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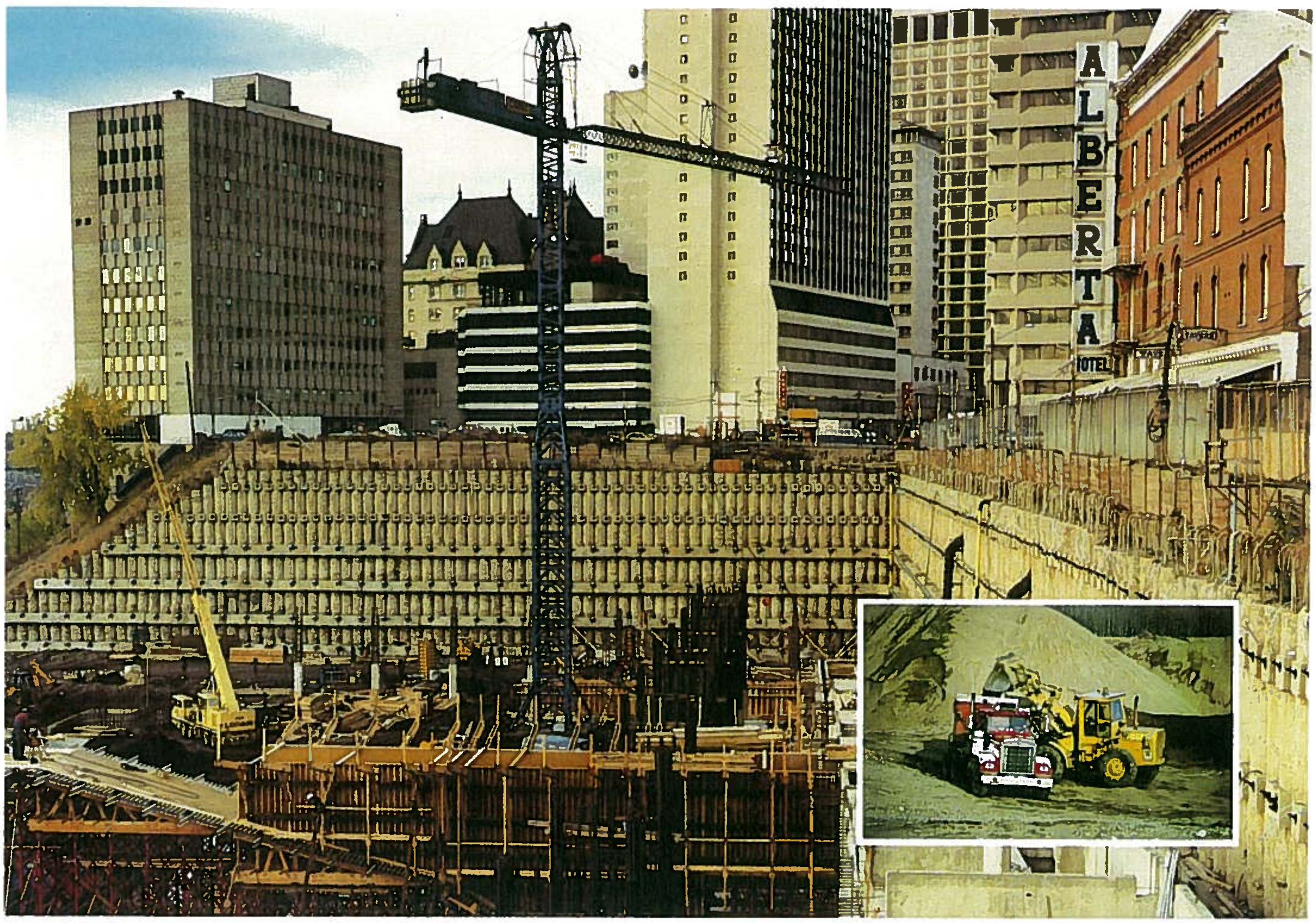
Aggregate resources
of the Edmonton / Lloydminster region

W.A.D. Edwards, R.B. Hudson,
D.W. Scafe



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W.A.D. Edwards, R.B. Hudson*,
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Cover:
Sand and gravel mined in the area surrounding Edmonton (inset photograph) forms an essential resource in the growth and development of the city. One example is Edmonton's Convention Centre which required more than 50,000 yards of concrete.

*MINERAL RESOURCES DIVISION
ALBERTA ENERGY AND NATURAL RESOURCES

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Abstract

In 1983 Alberta produced about 42 million tonnes of aggregate worth an estimated $116 million. Most of the aggregate produced in the province is sand and gravel, although burned clay (40 000 m³, 1983) and recycled aggregate (over 114 000 tonnes, 1983) are also produced and other materials are potentially useful.

This report describes and evaluates the aggregate resources in the Edmonton-Cold Lake-Lloydminster region, which produces about 40 percent of the province's aggregate. The commercial sector produces 75 percent of the aggregate, most of it being directed into road construction (52 percent), concrete production (18 percent) or asphalt production (11 percent). A compilation of geological data indicates that 1100 million m³ of gravel and 3900 million m³ of sand occur in the region. Although this reserve seems ample, consumption estimates established in this study predict that over 300 million m³ of gravel will be consumed by 2010. This 25 percent depletion estimate does not take into consideration loss of the resource to alternative land uses.

Each urban municipality and county in the region requires its own aggregate supply and has its own unique geological and economic conditions. An estimate of the quantity of resource and its projected use is given for each county and major market area in the region. The Edmonton metropolitan area is the largest market: firms based in the city account for 57 percent of regional aggregate production. By 2010 over half of the most useful gravel supplies in the current area of supply may be consumed. In the Cold Lake area, coarse aggregate is not plentiful: any new projects requiring aggregate could rapidly deplete existing supplies. Although predictions need refinement by means of additional scientific and economic input, they nonetheless confirm that aggregate resources are dwindling rapidly.

Present aggregate supplies should be extended through careful, co-ordinated management practices. County or municipal agencies and departments affecting aggregate use should make use of existing data in their resource management and planning. Current data on aggregate should be contained in an automated geological database that can be updated. A technical working group composed of the Alberta Research Council, Departments of Energy and Natural Resources, Transportation, Municipal Affairs, and Environment and the Sand and Gravel Association should be established to monitor aggregate resources and recommend action.

Preface

The authors of this report have been engaged in the inventory and management of aggregate resources in Alberta since 1976. During that time, the Alberta Research Council has been providing Alberta Energy and Natural Resources with geological maps and reports pertaining to aggregate. A close working relationship has developed between the two agencies, with the result that this aggregate information has been effectively used for land management of crown lands.

The evaluation and management of aggregate requires an integrated approach that includes both patented and crown lands and involves co-operation and information exchange among various departments, municipalities and sectors; therefore, the authors distributed aggregate inventory information to various agencies for use in their land management and planning. Since many groups do not have the manpower or technical expertise to compile, decipher and evaluate numerous geological data, we saw the need to provide a more comprehensive assessment of aggregate resources, including not only the resource inventory, but also production rates, projected demands and supply-demand relationships.

This report is the first attempt at providing this more comprehensive assessment of provincial aggregate resources, specifically for the Edmonton-Cold Lake-Lloydminster region. We realize that aggregate resources are only part of the large, complex land management situation, and that our discussion omits many aspects of the management picture (such as progressive rehabilitation, reclamation, public-industry-government interaction and the evaluation and establishment of priorities for alternative land uses). We feel, however, that the information generated by the aggregate inventory is an important and integral part of the natural resource base of Alberta. This report attempts to provide that information in a cogent and practical manner to those controlling the aggregate resource.

Introduction

In 1976 Alberta Energy and Natural Resources and the Alberta Research Council undertook an inventory of sand and gravel resources in the province. Designed to fill the information voids in the existing provincial natural resource database, the inventory attempted two things: first, the collection of aggregate data on public lands throughout the province (where Energy and Natural Resources had a strong interest) and, second, the collection of aggregate information around the major urban centers in the province (the largest consumers of sand and gravel). This information was published as geological maps or reports, showing the extent and some of the characteristics of the individual deposits.

The aggregate inventory was originally meant to provide information for a variety of users, including sand and gravel developers, land owners and municipal and provincial land-use planners. After several aggregate inventory maps and reports were produced, it became evident that the technical data were not suitable for all anticipated users. The information was useful for gravel developers and land owners because it gave geologic information on specific deposits (plate 1). For planners, however, these reports only provided technical information on various distinct sand and gravel deposits, not an

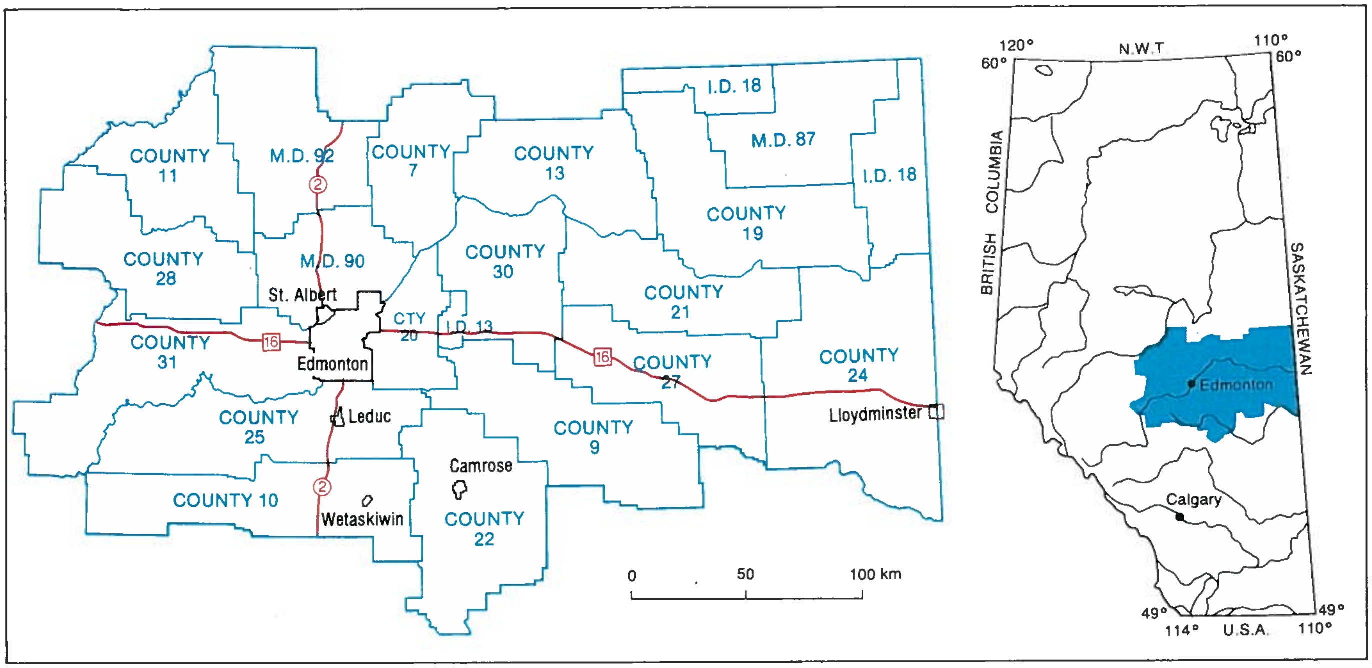


Figure 1. Study region

overall picture of the state of resource.

The object of this study, therefore, is a regional assessment of the importance of the aggregate deposits and their role in the future. We selected the study region (figure 1) because it is a major consuming area in Alberta, because complete aggregate inventory information was available and because one of the principal urban users of aggregate, Edmonton, is located almost in the center of the area. The study area boundary follows municipal boundaries as much as possible, so that municipal governments can derive an assessment of the aggregate resources within their jurisdiction.

This report is also designed to provide a single source for the existing technical information for the region. The regional production data collected by survey are included with the inventory information on each deposit. Some new research on expanded aggregate, done specifically for this study, is also included. The report thus gives a relatively complete picture of the aggregate resource situation in the region; coupled with the 1:50 000 aggregate resource maps (available from the Alberta Research Council or Alberta Energy and Natural Resources), the report is suitable for comprehensive planning and decision making.

Plate 1. Loader feeding a surge bin with sand and gravel from pit on the North Saskatchewan River west of Edmonton

Aggregate resources

Introduction

Aggregate is the term used for inert, hard construction materials, such as sand, gravel, crushed stone or slag, which can be mixed with a cementing material to form concrete and asphalt or are used alone in road building, railroad ballast or other construction or manufacturing activities.

In Alberta only sand and gravel, which constitute most of the provincial production, are of widespread commercial importance. Other natural materials in the region with potential as aggregate include bedrock, glaciolacustrine silts and clays, and till. Besides the natural materials, manufactured and recycled products (including recycled asphaltic and portland cement concrete, ash, glass, rubber, soil, solid waste and sulfur) are used, or have the potential to be used, as aggregate.

Sand and gravel

A total of 585 sand and gravel deposits have been iden-

Table 1. Sand and gravel production in Alberta (1981-1983)

Year	Tonnes (000s)	$(000s)
1981	48 860	97 323
1982	46 092	129 664
1983	42 500	116 000

Source: Statistics Canada, 1981. Mass figures adjusted from Alberta Research Council survey data.

tified within the study region (figures 2 and 3 in pocket, and appendix H). The total estimated sand and gravel (figures based on 462 deposits for which resource estimates have been made, see appendix F) is 1 157 991 000 m³ of gravel and 3 966 989 000 m³ of sand. The potential for the development of a sand or gravel pit depends on the physical characteristics of the deposit, the economic conditions and the zoning or development requirements. This section of our report describes the quantity, gradation and quality of sand and gravel (see appendix C), the amount of overburden and the location of the deposit.

In this study, granular aggregate is classified into four major categories based on the percentage of gravel in the deposit. *Gravel* is material which contains 75 percent or more gravel-sized clasts, *sandy gravel* contains 50 to 75 percent gravel, *gravelly sand* contains 25 to 50 percent gravel and *sand* contains less than 25 percent gravel (figure 4). Many deposits are developed primarily for the gravel-sized components — an essential size in the production of concrete (see appendix D) and a fraction that accounts for only 22 percent of the total granular aggregate estimated to be present in the study area (plate 2). As a source of gravel, the deposits listed as gravel, sandy gravel and, occasionally, gravelly sand are important. These deposits (226) represent 49 percent of deposits in the study region.

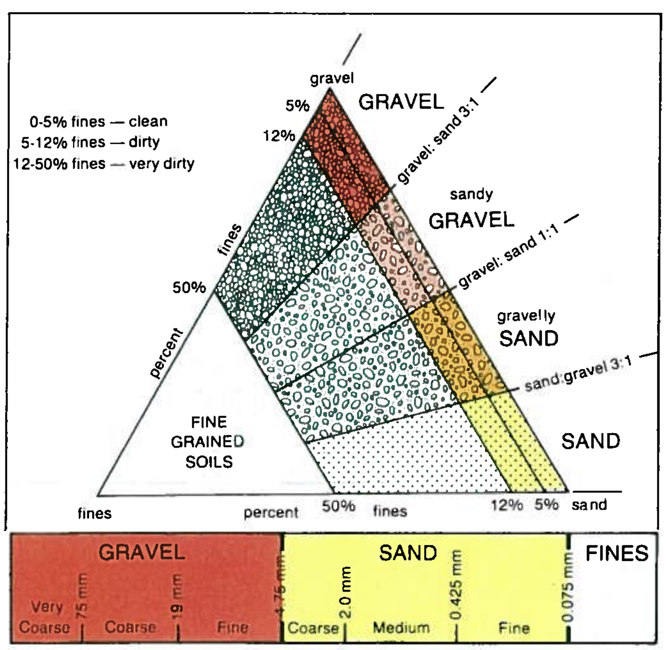


Figure 4. Grain size and sediment classification used in this report

Plate 2. Note variety of sizes and shapes of gravel in this glaciofluvial deposit, which has a high percentage (greater than 75 percent) of gravel.

For many uses (such as gravelling county roads), a deposit need not be large to be useful as a source of aggregate. To provide a continuing supply of aggregate to a large market such as Edmonton, however, large gravel deposits are required. Of the 226 deposits identified as possible sources of gravel in the study region, only 74 have over 1 million m³ of gravel.

Another factor which determines the value of a deposit is its physical location. Figure 5 shows the locations of deposits with 50 percent or more gravel and resources in excess of 1 million m³ of gravel (deposits containing known, significant "pockets" of gravel in an otherwise sandy deposit are also shown).

The quality of a deposit will, to some extent, determine the end uses to which the material can be applied. In many cases, however, material can be beneficiated to produce suitable products. In general, the gravel deposits referred to as "preglacial" have a higher quality than those of glaciofluvial or alluvial origin (plate 3, appendix A).

Overburden adds cost to the extraction and thus to the final price of the gravel or concrete. As pressure to find gravel increases, however, the thickness of overburden which can economically be stripped increases. Thus, in the Edmonton area some of the deposits producing large volumes of gravel have overburden in excess of 3 m thick. Appendix H indicates the average overburden thickness for each gravel deposit.

The tremendous volumes of sand and gravel in the study region do not give a true indication of the amount of economically available aggregate in any given area. In the Cold Lake area, for example, approximately 140 million m³ of sand and gravel are reported. Of this, 116 million m³ are sand, while only 24 million m³ are gravel. Even this number can be deceptive, however, in that only 6 million m³ of gravel occurs in deposits where the concentration of gravel is over 50 percent. In essence then, of the total granular material in the Cold Lake area, only about 5 percent is in deposits preferred for development. Table 2 lists the sand and gravel resources by county. Appendix H gives other information on individual deposits.

Plate 3. Note clay balls in gravel. They are one of several deleterious materials found in Edmonton area gravels.

Manufactured aggregate

In 1983 Consolidated Concrete Ltd. manufactured an estimated 40 000 m³ of synthetic aggregate in the study region, produced by the burning of clay materials. Probable provincial capacity for the production of synthetic aggregate is in the order of 200 000 m³ per year.

Common clay materials are an attractive source of aggregate. Since clay is available in most geographic regions, manufacturing plants may be built very close to the market in areas deficient in sand and gravel. Some of the characteristics of manufactured aggregate are also advantageous. When burned, many clay materials attain relative densities considerably lighter than natural aggregate. This lightness reduces both fuel costs for transport and the amount of reinforcing steel required in structures. Disadvantages of burned clays include the high cost of heating fuel, a lower crushing strength than that of many natural aggregates, and components in the raw feed such as grains of limestone, which produce deleterious effects in the fired product. At present about 90 percent of the synthetic aggregate manufactured in the region is used in concrete masonry block, 5 percent in structural concrete and 5 percent in specialty uses such as horticulture. In 1983 a cubic metre of manufactured aggregate cost $36-$40; about 30 percent of this price was related to energy costs.

Information on silt, clay, shale and till, potentially useful as synthetic aggregate was derived from a study by the Alberta Research Council. Appendix B gives technical information on the characteristics of the formations sampled and the testing procedure. Care should be taken in using the information provided by this study because its purpose was to establish the general potential of certain formations. The geological study did not attempt to assess the continuity, thickness or depth of burial of units sampled, nor to establish the potential reserves of clay in any given formation.

Bedrock

All of the bedrock formations in the study region were sampled and analyzed for basic properties useful in assessing the potential of the material as manufactured

Table 2. Sand and gravel resources in the region

Municipality	Total gravel (000s m³)	Total sand (000s m³)	Percent of total gravel in gravel and sandy gravel deposits
Edmonton	9 081	19 320	12
County 7	5 536	169 548	1
County 9	8 594	39 056	83
County 10	25 881	1 048 358	73
County 11	196 853	105 440	99
County 13	43 233	529 547	6
County 19	15 692	90 928	12
County 20	45 377	154 731	67
County 21	28 257	183 250	61
County 22	60 276	39 222	99
County 24	37 869	57 136	46
County 25	57 549	57 395	99
County 27	5145	40 393	61
County 28	52 331	47 722	91
County 30	21 042	84 950	7
County 31	343 551	395 926	88
M.D. 87	2382	3795	73
M.D. 90	165 503	659 394	97
M.D. 92	28 349	219 497	0
I.D. 18	5490	21 381	39
I.D. 13			
Grand total	1 157 991	3 966 989	80

M.D. - Municipal District
I.D. - Improvement District

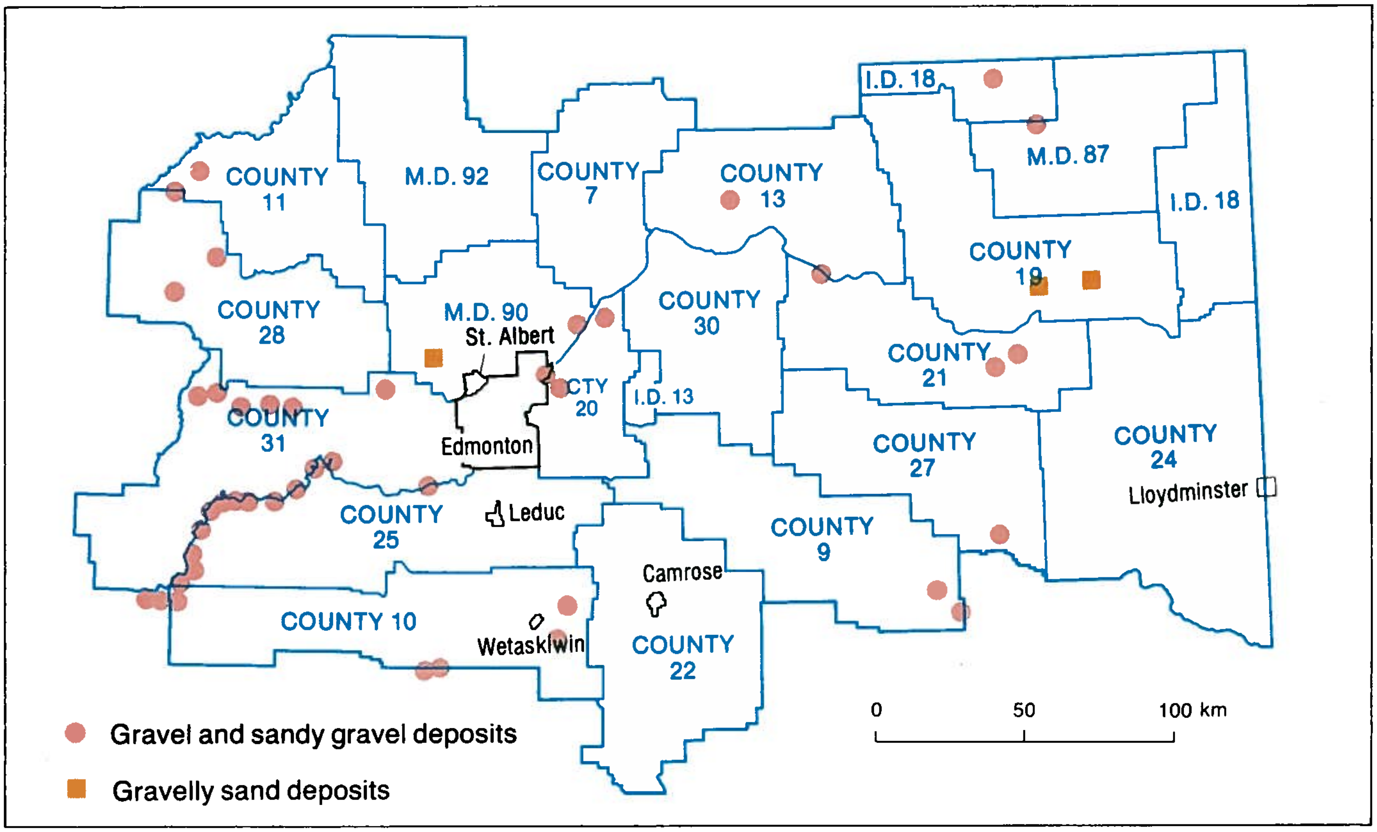


Figure 5. Location of deposits with more than 1 million m³ of gravel. Dots indicate gravel or sandy gravel deposits with more than 1 million m³ of gravel and gravelly sand deposits with gravel pockets of more than 1 million m³.

aggregate (see appendixes A and B). Material from the Paskapoo Formation may have promise as a source for burned synthetic aggregate. Low to absent carbonate is a positive property. Relative density is variable but commonly < 1, coating is common and steel hardness may be attained at low firing temperatures. The deep cracking may be controlled by mixing material from shale beds or by adding some of the sand that is abundant in the formation. The Scollard Formation has considerable potential since the formation is in an area where coal is currently being mined: concurrent mining of the raw material and use of the coal as a heat source could enable production of burned synthetic aggregate. Deep cracking of pellets and chunks during firing, which yields a fragile product, is a serious, deleterious characteristic of the Horseshoe Canyon Formation. Some of the more silty materials, however, seem to be less fragile and siltstones or more silty pellets may have some use. The Judith River Formation may be useful for production of burned synthetic aggregate in areas where natural aggregate is scarce. The Wapiti Formation could easily produce lightweight aggregate from its mudstones and shales; however, fragile pellets and chunks may not survive passage through a rotary kiln. Failure to reach steel hardness would preclude the use of this aggregate where abrasion is high.

Clay and silt

One of the two plants in Alberta that currently burns clay materials for aggregate is located in the Edmonton area, close to the silts and clays of former glacial Lake Edmonton. These fine materials are used as the feed for the rotary kiln at the plant. Glaciolacustrine clays and silts are relatively common in the region and occur at the surface: only the soil needs to be stripped for access to the deposit. Even the soil can be mixed with the material below because burning of organic matter in the soil helps to produce a more lightweight product.

Till

Till, (glacially deposited, nonstratified sediment containing clay and varying amounts of rock) is almost ubiquitous in Alberta. The very widespread geographic distribution, thickness, easy access and high clay content of till make it a candidate for consideration as a raw material for burned synthetic aggregate. The undesirable properties of till are numerous, however. Rocks of various size and angularity would have to be removed before the final material could be pelletized. Rocks could also endanger the refractory lining of a rotary kiln. In addition, sampling of tills in the region indicated that only 2 of the 70 samples were free of carbonate masses that could cause disintegration of the aggregate product.

It is unfortunate that such a widespread potential rock material for burned synthetic aggregate has so many undesirable fired properties. The two samples collected that contain no carbonate are from above the Paskapoo Formation. Given present technology, only this till, with the deleterious pebbles and boulders removed, can be recommended as a raw material for burned synthetic aggregate.

Crushed stone

In many areas of North America, crushed stone is the primary source of aggregate. Crushed stone has never played a significant role in Alberta, largely because there is an abundance of sand and gravel and the high demand areas are not near sources of stone. In any assessment of the aggregare resources of Alberta, stone must be considered, however, because of the almost unlimited potential of the mountains as a source of material.

The major problems with using crushed stone as aggregate are transportation costs and environmental concerns. For almost all of the province there are no accessible sources of suitable stone other than in the mountains and foothills. Yet these areas have many other important land uses, including use as parks, recreational areas and wildlife habitats. Quarries would thus have to conform to the overall management plans for the eastern slopes of the Rockies. This situation would limit the number of areas that could produce stone but there still would be a very large potential supply.

Transportation costs are a major factor with any aggregate source; they would be even greater with crushed stone. For the study region, the nearest source of quarry material is west of Hinton, about 300 km from Edmonton. This distance could necessitate transportation by rail rather than truck. Genstar Cement transports limestone from its quarry at Cadomin, southwest of Edson, to its cement plant in Edmonton by rail, at a cost of about $15/tonne; in comparison, the delivery cost for local aggregate currently being hauled into Edmonton by truck is $2 to $5/tonne.

While crushed stone has tremendous potential, it will not be competitive with sand and gravel in the near future. It may, however, prove to be extremely important in the twenty-first century and beyond.

Alternate sources of aggregate

In addition to the materials already discussed, there are numerous materials that can be used as substitutes or supplements for natural aggregate, thereby prolonging the useful life of the natural supplies. Very little use is currently being made of these materials, but they have considerable potential in the study region.

Ash

Ash is produced as a byproduct of burning coal at thermal power generating plants. Two basic physical forms of ash are produced: bottom ash, which falls to the bottom of the furnace; and fly ash, which is mechanically or electrostatically removed from the flue gases in the stack.

Bottom ash (sometimes termed boiler slag) is a coarse-grained material composed of irregularly shaped and often angular particles, ranging from porous to glassy. These materials are used extensively in some areas as granular fill and have been found satisfactory as road subbase and filter material. Bottom ash has also been used as aggregate in concrete.

Fly ash is a fine-grained material, with the majority of particles spherical in shape. Fly ash is generally in the same physical category as sandy silt. The major use for fly ash as an aggregate alternative is as construction fill. When combined with lime, fly ash has been used to stabilize soils for highway construction and in base courses in roads. Fly ash has also been used as a filler in asphaltic concretes.

There are four potential sources of ash in the study region: the Sundance, Wabamun and Keephills generating stations of TransAlta Utilities, and the Genesee generating station of Edmonton Power. Although some of this material is already being marketed commercially by Western Canada Fly Ash, large amounts of material will continue to be available.

Recycled concrete and asphalt

The recycling of concrete and asphalt from demolitions and road improvements is a viable source of aggregate in an urban situation. In the study region, only the Edmonton metropolitan area has sufficient quantities of these materials to warrant consideration of recycling.

The City of Edmonton, which has an active program of recycling concrete rubble and asphalt, has established three collection and crushing sites. All the materials are crushed to useful aggregate sizes and then re-used. The program has produced an increasing amount of material each year (table 3, pers. comm. A. Cepas, 1984, City of Edmonton), at a saving of some 20 percent of cost over conventional aggregates. The city views the program as having several benefits, including "...preservation of our mineral aggregates, a saving on excess hauling to disposal sites and conservation of sanitary landfill space."

Glass

Glass commonly is included in lists of recyclable materials suitable for use as aggregates. The material meets most requirements of a high quality aggregate suitable for use in asphaltic and portland cement concretes.

In the study region, the recycling firm Contain-A-Way Ltd. collects approximately 6.8 million kg of glass, which is crushed and sent to Canasphere Industries Alberta Ltd. in Calgary and Domglas Inc. in Redcliff for processing. Canasphere processes clear glass into reflective glass beads used for center-line striping on highways, while Domglas recycles the colored glass into bottles and containers.

Since all the glass collected for recycling is currently being used at a higher rate of return than glass used as aggregate, it is unlikely the material will ever be an alternative for aggregate in the study region or the province.

Table 3. Amounts of recycled concrete and asphalt used by the City of Edmonton (1980-1983)

Recycled aggregate (tonnes)			
1980	47 300	1982	68 900
1981	44 300	1983	114 000

Sulfur
Sulfur is included here, not because it is an aggregate replacement, but because it can be used as an extender in asphaltic concrete. Over the last decade, sulfur has been the object of much testing in asphalt mixes across North America. These tests have shown that sulfur-asphalt mixes can extend aggregate resources, although this is not the primary purpose of including sulfur in the mix.

A report prepared for the Roads and Transportation Association of Canada (Pavement Management Systems Limited, 1983) states that use of sulfur can reduce pavement thickness and, thus, the aggregate requirements for the pavement. When sulfur binders are used, another benefit is the improvement of low quality aggregates with respect to engineering specifications. This improvement is an important consideration where high quality aggregates are in short supply.

Aggregate production and uses

Aggregate is produced in every county and municipal district in the study region and even within the boundaries of the City of Edmonton (table 4). Throughout this region there are hundreds of sand and gravel pits, ranging in size from small pits receiving only occasional local use, to large commercial operations which produce hundreds of thousands of cubic metres of material per year. In 1981 these pits produced some 12 million m^3 of aggregate.

Edmonton dominates the sand and gravel market in the study area: approximately 50 percent of the total production goes into the city. This material comes from three major production areas: the Saskatchewan gravel deposits (see appendix A) west of Edmonton at Villeneuve (plate 4), the Tertiary deposits at Heatherdown and the river deposits at Clover Bar on the eastern edge of the city. Aggregate is also supplied to the city from many pits, some as far as 100 km away. The prominent role of Edmonton is apparent when we examine the aggregate production from the adjacent municipal jurisdictions (see table 4). The County of Strathcona 20 (Clover Bar deposits), the County of Lac Ste. Anne 28 (Heatherdown deposit) and the Municipal District of Sturgeon 90 (Villeneuve deposit) account for well over half of the aggregate produced in the study region, most of it destined for use in Edmonton.

Aggregate is produced by two distinct sectors: commercial and public (table 5). In the *commercial* sector, individuals or companies produce material for sale to other parties. In the *public* sector a level of government produces material for public works. Commercial operations produce about 75 percent of the aggregate in the study region. A large volume of this material is sold to the public sector. This production relationship is interesting because, while the public sector produces less than 25 percent of the aggregate in the study region, approximately 64 percent of the aggregate production is used in road construction and asphalt production, which would largely be public works consumption (see table 6).

Table 4. Aggregate production by municipal jurisdiction (1981)

Jurisdiction	m^3
Counties:	
Thorhild 7	232 000
Beaver 9	146 000
Wetaskiwin 10	184 000
Barrhead 11	137 000
Smoky Lake 13	254 000
St. Paul 19	96 000
Strathcona 20	2 112 000
Two Hills 21	91 000
Camrose 22	527 000
Vermilion River 24	440 000
Leduc 25	454 000
Minburn 27	124 000
Lac Ste. Anne 28	1 157 000
Lamont 30	216 000
Parkland 31	933 000
Municipal Districts:	
Bonnyville 87	258 000
Sturgeon 90	3 811 000
Westlock 92	218 000
Improvement Districts:	
Improvement District 18	21 000
Cities:	
City of Edmonton	572 000
Total	11 983 000

Plate 4. Gravel pits in Villeneuve area. Note mix of agricultural and extractive land use.

Table 5. Aggregate production by sector (1981)

Sectors	m^3	Percent
Public:		
Alberta Transportation	1 028 000	8.58
Counties, municipal districts	1 446 000	12.07
Cities, towns	420 000	3.50
Subtotal	2 894 000	24.15
Commercial:		
Firms based in Edmonton	6 902 000	57.60
Remainder of study region	2 187 000	18.25
Subtotal	9 089 000	75.85
Total study region	11 983 000	100.00

Table 6. Aggregate production by end use (1981)

	m^3	Percent
Road construction	6 303 000	52.60
Concrete production	2 213 000	18.47
Asphalt production	1 383 000	11.54
General construction including fill, drainage, unclassified general sales	1 185 000	9.89
Sand	844 000	7.05
Railroad ballast	55 000	0.46
Total	11 983 000	100.00

Although commercial production of aggregate is dominated by firms based in Edmonton, there is significant commercial production around all of the large urban municipalities in the study region. Around each of these towns and cities there is at least one major producer; but more commonly various companies compete for a share of the market. In Edmonton this competition is extensive: six companies produced more than 500 000 m^3 each in 1981, vying in a total market of some 7 million m^3.

Commercial aggregate operations range from the small producer of a few thousand m^3 to the large, integrated operation producing over 1 million m^3 annually. The larger operations tend to produce a greater variety of aggregate products through screening, crushing and washing. This enables them to sell

Plate 5. Conveyor belt feeding gravel into processing plant on North Saskatchewan River west of Edmonton

specific sizes and qualities of aggregate and to blend materials for contract specifications. Commercial operations, therefore, tend to have stockpiles of various aggregate products and sophisticated materials handling systems (plate 5).

Alberta Transportation, counties and municipal districts operate public works gravel pits to provide aggregate for road construction or maintenance purposes. Since transportation is the greatest factor in the cost of most aggregate, the ideal situation for these agencies is to have a gravel pit every 30 to 50 km, so that haul distances are never very great. Counties and municipal districts, therefore, attempt to have several gravel pits spread throughout their jurisdiction. Because of the nature of road construction and maintenance, however, these pits may be used only a few times a year or aggregate may be stockpiled in more convenient locations. With Alberta Transportation, it is even possible that a pit may not be used for several years if it is adjacent to a primary paved highway which needs no construction or repairs.

Sand is also produced for public works purposes. One of its major uses is for winter sanding of icy roads and sidewalks. The City of Edmonton and Alberta Transportation use large amounts of sand each winter. Edmonton obtains its street sanding supply through tenders, but operates its own sand pit at Rabbit Hill in the southwest corner of the city to supply approximately 250 000 m^3 of bedding sand for sewer and water installations each year.

Aggregate availability: planning and regulation

Although vast quantities of aggregate have been identified in the study region, the development of these resources can be affected by factors other than economics or the geology of the deposit. The land on which the deposit occurs may be committed to another land use or that land may be zoned so that aggregate extraction is not permitted. The many levels of government have regulations and by-laws which must be met before development can proceed. In addition to these limiting factors, the resource may be lost through sterilization of the deposit. Each of these factors must be considered when examining the aggregate supply situation of an area.

Land-use planning

In Alberta many governments have the responsibility for planning the use and development of land. Each level of government has planning agencies or departments with specific responsibilities in the establishment of land-use plans. Aggregate availability commonly is affected by land-use planning, since lands may be zoned or otherwise designated to preclude aggregate extraction. This is perfectly valid, if the planning agency had aggregate inventory information in hand during the planning process and considered the relative merits of extracting aggregate to other land uses. In the past, however, aggregate information was often not available, so some planning decisions were made without considering the resource or the effects of planning decisions on its future use.

In the provincial planning hierarchy there are three major levels that affect land use and resource development. The most broad-based of these is the provincial plan or policy, usually relating to a specific issue; an example is the Coal Development Policy, a provincial policy directed at a specific resource. There is no similar policy for aggregate because the resource has a much more localized importance than coal and there is no government department that has a comprehensive mandate over the resource and can advocate policy.

The first level of planning that has broad land-use impact is regional planning. The regional plan is a broad policy document that dictates overall land-use patterns in a large area. It is usually drafted by a regional planning commission, a body composed of representatives from each municipality included in the regional planning area. There may also be regional plans drafted by Energy and Natural Resources for the large blocks of Crown land under its control. In either case, the regional plan guides overall development patterns of the area it covers. It is, therefore, important to incorporate aggregate information into this level since subsequent planning often only refines the land-use patterns set in the regional plan.

Municipalities prepare general municipal plans conforming to the regional plans. Municipal plans are more detailed than regional plans and often form the basis of land-use by-laws directed specifically at aggregate deposits and operations. It is extremely important, therefore, for municipal planners and administrators to be aware of the aggregate resources within their jurisdiction and the role those resources play in the regional context.

Because aggregate is such an important commodity in our society, it should be fully considered in the formulation of any land-use plans. Several regional and municipal plans had already been developed before detailed aggregate information became available for all the study region. It may, therefore, be appropriate for those land-use plans to be re-examined and revised, as necessary, to incorporate aggregate data.

Reclamation and development legislation

For the most part, legislation in Alberta regarding the development and reclamation of aggregate resource sites has been directed at sand and gravel pits. The Sand, Gravel, Clay and Marl Surface Operations Regulations (Land Surface Conservation and Reclamation Act) apply to the privately owned lands in the province. These regulations stipulate that any development of a sand, gravel, clay or marl deposit that will disturb five or more acres must be approved by the Department of the Environment before operations begin. The regulations ensure that the pit or quarry development is well planned and includes reclamation (plate 6.)

The Surface Materials Regulations (Public Lands Act) apply to public lands in the province. These regulations serve much the same purpose as the Sand, Gravel, Clay and Marl Surface Operations Regulations on private lands; in addition, they provide for a resource lease arrangement between any prospective aggregate developer and the Crown. Since the Crown owns the aggregate on public lands, the Public Lands Act regulations concern not only reclamation, but also resource management.

The aggregate developer may also need municipal by-law approvals or development permits. Occasionally these approvals or permits relate to reclamation, but they usually concern traffic, visual screening, noise and dust control.

Resource sterilization

In some instances, an aggregate deposit may be permanently removed from potentially available supplies because of commitment of the land that excludes aggregate extraction. This resource sterilization usually results from placing permanent structures over the deposit or from a potential conflict with the adjacent land users (plate 7). As a consequence, a valuable resource may never be used, often because insufficient information was available to the people making land-use decisions.

In the study region there have been some instances of resource sterilization, fortunately not on a large scale. The most common location of resource sterilization is around large urban areas; the Edmonton area has examples. One river valley pit of the City of Edmonton is no longer used because the Riverbend subdivi-

Plate 6. Pit south of Smoky Lake being stripped of soil. Soil should be replaced after extraction to bring site back into agricultural use.

Plate 7. Airfield under construction on gravel deposit east of Elk Point

sion has been built around the area. This development effectively restricts access to the property; it is unlikely, therefore, that the remaining gravel will be removed.

Another case of sterilization that occurs fairly often in Alberta is the crossing of deposits by pipelines and transmission lines. In the development of any deposit with these hindrances, a considerable amount of material must remain untouched because of the buffer zone left around the line. In an important deposit north of Glendon, for example, a single pipeline has sterilized almost 15 percent of the deposit.

To prevent resource sterilization, it is important for land administrators and planners to recognize where aggregate deposits are in their area and what types of land-use might permanently remove those resources from production. Such awareness has been achieved to some extent in the study region. The old Edmonton Regional Planning Commission provided a particularly good example: the planning commission established a boundary around the important gravel deposit at Villeneuve, which restricted subdivision of lands where subdivision would have a negative effect on future development of the gravel within the boundary. Unfortunately, this measure is not proposed for inclusion in the regional plan of the newer Edmonton Metropolitan Regional Planning Commission.

Projected aggregate demand

Introduction

It is important in aggregate resource studies to be able to forecast demand because the forecast facilitates an evaluation of the sufficiency of the resource supply to meet the expected demands. In order to forecast aggregate demand we developed an economic model based on provincial economic and population growth. We have then related this model to historic aggregate production (see appendix G).

The Alberta Bureau of Statistics developed the population projections used in our forecasts. We have used the lowest of a series of population projections covering the years 1984 to 2011. The low projection, which assumes a low birth rate and a low net migration to the province, is considered to represent the most likely situation in Alberta. Strictly for comparison purposes, we have also generated an aggregate forecast using a high population projection.

Aggregate production figures were obtained from the annual census of mines, quarries and sand pits conducted by Energy, Mines and Resources. To ensure completeness in the production figures, we also conducted our own survey of producers for 1981. This survey pointed out a discrepancy in the federal figures: we found a much higher rate of production for the study region. After a thorough comparison of the two surveys, we concluded that the federal figures were lower than actual production because the annual census was using an incomplete mailing list of producers and not all companies responded to the survey. In accordance with our survey results, which were obtained through interviews, we have adjusted the annual production figures for the years 1961 through 1980 upwards by a factor of 1.81.

To illustrate more clearly aggregate demand and its effects across the study region, we have established three smaller areas within the region. These smaller areas more closely approximate market areas, while still following municipal boundaries. The Edmonton market area includes all the producers in Edmonton and in the Counties of Strathcona 20, Leduc 25, Lac Ste. Anne 28, and Parkland 31 and the Municipal District of Sturgeon 90. The Cold Lake-Bonnyville area includes the County of St. Paul 19, the Municipal District of Bonnyville 87 and part of Improvement District 18. The third area is Vegreville-Two Hills, which includes the Counties of Beaver 9, Two Hills 21, Minburn 27 and Lamont 30. The aggregate demand in these areas has been forecast by allocating a portion of the demand for the whole study region to these areas, in proportion to the percentage population in each area.

Projected aggregate demand

Assuming the region follows our economic model (appendix G), we expect the demand for aggregate in the study region to rise from 10.8 million m^3 in 1983 to 13.1 million m^3 by 2000 and to almost 14.5 million m^3 by 2010. This demand reflects the slower growth expected in Alberta following the recession of the early 1980s. The region is not expected to return to the 1981 consumption level until 1989.

In the Edmonton market area, aggregate demand should reach almost 8.7 million m^3 by 2010. According to our predictions, from 1981 to 2010 the Edmonton area will consume approximately 229 million m^3 of aggregate. Although we have used the lowest Alberta population projections, our prediction of demand may be slightly high, since there is currently a large surplus of office and commercial space in the area. It will probably take a few years for this surplus to be eliminated; consequently, the construction industry demand for aggregate could be depressed until the late 1980s.

The Cold Lake-Bonnyville and Vegreville-Two Hills areas consume approximately the same amount of aggregate each year. In 1983, this consumption amounted to approximately 250 000 m^3 in each area and will climb by 2010 to 330 000 m^3 each. Whereas the demand projections are similar, the basic economy of the two areas is not. The Vegreville-Two Hills area is largely an agricultural area that consumes aggregate for county roads and the towns in the area. The Cold Lake-Bonnyville area has a similar base but also has the demand of heavy oil development. If two or three commercial heavy oil plants come into operation in the Cold Lake area, aggregate demand could increase by 100 000 m^3 annually.

Since the rate of aggregate consumption and population growth, especially at the county level, fluctuates considerably, we expect divergence from the projected estimates. Moreover, the counties are not isolated and transport of aggregate across the county and provincial boundaries does occur.

Supply-demand relationships

Introduction

The consumption of aggregate in a region is a composite of the requirements of many different users in that region (figure 6 and Appendix E). The counties and municipal districts have a continuing, basic need for aggregate for road maintenance and construction. Superimposed on this primary consumption are the aggregate requirements of the cities and towns in proportion to their size and rate of growth. These urban consumers effectively act as distinct markets, drawing aggregate from their surrounding areas. Cutting across the region is a third category of consumer that includes the Department of Transportation and the railway companies. These consumers draw aggregate to their

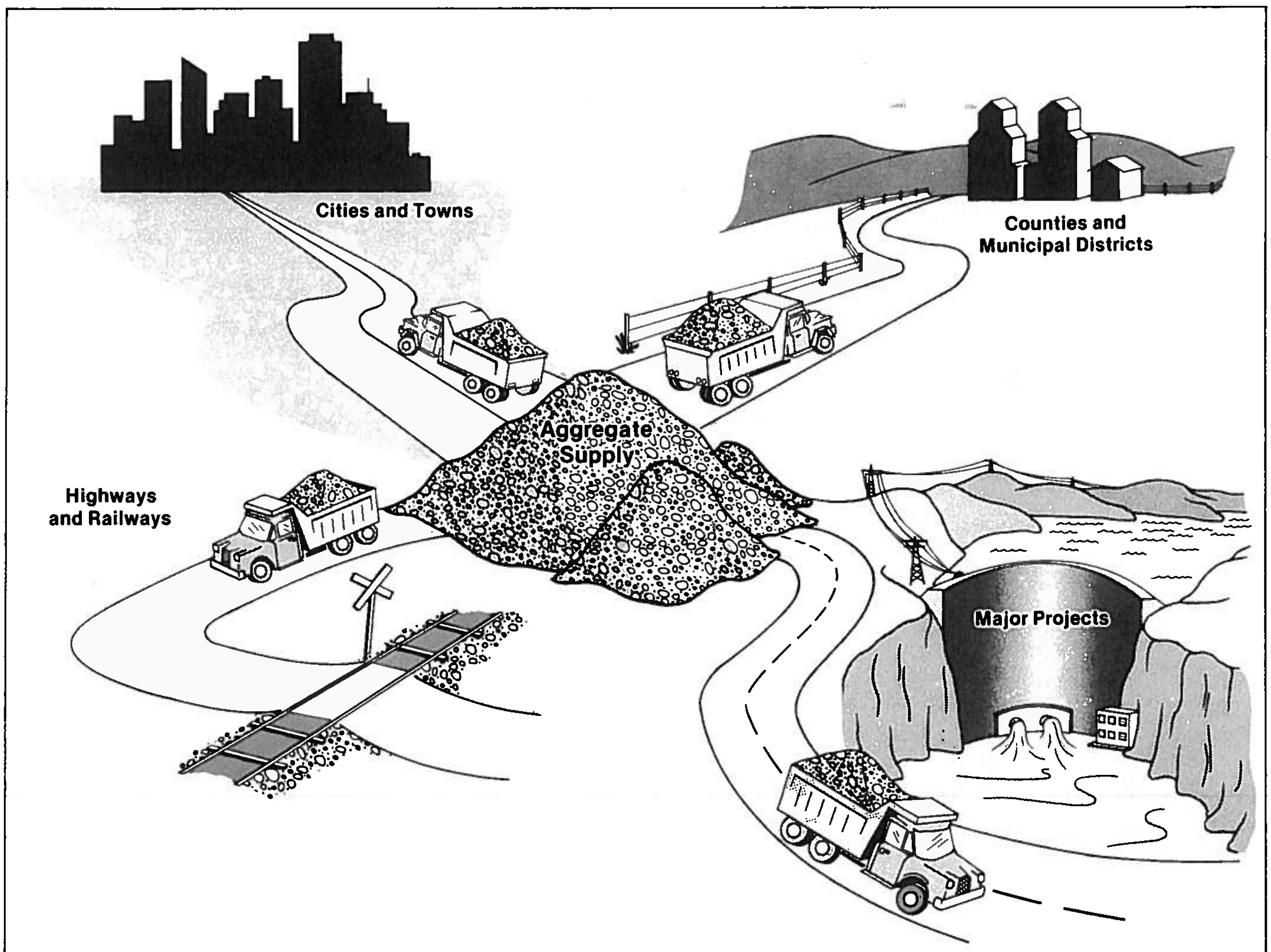


Figure 6. Major aggregate user groups

developments, often using large quantities in a relatively short time during construction, then using little material for years. The final category of consumer includes large individual projects, such as airports, dams, industrial plants or oil sands projects. These large projects can consume great quantities of aggregate, disrupting the availability and escalating the cost of the resource, particularly to the cities and counties.

Associated with each user group is a supply zone from which it obtains its aggregate. Although counties and municipal districts usually attempt to obtain their aggregate supply from within their own boundaries, cities and towns generally cannot meet their requirements in this way. The supply zone surrounding a city is determined by the geology of the resource, availability and ownership of deposits and transportation routes. Most aggregate used in a city is supplied by commercial operators. The supply zone for provincial highway maintenance and construction usually falls in a strip about 30 km wide along each highway. With railways, the supply zone also lies in a narrow strip along the right of way, but because transportation by rail is relatively inexpensive, the aggregate may be used a great distance from where it was extracted. Large industrial projects, much like a city, draw materials from an area around them. Since these projects generally need aggregate only at a given stage, however, they are often willing to pay a premium for material, or haul longer distances to guarantee their supply. The various users may be competing for the same supply in some circumstances.

Like gold or oil, natural sources of aggregate are specific deposits discrete in extent and finite in volume. Given certain assumptions concerning the "grade" of the deposit (such as the minimum quality and thickness of the deposit), the reserves can be estimated. The amount of aggregate produced and used in a region can be determined through a survey of producers and consumers. If such surveys are conducted over several years, the results can be correlated with population, gross provincial product or construction starts. Such interrelationships often disclose trends that can be extrapolated to give estimates of future aggregate usage, estimates such as the rate of resource consumption and cost due to sterilization of given deposits.

Edmonton area

The City of Edmonton is the largest consumer of aggregate in the study region. During this study, the authors conducted a detailed survey of production for 1981 which indicates about 7 million m³ of sand and gravel were used by the city during that year[1]. Projections suggest that by the year 2010 the city will consume another 229 million m³ of sand and gravel (figure 7). At present, the principal sources of aggregate for Edmonton lie within a radius of about 55 km in the Counties of Strathcona 20, Leduc 25, Lac Ste. Anne 28, Parkland

[1]Gravel consumption varies from 40 to 70 percent of the total aggregate used. A figure of 55 percent is assumed here, emphasizing the production survey completed for this study and the City of Edmonton report (1978).

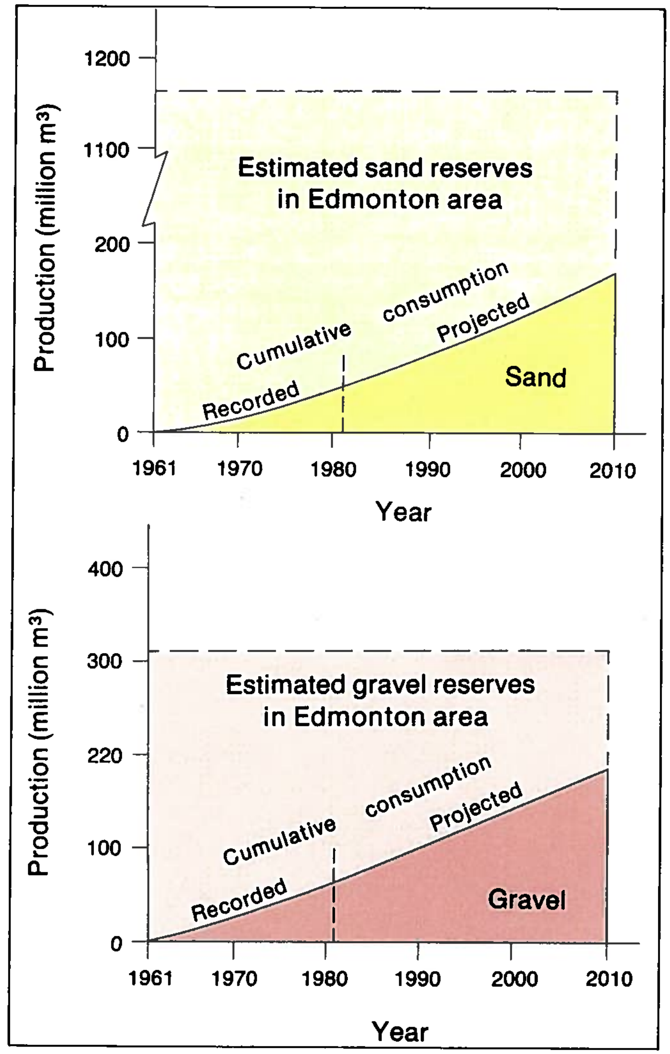


Figure 7. Projected consumption of sand and gravel by the City of Edmonton to 2010

31 and M.D. of Sturgeon 90. Geologically, the major sources are the alluvial deposits in the North Saskatchewan River valley (plate 5), the Saskatchewan sand and gravel deposit in the Villeneuve area (plate 4) and the upland preglacial deposits of the Heatherdown area.

By the year 2010 over half of the most useful gravel supplies in the present supply area may be depleted (figure 7). Because the resource estimates do not take into account loss during extraction, sterilization of deposits due to alternative development or restrictive zoning, this estimated consumption may be low.

Fortunately, other resources occur just outside Edmonton's present area of supply. In the same adjoining municipalities (Counties 20, 25, 28 and 31 and Municipal District 90), another 360 million m³ of gravel are found outside the present supply zone. Most of this material is in preglacial deposits in the Wabamun area (146 million m³) and in alluvium along the North Saskatchewan River (159 million m³) (figure 8). In this extended area, the forecast must also take into consideration the consumption of the counties to 2010. Figure 9 shows the projected combined Edmonton, county and

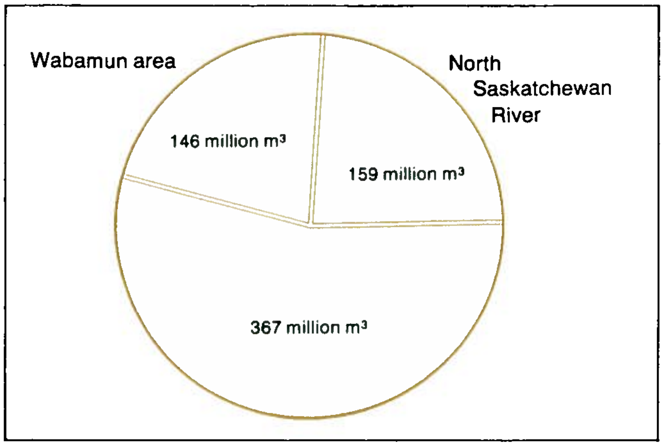


Figure 8. Gravel resources of the Edmonton and surrounding area.

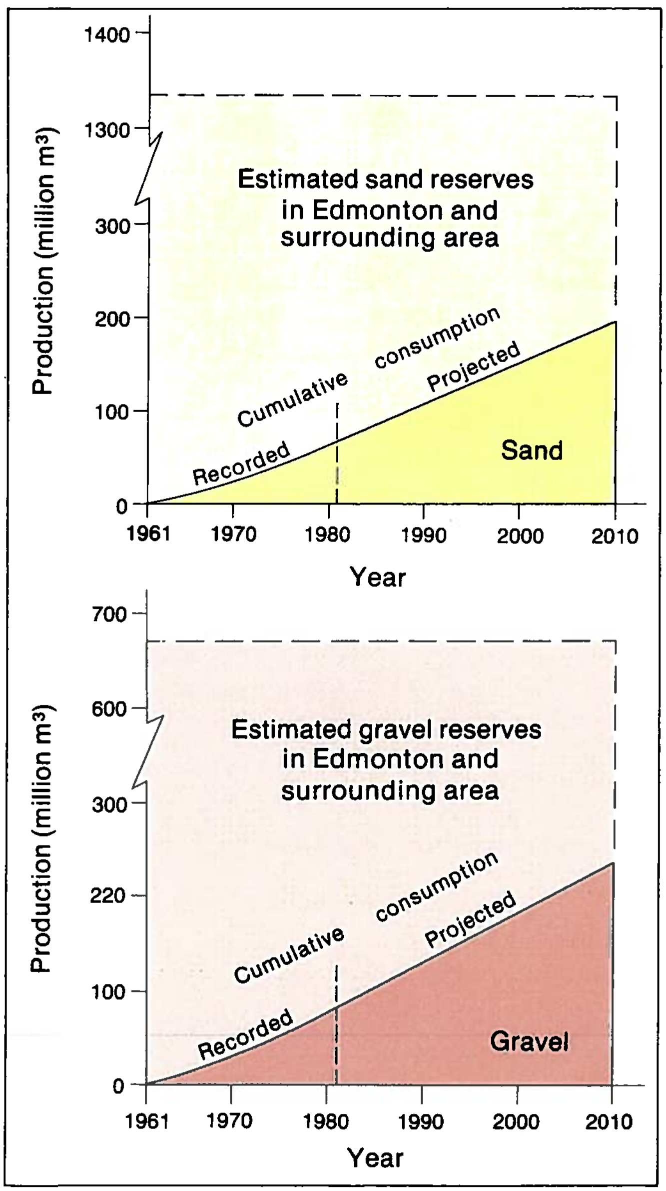


Figure 9. Projected consumption of sand and gravel by the City of Edmonton and surrounding counties to 2010

municipal district consumption to 2010.

While the available local gravel resource is adequate to the turn of the century, it is diminishing noticeably. Should any of the major resource areas (the North Saskatchewan River valley, the Villeneuve, Heatherdown or Wabamun areas) be directed into land uses that exclude aggregate development, Edmonton and the adjoining municipalities will encounter escalating aggregate costs.

Cold Lake area

Table 7 gives a forecast of demand for gravel and sand in the Cold Lake area (County 19, Municipal District 87 and part of Improvement District 18) and figure 10 shows projected cumulative consumption to the year 2010 (12.8 million m³). Our projection compares with the projection of Edwards and Fox (1980)[2] of about 15

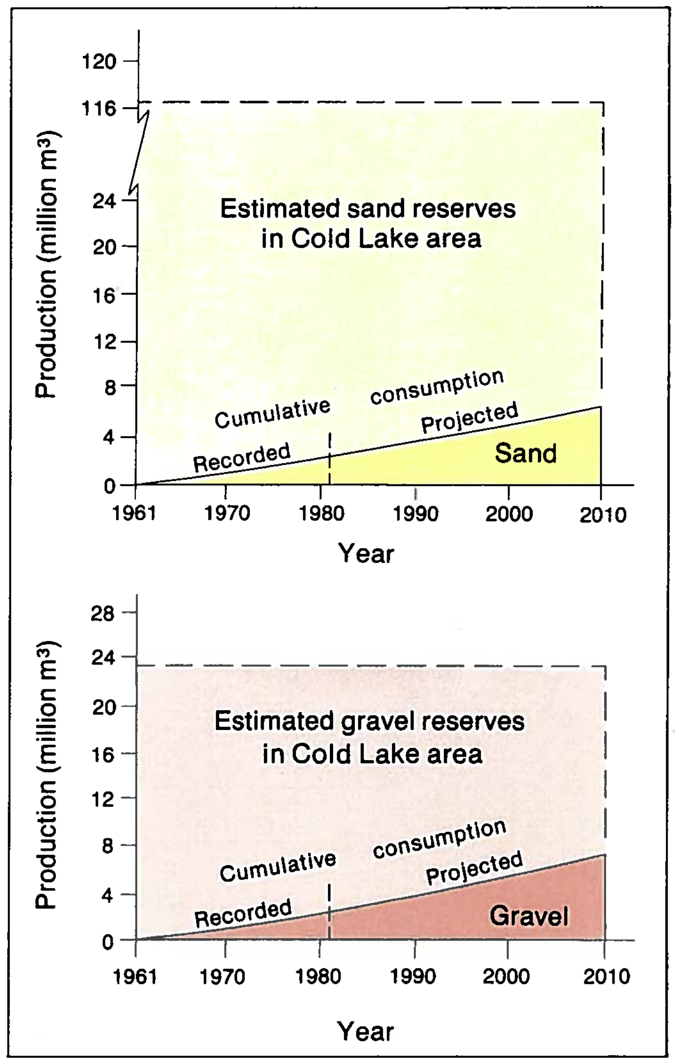


Figure 10. Projected consumption of sand and gravel by County 19, Municipal District 87 and part of Improvement District 18 to 2010

[2]Edwards and Fox based their projection on an annual per capita consumption of 10 m³ of aggregate, no oil sands development and a similar study region.

Table 7. Forecasts of gravel and sand consumption to 2010 for the study region and selected areas (low case forecast in millions m³)

	Edmonton #1	Area #2	Area #3	Area #4	Other #5	Study Region #6
1961	3.77847	1.03317	0.143200	0.147596	1.17826	6.2806
1962	4.04198	1.10523	0.153187	0.157890	1.26043	6.7187
1963	4.84313	1.32429	0.183549	0.189185	1.51026	8.0504
1964	5.03450	1.37662	0.190802	0.196660	1.56993	8.3685
1965	4.31420	1.17966	0.163504	0.168523	1.34532	7.1712
1966	3.86694	1.05737	0.146553	0.151052	1.20585	6.4277
1967	4.25731	1.16411	0.161347	0.166301	1.32758	7.0766
1968	4.08118	1.11595	0.154672	0.159421	1.27265	6.7838
1969	4.47236	1.22291	0.169498	0.174701	1.39464	7.4341
1970	4.81373	1.31625	0.182435	0.188036	1.50109	8.0015
1971	5.60509	1.53264	0.212427	0.218949	1.74786	9.3169
1972	6.16832	1.68665	0.233773	0.240950	1.92350	10.2532
1973	5.58331	1.52668	0.211601	0.218098	1.74107	9.2807
1974	6.72474	1.83880	0.254860	0.262685	2.09701	11.1781
1975	6.13755	1.67824	0.232607	0.239748	1.91390	10.2020
1976	7.35767	2.01186	0.278848	0.287409	2.29438	12.2302
1977	7.17173	1.96102	0.271801	0.280146	2.23640	11.9211
1978	5.68893	1.55557	0.215604	0.222224	1.77401	9.4563
1979	7.00350	1.91502	0.265425	0.273574	2.18394	11.6415
1980	6.62429	1.81133	0.251054	0.258761	2.06569	11.0111
1981	7.20440	1.96995	0.273039	0.281422	2.24658	11.9754
1982	6.56250	1.79440	0.248700	0.256300	2.09650	10.9085
1983	6.54438	1.78948	0.248025	0.255640	2.04077	10.8783
1984	6.73925	1.84276	0.255410	0.263252	2.10153	11.2022
1985	6.88157	1.88168	0.260804	0.268811	2.14592	11.4388
1986	6.94314	1.89852	0.263138	0.271217	2.16512	11.5411
1987	7.05408	1.92885	0.267342	0.275550	2.19971	11.7255
1988	7.14112	1.95265	0.270641	0.278950	2.22685	11.8702
1989	7.22268	1.97495	0.273732	0.282136	2.25228	12.0058
1990	7.28445	1.99184	0.276073	0.284549	2.27155	12.1085
1991	7.36707	2.01443	0.279204	0.287776	2.29731	12.2458
1992	7.44104	2.03466	0.282008	0.290666	2.32038	12.3688
1993	7.50062	2.05095	0.284265	0.292993	2.33895	12.4678
1994	7.53966	2.06163	0.285745	0.294518	2.35113	12.5327
1995	7.58823	2.07491	0.287586	0.296415	2.36628	12.6134
1996	7.61403	2.08196	0.288564	0.297423	2.37432	12.6563
1997	7.68947	2.10259	0.291423	0.300370	2.39785	12.7817
1998	7.74888	2.11883	0.293674	0.302691	2.41637	12.8805
1999	7.82066	2.13846	0.296395	0.305494	2.43876	12.9998
2000	7.89233	2.15806	0.299111	0.308294	2.46111	13.1189
2001	7.96642	2.17832	0.301919	0.311188	2.48421	13.2421
2002	8.04265	2.19916	0.304808	0.314166	2.50798	13.3688
2003	8.11823	2.21983	0.307672	0.317118	2.53155	13.4944
2004	8.19797	2.24163	0.310694	0.320233	2.55642	13.6270
2005	8.27710	2.26327	0.313693	0.323324	2.58109	13.7585
2006	8.35732	2.28520	0.316734	0.326458	2.60611	13.8918
2007	8.43682	2.30694	0.319746	0.329563	2.63089	14.0240
2008	8.51989	2.32966	0.322895	0.332808	2.65680	14.1621
2009	8.60434	2.35275	0.326095	0.336107	2.68313	14.3024
2010	8.68998	2.37617	0.329341	0.339452	2.70984	14.4448

1. Consumption recorded by the City of Edmonton and any companies using aggregate in the city.
2. Counties 20, 25, 28 and 31 and Municipal District (M.D.) 90.
3. County 19, M.D. 87 and that part of Improvement District (I.D.) 18 within the study region.
4. Counties 9, 21, 27 and 30 and I.D. 13.
5. Counties 7, 10, 11, 13, 22 and 24 and M.D. 92.
6. Refers to the entire study region and includes all of the above.

million m³ of aggregate. The total resource in the Cold Lake area is estimated to be 24 million m³ gravel and 116 million m³ of sand. Of this, 12 million m³ of gravel occurs in three deposits in the Elk Point area (168, 169 and 371) and 3 million m³ occurs in two deposits in Improvement District 18 north of Glendon. Aggregate (especially coarse aggregate) is not plentiful in this area. The authors hope that this report will aid a regional assessment of aggregate resources and will result in an efficient development plan for the available reserve.

Counties, municipal districts and improvement districts

The aggregate resource is important in each municipality. It is essential that each jurisdiction consider its total reserve, availability of the resource, location of deposits, and current and future requirements for aggregate.

Appendix I gives a summary of the status of the sand and gravel resource for each municipality. Possible indicators of approaching aggregate resource problems include small total reserves, especially of gravel; a high percentage of reserves zoned out (low availability), a high percentage of the resource in a few deposits or in one setting (described more fully below); large projects predicted within or close to the municipality; and neighboring municipalities or cities with a short supply or large consumption.

In several counties, a few deposits contain most of the gravel resource. In others most of the reserve is concentrated within one setting: in the County of Barrhead 11 the gravel is concentrated in the Athabasca River valley (99 percent), in the County of Parkland 31 along the North Saskatchewan River valley (47 percent) and the Wabamun Lake area (43 percent). In the Municipal District of Sturgeon 90 gravel occurs primarily in the highly productive Villeneuve area (93 percent). Such concentration of resources makes particular deposits or areas more important to the regions and means that the sterilization of a single deposit or setting (such as a river valley) can have very serious impacts.

The summary descriptions and the data presented in various figures and tables in this report provide preliminary information for the assessment of the aggregate resource. The authors are convinced that, as the municipalities adjust and supplement the data, an effective approach to aggregate resource management will emerge.

Recommendations

1. The counties, municipal districts, planning commissions and appropriate provincial departments within the study area should obtain aggregate resource maps for their jurisdictions. These maps will show where aggregate deposits occur within the municipal boundaries, the extent of those deposits and the types of material in them. This basic resource information is necessary for any future municipal planning or land-use zoning decisions.
2. When drafting regional plans, the regional planning commissions should consider aggregate resources, including both the needs and resources of the municipalities in the region and those demands and resources outside the region that may affect its jurisdiction.
3. The counties and municipal districts should evaluate their needs for aggregate, including the needs of the commercial operators. They should preserve those deposits required to meet the future needs of the municipality and prevent conflicting land uses and sterilization.
4. The provincial government should establish a technical working group to assist planning commissions and municipalities in the assessment of aggregate resource issues. This group should be able to provide expert consultation in aggregate geology, reclamation and planning. Representatives should come from the Alberta Research Council (Alberta Geological Survey), the Departments of Energy and Natural Resources, Environment, Municipal Affairs and Transportation, and the Sand and Gravel Association.
5. The aggregate producers should become more active in promoting the concerns of their industry, particularly in regard to the necessity for resource planning.
6. Aggregate resource information from the many departments which collect such data should be incorporated into one data bank. There should be a continuing effort to keep these data current and to add data where possible.
7. Those government departments which use large amounts of aggregate, such as Transportation and Environment, should be more aware of the impacts their consumption can have on the local supply. They should attempt to mitigate impacts through careful consideration of alternate deposits.
8. More research should be done on materials which could replace or extend the life of conventional aggregates. This research should include investigation of the use of lower grade materials for certain specifications in an effort to preserve high quality materials.
9. The Department of Environment and Energy and Natural Resources should develop guidelines and manuals for the reclamation of aggregate extraction areas. These manuals should be readily available to aggregate producers so they may understand what restoration is required of them. This will assist producers in their development, since a clear reclamation objective can guide extraction procedures.

Appendix A
Geology

Introduction
Geologically the study area is composed of four main components:

1. bedrock (figure 11)
2. preglacial sand and gravel (figure 12)
3. glacial materials (figure 13, in pocket)
4. postglacial dune sand and alluvial materials (figure 13)

Bedrock
Bedrock in the study region includes the Cretaceous Lea Park, Judith River, Wapiti, Bearpaw and Horseshoe Canyon Formations and the Tertiary Scollard and Paskapoo Formations.

The marine shales present in the northeast corner of the study area are the oldest sediments that outcrop in the region (figure 11). They comprise the Lea Park Formation. The formation is a uniform series of gray, silty shales with local intercalations of sandy shale, ironstone, concretionary bands and bentonite (Shaw and Harding, 1954). Thickness increases to the northeast and theupper boundary is gradational into the sands of the Judith River Formation.

The Judith River Formation is exposed best on the North Saskatchewan River east and west of Victoria Settlement (south of Smoky Lake). The undivided formation consists of a series of gray, brownish and greenish gray argillaceous, smectitic sands closely interbedded with brownish gray to gray carbonaceous shales and silts (Shaw and Harding, 1954). Thin carbonaceous layers are characteristic of the normal facies, and thin coal seams characterize the west to east transition of continental to marine beds. Northwest of Edmonton the sediments of this formation are indistinguishable from the sediments in the lower part of the Wapiti Formation (figure 11 cross section).

Above the Judith River Formation lie the marine, dark gray shales and sandy shales of the Bearpaw Formation. This formation pinches out in the subsurface approximately 80 km northwest of Edmonton and is absent at the surface west of the North Saskatchewan River.

The Horseshoe Canyon Formation (Irish, 1970) comprises an interbedded sequence of predominantly non-marine, fluvio-deltaic sandstone, siltstone, shale and mudstone or claystone (plate 8). Variable concentrations of coal, coaly shale, bentonite and ironstone concretions are intercalated throughout parts of the

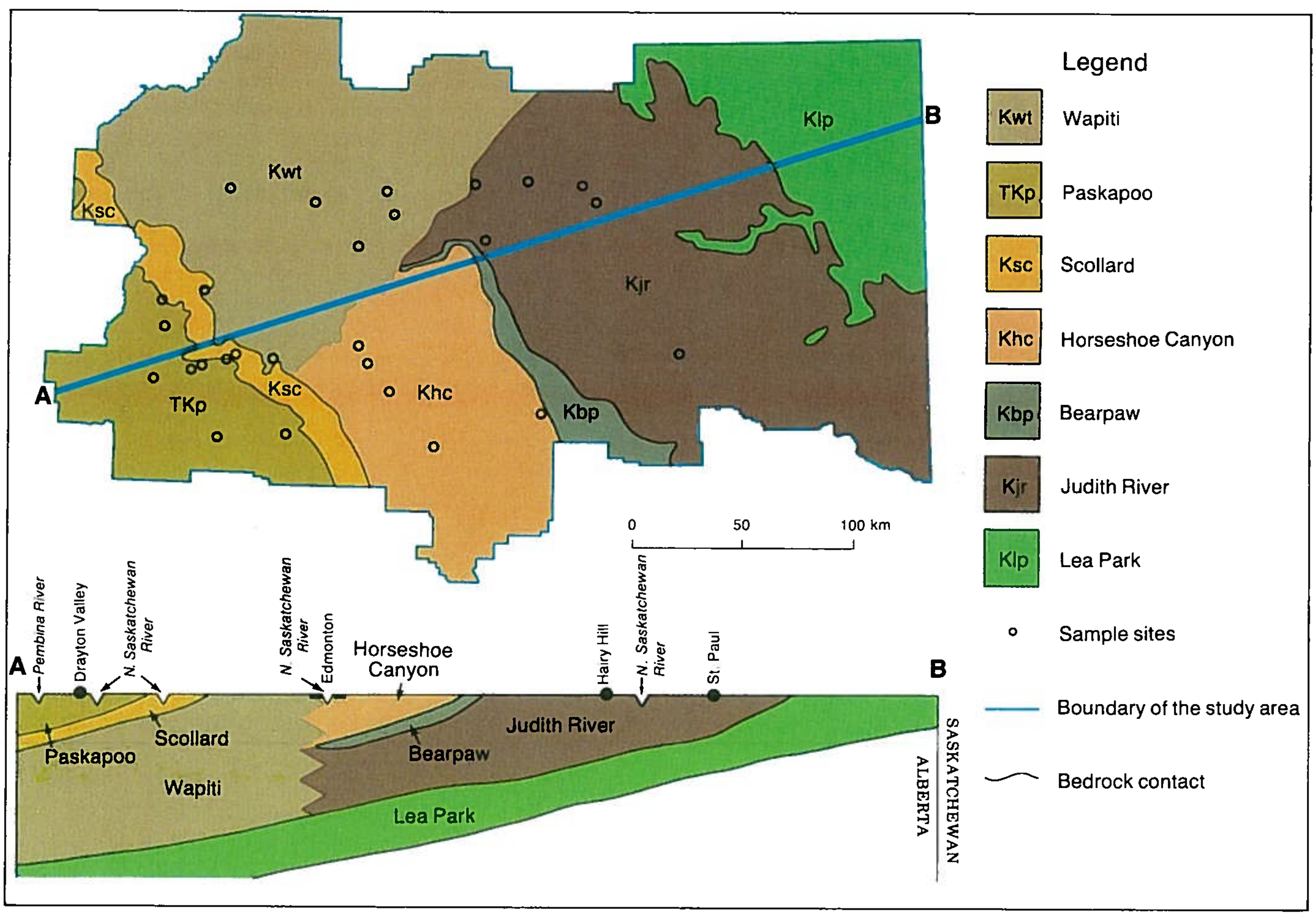


Figure 11. Bedrock geology

Plate 8. Horseshoe Canyon sandstone and coal exposed along Highway 2 south of Edmonton

succession (Gibson, 1977). Sandstone is the most common rock type, siltstone is the second most common and shale, mudstone and claystone are more abundant near the base of the formation. Northwest of Edmonton these sediments cannot be distinguished from similar sediments in the upper part of the Wapiti Formation (figure 11 cross section).

The Wapiti Formation underlies the northwestern corner of the study area. The name Wapiti Formation was first applied to a sequence of continental sandstones, shales and thin coal seams on the Wapiti River south of Grande Prairie. Subsequently, similar sediments were traced southeastward, and in the vicinity of Edmonton are indistinguishable from the sediments of the Horseshoe Canyon and Judith River Formations (figure 11). The sandstones are generally fine grained, light colored and smectitic. Shales are smectitic, light or dark gray and poorly stratified. Bentonite, coal, ironstone and freshwater limestone occur in varying amounts (Allan and Carr, 1946).

Abruptly overlying the Wapiti or Horseshoe Canyon Formations are the thin, contrasting Whitemud and Battle Formations. The Whitemud Formation weathers light gray to light greenish gray and is composed of argillaceous sandstone and mudstone with lesser amounts of siltstone and shale (Bigson, 1977). We did not encounter this formation during sampling. The overlying Battle Formation is a thin sequence of smectitic claystone or mudstone with volcanic tuff. The claystone is slightly silty to sandy in part and weathers to a diagnostic medium to dark purplish gray.

Overlying the Battle Formation is an interbedded, interfingering sequence of argillaceous sandstone, siltstone, mudstone and shale of Tertiary age called the Scollard Formation (Gibson, 1977). Coals mined in the Genesee and Wabamun areas are from this formation. The sandstones normally occur as lenticular beds up to 1.5 m thick. Light greenish gray weathering, smectitic, sandy to silty mudstone and argillaceous siltstone alternate with dark gray to dark purplish gray weathering, very smectitic, silty to sandy mudstone.

The Paskapoo Formation is the youngest bedrock formation outcropping in the study area and is composed of nonmarine fluvial and lacustrine deposits of massive, in part cross-bedded, medium to coarse-grained, buff-weathering sandstones, hard to soft fine-grained sandstones, and green and gray, friable, normally silty shales (Irish, 1970). Also present are lenses of lignite, pebble comglomerates and bands of laminated clays. The lower part of the formation is characterized by thick, buff-weathering, pale gray, cliff-forming sandstones. In the upper part, sandstones are soft, pale gray and interbedded with blocky, green and gray siltstones and silty mudstones. Only the shales, mudstones and silty mudstones, of this or any other formation, are of interest to producers of burned synthetic aggregate.

Preglacial sand and gravel

The preglacial sand and gravel, as their name suggests, were deposited in river valleys (figure 12) prior

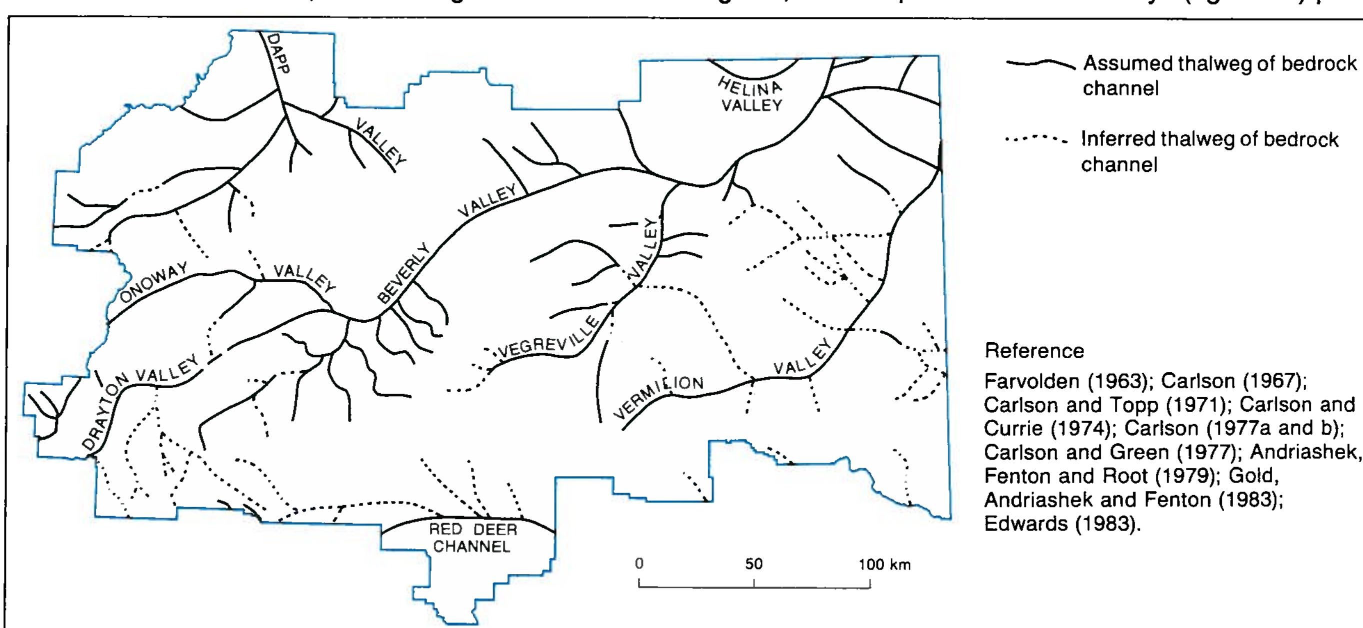


Figure 12. Preglacial thalwegs in study region

to the last continental glaciation. Many of these deposits have been eroded by glaciation or rivers, or buried to a depth which makes aggregate exploitation difficult (figure 14).

Table 8 and appendix C describe the physical nature of some preglacial gravel, based on analyses by the City of Edmonton (1978) and the Alberta Geological Survey (Edwards, 1983) of natural (pit run) materials.

On the basis of elevation, setting and age, preglacial sand and gravel can be divided into two main types: upland and Saskatchewan (Edwards, 1983).

Preglacial upland gravel of Miocene to Early Pleistocene age caps bedrock highlands throughout central and southern Alberta. Elevations range from 913 m above sea level on the Cypress Hills (Westgate, 1968) to 1310 m on the Swan Hills (St.-Onge and Richard, 1975). Around Edmonton, preglacial gravel caps Cretaceous shale and coal in the Wabamun-Heatherdown area. These deposits are higher and older than the adjacent valley-filling Saskatchewan gravels.

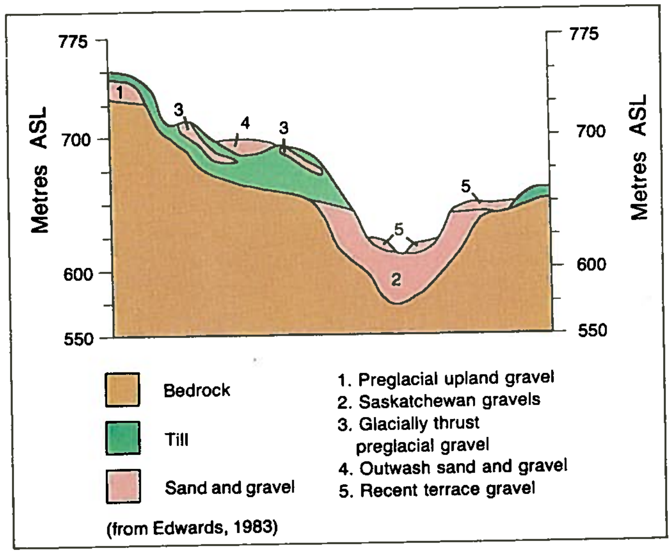


Figure 14. Schematic geologic setting of gravel deposits in Edmonton region

Table 8. Properties of some common types of gravel. This is a summary of properties of gravel from selected sites in the Edmonton region. For a description of the purpose of the test, the test reference and significance of the results, see appendix C.

Origin	Gradation-percent passing							Angularity*		Percent lightweight particles*
	75 mm	25 mm	4.75 mm	2.0 mm	0.425 mm	0.15 mm	0.075 m	75-12.5 mm	9.5-0.075 mm	
Preglacial upland gravel	95	60	24	20	12	2	1	rs,ss	rs,ss	0.04-0.4
Preglacial valley gravel[1]	97	82	37	29	22	22	1	rs,ss	rs,ss	0.04-0.4
Preglacial valley gravel[2]	98	83	49	44	31	2	1	rs,ss	rs,ss, sr,ar	2.0-22.0
Outwash gravel	81	48	29	20	5	2	1	ss,rs	rs,ss	0.5-0.7
Recent N. Sask. River terrace gravel	94	64	31	25	12	2	1	rs,ss	rs,ss sr,ar	2.0-22.0

Origin	Insoluble residue*	Percent wear	Organic impurities*	Percent clay and friable particles*	Percent loss soundness*	Petrography (percent)					
						A	B	C	D	E	F
Preglacial upland gravel	90.8-100	30	1.3	2.1-27.9	7.6-15.1	98	3	-	1	<1	-
Preglacial valley gravel[1]	90.8-100	22.3-25.1*	1.3	2.1-27.9	7.6-15.1	-	-	-	-	-	-
Preglacial valley gravel[2]	95.1-99.4	26.5*	5	1.6-52.2	16.1-27.9	95	5	-	-	-	-
Outwash gravel	83.8-90.9	29	5	5.6	17.4	69	6	24	-	1	-
Recent N. Sask. River terrace gravel	95.1-99.4	29	5	1.6-52.2	16.1-27.9	56	15	24	-	-	5

[1]Vileneuve area
[2]North Saskatchewan River valley NE
*from City of Edmonton, 1978

A - quartzite
B - sandstone
C - granite and gneiss

D - conglomerate
E - carbonate
F - shale and ironstone

rs - rounded, smooth
ss - subangular, smooth
ar - angular, rough
rr - round, rough
sr - subangular, rough

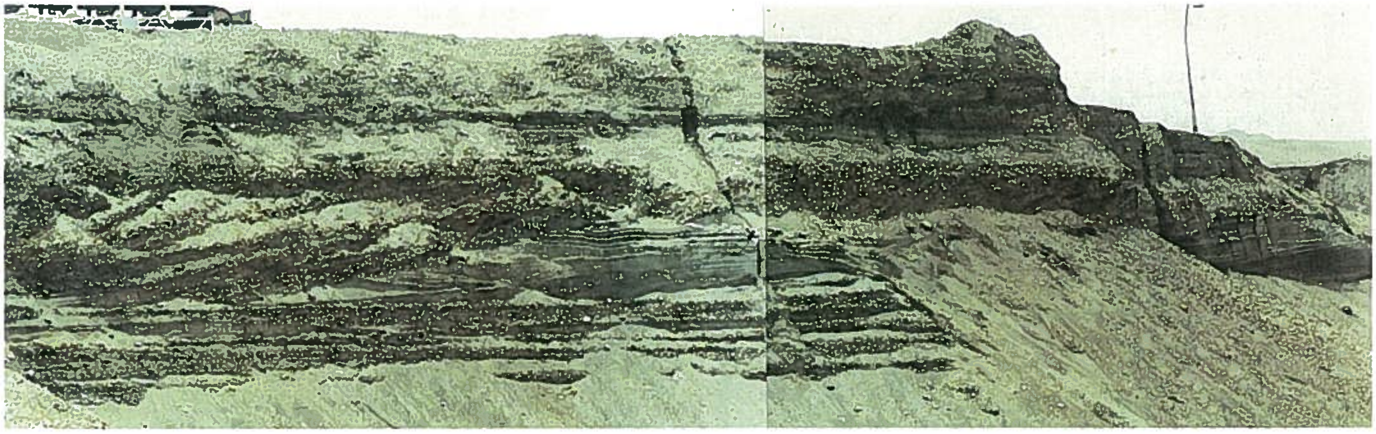


Plate 9. Preglacial sand and gravel are mined in Villeneuve area

The term "Saskatchewan gravels" (originally named "South Saskatchewan gravels" [McConnell, 1885]) refers to sand and gravel deposited in preglacial valleys (as valley fill or terraces) before the onset of continental Quaternary glaciation. Saskatchewan gravels occupy an extensive network of preglacial bedrock channels in the Edmonton region (figure 12). They apparently were deposited under periglacial conditions (Berg, 1969). Most aggregate production of Saskatchewan gravels is from the Villeneuve area (plate 9), where workings expose 8 to 15 m of sand and gravel lying on bedrock, under 5 to 12 m of lacustrine clay and till.

Glacial materials

The Pleistocene period or "Ice Age" in Alberta was dominated by glacial erosion/deposition and fluvial action. Glacial action deposited a poorly-sorted sediment called till (plate 10). The fluvial activity ensued when tremendous volumes of water were released by the melting of the continental ice mass. Debris (sand, gravel, silt and clay) carried in the ice was commonly deposited as well-sorted granular deposits in meltwater channels. Such glaciofluvial deposits are important sources of sand and gravel in the study area. The finer sediments which accumulated in glacial lakes are now the source of raw materials for lightweight aggregate in the Edmonton area.

The glaciofluvial deposits are generally scattered throughout the study area (figure 13). They are most concentrated in those areas where the melting ice front remained stationary for some time or along major meltwater channels. Most of the glaciofluvial deposits in the area (289 deposits) are sand and gravelly sand deposits. A small number (55) contain greater concentrations of gravel (plate 11) and these are distributed more widely than the preglacial deposits.

A particular type of glaciofluvial deposit, termed outwash, forms an important source of gravel. Analyses for outwash samples are shown in table 8. The outwash contains granite and gneiss (see petrography, table 8), rocks which had to be transported from the Precambrian Shield to the area by glaciers. The difference in transport history (glacial versus fluvial) between the preglacial and outwash gravel produces the difference in angularity shown in table 8. The characteristic petrography of the outwash (lower quartzite and higher sandstone and carbonate) results in a lower percent insoluble residue and higher percent loss of soundness.

A continental ice sheet originating on the Precambrian Shield advanced from the northeast and covered the Edmonton region several times. The last ice advance took place about 25 000 to 30 000 years ago. Melting of this glacier, complete about 9000 years ago (Bayrock, 1972), covered the area with various types of surficial materials, including till. Commonly at the surface or below glaciolacustrine or eolian deposits (plate 12), till is extremely useful as a construction foundation because of its engineering properties.

Tills of the Edmonton region consist mainly of local bedrock materials (disintegrated Cretaceous sandstones and smectitic shales with coal and sideritic ironstone fragments) with significant amounts of igneous and metamorphic rocks derived from the Canadian Shield to the northeast (Shield rocks 15 to 46 percent, N = 17 [Boydell, 1978]). The presence of rocks and minerals from the Shield (granite and metamorphic rocks) readily distinguishes the glacial deposits of the area from preglacial sands and gravels and local bedrock materials. The tills also contain

Plate 10. Till, a mixture of pebbles, sand and fines, is widespread in the region

Plate 11. Example of glaciofluvial gravel showing variation in gravel content and size

Plate 12. Glaciolacustrine clay (upper unit with fine laminations) resting on till. This type of silt and clay is used by IXL Industries to make brick, and by Genstar Incorporated to make expanded aggregate

Devonian carbonate rocks from outcrops along the Shield margin. Hence, although the local Cretaceous bedrock formations tend to be low in calcium carbonate, the tills are calcareous because of the presence of Devonian limestones (carbonate rocks 1 to 35 percent, N = 17 and average carbonate matrix 7 percent, N = 3 [Boydell, 1978]). Till in the region contains approximately equal proportions of sand, silt and clay. Tables 9 and 10 show till matrix grain size and clay mineralogy analyses from samples in or near the study region. Near-surface tills are oxidized and brown; deeper than 3 to 4 m from the surface, they are typically unoxidized and gray to dark gray.

Glaciolacustrine sediments are scattered through the region because numerous glacial lakes formed when meltwaters were impounded by the continental ice sheet. Most of the glaciolacustrine sediment is silt and clay. The clay mineralogy is described in table 11.

A large area in the west-central part of the region, adjacent to and including the City of Edmonton, is underlain by glaciolacustrine sediments (figure 13) deposited in a large proglacial lake called Lake Edmonton. Lake Edmonton formed during the recession of the ice sheet when a minor readvance of the glacier

Table 9. Matrix grain size of tills in the study region

	Percentages of matrix material			
Location	**Sand**	**Silt**	**Clay**	**Sample no.**
Sylvan Lake area[1]	30-70	8-48	8-43	45
Wabamun Lake area[2]	30 (S.D.*2.5)		40 (S.D.3.4)	36
	40 (S.D.2.6)		33 (S.D.3.3)	24
East-central Alberta[3]	40.1	31.9	28.0	42
Edmonton district[3]	40.1	31.9	28.0	42
City of Edmonton[4]	44	26	30	6

[1]Boydell (1978). Numbers used are approximate values obtained from diagrams.
[2]Andriashek, Fenton and Root (1979). Two principal surface tills were found.
[3]Bayrock and Hughes (1962).
[4]Bayrock and Berg (1966).
*Standard deviation.

Table 10. Semiquantitative estimates of clay minerals in till matrix. Sample sites are shown in figure 13 (in pocket).

Mineral	Low	High	Average percent
Smectite	15	75	40
Illite	15	50	35
Kaolinite	5	35	15
Chlorite	trace	15	10

Table 11. Semiquantitative estimates of clay minerals in glaciolacustrine silts and clays. Sample sites are shown in figure 13 (in pocket).

Mineral	Low	High	Average percent
Smectite	5	60	35
Illite	25	70	50
Kaolinite	5	20	10
Chlorite	trace	15	5

from the northeast blocked the regional drainage along the North Saskatchewan River valley (Bayrock, 1972).

In the western part of glacial Lake Edmonton (Stony Plain area), a pitted delta was formed by streams flowing southeast off the glacier and burying stagnant ice. This ice later melted to produce pits; the deepest are situated northwest of the old lake adjacent to the glacier-delta contact. This unit grades into generally finer and thinner glaciolacustrine sediment toward the city of Edmonton. These finer sediments are used by IXL and Genstar to make synthetic aggregate and brick products.

Recent alluvial and eolian deposits

Normal river drainage returned to Alberta following the retreat of the continental glacier. Terraces formed along the valley sides of the new rivers and bars in the river channels. Strong winds and little vegetative cover immediately following ablation of continental ice resulted in the formation of sand sheets and dune fields downwind (south and east) of outwash and terrace sand and gravel.

Recent fluvial (alluvial) deposits are present along many of the major and some of the smaller rivers (figure 13). Point bars occur on the inside of meander bends and channel bars in straight stretches of rivers: both can contain important quantities of gravel (plate 13).

Recent fluvial (alluvial) deposits are present along many of the major and some of the smaller rivers (figure 13). Point bars occur on the inside of meander bends and channel bars in straight stretches of rivers: both can contain important quantities of gravel (plate 13).

Since alluvial gravel in the North Saskatchewan River valley derives material from both preglacial and glaciofluvial sources as well as from local bedrock cut by the river, it contains a variety of rock types. The high percentage of sandstone, shale and ironstone in the gravel results in a high percentage of friable particles and a high percent loss of soundness. Coal from the local bedrock and organic impurities result in a high percentage of lightweight particles.

Eolian dune fields (figure 13) occur in the same area as glaciofluvial and high level river terraces because these are the sources of the fine sand picked up by the wind (plate 14). The sand has seldom moved more than a few kilometres from the source and may partially cover the source formation (Edwards, 1981). Sand from the Bruderheim dune field (Edwards, 1981) has a mean grain size of 0.19 mm and a sorting coefficient of 0.35 to 0.69 phi (moderately to well sorted).

Dunes contain about 10 percent of the sand in the study area. They do not contain any gravel. Highly developed dune fields have 35 to 45 percent of the area of the field covered by dune ridges 1 to 8 m in height. The interdune areas often contain bogs.

Plate 13. Terraces along the Beaver River south of Grand Centre are prized for their aggregate

Plate 14. Geological assistant sampling a large dune in the Bruderheim area

Appendix B

Laboratory methods and results of firing of bedrock, silt and clay, and till samples

Information on silt, clay, shale and till is derived from a study by the Alberta Geological Survey of samples collected from ditches, stream banks, quarries, new construction sites and drill holes. Fresh samples are preferred and chunks are collected where possible. Commonly, chunks can be collected only from bedrock exposures. The materials are taken to the laboratory, disaggregated (except chunks), mixed with sufficient water to form a plastic mass, then hand-rolled into pellets approximately 15 mm in diameter. At least 45 pellets are normally required for a complete firing sequence. After drying, three pellets are placed in a crucible, inserted into a furnace preheated to 1030°C, fired for 5 minutes, then removed and cooled. The procedure is repeated for 10 and 15 minute firing intervals on other pellets. Temperature in the furnace is raised 30°C and the 5, 10 and 15 minute firings are repeated on fresh pellets. The procedure continues until a time/temperature combination is reached that is sufficient to soften the surface of the pellets so that they are close to sticking to each other and to the crucible. Chunks are fired in a similar manner. After cooling, two pellets from each time/temperature firing are coated with paraffin and relative density is determined. The third pellet is observed with a microscope and is described. X-ray diffraction analysis is performed on all raw material to identify clay minerals and estimate their abundance.

Synthetic aggregate (that is, the most abrasion resistant) is fired until it is steel hard. Coating is a desirable characteristic related to steel hardness: the clay minerals melt to form a viscous binding fluid which slowly fills and seals the interstices between rigid, non-melting grains. This sealed, smooth surface is said to be coated and is desirable because the aggregate does not absorb water from a cement slurry to weaken the concrete product. This viscous fluid that cools to form a glass is not scratched by a steel point, quartz grains are harder than steel and most rock fragments present in these materials also are not scratched by a steel point. When tested, therefore, the product is said to be steel hard.

In addition to the formation of viscous fluid, heating also produces gases from the breakdown of sulfides, sulfates, carbonates and organic matter. If the rate of gas formation exceeds the rate at which the gas can escape through the viscous fluid, the gas will be trapped and expand the softened body. Expansion lowers the relative density, and lightweight aggregate is produced.

Paskapoo Formation

Steel hardness of Paskapoo samples may be achieved at a temperature as low as 1060°C but 1090°C or greater is more common. Some samples that are steel hard after firing at low temperatures are scratched easily after firing to higher temperatures because the higher temperature expands the pellet and produces many vesicles with thin walls. Of the samples tested, less than 40 percent have a relative density less than 1. The presence of carbonate is unusual. Coating is common. Chunks and pellets tend to crack deeply during firing at low temperatures and the material may be too fragile to survive passage through a rotary kiln. Those chunks or pellets that survive, however, would have sealed walls in the cracks and would absorb no water from a cement slurry.

Table 12 lists semiquantitative estimates of clay mineral abundance. The high average abundance of smectite explains the deep cracking of much of the material on firing. The low smectite value, however, indicates that certain deposits may produce material with little or no cracking. Testing is required to determine the extent of such deposits. The presence of smectite has such a marked effect on drying and early firing behavior because of the ability of this clay mineral to absorb water. During preparation of pellets the smectite absorbs many times more water than the other clay minerals present in the mixture. As the pellet dries, this water is driven off and the clay shrinks. The strong shrinkage forces generated during the large reduction in volume for the smectite produces cracks in the pellet. More smectite produces deeper cracking. Similar forces crack natural chunks as they dry.

Table 12. Semiquantative estimates of clay mineral abundance in the Paskapoo Formation

Mineral	Low	High	Average percent
Smectite	20	90	45
Illite	10	65	40
Kaolinite	absent	15	5
Chlorite	absent	20	5

Scollard Formation

The shales and mudstones from the Scollard Formation commonly are extractable as chunks so that pelletizing may not be necessary. Narrow cracks perpendicular and parallel to bedding are common, however, after drying. These cracks deepen and widen during the initial stages of firing. The cracking tends to make the chunks fragile and they may not survive passage through a rotary kiln. Other ceramic tests show, however, that these same materials dry and fire well when ground, mixed with water and extruded. Therefore, the material may be useful when pelletized. Steel hardness may be attained at temperatures as low as 1060°C but some samples are easily scratched even after the highest firing temperature. Relative density varies from little change to less than 1. Coating is common and the presence of carbonate is unusual.

Table 13 lists semiquantitative estimates of clay mineral abundance. The high average smectite content helps to explain the deep cracking; however, carbonaceous films on bedding planes may also have a deleterious effect on chunks as the carbon burns, produces carbon dioxide gas and splits the chunks along these planes.

Horseshoe Canyon Formation

Pellets or chunks of shale or mudstone from the Horseshoe Canyon exhibit deep cracks on drying. Fired pellets from some samples are very fragile, whereas other samples that seem to have equally deep cracks are very strong. Relative density varies from little change to less than 1. Crack walls are sealed even in the samples that expand and have relative density less than 1. Coating is common. Steel hardness is achieved only at the higher firing temperatures. Carbonate is present only in a few samples.

Table 14 lists semiquantitative estimates of clay mineral abundance. The high abundance of smectite explains the deep cracking on drying.

Judith River Formation

Chunks and pellets develop deep cracks on drying and during the early stages of firing. Pellets tend to remain strong. Chunks are less strong but not fragile and might survive passage through a rotary kiln. Steel hardness is uncommon and usually is reached near the highest firing temperatures. Coating and relative density less than 1 are common. Walls of the deep

Table 13. Semiquantitative estimates of clay mineral abundance in the Scollard Formation

Mineral	Low	High	Average percent
Smectite	20	70	50
Illite	14	65	40
Kaolinite	5	15	10
Chlorite	absent	5	≤5

Table 14. Semiquantitative estimates of clay mineral abundance in the Horseshoe Canyon Formation

Mineral	Low	High	Average percent
Smectite	70	100	85
Illite	trace	20	15
Kaolinite	absent	5	trace
Chlorite	absent	10	trace

cracks are sealed. Carbonate is absent.

Table 15 lists semiquantitative estimates of clay mineral abundance. The high smectite content explains the deep cracking during drying and early firing.

Wapiti Formation

Pellets may develop deep drying and firing cracks or may remain quite solid with only a few narrow cracks. Deep cracks are more common and pellets with deep cracks tend to be fragile. Chunks tend to be fragile and to develop cracks parallel and perpendicular to bedding. Steel hardness is unusual but coating may start at temperatures as low as 1060°C. All samples tested fire to relative density less than 1. This relative density probably results from gas produced during combustion of abundant coal fragments. Carbonate content is minor.

Glaciolacustrine silt and clay sediments

Steel hardness is common if glaciolacustrine material is fired to 1120°C and material from some deposits needs firing only at 1090°C to yield a steel hard product. The silts and clays of glaciolacustrine sediments commonly fire to a relative density less than 1 to produce an aggregate that will float on water. The shallow surface cracks which form during expansion usually become sealed and the walls of the surface between cracks become coated. The sealed walls prevent water absorption. A few samples expand very little and yield a dense aggregate.

Calcium carbonate is a potentially deleterious component present in some silt and clay deposits as coarse, silt-sized limestone grains, as very fine, disseminated calcite or as more concentrated pockets of calcite with indistinct boundaries. Burning converts calcium carbonate to calcium oxide that upon cooling is susceptible to reaction with water and carbon dioxide to reconvert to calcium carbonate. This reconversion causes expansion that stresses the body around the grain or pocket of carbonate material and spalling occurs. If sufficient carbonate material is present, cumulative stress may be sufficient to disintegrate the body. Fortunately, spalling is uncommon in pellets made from glaciolacustrine silts and clays from the study region. The fine grain-size of the carbonate probably does not produce sufficient stress to cause spalling. The danger is present, however, and should be considered.

One raw sample was cohesive enough to fire as chunks rather than formed pellets; however, the material expands parallel to bedding planes during firing and the chunks become fragile. The material may break apart too easily in the kiln and produce aggregate fragments that are too small.

Table 16 shows semiquantitative estimates of clay mineral concentration. Most deposits have clay mineral contents close to the average values but the wide range of smectite and illite values illustrate that firing characteristics of glaciolacustrine sediments may change with each deposit investigated. It is very important, therefore, to test extensively any deposit considered as a source for synthetic aggregate raw material.

Till

In the study region only 2 of 70 samples are free of carbonate masses, rounded grains, rosettes or blades. Spalling is usual above fired calcite grains greater than 1 mm diameter. Pellets containing abundant carbonate grains are in danger of disintegrating. Coating commonly begins at 1060°C but steel hardness may or may not be achieved by firing to 1150°C for 15 minutes, the temperature at which the pellets commonly begin to stick together. Expansion cracks are common; however, crack walls do not begin to seal until firing progresses 5 minutes at 1150°C. Even though expansion cracks are common, relative density is seldom less than 1. The fired relative density greater than 1 is probably related to the usual high content of sand-sized and larger fragments of rocks and minerals whose specific gravity commonly exceeds 2.5 and remains so after firing.

Comments

An unresolved problem exists with some material tested in the study region. Sixteen of 56 samples (29 percent) blew up in the furnace during firing at the initial temperature of 1030°C. Samples were dried thoroughly before insertion into the furnace to eliminate steam buildup. The suggestion that the volume increase during the change of low temperature to high temperature cristabolites could cause the

Table 15. Semiquantitative estimates of clay mineral abundance in the Judith River Formation

Mineral	Low	High	Average percent
Smectite	65	80	70
Illite	10	20	15
Kaolinite	10	15	10
Chlorite	absent	5	trace

Table 16. Semiquantitative estimates of clay minerals in Pleistocene glaciolacustrine silts and clays

Mineral	Low	High	Average percent
Smectite	5	60	35
Illite	25	70	50
Kaolinite	5	25	10
Chlorite	trace	15	5

pellets to explode is not supported by data. No cristabolite is identified in any size fraction from explosive material. Calcite and dolomite are common in the samples and produce gas upon heating but these minerals are in no greater abundance than in non-explosive samples. Parting along cleavage planes in feldspars could produce stress in a body. Feldspar concentration is, however, no greater in an exploding body than in a non-exploding body. The suggestion that explosive samples contain higher amounts of gas-producing organic matter than non-explosive samples remains to be checked.

Appendix C

Description and discussion of tests used in sand and gravel analyses (table 8)

Gradation

Purpose

To determine the proportion (weight percentage) of material in given size ranges so that the value of a deposit for a given use can be assessed.

Test reference or method

ASTM C136, sieve fractions used in the analyses were: 3 in, 1 in, #4, #10, #40, #100, #200. These have been converted to metric measurements in table 8.

Results

Test results must be compared against specifications for a given use.

Angularity

Purpose

To assess the roundness and smoothness of particles so that skid resistance and the degree of bonding and workability in concrete can be assessed.

Test reference or method

Particles were described as rounded and smooth (rs), subangular and smooth (ss), angular and rough (ar), round and rough (rr) or subangular and rough (sr); in the 3 in to 1/2 in (75 mm to 12.5 mm) and 3/8 in to #200 (9.5 mm to 0.075 mm) size ranges.

Results

In general, round, smooth clasts give less resistance to pouring and working of concrete but provide less resistance to skidding on an exposed surface.

Percent of lightweight particles

Purpose

To determine the amount of lightweight particles (especially coal) which may weaken concrete or produce marring of the finish.

Test reference or method

ASTM C123

Results

The lightweight particle percentage should not exceed 1 percent for use in concrete or 0.5 percent in concrete where the finish is important.

Percent insoluble residue

Purpose

To determine the proportion of carbonate materials (often softer) which may not be as resistant to wear.

Test reference or method

ASTM D3042

Results

Aggregate with good wear resistance properties usually has an insoluble residue of more than 70 percent.

Percent wear

Purpose

To determine the resistance to abrasion of the material by determining the mineral content.

Test reference or method

ASTM C131 and C535

Results

Wear resistance is considered good if the percentage is less than 30 percent.

Organic impurities

Purpose

To determine the amount of organic material which will weaken concrete.

Test reference or method

ASTM C40

Results

Aggregate generally suitable for concrete should give a reading of 3 or less.

Percent of clay lumps and friable particles

Purpose

The test determines the percentage of clay lumps and friable particles which affect the strength and durability of portland cement concrete.

Test reference or method

ASTM C142

Results

For use in portland cement concrete the percentage should be less than 3.0 percent.

Soundness

Purpose

Soundness measures the resistance of an aggregate to weathering.

Test reference or method
ASTM C88

Results
A maximum 12 percent (sodium sulfate) is allowed.

Petrography
Purpose
A determination of the proportion of various rock types in the aggregate is useful in understanding the results of other tests.

Test reference or method
ASTM C294 and C295

Results
A high percentage of quartzite will usually correspond to high percentage insoluble residue, low percentage wear and low percentage loss of soundness. Sandstone in the region may be soft and contain carbonate particles or cement. This may produce a lower percentage insoluble residue and higher percentage loss of soundness.

Appendix D
Classification and use of aggregate

The main factors affecting the use of sand and gravel deposits are gradation, lithology of the particles in the deposit, deposit size and proximity to market areas, designated land use and transport methods. Deposits are generally classified by their gradation, lithology and other chemical and physical characteristics. Classifications are not rigid, however, since material is rarely used as it was excavated; blending of materials of different sizes, or even from different deposits, is a common occurrence.

Gradation is an assessment of the various particle sizes within a deposit; it is established by running a sample through a series of standard sieve sizes. Sand and gravel are generally classified by the percentage by weight of the gravel content, sand content and silt and clay content (figure 4), and by the uniformity of the gradation of these materials. The exact mixes of sand to gravel vary with the specification sought but there is always a maximum acceptable level of silt and clay (often referred to as fines). The level of fines determines how "clean" or "dirty" the deposit is. The standards we use consider *clean* material to have less than 5 percent fines, *dirty* material to have from 5 to 12 percent fines, and *very dirty* material over 12 percent fines.

Another important factor in gradation is the proportion of gravel that can be crushed to smaller sizes. It is generally accepted that at least 35 percent of the material should be larger than 20 mm if a variety of aggregate products are to be produced. Too much material greater than 10 cm may be troublesome, however, because it will have to be crushed or removed.

Lithology is an assessment of the physical character of a deposit made through an examination of the rock types within it. It is important to know the composition of the deposit because the quality of an aggregate for various uses will depend upon the rock types present. Alberta sand and gravel deposits are often a complex mixture of rock types from the Canadian Shield, the mountains and local bedrock. Within any deposit, material can have come from these various sources; some lithologies will downgrade the overall quality of the deposit for certain uses. Among the lithologies that cause problems in Alberta are chert, shale, siltstone, ironstone and coal.

Other physical and chemical characteristics of the rocks in a deposit that affect its use include: *resistance to abrasion,* an indication of the hardness and toughness of the aggregate; *soundness,* an indication of resistance to deterioration due to freezing and thawing; *petrographic composition,* an identification of deleterious and weaker materials; and *absorption,* an assessment of the amount of water that aggregate will absorb (see appendix C).

Uses of aggregate

The main uses of aggregate are related to the inert qualities of the material, its drainage characteristics and its very low unit cost. The most important uses for aggregate are in the construction industry but there are industrial applications as well.

Road construction
Aggregate is the primary ingredient in all road construction in Alberta. It is used in its natural form for road base and for gravelling country roads. It may also undergo processing, such as crushing, washing and sieving, to produce a higher quality material for uses such as asphalt or concrete. This use of aggregate consumes about 52 percent of the production in the study region.

Building construction
Large quantities of aggregate are used in residential and non-residential building construction, mostly in the form of concrete but also as fill, in drainage layers and for roofing material.

Railroad ballast
Significant amounts of aggregate are used in rail line construction and maintenance. In Alberta this is one of the few areas where crushed stone plays a role. Most of the stone is brought in from British Columbia.

Engineering construction
Large engineering projects such as dams, plant sites and airports use aggregate as structural bases, drainage layers, backfill and as concrete. One unique use for aggregate in Alberta is in the oil sands: enormous quantities of aggregate are used at the plant site to provide a well-drained, sturdy foundation in the

predominantly muskeg terrain.

Concrete products
As ingredients of concrete, aggregates find varied uses in such products as sewer pipes, sidewalk blocks and steps, precast structures, ornamental planters and interlocking blocks.

Industrial uses
The many applications of sand in industry depend on factors such as uniformity of size and silica content. The industrial applications of sand include making glass products and mold for refractory work, use as an abrasive agent and a filtering agent and use in the hydraulic fracturing of oil and gas wells.

Appendix E

Using the data: a municipal example

The aggregate data presented in this report are meant to be useful to municipalities considering potential land use decisions or drafting general municipal plans. Appendix H contains the information necessary to make informed land use decisions, but municipalities may be uncertain how best to use the data. To illustrate how the technical data can be applied we have created a simple case study with a hypothetical county, using the type of data found in table 17.

Our hypothetical county (figure 15) contains a city, a town and a well-developed rural road network. The county historically has obtained its gravel requirements from three deposits: the gravel deposit (no. 1) in the northern part of the county, and the sandy gravel deposits (no. 2 and 3) in the southern portion of the county. Deposits 2 and 3 have been used for the town and city as well as for the rural needs in the southern portion of the county, while deposit 1 has only been used by the northern part of the county. The rate of gravel consumption (in 1983) from the three deposits is shown in table 18.

The aggregate resource commonly is developed to fill specific local needs and usually is governed simply by market demand. In this county market demand is growing by one percent per year. When this growth is added to the present rate of consumption (table 18), we can forecast that deposit 3 will last until 1995, deposit 2 until 2002, and deposit 1 will last well into the next century. If new demands are put on the aggregate

Table 18. Consumption of sand and gravel in the hypothetical county for 1983. Consumption is in thousands m³ from deposits 3, 2 and 1 (figure 15).

		3	2	1
City		1500		
Town			300	
County:	southeast		200	
	southwest	200		
	north			100
Total		1700	500	100

Table 17. Original sand and gravel resources of the hypothetical county

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Gravel	1	A	61 100	15 275	1.0	10.0	763	5
Total	1		61 100	15 275			763	
Sandy gravel	2	B	12 800	8 500	2.0	6.0	355	4
	3	B	38 700	31 600	4.0	10.0	703	4
Total	2		51 500	40 100			1058	
Sand	4	D	0	180	0.0	2.0	87	2
	5	D	0	140	0.0	2.0	17	2
	6	D	0	211 800	1.0	12.0	1757	1
Total	3		0	212 120			1861	
Total	**6**		**112 600**	**267 495**			**3682**	

Each deposit is identified by a *deposit number.* This number identifies the deposit on figure 15. *Type and reference* is a key to the source of information. Appendix H elaborates on this aspect for actual data. The *gravel* and *sand* columns indicate the estimate resource in thousands of cubic metres. The *overburden thickness* and *deposit thickness* are averages given in metres. *Deposit area* is given in hectares. The geological origin of the deposit *(genesis)* can be determined by applying the genesis number to the legend in appendix H.

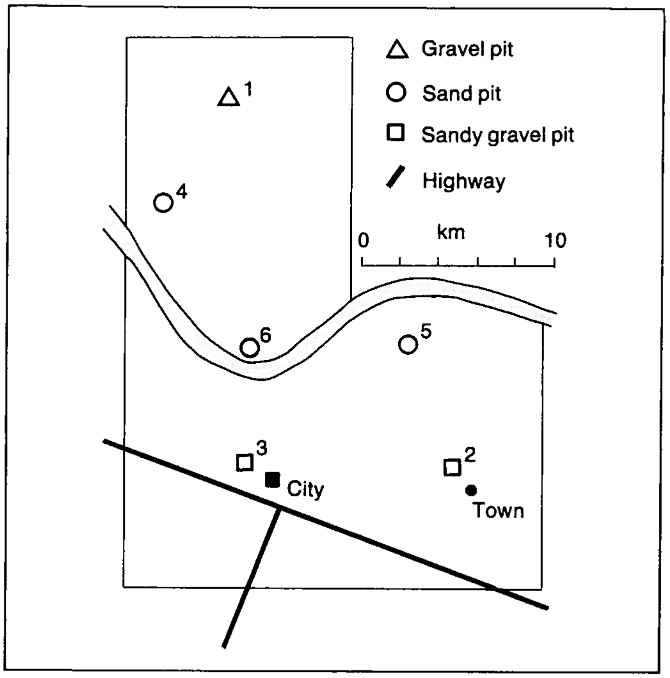


Figure 15. Location of deposits in municipal example

resource these projections will be incorrect, however, and this is the case in our hypothetical county. Two unexpected demands on the resource will emerge:

1. a proposal for the development (in 1985) of a regional airport at the location of deposit 1, and
2. a five-year highway upgrading and twinning project through the county, commencing in 1989, and consuming some 4 million m³ of gravel per year.

These unexpected demands for aggregate can present the municipal administrators with a dilemma since the two new projects will be competing with the traditional users for a diminishing gravel supply. The question is: How can the aggregate resource be used for the optimum long-term benefit of all county users? To show what could happen we have created two scenarios which take different approaches to the problem.

The first scenario has the gravel deposits developing in a fairly typical manner, that is, responding solely to market demands. In this case the county officials are unaware of the quality of aggregate resources in their jurisdiction, or the relative importance of the deposits. The second scenario differs from the first because the county officials have access to data on their aggregate resources (table 17 and 18) and recognize the importance of gravel to the economic development of the county. In this latter case the county is prepared to make land use decisions affecting the gravel resource and to lobby provincial officials to modify plans for both the airport and the highway. With the next closest deposit 60 km outside the county, the county officials appreciate the increased cost to their municipality if part of deposit 1 is sterilized by the airport and highway construction consumes all of deposits 2 and 3.

The following scenarios will assume that the cost of extracting and beneficiating gravel is $1/m³ and the cost of transporting one cubic metre is $0.10/km.

Table 19. Aggregate processing and transportation cost (million $) for scenario 1 (1983-2010)

	Processing	Transportation	Total
City	48.20	210.49	258.69
Town	9.65	42.20	51.85
County	16.00	73.03	89.03
Highway	20.00	45.27	65.27
Bridge*	3.00	4.50	7.50
Total	96.85	375.49	427.34

*A bridge is required for access to deposit 1 from the southern part of the county

Scenario 1

If allowed to develop according to demand, the resource will flow to the nearest market, be marketed to the highest bidder and be developed only if this is the most lucrative use of the land.

Thus, the highway project would initially draw aggregate from the closest deposit (3) and the land use decision involving the airport could evolve as follows: Given the fact that county extraction is already taking place and that the deposit is extensive, a probable response would be to test out an area with a 100 year supply (that is, 100 000 m³ x 100 = 10 000 000 m³; cost of testing — $20 000) and allow the remainder to be used as the airport. The available supply in 1986 from deposit 1 would therefore be reduced from 59 million m³ to 10 million m³ after airport sterilization. With the advent of the highway project in 1989, this would totally deplete deposit 1 by 1992 and increase the total cost of aggregate to consumers in the county to $473.34 million by 2010 because of increased transportation costs associated with hauling aggregate the additional 60 km from outside the county.

The cost of gravel to all users in the hypothetical county by 2010 is shown in table 19.

Scenario 2

This scenario assumes that an aggregate mapping and evaluation program has been conducted. This survey shows that all the gravel resources lie in three deposits (figure 16) and that these resources are limited (figure 17). Both southern deposits will be depleted by 1996 *without* any unpredictable demands. It is decided that the available gravel resource should be conserved if possible. An action plan is developed to maximize the use of the deposits for the primary consumers.

This plan would conserve the limited resources of deposits 2 and 3 for the ongoing users (the city, town and county south of the river), recognize the near-future requirements of various users for aggregate from deposit 1 and when the proposal for the airport is made, not allow construction until the aggregate is removed. The requirements of the highway project would be directed to deposit 1 or to the deposits outside the county, ensuring overall aggregate efficiency.

Based on the above actions, the resulting costs would be as indicated in table 20.

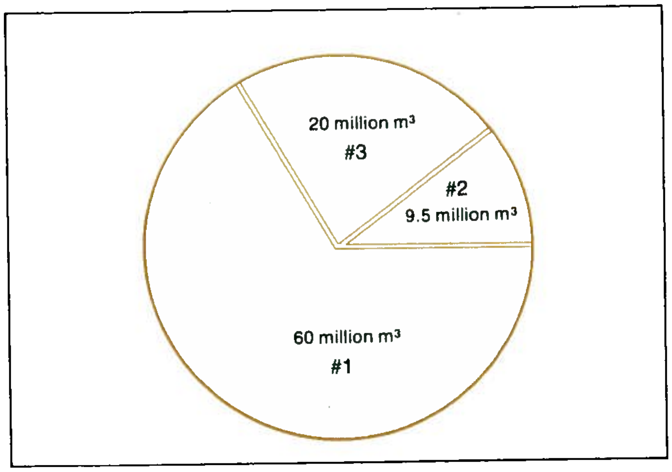


Figure 16. Available gravel supply in 1983 by deposit

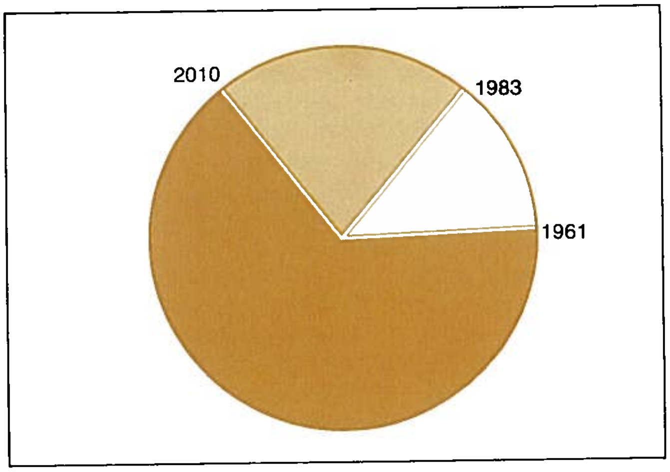


Figure 17. Consumption of original gravel reserve to 1983 and 2010

Conclusions
Table 21 gives the overall comparison of costs for the two scenarios.

The saving over a 27-year period (1983-2010) is over $200 million if the aggregate information is applied through land use management and planning. This saving results from the prevention of gravel resource sterilization by the airport and more effective use (lower transportation costs) of the resource. More effective use was obtained by having the highway project pay more initially to haul longer distances to provide immediate relief to the city, town and county and ultimate saving on its own project.

This example is hypothetical but the magnitude of the potential saving is real. In real life the issues are complex and each case is different but *all* cases require attention, adequate data for evaluation and an action plan.

Table 20. Aggregate processing and transportation cost (million $) for scenario 2 (1983-2010)

	Processing	Transportation	Total
City	48.20	79.89	128.09
Town	9.65	15.58	25.23
County	16.00	31.80	47.80
Highway	20.00	40.00	60.00
Bridge	3.00	4.50	7.50
Total	96.85	171.77	268.62

Table 21. Cost comparison of scenarios (millions $)

	1	2
City	258.69	128.09
Town	51.85	25.23
County	89.03	47.80
Province:		
Highway	65.27	60.00
Bridge	7.50	7.50
Geological survey	-	0.20
Testing	0.02	-
Total	472.36	268.82

Appendix F
Reliability of resource estimates

The reliability of resource estimates is based on the complexity and variability of the deposit and the amount of information available to the geologist making the assessment.

A straightforward case can be assessed with limited data such as air photo delineation of the deposit plus data from one pit or natural exposure or a testhole log. If the deposit is of variable depth or grain size, however, these same data can give an inaccurate resource estimate.

An example from the study area can be used to illustrate the need for caution in using resource estimates.

An outwash deposit (figure 18) is located 30 km southeast of St. Paul (deposit 371). This deposit is delineated and described as "outwash sand and gravel" in a surficial geology report (Ellwood, 1961). A pit with a depth of 9 m was located in this deposit. An initial aggregate resource estimate was made in 1977 from these data (figure 19) prior to geological mapping by the Alberta Geological Survey.

This procedure is similar to that used in many reconnaissance programs. Such a technique is described more fully in the *Edmonton Regional Aggregate Study* (City of Edmonton, 1978). The estimate indicated that 37 710 000 m³ of sand and gravel could be present. Geologic mapping of exposures and further air photo interpretation by the Alberta Geological Survey resulted in an aggregate resource estimate of 15 300 000 m³, of which 19 percent is gravel (figure

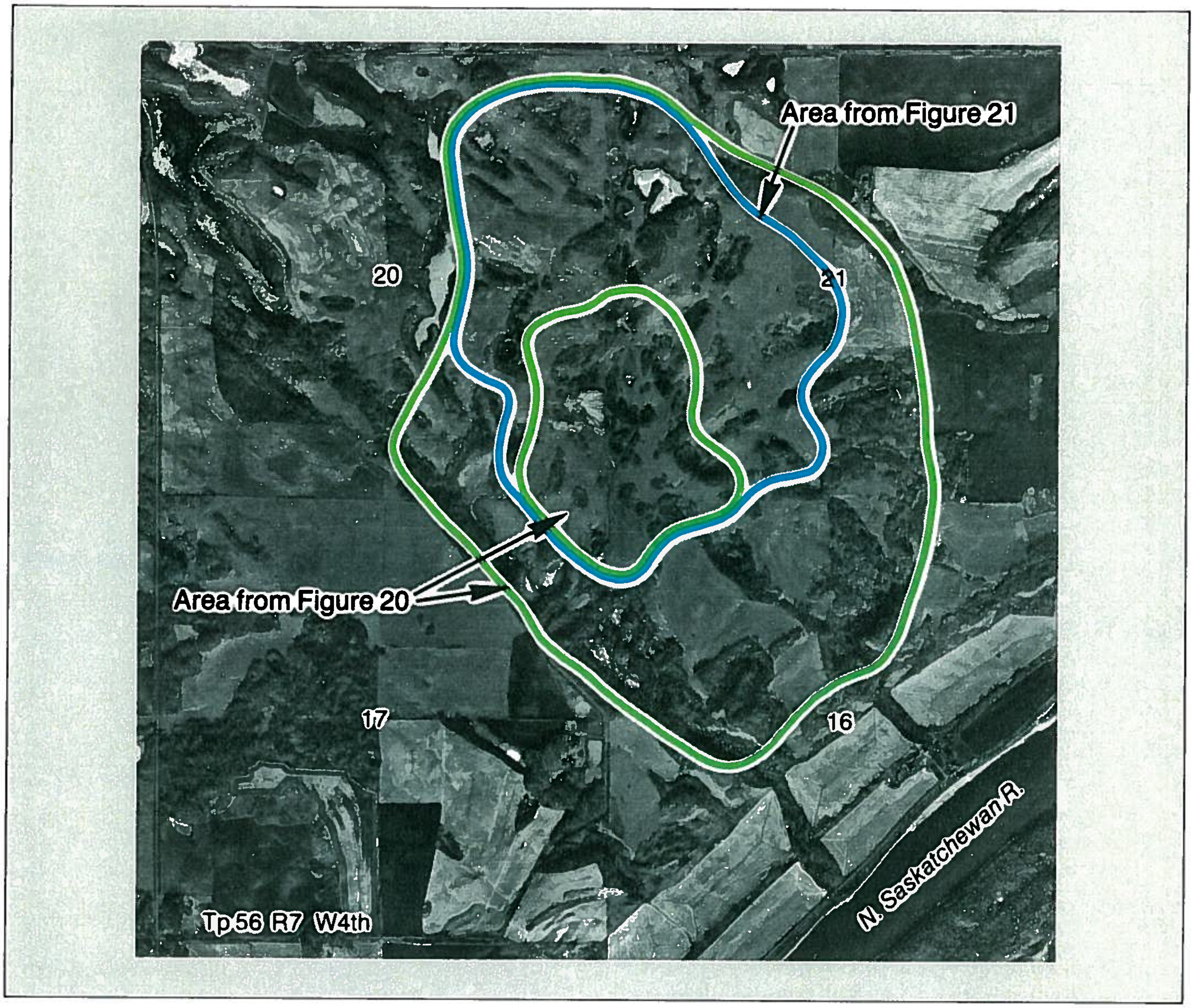


Figure 18. Delineation of an outwash deposit in the Elk Point area on an air photograph

20). Following the geologic mapping, some testhole drilling, a geophysical survey and additional sampling were performed (figures 21, 22 and table 22). Using all available data, a final resource estimate of 11 200 000 m³ aggregate with 29 percent gravel was made and used in this study.

Most of the deposits in this study were assessed on the basis of geological mapping, sampling or visual grain size estimates and air photo interpretation — and in most cases considerably fewer data were used than in the case of deposit 371. All figures should be used as estimates which can be revised as additional data are acquired. We expect that development of a deposit will proceed only after detailed testing and sampling has confirmed the presence of sufficient reserves.

Table 22. Petrographic analyses of pebbles (12 mm to 36 mm) from 6 sample sites in deposit 371

	Durable rock types				Potentially deleterious rock types				
	Granite (percent)	Quartzite (percent)	Hard sandstone (percent)	Gneiss (percent)	Schist (percent)	Friable sandstone (percent)	Carbonate (percent)	Local[1] rock (percent)	Chert (percent)
Average	51.2	5.8	24.3	4.5	0.8	2.2	0.2	10.5	0.5
Range	48-59	2-14	14-31	2-7	0-3	0-5	0-1	7-17	0-2

[1]Local rock types: shale, siltstone, ironstone, sandstone (see friable sandstone) and coal.

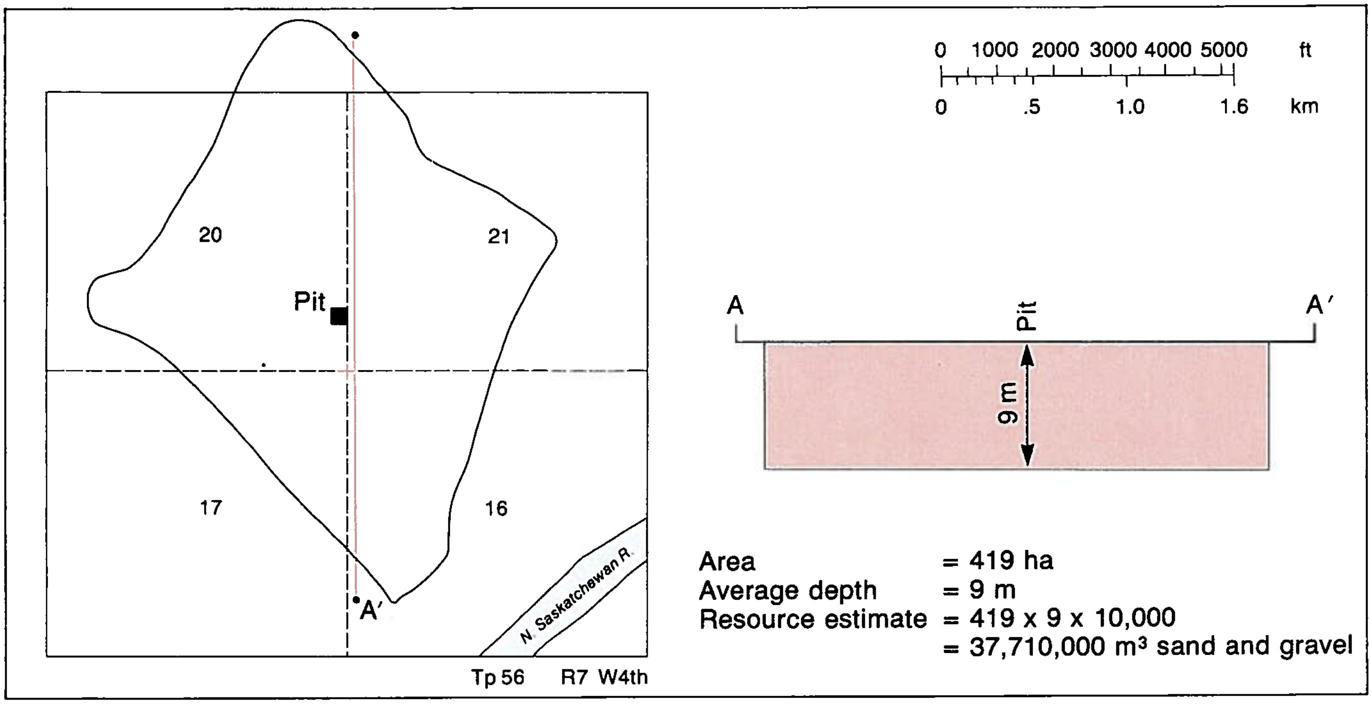
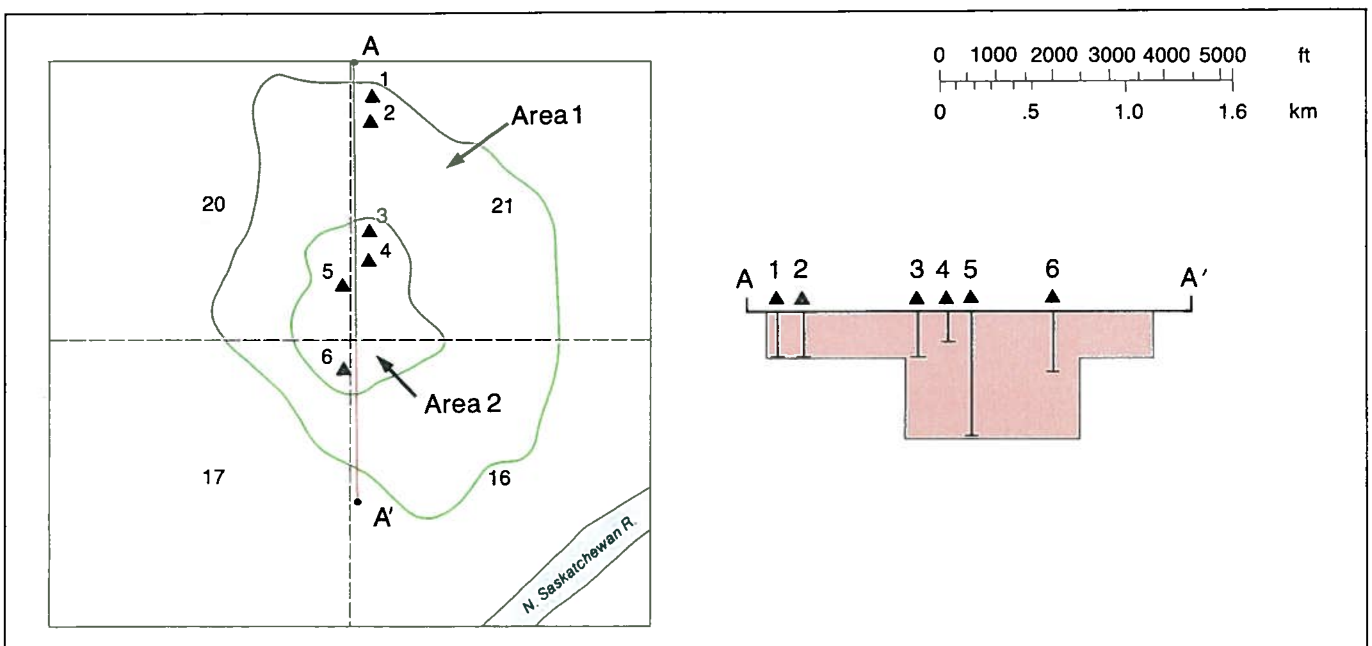


Figure 19. Resources estimate based on a surficial geology report and one site description

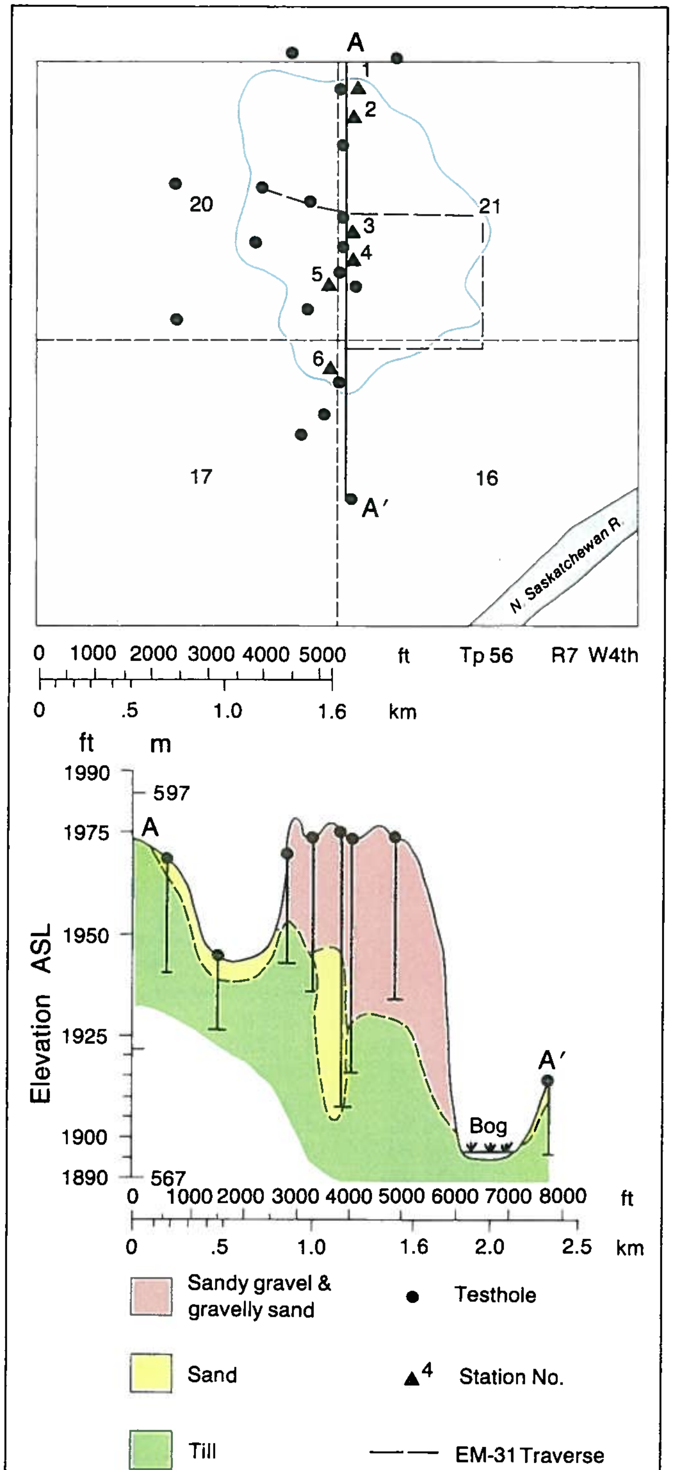


Area 1 (less area 2) = 330 ha; Area 2 = 60 ha

Depth and material (from site descriptions) = (1) sand over till, 3 m; (2) sand, 3 m; (3) gravelly sand, 3 m; (4) sandy gravel (gravel 55%, sand 45%), 2 m; (5) sandy gravel (gravel 55%, sand 45%), 9 m; (6) sandy gravel

Resource estimate	Area 1	330 x 3 x 10,000	= 9,900,000 m³ sand
	Area 2	55% (60 x 9 x 10,000)	= 2,970,000 m³ gravel
		45% (60 x 9 x 10,000)	= 2,430,000 m³ sand
Sub total	- sand		12,330,000 m³
	- gravel		2,970,000 m³
Total			15,300,000 m³

Figure 20. Resources estimate based on six geologic sites and an air photo interpretation of the area



Area - 215 ha (less 9 ha already developed)
= 206 ha
Material and depth - cross-sections and contour maps were developed.

Resource estimate -	gravel =	3,233,000 m^3
	sand =	7,967,000 m^3
Total		11,200,000 m^3

Figure 21. Resources estimate based on geological maping, sampling, testhole drilling and a geophysical survey

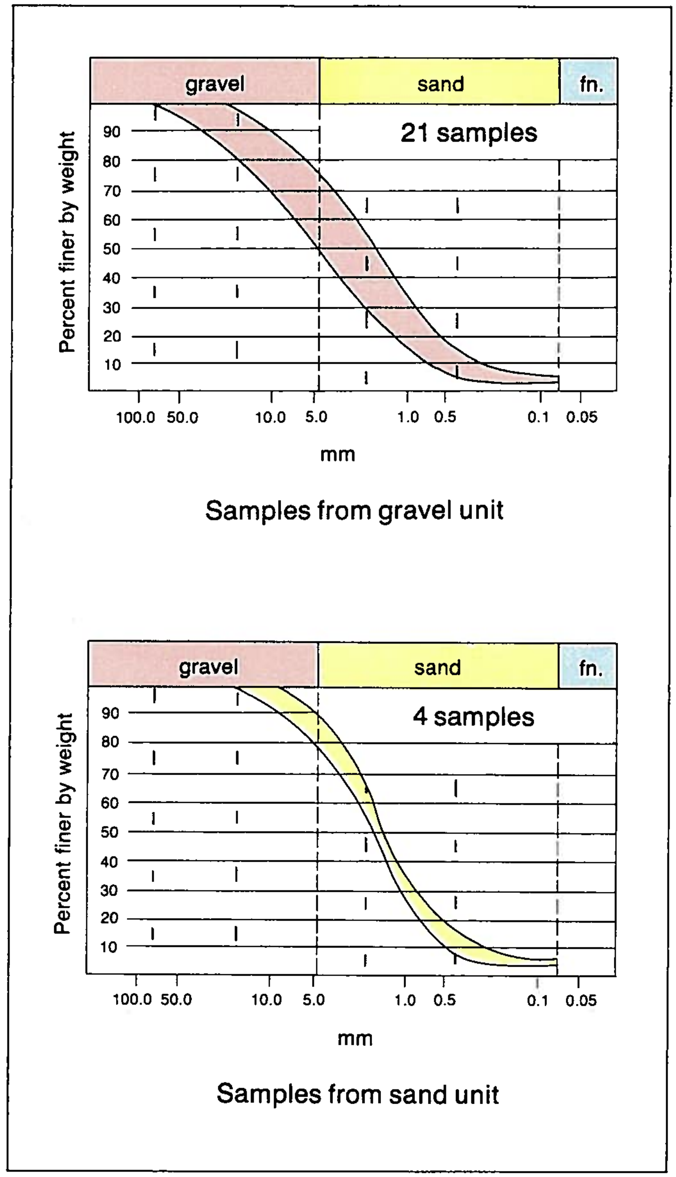


Figure 22. Grain size analyses of samples along cross section A-A′ (figure 21)

Appendix G

Sand and gravel forecast model

Dr. Sastry Madduri, Energy Economist (Economics Branch, Alberta Energy Resources Conservation Board) prepared an econometric model to forecast demand for gravel and sand. We selected the following relationship from several model specifications to explain the demand for gravel and sand in Alberta. We have specified that demand is equal to production, is a function of real per capita gross provincial product and a constant term. It is assumed that demand increases with increasing economic activity and population growth in the province. We have chosen a nonlinear equation which can be expressed as a semilog model.

$$C_t = f(Y_t/P_t) \quad (1)$$

This can be expressed as

$$\text{Exp. } C_t = A(Y_t/P_t)^B + U_t \quad (2)$$

Exp. C_t is the exponential of consumption or demand for gravel and sand (C_t), millions m^3

Y_t is the real gross provincial product, millions $, 1971

P_t is the provincial population, millions of people

Y_t/P_t is the per capita real gross provincial product, 1971 dollars

A, B are constants

U_t is the stochastic term in the model which carries regular characteristics of a regression model.

Taking logarithms on both sides of (2)

$$C_t = A + B\log(Y_t/P_t) + U_t \quad (3)$$

This is the semilog specification of the model. We have estimated this inherently linear model (equation 3) with ordinary least squares using time series data from 1961 to 1982. The estimated model was:

$$C_t = -147.029 + 19.7109\,\text{Log}(Y_t/P_t) \quad (4)$$

(6.2793) (7.1561)

$R^2 = 0.7051$; D.W. = 1.4835; S.E.R. = 2.5968; $F(1, 20) = 51.2090$

Numbers in the parentheses are the computed statistical values. They indicate that the estimated coefficients are significantly different from zero at the 99 percent level of significance. A negative constant term indicates that in the absence of any economic activity and population growth, the demand for gravel and sand will be declining. A positive sign on log (Y_t/P_t) indicates, however, that any change in the economic activity will have a direct and significant effect on the demand for gravel and sand. R^2, which is a measure of multiple correlation, indicates that 70.5 percent of the variation in C_t is explained by equation 4. Other measures, namely, D.W., S.E.R., and F (1, 20), fall under statistically acceptable limits.

Equation 4 was used to forecast the demand for sand and gravel for the period 1983 to 2010. The right-hand side variables were generated in the following way: forecast the real gross provincial product (Y_t) at a rate equal to the Canadian gross national product and use the Alberta population projection series 1 as developed by the Alberta Bureau of Statistics to forecast population. These series are shown in table 23.

In order to forecast the demand for gravel and sand for Alberta, the study region and selected study areas, the 1981 survey data gathered for this report were used to develop ratios. Assuming that these shares will continue in the future, the demand for gravel and sand for each county and other individual areas for the forecast period 1983-2010 has been allocated. Table 24 shows the forecast gravel and sand production in Alberta.

Table 23. Real and per capita gross provincial product and population (1961-2010)
Real gross provincial product 1971 dollars, million (RGPP), the population of Alberta, million (POPL), and per capita real gross provincial product, 1971 dollars (PCRGPP) for the period commencing 1961 and forecast to 2010

Year	RGPP	POPL	PCRGPP
1961	4650.00	1.33200	3490.99
1962	4904.00	1.36900	3582.18
1963	5130.00	1.40300	3656.45
1964	5376.00	1.43000	3759.44
1965	5728.00	1.45000	3950.35
1966	6165.00	1.46320	4213.37
1967	6391.00	1.49000	4289.26
1968	6722.00	1.52400	4410.76
1969	7146.00	1.55900	4583.71
1970	7373.00	1.59500	4622.57
1971	7841.00	1.62790	4816.64
1972	8401.00	1.65730	5069.09
1973	9257.00	1.68950	5479.13
1974	9608.00	1.72240	5578.26
1975	10213.0	1.77830	5743.13
1976	10640.0	1.83800	5788.90
1977	11127.0	1.91140	5821.39
1978	12676.0	1.98410	6388.79
1979	12770.0	2.05870	6202.94
1980	13557.0	2.14260	6327.36
1981	14414.0	2.23730	6442.59
1982	13702.0	2.32330	5897.64
1983	13848.0	2.35600	5877.76
1984	14568.0	2.39010	6095.14
1985	15168.0	2.42340	6258.97
1986	15564.0	2.45830	6331.20
1987	16116.0	2.49340	6463.46
1988	16620.0	2.53000	6569.17
1989	17124.0	2.56740	6669.78
1990	17580.0	2.60560	6747.01

Year	RGPP	POPL	PCRGPP
1991	18120.0	2.64460	6851.70
1992	18648.0	2.68440	6946.80
1993	19140.0	2.72480	7024.37
1994	19572.0	2.76610	7075.66
1995	20052.0	2.80840	7140.01
1996	20460.0	2.85180	7174.41
1997	21072.0	2.89610	7275.99
1998	21648.0	2.94250	7357.01
1999	22284.0	2.98870	7456.08
2000	22932.0	3.03480	7556.34
2001	23604.0	3.08090	7661.40
2002	24300.0	3.12700	7771.02
2003	25008.0	3.17310	7881.25
2004	25752.0	3.21930	7999.25
2005	26508.0	3.26530	8118.09
2006	27288.0	3.31150	8240.38
2007	28080.0	3.35750	8363.37
2008	28908.0	3.40340	8493.86
2009	29760.0	3.44900	8628.59
2010	30636.0	3.49430	8767.42

Table 24. Provincial sand and gravel production (1961-2010)
Alberta-1 represents a low case and Alberta-2 a high case (millions m³).

Year	Alberta-1	Alberta-2
1961	15.7017	15.7017
1962	16.7968	16.7968
1963	20.1260	20.1260
1964	20.9213	20.9213
1965	17.9280	17.9280
1966	16.0694	16.0694
1967	17.6916	17.6916
1968	16.9597	16.9597
1969	18.5853	18.5853
1970	20.0039	20.0039
1971	23.2924	23.2924
1972	25.6330	25.6330
1973	23.2019	23.2019
1974	27.9452	27.9452
1975	25.5051	25.5051
1976	30.5754	30.5754
1977	29.8027	29.8027
1978	23.6408	23.6408
1979	29.1036	29.1036
1980	27.5278	27.5278
1981	29.9385	29.9385
1982	27.1722	32.8062
1983	27.1958	30.2664
1984	28.0055	31.1534
1985	28.5970	31.8782
1986	28.8528	32.3499
1987	29.3138	32.9988
1988	29.6756	33.5830
1989	30.0145	34.1597
1990	30.2711	34.6751
1991	30.6145	35.2782
1992	30.9219	35.8604
1993	31.1694	36.3965
1994	31.3317	36.8624
1995	31.5336	37.3750
1996	31.6407	37.8064
1997	31.9542	38.4468
1998	32.2011	39.0423
1999	32.4994	39.6918
2000	32.7973	40.3456
2001	33.1051	41.0151
2002	33.4219	41.7000
2003	33.7360	42.3882
2004	34.0674	42.1023
2005	34.3962	43.8189
2006	34.7296	44.5491
2007	35.0599	45.2814
2008	35.4051	46.0376
2009	35.7561	46.8060
2010	36.1120	47.5863

Appendix H

Resource estimates for deposits within the study area

Index

Deposits are listed by jurisdiction (county, municipal district [M.D.], improvement district [I.D.], or City of Edmonton). Within each jurisdiction deposits are categorized by gradation (gravel, sandy gravel, gravelly sand, sand or unknown [see figure 4 for definition of each category]). Each deposit is identified by a *deposit number.* This number locates the deposit on figures 2 or 3. Each deposit is described from an existing source. The *reference* and the gradation category selected is keyed to the following:

A- Gravel B- Sandy gravel C- Gravelly sand D- Sand E- Unknown	Alberta Research Council aggregate map or report 1:50 000
F- Sandy gravel (unit 1) G- Gravelly sand (units 2,3,4) H- Sand (units 5,6,7) I- Unknown (unit 8)	Alberta Research Council aggregate map 1:250 000

J- Gravel K- Sand L- Unknown	 Alberta Research Council aggregate questionnaire survey
M-Gravel N-Sandy gravel O-Gravelly sand	Alberta Research Council aggregate map or report and aggregate questionnaire survey 1:50 000
Q-Unknown R-Sandy gravel S-Gravelly sand T- Sand U-Unknown	Alberta Research Council aggregate map and aggregate questionnaire survey 1:250 000
V- Unknown	Surficial geology map

The gravel and sand columns indicate the estimated resource in thousands of cubic metres. If the type of deposit is listed as *unknown*, the amount and gradation of the deposit is not known and therefore the amount of resource is not listed. The *overburden thickness* is an average for the deposit and is in metres. The *deposit thickness* is an average for the deposit and is in metres. The *deposit area* is given in hectares and is determined from air photographs. The *genesis* refers to the geological origin of the deposit. The following legend applies to the tables following and the surficial geology map (figure 13):

1 - Alluvial
2 - Eolian - dune
3 - Eolian - loess
4 - Glaciofluvial
5 - Fluvial (preglacial)
6 - Glaciolacustrine
7 - Organic, other
8 - Glacial
9 - Bedrock

Edmonton

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Gravel	0		0	0			0	
Total deposits	0		0	0			0	
Sandy gravel	312	B	1 131	900	3.0	5.0	104.0	1
Total deposits	1		1 131	900			104	
Gravelly sand	310	O	4 500	7 300	2.5	4.0	440.0	1
Total deposits	1		4 500	7 300			440	
Sand	082 083 309	D D P	0 0 0	180 140 10 800	0.0 0.0 1.0	2.0 2.0 8.0	87.0 87.0 550.0	2 2 1
Total deposits	3		3 450	11 120			654	
Unknown	409	E	0	0	0.0	0.0	65.0	1
Total deposits	1		0	0			65	
Total deposits	**6**		**9 081**	**19 320**			**1 263**	

County 7 - Thorhild

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Gravel	0		0	0		0		
Total deposits	0		0	0			0	
Sandy gravel	219	B	50	48	3.5	4.0	2.0	1
Total deposits	1		50	48			2.0	
Gravelly sand	214	C	300	870	2.0	3.0	40.0	1
	216	C	430	690	0.5	1.5	77.0	4
	217	C	520	930	0.5	1.0	150.0	4
	351	O	2 445	5 297	1.0	2.5	354	4
	352	O	520	1 352	0.5	1.0	211.0	4
Total deposits	5		4 215	9 139			832.0	
Sand	013	P	8	155	0.0	3.0	5.5	4
	015	P	0	77 460	0.0	2.5	5 354.0	2
	016	D	0	0	0.0	0.0	0.0	2
	017	D	0	2 000	0.5	1.0	2 240.0	
	018	D	0	600	0.5	1.0	60.0	4
	019	P	0	0	0.0	0.0	0.0	2
	020	D	0	730	0.0	1.0	70.0	4
	021	D	0	0	0.0	0.0	0.0	2
	022	D	0	550	0.0	1.0	58.0	4
	023	D	0	0	0.0	0.0	0.0	2
	029	D	0	0	0.0	0.0	0.0	2
	031	D	0	4 000	0.5	1.0	410.0	4
	033	P	0	13 494	0.0	3.0	775.0	2
	125	D	0	5 000	0.0	2.0	250.0	4
	140	D	0	3 510	0.0	2.0	195.0	4
	141	D	747	2 801	0.0	1.5	249.0	4
	142	D	398	18 914	0.0	2.5	1 244.0	4
	144	P	0	27 930	0.0	2.0	1 470	4
	145	D	0	2 214	0.0	1.5	164.0	4
	146	D	118	1 003	0.0	1.0	118.0	4
Total deposits	20		1 271	160 361			12 663.0	
Unknown	151	L	0	0	0.0	0.0	0.0	0
	188	I	0	0	0.0	0.0	0.0	0
	366	I	0	0	0.0	0.0	0.0	0
	378	E	0	0	0.0	0.0	32.0	1
	379	E	0	0	0.0	0.0	85.0	4
	525	L	0	0	0.0	0.0	0.0	0
	536	L	0	0	0.0	0.0	0.0	0
	568	V	0	0	0.0	0.0	0.0	8
Total deposits	8		0	0			117.0	
Total deposits	**34**		**5 536**	**169 548**			**13 614**	

County 9 - Beaver

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Gravel	0		0	0			0.0	
Total deposits	0		0	0			0.0	
Sandy gravel	304	B	2 750	2 000	0.2	4.5	111.4	4
	305	B	825	600	0.1	3.5	42.8	4
	330	B	3 600	1 800	0.5	2.5	223.0	4
Total deposits	3		7 175	4 400			377.0	
Gravelly sand	331	O	900	1 070	0.5	2.5	79.0	4
Total deposits	1		900	1 070			79.0	
Sand	066	D	518	5 702	0.0	1.5	450.0	4
	112	D	0	500	0.5	2.0	25.0	4
	113	D	0	100	0.0	2.0	5.0	4
	114	D	0	140	0.5	1.0	14.0	4
	115	D	0	140	0.5	1.0	14.0	4
	118	D	0	27 000	0.5	9.0	306.0	4
	119	D	1	4	0.3	2.5	0.5	4
Total deposits	7		519	33 586			815.0	
Unknown	182	E	0	0	0.0	0.0	0.0	4
	183	E	0	0	0.0	0.0	0.0	4
	528	U	0	0	0.0	0.0	0.0	8
	529	U	0	0	0.0	0.0	0.0	4
	530	U	0	0	0.0	0.0	0.0	4
	554	L	0	0	0.0	0.0	0.0	0
Total deposits	6		0	0			0.0	
Total deposits	**17**		**8 594**	**39 056**			**1 271**	

County 10 - Wetaskiwin

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Gravel	227	A	6 757	938 001	8 380.0	600.0	3 500.2	5
	306	A	2 930	1 180	0.3	2.5	175.0	4
	307	M	4 900	2 180	0.3	2.7	270.0	4
Total deposits	3		14 587	941 361			3 945	
Sandy gravel	207	B	95	55	0.3	2.0	79.0	4
	208	B	450	357	0.5	1.0	85.0	4
	209	B	1 200	1 650	0.3	3.0	111.0	4
	222	B	1 110	616	0.6	2.5	80.0	4
	223	B	435	1 280	0.3	2.0	87.0	4
	228	B	1 000	640	3.0	4.5	37.0	5
Total deposits	6		4 290	4 598			479	

County 10 - Wetaskiwin (continued)

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Gravelly sand	206	C	2 020	3 530	0.3	1.5	382.0	4
	229	C	84	144	0.0	3.0	8.0	4
	455	G	0	0	0.0	0.0	0.0	0
	456	G	0	0	0.0	0.0	0.0	0
	457	G	0	0	0.0	0.0	0.0	0
	459	G	0	0	0.0	0.0	0.0	0
	461	G	0	0	0.0	0.0	0.0	0
	462	G	0	0	0.0	0.0	0.0	0
	464	G	0	0	0.0	0.0	0.0	0
	465	G	0	0	0.0	0.0	0.0	0
Total deposits	10		2 104	3 674			390	
Sand	038	P	4 880	51 240	1.0	6.0	1 100.0	4
	039	P	0	21 865	0.0	6.0	1 166.0	2
	040	P	0	9 440	0.0	3.5	810.0	2
	077	D	0	9 504	0.0	6.0	400.0	2
	078	D	0	6 441	0.0	2.5	830.0	2
	308	D	20	235	1.5	3.5	8.0	1
	453	H	0	0	0.0	0.0	0.0	0
	458	H	0	0	0.0	0.0	0.0	0
	463	H	0	0	0.0	0.0	0.0	0
	474	K	0	0	0.0	0.0	0.0	0
Total deposits	10		4 900	98 725			4 314	
Unknown	454	I	0	0	0.0	0.0	0.0	4
	460	I	0	0	0.0	0.0	0.0	4
	476	L	0	0	0.0	0.0	0.0	0
	541	U	0	0	0.0	0.0	0.0	5
Total deposits	4		0	0			0	
Total deposits	**33**		**25 881**	**1 048 358**			**9 128**	

County 11 - Barrhead

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Gravel	155	A	160 000	36 000	4.0	8.0	2 520.0	1
	571	M	34 240	7 646	3.0	8.0	535.0	1
Total deposits	2		194 240	43 646			3 055	
Sandy gravel	444	F	0	0	0.0	0.0	0.0	0
	446	F	0	0	0.0	0.0	0.0	0
	447	F	0	0	0.0	0.0	0.0	0
	449	F	0	0	0.0	0.0	0.0	0
Total deposits	4		0	0			0	
Gravelly sand	442	G	0	0	0.0	0.0	0.0	0

County 11 - Barrhead (continued)

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Total deposits	1		0	0			0	
Sand	048	D	0	280	2.0	2.0	15.0	4
	173	D	0	0	0.5	0.0	220.0	4
	186	D	0	0	2.0	1.5	41.0	4
	192	D	135	2 430	1.5	3.0	90.0	1
	195	D	0	22 550	2.0	5.0	550.0	4
	196	D	2 358	16 506	3.0	3.0	1 310.0	4
	197	P	120	11 880	2.5	5.0	240.0	4
	198	D	0	8 148	1.0	6.0	140.0	4
	443	H	0	0	0.0	0.0	0.0	0
	445	H	0	0	0.0	0.0	0.0	0
	448	H	0	0	0.0	0.0	0.0	0
	450	H	0	0	0.0	0.0	0.0	0
	451	H	0	0	0.0	0.0	0.0	0
	452	H	0	0	0.0	0.0	0.0	0
Total deposits	14		2 613	61 794			2 606	
Unknown	538	U	0	0	0.0	0.0	0.0	1
	569	U	0	0	0.0	0.0	0.0	1
	570	U	0	0	0.0	0.0	0.0	6
	572	U	0	0	0.0	0.0	0.0	1
Total deposits	4		0	0			0	
Total deposits	**25**		**196 853**	**105 440**			**5 661**	

County 13 - Smoky Lake

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Gravel	0		0	0			0	
Total deposits	0		0	0			0	
Sandy gravel	325	B	1 200	1 164	0.5	3.0	130.0	4
	326	N	910	448	0.5	3.0	320.0	4
	327	N	342	204	0.5	2.5	24.0	4
Total deposits	3		2 452	1 816			474	
Gravelly sand	185	G	0	0	0.0	0.0	0.0	2
	332	C	108	244	0.5	3.0	16.0	4
	349	O	994	1 754	0.0	2.0	135.0	4
Total deposits	3		1 102	1 998			151.0	
Sand	090	D	13 490	206 810	1.0	8.0	2 810.0	4
	091	D	0	43 200	1.0	3.0	1 500.0	4
	092	D	0	7 306	0.0	3.0	820.0	2
	093	D	1 180	10 325	0.5	2.5	472.0	4
	094	D	5 324	89 056	1.5	4.0	2 420.0	4
	095	D	0	9 700	1.0	4.0	250.0	4

County 13 - Smoky Lake (continued)

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Sand	096	D	0	21 978	1.0	3.0	740.0	4
	123	D	0	760	0.0	2.0	38.0	4
	124	D	17 319	83 478	0.5	3.5	3 000.0	4
	127	D	0	11 900	0.5	2.0	700.0	4
	128	D	0	1 785	0.0	2.0	106.0	4
	129	D	0	2 040	0.0	1.5	160.0	4
	130	D	0	10 830	0.0	2.5	456.0	4
	131	D	0	810	0.0	2.0	46.0	4
	132	D	774	8 174	0.5	3.0	301.0	4
	133	D	0	1 344	0.0	2.0	82.0	4
	165	D	55	192	1.0	5.0	5.0	4
	324	P	1 537	16 045	0.5	2.5	720.0	4
Total deposits	18		39 679	525 733			14 626	
Unknown	187	I	0	0	0.0	0.0	0.0	0
	548	I	0	0	0.0	0.0	0.0	0
	573	L	0	0	0.0	0.0	0.0	0
	574	U	0	0	0.0	0.0	0.0	4
Total deposits	4		0	0			0	
Total deposits	**28**		**43 233**	**529 547**			**15 251**	

County 19 - St. Paul

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Gravel	362	B	850	705	0.0	3.5	45.0	1
	363	B	327	156	0.0	3.4	14.0	1
	372	B	655	414	0.0	12.0	9.0	4
Total deposits	3		1 832	1 275			68	
Gravelly sand	152	C	40	103	0.0	3.5	4.0	1
	364	C	66	196	0.0	4.5	6.0	4
	370	C	237	458	2.0	6.0	11.0	4
	371	C	3 233	7 967	0.0	6.0	209.0	4
	373	C	240	503	0.0	3.5	20.0	4
	374	O	357	642	0.0	1.5	68.0	4
	375	C	47	53	0.0	2.5	4.0	4
	376	C	443	8 056	0.0	6.0	26.0	
Total deposits	8		4 663	17 978			348	
Sand	159	D	476	3 150	0.0	3.3	111.0	1
	161	D	7	777	0.0	2.5	29.0	1
	166	P	96	374	1.0	4.0	12.0	4
	168	P	2 544	9 211	0.0	10.0	186.0	4
	169	P	6 039	57 713	0.0	7.0	1 073.0	4
	170	P	35	450	1.0	2.0	28.0	4
Total deposits	6		9 197	71 675			1 439	

County 19 - St. Paul (continued)

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Unknown	477	Q	0	0	0.0	0.0	0.0	0
	478	L	0	0	0.0	0.0	0.0	0
	489	E	0	0	0.0	0.0	0.0	0
	492	E	0	0	0.0	0.0	0.0	0
	493	E	0	0	0.0	0.0	0.0	0
	509	L	0	0	0.0	0.0	0.0	0
	510	L	0	0	0.0	0.0	0.0	0
	512	V	0	0	0.0	0.0	0.0	0
	513	L	0	0	0.0	0.0	0.0	0
	514	Q	0	0	0.0	0.0	0.0	0
	515	V	0	0	0.0	0.0	0.0	0
Total deposits	11		0	0			0	
Total deposits	**28**		**15 692**	**90 928**			**1 855**	

County 20 - Strathcona

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Gravel	0		0	0			0	
Total deposits	0		0	0			0	
Sandy gravel	211	N	1 800	1 400	1.0	3.0	110.0	1
	212	B	3 500	2 300	1.0	3.0	200.0	1
	213	N	500	1 400	1.0	3.0	65.0	1
	311	N	24 500	12 000	4.5	5.0	950.0	1
Total deposits	4		30 300	17 100			1 325	
Gravelly sand	0		0	0			0	
Total deposits	0		0	0			0	
Sand	001	D	12	117	0.0	2.0	6.5	4
	002	D	265	1 034	0.0	2.5	53.0	4
	010	P	3 000	24 000	0.0	1.5	1 890.0	4
	024	P	0	24 010	0.0	3.0	2 292.0	2
	079	D	0	1 270	0.0	0.0	254.0	4
	080	D	0	400	0.0	0.0	42.0	4
	081	P	8 000	72 000	0.0	0.5	216.0	4
	084	P	3 800	14 800	5.0	7.0	600.0	5
	180	D	0	0	0.0	0.0	73.0	4
	181	D	0	0	0.0	0.0	33.0	4
Total deposits	10		15 077	137 631			5 460	
Unknown	0		0	0			0	
Total deposits	0		0	0			0	
Total deposits	**14**		**45 377**	**154 731**			**6 785**	

County 21 - Two Hills

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Gravel	314	M	133	35	0.0	2.5	7.0	4
	315	A	255	66	0.0	3.0	10.0	4
Total deposits	2		388	101			17	
Sandy gravel	256	N	5 170	4 130	0.5	4.5	229.8	4
	257	N	1 980	1 100	0.2	4.3	79.0	4
	258	B	535	310	0.2	4.0	22.3	4
	317	B	98	58	0.0	2.0	8.0	4
	335	N	147	61	0.5	3.0	7.0	4
	340	N	8 882	4 788	0.5	6.0	260.0	4
Total deposits	6		16 812	10 447			606	
Gravelly sand	259	O	2 850	4 490	0.3	2.0	408.3	4
	316	O	937	1 150	0.0	3.0	71.0	4
	319	O	132	203	0.0	2.0	29.0	4
	320	C	168	426	0.0	3.0	20.0	4
	321	O	173	341	0.0	2.5	21.0	4
	333	C	2 115	2 444	1.0	5.0	94.0	4
	334	C	252	365	0.5	3.5	18.0	4
	336	O	910	307	1.0	3.0	41.0	4
	337	C	468	1 368	0.5	2.5	75.0	4
	338	C	71	344	0.5	3.0	14.0	4
	339	C	739	806	1.0	4.0	42.0	4
	341	C	213	629	1.0	2.5	54.0	4
Total deposits	12		9 028	12 873			887	
Sand	054	D	20	155	0.2	2.0	9.1	4
	055	D	24	192	0.2	2.5	9.6	4
	056	D	580	2 025	0.7	4.0	72.4	4
	085	D	15	279	0.0	3.0	10.0	4
	086	D	960	29 440	0.0	16.0	20.0	4
	087	D	0	9 120	0.0	25.0	38.0	4
	088	D	0	1 469	0.0	3.0	51.0	4
	089	D	235	10 349	0.0	8.0	147.0	4
	120	D	0	94 640	1.0	8.0	1 300.0	4
	121	D	0	9 408	0.5	2.0	480.0	4
	122	D	130	2 444	0.5	2.0	130.0	4
	318	D	65	308	0.0	5.5	7.0	4
Total deposits	12		2 029	159 829			2 274	
Unknown	400	E	0	0	0.5	3.5	64.5	4
	485	V	0	0	0.0	0.0	0.0	4
	486	U	0	0	0.0	0.0	0.0	4
	511	U	0	0	0.0	0.0	0.0	4
	532	U	0	0	0.0	0.0	0.0	4
Total deposits	5		0	0			65	
Total deposits	**37**		**28 257**	**183 250**			**3 849**	

County 22 - Camrose

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Gravel	497	A	0	0	0.0	0.0	0.0	4
	505	A	0	0	0.0	0.0	25.0	5
	549	M	481	138	0.5	2.5	25.0	4
Total deposits	3		481	138			51	
Sandy gravel	231	N	38 750	15 725	1.0	4.0	1 404.0	4
	498	B	1 872	1 656	4.0	4.0	90.0	5
	504	B	832	752	0.5	2.0	28.0	4
	507	B	392	1 624	1.0	2.0	28.0	4
	508	B	76	41	2.0	2.0	6.0	4
	542	B	6 246	3 318	1.0	8.0	122.0	4
	550	N	10 044	8 184	5.0	6.0	310.0	4
	552	N	751	531	0.5	3.5	37.0	4
Total deposits	8		58 963	31 831			2 077	
Gravelly sand	230	C	720	1 026	3.0	7.0	26.0	4
	467	G	0	0	0.0	0.0	0.0	0
	500	O	0	0	0.0	0.0	36.0	4
Total deposits	3		720	1 026			62	
Sand	076	D	18	1 512	1.0	3.0	60.0	4
	468	D	4	99	0.5	2.0	6.0	4
	469	D	0	211	1.0	3.0	8.0	4
	470	D	0	40	0.5	3.0	2.0	4
	482	P	90	4 365	0.5	3.0	150.0	4
Total deposits	5		112	6 227			226	
Unknown	466	I	0	0	0.0	0.0	0.0	8
	499	Q	0	0	0.0	0.0	0.0	0
	501	E	0	0	0.0	0.0	0.0	0
	527	L	0	0	0.0	0.0	0.0	0
	551	Q	0	0	0.0	0.0	0.0	0
	553	L	0	0	0.0	0.0	0.0	0
	558	L	0	0	0.0	0.0	0.0	0
	567	L	0	0	0.0	0.0	0.0	0
Total deposits	8		0	0			0	
Total deposits	**27**		**60 276**	**39 222**			**2 416**	

County 24 - Vermilion River

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Gravel	0		0	0			0	
Total deposits	0		0	0			0	
Sandy gravel	253	B	310	130	0.0	2.0	22.3	4
	263	B	260	140	0.5	4.5	10.1	4

County 24 - Vermilion River (continued)

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Sandy gravel	265	N	990	720	0.1	3.0	60.9	4
	271	N	6 600	5 450	0.3	6.5	204.1	4
	273	B	280	140	1.0	2.5	17.2	4
	274	B	1 900	1 900	0.4	2.3	158.0	4
	276	N	2 100	1 200	0.2	3.5	88.2	4
	277	B	270	270	1.7	2.0	30.2	4
	289	N	420	400	1.5	3.5	41.5	4
	292	B	530	250	0.3	1.7	40.0	4
	295	B	1 400	1 250	0.1	2.5	110.9	4
	298	B	525	360	0.4	1.8	60.4	4
	300	B	35	20	0.1	1.5	2.0	4
	303	B	1 650	1 320	1.5	5.3	60.9	4
Total deposits	14		17 270	13 550			907	
Gravelly sand	252	O	194	416	1.7	3.3	30.3	4
	254	C	320	350	0.2	1.5	46.6	4
	255	C	130	400	0.0	1.0	46.6	4
	261	C	170	450	1.0	3.5	21.2	4
	262	C	495	565	0.1	3.5	36.5	4
	264	C	200	350	0.0	2.0	28.4	4
	266	C	70	170	2.0	5.0	6.0	4
	267	O	510	640	0.3	1.7	57.8	4
	268	C	60	115	0.0	1.5	9.0	4
	269	C	45	130	0.2	2.5	9.1	4
	270	C	310	535	0.3	2.0	44.6	4
	272	O	4 000	6 000	0.2	6.7	253.0	4
	275	C	115	300	1.3	2.0	22.3	4
	278	O	2 500	4 900	18	3.5	367.9	4
	279	C	1 100	2 200	0.7	3.2	183.8	4
	280	O	620	1 550	0.4	3.3	74.9	4
	281	C	75	85	0.3	2.0	8.1	4
	283	C	170	360	0.5	2.0	35.4	4
	284	C	400	1 000	0.1	2.5	72.8	4
	290	C	30	40	0.0	1.2	7.6	4
	291	C	30	40	0.0	1.3	7.6	4
	293	C	320	430	0.2	2.9	38.3	4
	294	C	100	120	0.7	1.6	15.1	4
	296	C	70	290	2.4	2.1	22.7	4
	297	C	57	85	0.1	1.0	19.2	4
	299	C	225	1 075	0.7	2.0	68.9	4
	301	C	110	270	0.5	1.0	38.6	4
	302	C	5 600	7 000	0.5	4.0	354.7	4
Total deposits	28		18 026	29 866			1 927	
Sand	050	P	0	515	0.1	3.8	15.2	4
	052	D	61	515	0.2	2.0	30.3	4
	053	D	77	300	0.8	2.0	19.3	4
	058	D	40	400	1.0	1.5	29.4	4
	059	D	175	530	0.3	2.0	35.4	4
	060	P	75	285	0.5	2.0	12.1	4
	061	P	13	400	0.7	2.6	17.2	4
	062	D	240	850	0.5	1.5	80.6	4
	063	D	30	240	0.2	1.5	20.2	4
	064	D	1 100	4 000	1.5	6.4	113.4	4
	069	D	175	650	0.0	2.7	56.7	4

County 24 - Vermilion River (continued)

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
	070	D	30	150	0.0	2.7	9.0	4
	071	D	160	1 200	1.4	3.3	46.8	4
	072	D	17	570	0.1	3.6	17.0	4
	073	D	30	215	0.1	3.0	9.1	4
	074	D	0	1 200	0.1	7.0	21.7	4
	075	D	350	1 700	0.1	1.7	155.9	4
	479	K	0	0	0.0	0.0	0.0	0
	480	K	0	0	0.0	0.0	0.0	0
	481	K	0	0	0.0	0.0	0.0	0
Total deposits	20		2 573	13 720			689	
Unknown	517	V	0	0	0.0	0.0	0.0	4
	519	V	0	0	0.0	0.0	0.0	4
	521	L	0	0	0.0	0.0	0.0	0
	533	V	0	0	0.0	0.0	0.0	8
	534	L	0	0	0.0	0.0	0.0	0
Total deposits	5		0	0			0	
Total deposits	**67**		**37 869**	**57 136**			**3 523**	

County 25 - Leduc

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Gravel	537	M	24 019	6 953	2.5	7.0	903.0	1
	561	M	5 851	1 057	3.5	3.0	470.0	1
	584	M	13 056	3 779	2.5	4.0	859.0	1
Total deposits	3		42 926	11 789			2 232	
Sandy gravel	225	B	640	240	2.5	3.0	30.0	1
	240	B	115	35	0.0	1.5	11.0	1
	241	B	9 990	38 200	25.0	45.0	3 100.0	1
	244	B	1 450	2 600	1.0	1.0	414.0	4
	245	B	92	45	3.5	1.5	14.0	1
	391	N	0	0	0.5	1.0	25.0	4
	415	B	1 608	744	4.0	1.5	320.0	1
Total deposits	7		13 895	41 864			3 914	
Gravelly sand	246	O	728	1 742	0.5	2.0	130.0	4
Total deposits	1		728	1 742			130	
Sand	041	P	0	2 000	1.0	2.0	272.0	4
	172	D	0	0	0.0	0.0	322.0	1
Total deposits	2		0	2 000			594	
Unknown	380	Q	0	0	0.0	0.0	10.0	1

County 25 - Leduc (continued)

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Unknown	381	E	0	0	3.0	3.0	40.0	1
	382	E	0	0	0.0	0.0	22.0	1
	383	Q	0	0	4.0	0.0	20.0	1
	387	E	0	0	0.0	0.0	60.0	1
	389	E	0	0	0.0	0.0	0.0	1
	393	E	0	0	6.0	3.5	500.0	1
	394	E	0	0	5.0	4.0	490.0	1
	475	U	0	0	0.0	0.0	0.0	6
	531	U	0	0	0.0	0.0	0.0	6
	540	U	0	0	0.0	0.0	0.0	6
	560	L	0	0	0.0	0.0	0.0	4
	563	U	0	0	0.0	0.0	0.0	0
	565	L	0	0	0.0	0.0	0.0	6
	580	U	0	0	0.0	0.0	0.0	0
	581	U	0	0	0.0	0.0	0.0	6
Total deposits	16		0	0			1 142	
Total deposits	**29**		**57 549**	**57 395**			**8 012**	

County 27 - Minburn

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Gravel	0		0	0			0	
Total deposits	0		0	0			0	
Sandy gravel	248	N	585	300	0.5	4.3	31.0	4
	250	B	40	30	0.0	1.4	8.1	4
	282	B	400	300	0.2	2.0	35.2	4
	286	B	1 000	330	0.0	1.5	89.1	4
	287	N	675	575	0.1	4.5	31.4	4
	288	N	420	260	0.3	2.0	47.3	4
Total deposits	6		3 120	795			242	
Gravelly sand	210	O	34	166	0.0	1.0	20.0	4
	247	C	35	80	0.0	2.5	6.1	4
	249	O	460	490	0.0	3.0	32.4	4
	251	C	55	80	0.0	0.9	14.2	4
	260	C	255	510	0.1	3.0	28.4	4
	285	O	640	2 000	1.0	5.5	66.7	4
	323	C	410	1 197	0.0	2.0	82.0	4
	494	C	0	0	0.0	4.0	7.0	4
Total deposits	8		1 889	4 523			257	
Sand	009	D	0	800	0.0	2.0	40.0	4
	051	D	40	1 300	0.2	4.0	46.5	4
	057	D	25	425	0.1	0.6	45.6	4
	065	D	0	29 946	0.0	2.0	2 300.0	6
	067	D	15	65	0.0	1.0	8.3	4

County 27 - Minburn (continued)

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Sand	068	D	32	771	0.0	4.0	20.5	4
	111	P	0	460	2.0	2.0	23.0	4
	117	D	0	180	1.0	1.5	15.0	4
	322	D	24	128	0.0	2.0	8.0	4
Total deposits	9		136	34 075			2 507	
Unknown	399	E	0	0	0.1	2.3	83.0	4
	520	L	0	0	0.0	0.0	0.0	8
	522	V	0	0	0.0	0.0	0.0	4
Total deposits	3		0	0			83	
Total deposits	**26**		**5 145**	**40 393**			**3 089**	

County 28 - Lac Ste. Anne

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Gravel	432	A	1 460	480	3.0	4.0	50.0	5
	575	M	2 700	975	1.5	1.5	250.0	1
Total deposits	2		4 160	1 455			300	
Sandy gravel	232	N	41 333	27 693	4.0	5.0	1 260.0	5
	433	B	927	797	2.5	5.0	35.0	4
	578	N	840	600	0.0	6.0	40.0	4
	585	N	394	213	2.0	2.5	25.0	4
Total deposits	4		43 494	29 303			1 360	
Gravelly sand	190	C	259	446	1.0	2.0	90.0	4
	199	C	227	495	2.0	5.0	15.0	4
	236	O	660	907	0.0	2.5	66.0	4
	237	C	48	60	3.0	1.0	8.0	4
	238	C	56	70	1.0	1.0	35.0	4
	472	C	240	690	2.0	8.0	12.0	4
	576	O	1 128	1 176	0.0	4.0	60.0	4
Total deposits	7		2 618	3 844			286	
Sand	049	D	0	500	0.5	1.5	40.0	4
	174	D	0	0	0.0	0.0	50.0	4
	175	D	0	0	0.0	0.0	220.0	4
	176	D	0	0	0.0	0.0	200.0	4
	177	D	0	0	1.5	1.5	125.0	4
	178	D	0	0	0.0	0.0	70.0	4
	189	D	1 785	7 905	0.0	3.0	340.0	4
	191	D	0	233	2.5	4.0	6.0	1
	193	D	274	682	4.0	8.0	12.0	1
	194	D	0	0	0.5	2.0	35.0	1
	471	D	0	3 800	1.0	3.0	380.0	4

County 28 - Lac Ste. Anne (continued)

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Total deposits	11		2 059	13 120			1 478	
Unknown	179	U	0	0	0.0	0.0	30.0	8
	398	U	0	0	1.5	2.5	115.0	4
	547	U	0	0	0.0	0.0	0.0	4
	577	U	0	0	0.0	0.0	0.0	8
	582	U	0	0	0.0	0.0	0.0	4
Total deposits	5		0	0			145	
Total deposits	**29**		**52 331**	**47 722**			**3 569**	

County 30 - Lamont

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Gravel	346	M	420	162	1.0	2.0	48.0	4
Total deposits	1		420	162			48	
Sandy gravel	220	N	9	59	0.0	3.0	5.5	4
	221	B	220	216	1.0	3.0	15.0	1
	343	N	417	295	1.0	2.0	36.0	4
	348	B	504	336	1.0	3.0	35.0	4
Total deposits	4		1 150	906			92	
Gravelly sand	218	C	56	88	0.0	2.0	8.0	4
	328	C	3 150	5 760	0.5	3.0	300.0	4
	329	O	11 720	17 287	0.5	5.0	586.0	4
	342	O	1 485	1 749	1.0	3.0	110.0	4
	344	O	875	1 600	0.5	2.0	120.0	4
	345	O	504	864	1.0	2.0	72.0	4
	347	C	1 372	3 332	0.0	2.5	240.0	4
Toal deposits	7		19 162	30 680			1 436	
Sand	014	P	48	246	0.0	2.0	15.0	1
	034	D	161	756	2.0	7.0	7.0	4
	035	D	1	20	0.0	0.5	4.5	4
	036	P	51	272	0.0	7.0	8.5	4
	037	D	0	47 580	0.0	3.0	4 068.0	2
	116	D	0	3 500	0.0	0.5	758.0	6
	126	D	49	828	0.5	2.5	39.0	4
	483	K	0	0	0.0	0.0	0.0	0
Total deposits	8		310	53 202			4 900	
Unknown	523	U	0	0	0.0	0.0	0.0	8
Total deposits	1		0	0			0	
Total deposits	**21**		**21 042**	**84 950**			**6 476**	

County 31 - Parkland

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Gravel	224	M	1 900	500	3.0	5.0	56.0	1
	243	A	10 200	2 800	7.0	3.0	540.0	1
	516	A	87	22	0.0	4.5	2.5	1
	556	M	2 160	486	6.0	10.0	27.0	5
	564	M	42 660	10 260	4.5	4.5	2 400.0	1
Total deposits	5		57 007	14 068			3 026	
Sandy gravel	204	N	180	173	1.0	3.0	12.0	4
	205	B	116	80	1.5	1.0	20.0	4
	235	N	1 274	1 126	1.0	4.0	68.0	4
	239	N	10 300	4 300	3.5	5.7	430.0	1
	242	B	4 950	3 135	1.0	7.5	113.0	1
	384	N	0	0	4.0	2.0	68.0	1
	416	B	6 900	3 000	3.0	4.0	500.0	1
	417	B	16 537	9 450	3.0	6.0	875.0	1
	418	B	12 421	6 306	4.0	6.5	588.0	1
	427	B	24 624	8 892	6.0	3.0	1 140.0	5
	428	B	4 275	3 075	0.0	2.5	300.0	5
	430	B	800	768	0.0	10.0	16.0	5
	488	N	82 075	32 830	7.0	7.0	1 675.0	5
	518	B	5 617	3 464	3.5	3.5	535.0	1
	526	B	4 822	4 340	6.0	3.0	643.0	1
	539	N	14 824	5 846	5.0	4.0	1 440.0	1
	545	N	7 993	2 847	2.5	3.0	730.0	1
	555	N	708	317	1.5	3.0	47.0	1
	559	N	27 720	10 010	4.5	2.5	1 540.0	5
	583	N	20 471	7 784	3.0	9.5	607.0	1
Total deposit	20		246 607	107 743			11 347	
Gravelly sand	203	O	900	1 950	2.0	3.0	490.0	4
	226	C	72	48	0.0	3.0	6.0	1
	233	C	4 774	10 110	4.0	5.0	298.0	5
	234	O	960	1 320	3.0	4.0	60.0	5
	386	C	0	0	3.0	2.0	110.0	1
Total deposits	5		6 706	13 428			964	
Sand	006	D	33 176	129 640	13.5	22.5	784.0	5
	007	D	0	1 960	2.0	10.0	20.0	4
	042	P	0	100 000	0.0	3.0	13 700.0	2
	043	D	0	400	0.0	1.0	103.0	2
	044	D	0	8 980	0.0	2.0	1 300.0	2
	045	D	0	4 500	0.0	2.0	730.0	2
	046	P	48	893	0.0	4.0	24.0	4
	171	D	0	0	0.0	0.0	12.0	4
	184	D	0	14 077	0.0	2.5	2 723.0	2
	473	D	7	237	0.0	5.0	5.0	4
Total deposits	10		33 231	260 687			19 401	
Unknown	385	Q	0	0	0.0	0.0	193.0	1
	388	E	0	0	0.0	0.0	35.0	1
	390	E	0	0	3.0	0.0	70.0	1
	392	E	0	0	0.0	0.0	45.0	1
	395	E	0	0	0.0	0.0	40.0	4

County 31 - Parkland (continued)

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Unknown	396	U	0	0	5.0	2.5	93.0	1
	397	E	0	0	0.0	0.0	32.0	1
	487	U	0	0	0.0	0.0	0.0	6
	543	L	0	0	0.0	0.0	0.0	0
	562	U	0	0	0.0	0.0	0.0	1
	566	U	0	0	0.0	0.0	0.0	6
	579	L	0	0	0.0	0.0	0.0	1
Total deposits	12		0	0			508	
Total deposits	**52**		**343 551**	**395 926**			**35 246**	

M.D.87 - Municipal District of Bonnyville

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Gravel	0		0	0			0	
Total deposits	0		0	0			0	
Sandy gravel	360	N	1 750	1 680	0.0	4.0	80.0	
Total deposits	1		1 750	1 680			80	
Gravelly sand	353	O	395	1 455	0.0	0.0	0.0	0
	354	C	0	0	0.0	0.0	0.0	0
	355	O	200	300	0.0	8.5	15.0	1
Total deposits	3		595	1 755			15	
Sand	149	D	10	90	0.0	0.0	0.0	0
	158	P	27	270	0.0	1.0	30.0	4
	484	K	0	0	0.0	0.0	0.0	0
Total deposits	3		37	360			30	
Unknown	490	E	0	0	0.0	0.0	0.0	0
	491	E	0	0	0.0	0.0	0.0	0
	495	E	0	0	0.0	0.0	0.0	0
	496	E	0	0	0.0	0.0	0.0	0
	502	Q	0	0	0.0	0.0	0.0	0
	503	L	0	0	0.0	0.0	0.0	0
	506	L	0	0	0.0	0.0	0.0	0
	535	U	0	0	0.0	0.0	0.0	8
	544	U	0	0	0.0	0.0	0.0	4
	557	L	0	0	0.0	0.0	0.0	0
Total deposit	10		0	0			0	
Total deposits	**17**		**2 382**	**3 795**			**125**	

M.D.90 - Municipal District of Sturgeon

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Gravel	0		0	0			0	
Total deposits	0		0	0			0	
Sandy gravel	202	N	154 446	572 444	13.5	19.0	4 884.0	5
	215	B	584	544	2.5	3.0	40.0	1
	313	B	5 600	2 400	2.0	4.5	186.0	1
Total deposits	3		160 630	575 388			5 110	
Gravelly sand	201	C	400	900	0.5	2.0	75.0	4
Total deposits	1		400	900			75	
Sand	003	D	0	340	0.0	0.0	17.0	4
	004	D	0	160	1.0	2.0	8.0	4
	005	D	570	2 400	0.5	2.0	160.0	4
	008	P	0	19 000	2.0	8.0	244.0	6
	011	D	0	6 900	0.5	1.5	470.0	4
	012	P	0	0	0.0	0.0	0.0	2
	025	D	0	0	0.0	0.0	0.0	2
	026	D	1 700	5 600	0.5	2.0	370.0	4
	027	D	0	1 040	0.0	2.0	167.0	2
	028	D	0	1 710	3.0	5.0	2 680.0	5
	030	D	0	30 000	0.5	3.0	1 130.0	4
	032	D	0	5 700	0.5	1.5	510.0	4
	047	D	2 203	8 280	12.0	23.0	48.0	1
	134	D	0	1 976	0.5	1.5	7 737.0	4
Total deposits	14		4 473	83 106			13 541	
Unknown	377	E	0	0	0.0	0.0	40.0	1
	546	U	0	0	0.0	0.0	0.0	4
Total deposits	2		0	0			40	
Total deposits	**20**		**165 503**	**659 394**			**18 766**	

M.D.92 - Municipal District of Westlock

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Gravel	0		0	0			0	
Total deposits	0		0	0			0	
Sandy gravel	0		0	0			0	
Total deposits	0		0	0			0	
Gravelly sand	350	O	10 612	14 454	0.5	3.0	955.0	4
	411	G	0	0	0.0	0.0	0.0	0

M.D.92 - Municipal District of Westlock (continued)

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Gravelly sand	435	G	0	0	0.0	0.0	0.0	0
	440	G	0	0	0.0	0.0	0.0	0
Total deposits	4		10 612	14 454			955	
Sand	097	D	0	2 682	0.0	2.5	121.0	4
	098	D	0	900	0.0	1.0	100.0	6
	099	D	0	2 308	0.0	1.5	171.0	6
	100	D	0	2 835	0.0	1.5	210.0	6
	101	D	0	1 728	0.0	2.0	165.0	2
	102	D	0	1 120	0.0	1.5	83.0	6
	103	D	0	738	0.0	2.0	41.0	2
	104	D	0	7 582	0.0	2.5	342.0	6
	105	D	632	11 421	0.0	3.0	475.0	4
	106	P	1 822	9 720	0.5	5.0	293.0	4
	107	D	3 708	49 779	0.0	3.0	1 831.0	4
	108	D	0	1 292	0.0	4.0	34.0	4
	109	D	0	14 990	0.0	2.0	1 810.0	2
	110	P	0	1 134	0.0	2.0	63.0	2
	135	D	10	313	0.5	1.0	33.0	4
	136	P	4 328	17 304	0.0	3.0	737.0	4
	137	P	3 186	7 434	0.0	3.0	371.0	4
	138	D	3 385	60 939	0.0	3.0	2 270.0	4
	139	D	360	1 350	0.5	1.0	180.0	4
	143	D	306	9 180	0.5	2.0	510.0	4
	147	D	0	294	0.0	1.0	31.0	4
	200	H	0	0	0.0	0.0	0.0	0
	403	H	0	0	0.0	0.0	0.0	0
	404	H	0	0	0.0	0.0	0.0	0
	406	H	0	0	0.0	0.0	0.0	0
	408	H	0	0	0.0	0.0	0.0	0
	410	H	0	0	0.0	0.0	0.0	0
	412	H	0	0	0.0	0.0	0.0	0
	413	H	0	0	0.0	0.0	0.0	0
	414	H	0	0	0.0	0.0	0.0	0
	420	H	0	0	0.0	0.0	0.0	0
	422	H	0	0	0.0	0.0	0.0	0
	423	H	0	0	0.0	0.0	0.0	0
	424	H	0	0	0.0	0.0	0.0	0
	425	H	0	0	0.0	0.0	0.0	0
	426	H	0	0	0.0	0.0	0.0	0
	429	H	0	0	0.0	0.0	0.0	0
	431	H	0	0	0.0	0.0	0.0	0
	437	H	0	0	0.0	0.0	0.0	0
	438	H	0	0	0.0	0.0	0.0	0
	439	H	0	0	0.0	0.0	0.0	0
	441	H	0	0	0.0	0.0	0.0	0
Total deposits	42		17 737	205 043			9 871	
Unknown	405	I	0	0	0.0	0.0	0.0	0
	407	I	0	0	0.0	0.0	0.0	0
	419	I	0	0	0.0	0.0	0.0	6
	421	I	0	0	0.0	0.0	0.0	1
	434	I	0	0	0.0	0.0	0.0	0
	436	I	0	0	0.0	0.0	0.0	0

M.D.92 - Municipal District of Westlock (continued)

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Total deposits	6		0	0			0	
Total deposits	**52**		**28 349**	**219 497**			**10 826**	

I.D.13 - Elk Island National Park

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Gravel	0		0	0			0	
Sandy gravel	0		0	0			0	
Gravelly sand	0		0	0			0	
Sand	0		0	0			0	
Unknown	524	U	0	0	0.0	0.0	0.0	8
Total deposits	**1**		**0**	**0**			**0**	

I.D.18 - Improvement District 18

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Gravel	0		0	0			0	
Total deposits	0		0	0			0	
Sandy gravel	358	B	1 000	1 000	0.0	10.0	56.0	1
	359	B	500	480	0.0	4.5	26.0	1
	361	B	16	12	0.0	1.0	30.0	1
	365	B	623	498	0.0	3.5	32.0	1
	402	B	0	0	0.0	0.0	0.0	4
Total deposits	5		2 139	1 990			144	
Gravelly sand	357	C	44	47	0.0	2.0	4.0	1
	367	O	95	182	0.0	4.0	10.0	1
	368	C	910	561	0.0	3.1	50.0	1
	369	C	651	1 226	0.0	3.5	52.0	4
Total deposits	4		1 700	2 016			116	
Sand	148	D	100	900	0.0	0.0	0.0	0
	150	D	103	968	0.0	3.0	33.0	1
	153	P	241	2 668	0.0	1.5	126.0	1
	154	D	66	536	0.0	1.0	21.0	1

I.D.18 - Improvement District 18 (continued)

	Deposit number	Type and reference	Gravel	Sand	Overburden thickness	Deposit thickness	Deposit area	Genesis
Sand	156	D	0	1 000	0.0	2.0	49.0	1
	157	D	0	100	0.0	4.0	25.0	1
	160	D	46	874	0.0	3.0	31.0	4
	162	D	136	1 573	0.0	3.0	57.0	4
	163	D	85	337	0.0	1.0	42.0	1
	164	D	7	132	0.0	3.0	5.0	4
	167	D	116	5 684	0.0	4.0	146.0	4
	356	P	751	2 603	0.0	3.0	112.0	1
	401	D	0	0	0.0	0.0	0.0	4
Total deposits	13		1 651	17 375			647	
Unknown	0		0	0			0	
Total deposits	**22**		**5 490**	**21 381**			**907**	

Total of all deposits

	Deposit number	Gravel	Sand	Deposit area
Total deposits	**585**	**1 157 991**	**3 966 989**	**151 630**

Appendix I

Resource descriptions and projections for municipalities

This appendix contains, for each municipality:

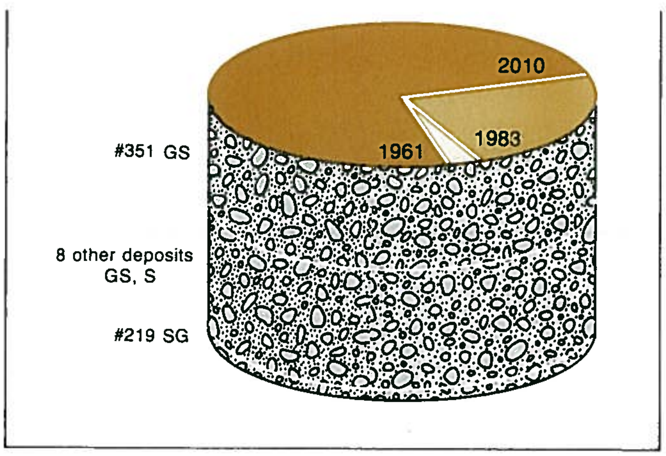
1. a summary of appendix H giving total number of deposits, total sand and gravel resources and a cylindrical diagram showing the percentage of the gravel resource contained in the most important deposits;
2. a pie diagram showing consumption of gravel from 1961 to 1983 as a proportion of the total resource;
3. the projected consumption of the total resource from 1983 to 2010 on the same diagram (light area);
4. a discussion of concerns brought to light by the data.

Gravel consumption projections for the municipalities are based on regional estimates—see *Projected Aggregate demand.*

Abbreviations in diagrams:
G = gravel
S = sand
SG = sandy gravel
GS = gravelly sand

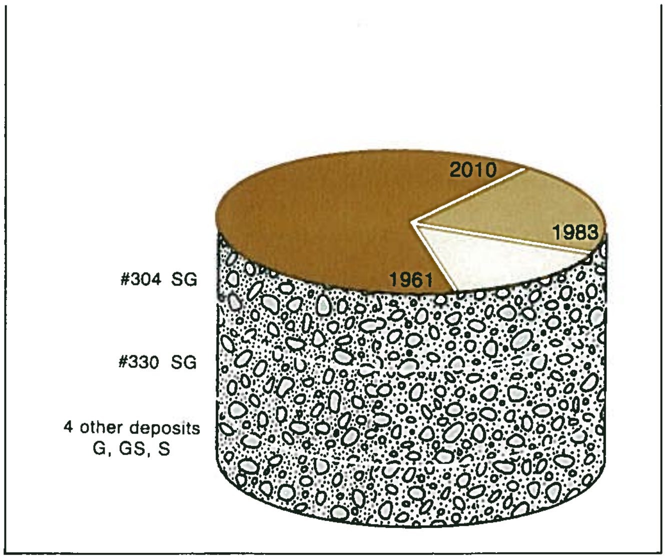
County 7 - Thorhild. Projected consumption shows adequate supplies for the future. Most of the gravel is disseminated through the large sand deposits in the county and is difficult and costly to retrieve.

Number deposits 34
Total sand (m^3) 169 548
Total gravel (m^3) 5 536



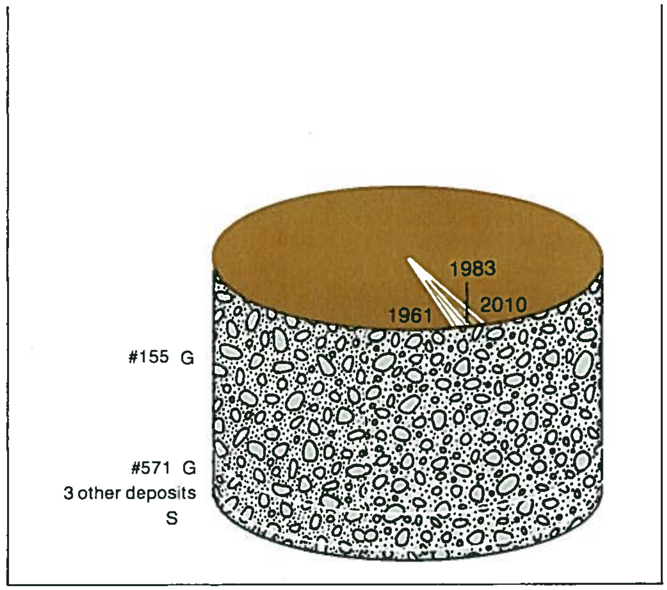
County 9 - Beaver. Consumption projections for the county indicate that a significant amount of the gravel reserves will be consumed by 2010. Most of the gravel resource (74 percent) lies within 2 deposits (330 and 304) and over 90 percent of the gravel resource occurs in only 4 deposits.

Number deposits 17
Total sand (m^3) 39 056
Total gravel (m^3) 8 594



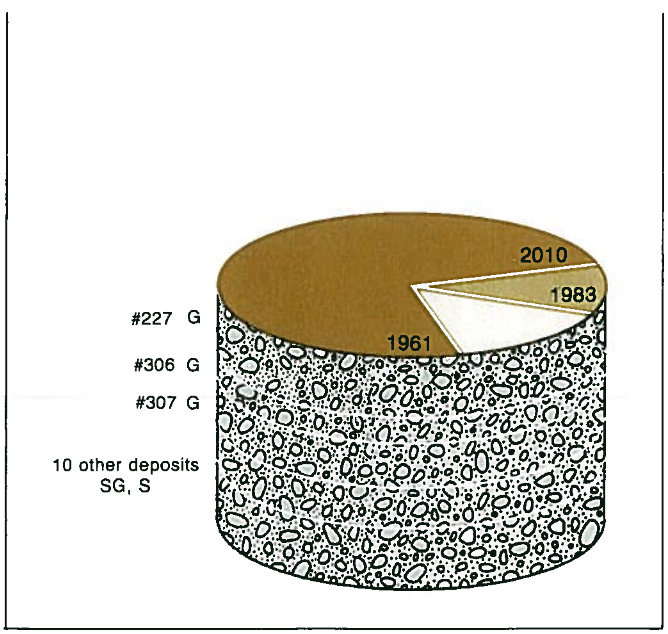
County 11 - Barrhead. Most of the gravel resource (81 percent) lies within deposit 155, and over 90 percent of the gravel resource occurs in 2 deposits in the Athabasca River valley. Projected consumption shows adequate supplies for the future.

Number deposits 25
Total sand (m^3) 105 440
Total gravel (m^3) 196 853



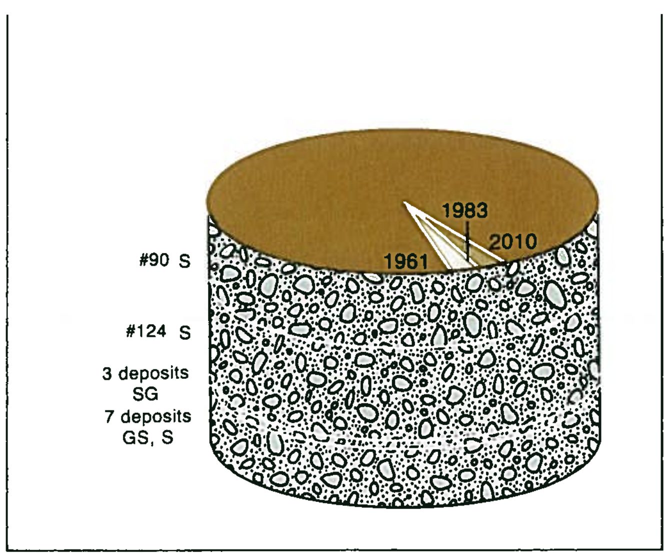
County 10 - Wetaskiwin. Consumption projections for the county indicate that a significant amount of the gravel reserve will be consumed by 2010.

Number deposits 33
Total sand (m^3) 1 048 358
Total gravel (m^3) 25 881



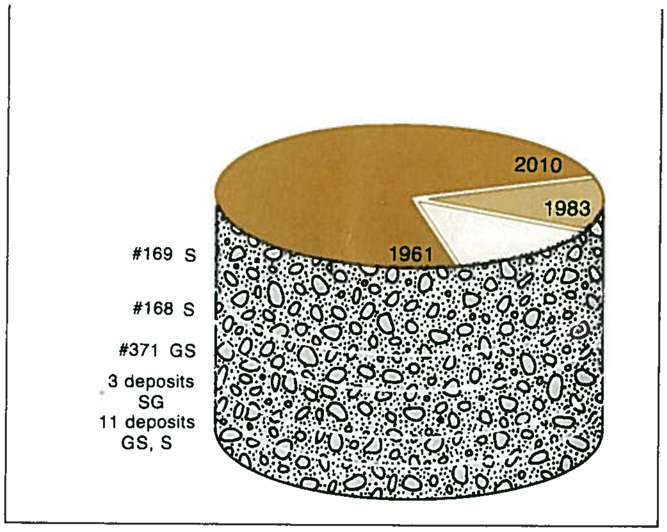
County 13 - Smoky Lake. Most of the gravel resource (71 percent) lies within 2 deposits (124 and 90). Projected consumption shows adequate supplies for the future.Most of the gravel is disseminated through the large sand deposits in the county and is difficult and costly to retrieve.

Number deposits 28
Total sand (m^3) 529 547
Total gravel (m^3) 43 233



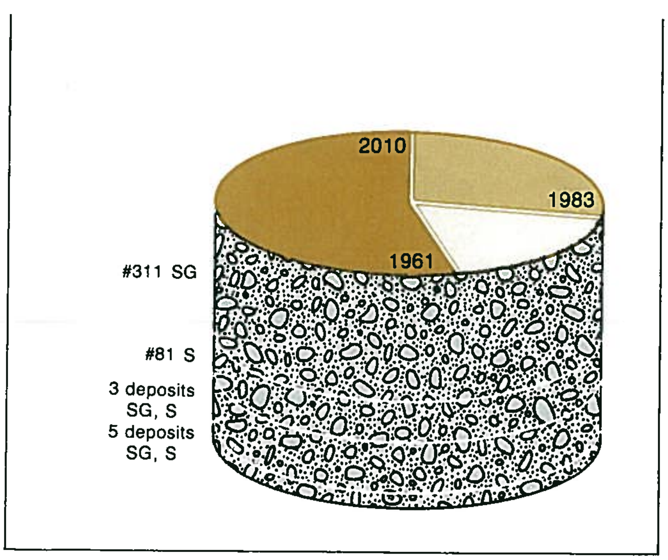
County 19 - St. Paul. Consumption projections for the county indicate that a significant amount of the gravel reserve will be consumed by 2010. An additional factor to consider is that most of the gravel resource (75 percent) is concentrated in the Elk Point area (deposits 168, 169, 371). Parts of two of these signficant deposits are already devoted to alternative land use.

Number deposits 28
Total sand (m³) 90 928
Total gravel (m³) 15 692



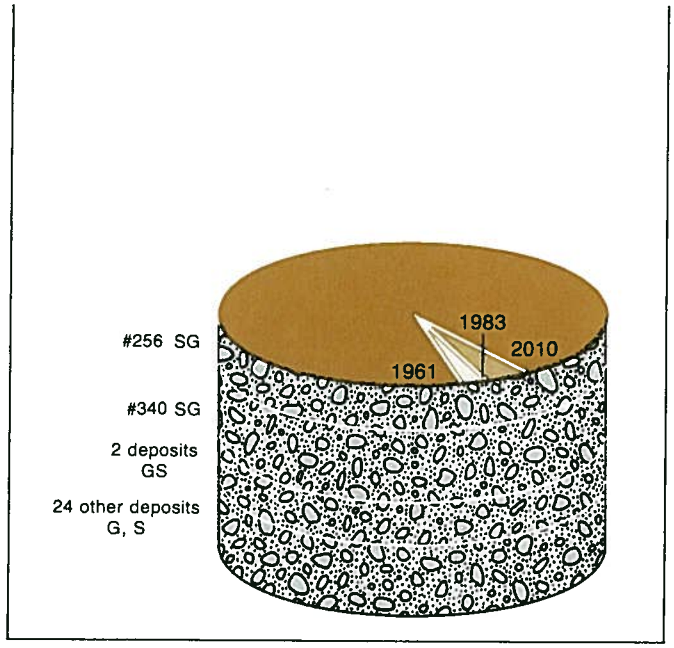
County 20 - Strathcona. Consumption projections for the county indicate that a significant amount of the gravel reserve will be consumed by 2010. Most of the gravel resource (72 percent) lies within 2 deposits (311 and 81) and over 90 percent of the gravel resource occurs in 5 deposits.

Number deposits 14
Total sand (m³) 154 731
Total gravel (m³) 45 377



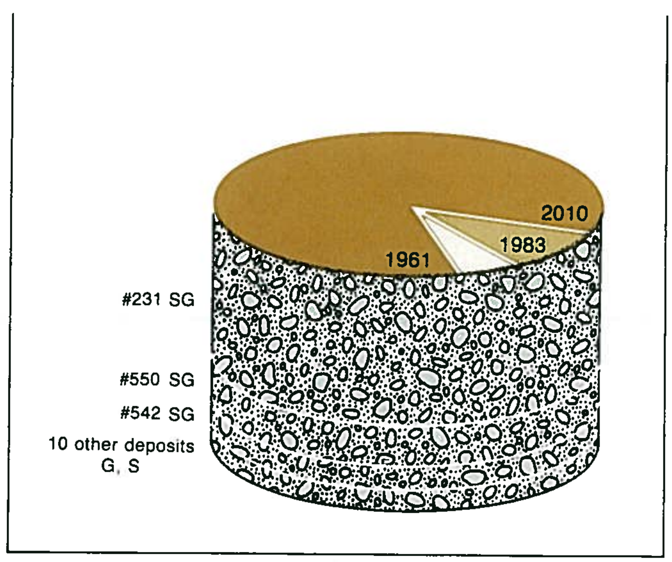
County 21 - Two Hills. Resources appear adequate to satisfy county demands. The resource is presently being exported for use in Vegreville.

Number deposits 37
Total sand (m³) 183 250
Total gravel (m³) 28 257



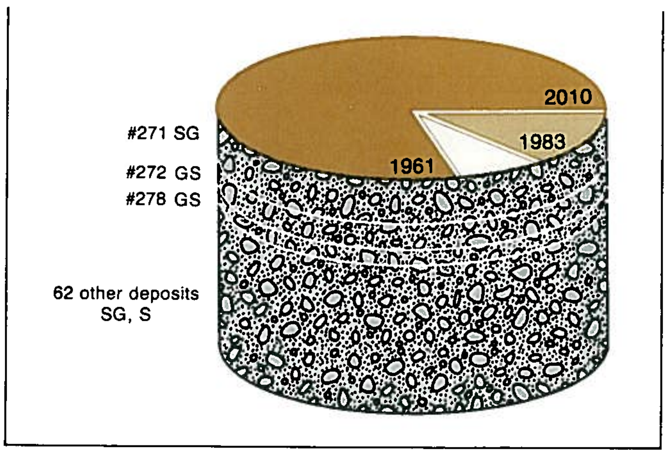
County 22 - Camrose. Most of the gravel resource (81 percent) lies within 2 deposits (231 and 550) and over 90 percent of the gravel resource occurs in 3 deposits. Projected consumption shows adequate supplies for the future. Aggregate is being hauled into Edmonton and this trend will increase in the future.

Number deposits 27
Total sand (m³) 39 222
Total gravel (m³) 60 276



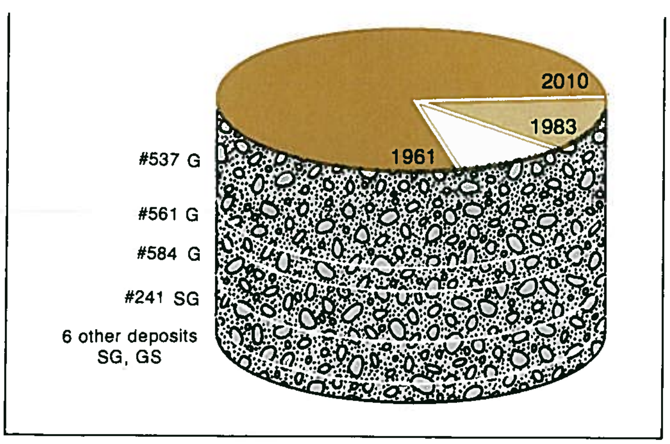
County 24 - Vermilion River. Even though projected consumption shows adequate supplies for the future, it should be noted that the gravel in the county is widely distributed among a great number of deposits (67) —none of which contain a large volume of material. Should a large demand for aggregate occur for a specific project (such as a highway project or heavy oil development), it could cause a critical shortage in that area and require a great increase in the haul distances (and cost) for ongoing uses.

Number deposits 67
Total sand (m^3) 57 136
Total gravel (m^3) 37 869



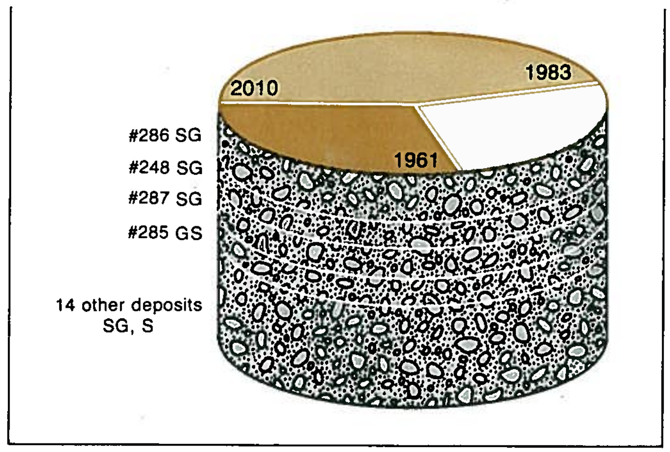
County 25 - Leduc. Over 90 percent of the gravel resource occurs in 4 deposits. The projected consumption and volume of reserves suggests that there is little cause for concern in the county about aggregate. Yet over 95 percent of the gravel occurs within the North Saskatchewan River valley and is therefore highly susceptible to resource sterilization due to alternative land use preferences. The City of Edmonton also could change the supply situation drastically should it begin to draw heavily on the reserves within the county.

Number deposits 29
Total sand (m^3) 57 395
Total gravel (m^3) 57 549



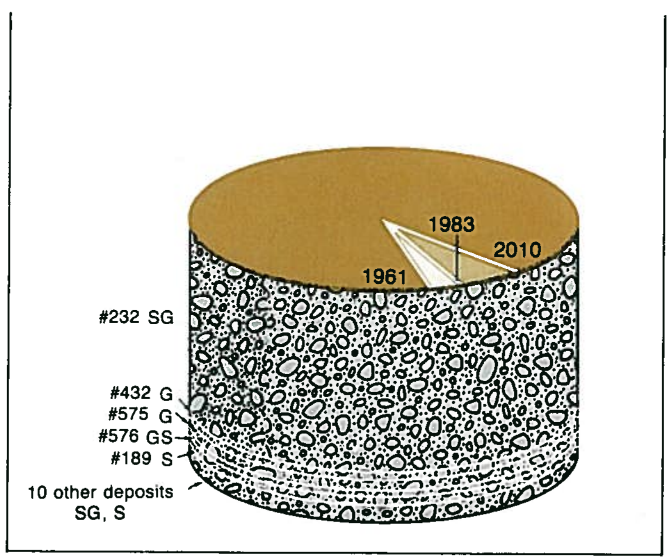
County 27 - Minburn. Minburn has a very limited amount of gravel (about 5 million m^3) and no large deposits. Consumption projections for the county indicate that the resource will be in critically short supply by 2010. In fact importation of gravel to Vegreville is already taking place from adjacent counties. This situation illustrates the fact that regional coordination is necesary to ensure the availability and access to aggregate supplies for resource-poor counties such as Minburn.

Number deposits 26
Total sand (m^3) 40 393
Total gravel (m^3) 5 145



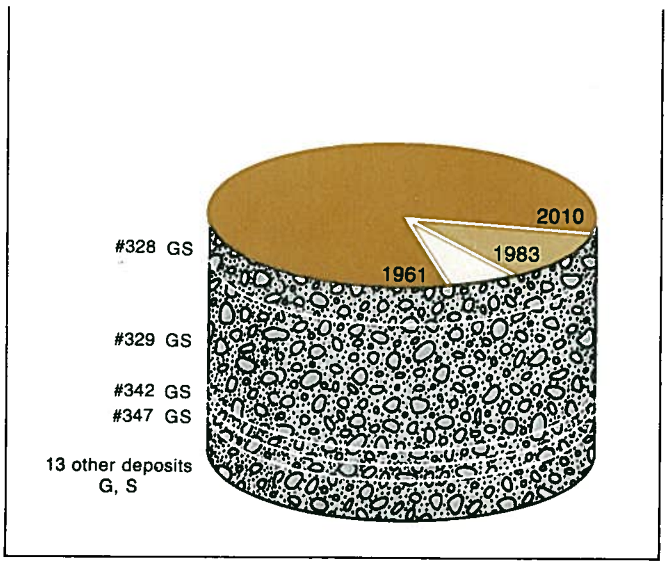
County 28 - Lac Ste. Anne. Most of the gravel resource (80 percent) lies within deposit 232 and over 90 percent of the gravel resource occurs in 4 deposits. Even though projected consumption shows adequate county supplies for the future, it should be recognized that most of the present gravel production is being hauled into the Edmonton market.

Number deposits 29
Total sand (m^3) 47 722
Total gravel (m^3) 52 331



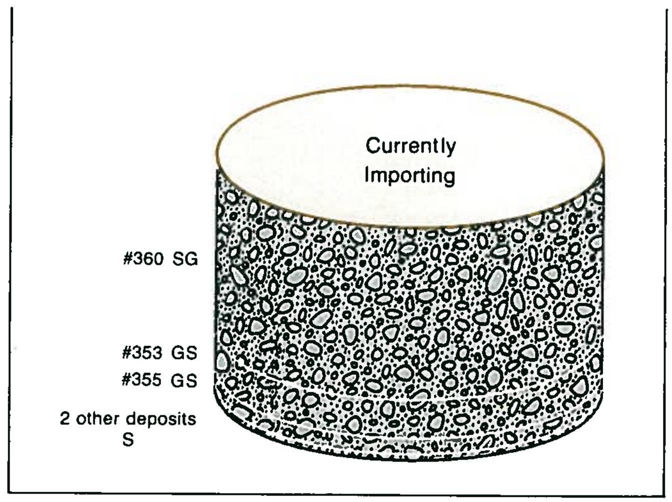
County 30 - Lamont. Projected consumption of gravel does not indicate cause for concern, but a more critical assessment is required. Estimates show 71 percent of the gravel resource occurs in two deposits in the extreme northeastern corner of the county and most of the remainder is in smaller sand-type deposits.

Number deposits 21
Total sand (m^3) 84 950
Total gravel (m^3) 21 042



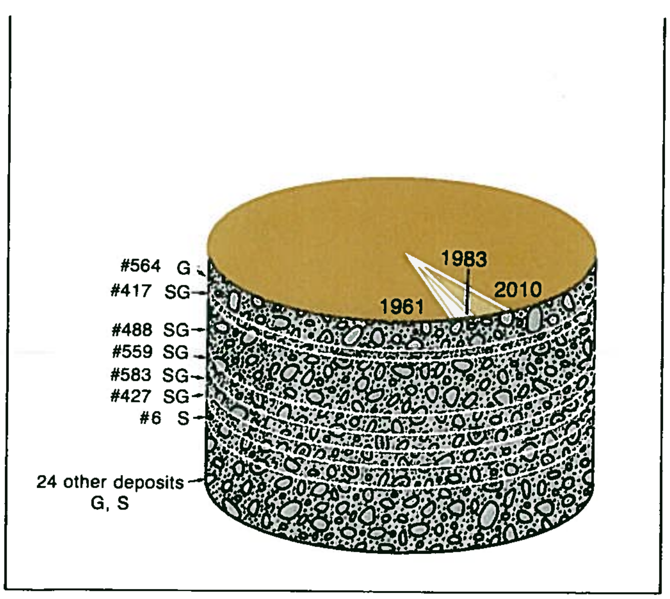
M.D. 87 - Municipal District of Bonnyville. The municipal district is currently importing gravel. Most of the gravel resource which remains (90 percent) lies within 2 deposits (360 and 353) north and west of Bonnyville. A coordinated plan for aggregate use involving M.D. 87, I.D. 18, County 18, and Alberta Energy and Natural Resources will be required to ensure most efficient use of supplies in the area.

Number deposits 17
Total sand (m^3) 3 795
Total gravel (m^3) 2 382



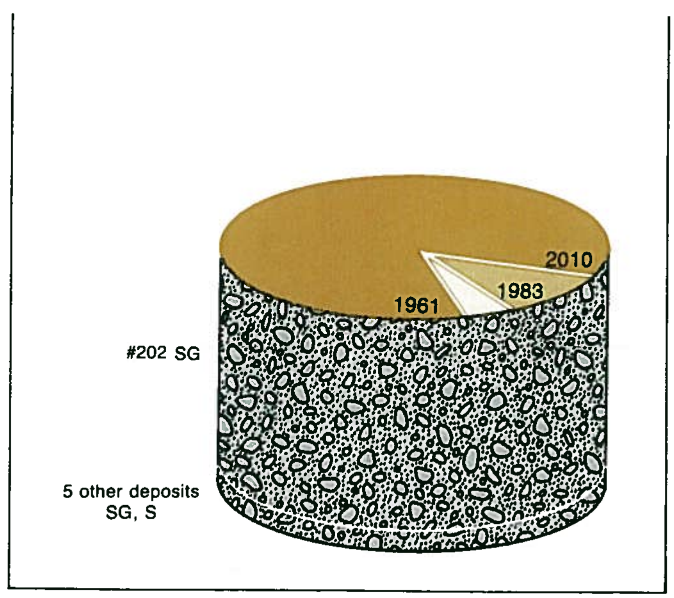
County 31 - Parkland. The County of Parkland has a very large reserve of gravel and is currently a major supplier of aggregate to Edmonton. Seven deposits, with 43 percent of the total gravel reserves, lie in the Wabamun area, and 25 deposits, with 46 percent, lie within the North Saskatchewan River valley.

Number deposits 52
Total sand (m^3) 395 926
Total gravel (m^3) 343 551



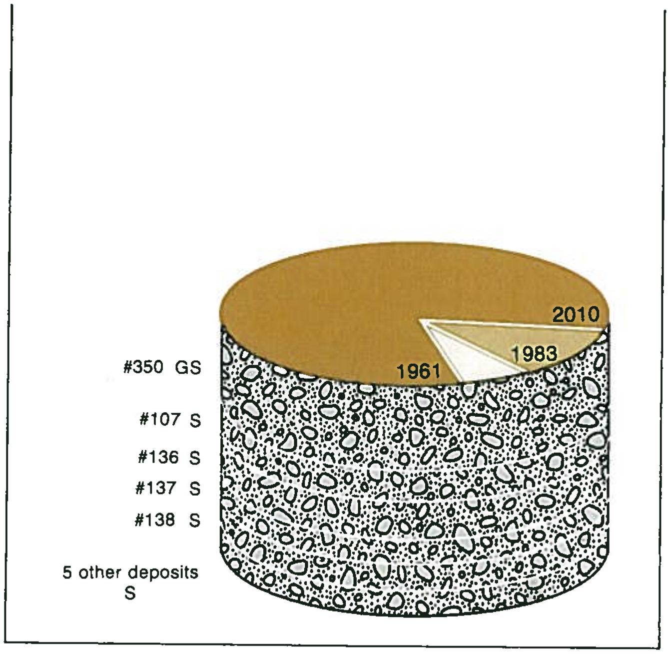
M.D. 90 - Municipal District of Sturgeon. Most of the gravel resource (93 percent) lies within the Villeneuve deposit. This deposit is the major supplier of concrete aggregate to the Edmonton market and the availability of this deposit for development as an aggregate source will be critical to the region.

Number deposits 20
Total sand (m^3) 659 394
Total gravel (m^3) 165 503



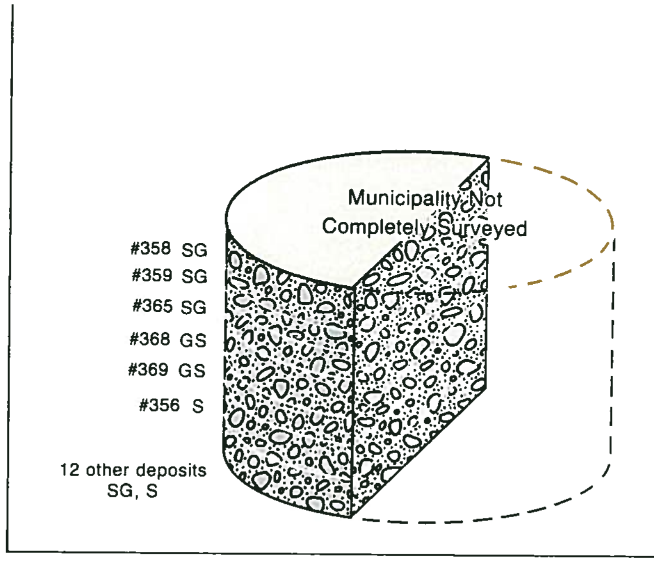
M.D. 92 - Municipal District of Westlock. The municipal district contains a large number of deposits and the supply is adequate. Most of the gravel is disseminated throughout sand deposits.

Number deposits 52
Total sand (m³) 219 497
Total gravel (m³) 28 349



I.D. 18 - Improvement District 18. The improvement district is a main supplier of gravel to the Municipal District of Bonnyville and some of the towns in the area. Some of the reserves lie on Crown land and coordination between Alberta Energy and Natural Resources, M.D. 87 and I.D. 18 must continue for effective use of the gravel in the area.

Number deposits 22
Total sand (m³) 21 381
Total gravel (m³) 5 490



References

Allan, J.A. and J.L. Carr (1946): Geology and coal occurrences, Wapiti-Cutbank area; Report 48 (NTS 83L, M); scale 1:190 000 (approx.); Edmonton: Alberta Research Council.

Andriashek, L.D., M.M. Fenton and J.D. Root (1979): Surficial geology of the Wabamun Lake area; scale 1:250 000 (NTS 83G); Edmonton: Alberta Research Council.

ASCE and ICE (1976): World resources — engineering solutions; Proceedings of the Third Joint Conference, American Society of Civil Engineers and Institute of Civil Engineers; London; p. 150.

Bayrock, L.A. (1967): Surficial geology of the Wainwright area (east half), Alberta; Report 67-4; Edmonton: Alberta Research Council.

Bayrock, L.A. (1972): Surficial geology of the Edmonton area; scale 1:250 000; accompanies Bulletin 32 and Earth Science Report 73-2 (NTS 83H); Edmonton: Alberta Research Council.

Bayrock, L.A. and G.M. Hughes (1962): Surficial geology of the Edmonton district, Alberta; Earth Sciences Report 62-6; Edmonton: Alberta Research Council.

Bayrock, L.A. and T.E. Berg (1966): Geology of the City of Edmonton, Part 1: Central Edmonton; Earth Sciences Report 66-1; Edmonton: Alberta Research Council.

Berg, T.E. (1969): Fossil sand wedges at Edmonton Alberta; Biuletyn Peryglacjaluy, v. 19, pp. 325-333.

Boydell, A.N. (1978): Multiple glaciations in the foothills, Rocky Mountain House area, Alberta; Bulletin 36; Edmonton: Alberta Research Council.

Boydell, A.N., L.A. Bayrock and T.H. Reimchen (1974): Surficial geology of the Rocky Mountain House area; scale 1:250 000 (NTS 83B); Edmonton: Alberta Research Council.

Carlson, V.A. (1967): Bedrock topography and surficial aquifers of the Edmonton district; Earth Science Report 66-3 (NTS 83H); scale 1:50 000; Edmonton: Alberta Research Council.

———.(1977a): Bedrock topography, Rocky Mountain House area; scale 1:250 000; Edmonton: Alberta Research Council.

———.(1977b): Bedrock topography, Tawatinaw area;

scale 1:250 000; Edmonton: Alberta Research Council.

Carlson, V.A. and D.V. Currie (1974): Bedrock topography, Vermilion area; scale 1:250 000; Edmonton: Alberta Research Council.

Carlson, V.A. and R. Green (1977): Bedrock topography, Whitecourt area; scale 1:250 000; Edmonton: Alberta Research Council.

Carlson, V.A. and L.M. Topp (1971): Bedrock topography, Wainwright area; scale 1:250 000; Edmonton: Alberta Research Council.

City of Edmonton (1978): Edmonton regional aggregate study; Edmonton: Engineering Department, City of Edmonton.

Edwards, W.A.D. (1981): Sedimentology of the Bruderheim dune field, Alberta; Geological Association of Canada Annual Meeting, Abstracts, v. 6, pp. A-16.

———.(1983): Geology of some gravel deposits in the Edmonton region, Alberta; Canadian Institute of Mining and Metallurgy, Special Volume 29, pp. 219-222.

———.(1984a): Aggregate resources maps; scale 1:50 000; Elk Island Park 83H/10, Open File Report 1984-16j; St. Albert 83H/12, Open File Report 1984-16l; Lamont 83H/15, Open File Report 1984-16o; Edmonton: Alberta Research Council.

———.(1984b): Aggregate resources maps; scale 1:50 000; Onoway 83G/9, Open File Report 1984-15i; Chip Lake 83G/11, Open File Report 1984-15k; Edmonton: Alberta Research Council.

Edwards, W.A.D. and J.C. Fox (1980): Sand and gravel resources of the Cold Lake area, Alberta; Open File Report 1980-8 (NTS 73E, L); Edmonton: Alberta Research Council.

Edwards, W.A.D. and R.J.H. Richardson (1983): Aggregate resources map; scale 1:250 000; Tawatinaw 83I, Open File Report 1983-19; Edmonton: Alberta Research Council.

Edwards, W.A.D. and K.G. Steele (1984): Aggregate resources map; scale 1:50 000; Barrhead 83J/1, Open File Report 1984-18a; Edmonton: Alberta Research Council.

Ellwood, R.B. (1961): Surficial geology of the Vermilion area, Alberta, Canada; unpublished University of Illinois Ph.D. thesis, 131 pp.

Farvolden, R.N. (1963): Bedrock topography, Edmonton-Red Deer map area, Alberta; scale 1 in = 6.5 mi; accompanies Bulletin 12; Edmonton: Alberta Research Council.

Fenton, M.M. and L.D. Andriashek (1982): Surficial geology Sand River, Alberta; scale 1:250 000 (NTS 73L); Edmonton: Alberta Research Council.

Fox, J.C. (1984a): Aggregate resources maps; scale 1:50 000; Genesee 83G/8, Open File Report 1984-15h; Lac La Nonne 83G/16, Open File Report 1984-15p; Edmonton: Alberta Research Council.

———.(1984b): Aggregate resources maps; scale 1:50 000; Holden 83H/1, Open File Report 1984-16a; Leduc 83H/5, Open File Report 1984-16e; Ryley 83H/8, Open File Report 1984-16h; Edmonton 83H/11, Open File Report 1984-16k; Morinville 83H/13, Open File Report 1984-16m; Redwater 83H/14, Open File Report 1984-16n; Edmonton: Alberta Research Council.

———.(1984c): Aggregate resources map; scale 1:50 000; Viking 73E/4, Open File Report 1984-11d; Edmonton: Alberta Research Council.

Gartner Lee Assoc. Ltd. and Proctor and Redfern Ltd. (1979): Sand and gravel resources of the Dauphin region; Winnipeg: Manitoba Department of Mines, Resources and Environmental Management, 2 vols.

Gibson, D.W. (1977): Upper Cretaceous and Tertiary coal-bearing strata in the Drumheller-Ardley region, Red Deer River valley, Alberta; paper 76-35; Ottawa: Geological Survey of Canada, 41 pp.

Gold, C.M., L.D. Andriashek and M.M. Fenton (1983): Bedrock topography of the Sand River map area (NTS 73L) Alberta; scale 1:250 000; Edmonton: Alberta Research Council.

Gravenor, C.P. and R.B. Ellwood (1957): Glacial geology of the Sedgewick district; Earth Science Report 57-1 and two maps; scale 1 in = 1 mi (NTS 73D); Edmonton: Alberta Research Council.

Green, R. (1972): Geological map of Alberta; Edmonton: Alberta Research Council.

Hester, B. and N.K. Jones (1984): Aggregate resources maps; scale 1:50 000; Paradise Valley 73E/1, Open File Report 1984-11a; Buffalo Creek 73E/3, Open File Report 1984-11c; Edmonton: Alberta Research Council.

Irish, E.J.W. (1970): The Edmonton group of south-central Alberta; Bulletin of Canadian Petroleum Geology, v. 18, no. 2, pp. 125-155.

Jones, N.K. (1984a): Aggregate resources map; scale 1:50 000; Marwayne 73E/9, Open File Report 1984-11i; Edmonton: Alberta Research Council.

———.(1984b) Aggregate resources map; scale 1:50 000; McLaughlin 73D/16, Open File Report 1984-10p; Edmonton: Alberta Research Council.

McConnell, R.G. (1885): Report on the Cypress Hills, Wood Mountain and adjacent country; Geological and Natural History Survey of Canada Annual Report, v. 1.

Nickless, E.F.P. (1973): The sand and gravel resources of the country around Hethersett, Norfolk; Report 7314; Institute of Geological Sciences, 80 pp.

Ontario Geological Survey (1980): Aggregate resources inventory of Blanshard Township, Perth County, Southern Ontario; Toronto: Ministry of Natural Resources, Engineering and Terrain Geology Section, Ontario Geological Survey, 31 pp.

Pavement Management Systems Limited (1983): Study of asphalt cement additives and extenders; Ottawa: Roads and Transportation Association of Canada.

Peat, Marwick and Partners and M.M. Dillon Ltd. (1980): Mineral aggregate transportation study, summary; Industrial Mineral Background Paper 1(a); Toronto: Ontario Ministry of Natural Resources, 26 pp.

Peterson, B.N. and B. Hester (1984): Aggregate resources map; scale 1:50 000; Grizzly Bear Creek 73E/2, Open File Report 1984-11b; Edmonton: Alberta Research Council.

Peterson, B.N. and N.K. Jones (1984a): Aggregate resources map; scale 1:50 000; Irma 73D/14, Open File Report 1984-10n; Edmonton: Alberta Research Council.

———.(1984b): Aggregate resources maps; scale 1:50 000; Mannville 73E/6, Open File Report 1984-11f; Vermilion 73E/7, Open File Report 1984-11g; Lloydminster 73E/8, Open File Report 1984-11h; Clandonald 73E/10, Open File Report 1984-11j; Myrnam 73E/11, Open File Report 1984-11k; Edmonton: Alberta Research Council.

Regional Niagara Planning and Development Department (1981): The Niagara sand and gravel study; Niagara.

Richard, S.H. (1979): Surficial geology Dapp Creek, map 1-1979; scale 1:100 000 (NTS 83I/SW); Ottawa: Geological Survey of Canada.

———.(1968): Unpublished surficial geology map 83I/2: Geological Survey of Canada.

Richardson, R.J.H. (1984a): Aggregate resources maps; scale 1:50 000; Drayton Valley 83G/2, Open File Report 1984-15b; Blue Rapids 83G/3, Open File Report 1984-15c; Easyford 83G/6 (in press); Tomahawk 83G/7, Open File Report 1984-15g; Isle Lake 83G/10, Open File Report 1984-15; Edmonton: Alberta Research Council.

———.(1984b): Aggregate resources maps; scale 1:50 000: Innisfree 73E/5, Two Hills 73E/12, Open File Report 1984-11; Edmonton: Alberta Research Council.

———.(1984c): Aggregate resources map; scale 1:50 000: Mundare 83H/9, Open File Report 1984-16; Edmonton: Alberta Research Council.

Sham, P. (1984a): Aggregate resources map; scale 1:250 000:Red Deer 83A, Open File Report 1984-04; Edmonton: Alberta Research Council.

———.(1984b): Aggregate resources map; scale 1:250 000: Rocky Mountain House 83B, in preparation.

———.(1984c): Aggregate resources map; scale 1:250 000: Whitecourt 83J, Open File Report 1984-07; Edmonton: Alberta Research Council.

———.(1984d): Aggregate resources maps; scale 1:50 000; Chain Lakes 83A/11, Open File Report 1984-13k; Bearhills Lake 83A/13, Open File Report 1984-13m; Wetaskiwin 83A/14, Open File Report 1984-13n; Ferintosh 83A/15, in preparation; Edmonton: Alberta Research Council.

———.(1984e): Aggregate resources map; scale 1:50 000; Hairy Hill 73E/13, Open File Report 1984-11m; Edmonton: Alberta Research Council.

———.(1984f): Aggregate resources maps; scale 1:50 000; Kavanagh 83H/4, Open File Report 1984-16d; Willingdon 83H/16, Open File Report 1984-16p; Edmonton: Alberta Research Council.

———.(1984g): Aggregate resources map; scale 1:50 000; Smoky Lake 83I/1, Open File Report 1984-17a; Edmonton: Alberta Research Council.

———.(1984h): Aggregate resources maps; scale 1:50 000; Thunder Lake 83J/2, Open File Report 1984-18b; Greencourt 83J/3, Open File Report 1984-18c; Edmonton: Alberta Research Council.

———.(1984i): Aggregate resources maps; scale 1:50 000; Warburg 83G/1; Open File Report 1984-15a; Mayerthorpe 83G/14, Open File Report 1984-15n; Sangudo 83G/15, Open File Report 1984-15a; Edmonton: Alberta Research Council.

Sham, P. and W.A.D. Edwards (1984): Aggregate resources map; scale 1:50 000; Bittern Lake 83H/3, Open File Report 1984-16c; Edmonton: Alberta Research Council.

Sham, P. and K.G. Steele (1984): Aggregate resources map;scale 1:50 000; Daysland 83A/16, Open File Report 1984-13p; Edmonton: Alberta Research Council.

Shaw, E.W. and S.R.L. Harding (1954): Lea Park and Belly River Formations of east-central Alberta; *in* Western Canada sedimentary basin, L.M. Clark, ed.; American Association of Petroleum Geologists Rutherford Memorial Volume, pp.297-308.

St. Onge,D.A. (1972): Surface deposits of the Tawatinaw map sheet; *in* Soils survey of the Tawatinaw Sheet(83-1), A.A. Kjearsgaard; Alberta Soil Survey Report 29; Edmonton: Canada Department of Agriculture Soil Research Institute.

St. Onge, D.A. and S.H. Richard (1975): Surficial geology Whitecourt (NTS 83J), map 1367A; scale 1:250 000; Ottawa: Geological Survey of Canada.

Stalker, A. MacS. (1960): Surficial geology Red Deer-Stettler: Memoir 306 and map 1081A; scale 1 in = 4 mi (NTS 83A); Ottawa: Geological Survey of Canada.

Steele, K.G. (1984): Aggregate resources maps; scale 1:50 000; Waskatenau 83I/2, Open File Report 1984-17b; Thorhild 83I/3, Open File Report 1984-17c; Westlock 83I/4, Open File Report 1984-17d; Edmonton: Alberta Research Council.

Westgate, J.A. (1968): Surficial geology of the Foremost-Cypress Hills area, Alberta (NTS 72E); scale 1:250 000; accompanies Bulletin 22; Edmonton: Alberta Research Council.

Glossary

ablation – all processes by which snow or ice is lost from a glacier.

abrasion – the mechanical wearing, grinding, scraping, or rubbing away of rock surfaces by friction and impact.

adsorption – adherence of gas molecules or of ions or molecules in solution to the surfaces of solids with which they are in contact.

aggregate – any of several hard, inert, construction materials (such as sand, gravel, shells, slag, crushed stone, or other mineral material), or combinations thereof, used for mixing in variously sized fragments with a cementing or bituminous material to form concrete, mortar, plaster, and so on, or used alone as in railroad ballast or in various manufacturing processes (such as fluxing).

aggregate reserve – an accurately demarcated volume of economically workable aggregate.

alluvial – pertaining to or composed of alluvium.

alluvium – clay, silt, sand or gravel deposited during comparatively recent geologic time by running water as a sorted sediment in the bed of the stream or on its flood plain or delta, or as a cone or fan at the base of a slope.

angularity – a term used for the property of a sedimentary particle now commonly described in terms of roundness (see roundness).

argillaceous – a sedimentary rock (such as shale) containing an appreciable amount of clay.

bar – a ridge-like accumulation of sand or gravel formed in the channel, along the banks, or at the mouth of a stream where a decrease in velocity induces deposition.

bedding plane – a plane of division separating individual layers, beds or strata.

bedrock – a general term for the rock, usually solid, that underlies soil or other unconsolidated surficial material.

beneficiate – to treat (a raw material) so as to improve properties.

bentonite – a rock term for montmorillonitic clay mineral deposits derived from volcanic ash.

burned synthetic aggregate – an aggregate manufactured by the burning of silt and clay.

calcite – a common rock-forming mineral: $CaCO_3$. Calcite is a detrimental ingredient, if present in silt, clay or shale used to make synthetic aggregate.

Canadian Shield – a large area of exposed Precambrian basement rock occurring in northern and eastern Canada, found in the extreme northeastern part of Alberta.

carbonate – a mineral compound characterized by a fundamental anionic structure of $CO_3^=$. Calcite ($CaCO_3$) is an example of carbonate.

channel bar – an elongate deposit of sand and gravel located in the course of a stream.

chert – a hard, extremely dense sedimentary rock, consisting predominantly of silica. Chert can be detrimental in concrete.

chlorite – a group of platy, monoclinic, usually greenish minerals associated with and resembling the micas.

clast – an individual constituent, grain or fragment of a sediment or rock.

clay – (a) a detrital particle of any composition smaller than a very fine silt grain, having a diameter less than 1/256 mm (4 μm, or 0.00016 in, or 8 phi units); (b) a loose, earthy, extremely fine-grained, natural sediment composed primarily of clay-size particles and a considerable amount of clay minerals (hydrous aluminum silicates). Clay forms a pasty, plastic, moldable, impermeable muddy mass when mixed with water, retaining its shape upon drying, and becoming firm, rock-like and permanently hard upon heating or firing.

clay mineralogy – the study and identification of clay minerals (common groups are the kaolin, montmorillonite and illite groups).

clean – sand or gravel is said to be clean it if contains less than 5 percent fines (silt and clay).

cleavage plane – that surface along which a rock tends to split, because of its texture or structure.

concretionary bands – bands consisting of concretions. *Concretion:* hard, rounded, subspherical mass formed by orderly and localized precipitation from aqueous solution in the pores of sedimentary rock.

Cretaceous – the final period of the Mesozoic era (after the Jurassic and before the Tertiary period of the Cenozoic era), thought to have covered the span of time between 136 and 65 million years ago; also rocks which formed during this time; much of the bedrock in Alberta is of this age.

cristobalite – a high-temperature polymorph of quartz (SiO_2), stable only above 1470°C.

crushed stone – quarried consolidated rock mechanically broken into fragments of consistent size, usually greater than 75 mm diameter.

deleterious – a material that has an undesirable effect, especially a rock type which has an undesirable effect in concrete (such as weakening, discoloring or causing spalling).

delta – the low, nearly flat alluvial tract of land deposited at or near the mouth of a river, commonly forming a triangular or fan-shaped plain. *Deltaic:* pertaining to or characterized by a delta.

dirty – sand or gravel is dirty if it contains 5 to 12 percent fines (silt and clay).

dolomite – a common rock-forming rhombohedral mineral [$CaMg(CO_3)_2$].

dune – a low mound, ridge, bank or hill of loose, wind-blown sand, either bare or covered with vegetation.

dune field – an area occupied by dunes, usually 35 to 45 percent of the area is in the form of dunes.

eolian – pertaining to the wind; deposits (such as dune sand) whose constituents were transported and laid down by the wind or of landforms produced by the wind.

expanded aggregate – burned synthetic aggregate which has expanded and has a lower relative density due to the trapping of gas formed during firing.

facies – general appearance or nature of one part of a rock body as contrasted with other parts.

feldspar – a group of abundant rock-forming minerals of general formula $[MAl(Al,Si)_3O_8$, where M = K, Na, Ca, Ba, Rb, Sr and Fe]. On decomposition, feldspars may yield a large part of the clay of soil and also the mineral kaolinite.

fines – very small particles, for example, the silt and clay fractions. An engineering term for the clay- and silt-sized soil particles (diameters less than 0.074 mm) passing U.S. standard sieve no. 200.

firing characteristics – the behavior of a mineral upon being heated in a furnace.

fluvial – produced by the action of a stream or river.

formation – a persistent body of rock that can be traced in the field and represented on a geologic map as a practical or convenient unit for mapping and description.

friable – describes a rock or mineral that crumbles naturally or is easily broken, puliverized or reduced to powder, such as a soft or poorly cemented sandstone.

glacial lake – a lake that derives much or all of its water from the melting of glacier ice.

glaciation – the covering of large land areas by glaciers or ice sheets. A collective term for the geologic processes of glacial activity, including erosion and deposition, and the resulting effects of such action on the earth's surface.

glaciofluvial – pertaining to the meltwater streams flowing from wasting glacier ice and especially to the deposits and landforms produced by these streams, such as kame terraces and outwash plains; relating to the combined action of glaciers and streams.

glaciolacustrine – deposits and landforms composed of material brought into a glacial lake, as glaciolacustrine silt or clay.

gneiss – a foliated rock formed by regional metamorphism, commonly found in the Canadian Shield.

gradation – the proportion of material of each particle size.

grain size – particle size.

granite – a plutonic rock predominantly made of quartz and feldspar, common to the Canadian Shield.

granular – describes a sediment consisting of grains, granules or particles of sand or gravel size.

gravel – an unconsolidated, natural accumulation of rounded rock fragments resulting from erosion, consisting predominantly of particles larger than sand (diameter greater than 4.75 mm), such as boulders, cobbles, pebbles, granules or any combination of these fragments.

hardness – the resistance of a mineral to scratching.

ice-contact deposit – stratified drift deposited in contact with melting glacier ice, such as an esker, kame, kame terrace or a feature marked by numerous kettles.

illite – a general name for a group of three-layer, mica-like, clay minerals that are widely distributed in argillaceous sediments (especially marine shales and soils derived from them).

impervious – not allowing the passage of water.

in situ – in the natural or original positon.

insoluble residue – the material remaining after a more soluble part of a specimen has been dissolved in hydrochloric acid or acetic acid.

interbedded – describes beds laid between or alternating with others of different character.

interstice – an opening or space between one thing and another, as an opening in a rock or soil that is not occupied by solid matter.

ironstone – any rock containing a substantial portion of iron compound, specifically an iron-rich sedimentary rock, either deposited directly as a ferruginous sediment or resulting from chemical replacement.

kaolinite – a high-alumina clay mineral of the kaolin group that does not expand appreciably under varying water content and does not commonly contain iron or magnesium.

lensing – the thinning out of a stratum in one or more directions.

lightweight aggregate – see expanded aggregate.

lithology – the nature and composition of rocks; the description of rocks on the basis of characteristics as color, structure, mineralogic composition and grain size.

manufactured aggregate – see burned synthetic aggregate.

marl – soft, loose, earthy and semifriable or crumbling unconsolidated deposits consisting chiefly of an intimate mixture of clay and calcium carbonate in varying proportions.

matrix – in a rock in which certain grains are much larger than the others, the grains of smaller size comprise the matrix.

meander – one of a series of sinuous curves or windings in the course of a stream. Synonym: meander bend.

organic – pertaining or relating to a compound containing carbon.

outwash – stratified detritus (chiefly sand and gravel) removed or "washed out" from a glacier by meltwater streams and deposited in front of or beyond the terminal moraine or the margin of an active glacier.

overburden – uneconomic sediment overlying an aggregate deposit.

Paleocene – an epoch of the early Tertiary period, after the Gulfian of the Cretaceous period and before the Eocene.

petrographic analysis – the description and classification of rocks by visual and microscopic examination.

phi – particle size diameter, expressed as the negative logarithm to the base 2 of the diameter in millimetres.

plasticity – the ability to retain a shape attained by pressure deformation.

platy – describes a sedimentary particle whose length is more than three times its thickness.

Pleistocene – an epoch of the Quaternary period, after the Pliocene of the Tertiary and before the Holocene.

pliable – supple enough to bend freely or repeatedly without breaking.

point bar – one of a series of low, arcuate ridges of sand and gravel developed on the inside of a growing meander by the slow addition of individual accretions accompanying migration of the channel toward the outer bank.

postglacial – the time interval since the disappearance of continental glaciers in middle latitudes or in a particular area.

precision – the deviation of a set of estimates or observations from their mean.

preglacial – pertaining to the time preceding a period of glaciation, specifically that immediately before the Pleistocene epoch; used to describe material underlying glacial deposits (for example, the loose sand and gravel lying beneath till).

proglacial – a term applied to deposits of glacial origin beyond the limits of the glacier itself; for example, as streams, deposits, loess.

quartz – crystalline silica, an important rock-forming mineral (SiO_2). Next to feldspar, quartz is the most common mineral.

quartzite – a very hard rock, originally sandstone, consisting chiefly of quartz grains that have been so completely and solidly cemented with secondary silica that the rock breaks across or through the individual grains rather than around them.

Quaternary – the second period of the Cenozoic era (following the Tertiary), thought to cover the last two or three million years. It consists of two epochs (the Pleistocene and the Holocene).

Recent – an epoch of the Quaternary period, from the end of the Pleistocene to the present time. Synonym: Holocene.

roundness – the degree of abrasion of a clastic particle as shown by the sharpness of its edges and corners. Roundness may be defined as the ratio of the average radius of curvature of the corners of the particle image to the radius of the maximum inscribed circle.

sand – a rock fragment or detrital particle smaller than a granule and larger than a coarse silt grain, having a diameter in the range of 0.075 mm to 4.75 mm; unconsolidated material consisting (75 percent or more) of sand-size particles.

sand sheet – a thin accumulation of sand characterized by an extremely flat or plain-like surface broken only by small sand ripples.

shale – a fine-grained, indurated, detrital sedimentary rock formed by the consolidation of clay, silt or mud and characterized by finely stratified structure and/or fissility that is approximately parallel to the bedding (along which the rock breaks readily into thin layers).

silt – a rock fragment or detrital particle smaller than a very fine sand grain and larger than coarse clay, having a diameter in the range of 0.004 mm to 0.075 mm; the upper size limit is approximately the smallest size that can be distinguished with the unaided eye.

siltstone - –an indurated or somewhat indurated silt having the texture and composition, but lacking the fine lamination or fissility, of shale.

smectite – the montmorillonite group of clay minerals, designates dioctahedral (montmorillonite) and trioctahedral (saponite) clay minerals (and their chemical varieties) that possess swelling properties and high cation-exchange capacities.

sorting – the dynamic process by which sedimentary particles having some particular characteristic (such as similarity of size, shape or specific gravity) are naturally selected and separated from associated but dissimilar particles by the agents of transportation (especially by the action of running water).

sound – free from flaws or defects which could cause weakness; especially important in concrete where the soundness of the coarse aggregate will determine the strength and durability of the finished product.

spalling – the chipping, fracturing or fragmentation of rock.

sulfide – a mineral compound characterized by the linkage of sulfur with a metal or semimetal, such as galena (PbS) or pyrite (FeS_2).

surficial geology – the study of glacial deposits and landforms.

synthetic aggregate – see burned synthetic aggregate.

terrace – commonly denotes a valley-contained, aggradational form composed of unconsolidated material as contrasted with a bench eroded in solid rock. A terrace commonly occurs along the margin and above the level of a body of water, marking a former water level.

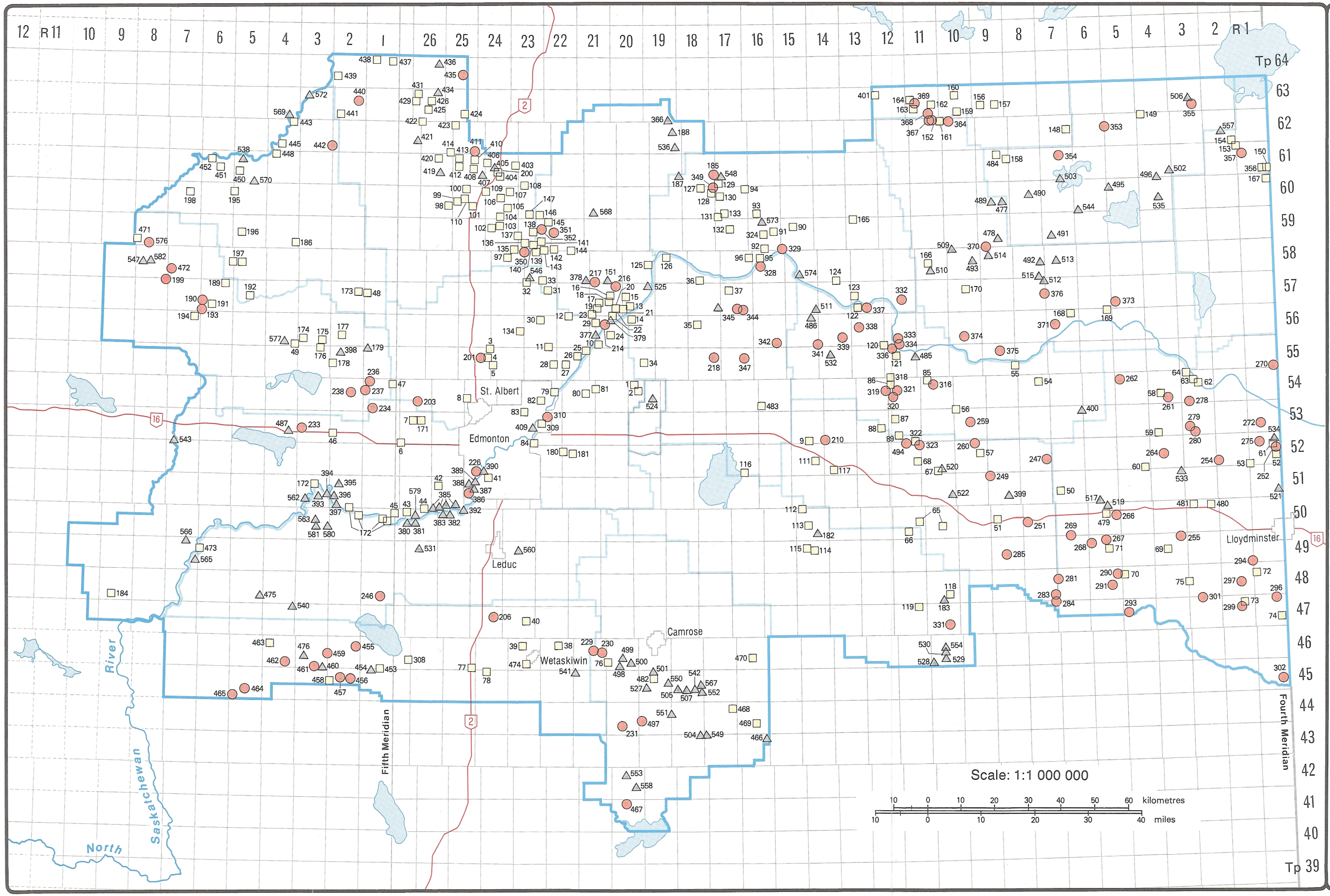
Tertiary – the first period of the Cenozoic era (after the Cretaceous of the Mesozoic era and before the Quaternary), thought to have covered the span of time between 65 and 3 to 2 million years ago.

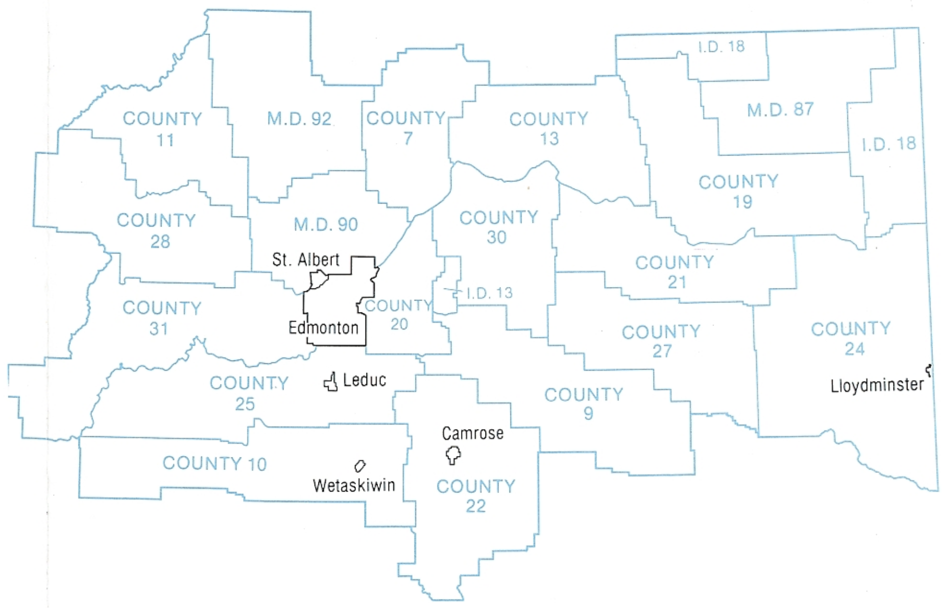
thalweg – the line joining the deepest points of a stream channel.

till – a heterogeneous mixture of clay, sand, gravel and boulders varying widely in size and shape and deposited by a glacier.

tough – a general descriptor for a material that is able to absorb stress by plastic deformation; that is, that has tensile strength.

viscosity – the property of a substance to offer internal resistance to flow.



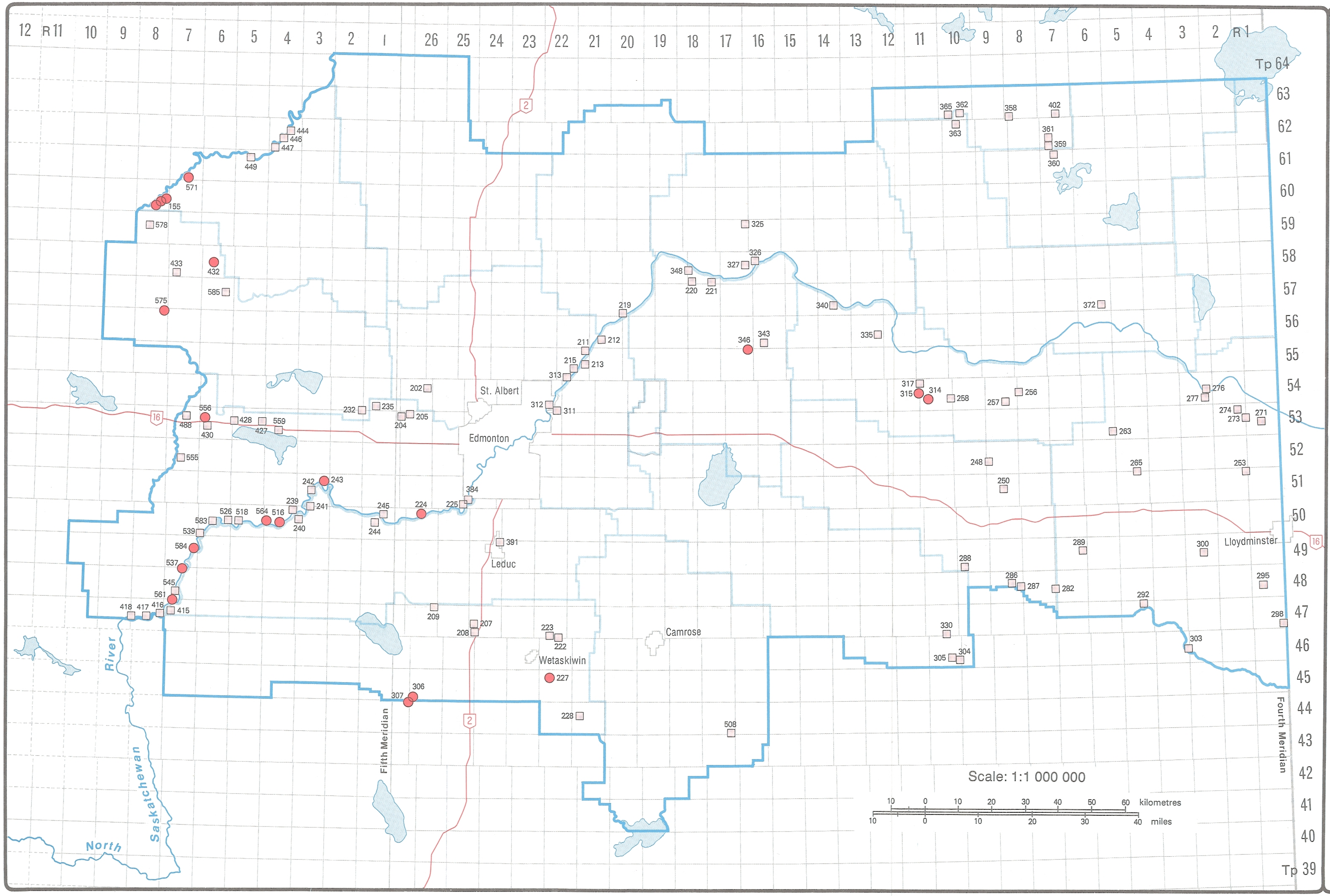


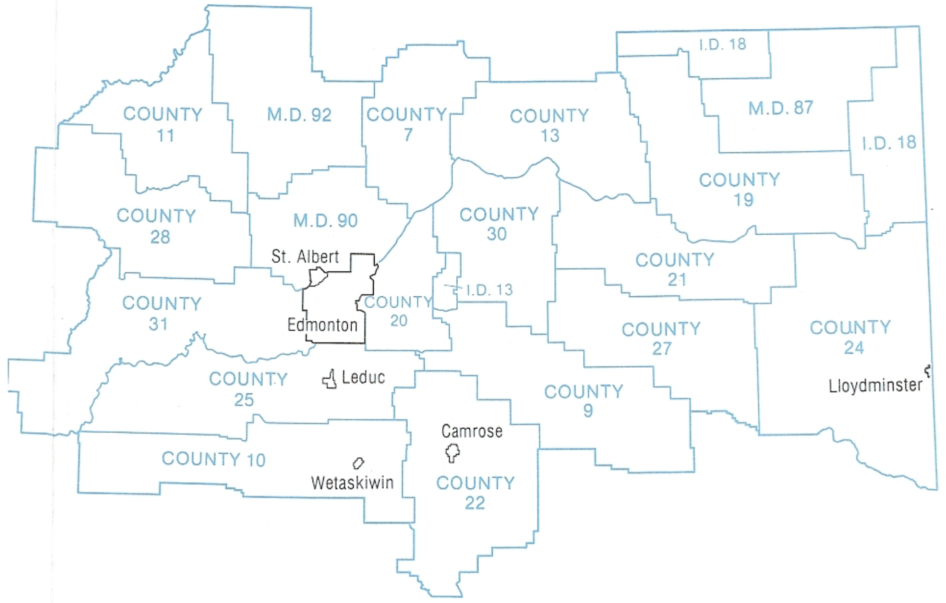
Study Area and Municipalities within Study Area

Gravelly sand and sand deposits

- ● Gravelly sand
- □ Sand
- △ Deposits of unknown grade
- 347 Deposit number

Figure 2



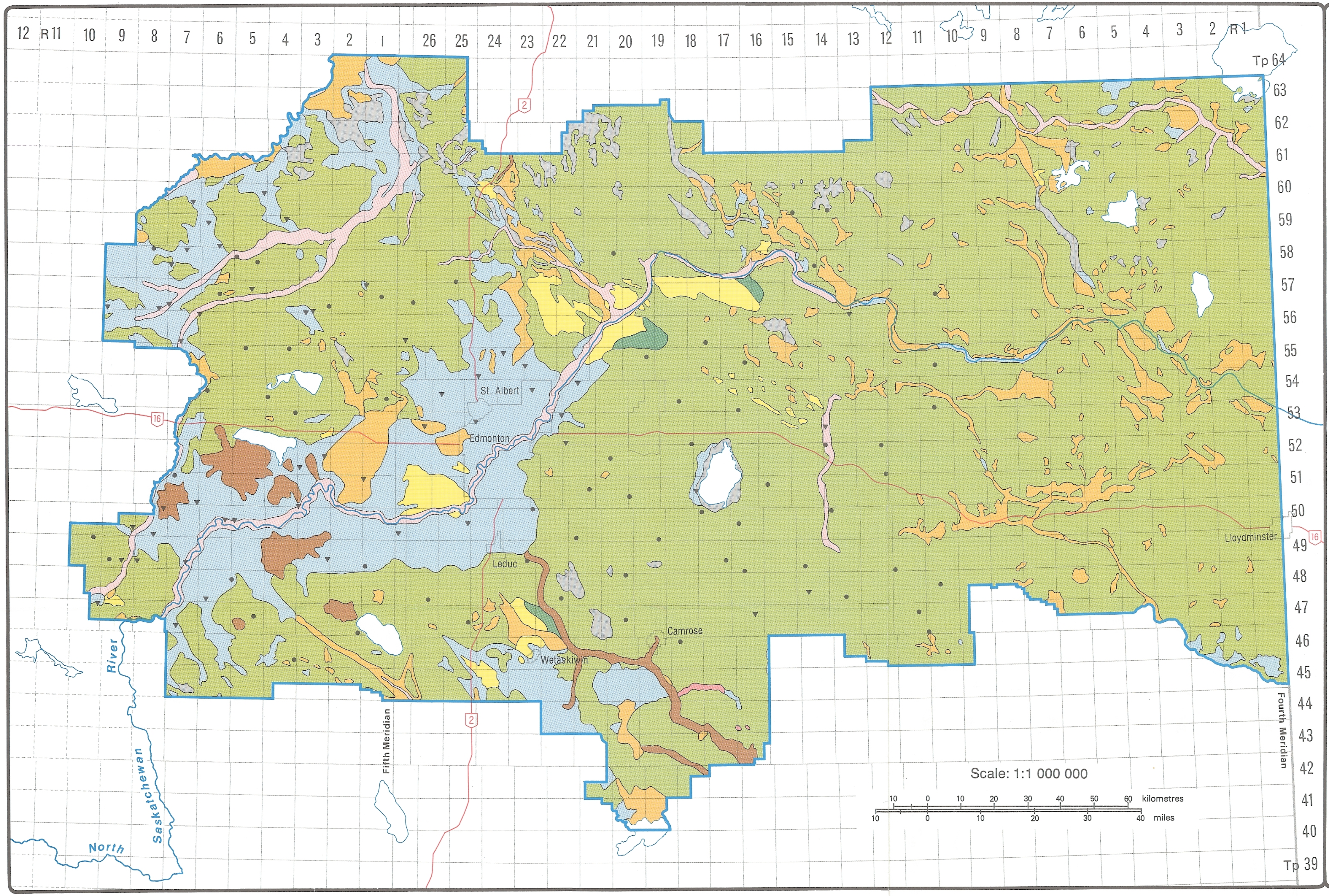


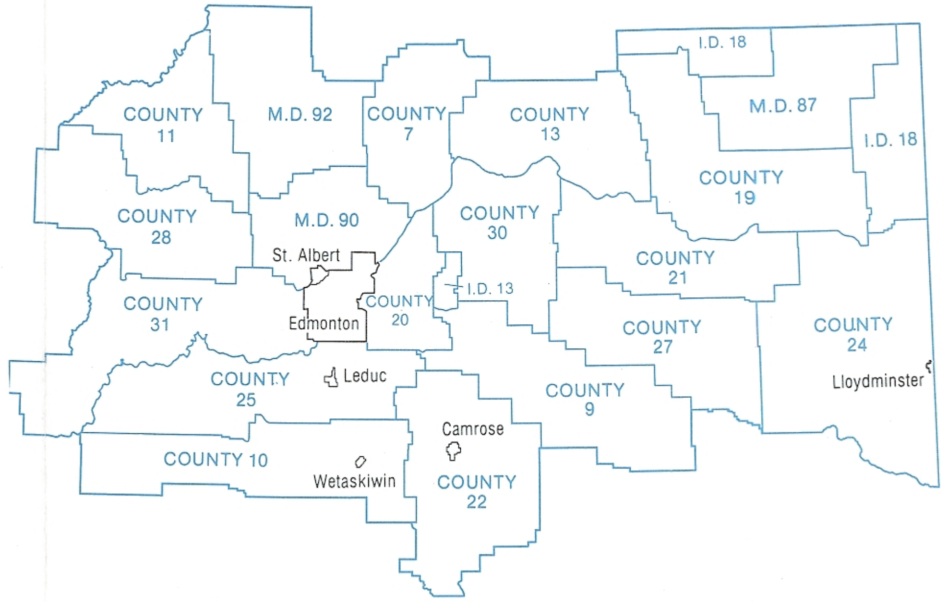
Study Area and Municipalities within Study Area

Gravel and sandy gravel deposits

- ● Gravel
- □ Sandy gravel
- 346 Deposit number

Figure 3





Study Area and Municipalities within Study Area

Surficial geology

Unit name	Material description
HOLOCENE (RECENT)	
ORGANIC/LACUSTRINE	peat, organics, silt, clay, sand
EOLIAN	fine sand
LOESS	silt
ALLUVIUM	gravel, sand, silt, clay
PLEISTOCENE	
GLACIOLACUSTRINE	silt, clay
GLACIOFLUVIAL	sand, gravel, silt, clay
TILL	unsorted mixture of sand, silt, clay, gravel
PLEISTOCENE/TERTIARY	
FLUVIAL	gravel, sand
TERTIARY/CRETACEOUS	
BEDROCK	sandstone, shale, coal
• Till sample sites	
▼ Glaciolacustrine sample sites	

References:

Gravenor and Ellwood, 1957; Stalker, 1960; Ellwood, 1961; Bayrock, 1967; Richard, 1968; Bayrock, 1972; Boydell *et al.*, 1974; St.-Onge and Richard, 1975; Andriashek *et al.*, 1979; Richard, 1979; Fenton and Andriashek, 1982.

Figure 13