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Gravel Resources, Urbanization and Future Land Use, Front Range Urban Corridor, Colorado

By

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With a section on

Calculation of Gravel Reserves, by

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GRAVEL RESOURCES, URBANIZATION AND FUTURE LAND USE

FRONT RANGE URBAN CORRIDOR, COLORADO

By JAMES M. SOULE

Abstract

An assessment of gravel needs in Front Range Urban Corridor markets to 2000 A.D., based on forecast population increases and urbanization, indicates that adequate resources to meet anticipated needs are potentially available, if future land use does not preclude their extraction. Because of urban encroachment onto gravel-bearing lands, this basic construction material is in short supply nationally and in the Front Range Urban Corridor. Longer hauls, increased prices, and use of alternatives, especially crushed rock aggregate, have resulted. An analysis of possible sequential land uses following gravel mining indicates that a desirable use is for "real estate" ponds and small lakes.

A method for computing gravel reserves, based on planimeter measurement of area of resource-bearing lands and statistical analysis of reliability of thickness and size distribution data, was developed to compute reserves in individual markets. A discussion of the qualitative "usability" of these reserves is then made for the individual markets.

Introduction

A demand for gravel in the Front Range Urban Corridor will continue well into the foreseeable future as population growth and urbanization foster continued construction activity, particularly in existing centers of expanding urbanization and population. Many of these population centers rest on or near high-quality gravel deposits. Many areas underlain by gravel are being used for other purposes, particularly agriculture.

Gravel is one of the most sought after mineral commodities in the United States (Yeend, 1973). Highway construction, residential, commercial and industrial building, and water works and flood control projects (dams) are the principal uses of gravel nationally and in the Front Range Urban Corridor area.

Most of the high-quality gravel in the Front Range Urban Corridor is found along major drainages, either under the floodplains or on adjacent stream terraces. Lower-quality gravels are found in older Quaternary alluvial deposits or on pediments near the mountain front.

In the Front Range Urban Corridor at the present time, concrete aggregates are made mostly from gravel. Alternative materials, such as crushed stone, quarried in nearby mountains, are coming into use as close-in supplies of gravel are being depleted. Gravel is a heavy, low unit value commodity whose cost at the site of use depends on its distance from the source of supply. Consequently, its cost, is least when haulage is minimal. In Denver, as in many other parts of the nation, urban encroachment onto gravel-bearing lands has resulted in longer hauls, higher prices, and use of other kinds of aggregate. If present urbanization trends continue, other parts of the Front Range Urban Corridor may soon experience the same situation. Crushed-rock aggregate currently is competitive with gravel in the Denver metropolitan area.[1/] The use of expanded shale light-weight aggregate also is increasing inasmuch as concrete made from light-weight aggregate has properties that give it a cost advantage in large or tall structures.

[1/] Adams, Arapahoe, Denver, and Jefferson Counties.

The Front Range Urban Corridor currently is experiencing a rate of population growth exceeded by few areas of the nation. As a result, there is a great demand for housing, commercial services, and the services of government. The location of the resulting new urbanization generally has been on the periphery of established population centers, but specific locations of new development have been controlled partly by land values, location of principal highways, physical attractiveness, or a combination of some or all of these factors.

In terms of area, the Front Range Urban Corridor is chiefly agricultural, forest, and residential land. Other important categories which require less area are industrial and commercial enterprises, roads, parks, and open space. Of all these categories, residential and agricultural uses are in most direct conflict. Nearly all the urbanized areas in the Front Range Urban Corridor formerly were farmland or grazing land. Also, most of the highest quality agricultural areas of the region are on or near flood plains of major drainages--the same areas that typically contain the highest quality gravel resources.

Long range development plans prepared by State, county, and local planning agencies exist for most of the Front Range Urban Corridor. These plans commonly offer forecasts of future population, location of urbanization, and analyses of economic factors based on stated assumptions about conditions affecting economic growth, desired lifestyle, and amount and location of new construction. The assumptions on which such forecasts are based vary among municipalities, and local concepts are hard to integrate into a meaningful regional plan. Furthermore, predictions for the future are subject to revision as time and conditions change.

Purpose, background, and method of study

The purpose of this report is to outline the projected needs for gravel or its likely alternative commodities to the end of the century, and to correlate these needs with forecast growth of principal market areas within the Front Range Urban Corridor. These estimates, when compared with estimates of reserves, suggest that reserves are adequate to meet future needs if proper land-use controls are established. Sequential land-use capability of mined gravel areas is evaluated. Current prices of sand and gravel[2/] materials are given and problems

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[2/] Prices, basic production statistics, and studies in other areas typically give comingled data for sand and gravel despite their different uses--see table 5.

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of using alternative materials are briefly discussed.

No previous study of this type has been made for the entire Front Range Urban Corridor, but the nature of sand and gravel occurrences in metropolitan Denver and problems associated with its extraction have been known for some time. The Colorado Sand and Gravel Producers Association (1957) published a map of Denver that showed the general location of sand and gravel areas and summarized the problems of extraction, estimates of reserves, and future need. The Inter-County Regional Planning Commission (1961), predecessor of the Denver Regional Council of Governments, made a similar study. Sheridan (1967) documented the problem and reached the same conclusions: that restrictive zoning, lack of general public understanding of sand and gravel occurrence and mining operations, and prior land use for residential and commercial urbanization would eventually cause a shortage of low-cost aggregate in Denver. Similar situations exist in other parts of the country (Hudec, 1969, p. 175; Davis and Meyer, 1971; Metropolitan Planning Commission, Portland, Oregon, 1964). In Denver, gravel and crushed rock aggregate are now competitively priced at $3.40/ton (Engineering News Record, March 7, 1974, p. 32), and the percentage of the aggregate market fulfilled by crushed rock is increasing. Legislation passed by the 1973 Colorado Legislature, the "open mining law", addresses this problem directly:

> 92-36-5 (Colorado Revised Statutes)
> After July 1, 1973, no board of county commissioners, governing body of any city and county, city, or town, or other governmental authority which has control over zoning shall, by zoning, rezoning, granting a variance, or other official action or inaction, permit the use of any area known to contain a commercial mineral deposit (gravel) in a manner which would interfere with the present or future extraction of such deposit by an extractor.

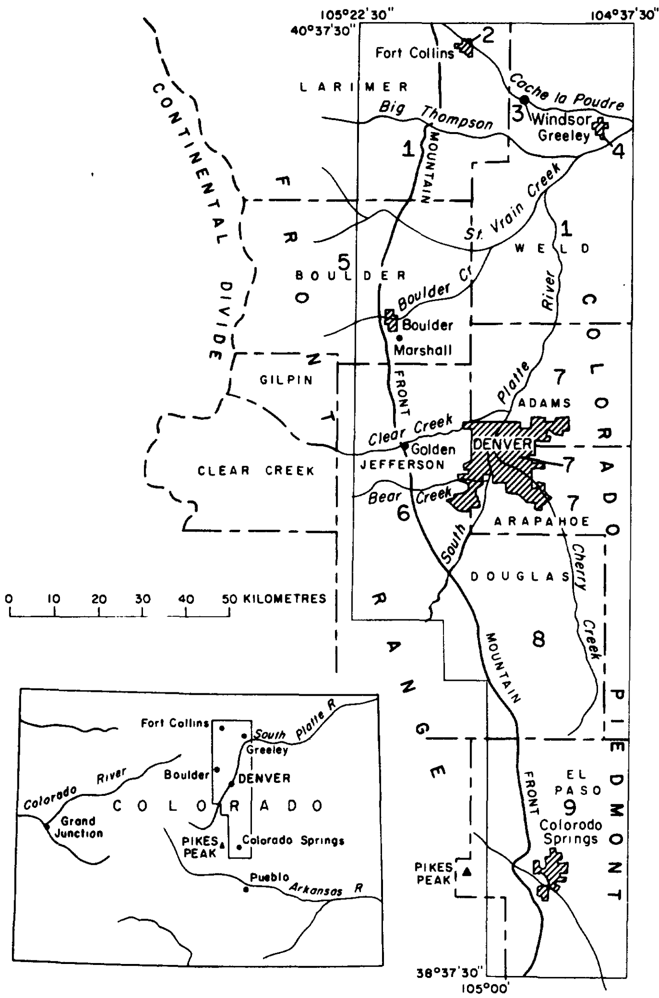
Prior to enactment of this law, most gravel-bearing areas in metropolitan Denver had already been preempted or zoned for other use. In other market areas, however, especially close to Boulder and Fort Collins, where large accessible reserves still exist, the new law may slow the shift to crushed-rock aggregate.

Most long-range forecasts of gravel need have been based on a linear projection of past and present per capita gravel consumption, consumption trends, and population growth. Such a method has the advantage of being straightforward and simple, but it disregards possible changes in the gravel market caused by changing social and economic conditions. Although these conditions are impossible to forecast precisely, an assessment of future mineral resource need should include factors other than population growth. The estimates of future need for sand and gravel in this report are based on a pragmatic evaluation of construction practices--particularly construction of housing and roads, legislation affecting land use, and the probable change in the competitive position of gravel with respect to other building materials. The maps showing areas of present and anticipated urbanization and areas underlain by commercial gravel deposits (plates 1, 2, 3) have been prepared from recent gravel resource maps of the U.S. Geological Survey (Colton and Fitch, 1974, and Trimble and Fitch, 1974a, b) and from a synthesis of current long-range plans (fig. 1). Plates 1, 2, and 3 are the basis for identifying the principal likely market areas for gravel and areas where urban expansion could curtail gravel extraction. These plates show gravel areas only in urban or potentially urban parts of the Front Range Urban Corridor. Reserves in the areas of inaccessible (urbanized) and accessible gravel have been computed (see p. 21), and the degree to which accessible reserves could fulfill future need is given in Table 4.

Environmental impact of gravel-mining operations is a matter of increasing social concern, and reclamation of mined-out land for other uses is becoming a part of the cost of future mining operations. From a survey of current relevant literature and practices in other parts of the country, the reclamation potential of sand and gravel mining areas for maximum social benefit and minimum environmental damage is indicated. Current prices and use of substitute materials are briefly discussed.

Regional Population Growth--Economic Growth

The current high rates of both population and economic growth in the Front Range Urban Corridor are accelerations of long-term trends. From the early nineteen hundreds to the late nineteen sixties the population increased at a rate of 3-4 1/2 percent per year (Regional Transportation District, 1972; p. 1-3, Denver Regional Council of Governments, 1971, fig. 10). Most of the population growth has been concentrated in the Denver Metropolitan area, Colorado Springs, Boulder, Fort Collins, and Greeley.



1. Larimer-Weld Regional Planning Commission, 1972, Regional Development Plan, Larimer-Weld Region.

2. Fort Collins City Planning Dept.

3. Colorado Division of Planning, 1969, Windsor Comprehensive Development Study
   Weld County Planning Dept.

4. Greeley City Planning Dept.

5. Boulder County Planning Dept.

6. Jefferson County Planning Dept.
   Reed, J. C., Jr., and Smedes, H., 1974, Current land-use map of Jefferson County, Colo.

7. Denver Regional Council of Governments.

8. Douglas County Planning Dept.

9. Pikes Peak Area Council of Governments, 1970, Pikes Peak regional land-use plan.

Figure 1.--Principal sources of information on land-use planning.

Table 1.--Typical Population Forecasts

Counties of the Front Range Urban Corridor

County	1970*	1980	1990	2000	A.D.
Larimer	89,900	135,000 2/ 159,262	200,000	N.A. 1/	
Weld	89,297	125,000 2/ 140,628 112,000	180,000 133,000	N.A. 1/ 157,000 3/	
Boulder	131,889	232,967 2/ 172,000	214,000	264,000 3/	
Jefferson	235,300	325,000 2/ 423,665	430,000	554,000 3/	
Adams	185,789	242,000 2/ 279,071	309,000	371,000 3/	
Denver	514,678	530,000	548,000 2/ 623,748	567,000 3/	
Arapahoe	162,142	236,000	317,000 2/ 259,322	419,000 3/	
Douglas	8,407	21,000 2/ 19,814	43,000	86,000 3/	
El Paso	235,972	N.A. 2/ 410,424	515,132	N.A. 4/	

N.A. = not available

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*U.S. Bureau of the Census, decennial report of population, 1970.

1/ Regional Development Plan, Larimer-Weld Region, 1971, Larimer-Weld Regional Planning Commission (Prepared by Alan M. Voorhees and Associates, Denver Colorado).

2/ Colorado County Population Estimates - 1970 to 1980, 1973, Colorado Division of Planning (Prepared by Dr. David Monarchi, demographer, Business Research Division, Colorado University School of Business Administration, Boulder.)

3/ County Profile(s), 1972, Regional Transportation District (Prepared by Development Research Associates, Inc., and Wallace, McHarg, Roberts and Todd, Inc.).

4/ Pikes Peak Regional Land-Use Plan, 1970, Pikes Peak Area Council of Governments.

The county population forecasts given in Table 1 are some of the best current estimates of planning agencies. In every case, the population projections are contingent on numerous assumptions made by the particular planning agency. For the Denver and Colorado Springs Metropolitan areas, most population projections assume that the employment market will continue to outgrow the local population, resulting in a continued high rate of in-migration (oral communications, staff, Denver Regional Council of Governments and Pikes Peak Area Council of Governments). Predictions for the near future usually are based on a continuation of current trends in land use and economic growth; long-range views, however, more closely reflect the belief of planners that growth will be restricted in some manner. Most population projections are based in part on past conditions and forecasts of future conditions of the employment market. Local economies, their need for a labor force, and the degree to which this need can be sustained locally probably will have more effect on where and how many people will locate within an area than any other combination of factors (Denver Regional Council of Governments, 1971). Corresponding to the dependence of the population on the employment market is the dependence of the amount and location of new residential urbanization on the preferred lifestyle of the purchasers and their ability to pay for housing, as well as on the current status of the real estate market. Table 2 summarizes the principal factors affecting interrelated employment-economic growth, lifestyle, and landuse currently operating in the Front Range Urban Corridor; especially important among these factors is the desire of most householders to own single-family homes and the results of an automobile-dominated transportation system.

Urban land use

In the Front Range Urban Corridor, space requirements for land uses are as shown in Table 3. Single-family residential subdivisions are the principal new land use. The consensus of planning agencies, builders, and real estate developers appears to be that this allocation of land will continue for the foreseeable future. For the counties given in Table 3, approximately two thirds of new urban land use will be for single-family housing; such an allocation probably is reasonable for other counties of the Front Range Urban Corridor as well.

For an analysis of future gravel needs, the rate and location of urbanization are as important as population increases and amounts and types of new construction. Because of haulage costs, the value of the gravel is greatly affected by the locations of the market areas and the sites of construction concentrations within market areas. The principal market areas for gravel in the Front Range Urban Corridor are: the Fort Collins-Loveland, Windsor, Greeley, Boulder-Longmont, Denver metropolitan, Douglas County, and Colorado Springs areas.

Table 3.--Land required for housing and some other typical urban uses, Front Range Urban Corridor, Colorado

Housing densities:
- single family houses: 4-5 units/acre
- townhouses: 6-10 units/acre
- mobile homes: 8-10 units/acre
- apartments (condominiums and rentals): 20-30 units/acre

Roadways and paved areas in:
- new single-family subdivision: 20-25 percent of land
- commercial zone, retail: 25-30 percent of land
- new multi-family townhouse subdivision: 25-30 percent of land
- new apartment complex: 25-30 percent of land
- industrial area: highly variable
- parks and open space: very small percentage

Forecast land needs for urbanization in Adams, Arapahoe, Boulder, Denver, Jefferson, and Weld Counties*:

	1971-1980 acres	percentage of total needed	percentage of total needed for housing
single family houses	12,915	62.2	74.6
multi-family housing	3,013	14.5	17.4
mobile homes	1,384	6.6	7.9
commercial	2,090	10.0	---
industrial	1,360	6.5	---

	1981-1990 acres	percentage of total needed	percentage of total needed for housing
single family houses	12,487	62.5	77.1
multi-family housing	2,608	13.0	16.1
mobile homes	1,110	5.6	6.8
commercial	2,400	12.0	---
industrial	1,360	6.8	---

	1991-2000 acres	percentage of total needed	percentage of total needed for housing
single family houses	14,688	65.8	78.9
multi-family housing	2,875	12.9	15.4
mobile homes	1,094	4.9	5.8
commercial	2,300	10.3	---
industrial	1,360	6.7	---

*Derived from "Regional Growth", Regional Transportation District (1972b). Percentages may not total 100 percent due to rounding.

Table 4.--Projected population and urbanized land in the year 2000 A.D. for specific areas of the Front Range Urban Corridor. Estimates of areas of urbanized land (right column) are based on current and projected housing patterns and other metropolitan land uses assuming the estimated population (middle column).

Area	Total Population	Total Newly Urbanized Land
Fort Collins	120,000-150,000[1/]	5,000 acres[2/]
Loveland	40,000[1/]	1,100 acres
Windsor	30,000[3/]	1,500 acres
Greeley	100,000[4/]	3,000 acres
Boulder	150,000[5/]	8,000 acres
Longmont	100,000[5/]	5,300 acres
Denver Metropolitan	2,100,000[4/]	71.25 square miles[6/]
Douglas County	50,000[7/]	7,500 acres
Colorado Springs	800,000[8/]	78 square miles

[1/] Estimate based on Larimer-Weld Regional Planning Commission, 1971; McPhail, 1972; oral commun., staff, Fort Collins City Planning Department

[2/] Acre = .4047 hectare

[3/] Estimate based on discussions with local planners and staff of Weld County Planning Department.

[4/] Estimate based on discussions with local planners.

[5/] Estimate based on projection of figures for 1990 A.D. (oral commun., James Liles, Boulder County Planning Department); discussions with local planners.

[6/] Square mile = 2.590 square kilometres

[7/] Estimate based on projection of figures for 1980 A.D. (Colorado Division of Planning, 1973, p. 29), allowing for more growth in the Castle Rock area.

[8/] Estimate by staff, Pikes Peak Area Council of Governments.

Urban Growth in the Front Range Urban Corridor

Fort Collins-Loveland area

Both Fort Collins and Loveland are expected to more than double their populations before 2000 A.D. (Table 4). Corresponding increases (Table 4) in urbanized land, as single-family housing and for other uses, are also foreseen, along the lines suggested by the Regional Transportation District study (1972). Future urbanization around Fort Collins is expected to be concentrated south, southeast, and southwest of the present location of the city; to the west, the hogback and Horsetooth Reservoir will constrain urban expansion. The initial thrust of development southward probably will be along U.S. Highway 287, followed by a 'filling in' between the hogback to the west and the Union Pacific Railroad right-of-way. Interstate Highway 25 east of the city is a stimulus to expansion in that direction; the present plan is to zone much of this area industrial (oral commun., Fort Collins City Planning Department). Loveland, like Fort Collins, expects development to be most strongly directed along U.S. Highway 287, constrained by the Big Thompson River floodplain to the south; moderate expansion is contemplated to the west and east (oral commun., Larimer-Weld Regional Planning Commission).

Windsor area

Before the installation of Eastman Kodak Company's large facility southeast of Windsor in the early nineteen seventies, Windsor, like most other small communities in the region, was growing very slowly. Since then, Windsor's recent rate of population increase has been among the highest in the region (Table 4), although many Kodak employees live in neighboring larger towns. It is likely that all of the Kodak property and areas contiguous to the present townsite will be subject to urbanization before 2000 A.D.

Greeley area

Most of Weld County's future population increases outside the Windsor area are expected to be at Greeley. Plate 1 reflects the planners' desire that Greeley expand to the west because this area is mostly dry-farmed land or grazing land. Despite this preference, the location of U.S. Highway 85 north and south of the city and the existing towns of Evans and La Salle immediately south of Greeley are strong influences on growth. Most of the areas contiguous to Greeley to the north and south are underlain by gravel deposits. If flood plain-agricultural zoning and Colorado's Open Mining Law are effective in stopping extensive growth in the South Platte and Cache la Poudre Valleys, high-density growth west of the city is likely.

Boulder-Longmont area

Significant population increases are forecast for the cities of Boulder and Longmont (Table 4). Boulder's total area probably will double by the end of the century. The city is expected to extend to South Boulder Creek in the vicinity of Marshall by 2000 A.D. (Boulder County Planning Commission, 1970). Longmont also will increase greatly, characterized by peripheral growth with an emphasis to the northwest toward McIntosh Lake. Other smaller communities are expected to meet or exceed these growth rates. For example, both Broomfield and Lafayette are expected to have populations of 40,000 by 1990 (oral commun., Boulder County Planning Commission). The area outside of incorporated municipalities most subject to urbanization pressure is the Gunbarrel Hill-Niwot area between Boulder and Longmont, due in large part to the location of the International Business Machines Corporation Manufacturing facility southwest of Niwot.

Denver Metropolitan area

The Denver Metropolitan area is by far the largest and most populous urban area in the Front Range Urban Corridor. At the end of 1972, it had a population of about 1,225,000; by the end of the century, a population of 2,100,000 is possible (Table 4). Currently the larger percentage of Denver's new urbanization is taking place in the southeast (vicinity of Cherry Creek Reservoir in Arapahoe County) and southwest quadrants (west of the South Platte River and south of Hampden Avenue to the foothills hogbacks in Jefferson County). But all suburban communities are growing rapidly. Industrial development is taking place both as expansion and redevelopment (Denver Urban Renewal Authority) of Denver's downtown area, and as relocation of major new industries to peripheral suburban locations. As in other areas, expansion of the metropolitan area's periphery has resulted in longer commuting distances from these suburbs to the principal employment center downtown. Thus, the need for roadways is increased and, consequently, the need for sand and gravel.

Future growth in the Denver Metropolitan area initially will follow the present urbanization pattern of greatest growth southwest and southeast of the metropolitan area (oral commun., staff, Jefferson County Planning Department; Regional Transportation District, 1972b; oral commun., staff, Denver Regional Council of Governments). Extensive development is unlikely south of County Line Road into Douglas County, inasmuch as several large private land holdings reportedly are unavailable for development (oral commun., William Noe, Douglas County Planning Department). Currently, however, developments are in progress south of the intersection of County Line Road and Interstate Highway I-25. To the southwest, development may eventually extend south of the Ken Caryl property to Roxborough Park. Chatfield Dam reservoir on the South Platte River and the possible construction of the Foothills Freeway (I-470) along the east side of the Dakota hogback would add stimulus to growth in this area (oral commun., staff, Jefferson County Planning Department). To the southeast, development could extend southeast along Cherry Creek to the vicinity of Parker, where several large developments (Pinery, Parker City) already are in progress. Immediately south of the metropolitan area, relatively large tracts are as yet undeveloped adjacent to Interstate Highway I-25. To the west, growth is considered possible, with varying densities, to the Table Mountains, and to the north and northwest to Northglenn, Broomfield, and the Rocky Flats Atomic Energy Commission facility. To the northeast, the Rocky Mountain Arsenal and Stapleton International Airport are constraints to growth; to the east, Aurora likely will extend beyond the north-south alinement of Interstate Highway 225 (oral commun., staff, Denver Regional Council of Governments).

Douglas County

Although the rate of population increase and urban growth in Douglas County has been the highest in the Front Range Urban Corridor in recent years, the net annual growth is still the least. This growth is mainly the result of the expansion of the Denver Metropolitan area immediately north of the County, of Colorado Springs' growth to the south, and of strong pressure for development by land owners. Peripheral growth around Castle Rock contrasts markedly with the style of development in other areas of the county: widely-spaced scattered subdivisions of variable, but typically low density. Estimates for continued growth along these lines are given in Table 4. Most interconnecting roads are not paved, and except for Interstate Highway 25, the County's road system is much less developed than that of other areas.

Compared to the growth of other areas, where future need for sand and gravel is as predictable as future population, construction, and road building patterns, Douglas County's growth seemingly will be highly varied in amount and location of population increases and in construction patterns and practices (oral commun., William Noe, Douglas County Planning Department). Currently, Douglas County's annual per capita and net amount of sand and gravel produced per person population increase are the highest in the Front Range Urban Corridor (Table 5). Although Douglas County is not a major market area in terms of net amount of sand and gravel produced and used, these high rates suggest that accelerated population growth accelerates the demand for sand and gravel, the bulk of which is being used for construction of housing and roads.

Colorado Springs area

Colorado Springs currently is the second fastest growing and second largest metropolitan area in the Front Range Urban Corridor; its population is expected to more than double by the end of the century (Table 4). Land estimates (Table 4) exclude land used for military purposes, but do include military personnel. The Pikes Peak Area Council of Governments (1970a, p. 38) estimates that by quadrants centered on the center of Colorado Springs, the percentage of total future urban land "consumption" will be: northeast--39 percent, southeast--36 percent, northwest--14 percent, southwest--11 percent. Growth of Colorado Springs is constrained by the U.S. Air Force Academy and Fort Carson, to the north and south respectively, and by the mountain front and the Garden of the Gods city park on the west. Consequently, the other major future growth areas are south along Fountain Creek toward Security, Widefield, and Fountain communities and southeast across the Sand Creek drainage. However, despite a low percentage of suitable gravel in these drainages, Sand Creek and Fountain Creek contain the highest quality gravel in the area (Trimble and Fitch, 1974b); moreover, both of these drainages are flood prone and, consequently, their floodplains are poor prospects for urban development (Pikes Peak Area Council of Governments, 1970b, p. 35-36).

Other communities in El Paso County are growing rapidly, and this trend is expected to continue. West of Colorado Springs, the towns of Cascade, Chipita Park, and Green Mountain Falls are expected to have considerable growth, although they are expected to remain relatively small compared to Colorado Springs. Monument, Palmer Lake, the corridor between them, and the new Woodmoor community east of Monument and Interstate Highway 25, also are future growth areas.

Future gravel needs

The probable long-range need for gravel has been estimated in three ways: (1) summation of total annual per capita need based on approximately 10 short tons (9.078 metric tons) of sand and gravel per person per year and population forecasts by market area and decade to 2000 A.D., (2) summation of 250 short tons per person maximum forecast increase in population to 200 A.D., and (3) allocation of specified amounts of sand and gravel for its principal uses--paving (highways and residential streets) and construction, particularly that of housing. Ten tons per person per year and 250 tons per additional person both approximate the average values for current sand and gravel production in the major market areas for sand and gravel in the Front Range Urban Corridor (Table 5).

Only commingled county production statistics for sand and gravel are reported by the U.S. Bureau of Mines (U.S. Bureau of Mines Minerals Yearbooks). Although crushed rock fulfills most of the aggregate need in the Colorado Springs market area and an increasing percentage in the metropolitan Denver market area, quarry rock used for this purpose is not reported separately from rock used for dimension stone, or limestone used for cement manufacture and decorative stone, making determination of exact amounts used for aggregate impossible. Additionally, production figures are not reported for counties with only one or one major producer of sand and gravel or quarry rock. Table 6 demonstrates that about four fifths of sand and gravel product in Colorado is gravel, and that about two thirds of this gravel is used for paving; most of the remainder is used for construction. Data are not available for individual Front Range Urban Corridor market areas, but, as most of the state's gravel is produced and used in the Corridor and construction patterns are similar throughout the state, this allocation probably is reasonable for the area(s) under study. Paved areas are chiefly highways, residential streets, and commercial areas (parking lots), and the bulk of new construction is housing, although water works, and major industrial and commercial projects do in some years account for a large part of the gravel used. The following allocation of sand and gravel for its principal uses was made by inquiring of builders, the Federal Housing

Table 6.--Current percentage allocation of uses for sand and gravel production in Colorado[1]

(1)	Total sand and gravel production, all uses (percent)	Sand	Gravel
		17.78	82.22
(2)	Total sand and gravel production (percent)	Sand	Gravel
	construction:	37.50	62.50
	fill:	44.35	55.65
	paving:	5.13	94.87
	other:	37.15	62.85
(3)	Total sand production (percent)		
	construction:	69.25	
	fill:	8.30	
	paving:	14.50	
	other:	7.95	
(4)	Total gravel production (percent)		
	construction	28.45	
	fill:	2.45	
	paving:	62.47	
	other:	6.63	

[1] Derived from production figures for Colorado as reported by the U.S. Bureau of Mines for 1971, 1972; U.S. Bureau of Mines Minerals Yearbooks (in press): from Walter Pajalich, U.S. Bureau of Mines, Arlington, Virginia.

Administration, the Colorado Division of Highways, and others and by field and aerial photograph study of areas currently being urbanized. This method and allocations closely parallel those used in the well-documented study of Bishko and others (1969, p. 98-112). Future need, based on factors consistent with current urbanization patterns (see Table 3) is shown in Table 7. In every case the factors given are maximum for the particular allocation. For example, the determination of the amount of sand and gravel used for highways assumes maximum highway development projected by the Colorado Division of Highways, based on maximum forecast population increases and current highway construction practices. Currently about 25 percent of the area of a typical new single-family housing subdivision is paved (including streets, highways, drives); this value probably is at least 10 percent higher than it was two decades ago. The increased number and size of cars, and the reduced sizes of single-family lots, have resulted in an increased amount of paving in residential areas. In higher density residential developments, such as apartment complexes and townhouses, the percentage of paved land area is even higher--30 percent or more. The percentage in mobile home parks is as great, although no sand and gravel are used in the construction of mobile homes themselves.

For commercial and industrial construction, it is impossible to estimate the allocation of sand and gravel by paved area or building type because of the variability of such projects. Analysis of current consumption of sand and gravel for commercial and industrial uses in the Front Range Urban Corridor area versus total need reveals that street and highway construction and housing account for about three fifths of consumption and all other uses account for approximately two fifths. Inasmuch as industrial and commercial growth parallels both population increase and residential construction, a simple allocation of two thirds of the amount used for street, highway, and housing construction was added to account for projected commercial and industrial uses. Major projects in given market areas or years are unpredictable and can alter this allocation considerably.

Most planning agencies conclude that a trend toward multi-family housing is due primarily to increased land costs, increased mortgage interest rates, and increased construction costs (Regional Transportation District, 1971, p. 30; Denver Regional Council of Governments, 1972, p. 58-62; Pikes Peak Area Council of Governments, 1973). These planning agencies indicate, however, that the current percentage of the market fulfilled by higher density housing probably is at a maximum, and that a decrease in any of the costs mentioned would result in a shift back to single-family housing. A pronounced shift in this direction would result in higher rates of gravel consumption for housing. In contrast, a possible shift away from large-scale highway construction projects may eventually lessen considerably the demand for sand and gravel.

Sequential land use--site rehabilitation

Like most surface mining, sand and gravel extraction results in a hole (pit). Many mined-out areas have been abandoned without rehabilitation,

Table 7.--Factors and assumptions used to allocate gravel for its principal uses, Front Range Urban Corridor, Colorado

(1) Land use--Typical planning projections indicate that about:

--Two thirds of newly urbanized land will be used for single family housing and attendant streets that will accommodate half of the maximum forecast population increase;

--One sixth of the land used will be for multi-family housing, trailer courts, and attendant streets which will accommodate 42 percent of the maximum forecast population increase;

--Eight percent of maximum forecast population increase will be accommodated in redeveloped high (or) density areas; one-sixth of the land will be used for all other purposes.

(2) Street and highway construction:

Streets	Highways	(Tons, sand and gravel/mile 2/)
25 percent of single family 1/ subdivision is paved.	8 lane	87,700
30 percent of multi-family 1/ subdivision is paved.	6 lane	72,700
30 percent of mobile-home 1/ subdivision is paved.	4 lane	52,800
	2 lane	17,300

(3) Housing:

--Single family home--3.6 people: 4 single family homes per acre 3/

--Multi-family home--2.4 people: 20 apts.-townhomes per acre 3/

--Housetrailer--3.0 people: 8 housetrailers per acre 3/

144 tons sand and gravel per single-family home 4/

40 tons sand and gravel per multi-family home 4/

(4) Sand and gravel needed for street and highway construction and housing construction is typically about 60 percent of total needed 5/.

(5) 80 percent of concrete is aggregate (oral commun., E. M. Harboe, U.S. Bureau of Reclamation, Denver, Colorado, Goldman; 1956).

(6) Probable average thickness of concrete and/or subgrade aggregate fill in paved areas is one foot 6/.

(continued next page)

Table 7.--Continued

1/ Based on aerial photograph study of newly urbanizing areas.

2/ Engineering Dept., Colorado Division of Highways. Estimates of sand and gravel need based on unpublished long-range planning maps of Colorado Division of Highways or Transportation Plan for Colorado Springs market area, Pikes Peak Area Council of Governments, 1971. Short ton = .9078 metric ton.

3/ Regional Transportation District, 1972, Regional Growth, Wallace McHarg Roberts and Todd, Inc., p. 26-31.

4/ Based on discussion with officials of Federal Housing Administration, Denver, Colorado.

5/ Determined approximate average 1970-1972 percentage for Front Range Urban Corridor counties.

6/ Based on discussions with paving contractors and measurement of pavement thickness of streets, sidewalks, and drives in several subdivisions.

although most sand and gravel mining sites are in areas that have the potential for other sequential use. The most desirable sequential use for any surface-mined area would permit redevelopment or restoration that is environmentally compatible and is of general social benefit. In the Front Range Urban Corridor, most gravel is mined from low-lying areas where sequential use can endanger the purity of the groundwater unless precautions are taken to protect it. Reuse in such areas also should be compatible with periodic flooding.

Some mined-out gravel pits in the Front Range Urban Corridor have been used as land fills because they afford a convenient low cost refuse disposal site (Sheridan, 1967, p. 20, 24, 30-31); the Denver Coliseum site, its parking lot, and an area near Clear Creek and Sheridan Boulevard are good examples. Although most land thus reclaimed can be used much as if mining had not taken place, precautions are advisable against possibly polluting valuable groundwater by leachate. Bacterial activity (biochemical oxygen demand) increases in water-saturated landfill sites (Schneider, 1970), and refuse leachate in permeable sands, gravels, and sandstones travels in the same direction as groundwater. Leachate movement can be halted or reduced by sealing landfills with engineered impermeable clay liners (Hughes, 1967, p. 12).

If groundwater quality is to be maintained, pits either must be filled with material that is nonpolluting, must be adequately sealed, or must be left open to fill with water. Thus, unless nonpolluting fill can be obtained, the environmentally safest use for mined-out sand and gravel pits in the Front Range Urban Corridor is landscaped recreational ponds or small lakes. The benefit of this use has been demonstrated for a few areas along Clear Creek in metropolitan Denver, and its likely economic benefit has been discussed by David (1968). This type of development is strongly supported by the National Sand and Gravel Producers Association, (Bauer, 1965; Schellie, 1963). The development of small lakes and ponds is compatible with sand and gravel mining practices, especially if this development is planned prior to mining, and tends to increase value of land adjacent to the lakes where, as in the Front Range Urban Corridor, such areas are at a premium (Bauer, 1965; Klosterman, 1974; Schellie, 1963).

Although the sequential use of mined-out sand and gravel pits as open-water areas is a desirable end, this use is not without problems. Areas with high water table are generally suitable for "real estate" lake development (Rickert and Spicker, 1971, p. 3-4), but if the groundwater is polluted, particularly with sewage effluent or fertilizers, the pollutants can accelerate eutrophication[5/]. To some degree all streams

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[5/] Eutrophication: the process by which lakes age. Nutrients in lake water cause plant growth that in turn results in accumulation of organic material that eventually fills the lake.

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in the Front Range Urban Corridor are polluted. In metropolitan areas this pollution comes principally from street runoff and lawn and garden fertilizers. In rural areas most of the water pollution probably comes from agricultural chemicals, feedlots, and untreated waste. If "real estate" lakes are to succeed sand and gravel mining, some provision should be made to insure against accelerated eutrophication.

General market economics and use of alternative materials

Relatively inelastic demand and uniform pricing policies are the most important factors influencing sand and gravel prices in the Front Range Urban Corridor, assuming that the costs of mineral lease acquisition, excavation, beneficiation and haulage, and site rehabilitation are constants in the short run. Relatively inelastic demand[6] for sand and

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[6] Relatively inelastic demand is a demand where a change in price of a commodity has relatively little effect on the demand for that commodity.

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gravel products is the result of the small percentage of the total cost of construction that these materials constitute. Uniform pricing tends to result when one or a few large operators dominate markets. Although prices of sand and gravel products range considerably in different Front Range Urban Corridor market areas, they tend to be uniform in any one market area. Table 8 shows that the highest prices are charged in the largest market areas with the greatest net annual growth. Moreover, the shortage of alluvial gravel aggregate in the Denver metropolitan area probably is the reason that large quarries, whose principal product is crushed rock aggregate, have opened recently along the mountain front west of the city. Crushed rock has been the main source of aggregate for some time in Colorado Springs, and quarrying will likely increase in other areas. Sand and low-quality fill gravels appear to be in adequate supply in all areas.

The computations of reserves and projected needs in potentially urban areas of the Front Range Urban Corridor (Table 5), indicate that alluvial gravels are adequate to supply all market areas past 2000 A.D. if these resources are adequately protected from urban encroachment and if the sand and gravel industry is permitted to exploit the deposits. As urbanization expands, however, longer hauls will cause higher prices. Furthermore, quarrying tends to increase (Dunn, 1974), although quarry development is encountering mounting public opposition. Considering the huge gravel reserves available along the South Platte and Cache la Poudre Rivers, and the possibility of relatively inexpensive rail haulage, it may eventually be cheaper for operators in the Denver metropolitan area to transship gravel aggregate from these sources than to quarry and crush rock. With similar constraints, other markets could experience the same situation.

Substitution of alternative materials for natural aggregates is usually not feasible, inasmuch as nearly all the alternatives are much

Table 8.--Current prices[1] for sand and gravel materials

Front Range Urban Corridor, Colorado

Market area	3/4" concrete aggregate	1 1/2" concrete aggregate	Sand	Fill
Ft. Collins-Loveland	2.25	2.25	2.10	1.20
Greeley-Windsor	1.85	1.65	1.50	.70
Boulder-Longmont	3.25	2.95	3.75	1.00
Denver Metropolitan	3.55 2.85[2]	3.25 2.85[2]	1.25	1.10
Douglas County	N.A.	N.A.	N.A.	N.A.
Colorado Springs	2.40[2]	2.40[2]	2.25	1.00

N.A. = not available

[1] Dollars per short ton/week of March 11, 1974. Price is that charged F.O.B. pit by one or more of the largest operators in that market area.

[2] Crushed rock aggregate.

more expensive (Dunn, 1974). About 97 percent of all aggregate used in the United States is natural aggregate (Bronitsky, 1973) and, for most uses, substitution of other materials is not possible. In the Front Range Urban Corridor, lightweight aggregate currently costs two or three times as much as gravel. The amount of lightweight aggregate produced is limited by fuel availability, and the price certainly will increase in the same order as the increasing cost of the fuel used to expand the shale (personal commun., Ed Dehill, Idealite Company, Denver, Colorado). Lightweight aggregate, brick, and tile have specialized uses for which concrete cannot be interchanged.

CALCULATION OF RESERVES

By

HAROLD R. FITCH

Reserves are known existing quantities of gravel that can be extracted at a profit. To qualify as reserves, gravel deposits must contain a certain minimum percentage of potentially salable gravel, and they must be within economic haulage distance of a market area. We have made the simplifying assumption that the first requirement is satisfied if 20 percent of the material in the deposit falls within the size range of 2.0 to 64 millimetres (.079 to 2.5 inches). In a few areas of the Front Range Urban Corridor, deposits with such a relatively low gravel content are being utilized. Such deposits may become economic in other areas, as a result of scarcity of other supplies or changes in requirements.

Only those reserves that lie within areas classified as potentially urbanized by the year 2000 are considered in this report. These are termed "critical reserves." All such reserves are within economic haulage distance of their market areas, so the second requirement for reserves is satisfied. The amounts of gravel already lost as a result of percent urbanization have also been calculated.

Other factors that play less important roles in determining what constitutes a reserve are size distribution within the gravel fraction, availability of other gravel of higher quality, difficulties of extraction and beneficiation, availability of alternate materials (crushed rock, bloated aggregate, etc.), and so on. Effects of these factors can be determined only by detailed analysis of each producing area. They were not considered in reserve calculation, but will be mentioned later where they are known to apply to specific areas.

For the purpose of reserves calculation, gravel deposits were divided into resource blocks for which areal extent (A), thickness (T), density (D), and percentage of gravel (P) are assumed to be constant within given limits of error (confidence limits). Reserve tonnage (R) for the resource block is the product of these four factors:

$$R = A \times T \times D \times \frac{P}{100}$$

Areal extent of each resource block was measured with a planimeter and converted to square yards. Thicknesses were drawn mainly from well-log information. Deep excavations (mostly gravel pits) provided some information also. Although the base of the usual gravel-bearing deposit is an irregular surface, an average thickness, expressed in yards, was estimated for each resource block.

The average density of the gravel-bearing materials in each deposit was taken from laboratory determinations made by the Colorado Division of Highways, and was expressed as tons per cubic yard. Percentage of gravel for each deposit was determined from size distribution data from the Front Range Urban Corridor gravel resource maps (Trimble and Fitch, 1974a,b; Colton and Fitch, 1974), and expressed as average percent by weight. Useable gravel was assumed to be represented by the total material in the size range of 2.0 to 64 millimeters (.079 to 2.5 inches). The distribution of gravel within this size range, however, may be such that there is an excess of certain sizes for which there is no market. Or, certain sizes may not have sufficient resistance to abrasion to be used for some purposes.

Confidence limits, or limits of likely error, were determined for all estimates made. Where data were sufficient, Student's t distribution was used to calculate confidence limits about the mean. First, the estimated standard deviation, s, must be determined:

$$s = \sqrt{\frac{\sum_{i=1}^{n} (X-X)}{n-1}}$$

where

X_i = value of the parameter for each observation or sample

$\overline{X}$ = estimated mean of the parameter

n = number of observations or samples

The confidence limit, L, is then determined:

$$L = \frac{ts}{\sqrt{n}}$$

where t is from table of Student's t distribution for n-1 and a certainty level of .95. The likely value of the parameter can then be expressed as $\overline{X} \pm L$, meaning that the true value of the mean, with a 95 percent certainty, or 20-to-one odds, will fall between $\overline{X} - L$ and $\overline{X} + L$. The confidence limits for the estimate of the gravel reserve within a resource block can be found, then:

$$L_R = \sqrt{L_A^2 + L_T^2 + L_D^2 + L_P^2}$$

where L_R, L_A, L_T, L_D, and L_P are confidence limits for the gravel reserve, area, thickness, density, and percentage of gravel, respectively, in terms of percent of their respective means. Operator error in using the planimeter is statistically insignificant. Total tonnage and confidence limits for each market area are simply the sums of the means and confidence limits (in tons), respectively, of the contained resource blocks.

In many areas, data were not sufficient for rigorous calculation of means and confidence limits. In these areas, estimates of means were based on extrapolation from similar areas with better data coverage, and on general knowledge or assumptions, based on geologic mapping and field experience. The expected range of values, based on such knowledge and assumptions, was used for the estimate of confidence limits. Such confidence limits generally are two to five times as large as those for areas with good data coverage. Fortunately, the areas of greatest reserves, in terms of both quantity and quality, generally had good data coverage. Of all the parameters of the resource blocked estimates of thickness generally are the most uncertain. Confidence limits for areal extent could not be calculated directly. It was assumed that errors in areal extent do not exceed ten percent.

Analysis of gravel reserves by market area

Fort Collins-Loveland

Most of the gravel reserves in this area lie along the Cache la Poudre and Big Thompson Rivers. These deposits are very good gravel sources and are heavily utilized. The Little Thompson River deposits constitute about five percent of the critical reserves; they contain a low percentage of useable gravel, and their utilization probably will be precluded by availability of nearby sources of higher quality, such as the Big Thompson and St. Vrain deposits.

Greeley-Windsor

Over 55 percent of the critical reserves in this market area are in the Cache la Poudre and Big Thompson alluvial deposits, which are very good sources. About 40 percent lie along the South Platte River. The South Platte deposits are about 50 percent gravel, but this gravel contains an excess of small sizes that may not be marketable. Both the Cache la Poudre and South Platte deposits thicken greatly in the vicinity of the junction of the two streams, to an average thickness of 70 feet or more. Excessive depth below the water table may prevent use of the total reserve. The gravel deposits in the Eaton Draw area, which includes a thick terrace along the north bank of the Cache la Poudre north of Greeley, are highly variable in gravel content and thickness and have thick overburden, and presently do not compete to any great extent with the Cache la Poudre gravel. They constitute about four percent of the critical reserves. The remaining one percent is along the Little Thompson River and Coal Creek; both areas are poor sources of gravel.

Boulder-Longmont

Gravel deposits along Boulder, South Boulder, and St. Vrain Creeks account for 87 percent of the critical reserves in the Boulder-Longmont market area. These generally have high gravel contents, and thicknesses of about 15 feet. They are now utilized quite heavily. The remainder of the critical reserves are in alluvial deposits of Coal Creek and Lefthand Creek. They average less than 15 feet in thickness and have low gravel contents.

Denver metropolitan area

The best and most heavily utilized gravel source in the Denver area borders Clear Creek. However, much of the gravel has been mined out or covered by urban development. The deposits remaining constitute about 11 percent of the critical reserves for the area. The valley of Bear Creek is a good source of gravel, although the deposits, which account for another six percent of critical reserves, are more variable, thinner, and of somewhat lower quality than those of Clear Creek. Most of the critical reserves (76 percent) are in alluvial deposits of the South Platte River. These deposits may contain amounts of fine material exceeding economic limits, especially downstream from Denver, although total gravel content is around 50 percent in most places. The remaining seven percent of the critical reserves of the Denver area are along minor tributary streams such as Ralston Creek and Deer Creek. These deposits generally are small, thin, and of low quality, and cannot compete, except perhaps very locally, with other sources of gravel. Crushed rock from quarries along the mountain front presently is competitive with natural gravel for some purposes.

In addition to the critical reserves in the Denver metropolitan market area, large gravel reserves are present in two areas that are not classified as presently or potentially (to the year 2000) urbanized, but are within economic haulage distance of the market area. The first area is along the South Platte River to a distance of about three miles downstream from potentially urbanized areas north of Denver. This source adds 176,000,000 tons, or an additional amount equal to 34.7 percent of the critical reserves. The second area considered is that of the Chatfield Reservoir. Potential gravel reserves were calculated for the South Platte and Plum Creek gravels within the Chatfield State Recreation Area above normal pool level of the reservoir. Part of this area is in Douglas County, but is actually within the Denver market area. These reserves amount to 83,700,000 tons along the South Platte River and 25,200,000 tons along Plum Creek, for a total amount equal to 21.5 percent of the critical reserves for the Denver area.

Douglas County

All of the critical reserves of Douglas County are in deposits along Plum Creek and East Plum Creek. These deposits are fine-grained and do not contain enough coarse gravel for some purposes, particularly concrete aggregate. Their thickness is quite variable. Dawson arkose and crushed volcanic rock (ash-flow tuff which caps some of the buttes) are used locally in place of natural gravel.

Colorado Springs metropolitan area

Gravel deposits of the pediments (mesa tops) as well as alluvium of the streams, were included in reserves in the Colorado Springs area. The pediment deposits contain generally low quality gravel (pebbles are weathered and overburden may be thick) that generally is not suitable for use as concrete aggregate. However, they are important gravel sources because of a shortage of other suitable sources, and have been utilized extensively. Pediment deposits can be divided into two groups: those to the west of the major drainages (Monument Creek and Fountain Creek), and those to the east. The former are relatively coarse, and are the coarsest natural gravel sources in the area. They constitute about 15 percent of the critical reserves. Pediment deposits to the east of Monument and Fountain Creeks, accounting for 20 percent of critical reserves, generally are finer-grained, except for a few areas adjacent to Fountain Creek, and thus are limited in use.

The deposits along the present streams in the Colorado Springs market area are fine-grained. Along Monument Creek and Fountain Creek the deposits contain a small percentage of gravel over .5 inches in diameter, and these pebbles generally are unsound and poorly resistant to abrasion. These deposits contain about 52 percent of the critical reserves of the market area. Deposits in the Sand Creek area make up the remaining 13 percent of reserves. These deposits are very fine-grained, with very little gravel larger than .25 inches in diameter.

There is essentially no source of high-quality natural gravel in the Colorado Springs area, and crushed limestone has filled the need for concrete aggregate.

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