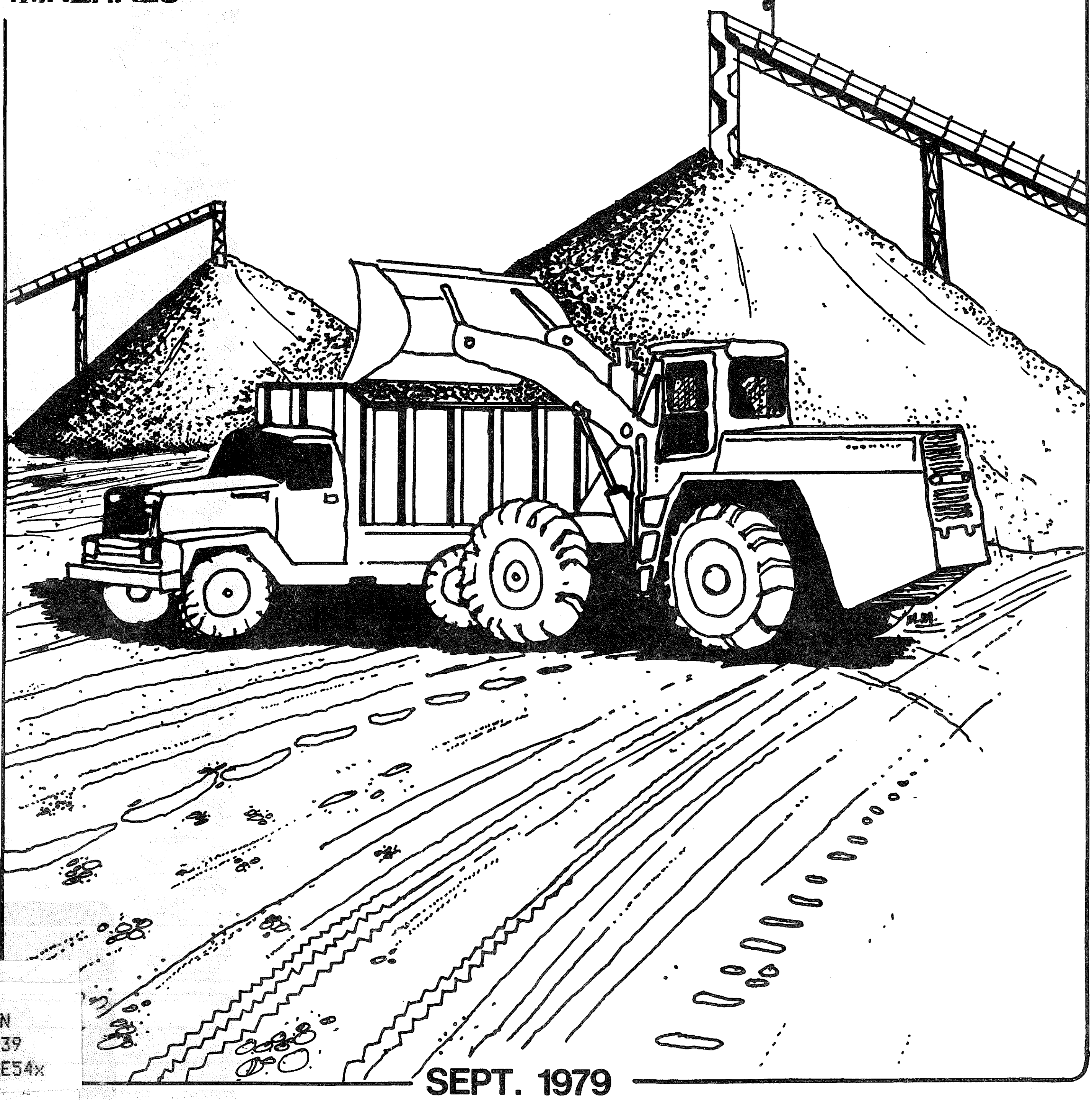
Minnesota

INDUSTRIAL MINERALS IN MINNESOTA

A Status Report On Sand, Gravel, And Crushed Rock

DEPARTMENT OF NATURAL RESOURCES
DIVISION OF MINERALS



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INDUSTRIAL MINERALS IN MINNESOTA:
A STATUS REPORT ON SAND, GRAVEL, AND CRUSHED ROCK

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DEFINITIONS

Aggregate	-	A mixture of rock and mineral particles that is mechanically separated into various sizes for mixing with cementing or bituminous material or for other special construction and manufacturing uses.
Aquifer	-	A waterbearing geological formation that will yield significant quantities of water to wells or springs.
Crevasse	-	A vertical crack or fissure in a glacier up to 200 feet deep caused by stresses in the ice.
Delta	-	A fan-shaped nearly flat tract of land containing stratified sand and gravel deposited near the mouth of a river entering a large body of water.
Des Moines Lobe	-	Part of a large continental glacier from Manitoba that followed a path along the Red River Valley and through southern Minnesota.
Dolomitic Limestone	-	A sedimentary rock rich in magnesium carbonate and the mineral dolomite.
Esker	-	A long, narrow, sinuous, steep sided ridge composed of irregularly stratified sand and gravel deposited by a subglacial stream flowing within the ice.
End Moraine	-	A complex series of irregular hills deposited by a glacier constructed of glacial till. Moraines form a continuous belt that marks the maximum extent of a glacier.
Glacial Lobe	-	A large tongue of glacial ice representing a regional extension of a continental glacier.
Ground Moraine	-	A rolling gently undulating topography constructed of unsorted glacial till deposited at the base of a glacier.
Glacio-fluvial deposits	-	Sand and gravel deposits transported and deposited by glacial streams beyond the glacier, such as in outwash, deltas, fans, terraces, and valley train.
Gravel	-	A natural accumulation of rock or mineral particles eroded and rounded by natural forces that range from 2^{mm} to 75^{mm} (1/12 to 3 inches) in diameter.
Ice-Contact deposits	-	Irregularly stratified sand and gravel deposited in contact with glacial ice such as eskers, kames, and crevasse fillings.
Kame	-	A cone shaped hill of irregularly deposited sand and gravel deposited within a hole in the glacial ice near the ice front.

Lake Plain - A nearly level topography marking the floor of an extinct lake usually constructed of laminated fine grained soil such as silt and clay.

Limestone - A carbonate sedimentary rock containing more than 95% calcite and less than 5% dolomite.

Outwash - Sorted stratified sand and gravel deposited beyond a glacial ice front by meltwater streams forming a broad level plain.

Quartzite - A very hard sandstone consisting chiefly of quartz grains that are so solidly cemented with secondary silica that the rock breaks across or through individual grains rather than around them.

Rainy Lobe - A glacier that entered northern Minnesota along the Rainy River, traveling as far south as the Twin Cities area.

St. Louis Lobe - Represents an offshoot glacier of the Des Moines Lobe that traveled east in the northern part of the state to as far as St. Louis County.

Till - Unsorted, unstratified glacial debris deposited directly by a glacier.

Terraces - A elongated level bench of land narrower than an outwash trending parallel to the valley of a former watercourse; usually constructed of sand and gravel.

Valley Train - A long narrow body of outwash deposited by glacial streams far beyond the margin of a glacier and confined within the walls of a valley.

INTRODUCTION

The Department of Natural Resources is responsible for managing state-owned metallic and non-metallic earth resources and for periodic review of the state's mineral industry. As part of this on-going responsibility, and in response to numerous inquiries, this status report on Minnesota Aggregate has been prepared for the general information of local and state government officials and concerned citizens. It is our intention to provide a new perspective and appreciation for Minnesota's valuable aggregate resources and some of the problems encountered in mining them. This paper documents four aspects of the aggregate industry:

1. The geologic deposition of sand and gravel,
2. The size of the industry, including historical trends and future predictions,
3. The environmental and land use problems that exist today, and
4. The status of existing governmental programs.

Because this is an informational document, policy recommendations are not included.

THE RESOURCE

Minnesota is fortunate to have abundant mineral resources. Besides producing 60% of the nation's iron ore, Minnesota has produced a variety of industrial minerals, including: abrasives, clay and shale, cement lime, dolomite, gneiss (pronounced nīs), industrial sand, lime, limestone, marble, marl, peat, quartzite, sand and gravel, sandstone and traprock (a dark crystalline rock). Table 1 lists industrial minerals that currently are being mined in Minnesota, and the number of companies currently operating such mines. The listing is based on information from the U. S. Bureau of Mines, which was current as of October 1978.

TABLE 1. INDUSTRIAL MINERALS AND NUMBERS OF OPERATORS

Abrasives	1	Limestone (dimensional)	3
Clays and Shale	3	Peat	4
Granite (dimensional)	4	Quartzite (crushed)	1
Granite (crushed)	5	Quartzite (dimensional)	1
Industrial Sand	3	Sand and Gravel	347
Limestone (crushed)	30	Traprock	1

The actual number of mines is larger than the number of operators. A tally of mines based on information from the U. S. Bureau of Mines[24] and the Mining Safety and Health Administration[23] shows there are 623 known, active, seasonal and intermittent sand and gravel mines and 102 active crushed stone mines in the state. Others have estimated that in the Twin Cities Metropolitan area alone, there are 613 aggregate mines[10]. No authoritative inventory exists for the number of aggregate mines in the State of Minnesota.

These two products (sand and gravel and crushed rock), collectively referred to as aggregates, make up most of the volume and dollar value of industrial mineral mining in the state. Output of sand and gravel accounts for about 5% of the total state value of mineral production.

GLACIATION AND AGGREGATE SUPPLY

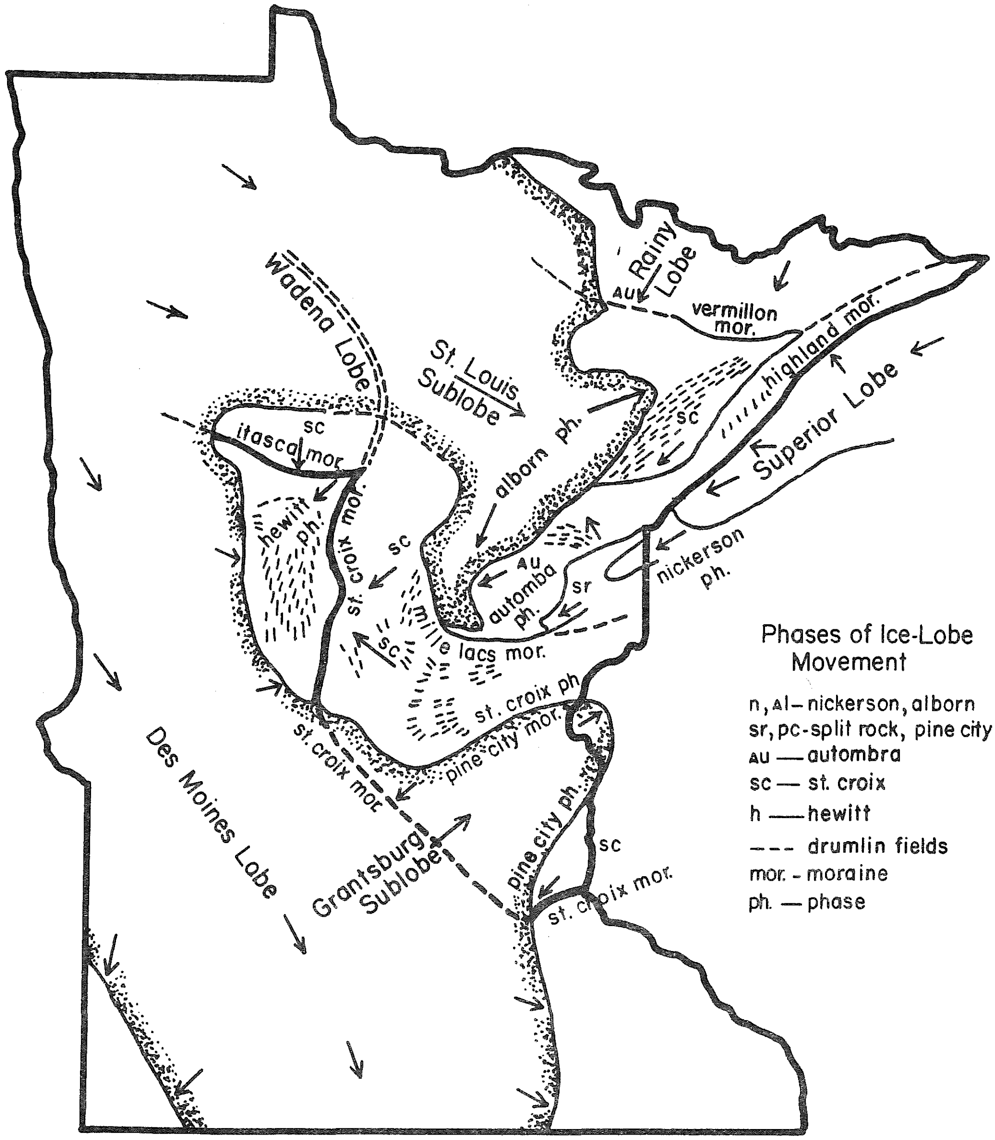
The availability of sand and gravel aggregate in Minnesota is directly related to glacial events that occurred over the last 2 million years during the Great Ice Age. Over this period of time, known as the Pleistocene Epoch, the state was subjected to multiple periods of glaciation.[25]

Each period of continental glaciation was separated by long interglacial periods when the climate moderated and the ice thawed and retreated back into the Arctic Regions. A precise picture of early glacial events is not easily constructed because most of the evidence of this glaciation was destroyed or altered by succeeding glaciers. However, nearly all of the surficial glacial features in the state resulted from events that occurred during the last period of glaciation (Wisconsin), which spanned a time from 10,000 to 100,000 years ago. Most sand and gravel was deposited in Minnesota during this period of time.

The glacial events associated with the multiple advances and retreats of major ice lobes during this period of glaciation is subdivided into phases related to the events of individual lobes (Figure 1). Each phase was separated from the next by warm periods of melting, which caused major lobes to diminish and retreat. This permitted other ice lobes to advance from different directions over previously glaciated terrain.

Glaciers incorporate rocks and soils from areas over which they flow. Usually each glacial till contains indicator rocks which, are helpful in determining the source, direction, and movement of glaciers. For example, the presence of limestone and shale in the Des Moines Lobe and St. Louis Sublobe tills are indicators of sedimentary rock formations from southern Manitoba. The limestone and shale in the till transported into Minnesota by glaciers passing across that area, and the sand and gravel associated with these glaciers would contain a high percentage of these materials. Agate, basalt, sandstone, and felsite are indicators of rock formations in the Lake Superior basin and the red tills of the Superior Lobe. Tills deposited by the Rainy Lobe are very granular and bouldery and are identified by the presence of gabbro, iron formation, granite, and the notable absence of Lake Superior agates.

The abundance of certain rocks in a glacial till tend to give it and the gravel derived from it certain characteristics. Gravels associated with the Rainy and Superior tills contain high percentages of hard, durable rocks and as a whole yield higher quality aggregates. Those gravels derived from softer sedimentary rocks, such as those of the Des Moines Lobe and the St. Louis Sub-lobe, have a higher clay and silt content and generally yield less durable aggregates because of their makeup of soft limestone and shale particles.



After H. E. Wright Jr. 1972

FIGURE 1, THE MOVEMENT OF GLACIERS THROUGH MINNESOTA

Gravel deposits are formed by the sorting action of meltwater along the margins of glaciers. Subsequently, gravel deposits are more abundant around the outer margins of end moraines and in the lower level ground beyond the glacier where large glacial streams deposited their heavy load of outwash sediment. This map indicates multiple glaciers were drawn into the lowlands in central Minnesota, which serves to explain why the extensive outwash plains and numerous ice contact deposits are concentrated in that area. Those lands located within the interior of the glacier consist primarily of undulating ground moraine or flat lakeplains. Here, gravel deposits are more limited both as to size, type, and abundance.

GLACIAL DRAINAGE The advance and retreat of these glaciers resulted in the discharge of enormous amounts of meltwater, which sorted out the glacial debris (till) into stratified deposits of sand and gravel. Consequently gravel potential is directly correlated with the former hydrologic system, which in effect is presently represented as a gravel system.

A typical glacial drainage system consists of a combination of ice contact gravel deposits such as eskers, kames, or crevasse fillings representing the headwater source area of subglacial streams within the ice. These streams contributed sediment and were tributary to the large outwash deposits beyond the ice (Figure 2). Several glacial river systems similarily discharged their meltwaters and sediment load into large outwash plains in Central Minnesota.

GLACIAL LAKES The melting glaciers produced large glacial lakes behind their moraines, which deposited fine sand, silt and clay in broad lake plains. Former shorelines of these lakes are now marked by long, narrow beach deposits. Some of the old glacial lakes that formerly existed in Minnesota are: Lakes Agassiz, Upham, Aitkin, Duluth, Nemadji, Norwood, Grantsburg, Benson, and Minnesota. However, only Lake Agassiz, which occupied Western Minnesota, and Lake Duluth, located in the Lake Superior basin, were large enough to produce the strong lake currents necessary to construct significant shoreline deposits of sand and gravel.

Some of these lakes were contemporary and drained from one to another at various times. Glacial Lake Agassiz, which existed betweeen 12,800 to 9,000 years ago, drained during an early stage to Lake Upham then to Lake Duluth, and finally to the headwaters of the St. Croix River. Lake Agassiz at various stages once covered over 200,000 square miles in Minnesota, North and South Dakota, and Canada (Figure 3). Former shorelines of Glacial Lakes Agassiz and Duluth contain important gravel and sand deposits in beaches, deltas, and off-shore

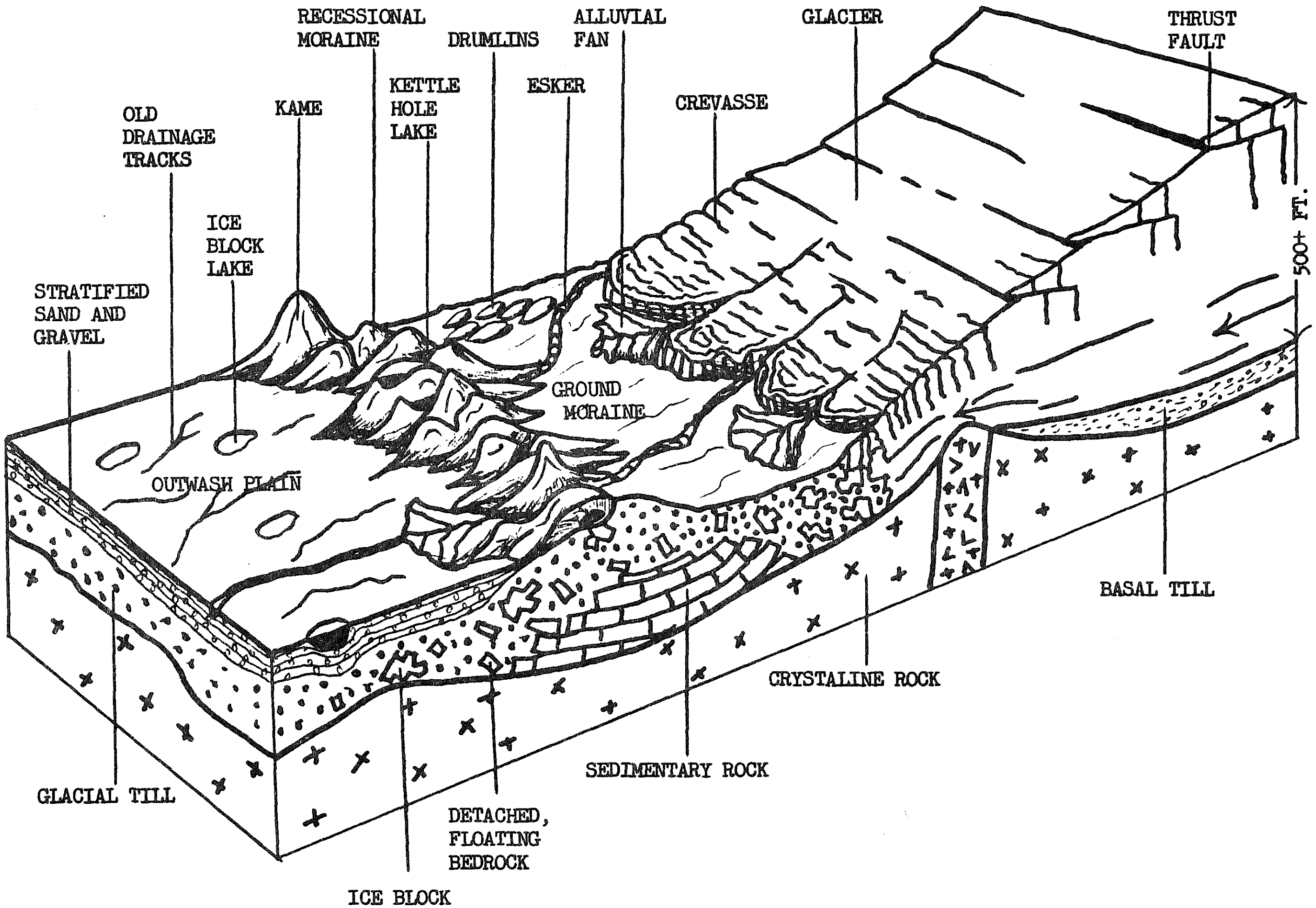


FIGURE 2, A three dimensional view of a glacier and its deposits

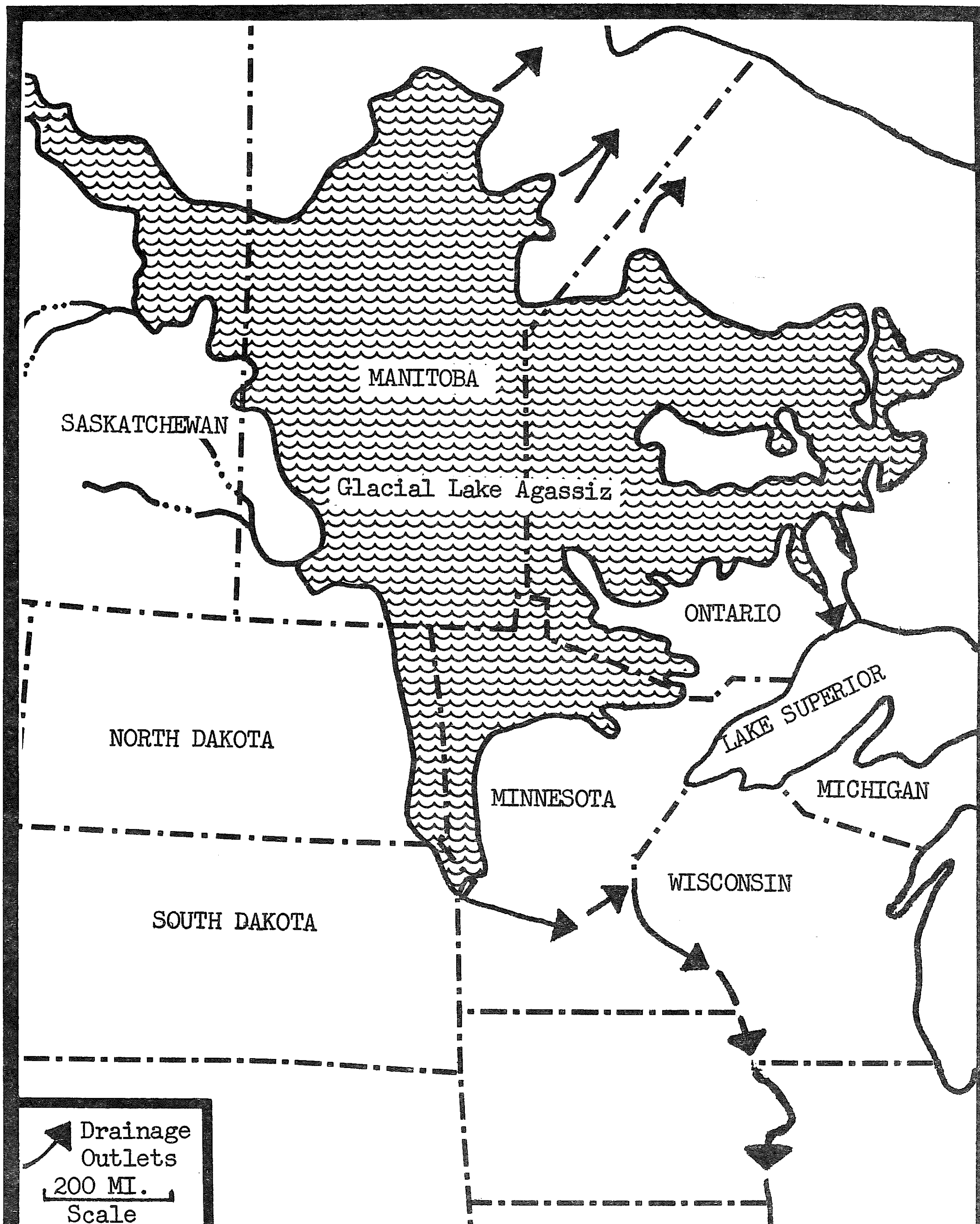


FIGURE 3 The area covered by Glacial Lake Agassiz during its various stages. Arrows show major outlets for the lake. Former shorelines and outlet water courses are important sources of sand and gravel in Northwestern and Southern Minnesota. (Modified from Elson 1967 and Arndt 1977)

bars, which are strategically located within gravel scarcity areas in western and northwestern Minnesota.

Lake Agassiz's outlet via the Glacial River Warren discharged enormous amounts of water through the deep valley now occupied by the present Minnesota River and the Mississippi River below St. Paul. The large gravel terraces deposited along the former watercourse now serves as one of the most important sources of sand and gravel in southern Minnesota.

<u>SAND AND GRAVEL DEPOSITS</u> The mechanical placement of sand and gravel is directly related to the hydraulic sorting of the glacial till. Broad glacial streams reworked the till and transported the finer-grained particles downstream. Their strong currents tumbled and rolled the large, heavy, gravel size particles along the channel bottom, causing them to be sorted, rounded, and redeposited as gravel. As the streams increasingly became overloaded with sand and gravel, they shifted their channels, thereby changing the velocity of the current, flow direction, rate of deposition, and size of material being deposited. Each resurgence of meltwater removed more of the finer particles thereby upgrading the quality of the gravel. Subsequently, the more uniform gravel deposits are those that have been reworked many times by strong currents and transported considerable distances.

Gravel deposits are subdivided into ice-contact deposits, or those deposited within the ice, and glacio fluvial deposits, or those deposited by meltwater beyond the ice.

ICE CONTACT DEPOSITS Examples of ice-contact deposits are kames, eskers, and crevasse fillings which are sand and gravel formations deposited in holes and meltwater channels within the glacier.

1. Kames are prominent cone-shaped hills of sand and gravel formed by water plunging into a hole in the ice. Kames frequently are found in clusters within the moraine near the ice front. Usually they are poorly sorted, are sandy near the top, and grade to gravel near the bottom (Figure 4). Kames occasionally rise to over 100 feet in height. An excellent example of a lone kame can be seen at the Twin Cities Arsenal plant in New Brighton, which contains over 140 feet of sand and gravel.

2. Eskers are narrow, sinuous ridges often miles in length formed in the channels of subglacial streams flowing through tunnels within or at the base of the glacier. Gravel pits opened in eskers display a complex slump-bedded pattern of deposition, reflecting structural collapse caused by the subsidence of supporting ice walls. The quality of gravel and grain size in these deposits is very irregular because of the hydraulic effect of ice movement on the velocity of streamflow. Eskers are important sources of sand and gravel because they frequently cross areas of ground moraine where other gravel deposits are unavailable. They range from fifty to several hundred feet wide at their base, but seldom rise more than 100 feet in height. Esker systems in Minnesota seem to be more abundant and better developed in the areas glaciated by the Rainy and Superior Lobes. The Finlayson esker is a good example of an esker system (Figure 5).

3. A Crevasse Filling is another type of ice contact deposit similar to a kame. Generally this term is applied to those ice-contact gravel deposits that cannot be readily explained or identified with other categories.

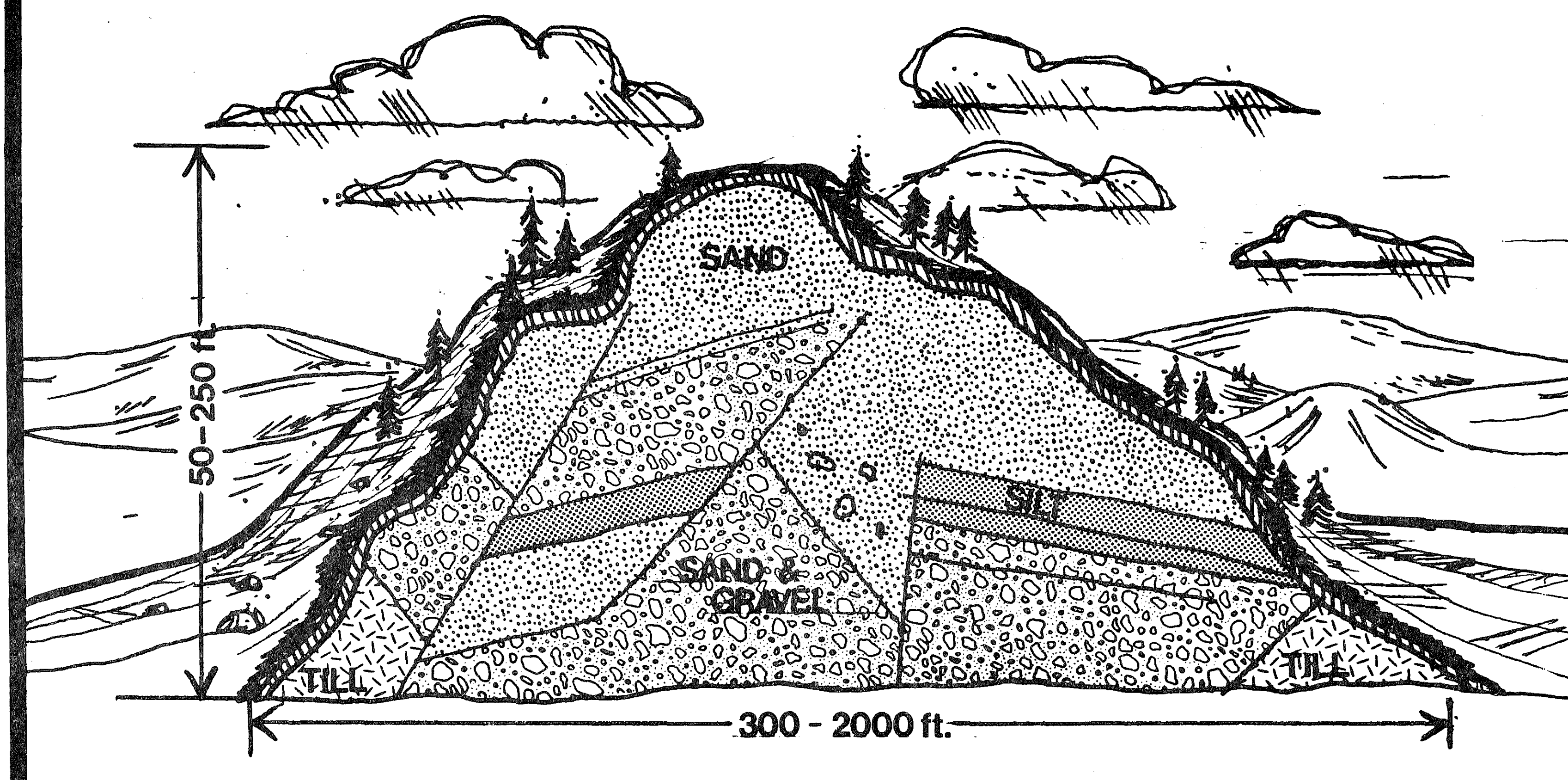


FIGURE 4, A schematic drawing of a kame deposit showing the typical collapsed bedding.

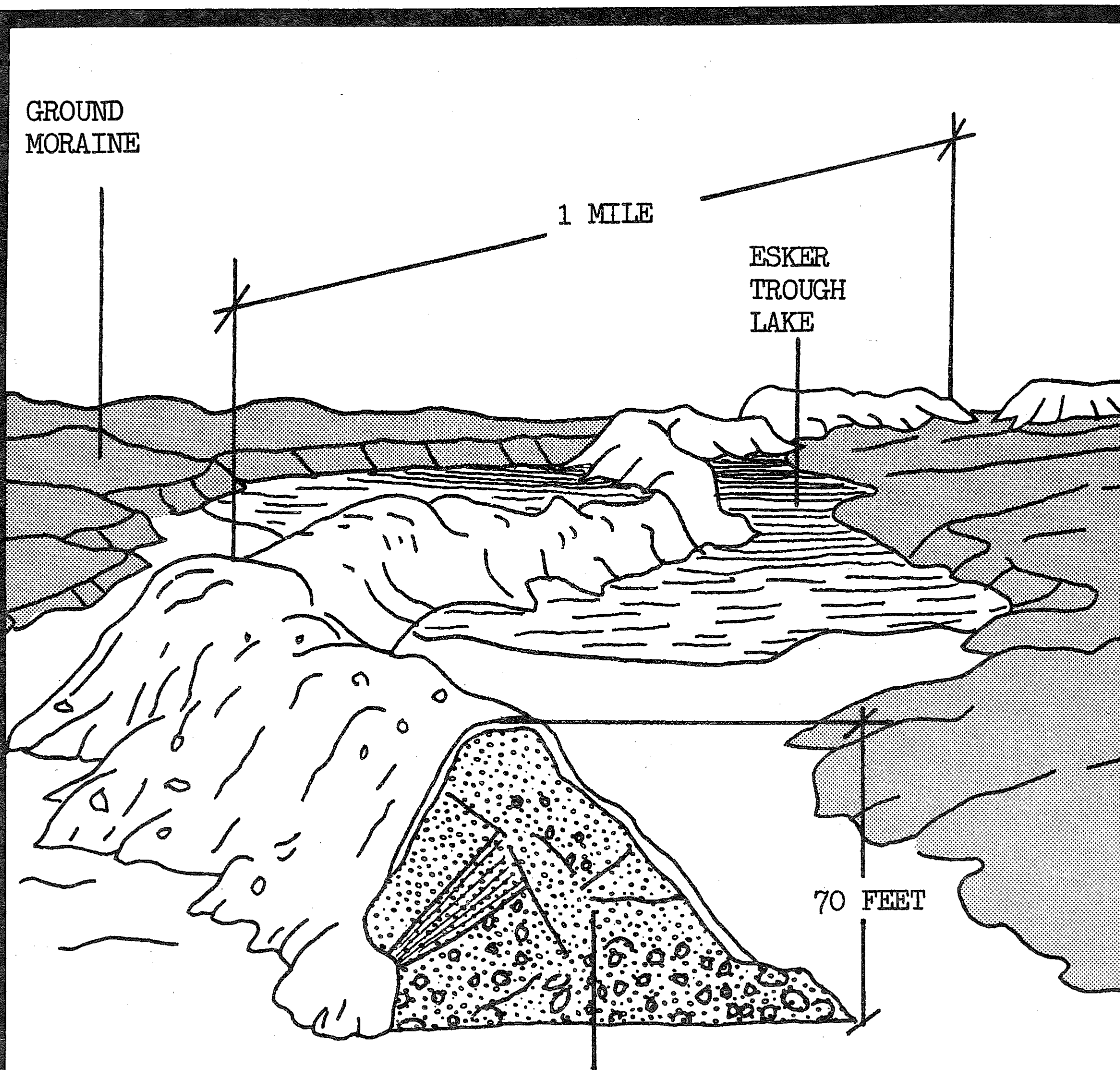


FIGURE 5. A schematic view of an esker near Finlayson, Minnesota showing its complex structure of sand and gravel. The esker trough with esker trough lakes marks the width of the subglacial drainageway.

They represent irregular steeply sloping landforms within the end moraine complex constructed of bouldery sand and gravel often mixed with inclusions of unsorted till.

GLACIO FLUVIAL DEPOSITS Glacio-fluvial deposits are deposited by streams beyond the ice front along the margin of the glacier. Shoreline deposits of glacial lakes have been included in this category. Typical deposits are glacial outwash, valley train, terraces, channel deposits fans, shoreline bars, deltas, and beaches.

Glacial Outwash This type of deposit is a broad outwash plain of sand and gravel deposited by overloaded streams. Glacial streams often shift their channels and merge to fill in large expanses many miles wide with a plain of uniformly stratified sand and gravel. This type of deposit usually contains better quality gravel because the material was subject to more intensive reworking and transported longer distances by the streams. Outwash deposits are preferred for mining because their quantity and quality are predictable. Central Minnesota contains large outwash plains of sand and gravel representing the meltwater drainages and deposition of multiple glaciers that were drawn into the central lowlands. In addition to being an important source of gravel, outwash deposits usually contain valuable groundwater resources for irrigation farming and potable water supplies for farms and municipalities.

Valley Trains and Terraces Valley trains and terraces are related sand and gravel deposits that form elongated terraces of stratified sand and gravel trending parallel to the valley walls of major rivers.

Terraces develop when the river starts to erode down through its valley fill of alluvial sand and gravel because of an increase in flow or a steepening of its channel gradient. Excellent examples of valley train terraces are found along the Minnesota and Mississippi river valleys.

Their value as a quality aggregate source is similar to that of a glacial outwash except that they are more limited in extent and may contain more silt layers.

Channel deposits Many of the deep preglacial river valleys were filled with sand and gravel by glacial streams. Parts of the lower Minnesota River below Mankato and the Mississippi River valley below St. Paul have large bedrock valleys containing over 100 feet of saturated gravel fill. Other significant preglacial bedrock valleys containing similar underwater gravel deposits are located in east central Minnesota.

Fans Occasional fan deposits may develop along the outer margin of a moraine. Deposits of this type occur infrequently and are difficult to recognize because of their variation in size and alteration by erosion. Fans can be found along the end moraines of the Des Moines Lobe in southwestern Minnesota and the end moraines of the Superior Lobe in east Central Minnesota. The larger deposits may exceed 50 feet in depth at the highest point near the moraine. The degree of slope is a significant factor in the distribution of grain size in fan deposits grading from gravel near the apex, to sand downslope along the margins.

Shoreline Deposits Shoreline deposits consist of beaches, deltas, and off-shore bars formed by currents and wave action of large glacial lakes. Only the largest glacial lakes possessed currents strong enough to develop significant shoreline sand and gravel deposits.

1. Beach gravel represents the sorting of material in selected areas by surf action and off-shore currents. Typically certain stretches of the shore may contain pea gravel having a very narrow range in grain size because of the selective sorting by the surf. Beach deposits of glacial lakes characteristically are long, narrow, and shallow, usually ranging

between 10 to 15 feet in depth. They are an important source of gravel in northwestern Minnesota.

2. Deltas form when sediment laden streams flow into a still body of water and velocity slows thereby causing the sediment load to be deposited. The larger,heavier material drops out first; the finer particles of silt and sand remain in suspension and are carried out farther into the lake basin before being deposited. Several delta deposits occur along the former shoreline of Glacial Lake Duluth inland from the Lake Superior coast.

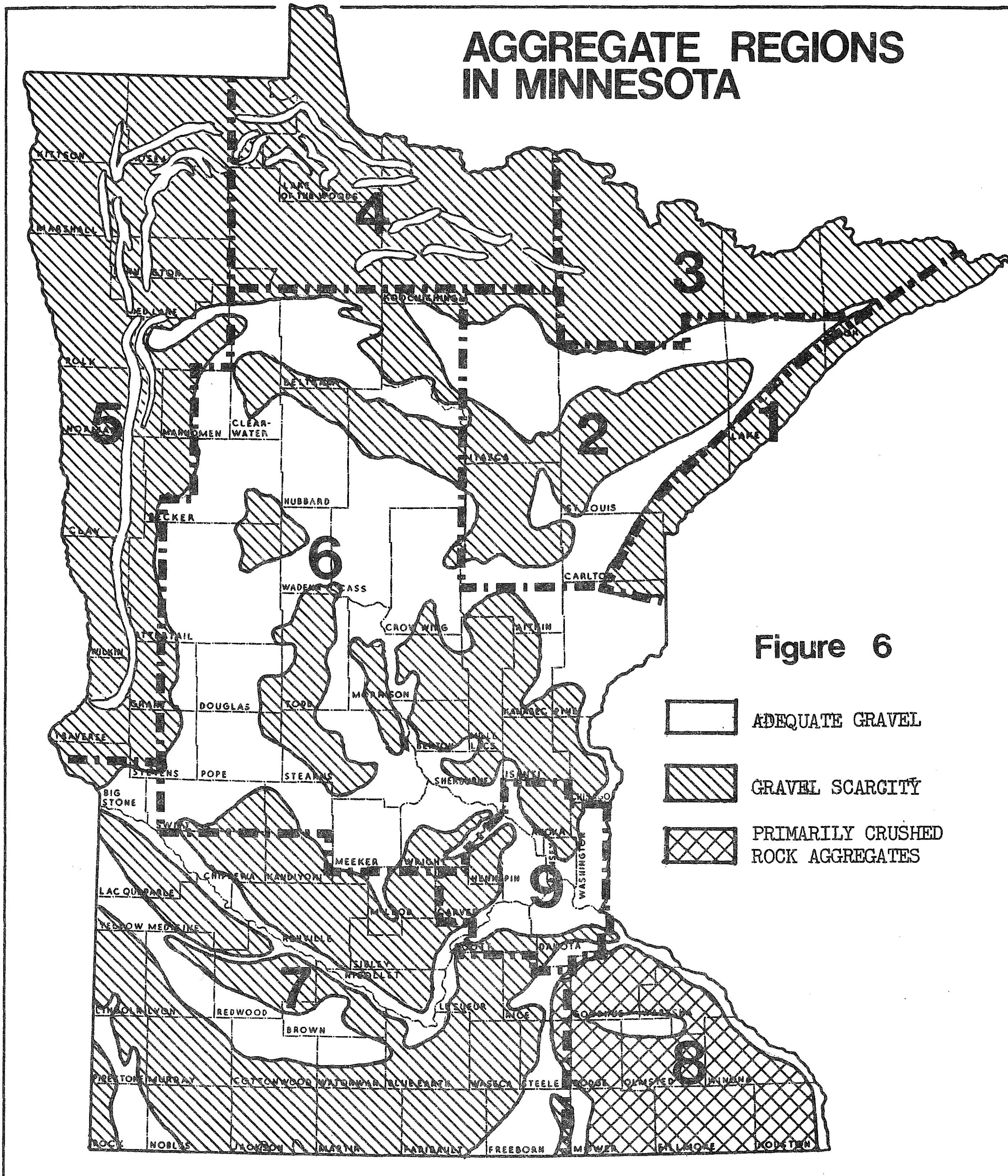
AGGREGATE REGIONS

Minnesota can be divided into nine aggregate regions as shown in Figure 6, based upon the availability, quality, and adequacy of gravel in each region and projected demands. Unshaded areas on the map indicate adequate gravel resources; shaded areas are inadequate. The following discussion generally describes the gravel resources in each region.

Region 1 - Lake Superior Coast

This region consists of a rocky coastline with steep precipitous slopes extending from Duluth to the Canadian border. Rock formations dominate the landscape in a belt that extends about three to six miles inland from the coastline. Farther inland, glacial landforms are more prevalent and the dominant feature is the Highland Moraine. It consists of a rugged rolling glacial topography constructed of red bouldery till deposited by the Superior Lobe. The crest of the Highland Moraine parallels the Superior coastline about 10 to 12 miles inland and forms the region's western boundary. Local surface relief is extreme, ranging between elevation 602 at the level of Lake Superior to over elevation 1600 along rocky uplands a few miles inland. It is not unusual for the surficial relief to vary 300-500 feet within one mile. The rocky character of the landscape emphasizes that this is an area of glacial erosion rather than deposition; the glacial till in this area is relatively thin.

Nearly all the gravel deposits along the North Shore of Lake Superior are associated with the various beach deposits of Glacial Lake Duluth (the predecessor of Lake Superior) and deltas deposited by streams entering the lake. All of these deposits are situated within a few miles inland of and parallel to the coastline of Lake Superior.



Region 1 - Lake Superior Coast

Region 2 - Mesabi

Region 3 - Border Lakes

Region 4 - East Agassiz

Region 5 - West Agassiz

Region 6 - Central Moraine and Outwash Complex

Region 7 - Minnesota River - Keewatin Area

Region 8 - Limestone

Region 9 - Metropolitan Area

At its maximum stage, Lake Duluth stood approximately 550 feet higher than Lake Superior. It had a similar rocky coastline that produced strong lake currents that washed and modified the area. Very little soil was available for lake currents to build extensive beach deposits of sand and gravel. As a result the landscape inundated by Lake Duluth contains only scattered narrow deposits of sand and gravel in lake beaches, bars, and spits. The interbeach area located between each shoreline generally contains fine grained lake sediments of clay, silt, cobbles, and bare rock.

Shoreline beach deposits are usually disconnected, narrow, and comparatively shallow in comparison with other glacial deposits. In addition the type of gravel in each deposit may vary considerably and have a narrow range in grain size because of the variable shoreline currents and the period of time each lake level persisted. Consequently the gravel potential on the North Shore is very limited and existing gravel pits do not contain large reserves.

The increased emphasis upon preserving the scenic environment and developing recreation along the North Shore has changed land use patterns. Mining is restricted, and nearly all of the proven gravel pits near the coastline are now located within scenic or dedicated lands and are unavailable for producing aggregates. Other gravel deposits may be found farther inland at scattered locations along the old shoreline of Glacial Lake Duluth.

The west side of the Highland Moraine in St. Louis and Lake counties contains extensive ice contact deposits of bouldery sand and gravel associated with kames, crevasse fillings, and eskers. They represent the headwater deposits of glacial drainage systems of the Superior and Rainy lobes, which drain southwest to the Cloquet River outwash deposits. Generally these deposits have poor road access because of the relatively undeveloped nature of the area; however, they represent the best alternative gravel resource for the North Shore.

A lake plain associated with Glacial Lake Nemadji occupies part of this region in Carlton County south of Duluth. This plain is heavily eroded and dissected by modern streams where they flow down the steep ice-contact slopes to Lake Superior. The Nemadji lake plain has practically no potential for gravel.

The Nickerson Moraine, located south of Duluth in Carlton County, has a gravel potential associated with ice-contact deposits. Scattered drainage channel deposits and shoreline deposits of Glacial Lake Duluth are also found in this area between Scanlon and Jay Cook State Park.

A small, shallow outwash of sand and gravel partly covered in places by lake sediments extends southwest from Wrenshall in Carlton County.

All of these factors tend to underscore that the Lake Superior coast is an area where gravel reserves are inadequate. Special attention should be given in making land use decisions, so that the remaining undeveloped gravel lands located in the Highland Moraine will always be available for mining aggregates.

Region 2 - Mesabi

Region 2 is named after the Mesabi Iron Range, which dominates the landscape and the economy of this area. It forms a wedge between the Giants Range and Vermilion Moraine on the north, the Highland Moraine on the east, and moraines of the St. Louis sublobe on the west. Generally sand and gravel reserves are considered to be adequate in this area. Locally the demand for sand and gravel for certain types of construction is diminished because of the availability of tailings from iron mining operations.

The beds of Lakes Upham and Aitkin which angle through the central part of the region contain few gravel deposits. Sand and gravel within the old lake plain is limited to scattered, thinly bedded shoreline deposits, deltas formed by inflowing streams, and gravel bars formed by shoreline currents. Most of these deposits contain some shale and limestone rocks. A few scattered pits are opened in the old Lake Upham basin in long, narrow ice-contact deposits covered by lake sediments. These deposits contain gravel rich in iron formation, granite, and gabbro rocks derived from Rainy Lobe.

Glacial outwash, terraces, and ice contact deposits associated with the Rainy, Superior, and St. Louis sublobe glaciers are being mined to fill the current demand for gravel in this region.

Superior - Rainy glacio-fluvial and ice contact deposits are abundant in the eastern part along the west side of the Highland Moraine. Outwash and esker systems are well developed along the Cloquet River Valley, with significant undeveloped deposits occurring near the Island and Boulder Lake Reservoirs.

Other important outwash deposits occur south of Hibbing, and along the Embarrass River valley between Aurora and Babbitt.

Several gravel quality problems occur in this region. One is related to the narrow range in particle size and the high percentage of oversize boulders found in the ice contact deposits of the Rainy and Superior Lobes. Another problem is associated with those pits located close to the Virginia rock formation along the southern edge of the Mesabi Range. Many of these pits are contaminated with Virginia Argillite, a gray greenish mica and clay rich siltstone, which breaks down easily in concrete and bituminous mixes.

Region 3 - Border Lakes

The Border Lakes region is characterized by numerous ice scoured rocky lake basins, and rock formations. This is an area of heavy glacial erosion rather than deposition; the mantle of glacial drift is very thin and gravel deposits in the eastern part are primarily limited to bouldery eskers and other types of ice-contact deposits associated with the Rainy Lobe.

The western part formerly was covered by an early phase of Glacial Lake Agassiz. Scattered shoreline deposits can be found southwest of Orr in St. Louis County, where the lake reworked the moraines of the Rainy Lobe. Gravel deposits are quite scarce in the vicinity of International Falls. Here scattered gravel deposits related to deposition by the receding Rainy Lobe occur at unpredictable locations buried beneath fine grained lake sediments, usually near rock outcroppings. Weakly developed beach deposits of early Lake Agassiz have been mined at scattered locations. Many of these deposits are shallow, often no more than a few feet deep.

Most of the Border Lakes region other than the International Falls area has a low demand for aggregates because of its low population density and dedicated land use for recreation and wilderness management.

Region 4 - East Agassiz

East Agassiz is representative of the primitive forested bogs associated with the Beltrami arm of Glacial Lake Agassiz which extended east into the Border Lake region. Peat bogs cover most of the south half of this region in Beltrami, southern Lake of the Woods, and Koochiching Counties. Most of the uplands and nearly all of the soils underlying the bogs consist of lake sand, silt, and clay; consequently gravel supplies are inadequate in this area. Gravel deposits are limited to remote shoreline beaches and off-shore bars related to the former levels of Lake Agassiz.

Ice contact deposits occur in the Beltrami Island area in southwest Lake of the Woods County, and in the moraines of the St. Louis Sublobe in southwest Koochiching County near Northhome.

Since this is a sparsely populated area containing large tracts of dedicated forest lands the demand for aggregates is quite low. Gravel pits located in shoreline deposits may have quality problems with shale or have a narrow range of particle sizes due to the selective sorting of the lake currents.

Region 5 - West Agassiz

This region encompasses the large lake plain associated with Glacial Lake Agassiz, bordered by a strip of ground moraine on the east, and the Bigstone Moraine on the south. Gravel supplies are considered severely inadequate because of limited resources in this region. Gravel deposits are limited to former beaches of Lake Agassiz and scattered glacio-fluvial and ice contact deposits buried beneath a heavy cover of lake clays and silts. The lake sediments in this region are highly saturated, and building sites usually require a special preparation of granular fill to provide adequate drainage.

Former shorelines of Lake Agassiz are clearly marked by a series of long continuous beach ridges trending north to south through the central part of the region. Each of these shorelines and their beach deposits mark the various stages of the lake. Usually the beach deposits are a few hundred feet wide and contain a shallow section of sand and gravel ranging from 5 to 15 feet deep.

Beach sand and gravel is quite variable as to quality, range of grain size, and depth. High quality gravel deposits are more prevalent along shorelines where the lake level stabilized for longer periods of time, or where the undertow and other shoreline currents were strong enough to form off-shore gravel bars.

Buried glacio-fluvial deposits occur at unpredictable locations beneath the thick lake sediments in the bed of Lake Agassiz, related to the receding ice front of the Des Moines Lobe. A typical example is the so-called Moorhead aquifer, located near Sabin. This deposit represents a narrow esker like ridge buried in lake sediments with only its summit exposed at the surface.

It serves a dual purpose as an aggregate supply and as a aquifer providing groundwater to the city of Moorhead. Similar buried gravel deposits occur near Crookston. Other surficial glacio-fluvial gravel deposits are found in the vicinity of Halma and Lake Bronson in Kittson County.

The demand for sand and gravel in this region is quite high. Additional large quantities of sand and gravel are shipped by rail and by truck in North and South Dakota, where gravel deficiencies prevail.

Region 6 - Central Moraine and Outwash Complex

Region 6 contains an excellent gravel resource because multiple glaciers focused meltwaters into the State's central lowland. Both ice contact deposits and glacio-fluvial deposits were sorted by successive glacial drainage systems that created a blend of gravels associated with each of the various glaciers. Blending of marginal quality Des Moines Lobe outwash gravels with Superior and Rainy Lobe gravels causes a variation in their quality, by adding or removing fine-grained and hard or soft particles.

At least eight significant outwash deposits are located within this region:

1. Park Rapids Outwash- Covers large parts of eastern Becker, southern Hubbard, and Wadena Counties.

2. Pine River - Pequot Lakes Outwash- This deposit occupies parts of southern Cass and the west half of Crow Wing Counties.

3. Bemidji Outwash- Located in southern Beltrami and Northern Cass Counties.

4. Otter Tail Outwash- Covers central and southeastern Otter Tail County.

5. Alexandria Outwash- In eastern Douglas County.

6. Glenwood-Brooten-Belgrade Outwash- This outwash trends east from Glenwood and covers eastern Pope, southwestern Stearns, and northern Kandiyohi Counties. Narrow drainage ways and valley train gravel deposits extend along the Sauk River to St. Cloud.

7. Pomme De Terre Outwash- This outwash parallels the Pomme De Terre River forming a narrow strip extending north to south through eastern Grant and Stevens counties. It then merges with a larger outwash in southwest Swift, southeast Bigstone, and west Chippewa counties.

8. Mississippi River Outwash- This outwash parallels the Mississippi River valley in a broad band several miles wide extending from Brainerd to the Twin Cities area. Its central location in the state, the high quality of its blended gravels, and its proximity to major communities with good transportation makes this one of Minnesota's most important gravel resources.

9. Hinckley Outwash- This outwash is associated with drainage from the Superior Lobe. It occupies a limited area in central Pine County and is relatively undeveloped as a gravel source.

10. Elk River Outwash- An important gravel source for the Twin Cities metropolitan area. This deposit is a narrow pitted outwash that extends north of Elk River to Zimmerman.

Ice-contact deposits are relatively abundant in the end moraines of the Des Moines, Rainy and Superior lobes. They are an important alternate source of gravel throughout the region where outwash deposits are not readily available as in the northern parts of Beltrami and Itasca counties, and in Pine, Aitkin, Crow Wing, and Kanabec counties.

The areas shown as having inadequate gravel resources in this region represent features of ground moraine, lake plains, or moraines of glacial till that contain little or no gravel resources. However, the inadequate areas are usually within a ten-mile haul distance of adequate gravel areas. The gravel demand in this region is quite high but is adequately supplied from the large number of gravel resources in the area.

A large quantity of crushed rock aggregates are also produced from the granite quarries near Cold Spring and St. Cloud, primarily for railroad ballast.

Region 7 - Minnesota River-Keewatin Area

Most of the gravel resources in this region are associated with meltwater drainage systems associated with a glacier (Des Moines Lobe) that originated from the Keewatin Ice Center in Manitoba, Canada. This glacier deposited a gray till in this region derived primarily from limestone and shale sedimentary rocks.

Excessive amounts of shale and other soft deleterious materials such as iron oxides and clay nodules occurs in many of the gravel deposits. The quality of gravel is a significant problem in this area especially in poorly sorted ice-contact deposits and in valley train deposits located along the minor meltwater channels. Gravel quality problems related to excessive shale content are especially severe in Lac Qui Parle, Yellow Medicine, and Waseca counties.

The primary gravel resources in this region are outwash associated with glacial meltwater streams discharging from the Des Moines Lobe and along the Minnesota River Valley. The Minnesota River Valley contains gravel terraces deposited by the early Glacial River Warren, which formerly served as one of Lake Agassiz's major outlets. Downcutting by the glacial stream through its valley fill resulted in the formation of the wide valley, leaving the gravel terraces perched high along the valley wall. Meltwater channel deposits and outwash are also distributed along the Cottonwood and Redwood river valleys in a northwest to southeast direction parallel to the Minnesota River. Both of these glacial drainage systems meander across the ground moraine of the Des Moines Lobe and are practically the only source for gravel in this area. Those areas shown to have inadequate gravel resources are representative of ground moraine, old lake plains, and clay till moraines. A major gravel scarcity area exists in the southern tier of counties, principally in Faribault and Martin counties.

Region 7 contains several large outwash deposits in the eastern part along the Cannon River in Rice and Steele counties and along the Shellrock River in Freeborn County, which provide adequate reserves of gravel for the communities in this area. Shale content sometimes is a problem for both outwash and ice contact deposits in Freeborn county.

Substantial quantities of crushed rock aggregates are mined from dolomite and quartzite rock formations located along the Minnesota River Valley near New Ulm (quartzite) and Mankato (dolomite), and in the southwest near Pipestone and Luverne (quartzite).

Region 8 - Limestone Area

This region is representative of the area in southeastern Minnesota, which was only lightly glaciated. Bedrock formations with deep erosional valleys dominate the landscape. Quarried crushed limestone and dolomite rocks provide most of the aggregates in this region.[19]

Not all of the rock formations in this region are suitable for mining. Crushed rock aggregate must meet rigid tests on gradation, deleterious materials, and soundness before it will qualify for certain types of construction uses.

Minnesota's Paleozoic rock formations and their members are listed on following page from youngest to oldest. An asterisk denotes important formations commonly used as a source for crushed rock aggregates.

Formation	Rock Types
Devonian	
*Cedar Valley formation	Dolomite, limestone
Ordovician	
Maquoketa formation	Shaly limestone
Galena formation	
* Stewartville member	Dolomite
* Prosser member	Limestone, shaly limestone & dolomite
Decorah formation	Shale, with thin limestone beds
* Platteville formation	Dolomitic limestone
St. Peter sandstone	Sandstone
* Shakopee dolomite	Dolomite
Root Valley sandstone	Sandstone
* Oneota dolomite	Dolomite
Cambrian	
Jordon sandstone	Sandstone
St. Lawrence formation	Silty dolomite
Franconia formation	Sandstone
Dresbach formation	Sandstone, shale

The following is a general summary by county of geologic formations mined for aggregates in Region 8:

County	Formation	Remarks
Dodge	1. Galena formation Stewartville member	-A few quarries opened near Mantorville.
	2. Maquoketa formation	
Fillmore	1. Galena formation Stewartville member Prosser member	-Most quarries opened in Prosser.
	2. Plattsville formation	-A few quarries opened.
	3. Oneota dolomite	-Near Preston.
Goodhue	1. Oneota dolomite	-Primary aggregate source.
	2. Shakopee dolomite	-Near Cannon Falls
	3. Plattville formation	-Limited mining south of Cannon Falls.
Houston	1. Plattville formation	-Southwest part.
	2. Oneota dolomite	-Mined at scattered locations.
Mower	1. Cedar Valley formation	-Mined throughout the county.
Olmsted	1. Galena formation Stewartville member Prosser member	-Most used quarries are in the Prosser.
	2. Plattville formation	-Mined near Rochester, produces quality aggregate.
Winona	1. Oneota dolomite	-Primary source of aggregates in county.
	2. Plattville formation	-Quarries near St. Charles.
Wabasha	1. Plattville formation	-Quarries near Elgin.
	2. Oneota dolomite	-East and central parts.
	3. St. Lawrence formation	-Near Lake City and Wabasha.

Glacial sand and gravel deposits are limited to certain areas of valley train and outwash along the Zumbro and Root Rivers. Terrace deposits of the Glacial River Warren are situated along the valley wall of the Mississippi River. Extensive gravel deposits are found and are being mined in the broad terraces near Wabasha, Kellogg, and Winona. Large underwater gravel deposits exist in the old River Warren channel that have not yet been evaluated or developed.

The demand for aggregates is very high in this region because of expanding urban centers in the Rochester area and the numerous communities along the Mississippi River Valley.

Region 9 - Metropolitan Area

The majority of the gravel resources in the Twin Cities area were deposited during the early St. Croix phase of the Superior and Rainy lobes. This glacier originated from the Lake Superior region and constructed the St. Croix Moraine of red till that trends northeast to southwest through the Twin Cities. Extensive glacial outwash was deposited from this moraine in a broad plain extending south and southeast along the St. Croix River and along the Vermilion and Cannon rivers in Dakota County.

Later the Des Moines Lobe overrode the St. Croix Moraine, capping it with its gray till. Meltwater from this glacier cut through, reworked, and blended with the earlier outwash, constructing outwash terraces in Dakota County. The large outwash near Rosemount is probably the most valuable aggregate resource in Minnesota because of its depth, the quality of material, and its location close to the Twin Cities area market.

Large gravel resources with commercial aggregate development are also located in outwash terraces along the lower St. Croix River in eastern Washington County. Other significant outwash valley train and terrace deposits are found along the Mississippi and Minnesota rivers near Anoka and Shakopee. The Glacial River Warren has filled the preglacial bedrock valley along the lower Minnesota River and the Mississippi River below St. Paul with over 100 feet of gravel. Most of this material is unavailable because of urban zoning ordinances and other dedicated land use, as discussed later in this report.

The major commercial operations furnishing aggregate to the metropolitan market are mining both glacio-fluvial (outwash) and ice-contact deposits (kames, eskers, et.). A large kame complex deposited in the St. Croix Moraine near Osseo has supplied aggregate to much of the Minneapolis area for many years but now is nearly depleted. One pit at Osseo has excavated gravel down to 90 feet below the original land surface. Many of the aggregate firms near Osseo have relocated their operations to the "perched outwash" located north of Elk River in Sherburne County. This deposit provides significant amounts of aggregate to the metropolitan area.

Another commercial ice-contact aggregate source comes from a kame deposit at the Twin Cities Arsenal near New Brighton, which is known to contain over 140 feet of sand and gravel.

Sand and gravel aggregate was mined for many years from outwash deposits in St. Paul south of the Minnesota State Fair Grounds. These pits are now depleted, but the remainder of the outwash deposit extends north through the State Fair Grounds and the University of Minnesota St. Paul Campus.

Presently both sand and gravel aggregate and crushed rock aggregate are barged up the Mississippi River into the heart of St. Paul from gravel and rock terraces (Oneota dolomite) near Grey Cloud Island formed by Glacial River Warren. The Shakopee and Oneota dolomite, quarried extensively along the lower Minnesota River, is the primary source of crushed rock in this region.

The fine sand in the Anoka sandplain in Anoka County presently has no economic value to the sand and gravel industry, This area is indicated on the map as having inadequate aggregate resources. A preglacial valley filled with approximately 100 feet of sand and gravel and buried beneath the sandplain trending northeast-southwest along the Rice Lake chain of lakes to New Brighton may have potential when surface deposits become depleted.

THE INDUSTRY

MINING METHODS

There are many ways to mine aggregates, but basically there are three main types of mining operations:

1. underground operations,
2. open pit operations,
3. dredging operations.

Currently there are no underground aggregate mines in operation in the state. However it is possible the mining operations for crushed rock aggregate may use this method sometime in the future.

Dry open pit mines are the most common operation. They are developed where deposits are located above the groundwater table, or where the groundwater table can easily be lowered by pumping. Most crushed rock mines also fall into this category.

Dry open pit mining operations can be as shallow as 5 feet and as deep as 100 feet. The pit area can be as small as one acre or as large as a square mile depending upon the type of deposit being mined.

Mining is commenced by stripping off the overburden which consists of unmarketable soils and/or rock. The fertile top soil stripped and stockpiled prior to mining can either be sold as black dirt or retained for future use in reclamation. Stripping must stay ahead of the advancing working face in order to prevent it from sloughing and caving into the clean aggregate strata.

The exposed sand and gravel, or the blasted rock is loaded by shovels, drag-line or front end loaders onto trucks and hauled to a nearby processing plant. At the plant it is graded by size, crushed, washed, and recombined to comply with the aggregate specified for the job. Those deposits containing excess sand or unsound rock frequently are processed to improve their quality by rejecting sand or adding imported crushed rock.

As the pit is excavated deeper, it frequently intercepts the water table and water must be pumped out in order to continue mining. One of two methods may then be used to mine the deposit. The most common method is to install wells to dewater the pit so that mining can continue using conventional equipment. When the dewatering ceases the pit soon fills with groundwater and a cold water lake or pond is formed. Another method is to use a dragline or clamshell. This type of equipment can excavate as much as 40 feet below the water table.

Dredging is another type of mining used specifically in deep underwater pits and to mine sand and gravel deposits found beneath the beds of lakes and streams. Under this procedure sand and gravel is mined from a barge by using a suction device, a rotating bucket wheel (like a water wheel), a ladder, or a cutter head dredge. After excavation, the material is either processed on the barge or is pumped as a slurry through a pipe and processed on shore. Disposal of the waste material is a limiting factor as it must be pumped to an enclosure, or a fill area nearby.

PRODUCTION

Aggregate production in Minnesota during the past three years is listed in Table 2. Dollar values listed in the table include all production costs of mining and processing but exclude transportation costs.

TABLE 2. AGGREGATE PRODUCTION-U.S. BUREAU OF MINES[2]
All values presented are in thousands

Commodity	1976 Tons	1976 Dollars	1977 Tons	1977 Dollars	1978* Tons	1978* Dollars
Sand & Gravel	33,486	44,503	30,713	59,629	31,000	61,000
Limestone (crushed)	5,499	11,608	5,469	11,330		
Granite (crushed)	1,605	3,365	1,962	4,437		
Traprock (crushed)	W'	W'	W'	W'		
Quartzite (crushed)	W"	W'	W'	W'		
Total (crushed)	7,530	15,950	7,831	16,991	8,580	18,800

*Preliminary
W' Withheld

Table 3 lists the uses for sand and gravel during 1977. This information is based upon a voluntary survey conducted by the U. S. Bureau of Mines. Note that industrial sand, used for making glass and ceramics, represents 2% of production, but 9% of the value.

Table 4 describes crushed stone production by use for 1977.

Demand

Historical Production

Production of aggregate in Minnesota since 1951 is plotted in figure 7. The sharp peak starting in 1964 and continuing through 1976 represents the aggregate demand created by the construction of the interstate highway system. It is assumed that data for 1977 and 1978 is due to normal construction demands.

TABLE 3 SAND AND GRAVEL DISTRIBUTION BY USE
1977 production U.S.B.M. questionaire

(1) Use	(2) Number of companies responding	(3) Million short tons produced	(4) Million dollars, processed @ mouth of mine	(5) Unit Value (4)÷(3)	(6) % of total volume (3)÷total	(7) % of total value (4)÷total
CONSTRUCTION	300	30.030	54.297	1.81	98	91
Concrete aggregate	170	9.576	20.722	2.16	31	35
Road base	213	8.710	14.289	1.64	28	24
Asphalt aggregate	84	4.861	8.402	1.73	16	14
Fill	183	3.418	3.497	1.02	11	6
Concrete products	52	2.977	6.666	2.24	10	11
Railroad balast	3	0.015	0.024	1.60	0	0
Other	28	0.473	0.696	1.47	2	1
INDUSTRIAL SAND	3	0.683	5.332	7.81	2	9
		30.713	59.629			

TABLE 4 CRUSHED STONE DISTRIBUTION BY USE[1]

1977 production U.S.B.M. questionaire

(1) USE	(2) MILLION SHORT TONS PRODUCED	(3) MILLION DOLLARS, PROCESSED @ MOUTH OF MINE	(4) UNIT VALUE (3)-(4)	(5) % OF TOTAL VOLUME (2)-TOTAL	(6) % OF TOTAL VALUE (3)-TOTAL
Road Base	2.700	5.199	1.93	34	30
Railroad Ballast	1.595	3.518	2.21	20	21
Other Construction Aggregate & roadstone	.737	1.633	2.22	9	9
Concrete Aggregate	0.715	1.893	2.65	9	11
Bituminous Aggregate	0.611	1.367	2.24	8	8
Other Uses[2]	0.480	0.966	2.01	7	6
Agricultural lime	0.431	1.034	2.40	6	6
Surface Treatment	0.414	0.782	1.89	5	5
Riprap	0.136	0.296	2.18	2	2
Filter Stone	0.012	0.024	2.00	--	0
Macadam Aggregate	W'	0.279	--	--	2
TOTALS[3]	7.831	16.991		100	100

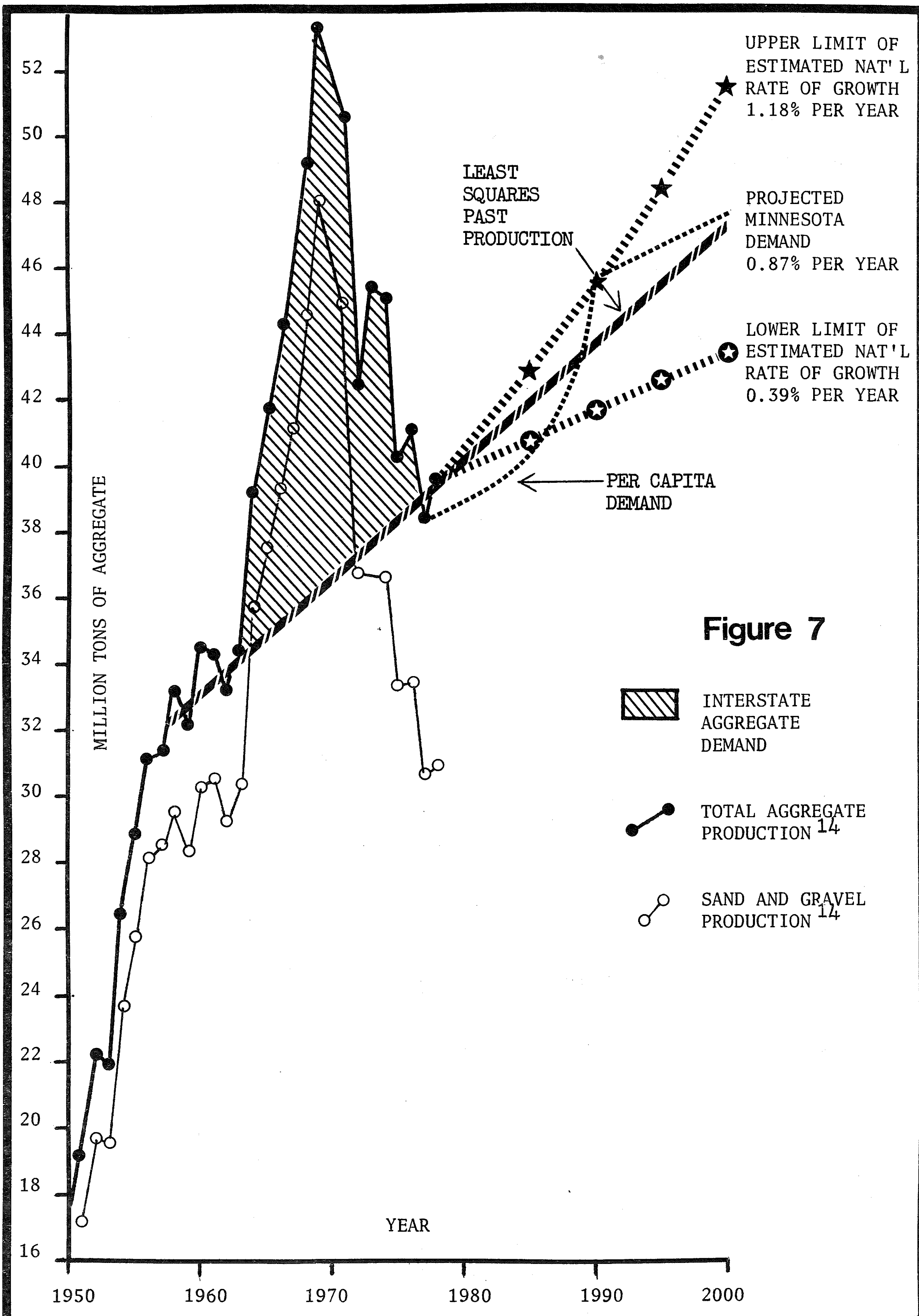
1 Includes granite, limestone, quartzite, and traprock.
2 Includes stone used in asphalt filler, drainfields, fill, mineral food and poultry grit.
3 Data may not add to totals shown because of independent rounding.
W' Withheld to avoid disclosing individual company data; included with "Other uses."

Production of sand and gravel is also plotted for the same time span. The demand for sand and gravel appears to have leveled off at about 31 million tons per year. Since the difference between sand and gravel production and total production of aggregate consists of crushed stone production, it can be concluded that increased aggregate demand has been met by expanding production of crushed stone. This condition, unique to Minnesota, is due to two principal reasons. The first is a change in aggregate specification, that substituted crushed stone for aggregate where previously only sand and gravel was allowed. The second is the more rapid rise of the cost of sand and gravel than of crushed stone. Crushed stone is actually cheaper in southeastern Minnesota because it is more readily available.

Future Demand

Suotracting the temporary growth due to interstate highway construction, long-term growth in demand is estimated using least squares analysis for years including 1956-63 and 1977-78 (see Figure 7). If this trend is projected into the future, the demand for aggregate in Minnesota is expected to grow by 0.87% per year. Demand for aggregate based on per capita use has been calculated using national per capita demand figures applied to Minnesota population projections. This study also indicates an overall average annual growth rate of 0.87% (see Figure 7). This data is plotted along with upper and lower limits of the national growth established by the Bureau of Mines.

Other estimates are reproduced in Table 5 for purposes of comparison. Techniques used included least sqaures regression analysis of past production, regression analysis of historical data on the mineral commodity's end-use consumption in comparison with macroeconomic variables (also known as "contingency analysis" said to be "highly qualitative and judgmental")[13], and national per capita demand applied to Minnesota population projections.



UPPER LIMIT OF ESTIMATED NAT'L RATE OF GROWTH 1.18% PER YEAR
LEAST SQUARES PAST PRODUCTION
PROJECTED MINNESOTA DEMAND 0.87% PER YEAR
LOWER LIMIT OF ESTIMATED NAT'L RATE OF GROWTH 0.39% PER YEAR
PER CAPITA DEMAND
MILLION TONS OF AGGREGATE
YEAR
52
50
48
46
44
42
40
38
36
34
32
30
28
26
24
22
20
18
16
1950
1960
1970
1980
1990
2000
Figure 7
INTERSTATE AGGREGATE DEMAND
TOTAL AGGREGATE PRODUCTION 14
SAND AND GRAVEL PRODUCTION 14

Table 5a PROJECTED ANNUAL GROWTH

DATE OF PREDICTION	SOURCE	GEOGRAPHIC REGION	COMMODITY	METHOD OF PREDICTION	TIME SPAN	ANNUAL GROWTH %
1979	DNR	Minnesota	Aggregate	Past Production	1979-2000	0.87%
Sept. 1978	USBM[23]	USA	Sand & Gravel	Past Production	1976-2000	Past 20 Yr trend 1.18*
		West North Central Region	Sand & Gravel	Past Production	1976-2000	0.87
		USA	Sand & Gravel	Past Production	1976-2000	Past 15 Yr. trend 0.39*
1979	USGS[10]	West North Central Region	Aggregate	Past Production	1985-2000	0.8
1979	USBM[25] & DNR	Minnesota	Aggregate	Per Capita Demand Applied to MN Population Projection	1976-2000	0.87*
1979	USBM[24]	USA	Sand & Gravel	-------	1976-1985	1.6
1979	USBM[25]	USA	Aggregate	End use Demand	1976-1985	4.1
					1985-2000	3.7

*Plotted in Figure 7

Table 5b PROJECTED ANNUAL GROWTH BY USE

1979	USBM	West North Central Region	Sand & Gravel	End use Demand	1979-2000	Concrete products 0.73 Asphalt concrete 0.87 Road base 0.93

These projected demands are based on historical trends. Changing public attitudes could significantly alter the actual demand-growth rate. For example, increasing energy conservation efforts could cause a trend toward higher density urban areas (to cut down on energy used for transportation). Increasing density will cause a shift from wooden structures to structures made of concrete and steel, thus increasing aggregate demand. Or, decreased road construction due to higher density living could reduce the demand for aggregate. Improved technology in recycling concrete, bituminous, glass, mine wastes, fly ash, and processed solid wastes is another possibility that could decrease the demand. The Bureau of Mines states that "The potential use of substitute materials to fill the old demand for sand and gravel can play havoc with future forecasts."[6]

Prices

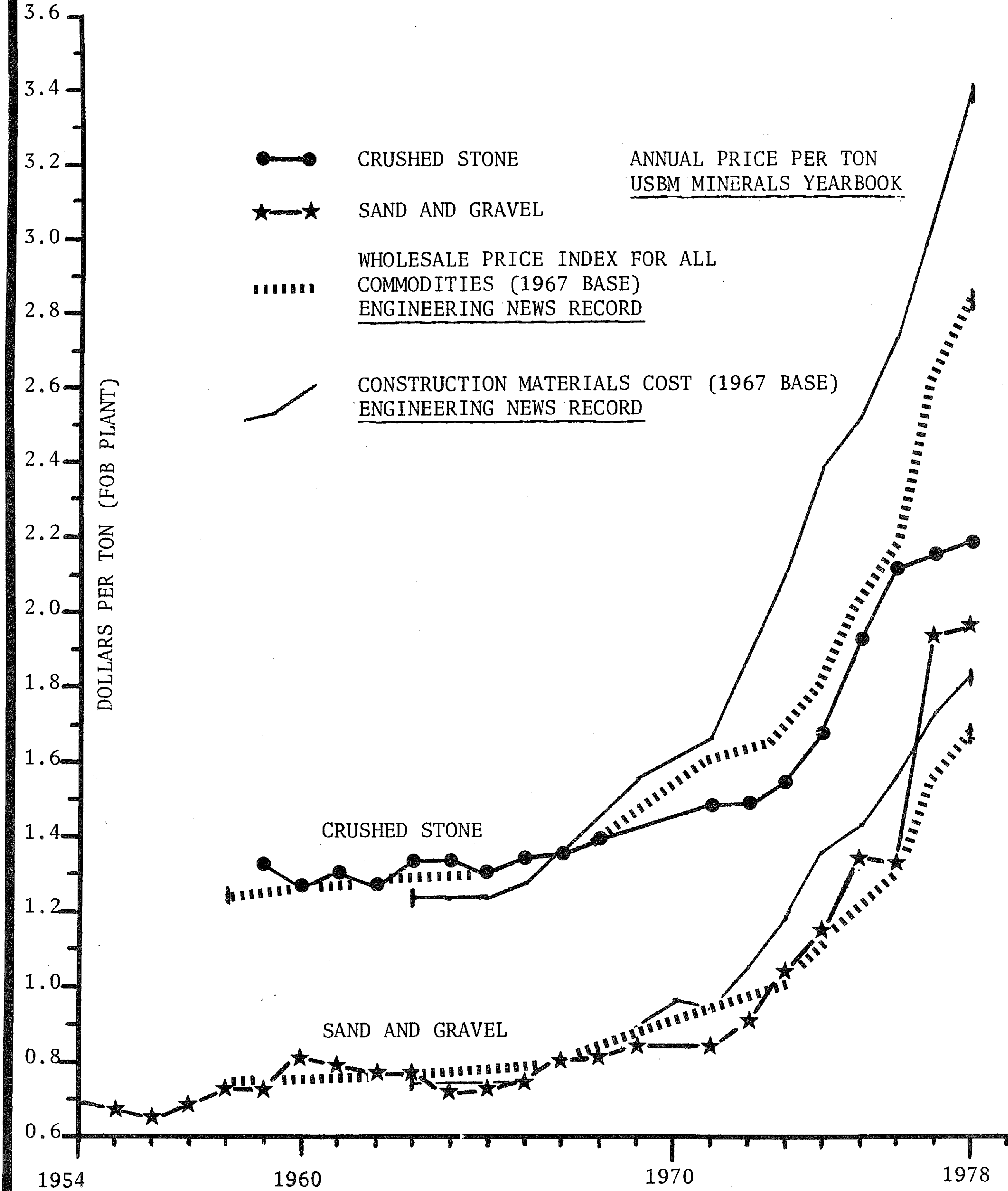
Aggregate prices can be separated into two parts: production costs and transportation costs. The production costs include all costs of mining and processing, pollution control, and reclamation. Data was gathered for the years 1959 through 1978 (see Figure 8)[2,14]. Also plotted, is the projected price of each material based on the Wholesale Price Index for All Commodities (WPI-AC) and the Construction Materials Cost Index (CMC), as reported in Engineering News Record. Both projections are normalized to a 1967 base.

Note that construction material costs have risen faster than the average of all commodities. The price of sand and gravel has generally followed other inflation indicators, but increased faster than WPI-AC since 1973 and exceeded CMC in 1977. In fact, there was a great jump in price from 1976 to 1977.

Figure 8

ANNUAL PRICES(FOB) FOR SAND AND GRAVEL

AND CRUSHED STONE IN MINNESOTA 1954-1978



Crushed stone prices have consistently risen slower than either WPI-AC of CMC. In recent years (1976-78), the price of crushed stone has risen much slower than the indicators. This stability has allowed the crushed stone industry to gain a larger share of the aggregate market.

The price of aggregate products is highly dependent on transportation costs. Figure 9 shows the retail cost per ton vs. the distance to market for road base material (a mixture of sand and gravel or crushed rock). Economics of scale are maximized in this type of high volume operation. The production price taken from the Bureau of Mines 1977 statewide survey, is the average cost of aggregate. Various aggregate producers in the Twin Cities area were interviewed to determine their cost of transportation. This range is the shaded area in Figure 9. The steep slope of this curve reflects the relatively greater impact of loading, weighing, and dumping for short haul distances. As haul distances increase, these operations become less significant and the slope flattens. The production cost can double between the first loading for delivery and a nine-mile haul distance. Beyond that distance, each additional mile of transport raises the price ten to thirteen cents per ton. It is essential to keep the costs for transporting aggregate at a minimum because it is a major component of the total cost of construction.

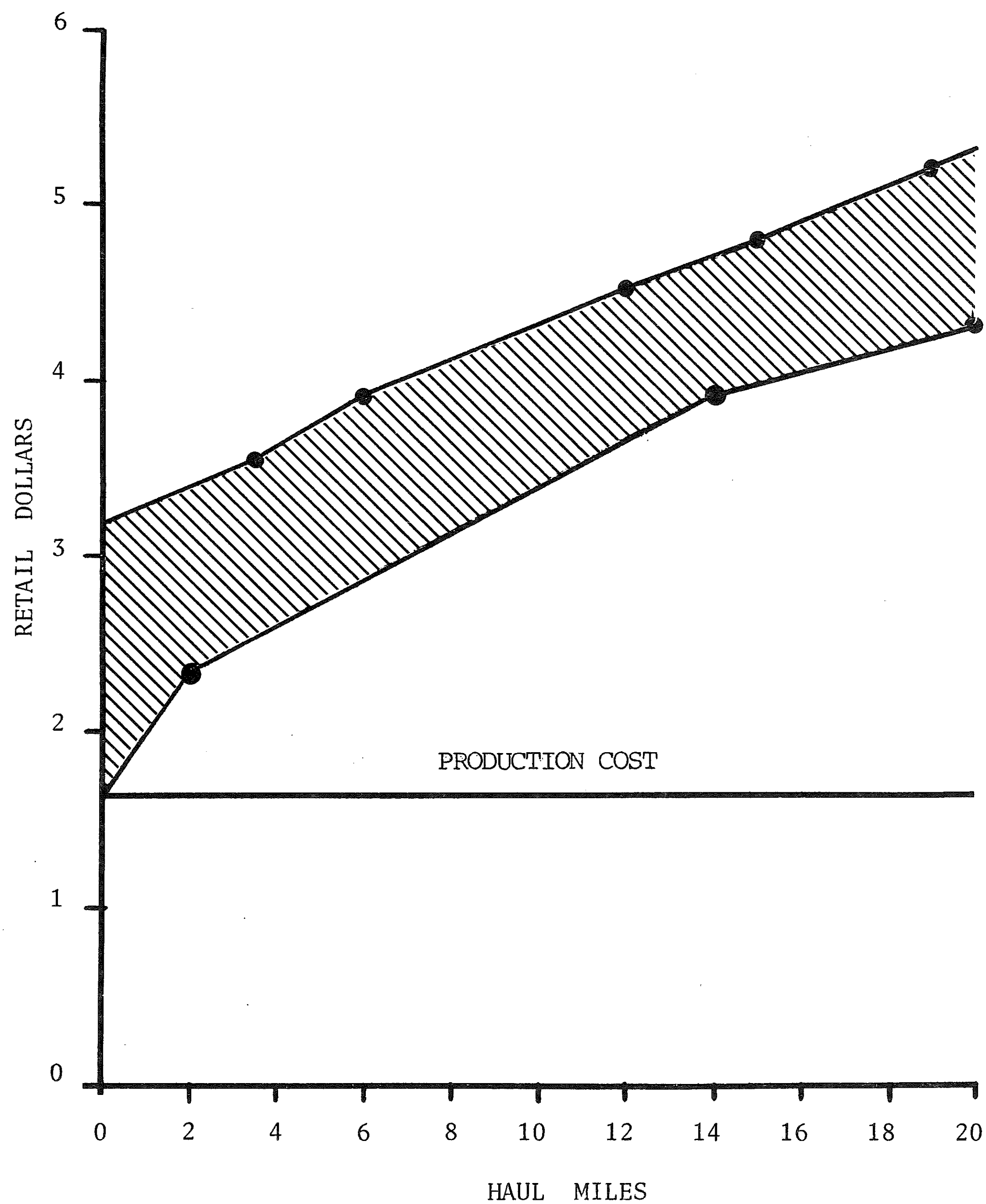
Taxes

Seven Minnesota counties levy a sand and gravel occupation tax on those firms engaged in extracting sand and gravel. This tax is essentially a severance tax. A maximum rate of five cents per cubic yard of gravel is levied in Becker, Clay, and Wilkin counties, and a maximum rate of ten cents per cubic yard is levied in Kittson, Marshall, Norman, and Polk counties. Ninety percent of this tax is to be spent on repair and maintenance of roads and bridges used to transport aggregate. The remaining ten percent is used

Figure 9

TRANSPORTATION COSTS

FOR ROAD BASE MATERIAL



to reclaim abandoned sand and gravel mines. According to the latest data available (1977), $74,000 was collected by four of the counties reporting income from this tax. Additionally, incorporated nonmetallic producers pay corporate income tax. Eighty-three such companies are listed with the Department of Revenue as miners of sand and gravel, crushed and broken stone, and dimension stone. In 1976, these corporations paid $282,000 in income tax. All mineral firms contribute to the state's general revenue through payment of sales and use taxes for items sold at retail or for purchased equipment.

ENVIRONMENTAL IMPACTS

As with all types of mining, aggregate mining impacts the environment. The type and magnitude effects vary according to the type of deposit, the mining method, and its location relative to sensitive areas.

Water

Water pollution in the aggregate industry is usually limited to an increase in suspended solids. Another minor impact may occur from leakage of oil fluids from equipment and other miscellaneous chemicals.

All streams transport suspended solids as a result of natural erosion processes within the watershed. Each stream system has a natural balance between its suspended sediment material and its hydraulic and erosional characteristics. The sediment load increases or decreases when these natural processes are disrupted. When higher concentrations of suspended solids are introduced, the stream must readjust to a new balance. Increased sediment causes degradation of water quality, aquatic habitat, and accelerated filling of lakes, streams, and reservoirs.[12,15]

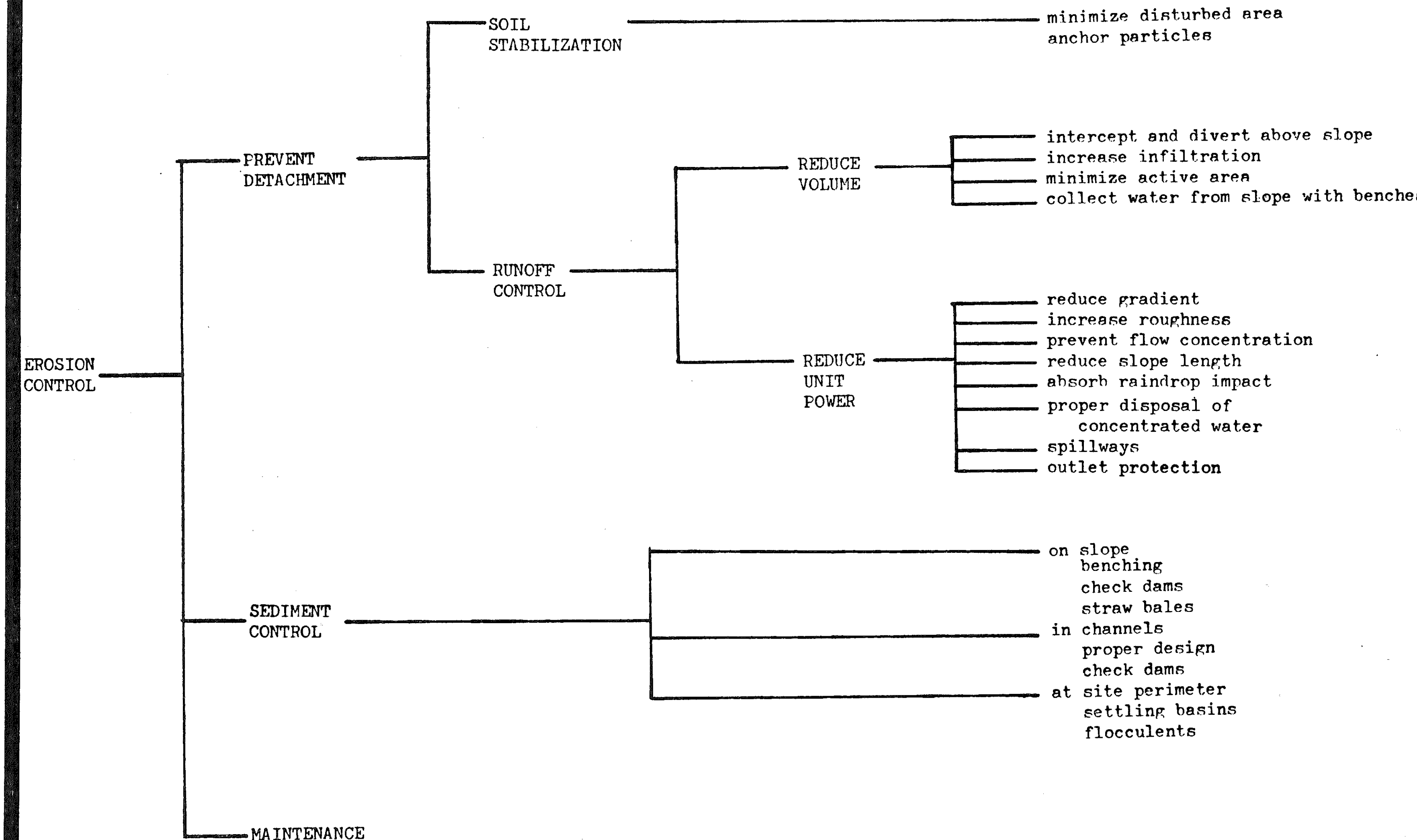
The flow duration of a stream is an important factor in sedimentation. During peak flows in the natural drainage system, high increases of suspended solids occur during short-term, periodic storm runoff. This temporary increased load is readily accommodated by the existing ecosystem. Thus, a short-term (several days) increase in sediment discharge may not cause significant damage to the ecosystem. However, a long-term increase in sediment load cannot be accommodated without adjustments in the hydraulics and ecology of the system.

Several possible sources of high suspended solids from aggregate operations are

(1) uncontrolled runoff from mine areas,
(2) poorly designed or maintained roadways,
(3) process water used to remove fine grained material,
(4) pit dewatering (wet pits only),
(5) dredging, and
(6) fugitive dust from crushers, mixing plants, and haul roads.

Uncontrolled runoff is the greatest potential contributor of sediment. Prior to production of aggregate material, overburden material must be removed and stockpiled. This material, usually topsoil or fine grained glacial till, is easily eroded. The raw, steep, unprotected slopes of these stockpiles can contribute large amounts of new sediment to watersheds. Well-developed technology exists for the stabilization and control of slopes (see Figure 10). In general, it is more desirable to prevent erosion from occurring than to trap sediment after it has been eroded. Toward this goal, an operator can employ the techniques in the order listed until the runoff water is acceptable and meets PCA water quality standards.

FIGURE 10 EXISTING TECHNOLOGY FOR EROSION CONTROL



Haul roads in the mine area are another source of erosion. Most of these roads exist for the duration of mining and exposed to erosion. Precipitation cannot infiltrate readily and runs down the steep slopes eroding vulnerable soils. Long steep grades, unstable cut and fill areas, portions adjacent to streams, and stream crossings are the major erosion areas that can contribute to the sediment load of streams. Technology is also well developed for controlling erosion during construction and operation. Proper siting, slope stabilization, foundation, drainage, armoring, and maintenance will assure a stable roadway.

Pit run gravel may contain as much as 10-15% silt and clay sized particles. Before it is sold, it must be washed to remove these fines and other undesirable materials such as iron oxide nodules, shale, wood, and clay lumps. Frequently excess sand is rejected in the pit to meet the specifications. Wash water, averaging 600 gallons for each ton processed, may contain several hundred to tens of thousands of parts per million (ppm) of suspended matter.[16] The slurry is pumped to an enclosed basin where the sediment settles out and the water is recycled back to the plant. Most large scale aggregate quarries use this closed system for disposal of their undersized waste materials. However, many small-scale or short duration quarries are not monitored and frequently such measures are not employed.

Pit dewatering is another possible source of sediment pollution. To avoid the problem, the water table can be lowered either by surrounding the pit area with wells that pump clean (gravel filtered) groundwater or by maintaining a sump (low point) in the pit, where water from the remainder of the working pit gathers to be pumped out. If clean practices are followed and sufficient settling methods are used, discharge water standards can easily be met.

Dredging is another possible source of sediment because agitating the bottom sediment in a stream or lake can easily disrupt delicate aquatic ecosystems. The amount of fines suspended in a stream or river from a dredging operation is highly dependent upon many factors such as the point of discharge, velocity, the body of water, and the hydraulic characteristics in each stream. Depending on these factors, the effect on a stream from underwater mining can be seen for miles downstream.[16]

According to the Environmental Protection Agency, "current technology pertaining to successful treatment of barge effluents is inadequate. Flocculants, silt curtains and baffles have been tried with only temporary and uneconomical success."[16] Placement of wash water on land behind dikes is the only known effective method of eliminating downstream siltation from dredging operations.

Despite all of these potential problems, the major aggregate producers appear to have successfully controlled their water pollution problems. In the Metropolitan Council's "Assessment of Water Pollution from Mining Activities"[10] in the metro area, they concluded:

> "Mining operations in the Metropolitan Area are not a major contributor to water pollution problems. All of the major discharges are well under PCA's relatively stringent discharge standards..."
>
> "The aggregate industry in the Metropolitan Area has responded well to the need to improve the quality of our water resources. Many operations have gone to recycling systems for washwater and have developed plans for site reclamation, but further effort is needed to reclaim the smaller, less frequently used or depleted mining sites."
>
> "The lack of generally identificable pollution problems due to mining activities in the Metropolitan Area, the apparent success of governmental agencies to control pollution, as well as the interest of the industry in policing itself, indicate that ther is not need to further study the problem at this stage. A low level priority will be given to this activity in any future 208 work program for the Metropolitan Area." (The 208 program mentioned is a nationwide effort mandated by federal law to assess and prioritize nonpoint pollution problems).

Air

Dust and noise are two air pollutants commonly associated with aggregate mining. Dust is generated fron unpaved roads, transportation transfer points, conveyors, crushers, plants and yard areas. If uncontrolled, it may cause safety hazards to the public and damage adjacent land. Some common complaints are traffic hazards caused by reduced visibility and dust damages to homes, businesses, cars, and laundry.

Dust problems can be controlled by a number of techniques. First, the amount of land disrupted must be kept to a minimum. This can be done by preserving natural ground cover, vegetating yard areas, and mining the aggregate in such a manner that revegetation can be quickly accomplished. Paving, watering, or spraying with chemical binders can successfully control dust from roads. Careful pit screening at material transfer points and conservative loading practices can help to reduce dust.

Noise

Typical mining equipment generates noise levels as high as 88 dBA measured 50 feet away from the source. Enclosed crushers can generate up to 78 dBA measured from 50 feet outside the enclosure. Table 6 describes decibels (dBA by comparison to familiar environments. The Minnesota Pollution Control Agency has established noise standards that include noise from mining activities. They state in NPC 2 that 'acceptable sound levels for the receiver are a function of the intended activity in that land area. Further, they say: "These standards describe the limiting levels of sound established on the basis of present knowledge for the preservation of public health and welfare.

These standards are consistent with speech, sleep, annoyance, and hearing." Their allowable noise level standards range from 50 dBA to 80 dBA.

TABLE 6. NOISE LEVEL COMPARISON

Decibels (dBA)	Common Sounds
160	Medium jet engine
140	Large propeller aircraft, air raid siren
120	Disco
100	Canning plant, heavy city traffic, subway
80	Busy office
60	Normal speech
50	Private office
40	Quiet residential neighborhood
20	Whisper
0	Threshold of hearing

Noise from mining can be controlled by maintaining adequate buffers such as: the distance away from receivers, by shaping landforms, constructing artificial barriers, insulating and containing noisy machinery, and keeping equipment in good repair.

Crushed stone quarrying operations also have blasting problems. Ground vibration, air shock, flyrock, and dust are all products of blasting that require special consideration.

The technology for blasting control has improved greatly during recent years. Problems caused by climatological conditions such as wind direction and temperature inversions are now more predictable. Planned ignition time delays are now more frequently used to create a series of small efficient blasts, rather than one large blast. Proper blast hole stemming and use of low energy primer cord also help reduce noise effects of blasting.

Flyrock from blasting is now controlled to the point that construction blasting in downtown areas can be conducted in immediate proximity to large buildings without fear of damage.

Sixteen of 65 municipalities in the Twin Cities metropolitan area and 11 of 87 counties in the state have blasting control standards. There is no existing control beyond these local levels for regulating the effects of blasting on the general public. The U. S. Bureau of Mines (Twin Cities office) is currently conducting extensive research on quarry blasting and plan to publish recommendations soon for standards on air shock and groun vibrations.

Land

The terrain of the mineland itself may become a problem. In many instances, exhausted or inactive pits are left unreclaimed exhibiting rough, desolate terrain, rusting equipment, boulder piles, and dangerous ponds of water. Steep, irregular slopes lead to long-term erosion problems, which often require significant alterations to the drainage pattern in the area. Abandoned pits excavated below the water table usually will fill with water to that level. Steep banks and deep water, or shallow, stagnant pools are a safety hazard. If uncontrolled, such areas are dangerous and a public nuisance. This desigation places the burden of liability on the aggregate producer.

It is difficult to reestablish vegetation on infertile granular sub-soils exposed by mining. In urban areas the fertile topsoil is frequently stripped and sold prior to mining. When the time comes to reestablish vegetation, topsoil must be imported to provide a favorable environment for the germination of seeds.

Preplanning for reclamation can reduce or eliminate many of these problems. Usually topsoil can be saved, stockpiled, and replaced on the surface of the postmining landforms. Grading and planting can reduce erosion, improve runoff water quality, and create usable landforms. The following pictures show examples of successful reclamation.

LAND USE PROBLEMS

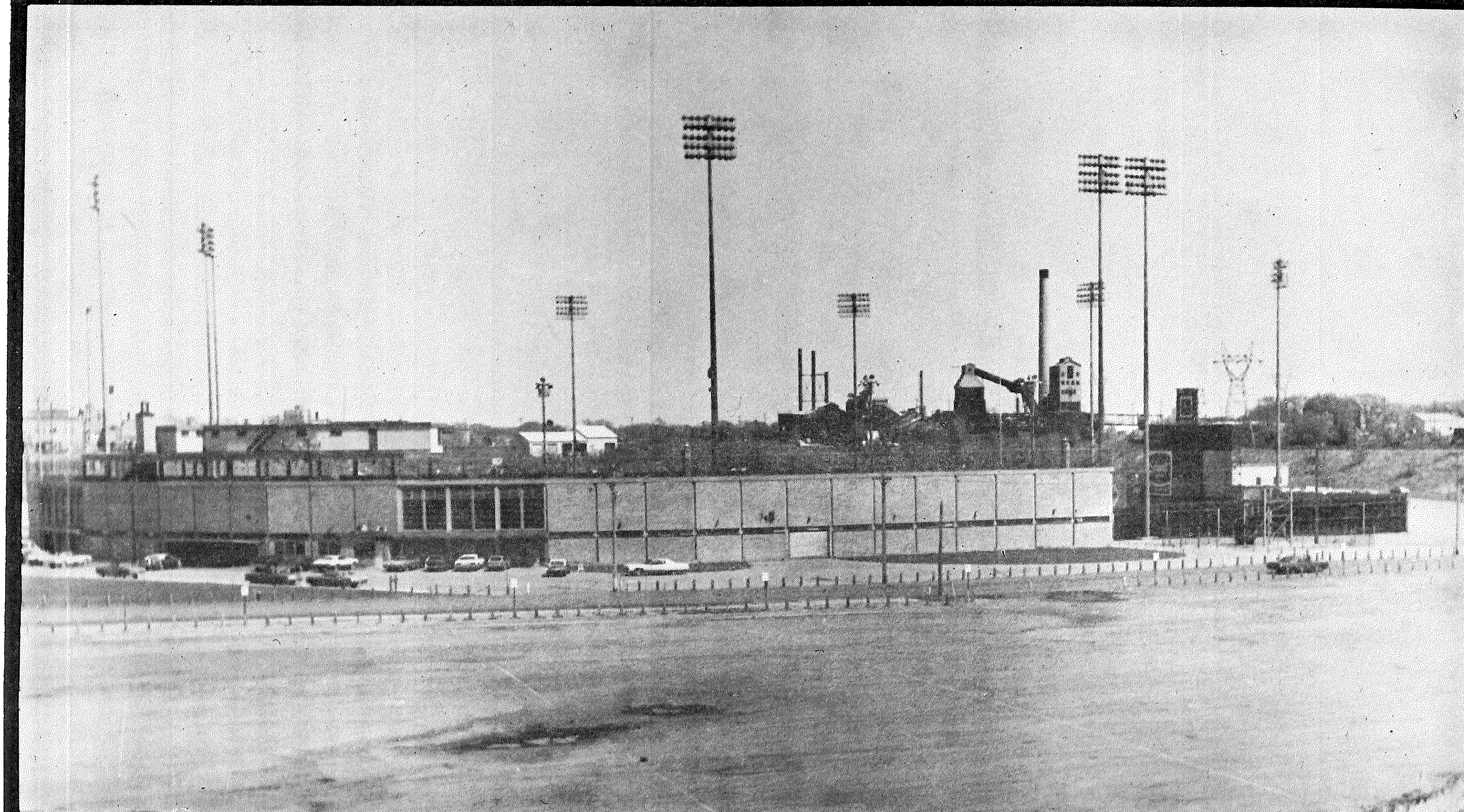
Urban areas sually experience more acute land use problems than rural areas. These primarily involve resource encumbrance and the compatibility of mining with other urban land uses.

Compatibility

Aggregates are low unit value products. This means the cost of an aggregate product is highly dependent on transportation costs. The production cost can double anywhere from the first loading for delivery to as far as nine miles away. Beyond that distance, each additional mile of transport raises the price 10 to 13 cents per ton. Therefore, it is essential that transportation costs be minimized because it is a major component to total cost of construction.

The importance of proximity to the consumer has been recognized by government and industry. The Metropolitan Council has stated that the number one problem of aggregate production is"that valuable raw materials are being excluded from development by urban growth into prime sand and gravel and crushed stone production zones."[10] Elsewhere they state: "If not properly managed, valuable resources may be lost to the Metropolitan Area. Permanent urban density development over these deposits would eliminate them from future use. Current planning and land use controls do not protect mineral deposit areas."[11]

This area, known as McMurray Field, in Como Park, was part of a large sand and gravel mine which was operated between 1924 and 1953. The site was mined until all marketable material was removed. It was converted to public use after mining was completed. As long as the steep slopes are maintained, they form natural bleachers for spectators while the flat pit bottom makes an excellent, well drained playing surface.



Midway Stadium is also part of the gravel area which was active from 1924 to 1953. Large areas on both sides of Snelling Avenue have been mined for sand and gravel, and reclaimed into athletic facilities, shopping centers, apartments warehouses and offices. Again, reclamation was a post-mining activity, brought about by increasing land values and public need for public space.

Lac Lavon is a man made lake, created by mining sand and gravel, from 1957 to 1977. It is an extremely clear, 65 acre lake with a maximum depth of 34 feet over a course gravel bed. It was stocked with bass, northerns and blue gills, some years ago. This site, a pre-planned reclamation project was originally intended to be developed as lake-front homes. It is now being considered for a future recreational open space.

Resource Encumbrance

Once the extractive industry is forced out of operation by local decree, the land soon becomes converted to urban uses and another valuable mineral resource is lost forever. Aggregate producers forseeing these events relocate to outlying areas and establish new outlets, but eventually the market saturation and social conflict cycle recur.

Furthermore, this results in relocating the gravel production areas farther away from the expanding metropolitan centers, and aggregates must be imported from increasingly distant sources at greater cost.[18]

In addition to the difficulty encountered by established mining operations potential mining sites are also lost through surface development. Surface development is drawn to outwash gravel deposits because of their level terrain, well-drained soils groundwater potential, and stable foundations. Often the landowner is unaware of the gravel potential and will negotiate a sale with a housing or industrial developer - rather than wait an indefinite period for those wanting to purchase or lease the land for gravel. In most instances, when a zoning authority permits urban construction over areas having aggregates, the resource will never be recovered.

In Denver, Colorado, as of 1967, only 100 million tons of the total 840 million tons of sand and gravel resource (thirteen percent) within a 15 mile radius remain accessible. Of this remainder, 70% is poor grade, low recovery gravel.[18] Such resource losses prompted the state of Colorado to pass a law prohibiting surface development of aggregate deposits until the mineral resources have been removed.

The Department of Natural Resources (DNR) Division of Minerals has undertaken a survey of sand and gravel encumbrance in the seven county Metropolitan

Area. A map of sand and gravel soil units was prepared using data from the Minnesota Geological Survey, the U. S. Soil Conservation Service, the Agricultural Extension Service, and the DNR (20,21,22). This map was overlayed with the "Generalized Land Use 1978" map prepared by the Metropolitan Council. Sand and gravel resource areas covered by surface urban development were delineated. The map is general and is only intended to be used to estimate aggregate resource encumbrance in a general way (Figure 11).

The map is marked at five-mile intervals from city centers because haul distance costs are of major importance. Area estimates of encumbrance are divided into these same five-mile intervals. The assumption is that demand for aggregate to be used in construction will occur from city centers. This will not always be the case as construction in the suburbs and urbanized fringe will have easier access to aggregates. The results of the encumbrance study summarized in Figure 12 shows that 86 pecent of the gravel lands within a 10-mile radius is encumbered by development. It seems the Twin Cities metropolitan area aggregate situation is much like Denver's. Most of the metropolitan areas's unencumbered gravel resources are located in terraces along the major rivers and in outwash plains in Dakota and Washington counties. Based on the Metropolitan Council's "Development Framework Plan", significant additional sand and gravel resources in Washington and Hennepin counties may be encumbered by 1990.

Aggregate resource encumbrance, as demonstrated in may urban areas, is the prevailing land use sequence of urban sprawl. No improvement can be expected unless this trend stops or our mineral lands are otherwise protected.

Figure 11

SAND & GRAVEL ENCUMBRANCE IN THE SEVEN COUNTY METRO AREA

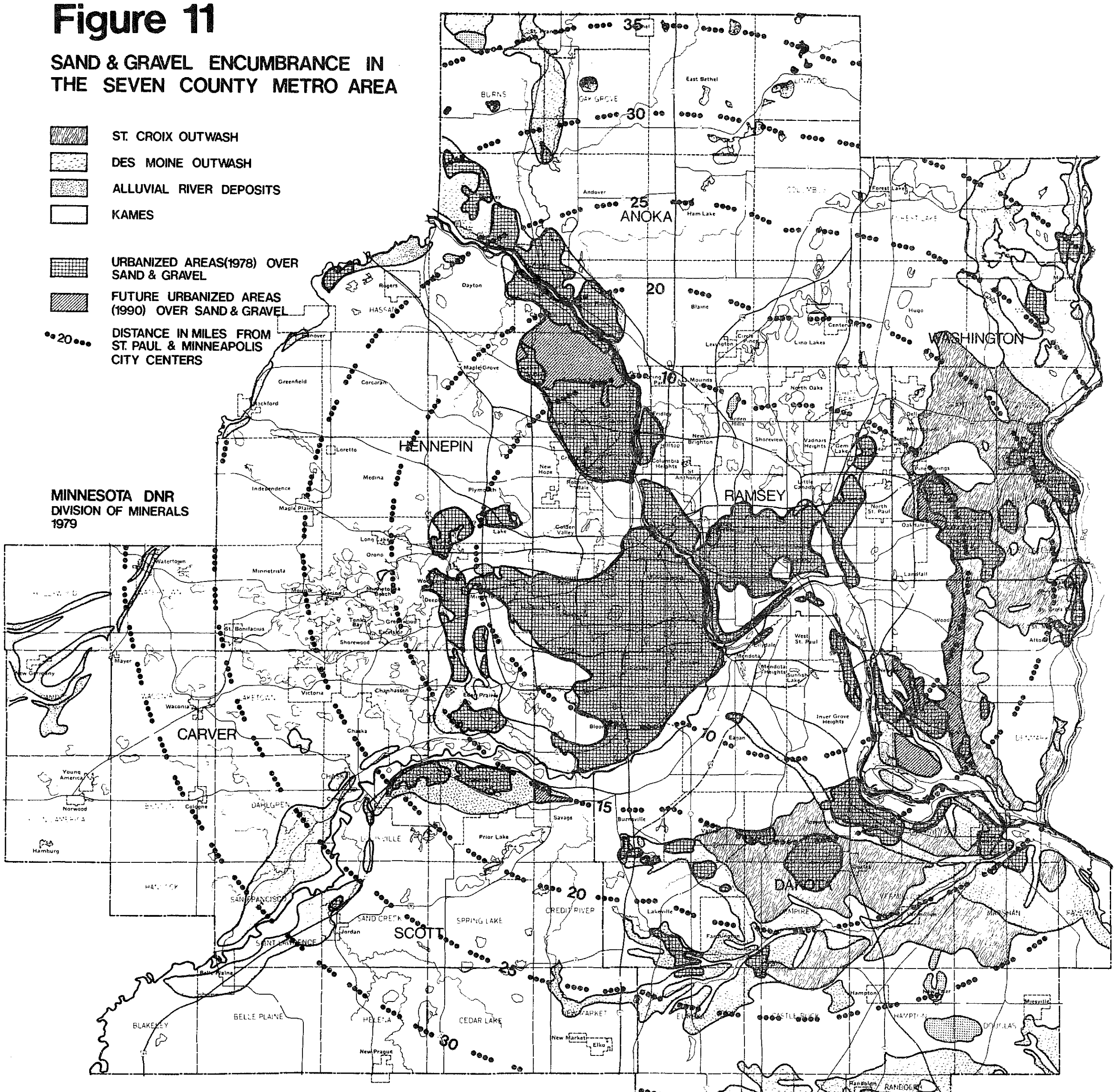
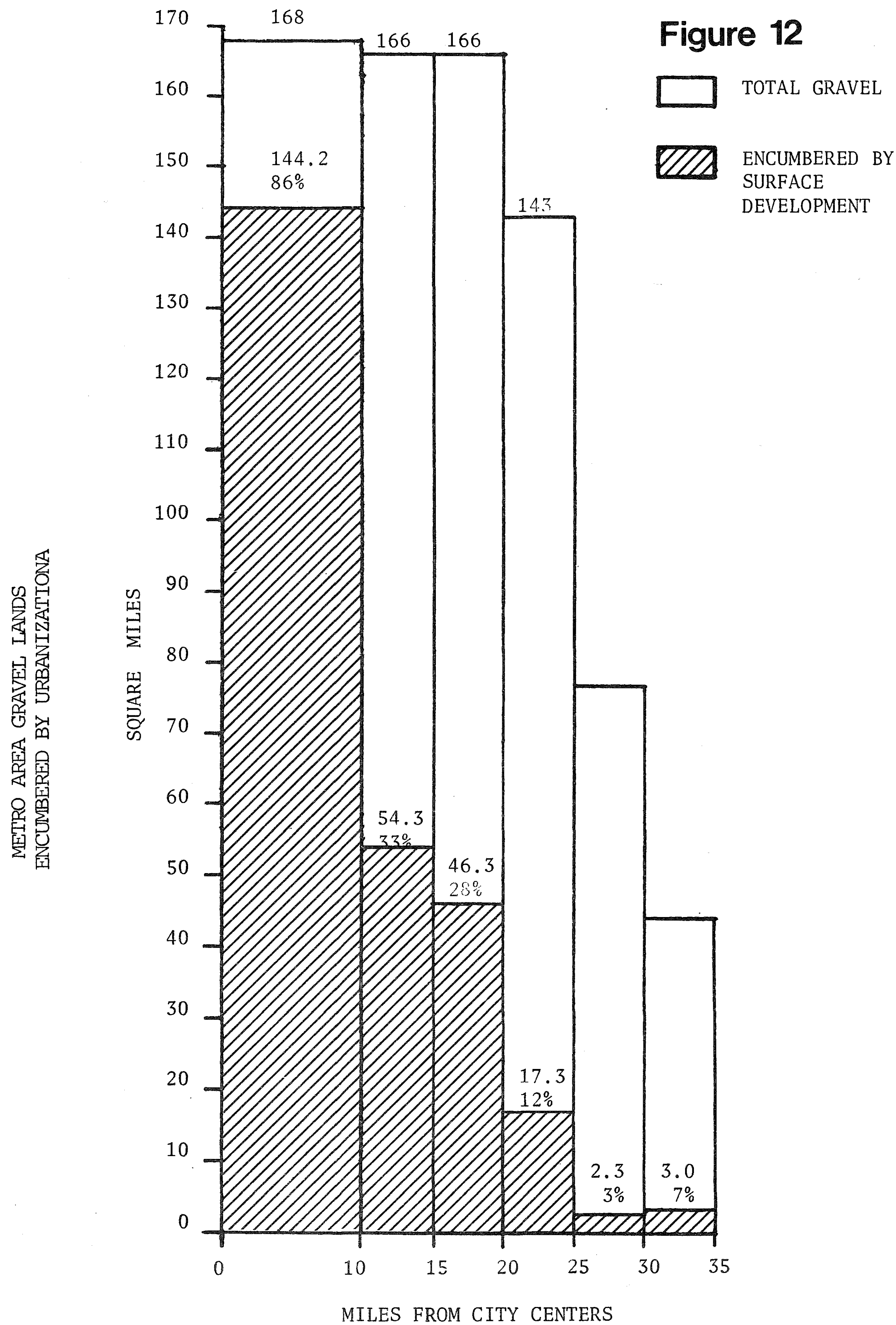


Figure 12



TOTAL GRAVEL
ENCUMBERED BY SURFACE DEVELOPMENT
METRO AREA GRAVEL LANDS ENCUMBERED BY URBANIZATIONA
SQUARE MILES
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
168
166
166
143
144.2
86%
54.3
33%
46.3
28%
17.3
12%
2.3
3%
3.0
7%
0
10
15
20
25
30
35
MILES FROM CITY CENTERS

In summary, there are strong arguments for reserving our mineral lands for aggregate production:

1. The occurrence of marketable mineral aggregates are limited to those particular locations where they were deposited. Unlike other industries which can locate at alternate locations, aggregates must be produced and processed where they occur.

2. Aggregate products are essential for economic growth because of their use in all types of public and private construction.

3. To minimize costs, the aggregate must be produced as near as possible to points of consumption. Consequently, encumbrance of mineral resources by surface development inflicts an economic loss on the community.

4. Technology for mitigation of conflicts and reclamation is well established and usually required by governmental permits.

5. Aggregate mining is a temporary use of the land. Once mined, the land can be reclaimed for some other beneficial use.

6. Mineland can act as a land bank to be used at a future date to satisfy community needs.

In the section "Existing Laws, Regulatory Control and Governmental Policies," the Metropolitan Council has recognized this problem in their development policies on mineral lands and urban sprawl. Municipal comprehensive plans required by the Metropolitan Land Planning Act of 1976, must contain plans consistent with the Council's policies in order to receive approval of the plan.

Elevated Land Values

Commonly, open gravel lands within or near an urban complex may be evaluated at prices beyond the means capacity of the aggregate producer but within purchase limitations of housing or industrial developers who plan immediate and more renumerative land uses. In other instances the landowner, fearing depreciation of his surrounding properties, will refuse to deal with the mineral operator at any price.

Spiraling land prices caused by urban sprawl is a problem common to the urban farmer and the aggregate producer. Agricultural lands abutting urban expansion have been known to increase in value nearly 300% beyond inflation over a ten-year period.[7] Studies have indicated that anticipation of urban demands for land drives land prices upward. As this happens, the ratio of urban to rural land values increases far beyond the land's potential for agricultural production. Rising taxes encourage the farmer to sell, usually to speculators or developers, thus surrendering the land to subdivision and urban development. The urban farmer and gravel producer share the same impacts of urban sprawl. Both desire to stem the advance of urbanization upon their property. With property tax relief, the urban farmer would have an incentive for remaining. This would check uncontrolled urbanization and provide a buffer zone for potential gravel resources preserving them for future use. Such coordinated protection of aggregate production lands and urban farm lands could provide adequate time for planning an orderly development for the area.

Land Use Evolution

In most locations throughout the state, aggregate producers must present a plan for subsequent end use of the land to be mined. Originally most aggregate producers were located in rural areas near the periphery of urban centers. However, during the long life span of some suburban mines (as much as 50 years), the surrounding land use often changed dramatically. Frequently, the post-mining land use proposed by the operator was no longer appropriate.

Land use changes are continually evolving with each decision made by government. Too often miners and zoning-planning officials do not maintain open channels of communication beyond the original date of zoning approval. Maintaining a continuous exchange of information will develop a well planned end use that is satisfactory to all parties.

Intermittent Use

Many deposits are mined on an intermittent basis relative to weather conditions and market demand. In Minnesota, it is estimated that, only 11% of all sand and gravel operators are active 12 months out of a year, and 49% appear to be inactive for periods greater than six months. Two-thirds of the crushed stone quarry operators are active year-around.

Since transportation costs are a major component of total cost, short term intermittent operations play a significant role in reducing construction costs. Were it not for such operations, the cost of Minnesota highways would increase substantially, and construction in certain areas of the state would be restricted, not by demand, but by aggregate availability.

There are essentially two types of intermittent operations. One type may be operated three seasons per year for several years from the same mine area. This type of operation is nontransient. It is only shutdown in winter months because of the decline of construction at freeze up. Little pollution will occur from this type of operation during the winter freeze because there is no water runoff when the ground is frozen. However during spring runoff, a large load of suspended solids can be washed from the site if the terrain is not graded properly.

Safety is an important consideration during slack winter months in this type of operation. Idle gravel pits, equipment, and processing plants are dangerous hazards to curious children. Proper planning for shutdown of the operation can secure the area against vandals and children, as well as protect the owner from legal claims by trespassers.

Another type of intermittent operation is the small transient type. In this case, the aggregate deposit usually remains inactive from months to several years and is reactivated only during a short-term peak aggregate demand.[16] For example, a contractor may use it only if he has a job nearby. Usually portable processing equipment is brought in and used until the job is done. Subsequently, all equipment is removed to another yard or to the next aggregate site, and the area is abandoned again until a new job develops.

Pollution potential is greater with this type of mining because erosion and subsequent water pollution are somewhat time dependent. Excluding high intensity rainstorms most erosion occurs within one year after the initial disturbance. Thus each time a mine is reactivated, the erosion cycle is repeated over and over again. "Storm runoff from one of these (temporary) (intermittent) operations is capable of producing a silt load exceeding the yearly output of a well managed sand and gravel plant."[16] While it is true that this happens at all sand and gravel mines, such erosion can be controlled if the operator is at the site with equipment and personnel to continuously monitor and control runoff. With the transient operator, this supervision is lacking during the abandoned periods.

Intermittent use also results in longer land use and aesthetic commitments of the mine area and raises a great deal of questions pertaining to the extent of and need for temporary pollution control and reclamation efforts.

Generally, operators are responsible to governing authorities for leaving a site in a safe, nonpolluting condition during the time of abandonment, but frequently small intermittent, especially transient operations do not receive proper inspection to insure compliance with these obligations. In fact, as evident from the inadequate and inconsistent inventories of aggregate operations, usually none of the regulatory agencies know about their existence.

The question of when and how much reclamation should occur in a transient aggregate operation is a difficult problem. This difficulty does not arise from technology deficiencies, but from economics, specifically costs versus benefits. Regrading and other types of permanent reclamation are of questionable benefit considering their cost if a pit is to be used again.

Determining when a deposit is depleted can be a complex question. A pit considered depleted today, might become a viable resource tomorrow, depending on future technological advances, availability of material, and economics. How long must a pit remain inactive before it is permanently rehabilitated and converted to another use? Usually this decision rests solely upon the owner.

EXISTING GOVERNMENTAL PROGRAMS IN THE AGGREGATE INDUSTRY IN MINNESOTA

The most comprehensive control of aggregate mining occurs at the county or municipal level, but other levels of government are also involved in the industry. The following is a description of governmental programs and rules that pertain to the aggregate industry.

Federal

At the federal level, the Environmental Protection Agency has established programs pertaining to water discharges and air emissions. Rules and standards for these programs have been promulgated and are enforced by the Minnesota Pollution Control Agency (MPCA).

Although the federal "Surface Mining Control and Reclamation Act of 1977" applies only to coal, section 709 of this act does apply to sand and gravel. The National Academy of Science, under contract with the federal Council on Environmental Quality (CEQ), was to conduct "...an in-depth study for current and developing technology for surface and open pit mining and reclamation for minerals other than coal designed to assist in the establishment of effective and reasonable regulations..." Aggregate mining has received the first priority for this $500,000 study. Inquiries about the project can be addressed to the head of the aggregate panel, located at the National Academy of Sciences, 2101 Constitution Avenue N. W., Washington, D.C. 20418. They recently have completed a scientific and technical report on aggregates for the National Academy of Sciences committee office of publications. This committee will combine the aggregate report with reports on other minerals and submit it to the CEQ. Upon review of these reports, CEQ will make recommendations to Congress concerning reclamation legislation.

The Federal Mining Safety and Health Administration regulates worker safety in the mining and milling portions of an operation. The Occupational Safety and Health Administration regulates safety in ready mix and asphalt mixing operations.

State

The Minnesota Pollution Control Agency (MPCA) has authority to issue two types of permits relevant to the mining industry. Title IV of Public Law 92-500 states that any discharge to a navigable water must be regulated through the National Pollution Discharge Elimination System (NPDES). The NPDES permits require monitoring of both volume and quality of water to assure that discharge standards set by MPCA are maintained. Additionally, MPCA controls all discharges to surface and groundwaters and all "pollution control devices" through the State Disposal System Permit procedure outlined in M.S. 115.07. This section covers such mining related topics as seepage, pit drainage, and recycling systems. Sand and gravel and crushed stone mining in the metro area has not historically been a priority water quality consideration for MPCA because the pollution threat is not as great as other industrial, municipal, and nonpoint discharges. The large mining operations that discharge water have all been regulated and are under discharge quality standards. Table 6 lists all of the active Metro Area MPCA mining permits and the discharge standards required.[10]

The MDNR Division of Waters has developed minimum Shoreland Management rules, pursuant to M.S. 105.485 for counties (NR 70-77) and municipalities (NR 82-84). Under these rules, any grading, filling, or change in topography on lands sloped toward a shore may require a special use permit from the county. Such a conditional use permit is designed to assure control of erosion and damage to the hydrology of the lake.

The Division of Waters also issues Water Appropriation Permits, authorized under M. S. 105.41, to applicants who wish to utilize a certain volume of water for a specific purpose. The Division evaluates the quantity requested relative to the surface and groundwater hydrology of the subject area and denies or approves a permit for use. Most mining ventures utilize water for only about eight months of the year (April-November), closing active extraction during the cold weather. Table 6 lists active DNR Water Appropriation Permits for the metropolitan area, along with the source of the water, and volume used.[10] Permits for changing the course, current, or cross-section of public waters under M.S. 105.42 for working in the beds of lakes and streams are also administered by the Divison of Waters.

The MDNR Division of Lands leases state lands for the purpose of mining sand and gravel. Over 90% of these leases are granted to the Minnesota Department of Transportation (Mn/DOT) and county highways departments. A royalty is charged that varies according to the location and availability of aggregates in the area, ranging from 5 to 25 cents per ton. The lessee is required to "...keep and leave the premises neat, clean and (in a) safe condition." Occasionally, additional terms include requirements for sloping of the pit walls and revegetation. Reclamation has generally not been required because the deposit is rarely exhausted by the lessee. State leases are granted for as little as 1 year and as long as 25 years. The state does not require bonds from lessees. Prior to termination of the lease, regional or district personnel visit the site to verify compliance with the terms of the lease.

The MDNR Division of Minerals also leases iron mine rejects, usually coarse tailings, for use as construction material with a royalty rate currently set at 70 cents per yard.

TABLE 7 Mining and Related Activity Permits (Active)

County	Location*	Watershed	Permit No.** DNR/PCA	Operation	Water Volume*** gpm/MGY	Source	Use	PCA Discharge Requirement Flow mgd	TSS Mg/l	Turbidity JTU
Anoka	S6T31R24	Mississippi River	75-6189/NPR	Anoka Ready Mix	60/3	Groundwater	Manufacture concrete; no pit			
	S35T32R25	Mississippi River	76-6101/In process	Harbor Development, Kings Island	200/17.5	Artificial pond	Wash sand and gravel			
	S6T31R24	Mississippi River	66-5020/NPR	Anoka Ready Mix	60/3	Groundwater	Manufacture concrete; no pit			
Carver			None for county							
Dakota	S33T27R24	Minnesota River	59-0286/MN 0002224	Edward Kraemer & Sons	1600/620	Groundwater	Wash crushed stone	0.2	30 (50 max.)	25
	S27T115R20	Vermillion River	66-0057/NPR	Fischer Sand & Gravel	1200/180	Groundwater	Wash sand and gravel			
	S32T115R20	Vermillion River	57-0283/NPR	Northwestern Gravel Co.	1000/120	Groundwater	Wash sand and gravel			
	S26T114R21	Vermillion River	72-0513/NPR	North Star Concrete Co.	100/12	Groundwater	Manufacture concrete; no pit			
Hennepin	S23,26T119 R22	Shingle Creek	74-5010/MN7846 (for closed system)	Barton Contracting	600/92	Groundwater	Wash sand and gravel	No surface water discharge		
	S10T29R23	Mississippi River	65-1355G/NPR	Flittie Redi-Mix	60/7.2	Groundwater	Processing ready mix ; no pit			
	S23T29R24	Mississippi River	65-0912/NPR	Ready Mixed Concrete	200/4.2	Groundwater	Manufacture concrete			
	S23T119R22	Mississippi River	61-0002/NPR	Chas. W. Freidheim Co.	1200/144	Groundwater	Wash gravel			
	S3T29R24	Mississippi River	67-0720/MN 0001899	Dundee Cement Co.	150/5	Groundwater	Manufacture concrete; no pit	0.7	30	25
Ramsey	S10T30R23	Rice Creek	NPR/MN0002518	Arsenal Sand & Gravel	-	Groundwater	Process sand & gravel	0.384	20 (30 max.)	25
	S34T29R22	Mississippi River	76-6022/NPR	Cemstone Products	100/48	Groundwater	Manufacture ready mix			

TABLE 7 continued

County	Location*	Watershed	Permit No.** DNR/PCA	Operation	Water Volume*** gpm/MGY	Source	Use	PCA Discharge Requirements Flow mgd	TSS Mg/l	Turbidity JTU
Scott	S20,29T115 R23	Minnesota River	NPR/MN0003701	Bryan Rock Products	-	Groundwater	Process sand and gravel	Under compliance schedule effective Sept. 1, 1976		
	S20,29T115 R23	Minnesota River	68-1367/NPR	River Warren Aggregates, Inc.	250/15	Gifford Lake	Wash sand and gravel; not currently active			
	S2T115R22	Minnesota River	67-0186/MN 0030732	W.G. Pearson Inc. (formerly B&R Rock)	300/113	Groundwater	Dewater quarry	0.11	30 (45 max.)	25
	S2T115R22	Minnesota River	67-0172/MN 0001295	J.L. Shiely III	7000/1814	Groundwater	Dewater quarry	4.564	30	25
	S22T113R21	Vermillion River	64-0549/NPR	Winona Aggregate Co.	500/47	Groundwater	Wash sand and gravel			
Washington	S18T32R19	St. Croix River	NPR/MN7959 (for closed system)	Barton Contracting	-	-	Wash sand and gravel	No surface water discharge		
	S16T28R21	Valley Branch to St. Croix River	66-0761/NPR	Alexander Construction Co.	50/1.8	Groundwater	Wash sand and gravel			
	S4T28R20	Valley Branch to St. Croix River	72-0365/MN7845 (for closed system)	Barton Contracting Co.	500/77	Groundwater	Wash sand and gravel	No surface water discharge		
	S10T30R21	Browns Cr. to St. Croix River	68-0744/NPR	Ashbach Aggregates, Inc.	800/92	Groundwater	Wash sand and gravel; depleted, will not activate			
	S36T27R22	Mississippi River	67-0201/MN 0001309	J.T. Shiely Co. (Nelson Plant)	7000/1057	Groundwater	Dewater quarry	4.2	30	25
	S26T27R22	Mississippi River	67-0200/MN 0030473	J.T. Shiely Co. (Larson Plant)	1000/151	Groundwater	Dewater quarry	0.43	20 (30 max.)	25
	S10T30R21	Browns Cr. to St. Croix River.	57-0097/NPR	Ashbach Aggregates	1000/151	Unnamed lake	Wash sand and gravel; depleted, will not activate			

* By Section, Township and Range

** DNR Water Appropriation Permit and PCA State Disposal System or NPDES Permit; NPR=No Permit Required

*** Where gpm = gallons per minute
MGY = Million gallons per year; maximum allowable volume.

Minnesota's Mineland Reclamation Act (M.S. 93.44-93.51), administered by the Division of Minerals, applies only to metallic mining and thus excludes aggregates.

The Minnesota Department of Transportation Aggregate Group collects, analyses, and disseminates aggregate information for proposed state highway projects in order to promote open competitive bidding and facilitate economical use of aggregate resources. Existing information is continually updated and supplemented to provide a statewide network of state-owned and leased aggregate sources (gravel pits). When a gravel pit is indicated in project plans as a possible source of aggregates, the pit data is made available to all bidders and the successful bidder has the option of using this aggregate source subject to leasing terms.

New highway construction programming sets priorities for collection and updating of aggregate information. Since the cost of aggregates is a major factor in construction costs it is essential to locate the closest gravel deposit to the project so it may be included in the road plans. New potential deposits are usually located through aerial photo interpretation and geologic field reconnaissance. A list of prospects is then compiled and checked by exploratory drilling. Proven prospects are then referred to the Mn/DOT Material Acquisition Group for leasing. Leased gravel pits are then completely tested on a grid to determine depth and lateral extent. Samples obtained are tested in a Mn/DOT materials laboratory for gradation and quality. All test hole data is then placed on pit sheets that give detailed information on the material in each hole. The pit is then included in the project plans for bidding purposes and made available to the public.[17]

County

All counties within the state produce aggregates. Surveys were conducted by MDNR in 1974 and 1978 to determine the amount of regulatory control at the county level. During this four year period, the amount of county regulation increased by nearly 300%. The results of this survey is summarized in Figure 13. Operational plans and performance standards deal basically with environmental and pollution factors. Site rehabilitation addresses reclamation to acceptable conditions and uses. All references to safety apply only to the general public, they do not cover worker safety.

Note that Anoka, Dakota, Hennepin and Ramsey counties are prohibited by law from issuing regulations of this kind. This responsibility has been delegated to the municipalities in those areas.

All counties have rules promulgated for shoreland management that include aggregate mining within those areas. There is some evidence that several counties do not apply these shoreland rules, since survey responses indicated that several counties have no regulation at all.

Apparently reclamation of aggregate mines is not handled in a consistent manner. This is due partially to the unique condition in each county and partially to differences in priorities and philosophies of county boards. Some counties do not require any permits, while others have extensive procedures and regulations.

Metropolitan Council

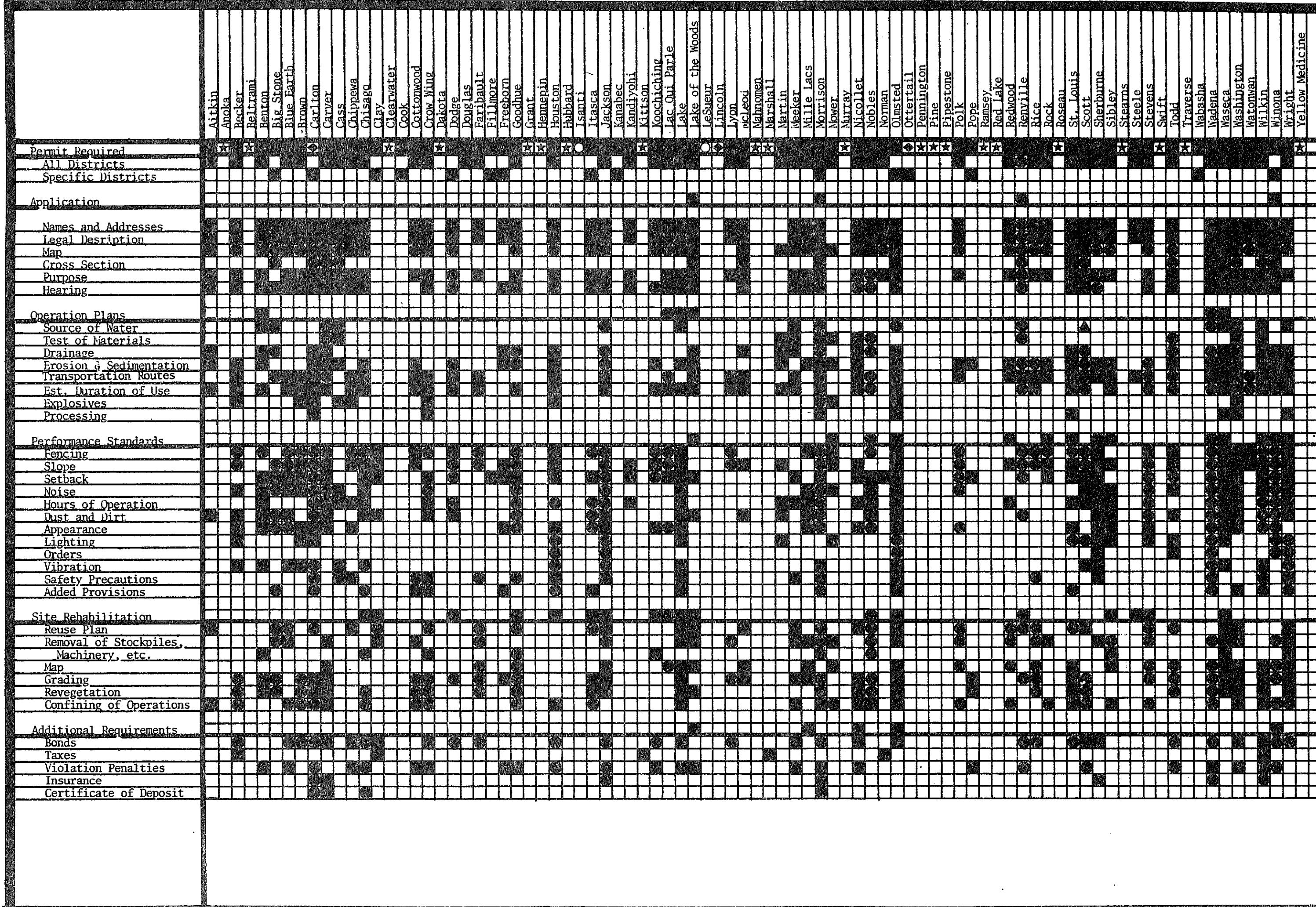
The Metropolitan Council has been directed (in M.S. 473.204) to "promulgate standards and criteria and suggested model ordinances for the regulation of the use and development of the land and water within the metropolitan area

COUNTY ZONING REGULATIONS (SAND & GRAVEL)

Figure 13

KEY

- REQUIRED BY COUNTY
- MAY BE REQUIRED
- PROPOSED
- NO REGULATIONS
- SHORELAND REGULATIONS
- NO DATA YET RECEIVED



which will provide for ... the regulation of the extraction of minerals, including sand and gravel, to minimize undesirable environmental effects and provide for future utilization of the land involved." Such standards were promulgated in March of 1977 to serve as a model ordinance. Municipalities are not required to adopt these rules.

Thus, municipalities are required by the Metropolitan Land Planning Act of 1976 to develop comprehensive plans that must be approved by the Metropolitan Council. The Council's Comprehensive Development Plan which is to be used as a guide for local plans[8], makes the following observations:

> "Lands for mineral production are lands with commercially valuable mineral deposits, such as sands, gravels, shale, dolomite, limestone, peat and clay. They constitute a regional source of construction material, and their "close-in" locations can lower costs.
>
> Proper management can ensure that the resources will be available when needed and that these lands will be reclaimed so that subsequently they will be suitable for other uses, including public open space.
>
> If not properly managed, valuable resources may be lost to the metropolitan area. Permanent urban density development over these deposits would eliminate them from future use. Current planning and land use controls do not protect mineral deposit areas. Often, surface mining excavations are left as major scars on the landscape. If restoration does take place, it is usually after the operation is over, increasing the cost to the operator and the local unit of government. Concurrent reclamation is slowly becoming more common. Local governments frequently do not require reclamation and restoration programs."

On the basis of these observations, four policy statements that relate to sand and gravel have been formulated by the Council.

1. Local comprehensive plans should include policies for interim use, development, and reuse of mineral deposit areas.

2. Counties and municipalities should adopt and enforce performance standards for mining operations; and conditional use permits for mining operations should be used.

3. Reclamation and restoration plans for mining operation sites should be submitted to and approved by the local unit of government with jurisdiction before permits are granted.

4. Reclamation and restoration of the landscape should be concurrent with mining operations.

In terms of mineral resources, each plan submitted under the Metropolitan Land Planning Act must contain policies and programs consistent with the Council's policies. Some of these plans are due in 1979, others are due in 1980.[8]

Municipalities

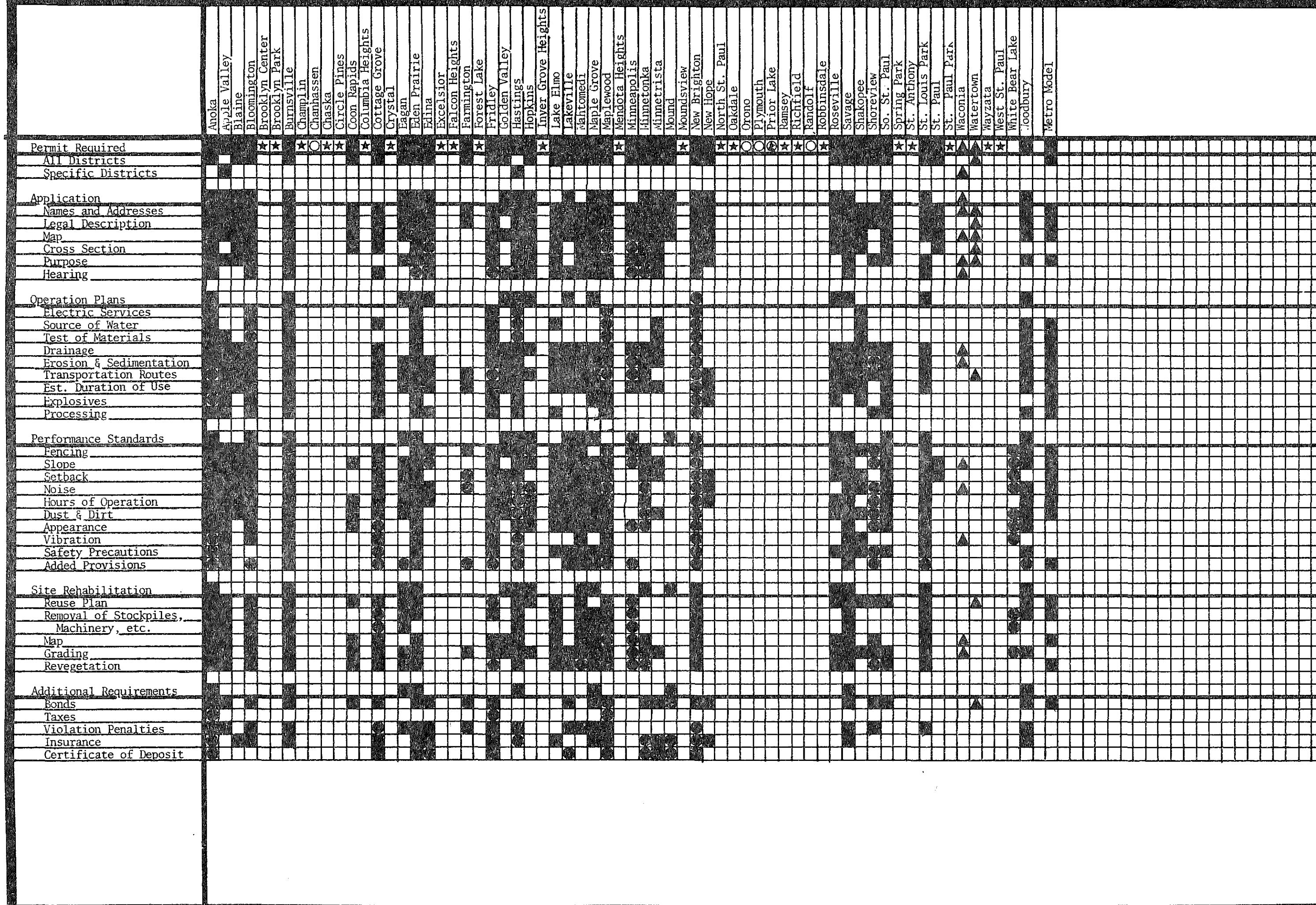
Municipalities within the metropolitan area were surveyed to determine the amount of regulatory control over aggregate mining. Results of this survey are presented in figure 14. In the last column, provisions of the Metropolitan Council's model ordinance are listed for comparison. Again, inconsistency can be observed. Unlike the county survey, many of the municipalities indicated there is no mining in their area. None of the municipalities are empowered to tax minerals.

METRO AREA ZONING REGULATIONS (SAND & GRAVEL)

Figure 14

KEY

- ■ REQUIRED
- ● MAY BE REQUIRED
- ☆ NO REGULATIONS
- ▲ PROPOSED ORDINANCE
- ○ NO DATA YET RECEIVED



REFERENCES

1. Barton-Aschman Assoc. Inc. Appendix F "Noise" Draft Environmental Impact Statement Technical Appendix: Reserve Mining Company's Proposed On Land Tailings Disposal Plan, October, 1975.

2. Briggs, Ronald, State Liaison Officer, U. S. Bureau of Mines, Twin Cities Office. Personal Communications, 1979.

3. Briggs, Ronald C.; Elwood F. Rafn Minerals in the Economy of Minnesota, U.S. Dept. of the Interior, Pittsburgh PA: 1979.

4. Evans, James R. "Forecasting Sand and Gravel, Crushed Stone, and Aggregate Demand in the United States." Mining Engineering, January 1979. pp 54-61.

5. Evans, J.R. Mineral Commodity Summaries 1979, U. S. Bureau of Mines, 1979.

6. Evans, J. R. Sand and Gravel - Mineral Commodity Profiles, MCP-23.

7. French, R. R.; A. W. Stuart; D. H. White, Socioeconomic Aspects of Mining in Selected Cities - Urbanization and Surface Mining, Atlanta, GA, U. S. Bureau of Mines Information Circular 8477. Washington D.C.: U.S. Government Printing Office, 1970.

8. Jouseau, Marcel, Manager of Natural Resources for the Metropolitan Council. Personal Communication. 1979.

9. Menininger, R.C.; F. A. Renninger, "Environmental Factors in the Aggregate Industry." Environmental Quality Conference, American Institute of Mining Engineers, Washington D.C.: 1971

10. Metropolitan Council. Assessment of Water Pollution From Mining Activities (Technical Report), June, 1977.

11. Metropolitan Council. Metropolitan Development Guide, Volume two. Open Space, Page 19, 1973.

12. Mills, Thomas R. Michael Clar, et al. Erosion and Sediment Control - Surface Mining in the Eastern United States - Planning, Environmental Protection A lency Technology Transfer Seminar Publications, EPA-625/3-76-006, October 1976.

13. ____________. Mineral Trends and Forecasts, U. S. Bureau of Mines, 1979.

14. ____________. Minerals Yearbook, U. S. Bureau of Mines, Data taken from volumes for years 1951-1975.

15. Murphy, Earl F. Governing Nature, Chicago: Quadrangle Books.

16. Newport, Bobby D.; James E. Moyer. State-of-the-Art: Sand and Gravel Industry, EPA-660/2-74-066. Mining Waste Section, Treatment and Control Technology Branch, Robert S. Kerr Environmental Research Laboratory, Ada OK, 1974.

17. Pladsen, Warren O., Materials Engineering Section, Minnesota Department of Transportation. Memo, March 1979.

18. Sheridan, Matthew J. Urbanization and its Impact on the Mineral Aggregate Industry in the Denver, Colorado Area, U. S. Bureau of Mines Information Circular 8320, 1967.

19. Stauffer, Clinton R., 1950. "The High Magnesium Dolomites and Dolomitic Limestones of Minnesota." Minn. Geological Survey, University of Minnesota.

20. Soils Science Dept., Univ. of Minnesota, Agricultural Experiment Station, Report 120 - 1973, Minnesota Soils Atlas, St. Paul Sheet. In cooperation with the U. S. Dept. of Interior Soils Conservation Service, and the Minn. Geological Survey.

21. ------------------------------, Soil Landscapes and Geomorphic Regions Twin Cities Metropolitan Area, in cooperation with the U. S. Dept. of Interior, Soils Conservation Service, and Minn. Geological Survey.

22. Stone, John E., 1965. Reconnaissance Map of the Surficial Geology of the Minneapolis - St. Paul area: Minn. Geological Survey, Univ. of Minnesota. (Open file map scale 1:250,000).

23. U. S. Department of Labor, Mine Safety and Health Administration. "Metal-Nonmetal Mine File Reference," May 2, 1978.

24. U. S. Department of Interior, Bureau of Mines. "Mineral Industries Establishments in Minnesota," March 2, 1978.

25. Wright, H.E., Jr. "Quaternary History of Minnesota". Geology of Minnesota: A Centennial Volume, Minnesota Geological Survey, University of Minnesota, 1972.