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ABSTRACT

This is the first study in the U.S. of wastewater disposal costs in mountain areas. The purpose is to improve efficiency in water quality management. Model wastewater disposal systems are analyzed. Engineering-economic cost methods are employed. Investment costs are 30 to 50 percent higher than in other areas. Physical conditions associated with elevation explain most of the difference in costs. Temperatures, soil permeability, topography, water quality and labor productivity are among the important physical conditions related to elevation. Economic conditions include higher land values, interest on investment, peak loads, growth rates and septic tank installation costs. The results contribute to decisions concerning efficient land use. Minimum and maximum levels of land subdivision are shown for typical environmental conditions. Under severe physical restrictions, wastewater transmission costs are prohibitively high. Where septic tanks result in water pollution, development should be disallowed. Under other physical conditions, residential development may be encouraged up to optimum community size of about 12,800 people. Optimum size is much smaller than in other areas of the U.S. because transmission costs rise in narrow mountain valleys. Land subdivision which would increase population beyond the optimum level would increase costs per capita and may result in decisions to limit growth.

CONTENTS

APPENDICES

Appendix A

Appendix B

SUMMARY

The purpose of this study is to aid decision makers in water quality management to improve wastewater disposal efficiency in mountain areas. Model wastewater disposal systems are analyzed to show the effect of physical and economic conditions associated with elevation on wastewater disposal costs. Engineering-economic cost methods are employed.

Mountain elevation is an important determinant of construction costs. At 6,000 feet, investment in sewer lines increases 10 percent. At 8,000 feet, investment in treatment plants increases by an average of 40 percent and investment in sewer lines by 30 percent. At 10,000 feet, investment in treatment plants increases by 50 percent, and investment in sewer lines by 40 percent.

Investment amounts to about $5 million for a sanitation district with a capacity of 1 million gallons per day serving a design population of 10,000 people located at 8,000 feet elevation. Investment is about $19 million for a consolidated sanitation district with a capacity of 5 million gallons per day serving a design population of 50,000 people at the same elevation.

A treatment plant with capacity of 1 million gallons per day located at 8,000 feet elevation has average costs of $21.63 per capita compared to $17.55 for plants in other areas of the U.S. or 23 percent more. Higher elevations than 8,000 feet have only slightly higher costs. Costs at 10,000 feet are only about $0.77 per capita higher than at 8,000 feet.

Collection line costs at 8,000 feet average $24.09 per capita, 30 percent more than for collection lines in other areas of the U.S. In this comparison, density is held constant at 4 persons per acre. Costs at 10,000 feet are about $1.83 per capita higher than at 8,000 feet.

Temperature is the most important physical condition affecting wastewater treatment costs in mountain areas. It accounts for fully 70 percent of the increased costs of constructing wastewater treatment plants. The primary reason

is the added cost of enclosing the entire treatment facility in a weather tight building, to allow incoming sewage to be maintained at a temperature of at least 45 degrees F, the minimum temperature necessary for the treatment process to function properly.

The only types of wastewater treatment plants suitable for mountain areas are the more expensive activated sludge and package plant systems. Both systems can be enclosed and heated to temperatures necessary for adequate sewage treatment. Trickling filter and stabilization pond treatment systems are not suitable at elevations over 7,000 feet where temperatures tend to be colder than required for efficient operation. Stabilization ponds may be used below 7,000 feet in small mountain communities.

Water quality sufficient to support game fish increases substantially at elevation of 8,000 feet and above where the lower air pressure results in less natural dissolved oxygen recharge in streams and lakes. An elevation of 8,000 feet requires seven to eight parts per million dissolved oxygen compared to four parts per million at sea level.

Costs will increase as sanitation districts in mountain areas install additional tertiary wastewater treatment facilities to meet the higher fish and wildlife standards. Tertiary treatment refers to several processes additional to the usual secondary treatment level. They remove toxic nutrients such as ammonia and phosphate which accelerate eutrophication of streams and lakes, reducing the dissolved oxygen available for fish life. Ammonia removal increases secondary treatment costs by about 25 percent or $5.41 per capita.

Soil permeability is the most important variable affecting the costs of sewer lines. It accounts for about half of the increase in their costs in mountain areas. Installing sewer lines through bedrock increases costs by about 150 percent, weathered granite 50 percent, and bouldery glacial material 25 percent.

Steeply sloping topography affects wastewater collection costs in mountain areas. Locating sewer lines horizontal to a slope of 20 degress or more may double collection costs as the line can serve only those dwellings that are located above it.

Economic conditions associated with elevation explain a significant amount of the difference in wastewater disposal costs in mountain areas. Land values are generally higher in recreation areas averaging $10,000 per acre compared to $3,000 per acre in other areas. However, the amount of land required for enclosed activated sludge treatment plants is not large, so the effect of land prices on wastewater treatment costs is small.

Interest on capital investment in wastewater systems averages about 15 to 36 percent higher in mountain areas of Colorado than in other areas. Average cost of capital in mountain areas was calculated as 7.5 percent in 1975, or 1-2 percentage points higher than for other areas, as most sanitation district bonds are medium grade in mountain communities with a single economic base and limited security.

Labor productivity declines at elevations of 8,000 feet and above, with less oxygen available to the brain and muscles, it takes half again as much time or as many men to perform the same work as at sea level.

Private residential installation of wastewater disposal systems such as the septic tank and leach field cost approximately twice as much in mountain areas of Colorado as in other areas owing to the lower percolation associated with rocky soils. Investment averages $1,870 and average costs $44 per capita annually.

Plant size is an important determinant of cost. Small treatment plants (one-half million gallons per day) have average costs of $28.06 per capita compared to $12.37 for plants with capacity of 5 million gallons. Larger plants have somewhat lower costs. Costs of a 10 million gallon plant are about $2.45 per capita lower than a 5 million gallon plant.

These costs are calculated for design population levels and are lower than actual costs of operating plants. In practice, disposal systems rarely operate at 100 percent of design capacity because that would require zero population growth. Population growth affects the rate of utilization of wastewater disposal systems and costs. A 3 percent annual growth in population increases average costs by 34.4 percent. Ten percent growth increases costs by 159.4 percent.

Plant utilization is an even more important determinant of costs than plant size. For example, the average costs of plants designed to treat 1 million gallons per day are about $32.85 per capita more when operated at 25 percent of capacity (one-quarter million gallons) than at 100 percent of capacity.

Peak load costs are substantially higher in mountain areas of Colorado than in other areas. Wastewater flows are more variable in seasonal resort areas. The peak to average flow ratio ranges from 2.3 to 12.6 compared to 1.68 in other areas. Peak load increases costs by $11.52 to $68.10 per capita compared to $8.40 in other areas.

Ths social costs of wastewater treatment are higher than the costs to sanitation districts with Environmental Protection Agency grants. When capital costs of investment in a 1 million gallon per day treatment plant are reduced by 75 percent as a result of an EPA grant, district costs fall by $8.11 per capita or by 17.6 percent.

Social costs of investments in wastewater disposal facilities are substantially higher than the 7.5 percent average interest paid on tax free municipal bonds. Actual costs are difficult to measure, but an estimate of 11.6 percent seems reasonably close to the social cost of local investments in wastewater disposal systems.

Converting septic tanks and leach fields to collection and treatment by disposal plants has been slow in mountain areas because with average costs of \$44 per capita, septic tanks are cheaper. Break even point between a small treatment plant and septic tanks occurs at very high population levels, when population level reaches 8,600 persons with density of 16 persons or 4 dwellings per acre. At the same density level, the break even point between septic tanks and transmitting the wastewater to a regional treatment plant in the nearest town occurs at even higher population levels, 9,820 people.

Social costs of water pollution vary among the 3 alternative wastewater disposal methods in mountain areas. The alternative with the highest level of pollution effects is the septic tank . More than one-third pollutes domestic wells when located on scattered tracts, compared to about two-thirds when located in densely developed tracts. Small package treatment plants with part-time operators tend to be more polluting than medium to large size activated sludge treatment plants, which can more readily adopt the latest tertiary treatment technology. Reducing ammonia discharge by 95 percent increases treatment costs by about 25 percent and total sanitation district costs by about 12.5 percent.

Optimum least-cost wastewater disposal occurs at a much lower size in mountain areas than in other areas of the U.S. Consolidation of wastewater disposal districts is a viable option up to a population of 12,800 people in a narrow mountain valley with 4 persons per acre located within 5 miles of the treatment plant. This is the least-cost wastewater disposal system with costs of \$52.63 per capita. For subdivisions located farther away than 5 miles, consolidation with the sanitation district would increase average total costs. The reason why wastewater disposal costs rise for population levels above 12,800 people is wholly due to transmission costs which rise continuously as wastewater is transported greater distances.

For scattered developments averaging 1 dwelling every 4 acres, wastewater transmission would be prohibitively high, averaging $194 per capita when located 5 miles from the treatmant plant and $389 per capita when located 10 miles away. With 1 in 3 chance of polluting rivers and domestic wells by septic tanks on scattered residential tracts, decisions to restrict residential development may result.

Standards for optimal pricing of wastewater disposal services would allocate the increased costs of low density and distant subdivisions to residents of those areas. For example, sewer rates are 37 percent higher in the service area outside of the town of Aspen than in town. Improvements in rate making that reflect actual social costs of service would discourage over-investment in wastewater disposal systems and premature development of land at the rural-urban fringe.

Standards for optimal pricing of peak load services would allocate increased costs of seasonal recreation use of waterwater disposal services in mountain areas to users during the peak hours. Under current uniform rates, recreational peak loads cost the average resident $22.58 annually. If this cost could be shifted to peak recreation users, their costs would average only $5.71 per capita.

The results of this study contribute to decisions concerning efficient land use. Minimum and maximum levels of land subdivision can be shown for typical environmental conditions in mountain areas. Under severely restricting physical conditions in some mountain areas, wastewater transmission and treatment costs would be prohibitively high. The resulting pollution of rivers and domestic wells by septic tank use may result in decisions to disallow residential development. Under other physical conditions, transmission and treatment may be a viable option and residential development may be encouraged up to the optimum community size. Under severely restricting physical conditions in mountain areas, an optimum least-cost wastewater disposal occurs at a much lower size than in other areas of the U.S. Land subdivision which would increase size beyond optimum would increase average costs per capita and may result in decisions to limit growth.

EFFICIENCY OF WASTEWATER DISPOSAL IN MOUNTAIN AREAS[1/]

Richard G. Walsh, Jared P. Soper and Anthony A. Prato[2/]

INTRODUCTION

Increased attention has been focused in recent years on the development of seasonal residential subdivisions in mountain areas. Until recently, most mountain communities and state governments welcomed and encouraged land development as a source of new income and general economic growth. It is now becoming apparent that costs of providing public services and healing environmental wounds resulting from land development may exceed the new revenues it provides [23].[3/] The people involved are interested in what can be learned from recent experience that will help formulate sound land development policies for the future.

The purpose of this study is to provide answers to some of the questions that have been raised about wastewater disposal costs in mountain areas. How much do costs increase for subdivisions located at high elevations with extreme climatic conditions? Can standard types of treatment plants be used effectively? What are the effects of reduced permeability of rock and soil? Can a system be efficient when located in mountain topography with narrow valleys and steeply rising slopes? How does the number of dwellings per acre affect the feasibility of wastewater disposal systems in mountain areas?

In the past, the most common method of wastewater disposal in mountain subdivisions was the septic tank. This has become increasingly unsatisfactory. Waltz [17] found that most Colorado mountain septic tanks violate pollution control standards. This is expected to worsen in the future. With continued building on vacant land, dwellings tend to be located nearer one another. And, the more dense a residential development, the more frequent contamination of domestic wells by septic tank effluent. Waltz showed that more than one-third of septic tanks serving dwellings located on scattered tracts were polluting domestic wells compared to about two-thirds of those located in densely developed tracts. In addition, unsuitable soil conditions for septic tank systems result in the pollution of streams and reservoirs. Approximately 30 percent of the lakes and streams in Colorado are polluted [52] nearly identical to water pollution levels reported for the U.S. as a whole.

The objectives of this report are to show:

(1) the costs of wastewater disposal in mountain areas including the effect of:
    (a) topography, climate, and soil conditions; and
    (b) the volume of sewage collected, the timing of flows, the distance the sewage is transmitted, the density of residential development, and the level of wastewater treatment;
(2) the economic feasibility of converting septic tanks to community wastewater disposal systems; and
(3) guidelines for land use planning of residential subdivisions in mountain areas with adverse physical conditions.

This study is an engineering-economic cost analysis of wastewater disposal in mountain areas of Colorado. Appendix A shows the basic sources of information, several cross-sectional studies of wastewater disposal costs in other areas of the U.S.[4/] These studies provide a data base. These results are updated, averaged and adjusted for the effects of elevation in mountian areas. The adjustment is based on knowledge of several water quality engineers with experience in planning and operating wastewater disposal facilities in the Rocky Mountains. The small sample size, which is characteristic of the engineer-economic approach, prevents application of the usual statistical tests of reliability when a random sample of a cross-section of operating plant managers are interviewed [50]. However, reliability can be tested by repeating the study under similar conditions and comparing results. On the other hand, engineering-economic studies have an important advantage over the cross-sectional survey approach. Conditions which affect costs such as the age of plant and rate of capacity utilization can be more easily held constant. The engineering-economic approach enables us to separate out one by one the economic effects of several important physical conditions such as elevation, topography and soil type.

Costs of wastewater collection and treatment are paid by residents in a community as initial hook-up fees, property tax levies and sewer-water bills. Residents are vulnerable because they are too small in size and too many in number to exert either singly or collectively effective countervailing market power on their sanitation district through voluntary restriction of sewer usage. This means it is important to residents that wastewater collection and treatment be efficient and that sewer charges reflect that efficiency.

Much has been done to improve the efficiency of wastewater collection and treatment in other areas of the U.S. However, there has been resistance to changes in methods of wastewater disposal in mountain areas. Papers presented at a recent workshop [36] in Colorado identified several of the problems unique to mountain wastewater disposal including cold temperatures, rapid population growth and high peak to average flow ratios. However, no information was presented on costs or efficiency in mountain areas. A number of studies have been made of the costs of wastewater disposal systems in other areas. Most notable is the work by Downing [2] in Wisconsin. His costs of treatment, collection, and transmission were updated as shown in Appendix A of this report. Sloggett and Badger [39] showed that wastewater volume and customer density explained 93 percent of variation in costs of wastewater disposal systems in small Oklahoma communities. Golstein and Moberg [3] estimate that 30 percent of the people in the U.S. are not served by a sanitation district, and show the costs of wastewater disposal alternatives. The Environmental Protection Agency has published several planning guides with costs applicable to other areas of the U.S. [25]. But no previous study has been made of the costs of wastewater disposal systems in mountain areas.

This report is intended to aid decision makers in water quality management planning at all levels of government. It should prove effective in making preliminary cost comparisons of alternative mountain wastewater disposal systems in the project formulation stage. The cost information will aid the development of efficient wastewater treatment systems under the Federal Water Pollution Control Act. In the past, governmental agencies in mountain areas have lacked the kind of information presented in this report and thus have had no alternative but to rely on cost standards established for other areas. Fred W. Matter, Pollution Engineer, Colorado State Department of Public Health reports that: " . . . townships in mountain areas too often rely on the 'rules of thumb,' established for plains areas in their evaluation of sewage disposal alternatives" [34].

The cost information presented in this report should be updated periodically and adjusted for improvements in wastewater disposal techniques. Also, the unique circumstances of particular mountain situations may alter the costs presented. However, sufficient variations in physical and economic conditions are shown in this report to allow most of the adjustments to be made for unique mountain locations.

The elevations considered in this study are 6,000, 8,000 and 10,000 feet above sea level. This range includes most mountain communities in Colorado: Glenwood Springs, 5,746 feet, Steamboat Springs 6,695 feet, Aspen 7,908 feet, Vail 8,150 feet, Breckenridge 9,603 feet, and Leadville 10,152 feet [24].[5/]

Size of the six model wastewater treatment plants studied range from 50,000 to 10 million gallons per day. This includes the extremes in size of plants found in most mountain areas. Few activated sludge plants of less than 100,000 gallons per day operate in the mountain areas of Colorado, and none larger than 5 million gallons per day have been constructed thus far.

Three types of wastewater treatment are studied: activated sludge, stabilization pond and package plants. The standard primary and secondary level of wastewater treatment is compared to tertiary removal of ammonia and phosphate pollutants. Most wastewater treatment plants in mountain areas currently are of the activated sludge type and remove 90 percent of BOD using primary and secondary processes. Few plants have adopted tertiary treatment, although this is expected to increase in the future.

These model plants have design capacities to serve 500 to 100,000 people with average daily flow of 100 gallons per capita. Most mountain communities in Colorado have populations at the low end of this range.[6/] Aspen has a resident population of 9,234 and a peak recreation population of 20,758. Snowmass at Aspen has 794 residents and a 7,265 peak. Breckenridge has only 1,500 residents and a 19,000 peak. Vail has 4,570 residents and a seasonal peak of 22,645. Vail has a proposed peak of 26,445 persons, and Beaver Creek Ski area may be added to the Vail district with a proposed peak of 21,000 persons.

Levels of density studied range from 0.4 to 64 persons per acre. The lowest is equivalent to 2.5 acres per person or 10 acres per dwelling of four persons. The highest is equivalent to 16 dwellings per acre. Most mountain communities have densities at the low end of this range. Aspen has a resident population of about 5 persons per acre and a seasonal peak of approximately 14. In comparison, Denver has a density of 9 persons per acre and New York City 41.

Annual rates of population growth studied range from zero to 15 percent. Growth rates of 10 to 15 percent have occurred in popular recreation areas and other boom towns in mountain areas. Low to moderate population growth rates of 3 to 5 percent are typical of recreation communities restricting growth and other stable mountain towns.

Rates of capacity utilization range from 6 to 100 percent, and are related to population growth rates. New wastewater systems have a long life and are planned with sufficient excess capacity in the early years to serve a "design population" 20 years in the future. With 5 percent annual growth, midyear utilization 10 years hence becomes 60 percent of capacity.

Transmission lines studied range from 5 to 30 miles in length. Costs are shown for extension of wastewater service to subdivisions of varying population levels located 5 to 30 miles away from the treatment plant.

Soil conditions studied range from bedrock to alluvial soil. Costs are developed for installation of sewer lines through bedrock, weathered granite, bouldery glacial materials, gravel, and alluvial soil. Most mountain soils even at the higher elevations are alluvial, gravel and rippable weathered granite.

PHYSICAL CONDITIONS

Physical conditions associated with elevation explain most of the difference in wastewater disposal costs in mountain areas. Temperatures, soil permeability, topography, water quality, and labor productivity are among the important conditions related to elevation. Temperatures are generally lower and the cold tends to persist for longer periods of time. Soil generally becomes more rocky and less permeable. More of the terrain is irregular and steeply sloping. With less air pressure, water quality standards rise with respect to dissolved oxygen levels for fish production. With less oxygen available to the brain and muscles, labor productivity declines. Thus, the costs of constructing, maintaining and operating wastewater disposal systems increase with elevation.

Cold Temperatures

Temperature is the most important physical condition affecting wastewater treatment costs in mountain areas. It accounts for fully 70 percent of the increased costs of constructing wastewater treatment plants. On the average, cold temperature increases plant construction costs by 28 percent at 8,000 feet and by 35 percent at 10,000 feet [57]. The primary reason is the added cost of enclosing the entire treatment facility in a weather tight building. This allows incoming sewage to be maintained at a temperature of at least 45 degrees Fahrenheit, the minimum temperature necessary for the treatment process to function properly [36].

The costs of operation and maintenance of treatment plants usually are not affected by cold temperatures. Most mountain plants use aerobic digestors and natural oxidation produces temperatures between 80 and 100 degrees Fahrenheit. Thus, the treatment process heats both the building and the incoming sewage. However, for some plants located at high elevations with periods of extremely cold temperatures, the provision of additional facilities for heating increases costs of operation and maintenance by as much as five percent [58].

Cold temperatures also were expected to increase sewer line installation costs at higher elevations. However, the experience is mixed. Where extremely cold temperatures occur, costs increase. Breckenridge, Colorado, at an elevation of about 10,000 feet, has a minimum allowable depth for sewer line construction of 8.5 feet [35], and costs of installation increase by 36 percent. At lower mountain elevations with less extremely cold temperatures, there is little problem of sewer line freezing. Only three to four feet of ground cover is adequate to protect most sewer lines from freezing, the same as in other areas. Given the initial temperatures of wastewater, there is little problem of sewer line freezing. Depth standards for sewer lines differ from water lines. The effects of temperature in mountain areas require a minimum of six feet of ground cover for water lines compared to 4.5 feet of cover in other areas. At extreme elevations, this standard may be insufficient. At an elevation of about 10,000 feet in Breckenridge, Colorado, a six inch line froze at a depth of 18 feet [35].

Rocky Soil

Soil permeability is the most important physical condition affecting the costs of sewer lines. It accounts for about half of the increase in their cost in mountain areas. Table 1 shows that rocky soil increases the cost of sewer line installation by five percent at an elevation of 6,000 feet, 15 percent at an elevation of 8,000 feet, and 20 percent at an elevation of 10,000 feet. The primary reason is that with higher elevations, more of the soil becomes rocky and less permeable. Installing a sewer line through bedrock increases its costs by about 150 percent. This compares to a 50 percent increase for weathered granite, and a 25 percent increase for bouldry glacial material, alluvial soil, and gravel. Soil conditions vary considerably among elevation levels and at the same elevation. Seldom will the soil in a mountain subdivision be all of the same type and permeability. Thus, typical soil conditions associated with elevation levels were obtained from soil surveys in Colorado, and sewer line installation costs were developed for each of the combination of soil types described in Table 1 .

Rocky soil affects the costs of constructing wastewater treatment plants to a lesser extent. On the average, mountain soil conditions increase wastewater treatment plant construction costs by four percent at an elevation of 8,000 feet, and by five percent at 10,000 feet. With soils less suitable for building, for example alluvial soil and high ground water, treatment plant construction costs can increase by 10 percent at all mountain elevations.

Table 1 Percentage Increase in Sewer Line Installation Costs Associated with Various Mountain Elevations and Soil Conditions, Colorado 1976.

Elevation (feet above sea level)	Average Percent Increase in Sewer Line Installation Costs	Hypothetical Soil Types[a]	Percent Increase in Sewer Line Installation Costs
4,000	0	Deep to moderately deep, well-drained soil; mostly sand and loam	0
6,000	5	20 percent sand and clay 80 percent alluvial soil	20
8,000	10	15 percent sand and loam 80 percent alluvial soil 5 percent bedrock	27.5
10,000	20	10 percent sand and loam 50 percent alluvial soil & gravel 30 percent rippable weathered granite 10 percent bedrock	42.5

[a] Although soil is generally less permeable at higher elevations, the relation between elevation and the hypothetical soil types shown here is not direct. Estes Park at an elevation of 7,522 feet has less permeable soil than does Leadville at an elevation of 10,152 feet.

Source: Adapted from soil surveys in Colorado and cost estimates [42, 43, 57].

Steeply Sloping Topography

Topography has a number of important effects on wastewater collection costs in mountain areas. Irregular terrain can result in the installation of additional pumping stations and steep slopes can double the number of sewer lines. Locating a residential subdivision on a slope of 20 degrees or more can increase sewer line installation costs by 50 to 100 percent. The reason is that a sewer line installed horizontal to steep slopes can only serve those dwellings that are above it. Thus, when subdivision lots front on a road horizontal to a slope of 20 degrees or more, double sewer lines become necessary. A sewer line is installed behind each row of dwellings.

On slopes of less than 10 degrees, a single sewer line can be installed in the road right of way horizontal to the slope, and serve dwellings on both sides of the line. On slopes of 10 to 20 degrees, a single sewer line can be effective if it has a constant 6 percent grade.

Water Quality

Water quality sufficient to support game fish increases substantially at elevations of 8,000 feet and above, where the lower air pressure results in less natural dissolved oxygen recharge in stream and lake waters. The roaring Fork River near Aspen, Colorado requires seven to eight parts per million (ppm) of dissolved oxygen (DO) compared to four ppm at sea level.

As a result, communities may be required to install additional tertiary wastewater treatment facilities to meet the higher fish and wildlife standards for streams and lakes in mountain areas [35]. Tertiary treatment refers to several processes additional to the usual secondary treatment level. They remove toxic nutrients such as ammonia and phosphorus, which accelerate eutrophication of streams and lakes, reducing the dissolved oxygen available for fish life. Average U.S. costs of tertiary treatment processes were adjusted for mountain conditions [49].

A successful method of ammonia removal is by breakpoint chlorination. It has the advantage of moderate investment costs, although this is offset by high costs of operation and maintenance. EPA reports that ammonia removal would increase capital costs by an average of 24 percent and operation and maintenance costs by 79 percent. This would increase wastewater disposal costs by $11.15 per capita. A 1 million gallon per day wastewater treatment plant would include preliminary treatment, primary sedimentation, activated sludge plus alum, and breakpoint chlorination.

The Upper Eagle Valley Sanitation District with a plant on the Eagle River at Avon, Colorado, serves a population of 8,000 people, including Vail with 4,570 people. The U.S. Forest Service reports that to add the proposed Beaver Creek ski area with a resident population of 4,286 will require tertiary treatment for ammonia removal [31]. The district's present secondary treatment leaves ammonia concentration of 15 mg/1 in the treated wastewater discharged into the Eagle River. To reduce this by 85 to 95 percent to 1 mg/1 is reported to cost 10 cents per 1,000 gallons or about $3.65 per capita annually. To remove 99 percent of ammonia, treatment costs would be approximately double those for secondary treatment [31]. Fortunately, standards of the Colorado Water Quality Control Commission are such that the degree of tertiary treatment needed in the Upper Eagle Valley is less than 90 percent removal of ammonia, so costs are moderate. However, if population growth continues unabated, the higher levels of water treatment will be necessary to protect water quality.

Phosphorus can be removed by a two-stage tertiary lime treatment. It would increase capital costs by 42 percent and costs of operation and maintenance by 32 percent. This would increase wastewater disposal costs by $8.01 per capita. Plants of 1 to 5 million gallons per day would include preliminary treatment, primary sedimentation, conventional activated sludge, and two stage tertiary lime treatment. The Breckenridge Sanitation District recently was required to reduce residual chlorine from .05 to .02 parts per million to protect the brown trout in the Dillion Reservoir [58]. It has increased capital and maintenance costs.

Labor Productivity

Labor productivity declines sharply at elevations of 8,000 feet and above, where less oxygen is available to the brain and muscles. Studies by the University of Colorado Medical Center show that it takes half again as much time or as many men to perform the same work as at sea level [18]. Mental ability, vision, and physical strength are impaired at elevations of 8,000 to 10,000 feet. Symptoms of mountain sickness such as headache, loss of appetite, and nausea usually end after one to three days at higher elevations, as the kidneys compensate and adjust the acid base in the blood to normal. Also, reductions in ability to work are usually less noticeable below 8,000 feet. However, indications are that nerves and muscles receive less oxygen at 8,000 feet and above, no matter how deeply one breathes or for how long one lives at the higher elevation. The result is lower labor productivity and higher costs to construct, operate and maintain wastewater disposal systems.

Higher labor costs account for 10 percent of the increased costs of constructing wastewater treatment plants. On the average, higher labor costs increase plant construction costs by 4 percent at 8,000 feet elevation and by 5 percent at 10,000 feet [57].

Labor productivity has even more affect on the costs of installing sewer lines in mountain areas. Higher labor costs account for about 30 percent of the increased costs of sewer lines compared to 10 percent of the costs of plant construction, operation and maintenance. On the average, higher labor costs increase sewer line costs by three percent at 6,000 feet elevation, by nine percent at 8,000 feet and by 12 percent at 10,000 feet.

Labor accounts for virtually all of the increased costs of plant operation and maintenance in mountain areas. On the average, higher labor costs increase plant operation and maintenance costs by 10 percent at elevations of 8,000 feet and above.

ECONOMIC CONDITIONS

Economic conditions associated with elevation explain a significant amount of the difference in wastewater disposal costs in mountain areas. Land values, interest on investment, peak loads, and septic tank installation costs are related to elevation. Land values are generally higher in recreation areas and land suitable for wastewater treatment plant construction is more scarce. Depreciation appears to be unaffected by elevation. Interest on investment tends to be higher as most sanitation district bonds are medium grade in mountain communities with a single economic base and limited security. Wastewater flows are more seasonal in mountain resort areas and peak load costs are higher. With the lower percolation associated with rocky soil, septic tank installations are more costly. These are among the more important conditions which contribute to the increased costs of wastewater disposal systems in mountain areas.

Land Values

The price of land suitable for location of wastewater treatment plants is several times higher in mountain areas of Colorado than in other areas. For example, capital investment in land by a mountain sanitation district serving 10,000 people averages $10,000 per acre compared to $3,000 per acre in other areas [57]. Although land prices are substantially higher in mountain recreation areas than in other areas, the amount of land required for enclosed activated sludge treatment plants is not large, so the effect of land prices on wastewater treatment costs is small.

The price of land suitable for wastewater plants varies considerably. Suitable land is usually more scarce in mountain areas of Colorado than in other areas. Price ranging from $500 to $40,000 per acre depends on the demand for other uses of the land and the location of the plant. As a general rule, the greater the distance from the core of the community, the lower land prices. In addition, wastewater treatment plants tend to be located adjacent to rivers and lakes, and shoreline property may be higher priced in mountain areas because of its greater recreational potential.

Table 2 shows the minimum land area required for three types of wastewater treatment plants. Stabilization pond treatment is the largest user of land by far. With limited available land in most mountain communities, it is suitable only for use in communities with low levels of population, 500 to 1,000 persons. As size of stabilization pond plants is increased, the amount of land required per capita does not decrease appreciably. A community of 500 people would require a stabilization pond treatment area of 8 acres and 1,000 people 15 acres. Larger mountain communities than this use conventional activated sludge treatment or package plants. At elevations above 7,000 feet, these plants enclose all equipment and holding tanks, to maintain suitable temperatures. The design of enclosed plants is more complex but requires a smaller amount of land. The number of acres required for enclosed activated sludge and package

Table 2. Land Required for Wastewater Treatment Plants in Mountain Areas of Colorado, 1975.

Type of Treatment Plant	Number of People Served					
	500	1,000	5,000	10,000	50,000	100,000
	Size of Plant (Gallons per Day)					
	50,000	100,000	500,000	1,000,000	5,000,000	10,000,000
	Acres					
Activated Sludge and Package Plant	1	2	4	4	6	8
Stabilization Pond	8	15				
	Acres Per 1,000 People Served					
Activated Sludge and Package Plant	2.0	2.0	0.8	0.4	0.12	0.08
Stabilization Pond	16.0	15.0				
	Total Capital Investment					
Activated Sludge and Package Plant	$10,000	$ 20,000	$40,000	$40,000	$60,000	$80,000
Stabilization Pond	$80,000	$150,000				
	Average Total Cost Per Capita					
Actiavted Sludge and Package Plant	$ 1.50	$ 1.50	$ .60	$ .30	$ .09	$ .06
Stabilization Pond	$12.00	$11.25				

Source: [57] Average total cost per capita = total capital cost ÷ the design population x .075 interest rate. Land has no depreciation cost.

plants decreases as size of plant is increased. An activated sludge plant serving 10,000 people requires only 4 acres of land or 0.40 acres per 1,000 persons served. A plant serving 50,000 people requires 6 acres or only 0.12 acres per 1,000 persons served.

Sanitation districts may purchase more land than currently required by their treatment plant. The exact acreage needed may not be available. They may anticipate future expansion either to improve the quality of treated water or to expand the size of the treatment plant. For example, the Breckenridge Sanitation District located 60 miles west of Denver operates a 2 million gallon per day activated sludge plant with tertiary treatment, on 9.96 acres [58]. This is more than three times the minimum acreage required for an activated sludge plant of this size.

Depreciation

Depreciation costs for wastewater systems in mountain areas apparently average no higher than in other areas. Sanitation engineers report that the useful life of wastewater facilities in mountain locations is considered identical to other areas [57]. Although the weather is much more severe in mountain areas, no reduction in the useful life of facilities was found in this study.

Depreciation of public facilities is calculated by the straight line method. Annual depreciation is the cost of the facility minus the salvage value divided by the useful life of the facility. There is no depreciation of land. Structures are assumed to have zero salvage value unless they can be used at the end of their service life. Normally the salvage value for sewage structures is zero [49]. Annual depreciation for an activated sludge treatment plant is its cost divided by 25 years, the expected useful life of the structure. Annual depreciation for a package plant is its cost divided by 20 years. Annual depreciation for collection and transmission lines is cost divided by the expected useful life of 50 years.

In calculating depreciation costs, a standard mortgage table was consulted showing the equal annual payments which will recover capital investment over a given number of years. The effect is to treat depreciation as equal to payments on the principle. Depreciation is combined with interest into a single lump sum. For example, the annualized cost of capital investment in an activated sludge plant over its useful life of 25 years is 8.971 percent, of which 7.5 percent is interest and 1.471 percent is depreciation in the first year. Over time, as capital is recovered and interest on the outstanding balance declines, depreciation rises. The annualized cost remains 8.971 percent throughout the 25 year period.

Interest

Interest on capital investment in wastewater systems averages about 15 to 36 percent higher in mountain areas of Colorado than in other areas. Average cost of capital in mountain areas was calculated as 7.5 percent in 1975, which was 1 to 2 percentage points higher than for other areas.

Cost of capital in mountain areas was derived by averaging the yield on 20 year municipal bonds and 20 year U.S. treasury bonds [45]. The yield on treasury bonds is the cost of money to the federal government and the yield on medium grade municipal bonds is the cost of money to mountain sanitation districts. Total capital invested in wastewater systems is shared about equally between federal and local units of government. Most mountain communities in Colorado obtain Environmental Protection Agency (EPA) grants of up to 75 percent of investment in new construction or modification of wastewater systems. Not all capital investments qualify for the Federal grants program. For example, investment in sewer collection lines are excluded. Also, many facilities were constructed before the EPA program was started. Thus, it is reasonable to assume that approximately 50 percent of wastewater system investment is federal funded and 50 percent local government funded.

Interest on a municipal wastewater facility bond issue depends on money availability and credit rating of the municipality. These tax exempt bonds will be purchased if the interest is equal to or greater than the after tax yield for taxable bonds of equivalent rating. Most are rated as medium grade because of the limited economic base of mountain communities with one industry, often mining or recreation, providing limited security to prospective bond buyers. Municipal revenue bonds for wastewater systems are payable from specified sources such as real estate tax and sewer use fees. The primary determining factor in rating the bonds is whether the revenue will be adequate to pay the principal and interest on the bonds.

Two sanitation district bonds issued in the Spring, 1976 illustrate the higher cost of capital in mountain areas. The mountain district pays 2.15 percent more than a district located in the Denver Metropolitan area. Copper Mountain Ski Area located 90 miles west of Denver on Interstate 70, has a limited economic base with an uncertain economic future, and pays 8.25 percent on a $500,000 20-year general obligation bond [62]. A joint sewer-water district in Aurora, part of the Denver Metropolitan area, has a relatively diversified economic base, and pays 6.1 percent on a $10 million 18-year general obligation bond [63].

Peak Load

Peak load costs are substantially higher in mountain areas of Colorado than in other areas. The reason is that wastewater flows are more variable in mountain resorts than in other communities. The peak to average flow ratio in mountain areas ranges from 2.3 to 12.6 compared to 1.68 in other areas [2]. Table 3 shows peak load costs in other areas of $8.40 per capita more than with average wastewater flow, about half peak load costs of $17.40 per capita with a peak load ratio of 2.5 at 8,000 feet elevation. With a peak load ratio of 5.0 at the same elevation, costs rise by $34.10 per capita. With a peak load ratio of 10.0 at the same elevation, costs increase $68.10 per capita. Other peak load costs are shown in Table 4.

Wastewater flows vary among the months of the year, the days of the week and the time of day. In mountain areas, wastewater flows are high during the Christmas holiday, Easter week, Labor Day weekend, Fourth of July weekend and Memorial Day weekend. When peak wastewater flows are substantially larger than average daily flows, operational problems can occur in the treatment plant. This is especially true for winter resort areas. A flow equalization process to handle peak flows in the winter months must be enclosed to maintain suitable temperature for wastewater treatment. Special wastewater system design is required to ensure adequate treatment [36].

As a result, residential fees for wastewater disposal services in mountain areas of Colorado average about one-half (47 percent) more than in other areas. The annual residential sewer bill was typically $21 per capita in mountain areas compared to $14.25 per capita in other areas of Colorado. In the ski resort town of Breckenridge, the annual residential sewer bill was $22.50 per capita, compared to $300 annually for automotive service stations, restaurants $12 per seat, rooming houses $12 per bed, hotels and motels $36 per rental unit without

Table 3. Peak to Average Flow Ratios in Mountain Recreational Areas, Colorado, 1975.

	Resident Population	Peak Population	Ratio of Resident to Peak
Aspen	9,234	20,758	2.3
Snowmass at Aspen	794	7,265	9.2
Breckenridge	1,500	19,000	12.6
Vail	4,570	22,645	5.0
Proposed		26,445	5.8
Beaver Creek			
Proposed	4,286	21,000	4.9

Table 4. Peak to Average Flow Ratios and Costs of Wastewater Disposal in Mountain Areas, Colorado, 1975.

Peak to Average Flow Ratio	Other Areas at Lower Elevations	Mountain Elevation		
		6,000 feet	8,000 feet	10,000 feet
1.68	$8.40	$8.74	$11.52	$12.26
2.5	12.52	13.01	17.05	18.28
5.0	25.07	26.08	34.10	36.61
10.0	50.10	52.11	68.10	73.15

Source: [2] Costs were 60 percent treatment and 40 percent collection, updated to April 1975 as shown in Appendix A, adjusted for mountain elevations, increased by 34 percent to adjust source data from a base population of 100,000 people to a typical mountain population of 10,000 people.

kitchen and $90 per unit with kitchen (the same as residential assuming 4 persons per unit), medical facility $120, laundry $120 for first machine and $48 each additional machine, school $3.60 per student, and grocery store $90. Rates for service outside of the Sanitation District are higher.

Septic Tanks

Private residential installation of wastewater disposal systems such as the septic tank and leach field usually cost twice as much in mountain areas of Colorado as in other areas. Capital investment in a septic tank system engineered to serve a three bedroom house with four residents in a mountain area ranges from $1,400 to $2,800 and averages $1,870. Average total costs are $44 per capita annually. Septic tank costs are a function of soil conditions and accessibility of the dwelling. Mountain soil is typically rocky with slow percolation rates. Thus, most residential septic systems are of the more costly engineered type, with larger drainage fields, with partial evapotranspiration and aerobic action.

Investment of $1,870 is equivalent to $152.37 per year or $38.09 per capita based on a 35 year life and 7.5 percent interest. Maintenance includes pumping out and hauling away the sludge in the septic tank every two years at a cost of $46.75 or $23.38 per year, $5.84 per capita. Thus, average total costs of septic tank systems are about $44 per capita annually ($38.09 + $5.84).

The system includes a septic tank which removes the settleable solid material and a leach field which filters the liquid effluent from the septic tank [3]. The suitability of a septic system to adequately meet the wastewater disposal requirements of a private residence depends on the ability of the soil to filter the liquid sewage. A percolation test can determine whether soil will adequately absorb the liquid waste. Percolation is a measure of the movement of water in the soil after it has entered the top soil layer [3]. The percolation rate is a measure of water movement through the soil in minutes per inch. If the percolation rate is below a standard level, subsurface soil absorption systems are not permitted. In Larimer County, Colorado, percolation rates of less than one inch per 60 minutes are considered too low for adequate subsurface soil absorption [17]. To compensate for slow percolation, a non-conventional or engineered system may be installed including partial evapotranspiration and aerobic action. Or a water tight vault may be installed, with the disadvantage that it must be pumped out and hauled away more frequently at higher cost. A Clivus Multrum system [20] from Sweden decomposes kitchen and toilet wastes in an aerobic composting chamber in the basement of a residence. The wastes are converted to rich organic soil which can be used as garden fertilizer. However, investment is estimated as $1,600 to $2,000. And since the composting chamber does not handle wastewater from shower, sink and garbage disposal, a conventional septic tank system is needed to receive this wastewater. Thus, the system would nearly double residential investment and costs per capita.

Operation and Maintenance

Operation and maintenance costs of wastewater disposal systems in mountain areas average 10 percent higher than in other areas. Below 8,000 feet elevation, operation and maintenance costs are not increased. With the same level of wastewater treatment in both areas, higher labor costs account for nearly all of the increased cost of operation and maintenance in mountain areas. Wage rates tend to be lower in mountain areas, but this advantage is more than offset by declines in labor productivity at elevations of 8,000 feet and above, owing to the reduced level of oxygen available to the brain and muscles. Qualified personnel are required to monitor and maintain wastewater treatment plants. Constant monitoring prevents treatment failure which would allow untreated wastewater to flow into lakes and stream causing damages to the environment and to human health.

Other important operation and maintenance costs are utilities and chemicals. Electricity energizes the pumps and moveable parts in the treatment process. Bottled gas may be used to heat the incoming sewage and the building. Normally, operation and maintenance costs are not affected by cold temperatures. In cases where extreme cold temperatures occur, heating costs may increase costs of operation and maintenance by as much as 5 percent.

Chemicals are used in the wastewater treatment process, including alum, chlorine, ferric chloride and lime. The more advanced the treatment process, the more chemicals are used, and chemical costs become a larger proportion of operation and maintenance costs.

COST RESULTS

Costs of wastewater disposal systems are affected by economies of size in treatment plants, utilization of capacity, density of residential development, and diseconomies in transmission costs per mile. Each of these is examined one at a time holding the remaining variables constant. For example, when considering the effect of plant size on treatment costs, rate of plant utilization, density and transmission costs are held constant. It will be shown that economies of size exist in both capital and variable treatment costs. Total costs of collection lines decline with increases in the density of residential development. However, substantial diseconomies of scale occur in transmission costs per mile. A substantial amount of capital is invested in wastewater disposal systems, with the treatment plant itself representing a minor part. Capital of about $5 million is required for a 1 million gallon per day system to serve a design population of 10,000 people. The treatment plant accounts for only one-fourth of total capital investment, compared to nearly one-half in collection lines and one-fourth in transmission lines, although the latter can vary widely.

Capital Investment

Tables 5, 6, and 7 show total capital investment in model wastewater treatment plants and in wastewater collection and transmission lines. Physical conditions in mountain areas require substantially higher capital investment than in other areas. Typical mountain topography and soil conditions increase collection and transmission line investment by an average of 10 percent at 6,000 feet elevation, but do not increase investment in treatment plants. At 8,000 feet elevation, investment in treatment plants increase by an average of

40 percent, and investment in wastewater collection and transmission by 30 percent. At 10,000 feet elevation, investment in treatment plants increase by 50 percent, and in collection and transmission by 40 percent.

Table 5 shows total capital investment for three types of wastewater treatment plants excluding land. Physical conditions including cold temperatures and limited usable land affect the type of wastewater treatment system adopted. This is important because capital investment in the wastewater treatment plants ranged from about $100,000 to over $7 million. Where applicable, package plant and stabilization pond treatment systems have substantially lower capital investment than an activated sludge system. The capital treatment costs of a 100,000 gallon package plant are 63 percent less than a 100,000 gallon activated sludge plant for all elevations. At 6,000 feet elevation, capital for a stabilization pond system are 44 percent less for a 500,000 gallon system and 87 percent less for a 10 million gallon system.

Trickling filter and stabilization pond treatment systems are not suitable at elevations over 7,000 feet where temperatures are colder than required for these systems to operate efficiently at a reasonable capital cost [57]. Even under 7,000 feet, trickling filter systems are seldom used because of the large land requirement and the low degree of process control. Stabilization ponds may be used under an elevation of 7,000 feet in small mountain communities. A stabilization pond system for a community of 1,000 persons requires 15 acres, 7.5 times the land required by an activated sludge plant [57]. Activated sludge and package plant systems can be adapted for use in mountain communities. Both systems can be enclosed and heated to temperature levels necessary for adequate sewage treatment. For both systems, land requirements are slight, two acres for a plant serving 1,000 persons and four acres for a plant serving 10,000 persons. In discussing cold weather sewage treatment in mountainous

Table 5. Capital Investment in Model Wastewater Treatment Plants in Mountain Areas, Colorado, 1975.

Type of Treatment	Number of People Served					
	500	1,000	5,000	10,000	50,000	100,000
	Size of Plant (Gallons per Day)					
	50,000	100,000	500,000	1,000,000	5,000,000	10,000,000
			6,000 Feet Elevation			
Activated Sludge	$94,915	$156,400	$518,600	$859,600	$2,850,500	$4,701,000
Package Plant	39,050	57,900				
Stabilization Ponds	52,880	51,600	131,300	179,600	326,000	604,000
			8,000 Feet Elevation			
Activated Sludge	132,880	218,960	761,050	1,203,400	3,990,500	6,581,000
Package Plant	54,735	81,060				
			10,000 Feet Elevation			
Activated Sludge	142,375	234,600	815,400	1,289,400	4,278,000	7,056,000
Package Plant	58,645	86,850				

Source: Appendix Table 1. Average capital investment in mountain treatment plants are 100 percent at 6,000 feet, 140 percent at 8,000 feet and 150 percent at 10,000 feet.

Table 6. Capital Investment in Wastewater Collection Lines in Mountain Areas, Colorado, 1975.

Average Population Density Per Acre	Number of People Served (Design Population)					
	500	1,000	5,000	10,000	50,000	100,000
			6,000 Feet Elevation			
.4	$688,385	$1,376,770	$6,883,850	$13,767,700	$68,838,500	$137,677,000
1.0	298,853	597,705	2,988,530	5,977,060	29,855,300	59,770,600
4.0	132,254	264,509	1,322,544	2,645,088	13,225,440	26,450,880
16.0	99,575	199,151	995,754	1,991,508	9,957,540	19,915,080
64.0	25,075	50,151	250,755	501,510	2,507,549	5,015,098
			8,000 Feet Elevation			
.4	813,546	1,627,092	8,135,460	16,270,920	81,354,600	162,709,200
1.0	353,190	706,379	3,531,895	7,063,790	35,318,950	70,637,900
4.0	156,301	312,601	1,563,006	3,126,012	15,630,060	31,260,120
16.0	117,680	235,360	1,176,800	2,353,601	11,768,005	23,536,010
64.0	29,635	59,269	296,347	592,693	2,963,467	5,926,934
			10,000 Feet Elevation			
.4	876,127	1,752,254	8,761,270	17,522,540	87,612,700	175,225,400
1.0	380,358	760,716	3,803,580	7,607,160	38,035,800	76,071,600
4.0	168,324	336,648	1,683,238	3,366,476	16,832,380	33,664,760
16.0	126,732	253,465	1,267,324	2,534,647	12,673,235	25,346,470
64.0	31,914	63,829	319,143	638,285	3,191,426	6,382,852

Source: Appendix Table 3. Average capital investment in mountain collection lines is 110 percent at 6,000 feet, 130 percent at 8,000 feet and 140 percent at 10,000 feet. Collection costs do not increase with distance.

Table 7. Capital Investment in Wastewater Transmittion Lines in Mountain Areas, Colorado, 1975.

Miles From Treatment Plant	Design Population							
	64	160	640	2,560	10,240	20,480	40,960	81,920
				6,000 Feet Elevation				
5	$341,623	$341,623	$414,278	$513,103	$870,144	$1,249,629	$2,052,301	$2,854,749
10	686,034	683,943	808,741	1,031,867	1,740,063	2,499,257	4,104,602	6,068,142
15	1,026,262	1,026,261	1,213,119	1,550.546	2,610,207	3,635,283	6,156,903	9,280,635
20	1,380,433	1,368,579	1,617,475	2,180,795	3,480,463	4,884,912	8,209,204	12,493,128
25	1,709,508	1,710,903	2,021,853	2,699,530	4,350,382	6,134,541	10,261,505	15,705,621
30	2,052,523	2,053,220	2,426,216	3,218,209	5,220,526	7,384,170	12,313,806	18,919,014
				8,000 Feet Elevation				
5	341,623	341,623	477,901	606,395	1,028,352	1,476,834	2,425,446	3,373,794
10	810,767	808,296	955,785	1,219,479	2,056,438	2,953,668	4,850,893	7,171,441
15	1,212,855	1,212,854	1,433,686	1,832,463	3,084,790	4,430,501	7,296,339	10,968,023
20	1,631,421	1,617,412	1,911,562	2,577,303	4,113,275	5,907,335	9,701,786	14,764,606
25	2,020,327	2,021,976	2,389,462	3,190,354	5,141,361	7,384,169	12,127,232	18,561,188
30	2,425,709	2,426,534	2,867,347	3,803,338	6,169,713	8,861,003	14,552,678	22,358,835
				10,000 Feet Elevation				
5	434,792	434,792	514,662	653,041	1,107,456	1,590,436	2,612,019	3,633,316
10	873,134	870,473	1,029,307	1,313,285	2,214,625	3,180,873	5,224,038	7,723,090
15	1,306,151	1,306,151	1,543,969	1,973,422	3,322,081	4,771,309	7,836,057	11,811,717
20	1,756,914	1,741,828	2,058,605	2,775,557	4,429,681	6,361,746	10,448,076	15,900,345
25	2,175,737	2,177,513	2,573,267	3,435,766	5,536,850	7,952,182	13,060,095	19,988,972
30	2,612,302	2,613,191	3,087,912	4,095,903	6,644,306	9,542,618	15,672,114	24,078,746

Source: [2] Average capital investment in transmission lines in mountain areas are 110 percent at 6,000 feet, 130 percent at 8,000 feet and 140 percent at 10,000 feet.

regions of Colorado, McLaughlin states: ". . . properly designed and operated activated sludge secondary treatment plants can operate efficiently at all times, even under cold and adverse conditions" [36].

Tables 5 and 6 show total capital investment in wastewater collection and tramsmission lines. Collection line investment is primarily related to population density or the number of people per acre. Capital investment in the wastewater collection system include the patchwork of trunk lines along every street to which residential houses connect and includes sufficient capacity to carry sewage to a treatment plant at the edge of the residential area. The latter represents a minor part (0.63 percent) of the collection line investment in contiguous mountain towns. Collection costs are entirely capital investment, as properly installed lines are self-cleaning and thus there are vitually no variable sewage collection costs.

Table 7 shows capital investment in wastewater transmission lines. Transmission line investment was primarily related to the distance in miles from a residential subdivision or town to the treatment plant. Transmission lines transport wastewater from the edge of a residential subdivision to the treatment plant. Transmission investment varies with distance, volume, and the number of feet of lift between the subdivision and the treatment plant. Transmission lines were of sufficient size to carry the volume of wastewater from the subdivision and included lift stations every two miles.

Total capital investment would be about $5 million for a sewer district serving two typical mountain towns with a design population of 10,000 people located at 8,000 feet elevation. This would include about $1.2 million invested in an activated sludge treatment plant with 1 million gallons per day capacity (Table 5). Land investment would be $40,000 for 4 acres. With an average of 16 persons per acre, $2.4 million would be invested in wastewater collection lines (Table 6). Investment of $1.2 million in transmission lines would be required to serve a second town of 2,500 people located 10 miles from the treatment plant (Table 7). The remaining 7,500 people served by the sewer district live in a town adjacent to the wastewater treatment plant with no additional investment in transmission lines.

Total capital investment would be about \$19 million for a consolidated sewer district serving two mountain towns with a design population of 50,000 persons located at 8,000 feet elevation. This would include about \$4 million capital invested in an activated sludge treatment plant with 5 million gallons per day capacity (Table 5). Land investment would be \$60,000 for 6 acres. With average population density of 16 persons per acre, about \$11.8 million would be invested in wastewater collection lines (Table 6). An additional investment of about \$3 million in transmission lines would be required to transmit wastewater from the second town, for example, a new recreation development of 20,000 persons located 10 miles from the treatment plant (Table 7). The remaining 30,000 people served by the sewer district live in a town adjacent to the wastewater treatment plant, with no additional investment in transmission lines.

Economies of Size

Size of the six model wastewater treatment plants studied range from 50,000 to 10 million gallons per day. This included the extremes in size of plants found in most mountain areas. Few activated sludge plants of less than 100,000 gallons per day are found in the state, and none larger than 5 million gallons have been constructed thus far.

Table 8 divides wastewater treatment costs into fixed capital costs and variable costs. Capital costs include investment in land, plant, and equipment. Variable costs include outlays for operation and maintenance of the treatment plant, and administrative costs of a sanitation district. Administrative costs include bookkeeping, accounting, and customer service.

Figure 1 illustrates the effect of plant size on average total costs of wastewater treatment. Substantial economies of size or scale exist in both capital and variable treatment costs. Per capita costs of activated sludge treatment plants decrease by 84 percent throughout the range of size shown for all mountain elevations. Economies of scale result from the fact that plant and equipment costs increase at a decreasing rate and from the specialization of labor. Most economies of scale occur at the lower plant size levels. Increasing size of plant from 50,000 to 1 million gallons per day reduces annual costs by nearly $32 per capita. Up to this size, average costs declined rapidly. Beyond it, costs declined more slowly. Costs of a 10 million gallon plant were only about $10 per capita lower than a 1 million gallon plant.

Table 8 shows that variable treatment costs for stabilization ponds are less than for a comparable sized activated sludge plant. Variable treatment costs for package plants are 11 percent higher than for activated sludge plants processing 50,000 gallons per day and virtually identical for plants processing 100,000 gallons. Package plants of larger size usually are not as efficient as regular activated sludge plants.

Wastewater treatment costs would vary with the quality of the incoming sewage and the desired quality of water discharged into a stream after treatment. Nearly all of the incoming sewage in mountain areas comes from residential areas. Typical residential wastewater contains a 5 day biochemical demand of approximately 50 grams of oxygen, 50 to 60 grams of suspended solids and 12 grams of nitrogen per person. Residential wastewater has a temperature of 65° F [55]. Average residential wastewater in the Denver Metropolitan Area contains a BOD of 43.75 grams of oxygen and 56.25 grams of suspended solid. Currently, all wastewater treatment plants in mountain areas are required to include both primary and secondary processes. Primary treatment removed 50 percent of the heavy suspended solids (SS) and 35 percent of the biochemical oxygen demand (BOD) by gravity. Secondary treatment relies on the biological action of bacteria with oxygen to reduce suspended solids and biochemical oxygen demand by 90 percent.

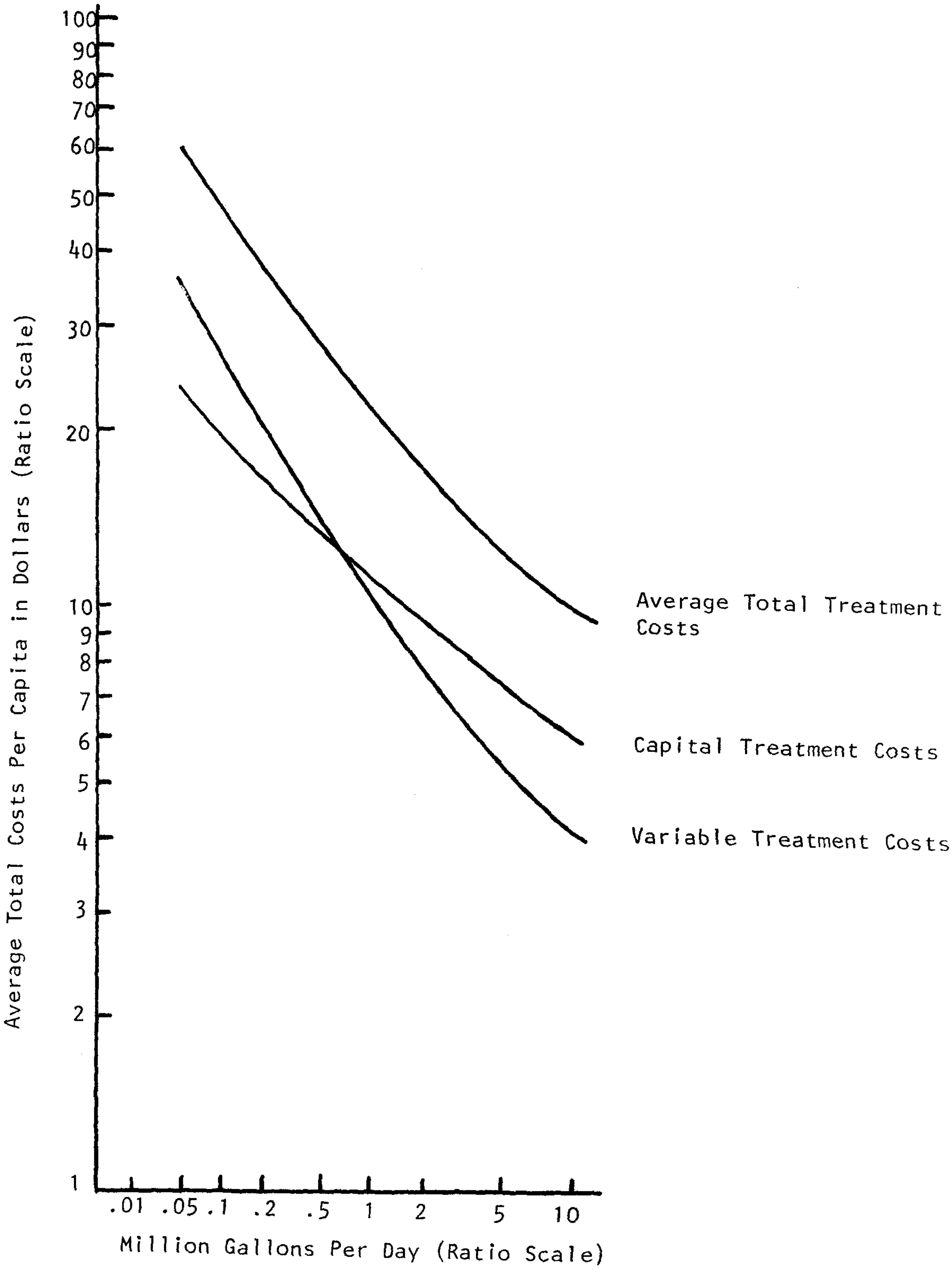

Figure 1. Average Total Costs Per Capita for Wastewater Treatment at a Mountain Elevation of 8,000 Feet, Colorado, 1975.

Table 8. Average Total Costs Per Capita for Model Wastewater Treatment Plants in Mountain Areas, Colorado, 1975.

Type of Treatment Plant and Cost	Number of People Served					
	500	1,000	5,000	10,000	50,000	100,000
	Size of Plant (Gallons per Day)					
	50,000	100,000	500,000	1,000,000	5,000,000	10,000,000
	Elevation 6,000 feet					
Activated Sludge						
Variable	$32.45	$24.18	$13.10	$ 9.84	$ 4.73	$ 3.65
Operation and Maintenance	9.97	8.17	5.71	4.59	3.22	2.57
Customer Service	6.94	5.04	2.46	1.78	.55	.40
General and Administration	15.45	10.97	4.93	3.47	.96	.68
Capital	17.03	14.03	9.75	7.71	5.11	4.22
Total	49.48	38.21	22.85	17.55	9.84	7.87
Package Plant						
Variable	36.05	24.50				
Operation and Maintenance	13.66	8.49				
Customer Service	6.94	5.04				
General and Administration	15.45	10.97				
Capital	7.67	5.68				
Total	43.72	30.18				
Stabilization Pond						
Variable	24.50	17.49	8.14	5.80	1.79	1.28
Operation and Maintenance	2.02	1.48	.75	.55	.28	.20
Customer Service	6.94	5.04	2.46	1.78	.55	.40
General and Administration	15.45	10.97	4.93	3.47	.96	.68
Capital	9.49	4.63	2.36	1.61	.58	.54
Total	33.99	22.12	10.50	7.41	2.37	1.82

Table 8. continued

Type of Treatment Plant and Cost	Number of People Served					
	500	1,000	5,000	10,000	50,000	100,000
	Size of Plant (Gallons per Day)					
	50,000	100,000	500,000	1,000,000	5,000,000	10,000,000
	Elevation 8,000 feet					
Activated Sludge						
Variable	$35.59	$26.59	$14.41	$10.83	$ 5.21	$ 4.02
Operation and Maintenance	10.96	8.98	6.28	5.05	3.54	2.83
Customer Service	7.64	5.54	2.71	1.96	.61	.44
General and Administration	16.99	12.07	5.42	3.82	1.06	.75
Capital	23.84	19.64	13.65	10.80	7.16	5.90
Total	59.43	46.23	28.06	21.63	12.37	9.92
Package Plant						
Variable	39.65	26.95				
Operation and Maintenance	15.02	9.34				
Customer Service	7.64	5.54				
General and Administration	16.99	12.07				
Capital	10.74	7.95				
Total	50.39	34.90				
	Elevation 10,000 feet and above					
Activated Sludge						
Variable	35.59	26.59	14.41	10.83	5.21	4.02
Operation and Maintenance	10.96	8.98	6.28	5.05	3.54	2.83
Customer Service	7.64	5.54	2.71	1.96	.61	.44
General and Administration	16.99	12.07	5.42	3.82	1.06	.75
Capital	25.54	21.05	14.63	11.57	7.68	6.33
Total	61.13	47.64	29.04	22.40	12.89	10.35
Package Plant						
Variable	39.65	26.95				
Operation and Maintenance	15.02	9.34				
Customer Service	7.64	5.54				
General and Administration	16.99	12.07				
Capital	11.50	8.52				
Total	41.15	35.47				

Source: Capital costs investment from Table 5 x .08971 for activated sludge and stabilization pond systems and x .09809 for package plant systems. Activated sludge and stabilization ponds have a useful life of 25 years and thus an annualization factor of .08971. Package plants have a useful life of 20 years and thus an annualization factor of .09809. Variable costs from Appendix Table 2 are 100 percent for 6,000 feet, 110 percent for 8,000 feet and 110 percent for 10,000 feet.

Table 9. Average Total Costs Per Capita For Wastewater Collection in Mountain Areas, Colorado, 1975.

Average Population Density Per Acre	Elevation in Feet		
	6,000	8,000	10,000
0.4	$105.96	$125.23	$134.86
1.0	46.07	54.44	58.63
4.0	20.39	24.09	25.94
16.0	15.34	18.13	19.53
64.0	3.87	4.57	4.92

Source: Capital investment from Table 6 x .07707. Collection systems have a useful life of 50 years and thus an annualization factor of .07707.

Table 10. Average Total Costs Per Capita For Wastewater Transmission Lines in Mountain Areas, Colorado, 1975.

Miles From Treatment Plant	Design Population							
	64	160	640	2,560	10,240	20,480	40,960	81,920
				6,000 Feet Elevation				
5	$411.39	$164.56	$49.89	$15.44	$6.55	$4.71	$3.68	$2.68
10	826.13	329.45	97.39	31.06	13.10	9.42	7.72	5.71
15	1,235.84	494.49	146.09	46.68	19.65	14.12	11.40	8.73
20	1,662.34	659.23	194.78	65.65	26.20	18.83	15.08	11.75
25	2,058.62	824.12	243.47	81.27	32.74	23.54	18.76	14.77
30	2,471.68	989.01	292.17	96.88	39.29	28.25	22.44	17.78
				8,000 Feet Elevation				
5	486.19	194.47	57.55	18.26	7.74	5.56	4.56	3.17
10	976.34	389.35	115.10	36.71	15.48	11.12	9.13	6.75
15	1,460.54	584.22	172.65	55.17	23.22	16.68	13.69	10.32
20	1,964.59	777.09	230.20	77.59	30.96	22.24	18.25	13.88
25	2,432.92	973.96	287.74	96.05	38.70	27.80	22.82	17.46
30	2,921.08	1,168.83	345.29	114.50	46.44	33.36	27.39	21.01
				10,000 Feet Elevation				
5	523.59	209.43	61.98	19.66	8.34	5.99	4.91	3.42
10	1,051.44	419.30	123.95	39.54	16.67	11.98	9.83	7.27
15	1,572.89	629.16	185.93	59.41	22.94	17.97	14.74	11.12
20	2,115.71	839.02	247.90	83.56	33.34	23.96	19.66	14.95
25	2,620.06	1,048.88	309.88	103.44	41.67	29.95	24.57	18.80
30	3,145.78	1,258.74	371.85	123.31	50.01	35.94	29.48	22.62

Source: Capital investment from Table 7 x .07707. Transmission lines have a useful life of 50 years and thus an annualization rate of .07707.

Size of the wastewater disposal system does not affect collection line costs, which are entirely a function of the number of people per acre. Table 9 shows the relationship between collection costs and population density at an elevation of 8,000 feet. The higher density, the lower costs of wastewater collection. Most of the decline (56.5 percent) occurs at low density levels, between 0.4 and 1.0 persons per acre. With 4 persons per dwelling, this is equivalent to 10 and 4 acres per dwelling. At these low densities, collection costs fall from $125 per capita to about $55, or by $70 per capita annually. With 4.0 persons per acre, or one dwelling, collection costs fall by about $11 more. At a density of 16.0 persons per acre, or 4 dwellings, collection costs fall by $6 more. No mountain community in Colorado has average densities that great, although peak seasonal recreation days may approach that level in Vail and Aspen. As size of city increases, there is a tendency for density also to increase (Appendix Table 4). However, there are definite limits to population density as crowding reduces psychological well-being. Although Manhattan Borough has a density of 106 persons per acre, New York City has an average density of 41 persons per acre, Chicago 24 and Boston 22 [48].

There are diseconomies of distance in wastewater transmission. Table 10 shows the effect of distance on transmission costs at an elevation of 8,000 feet. The costs to annex a subdivision of 2,560 people five miles away from the treatment plant are $18 per capita. This cost doubles to $36 to annex a subdivision 10 miles away and doubles again to $72 for 20 miles. To annex a subdivision 30 miles away would cost $115 per capita. The additional cost per mile of transmission is constant for each population level.

Transmission costs per mile are lower for large subdivisions or towns located the same distance away from the treatment plant than smaller ones, owing to efficiencies in the use of larger diameter transmission pipes. Table 10 shows the effects of population on transmission costs. It would cost $11 per capita to transmit the wastewater from a town of 20,480 people to a treatment plant 10 miles away compared to $36 per capita from a subdivision of 2,560 people.

Average total cost would be about $40 per capita for a sewer district with a design population of 10,000 people located at an elevation of 8,000 feet. This would include costs of $21.63 per capita to operate an activated sludge treatment plant with 1 million gallons per day capacity and administrate the sewer district. Land costs would average $0.30 per capita. With an average of 16 persons per acre, the wastewater collection system would cost $18.13 per capita (Table 9). If the population of one mountain town is less than 10,000 so that sufficient treatment capacity is available to bring a second town of 2,500 people into the district, 10 mile transmission costs would average $36.71 per capita for the 2,500 additional people (Table 10). Transmission costs would average $9.18 per capita if averaged over the 10,000 people served by the sanitation district. Thus, average total costs would rise from $40 to $49 per capita as a result of consolidation of the two districts.

For a sanitation district with a design population of 50,000 people, average total costs would fall to about $31 per capita if located at the same elevation. This would include costs of about $12.37 per capita for a 5 million gallon treatment plant and sanitation district. Land costs would average $0.09 per capita. With 16 persons per acre, wastewater collection would cost $18.13 per capita. If the district's population is 30,000 so that sufficient treatment capacity is available to bring a second town of 20,000 into the district, 10 miles transmission costs would average $11.12 per capita for the 20,000 persons added to the system. If averaged over the entire sanitation district, transmission costs would be $4.45 per capita, and average total costs of the wastewater system would rise from $31 to $35.

Costs of model wastewater disposal systems developed in this section are lower than actual costs of operating plants. The reason is that in developing these model costs, each wastewater disposal system was assumed to operate at 100 percent of design capacity. A 500,000 gallon per day wastewater system designed to served 5,000 people is assumed to serve exactly 5,000 people. In the actual operation of wastewater disposal systems plants rarely operate at 100 percent of design capacity. This is because the population served rarely equals the design population. If population is less than design population, costs rise. There are a number of reasons why this is the case, the most important of which is believed to be population growth.

Utilization of Capacity

Population growth affects the rate of utilization of wastewater systems and costs. The reason is that new wastewater systems have a long life and are planned with sufficient excess capacity in the early years to serve a "design population" 20 years in the future [49]. The more population is expected to grow the more excess capacity is necessary in the early years of operation with resulting higher costs. Table 10 shows that with zero population growth, utilization of capacity can be nearly 100 percent over 20 years with no increase in costs. With 3 percent percent annual growth in population, costs 10 years hence, midyear in the planning period, are increased by 34.4 percent. With 10 percent growth, midyear costs increase by 159.4 percent. A 15 percent annual population growth increases midyear costs to a level 304.5 percent higher than with zero population growth.

The population growth rates shown in Tables 11 and 12 are based on recent growth rates in mountain areas. Rapid growth rates of 10 and 15 percent have occurred in popular recreation areas and other boom towns in mountain areas. Population of Aspen increased by more than 10 percent per year between 1960 and 1975 [60]. Other towns with rapid population growth both in permanent

Table 11. Effects of Population Growth on Rate of Plant Utilization and Average Total Costs of Capital Per Capita, Model Wastewater Treatments Plants at 8,000 Feet Elevation, Colorado, 1975.[a]

Annual Population Growth Rates	Percent Increase In Costs	Treatment Plant Capacity (Gallons per Day)					
		50,000	100,000	500,000	1,000,000	5,000,000	10,000,000
Zero Growth or Design Population							
20 years hence	0	$23.84	$19.64	$13.65	$10.80	$7.16	$5.90
Population		500	1,000	5,000	10,000	50,000	100,000
3 Percent Growth							
Midterm (10 yrs hence)	34.4	$32.04	$26.40	$18.35	$14.51	$9.56	$7.93
Population		372	744	3,720	7,440	37,202	74,404
First Year	80.5	$43.03	$35.46	$24.67	$19.50	$12.93	$10.66
Population		277	554	2,768	5,537	27,685	55,371
5 Percent Growth							
Midterm (10 yrs hence)	62.8	$38.83	$31.99	$22.23	$17.57	$11.66	$9.61
Population		307	614	3,071	6,142	30,712	61,425
First Year	165.3	$63.07	$52.10	$36.18	$28.61	$18.97	$15.65
Population		189	377	1,886	3,773	18,868	37,736
10 Percent Growth							
Midterm (10 yrs hence)	159.4	$61.77	$50.89	$35.41	$27.99	$18.56	$15.31
Population		193	386	1,928	3,856	19,283	38,566
First Year	572.7	$158.94	$131.83	$91.64	$72.45	$52.86	$39.62
Population		75	149	745	1,490	7,451	14,903
15 Percent Growth							
Midterm (10 yrs hence)	304.5	$96.13	$79.53	$55.24	$43.65	$28.95	$23.88
Population		124	247	1,236	2,472	12,364	24,728
First Year	1,536.7	$384.54	$322.01	$223.12	$176.40	$117.07	$96.53
Population		31	61	305	611	3,054	6,116

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[a] This is for elevations of 8,000 feet; for elevations of 6,000 feet and below reduce costs shown by 28.57 percent; for 10,000 feet elevation increase costs by 7.15 percent.

Table 12. Effects of Population Growth on Rate of Utilization and Average Total Costs Per Capita, Wastewater Collection Lines at 8,000 Feet Elevation, Colorado, 1975.[a]

Annual Population Growth Rates	Average Number of People Per Acre				
	.4	1.0	4.0	16.0	64.0
Zero Growth or Design Population 20 years hence	$125.23	$ 54.44	$ 24.09	$ 18.13	$ 4.57
3 Percent Growth					
Midterm (10 years hence)	168.55	73.17	32.38	24.38	6.14
First Year	226.35	98.27	43.49	32.74	8.24
5 Percent Growth					
Midterm (10 years hence)	204.23	88.67	39.24	29.54	7.44
First Year	331.75	144.02	63.74	47.99	12.08
10 Percent Growth					
Midterm (10 years hence)	324.87	141.04	62.42	46.99	11.83
First Year	836.00	362.64	160.61	120.93	30.45
15 Percent Growth					
Midterm (10 years hence)	505.64	219.52	97.15	73.14	18.42
First Year	2,022.58	878.07	388.58	292.57	73.67

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[a] This is for elevations of 8,000 feet; for elevations of 6,000 feet and below reduce costs shown by 28.57 percent; for 10,000 feet elevation increase costs by 7.15 percent.

year around and peak recreation season populations include Vail and Breckenridge. It is generally assumed that new recreational areas such as Copper Mountain and Beaver Creek will experience rapid population growth similar to that of Aspen, Breckenridge and Vail. Low to moderate population growth rates of three to five percent are typical of recreational communities restricting growth and other stable mountain towns. An Aspen population study prepared for a water quality management program projected annual population growth of three percent for the next 15 years. This was based on a recent slow growth policy established under the Growth Management Plan for Aspen and Pitkin County [61].

Large treatment plants have lower average costs when used at or near capacity levels. However, when the present population is low and growth rapid, a smaller plant designed to handle the limited volume for 5-10 years would be more efficient than a larger plant with sufficient capacity to meet wastewater treatment needs of the community for 20 years. With 10 percent growth and a current population of 1,500 to 2,000 people, a new 500,000 gallon plant would have costs about $3 per capita lower than a plant designed to handle 1 million gallons. However, the larger plant would have lower costs over the long run than two of the smaller plants.

Collection costs developed in this report for 60 percent utilization of capacity are nearly identical to U.S. average costs when the latter are adjusted for mountain conditions. Appendix Table 4 shows sewer line costs for a sample of 1,516 wastewater systems in other areas serving an average population of 6,312 persons with density of 4 persons per acre. Average costs updated to 1975 were $29.82 per capita. This was calculated with 7.5 percent interest and 50 year life or 7.7 percent of capital costs of $386.90 per capita. Adding 30 percent for mountain elevations of 8,000 feet, collection costs become $38.76 per capita. This is $14.57 per capita higher than the $24.09

per capita costs for collection shown on Table 12, also for 4 persons per acre. However, it is nearly identical to the $39.24 midterm collection cost for communities with 5 percent annual growth in population. Midterm utilization of collection line capacity with 5 percent growth is 60 percent.

Not all costs increase with underutilization of capacity. Most variable costs of treatment and costs to administer the sanitation district vary directly with the volume of wastewater processed and thus per capita costs for them remain virtually unaffected by population growth and underutilization of the wastewater system. Capital costs are affected by underutilization of capacity. These include investment in the treatment plant, land, collection lines, and transmission lines. Table 11 shows the capital costs for treatment plants. Table 12 shows the costs for collection lines, all of which are capital. Capital costs for transmission lines are not developed in table form, however, they can be calculated by multiplying the percent increase in costs shown as column 1 of Table 11 by the per capita costs of transmission shown in Table 10. Totaling the costs of these three divisions of the wastewater disposal system provides a reasonably close estimate of the total costs of underutilization of capacity.

For example, at 60 percent utilization of capacity, average total costs would be about $58 per capita for a sewer district with a design population of 10,000 people located at an elevation of 8,000 feet. This would be midyear utilization at 5 percent annual growth. This would include about $17.57 per capita for capital costs and $9.84 for variable costs to operate a treatment plant with 1 million gallons per day capacity. Land costs would average $0.49 per capita. With an average of 16 persons per acre, the wastewater collection system would cost $30 per capita (Table 12). If the district includes a second town 10 miles away with a design capacity of 2,500 people, transmission costs would average $60 per capita at 60 percent utilization of capacity. Transmission costs would average $15 per capita if averaged over all 6,000 people served by the sanitation district. Thus, average total costs would rise from $58 to $73 per capita as a result of consolidation of the two districts.

With 60 percent utilization of capacity in a sanitation district with a design population of 50,000 people, average total costs would fall to about $47 per capita at the same 8,000 feet elevation. Sixty percent utilization of capacity is equivalent to midyear utilization at 5 percent annual growth. Costs would include about $11.66 per capita for capital costs and $4.73 for variable costs to operate a treatment plant with 5 million gallons per day capacity. Land costs would average $0.15 per capita. With an average of 16 persons per acre, the wastewater collection system would cost $30 per capita. If the district includes a second town 10 miles away with a design capacity of 20,000 people, transmission costs would average $18 per capita at 60 percent utilization of capacity. Transmission costs would average $7.25 per capita if averaged over all 30,000 people served by the sanitation district. Thus, average total costs would rise from $47 to $54 per capita as a result of consolidation of two districts.

POLICY IMPLICATIONS

The results of this study can contribute to decisions concerning efficient land use. Social decisions should be based on social costs meaning the total costs to society. Social costs of wastewater disposal in mountain areas are difficult to measure accurately. Costs of sanitation districts are affected by the Environmental Protection Agency subsidy grants program and by the tax free status of municipal bonds. In addition, there are social costs of water pollution by septic tanks, small package treatment plants and larger activated sludge plants. As a result, social costs tend to be higher than the accounting cost experience of sanitation districts.

Improvement in rate making to reflect actual social costs of service would discourage over-investment in wastewater disposal systems and premature development of land at the rural-urban fringe. Minimum and maximum levels of land subdivision can be shown for typical environmental conditions in mountain areas. Standards of effective wastewater disposal pricing allocate increased costs of low density and distant subdivision to residents of those areas. They also allocate peak load costs of seasonal recreation use of wastewater service to users during the peak hours. Under the severely restricting physical conditions of mountain areas it will be shown that optimum size is much lower than in other areas of the U.S. Land use subdivision which would increase size beyond optimum would increase average costs and may result in decisions to limit growth.

Tax Free Status of Municipal Bonds

Municipal bond yields do not reflect their total cost to society. The interest received from the investment in municipal bonds is exempt from federal income tax. Tax exemption allows the sale of municipal bonds at interest rates lower than required for taxable corporate bonds. Municipalities borrow at rates lower than the market rate which levies a cost on all society.

Another cost to society results from the fact that the distribution of benefits from ownership of tax exempt municipal bonds is not equitable or efficient. This is primarily due to progressive nature of the federal and state income tax rates. High income investors in tax exempt bonds may realize a "tax savings." For example, assume that the market rate of interest on taxable money is 10 percent. A local government needs to raise $1,000 in capital for a wastewater improvement project. Investor A is in the 60 percent income tax bracket and invests $800 in tax exempt bonds. He is willing to invest $800 at a 4 percent non-taxable rate which to him equals a 10 percent taxable rate. The municipality needs $200 more, thus it must offer an interest rate that attracts Investor B, who is willing to invest $200. Investor B is in the 40 percent income tax bracket, thus he will accept a non-taxable rate of 6 percent.

Since the bond market is undifferentiated, all buyers receive the same yield as the marginal buyer, or 6 percent in this example. Thus, Investor A receives a tax savings of $16 (20% x $80). Tax exempt bonds are a subsidy to people in high income brackets.

The example also illustrates the inefficiency caused by tax exempt bonds. The local government saves $40 from the lower tax exempt interest ($100 - $60). But federal and state governments lose $56 in revenue because of the tax exempt bonds ($80 x 60% + $20 x 40%). All governmental levels combined lose a net $16. This means that $1000 capital invested in wastewater disposal systems can end up costing society $116 or 1.6 percentage points more than the market rate of interest of 10 percent on taxable bonds.

Environmental Protection Agency Subsidy Program

Many mountain communities receive Environmental Protection Agency (EPA) grants to help finance improvements in their wastewater disposal systems. Sanitation districts that meet State Health Department standards are eligible to receive EPA grants representing 75 percent of the capital investment in wastewater treatment plants and interceptor sewers. How much does an EPA grant reduce sanitation district's costs and customer charge?

If capital costs of investment in a 1 million gallon per day treatment plant are reduced by 75 percent as a result of an EPA grant, costs of serving 10,000 people fall by $8.11 per capita or by 17.6 percent.

Table 13 shows costs for other plant sizes with and without an EPA grant. Costs are shown on a monthly basis for households of four persons. Monthly costs to households are equivalent to the average residential sewer bill. For a wastewater disposal system to be economically self-sustaining either the average sewer bill equals average costs or the district makes up the difference through tap fees assessed new dwellings added to the system or relies on a property tax mill levy for part of their revenue needs.

Table 13. Average Total Costs Per Capita For Wastewater Disposal With and Without an Environmental Protection Agency Grant, Mountain Areas of Colorado, 1975.[a]

Type of Costs	Number of People Served					
	500	1,000	5,000	10,000	50,000	100,000
	Size of Plant (Gallons per Day)					
	50,000	100,000	500,000	1,000,000	5,000,000	10,000,000
	Activated Sludge Plant					
Dollars per capita per year						
With	$67.14	$57.11	$42.56	$37.97	$31.38	$29.88
Without	85.02	71.85	52.81	46.08	36.76	34.31
Dollars per capita per month						
With	5.60	4.76	3.55	3.16	2.62	2.49
Without	7.09	5.99	4.40	3.84	3.06	2.89
Dollars per household per month						
With	22.40	19.04	14.20	12.64	10.48	9.96
Without	28.36	23.96	17.60	15.36	12.24	11.44
	Package Plant					
Dollars per capita per year						
With	67.93	54.55				
Without	75.99	60.52				
Dollars per capita per month						
With	5.66	4.55				
Without	6.33	5.04				
Dollars per household per month						
With	22.64	18.20				
Without	25.32	20.16				

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[a] With a density of 4 people per acre at 8,000 feet elevation.

Source: Tables 8 and 9.

Converting Septic Tanks

Septic tanks and leach fields are a temporary solution to the wastewater disposal problem under certain conditions. As a subdivision is developed and population grows, a wastewater collection and treatment system may become necessary to maintain water quality. If so, when should the wastewater system be constructed, at the time the subdivision is begun, when it is completely developed, or at some time in between? Downing [2] suggests that the relevant economic consideration is whether the annual costs of the wastewater collection and treatment system is more or less than the current annual costs of septic tanks and change over costs. Investment in septic tanks and leach fields is sunk and the undepreciated portion of that investment would be lost. Homeowners would incur conversion costs of removing or filling in septic tanks on their property. Tearing up existing streets to install new sewer lines also would increase costs.

It is not surprising that the most common method of wastewater disposal in mountain subdivisions is the septic tank and leach field. From the point of view of the individual homeowner, it is the most economical method of wastewater disposal under most conditions. Average annual costs are estimated as $44 per capita. This is substantially less than the alternatives in mountain areas: transmitting wastewater to a regional treatment plant in the nearest town, or constructing a small activated sludge or package plant at the edge of the subdivision.

Table 14 shows that transmitting wastewater to a regional treatment plant in the nearest town could cost $103.45 per capita, nearly 2.4 times the costs of septic tanks. This would be the cost for a small subdivision with a population of 640 people and a density of 4 persons or one dwelling per acre located 5 miles from an existing treatment plant serving a town of 10,000 people. Both the subdivision and the town are at an elevation of 8,000 feet. Costs would be

Table 14. Effect of Subdivision Location on Average Total Costs Per Capita For Sewage Disposal, Mountain Areas of Colorado, 1975[a]

Number of People Per Acre	Subdivision Population	Cost Category	Miles From Treatment Plant					
			5	10	15	20	25	30
.04	64	Transmission	$486.19	$976.34	$1,460.54	$1,964.59	$2,432.92	$2,921,08
		Collection	125.23	125.23	125.23	125.23	125.23	125.23
		Treatment	21.92	21.92	21.92	21.92	21.92	21.92
		Total	633.34	1,123.49	1,607,69	2,089.82	2,580.07	3,046.31
1.0	160	Transmission	194.47	389.35	584.22	779.09	973.96	1,168.83
		Collection	54.44	54.44	54.44	54.44	54.44	54.44
		Treatment	21.90	21.90	21.90	21.90	21.90	21.90
		Total	270.81	465.69	665.56	855.43	1,050.30	1,245.17
4.0	640	Transmission	57.55	115.10	172.65	230.20	287.74	345.29
		Collection	24.09	24.09	24.09	24.09	24.09	24.09
		Treatment	21.81	21.81	21.81	21.81	21.81	21.81
		Total	103.45	161.81	218.55	276.10	333.64	391.19
16.0	2,560	Transmission	18.26	36.71	55.17	77.59	96.05	114.50
		Collection	18.13	18.13	18.13	18.13	18.13	18.13
		Treatment	21.45	21.45	21.45	21.45	21.45	21.45
		Total	57.84	76.29	94.75	117.17	135.63	154.08
64.0	10,240	Transmission	7.74	15.48	23.22	30.96	38.70	46.44
		Collection	4.57	4.57	4.57	4.57	4.57	4.57
		Treatment	19.99	19.99	19.99	19.99	19.99	19.99
		Total	32.30	40.04	55.52	55.52	63.26	71.00

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[a] At a mountain elevation of 8,000 feet.

Source: Tables 8, 9 and 10.

higher if the subdivision was located a greater distance from the treatment plant. Transmitting the wastewater 10 miles raises costs to $161.81 per capita, or 3.7 times the cost of septic tanks. Costs would be lower if population or density were higher. Costs fall to $57.84 per capita when population is increased to 2,560 persons and density to 16 persons or 4 dwellings per acre, only about one-third more than the costs of septic tanks. The break even point where the costs of transmitting wastewater to a regional treatment plant equals the cost of septic tanks of $44 per capita occurs at a population of 14,000 persons and a density of 16 people per acre.

It is often cheaper to form a new sanitation district than to join an existing one. Table 15 shows that constructing a small activated sludge or package plant at the edge of the subdivision would cost $68.62 per capita, nearly 1.6 times the costs of septic tanks. This is for a subdivision with 640 people and a density of 4 persons or one dwelling per acre. Costs would be higher if the subdivision had fewer people or lower density. With a population of only 160 people, and the same density, costs increase to $113.82 per capita, or 2.6 times the cost of septic tanks. With a density of one person per acre, and population remaining 640 people, costs increase to $98.97 per capita, or 2.3 times the cost of septic tanks. Costs fall when population or density is increased. With a population of 10,240 persons and the same density of 4 persons per acre, costs decline to $45.97 per capita, only 4 percent higher than for septic tanks. Increasing density to 16 persons or four dwellings per acre with the same population of 640 persons, costs are $62.66, about 42 percent higher than for septic tanks. The break even point where the costs of a small activated sludge plant equals the cost of septic tanks of $44 per capita for a density of 16 persons or 4 dwellings per acre occurs at a population of 8,600 persons. At a density of 8 persons or 2 dwellings

Table 15. Average Total Cost Per Capita For Sewage Collection and Treatment by Package Plants and Activated Sludge Plants, Mountain Areas of Colorado, 1975.[a]

Number of People Per Acre	Cost Category	Population				
		64	160	640	2,560	10,240
				Package Plant		
0.4	Collection	$125.23	$125.23	$125.23	$125.23	$125.23
	Treatment	130.80	89.73	44.53	40.29	21.88
	Total	256.03	214.96	169.76	165.52	147.11
1.0	Collection	54.44	54.44	54.44	54.44	54.44
	Treatment	130.80	89.73	44.53	40.29	21.88
	Total	185.24	144.17	98.97	94.73	76.32
4.0	Collection	24.09	24.09	24.09	24.09	24.09
	Treatment	130.80	89.73	44.53	40.29	21.88
	Total	154.89	113.82	68.62	64.38	45.97
				Activated Sludge Plant		
16.0	Collection	18.13	18.13	18.13	18.13	18.13
	Treatment	130.80	89.73	44.53	40.29	21.88
	Total	148.93	107.86	62.66	58.42	40.01
64.0	Collection	4.57	4.57	4.57	4.57	4.57
	Treatment	130.80	89.73	44.53	40.29	21.88
	Total	135.37	94.30	49.10	44.89	26.45

[a] At a mountain elevation of 8,000 feet.

Source: Tables 8 and 9.

per acre, the break even point occurs at a population of 9,820 persons. At higher population or density levels, small treatment plants are cheaper than septic tanks.

External Costs

Decisions about converting septic tanks to alternative wastewater disposal methods also depend on external costs. The most important external costs of wastewater disposal is water pollution by fecal coliform and oxygen demanding materials, nutrients which contribute to eutrophication including phosphorus and nitrogen, heavy metals, pesticides and dissolved solids. Water pollution imposes a number of external costs on society. A recent estimate of the external cost of aesthetic damages from water pollution in Colorado was $80 million annually [52]. Total damages including human health and materials damages are not known.

External costs are imposed by each of the three alternative wastewater disposal systems in mountain areas. The alternative with the highest level of pollution is the septic tank. Package plants tend to be more polluting than larger activated sludge plants, which can more readily adopt the latest tertiary treatment technology.

In the past, the most common method of wastewater disposal in mountain subdivisions was the septic tank. This has become increasingly unsatisfactory. Waltz [17] found that most Colorado mountain septic tanks violate pollution control standards. This is expected to worsen in the future. With continued building on vacant land, dwellings tend to be located nearer one another. And, the more dense a residential development, the more frequent contamination of domestic wells by septic tank effluent. Waltz showed that more than one-third of septic tanks serving dwellings located on scattered tracts were polluting domestic wells compared to about two-thirds of those located in densely developed tracts. Contamination of well water results from faulty evaluation of soil conditions and impropor installation of the septic system. A percolation test may not adequately indicate how well soil overlying fractured rock will filter the liquid sewage in the long run [17]. At the time of the percolation test, the soil may be adequate to filter the sewage, but after a few years of operation the filtering ability of the soil may deteriorate. Further tests may indicate that the soil is not longer able to filter the sewage.

Package plants tend to have more operating problems than larger activated sludge plants. Most are small and have part-time operation and maintenance personnel. The use of part-time service operators results in inefficient sewage treatment. The California State Department of Public Health, Bureau of Sanitary Engineering, conducted a study of small community sewage disposal systems in the Sierra Nevada Mountains and part of the San Bernadino Mountains [3].

> "The results indicated that 56 percent of the plants had experienced equipment outages during the preceding year . . . Thirty-three percent of the plants reported the necessity of bypassing untreated sewage for periods ranging from 6 hours to an incredible 300 days!"

The Bureau concluded that there is a need for full-time package plant operators to provide reliable treatment plant operation to protect the public health.

Medium to large size activated sludge treatment plants potentially have low external costs when they adopt the latest tertiary treatment technology. Activated sludge plants with secondary treatment remove 90 percent of the BOD from effluent flowing from the plant into a stream or lake. The Colorado Public Health Department has determined that the effluent from secondary treatment may be harmful to the state's fish and wildlife [26]. The Colorado Water Quality Standards (C.R.S. 6-28-202 (a) and 66-28-203) require that "all state waters shall be . . . free from substances . . . in concentrations or combinations which are toxic or harmful to human, animal, plant or aquatic life." No criteria are established for ammonia or any other potentially toxic substances. However, the Water Quality Control Commission is considering the adoption of ammonia standards to implement the above statute. The Upper Eagle Valley Sanitation District, as well as other entities discharging to the Upper Eagle River drainage basin, will be regulated by ammonia restrictions contained in their Pollution Discharge Elimination System permits [31]. Some sanitation districts in mountain areas have incurred substantial costs to lessen external costs. Breckenridge in Summit County, Colorado, was required to reduce residual chlorine from .05 parts per million to .02 parts per million [58].

Consolidation of Sanitation Districts

The results of this study can contribute to decisions concerning the most efficient use of mountain land. Minimum and maximum levels of residential development can be shown for typical environmental conditions in mountain areas. Would consolidation of wastewater disposal districts be efficient when located in mountain topography with narrow valleys and steeply rising slopes? For example, consider a valley one-fourth mile wide lined with steep mountain slopes, limiting development to a strip of 160 acre subdivisions extending up the valley 15 miles above the treatment plant.

With limited available land area for residential subdivision in mountain areas, the optimum size wastewater disposal system is much smaller than in other areas of the U.S. Figure 2 shows that the least-cost wastewater disposal is $52.63 for a 1.28 million gallon plant serving a population of 12,800 located within 5 miles of the treatment plant. This is less than 10 percent more than septic tank costs. Figure 2 also shows optimum plant size for population densities of 1 and 16 persons per acre. The optimum size wastewater disposal system for the lower density ranges from 2,500 to 6,500 people. For the higher density level, the optimum size wastewater disposal system serves 51,200 people.

Up to optimum size, consolidation of sanitation districts is a viable option, and residential development may be encouraged up to an optimum community size of 12,800 people. For subdivisions located closer than 5 miles, consolidation of new subdivisions lowers average total costs of the district. For example, adding subdivisions located from 1 to 2.5 miles from the treatment plant increases population to 6,400 and lowers cost from $65.57 to $53.85 per capita or by 18 percent.

For subdivisions located farther away than 5 miles, consolidation with the sanitation district would increase average total costs. For example, consolida-

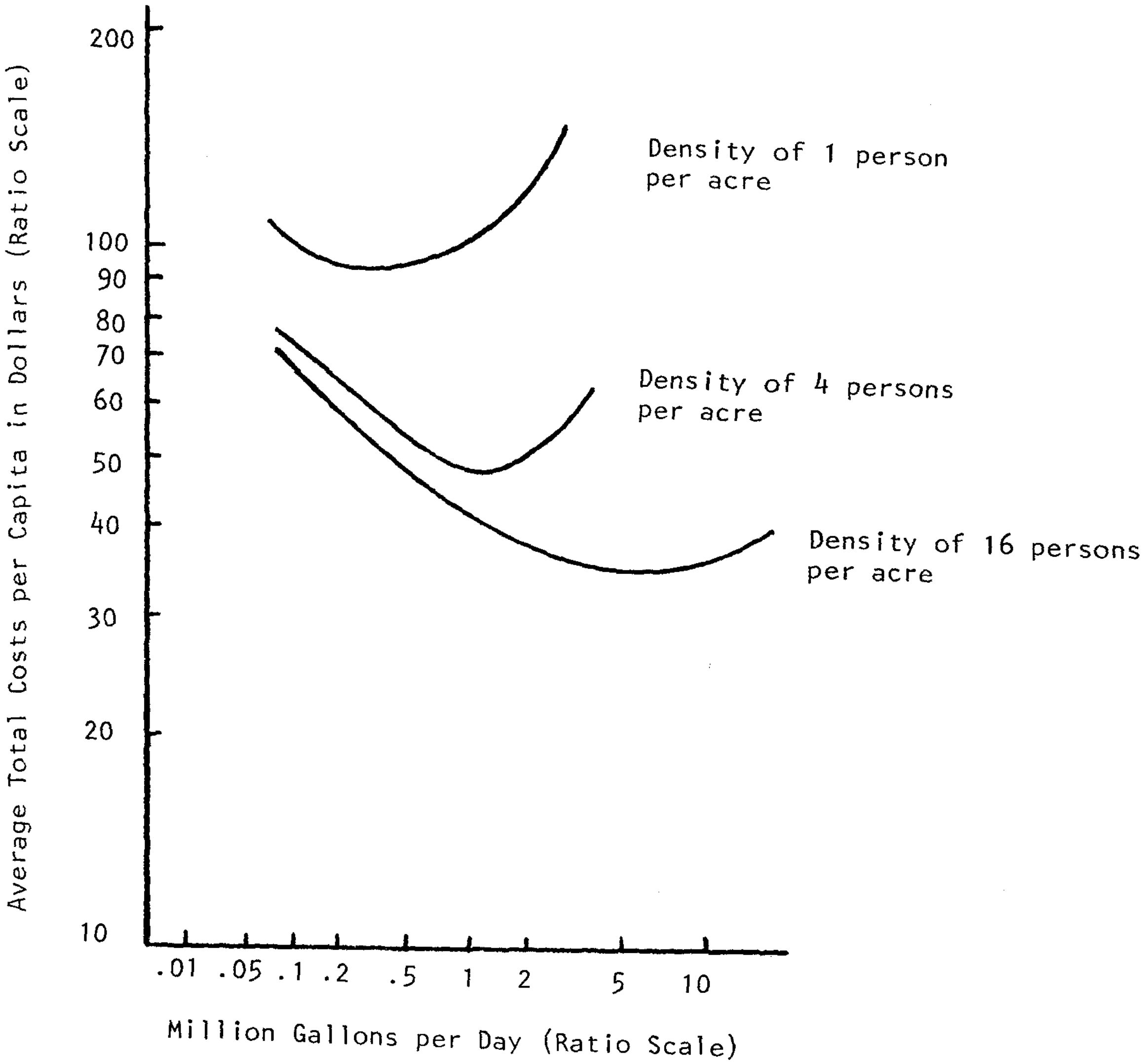

Figure 2. Average Total Costs Per Capita For Treatment, Collection and Transmission of Wastewater at a Mountain Elevation of 8,000 Feet, Colorado, 1975.

Table 16. Average Annual Costs Per Capita For Wastewater Disposal in Mountain Areas, Colorado, 1975.

Average Population Density Per Acre	Cost and Miles	Number of People Served (Design Population)											
		640	1280	2560	3840	6400	12,800	25,600	38,400	51,200	76,800	89,600	102,400
1.0	Transmission	$ 1.99	$ 3.97	$ 7.94	$12.90	$21.84	$41.69	$81.50					
	Treatment	57.24	46.40	40.29	33.51	26.78	21.40	18.24					
	Collection	54.09	54.09	54.09	54.09	54.09	54.09	54.09					
	TOTAL	113.32	104.46	102.32	100.50	102.71	117.18	153.83					
	Miles	1	2	4	6	10	20	40					
4.0	Transmission	.29	.59	1.19		2.98	7.14	13.18	$24.99				
	Treatment	57.24	46.40	40.29		26.78	21.40	18.24	15.21				
	Collection	24.09	24.09	24.09		24.09	24.09	24.09	24.09				
	TOTAL	81.60	71.08	65.57		53.85	52.65	55.05	64.29				
	Miles	¼	½	1		2½	5	10	15				
16.0	Transmission	.06	.13	.26		.65	1.30	2.77	3.88	$ 5.18	$ 7.76	$ 8.80	$10.35
	Treatment	57.24	46.40	40.29		26.78	21.40	18.24	15.21	12.36	11.07	10.43	9.92
	Collection	18.13	18.13	18.13		18.13	18.13	18.13	18.13	18.13	18.13	18.13	18.13
	TOTAL	75.43	64.66	58.68		45.56	40.83	39.14	37.22	35.67	36.96	37.36	38.40
	Miles	1/16	1/8	1/4		5/8	1¼	2½	3 3/4	5	7½	8 3/4	10

tion of a strip of subdivisions extending 10 miles from the plant increases total population of the district to 25,600 people, but average total costs rise to $55.05 per capita, or 5 percent more than least-cost operations with 12,800 people within 5 miles of the treatment plant. Consolidation of subdivisions extending 15 miles from the plant increases total population to 38,400 and average total costs rise to $58.34, or 11 percent more than least-cost operations. The reason why wastewater disposal costs rise for population levels above 12,800 people is wholly due to transmission costs. Treatment costs decline from $40.29 per capita for the first 2,560 residents located within 1 mile of the plant to $15.21 per capita for 38,400 persons living within 15 miles of the plant. Collection costs do not change because they are related to density of development which is a uniform 4 persons or 1 dwelling per acre throughout the residential area. Transmission costs are calculated as $2.38 per mile [2]. Figure 2 shows that transmission costs rise continuously as wastewater is transported farther and farther from residential development to the treatment plant.

The costs of transmission presented in Figure 2 are considerably lower than transmission costs presented in Table 10 . Figure 2 illustrates a case in pre-planning when the design capacity of the sewer pipe between the added subdivision and the treatment plant can be increased in size. The transmission costs shown are the costs of installing sewer pipe of additional capacity sufficient to carry the wastewater from the subdivision in addition to the wastewater the pipe was designed to carry without the subdivision's load. This would be true only if the pipe has not yet been laid. Once the pipe is installed, its capacity cannot be increased. Extra capacity can be obtained only by installing a second pipe. The costs of transmission shown in Table 10 are for new sewer pipe of sufficient capacity to carry only the wastewater of the subdivision in question. Thus, it has higher costs. Under these conditions, with scattered development averaging 1 dwelling per every 4 acres, wastewater transmission would be prohibitively high, averaging $194 per capita when 5 miles from the treatment plant, $389 per capita when 10 miles, and $584 when 15 miles. This is shown in Table 10 . For an average family of 4 persons, located 5 miles from the treatment plant, transmission costs alone would average $776 per year, plus collection costs of $218 and treatment costs of $86, totaling $1,080 annually. This would equal 4.3 percent of the annual income of $25,000 reported as the modal level for Aspen skiers in 1974 [51]. For developments with dwellings even more scattered, 1 dwelling per 10 acres, annual costs rise an additional $1,452 per residence and total wastewater disposal costs rise to 10.1 percent of an income of $25,000. With a 1 in 3 chance of polluting rivers and domestic wells by septic tanks on these scattered residential tracts, decisions to restrict residential development may result in this case.

Peak Load Pricing

The information presented in this report has several important policy implications for rate making. Uniform pricing of wastewater disposal services seems less suited to mountain areas than to other areas of the U.S. Peak load problems are more severe in mountain areas because of the seasonal nature of recreation activity. Spatial problems are more severe in narrow mountain valleys owing to the limits on density of residential development and the extension of sewer lines over greater distances.

Table 3 shows that most mountain areas have distinct seasonal recreation peaks, as for example, during the Christmas holiday or on the Fourth of July weekend. For purposes of rate making, the peak is defined as those days in which the wastewater disposal capacity is operated at or close to maximum available collection and treatment capacity. Peak recreation users require substantial investment in collection and treatment capacity which stands idle or only partially used during most of the year.

Standards of peak load pricing would allocate costs of providing peak loads to users during the peak hours. No peak capacity costs would be assigned to off-peak consumption by year around residents, who would be charged off-peak costs. This suggests that sanitation districts should explore the merits of a variable pricing schedule in which peak seasonal users would pay wastewater disposal costs attributed to them and year around residents would pay substantially lower sewer rates.

Table 17 shows that to include all peak load costs in uniform rates levies a substantial tax burden on residents for which they are not responsible. However, if peak load costs could be shifted to peak recreation users, the cost per capita would be very small. The normal peak to average flow ratio for residential areas is 1.68 [2]. Aspen has a peak to average flow ratio for residential areas of about 5.0 so 3.32 of the peak flow is attributed to the

18,075 peak users, primarily skiers. Table 17 shows that under a uniform rate pricing system, seasonal recreation use costs the average resident an estimated $22.58 annually. If this cost could be shifted to the peak recreation users, their costs would average $5.71 per capita. If the peak load cost could be shared by all seasonal recreation users, the average cost would be $0.34 per day. Table 17 also shows the peak load costs associated with recreation users at Aspen with a lower peak ratio and Breckenridge with a much higher peak ratio.

Facilities used by tourists such as motels, condominiums, restaurants and ski lodges could be charged a sewer bill which in total equaled the proportion of total wastewater disposal costs attributed to the peak load of seasonal recreation users. Presumably, these recreational businesses could pass on these higher sewer fees to tourists in the form of higher food and lodging prices.

Uniform pricing of wastewater disposal services also imposes a tax on residents who are located in high density areas or near the treatment plant. It gives a subsidy to residents in lower density subdivisions located farther from the treatment plant. Uniform pricing encourages over-investment in wastewater collection and transmission lines, and premature development of land at the rural-urban fringe.

Standards of wastewater disposal pricing would allocate increased costs associated with low density and distant development to residents of those areas. Other residents would pay only for the costs associated with their higher density and closeness to the treatment plant. This suggests that sanitation districts.should explore the merits of a variable pricing schedule in which users on the rural-urban fringe would pay for wastewater collection and transmission costs attributed to them and residents of the developed town would pay a substantially lower rate. Rates would increase as development occurred farther

Table 17. Average Annual Peak Load Costs of Seasonal Recreation Use of Wastewater Disposal Services in Mountain Areas, Colorado, 1975.

Variable	Aspen	Vail	Breckenridge
Elevation in Feet	8,000	8,000	10,000
Peak Load Ratio	2.5	5.0	10.0
Normal Residential Peak Load	1.68	1.68	1.68
Peak Load of Seasonal Recreation Users	0.82	3.32	8.32
Total Annual Recreational Peak Load Costs	$51,064	$103,191	$92,335
Resident Population	9,234	4,570	1,500
Additional Costs of Recreation Peak Load to Residents	$8.52	$22.58	$60.89
Peak Recreation Population	11,524	18,075	17,500
Additional Costs of Recreation Peak Load to Recreation Users	$4.43	$5.71	$5.22
Total Annual Recreation Visitor Days (1973)	369,200	301,700	138,500
Additional Costs of Recreation Peak Load per Visitor Day	$0.14	$0.32	$0.67

Source: Tables 3 and 4.

away from the treatment plant. Increased rates should reflect the increased costs associated with the increased distance.

The Aspen Sanitation District has a variable pricing schedule. The average sewer rate is 37 percent higher in the service area outside the town than in Aspen. Also, new residential tap fees are a flat $400 within the town of Aspen, compared to variable tap fees of $400 to $4,000 outside of town, depending on the volume of sewage and distance from the treatment plant. Their pricing schedule could be further improved by varying sewer rates outside the town with costs of density and distance. For example, at a density of 4 persons per acre, the added costs of consolidating a sanitation district 5 miles away on the rural-urban fringe of a town would average $52.65 per capita if the transmission line had not yet been laid between the treatment plant and the subdivision in question, and the intervening land area had been completely built up. However, the added costs of consolidating the same sanitation district with the central town would average $103.45 per capita if the sewer pipe for intervening subdivisions had already been laid, so that a new 5 mile transmission line would be required serving only the new subdivision. At a density of 1 person per acre, these costs would rise to $101.41 and $270.81 respectively. At a density of 16 persons per acre, costs would fall to $35.67 and $57.84 respectively.

Appendix A

COSTS IN OTHER AREAS OF THE U.S.

The purpose of this appendix is to show the sources of information on the costs of wastewater treatment and collection in other areas of the U.S. These studies provide a data base for this report. They were averaged, updated, and adjusted for the effects of elevation to estimate wastewater disposal costs in mountain areas.

Treatment Costs

Appendix Table 1 shows the results of recent studies of the costs of constructing wastewater treatment plants updated to April, 1975.[7] These capital investment costs were updated using the Environmental Protection Agency Water Quality Office, Sewage Treatment Plant Index for Denver [14]. Shown below are the citations to the studies included, location, date, and appropriate index number to update the results to April 1975.

Capital Investment Sources

Source	Location	Date	Index
[14]	Denver	April 1975	211.70
[3]	U.S.	1973	181.60
[3]	U.S.	1973	181.60
[54]	Dallas	December 1974	198.24
[2]	U.S.	1957-1959	100.00
[28]	U.S.	1972	170.00
[13]	Dallas	December 1974	198.24

Goldstein [3] adjusted 1968 costs presented by Smith and Eilers [41] to 1973 dollars on the basis 6.25 percent annual inflation. Smith and Eilers' costs are a best-fit estimating relationship of form, $Y = AX^B$. Y is the per capita cost for a community of population X. A and B are constants used to allow the curve to fit the points on a graph relating per capita costs to

Appendix Table 1. Comparison of Recent Studies of Total Construction Costs of Wastewater Treatment Plants in Other Areas of the U.S., Updated to 1975.

Type of Treatment	Source	Number of People Served					
		500	1,000	5,000	10,000	50,000	100,000
		Size of Plant					
		50,000	100,000	500,000	1,000,000	5,000,000	10,000,000
		Total Costs					
Activated Sludge	a	$106,225	$171,510	$521,700	$842,400	$2,562,500	
	b	83,605	144,560	515,450	891,400	3,138,000	
	c		170,220		969,900		$5,541,000
	d		139,300		734,600		3,874,000
Average:		94,915	156,400	518,600	859,600	2,850,500	4,701,000
Trickling Filter	a	108,830	175,510	532,400	858,700	2,604,500	
	b	72,680	126,540	458,550	798,400	2,893,500	
	c		161,710		775,000		4,127,000
	d		157,930		726,100		3,345,000
Average:		90,755	155,420	495,500	789,600	2,749,000	3,736,000
Stabilization Ponds	a	52,880	69,540	131,300	172,700	326,000	428,000
	c		33,780		186,500		779,000
Average:		52,880	51,600	131,300	179,600	326,000	604,000
Package Plants	c		76,890				
	e	36,725	55,150	130,750			
	f	41,465	41,650				
Average:		39,050	57,900	130,750			

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a Findings attributed to Michel in Smith and Eilers [41] and shown in Goldstein. Operation and maintenance costs for the 5 million gallon per day plant were developed from an equation in Smith and Eilers [41].

b Findings attributed to Smith in Smith and Eilers [41] and shown in Goldstein. Operation and maintenance costs for the 5 million gallon per day plant were developed from an equation in Smith and Eilers [41].

c Young and Admed [54].

d Data from a 1964 Public Health Service study in Downing [2].

e These are basic plant costs excluding the costs of freight to the site, installation, and service agreement [28].

f Qasim and Shah [13].

community size. Shown below are the A and B constants used by Smith and Eilers [41] in their best fit equation, and the basic data sources for their analysis.

		$Y = AX^B$	
Treatment System	Source	A	B
Capital Treatment Costs			
Stabilization Ponds		3,865.24	-0.6050
Activated Sludge		1,232.19	-0.3088
		524.81	-0.2100
Trickling Filter		1,275.78	-0.3105
		428.73	-0.2000
Variable Costs (Dollars per Year)			
Operation and Maintenance			
Stabilization Ponds		23.46	-0.4172
Activated Sludge		40.64	-0.2460
		40.05	-0.2400
Trickling Filter		74.24	-0.3569
		71.04	-0.3400
Customer Service and Accounting		101.55	-0.4500
General and Administrative		309.29	-0.5000

Appendix Table 2 shows the results of recent studies of variable costs including operation and maintenance, customer service, and general and administrative, updated to April 1975. Updating of variable costs was based on reported average weekly earnings for nonsupervisory workers in water, steam and sanitary systems [14]. For 1957-59, the basis for updating was the average weekly earnings for nonsupervisory workers in electric power systems. Shown below are the citations to the studies included, location, date, and appropriate index number to update the results.

Variable Cost Sources

Source	Location	Date	Average Weekly Earning
[14]	Denver	April 1975	196.25
[3]	U.S.	1973	175.14
[3]	U.S.	1973	175.14
[54]	Dallas	December 1974	195.88
[2]	U.S.	1957-1959	100.56
[13]	Dallas	December 1974	195.88

Appendix Table 2. Comparison of Recent Studies of Variables Costs of Wastewater Treatment in Other Areas of the U.S., Updated to 1975.

Type of Treatment and Costs	Source	Number of People Served					
		500	1,000	5,000	10,000	50,000	100,000
		Size of Plant					
		50,000	100,000	500,000	1,000,000	5,000,000	10,000,000
Activated Sludge Operation and Maintenance	a	$4,927	$8,290	$27,975	$47,010	$156,850	
	b	5,040	8,506	29,110	49,270	165,300	
	c		9,015		50,110		$279,800
	d		6,848		37,110		231,700
Average		4,983	8,167	28,540	45,880	161,000	257,200
Customer Service		3,477	5,040	12,300	17,800	27,500	39,600
General & Admin.		7,725	10,970	24,650	34,700	48,000	67,800
TOTAL		16,179	24,177	65,490	98,380	236,500	364,600
Trickling Filer Operation and Maintenance	a	4,536	7,056	20,160	31,270	86,650	
	b	4,814	7,611	21,855	34,670	99,400	
	c		7,008		33,060		160,100
	d		8,996		27,410		143,200
Average		4,677	7,668	21,005	31,650	93,250	151,700
Customer Service		3,472	5,040	12,300	17,800	27,500	39,600
General & Admin.		7,725	10,970	24,650	34,700	48,000	67,800
TOTAL		15,873	23,678	57,955	84,150	168,750	259,100
Stabilization Pond Operation and Maintenance	a	1,008	1,451	3,770	5,560	14,150	20,700
	c		1,507		5,370		18,800
Average		1,008	1,479	3,770	5,460	14,150	19,800
Customer Service		3,472	5,040	12,300	17,800	27,500	39,600
General & Admin.		7,725	10,970	24,650	34,700	48,000	67,800
TOTAL		12,204	17,489	40,720	57,960	89,650	127,200
Package Plant Operation and Maintenance	f	6,830	8,487				
Average		6,830	8,487				
Customer Service		3,472	5,040				
General & Admin.		7,725	10,970				
TOTAL		18,025	24,497				

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[a] Findings attributed to Michel in Smith and Eilers [41] and shown in Goldstein. Operation and maintenance costs for the 5 million gallon per day plant were developed from an equation in Smith and Eilers [41] .

[b] Findings attributed to Smith in Smith and Eilers [41] and shown in Goldstein. Operation and maintenance costs for the 5 million gallon per day plant were developed from an equation in Smith and Eilers [41] .

[c] Young and Admed [54].

[d] Data from a 1964 Public Health Service study in Downing[2].

[e] These are basic plant costs excluding the costs of freight to the site, installation, and service agreement [28].

[f] Qasim and Shah [13].

Collection Costs

Appendix Table 3 shows the effect of number of people per acre on the costs of wastewater collection lines in other areas of the U.S. updated to April 1975. Collection costs are shown for varying densities of population within a 160 acre area. The geographic area was held constant because distance also affects wastewater collection line costs. Daily pipe capacity was 225 gallons per capita compared to standard average daily flows of 100 gallons per capita, thus allowing for peak flow periods [2]. Manholes were spaced every 300 feet. Sandy loam soil conditions in southern Wisconsin allowed easy trenching.

Appendix Table 4 shows the effects of population on average costs of construction and length of wastewater collection lines in other areas of the U.S. updated to 1975. The data are averages for a nationwide sample of nearly 13,000 wastewater collection systems. The data presented in Appendix Table 3 were used as a basis for analysis of wastewater collection costs in mountain areas of Colorado. The principle use of data presented in Appendix Table 4 is to verify the general relationships developed.

Wastewater collection costs presented in Appendix Tables 3 and 4 were updated based on the Environmental Protection Agency, Water Quality Office, Sewage Treatment Plant Index for Denver [14]. Shown below are the citations to the studies used, location, date, and appropriate index number to update the results to April 1975.

Wastewater Collection Sources

Source	Location	Date	Index
[14]	Denver	April 1975	217.0
[2]	U.S.	1957-1959	100.0
[3]	U.S.	1973	196.5

Appendix Table 3. Effect of Number of People Per Acre on Costs of Wastewater Collection Lines in Other Areas of the U.S., Updated to 1975.

Density (people/acre)	Population per 160 Acre Area	Total Sewer Cost for 160 Acre Area ($)	Total Sewer Cost ($/capita)	Annual Sewer Costs ($/capita/yr)
.4	64	$ 80,103	$1,249.92	$90.62
1.0	160	86,939	543.37	39.39
4.0	640	153,896	240.46	17.43
16.0	2,560	463,508	180.98	13.12
64.0	10,240	467,129	45.61	3.31
128.0	20,480	476,033	23.24	1.68
256.0	40,960	419,077	10.22	.74
512.0	81,920	483,637	5.90	.42

Source: [2]

Appendix Table 4. Effects of Population on Average Cost of Construction and Length of Wastewater Collection Lines in Other Areas of the U.S., Updated to April 1975.

Population (persons)	Number of Systems	Average Served Population per System	Average Sewer Cost/Capita	Average Sewer Length per Capita (feet)	Average Sewer Cost per Foot (dollars/foot/capita)	Persons Per Acre[a/]
Less than 500	1,791	387	$746.72	36.93	$20.22	1.794
500-1,000	2,259	809	627.70	32.10	19.55	2.226
1,000-5,000	5,375	2,304	490.58	26.32	18.64	3.022
5,000-10,000	1,516	6,312	386.90	21.73	17.80	4.058
10,000-25,000	1,200	12,920	326.82	18.96	17.24	5.004
25,000-50,000	422	30,089	267.80	16.15	16.58	6.407
50,000-100,000	203	66,114	222.46	13.91	15.99	8.06
100,000 & over	145	511,212	137.40	9.43	14.57	14.72

[a/] Feet of installed sewer/capita = 54 $(\text{persons/acre})^{-.65}$

Source: [3]

APPENDIX B

ADJUSTING TREATMENT COSTS FOR MOUNTAIN INSTALLATION IN COLORADO

(1) How much are construction costs of sewage treatment plants expected to increase in mountainous areas?

a. At elevations of:
6,000 feet ________ percent
8,000 feet ________ percent
10,000 feet ________ percent

b. What proportion of this expected increase in the cost of construction results from:
Soil conditions ________ percent
Cold temperatures ________ percent
Inaccessibility ________ percent
Other ________ percent (specify what________________)

(2) How much are operating and maintenance costs of sewage treatment plants expected to increase in mountainous areas?

a. At elevations of:
6,000 feet ________ percent
8,000 feet ________ percent
10,000 feet ________ percent

b. What proportion of this expected increase in the cost of operation and maintenance results from:
Soil conditions ________ percent
Cold temperatures ________ percent
Inaccessibility ________ percent
Other ________ percent (specify what__________
______________________)

(3) How much are sewer line installation costs expected to increase in mountainous areas?

a. At elevations of:
6,000 feet ________ percent
8,000 feet ________ percent
10,000 feet ________ percent

b. What proportion of this expected increase in cost of sewerline installation result from:
Soil conditions ________ percent
Cold temperatures ________ percent
Inaccessibility ________ percent
Other ________ percent (specify what__________
______________________)

c. With soil types:
Bedrock ________ percent
Weathered granite ________ percent
Bouldry glacial materials ________ percent
Aluvial soil and gravel ________ percent

(4) What are the typical land requirements for treatment plants in mountain areas? Number of acres.

Number of persons served:	Type of treatment: Activated sludge	Trickling filter	Stabilization pond	Package plant
500	________	________	________	________
1,000	________	________	________	________
5,000	________	________	________	________
10,000	________	________	________	________
50,000	________	________	________	________

(5) What are the typical costs per acre for the required land? $________per acre.

(6) Other comments about mountain treatment costs?______________________________
____

FOOTNOTES

[1/] This study was funded by the Experiment Station, Colorado State University, and by the Eisenhower Consortium, Forest Service, U.S. Department of Agriculture. The assistance of Raymond Ericson and James P. Waltz is gratefully acknowledged.

[2/] Dr. Walsh is Professor of Economics, Mr. Soper was formerly a graduate student, and Dr. Prato was formerly Associate Professor of Economics, Colorado State University, Fort Collins.

[3/] The costs of Jackson County, Wyoming, governmental services (fire, policy, roads, schools, social services, etc.) exceeded revenues from taxes paid by seasonal, or second home, type of subdivision development where housing values were in the medium range of $31,000 or below. County services studies did not include water or sewer districts, however the study concluded that cental sewer systems were not generally cost-effective unless the density or development was greater than one house per two acres [23].

[4/] Also see the unpublished M.S. thesis prepared by Mr. Soper under the supervision of Dr. Walsh. It is entitled, "Costs of Wastewater Collection and Treatment in Mountain Areas," Department of Economics, Colorado State University, 1977.

[5/] Elevations of other Colorado mountain towns are as follows: Alamosa 7,544 feet, Buena Vista 8,020 feet, Craig 6,231 feet, Crested Butte 8,867 feet, Dillion 9,156 feet, Durango 6,512 feet, Estes Park 7,522 feet, Fairplay 10,000 feet, Fraser 8,550 feet, Grand Lake 8,579 feet, Gunnison 7,694 feet, Salida 7,050 feet, Telluride 8,745 feet, Winter Park 9,084 feet [24].

[6/] Population of other Colorado mountain towns in 1974 are as follows: Buena Vista 2,071, Craig 4,437, Durango 12,500, Glenwood Springs 4,642, Gunnison 5,313, Leadville 4,423, Salida 5,139, Steamboat Springs 4,000, Telluride 1,000 [24].

[7/] To update capital investment costs from April 1975 to January 1977, apply the index for Denver, Colorado. Costs of capital construction increased 13.6 percent for wastewater treatment plants and 8.2 percent for sewer lines [14].

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