaching, and the greatest accumulation of organic material. On agricultural lands, the topsoil is normally limited to the depth of cultivation, approximately fifteen to thirty centimeters.[67] The organic matter content is extremely important to soil productivity because it:

1) functions as a granulator, which makes the soil more friable.
2) can withstand compaction better due to its friable nature.
3) stores important nutrients (nitrogen and phosphorus).
4) is the main source of energy for microorganisms which make the nutrients available to plants.
5) increases the soils moisture-holding ability.[68]

Subsoil (B horizon) may extend to a depth of one metre as a transitional soil horizon between the topsoil and the underlying overburden zone. The subsoil is typically low in organic matter and often contains an accumulation of clay-sized particles.[69] Under natural conditions, the subsoil is usually well-structured and is the zone from which plants must obtain much of their moisture requirements.[70]

Overburden (C horizon) refers to the parent material of the soil overlying the consolidated limestone bedrock and underlying the subsoil. This zone is comparatively unaffected by soil-forming processes. The overburden within the Rockwood region is typically extremely calcareious glacial till.

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67 Mozuraitis and MacIntosh, Rehabilitation of Aggregate Extracted Lands for Agricultural Production (Ontario Ministry of Natural Resources, 1982), p. 12.

68 Ibid, and The Restoration of Sand and Gravel Workings (London, British Ministry of Agriculture, Fisheries, and Food, 1973), p. 3.

69 Mozuraitis and MacIntosh, p. 12.

70 Manitoba Soils, p. 17.

13.3 Soil Characteristics Affecting Plant Growth

The main characteristics of soils that can be utilized to assess its value for rehabilitation are as follows:

1) Soil Texture: Soil material is comprised of organic and mineral particles of which the mineral particles are grouped into the different size classifications of sand, silt, and clay. See TABLE 17. The relative proportions of these mineral particles within a soil determines its soil texture. For example, a fine-textured soil is characterized by a high clay content, while coarse-textured soils have a high sand content.

Soil texture is an important characteristic because it affects the soil's;

a) natural fertility,
b) ability to drain properly (infiltration and runoff),
c) capacity to hold water, and
d) erodibility.

TABLE 17

SOIL TEXTURE AND ITS EFFECT ON SOIL PROPERTIES (Generalized)

Soil Texture	Natural Fertility Potential	Drainage Infiltration	Potential Runoff	Water Holding Capacity	Erodibility
Fine Textured Clayey Soils	H	L	H	H	M
Medium Textured Loamy Soils	M	M	M	M	M
Coarse Textured Sandy Soils	L	H	L	L	L

2) Soil Structure (Tilth): The structure of a soil refers to the aggregation of mineral and organic particles into secondary

particles termed units or peds. Individual soil particles are loosely bound so that peds contain pores and channels which are important for air, water, and organism movement, as well as root penetration.

3) Soil Compaction (Bulk Density): The degree of compaction of a soil determines both the size and the amount of soil pores. The degree of compaction is measured by its bulk density; a measure of the weight of dry soil per unit volume (usually expressed as grams per cubic centimeter - g/cm^3). Under field conditions most soils range from 1.2 - 1.6 gms/cm^3).[71]

4) Available Soil Water Storage: This is a measure of the amount of water a soil is capable of storing within the plant roooting zone (1.2m). Several physical and chemical properties affect a soil's available water storage capacity.

TABLE 18

AVAILABLE WATER CAPACITY IN SOME MANITOBA SOILS BY SOIL TEXTURAL CLASS

Soil Textural Group	Kinds of Soil	Available Soil Water to 1.2 meters
Coarse textured	sand, loamy sand	14.5 cm
Medium textured	very fine sandy loam, loam silt, loam and silt	25.5 cm
Fine textured	sandy clay, silty clay, clay	26.0 cm

Source: Manitoba Soils and Their Management
Manitoba Department of Agriculture, p. 56.

Two points are significant in the figures in the table above:

a) soils vary in their ability to supply moisture to plants; coarse textured soils are extremely poor in available soil water while medium and fine-textured soils hold relatively the same amount.

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[71] Mozuraitis and MacIntosh, p. 14.

b) crop roots must penetrate deep into the soil if adequate moisture reserves are to be reached. Plant roots must be capable of penetrating up to one meter to obtain adequate soil moisture.[72]

5) Soil Drainage: This refers to the rapidity and the extent of the removal of surface and subsurface soil water in relation to its addition. (precipitation) When water fills all the spaces or pores between the soil particles, the soil becomes saturated, air movement is restricted, and the soil becomes depleted of oxygen. Plant roots require oxygen to function properly and their growth may be severely restricted if saturation conditions persist. This is termed waterlogging.

6) Stoniness: Stones are a common problem in the shallow soils of the Stonewall area. Stony or rocky soils are detrimental for agricultural, recreational, or engineering applications. Excessive stoniness may damage farm equipment (such as seeders), while it hinders seedbed preparation and crop cultivation. Stony soils limit the types and quality of recreational experience, while they are difficult to work for many engineering applications.

7) Soil Depth: (Plant rooting depth): This refers to the depth of soils which can normally permit the entry of roots of plants and sustain their growth. Root growth may be impeded by a shallow depth to bedrock, compacted layers of soil, waterlogged conditions, toxic chemicals, hard pans, or consolidated subsoils.[73]

8) Relief: The principal components of relief are slope gradient, slope aspect, and slope position. Relief influences water drainage, infiltration, runoff, and erosion, while also affecting the soil exposure to sun and wind. Limestone quarrying may alter the relief of the landscape with positive or negative results.

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[72] Ibid.

[73] Mozuraitis, MacIntosh. p. 14.

TABLE 19

SOIL FACTORS AFFECTING PLANT GROWTH

Criteria: The following characteristics are indicators of potential quality of soils in relation to plant growth.

Factors	Favorable Characteristics	Unfavorable Characteristics
1. Soil Texture	Mixture of sand,silt,and clay(medium texture or loams) have optimum moisture capacity.Clays are chemically active,promoting availability of nutrients.Sand loams,silt loams,and loams,are preferred to clay loams.	Too much clay decreases water availability due to high matric potential and are difficult to work when wet(more than 60% clay).Too much sand produces low water-holding capacity and low availability of nutrients.Silts are easily eroded and crust easily.
a) Organic Matter	High levels improve aggregation and infiltration capacity and increase availability of nutrients; 1.5% or more is very favorable.	Lower levels inhibit aggregation,lower infiltration rates and reduce availability of nutrients.Less than .5% organic matter is unfavorable.
2. Soil Structure	Granular structure improves infiltration and is resistant to the impact of rain drops.Blocky and prismatic structures improve permeability(except when part of a clay pan).Coarse fragments limited to a 0-10% of volume.Generally 50-60% soil voids is favorable.	Platy and massive structures are less favorable for infiltration,permeability,and rooting. Crusting at surface may inhibit seedling emergence.Coarse fragments more than 35% of volume.Generally below 35% voids is unfavorable to most plants.
3. Soil Compaction (Bulk Density)	Low values indicate high organic matter content, good granulation,high infiltration,and good aeration,majing for a good rooting medium. Generally less than 1.4 gms./cm^3 is favorable.	High values generally indicate low aggregation, inhibited root penetration,and low infiltration and permeability rates.Generally greater than 1.6 gms./cm^3 is detrimental to root penetration
4. Available Soil Water Storage	High capacity allows storage of water for plant growth during periods of low precipitation.In Edmonton,available water storage is rated high for a soil with capacity of 25 cm./1.2 meters (plant rooting zone).	Low capacity means plant growth is reduced by moisture stress during periods of drought.In Edmonton,available water storage is rated low for a soil with capacity of 5 cm./1.2 meters (plant rooting depth).
5. Soil Drainage	Moisture content of soils does not normally exceed field capacity except immediately after water additions.Field capacity of a soil is when the water content in a wetted soil becomes constant.	Water moves so slowly that the soil remains wet for a long part of the time.Sandy soils generally have very rapid drainage characteristics while clay soils typically exhibit very slow downward drainage(possibility of ponding or rapid surface runoff).
a) Infiltration	High infiltration increases soil moisture and decreases runoff and erosion.	Low infiltration increases runoff and erosion and decreases moisture in soil.
b) Permeability	Moderate to high permeability increases soil moisture and decreases runoff under saturated conditions.Generally permeability rates of 1.5-15 cm./hr. are favorable.	Very low permeability may mean less available water if associated with restricted rooting depth or high clay.Very high permeability may mean water is not retained in upper levels of the soil profile.Generally permeability rates of less than .5 cm./hr. or greater than 15 cm./hr. are unfavorable.
6. Soil Stoniness	No,or very few stones do not interfere with seedbed preparation or cultivation,and they do not interfere with installation of roads,services, septic fields, etc.	Very stoney soils seriously impede cultivation and installation of infrastructure.Increased numbers of stones reduce the volume of soil that plants can extract nutrients and moisture from.
7. Soil Depth Plant Rooting Depth	Unrestricted rooting depths allow plants to make maximum use of water and soil nutrients.	Restricted depth reduces water and nutrients available to plants.
8. Relief		
a) Slope Gradient	Nearly level and moderate slopes enhance infiltration of water and are less susceptible to erosion.	Flat slopes and depressions drain poorly and thus limit availability of oxygen to roots. Steep slopes allow less water to enter the soil and are more prone to erosion.
b) Slope Aspect (most significant on steep slopes)	North and east facing slopes generally have better moisture retention and reduced surface temperatures.	South and west facing slopes generally have lower moisture retention and higher surface temperatures.
c) Slope Position	Toeslopes and bottomlands retain most moisture.	Narrow ridge tops retain least moisture.
9. Soil pH	Soil pH of 6.1-7.8 is preferred for the growth of most prairie plants and crops.	A soil pH less than 5.0 and greater than 8.5 is unfavorable for the growth of many prairie plants and crops.

SOURCES: TABLE adapted from National Research Council Surface Mining, Soil, Coal, and Society; National Academy Press, Washington, 1981, pgs. 104-105

Information added from:

- U.S.D.A. Forest Service, User Guide to Soils, 1979, pg. 25
- Manitoba Department of Agriculture, Manitoba Soils and their Management.
- Pedology Consultants, Soil Survey and Interpretations of the Villeneuve Study Area; Edmonton 1976.
- Michalyna, Gardiner, Podolsky, Soils of the Winnipeg Region Study Area; Prepared for Province of Manitoba Municipal Planning Branch, Winnipeg, 1975.

9) Soil Reaction (pH): This refers to the degree of alkalinity or acidity in the soil. It is dependent on the hydrogen ion (H+) activity or concentration in the soil. Soil reaction is expressed in terms of pH on a scale from 0 to 14. A pH of 1 - 7 is considered acid, 7 is neutral, while 7 - 14 is alkaline. The intensity of reaction increases ten times with each unit in pH (i.e. a pH of nine is ten times as alkaline as pH 8).

The solubility and availability of many important plant nutrients is closely related to pH. As the alkalinity of a soil increases, the availability of certain plant nutrients may decrease. Plants and microorganisms function best at a certain pH. For example, cereal crops grow best in medium acid to mildly alkaline soils.[74] Most trees prefer a soil pH of between 5.5 to 7.0 unless adapted to the site.[75] See TABLE 19 for a chart outlining the soil factors which may affect plant growth.

13.4 Reconstructed Soil Properties of Typical Mined Soils

A mined soil refers to the resultant surface material after mining in which plants are grown. This may either be reshaped raw overburden, or overburden covered with a subsoil/topsoil mixture. Mined soils replaced upon the quarry floor and backslopes are obviously not the same as the virgin soils they were prior to quarrying. They are now an unorganized mass of material whose soil properties have been dramatically altered in the following ways:

1) Soil Texture. Mined soils may be made finer due to the mixture of subsoil and topsoil layers. Translocated clay particles will be reintroduced to soil surface layers which may cause decreased water infiltration with increased water runoff.

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74 Manitoba Soils, p. 19.

75 P. Pirone, Tree Maintenance (New York: Oxford University Press, 1965), p. 18.

If overburden is mixed with the soil mixture, coarse particles and stones may be added to the surface plant rooting zone. Mixing also leads to lower levels of organic materials, which may cause decreased seed germination and reduced seedling viability rates.[76]

2) Soil Structure. The soil structure of mined soils is completely destroyed due to the mixing of horizons.[77] Due to reduced organic matter, there is a weaker aggregation of soil particles which may contribute to reduced infiltration rates and reduced water-holding capacity.[78]

3) Soil Compaction. Increased compaction of the soil due to machinery typically causes the following:

a) increased bulk densities at the surface.[79] Bulk densities were increased 54 percent on Montana reconstructed soils (compared to native range soils).

b) bulk densities may be lower than normal on lower levels while being high at the surface.[80] The bulk density of loosely spread soil was 1.2 grams/cm^3 compared with 2 grams/cm^3 when the same soil was compacted by the rear wheels of a wheel scraper.[81]

If large quantities of soil are replaced in one operation, lower layers of the soil may not receive compaction, creating voids or cavities in the soil. This will serve to reduce the soil's moisture holding-ability as water will drain rapidly at depth.[82]

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[76] T. M. Macyk, "The Relationship of Soils to Reclamation in the Grande Cashe Area", Soil Conservation, Reclamation and Research; Proceedings of the Alberta Soil Science Workshop, 1977 (Edmonton: 1977) p. 126.

[77] Ibid.

[78] National Research Council, Surface Mining, p. 138.

[79] Ibid.

[80] Ibid.

[81] N. Pollack "Sand and Gravel Restoration", Research paper University of Guelph, p. 4.

[82] National Research Council, Surface Mining, p. 138.

c) high bulk density may impede root penetration.[83] Crop root penetrations are severely restricted with bulk densities of 1.6 gms/cm^3 or more.[84]

d) a decrease in soil pore space lowers the infiltration rate of water into the soil and therefore increases surface runoff and ponding.

e) infiltration rates were 60 -80% higher on native range soils than on reconstructed mine soils in Montana.[85] Altogether more than 1.5 times more water moved through range soils than through mine reconstructed soils.[86]

f) In general, the higher the water content and the finer the texture of the material, the greater the potential for overcompaction.

4) Available Soil Water Storage. Due to reduced infiltration of water caused by surface compaction, crusting, and reduced water holding capacity at depth (due to large voids in uncompacted lower layers), the available water storage of reconstructed soils will almost assuredly decrease from their undisturbed values. Shallow soils in the Stonewall area have been observed as being seasonally droughty even before quarry activity.[87]

5) Soil Drainage. If care is not taken during the grading operations, low lying shallow soils may become seasonally innundated with high water levels. If saturation of soils persists, vegetation will be severely hindered from establishing upon those sites.

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[83] Ibid; and Mozuraitis and MacIntosh.

[84] Mozuraitis and MacIntosh.

[85] National Research Council, Surface Mining, p. 138.

[86] Ibid.

[87] Michalyna, Gardiner, and Podolsky, Soils of the Winnipeg Region Study Area (Winnipeg: Manitoba Municipal Planning Branch, 1975).

6) Stoniness. The shallow soils of the Stonewall region are stony prior to quarrying operations. Reconstructed soils may be made increasingly stony if the overburden is mixed with the soil layers.

7) Soil Depth. If thin layers of soil are placed over solid bedrock, plant rooting depths will be restricted.

8) Relief. Due to the nature of the quarry, varying slope aspects and gradients will be developed, which may cause high variability in the vegetative cover. Optimumn growth rates will typically be recorded on gentle north-east facing slopes.[88] Poorest growth rates will typically be recorded on south-west facing slopes.

13.5 Characteristics of Limestone Quarries as Growing Mediums

Limestone is almost pure calcium carbonate which makes quarries seemingly very hostile to any type of plant establishment. However, despite the lack of some basic nutrients, calcium carbonate itself is not toxic nor inhospitable to plant growth.[89] Despite its large magnesium component, dolomite possesses similar physical characteristics as limestone.

Limestone (including dolomite) decomposes very slowly and generally produces rocky soils of low fertility.[90] The pH is not extreme, typically less than pH 8 [91] (moderately alkaline soils range from pH 7.9 to 8.4),[92] and should not cause any major problems for plant growth. The main problems with limestone and their corresponding soils serving as a growing medium are as follows:

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[88] National Research Council, Surface Mining, p. 138.

[89] A. D. Bradshaw and M. U. Chadwick, The Restoration of Land (Oxford: Blackwell Scientific Publications, 1981), section 10.2.

[90] H. Schiechti, Bioengineering for Land Reclamation and Conservation (Edmonton: University of Alberta Press, 1980), p. 248.

[91] Bradshaw and Chadwick, section 10.2.

[92] Manitoba Soils.

1) Severe to Slight Deficiencies in Plant Macronutrients: TABLE 20 provides a list of plant macronutrients and explains their relative importance to plant growth. Limestone soils typically show a severe deficiency of nitrogen, phosphorus, and a slight deficiency of potassium.[93] Phosphorus is locked up in the form of apatities, which makes it unavailable in most plants other than specially adapted calcicoles.[94] Generally, nitrogen will be the limiting factor in plant productivity, while phosphorus is frequently the limiting factor in plant establishment.[95] Most Manitoba soils have sufficient potassium for maximum plant growth.[96]

The high magnesium level in dolomite developed soils may cause a severe reduction in calcium ions available to the plant. In severe cases, the soil may develop too many mineral salts (such as calcium and magnesium) which can cause a saline soil condition toxic to many plants. A calcium / magnesium ration exceeding 1:10 may be toxic.[97]

2) Deficiencies of Plant Micronutrients: The alkaline nature of these soils frequently makes iron ions unavailable to some plants, causing iron chlorosis. If a plant is growing in an alkaline soil (above pH 7), there is a strong possibility that it will suffer from iron deficiency and that its leaves will become chlorotic.[98] Iron may be present in the soil but not in a form that can be absorbed by the plant. Amur Maple Acer ginnala is very susceptible to this condition.

3) Poor to Nonexistent Soil Structure: Poor soil structure of recontoured quarry floors may cause a major deficiency in the potential revegetation of these soils. Many plant nutrients cannot remain in the soil zone useful to vegetation. In a developed soil, there is a

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93 Bradshaw and Chadwick, section 10.2

94 Ibid.

95 User Guide to Vegetation (U.S.D.A. Forest Service, 1979), p. 60.

96 Manitoba Soils, p. 65.

97 User Guide to Vegetation, p. 62.

98 Pirone, p. 18.

TABLE 20

PLANT MACRONUTRIENTS AND THEIR IMPORTANCE TO VEGETATION

Nitrogen (N)
- regulates plant growth
  .. if in excess-Plant grows too fast with a poor root development (may damage roots).
  .. when deficient- Plant growth is stunted.
- Nitrogen deficiency is usually a limiting factor in plant productivity.
- Nitrogen is the most mobile of the macronutrients and can readily be leached from rain or snowmelt.
- Fertilizer in the form of organic nitrogen can only be made available to plants after it is decomposed by soil micro-organisms (principally bacteria).
- Legumes such as clover, fix atmospheric nitrogen (when innoculated with bacteria) and make it available in the soil. Nitrogen is contained in the organic matter - but it is insoluble and therefore unavailable to plants. Bacteria releases the nitrogen from organic matter.

Plant Symptoms (lack of N)
.. sickly yellow colour.
.. slow and dwarfed growth.
.. drying up of leaves (from bottom upwards).

Phosphorus (P)
- stimulates root growth.
- hastens maturation of plant tissue.
- Phosphorus deficiency may be the limiting factor in plant establishment.
- Phosphorus as used by the plant is in the form of phosphates (P_2O_5) which are very immobile. Therefore, this nutrient should be worked into the soil or around the root zone of any vegetation.(2)
- Phosphorus fertilization has a long-lasting effect so there may need to be only 1 P application
- Phosphorus is scarce or locked up (unavailable) in unweathered material.

Plant Symptoms (lack of P)
.. Plant is retarded in all stages of growth.
.. purplish leaves, stems, and branches.
.. slow growth and maturity.
.. low yields of seed.

Potassium (K)
- promotes plant's ability to resist disease.
- again susceptible to leaching.
- applied in the form of potash (K_2O).
- It must be present in the manufacture of sugars and starches and their subsequent use by the plant.
- Most Manitoba soils have sufficient available potassium for maximum crop production.(3)

Calcium
- It is essential for growth and cell division. (2)
- It overcomes the effects of excess amounts of aluminum and iron salts. (2)
- favors development of beneficial bacteria. (2)
- abundant in limestone formed soils (calcium carbonate).

Magnesium
- aids in the transportation of phosphorus and is a chemical constituent of chlorophyll. (2)
- abundant in dolomite formed soils (magnesium carbonate).

Sulphur
- constituent of plant proteins. (2)
- Only form of sulphur which is water soluble and available to plants, is the sulphate ion (SO_4). (3)
- SO_4 is made available in the soil through the dissolution (and oxidation if required) of sulphur containing minerals. (3)
- It is released from organic matter as it is decomposed. (3)

Plant Symptoms (lack of Sulphur)
.. leaves cupped and turn purplish in colour.
.. manifested during early growth stages.

Micronutrients

Boron	Iron
Manganese	Molybdenum
Copper	Chlorine
Zinc	Sodium

Sources:
(1) U.S.D.A. Forest Service, User Guide to Vegetation, pg. 56
(2) Pirone, P., Tree Maintenance, Oxford University Press, pg. 50
(3) Manitoba Department of Agriculture, Manitoba Soils and Their Management, pg. 61
(4) U.S.D.A. Forest Service, User Guide to Soils, pg. 51

long-term supply of plant nutrients as well as a labile pool from which plants may draw nutrients when required. In a reconstructed soil of overburden, neither is present. Many plant nutrients are leached out of the soil by precipitation, while there is no organic matter present to store the nutrients.[99] Nitrogen, for example, is readily leached out of the plant root zone. If such nutrients are not utilized immediately by the plant, they will be quickly rendered unavailable.

4) Poor Soil Moisture Holding Ability. (Poor Soil Texture): Large solid particles within these overburdens and soils (many above 10 mm. in diameter) are too large to hold water by capillarity, while low levels of organic matter are not present to absorb and hold moisture beneath the soil surface.[100] These types of soils are susceptible to severe drought and make plant establishment risky, since a reliable source of water will be required in the plant's early stages of growth. A soil texture must be below .2 mm. to provide good soil moisture holding ability.[101] Clay soils, for example, possess high moisture storable ability.

Soil permeability is also a factor as limestone overburden will typically possess high permeability rates. Flooding, then, will not be a problem. If, however, clays are utilized for the quarry rehabilitation, they are fine textured, causing low permeability which may cause spring flooding conditions.[102]

5) High Surface Soil Temperatures: Due to the unprotected soil surfaces (void of vegetation or cover) on quarry floors, soil temperatures during daylight hours will generally be higher than on similar protected soil surfaces. Surface temperatures on sand and

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[99] Bradshaw and Chadwick, section 5.5.

[100] Ibid.

[101] Ibid.

[102] User Guide to Soils (U.S.D.A. Forest Service, 1979), p. 56.

gravel spoils may reach 40°C.[103] Combined with the moisture reducing abilities of the wind, newly-established plants will suffer from increased stress in these conditions. Further establishment of plants would have a modifying influence on the microclimate of the immediate environment.[104]

6) High Surface Soil Compaction: Quarry floors and the overburden spread over them will frequently be compacted by the heavy construction equipment utilized. Compaction can cause the reduction or total blockage of vegetation root penetration.[105] Plant establishment can be literally negated from soil surfaces which are heavily compacted.

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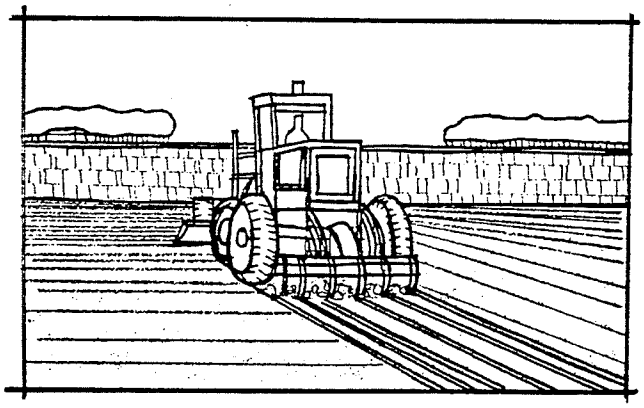
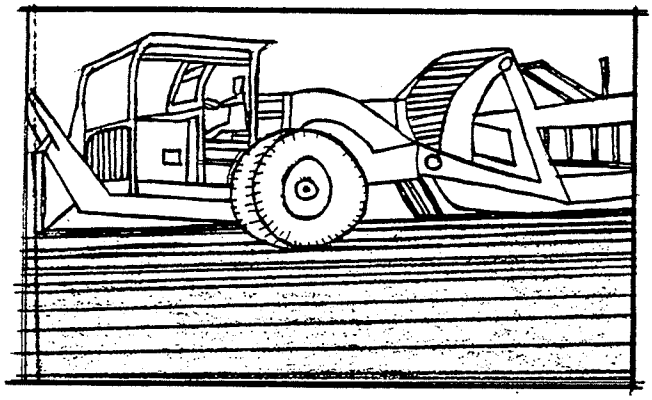
[103] Schellie, p. 162.

[104] G. Robinette, Plants, People and Environmental Quality (Washington: U.S. Department of the Interior, 1972), pp. 95-97.

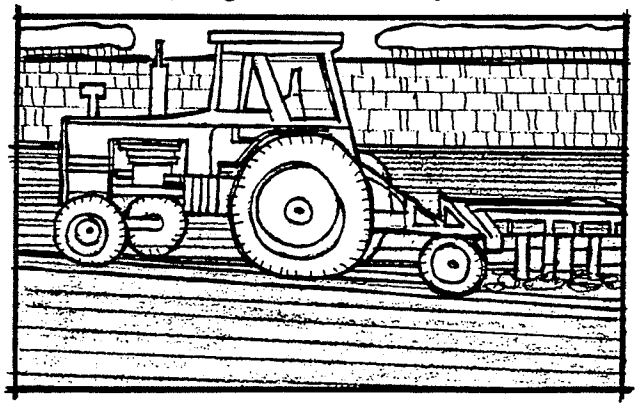
[105] User Guide to Soils, p. 64.



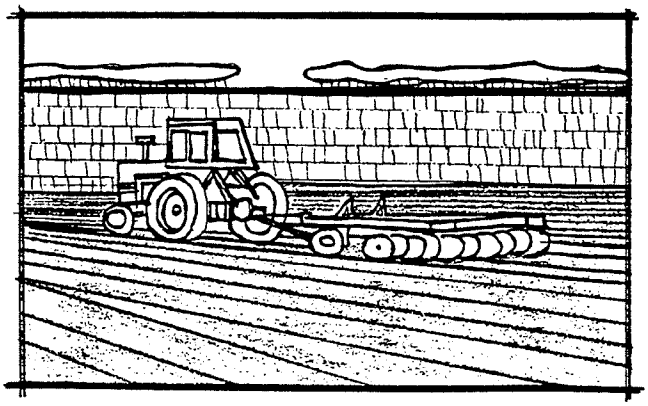
1 Ripping Bedrock Floor



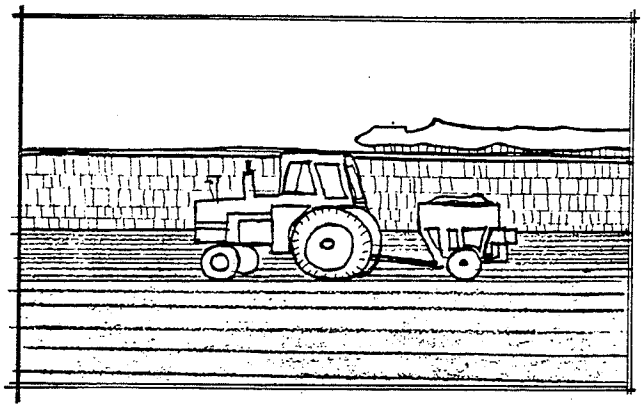
2 Laying Down Topsoil



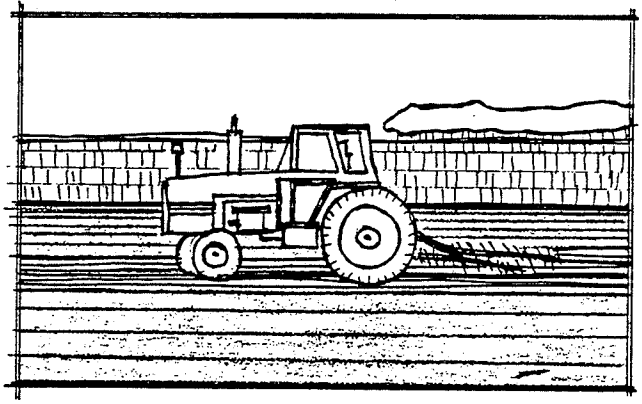
3 Ripping Topsoil



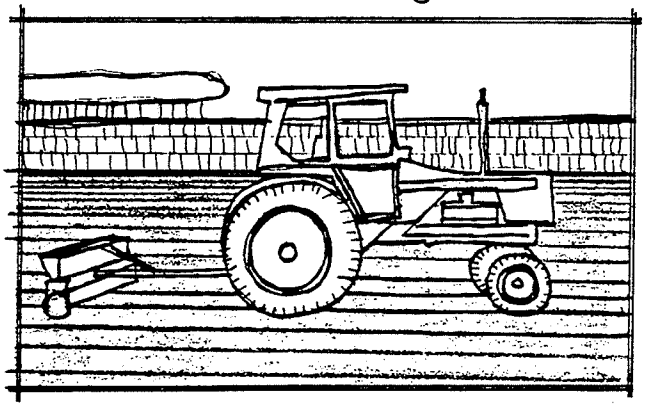
4 Disking



5 Fertilizing



6 Harrowing



7 Seeding



8 Hydromulching

FIGURE 12 TECHNIQUES OF REHABILITATION

TECHNICAL REHABILITATION GUIDELINES

14.1 Purpose

One of the major problems of current rehabilitation practice within North America is that rehabilitation techniques are seldom documented, and their relative costs, successes, or failures remain unreported. Therefore, poor rehabilitation techniques may be unknowingly repeated, while good methods remain unheralded and unavailable to others.

The purpose of this section is to document technical rehabilitation guidelines. The benefits of documentation are twofold;

1) It provides a guide for the rehabilitation of crushed limestone quarries.
2) It provides an information base to which more relevant or detailed information can be added (or information deleted), as new techniques are discovered and successfully applied.

Because a discussion of technical rehabilitation guidelines would require a topic in and of itself, I have limited my discussion to that of the techniques of revegetation of crushed limestone quarries.

14.2 Selection of Revegetation Species

One of the most critical steps in the rehabilitation process is the selection of the plant species to be utilized on the site. The consultant must first be familiar with the legal requirements of revegetation. Legal requirements can be considered the minimum standard for rehabilitation revegetation plans. The Manitoba Rehabilitation Regulation simply requires that vegetation cover be established that is appropriate to the area.[106] Probably the most important factor in

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106 Manitoba Quarrying Minerals Regulation 226/76, Being a Regulation under the Mines Act Governing the Disposition of Crown Minerals and the Rehabilitation of Commercial Quarries.

species selection will be the identification of the future land-management goals for the site. For example, if the area is to be rehabilitated for livestock grazing, then the selected species should be palatable and useful forage species.[107]

Despite the knowledge of these first important criteria, correct species selection will be a difficult task for the constultant. Correct revegetation of the site is essential for providing the area with a permanent vegetative cover which will prevent erision and will eventually return the site to an ecologically productive state. For these reasons species selection should also involve the analysis of the following interacting parameters:[108]

1) Rehabilitation Value of the Species: This may include biotechnical aspects of the species. For example, deep-rooting plants are valuable for slope stabilization. Nitrogen-fixing plants may also be valuable for rehabilitation. Most legumes have the ability to fix atmospheric nitrogen and transform it into a plant soluble form.

2) Nature of the Site: Plants must be adapted to:
   a) the soil (edaphic) conditions of the site. Soils following re-establishment on the quarry site are usually not soils in a pedological sense, but initially only dead substrates or raw mineral soils.[109] The texture, depth, fertility, permeability, water-retention capacity, and pH of the soil must be analyzed.

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107 User Guide to Vegetation, p. 13.

108 For a complete discussion of species selection for rehabilitation, see User Guide to Vegetation, pp. 14-15; S. B. Lowe, Trees and Shrubs for the Improvement and Rehabilitation of Pits and Quarries (Toronto, Ontario Ministry of Natural Resources, 1979) pp. 27-31; Watson, Parker, and Polster, Manual of Species Suitability for Reclamation in Alberta (Edmonton, Alberta Land Conservation and Reclamation Council 1980), pp. 4--5; Schiecht, p. 163; and Vegetation for the Rehabilitation of Pits and Quarries in Ontario (Toronto, Ontario Ministry of Natural Resources, 1975), p. 12.

109 Shciechti, p. 65.

b) the climatic conditions of the site, including precipitation, local temperatures, and wind velocities.

c) the slope conditions, which may determine the amount of incident solar rediation received and soil stability.

d) the aspect conditions which may determine the solar radiation load, the growing season, and the amount of daylight.

3) Ease of Propagation: Some species establish much more easily than others.

4) Mechanical Limitation: Some species require specific planting requirements which may be unsuitable for certain areas within the site.

5) Time of Planting: If planting is restricted to a specific time of the year, it may eliminate species which should not be planted at that time.

6) Species Compaticility: When planting a mixture of species, care must be taken not to plant competing species. For example, when annuals and perennials are mixed, only 10 percent or less annuals should be used as they may outcompete perennials.[110]

7) Seed and Seedlings Availability and Cost: It is difficult to get seed for many species of grasses, forbs, and native shrubs, while other species are cost prohibitive.

8) Nutrient and Maintenance Requirements: Some species will require more nutrition and maintenance than others.

9) Resistance to Disease and Insects: Many native species are susceptible to both disease and insect infestations.

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110 User Guide to Vegetation, p. 15.

One of the easiest and most effective methods of determining species selection is to observe old quarries that have been recolonized by native vegetation. This process provides us with a list of species that are naturally adapted to the conditions of a limestone quarry. By utilizing the primary (low end) successional species which actively colonize within quarries, one would almost be assured of a successful revegetation program. Little Mountain Limestone Quarry (operation ceased 1906)[111] is one of the best locations to study the recolonization of a limestone quarry.

A general comparison could also be made between the site to be revegetated and a similar condition. For example, highway shoulders possess circumstances comparable to those of quarry floors, in that both are infertile, highly compacted, and highly exposed sites. Plant species that thrive on highway shoulders (especially those beside Highway No. 7 in the Rockwood Region) may well be considered for use within limestone quarries.

Acutecological species lists and tables that compare species site requirements in relation with one another, are also of benefit when selecting species for the different microsites within a quarry. Further, plant association lists will help the consultant in selecting species which are compatable within an ecological community (i.e., are the species found in association with one another in nature?).

A general rule of thumb is that the more severe the site, the more species-rich the site should be planted. Species-rich ecosystems are typically healthier, more stable, and more resistant to damage and disturbances than those which are species-poor.[112]

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111 B. Bannatyne Industrial Minerals Geologist's File (Winnipeg: Mineral Resources Division).

112 Schiechti, p. 163.

Ornamental or introduced species can be utilized as long as they are "adapted" to the site. Adaptability is intimately tied to the ability of a plant to complete its entire life cycle and to reproduce itself from year to year over a long period.[113]

Native plant material should likewise be scrutinized for its "adaptability" for use on a site. Many so-called native species grow in the acidic soils of the Canadian Shield and would probably be unacceptable for use in the alkaline soils found in the region of the limestone quarries.

A useful guide for the selection of plant material is Manitoba Publication #271, Recommended List of Ornamental Trees, Shrubs, Climbers, and Ground Covers for Manitoba. This pamphlet should be utilized in conjunction with consultation with a professional nursery man (preferably a nursery grower) or seed supplier, and reference to the information provided in this study. Combined, the consultant should then be capable of providing a planting plan which will be suitable for the stated objective of the site. See TABLE 21 for a guide to the selection of specific species for revegetation.

14.3 Selection and Techniques of Revegetation

As the plant species are being selected, a simultaneous determination must be made as to the type of plant material to be used.

Types of Plant Material Suitable for Use in Quarry Rehabilitation

Seeds	Sprigs (Tillers)
Bare-Root Stock	Rhizomes
Containerized Seedlings	Plugs
Cuttings	Wildlings

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113 User Guide to Vegetation, p. 14.

Table 21

REVEGETATION SPECIES SELECTION GUIDE

	Advantages & Constraints	Growth Habits	Precipitation Required	Soil Texture			Soil Drainage				Soil Fertility			Drought Tolerance	Potential Erosion Control
				sandy	loamy	clayey	dry (not droughty	well-drained	mod. well-drained	poorly drained	low	medium	high		
TEMPORARY GRASSES															
Barley *Hordeum vulgare*	Can be used in rotation to prevent soil erosion			○	○○	○○		□	□						Can retard soil erosion
Oats *Avena sativa*	Fast establishing cover crop-retards soil erosion.			○	○○	○○		□	□						Can retard soil erosion
Rye *Secale cereale*	Fast establishing cover crop-retards soil erosion			○○	○○	○○		□	□						Can retard soil erosion
Perennial Ryegrass *Lolium perene*	Rapid seedling growth, fast cover-nurse crop retards soil erosion.	erect tufted 30-60 cm. tall	75-125	○○	○○	○○		□	□			◇	◇	●	Fibrous root system Moderates sod. Former provides fast cover.
PERMANENT GRASSES															
Canada Bluegrass *Poa compressa*		Erect medium sod former 30-60 cm.-tall		○	○○		□	□	□	□	◇	◇		○	Good for poor sites
Creeping Red Fescue *Festuca rubra*	Useful on dry, sandy, shady areas.	loose tufted sod former		○	○○	○○	□	□	□		◇	◇	◇	○	Sod builder, deep rooter, extensive rhizomotous roots
Crested Wheatgrass *Agropyron cristatum*	Good slope stabilizer, large deep roots, suitable on dry slopes.	erect tufted bunchgrass 50-70 cm. tall	23-38	○○	○○		□	□	□		◇	◇		○	Excellent erosion control, deep rooter, extensive roots
Kentucky Bluegrass *Poa pratensis*		dense sod-former 30-80 cm. tall		○	○○	○○		□	□	□		◇	◇	●	Dense rhizomatous sod, fast cover rate
Western Wheatgrass *Agropyron smithii*		sod, former 30-60 cm. tall	prefers >35		○○	○○		□	□	□		◇	◇	○	High soil stabilizing potential may be used on slopes.
Tall Fescue *Festuca elatior*	One of the best grasses for poorly drained soils, remains green.	tufted bunchgrass to 100 cm.		○	○○	○○		□	□	□		◇	◇	○	Tough and coarse roots, excellent erosion control
Orchard Grass *Dactylis glomerata*	Requires high fertility, high yielding ability, draws on soil nutrients.	tufted bunchgrass 60-100 cm.	30-45	○	○○		□	□	□	□		◇	◇	◑	
LEGEND				○	○○			□			◇	◇		○	Drought tolerant
	Prefers loamy soils Requires well-drained soils Requires low to medium fertile soils													●	Not drought tolerant
														◑	Moderate tolerance

Table 21

REVEGETATION SPECIES SELECTION GUIDE

	Advantages & Constraints	Growth Habits	Precipitation Required	Soil Texture			Soil Drainage				Soil Fertility			Drought Tolerance	Potential Erosion Control
				sandy	loamy	clayey	dry (not droughty	well-drained	mod. well-drained	poorly drained	low	medium	high		
PERMANENT GRASSES															
Timothy Phleum pratense	establishes easily,withstands severe grazing,and low seed cost	erect bunchgrass	prefers 45 cm. or more	○	○○	○○	□	□	□			◇	◇	●	rapid soil coverage, moderate erosion control.
Reed Canary Grass Phalaris arundinacea	low land colonizer,does well on poorly drained land(swamp grass).	tall,coarse grass .6 to 1.5 m. tall		○	○○	○○		□	□	□	◇	◇		○	
Smooth Brome Bromis. inermis	early spring growth,good ground cover,good for steep slopes.	tall,leafy sod-former	28 cm. or more	○	○○	○○	□	□	□	□		◇	◇	○	deep rooted,good for steep slopes,good growth rate, develops tight sod,good soil stabilizer.
Redtop Agrostis alba		relatively low growing,erect species approx. 60 cm. tall	prefers 50 cm.			○○	□	□	□	□	◇	◇		◑	good,if adequate moisture, strong rhizomatous habit.
LEGUMES															
Crownvetch Coronilla varia	requires 2-4 years to establish a good stand.Excellent persistence once established.						□	□	□		◇	◇			provides erosion control on steep slopes.
Dutch White Clover Trifalium repens	shallow root system,suited to shallow soils.	a low creeping species			○○	○○		□	□	□	◇	◇		●	
Alfalfa Medicago sativa	well adapted to high lime soils, ideal soil improver,excellent forage crop.	slender erect stems up to 1 m. high.		○	○○	○○	□	□	□			◇	◇	○	provides dense cover, improves soil structure.
Birdsfoot Trefoil Lotus corniculatus	on good sites provides erosion control,adapted to poor soils.	similar to Alfalfa and range from 30 to 75 cm.		○	○○	○○	□	□	□	□	◇			◑	well developed tap-root, numerous lateral branches.
Red Clover Trifolium pratense	easy to establish,rapid growth	erect or spreading typically 40-80 cm. tall	needs more than 30 cm.	○	○○	○○	□	□	□		◇			◕	tap-root and lateral branches
Alsike Clover Trifolium hybridum	potential as nurse crop, short lived non-spreading legume	erect to decumbent plant 20-80 cm. high	45 to 135 cm. annually	○	○○	○○		□	□	□		◇		○	tap-root deep and abundant. Used on 70% slopes,widely branched,soil stabilizer.
Sweet Clover Melilotus spp.	excellent soil builder,converts potassium to more available form in the soil.Soil builder.	an erect plant .2 to 2.5 m. high	38-85 cm. yearly	○	○○	○○	□	□	□	□	◇	◇		◕	good growth builder,creeping growth form.

Table 21

REVEGETATION SPECIES SELECTION GUIDE

	Advantages & Constraints	Growth Habits	Precipitation Required	Methods of Establishment	Soil Moisture			Soil Fertility			Drought Tolerance	Potential Erosion Control
					dry	moist	wet	low	medium	high		
GROUND COVERS												
Common Juniper Juniperus communis	shows excellent growth in gravel pits,tolerates dry,infertile, shallow,high pH soils,prefers coarse soils.	low,evergreen shrub,growing to 1 m.		propigated by cutting, seed,seedlings,or small plants(up to 12")b+b or container.	○	○		□	□		○	good cover protection
Creeping Juniper Juniperus horizontalis	tolerant of very dry,rocky,infert. alkaline soils,good growth in gravel pits.	low evergreen shrub,grows to .3 m.		prop.by cuttings,seed seedlings,and trans-plant(up to 12")b+b or container.	○	○		□			○	good cover protection
Mugo Pine Pinus mugo	prefers moist soils,but tolerates high exposure pH,wind,dust,and road salt.	conifer shrub growing to 3 m.		transplants(up to 12" bare root,b+b,or container.	○	○		□	□		○	
Virginia Creeper Parthenocissus quinquefolia	tolerates poor soils,slow to leaf out but very attractive,outstanding growth in gravel pits	trailing or climb-ing deciduous shrub									○	good climbing habit for steep slopes
SHRUBS												
Amur Maple Acer ginnala	susceptible to lime-induced chlorosis	large,dec.shrub or small tree-up to 5 m.		from seed,bare root (up to 1m.)container or b+b(up to 1.6m.)		○			□	□		
Caragana Caragana arborescens	fixes nitrogen in the soil,high drought tolerance,available from P.F.R.A. Tree Farm	dec. shrub grows to 3m.		prp.vegetatively by cuttings,or budded or grafted bare root(up to .6m.)	○	○		□	□		○	suckers profusely,produces thickets,good soil stabilizer
Red osier Dogwood Cornus stolonifera	native species,quarry colonizer, aesthetic value in winter	decid. shrub, grows to 2m.		prp. by greenwood cut-tings,bare-root(up to .6m).	○	○	○		□	□	●	spreads by root suckers, and produces thickets,good soil stabilizer
Silverberry Elaeagnus commutata	fixes nitrogen in soil,adapted to dry,alkaline,infertile soils,may possibly direct seed plant	decid. shrub,grows to 2m.		possible direct seed, seedlings,suckers,or bare-root(up to .5m)	○	○		□	□		◐○	good soil stabilizer, suckers profusely
Tatarian Honeysuckle Lonicera tatarica	adaptable to poor alkaline soils, prefers moisture	dec. shrub grows to 3m.		prp. by cuttings,smal plants or bare-root (up to .6m)		○	○		□	□		
Potentilla Potentilla fruiticosa	prefers full sun,tolerates poor dry sandy soils and extremes of temps. optimum slope for establishment 9-30%.	decid. shrub,grows to 1m.		prp. by greenwood cut tings,small plants, bare-root(up to.6m) container or b+b	○	○		□	□		◐○	moderate potential,fibrous root system

Table 21

REVEGETATION SPECIES SELECTION GUIDE

	Advantages & Constraints	Growth Habits	Precipitation Required	Methods of Establishment	Soil Moisture			Soil Fertility			Drought Tolerance	Potential Erosion Control
					dry	moist	wet	low	medium	high		
SHRUBS												
Snowberry *Symphoricarpos albus*	tolerant of most conditions including high lime soil, prefers open sites, tolerates coarse textured rocky soils	decid. shrub growing to 1-2m.		division, hardwood, softwood cuttings, budded or grafted, small plants (up to .6m) bare-root	○	○		□	□		◑	good soil stabilizer, suckers profusely, and produces thickets
Common Lilac *Syringa vulgaris*	slow to establish, prefers moist soils, with medium fertility	decid. shrub growing to 3-5m.		prp. vegetatively frm cuttings, budded, or grafted, sm. plts (up to 1m) bare-root		○			□	□		good potential, suckers
Nannyberry *Viburnum lentago*	prefers moist or wet medium fertile soils	decid. shrub growing to 3-6m.		hard to propigate seed or cuttings small plants (up to 1m bare-root		○	○		□			good potential suckers
Highbush Cranberry *Viburnum trilobum*	prefers good moist soils	decid. shrub growing to 3m.				○	○		□	□		
Saskatoon *Amelanchier alnifolia*	tolerant of moderately alkaline soils, prefers open sites, light well-drained soils	decid. shrub growing to 6m.		seeds, difficult to prp., transplants well	○	○		□	□		○	good soil stabilizer, spreads by stolons to form thickets
Prickly Rose *Rosa acicularis*	tolerates wide range of soil conditions and textures, found volunteering in Stonewall quarry	decid. shrub 0.5 to 1.5m. in height		seeds, root cuttings, hardwood, softwood cuttings, recommend bare stem cuttings	○	○	○	□	□		◑	good-rapid spreading by rhizomes and thicket forming.
Common Wild Rose *Rosa woodsii*	prefers full sun, moister soils, tolerates dry, high pH and lime soils, found volunteering in Stonewall quarry	decid. shrub 0.3 to 2m. in height		seeds, hardwood tips, bare-root cuttings, budding, suckers, trans plants easily	○	○		□	□		◑	good-rapid spreading by rhizomes-thicket forming, shallow, dense roots
Bebb Willow *Salix bebbiana*	tolerates moderately alkaline soils, tolerates flooding	decid. shrub or small tree up to 10m.		transplants easily, stem cuttings or rooted cuttings	○	○	○	□	□		●	good soil stabilizer, shallow dense roots
Buffaloberry *Shepherdia argentea*	fixes nitrogen, prefers light, well drained soils, can tolerate poor, moderate alk. soils (pH 8-8.4) well suited to dry, rocky banks	decid. shrub or small tree up to 5m.		prp. from seed, root cuttings, transplants easily	○	○		□	□		◑	good soil stabilizer, forms thickets
Buckbrush *Symphoricarpos occidentalis*	tolerates moderate alkalinity	small decid. shrub grows to 1m.		seed, division, hardwood and softwood cuttings, suckers, transplants		○	○	□			◑	good soil stabilizer, and thicket former

Table 21

REVEGETATION SPECIES SELECTION GUIDE

	Advantages & Constraints	Growth Habits	Precipitation Required	Methods of Establishment	Soil Moisture			Soil Fertility			Drought Tolerance	Potential Erosion Control
					dry	moist	wet	low	medium	high		
TREES												
Manitoba Maple Acer negundo	grows almost anywhere(dry,infertile high pH soils)recommended on sites with sufficient soil moisture	decid. tree up to 8-15m.		seedling,bare-root (up to 3')unrooted cuttings,potential for direct seeding	○	○	○	□	□		●	good soil stabilizer-good when planted as cuttings and grows as a hedge.
Silver Maple Acer saccharinum	susceptible to lime induced iron chlorosis,grows well on very wet sites	decid. tree to 15-25m.		seed prp.,seedlings, bare-root(up to 5')		○	○	□	□		●	
Paper Birch Betula papyrifera	requires relatively high maintenance,susceptible to insects,prefer well-drained soils			seed,seedlings, transplants well	○	○	○		□		●	good soil stabilizer
Green Ash Fraxinus pennsylvanica var subintegerrima	prefers well-drained soils,tolerates dry,low fertility,high pH soils	decid. tree to 12m.		seed prp.,transplants easily,seedlings(up to 5')bare-root	○	○		□	□		○	good fibrous root system
Tamarack Larix laricina	prefers moist well-drained soils	conif. tree to 15-22m.		seed prp.seedlings, transplants(up to 2') container or b+b	○	○		□	□		●	fair,shallow root system
White Spruce Picea glauca	prefers moist well-drained soils, will not perform well on dry sites or exposed sites-needs protection.	conif. tree to 15-25m.		seed prp.,seedlings or transplants(up to 2')container,b+b	○	○	○	□	□		◑	poor, unsuitable
Jack Pine Pinus banksiana	tolerates calcareous sites,not alkaline sites,but adaptable to poor dry soils	conif. tree to 8-20m.		bare-root,seedlings	○	○		□	□			good-especially in sandy areas
Scots Pine Pinus sylvestris	tolerates dry,infertile,high lime soils,prefers dry sandy sites,not exposed sites	conif. tree to 10-25m		seed,seedlings(bare root)	○	○		□	□		○	
Balsam Poplar Populus balsamifera	susceptible to rodent damage,found volunteering in Stonewall quarry	decid. tree up to 12-15m.		seed,seedlings,root & stem cuttings,transplants up to 7' seedlings up to 5'	○	○	○	□	□		●	fair,shallow root system
Cottonwood Populus deltoides	often found growing naturally in pits & quarries in eastern Canada	decid. tree to 15-20m.		seedlings to 3',bare-root hardwood cutting		○	○		□	□		good,extensive root system

Table 21

REVEGETATION SPECIES SELECTION GUIDE

	Advantages & Constraints	Growth Habits	Precipitation Required	Methods of Establishment	Soil Moisture			Soil Fertility			Drought Tolerance	Potential Erosion Control
					dry	moist	wet	low	medium	high		
TREES												
Trembling Aspen Populus tremuloides	tolerates poor dry sites-will volunteer in quarries	decid, tree up to 12-15m.		seed,seedlings,bare-root(up to 5'),root cuttings,transplants, green cuttings	○	○		□	□		◑	good soil stabilizer,but shallow wide-spreading root system
Hybrid Poplars Populus sp.	short-lived under arid conditions (20-25 years)	decid. tree up to 15-25m.				○	○	□	□		●	good soil stabilizer but shallow wide-spreading root system
Pin Cherry Prunus pennsylvanica	tolerates dry infertile sites				○	○		□	□		◑	
Chokecherry Prunus virginiana	prefers moist well-drained sites susceptible to black knot disease	decid. shrub or tree,grows up to 4-5m.		seed, seedlings	○	○			□		◑	very good for soil stability
Eastern White Cedar Thuja occidentalis	prefers moist soils,tolerant of dry,high lime,infertile soils	conif. tree up to 12m.		transplants(up to 2')	○	○	○	□	□			
Siberian Elm Ulmus pumila	prefers well-drained soils,tolerate infertile,dry,alkaline soils, tolerant of dust and salt	decid. tree up to 15m.		seed propigated,bare root(up to 3') seedlings	○	○		□	□		○	very good,strong lateral roots, but shallow
Laurel Leaf Willow- Acute Willow Salix sp(pentandra) (acutifolia)	prefers moist well-drained sites-laurel willow susceptible to chlorosis.	decid. tree up to 12-15m.		cuttings		○	○	□	□		○	very good,many lateral roots on suitable sites

SOURCES: - Alberta Land Conservation and Reclamation Council, Manual of Plant Species Suitable for Reclamation in Alberta;
Volume 1 Grasses
Volume 2 Forbes, Shrubs, and Trees
Report # RRTAC 80-5, 1980

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

- Coates, W. E., Screen Plantings for Pits and Quarries; Aggregate Producers Association of Ontario, Downsview, 1981

- Ministry of Natural Resources, Vegetation for the Rehabilitation of Pits and Quarries; Forest Management Branch, Toronto, 1975

TABLE 22

TEMPORARY SEEDING GUIDE (NORTHERN MICHIGAN)

Types of Seed	Recommended Planting Season						
	April	May	June	July	August	Sept.	Oct.
Spring Oats Avena sativa		X	X	X			
Barley Hordeum vulgare		X	X	X			
Domestic Ryegrass		X	X	X			
Rye Secale cereale					X	X	
Perennial Ryegrass Lolium perene					X	X	
Wheat Triticum aestivum						X	

Rate of Application:	per/93 sq.m. (per/1000 sq. ft.)	per acre
Oats/Barley	.9 kg. (2 lbs)	3 bushels
Domestic Ryegrass	.2 kg. (½ lbs)	9 - 11.3 kg (20-25 lbs)
Rye	1.4 kg. (3 lbs)	2 - 3 bushels
Perennial Ryegrass	.2 kg. (½ lbs)	9 - 11.3 kg (20-25 lbs)
Wheat	1.4 kg. (3 lbs)	2 - 3 bushels

Source: Beckett, Jackson, Raeder Inc., Soil Erosion and Sedimentation Control; Environmental Design Press, Reston 1981, pg. 44

TABLE 23

ONTARIO MINISTRY OF TRANSPORTATION AND COMMUNICATIONS ROADSIDE STANDARD

Seed Mixture: The following standard grass mixture should be sown at 80 lbs./acre (90 Kg/ha).

Creeping Red Fescue *Festuca rubra* L.	55%	Permanent Grass
Kentucky Blue Grass *Poa pratensis* L.	25%	Permanent Grass
Red Top *Agrostis alba* L.	5%	Short-lived interim grass, germinates quickly, reseeds itself.
Companion Crop*	12%	May be increased if hydroseeded.
White Dutch Clover *Trifolium repens* L.	3%	May be increased for heavier soils.

Fall Seeding* The mixture is supplemented by the addition of 1 bu. wheat/acre, or 1 bu./acre of fall rye.

Spring Seeding 1.5 bu./acre of oats.

Source: Ontario Ministry of Natural Resources, Vegetation for the Rehabilitation of Pits and Quarries in Ontario; pg. 17

Additional Notes: The following were suggested amendments to the MTC Standard Seed Mixture.

Tall Fescue *Festuca elatior* var. *arundinacea*	May be mixed 50/50 or 25.75 with previous blend. Remains green under adverse summer conditions, plus greens up quickly after mowing.
Creeping Red Fescue *Festuca rubra* L. Pennlawn Selection	Suggested selection of Creeping Red Fescue reported to perform well on north and east facing banks, shade tolerant, excellent spreading habit, drought tolerant, persists better on low fertility soils.
Canada Blue Grass *Poa compressa* L.	May be utilized instead of Kentucky Blue Grass.

Source: Tucker, P.,"Vegetative Methods of Slope Stabilization"; Paper presented at 3rd. Annual Workshop of the Ontario Cover Crop Committee, 1974, pg. 5

The Ontario MTC has the responsibility to establish low cost, high quality roadside plant communities that are ecologically tuned, easy to maintain, and that meet safety standards.

TABLE 24

RECOMMENDED STONEWALL AREA GRASS SEED MIXTURES FOR LIMESTONE QUARRIES

Creeping Red Fescue *Festuca rubra* L.	40%	germinates quickly 10-14 days,excellent sod former, grows well on poor soils,shade tolerant,extensive fibrous root system,good soil builder,drought tolerant
Kentucky Blue Grass *Poa pratensis* L.	40%	germinates slowly 21-30 days,does well on soils of limestone origin,good soil former,excellent grass for soil erosion when under favorable conditions.
Annual Rye Grass *Secale cereale* L.	15%	very fast germinating 7 days,acts as a nurse crop for the rest of the mixture.
White Dutch Clover *Trifolium repens* L.	5%	preparatory crop,provides turf-like cover,nitrogen fixing legume,well suited to shallow soils,one of the best legumes to use on poor soil beds.

Seeding Rate: 200-400 lbs./acre (200 lbs. on quarry floor,400 lbs. on quarry backslope).

Fertilizer Application:
1. with seeding: 11-48-0. High phosphorus content for better root growth.
2. after well established: 11-48-0. Keeps grass green, promotes root growth,surface of plant will not grow rapidly,so requires less cutting.

Method of Application: Best Method - Seed drill
Also possible - Broadcasting - Suggest broadcasting with fertilizer & then harrowing into the ground.

Cost:Seed (1982 price) 98¢/lb. or $196.00 - $392.00/acre.

Maintenance: You would have to mow this mixture a couple of times a summer to promote dense turf. If not mowed, Quack Grass, *Agropyron repens* L. would probably invade.

Steep Slope Grass Seed Mixture

Add: Annual Rye Grass *Secale cereale* L. with the standard grass seed mixture at approx. 1 bu./acre. Annual Rye acts as a nurse crop for grass mixtures, as it germinates quickly (7 days) and provides a stabilizing root growth. Less competitive than Annual Oats, which would out-compete the grass mixtures. Harrow across the face of the slope and not down the slope face.

Perpendicular Quarry Walls or Problem Areas:Quack Grass *Agropyron repens* L., very hardy, persistent weed-like plant will grow almost anywhere, seed subject to availability, but relatively cheap. (1982 price) 50¢/lb.

Recommended Grass Sod Establishment

Lloyd Dick (Brett Young Seeds) recommends establishing the entire area to be reclaimed with the Pasture or Hay Seed Mixtures and maintain the pasture for a minimum of 3 growing seasons. By then,there should be a layer of 3" - 4" of topsoil in which to establish the grass seed mixture. Plow pasture under and direct seed or broadcast the new mixture into this.

Source:personal conversation with Lloyd Dick, Brett Young Seeds Ltd., May 1982.

TABLE 25

MANITOBA DEPARTMENT OF HIGHWAYS STANDARD SEED MIXTURE FOR HIGHWAY NO. 7

Right - of - Ways Around Stonewall

The following standard grass mixture was sown at 20 lbs./acre.

Bromegrass *Bromus inermis* Leyrs	35%
Creeping Red Fescue *Festuca rubra* L.	20%
Meadow Fescue *Festuca elatior* L.	20%
Timothy *Phleum pratense*	15%
Alsike Clover *Trifolium hybridum*	10%

Fertilizer was initially applied at 100 lbs./acre (no specific fertilizer mixture was suggested although 5 - 20 - 10 was utilized extensively for initial fertilizing in Ontario).

Source: Personal communication with Don Mattson, Manitoba Department of Highways, District 12 Engineer, May 1982.

TABLE 26

MILTON QUARRY ONTARIO STANDARD SEED MIX

Creeping Red Fescue Festuca rubra L.	30%	Permanent Grass
Perennial Ryegrass Lolium perenne	20%	
Kentucky Bluegrass Poa pratensis L.	20%	Permanent Grass
Kentucky 31 Fescue	10%	Permanent Grass
Annual Ryegrass Secale cereale L.	10%	Companion Crop
Red Top Agrostis alba L.	10%	Short-lived interim grass, germinates quickly, reseeds itself.

Notes: This mixture was chosen for rapid growth in marginal soil conditions.

Rates of Application

Seed Mixture - 175 lbs./acre (hydroseeded)

Fertilizer - 5 - 20 - 10 at 500 lbs./acre. This fertilizer used and at this rate because of its suitability for establishing rapid growth in marginal soils.

Straw Mulch - 1 1/2 - 2 tons of straw per acre.

Asphalt Emulsion - (mulch) 80 - 100 gal. per acre

Depth of Topsoil 4 inches average

Fertilizers: 1. 5 - 20 - 10 as mentioned with initial seeding
2. 34 - 0 - 0 applied to establish grass area in spring at 150 lbs. per acre.

Source: DeWitt, F. J.,"Environmental Planning and Rehabilitation at Milton Quarry"; pg. 44

TABLE 27

NELSON CRUSHED STONE STANDARD BACK SLOPE SEED MIX

The following standard grass mixture should be sown at 80 lbs./acre (90 kg/ha)

Creeping Red Fescue Festuca rubra L.	33%
Brome Grass Bromus inermis Leyrs	29%
Annual Rye Grass Secale cereale L.	17%
White Dutch Clover Trifolium repens L.	4%
Companion Crop (rye grass)	17%

Notes:

This seed mix is a slight variation of the Ontario Ministry of Transportation and Communications standard seed mixture.

Nelson Crushed Stone Standard Shade Seed Mix

Rough-Stalked Blue Grass Poa trivialis	75%
Creeping Red Fescue Festuca rubra L.	25%

Source: Yundt,"A Case Study of Materials and Techniques Used in the Rehabilitation of a Pit and Quarry in Southern Ontario"; Paper presented at the 1977 Annual General Meeting of the Canadian Land Reclamation Association.

TABLE 28

ENVIRONMENT CANADA SUGGESTED WILD WOODLAND BORDER FOR WILDLIFE HABITAT

The following seed mixture should be sown at a rate of 12 lbs.(5 kg) per acre.

Intermediate Wheatgrass Agropron intermedium (Host)	45%
Tall Wheatgrass Agropyron elongatum (Host)	25%
Alfalfa Medicago spp.	20%
Sweet Clover Melilotis spp.	10%

Source: Environment Canada, Wildlife Habitat 1981; pg. 12

Many of the native plant species materials are not available from the nurseries, they are difficult to propagate, and they do not transplant effectively. Other plant species may be expensive and limited in availability, or may require specialized methods of planting. The selection of one type of plant material over another depends mostly on site requirements. Each of the types of plant materials have their relative merits and demerits which can be weighed against one another. However, many plant species will be established upon a site more cost efficiently and effectively by utilizing one type of plant material over the others.

This section will discuss the basic considerations for choosing plant materials,[114] and outline the techniques of revegetation suitable for their establishment.[115]

Seeds

1) Planting Seeds: Planting seeds is usually the least expensive and most efficient method of revegetating a site. Generally, seeds should be utilized when the selected species can be expected to germinate easily and sufficient moisture for germination is expected.[116] Basically, in rehabilitation practice, grasses and forbs are established by other types of plant material, since tree and shrub seedlings cannot compete with the more aggressive grasses and forbs. Seeding is best for establishing plant material in large areas that require complete coverage (i.e. quarry floors). Either one or several seed species can

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114 For a complete discussion on selection of plant materials, see User Guide to Vegetation, pp. 19-26; Schiechti; and Banks and Boras, "An Investigation into the Revegetation of Gravel Pits", Research paper University of Guelph 1981.

115 For a complete discussion on the techniques of plant establishment, see User Guide to Vegetation, pp. 39-41; Schiechti, Vegetation for the Rehabilitation of Pits and Quarries (Toronto: Ontario Ministry of Natural Resources, n.d.), pp. 11, 20-21; and Handbook Equipment for Reclaiming Strip Mined Land (U.S.D.A. Forest Service, 1977), p.55.

116 User Guide to Vegetation. p. 19.

be down at the same time. The disadvantages of seedling are that with the exception of hydroseeding, it does not provide an immediate form of erosion control and that seed establishment relies almost entirely upon the weather.

The rate of seeding must also be carefully controlled. Seeding too densely can be as disadvantageous as seeding too lightly, because the slower-growing permanent species may be overwhelmed by the faster-growing nurse crop.[117]

Generally there are two basic techniques for planting seeds, seed drilling or seed broadcasting, which includes hydroseeding. The decision on which technique is most suitable will be based upon a number of factors such as:

a) characteristics of the site.
b) capability of the equipment.
c) availability of the equipment.
d) cost differences between techniques.
e) site treatment required.[118]

TABLE 29 discusses the relative advantages and disadvantages of the different techniques.

2) Seed Drilling: Seed drilling is the superior technique when site conditions permit. Holes or furrows created by the drill are filled with seeds and subsequently covered with earth in one operation. Drilling can be conduted by either hand or machine utilizing specialized equipment.

The advantages of seed drilling include: the seed is set at the proper depth; it offers the lowest seeding rate; no additional mulch is required; and soil compaction can be accomplished with packer wheels attached to the drill.[119]

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[117] Schiechti, p. 180.

[118] User Guide to Vegetation, p. 39.

[119] Ibid.; and Vegetation for Rehabilitation, p. 11.

TABLE 29

SEEDING METHODS: ADVANTAGES/DISADVANTAGES

Characteristics	Drilling		Broadcasting			
	Machine	Hand	Hydroseeding	Other Machines	Hand	Aerial
Topography	Steep slopes and access are problems; if slopes are greater than 3:1, broadcasting recommended	Less limited	Can handle steep terrain, depending on distance	May be limited by steep terrain	Less limited	Unlimited
Obstructions	Limits use	Unlimited	Unlimited	Somewhat limited	Unlimited	Unlimited
Compacted Soil	Possible	Possible	Not acceptable	Not acceptable	Not acceptable	Not acceptable; soil must be rough enough for wind and rain to cover seeds
Seeding Depth	Variable and controlled	Variable; somewhat less controlled	Lays on top of the soil	No direct control; depends on soil	No direct control	No direct control
Seed Size	Variable if drills can be adjusted	Variable if hand-held machines can be adjusted	Small seed	Variable	Variable	Variable
Season	Limited by moisture	Limited by moisture	Limited by low expected moisture	Less limited	Less limited	Less limited
Precipitation	Slightly critical	Slightly critical	Very critical; more success when annual precip. exceeds 12-14 inches	Very critical	Very critical	Very critical
Soil Texture	Not critical	Not critical	Critical	Critical	Critical	Critical
Seed Distribution	Uniform	Uniform if person is well trained; seeds can be precisely placed	Less uniform	Less uniform	Not uniform but can be specific to one area	Not uniform
Mulching	Separate treatment	Separate	Same treatment possible but not advised	Separate	Separate	Separate
Cost	Medium	Depends on how many people needed	High	Low	Depends on number of crews needed	Low if surface area to be covered is extensive
Equipment	Special in some cases	Some hand-held equipment available	Scarce	Available	Some hand-held equipment available	Various types available; can be contracted out
Seed Rate	Less than broadcasting; drastically disturbed sites such as spoils require much heavier seeding rates than do sites where topsoil and some plant cover are intact. Examples: 10-15 lb/acre drilled on north-facing gentle slopes with small grass seed; 25-30 lb/acre if species seed is large; 40-45 lb/acre if conditions are severe, such as south-facing steep slopes	Same as machine drilling	More; as much as double the drilling rate	More	More	More; 1/3 more than drilling
Trash in Seeds	Must be cleaned from seeds	Must be cleaned from seeds	Cleaning not critical	Cleaning not critical	Cleaning not critical	Cleaning not critical
Time required/acre to seed	Middle range	High range	Low range	Low range	High range	Lowest

Source: User Guide to Vegetation;(U.S.D.A. Forest Service, 1979), General Technical Report INT - 64, pg. 40

Major limitations to this seeding technique include the drill may only be used on slopes of 3:1 or less, and farmer's seed drills may not be durable enough for use on rocky soils.[120]

When seed mixtures are specified, seed drills must be capable of properly distributing different size seed types, otherwise differing seed sizes have to be drilled separately.[121]

3) Broadcasting Seed: Broadcasting of seed is considered to be less favorable as seeds are scattered on the ground's surface where they may or may not be covered with earth in subsequent operations. Again, broadcasting may be done by hand or machine utilizing specialized equipment. This technique includes hydroseeding and aerial seeding which will be discussed separately.

The advantage of this technique are that it is the most economical; the seed and the fertilizer can be distributed together; the slope of the land is not usually critical; and seed mixtures can be distributed in one operation.[122]

Major limitations to this seeding technique are that the seeds are perched on top of the soil where germination and establishment are difficult. Mechanical treatment should be incorporated to prevent rodents and birds from eating the seed. A mulch such as straw fibres is usually required too prevent seed drifting, reduce soil temperatures, and lessen soil moisture losses. A binder such a asphalt emulsions, pastes, or dry-powder concentrates are often incorporated to prevent the straw mulch from drifting.[123]

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120 Personal communication with Lloyd Dick, Brett Young Seeds Ltd., in May 1982.

121 User Guide to Vegetation, pp. 48-49.

122 Personal communication with Lloyd Dick, Brett Young Seeds Ltd., in May 1982.

123 User Guide to Vegetation, p. 38; and Vegetation for Rehabilitation, p. 11.

4) Hydroseeding: Hydroseeding is the most expensive seeding technique. Seeds, fertilizer, and soil amendments (such as a wood fibre mulch) and a soil stabilizer (binder) are held in continuous aggitation and the slurry is applied in a high-pressure stream of water. Up to 112,500 litres of slurry can be sprayed in fifteen minutes. Up to 900 kg. of slurry per .4 ha may be required.[124]

There are several advantages to this seeding technique. Hydroseeding is very fast and efficient and offers complete area converage up to 65 m. The seed, mulch, and binder can be applied directly to steep slopes. The technique also provides erosion and drought control until the new vegetation is established.[125]

Disadvantages of hydroseeding are that it is typically the most expensive method of seeding. If the seed and the slurry are mixed for over thirty minutes germination rates may be reduced. The seed may not come into direct contact with the soil if seed, mulch, and binder are applied in a single operation. Germination rates are much improved if hydroseeding is conducted in a two stage operation. Seed and fertillizer should be sprayed first, followed by an application of mulch and a binder.[126]

In Europe, up to five percent failure of hydroseeding is normal. On heavy soils a second seeding application covering approximately half of the area must be calculated.[127]

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[124] Handbook Equipment, p. 49; Verdyol Mulch of Canada Ltd. Product Catalogues; Schiechti; and User Guide to Vegetation, p. 43.

[125] Ibid.

[126] Ibid.

[127] H. G. Lloyd "Physical and Chemical Methods of Slope Stabilization", 3rd Annual Cover Crop Committee Workshop, 1974 (Guelph, 1974), p. 4.

5) Aerial Seeding: Aerial Seeding may be conducted by either fixed-wing aircraft or helicopter at sites which are too rough to use land-going equipment. The technique is probably not required or practical in the rehabilitation of limestone quarries.

Bare-Root Stock

Bare-root stock is nursery grown stock that has been grown in seed beds for one or two years, dug up when dormant and the soil shaken from their roots. Bare-root planting provides a means of establishing a fast growing cover on a site, and is less expensive than planting container grown nursery stock. Bare-root plants are also easier to ship, store, handle, and plant than container-grown plant material. This technique is however limited in use to specific seasons (early spring and late fall) and the plants are more difficult to cultivate than container-grown nursery stock.

Some recommendations for planting of bare-root plant material are:

1) Bare-root plants should have roots long so deeper soil moisture is available to the transplant. Plants with longer roots are difficult to transplant in rocky soils.
2) Spacing of individual plants ought not to be less than 1-1 1/2 times the diameter of the mature plant.
3) When planting where risk of plant failure is high (i.e. south facing steep slope) research recommends cross-wind furrowing, mulching to conserve moisture, and water maintenance for one of two growing seasons.[128]

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128 User Guide to Vegetation, pp. 24, 44-45.

Containerized Seedlings

Containerized forest seedlings are a relatively recent development in Manitoba:

> Fungicide treated seed, again spruce or pine, is deposited on the surface of small, peat filled paper tubes which are bonded together with a water soluble glue and stretched apart in wooden or plastic trays much like an accordian.... following approximately ten weeks of growth....the seedlings are hardened for another two weeks, then finally outplanted.[129]

On sites over 2 ha, or when more than 5,000 seedlings are to be planted, the use of a machine should be utilized unless the site is too steep or stoney for safe tractor operation.[130] Otherwise hand planting techniques, should be conducted as described in a number of publications.[131]

The basic advantages of using containerized seedlings over bare-root stock are that production of the seedlings is more flexible, the planting season is extended considerably, and the seedlings are not effected by transplant shock. (the container itself is planted.)[132]

Cuttings, Rhizomes, and Sprigs

Cuttings are pieces of stems, (usually from a weedy plant,) that are either rooted and then planted on the site or directly cut from a plant and replanted on the quarry site. Rhizomes are underground stems of grasses, sedges, or forbs which are rooted and replanted on site. Sprigs are pieces of grasses or sedges that can be rooted and transplanted on site.

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129 Pineland Forest Nursery (Manitoba Department of Natural Resources, pamphlet, 1976).

130 Steps to Successful Tree Planting (Ontario Ministry of Natural Resources, pamphlet, 1974); and Vegetation for Rehabilitation, p. 21.

131 Ibid. and Lowe.

132 Pineland Forest Nursery.

The advantages of cuttings is that they are very compatible with direct seeding, they are easily propagated, and usually they provide a ground cover within a short period of time. However, they can only be acquired and planted in the early spring.[133] Sprigs and rhizomes are normally removed from herbaceous plants and rooted in containers or flats. Sprigs are better for some grasses than seeding (for example, Phragmites communis or Common Reed Grass).[134]

Some recommendations for planting of cuttings that have not been rooted are as follows:

1) Cuttings should be planted before they have broken dormancy. Plant when the period of high soil moisture and cool temperatures is expected for at least 30-45 days.
2) Leave a minimum amount of top exposed above the soil--less than 50 mm on a .3m. long cutting.
3) Pack the soil closely around the cuttings so that there are no air spaces.
4) On slopes .75 - 1.2M cuttings should be used and planted as branches with all their side growth still intact.
5) Cuttings placed horizontally provide better root growth.
6) Root cuttings must be rooted in the nursery before their use on a site.[135]

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[133] User Guide to Vegetation, pp. 24-25.

[134] Schiechti, p. 191.

[135] Ibid. pp. 190-191; and User Guide to Vegetation, pp. 45-46.

Container-Grown Planting Stock

Container-grown plant material is simply nursery grown bare-root stock which has been potted in a container and grown for a period of one to two years. This type of plant material should be utilized when immediate protection from erosion or a particular aesthetic effect is required. Container-grown planting stock is also recommended for harsh rocky sites, sites where precipitation is erratic or low, and sites where superior survival rates (over bare-root, cuttings, rhizomes, sprigs) are required. The disadvantages of container-grown stock is that it is cost prohibitive in most situations; it is quite heavy and therefore difficult to handle; and it is substantially more time consuming to plant (requiring high labour costs.)

Some recommendations for planting container-grown plant material are as follows:

1) Container-grown stock can be planted anytime throughout the growing season, but watering maintenance should be conducted throughout the first one or two summers.
2) Dig the hole larger than the size of the container, remove the plant from the container, place it into the hole without disturbing the rootball, and firm the soil around the plant to eliminate the air spaces.
3) Spacing of the plants should not be less that 1 - 1 1/2 times the diameter of the mature plant.[136]

Tree Spade Plugs or Native Wildings

Plugs is the term given nursery-grown, native, or adapted clumps of vegetation which are dug up and replanted on another site. Wildings are individual plants transplanted from the wild to another site. Native plant material from the site or in close proximity to the quarry may be utilized by digging it up with a front-end loader or a tree spade and transplanting it at its new site.

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136 User Guide to Vegetation, p. 44.

Tree-spades such as the Vermeer tree-mover have been developed for replanting small-to-medium-sized trees. The spade works hydraulically and digs, balls, transports, and replants vegetation. When using the tree spade, it is desirable to dig a hole larger than the size of the trees rootball, so that the depression created can catch available moisture. In heavy clays, transplanting of a large tree or shrub into a snug hole creates a situation similar to a plant being placed in a clay pot--its feeder roots will not enter the clay surrounding the root ball. Despite higher costs, the larger the hole the better the chances of vegetation success.[137] A disadvantage of using the tree spade is that it is limited to slopes of fifteen percent or less, because the digging platform must remain level to ensure that the tree is planted with its trunk vertical.[138] Trees with long tap roots, such as Bur Oak, should not be transplanted.

Seedlings dug from surrounding areas should only be utilized in special cases because of the high losses suffered through transplant shock. The percentage of losses is higher with transplanted native material than with revegetation using suitable nursery material.[139]

14.4 Time to Plant

The correct time to plant depends upon many factors including:

a) climate.
b) type of planting stock and soil.
c) moisture requirements of the species.
d) frost heaving problems.
e) anticipated erosion problems.
f) sufficient dryness to allow equipment on the site.
g) time of year quarry activities are concluded.[140]

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137 Vegetation for Rehabilitation, p. 20.

138 User Guide to Vegetation, p. 48.

139 Schiechti, p. 172.

140 User Guide to Vegetation, p. 35.

Generally, however, planting times should coincide with the longest precipitation season, or favorable period of time that may be available for seeding or transplant establishment.[141] See TABLE 30 timing matrix.

The preferred seasons for grass seeding is in early spring (from the time the frost leaves the ground until early June), August, and early September. Legumes can be seeded until the middle of July or after growth has stopped in the fall or winter.[142] Lloyd Dick recommends the following times to plant seeds in Manitoba:[143]

1) The best time is very early in the spring, due to availability of moisture and no hot nights.
2) The second best is at the end of July or early August, due to cooler nights and the crop should be able to catch solidly before winter.
3) The third best is last thing in the fall prior to winter. Hopefully, most of the mixture should germinate in the spring.[144]

In general, evergreen trees as a group are best moved earlier in the fall and later in the spring. Roots cease growing during hot dry summer months, so best success in moving trees is found during August and early September when the soil is warm and root growth continues immediately.[145] However, if evergreens will be exposed to high winds on the transplanted site, then spring is the best planting time.[146]

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141 Ibid, p. 35.

142 Vegetation for Rehabilitation, p. 12.

143 Ibid.

144 Personal communication with Lloyd Dick, Brett Young Seeds Ltd., in May 1982.

145 Pirone, p. 29.

146 Ibid.

TABLE 30

TIME TO PLANT, NORTHERN GREAT PLAINS TIMING MATRIX

	Spring		Summer		Fall[1]		Winter	
Activity	Advantages	Disadvantages	Advantages	Disadvantages	Advantages	Disadvantages	Advantages	Disadvantages
Direct seeding[2]	Most optimum conditions probable between early March and late April. Seedlings must emerge before start of spring rains. Topsoil receives best protection at this time	Access can be a problem		Optimum planting conditions have passed—would require irrigation. Postpone seeding to fall	Provides best access and weather for planting. Stratification important to native and shrub seed. More time available to plant	Topsoil and seedbed protection a problem		Seeding on snow is possible but wind may destroy seedling. Seedbed preparation and access are difficult
Bare root	Essential to plant early between frosts and snowstorms so that roots will develop before buds break dormancy. Plant immediately prior to maximum soil moisture season	Timing is very critical		Storage a problem. Seed dormancy broken. Soil too dry. Plants will burn. Lack of necessary moisture	Plants can be planted when dormant and become better acclimated to site if planted after frost	Some species not adapted to fall planting	Not recommended	
Containerized	Most optimum conditions exist very early in spring between frosts and snowstorms	Disadvantage is that stock is usually not ready or available. Access sometimes a problem	Not recommended		Same as above	Same as above	Not recommended	

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Climate Summary: Considered a continental climate, with warm summers and cold winters. Temperatures can range from -40° F to +105° F. Average precipitation about 12 inches, but can vary from 4 to 18 inches annually in various localities. Precipitation dependent on snowmelt and spring rains that fall between April and mid-June. High wind and high evaporation rates common.

[1] Fall season implies terminal season of the year and that seeds and plants will remain dormant until spring.

[2] Direct seeding involves the use of machinery to place seed in a shallow furrow and cover it with soil. Firming of soil around seeds and placement of fertilizer near to seeds may be accomplished on sites where required. If seeds are broadcast rather than drill seeded, some action to cover them with soil is essential unless it is on freshly graded spoils where natural sloughing will cover the seed.

Source: User Guide to Vegetation; (U.S.D.A. Forest Service 1979), General Technical Report, INT - 64, pg. 36

Planting of deciduous trees and shrubs can be carried out in the spring or fall, although spring is the preferred season. In spring, the plants can be moved from the time the frost leaves the ground until the leaves have begun to unfurl. Planting in the fall after the plants have begun dormancy is more risky, as they have not had a chance to set new roots and are susceptible to frost heaving.[147]

Container-grown trees and shrubs can be planted during the growing season. However, it is not recommended because of the increased maintenance needed to prevent high mortality rates.

14.5 Maintenance of Plant Materials

Trees, shrubs, and many seed mixtures (especially turf grasses), should be maintained for a minimum of one to two years after planting. Most species require this amount of time to establish themselves in the harsh growing conditions of the quarry. The cost of a maintenance program should be justifiable, considering the previous substantial investments in site preparation, plant material, and planting costs.

Maintenance of Tree and Shrub Beds

1) Watering: Recently planted trees and shrubs must be watered throughout the dry summer months or during any other droughty periods.

2) Fertilizing: Most reconstructed soils will display a deficiency in both nitrogen and phosphorus, as well as a biologically inert profile. Trees and shrubs should be examined for symptoms of nutrient deficiencies, and should be dealt with accordingly. See TABLE 31 for fertilizer application guidelines.

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147 Lowe, p. 19.

TABLE 31

FERTILIZER APPLICATION GUIDELINES

Trees and Shrubs

At Time of Planting: U. of M. Department of Horticulture recommends:

1. Starter solution of 2.25 kg of 10 - 52 - 17 per 375 litres of water. Place the tree or shrub in the hole and backfill the hole half-way before pouring in the solution. Apply ½ to 5 litres of water on large shrubs and trees, depending upon their size.

P. Tucker, U. of Guelph, recommends:

2. Starter solution of 1.36 kg of 20 - 20 - 20 per 375 litres of water. Do not apply either fertilizer later than mid-July to avoid late succulent growth which will not harden off before winter.
3. Pellet-type fertilizer (i.e. Osmocote or Mag-Amp.)

Established Trees and Shrubs(U. of Manitoba recommendations)

The ideal time to apply fertilizer to trees and shrubs is in the early spring just before growth starts.

Deciduous Tree and Shrub Beds: In cultivated ground,broadcast and lightly work into the soil under the branches 16 - 20 - 0 or 14 - 14 - 7 at the rate of ½ litre/10 sq. meters. Note: Do not broadcast fertilizer if sod or pasture is around the tree or shrub bed.

Evergreen Trees and Shrubs: require less fertilizer than deciduous species. In cultivated ground, broadcast under the branches 16 - 20 - 0 or 14 - 14 - 7 at the rate of ¼ litre/10 sq. meters. Note: The root systems are very shallow so it is preferable not to work fertilizer into the soil.

Turf Seeded Areas:(U. of Manitoba recommendations)

At Time of Seeding: Just prior to seeding, broadcast 10 - 30 - 10 or 11 - 48 - 0 at a rate of 5 kg./100 sq. meters and work into the upper 4 inches of soil.

Established Lawns: Nitrogen may be applied at least twice during growing season- in early spring and early September.

Suggested rate is 1.5 - 2.5 kg. of nitrogen/100 sq. meters/year. Phosphate may be applied (if required) in spring at a rate of 500 grams/100 sq. meters.

Sources: 1. Faculty of Agriculture, Fertilizer Recommendations for the Home Garden; University of Manitoba, 1975, pg. 3

2. P. Tucker, Grounds Department, University of Guelph. (from an article)

3) Mulching: Mulch can be utilized around tree or shrub beds for the following purposes:
   a) to prevent erosion (wind and water).
   b) to facilitate water infiltration.
   c) to inhibit evaporation.
   d) to moderate soil temperatures. Temperatures may also be raised or lowered by using dark (asphalt) or light (straw) colored mulch.
   e) to improve germination conditions and provide protection for seedlings.
   f) to reinoculate soil micro-organisms.
   g) to suppress weed growth.[148]

Disadvantages with mulching may include nutrient and waste immobilization. Nitrogen may become unavailable to plants because introduced soil micro-organisms are more efficient at utilizing inorganic nitrogen than are plants. Straw and wood waste mulches may cause this. Some mulches may be toxic to plant growth, (for example, asphalt). Mulch may attract insects, fungi, diseases, rodents, and weeds. If the incidence of mice is high, mulch should be removed before winter.[149] TABLE 32 compares the advantages and disadvantages of commonly used mulches.

4) Mowing: If cultivation or spraying is not used, mowing should be conducted two or three times per growing season to reduce ground cover competition around trees and shrubs. Weeds must be kept below 30 cm.[150]

5) Cultivation or Spraying: It is essential that weed and grass growth be controlled around trees and shrubs for at least six months after planting.[151] Cultivation mixes the soil material, controls weeds, reduces soil crusting, improves water infiltration, and promotes soil erosion.[152]

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148 User Guide to Vegetation, p. 53; and Schiechti, pg. 289.

149 Ibid.

150 User Guide to Vegetation, p. 66.

151 Ibid.

152 Ibid.

TABLE 32

ADVANTAGES AND DISADVANTAGES OF COMMONLY USED MULCHES

Type of Mulch	Advantages	Disadvantages	Comments
Crop residues: Straw or hay	Generally most economical Usually satisfactory under many circumstances	Weed seeds usually present: even hay seeds may be considered a weed on a particular site Straw may "wick-out" moisture from soils in very dry conditions, thus resulting in poor germination and seedling establishment	Anchor mulch, especially on slopes by crimping, or using plastic meshes, jute, chemical tackifiers Long-stemmed best, especially for crimping Uniform application important Generally, 2 tons/acre adequate In Utah, it was found that rotovating mulch 6-8 inches into soil increased grass seedling survival Can be spread with modified farm manure spreader
Native grasses: prairie hay	Adds desirable native species seeds to area and mulches at same time	May harvest weeds along with native species	
Wood residues: sawdust, woodchips, bark, shavings	Protects surface Adds organic matter No weed seeds More fire resistant than straw Long lasting Easy to apply Chips resistant to wind movement	Shavings and sawdust blow Nitrogen deficiency Packing may occur resulting in less aeration May float on running water May prevent precipitation from reaching spoil	Chips: 2 tons/acre usually adequate; chip size, 1/2 inch to 1/50 inch
Plastic film	Excellent vapor barrier Good weed control Light-colored, perforated, found effective in New Mexico: soil temperature in summer 18° F lower than in soil with no mulch	Labor intensive High cost	Information on temperature effect varies Color is important because of reflection, absorption
Fiber tackifiers and soil binders	SBR Styrenebutadiene and SS Super Slurper have been found to be very absorbent and thus help provide water	Quite expensive Must be applied correctly in order to have maximum effectiveness With SBR Styrenebutadiene and SS Super Slurper premature germination may occur In high wind areas, it can solidify, break into pieces and blow away	Typically added into water carriers; can also be added with seed slurries 500-1,000 lb. of solids/acre usually sufficient, dilution rates of 5:1-7:1 optimum
Rocks, gravel, pebbles	Effective at specific sites Are permanent—do not disintegrate	Smaller than 1/12 inch in diameter not good for wind erosion	Choose sizes greater than 1/12 inch in diameter Must nearly cover entire ground surface—1-2 inch thick is effective control (135 tons/acre = about 1 inch depth)
Mixtures	Add micro-organisms to soil over short and long term (Ex.: straw and bark)		
Hydraulic mulching	Labor costs low Typical green color allows operator to get uniform distribution Hydromulching and hydroseeding can be done at the same time, if it is impossible to do the two operations separately Wood cellulose fiber mixed with seed and fertilizer can be sprayed on steep slopes	Of little value unless it adheres to the soil surface and remains intact during rainstorms, wind Hydromulch with fiber improves germination, but does not improve production When hydromulch and hydroseeding are done together, seeds may not have adequate soil contact	Application rate of 1,500 lb/acre appears adequate for most situations; may need more for quite steep slopes May need to add N to hydromulch to compensate for C:N ratio of mulch chosen Always put some seed in mulch Hydroseeding and hydromulching together should be reserved for special cases when moisture is sufficient to keep the seed moist for 2-3 weeks after seeding
Fabric or mats: jute, excelsior, woven, paper, plastics, nets	Especially useful on steep slopes Nets good in high wind areas	Expensive: 4-5 times more than tacked straw High labor input for anchoring Not effective on rough surfaces or rocky areas Erosion from beneath may be a problem	Used only on limited critical areas because of cost
Manure and sewage sludge	Can protect soil surface and adds nutrients, such as N, P, K, S	When used alone, it becomes wet, then dry, can lose much of N through volatilization of ammonia	Needs 5, 10, 15 tons/acre in order to protect soil On bentonite spoils, a grass establishment study showed that an application of wood chips as mulch and sewage sludge as N supplier was more effective than a high application (400 parts per million) of inorganic N
Asphalt	Rapid-curing asphalt keeps straw and other materials in place Slow-curing asphalt allows for growth of seedlings before it cures Coats surface, remains intact 4-10 weeks A stabilizer for straw Nonporous, and conserves water underneath it Some plants react positively to it	Nonporous, thus causes surface water to run off Some plants react negatively to it	Make decision based on type of asphalt (slow, medium, rapid curing) desired Make decision based on reaction to asphalt by plant species desired 1,200 gal/acre an average application Typically, heated and spread by spraying Apply from top of slope down, so impermeable caps are built on clods of soil down the slope, leaving sides free for seedlings to come out of and to absorb water

Source: User Guide to Vegetation (U.S.D.A. Forest Service, 1979), General Technical Report INT - 64, pp. 58-59.

Spray maintenance provides weed control and thus, reduced competition for the new plants. Typical sprays include herbicides (i.e. Paraquat), defoliants, and desiccants (accelerate drying out of plant tissues).

6) Checking Stakes and Tree Guards: Staking of tall trees is recommended for a minimum of two years due to the risk of toppling. After the tree has been sufficiently anchored, removal of the tree ties is essential to prevent girdling of the trunk.

7) Replacing Dead Plant Materials: Depending upon the land use objectives of the site and the relative need for specific plants, replacement of dead plant material is recommended for a minimum of one growing season. If nursery guarantees are still valid, they should be utilized to replace dead plant stock.

Maintenance of Turf Seeds Areas

A healthy turf growth is the first line of defense against such problems as weeds and erosion.

1) Watering: Initial watering may be required to ensure seed germination. After turf establishment, watering should only be required during drought conditions.

2) Levelling: If the ground is to be walked upon, ruts and gullies should be filled in and reseeded.

3) Mowing: Initially as the grass reaches 7.5 cm., it should be mown to a height of 5 cm.[153] This practice helps to inhibit weed development and aids in the establishment of a vigorous turf root system. Once established, the grass should be mown

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[153] Schellie, p. 162.

to the optimal heights of the specific species. For example, the optimal height for Kentucky Bluegrass is 2.5 cm. while that for the Fescues if 5 cm.

4) Fertilizing: Annual fertilizing of grassed areas is recommended at a rate to be determined through the results of a soil analysis. Lloyd Dick recommends a commercial 11-48-0 fertilizer for quarry applications. The phosphorus will promote a vigorous root growth, while the nitrogen will keep the grass green and yet not provide for rapid blade growth.[154]

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[154] Personal communication with Lloyd Dick, Brett Young Seeds Ltd., in May 1982.

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