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Preliminary Report on Aggregate Use and Permitting Along the Colorado Front Range (Paper version)

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By David R. Wilburn[1] and William H. Langer[1]

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[1]U.S. Geological Survey, Denver, Colorado, 80225-0046

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ABSTRACT

Regional growth, transportation, and land use planning all will be affected by the ability of the aggregates industry to meet future demand for high quality aggregate resources. Increased environmental awareness, public opposition, and stricter zoning regulations have made it more difficult to obtain permits to develop new aggregate mines or expand existing operations in urban areas such as the Colorado Front Range. Local demand for aggregates in the short term is expected to continue at reasonably high levels due to the projected population growth and associated demand for infrastructure improvements to accommodate such growth.

Although the Colorado Front Range has an abundance of potential aggregate resources, recoverable resources are coming from greater distances as local resources are becoming inaccessible for extraction. Available resources are becoming more difficult to recover and more expensive to produce due to longer transportation distances, poorer quality of locally available sources, more involved permitting requirements, and the encroachment of other land uses on undeveloped potential resource.

The study indicates that the amount of aggregates being permitted has steadily decreased over time. The Denver metropolitan area has been producing more aggregates than it is permitting since 1991, and the Fort Collins-Greeley area is currently permitting about what it is producing. If this trend continues, aggregate operators may be forced to move to resource areas even farther away from local markets, resulting in even higher transportation costs. Increased costs for these aggregates would be passed along to the State or counties as higher construction bids, to the contractor as higher supply costs, and ultimately to the consumer in the form of higher taxes or user fees.

INTRODUCTION

Meeting 21st century aggregate demands on the Colorado Front Range (CFR) will be a challenge to local suppliers. Regional growth, transportation, and land use planning all will affect the ability of the industry to meet future demand for aggregate resources — high quality rock and sand and gravel. Where are our aggregate resources, how much is there, and how good are they?

Previous studies have addressed these questions, and have found that the CFR, in general, is blessed with an abundance of suitable quality aggregate resources. However, the aggregate resources in the CFR can only be extracted if the land where the resources exist has been permitted for mining. In the CFR, permitted resources make up only a small fraction of the total resource base. Increased environmental awareness, public opposition, and stricter zoning regulations make it difficult to obtain permits to develop new mines or expand existing operations. This study, therefore, addresses the question: "Are aggregate resources being permitted fast enough to meet the short and long term demand?"

This study investigates the supply and use of aggregates along the northern portion of the CFR, extending south from the Colorado-Wyoming border to just south of the Denver metropolitan area, a distance of about 180 kilometers. The area includes the counties of Adams, Arapahoe, Boulder, Denver, Douglas, Jefferson, Larimer, and Weld (fig. 1). Because truck transportation of aggregates over long distances is expensive, aggregate use is typically local, as long as local sources are available. Ideally, truck haulage of aggregates (the most common mode of transportation) from source to market seldom exceeds 56 kilometers (Socolow, 1995). Consequently, this portion of the CFR has been subdivided into two segments for this study: the Fort Collins-Greeley area and Denver metropolitan area. Each area is a population center and market area with a radius of about 56-kilometers.

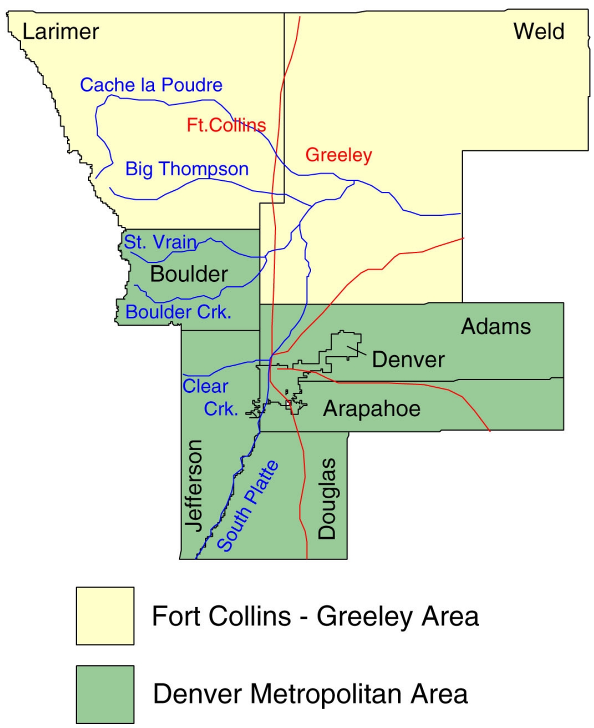

Figure 1. - Index map showing two segments of study area.

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TYPES OF AGGREGATE RESOURCES IN THE COLORADO FRONT RANGE

Sand and gravel

Lindsey (1997) described four general types of sand and gravel deposits in the Colorado Front Range (fig. 2). These four deposit types are: alluvial fans, high dissected terraces, terraces, and floodplains and low terraces. Floodplains and low terraces are the principal sources of aggregates that are recovered along the CFR. Sand and gravel deposits underlying the alluvial fans and high dissected terraces commonly are not used as specification aggregates because of inferior quality.

The surficial geologic units of the study area are mostly Quaternary in age (up to 2 million years old). During the Quaternary, some of the mountainous part of the study area was exposed to repeated glaciations. Glacial activity provided large amounts of sediment, as well as meltwater to transport the sediment to the streams along the CFR. Consequently, gravel in the CFR area is largely restricted to major streams with headwaters in the mountains. These streams include the South Platte River, Clear Creek, Boulder Creek, St. Vrain Creek, Big Thompson River, and the Cache la Poudre River. Much of the coarse sediment load was deposited near the mountain front. The amount and maximum size of coarse material decreases in a downstream direction. However, along the South Platte River this trend may be changed where high energy tributary streams provide an influx of coarse material to the deposits downstream from their confluence with the South Platte River. Streams that have their headwaters on the plains commonly lack coarse aggregates.

Crushed stone

Ideal quarry aggregates should be strong and resistant to rough handling and use under both wet and dry conditions or freeze/thaw cycles, and not chemically reactive with cement. Most crushed stone is quarried in the mountains in Jefferson, Boulder, and Larimer Counties, although a small amount is quarried from rock capping buttes in Douglas County.

The rocks in the mountains are mostly of metamorphic and igneous origin. Banded rocks called gneiss and micaceous rocks called schist originally were sedimentary or volcanic rocks that have been recrystallized by the heat and pressure of metamorphism. Ribbons of light colored, coarse crystalline rocks called pegmatite were injected as molten rock into cracks in the metamorphic rocks. Great masses of granite also intrude the metamorphic rocks. The physical properties and mineralogy of these rocks determine their suitability for use as aggregates. Many, but not all, of the gneisses, pegmatites, and granites make good crushed stone.

The rocks on the plains are mostly relatively soft shales, sandstones, and limestones of sedimentary origin. In places near Castle Rock, a volcanic rock called rhyolite overlies the sedimentary rocks and forms a capstone on the buttes. Of the rocks in the plains, rhyolite may be used as aggregates, although it may contain minerals that chemically react with cement. Some of the harder sandstone or limestone may also be used in some lower-specification applications.

RESOURCE AVAILABILITY

A number of studies have been undertaken to determine the location and distribution of aggregate resources in the CFR. Colton and Fitch (1974), Trimble and Fitch (1974), and Schwochow and others, (1974a and 1974b), all prepared maps delineating aggregate resources in the CFR, and it is, therefore, unlikely that a significant amount of new resources will be discovered in the CFR.

Aggregate resources have a very low ***unit value***. Much of their value comes from their location, thus they have a high ***place value***. A sand and gravel deposit located many miles

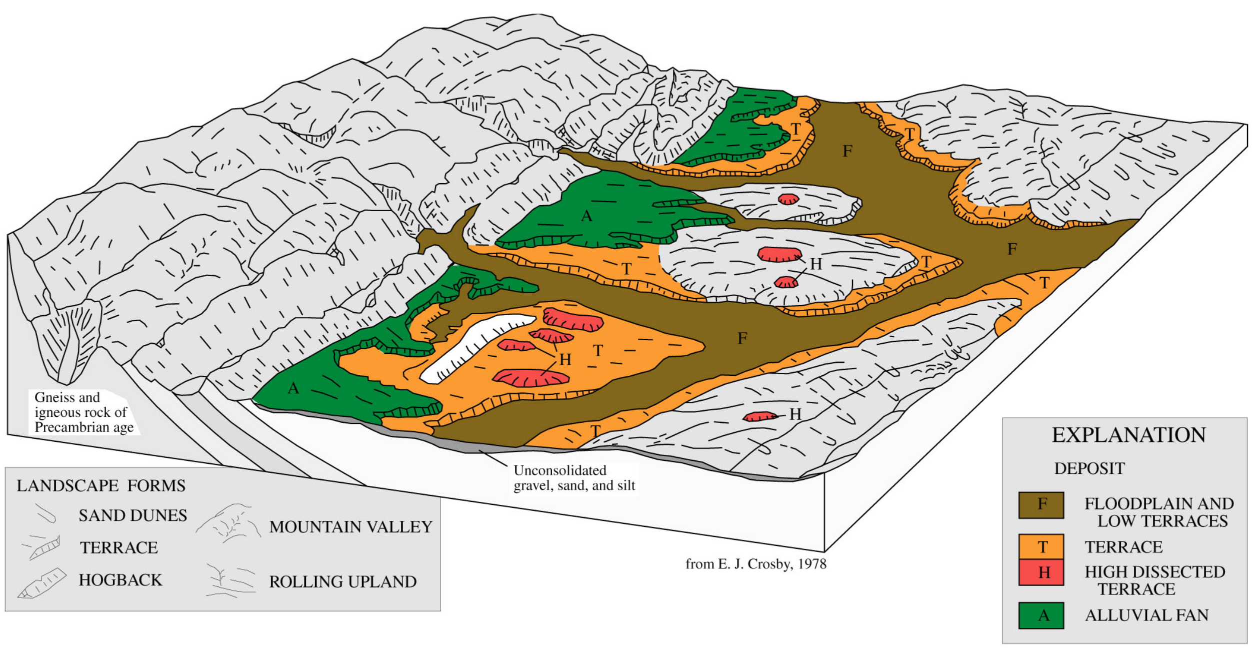

Figure 2. - Block diagram showing landforms of alluvial deposits in the Colorado Front Range study area.

from the market commonly has little or no economic value for use as aggregate. The place value of such a deposit may change over time, however. As local reserves are depleted or as a city (market area) grows outward, the once-distant resource may become the closest resource to the market area. Its place value may increase to the point where the resource becomes economic to mine.

Increased demand and technological advances both can upgrade resources into economic reserves. For example, as long as sand and gravel was being mined along Clear Creek, the sand and gravel resources along the South Platte River between Commerce City and Brighton were not developed. Now that sand and gravel mining along Clear Creek is limited, the resources along the South Platte River between Commerce City and Brighton are being mined. Similarly, the cost of preparing crushed stone limited its past production. Technological advances have now made crushed stone competitive with sand and gravel for use as aggregate.

Land use issues can decrease the availability of resources. Even where aggregate resources of suitable quality exist, competing land uses can make extraction of the resources uneconomical. For example, it is not presently cost effective to raze buildings in order to mine aggregate from under them. Reports by the Colorado Sand and Gravel Producers Association (1957), the U.S. Geological Survey (Soule and Fitch, 1974), and the U.S. Bureau of Mines (Sheridan, 1967), demonstrate that preemptive land use has eliminated more resources in the CFR than has depletion by mining.

PRODUCING AGGREGATES FOR USE

Aggregate producers have limited facilities for storing product, so stockpile changes are insignificant compared to annual production. Therefore, use of aggregate in the CFR is considered to be equal to production. Production figures reflecting mine shipments, sales, or marketable production (including use by producers) were reported by the U.S. Bureau of Mines (1951-1995) until 1996, by both the U.S. Bureau of Mines and U.S. Geological Survey (1996), and by the U.S. Geological Survey (1997) since then.

Aggregates are generally high density, low value materials, and long distance transportation costs can be prohibitive. Industry data suggest that, with noted exceptions (such as the importation of aggregates from Wyoming for Denver International Airport), most aggregates produced in Colorado are used locally, generally within a 56-kilometer radius of the source of production. Discussion with CFR producers has led the authors to conclude that, although much of the material is used within a localized area, some aggregate materials are transferred from county to county. For example, sand and gravel is shipped from Weld and Larimer counties to the Denver metro area, and crushed stone is shipped from Jefferson County to counties to the east that have no exposed bedrock that is suitable for crushing. This study assumes, therefore, that reported production figures provide a reasonable approximation of use for the entire study area, but that production in each of the two market areas does not necessarily equal use in that same area. It should also be noted that this study uses the term "***use***" rather than "***consumption***" to avoid the inference that aggregates are being destroyed when consumed.

Historical production data used in this report were compiled from the *Mineral Industry of Colorado* reports published annually by the U.S. Bureau of Mines and the U.S. Geological Survey in their Minerals Yearbook series (Bolen, 1998; Tepordei, 1998). Major operators are the primary source for these figures, and data are occasionally withheld to prevent release of company proprietary information. These figures also do not reflect the production from many smaller operators. Therefore, the use figures are conservative production values and are used only to monitor trends of general production cycles and provide an approximation of aggregates production activity.

HISTORY OF COLORADO AGGREGATE PRODUCTION

Aggregates production data from sand and gravel and crushed stone sources in Colorado are shown in figure 3. Data for crushed stone are shown in blue and sand and gravel are shown in yellow. Population data are shown by the red line. Figure 3 also shows time frames for major Colorado construction projects that used significant quantities of aggregates. CFR projects are in bold type. Construction project data were compiled from U.S. Bureau of Mines publications and *Rocky Mountain Construction*, a regional trade publication. Correlation of production and population with major construction activities can provide information useful in estimating future demand projections for aggregates.

The 1950s and 1960s reflected a period of increasing production for construction aggregates, primarily for large Federal Government projects. The Federal Aid Highway Act of 1953 and Highway Revenue Act of 1956 provided funding for accelerated highway construction in the United States. Much of the Interstate Highway System in Colorado was built over a 20-year period from 1953 to 1974, although the Glen Canyon segment of I-70 through the Rocky Mountains wasn't completed until 1990. The U.S. Bureau of Reclamation constructed several major water

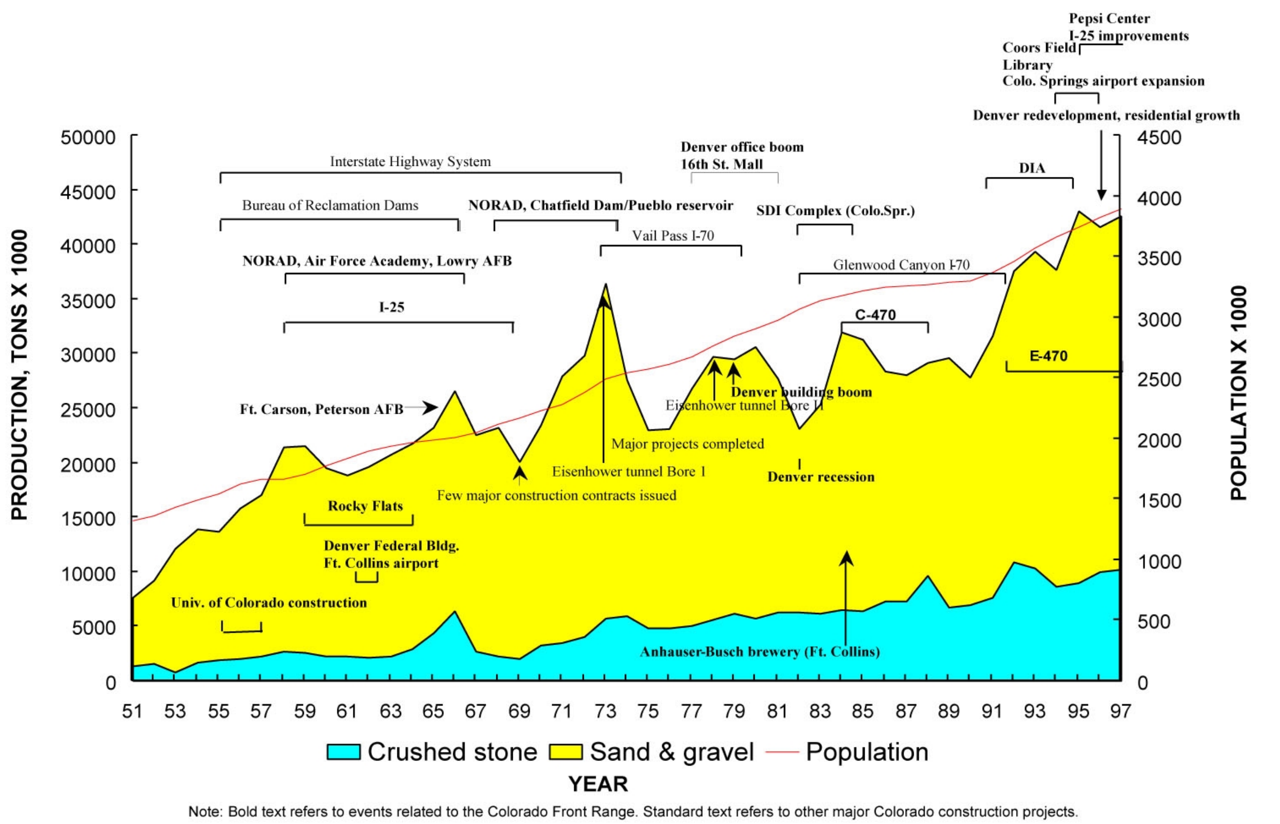

Figure 3. - Significant events affecting Colorado aggregates use, 1951 - 1997.

storage and flood control projects during this period, including the Dillon Reservoir and Cherry Creek Dam projects, which provide water for the Denver metropolitan area.

Cold war concerns led to increased military construction along the CFR. During the late 1950s and 1960s, construction of Fort Carson and Peterson Air Force Base (Colorado Springs), the NORAD facility (Colorado Springs), Lowry Air Force Base (Denver), and the Air Force Academy (Colorado Springs) all used large amounts of construction aggregates. Much of the infrastructure (roads, bridges, airports, and dams) in use today were conceived or constructed during this period.

Infrastructure built during the 1950s and 1960s supported population growth that occurred during the early 1970s. This growth stimulated non-Government construction, both residential and commercial. Large Government-mandated projects were less frequent, and reflected expansions (NORAD), completions of technically challenging projects (Eisenhower Tunnel, I-70 corridor), or selected high-priority projects (Chatfield and Bear Creek dams, and the Frying Pan-Arkansas water collection system, including the Turquoise and Pueblo Reservoirs). Major flooding occurred in the Denver area in 1965 resulting in the need for additional flood control, and subsequent urban growth along the Front Range produced a need for additional water storage capabilities.

The building boom in the late 1970s was followed by an economic recession period that began in the early 1980s and was marked by a decline in commercial construction in Colorado. Construction increased again during the mid-1980s, primarily as a result of Federal construction projects (I-70 Glenwood Canyon segment, defense-related military construction in Colorado Springs area), which proceeded in spite of the economic downturn during this period. In spite of this construction downturn, aggregates use remained strong as continued population growth sustained the need for housing and related infrastructure. Both sand and gravel and crushed stone production showed gradual growth during this period.

Commercial development projects during the early 1990s stimulated the construction industry as well as the growth of CFR communities. The largest construction project during this period was the Denver International Airport, where an estimated 6 million tons of concrete were required for the runways and aprons and an estimated 500,000 tons of concrete for associated buildings. Local aggregates production was not adequate to meet the entire local aggregates demand (Colorado use exceeded Colorado production), so aggregates were imported by rail approximately 180 kilometers from Wyoming. It should be noted that aggregates production from Wyoming has not been included in figure 2.

Other large commercial development projects that occurred in the early 1990s included redevelopment of the Lower Downtown (Lodo) area of Denver, the construction of Coors Field baseball stadium, a new Denver library, and expansion of the Colorado Springs airport.

Commercial construction in the Denver metropolitan area continued into the late 1990s, with development of the Pepsi Center sports complex, a new aquarium, improvements of I-25 through Denver, continued construction of E-470, and the commencement of construction on a new football stadium. Population growth in the Denver metropolitan area continued to foster residential construction. Housing permits for this region in 1998 were the highest since 1983. Douglas County, Colorado, was reported to be the fastest growing county in the United States in 1997 and number 2 in 1998, in terms of population growth.

Figures 4 and 5 suggest that the structure of aggregates production from both sand and gravel and crushed stone sources along the CFR has changed dramatically since the 1950s. In the 1950s and 1960s, approximately 38 percent of Colorado sand and gravel production and 30 percent of Colorado crushed stone production came from the 8-county CFR area. By the 1990s, the percentage of the Colorado aggregates produced along the Colorado Front Range had increased to approximately 54 percent of sand and gravel and 70 percent of crushed stone (excluding the Colorado Springs/ Pueblo area).

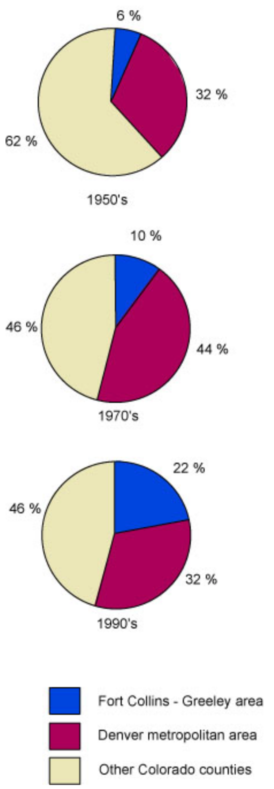

Figure 4. - Colorado sand and gravel production by region and years.

During the 1990s, the 6-county Denver metropolitan area produced about the same share of total Colorado sand and gravel as it did in the 1950s, but significantly less than in the 1970s. The Denver metropolitan area has increased its share of Colorado crushed stone production from just 3 percent in the 1960s to 56 percent in the 1990s as a result of the opening of several large quarries in the foothills west of Denver during the 1970s.

In 1997, aggregates produced in the Denver area were derived from sand and gravel sources (55 percent), crushed stone (31 percent) and recycled aggregates (14 percent). In contrast, aggregates in 1960 were derived principally from sand and gravel sources (99 percent).

The Fort Collins-Greeley area currently accounts for about 22 percent of all of Colorado's sand and gravel production, reflecting a shift in CFR sand and gravel production further north away from the Denver metropolitan area. Overall, crushed stone production in the Fort Collins-Greeley area has increased since the 1960's. However, as stone production from the Denver area quarries increased, the Fort Collins-Greeley area percentage of total State crushed stone production dropped from 27 percent during the 1960s to 14 percent during the 1990s.

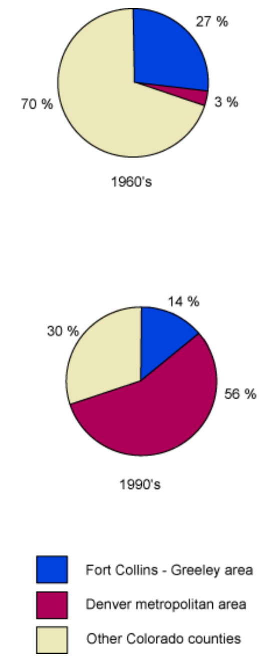

Figure 5. - Colorado crushed stone production by region and years.

HISTORY OF COLORADO FRONT RANGE AGGREGATE RESOURCE ACCESSIBILITY

Although the CFR has an abundance of aggregate resources, many of those resources are not accessible for extraction. Despite the dependency of growth on aggregates, urban expansion has worked to the detriment of its production. Sand and gravel operations commonly began from suitable deposits as close as possible to the consuming areas - the population centers – to minimize hauling costs. The population centers have built out and gradually encroached upon existing deposits, thus rendering some nearby resources inaccessible.

In 1957, the Colorado Sand and Gravel Producers Association produced an air photo map to call attention to the diminishing available sand and gravel resources in the Denver area. Ten years later, Sheridan (1967) of the U.S. Bureau of Mines predicted that restrictive zoning, lack of general public understanding of sand and gravel occurrence and mining operations, and conflicting land uses would cause a shortage of near-by, low-cost aggregates in Denver. James Cooley (1971) restated the problem at the 74th National Western Mining Conference.

During 1973, the Colorado legislature officially recognized the problem and passed House Bill 1529. That act declared that: 1) the State's commercial mineral deposits were essential to the State's economy, 2) the populous counties of the State faced a critical shortage of such deposits, and 3) such deposits should be extracted according to a rational plan, calculated to avoid waste and cause the least practical disruption to the ecology and quality of life of the citizens.

H.B. 1529 did not succeed at protecting existing aggregate resources in the Denver area. County action taken to protect citizens from mining worked against the need for mineral resources. The U.S. Department of Labor (1981) pointed out that the availability of aggregate resources in the Front Range continued to decline. They blamed the decline on zoning regulations driven by environmental and visual concerns, noncompliance with H.B. 1529, increased production, and reduced resource quality (i.e., inadequate grain size to meet specifications).

While encroachment continues to remove large amounts of aggregate resources from possible extraction, citizen opposition, zoning, and other land use restrictions may exact an even bigger toll on the availability of aggregate resources. Poulin and others (1994) concluded that permits and regulations restrict development or expansion of aggregate deposits in established areas more than actual resource availability.

Producers responded to the increasingly limited access to aggregate resources near Denver in a variety of ways (Schwochow, 1980). They developed lower-grade deposits farther away from the market area, they used rail to haul sand and gravel great distances to the market area, and they developed crushed stone quarries near the market.

During the 1980s, sand and gravel operators opened new facilities downstream (north) of Denver along the South Platte River. The sand and gravel deposits that had previously been mining farther upstream were about 50 percent gravel and 50 percent sand. The deposits mined north of Denver were about 20 percent gravel and 80 percent sand. Developing these deposits required more land area and more processing, generated more waste material, required a longer transport to the market, and resulted in a more costly product.

During 1975, Western Paving Construction Company began using unit trains to haul gravel over 70 km from its loading site at Lyons, Colorado, to its asphalt plant on Clear Creek at Pecos Street in Westminster, Colorado. Gravel currently is transported over 100 km to Denver by rail from a site near Carr, Colorado.

Operators also began replacing sand and gravel aggregates with quarried crushed stone. Actually, crushed stone has been produced in the CFR since the start of the 20th century (Schowchow, 1980). Four quarries mined crushed stone at South Table Mountain, with the first operation starting as early as 1905. These operations worked intermittently until the 1950s, and provided concrete and asphalt aggregates. One of these four quarries, the Wunderlich quarry, provided rip-rap for Cherry Creek Dam. The Rogers Brothers quarry, started in 1925, mined crushed stone from North Table Mountain and provided concrete aggregates for Harlan County dam near McCook, Nebraska (Argall, 1949). Two crushed stone quarries operated north of Golden at Ralston Reservoir. The Bertrand quarry, operating at mouth of Clear Creek Canyon in Golden, started in 1926, but closed in 1975 because of a threatening landslide.

Six crushed stone quarries operate in the CFR area today. Three quarries provide metamorphic gneiss. The Holloway quarry on Jackson Gulch south of Golden started in 1965, and produced rip-rap for Chatfield Dam. Lafarge Corporation now owns that quarry, which is referred to as the Specifications Aggregate Quarry. Two other quarries, now operated by Aggregate Industries, are the Deer Creek Canyon Quarry, started in 1970 in Deer Creek Canyon west of Chatfield Reservoir, and the Strain Gulch Quarry, started in 1971 and located south of Morrison. The Asphalt Paving Company mines latite from a quarry located north of Golden at Ralston Reservoir that was first permitted in 1975. The Andesite Rock Company mines andesite from a quarry located southwest of Lyons. Colorado Lien Inc. mines limestone from a quarry located in northern Larimer County that was permitted in 1978. Unit trains also haul crushed stone to the Denver market area. Meridian Aggregates Co. transports granite from a quarry located west of Cheyenne, Wyoming, to two distribution yards in the Denver area. Other quarries in the area mine limestone for use in the manufacture of cement or dimension stone for building and decorative use. Their production is not considered in the analysis of aggregate resources.

Today, crushed stone serves an important function beyond replacement for sand and gravel. Some specific applications require the use of crushed stone. Specifications for runway aggregates at Denver International Airport required crushed stone. Similarly, asphalt highways typically require crushed stone aggregates in order to achieve required strength parameters. Highways being constructed with money from the Federal government commonly must meet SUPERPAVE specifications, which in effect require the use of sand manufactured from the crushing of rock, and prohibit the use of natural sand.

FUTURE PRODUCTION OF AGGREGATES

There has been a steady increase in production of aggregates from both sand and gravel and crushed stone sources in Colorado since the 1950s. Figure 2 suggests that even if large construction projects were to cease, production of aggregates in the short term would continue at reasonably high levels due to population growth and the associated demand for infrastructure improvements to accommodate such growth. It is reasonable to expect that the Colorado portion of the Interstate Highway System (some portions are over 40 years old and designed for 1960s road use patterns) will require increased maintenance or replacement. Many of the early interstate highways are insufficient to meet the anticipated traffic volume projected for the new millennium. Road repair is a continual process Statewide.

The Transportation Equity Act for the 21st Century (TEA-21), which was signed into law in 1998, will govern Federal highway spending until 2003. Federal funding for Colorado transportation projects (including highway and mass transit projects) will gradually increase from about $260 million in 1998 to about $325 million in 2003. Under this 6-year reauthorization law, Federal funding for Colorado increased about 44 percent from the previous 6-year reauthorization law. As a result, Colorado and many other States have proposed numerous highway construction projects to make infrastructure improvements and accommodate regional growth. Major proposals include widening of I-25 from six to up to ten lanes and expansion of light rail service in portions of the Denver metropolitan area. Such projects would require significant amounts of construction aggregates from both new and recycled sources.

One method of forecasting aggregate production is to use sophisticated computer models that analyze such factors as the overall health of the local economy, proposed highway construction, housing development, and the commercial construction outlook. These models are difficult to construct and require input data that is not always readily available. A simpler approach was used, in which production of aggregates was estimated by reviewing historical production and use patterns, relating aggregates use to population growth trends, and then using these observations toselect reasonable production scenarios based upon per capita production. Per capita production rates estimated from historical data were compared to industry estimates reported in previous aggregates use studies.

Projections were made based upon population growth estimates for the counties under consideration provided by the Denver Regional Council of Governments (DRCOG, 1999a,b) and the State of Colorado. It is not the purpose of this study to provide precise forecasts of aggregate production, but rather to suggest a range of possibilities that accurately reflect past historical trends and current data. Production projections have been developed for each of the two regional population centers. In some cases, data for a particular area were not available, so were estimated. Where data includes proprietary information, plots are shown without units or proprietary data are combined with other data to avoid disclosure.

Historical production patterns for aggregates can provide an indication of future trends. Based upon historical data, there appears to be a high degree of correlation between population and aggregates production (fig. 3). Historical production figures were correlated with population projections for the CFR on a yearly basis to estimate the region's total aggregates production for the year 2000. Population projections were derived from estimates of the DRCOG and the State of Colorado. Population data (actual and projected) for the period 1990 to 2010 are shown in table 1.

Table 1. Population Data for the northern Colorado Front Range

County	1990	1995	2000(p)	2005(p)	2010(p)
Adams	265,038	299,755	337,694	379,470	426,034
Arapahoe	391,511	446,200	486,389	514,537	536,620
Boulder	225,339	256,737	281,428	303,331	324,662
Denver	467,610	496,171	511,487	522,127	535,291
Douglas	60,391	104,623	160,072	206,457	246,068
Jefferson	438,430	491,089	520,712	542,666	561,772
Denver Metro Total	**1,850,309**	**2,096,590**	**2,299,782**	**2,470,593**	**2,632,457**
Larimer	186,136	217,127	243,411	269,905	294,750
Weld	131,821	148,417	168,234	187,976	208,415
Larimer-Weld Total	**317,957**	**365,544**	**411,645**	**457,881**	**503,165**
8-County Total	**2,166,276**	**2,460,139**	**2,709,427**	**2,926,469**	**3,133,612**

Source: State of Colorado Division of Local Governments (1998), and Colorado General Assembly, Legislative Council, (1997) (p) - projected population estimate

Per capita (per person) production estimates were used in this study to provide an indication of present and future aggregates production. The weighted average per capita production of aggregates along the northern 8-county CFR has remained steady for the past 10 years at about 8.8 tons per capita for the period. Actual production was lowest during the recession year of 1990, and highest in 1995 as Denver International Airport was completed and associated developments were finalized. The weighted-average per capita aggregates production rate in the 6-county Denver area since 1960 was estimated to be 8.3 tons based on historical production data.

A linear regression analysis of the historical data, however, indicated that production of aggregates in the Denver area has increased over time. Aggregates production per capita reported for the 6-county Denver metropolitan area during the past 10 years is shown in figure 6. The data suggest that per capita production in the Denver area has increased from more than 5 tons per person in 1988 to over 7 tons per person in 1997. Since 1994, per capita production appears to have leveled off, or may have declined slightly as the second order polynomial equation suggests (fig. 6).

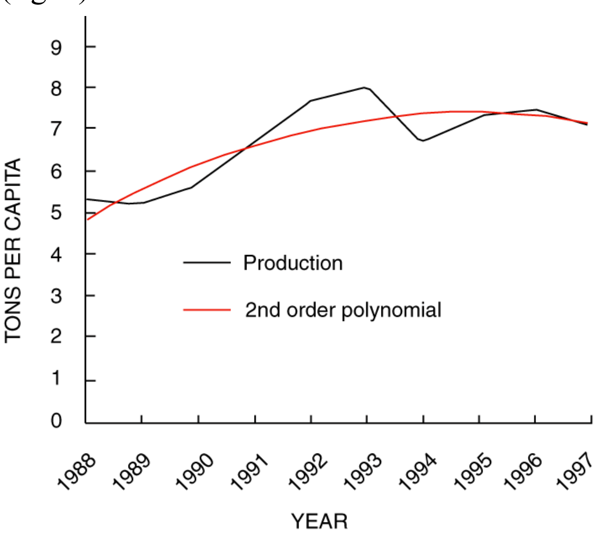

Figure 6. - Per capita production of aggregates, Denver metropolitan area, 1988 - 1997.

Regression analyses for the period 1988 to 1997 were performed in a similar manner for the Fort Collins area. When projected to the year 2000, a production figure of about 22 tons per capita was estimated for the Fort Collins area. This per capita figure reflects the high level of production (approximately 22 percent of all Colorado aggregates derived from sand and gravel were produced in the Fort Collins area) from a region with relatively low population density. Historical data suggest that this region is supplying an increased percentage of aggregates from sand and gravel sources to the Denver metropolitan area, as local supplies are restricted from development or as quality of the material in the Denver area diminishes.

One method for estimating aggregates production for the period 1998 through 2010 would be to assume that the projected regional per capita use rates for 2000 would reflect an approximation for regional production rates over the entire 13-year period. Figure 7 illustrates the cumulative aggregates production for each of the two reported CFR population centers using such an approach. Based upon these data, aggregates production for the period 1998 to 2000 would amount to over 80 million tons for the 1998 through 2000 period. CFR production could be distributed as 68 percent for the Denver area, and 32 percent for the Fort Collins area. Similarly, over 401 million tons of aggregates would be produced from the 8-county CFR region over the 1998 through 2010 period.

Aggregates production rates change with time, however, and the construction industry tends to be cyclical. Consequently, models that provide a range of aggregates production (8, 9.5, and 11 tons per capita of use) were developed. These values generally correspond with values used in unpublished proprietary industry studies, as well as historical data reported previously in this study. The lowest production level would most closely reflect recent historical production in the Denver metropolitan area when no large construction projects are considered ("low-growth scenario"). The mid-range production level might represent an "average" construction year (average-growth scenario). The Colorado Geological Survey has been using a use value of 10 tons/capita as a method of predicting aggregates production in their long-range analyses of aggregates needs (Nasser, 1987). Some local producers have used the 11 tons per capita level in their demand projections. This corresponds to the "high-growth scenario", reflecting continued construction and population growth or where multiple large projects are being constructed concurrently.

Figure 8 plots the projected annual production for the three rates assumed. For the "low-growth scenario", annual aggregates production is projected to vary from 21 million tons per year to 25 million tons per year. An average of approximately 23 million tons per year would be required based on this production scenario. Extrapolation to 2000 of previously reported production data for the 8 northern CFR counties over the past 37 years generates an aggregates production level that would fall within the range of this scenario.

The "average scenario" of 9.5 tons per capita production rate indicates a range of aggregates production from about 25 million tons per year to 30 million tons per year. An average of approximately 28 million tons would be produced based on this scenario. Linear extrapolation to 2000 of aggregates production data for the 8 northern CFR counties over the past 12 years generates an aggregates production level that would fall within the range of this scenario.

The "high-growth scenario" reflects annual aggregates production ranging from about 29 million tons to 35 million tons per year. An average of approximately 32 million tons would be produced based on this sce-

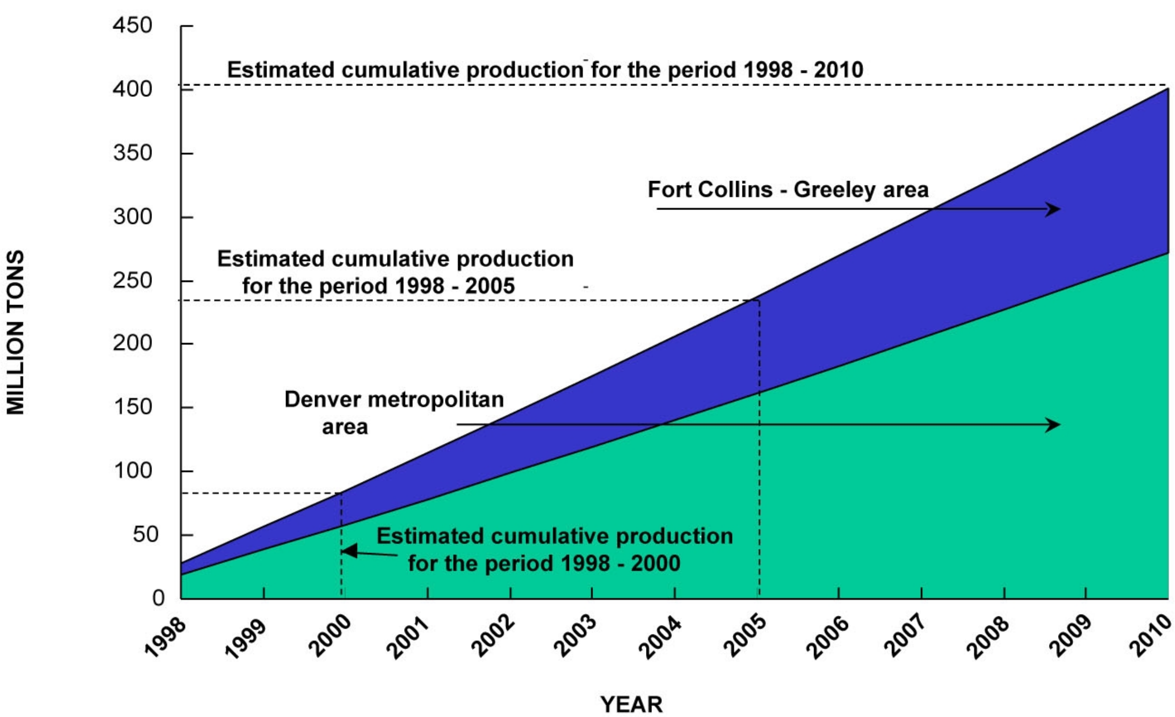

Figure 7. - Cumulative production of aggregates, 1998 - 2010, assuming regional use rates projected for 2000.

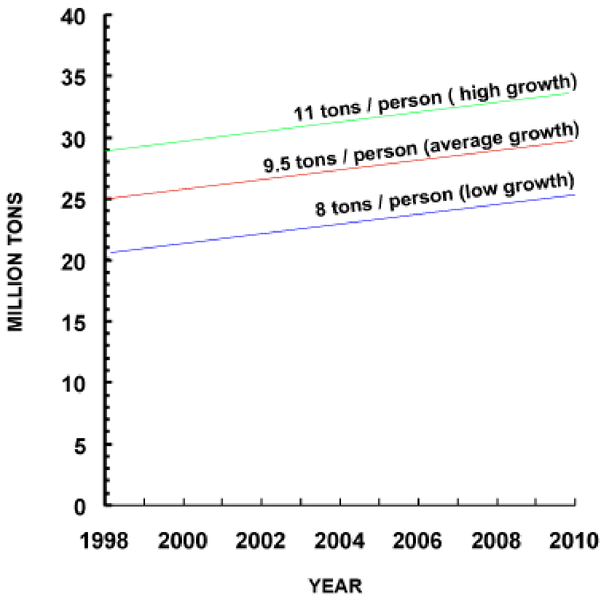

Figure 8. - Projected annual aggregates use, Colorado Front Range, 1998 - 2010.

nario. Estimates derived by combining projected production from the two population centers along the northern CFR generate an aggregates production level that would fall within the range of this scenario. This is to be expected, as recent production figures reflect the growth and high level of construction that has occurred along the CFR region.

Figure 9 plots the cumulative production for CFR aggregates indicated by the three scenarios. Based upon the "low-growth scenario" of 8 tons per capita, about 64 million tons of aggregates would be produced during the 1998 through 2000 period, slightly lower than the actual production from this 8-county area for the 1995 through 1997 period. Figure 9 suggests that 178 million tons would be produced through 2005, and about 300 million tons would be produced through 2010.

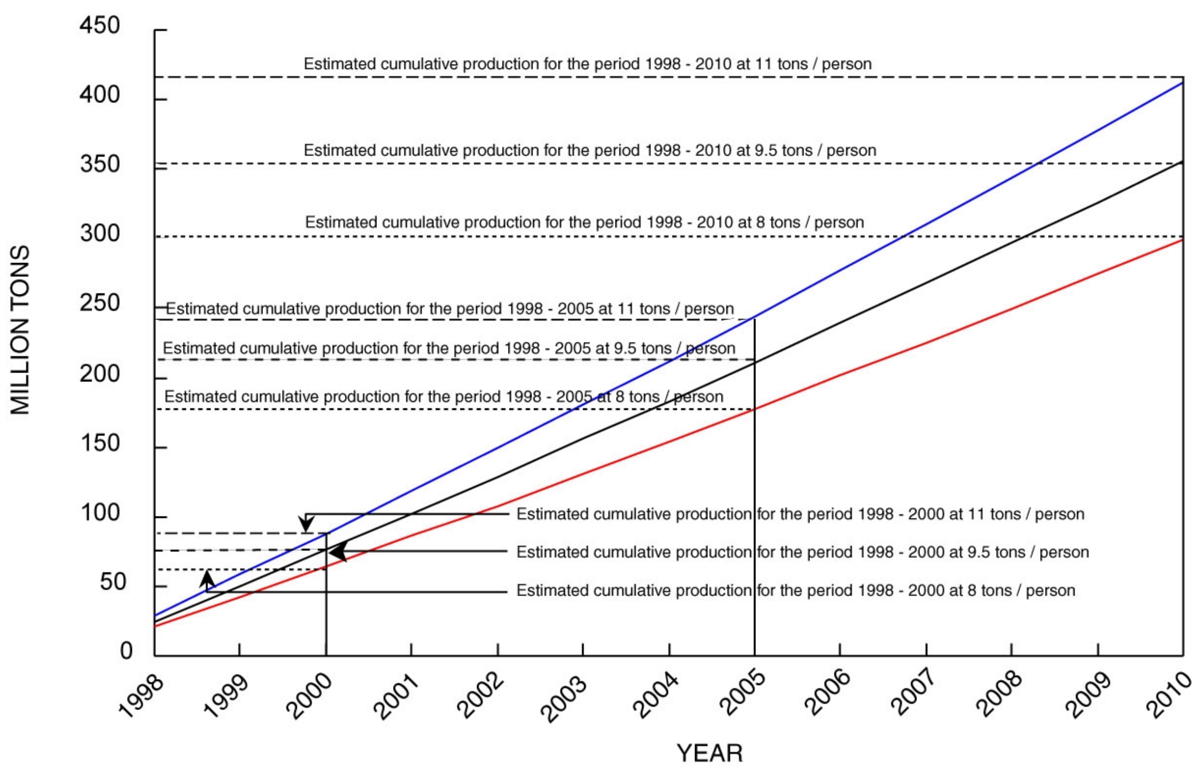

Figure 9. - Projected cumulative aggregates production, 8-county northern Colorado Front Range.

The "average scenario" of 9.5 tons per capita suggests that a cumulative 76 million tons of aggregates would be produced for the period 1998 through 2000, about 211 million tons would be produced through 2005, and about 356 million tons through 2010. Values generated from this scenario are comparable to those estimated using the regional production projections (figure 8) for the 2-year period 1998 to 2000, but become much lower as the time interval increases.

The "high-growth scenario" of 11 tons per capita suggests that a cumulative 88 million tons of aggregates would be produced for the period 1998 through 2000, approximately 244 million tons for the period 1998 through 2005, and about 412 million tons for the period 1998 through 2010. This scenario most closely corresponds to the production projections shown in figure 7, when the full time interval is considered.

FUTURE SUPPLY OF AGGREGATES IN THE COLORADO FRONT RANGE

The Colorado Division of Mines and Geology (CDM&G) maintains a database on information related to mining permits in Colorado including permits for sand and gravel and crushed stone mining. Among other things, the database includes information on type of commodity mined, location of the permitted property, total acres permitted, and the year the permit was issued.

The area permitted for aggregate extraction alone does not indicate the actual amount of permitted resources contained in the area, and many aggregate companies are reluctant or unwilling to discuss the particulars of their operations. However, methods were developed to estimate permitted sand and gravel and crushed stone by combining the permitting data with geologic information on potential aggregate resources compiled by the Colorado Geological Survey and the U.S. Geological Survey.

Sand and gravel

A two-step process was used to calculate permitted sand and gravel resources (fig. 10). The first step determined the tons of permitted sand and gravel by multiplying area permitted times deposit thickness, then multiplying that value by a constant to convert from volume to tons. The second step diminished those resources to account for permitted land that will be set aside due to setbacks, operational requirements, and environmental restrictions, and to account for loss of resources due to inadequate aggregates quality.

Tonnage calculations – CDM&G data were used to estimate the amount of area of sand and gravel resources that are being permitted over time. Information regarding sand and gravel thickness and quality was then used to calculate volumes of sand and gravel permitted. Thickness was estimated from existing maps and reports (Schwochow and others, 1974b; Trimble and Fitch, 1974, Colton and Fitch, 1974). The resulting volume (acre feet of sand and gravel) was converted to a unit of weight (metric tons) by multiplying by a constant (2,134) that takes into account the density of sand and gravel.

Adjustments for areas set aside – Commonly not all the land permitted will be mined for aggregates. Most permits or regulations require setbacks from certain other land uses such as residential developments, neighboring buildings, and setbacks from property lines, pipelines, transmission lines, roads, and streams. A requirement for a 100 ft. setback from property lines would eliminate about 20 percent of a 100-acre site. Today, in order to isolate operations from neighboring areas, some sites have buffer areas in excess of one half the permitted area.

The operation itself requires land for the construction of buffers, access roads, scale house, processing facilities, equipment stor-

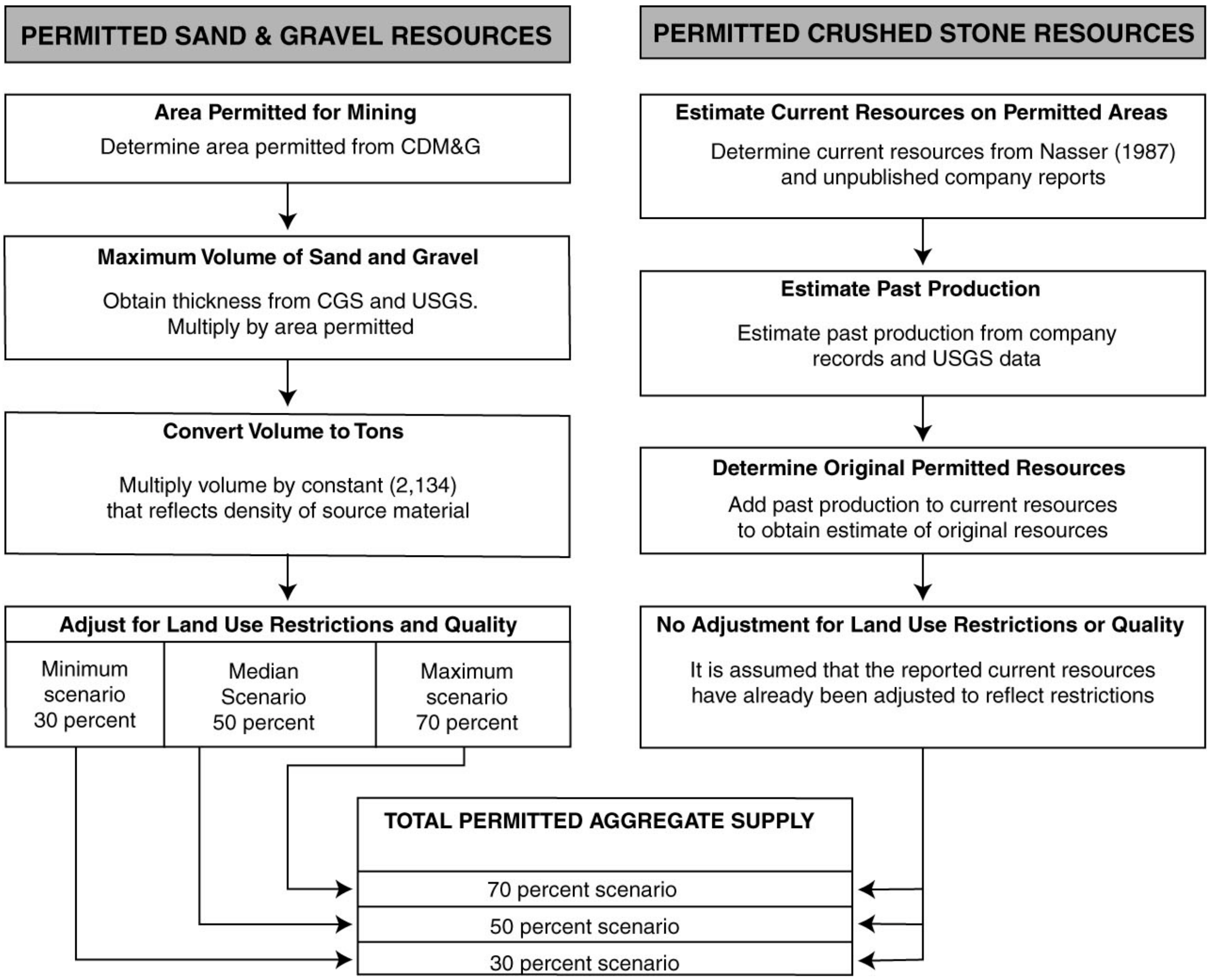

Figure 10. - Flow diagram showing method to determine permitted aggregate resources.

age, settling ponds, and stockpiles, which can occupy a significant part of the permitted mine site. Processing and load-out areas, for example, may be very small or may occupy more than 20 acres. Areas set aside for storing unused equipment may also require extensive space.

New more stringent environmental requirements further reduce the amount of permitted land that actually can be mined. Regulations may prohibit mining from areas of wetlands, floodplains, large stands of trees, and specific wildlife habitat such as those that contain rare or endangered species. During the 1970s, many companies avoided excess fees by permitting only the land to be used for the mining process. Today, some companies permit extensive areas to avoid having to repeat the permit process. For example, a company may own or lease an entire section (640 acres) of land, only some of which is underlain with aggregate. Nevertheless, they may permit the entire section for mining.

Adjustments for material of unusable quality– In those permitted areas where aggregates can be mined, some of the underlying deposits will not meet the quality requirements for use as aggregates. Sand and gravel deposits along the Front Range commonly are overlaid by a layer of silt and clay (overburden). Although the stripping ratio of overburden to gravel may be as low as 1:9, (the overburden may comprise 10 percent of a deposit), the Colorado Geological Survey (Schowchow and others, 1974a) considered deposits under floodplains and low terraces to be of commercial grade if the maximum stripping ratio of overburden to gravel is 1:3 (the overburden may comprise up to 25 percent of a deposit). They considered deposits under high terraces and upland deposits to be of commercial grade if the maximum stripping ratio of overburden to gravel is 1:1 (the overburden may comprise up to 50 percent of a deposit). In addition, sand and gravel may contain layers of silt and clay within the deposit (interburden), and undesirable fine material or other deleterious (poor quality) materials may be dispersed throughout the deposit.

In summary, it is reasonable to expect from 20 percent (i.e. 100 foot setbacks in a 100 acre site is about 20 percent of the area) to 50 percent (estimated as a reasonable maximum by authors) of the permitted area to be unavailable for aggregate extraction. It also is reasonable to expect from 10 (minimum stripping ratio) to 40 percent (estimated as a reasonable maximum by authors) of the permitted sand and gravel resources to be unsuitable for use as aggregates.

The total permitted sand and gravel resources can be estimated as follows:

a) total permitted area - % area set aside = % available

b) % available – (% available X % unusable) = % total permitted area available and useable

The total permitted area of available and useable sand and gravel will range from a best case of about 70 percent to a worst case of about 30 percent of the volume within the permitted area. The best case scenario (20 % set aside, 10 % unusable) is:

a) 100 –20 = 80 %

b) 80 % - (.1 X 80) = 72 % total permitted area available and useable

The worst case scenario (50% set aside, 40 % unusable) is:

a) 100 –50 = 50 %

b) 50 % - (.4 X 50%) = 30 % total permitted area available and useable

The authors believe that 30% useable sand and gravel tends to reflect current conditions in the study area, and that 70% useable sand and gravel tends to reflect conditions in the study area during the 1970s. A 50% useable sand and gravel level represents an average or intermediate level.

Crushed stone

Estimating resources of crushed stone is problematic and requires a different approach (fig. 10) than that used for estimating sand and gravel. Only seven quarries are currently producing crushed stone in the CFR study area. The quarries were permitted in such a manner that disclosing the crushed stone resources and the years that those resources were permitted would make it possible to calculate resources for individual operations. To avoid disclosing proprietary data, generalized resource data from several sources [Nasser (1987), proprietary data on resource estimates from a number of aggregates companies' unpublished reports, and proprietary production rates] were used. Back calculating allowed the estimation of original resources at the time of permitting. It was not necessary to diminish the tonnage of crushed stone to account for unmined land or poor quality because the data already accounted for those factors.

Recycling

Even as production of aggregates from natural sources (sand and gravel, crushed stone) has increased, production of aggregates from recycled sources has also increased, particularly in large urban areas such as Denver. Estimated production of recycled aggregates in the 6-county Denver metropolitan area grew from about 1.2 million tons in 1997 to 2.5 million tons in 1998, with a projected 1999 production of about 4 million tons. Increasingly, large construction projects include the recycling of cement and asphaltic concrete in redevelopment plans. Consequently, redevelopment of Lowry Air Force Base, Stapleton Airport, Cinderella City Mall, Northglenn Mall, and road construction all around the Denver area increased both demand and supply of aggregates since 1996. Redevelopment of the former Stapleton Airport in Denver will generate a total of 6 million tons of recycled concrete (Carder, 1999), from demolition of runways and terminal buildings. Recycled material could supply over 15 percent of projected demand for aggregates by 2000, if historical production trends above hold true. Not all construction materials suitable for recycling as aggregates, however, meet the quality specifications for construction aggregates. Consequently, there is not a total substitution between natural aggregates and recycled aggregates in all applications.

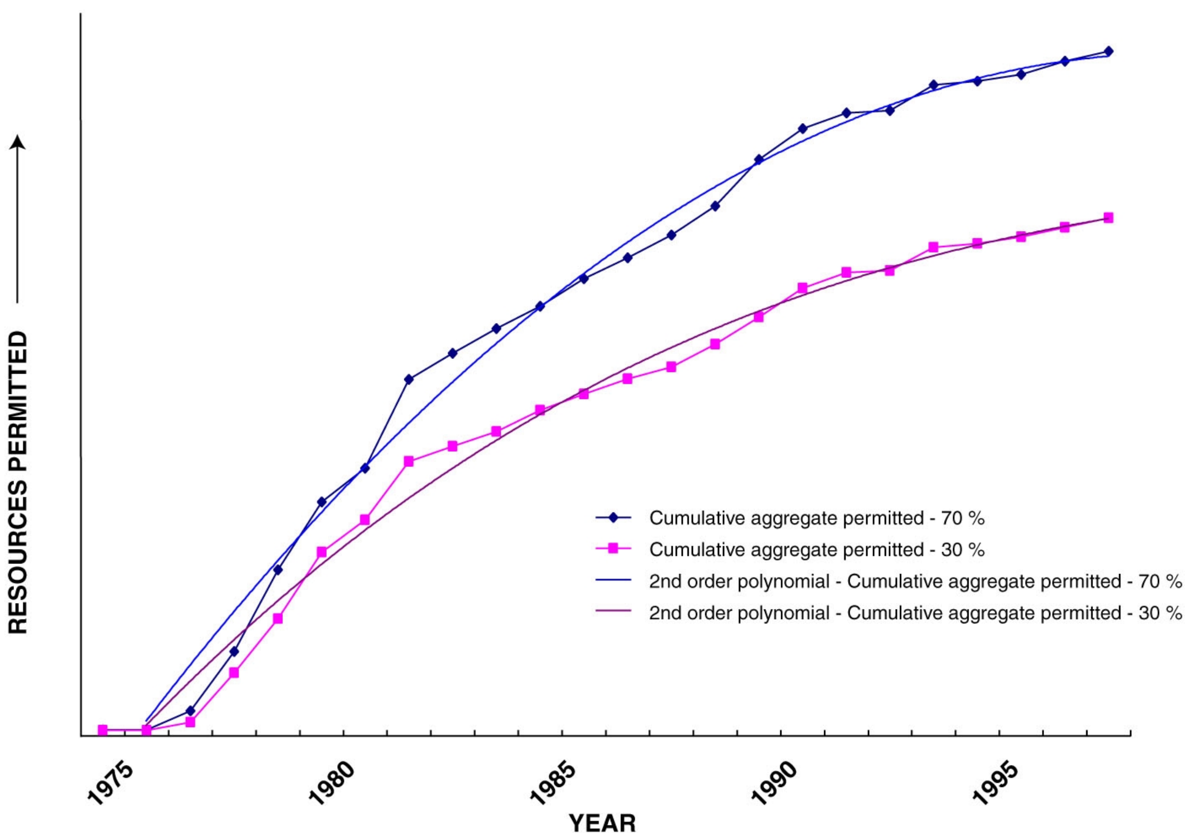

Figure 11. - Cumulative aggregate permitted. Vertical scale is relative.

DISCUSSION

Three scenarios for sand and gravel in the CFR area establish a range that brackets the estimated rate that aggregate resources are being permitted. The scenarios are based on 70 percent, 50 percent, or 30 percent recovery of the sand and gravel resources, and 100 percent recovery of the crushed stone resources. Discussions in this report refer to the 50 percent scenario, except as noted.

Figures showing permitting of aggregate resources (figs. 11 and 14) are based in large part on proprietary data. Therefore, although the graphs were created using calculated values, the graphs are dimensionless and show only relative values.

Figure 11 plots the cumulative aggregate resources permitted by year at the 70 percent and 30 percent rates, for the 8-county study area. The curves were smoothed using a 2^{nd} order polynomial trend analysis. By using cumulative figures, the slope of the line directly reflects the rate of permitting; the steeper the slope, the faster the rate of permitting. A horizontal line would mean no new material is being permitted. The line can never have a negative slope because the line portrays cumulative values.

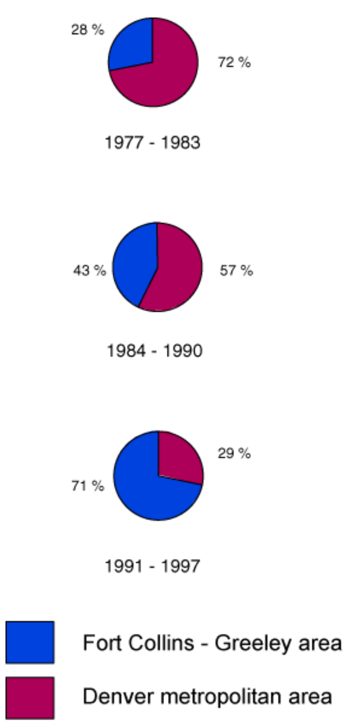

Figure 12. - Aggregate permitted each 7-year period, by region.

The actual rate of permitting resources probably lies somewhere between the 70 percent and 30 percent curves, and probably is moving away from the 70 percent value towards the 30 percent value due to environmental, regulation, and quality issues. Under either scenario, figure 11 demonstrates that the rate that aggregates have been permitted in the CFR has been steadily decreasing since 1974.

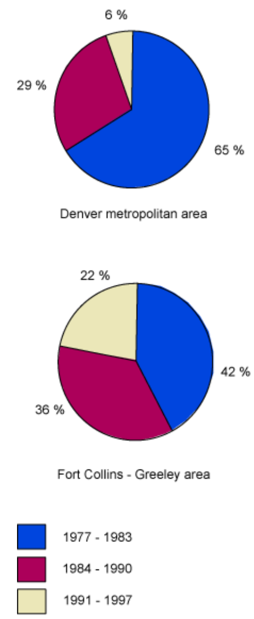

Figure 13. - Aggregate permitted in each region, by 7-year period.

To identify permitting trends over time, the permitting of aggregate resources was divided into three 7-year time periods. During the period from 1977-83, about 72 percent of the aggregates permitted in the total study area was in the Denver metro area. The percentage of aggregates permitted in the Denver metro area decreased to about 57 percent and 29 percent during the periods 1984-90 and 1991-97, respectively (fig. 12).

In both the Denver metropolitan area and the Fort Collins-Greeley area the amount of aggregates permitted has steadily decreased over time. In the Denver metropolitan area, about 65 percent of the aggregates permitted during the entire 21-year study period was permitted during the period 1977-83 (fig. 13). About 29 percent was permitted during the period 1984-90, and only 6 percent during the period 1991-97. A similar trend occurred in the Fort Collins-Greeley area, with values of about 42 percent, 36 percent, and 22 percent for the three time periods.

Figure 14 shows the relative percentages of all aggregates permitted in the study area by time period. The Fort Collins-

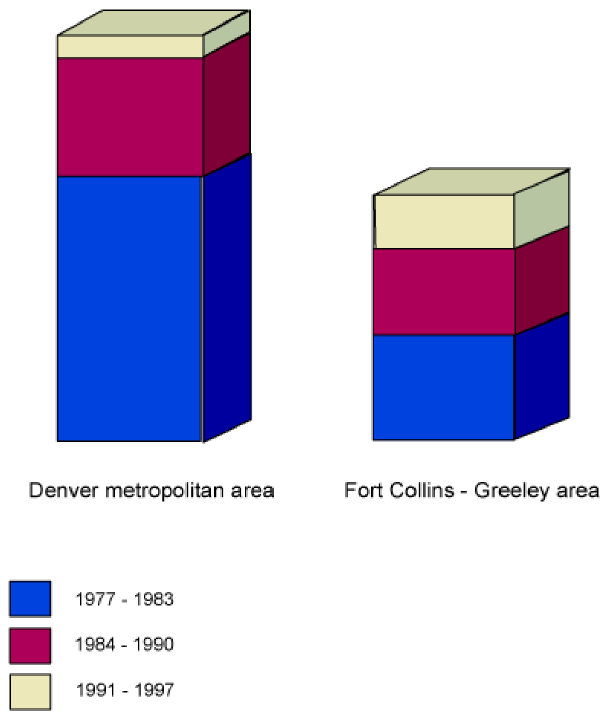

Figure 14. - Relative amount of aggregate permitted in 2 regions, by 7-year period.

Greeley area permitted about the same amount of aggregates as the Denver metro area during 1984-1990 period, and permitted most of the aggregates for the 1991-97 period.

To continuously meet projected production, the amount of aggregates permitted must, on the average, equal or exceed the amount produced. Furthermore, because aggregates production generally relates to population, the per capita amount of aggregates permitted must equal or exceed the per capita amount of aggregates produced. Figure 15 plots:

(aggregates permitted / population) – (aggregates produced / population)

From one year to the next, the amount of aggregates permitted can vary greatly. To account for these irregularities, the curves showing aggregate permitted have been smoothed by using a five-year moving average.

Aggregate producers started to move away from the Denver metro area during the

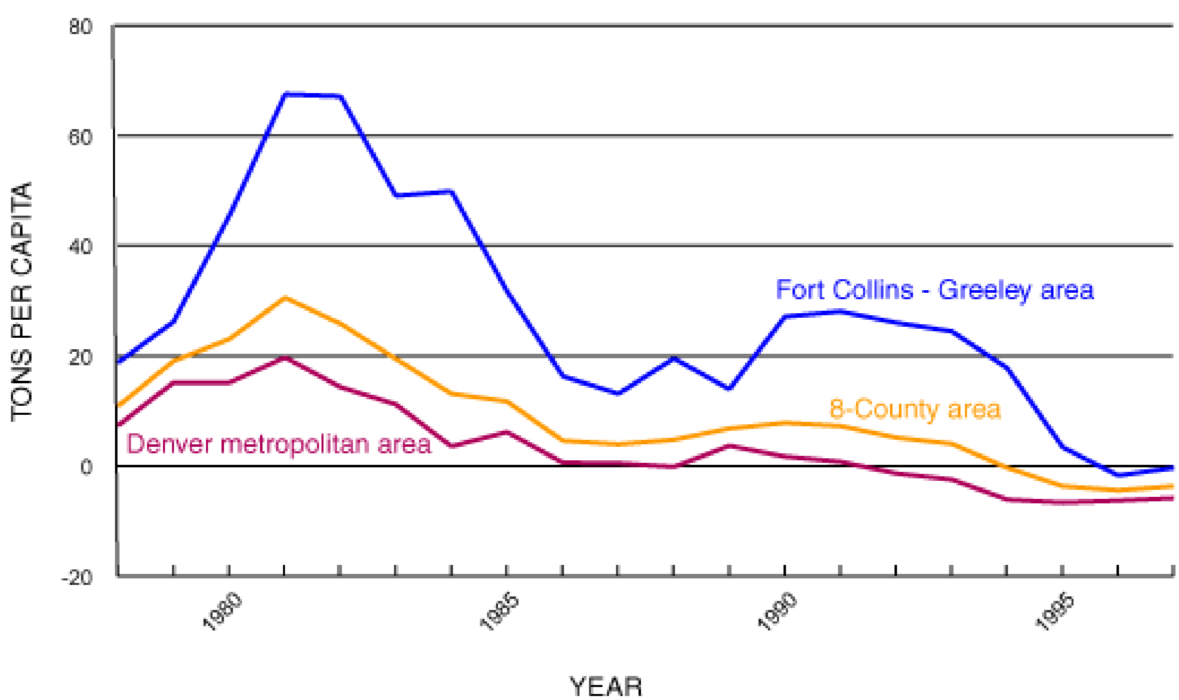

Figure 15. - Graph showing per capita aggregate permited minus per capita aggregate produced. Plots are smoothed using a 5-year moving average.

late 1970s to mine sand and gravel from the St. Vrain River valley to the north. Starting in 1979, the per capita permitting rate for the Fort Collins-Greeley area grew dramatically in comparison with the Denver metro area. Figure 15 illustrates that the Denver metro area has produced more aggregates than it permitted since 1992. The Fort Collins-Greeley area currently is permitting about what it is producing. The entire study area has been permitting less than it produces since 1994. In general, when the lines on fig. 15 cross the zero line (horizontal axis), more aggregate is being produced than permitted. This may signal potential problems regarding future aggregates availability.

SUMMARY

There has been a steady increase in production of aggregates from both sand and gravel and crushed stone in Colorado since the 1950s. In the 1950s and 1960s, approximately 38 percent of Colorado sand and gravel production and 30 percent of Colorado crushed stone production came from the 8-county CFR area. By the 1990s, the percentage of the aggregates produced along the northern Colorado Front Range had increased to approximately 54 percent of sand and gravel and 70 percent of crushed stone.

The structure of aggregates production from both sand and gravel and crushed stone sources along the CFR has changed dramatically since the 1950s. In 1960, production of aggregates in the Denver area was principally from sand and gravel sources (99 percent). In 1997, estimated aggregate production of sand and gravel sources was 55 percent, crushed stone was 31 percent, and recycled aggregates was 14 percent.

There has been a shift in CFR sand and gravel production further north away from the Denver metropolitan area. The Fort Collins area currently accounts for about 22 percent of all of Colorado's sand and gravel production. This overshadows a drop in crushed stone production from the Fort Collins area because about 75 percent of aggregates produced in Colorado is from sand and gravel deposits.

The rate of permitting of aggregate resources has dropped dramatically since it peaked during the late 1970s and early 1980s, when the granting of permits for several large crushed stone operations introduced a large amount of newly permitted resources into the CFR area. Existing resources are currently being used faster than new resources are being permitted.

CONCLUSIONS

The steady increase in aggregates production and use that has occurred since the 1950s is expected to continue. The data suggest that even if large construction projects were to cease, demand for aggregates in the short term would continue at reasonably high levels due to projected population growth and associated demand for infrastructure improvements to accommodate such growth.

Although the CFR has an abundance of aggregate resources, recoverable resources are coming from greater distances as local resources are becoming inaccessible for extraction. Available resources are becoming more difficult to recover and more expensive to produce, due to longer transportation distances, poorer quality of locally available sources, more involved permitting requirements, and the encroachment of other land uses on the potential resource.

Up until the mid-1970s, the majority of the aggregate within the Denver metropolitan area was produced from sand and gravel. During the mid-1970s, several crushed stone quarries began operating in the Denver metropolitan area. The increase in demand for aggregate in the Denver metropolitan area during this period was met largely from these new stone quarries. During the 1980s changing conditions caused the aggregate industry to start import sand and gravel to the Denver metropolitan area from the Fort Collins – Greeley area to meet aggregate needs of the Denver metropolitan area. Many of the remaining sand and gravel deposits in the Denver metropolitan area were excluded from development because of conflicting land use, poor quality, and citizen opposition. No new crushed stone operations had been permitted, and existing operations are operating at or near capacity.

The study indicates that the amount of aggregates being permitted has steadily decreased over time. The Denver metropolitan area has been producing more aggregates than it is permitting since 1992, and the Fort Collins-Greeley area is currently permitting about what it is producing. If this trend continues, aggregates operators may be forced to move to resource areas even farther away from local markets, resulting in even higher transportation costs. Increased costs for these aggregates would be passed along to the State or counties as higher construction bids, to the contractor as higher supply costs, and ultimately to the consumer in the form of higher taxes or user fees.

Today the Denver metropolitan area and the Fort Collins-Greeley are becoming one integrated production – use area for aggregates. Average transportation distances tend to exceed the 56-kilometer rule-of thumb because of the large size of this 8-county area. This has led to increased costs for aggregate, at the point of use.

As growth continues and more road and building construction projects are proposed, it is essential that developers, contractors, and governmental officials consider where future aggregates supply will come from to support such projects. This study suggests that while permitted resources are sufficient for the short term, the rate of permitting may not be sufficient in the future if strong demand for aggregates continue. Longer haul distances and higher costs could occur unless policy makers choose to enforce H.B. 1529, producers apply for increased permit areas, planners approve such permits, or alternatives such as recycling increase.

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