ENVIRONMENTAL INVENTORY AND LAND USE RECOMMENDATIONS FOR BOULDER COUNTY, COLORADO

Richard F. Madole

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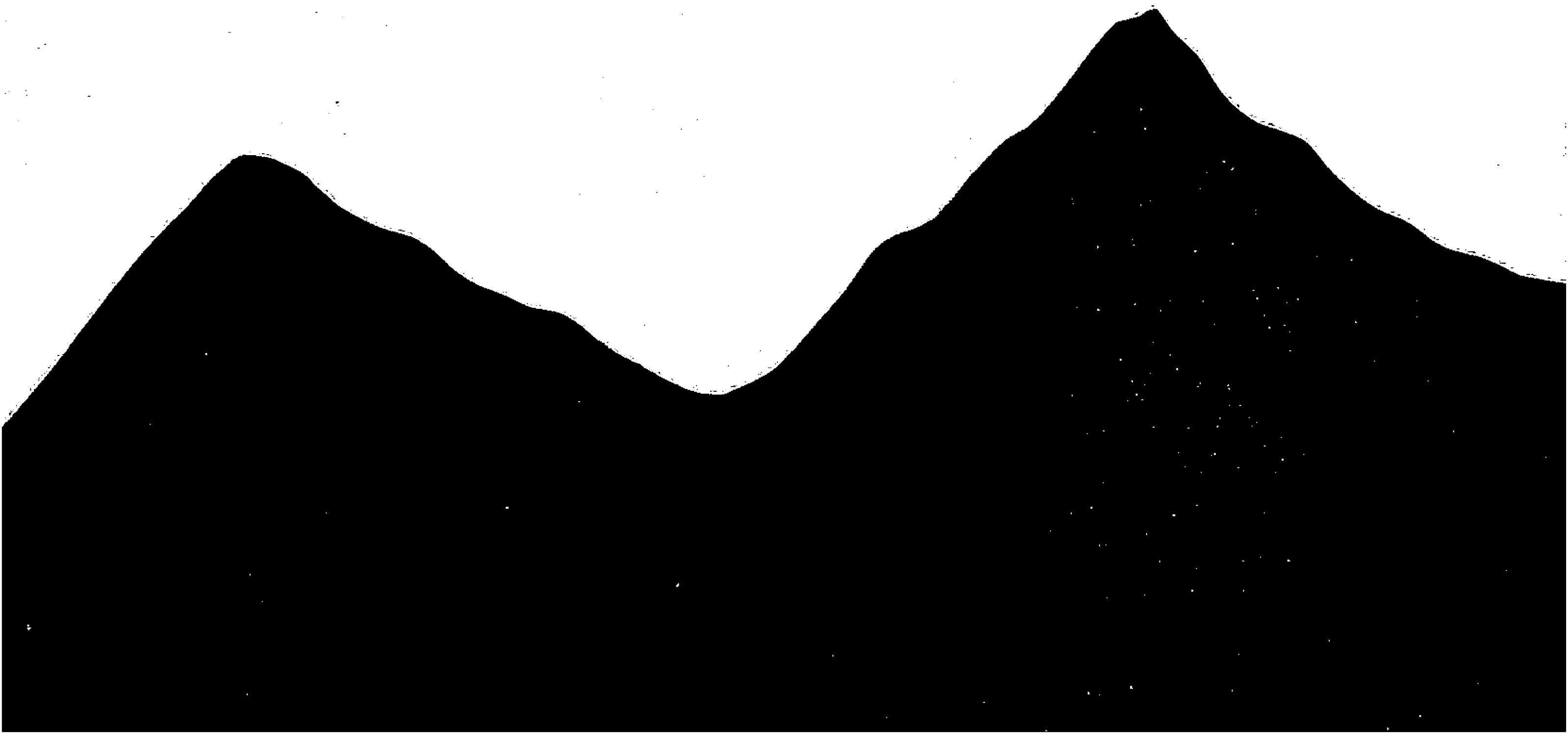

ENVIRONMENTAL INVENTORY AND LAND USE RECOMMENDATIONS FOR BOULDER COUNTY, COLORADO

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PREFACE

Since 1968 INSTAAR has been developing a long-range program of interdisciplinary research relating to the study of cold-stressed environments, both alpine and arctic. Because the University of Colorado is our home, it is natural that the alpine part of the program would be primarily Colorado-based with particular emphasis on the Front Range where the Institute's Mountain Research Station is located.

It was quite fortuitous that INSTAAR's establishment of a scientific foundation for geoecological study of mountain regions was paralleled by a growing awareness of and concern for environmental problems within North America in general, and in Colorado in particular. The application of our expanding fund of environmental data and expertise to some of Colorado's more pressing land use-natural resource problems is a logical development. Thus we have begun to examine the possibilities for applied geoecological research within the State. Some of our more recently funded research tasks include avalanche prediction, analysis of the ecological impact of cloud seeding in high mountain areas, and the application of space science and remote sensing technology to the study of complex mountain regions. We are also assessing the value of permafrost and freeze-thaw data, study of downslope wind storms in the Boulder area, and analysis of slope processes, such as rates of erosion and mass movement, to engineering requirements in the broadest sense.

INSTAAR's involvement with the Boulder Area Growth Study Commission was happily fortuitous. The following report may read as though the Commission's request for support had been anticipated and planned for, which was not the case. Although this was a fortunate coincidence, it should not obviate our emphasizing the somewhat preliminary and imperfect nature of the report. Nevertheless, if a university organization enters the real world of resource management and land-use planning, then it must be prepared to abandon the time-honored ivory tower approach to perfection for its own sake and risk the consequences of meeting tight production schedules.

The project described in this report owes any measure of success that it may deserve to the initiative and persistence of Dr. Richard

Madole and his team of current and former INSTAAR graduate students. The personal trust and constant support of Mr. Joe Vitale of the Office of University Affairs of NASA was the other essential ingredient.

As the Director of INSTAAR, I am happy to offer this contribution to the Boulder Area Growth Study Commission and to the people of Boulder County. Our decision to include it as one of a series of INSTAAR Occasional Papers is based in part on a natural desire to recognize it as a first step in a long-term plan to publish a complete geoecological study of our home county, and in part to ensure a wider circulation and availability to interested persons than is required of the Commission. An initial price of $6 per copy is designed to alleviate some of the budgeting stress incurred by our collaboration with the Commission.

The support and cooperation of many individuals and organizations are acknowledged in Dr. Madole's introduction. But perhaps the overriding acknowledgment must be to the Regents of the University of Colorado, and through them, to the people of Colorado, for allowing a research institute, such as ours, to experiment outside of the formal academic departmental setting. Hopefully, continued application of our geoecological experience will, at least in some small measure, contribute to the solution of state and county problems.

Jack D. Ives

Jack D. Ives
Director
Institute of Arctic and Alpine Research

SECTION 1

INTRODUCTION

R. F. Madole

1.1 GENERAL

Straddling the zone where mountains meet plains, Boulder County has a diversity of topography, geology, climate, vegetation, and soils rivaled by few other counties in the United States. This great diversity produces a richness of natural resources, an invigorating environment in which to live, and unfortunately, a complexity of problems including those of both mountains and plains. These same problems are already confronting, or ultimately will confront, the remainder of the Front Range urban corridor.

Over the years, the Boulder County Planning and Health Departments have risen to these challenges creating far-sighted zoning ordinances, health regulations, flood protection, a concern for the danger of forest fire, and other legislation aimed at protecting the environment. House Bill 1415 concerning preservation of environmental conditions in recreational areas within the state and House Bill 1553 concerning individual sewage disposal systems were authored in Boulder County. Furthermore, Boulder County officials participated in writing Senate Bill 390 concerning water quality control (D. F. Marmande, Director, Environmental Health, Boulder County, pers. comm., 1973).

City and county leadership developed the Boulder Comprehensive Plan in 1970. Then in 1971 Boulder City Council offered the electorate an alternative to the zero population growth resolution in the form of a Boulder Area Growth Study Commission. On election day, November 1971, the voters of Boulder approved establishment of the Growth Study Commission which was charged with organizing study teams to obtain the demographic, economic, political, legal, sociological, and environmental data "Necessary for informed, intelligent action on growth."

In October 1972, Mr. Robert Bronstein, Project Director requested support from INSTAAR's study team which had only a few months previously been funded by the National Aeronautics and Space Administration (NASA) to gather the kinds of environmental data called for in the City Council's counter-resolution. Hence, the INSTAAR group became the environmental-ecological consultant team of the Growth Study Commission.

NASA funding for a Boulder area study evolved out of two relatively large-scale INSTAAR projects, one involving ERTS-1 (Earth Resources Technology Satellite-1) data, the other, high altitude aircraft imagery provided by a program supported by the NASA Office of University Affairs. Both projects combine INSTAAR's historic interest in basic research in mountain environments with space science and the latest remote sensing technology. The ERTS-1 project entitled "An Interdisciplinary Evaluation of Colorado Mountain Environments Using ADP (automatic data processing) Techniques" is an experiment conducted jointly with LARS (Laboratory for Applications of Remote Sensing) of Purdue University. In contrast, the NASA-PY (Office of University Affairs) program is a forthright effort to apply new technology to existing environmental, land use, and natural resource management needs in mountainous Colorado. NASA-PY program guidelines were to (1) identify problems in specified geographic and disciplinary areas of interest to which space science and remote sensing technology might be applied, (2) identify user groups who are interested in having these problems worked on and are willing to act upon the study results, and (3) devise solutions to the problems identified.

The Boulder Area Growth Study Commission and its environmental data requirements clearly comply with the NASA-PY program guidelines. In this case, the principal task was to compile and collate existing data which was then tied together where necessary by information obtained mainly from high altitude aircraft imagery. The time and financial constraints inherent in the resolution governing the Commission offered little opportunity to do more. In addition, for most INSTAAR personnel involved, the project was either short term or part-time because of other commitments. The need for organizing existing data is great and for Boulder County there is much to do. The number of studies by individuals from within and outside the state is surprisingly large. Identification and synthesis of these studies is a sizeable chore in itself. Despite the amount of information available, even more is needed. The task is far too large to be accomplished within a few months.

Acquisition of basic environmental data is generally a slow and/or costly process. As noted in the next section, only about 15% of Boulder County is mapped geologically at scales as large as 1:24,000 and many people-years of work are required to complete mapping the entire county at this scale. The amount and detail of available environmental data varies widely. Some simply do not exist or are very sketchy while others exist, occasionally in abundance, but are not easily accessible or in readily usable form.

The most difficult data to produce are those involving an understanding of process or rate of change. The studies that provide this kind of information require data collected over long periods of time. With few exceptions the requisite data do not exist. The rapid expansion of computer science and parallel advances in statistical methodology have provided exciting new means for investigating processes and rates of change, but the studies spawned by these developments are still in their infancy. In a real sense, we have been caught short. Precise answers concerning questions such as rate of erosion cannot be answered on the basis of a study or two lasting a few years. The ability to estimate on the basis of such studies may be valuable, but most researchers know only too well the problems inherent in treating interpretation as fact.

Despite the problems involved in collecting environmental data, it must be done and there is no time for delay. The work reported on here has identified more information needs than it has filled. However, this is an important first step and a contribution in itself. From its inception, this volume was intended to serve not only the Growth Commission, but all groups interested in the environment of Boulder County. It was also intended to provide a foundation for independent studies and theses in a continuing effort aimed at understanding the natural environment of a complex area containing mountains and plains. Because these chapters were written for individuals from a variety of backgrounds, many terms are defined in textbook fashion and a Glossary is included at the end of this volume.

The problems of mapping and acquiring basic environmental data are not unique to Boulder County. They are of national and international proportions. The need to fill information gaps in the shortest time possible is one reason NASA is turning the space program earthward and is becoming involved in environmental studies at the local level. The new technology accruing from the space program and research in remote sensing offers enormous potential for overcoming these problems. We certainly cannot afford not to try to apply this technology. Hopefully, in the months ahead, imagery from ERTS-1 and NASA high altitude aircraft can be turned to meeting some of the information gaps delimited by this study.

The organization of this volume tends to follow the categories of basic environmental data listed in Table 1. Sections on geology, vegetation, and climate are presented first and in a more academic fashion because they are the basis for the more topical sections that follow. The latter deal with those aspects of earth, water, and air that are most affected by land use decisions. These are discussed in successive sections entitled mineral resources, soils, water resources, air pollution, natural hazards, and land use and tenure. Recommendations for each of these topics are listed in the Section 2.

1.2 ACKNOWLEDGMENTS

Acquisition and analysis of the data presented in this volume as well as preparation of the volume itself was made possible by the National Aeronautics and Space Administration (NASA), Office of University Affairs, Grant NGL-06-003-200. Drafting and cartographic work contained in this volume was paid for by HUD through Comprehensive Planning Grant Project CPA-CO-08-00-0111, Contract DEN-264 administered by the Boulder Area Growth Study Commission.

Acknowledgment is due the following city, county, and federal officials who read portions of the report and contributed many helpful suggestions: Donald F. Marmande, Director, Environmental Health, Boulder County; Donald C. Moreland, Soil Scientist, U. S. Soil Conservation Service, Longmont Office; James A. Pendleton, Geologist, Division of Engineering, Department of Public Facilities, City of Boulder; and Vincent J. Porreca, Planning Director, Boulder County. Colorado Division of Game, Fish, and Parks personnel who provided information and other assistance include John Monarch, Boulder area officer; and Dick Norman and Jerry Whitacre, Wildlife Branch, Fort Collins.

Individuals who contributed to the section on mineral resources include Clarence C. Burleson, Martin Marietta who provided pertinent

TABLE 1

Basic and derivative environmental data maps *

BASIC ENVIRONMENTAL DATA MAPS

Bedrock Geology[3]
Surficial Deposits[2]
Vegetation[1]
Climatic Data[4]
Soils[3]
Hydrologic Features[2]
Wildlife Data[4]
Natural Hazards[1]
Land Use[1]
Human Population[1]

1-imagery is excellent for obtaining data
2-imagery is good to excellent for obtaining data
3-imagery is poor to good for obtaining data
4-imagery is not the primary source of data

DERIVATIVE MAPS#

Slope Grade and Aspect
Wildlife Habitat and Areas Critical to Endangered Species
Fire Hazard Potential
Unique or Critical Plant Communities
Nonrenewable Resources
Erosion Potential
Fault and Fracture Zones
Areas of Steep Slope Underlain by Shale
Areas of High Water Table
Aquifer Recharge Areas
Zones of Cold Air Drainage, Air Pollution, and Frost Pockets
Zones of Frequent Air Temperature Inversions
Delimitation of Scenic Areas
Delimitation of Areas of Geologic Interest

*Basic maps depend on collection of data be it by field work or remote sensing, while derivative maps are generated from basic maps without recourse to extensive collection of new data.
#Not all map types listed are part of this study.

information with regard to the cement industry in Boulder County; William G. Freeman, Allied Chemical, who read the entire section and made several important comments; A. C. Gunning, Denver Brick Company, who reviewed clay production data; Edward McDowell, Flatiron Resource Manager, who checked statistics and commented on sand and gravel production; and David Nystrom, C & M, who also reviewed the unit dealing with sand and gravel.

Special thanks are due Emily L. Hartman, Department of Biology, University of Colorado at Denver, who critiqued the manuscript as a whole and especially those parts relating to biology. Similar credit goes to Roger G. Barry, INSTAAR and Department of Geography, Richard L. Reynolds, Department of Geological Sciences, Robert E. Stoecker, INSTAAR and Department of Biology, University of Colorado at Boulder, for checking aspects of climate and wind, bedrock geology, and wildlife respectively. The cooperation of David and Johanna Whiteman, National Oceanographic and Atmospheric Administration (NOAA) in providing unpublished data on wind and Diane Johnson of NCAR for photographs is appreciated. Lastly, the writer is grateful for the suggestions received from Sandy Cooper, Steve Williams, Ann White, Ricky Weiser, and other members of the Growth Study Commission who reviewed the rough draft of this volume.

SECTION 2

RECOMMENDATIONS

R. F. Madole

2.1 INTRODUCTION

The recommendations made below are those considered to be most relevant to land use decisions. The rationale for them is contained in the various sections from which they were derived. To a degree, the recommendations summarize the sections on mineral resources, soils, water resources, air pollution, wildlife, and natural hazards.

2.2 MINERAL RESOURCES.

1. A detailed inventory should be made of the county's mineral resources including (a) identification of the more easily located non-metallic minerals whose exploitation is apt to conflict with other land use options and (b) documentation of current and past production, particularly of the metallic deposits of western Boulder County, inasmuch as 70 to 90% of exploration is now concentrated in known mining districts (W. G. Freeman, pers. comm., 1973). This work should build on that already accomplished by the Colorado Bureau of Mines and Colorado Geological Survey.

2. Encourage a detailed study of the researves of (a) sand and gravel, (b) minerals used in the manufacture of cement, and (c) clay, all of which are involved in construction and maintenance. This should include a review of the economics of the sand and gravel industry, substitutes for this resource, and experience gained elsewhere with regard to gravel consumption and urban growth. In part, this and the preceding recommendation are required by House Bill 1529. However, it should be noted that HB 1529 applies mainly to sand, gravel, and other aggregate used in the preparation of concrete, asphalt, and road construction materials. It does not apply to all mineral commodities discussed in Section 7. More important, HB 1529 contains far-reaching ramifications which may limit the exercise of land use options in favor of the mineral industries.

Because this may run counter to community or county interests, it would be wise for local government to take the initiative in the inventory recommended above so that the inevitable conflicts may be decided on the basis of fact rather than speculation.

3. Promote public education with respect to community dependence on minerals, their impact on the local economy, the requirements of sound exploitation and well-planned rehabilitation, and recognition of a good or bad operation. Exploitation of nonrenewable resources poses a challenge to the environment and to human ingenuity and creativity.

2.3 SOILS

1. Preserve the best agricultural soils from urbanization to the fullest extent possible. Urge that urbanization be channeled into areas that are less than ideal from a soils standpoint, but which are free from predictable natural hazards. Good planning and engineering can surmount most of the soil problems which lead to ratings of "poor for urbanization." Swelling soils can produce considerable damage. However, if recognized in advance, this and similar constraints can be dealt with effectively and relatively inexpensively, if not today, then perhaps in the near future. Inexpensive is a highly relative term. In this instance, the extra cost incurred in utilizing the second or third best soil for urbanization seems inexpensive relative to losing productive cropland in an age when the prospect of world famine is a serious concern.

2. Success in preserving productive agricultural land is dependent on recognition and solution of a serious, complex, and much less visible problem involving land ownership and contemporary economics. That problem is the simple truth that land which brings a few hundred dollars per acre for agricultural use can yield several thousand per acre for housing and commercial development. The incentives for "selling-out" to developers are so great, it is a wonder that so many farmers and ranchers resist. Clearly, there is a global, if not national, need to preserve all important food-producing lands beginning immediately. Yet, this need is difficult to comprehend at the local level. Furthermore, it is unreasonable to expect the farmer and rancher to deny themselves and bear the cost of preserving these lands. Hence, a solution to this dilemma must be achieved in such a way that all society shares the burden.

3. Encourage development of foundation and sewage treatment schemes for residential housing that ensure the feasibility of constructing such, at little increased cost, on terrain that is least desirable for agriculture.

4. Request that money lending institutions add the following to their foundation information requirements: shrink-swell potential as a function of parent material and slope, potential for hydrocompaction where loessal soils (mainly wind-deposited silt) are involved, kind and thickness of soil parent material, type of underlying bedrock where the soil cover is thin, and depth to water table.

2.4 WATER RESOURCES

1. Protect the unconfined aquifers that underlie the major valleys from pollution from agricultural, industrial, and domestic sources. The high permeability of these aquifers is illustrated by the fact that florescent dye moved 1500 feet in three days in the gravel underlying the floodplain of Boulder Creek (J. Pendleton, pers. comm., 1973). Avoid degradation of water quality as was done in the Windsor area of Weld County by agricultural practices and at Brighton in Adams County by industrial wastes.

2. Endorse and otherwise support the Environmental Health Branch of the County Health Department in acquiring a federal grant to study the complex ramifications of the problems cited in the following item and in recommendations 4 and 5 under Wildlife.

3. Reformulate regulations for sewage treatment systems in the crystalline rock region of western Boulder County. The widespread occurrence of fracture systems in such rocks provides a potential for pollution that does not exist in eastern Boulder County. If necessary, a separate set of regulations should be developed for the mountainous area. Compliance with County Health Department regulations for systems employing a septic tank and leach field is very difficult in most places without resorting to building up soil to meet the thickness requirement. Deeply weathered bedrock is treated as soil because it is easily excavated. However, this practice is questionable considering the permeable nature of the material involved and the underlying fracture systems. It would be safer to require that at least 4 feet of soil overlie the surface of disintegrated bedrock. A majority of mountainous Boulder County does not have a soil cover this thick.

4. Encourage development of sewage treatment facilities for individual homes that overcome the limitations imposed by thin soil and fracture-aquifers.

5. Urge rigorous enforcement of existing floodplain regulations and promote public education as to the reasons for them. Such education should definitely include the aspects of human impact on stream behavior discussed in Section 12.

6. Protect aquifer recharge zones by limiting impervious surface area to 25% or less. It may be necessary to determine the relative amounts of impervious surface area created by various categories of development for the Boulder area and its impact on storm runoff and baseflow characteristics of streams. An important aspect of this problem is the disruptive effect that roads, driveways, ditches, and storm sewers have on natural drainage, the riparian ecosystem, and the aesthetic quality of streams.

7. Compile water well data for mountainous Boulder County and continue to evaluate relationships between depth, yield, and rock type to determine the validity of our preliminary conclusions that (a) water yield depends mainly on fracture density; (b) that if an adequate water supply is not obtained within 100 feet, it may be better to drill two 100-foot wells than one 200-foot well; and (c) groundwater supply in fracture-aquifers is uncertain and meager with a high percentage of wells failing to achieve or sustain a yield of 120 gallons/hour which is a quantity widely used by lending institutions for approval of loans.

8. Encourage money lending institutions and insurance companies to discriminate between environmentally sound and unsound developments. Loss of water supply and degradation of either surface water or groundwater poses a serious financial risk. Entire communities should not be made to pay the cost of poor planning. At present, these institutions could probably exert more influence on behalf of good development and intelligent growth than can legislation.

2.5 AIR POLLUTION

1. Discourage industry from locating in valley bottoms or other topographic lows.

2. Avoid routing major roads along the axes of valley bottoms and through other localities that tend to concentrate air pollutants.

2.6 WILDLIFE

1. Encourage public cooperation with the Colorado Division of Game, Fish, and Parks in seeking a means of stabilizing the declining deer population in western Boulder County. Such a program must include control of marauding dog packs as well as preservation of some of the prime winter habitat on south-facing slopes in the montane life zone.

2. Post warnings regarding bears at garbage disposal sites located in the mountainous part of the county.

3. Encourage improvement of small animal and bird habitats by planting vegetation, and preserving existing cover along streambeds and in greenbelt areas. Preservation of the riparian ecosystem which is recommended elsewhere has obvious benefits to small animals, birds, and fish.

4. Maintain strict policies concerning sewage and wastewater disposal west of highways 7 and 93. That fracture-aquifers are prone to pollution from sewage is an unfortunate, but well-known fact to mountain dwellers. The tendency for this situation to develop in crystalline rocks has been recently documented by Biesecker and Hofstra (1973) in the U. S. Geological Survey study of the Jefferson County mountain area. Stream pollution from these sources is as much a concern as pollution of water wells. All effluent from sewage treatment facilities should be clear, fairly free of sediment and fecal bacteria, and should not impair the life sustaining qualities of the stream in which it is disposed.

5. Encourage stream monitoring above and below each lodge, cluster of dwelling places, public facility, or mining operation to detect water pollution. Lefthand Creek and James Creek are examples of streams that can be directly influenced by present-day mining activities.

6. Promote public recognition of the magnitude of the demands placed on the Environmental Health unit in terms of dealing with pollution problems and the enormity of the task of enforcing and monitoring existing regulations for the whole county.

7. Dewatering should be kept to a minimum west of the line formed by highways 7 and 93 and studies should be encouraged to determine whether or not its detrimental effects can be remedied where existing habitat is capable of supporting trout. Similarly, the extent of water loss through evapotranspiration of small irrigation ditches should be examined as well as the impact on fisheries of widely fluctuating stream discharges controlled by water release from reservoirs.

8. Halt stream channelization and expand existing fisheries by initiating improvement projects employing construction of log and rock baffles to create riffles and pools, particularly along Boulder Creek from the junction of Colorado 119 and Arapahoe eastward to 30th Street and along South Boulder Creek from Eldorado Springs eastward to the Boulder-Denver Highway. Encourage revegetation of streamsides to provide food and shade for fish and other organisms.

9. Restrict fishing on those lakes which are naturally reproducing to "fly and lure only."

10. Promote access to privately owned warm water lakes in the eastern half of the county through leasing or purchase of fishing and recreational rights.

2.7 NATURAL HAZARDS

1. Require evaluation by an engineering geologist of all building sites proposed in areas underlain by the Lykins Formation and Pierre Shale, and on old landslides associated with rocks of the Dakota Group. These areas are not categorically offlimits to construction because they are potential slide areas, but development must be preceded by thorough planning and engineering. Plans which call for extensive excavation or which are apt to disrupt or reroute natural drainage deserve special scrutiny.

2. Discourage, if not prohibit, high angle cuts or excavation of benches on scarps, mesa edges, or steep slopes underlain by Pierre Shale or the Lykins Formation.

3. Require that building sites proposed for areas on debris or landfills be identified as such and that the nature of the fill be determined and taken into account in the type and design of the foundation selected. Identification of landfill areas would probably require a monitoring system.

4. Prohibit building on organic rich soils without proper foundation design and require removal of organic matter including the A-horizon of the soil profile from areas underlying spread footing foundations and basements. Eliminate the practice whereby material is excavated from the uphill side of a sloping site and built out over the vegetation-covered downhill side.

5. Foster public recognition of the difficult task facing the County Planning Department with regard to enforcing zoning regulations and solicit their cooperation and assistance. This is especially true with regard to the comprehensive set of regulations currently governing land use within the limits of the 100-year flood. Proper land use within this zone benefits everyone in more ways than just eliminating the need to spend tax dollars on rescue, relief, and flood clean-up operations.

6. Regulations similar to those governing land use on floodplains should be drafted to cover other types of hazardous locations identified in Section 12.

7. Support enforcement of the new building codes adopted after the January, 1969, windstorms that pertain to roof and fence construction

and to the licensing of contractors to ensure their cooperation with building regulations.

8. Promote awareness and compliance with the mobile home tie-down regulations drafted after the severe windstorm of January, 1972. That storm wrought more than twice as much destruction to mobile homes oriented north-south as to those oriented east-west (Miller, 1972; Miller, Brinkmann, and Barry, in press).

9. Require that shutters be installed, at least on west-facing windows, in the known areas of severe wind.

10. Consider requiring developers to plant trees in housing areas to act as wind breaks in future years, particularly along the southern edge of the city where effective wind speeds appear to be highest. Damage to structures should decrease as the trees mature and provide shelter. Needless to say, the attractiveness of the city would also be enhanced.

11. Encourage continuation of the research aimed at improving windstorm forecasting, building upon the foundation laid by Brinkmann, 1973, and Klemp and Lilly, 1973. Should the National Oceanographic and Atmospheric Administration windspeed monitoring program be abandoned, urge local government to take up this project where NOAA left off.

12. Require test borings for development proposed within or near the mined-out areas of the Boulder-Weld County Coal Field as mapped by Colton and Lowrie (1973) to ascertain the potential for subsidence. Note that subsidence may be broader than the mined-out area, and may occur long after mining operations have ceased (Gaz, pers. comm., 1973). Furthermore, the surveys upon which the subsidence map is based have been found to be inaccurate in places.

13. Urge compliance with existing regulations governing slope and land use in mountainous Boulder County. Many driveways leading to mountain homes are too steep and narrow to accommodate fire fighting equipment. Some are so steep they produce extensive erosion and sediment derived therefrom locally degrades water quality in nearby streams.

14. Promote the program of public education regarding forest fire developed by the State Forest Service and the recommendations of Hulbert (1972).

15. Publicize the danger of avalanches to those interested in offroad winter recreation such as snowmobiling and cross country skiing. Some people who take up these pursuits have little experience with winter mountaineering and do not affiliate with organizations such as the Colorado Mountain Club.

16. Acquaint lending institutions and insurance companies with the ramifications of development in hazardous areas. Request that they require information on all the hazards discussed in Section 12.

2.8 GENERAL REMARKS

Whereas the rationale for the preceding recommendations is contained in the sections to which they pertain, the following remarks derive from the study as a whole.

1. Environmental considerations are so basic to intelligent land use that they cannot be viewed as options or alternatives, but must be regarded as requisites for whatever growth model is adopted.

2. We believe that when the entire system is considered, it becomes apparent that what is best environmentally is also best economically.

3. There is a tendency for constraints and opportunities to compound or reinforce one another. For example, urbanization of floodplains not only exposes property to the threat of floods, but contributes to ground-water pollution, air pollution, and loss of valuable non-renewable resources. Similarly, urbanization of the mountain front and nearby mesa edges can simultaneously lead to problems involving landslides, high speed winds, and aesthetics.

4. It is important to recognize that most environmental constraints are relative and ephemeral. They can change as rapidly as they are defined. The majority are a function of the technology, social attitudes, and economic climate of the time. Prophesies based on projecting past and current trends into the future have an impressive record of failure.

5. Boulder County has more environmental information than most counties, but needs additional data because of its greater complexity and sensitivity. However, even the more homogeneous flat lands are complex from an environmental standpoint. We know that environment is like an intricate web, with one part linking to and influencing another. The system tends to be in a dynamic equilibrium such that tampering with one part results in changes in others. As our comprehension of this complexity increases, so does our reluctance to embrace piecemeal solutions.

6. Land does have optimum uses, carrying capacities, and finite limits of space and vital resources. Determining these limits is an immense undertaking that here and elsewhere is far from complete. Unfortunately, most environmental data is not easily obtained. Hence, this study is more a beginning than an end.

7. Widespread adoption of environmentally sound land use practices will depend on demonstrating that they truly are more economical. Methods for proving this at the regional level must be developed. The slow and costly acquisition of the necessary basic environmental data will be a stumbling block, but the work must begin to go forward now.

8. As the title page indicates, this report is an inventory of our environment and its resources. For reasons delineated in the remarks above, it cannot be a catalog of physical and biological constraints on growth. We recommend that speculation on long-term constraints be avoided in favor of concentrating on what we know and can do about existing problems, including closing the information gaps cited in various parts of this report.

SECTION 3

BEDROCK GEOLOGY

R. F. Madole

3.1 ROCK CLASSIFICATION AND NOMENCLATURE

3.11 Introduction

All rocks can be grouped into three broad genetic categories known as igneous, sedimentary, and metamorphic. Igneous rocks, whose name denotes their fiery origin, comprise 95% of the earth's crust. However, in most places, they are covered by a veneer of sedimentary rocks, the sediment (i.e. gravel, sand, mud) for which was derived from the weathering and erosion of other rocks. Sedimentary rocks comprise only 5% of the earth's crust, but cover 75% of its land surface. Metamorphic rocks are those that have been transformed (metamorphosed) into new crystalline aggregates from some pre-existing material. Volumetrically, they are a minor component of the earth's crust, but in Boulder County they are a major component.

The mountains which span nearly two-thirds of the county are comprised entirely of igneous and metamorphic rocks, while from the foothills east, sedimentary rocks prevail except for a few Tertiary (see Fig. 1) intrusives such as Valmont dike. The sedimentary rocks which were initially deposited in a horizontal position were subsequently warped upward when mountain building elevated the crystalline (igneous and metamorphic rocks) core of the Front Range. During the millions of years that ensued, erosion has removed the sedimentary veneer from the rest of the range exposing the crystalline rocks beneath. The genesis of the Front Range is shown schematically in Figure 2.

3.12 Igneous Rocks

Igneous rocks solidified (crystallized) from a white-hot silicate melt, either at the surface as in the case of lava, or deep

Era	Period	Epoch	Duration Before Present in Millions of Years	
Cenozoic	Quaternary	Holocene		
		Pleistocene	1.5-2	
	Tertiary	Pliocene	5-5.5	
		Miocene	19	
		Oligocene	11-12	
		Eocene	15-17	
		Paleocene	11-12	
				65
Mesozoic	Cretaceous		71	
	Jurassic		54-59	
	Triassic		30-35	
				225
Paleozoic	Permian		55	
	Pennsylvanian		45	
	Mississippian		20	
	Devonian		50	
	Silurian		35-45	
	Ordovician		60-70	
	Cambrian		70	
				570
Precambrian	Precambrian time			

Figure 1. The geologic time scale.

within the ground. Most of the igneous rocks in Boulder County are of the latter type known technically as intrusive igneous rocks. Their exposure at the surface is the result of uplift during mountain building followed by a long episode of erosion. The different kinds of igneous rocks formed depends upon the chemical composition of the molten mass and conditions of temperature and pressure at the depth and time of formation. As a result, igneous rocks vary widely in texture (arrangement, size, and shape of the component mineral grains) and mineral composition. Their classification depends chiefly upon texture and the proportions of key minerals present. The four categories of igneous rocks shown on Plate 1 include (1) Boulder Creek "granite" (actually granodiorite), (2) quartz monzonite, (3) Silver Plume "granite" (more nearly a quartz monzonite), and (4) small intrusives emplaced during the Tertiary Period. The first three categories were intruded during Precambrian time which, as shown in Figure 1, was vastly earlier than the fourth category. Most ore deposits of Boulder County relate to the igneous activity of Tertiary time.

3.13 Sedimentary Rocks

Most of the sedimentary rocks of Boulder County are termed clastic, which denotes the fact that they are composed of particles that were deposited in water or from the air. The particles became rock by compaction and/or crystallization of cementing materials in the voids between particles. Clastic sedimentary rocks are classified according to texture (grain size) and mineral composition. Conglomerates include particles of pebble-size or larger, while as their names imply, sandstone, siltstone, and claystone contain predominately sand, silt, and clay respectively. Shale is composed mainly of silt and clay-sized particles, but is distinguished from siltstone or claystone in being thinly laminated (fissile). Adjectives are used to indicate other constituents as, for example, arkose or arkosic refers to a sandstone or conglomerate that contains abundant visible fragments of orthoclase feldspar.

Although minor insofar as Boulder County is concerned, some sedimentary rocks form by precipitation of substances dissolved in sea water. Although limestone (mainly calcium carbonate) is often listed as a nonclastic or chemical precipitate, much is clastic. Coal is the only nonclastic sedimentary rock to occur in appreciable quantities in Boulder County. Even so, it exists only in beds ranging from a few inches to sixteen feet in thickness. It is of subbitumenous rank and occurs in the Laramie Formation in southeast Boulder County. Coal consists of carbonized plant remains.

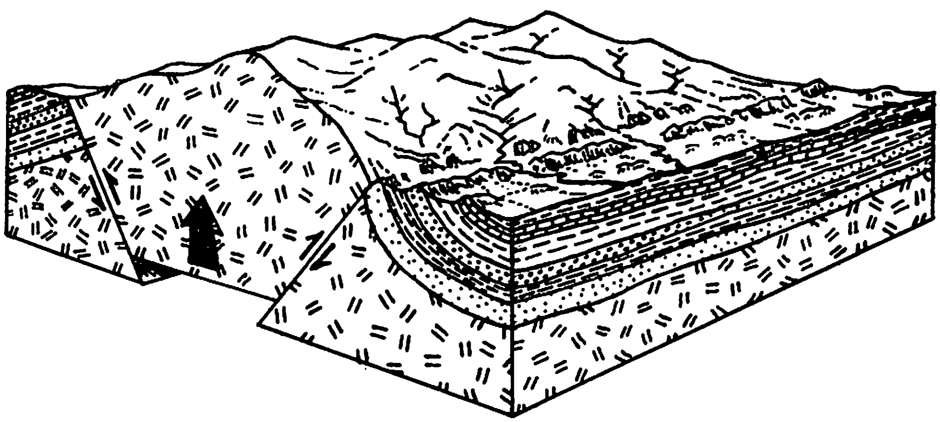


Figure 2. Schematic representation of the genesis of the Front Range (after U.S. Geological Survey).

Most sediment accumulates in nearly horizontal layers and the resulting stratification is one of the most distinctive characteristics of sedimentary rocks. Although deposited in a horizontal position, these layers may be tilted, folded and faulted by stress generated within or beneath the earth's crust. Uplift of the Front Range caused the sedimentary rocks which form the foothills to tilt eastward, and, in many places, to fold and fracture. Erosion has exposed rocks of varying ages at the surface, some of which have subsequently become buried by the unconsolidated deposits discussed in the next section. Figure 3 illustrates the relationship between the sedimentary rocks of eastern Boulder County and the crystalline rocks to the west.

3.14 Metamorphic Rocks

Metamorphic rocks are those which show evidence of having been altered from some other kind of rock by high temperature, pressure, and possibly chemical change. The most conspicuous feature of metamorphic rocks is a layering termed foliation produced by alignment of platy and prismatic minerals under the pressure of directed stress. The oldest bedrock in Boulder County is metamorphic and includes gneiss, a hard, coarse-grained rock with alternating bands of light and dark minerals, and schist which is similar to gneiss except that banding is absent and platy minerals such as mica predominate. Some schists break easily along micaceous bands, particularly when highly weathered. Quartzite is another metamorphic rock which occurs in small bodies in several places in the central part of the county, but is shown on Plate 1 only where it occupies a larger area near Eldorado Springs. Quartzite is an extremely hard, durable rock composed predominately of the mineral quartz.

3.2 GEOLOGIC MAPS

A geologic map shows the distribution of rocks and various unconsolidated deposits at the earth's surface. Some maps emphasize bedrock geology, while others emphasize the unconsolidated surficial deposits, showing bedrock only where it is exposed. Because a detailed knowledge of surficial deposits as well as the bedrock beneat is important to planning and land management, separate maps have been prepared for each. Hence, the bedrock map of this report, Plate 1, omits the alluvium covering the broad floodplains of eastern Boulder County as well as the glacial deposits of the western part of the county. This departure from custom is made because many properties of the underlying bedrock are important to land use decisions and are often greatly different from those of the overlying surficial

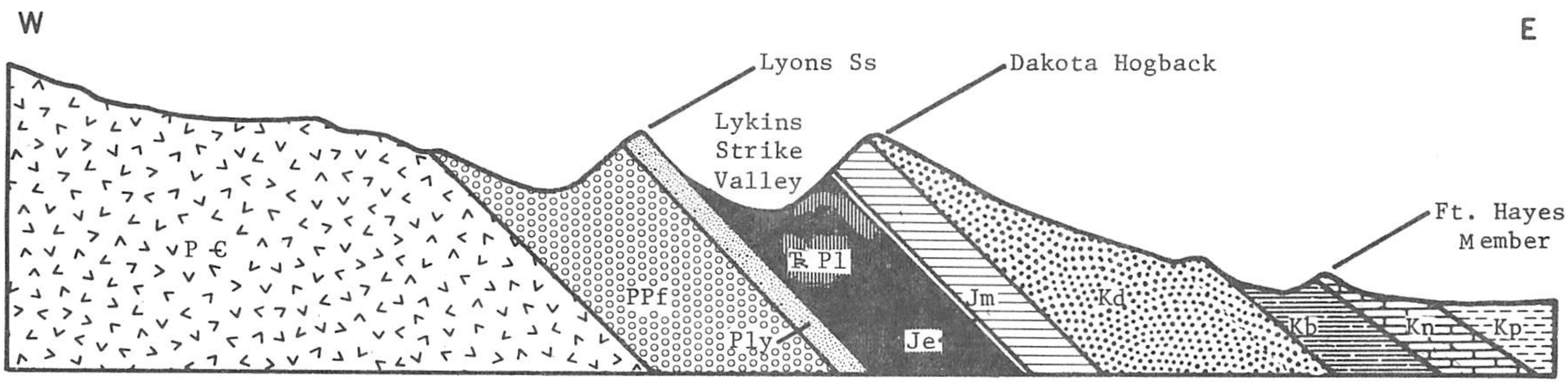


Figure 3. East-west cross-section showing structural and stratigraphic relations along the mountain front north of Boulder. Capital letters in the symbols identify geologic age or system while lower case letters stand for formation names (see Fig. 4 and Plate 1).

deposits. For example, Pierre Shale which underlies much of the area is an aquiclude (a barrier to ground water movement) while the alluvium which overlies it in many places is an aquifer (contains ground water). Moreover, the alluvium may be quite suitable for foundations, while the shale beneath may have a high shrink-swell potential and pose serious problems for foundations if not recognized in advance. Should the alluvium be thin, unforeseen problems could be encountered because of the underlying shale. Problems of this sort are discussed in subsequent sections. Likewise, surficial deposits are shown in Plate 2 and described in the next section.

Plate 1 depicts the distribution of units of bedrock in Boulder County. The fundamental rock-stratigraphic unit used in geologic mapping is the formation. These units are given geographical names, generally after the place where they were first described, followed by the word formation or the name of the dominant rock type present, as for example, the Morrison Formation or Lyons Sandstone. Although formations are defined on the basis of visible physical characteristics, they are not necessarily homogeneous. Sometimes they are recognized by their extreme heterogeneity, and in many cases their unity derives from the fact that they consist of alternating layers of different rock types which form a section distinctly different from the rocks above and below.

References to map scale stated as ratios (e.g. 1:24,000) appear in several places in this volume. These representative fractions or R. F. scales indicate the relationship between map distance and the distance on the ground that it represents. The ratio is valid for any linear unit, but obviously inches or similar units are the most practical insofar as the map itself is concerned. With the 1:24,000 scape map, 1 inch on the map is equivalent to 24,000 inches on the ground, or simplified, 1 inch equals 2000 feet. The 1:24,000 scale maps are the most detailed level of geologic quadrangle mapping currently being done by the U. S. Geological Survey, the principal agency charged with this task. Select portions of the state have been mapped at a scale of 1:62,500 (approximately 1 inch = 1 mile) including much of Boulder County, but only about 40 of Colorado's 900 1:24,000 scale quadrangles have been mapped geologically. Of those mapped, four are at least partly in Boulder County. This amounts to about 15% of the county. However, this figure should double within the next year or so with the publication of four maps which are now nearing completion.

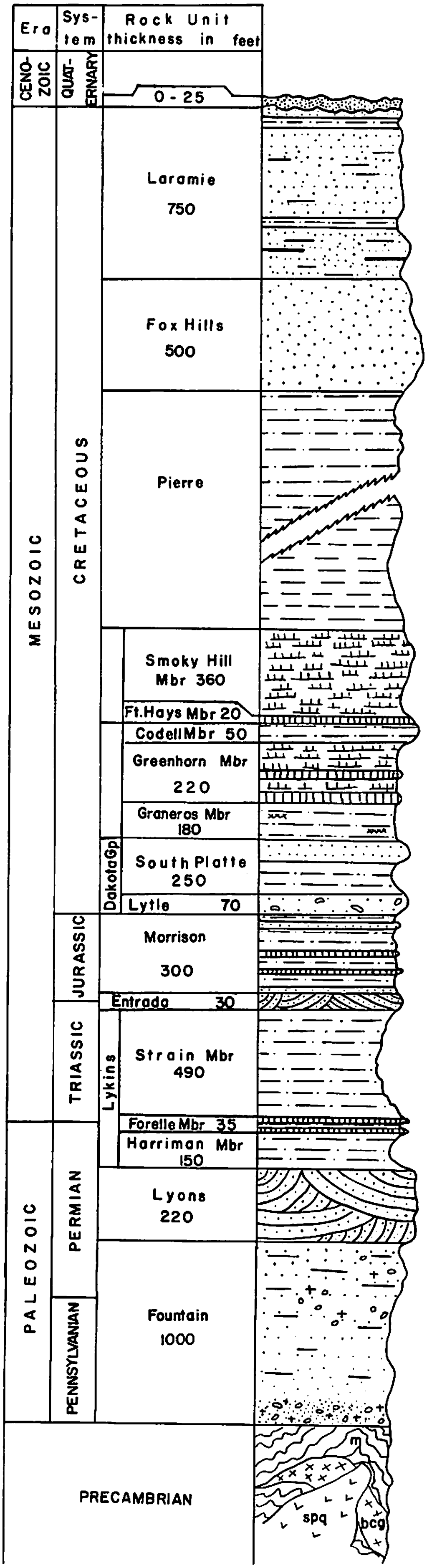
Because of geologic complexity, rugged terrain, and limited access, the mountain quadrangles of Boulder County are among the most difficult to map. The westernmost of these require three or more summers to complete at a scale of 1:24,000. Large-scale geologic mapping obviously requires a great deal of time and effort. Consequently, the bedrock geologic map of this report is a compilation from the several sources identified on Plate 1. The reliability of the source maps varies with their scale and intended use. The southern part of Plate 1 is the most reliable inasmuch as it was derived from 1:24,000 scale U. S. Geological Survey maps of the Louisville Quadrangle (Spencer, 1961), Eldorado Springs Quadrangle (Wells, 1967), Nederland Quadrangle (Gable, 1969), Tungsten Quadrangle (Gable, 1972), Ward Quadrangle (Gable and Madole, in progress), and the Boulder Quadrangle (in progress, but available in open file). Although mapping of the Gold Hill and Niwot quadrangles is in progress, information pertaining to them was unavailable at the time of compilation. These maps, however, should be completed and on sale within the next year or two.

Narrow strips along the easternmost and northwestern fringes of the county were mapped using the extremely generalized, 1:500,000 scale geologic map of Colorado. The remainder of the county was compiled mainly from geologic maps with scales of 1:62,500, the principal one being that of Lovering and Goddard (1950). Note that where glacial deposits are omitted from Plate 1, the contacts (boundaries) between rocks are inferred and shown by a succession of dots. This practice is questionable because the boundaries of crystalline rocks, unlike those of sedimentary rocks, are essentially unpredictable for any distance. Generalized maps such as Plate 1 are to provide data for regional or area planning, but are inadequate for detailed planning for specific sites without additional fieldwork. The same can be said, however, for the 1:24,000 scale maps, even though these are by far the best and most detailed maps available.

3.3 ROCK UNITS OF BOULDER COUNTY

3.31 General

Rocks formed in all geologic eras (see Figs. 2 and 4) exist in Boulder County. The Front Range uplift is a complex of Precambrian igneous and metamorphic rocks, intruded by stocks and dikes of early Cenozoic age and flanked by hogbacks of sedimentary rocks of Paleozoic and Mesozoic age. All systems from Pennsylvanian to Cretaceous are represented, but rocks of Late Cretaceous age are especially thick.



Gravels sands, and silts in stream flood plains, terraces, pediments, and slope deposits.
*The Cretaceous and Paleocene Denver and Arapaho Fromations of nonmarine origin are preserved 15 miles to the southeast of Boulder.

Sandstone, light gray and tan, occasional coal, gray shale, and claystone interbeds; nonmarine and marginal marine.

Sandstone, light tan, fine to medium grained, friable; shallow marine.

Shale, dark gray, some si..y, upper 1000' sandy. Hygiene Ss Mbr is 1600-2300' above the base; marine.

Shale, dark gray, calcareous, fossiliferous; marine.

Limestone, light gray, hard, fossiliferous, thickly bedded; marine.
Sandstone, fine grained, brown, shaly, numerous burrows; shallow marine.

Shale, light gray, calcareous, and thin limestone beds; marine.

Shale, dark gray, with some thin bentonite beds; siliceous in lowermost part; marine.

Shale, dark gray, silty, with platy sandstone (Plainview Mbr) at base and prominent ridge-forming tan sandstone at top (Muddy Mbr); marine and marginal marine.

Sandstone and conglomerate with occasionally interbedded light-colored claystones, forms prominent hogback; fluvial origin.

Claystones and siltstones, gray, tan red, with subordinant beds of brown sandstone and gray siliceous limestone; fluvial and lacustrine in origin.
Sandstone, light gray, fine grained, well sorted, large sets of tabular cross-beds; interpreted as aeolian.

Shale and siltstone, red with prominent sandstone beds near the top, forms valley; marine and marginal marine origin.

Limestone, pink and gray crenulated; algal origin in shallow marine, or hypersaline environment.
Shales and siltstones, red; probable marine orgin.

Sandstone, tan or pink, siliceous, fine to medium grained, well sorted, typically composed of very large sets of thin and medium, very regular cross-strata; interpreted to be a dune deposit.

Sandstone, and conglomerate, reddish-brown and tan, arkosic, poorly sorted, and subordinate beds of red shales and siltstones; abundant trough cross-bedding; occasional loud-casts, tool and scour marks and mud cracks; individual units laterally discontinuous. The upper 140' consists of alternating tongues of Fountain-like and Lyons-like lithologies; interpreted to be a fanglomerate.

m, metamorphic rocks including amphibolite, mica schists, and quartzite.
bcg, Boulder Creek granodiorite, about 1.7 billion years old.
spq, Silver Plume quartz monzonite, about 1.4 billion years old.
Pegmatites common.

Figure 4. Boulder area stratigraphic column.

3.32 Precambrian Rocks

All Precambrian rocks of Boulder County are crystalline which is to say they are either metamorphic or igneous. The term crystalline refers to the fact that they consist of interlocking crystals or crystalline grains of various minerals. This characteristic contrasts markedly with the way the grains of sedimentary rocks fit together. In the latter, particles are merely compacted and invariably a certain amount of void space is left between, varying percentages of which become filled with cementing material such as silica or calcium carbonate. Crystalline rocks have formed by crystallization of a molten mass or recrystallization from some pre-existing material. The grains have grown together consuming all available space. This difference between crystalline rocks and sedimentary rocks is of fundamental importance in matters concerning groundwater potential, waste disposal, ease of excavation, and foundation stability.

Gneiss. The area shown as gneiss on Plate 1 encompasses a complex of gneiss and schist, most of which has been mapped previously as Idaho Springs Formation (Lovering and Goddard, 1950). Also included in this category are scattered outcrops of the Swandyke hornblende gneiss of Lovering and Goddard (1950). These are the oldest rocks of the Front Range and they crop out across 25-30% of the mountainous portion of Boulder County. They are particularly prevalent in the northwest and southwest corners of the county and in a broad irregular east-west trending belt that reaches from Gold Hill to the southern part of the Indian Peaks. Whether schist, gneiss, or interlayered gneiss-schist, these rocks are well-foliated and gray in color where freshly exposed and brownish where deeply weathered.

Quartzite. Genetically and chronologically, the quartzite mapped separately near Eldorado Springs belongs to the ancient complex of gneiss and schist described above. Its occurrence in Boulder County is perhaps too limited to warrant this subdivision. However, it broadens rapidly southward into Jefferson County to a sizeable mass informally referred to as the Coal Creek quartzite.

Boulder Creek "granite". The Boulder Creek "granite" is the oldest major igneous intrusive in the Front Range. Except at Gold Hill, it is not a granite, but in most places is a quartz monzonite. In terms of average composition it is a granodiorite and this name is applied to it in the more recent literature. Generally, the rock is dark gray, coarse-grained, and slightly prophyritic. Locally, it is pinkish gray or gray. It crops out over an extensive area between Gold Hill and the city of Boulder, and extends from Coal Creek south of Boulder to Lefthand Creek about seven miles to the north. The unit is aptly named because along Highway 119 one sees virtually nothing but this rock from the mouth of Boulder Canyon to Barker Reservoir. At that point the highway crosses on to the schists and gneisses described above. In general, Boulder Creek granodiorite is deeply weathered (a general term for the chemical decomposition and physical breakdown of rock) and much of the uppermost part is easily disintegrated. For more details concerning these rocks, see Wells (1967) and Gable (1969 and 1972).

Silver Plume "granite". The Silver Plume or Longs Peak granite of Fuller (1924) and Boos and Boos (1934) is the youngest major Precambrian rock unit in the Front Range, and is the most extensive of Boulder County's three major Precambrian units. Beginning near the Continental Divide, this "granite" (actually more a quartz monzonite) stretches almost monotonously eastward across St. Vrain drainage basin. North of Lefthand Canyon and Niwot Ridge, Silver Plume "granite" comprises about 85% of the mountain area. This rock appears almost continuously along the highways linking Peaceful Valley to the towns of Estes Park and Lyons. In most places, the rock is medium to coarse-grained and is light-gray to brownish-gray in the outcrop. Its seldom seen fresh color is pinkish-gray.

3.33 Paleozoic Rocks

The sedimentary rocks, both Paleozoic and Mesozoic, of eastern Boulder County are described graphically and verbally in Figure 4, the Boulder area stratigraphic column. Additional details describing thickness and occurrence for the county as a whole are provided below. Three formations of Paleozoic age occur in the county, although part of the uppermost, the Lykins Formation, is Mesozoic. Ages for the time terms used are listed in Figure 2 and relative succession is also shown in Figure 4.

Fountain Formation.--Pennsylvanian and Permian. This formation includes about 1000 feet of mainly maroon-colored arkosic sandstone and conglomerate which lie unconformably on crystalline rock of Precambrian age. Together with the overlying Lyons Sandstone, it forms the high, prominent inner hogback (steeply upturned ridge of sedimentary rock) notable for its continuity along the east flank of the Front Range.

Lyons Sandstone.--Permian. The Lyons Sandstone consists of 100 to 400 feet of cream to red, fine to medium-grained, well sorted sandstone. It is quarried in several places near the town of Lyons, its type locality, north of which it thins out rapidly.

Lykins Formation.--Permo-Triassic. This formation contains 500 to 1100 feet of redbeds that are easily eroded. Their erodibility has given rise to the valley between the prominent hogbacks formed by the Dakota and Morrison formations on the east and the Fountain and Lyons formations on the west (see Fig. 3). The Lykins Formation contains three units which thicken northward (Hunter, 1955). These include (1) the lower red shales of Permian age, (2) some 20 to 40 feet of silty dolomite and limestone of the Forelle Member also of Permian age, and (3) upper red shales and siltstones of Triassic age, the Strain Member of Figure 2.

3.34 Mesozoic Rocks

Most of the sedimentary rocks of Boulder County are of Mesozoic age, the "age of reptiles." Although described above, the upper three-fifths of the Lykins Formation is Triassic, the first of the three periods comprising the Mesozoic (see Figs. 2 and 4). The reader may wonder why formations can span major time breaks. The reason is that geologists maintain a distinction between rock-stratigraphic units and time-stratigraphic units. The formation, a rock-stratigraphic unit, is defined for mapping purposes solely on the basis of its visible physical characteristics. Time units on the other hand are defined mainly on the basis of fossils, and more recently by radiometric dating techniques, which permit regional to intercontinental correlation of events. Initially, time units were linked to rock units. However, once established, time-unit boundaries had to be extended irrespective of the physical units.

Entrada and Jelm Formations.--Triassic-Jurassic. The Jelm Formation is a very thin sandstone that pinches out coming southward into the Boulder area. It is equivalent to part of the Entrada Sandstone west of the range.

Morrison Formation.--Upper Jurassic. This formation is 300 to 400 feet thick and is comprised of two parts. An upper part consists of massive, friable, light-colored sandstones intercalated with maroon and purplish, varigated, sandy shales. The lower part contains thin-bedded green-gray, and maroon shales, gray to brown calcareous sandstone, and thin beds of freshwater marlstone. The Morrison underlies rocks of the Dakota Group, and is exposed best along the east wall of the valley formed in the Lykins Formation (see Fig.3).

Dakota Group.--Lower Cretaceous. The 200 to 400 foot thick Dakota Group includes the Lytle and South Platte formations. The Lytle Formation caps the first high, very continuous hogback that in most places is the mountain front. The South Platte Formation is predominately shale in its lower part and sandstone in its upper part. The latter, known as the Muddy Member, is a light gray, massive sandstone that, in places, forms a minor ridge along the base of the mountain front.

Benton Shale.--Upper Cretaceous. This formation contains about 500 feet of fissile black organic shale, a few thin dark limy beds, and some thin layers of bentonite. In most places, it is covered by vegetation, and forms a gentle slope at the base of the mountain front, or in places, a slight valley between the low ridges formed by the Muddy Member of the South Platte Formation on the west and the Fort Hayes Member of the Niobrara Formation on the east. The Fort Hayes Member stands out as a discontinuous small ridge in many places along the mountain front.

Niobrara Formation.--Upper Cretaceous. This formation is 300 to 500 feet thick, and is comprised of the Fort Hayes and Smoky Hill members. The Fort Hayes Member is a light-gray massive, fine-grained limestone with shaly partings that forms the low ridge mentioned above. The Smoky Hill Member consists of gray limy shales, thin-bedded discontinuous limestones, and limy sandstone.

Pierre Shale.--Upper Cretaceous. Pierre Shale is 5000 to 8000 feet thick, consists of gray to black clay and sandy shale and is the most widespread formation in eastern Boulder County. It is quite homogeneous, the only pronounced change in lithology being that of the Hygiene Member which is a thin band of drab brown to buff sandstone and sandy shale, topped by massive cross-bedded buff sandstone. The Hygiene Member forms a small but conspicuous hogback that zigzags through the area. It is most prominent from Table Mountain north-northeast to Independent Reservoir where it forms an almost continuous wall-like ridge that ponds several small lakes.

Fox Hills Sandstone.--Upper Cretaceous. The Fox Hills Formation is so similar lithologically to the overlying Laramie Formation, that the two are difficult to distinguish over large areas. The formation consists of interbedded sandstones and shales that thin northward from a thickness of 500 feet.

Laramie Formation.--Upper Cretaceous. This formation consists of about 600 to 750 feet of light-gray or buff colored interbedded sandstones and shales that contain coal and clay. Massive, friable sandstone of this formation crops out in cuts along highways ascending Davidson Mesa and in the cliffs on the south of Gunbarrel Hill.

3.35 Cenozoic Rocks

Rocks of Cenozoic age include igneous intrusions emplaced during the Tertiary Period and an abundance of unconsolidated stream deposits and glacial till laid down during the Quaternary. Inasmuch as the Quaternary deposits are the subject of Section 4, only the Tertiary intrusives are described here. With the exception of a few dikes, such as the Valmont dike, Tertiary rocks of Boulder County are confined to the crystalline core of the Front Range. Most of these lie on the edge of the southwest-northeast trending "mineral belt" also referred to as the "porphyry belt," of the Front Range whose northeastern terminus lies in Boulder County. Most of these intrusives are monzonite, quartz monzonite, or granodiorite, rocks of a "granitic" nature.

The largest of these intrusives include (1) the Audubon-Albion stock near the Continental Divide at the head of North Boulder and South St. Vrain creeks, (2) the Caribou stock west of Nederland, and (3) a large stock at Jamestown. However, they are of limited extent compared to those of Precambrian age. Nonetheless, their importance is not measured in size, but in terms of their impact upon the region's economy, for it was these episodes of intrusion that gave rise to metallic mineral deposits of Boulder County.

SECTION 4

SURFICIAL DEPOSITS

R. F. Madole

4.1 INTRODUCTION

Surficial deposits are unconsolidated sediment overlying solid rock. Most are of Quaternary age (Fig. 1) and belong to two broad genetically-defined categories referred to here as transported and residual. Transported surficial deposits are those moved from elsewhere by wind, water, ice, or the force of gravity and deposited upon a pre-existing surface or landscape. In contrast, residual surficial deposits were formed in place by the chemical decomposition and mechanical breakup of the underlying bedrock. A knowledge of the types and distribution of surficial deposits is vital to sound land use management. They are a major factor in planning for solid waste disposal, sewage treatment, foundation, slope stability, drainage, availability of ground water, and reserves of sand and gravel.

In terms of its surficial deposits, Boulder County is divisible into three sectors. The western sector which extends from the Peak-to-Peak Highway to the Continental Divide is dominated by transported surficial deposits of glacial and periglacial origin. The area between the Peak-to-Peak Highway and the foothills to the east is one of thin residual surficial deposits interrupted by outcrops of bedrock, small meadows filled with alluvium and colluvium (slope wash), and bands of alluvium along the larger mountain streams. The eastern sector or plains of Boulder County is dominated by transported deposits of fluvial (stream) and eolian (wind) origin. Stream deposits are particularly dominant for approximately 5 to 7 miles east of the mountain front. Beyond 7 miles, wind-blown deposits begin to abound on uplands between major valleys.

4.2 WESTERN SECTOR

4.21 General Description

Between 50% to 60% of the sector west of the Peak-to-Peak Highway is mantled by glacial deposits, and much of the remaining area

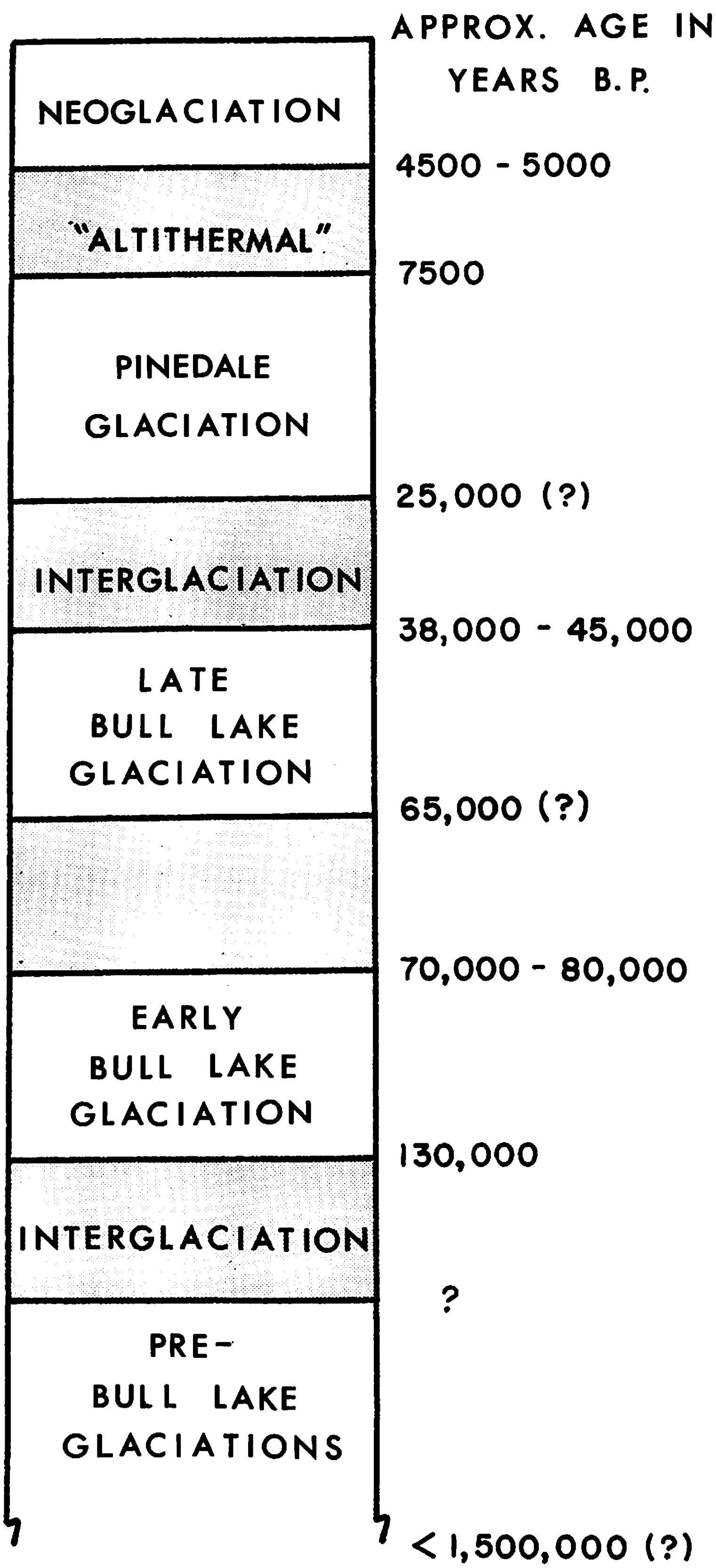


Figure 5. Front Range glacial chronology

consists of rocky peaks and slopes containing periglacial deposits such as talus, rock glaciers, and solifluction lobes. Most of this area is public land (National Forest) and available to the populace of the Boulder area only for recreation. Nonetheless, the sector will be discussed in the same level of detail as the others.

One of the reasons for discussing glacial deposits is that they are very different from the residual deposits that prevail over most of mountainous Boulder County. They would be preferred sites for subdivisions were they at lower altitudes. However, the major valley glaciers terminated at or just below the Peak-to-Peak Highway. Except for the town of Nederland, few homes are built on till.

The term till refers to sediment deposited directly by glacier ice. Such deposits characteristically include a large range of particle sizes from clay at one extreme to huge boulders at the other. The viscous nature of ice gives it a transporting power unrivaled by wind and water. It transports the tiny and the immense with equal ease. Till generally lacks stratification or layering, except in small pockets reworked by meltwater. In most of mountainous Colorado, it looks like a mass of dirt (sand, silt, and clay) strewn with boulders.

Glacial deposits range from a few feet to tens of feet in thickness while residual deposits vary from zero to a few feet. Although most residual deposits have high permeability, till tends to have moderate to low permeability. Excavation in the downvalley part of the glaciated area is not likely to encounter bedrock except at the very margin of the deposits. However, large boulders 2 to 10 feet long will aggravate excavating equipment operators.

Glaciation occurred repeatedly in westernmost Boulder County (Fig. 5) in five major valley systems that include, from north to south, the valley of North St. Vrain Creek, Middle St. Vrain Creek, South St. Vrain Creek, North Boulder Creek, and Middle Boulder Creek. The glaciated portion of South Boulder Creek is mainly in Gilpin County. A minor amount of ice spilled into the head of Lefthand Creek from the main glacier moving down the valley of South St. Vrain Creek. Coal Creek, the only other major stream in the county, shows no signs of having been glaciated during late Pleistocene time.

Although glaciation was multiple, all till regardless of age is shown by a common symbol on Plate 2, except for Neoglacial deposits. Nonetheless, a brief description of the different ages of deposits is given below. Maps showing their distribution in more detail are in Madole (1969, 1972, and in press) and in Gable and Madole (in preparation).

4.22 Pre-Bull Lake Tills

The term pre-Bull Lake refers to all Pleistocene glaciations which preceded Bull Lake time, be it by 100,000 or 1,000,000 years. At least three separate pre-Bull Lake tills are recognized in parts of Utah, Wyoming, and Montana, but the same distinction is not possible in the Front Range even though the equivalents of these deposits may exist here.

Most of the deposits regarded as pre-Bull Lake till occur on ridge tops near the Continental Divide at altitudes of 11,400 to 12,400 feet. Two of the best examples are on Niwot Ridge and nearby Toll Ridge (an unofficial name) at the head of South St. Vrain Creek. Similar deposits occupy broadly U-shaped valleys between Isolation Peak and Mahana Peak in the southeast corner of Rocky Mountain National Park, and Kiowa and Albion peaks in the Boulder watershed (see Fig. 6).

A second mode of occurrence for these old tills is in valley bottoms beyond the outer limit of Bull Lake till. However, in this setting, they are often largely buried by younger materials or are so eroded that their age, if not origin, is debatable. Examples exist at Lakewood Reservoir near the Peak-to-Peak Highway where it crosses North Boulder Creek (Bonnett, 1970) and in Tahosa Valley near the northern boundary of the county (Richmond, 1960).

Unique deposits that have been mapped as pre-Bull Lake till and associated outwash (Wahlstrom, 1947; Ives, 1953; and Gable, 1972), but whose origin is questioned, occur atop Tungsten Mountain and nearby Winiger Ridge in the Tungsten Quadrangle. Because this area is in the Central Sector, description of these deposits is deferred to Section 4.3.

4.23 Bull Lake Glaciation

Till of the Bull Lake Glaciation exists largely as an undulating blanket of rocky debris which retains little morainal form. Generally, it occurs only near the lower limit of glaciation and does not extend more than a half mile or so beyond the prominent lateral and terminal moraines of the younger Pinedale Glaciation and, in places, it was completely overrun. At varying distances upvalley, these deposits are truncated or buried by Pinedale moraines.

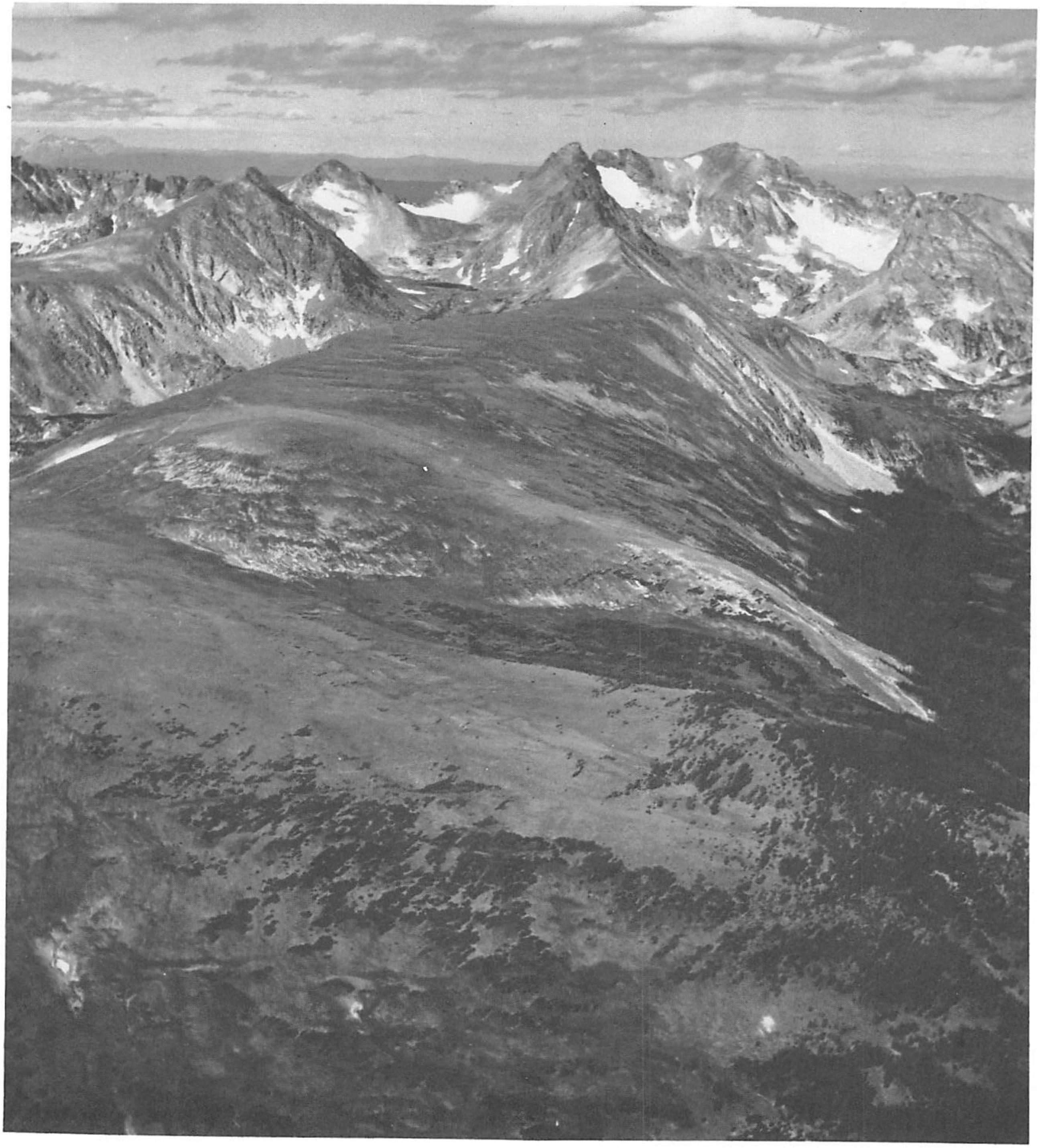


Figure 6. View west onto Niwot Ridge (center) with the "saddle" between Albion and Kiowa peaks partly visible at the upper left. Both sites are mantled by what are believed to be pre-Bull Lake glacial deposits. A Gannett Peak moraine appears along the lower edge of Isabelle Glacier (upper right) and gray talus, also of Neoglacial age, is evident near Lake Isabelle (upper right). The dark stripes along Niwot Ridge and at the lower left are solifluction lobes (photo by J. D. Ives).

Two stades (subdivisions of a glaciation characterized by a readvance of glaciers) of Bull Lake Glaciation, probably of very different ages, can be distinguished in a few places such as the valley of Lefthand Creek. However, separation is not possible over most of the area. Besides lacking the rugged moraines and constructional topography of Pinedale deposits, the greater antiquity of Bull Lake deposits is indicated by thicker soil profiles and the greater degree to which they are weathered. Also, while streams have not intricately dissected them, undrained depressions are practically non-existent, a characteristic which contrasts with Pinedale till.

4.24 Pinedale Glaciation

Because they are the product of the last major glaciation, Pinedale deposits mantle 90% of the glaciated area. Most till lies between altitudes of 8,000 and 10,500 feet, above which it rapidly becomes thin and discontinuous and features of glacial erosion dominate. One of the outstanding characteristics of Pinedale till is the magnitude and abundance of steep, sharp-crested moraines, and extensive knob and kettle topography. Erosion and mass movement have not greatly modified the terrain. Moraine-dammed lakes, swamps, and perennial kettle-hole ponds are numerous, and control of streams by lateral moraines is common.

The moraines that usually mark the outer limit of Pinedale till commonly rise 100 feet or more above the terrain beyond (Fig. 7). However, in some valleys, that of Middle St. Vrain for example, terminal moraines were either never well-developed and/or were subsequently eroded. For details regarding distinguishing characteristics of Bull Lake and Pinedale tills in this area see Madole (1969).

4.25 Neoglaciation

Neoglaciation began about 4,500 years ago following an interval referred to as "altithermal time" (Fig. 5) during which glacier ice is believed to have disappeared completely from the Front Range. While the end of Pinedale time is not yet precisely known, only remnants of its glaciers remained near the Continental Divide 8,000 years ago. The small existing glaciers of western Boulder County are remnants of the most recent episode of Neoglaciation, all of which was very minor compared to Pinedale Glaciation.

Although Neoglacial deposits are of very limited extent, they are important to studies of recent climatic history, and the associated glaciers and snowfields continue to provide much of the water upon which the adjacent plains depend. These deposits are diverse and relate to three stades of Neoglaciation currently termed Temple Lake, Audubon, and Gannett Peak. Figure 7 shows their size and altitudinal relations schematically. Madole (1972) groups the various deposits of each of these stades into four categories which include (1) talus and protalus ramparts; (2) lobate rock glaciers, also called valley-wall rock glaciers in the Front Range by Outcalt and Benedict (1965); (3) tongue-shaped rock glaciers or cirque-floor rock glaciers in the Outcalt and Benedict terminology; and (4) ice glaciers and moraines.

Temple Lake Stade. The Temple Lake Stade is believed to have occurred approximately between 2,600 and 4,500 years ago. Most moraines of this stade are only 15 to 35 feet high, turf-covered, and restricted to valley heads above timberline where some dam small lakes. Where deposits consist of coarse rock rubble, which is the case for almost all rock glaciers and talus, vegetation is scant except for abundant lichens. Because of the difference in quantity of lichens and other vegetation, deposits of this stade appear distinctly different from the gray, more barren, younger deposits of both Audubon and Gannett Peak age.

The largest glacier of Temple Lake time originated in the present location of Arapahoe Glacier and descended eastward about one mile to an altitude of approximately 11,250 feet. In places, Temple Lake glaciers barely exceeded the treads of high rock staircases lying just downvalley from their cirques. Instead of leaving identifiable moraines, these glaciers scattered till over steep risers into valley floors below where it tends to be obscured by younger rock debris.

Tongue-shaped rock glaciers of Temple Lake age occur in only a few places while lobate rock glaciers are abundant. Most talus seen in the valley heads is of Audubon or Gannett Peak age.

Audubon Stade. The Audubon Stade is believed to have occurred approximately between 950 and 1,850 years ago (Benedict, 1968). Deposits of Audubon age are identified mainly on the basis of the size of diagnostic species of lichen and percentage of total lichen cover (Benedict, 1967, 1968; Mahaney, 1972, 1973). Moraines of Audubon age are not widespread. Except for a few in cirques not reoccupied by Gannett Peak glaciers, most occur adjacent and parallel to moraines of Gannett Peak age. Audubon glaciers were scarcely larger than those of Gannett Peak time, and in neither

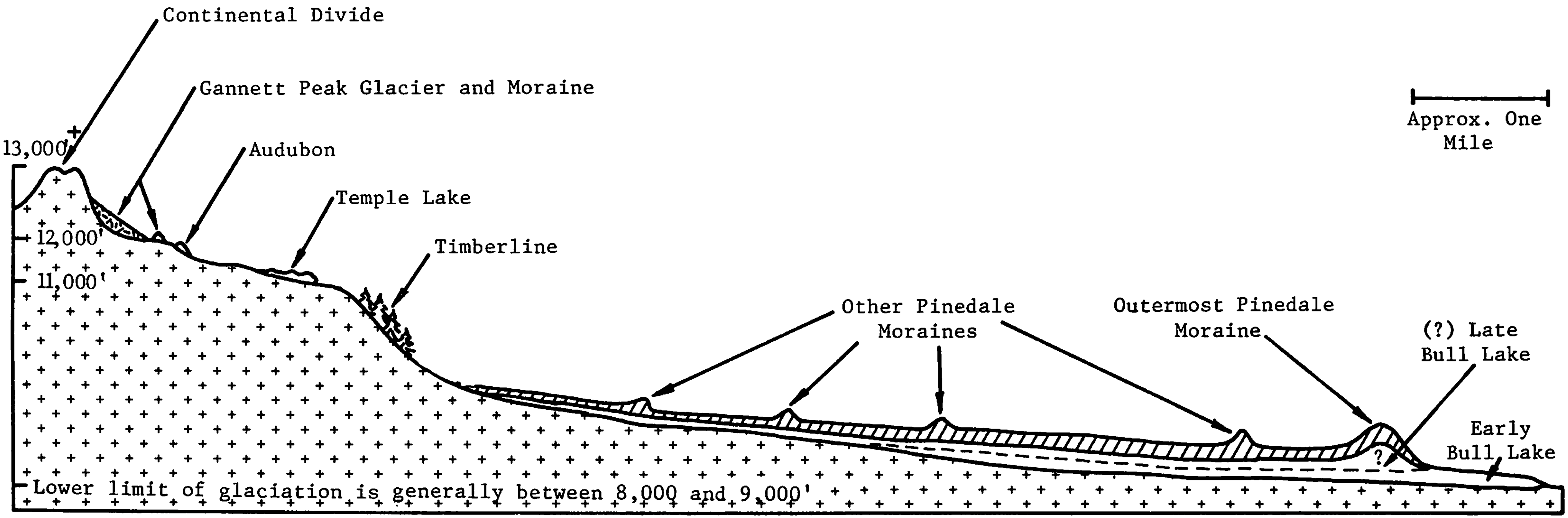


Figure 7. Schematic representation of the size and altitudinal relations of glacial deposits in western Boulder County.

age were cirque thresholds greatly exceeded. Till and other deposits of both stades are easily distinguished from Temple Lake deposits, but are not easily distinguished from each other without resorting to lichenometry.

Gannett Peak Stade. The Gannett Peak Stade began about 350 years ago. Several cirque glaciers formed during this time, mainly on the east side of the Continental Divide. Were it not for the slightly anomalous topography of the Indian Peaks, which favored development of a few north-facing cirques, there would probably be no glaciers west of the Divide. The prevalence of glaciers on the east slope is the result of wind-drifting of snow as described by Outcalt and MacPhail (1965) accompanied by the rotor effect detected by Lloyd (1970). The talus and moraines that enclose the few small glaciers of this stade have a notable fresh, gray, unweathered appearance. A few alpine plants grow on them in protected places, but plant cover, including lichens, is scant.

4.26 Nonglaciated Interstream Areas.

Most of the interstream uplands such as Caribou Mountain, Niwot Ridge, and St. Vrain Mountain are mantled by variable amounts of residual deposits much of which have moved slowly under the influence of gravity from topographic highs into lows. Hence, interstream divides tend to consist of rock knobs and/or knolls thinly veneered with residual regolith separated by "saddles" filled, in places, by more than 100 feet of unconsolidated debris. Solifluction lobes (Fig. 8) are relatively common landforms on these interfluves. They occur in wet localities and are the product of slow downslope movement aided by the presence of frozen ground. Most of the surficial deposits on these interfluves are thicker than the residual deposits of the central sector described next.

4.3 CENTRAL SECTOR

The central sector is nearly conicident with what has been termed the Subsummit or Rocky Mountain erosion surface. This surface is a rolling upland formed on deeply weathered crystalline rocks that spans up to 20 miles as it descends eastward from about 9,500 feet to 7,000 feet at the mountain front. The remarkable uniformity of the interstream summits shown in Figure 9 is not so apparent on the ground because of dissection by streams and canyons more than 1,000 feet deep.

As with all sectors, geologic history has largely determined the characteristics of the surficial deposits. The central sector

Figure 8. Hummocky terrain produced by solifluction on the north side of Caribou Mountain. These landforms are common in wet localities in the alpine tundra. Deposits moved by solifluction, slow downslope flow of water-saturated surficial deposits, occupy a large portion of the landscape shown in Figure 6.

bears the imprint of long-continued weathering and erosion since uplift in Tertiary time. Hence, it is characterized by a thin mantle of residual deposits overlying deeply weathered bedrock. In marked contrast to the other sectors, particularly the eastern, transported deposits are a minor part of the landscape.

The surficial deposits of the central sector include (1) residual regolith, (2) alluvium-colluvium filled meadows, (3) till-like deposits of questionable age and origin (the Tungsten Mountain and Winiger Ridge deposits) in the southern part of the sector, (4) stream deposits along the major valleys, and (5) colluvium-veneered valley sides. Residual regolith (unconsolidated material above solid bedrock) is by far the dominant category. Detailed mapping might eventually allow this unit to be subdivided according to the kind of bedrock from which it was derived. Residual regolith is designated on Plate 2 simply by reference to whether it was derived from metamorphic or "granite" type rocks.

Residual deposits in most upland areas are only a few inches to a few feet thick. Their thinness creates problems for mountain subdivisions with regard to water supply and sewage treatment. Compliance with County Health Department regulations governing septic tanks and leach fields is generally difficult without resorting to building-up the soil to meet thickness requirements. Where Boulder Creek granodiorite is involved, which is much of the area, deeply weathered bedrock is often treated as soil because it is easily excavated by a backhoe or front-end loader. Considering the permeable nature of this material and the tendency for ground water pollution of the underlying fractured aquifers (Section 9) this practice is questionable.

Groundwater pollution from sewage is known in Boulder County, and the U. S. Geological Survey study in mountainous Jefferson County revealed that groundwater in 40% of their study area was chemically or biologically polluted (Biesecker and Hofstra, 1973). It would be safer to require that there be 4 feet of soil between the bottom of the leach field and the top of weathered bedrock. This of course would require a soil, in the engineering sense, 7 feet thick. Residual deposits this thick occur in only a small portion of the central sector.

Two types of deposits that do attain thicknesses of 7 feet are the alluvium-colluvium filled upland meadows in the montane zone and the anomalous deposits on Tungsten Mountain and Winiger Ridge. As noted earlier, the latter have been mapped as till, and they are grouped with till on Plate 2. However, Glenn Scott (U. S.

Figure 9. View of the Front Range showing the apparent evenness of summits that evoked the concept of a Rocky Mountain or Subsummit erosion surface (photo by NCAR).

Geological Survey, pers. comm., 1973) believes them to be remnants of Tertiary stream deposits which were once graded to the plains. According to this view, they would predate most of the denudation that has given rise to the mountain front as we know it. Regardless of their true origin, these deposits more closely resemble pre-Bull Lake till than anything else. They contain huge boulders, many of which are so highly weathered they crumble easily. Because of their thickness, permeability, and other properties, they are two of the better locations for mountain subdivisions.

Alluvial deposits of the major valley bottoms also exceed thicknesses of 7 feet, but the seasonally high water table and the threat of flooding (see Section 12) can be constraints. Likewise, colluvium (slope wash) is more than 7 feet thick in places along valley walls, but many such occurrences are on slopes too steep to develop. Valley-side colluvium is difficult to map without detailed field work, and hence, is not included as a unit on Plate 2.

4.4 EASTERN SECTOR

4.41 Introduction

The plains portion of Boulder County abounds with sediment deposited by streams and wind. Stream deposits are especially abundant on terraces and on at least three different levels of pediments that project eastward from the mountain front. Wind transported deposits do not become stratigraphically significant in most places until east of a north-south line connecting the town of Niwot, Gunbarrel Hill, and the northeast end of Davidson Mesa.

4.42 Pre-Bull Lake Stream Deposits

Whereas deposits related to the most recent major glaciation dominate in the mountains, older deposits (pre-Bull Lake) are the most extensive on the plains. Although several different ages of pre-Bull Lake stream deposits can be identified, their stratigraphic characteristics are so similar that they are mapped and described collectively. Near the mountain front, they overlie upturned, beveled beds of Benton Shale and Niobrara Formation. Elsewhere, they rest upon crumbly, weathered, grayish-brown Pierre Shale. They are scarcely more than a blanket of rounded rock debris. Thickness varies from 25 to 35 feet in channel ways to 3 or 4 feet in interchannel areas, but is 10 to 15 feet in most places. The deposits consist of a few boulders and many cobbles, whose size and roundness vary with the source stream and distance from the mountain front, in a matrix of reddish-brown sand which increases in abundance eastward.

Deposits and soils of pre-Bull Lake age are generally easily recognized because (1) the deposits are oxidized reddish-brown throughout, even where 25 feet thick; (2) the reddish hues of the B horizon are much stronger than in younger soils; (3) the greater quantity of clay is relatively obvious; (4) strong prismatic structure exists where profiles are well developed; and (5) pronounced development of caliche does not occur in younger soils. Even the most mature early Wisconsin (Bull Lake) soils are not oxidized to depths of more than 6 feet and lack the build-up of clay, caliche, and development of a strong prismatic structure. However, differences in weathering and soil profile development on the various ages of pre-Bull Lake deposits are not sufficiently distinct to use as a means of determining their relative age or for correlating them from one region to another.

4.43 Bull Lake and Pinedale Stream Deposits

Louviers gravel. The Louviers gravel, named and described by Scott (1960) in the Littleton area south of Denver, occurs in inconspicuous terraces 8 to 12 feet above present stream level. These deposits which are thought here to correlate with Bull Lake Glaciation are poorly preserved near the mountain front, but become more distinct and extensive downvalley.

Broadway Gravel. The Broadway gravel, described by Hunt (1954) in the Denver area, is considered to relate to Pinedale Glaciation. It does not occur in terraces until about 15 miles east of the mountain front. Nearer the mountains it is exposed in several gravel pits on the flood-plains of major streams concealed beneath 1 to 4 feet of younger alluvium. Where they are topographically higher than the younger alluvium, Louviers and Broadway gravels are mapped collectively as Ay on Plate 2.

4.44 Post-Pinedale Deposits

Two alluvial deposits of recent (Holocene) age cover the flood-plains of the area and are designated Ar on Plate 2. These are thought to be correlative with the Piney Creek alluvium named by Hunt (1954) in the Denver area and to the post-Piney Creek alluvium described by Malde (1955) in the Louisville Quadrangle. Near the mountain front, post-Piney Creek alluvium covers almost the entire floodplain restricting Piney Creek deposits to small fans along the valley sides and scattered islands within the floodplain Post-Piney Creek alluvium tends to become thicker in a downstream direction and confined to a more definite, narrower channel. Channel trenching subsequent to deposition of post-Piney Creek alluvium formed a still younger set of small terraces and numerous shallow channels across the surfaces of the major floodplains.

4.45 Surficial Deposits and Land Use Problems

The surficial deposits of eastern Boulder County are more voluminous and exert more influence on land use options than those of the other sectors. They are very much a part of the sand and gravel problem discussed in Section 7; are a determining factor in the kinds of soils that form, their optimum uses, and some of the associated problems discussed in Section 8; and are involved in aspects of landslides and unstable soils discussed in Section 12.

SECTION 5

VEGETATION

P. V. Krebs

5.1 INTRODUCTION

During the last decade the improvements made in the analysis of natural resources and man's impact on the environment can be attributed to three essential components. The first of these is an intensification of man's ecological awareness. The concern is of man's relationship to his environment. As a result, the integrative approach to resource management has overshadowed the single discipline analysis. The second component is the growing preference for remote sensing as a reliable information source and a technique to obtain this information more rapidly. And third, the availability of high quality remote sensing products makes the synoptic viewpoint plausible. No longer is analysis limited to the detailed ground work alone, but rather has expanded to include larger areas without regard for fencelines and political boundaries. All three of these components are necessary in today's emphasis on the direct application of environmental research to comprehensive, ecological resource planning and effective land use management.

The efforts of the INSTAAR environmental research team, funded by a NASA-PY project grant, draw together and help clarify the interrelationships of vegetation, soils, geology, geomorphology and hydrology. One main interpretive measure for this synthesis of information into a usable land use planning format is through the vegetation which reflects the effective environment. Through vegetation analysis, the land use planner is able to detect environmental potentials and limitations. This approach also makes possible the assessment of related man-imposed modifications of the natural landscape to the basic ecosystem units so that land and resource suitability can be judged and extrapolated in an ecological framework. The natural ecological unit of the landscape is often detected or inferred by vegetation (Poulton, 1972). It is this natural ecological unit which becomes the base through which management policies, research results, and related information can best be generalized. This becomes the necessary endpoint as man's future activities are guided to achieve compatibility with the potentials and limitations of the environment.

5.2 VEGETATION MAPS

Vegetation maps provide information useful in several contexts. For example, the ecosystem approach to land management is based on natural vegetation. Moreover, vegetation is an indicator of geologic, pedologic, topoclimatic, and hydrologic characteristics as well as of the potential for landslides and avalanches. A knowledge of plant communities is important to planning inasmuch as they reduce air, noise, and water pollution, are important in controlling erosion and sedimentation, and so determine the esthetics of the landscape that they cannot be ignored. Furthermore, the distribution of plant types is a major input in fire hazard mapping and is basic to determining and managing wildlife habitat.

The role of vegation maps in land management and planning is directed toward optimal land use. Because there are different types of vegetation maps and different purposes that these maps serve, the character of the maps is controlled by scale, vegetative classification scheme, and intended use. Considering these controlling criteria vegetation maps permit a broadened insight into the landscape, the nature of its vegetation, and the delineation of the stability and/or instability of local areas.

Vegetation maps are inventories of plant cover type units existing at a given time and place. From such maps the areal distribution of vegetation types in the landscape can be determined. An evaluation can then be made of what is valuable and desirable, and what is not. Vegetation maps can also provide the means for analyzing the natural environment. Once correlations are made between vegetation cover types and environmental parameters, the influence of such parameters can often be deduced from the vegetation. Hence, vegetation maps show units of vegetation, and, directly or by implication, the quality of the sites on which they grow.

U. S. Geological Survey topographic quadrangle maps at a scale of 1:24,000 were selected as the base maps for vegetation mapping in Boulder County. This scale is compatible with accurate and moderately detailed mapping of major vegetative units encountered in the county. The superior quality of available NASA aircraft photography in color infrared, while at a scale of 1:55,000 and

1:110,000, provides the following advantages: reliability, synoptic view, extensive coverage, favorable interpretation, rapid acquisition of data, and up-to-date photography.

Since there has been little or no mapping in Colorado of a magnitude suitable to the purposes of this study, a classification symbol system was designed. This system employs a combination of mapping approaches of dominant vegetation cover types which has statewide application in mountainous areas (Table 2). The symbol system is currently being used in several other vegetation mapping projects in the state (Krebs and Keammerer, 1973). A graded color code for the cover types provides an effective detailed representation on the finished map product.

The procedure followed in generating the series of detailed vegetation maps from which Plate 3 was compiled is a modification of Küchler's (1967) comprehensive method. All distinct areas are outlined on the air photography and then transferred to the U.S.G.S. quadrangle base map. Photointerpretation for the various vegetation cover types is based on "training samples" or control data for preselected sites in which the cover type has been field checked. Once the photo characteristics of each cover type have been determined from these standards, other areas having similar characteristics can be identified. The descriptive characteristics include landscape features, local relief, density contrasts and variations, boundaries, size relations, and other comparisons among features of the landscape and observable elements on the photograph.

The primary concern in establishing such standard areas is to include characteristic examples of all types of vegetation and sites to be encountered in the study. The correlation between vegetation and site is of fundamental importance such that it should be made wherever possible. Detailed information of this type permits, in some instances, the identification of vegetation cover types on the basis of site characteristics. In other instances, the site qualities can be deduced from the vegetation cover types. Through proper use and interpretation of the information contained in or implied by vegetation maps, the mapped units can be viewed as tools for analyzing the natural environment through the interrelationship of the environment and the mosaic of plant communities (Krebs, 1972). In mountainous terrain the three-dimensional aspect of the distribution of vegetation types must also be represented on the map. In part, the landscape determines the character of the vegetation, and in part, the character of the landscape can be deduced from the vegetation. This information on site character representativeness for the various cover types is summarized in Table 3.

TABLE 2

Vegetation mapping symbol system

Non-Vegetated

- 00.
  - 01. Water
  - 02. Residential

Vegetated

- 100. Non-Forested
  - -110. Grassland
  - -120. Flood plain/Riparian community
  - -130. Meadow (Subalpine/Montane)
  - -140. Tundra
  - -150. Shrub
    - 151. Sagebrush/Rabbitbrush/Potentilla
    - 152. Mt. Mahogany/Rose/Ninebark/Snowberry/ Thimbleberry
    - 153. Willow/Alder/Birch
    - 154. Rocky Mt. Maple/Ribes (Gooseberry)
    - 155. Oak.
  - -160. Agricultural
    - 161. Grazing
    - 162. Crop

- 200. Forested
  - 210. Deciduous
    - -211. Aspen
  - 220. Coniferous
    - -221. Piñon Pine - Rocky Mt. Juniper
    - -222. Ponderosa Pine (with shrub)
      - 222.1. with oak
      - 222.2. with other shrub
    - -223. Ponderosa Pine - Rocky Mt. Juniper
    - -224. Ponderosa Pine - Douglasfir
    - -225. Engelmann Spruce - Subalpine Fir
    - -226. Lodgepole Pine
    - -227. Limber Pine/Bristlecone Pine
    - -228. Mixed Coniferous (3 or more species)
      - 229.1. Ponderosa Pine - Rocky Mt. Juniper - Douglasfir

Table 2 (continued)

229.2. Douglasfir - Ponderosa Pine with
Engelmann Spruce/Colorado Blue
Spruce

229.3. Douglasfir - Engelmann Spruce -
White Fir/Subalpine Fir

229.4. Lodgepole Pine with
Ponderosa Pine - Rocky Mt. Juniper
Ponderosa Pine - Douglasfir

229.5. Lodgepole Pine - Douglasfir -
Engelmann Spruce/Subalpine Fir

230. Coniferous - Deciduous

231. Ponderosa Pine/Douglasfir - Aspen

232. Douglasfir/White Fir - Aspen

233. Douglasfir/Engelmann Spruce - Aspen

234. Engelmann Spruce - Subalpine Fir -
Aspen

235. Lodgepole Pine - Aspen

236. Lodgepole Pine - Ponderosa Pine/
Douglasfir/Engelmann Spruce/
Subalpine Fir - Aspen

TABLE 3. Vegetation of the Boulder area (Marr, 1967)

Regions and Altitudinal Range		Vegetation	Topographic Relations: S-facing slope	Topographic Relations: Ridge top	Topographic Relations: N-facing slope	Ecology: Successional	Ecology: Climax
Plains	A.	Little bluestem	Slopes; coarse and/or eroding soil			X	X
Grassland	B.	Needle grass-grama grass	Slopes; coarse and/or eroding soil			X	X
up to	C.	Grama grass-linear leaf wormwood	Slopes; coarse and/or eroding soil			X	X
5,600 ft.	D.	Cheatgrass-wheatgrass grama grass	Lowlands; deep, compact soil			X	
Lower	A.	Ponderosa pine-grama grass	X			X	X
Montane	B.	Douglas fir-ponderosa pine		X	X	X	X
6,000 to	C.	Douglas fir			X	X	X
7,700 ft.	D.	Dry grassland	X	X		X	?
	A.	Ponderosa pine	X	Coarse soil	Coarse soil	X	X
Upper	B.	Ponderosa pine-Douglas fir	X			X	X
Montane	C.	Douglas fir-ponderosa pine		X	X	X	X
8,000 to	D.	Limber pine		Coarse soil and wind exposed		X	X
9,000 ft.	E.	Lodgepole pine	X	X	X	X	
	F.	Aspen	X	X	X	X	
	G.	Dry grassland	X	X		X	?
	A.	Spruce-fir	X	X	X	X	X
Subalpine	B.	Lodgepole pine	X	X	X	X	
Forest	C.	Aspen	X	X	X	X	?
9,300	D.	Limber pine		Coarse soil and wind exposed			
to	E.	Dry meadow	X	X		X	?
11,000 ft.	F.	Wet sedge-grass meadow		High water table		X	X
	A.	Kobresia meadow		Level or slight slope Snowfree all winter			X
Alpine	B.	Hairgrass meadow		Snow-covered all winter, early snow melt; well watered			X
Tundra	C.	Parry's clover		Shallow snow accumulation?			?
11,300	D.	Adoneus buttercup		Deeper snow accumulation			X
to	E.	Cushion plants		Rocky ground; wind exposed		X	X
mountain	F.	Dryad		Coarse, eroding soil		X	X
tops	G.	Sedge-grass wet meadow		Little snow cover			X
	H.	Willow-sedge hummocks		High water table			X

The vegetation maps of Boulder County represent the "extensive mapping" type of approach (Küchler, 1967). Air photographs are most desirable in extensive mapping because of the ease of "access" to areas not accessible on the ground. The amount of detail represented on NASA high flight imagery is most applicable to extensive mapping and has been frequently found to suffice for the preparation of the maps. The different types of vegetational landscapes occupy the center of attention. The uppermost stratum of the vegetation is considered as the significant features. The dominant species is listed for each established type but no attempt was made to detail floristics which lies beyond the scope of extensive mapping.

A detailed floristic analysis for the purpose of selected intensive mapping sites is, however, being prepared by the ecological task force of the Boulder County Planning Project under sponsorship of the World Design Institute, College of Environmental Design, University of Colorado. The cooperation of this group in extending and quantifying information for the Boulder County study is gratefully acknowledged.

From the detailed maps (1:24,000) a specific cover type can be located and its areal extent determined. Perhaps the specific vegetation type is one which represents preferential browse for large game animals or a critical habitat type for some other animal of interest. The information from the detailed vegetation maps can be generalized to indicate the stability/instability of the vegetation in response to disturbance. Several interpretations may be made from climax vegetation stand types and successional stand types which are indicative of past disturbance and/or the relative degree of disturbance. Correlations between vegetation and disturbance provide a sliding scale for predicting what additional disturbance an area can tolerate before a successional trend becomes irreversible. This would also provide a means of assessing the esthetic value of each area. Answers to such questions as how similar is a particular area to others could be found from proper interpretation of map information.

5.3 BOULDER COUNTY VEGETATION MAP

Detailed vegetation maps of Boulder County were originally prepared at a scale of 1:24,000. These maps are housed in the map files at INSTAAR where they are available for use by interested individuals. For the purposes of this report the final vegetation map (1:96,000) portrays a generalized trend of vegetation which has been reduced from the more detailed component maps. The included categories are urban, non-vegetated, agricultural, grassland, floodplain-meadow, mixed coniferous, deciduous, conferous-deciduous, spruce-fir, and tundra. Characteristics of community stand types incorporated within the map categories have been discussed by Marr (1964), Marr (1967), Daubenmire (1943), and Hartman (unpub). When reading the following descriptions of the categories, frequent reference to the vegetation map (Plate 3) is advisable as many land use trends are evident in the vegetation pattern.

5.31 Urban

Areas of population concentrations show altered vegetation patterns which differ markedly from the natural vegetation. No attempt has been made to categorize vegetation within these centers of population.

5.32 Non-vegetated

This applies to areas where surfacing rock outcrops or relatively bare soil predominates.

5.33 Agriculture and grasslands

Colorado's major grassland extends from the Eastern border of the state west to an elevation of 5,400 ft. This area lies within the Great Plains and reflects widespread disturbance, both past and present. The lowlands are irrigated and under cultivation. The slopes and uplands are grazed. Boulder lies within the Grassland-Lower Montane ecotone (5,400-6,000 ft.) which is an area of transition between the short grass plains and the forested foothills. The dominant grasses are blue grama and buffalo grass on the slopes and uplands. Both of these are relatively unpalatable to grazing animals. Yucca and prickly pear cactus are the predominant herbs where the land has been overgrazed. Occasionally in relatively undisturbed areas such as along railroads or in moist ravines, both big and little bluestem, needle grass, and side-oats grama can be found. These grasses are characteristic of the uplands in the tall-grass prairie. Two grasses which are cultivated, often escape and become naturalized are cheatgrass and western wheat grass. Some woody plants are able to invade ravines. These include mountain mahogany, sumac, buck-brush, and bitter-brush.

5.34 Floodplain-meadow

Certain small grass communities occur in each of the mountain zones from the Lower Montane through the Alpine. Grass community types in the Lower Montane are dominated by blue grama. These may be frequent on ridgetops, broad valleys and south-facing slopes and probably result from clearing done in the past. It is believed that many of the ponderosa pine-grass areas now so prevalent in the Lower Montane were at one time park-like. The trees were widely scattered with very few seedlings and considerable grass cover. These park-like areas are best seen now on the Western Slope of the Front Range and the Western Slope of the Rockies.

Prior to the time of early settlement, tree seedlings could not compete with the grasses so tree density was kept low. Then grazing by the animals of the early settlers weakened the grass cover. Fires also probably figured into the picture. Both fire and settler activities reduced the competitive capacity of the grasses and thus allowed tree seedlings to form dense forests of young timber. The grass areas are now maintained by disturbance.

In the Upper Montane grass areas are similar to those of the Lower Montane except that they are dominated by spike fescue and related grass-like sedges. Here the grass areas are edaphic climaxes (responding to soil factors) and are not maintained through disturbance to the land area.

Grass areas in the Subalpine zone are usually associated with lakes where there is always adequate moisture. Surrounding the lakes may be grass-sedge meadows with shrubs interspersed. Dominants include Koeleria (grass), blue grass, and Carex (sedge). Eventually shrubs will come to dominate as a successional stage as the area vegetationally moves toward its climax, the spruce-fir forest. In other words, the grass areas in the Subalpine zone are successional.

The floodplains east of the foothills are characterized by the plains cottonwood. Typical creek and floodplain communities in the mountainous area of Boulder County include Colorado blue spruce, narrow-leaved cottonwood, willows, alder, Rocky Mountain birch, and chokecherry. Willow, birch, and alder often form dense thickets along river banks.

5.35 Mixed coniferous

In both the Lower and Upper Montane zones various disturbances such as mining, lumbering, fires and grazing have resulted in a diversification of plant communities. The predominant vegetation consists of an open forest of broad-crowned evergreens, ponderosa pine and douglasfir, interrupted by grassy openings. Young stands are dense and mature stands on north exposures may have a nearly closed canopy while south exposures may be park-like. In the Lower Montane ponderosa pine dominates on south-facing slopes and on exposed ridges of north-facing slopes while douglasfir dominates on north-facing slopes and along creeks bordering south-facing slopes. Rocky Mountain juniper may be scattered with ponderosa pine in more xeric areas.

The Upper Montane is often referred to as the douglas fir zone because of the predominance of dense or open stands of douglasfir and/or ponderosa pine. It is probable that douglasfir is the climatic climax vegetation type of the Upper Montane although in many areas the coarse soil prevents this climax. Mature douglasfir stands are so dense that very few herbs are found beneath the trees. The forest understory is mainly kinnikinick and a duff layer may accumulate on the forest floor. Dense stands of lodgepole pine and groves of aspen (see coniferous-deciduous category) are interspersed in the douglasfir/ponderosa pine stands. The general appearance of vegetation in the Upper Montane is similar to the Lower Montane, but some noticeable differences occur. The forests have a greater overall density, the douglasfir is more abundant on south-facing slopes, and lodgepole pine and aspen occur on upland sites. Ridgetops and rolling uplands support mixed douglasfir and ponderosa pine stands. North-facing slopes are dominated by douglasfir if conditions are moderate. If the slope has unusually coarse or shallow soil, ponderosa pine dominates. South-facing slopes may have topoedaphic climax stands of ponderosa pine. Young lodgepole pine stands are extremely dense with usually no vegetation on the forest floor. Older lodgepole pine stands are more open and are eventually successional to the climax douglasfir and/or ponderosa pine. Limber pine may be scattered among other forest tress but cannot compete rigorously with them. Under adverse conditions (strong ridgetop winds and/or coarse soil) limber pine will thrive as a topographic or topoedaphic climax.

In the Upper Montane-Subalpine ecotone at higher elevations (approximately 9,000-9,300 ft.) the mixed coniferous category represents the blending of the predominate tree species of the two zones. The tree species included are douglasfir, engelmann spruce, subalpine fir, and on occasion, ponderosa pine.

5.36 Deciduous

There is no extensive area of a homogeneous deciduous vegetation component in Boulder County. However, there are many localized areas where either aspen or shrubs predominate. Young groves of aspen may be very dense. As they mature the aspen become thinned and eventually allow enough light to penetrate the forest floor to support understories of grass, herbs, and creeping shrubs. Aspen is generally an indicator of disturbance (extensive logging, fire, mining, and landsliding), and is a successional species. In Boulder County the occurrence of aspen above 10,000 ft. is infrequent. Shrub communities have been included in the deciduous category. Antelope-brush, thimbleberry, squaw-current, and sumac are found on rocky slopes and relatively steep south-facing slopes. Wild rose, ninebark and serviceberry are found along creeks and also on hillsides. Wet marshy areas around lakes in the Subalpine zone support dense shrub communities of willow and dwarf birch. These communities are successional in most moist sites but in areas where the water table is high, they are probably topo-edaphic climaxes.

5.37 Coniferous-deciduous

In areas where there has been past disturbance (usually fire, logging and mining) the appearance of the vegetation is one of a mixture of aspen with coniferous species. The vegetation map of Boulder County (Plate 3) clearly reflects this region of a disturbed nature approximately between 8,000 and 10,000 ft. For the most part aspen is found with lodgepole pine in the more extensively or intensely disturbed sites. This is a successional stand type giving way to a coniferous-deciduous component of aspen with douglasfir/ponderosa pine or sometimes engelmann spruce/subalpine fir at the higher elevations. Eventually the vegetation climax of either douglasfir/ponderosa pine or engelmann spruce/subalpine fir will predominate if the causes of disturbance are minimized or eliminated.

5.38 Spruce-fir

The spruce-fir stand type in general gives the appearance of being homogeneous, simple and continuous throughout its distribution in the Front Range. Engelmann spruce and subalpine fir are the predominant tree species of the Subalpine zone. This zone supports the most luxuriant vegetation of all the mountain zones, primarily as the result of the abundant moisture, and the fairly uniform distribution of precipitation throughout the year. Unlike the Montane zones, the contrast between vegetation on the slopes is not evident in the Subalpine zone. There are changes in vegetation from place to place but the direction of slope exposure is not the determining factor. A dense forest of spruce-fir stretches across valleys and ridges. Occasionally stands of lodgepole pine and aspen are found.

Also on the more exposed ridgetops limber pine may be interspersed within the spruce-fir forest. Due to remoteness, rough terrain, snow accumulation, and relatively low timber values, disturbances have been minimal.

In the upper region of the Subalpine zone the spruce-fir forest becomes dwarfed and distorted at timberline. The latter is considered to be the ecotone between the Alpine and Subalpine zones and is often called krummholz (meaning twisted wood). Some ecologists differentiate between tree line and timberline. Tree line marks the upper limits of the true dendroid (tree-like) growth form, whereas, timberline marks the upper limits of all woody plant species.

5.39 Tundra (Alpine zone)

In general tundra may be characterized as having low-growing (dwarfed) vegetation of perennial species of sedges, grasses, herbs, and minute shrubs. The spatial relationships of the plant communities present is one of the most striking features. Plant community aspects can change markedly within the space of a few feet. The fell-field community consists of lichens growing on rock surfaces, cushion plants such as moss campion and alpine sandwort, sibbaldia, and mountain-sorrel growing in the rock crevices. If a coarse gravelly soil has accumulated between the boulders to the extent that only the tops of the rocks are exposed, the plant cover is more extensive. This cover would include moss campion, mountain dryad, alpine sandwort, fleabane daisy, alpine forget-me-not, phlox, nailwort, arctic woodrush, and sky pilot.

Alpine meadows are more favorable habitats for sedges such as *Kobresia* and *Carex*; grasses such as bluegrass, alpine timothy, tufted hairgrass, needlegrass, arctic bentgrass, and fescue; and herbs such as clover, lousewort, bistort, cinquefoil, and alpine avens. The latter is probably the most abundant flower found above timberline. These alpine meadows are sometimes called *Kobresia* meadows. They remain snow-free throughout the winter and are found on wild-swept, gentle slopes which have a thick soil accumulation that remains moist. Other meadow situations in the tundra include grass meadows dominated by hairgrass and Parry's clover meadows dominated by that species. Both of these meadow types contain bistort and alpine avens.

Steeper slopes which retain more snow later in the spring are dominated by the snow buttercup with the other species mentioned in the hairgrass and Parry's clover meadows assuming dominance as the season progresses. Snowbank areas which accumulate snow early and retain it late into the growing season are dominated by sibbaldia, lichens and mosses. If the area is well-drained, sedges and grasses assume dominance after the snow melts. Cushion plant stands composed of moss campion, sandwort and alpine forget-me-not occur on sloping surfaces which are exposed to the prevailing winds. Willow-sedge hummocks occur on moist gentle slopes. The depressions between the hummocks may be water-filled during the summer. The tundra areas found in the western part of Boulder County have a particularly good representation of all of the community types thus far described.

The uniqueness of being able to progress through the life zones from the short grass plains to the tundra in a relatively short distance gives Boulder County a feature of high esthetic value. Although there is a 100-year history of various types of disturbances in the county, careful land-use planning can preserve the natural vegetation components. Three recommendations can be made at this time. Clear-cutting practices often employed in mountainous housing developments for roadways and building sites should be kept to a minimum. Artificially cleared areas tend to experience greater wind velocities resulting in windthrow of vulnerable trees located near the edges of the clearing. This certainly would increase the hazard to buildings and access if roadways are involved. Creek communities should be left undisturbed as a means of controlling the natural stream channels and reducing damage from flooding. Minimal or no disturbance should be allowed in the tundra by not providing additional road access. Currently there is adequate access to the alpine zone for those who wish to enjoy it. Certainly no major highway should ever be considered.

5.4 SLOPE MAPS DERIVED FROM VEGETATION

The detailed extensive vegetation maps can be used to generate other maps to answer specific questions. One such derivative map type is a slope maps displaying eight categories which are of interest to land use planners. Slope maps for the U. S. Geological Survey quadrangles of Lyons (Fig. 10), Boulder, and Eldorado Springs were produced from an interpretation of the site characteristics of vegetation cover types, subjective consideration of the contour intervals on the base maps and the shadow effect of slope aspect and vegetation combined. The detailed slope maps of these three quadrangles are on file at INSTAAR for use by interested individuals. The following eight categories were designated:

- all of slope greater than 25% and north-facing
- 3/4 of slope greater than 25% and north-facing
- 3/4 of slope less than 25% and north-facing

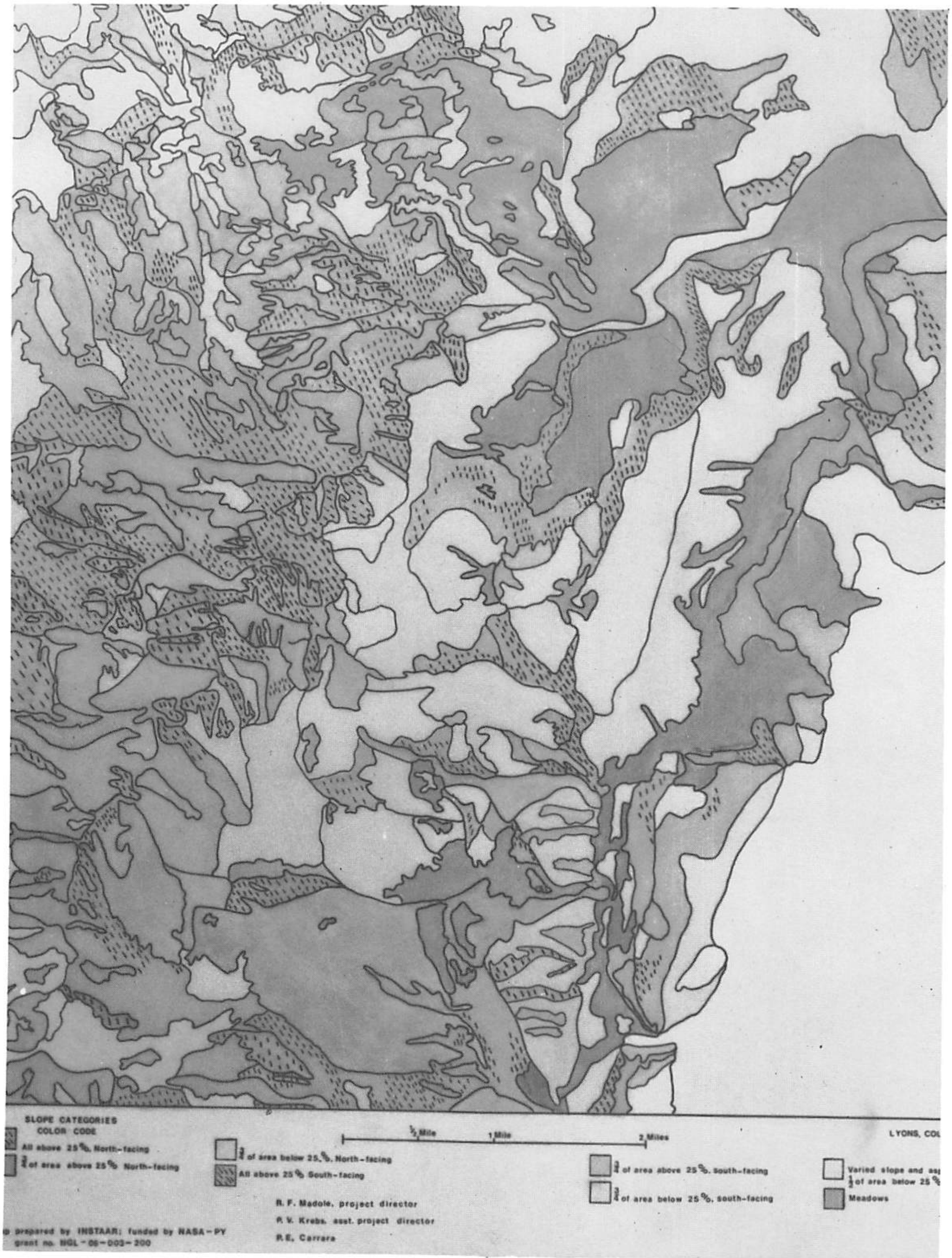


Figure 10. Slope map derived from maps of natural vegetation for a portion of the Lyons Quadrangle (1:24,000). Inasmuch as the source document was color-coded, various categories show only in shades of gray. Dashes = areas which are entirely in excess of 25% slope; dark gray - meadows of moderate to low slopes; medium gray - 3/4 of area above 25% slope; light gray - 3/4 of area below 25% slope; and white (except for plains in southeast) = areas of varied slope and aspect.

- all of slope greater than 25% and south-facing
- 3/4 of slope greater than 25% and south-facing
- 3/4 of slope less than 25% and south-facing
- flat meadow areas
- at least 1/2 of slope less than 25% but of varied aspect

This map can be used to help land use planners determine what areas are suitable for construction of dwellings, road construction and winter road maintenance, hazard of rapid forest fire spread due to crown fires, the potential for moderate to rapid mass movement, and increased erosion rates if the vegetation cover is drastically altered.

SECTION 6

CLIMATE

R. S. Bradley

6.1 INTRODUCTION

Boulder County is extremely diverse in its topography and hence in its climate. Total relief within the county exceeds 8,000 feet and so any attempt to summarize the climate must necessarily be rather generalized. For the purposes of this overview, the county will be considered in two halves -- the eastern plains and the mountains, separated, for convenience, by the 6,000 foot contour.

6.2 PLAINS

Figure 11 shows average monthly temperature at Boulder and Longmont. The annual range is about 40 degrees F with highest mean temperature in July at both places. At Boulder the coldest two months are January and February, whereas at Longmont, December and January are coldest. The difference in temperature between Boulder and Longmont is greatest in winter months, and this may reflect the inversion structure across the area.[1] At Longmont, temperature inversions may be more common in winter than at Boulder where turbulence at the mountain front would tend to mix the air and frequently prevent the development of a cold surface layer.

Figures 12 and 13 illustrate the average daily minimum and maximum temperatures in Boulder County during January. Minimum temperatures across the plains range from approximately 11 -19 degrees F. Average maximum temperatures are less variable with values of approximately 42-45 degrees F.

Figures 14 and 15 show mean daily minimum and maximum temperatures in Boulder County during July. For the plains, average daily maximum temperatures are from 84-88 degrees F.

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1. An inversion is a reversal of the normal decrease of temperature with altitude.

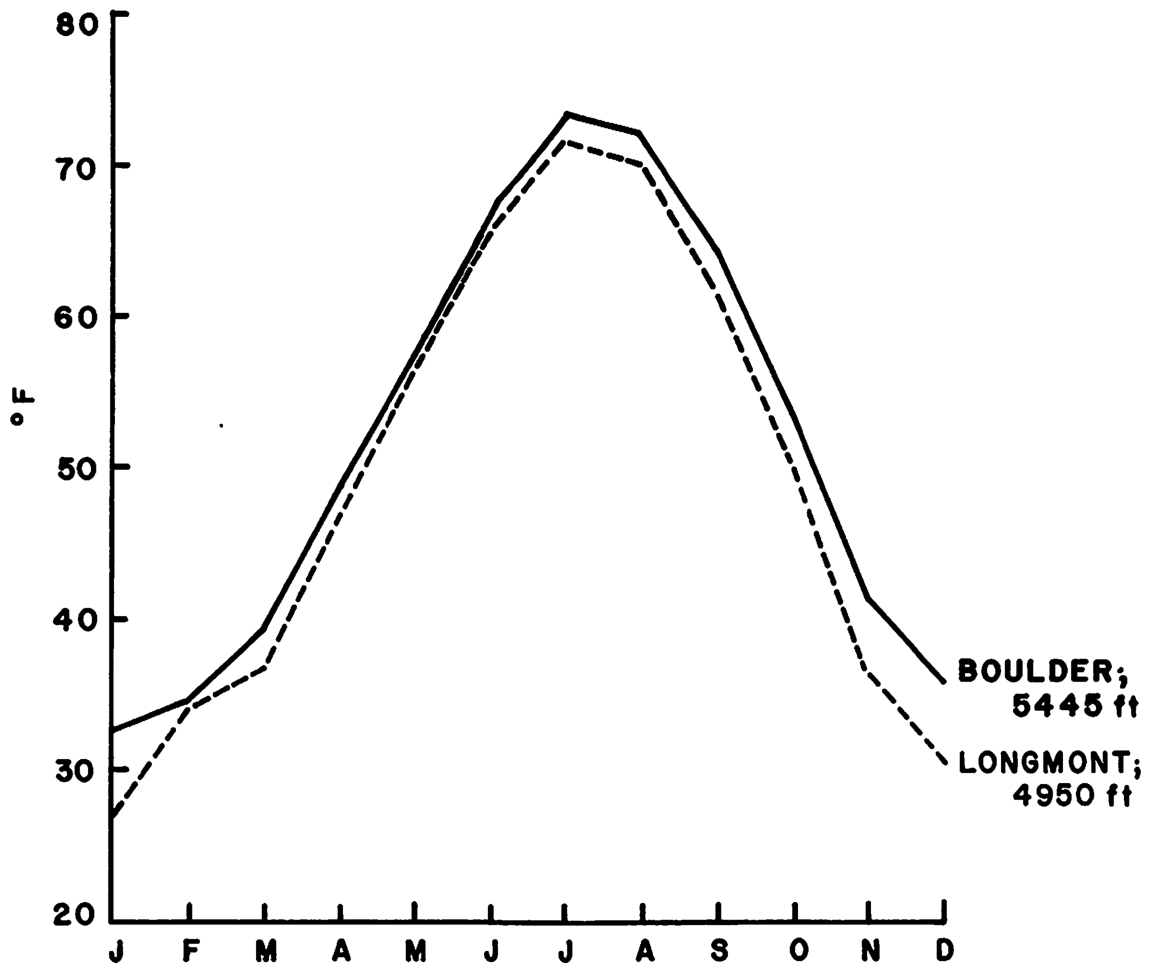

Figure 11. Mean monthly temperatures (°F), 1931 - 60, Boulder and Longmont.

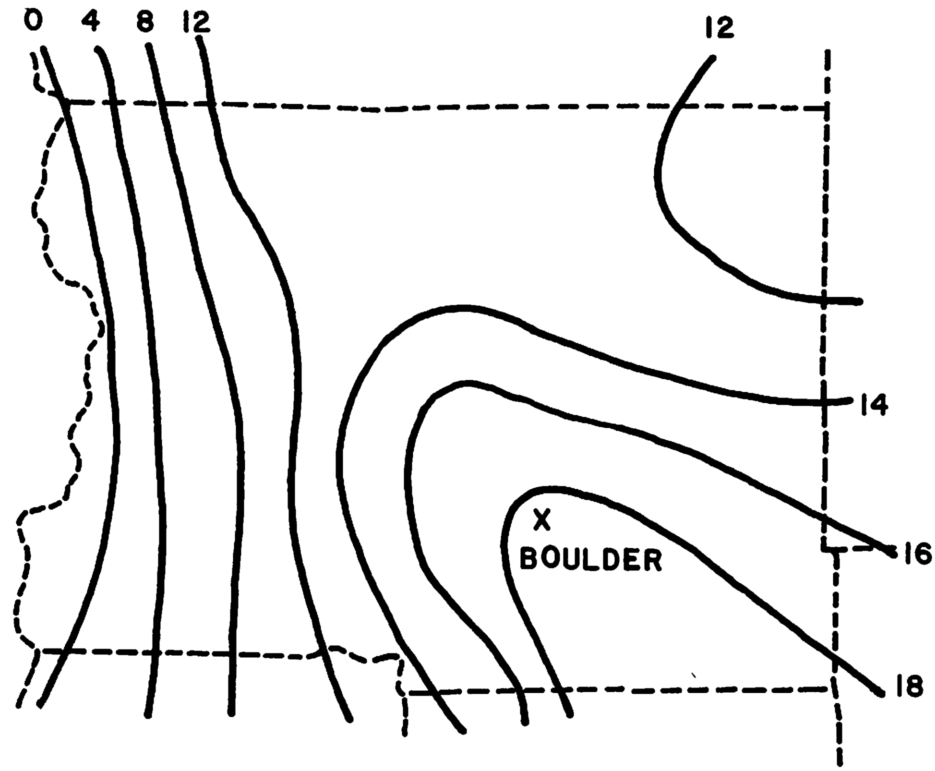

Figure 12. Generalized mean minimum temperatures (°F) for January, 1931 - 52, Boulder County.

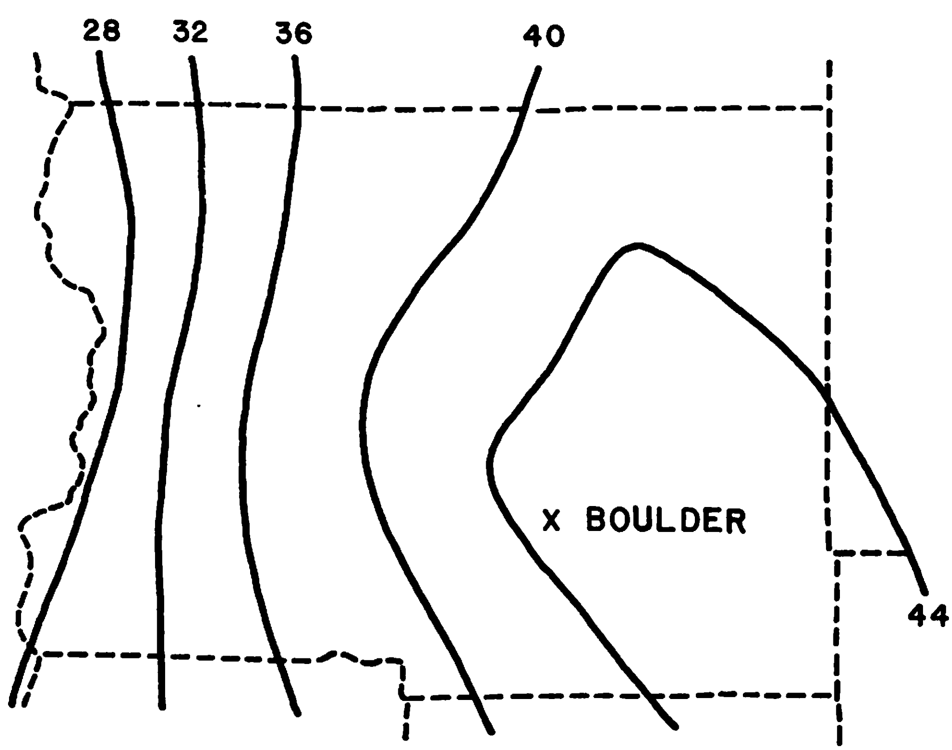

Figure 13. Generalized mean maximum temperatures (°F) for January, 1931 - 52. Data for 1952 - 70 (Barry, 1973) give values of 14°F on Niwot Ridge less than 2 miles from the west edge of the county.

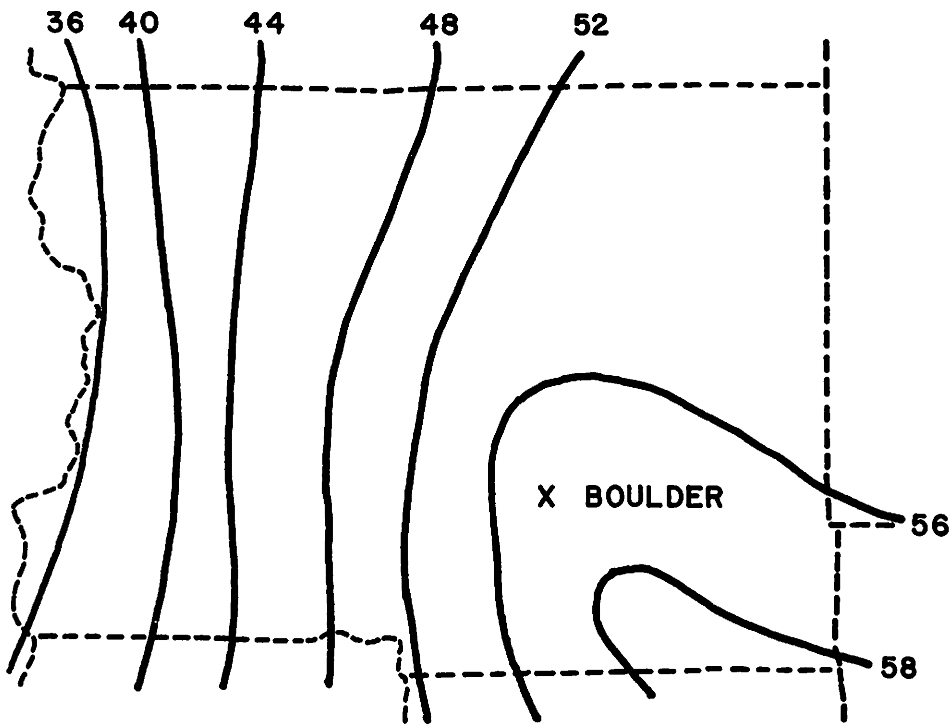

Figure 14. Generalized mean minimum temperatures (°F) for July, 1931 - 52, Boulder County.

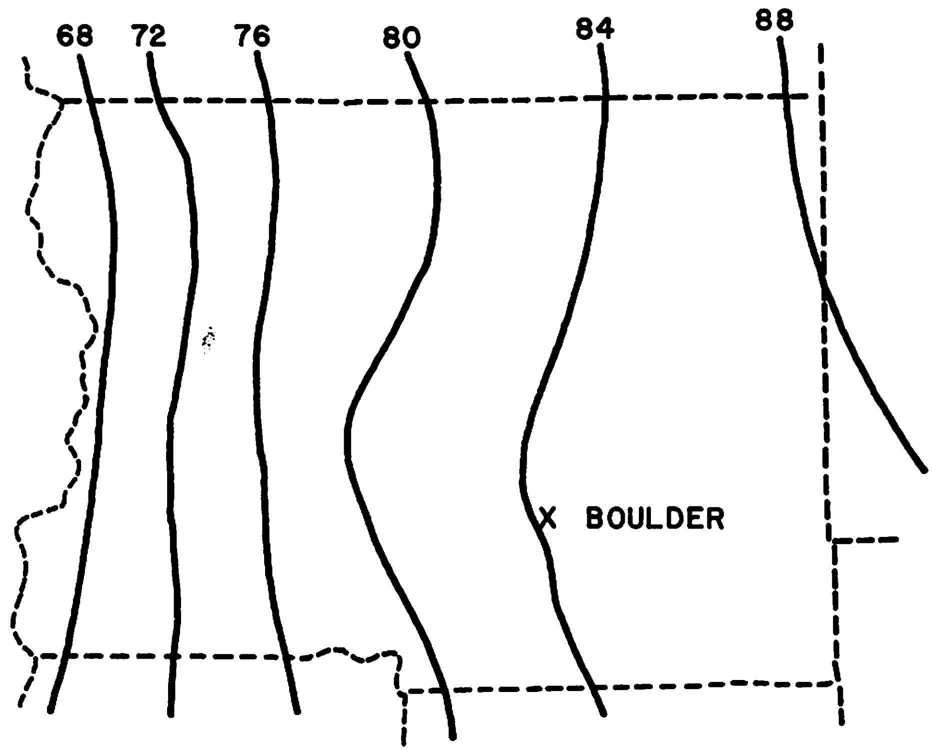

Figure 15. Generalized mean maximum temperatures (°F) for July, 1931 - 52, Boulder County.

Some idea of the length of the frost-free season is given in Table 4. At Boulder, the frost-free season begins, on the average, around May 9th; and ends, on the average, around October 8th to give a frost-free season of about 152 days. At Longmont the season is about 144 days -- beginning at the same time as in Boulder but ending slightly earlier, on average.

Figure 16 shows monthly precipitation totals (all kinds -- rain, snow, hail, etc.). Maximum precipitation is in May with average values 4 to 5 times the monthly averages for November - February. The high May values reflect the movement of warm moist air northwards at this time of year. Mixing of this air with colder air from the north results in relatively heavy precipitation. The importance of this monthly distribution pattern, with a maximum in May is that this time of year is also the time of maximum runoff from snowmelt. Thus, heavy precipitation coupled with high river levels can cause flooding.

The crucial problem is whether the precipitation in any one storm will fall as rain or snow. If a major May storm deposits rain, river levels will rise very rapidly and flooding may result. To take a broader view, the three months April through June form the major period of potential flood hazard.

The strong downslope winds often referred to as chinooks or fohns are a significant component of the climate of eastern Boulder County. Interestingly enough, strong winds on the plains are not necessarily in phase with wind activity in the mountains (Brinkman, 1973). Furthermore, detailed analysis by Brinkman (1971, 1973) indicates that the strong downslope winds do not fit the classical definition of chinooks in all respects. Because winds of hurricane-force occur in eastern Boulder County one or more times per year (Julian and Julian, 1969; Whiteman and Whiteman, pers. comm., 1973), they are treated as a natural hazard and discussed in more detail in Section 12.

6.3 MOUNTAINS

The mountain environment is very diverse climatically and there are few data available to describe this diversity adequately. Hence, generalizations may not be applicable to individual topographically-controlled climatic environments.

Figure 17 illustrates the mean monthly temperatures at Allenspark (8500 ft) and at two research stations operated by the Institute of Arctic and Alpine Research on Niwot Ridge near the Continental Divide. These stations give some information on the high mountain

TABLE 4

Length of frost-free season

	Boulder (30 yrs)	Allenspark (10 yrs)	Longmont (30 yrs)
Mean date of last Spring occurrence of temperatures $< 32^{o}F$	May 9th	June 10th	May 9th
Mean date of first Fall occurrence of temperatures $< 32^{o}F$	Oct. 8th	Aug. 22nd	Sept. 30th
Mean length of frost-free season	152 days	71 days	144 days

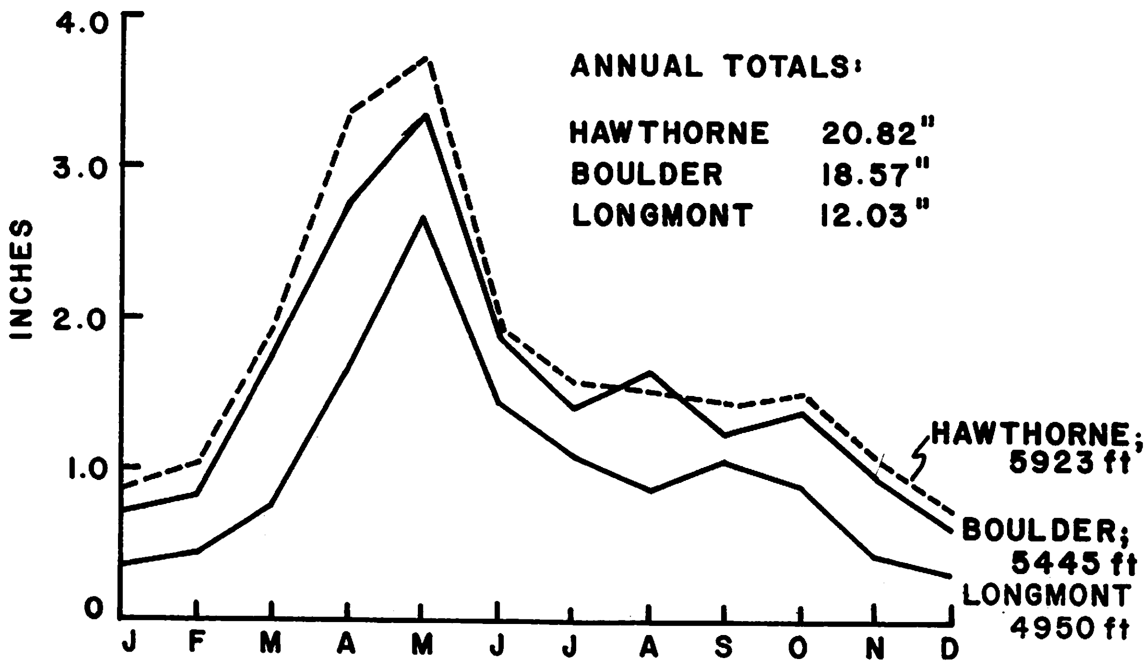

Figure 16. Mean monthly precipitation (water equivalent), 1931 - 60.

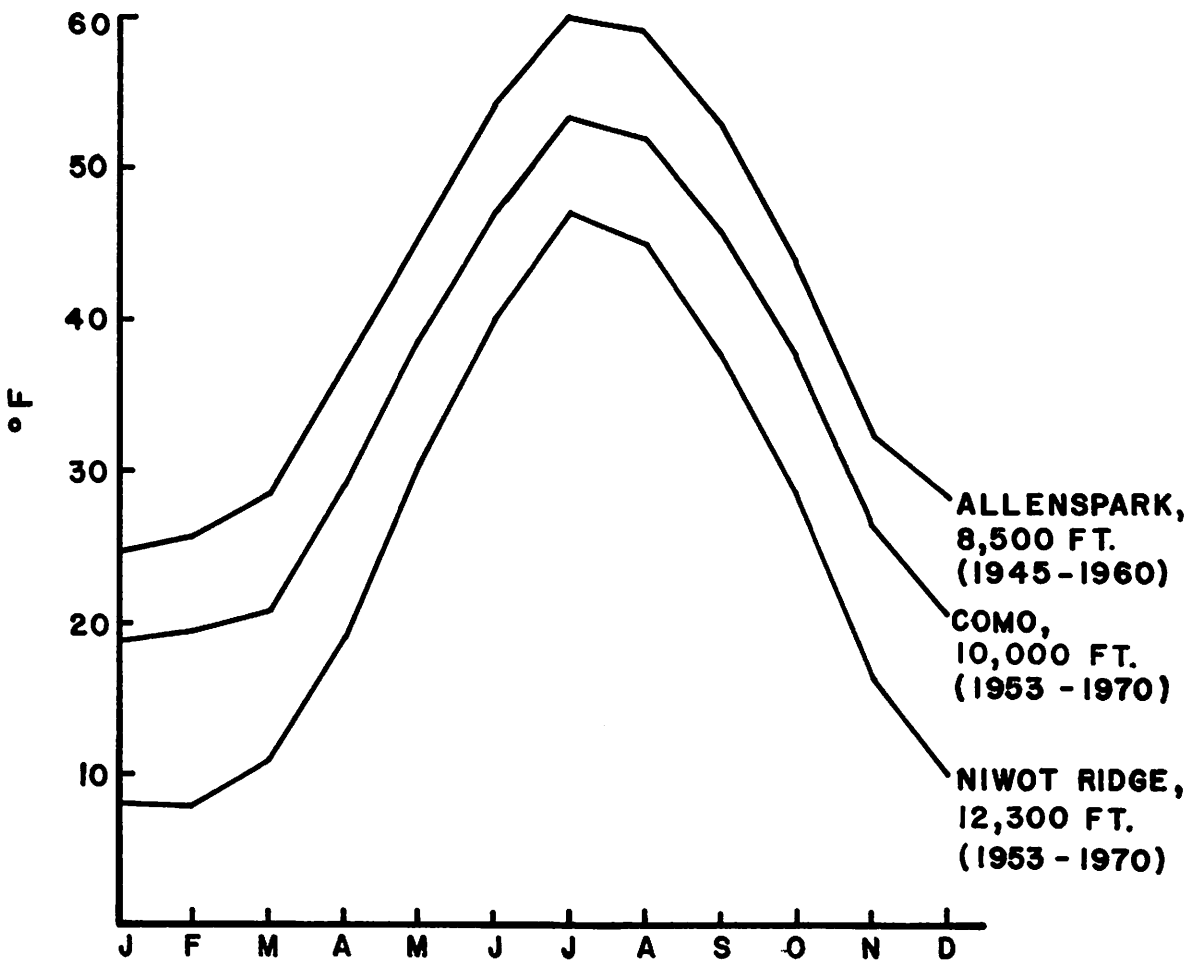

Figure 17. Mean monthly temperatures (°F) for three mountain stations (after Barry, 1973).

climate of Boulder County. Niwot Ridge is an open ridge, tundra site whereas Como is in the forest at 10,000 feet. January and February are the coldest months of the year and July is the warmest. The annual range is close to 35 degrees F at each of the stations. Average January daily minimum temperatures in the mountains (Fig. 12) range from less than 0 degrees F near the Divide to approximately 16 degrees F along the eastern mountain edge. Daily maximum January temperatures (Fig. 13) average approximately 27 degrees F near the Divide to 42 degrees F near the mountain front. In July average daily minimum temperatures (Fig. 14) range from 35 degrees F to 56 degrees F and maximum temperatures (Fig. 15) average from 66 degrees F to 83 degrees F. In winter months, cold air drainage into valley bottoms can result in locally extremely low temperatures. Furthermore, higher wind speed during winter months increases the wind chill factor and make the apparent mountain temperatures seem much colder. Figure 18 illustrates average wind speeds at Como and Niwot Ridge by months. Very high winds on the exposed ridge site are experienced from October to May; gusts frequently exceed 100 miles per hour in mid-winter months. At Como, in the forest environment, average wind speeds are considerably lower but high winter maxima are again experienced.

The "frost-free season" varies widely through the mountain region with some areas experiencing frosts all year round. At Allenspark (Table 4), the season is 71 days on the average, beginning about June 10th and ending about August 22nd (2-3 months shorter than on the plains).

Monthly precipitation values are shown in Figure 19. The extremely variable record at Como and Niwot Ridge is a reflection of the short period of record. Maximum precipitation at Allenspark and Como occurs in May though presumably the proportion falling as snow is higher than at Boulder and Longmont. Late spring and summer are the periods of maximum precipitation at these stations. At Niwot Ridge, however, the maxima are clearly in November and January with high values also from February to May. The lowest values of precipitation are recorded in October. How typical this high tundra is of other tundra/ridge areas in the county is difficult to say, but it seems likely that the major characteristics of the climate will be similar. Recent reports by Barry (1972, 1973) provide much detailed information on the climate of the east slope of the Rocky Mountains.

6.4 PRECIPITATION FREQUENCIES - MOUNTAIN AND PLAINS

Estimates of precipitation frequencies with a 100-year return period have been made by the Office of Hydrology, NOAA (National

Figure 18. Mean monthly wind speed (1965 - 70) for a station in the subalpine (Como) and another in the alpine (Niwot Ridge) after Barry (1973).

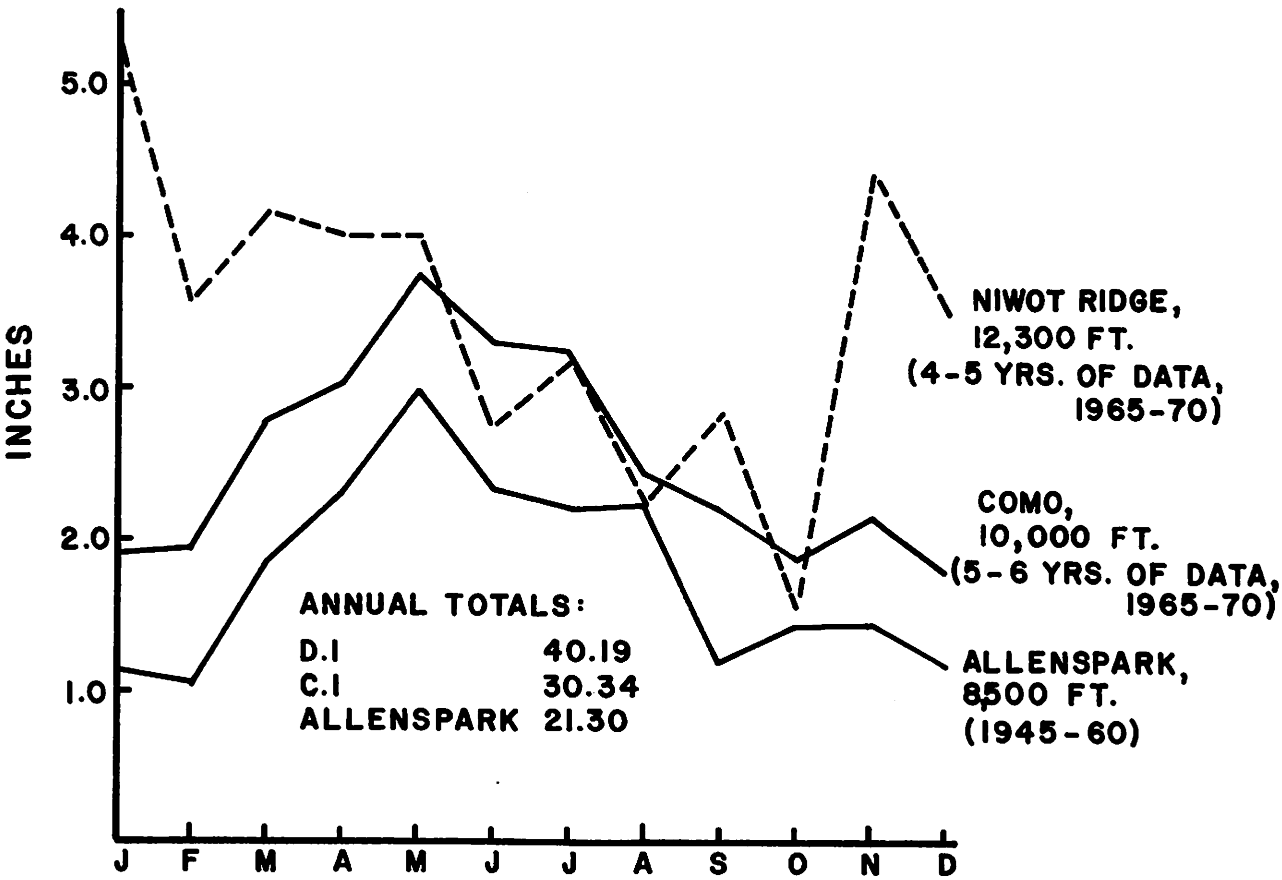

Figure 19. Mean monthly precipitation (water equivalent) for three mountain stations (modified after Barry, 1973).

Oceanographic and Atmospheric Administration), for Colorado as a whole. Figures 20 and 21 show the estimates of 100-year, 24-hour precipitation amounts and 100-year, 6-hour precipitation amounts respectively. These maps illustrate the maximum amount of precipitation which might reasonably be expected to fall in a 24 or 6 hour period over 100 years (i.e., with a 1% probability). Thus, Figure 20 shows that Boulder might expect 5 inches of precipitation in a 24-hour period on a frequence of (at least) once in a hundred years. Similarly, Fig. 21 shows that Longmont could experience 3.7 to 3.8 inches of precipitation in a 6-hour period (at least) once in a hundred years.[2] It should be noted that the occurrence of such an event in a particular year is not a guarantee that it will not reoccur for 100 years or that it may not be followed by a larger 1000-year event. These data only reflect long-term statistical probabilities.

2. To put these figures in perspective, the mean annual precipitation at Boulder and Longmont is 18.6 and 12.0" respectively (over the period 1931-60).

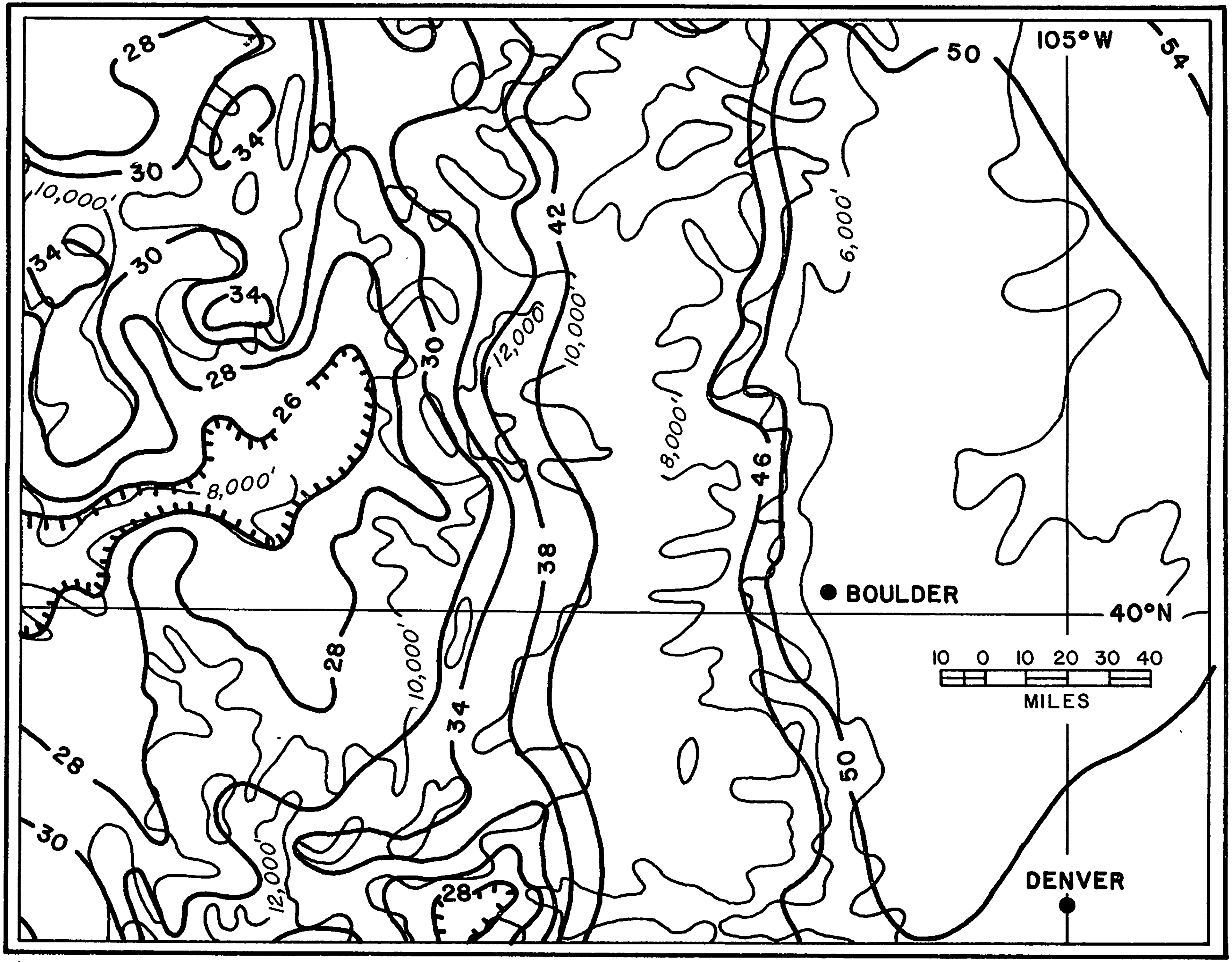

Figure 20. The 100-year event in terms of maximum precipitation in tenths of an inch for a given 24-hour period (after U.S. Dept. Commerce, 1967).

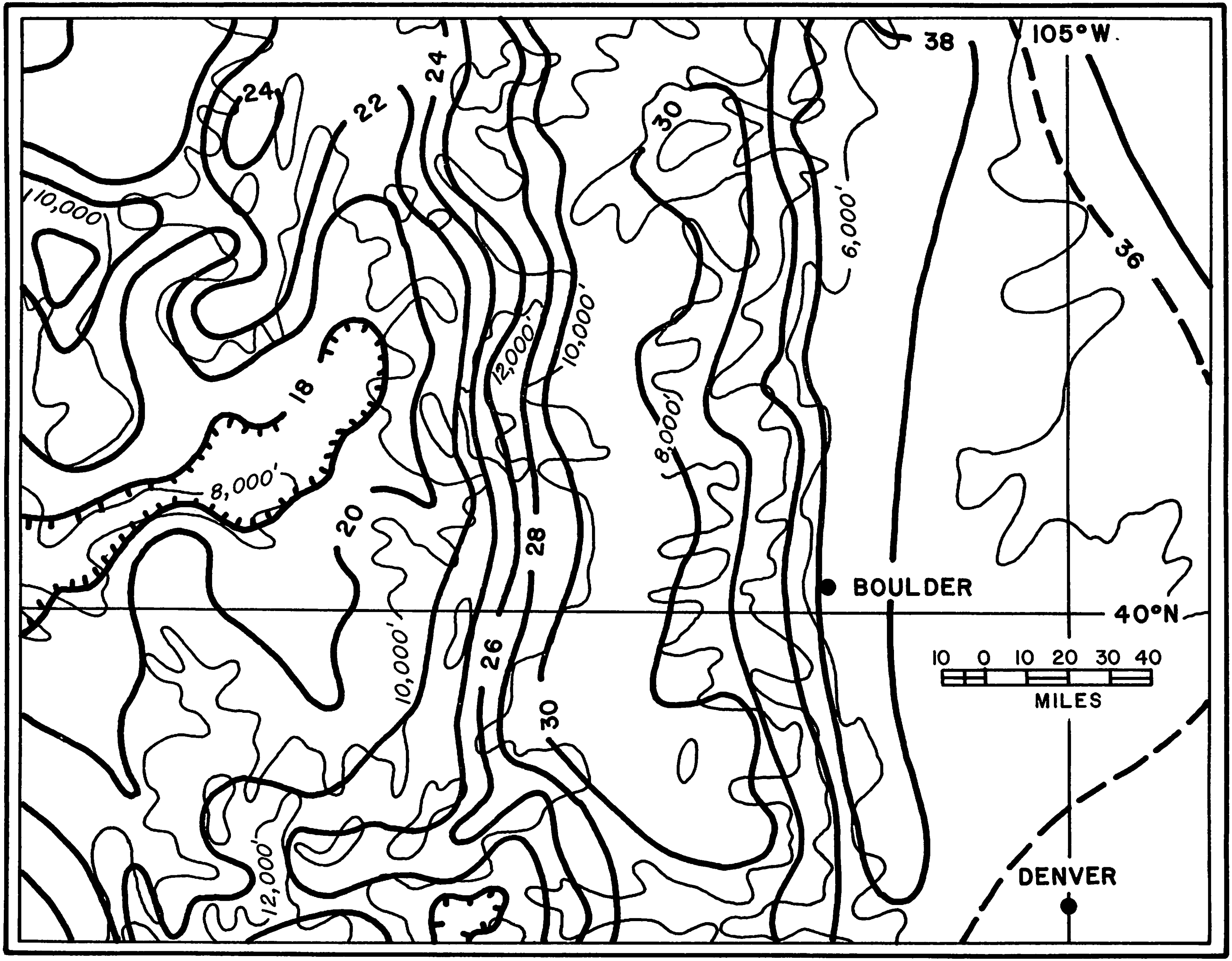

Figure 21. The 100-year event in terms of maximum precipitation in tenths of an inch for a given 6-hour period (after U.S. Dept. Commerce, 1967).

SECTION 7

MINERAL RESOURCES

R. F. Madole

7.1 INTRODUCTION

As a consequence of being part crystalline rock (igneous and metamorphic) and part sedimentary rock, Boulder County has a particularly diverse and economically important inventory of mineral resources. Most nonmetallic resources tend to be derived from sedimentary rocks, while metallic minerals are mainly associated with crystalline rocks. Tables 5 and 6 adapted from the Colorado Bureau of Mines reflect this diversity.

The industrial society in which we live is highly dependent on minerals. Almost everything used involves mineral products from carpets and clothes to automobiles, buildings, and hardware. Sound planning requires that our mineral requirements be carefully considered. As unpleasant as it is to some, common resources such as sand and gravel, limestone, and clay must be exploited and are an essential land use. The problems that derive from building subdivisions and shopping centers over prime reserves of sand and gravel are discussed in the following paragraphs, and many of the same statements made there apply to other resources which are dealt with even more briefly. This is certainly true for the resources used in the manufacture of cement, a commodity whose consumption closely parallels that of sand and gravel.

Resources such as gold, silver, coal, and tungsten should not be disregarded simply because they are not impacting the economy significantly at present. We know from history that a small improvement in technology or economic climate can quickly revitalize a dormant mining district. By the end of World War II, mining had virtually ceased in the gold and silver districts of western Boulder County. Now, with the recent price increases for silver and gold, exploration is on the upswing. Long range planning should consider the location and distribution of past mining activity, because 70%

to 90% of exploration is currently concentrated in and around known mining districts (W. Freeman, pers. comm., 1973).

7.2 NONMETALLIC MINERALS

7.21 Sand and Gravel

Sand and gravel is the most important mineral commodity in Colorado and the nation as a whole both in volume and value, outranking all other minerals including petroleum, gold, and other metals. The impact of this mineral product on the economy of communities is direct, profound, and far-reaching. According to G. D. Odiorne *in* Davis and Meyer (1971) the value of the raw material leaving the gravel pit undergoes an increase of as much as eightfold by the time it reaches the consumer. In the example cited, some $7.5 million worth of sand and gravel produced in 1969 in counties along Utah's Wasatch Front, which in many ways is similar to the Colorado Front Range, had an economic impact of $60 million. A ramification of this impact that is often overlooked is that each person employed in mining sand and gravel supports about eight people in trade, business, and services (G. S. Odiorne in Davis and Meyer, 1971). Our reserves of sand and gravel are limited, and to ignore the need to preserve what does exist can have serious consequences which affect nearly everyone.

At present, the average consumption of sand and gravel in Colorado is 10 tons per person per year (Colorado Geological Survey statistics). Consequently, Boulder requires nearly 750,000 tons of sand and gravel per year. However, tonnage requirements are only part of the story. The uses to which sand and gravel are put and its high place value-low unit value are equally important considerations. A substantial proportion of sand and gravel goes to the production of concrete aggregate which is used mainly for construction projects and paving. A large amount is also consumed in the production of asphalt mix. Interestingly enough, more than half of the sand and gravel produced goes to maintenance of existing facilities. Because little construction can proceed without this resource, it is a good barometer of economic activity. Loss of supply would tend to depress local economy, produce unemployment, and lead to a general deterioration of facilities. Because sand and gravel have a low unit value, about $2 plus per ton, they cannot be hauled far and remain profitable. According to Harold Short (Flatiron President, pers. comm., 1973), present haulage rates are 7¢ per ton-mile and the economic limit for hauling is about 13 miles. A. L. Hornbaker, Colorado Geological Survey, reports haulage costs of 8 to 10¢ per ton-mile elsewhere in the state. Obviously, unless local sources or substitute materials can be utilized, the cost of construction and maintenance can become excessive.

Commercial reserves of sand and gravel on the plains are restricted to those valleys that contained large glaciers during late Pleistocene time. Most of this resource is extracted from the Broadway gravel discussed in Section 4. Louviers gravel is also valuable, but in Boulder County it is considerably less extensive than the Broadway gravel. Streams such as Coal Creek and Lefthand Creek which either were unglaciated or contained only a small amount of ice do not provide commercial quantities of sand and gravel under present market conditions.

The older gravels (pre-Bull Lake) which occur so abundantly are also possibly a product of glacial times. Outwardly, they would seem to provide an enormous reserve of sand and gravel. Unfortunately, they have been exposed to the atmosphere so long that deep weathering has rendered much of them unsuitable for concrete aggregate and bitumenous mix. Their clay content is generally too high as is their loss on the Los Angeles abrasion test which measures their toughness and durability. Portions of some channel deposits probably have a clay content low enough to be satisfactory for use as subbase and base course in road construction. Although clay can be removed by washing, most pre-Bull Lake gravels occur on high terraces and pediments where a general lack of water is an additional handicap to processing.

The highest quality reserves of sand and gravel underlie the floodplains of the larger streams near the mountain front. Examination of a map of Colorado will quickly reveal that in the Front Range urban corridor, existing population centers are located over much of the best sand and gravel. Urbanization in Boulder has already eliminated a large portion of the best reserves and threatens to continue doing the same. The deposits tend to diminish in value farther downstream, because of the decrease in gravel and proportionate increase in finer-grained sediment. Where sand becomes the dominant fraction, gravel must be added to produce a proper blend.

Harold Short (Flatiron President, pers. comm., 1973) maintains that present market conditions require 12 feet of gravel to justify stripping 5 feet of overburden. This overburden which consists of a sandy silt or silty sand alluvium tends to increase in thickness and horizontal extent in a downstream direction. Gravels in streams such as Coal Creek and Lefthand Creek tend to be much more limited and to be overlain by a greater thickness of alluvium. Consequently, they are of minor significance and virtually uneconomical to mine under present conditions.

In the early 1970's, production of sand and gravel in Boulder Valley amounted to about 700,000 tons per year, of which Flatiron accounted for 500,000 tons while C & M and Boulder Ready-Mix produced most of the remainder. Table 5A shows the steady increase in value of sand and gravel produced from 1955 to 1971. This increase is a function of both a dramatic rise in population and inflation. The total dollar value for this period amounts to $14,311,050, of which more than half ($7,964,962) was produced during the last five years of record. The rate of consumption of sand and gravel and its importance to the overall economy of the area demand that this vital resource be preserved wherever possible. More important, it virtually forces consideration of "multiple sequential land use" on floodplains.

It will be necessary to rehabilitate the mined out areas for subsequent land uses. Shelton (1972) has shown that a number of options are available insofar as rehabilitation is concerned including several types of recreational uses, disposal of fly ash and other wastes, backfilling for return to agriculture, or backfilling for urban use such as was done at Cherry Creek Shopping Center and the Denver Coliseum. Long range planning must also consider the question of materials that can supplement and/or someday replace the conventional aggregates currently used.

7.22 Clay

Eastern Boulder County has significant reserves of clay suitable for production of bricks, tile, blocks, pipes, and culverts. Quality refractory clays, however, are limited to the South Platte Formation of the Dakota Group in the south-central part of the county (Waagé, 1961). The Laramie Formation which is also largely limited to the southern part of the county is another principal source of clay. Consequently, almost all clay produced in Boulder County comes from the Eldorado Springs, Superior, Marshall area which is actually the northern terminus of a belt of richer production located in Jefferson County. Farther north and east, high grade reserves either do not exist or are too deep to mine profitably at present. A depth of about 60 feet is the economic cutoff for clay mining. Because pit walls must not exceed a slope of 30%, a prohibitive amount of overburden would have to be removed in order to mine below this depth.

A limited amount of clay is mined outside the south-central part of the county, mainly near manufacturing sites where it is used as an additive or supplement to that imported from elsewhere in the state. The Lykins, Morrison, and Benton formations contain

TABLE 5A

Nonmetallic Mineral Production *

Year	Flourspar	Stone	Soil & Peat	Clay	Petroleum	Sand & Gravel
1946	390,758					
1947	562,013					
1948						
1949	181,906	78,084				
1950	181,906	78,084				
1951	215,997	130,715				
1952	528,646	193,322	6,000			
1953	1,394,580	401,254	23,100	2,483		
1954	1,130,000	1,561,100	35,000	4,490	5,042	
1955	1,702,290	1,562,000	35,000	4,200	5,193	290,000
1956	1,733,465	1,242,000	35,000	4,100	7,645	289,000
1957	2,070,000	1,410,000	24,000	6,500	10,228	299,500
1958	1,409,102	75,134		37,500	7,455	1,133,019
1959	1,401,453	93,659	250	30,375	4,928	372,263
1960	1,239,444	95,200	970	14,000	7,076	55,199
1961	1,427,616	97,770	13,172		7,465	285,840
1962	1,619,460	195,212	14,521		7,474	464,314
1963	438,075	230,317	27,391	40,000	6,578	837,073
1964	565,740	257,209	30,445	137,657	5,743	967,983
1965	630,750	293,902	30,917		6,636	1,214,583
1966	927,700	306,941	33,705	19,335	5,771	137,315
1967	829,230	111,376	3,600	30,685	4,652	1,440,116
1968	1,277,640	108,032	2,775	38,434	4,443	1,627,415
1969	862,845	34,771	431	53,880	26,525	1,791,894
1970	997,845	25,400	542	40,528	3,441	1,049,627
1971	1,064,210	174,862	3,235	26,200		2,055,910
Total Prod.	24,782,671	8,756,344	320,054	497,060	102,395	14,311,050

*Production is in dollars unadjusted for periods of inflation or depression.

TABLE 5B

Nonmetallic mineral production*

Year	Feldspar, Mica, Beryl	Gems	Limestone, Dolomite	Cement	Miscellaneous
1957	2,180				
1958					
1959					
1960					
1961					
1962					
1963		1,200			
1964		1,300			
1965		1,300			
1966					
1967					35,000
1968					3,200
1969			2,000		
1970				4,906,000	
1971					5,752,659
Total Prod.	2,180	3,800	2,000	4,906,000	5,790,859

*Production is in dollars unadjusted for periods of inflation or depression.

clays suitable for manufacturing the construction materials listed above, but have a limited outcrop area. The Pierre Shale represents a huge, but marginal, reserve. However, improved technology, particularly in the construction of kilns whose firing-temperature can be more precisely controlled, may eventually render this formation highly usable. The Pierre Shale is currently mined at a site just south of the county line for manufacture of light weight aggregate. This formation can provide an abundant supply of bloating clay (actually shale) for this use. The dollar value of clay mined in Boulder County from 1953 to 1970 amounts to $497,060 (see Table 5A).

7.23 Limestone and Cement

Many of the same economic relationships described for sand and gravel apply equally well to the cement industry and the mineral resources upon which it depends. Obviously, these commodities go together. At present, there is a general shortage of locally manufactured cement for the Front Range region as a whole, principally because of the unavailability of the necessary mineral resources.

Limestone production reported for 1969 totalled only $2,000. However, shortly thereafter, production rose dramatically with installation of the Martin Marietta cement plant just east of Lyons. The Fort Hayes limestone member of the Niobrara Formation is the principal source. This unit forms a low ridge parallel to the mountain front from north Boulder to St. Vrain River where it is being mined for cement by Martin Marietta.

Martin Marietta, the sole manufacturer of cement in Boulder County, began production in 1970. By 1971, the dollar value of cement produced was nearly three times that of all other minerals combined for the whole of Boulder County. This is several times greater than the highest dollar totals ever amassed in a single year by gold and silver combined. Clearly, this mineral commodity is important to Boulder County. The interrelationship between limestone and cement is illustrated in the following tabulation.

Year	Tons of Limestone Produced	Tons of Cement Produced	Estimated Value of Finished Cement
1970	450,000	265,000	$6,400,000*
1971	540,000	300,000	$7,600,000
1972	800,000	375,000	$10,000,000

*These figures were supplied by Mr. Clarence C. Burleson of Martin Marietta, August, 1973. That with an asterisk is higher than the Colorado Bureau of Mines' total listed in Table 5B.

7.24 Fluorspar

This is one of the few non-metallic mineral deposits associated with crystalline rocks. All production for Boulder County has come from the Jamestown District where Allied Chemical is the operator. Production from 1946 to 1971 netted $24,782,671. Fluorspar is an important resource for Boulder County and is also one of those minerals in which the nation is not well endowed. It is the principal source of fluorine from which hydrofluoric acid and fluoride compounds are manufactured.

7.25 Loam and Peat

Peat is mined commercially near Caribou townsite west of Nederland, at Beaver Reservoir northwest of Ward, and until recently at Lefthand Reservoir near Red Rock and Brainard lakes. The net dollar value of loam and peat produced between 1952 and 1971 amounted to $320,054. Peat reserves are restricted to westernmost Boulder County. Although not calculated officially, they are substantial.

7.26 Stone and Silica Sand

This category does not include limestone and shale used in the manufacture of cement nor the crushed aggregate derived from lavas of Tertiary age near Lyons. The principal product of this category is building and ornamental stone of which the Lyons Formation is the outstanding contributor. Stone has netted $8,756,455 for the period 1949 to 1971.

Silica sand is mined locally in Boulder County for use in the manufacture of cement and clay products. The principal source is sandstone in the Dakota Group. Most mining is done by small companies who also deal in other stone products. Because production of this commodity is not reported separately by the Colorado Bureau of Mines, it does not appear in Table 5A and 5B. However, an indication of its relative importance is reflected by Martin Marietta's consumption of approximately 55,000 tons, valued at $4 per ton, for the period 1970 through 1972 (C. C. Burleson, pers. comm., 1973).

7.27 <u>Coal</u>

Coal production in Boulder County declined in the years following World War II to the point of cessation. Whether there will be renewed activity in light of the current energy crisis and Colorado's impending role as a chief energy state remains to be seen. Although the reserves of the Boulder-Weld field are extensive, coal is of subbitumenous rank. As of 1958 (Del Rio, 1960), estimated reserves overlain by less than 1,000 feet of overburden were 425 million tons in an area of 58 square miles. As described in Section 12 in connection with subsidence, the coal occurs principally in three beds in the Laramie Formation.

7.28 <u>Petroleum</u>

Although Table 5A shows production from only 1954 on, petroleum has been produced in Boulder County since the discovery of the Boulder field in 1902. Despite an early start, Boulder County never became a significant petroleum producer. Discovery of the Highland field which spans the Laramie County border eventually increased the county's total, but additional tests have added nothing more. Present production is from the Hygiene sandstone member of the Pierre Shale, from fracture zones in this same shale, and from sandstones of the Dakota Group. Production in Boulder County amounted to $102,395 for the period 1954 through 1970.

7.29 <u>Feldspar, Mica, Beryl and Gemstones</u>

Feldspar, mica and beryl come from pegmatites (small, very coarse-grained igneous intrusions) which sometimes contain a variety of rare minerals in addition to quartz, orthoclase, and mica. Production totalling $2,180 is recorded for these three minerals from only one year (see Table 5B). This included a small amount of columbite and cerite all of which came from a zone of pegmatites seven miles north-northwest of Boulder and south of Gold Hill (Del Rio, 1960). Production of gemstones from Boulder County for the years 1963 through 1965 netted $3,800.

7.3 METALLIC MINERALS

Metallic minerals have been mined in western Boulder County since the discovery of gold at Gold Hill in January, 1859, and at Jamestown in 1865. Ultimately six districts were established which include the Central (Jamestown), Gold Hill (Salina, Rowena, and Sunshine), Magnolia, Sugarloaf, Ward, and Grand Island

(Cardinal, Caribou, Eldora, and Nederland). The metals produced include, in descending order of importance, gold, silver, tungsten, copper, lead, zinc, and tin. Uranium has also been produced, but tonnage and dollar value have remained classified. Production figures by year and dollar value are listed in Table 6. Details concerning geology and mineral production for each of these districts are given by Vanderwilt (1946) and Del Rio (1960).

Most of the metallic minerals of Boulder County are from lode production, although placer operations have contributed substantially in places. The ore occurs in veins in "granite" and schist of Precambrian age. They were introduced into fractures of diverse age during intrusion of the dikes and stocks of Tertiary age shown on Plate 1. Gold and silver are the principal metals in each district with lead, copper, and zinc occurring in different proportions from place to place. Tungsten is of particular importance in the Grand Island District (Cardinal, Caribou, Eldora, and Nederland), but occurs also in small veins in the Magnolia and Sugarloaf districts. Despite their relative extensiveness, these deposits have remained noncompetitive with those of other regions. Their exploitation has been mainly during times of emergency when subsidized heavily by government. Uranium comes from the Jamestown (Central) District, but as noted earlier, production figures are classified information.

TABLE 6

Metallic Mineral Production

Year	Gold	Silver	Copper	Lead	Zinc	Tungsten	Tin	Miscellaneous
Pre-1897	9,442,842	5,265,111	37,691	16,505				
1897	512,657	82,744	6,140	10,448				
1898	581,302	53,259	2,694	326				
1899	547,858	45,502	13,880	1,254				
1900	607,016	55,470	3,365	3,598				
1901	774,298	67,074	3,673	8,321				
1902	538,702	43,142	1,318	549				
1903	431,569	33,050	814	4,877				
1904	411,581	32,858	3,349	2,671				
1905	355,338	59,295	2,199	857				
1906	254,034	34,082	4,368	3,194				
1907	184,872	16,277	4,205	1,938				
1908	173,480	15,466	1,627	4,847				
1909	161,839	25,622	1,391	17,628		396,000		
1910	132,910	23,613	2,760	2,307		736,700		
1911	163,051	25,546	4,677	6,765		444,000		
1912	101,446	33,290	5,453	14,001		525,000		
1913	57,468	67,646	5,051	22,564		422,100		
1914	131,025	125,130	21,524	6,700		247,500		
1915	160,433	137,545	15,169	41,832				
1916	119,299	192,678	15,918	59,639				
1917	66,841	242,565	8,057	49,500				
1918	52,265	156,731	4,418	18,624				

Table 6 continued - 2

Year	Gold	Silver	Copper	Lead	Zinc	Tungsten	Tin	Miscellaneous
1919	54,653	252,542	2,054	10,950				
1920	42,428	162,229	1,230	20,887				
1921	34,042	112,957	39	6,315				
1922	37,037	121,073		3,766				
1923	27,146	32,436		1,871				
1924	25,385	11,670	363	1,773				
1925	54,566	28,754		10,718				
1926	114,877	44,772	392	16,516				
1927	88,183	23,586	450	10,539				
1928	97,353	29,463	556	8,340				
1929	33,528	4,185		2,263				
1930	16,516	1,272		245				
1931	27,608	1,028		170				
1932	79,669	2,829		56				
1933	112,528	4,174	256	962				
1934	612,900	36,959	1,712	2,553				
1935	770,070	25,383	2,100	2,000				
1936	908,712	45,759	2,944	6,210				
1937	739,711	32,347	6,171	7,139				
1938	806,729	25,059	8,330	7,544				
1939	1,012,690	27,182	16,848	3,901				
1940	1,176,735	28,517	18,306	8,350				
1941	1,075,515	44,640	12,154	12,825	825			
1942	557,200	19,129	4,828	9,896	530			
1943	78,085	8,608	2,600	8,475	2,376			
1944								
1945								
1946	119,000	8,122	1,296	14,824		306,096		
1947	72,065	12,996	2,310	23,285		300,000		

Table 6 continued - 3

Year	Gold	Silver	Copper	Lead	Zinc	Tungsten	Tin	Miscellaneous
1948	48,195	19,216	1,736	33,294				
1949	76,825	70,816	3,152	37,920				
1950	57,855	69,260	5,824	41,850	852	8,650		
1951	26,215	108,883	6,292	31,968		127,776		
1952	27,545	253,551	8,712	63,434		345,202		
1953	4,585	22,022	4,592	26,200		1,139,555		
1954	4,550	4,344	4,157	16,320		3,062,300		
1955	7,350	40,999	5,180	26,820		1,256,997		
1956	7,500	36,500	4,200	24,100		1,060,000		
1957	4,000	8,000	1,000	8,000		20,000		
1958	200	3,465		1,777				
1959	877	265	65	100				
1960	2,210	6,643	266	2,399		37,675	2,500	
1961						10,000		5,578
1962								5,000
1963	8,386	2,272						2,000
1964								8,500
1965						650		8,000
1966						30,914		1,849
1967	15,213	3,207				46,293		7,200
1968	5,062	1,578				23,116		4,000
1969	2,725	915				67,230		
1970	20,000							
1971				8,232		5,760		16,056
Total Prod.	25,056,350	8,633,303	299,856	863,132	4,583	10,619,514	2,500	58,183

SECTION 8

SOILS

R. F. Madole

8.1 INTRODUCTION

Data obtained mainly from Moreland and Moreland (in press), Sweet and Dodson (1930), and Harper et al. (1932) were used to delimit six soil categories that compare agricultural versus urban land use options. Maps were constructed for each category, but as was the case with surficial deposits, vegetation, and slopes, the data are too detailed to be useful when displayed on the 1:96,000 scale plates of this publication. Nonetheless, the maps are on file at INSTAAR and available to interested user groups. Also, the information provided here can be used directly in conjunction with the 1:20,000 scale Soil Conservation Service sheets of Moreland and Moreland which are on file at district Soil Conservation Service offices in Boulder and Longmont. Besides the fact that these sheets were the source for the six maps referred to, the 1:20,000 scale is clearly superior for practical applications.

Because the new survey by Moreland and Moreland with its great wealth of soil data is scheduled for publication at about the same time as this report, discussion will be limited to the rationale upon which the six soil categories are based. The reader is referred to the new survey for additional information on slope, soil capability; management of irrigated soils, woodlands, and native grasslands; and soil properties important to engineering, urban, and recreational land uses.

8.2 PROBLEMS INHERENT IN LAND USE EVALUATION MAPS

Maps depicting land use constraints and options generally do so with units defined in relative terms such as good, moderate, slight, etc. Although maps defined by physical properties would have greater longevity, they would tend to be used only by persons familiar with the technical jargon involved. As indispensable as the relative term is to widespread use of land evaluation maps, it is important to note that it is based on existing technology, economic conditions, and social attitudes all of which can change very rapidly. Therefore, although highly useful and necessary, these maps are ephemeral. Today's "good" can be tomorrow's "bad" and vice versa. Equally important is the fact that design and engineering can overcome most constraints provided enough money is available. Hence, terms such as constraint and limitation are difficult to define.

A second problem associated with some "evaluative" maps is that they are one-dimensional, independent comparisons with some "ideal". In the case at hand, soils may be rated good or poor for urban or agricultural use independent of priorities. Then when priorities are introduced which restrict choice, these relative terms tend to continuously readjust to fit supply in such a way that the "moderate" rating when supply was plentiful becomes "good" as supply dwindles.

The problem is complicated further by use of the same adjective for evaluating options such as "poor agriculture and poor urban". This can inadvertently lead to an erroneous equation of the degree of limitation. A "poor urban" rating may derive from conditions which in many cases can be overcome with a nominal expenditure, whereas a "poor agricultural" situation is generally not rectifiable inexpensively, if at all. Put another way, can the monetary savings gained by using prime agricultural land for subdivisions be justified? What would be the cost of restoring such land to crop production? In the long run, it may be much less expensive if subdivisions are restricted to land currently rated as "poor" or "mediocre" for urbanization.

8.3 SOIL CATEGORIES

A major recommendation of this report is that nonrenewable resources, namely soil in the form of best agricultural land and reserves of sand and gravel be given top priority and preserved from urbanization to the fullest extent possible. Urbanization should be channeled into areas that are less than ideal from a soils standpoint, but which are free from the common and more predictable natural hazards described in Section 12. The following discussion is organized according to this bias, beginning with soils for which some urbanization is feasible and concluding with prime agricultural soils for which urbanization is feasible, but not recommended.

8.31 Noncropland Suitable for Urbanization

The soil series listed below have limitations for cropping of such extent that they are used mainly for pasture.

1. Ascalon - Otero complex on slopes of 9-20%
2. Nederland very cobbly sandy loam
3. Valmont cobbly loam

Soils of the Ascalon-Otero complex are thick, well-drained, and fertile. However, on slopes of greater than 9% grade, they are prone to severe erosion which limits their productivity for crops. Neither soil series has serious limitations with respect to suitability for septic systems, excavation, or foundations. Their use for urbanization would not compromise either urban or agricultural interests.

The Nederland series and Valmont cobbly clay loam were formerly included in the Larimer series of Sweet and Dodson (1930) and Harper et al. (1932). These soils are presently used mainly for range. Stoniness is the chief reason that they are not in crops. Because they are developed on deposits of pre-Bull Lake age (i.e., range from $>$ 100,000 to possibly as much as $<$ 1,000,000 years), a considerable quantity of clay has developed in the B horizon giving rise to a sticky, plastic, low permeability soil. However, these characteristics disappear below depths of 25 to 30 inches where the gravel has a high bearing capacity, good drainage, an insignificant shrink-swell potential, andis suitable for septic systems.

8.32 Mediocre Cropland Suitable for Urbanization

The series listed below are prime cropland soils on slopes between 0 and 3-5%. However, productivity is restricted on slopes greater than 5% and in the case of the Hargreave series, production is restricted on slopes greater than 3%. Consequently, they cannot be considered as prime cropland, but most can be successfully urbanized despite some limitation (see asterisks). Soils in this category include:

1. Ascalon sandy loam on slopes between 5 and 9% grade
2. Ascalon - Otero complex on slopes between 5 and 9% grade.
3. Colby silty clay loam on slopes between 5 and 9% grade.
4. *Colby-Gaynor association.

5. *Hargreave fine sandy loam on slopes between 3 and 9% grade
6. *Nunn clay loam on slopes between 5 and 9% grade

The soils denoted by asterisks are marginally suitable for urbanization. The principal limitation for Gaynor and Hargreave soils is the shallowness of bedrock which poses problems for excavation and installation of septic systems. With proper design and planning, which are possible if this limitation is recognized in advance, this constraint can be relatively minor. In contrast, the Nunn soils are very thick, but are so clayey that excavation is somewhat difficult, bearing capacity is low, as is permeability. The latter pose some difficulties for foundations and septic systems. However, as above, both limitations can be surmounted.

8.33 Poor Cropland Also Poor for Urbanization

The following form a well-defined group of multi-problem soils:

1. Laporte very fine sandy loam
2. Longmont clay
3. Renohill loam
4. Samsil clay
5. Shingle loam
6. Samsil-Shingle Complex
7. Shingle-Gaynor Complex

The Laporte series, Shingle loam, Samsil-Shingle complex, and Shingle-Gaynor complex have the combined disadvantages of steep slopes (5 to 25%) and bedrock very close to the surface. Much of this rock is hard and difficult to excavate and/or is shale in which excavating benches for foundations should be discouraged.

The Longmont clay, Renohill clay loam, and Samsil clay all have very low permeability, low bearing capacity, and high shrink-swell potential. All are included in the map showing the distribution of swelling soils. Except for the Renohill series, all have a high salinity and strong potential for corrosion. The Longmont series is the worst of the group having in addition to these other deficiencies a very shallow water table (1-2 feet).

8.34 Mediocre Cropland - Poor for Urbanization

The soil series listed below are tilled but generally return lower yields than most other soils planted in similar crops. Likewise, they are not ideally suited to urbanization either.

1. Gaynor silty clay loam
2. Heldt clay
3. Kutch clay loam
4. Renohill silty clay loam

These soils are all thin (20 to 40 inches to bedrock) except Heldt clay, have a high shrink-swell potential, low bearing capacity, and low permeability. Their thinness and low permeability pose problems with respect to excavation for foundations and installation of septic systems. Similarly, their low bearing capacity and high shrink-swell potential are problems insofar as foundations are concerned. The latter can be dealt with relatively easily with good design and engineering while money and/or technology can overcome the excavation and septic system problems. The soil types listed above are also included in the map showing the distribution of swelling soils.

Admittedly, the damage that can be wrought by swelling soils and the remedial action necessary to correct it can be very costly. However, if the problem is recognized in advance, it may be dealt with effectively and relatively inexpensively. If not today, perhaps in the future. Inexpensive is another highly relative term. In this instance, the extra cost incurred in utilizing the second or third best soil for urbanization seems inexpensive relative to losing productive cropland in an age when world famine is a threat.

8.35 Floodplain Soils

Floodplains and the best reserves of sand and gravel are in part mutually inclusive categories. The soil series involved include:

1. Loveland soils
2. Niwot soils
3. Manter soils (in places)

The Loveland and Niwot series are associated with Neoglacial deposits (discussed in Section 4) on the major floodplains of eastern Boulder County. They appear to be nearly coincident with the zone affected by the 100-year flood where county planning regulations prohibit urbanization. Commercial reserves of sand and gravel underlie these soils. Additional reasons for not urbanizing them is that they occur in areas of very shallow water table which limits excavation, foundations, and sewage disposal, and they overlie the best and most easily polluted aquifer in the area. Fluorescent dye introduced into the gravel underlying the floodplain of Boulder Creek moved 1500 feet in three days (J. Pendleton, pers. comm., 1973).

Manter soils are included in this map category because, in places, they are developed on alluvium capping low-lying stream terraces underlain by what appears to be Broadway gravel. In addition, the Manter series contains some of the best topsoil in the county. Manter soils are also included with the marginally prime cropland soils delineated in the next section which is an additional reason for preserving them from urbanization where possible.

8.36 Prime and Marginally Prime Cropland Soils.

If color coded, this category would be shown in red and labeled "to be avoided". The following soils, where developed on slopes of 0 to 3% grade are the best agricultural soils in the county.

1. Ascalon sandy loam
2. Ascalon - Otero complex
3. *Calkins sandy loam
4. *Colby silty clay loam, wet
5. Manvel loam
6. McClave clay loam
7. *Nunn sandy clay loam
8. *Nunn clay loam
9. *Nunn-Kim complex
10. *Weld fine sandy loam
11. *Weld loam
12. *Weld-Colby complex

Those soil types with an asterisk are not considered to be prime land for urbanization. The Colby silty clay loam, wet; Calkins; and McClave soils have a seasonally high water table. The Nunn and Weld soils listed are so clayey that they have low permeability, are moderately difficult to excavate, and have a moderate to severe shrink-swell potential. All of these factors affect suitability for septic systems and foundations.

The series listed below are considered marginally prime. Where they can be irrigated, all are ranked in capability class III by the Soil Conservation Service which means that they "have severe limitations that reduce the choice of plants, require special conservation practices, or both". Where irrigation is not possible, most of these soils would be in an even higher capability class, which means they would be even less desirable as cropland. For most, the principal limitation is a tendency for serious erosion on slopes greater than 3%. The maximum slope for soils in this group is generally 5%.

1. Ascalon sandy loam, 3-5% slope
2. Ascalon-Otero complex, 3-5% slope
3. Colby silty clay loam, 3-5% slope
4. Hargreave fine sandy loam, 1-3% slope
5. Manter sandy loam, 0-3% slope
6. Nunn clay loam, 3-5% slope
7. Valmont clay loam, 1-3% slope
8. Weld loamy sand, 1-4% slope
9. Weld-Colby complex, 3-5% slope

SECTION 9

WATER RESOURCES

A. E. Mears, D. R. Sharpe & R. F. Madole

9.1 INTRODUCTION

This section deals primarily with availability of groundwater and aquifer (any geologic unit capable of transmitting groundwater) recharge. Most surface water draining from the mountains and that stored in lakes and reservoirs in both the mountain and plains portions of the county is owned by various user groups on the plains. Disposition of this surface water and area water rights are described at length by Black and Veatch (1966) in their "Report of Long-Range Comprehensive Water Study, Boulder, Colorado."

9.2 SURFACE WATER

Flow from the major streams of Boulder County has been developed into water supply systems for the cities of Boulder, Denver, and Longmont. Other major users of Boulder Creek, St. Vrain Creek and their tributaries include the Public Service Company of Colorado, the towns of Lafayette and Louisville, and many private users with water rights downstream. The water supply for the town of Nederland comes from infiltration galleries in the gravels of Middle Boulder Creek.

Certain small mountain streams may be developed as water sources if the rights exist or can be purchased, but they may not serve as reliable sources of water during periods of low flow in the winter. The flow of small streams was not studied because of the lack of gaging stations on them. However, the annual fluctuation of runoff in the tributaries of Boulder Creek and St. Vrain Creek can be used to illustrate the general behavior of smaller streams in western Boulder County.

As shown in Table 9 (Section 12), the average minimum monthly runoff on these streams is only 0.72% to 2.45% of the average annual runoff. The minimum runoff usually occurs in February. If a stream is tc be developed for water supply, it must have an adequate flow throughout the winter. The probability of occurrence of a critically low flow must be determined for a specified number of future winters. This is accomplished by correlation with similar streams for which there are gaging records. The potential for developing surface water for mountain populations is not good. Most homeowners and developers must turn to groundwater, the availability of which is considered next.

9.3 GROUNDWATER

The groundwater data illustrated on Plate 4 and described here are from well records on file at the Colorado Water Conservation Board and information in Jenkins (1961). Five simplified hydrologic map units are delimited on the basis of water yield. The plains portion of the county includes three of these units (see Plate 4) defined qualitatively as high to moderate yield, moderate to low yield, and very low yield. The mountainous portion of the county, not including the sedimentary hogbacks of the foothills, contain just two units. One of these encompasses the crystalline rocks which have a highly variable water supply which will be discussed in more detail later, while the other is comprised of sediments with low to high yields, depending on sediment type. The sediments consist of Quaternary drift (mostly till), alluvium, and alluvium-colluvium filled valleys and topographic lows. The latter, however, are mostly removed from the areas where need for ground water is greatest. Also, to pump from the alluvial aquifers of the major streams would interfere with the priorities of those owning the rights to the surface water.

The importance of geology in evaluating the groundwater potential of a specific area cannot be underestimated. Seemingly random occurrences of good or poor groundwater supply are usually controlled by structures (including fracture systems), or lithology (rock types).

9.31 Plains Portion of Boulder County.

High Yield Aquifers. The late Pleistocene sand and gravel underlying the floodplains of major streams draining from the mountains are the best aquifers in Boulder County. The modern valley sides define the approximate limits of these aquifers as well as their recharge areas (places where surface water can enter the aquifer). These gravels exceed thicknesses of 30 feet in places, although 15 feet is more typical. Although 20 to 25 gallons/minute is the average, yields as high as 45 gallons/minute (5 gal/min is a good domestic water supply, if it is constant) have been recorded. Gravels underlying low-level terraces flanking the modern floodplains also yield water locally.

Moderate-Yield Aquifers. The Fox Hills Formation along with the Dakota, Arapahoe, Lyons, and Entrada formations all contain moderate yield aquifers of permeable sandstone (permeability being a measure of the ease with which a fluid will pass through the rock). Their potential for supplying groundwater in the future is largely dependent on land use practices in their respective recharge zones, i.e., areas where the aquifer is exposed at the ground surface or is in contact with permeable surficial deposits. Precipitation falling in the recharge zones of these aquifers supplies wells to the east and southeast, the directions in which these rocks are inclined below ground surface.

Yields as high as 40 gallons/minute (15 to 30 being average) have been recorded for the Fox Hills Formation. These yields rival those of the unconfined aquifers described above, but wells in the Fox Hills cost more because it is a confined aquifer (rock in a sedimentary sequence) and is usually substantially deeper than the alluvial deposits. The Dakota, Lyons, and Entrada formations are all steeply dipping and, therefore, are useful only along a narrow strip immediately east or downdip of their recharge zones.

Low-Yield Aquifers. The Niobrara Formation, Morrison Formation, and Hygiene Member of the Pierre Shale provide groundwater locally, but the supply is low and their extent is limited. They are at best poor aquifers. The small water supply available comes from interbedded sandstones or the weathered regolith. The section is otherwise relatively impermeable and does not yield groundwater inasmuch as it consists mainly of shale, claystone, and limestone.

The Fountain Formation is a coarse, permeable sandstone, but it dips so steeply that it provides only a small, very local supply of water. The Laramie Formation contains beds of permeable sandstone which may provide adequate water for domestic uses in some sites. The problem with this formation is that it also contains interbedded units which are impermeable and prevent recharge of the more permeable strata.

Very Low-Yield Aquifers. The Pierre and Benton shales are almost entirely impervious and provide only meager amounts of groundwater in places from fracture zones and the weathered regolith. Pierre Shale covers most of eastern Boulder County and prevents aquifers lower in the stratigraphic section from recharging, i.e., acts as an aquiclude.

Wells drilled in these shales are either "dry" or nearly so, although some are capable of producing one or two gallons per minute on a limited basis.

9.32 Mountainous Boulder County

Variable-Yield Fracture Aquifer. Groundwater is the principle source of water for most inhabitants of mountainous Boulder County. In order to obtain this water, wells must be drilled in the crystalline rocks (igneous and metamorphic) of which most of the western portion of the county is comprised. The water bearing properties of these rocks are extremely variable (Lewis and Burgy, 1964) and difficult to determine because of the inhomogeneous nature of crystalline rocks. Where the rock is not fractured, water bearing capacity and permeability are essentially zero. Permeability is entirely dependent on the fractures present in the rock mass, and the volume and interconnectedness of these fractures tends to decrease with depth (Davis and Turk, 1964) because of increased pressure. Consequently, there may be some maximum depth below which wells should not be drilled because the unit cost of water increases with depth. Davis and Turk (1964) suggest that depths of 150 to 250 feet should not be exceeded for domestic water supplies. This suggestion is supported by Figure 22 from Gable (1973). Figure 23 also from Gable (1973) indicates that of 328 wells examined in the Tungsten Quadrangle, 55% yield less than 3 gallons/minute.

Summers (1972) found that the higher yield wells in crystalline rocks in the vicinity of Rothschild, Wisconsin, are in areas where surface fracture density is maximum. Unfortunately, such areas are not always easy to locate because of the presence of overlying soils and plant cover. Results of several trend surface analyses of well-yield data of Boulder County support Summers' (1972) findings. In these analyses, the value of well yields were used as the variable in the vertical direction. It was found that a smooth surface could not be drawn to accurately represent the data, because of the extreme variability of well yields over very short distances. This variability within a given rock type supports the conclusion that water availability is more closely related to fracture density than to rock type. Small quantities of groundwater can usually be obtained from shallow wells in the weathered regolith. However, in the mountains, this too is also highly variable in terms of thickness, ranging from a few to several tens of feet.

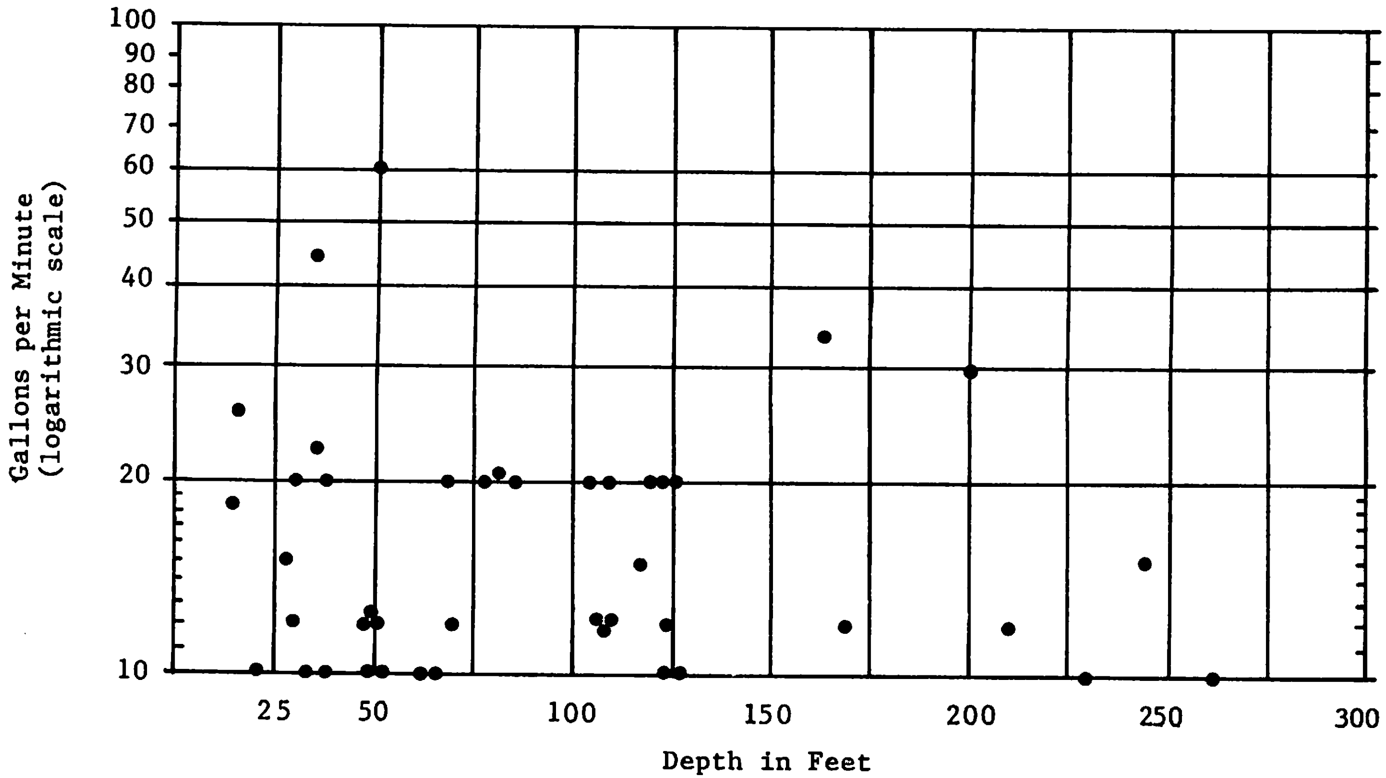

Figure 22. Comparison of water yield and well depth from Gable (1973) supports Davis and Turk (1964) and other data cited in the text in suggesting that it might be better to drill two 100-foot wells rather than one 200-foot well if an acceptable yield is not obtained in the first well within a depth of 100 feet. According to Gable (1973), of the wells yielding more than 10 gals/min, 37% are 50 feet or less in depth.

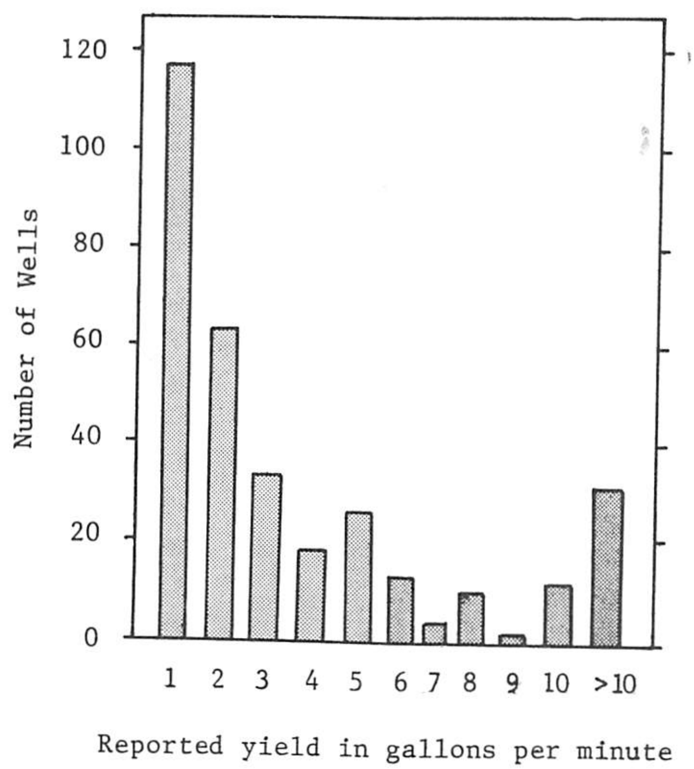

Figure 23. Of 328 wells tabulated by Gable (1973) in the Tungsten Quadrangle, 55% yield less than 3 gallons of water per minute.

Low to High-Yield Unconfined Aquifers. Gravels, mostly glacial outwash, underlying the floors of the larger valleys produce copious supplies of groundwater. However, these gravels are of limited extent and occur mainly at altitudes too high for permanent residences. Besides, their water content has a direct influence on stream flow, the rights to which are owned by others.

Glacial drift, mostly till, underlies a large portion of westernmost Boulder County. These deposits also yield groundwater, although not in quantities so great as the outwash gravels. However, most of these deposits are on public land and are at or above the limit where year round residences become environmentally and economically impractical.

SECTION 10

AIR POLLUTION

R. S. Bradley

10.1 PARTICULATE AND BENZENE SOLUBLE POLLUTANTS

No pollutant data are available for Boulder County prior to 1965. Suspended particulate material has been monitored at Boulder and Longmont over the past eight years. For Boulder, this material has been further analyzed for benzene soluble substances which give an indication of pollution resulting from gasoline combustion. Figures 24 and 25 illustrate the pollutant values for these two emission categories. Pollutant counts are considerably higher at Longmont which may reflect (a) more frequent and/or stronger inversion development away from the turbulence of the mountain front, and/or (b) more particulate material resulting from agricultural activity. An upward trend in Longmont pollution is apparent with mean particulate pollutant counts increasing by 30 to 50% over the 8-year period. It is not yet possible to determine whether the 1970 Colorado Air Pollution Control Act has had any effect in reducing Longmont particulate pollutant levels.

Boulder particulate pollution levels for 1970-72 are similar to those recorded in the period 1965-67. 1968-69 was a period of above normal pollution. From the particulate counts it is difficult to assess whether the 1970 Act has resulted in lower pollutant levels or whether there were less frequent inversions and/or stagnant conditions 1970-72 than 1968-69. However, the benzene soluble counts do show a reduction since 1970 which suggests the 1970 Act may be having desirable results in Boulder County.

10.2 INVERSIONS AND SEASONAL VARIATION

At both stations the highest pollutant concentrations are recorded in winter months. This reflects the stronger and more frequent inversion development and shallower mixing depths during this part of the year. An inversion is an atmospheric condition in which there is warmer air aloft than at the surface. Consequently, as long

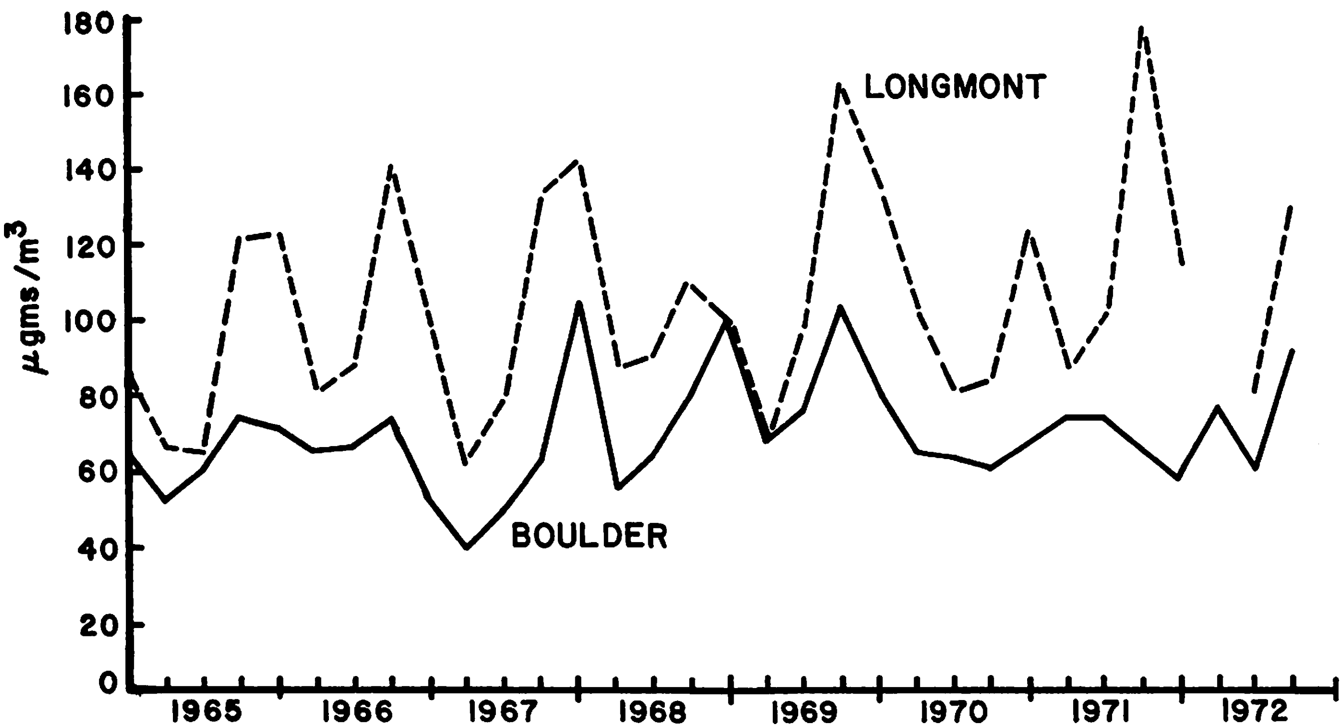

Figure 24. Quarterly suspended particulate pollutant levels in micrograms per cubic meter of air. 1= Jan., Feb., March. 2= April, May, June. 3= July, Aug., Sept. 4= Oct., Nov., Dec.

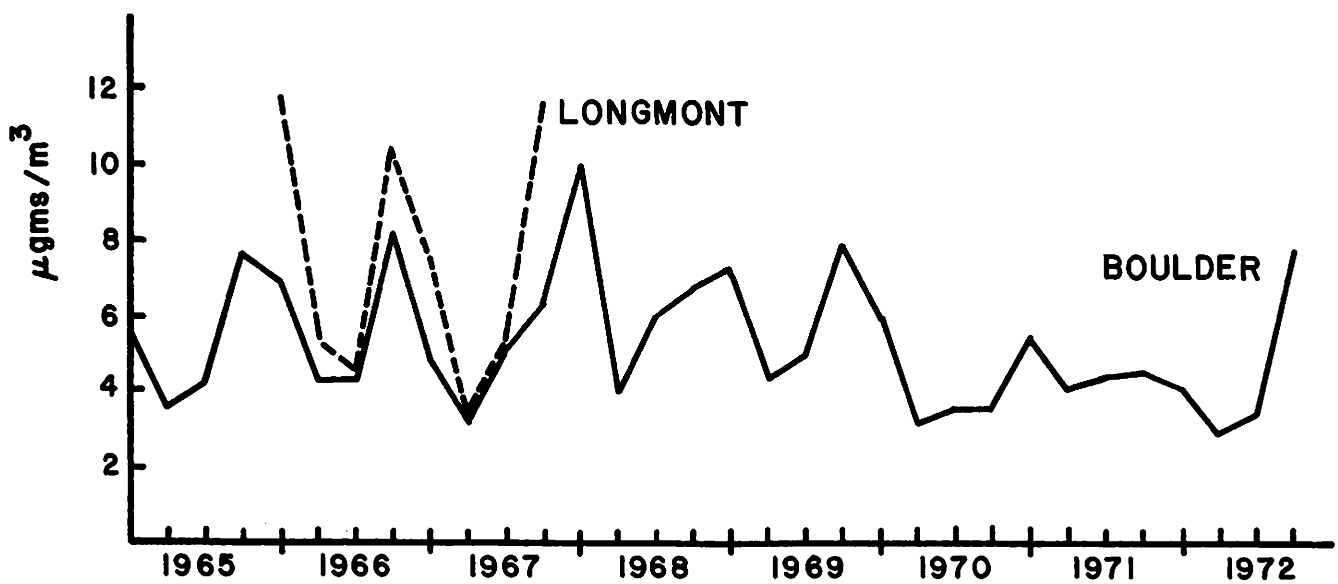

Figure 25. Quarterly benzene soluble pollutant levels in micrograms per cubic meter of air. 1= Jan., Feb., March. 2= April, May, June. 3= July, Aug., Sept. 4= Oct., Nov., Dec.

as the inversion persists, vertical mixing of the air is restricted to the depth of the inversion layer. Table 7 shows the frequency and mean depth of surface inversions at Stapleton Airport for the winter months (October - March) 1964-65 to 1968-69. No other upper air soundings are available for the eastern half of the state. Although it is probable that these data do not correspond closely to inversion frequencies over Boulder (due to turbulence along the mountain front) it is likely that they are pertinent to pollutant problems in Longmont.

The 1200 GMT (Greenwich Mean Time or 0500 Mountain Standard Time) soundings give a picture of night-time inversions, some of which disperse during day-time heating. Critical pollution episodes occur when inversions persist over a number of days causing maximum mixing depths (the depth of air through which pollutant dispersal can occur) to be restricted. Figure 26 shows monthly values of afternoon mixing depths for the 5 years (1960-64).at Stapleton Airport. Mixing depths are 2-3 times higher in summer months than in winter months. Thus it can be seen that the high frequency of winter night-time inversions and low mixing depths during the day are conducive to high winter pollutant levels in the eastern part of Boulder County.

In the mountainous western area no data are available. However, it is well-known that cold-air drainage into the valley at night results in strong inversions which may persist over a number of days if cold, calm conditions predominate. In such situations pollutant concentrations may rise to very high levels. This leads us to an important consideration in planning for future highways in Boulder County. To minimize the occurrence of areas of high pollution concentration, highways should not be routed along valley bottoms. Neither should industry be encouraged to site in valley areas, a pattern which has been encouraged in many of our major cities. Here we can learn a lesson from Denver. Figure 27 shows suspended particulate pollutant levels 1968-69 in Denver as a function of distance from the South Platte River. The higher pollutant levels near the river reflect several things: (a) inversions tend to be more persistent over the lower land areas, (b) in Denver, major transport arteries follow the valley bottoms, (c) many industries are located in the South Platte valley (see Bradley, 1972; Riehl and Herkhof, 1972). Boulder County can do nothing about problems such as (a), but can try to avoid problems resulting from (b) and (c).

TABLE 7

Summary of 1200 GMT inversion data for Stapleton Airport, Winters 1964-65 to 1968-69

	64-65	65-66	66-67	67-68	68-69	All Winters
Mean depth of surface inversions (feet)	961	1079	1014	1096	1073	1043
Total number of days with surface inversions at 1200 GMT, as a percentage of all winter days	78	89	83	80	75	82

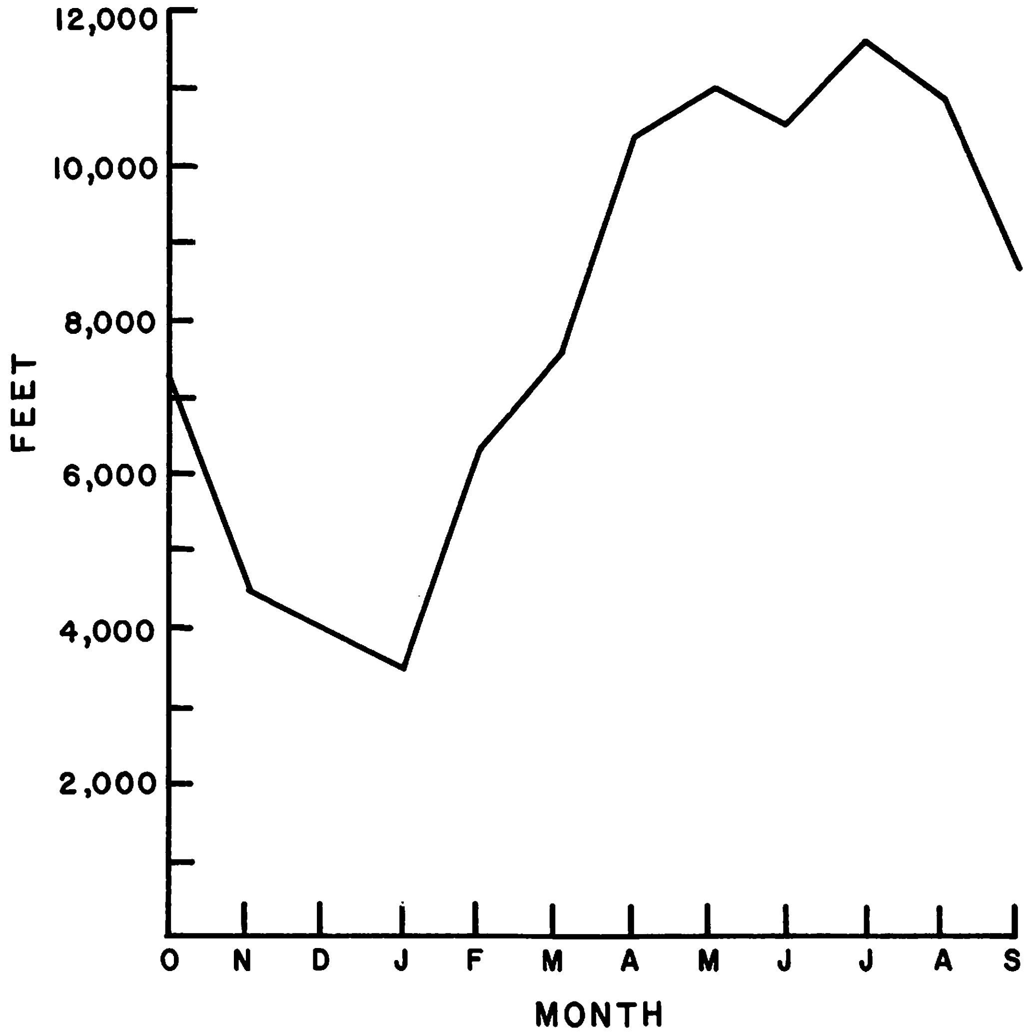

Figure 26. Average afternoon mixing depth by months, 1960 - 64, at Stapleton Airport.

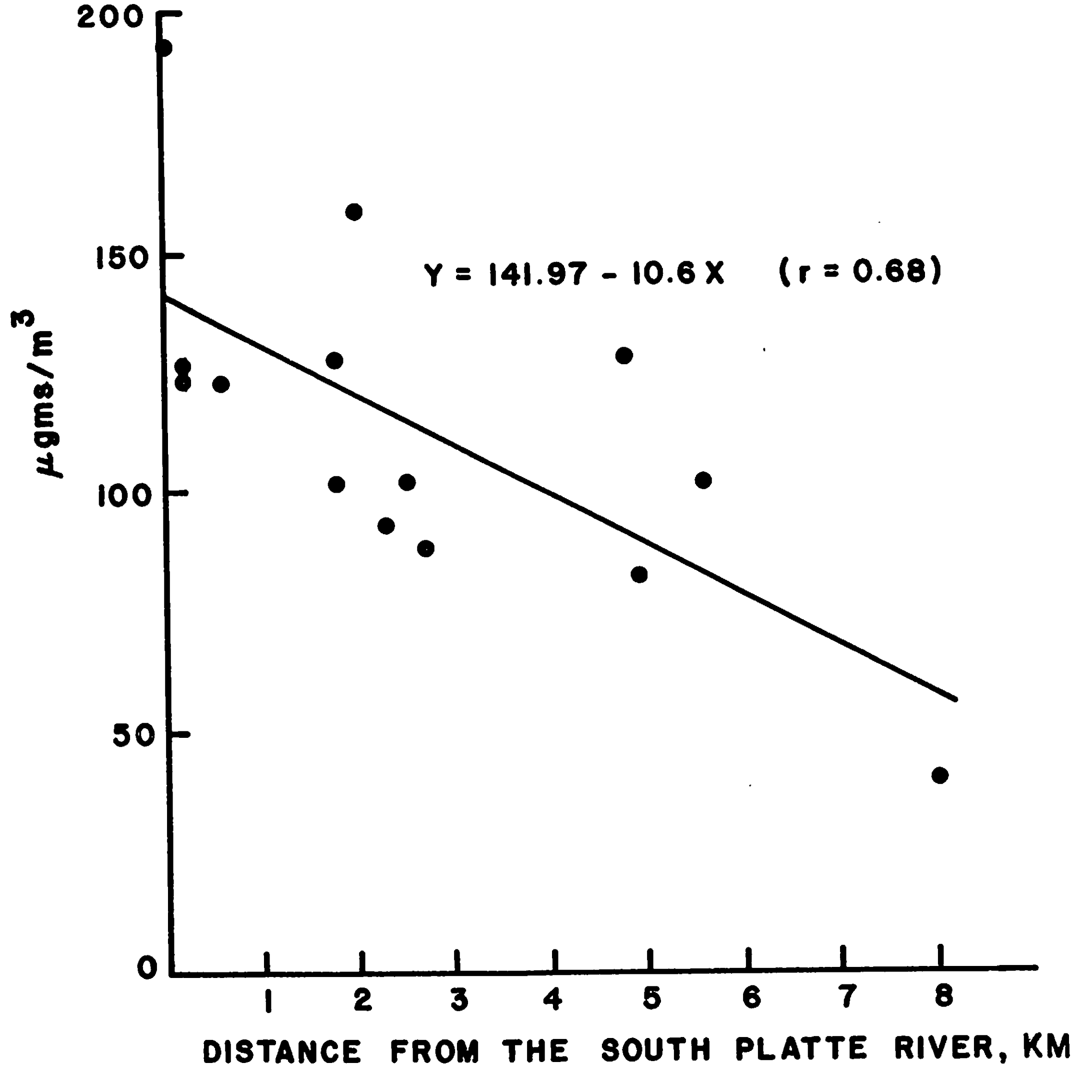

Figure 27. Particulate pollutant levels October 1968 to March 1969 as a function of distance from the South Platte River.

SECTION 11

WILDLIFE

David P. Groeneveld

11.1 INTRODUCTION

Compilation of wildlife data was undertaken jointly by INSTAAR under the direction of D. Groeneveld and the Ecological Task Force of the Boulder County Planning Project, World Design Institute, University of Colorado, a large-scale student directed independent study. Ecological Task Force members M. Japhet and D. Lehr were particularly instrumental in compiling data pertaining to birds and mammals while M. Japhet, D. Cifelli, B. Northcutt, and P. Hegerman were the same with respect to Boulder County fisheries. Colorado Division of Game, Fish, and Parks have been an invaluable source of information. John Monarch, the Boulder area officer, supplied the information for mapping big game herds (Plate 5). Mapping techniques were provided by Dick Norman of the wildlife branch in Fort Collins. Select references in mammals and birds include Stoecker (1972), Warren (1960), Alexander (1937), Bailey (1963), and Fisher, Simion, and Vincent (1969). References pertaining to fisheries and the ecology of local streams include Windell (1972), Bock (1972), and Bock, Windell, and Bock (1972).

11.2 MAMMALS AND BIRDS

11.21 Large Mammals

There are five species of big game animals in Boulder County. These include mule deer, white-tail deer, black bear, elk, and the now rare mountain lion which is occasionally sighted in sparsely inhabited mountain areas east of the Peak-to-Peak Highway.

Deer. At present, there are an estimated 1800 mule deer scattered through the mountainous portion of the county and about two dozen white-tail deer on the plains east of Highway 287. According to John Monarch, the county will lose its deer herds, if the present rate of herd decimation is not halted. Dog packs roam the entire county harassing small and large game alike. However, uncontrolled dogs are particularly damaging to deer herds. Actually, the problem is twofold. Housing subdivisions and cabins built on the prime winter deer habitat of south-facing slopes have limited the available range. Then the dog packs, some of whose members may reside in these subdivisions, attack the concentrated herds. Under these conditions the losses that result tend to be high.

Elk. Elk are not as severely affected by dog packs as deer, mainly because of their larger size and relatively greater isolation from man. Elk appear to be taking over some range formerly held by deer. The elk of Boulder County are predominately in the four major areas listed in Table 8 inclusive of discrete winter and summer ranges (see Plate 5).

TABLE 8

Location and size of major elk herds in Boulder County

Herd	Census Numbers
Buttonrock	200-250
Balarat	50
Sugarloaf	50-60
Winliger Ridge	100

Black Bear. Information with respect to the number of bear in the county is not available, but they are numerous enough in places to be a management problem due to their appetite for garbage. Most large garbage dumps within the mountains receive these potentially dangerous visitors on a regular basis. Because of this, garbage and landfill sites should be located away from areas of habitation.

Management Considerations. The destruction of deer by uncontrolled dogs is clearly one of the most serious problems confronting wildlife in Boulder County. The location of garbage dumps in the mountains with regard to foraging bears is less serious, but could result in tragedy if the potential danger is not minimized. The public should be made aware of the problem. Domestic livestock is limited in the mountainous part of the county and is not a source of competitive pressure for existing forage.

Snowmobiling does not, at present, represent a problem, because snow depth, both too shallow and too deep, restrict this activity to a narrow zone, mainly in the subalpine. Most big game have usually moved to their winter range at lower altitudes by the time snowmobiling and cross-country skiing begin. However, the competition for range with humans engaged in summertime recreational activities may be another matter. Summer is the season when 4-wheel drive vehicles and trail bikes become a problem, especially in those areas in the subalpine where there is a significant amount of private land.

11.22 Small Mammals and Birds

There are no practical means for managing small animal and bird populations in Boulder County, except to improve and expand existing habitat. This can be accomplished by planting vegetation or preserving existing cover along stream beds and in the greenbelt. Protection of riparian ecosystems should be encouraged because they represent very important habitat to small mammal and bird populations. Floodplains provide the nesting cover and food supply attractive to many native species of birds and small mammals. Sand and gravel pits compete for the floodplains on a temporary basis. While in progress, this mining is highly disruptive, however, once this vital resource is extracted the artifically produced wetlands can, if engineered properly, again become desirable habitats for many species. Well-planned rehabilitation of these sand and gravel pits can make them appealing to humans as well. Sand and gravel mining can be converted to greenbelt and wildlife sanctuaries. Species intolerant of man such as the pine marten, prairie falcon, and peregrine falcon will probably decrease as human population increases.

Continuing studies by members of the Boulder County Planning Project involve compilation and verification of information pertaining to 20 to 40 species of resident birds. The Audubon Christmas bird counts provide the control data. Determination of the present stability and size of bird populations as well as trends since 1950 are principal objectives of these studies.

11.3 FISHERIES

11.31 General

Boulder County contains a diverse array of fishing opportunities ranging from the warm water lakes of the plains to a cold water fishery extending from the foothills to high elevation lakes near the Continental Divide. As the county population increases, existing public waters will experience progressively more fishing pressure. As a consequence, management policy will need to consider ways in which to increase the available fishery both in quantity and quality to meet future recreational needs. An increase in available fishing waters, should in itself, improve fishing quality. Stocking information for the 1971 and 1972 seasons was supplied by Jerry Whitacre of the Wildlife Branch, Colorado Division of Game, Fish, and Parks at Fort Collins. Because quality fishing waters do not exist within the county, stream and lake values must be judged in terms of recreational use. Information on fishing pressure and water pollution level is shown on Plate 5 and tabulated in Appendix A.

11.32 Stream Fisheries

Dewatering, sewage and wastewater disposal, and channelization all combine to lower the fish carrying capacity of county streams. Because these conditions are man induced, they can likewise be reversed by better management. Sewage disposal should be held to an acceptable minimum and research conducted to determine whether or not the deleterious effects of agricultural dewatering can be remedied in those areas where the existing stream habitat is capable of carrying trout. Likewise, research is needed to examine the extent of water loss through evapotranspiration from numerous small and largely inefficient irrigation ditches.

Water need not be free of sewage effluent for agricultural use, but it must be nearly free for use as a fishery. Recreation as a use category of water is perhaps even more important today than in the past. Unfortunately, this use is often preempted by industrial and agricultural uses, both of which can degrade water quality to the extent that it is no longer useable by humans or wildlife. Recent studies reported on from the Windsor area project (Edgerton, 1973) indicate that agricultural uses have degraded water to the extent that it is no longer practical to treat it for human use. Irrigation and excessive use of commercial fertilizers are the principal causes. Industrial use has done the same to both surface and groundwater in the Brighton area (Colorado Ground Water--Basic Data Report No. 15, 1964). Extending and improving the cold water fisheries of Boulder County depends on careful stream monitoring and law enforcement to eliminate mine and sewage induced stream degradation.

Stream improvement projects involving emplacement of rock and log baffles and small dams would increase the carrying capacity of the existing fishery as well as to allow fish to reinhabit previously channelized streams. Revegetation of streamsides should be encouraged to provide food and shade for fish. As demonstrated by Vannote (1972, Oral pres., Annual Mtg., Geol. Soc. Amer.) trees falling into streams are the source of aggravation to stream channelizers, but their removal from the bank area represents a significant loss of habitat for fish.

11.33 Lake Fisheries

Lakes constitute the major fishery within the county. In general, there are no practical methods for increasing the size or quantity of county lakes. Quality fishing can be judged on the criteria of reproduction and self-maintenance. Those lakes which are naturally reproducing should be protected with a "fly and lure only" restriction. An effort should be made to acquire fishing and recreational access to privately owned warm water lakes by buying or leasing.

SECTION 12

NATURAL HAZARDS

R.F. Madole, R.S. Bradley, P.E. Carrara and A.E. Mears

12.0 INTRODUCTION

A natural hazard is any threat to human beings or their works by a process that is part of the natural environment. Discussion is confined mainly to those hazards which are essentially geological in nature and which are common to this part of Colorado. Natural hazards such as tornadoes and hail are beyond the scope of this publication. Most of the hazards discussed are normal processes which only become a problem when humans get in their way or human activities upset their equilibrium and trigger or accelerate them to a hazardous level. Those capable of taking lives and/or doing much property damage include floods, avalanches, and landslides. Those with more limited destructive potential include subsidence, rock glaciers, rockfall, problems associated with debris fans, and problem soils. Although not a significant threat to human life, swelling soils cause more property damage annually than do hurricanes, tornadoes, landslides and earthquakes combined (Jones, in press). The swelling soils (those with a high shrink-swell potential) of Boulder County are identified in Section 8. Therefore, they are not discussed as a separate category in this section.

12.1 LANDSLIDES

Landsliding, defined by Varnes (1958) as the downward and outward movement of slope-forming materials including rock, soil, artifical fill, or combinations of these, is a significant problem in the zone where mountains meet plains. Unfortunately, this is also a zone where pressure for continued development is intense. Three geologic units are particularly susceptible to landsliding. In chronological order, these include the Lykins Formation, the upper part of the Dakota Group, and the Pierre Shale. The distribution of landslide-prone areas is shown on Plate 6.

Figure 28 shows one of the many ancient landslides along the mountain front. Of more concern, however, are the slides which may be released in the future (see Figure 29). There are four basic mechanisms for initiating landslides, all of which can be naturally or artifically induced. These include (1) removal of support at the base or along a portion of a pre-existing landslide or slope underlain by a weak material; (2) loading the sites just described with the weight of structures or landfill; (3) wetting the material involved, thereby adding weight while simultaneously reducing internal cohesion and strength; and (4) shocking or vibrating material by earthquakes, blasting, or the frequent passage of heavy vehicles.

The predominantly fine-grained red shales and siltstones of the Lykins Formation as well as the colluvium and residual regolith derived from them are inherently weak and heavy loading alone can cause failure. Likewise, wetting may be a singular cause of landsliding. Wetting can be caused by leaking irrigation ditches, obstructed natural drainage, leaking pipes, or excessive watering of lawns. Obviously, a combination of excavation, loading, and wetting is very likely to produce trouble.

The Lykins Formation underlies the strike valley between the hogback formed by the Lyons Sandstone on the west and the Dakota hogback on the east. In part, the problems with these redbeds are linked to the permeable Lyons Sandstone which is an aquifer and leaks water into the Lykins Formation. Were these formations horizontal, there would be no problem. However, their inclination, inherent weakness, and the tendency for water to seep into them from the Lyons Sandstone creates a potential for instability which human activities can easily trigger. Rigid specifications should be imposed on development in this area in order to prevent initiation of landslides. All construction should be preceded by thorough site investigation and the specifications imposed should be firmly enforced.

The tendency for landsliding in the Pierre Shale is equally serious, but derives from different conditions. Expansive or swelling clays are the principal source of trouble. Such clays have a high swell-shrink potential and when exposed to the atmosphere by excavation tend to be pried apart by alternate wetting and drying. The result is a reduction of internal cohesion. When the site involved is on a moderate to steep slope, this reduction in strength coupled with the loss of support caused by excavation is very likely to lead to slope failure. As a general rule, benches for foundations or roadbeds should not be excavated in slopes directly underlain by Pierre Shale. The City of Boulder regulates this sort of activity through their engineering geologist (Pendleton, per. comm., 1973), but the county does not have someone to do the same.

Figure 28. Ancient landslide in rocks of the Dakota Group north of Boulder showing characteristic hummocky and bulging surface where it spreads out near its lower limit. It descends in almost stream-like fashion from its source, the concave somewhat bowl-shaped area, upper center.

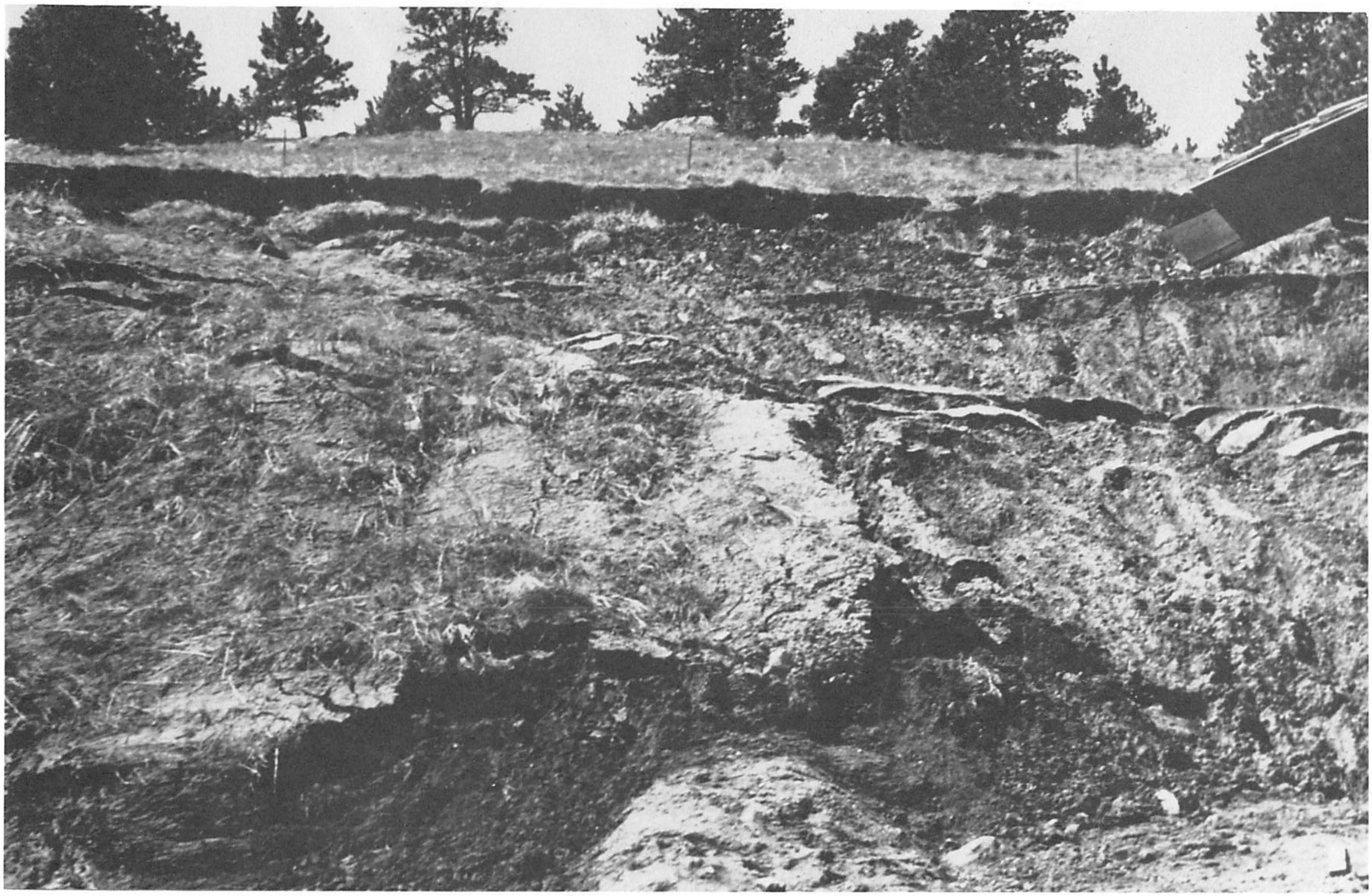

Figure 29. What had been a slope in equilibrium is now a geologic hazard because of human activities (photo by J. A. Pendleton).

The Pierre Shale is the most widespread sedimentary formation in the county and the scenic slopes flanking most of the pediments and mesas (Figure 30) in the area are cut in this rock. These include the prominent escarpment surrounding the pediment upon which NCAR is built, the slopes of Haystack Mountain, Table Mountain, Flat Top Mountain, and other uplands north of Boulder. Unfortunately, this scenic value can be easily replaced by a major liability in the form of progressive landsliding. Once undercut, slopes on Pierre Shale will tend to fail repeatedly at ever higher levels until the entire surface may be scarred. Besides contributing to landsliding, the high swell-shrink potential of the Pierre Shale is also responsible for foundation problems, a topic dealt with elsewhere in this report.

The Dakota hogback, which forms the mountain front, has in times past been the scene of large-scale landsliding. Although their geologic age is unknown, they are all quite old and examples of recent movement such as exists for the Lykins Formation and Pierre Shale is generally lacking. This raises the question of the stability of old landslides. As might be expected, a standard answer is not possible.

Landsliding tends to destroy the strength of the material involved, but having slid, landslides can stabilize and some actually reacquire strength by compaction and weathering through time. If the slide mixed strata, interspersing coarse and fine sediment, including blocks of sandstone and/or crystalline rocks, the resulting aggregate may have reasonably good strength. If on the other hand, the strata are mainly fine-grained (silt and clay or mixtures of shale and siltstone) and sliding succeeds in pulverizing them, the resultant material may remain very weak and react adversely to the slightest disturbance. Even so, proper engineering may be able to surmount the problem given enough funding. Hence, while some landslides should be made off limits to development, others need not be. The distinction requires field work. In those landslides where some development is possible, extreme care must be exercised.

Although the slides leading down the dipslope of the Dakota hogback do not appear to be as potentially troublesome as the Lykins Formation, or slopes underlain by Pierre Shale, their presence should be publicized and all development proposed for them should be carefully regulated. High density development may have to be discouraged. However, these slides have yet to experience intense development, so little data exists for testing this assumption.

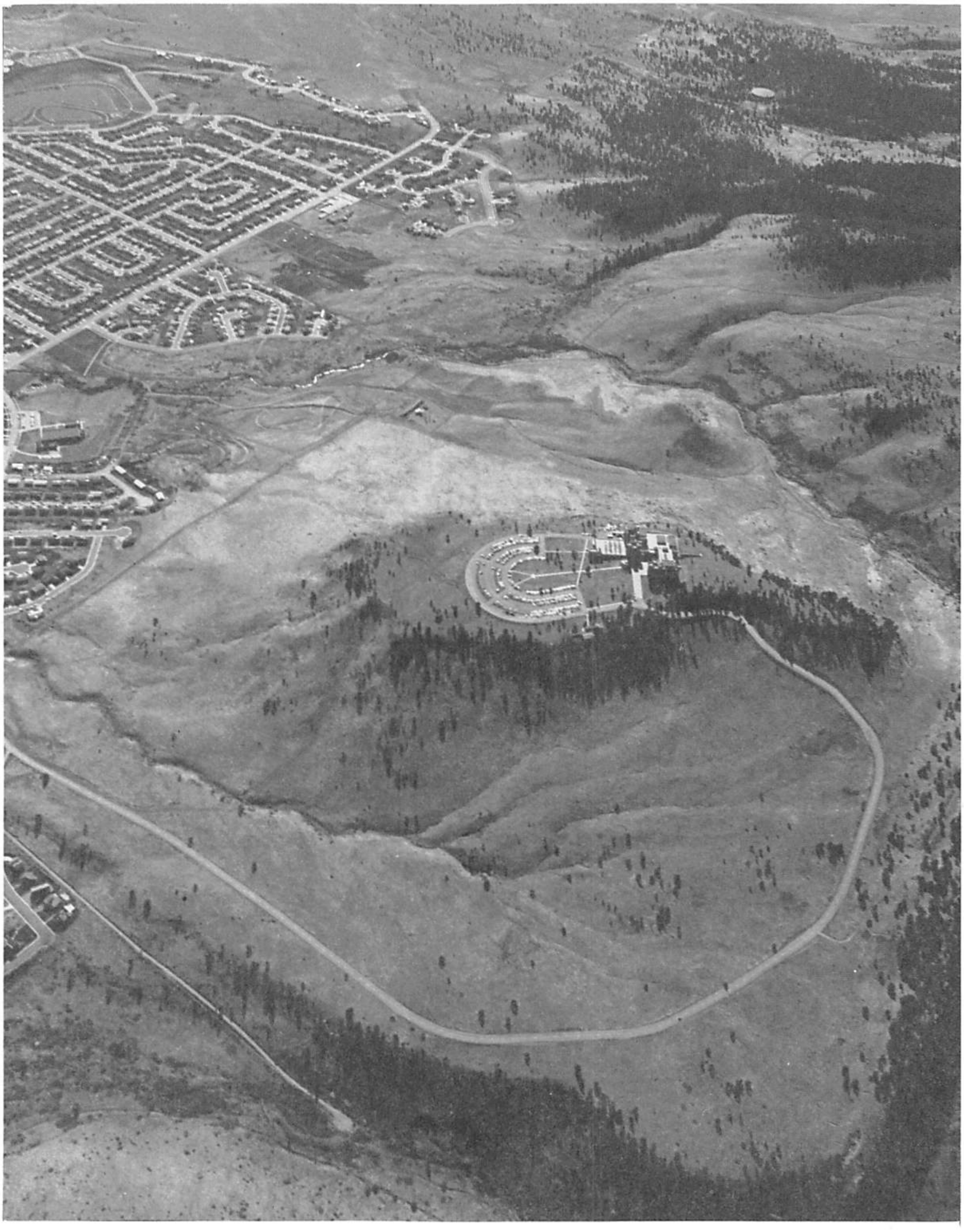

Figure 30. Slopes underlain by Pierre Shale such as those from NCAR, center, north to Chatauqua are vulnerable to landsliding when notched or "bench cut" for roadbeds or foundations (photo by NCAR).

12.2 FLOODS

12.21 General

Suggestions for prudent use of floodplains in metropolitan regions were made as long ago as 1910 when Frederick Law Olmstead suggested the first floodplain planning. In general, man has been slow in responding to these suggestions, and large floods have all too frequently reached populated areas causing considerable damage in highly populated areas. Fortunately, Boulder is again ahead of most counties in this regard. Section XVIII, part 18.5, p. 41-53 of the Zoning Resolution adopted October, 1965, is a comprehensive document governing land use practices on floodplains, especially that portion within the limits of the 100-year flood, the event that is widely used as the standard for flood planning. Most of the environmental safeguards recommended in publications appearing since 1965, as for example the Lake Tahoe Hydrology and Water Resources study (1971), were covered by the Boulder County Zoning Resolution.

The data base for flood planning in Boulder County is becoming substantial. The U.S. Geological Survey published a map of the Boulder Creek floodplain in 1960 showing the extent of the area which would be flooded by the 25, 50, and 100 year floods. More recently, the U.S. Army Engineer District, Omaha Corps of Engineers has published four volumes of floodplain information and a special report on the major streams of eastern Boulder County. These publications describe valley characteristics, developments and structures on the floodplains, a summary of past floods, and a discussion of flood potential in terms of the intermediate regional flood, standard project flood, greater floods, and associated hazards.

Floodplain Information Volume I (1969) deals with Lefthand Creek from the mountain front to its junction with St. Vrain Creek. Volume II (1969) concerns the two Boulder Creeks from the mountain front east to within about a mile of the county line. Volume III (1972) and IV (1972) deal with St. Vrain Creek from just west of Lyons to the county line east of Longmont. The Special Report (1972) provides flood hazard information for that stretch of North Boulder Creek within the City of Boulder. Additional floodplain planning is in progress for smaller tributaries within and near the City of Boulder by private consulting firms.

The flood control system to be adopted in the City of Boulder and method for funding it have been debated and formulated during the first half of 1973. Boulder County is well along the road to solving its problems related to floods. Flood limits determined by the U.S. Army Corps in eastern Boulder County are shown on Plate 6.

12.22 Western Boulder County

Because of the extensive flood planning already accomplished in eastern Boulder County, the INSTAAR effort was limited to the mountainous part of the county for which flood discharge-frequency data was not previously available. Consequently, compilation and analysis of flood data was undertaken for the major mountain streams. The results of this work are discussed in the following paragraphs and displayed on Plate 6.

Although floods in the mountainous part of the county are generally less massive than on the plains, they can still be very destructive. The most recent large floods in this area occurred when nearly 7 inches of rain fell during the first few days of May, 1969. In addition, 34 inches of snow containing 6.5 inches of water equivalent were recorded at one of INSTAAR's meteorological stations at the 10,000-foot elevation between Ward and Nederland. Damage to roads and property from the resulting flood exceeded $500,000. Roads in Fourmile, Lefthand, and South St. Vrain Canyons were impassable, and Jamestown was isolated when floodwaters severed the highway along James Creek. North St. Vrain Creek had a discharge of over 1800 cfs (cubic feet/second) where it emptied into Button Rock Reservoir located at an elevation of approximately 6,500 feet. Had the precipitation in the high country been received as rain rather than snow, peak discharges and resultant flood damage would have been significantly greater. Portions of high mountain valleys shown on Plate 6 would have experienced more destruction as discharges there would have been increased notably.

Method Used in this Flood Study

There are several methods available for developing a flood discharge frequency relationship. The one chosen here is similar to that used by the U.S. Geological Survey (Dalrymple, 1960). This method is applicable here because of the considerable overlap of existing discharge records from streams of a common physiographic setting in western Boulder County.

Results of the Flood Study

Table 9 shows discharges for floods with recurrence intervals of 10, 20, 50, and 100 years. The streams listed are those suitable to analysis by the method cited above.

TABLE 9

Flood Discharges in cfs (cubic feet per second) for Various Return Periods for Streams in Mountainous Boulder County

STREAM	DRAINAGE AREA, MI^2	County GAGE ELEV. FT.	CFS FOR RETURN PERIODS IN YEARS 10	20	50	100
No. St. Vrain Ck.	32.6	8230	600	730	895	1020
Middle St. Vrain Ck.	28.0	7560	555	675	830	950
So. St. Vrain Ck.	14.4	9372	350	420	520	595
No. Boulder Ck.	44.0	6900	720	875	1075	1230
Middle Boulder Ck.	36.2	8186	630	765	940	1075
So. Boulder Ck.	42.7	8380	705	855	1050	1200

Technically, the flood discharges calculated are accurate only at the elevation of the stream gaging station where the base data were obtained (column 3 of Table 9). However, they are approximately valid for reaches of streams near that elevation providing they are not miles away or significantly farther east inasmuch as flood discharges increase in a downstream direction.

Evaluation of Existing Flood Hazards

A flood hazard does not exist over most of the area examined because the streams flow at the bottom of steep-sided valleys that have no floodplains on which to spread. Locally, the valleys do widen and invariably are populated because of easy access by highway; the existence of flat, stable foundation sites; and availability of groundwater. Localities which might be vulnerable to floods of longer recurrence intervals include:

North St. Vrain Creek (Area 1). The floodplain immediately east of the intersection of Highway 7 and North St. Vrain Creek is susceptible to flooding. Present development is probably not threatened because it is substantially above the creek.

Middle St. Vrain Creek (Area 2). The towns of Peaceful Valley and Raymond lie on the floodplain of Middle St. Vrain Creek. During the 50 and 100-year floods, this area would experience some flooding and erosion of the highway could be a problem in places.

Middle Boulder Creek (Area 3). This stream meanders across its almost level floodplain about one mile east of Eldora. Flooding is not an important hazard here, although it probably could occur. Large flood discharges would probably cause erosion damage near the center of Nederland.

Jamestown is also threatened by floods, but flood flow analyses were not attempted for Lefthand Creek, James Creek, or their tributaries because flow in these streams is regulated and the flood discharge-frequency method cited above does not apply. Other types of discharge-frequency methods can be applied to these streams, but this has not been attempted in this report.

Accurate mapping of the flood plains is best accomplished using large scale topographic maps. A scale of 1:2400 with a 2-foot contour interval is suitable. If these maps become available, the flood discharges given in this report can be used to map the limits of floods of desired recurrence intervals.

12.23 Human Impact on Stream Behavior

General

The flood discharge-frequency relationships derived in the preceding section were developed on streams which have remained essentially unchanged and unregulated. Stream behavior can be greatly altered by man's activities, not just by diversion or augmentation of stream flow, but also by land use practices on and adjacent to the floodplain. Stream channels are only part of the drainage basin. They are the means of conveying runoff and sediment from the interstream areas. Under natural conditions, stream channels tend to attain an equilibrium within their environment such that a balance is maintained between mass import and export of sediment over a period of time. In short, such streams neither erode nor deposit excessive amounts of sediment. When the environment is altered, streams must readjust to attain equilibrium under the new conditions. During readjustment considerable erosion and/or deposition may occur which can have subtle, far-reaching effects. Urbanization has a profound impact on stream equilibrium.

As streams of western Boulder County flow from Continental Divide to the plains, they pass through several ecological zones. Throughout much of the mountain environment, the runoff from undisturbed forest is kept to a minimum. The trees maintain a storage potential by depleting soil moisture through transpiration. Consequently, much of the overland flow through the forest is absorbed into the soil. The trees also intercept 18 to 25% of the precipitation (Lull and Sopper, 1969), preventing it from impacting the ground surface. Much of the intercepted precipitation is returned to the atmosphere via evaporation without reaching the ground.

Patric and Reinhart (1971) show that deforested areas tend to accumulate more snow and contribute more runoff. The increased radiation on these treeless areas tends to produce a more rapid melt during the spring which increases runoff at the expense of infiltration while simultaneously promoting greater erosion.

Changes to the Stream Environment

Devegetation. Development or urbanization tends to decrease the amount of natural vegetation and increase the amount of impervious surface area (area water cannot infiltrate). Foundations, driveways, and roads remove vegetation and replace it with stone, concrete, and asphaltic materials which prevent precipitation from infiltrating to water table. This affects the base flow of streams and the water level of ponds and lakes. These tendencies compound to increase runoff while reducing the amount going into groundwater storage.

Devegetation results in the loss of the beneficial effects of interception, surface detention, and maintenance of the soil moisture storage potential referred to above. Raindrop impact gradually seals bare surfaces further reducing the opportunity for infiltration, while promoting an increased runoff. The sediment removed by rainsplash and an increased rate of runoff generally has a devastating effect on the riparian ecosystem. Likewise, should the streams involved flow into lakes, the concentrated dose of nutrients contained in the sediment tends to unbalance the ecosystem there.

Increased Impervious Surface Area prevents infiltration and simultaneously provides efficient systems for speedily conveying precipitation directly to the nearest channel. Interception by ditches, roadways, gutters, and storm sewers replaces interception by vegetation. Unfortunately, some of these man-made structures are very efficient in doing what they were designed for, namely removing surface water quickly. From tombstone to shopping center, man eliminates the surface area available for recharging the natural groundwater storage system. The most important effects of increasing runoff at the expense of infiltration include:

1. An increase in the magnitude of discharge at the flood peak accompanied by a decrease in the lag time between onset of storm and time of peak discharge. Misuse of flood plains can result in both more and larger floods than should normally occur.

2. An increase in stream sediment load. O'Bryan and McAvoy (1966) show the following relationship between sedimentation and urbanization:

Land Use	Sediment Yield in Tons/Mi^2/Year
Forest	about 50
Urban & Suburban Land	50 to 100
Farmland	1,000 to 5,000
Stripped for Construction	15,000 to 50,000

3. Below normal stream flow periods between storms. Base flow, as this is termed, is reduced because water that should have infiltrated and been stored to sustain flow went almost directly into stream channels.

4. Stream quality is degraded because the influx of waste materials is increased both during and between storms. Reduction in base flow between storms results in a loss of the stream's capacity to dilute wastes.

5. Stream channel geometry is altered inasmuch as width and depth are controlled by discharge. Misuse of the floodplain which leads to increased runoff and larger floods enlarges the channel. This may adversely affect man-made structures such as bridges. An enlarged channel coupled with reduced base flow diminishes the aesthetic quality of streams.

12.24 Reducing Human Impact on Streams

The Lake Tahoe Hydrology and Water Resources study (1971) provides several recommendations applicable to the Boulder area for land use adjacent to streams. These include:

1. Developers or proponents of a change in land use near streams should be required to submit a plan showing how their activities will alter runoff and stream hydraulics including an estimate of the magnitude of change. They should also be asked to show how the excess water from any additional overland flow will be stored for gradual release into the stream.

2. Developments should be located as far from streams as possible so runoff from impervious surfaces can be absorbed by the ground on its way to the streams.

3. Areas adjacent to streams should be preserved in their natural state to serve as catchment and storage zones for overland flow.

4. A streamside environmental zone should be established wherever possible with a width equal to that of the 100-year floodway plus either 25 feet vertically or 100 feet horizontally, whichever comes first. The 100-year or "intermediate regional floodway" has been determined for Boulder Creek, South Boulder Creek, Lefthand Creek, and South St. Vrain Creek, east of the mountains by the U.S. Army Corps of Engineers. If detailed ground topography becomes available for mountain areas 1, 2, and 3, these widths can also be determined.

Recommendation 4 would tend to force development away from the flat areas along canyon floors. In many cases, this would invite development on steeper slopes which also may be unsuitable because of problems related to fire, road maintenance, and erosion.

12.3 DEBRIS FANS

Debris fans are deposits of sediment formed where small mountain streams encounter a marked reduction in gradient as they reach the plains or the valley floor of a larger mountain stream. They are generally a composite of fine-grained material deposited by runoff from rain and meltwater, and coarse sediment and boulders deposited during heavy storms, or by debris flows or, in places, by avalanches. Natural levees, the product of debris flows, are visible on some, while others appear to be comprised mainly of alluvium (sediment deposited by streams).

Cloudbursts, floods, and debris flows are related phenomena. The potential for these is present along the mountain front in Boulder County. A search of historical records, as well as the geologic record, should document their occurrence. It is also probable that in places subdivisions conceal the deposits of debris flows. However, little work has been done on the problem in this region. Marsell (1971) describes cloudburst and snowmelt floods along the Wasatch Front of Utah, an area which is relatively similar to the mountain front of the Denver-Boulder area.

Although debris fans are not as common in mountainous Boulder County as in other parts of montane Colorado, they do occur where side gullies meet the floors of major canyons below the lower limit of glaciation, i.e., below 9,200 to 8,200 feet. Most could be appropriately termed alluvial fans as they were deposited mainly by flowing water. Likewise, most are too small to show at the 1:96,000 scale of Plate 6. They tend to be particularly attractive building sites inasmuch as they are often the only places affording enough level ground between stream, road, and valley wall upon which to build. Unfortunately, they are subject to infrequent but potentially devastating floods. Proposed construction on them should be carefully scrutinized at some level of local government. Figures 18 and 19 of the section on climate show the amount of rain for a 24-hour and 6-hour period that has a 1% probability of occurrence in a given year (i.e., the 100-year events). Three inches of rain in 6 hours would produce flooding and mass movement on these fans.

Debris fans, be they associated with large or very small gully systems, are in themselves an indication of a potential for sedimentation. The fact that they may be overgrown with mature aspen trees, or other vegetation, does not lessen the threat. In fact, this may merely indicate that the interval between episodes of major deposition is long. When the rare event does occur, vegetation may add to the destruction by blocking culverts and deflecting flow into unforeseen paths. Culverts and similar man-made structures are often designed as though they will be conveying just water when in fact they may carry great quantities of boulders, trees, and man-made debris. If a large log jams the channel creating a trap or barrier to other debris, the water and/or debris tends to overtop the channel to wreak havoc in unanticipated ways and places.

12.4 WIND

Severe windstorms have occurred in Boulder more than once per year, on the average, since records began (Julian and Julian, 1969; Whiteman and Whiteman, pers. comm., 1973). Windstorm periods are defined by Miller, Brinkmann, and Barry (in press) as having maximum wind speeds in excess of 50 mph with at least one station recording a gust over 73 mph (a hurricane-force wind) at a height of 11 feet above ground. On the basis of 216 windstorm days (as reported in the local press since 1869), D. and J. Whiteman have estimated the frequency of storms annually and diurnally (Figures 31, 32, and 33). Figures 31 and 32 indicate that storm activity is concentrated in winter months, particularly January, though an interesting wind peak is apparent in late June (Figure 32). On a daily basis, peak winds occur most often at night, with a maximum shortly after midnight, and a secondary peak in the early afternoon (Figure 33).

Aspects of the origin of downslope windstorms and their physical characteristics, some of which are listed below, are presented by Brinkmann (1973). The most striking characteristics of Boulder's windstorms are their hurricane-force velocities, extreme gustiness, rapid and frequent fluctuation in speed, and the extremely low relative humidity associated with them. It is also interesting to note that the onset of a windstorm in Boulder does not bear any simple

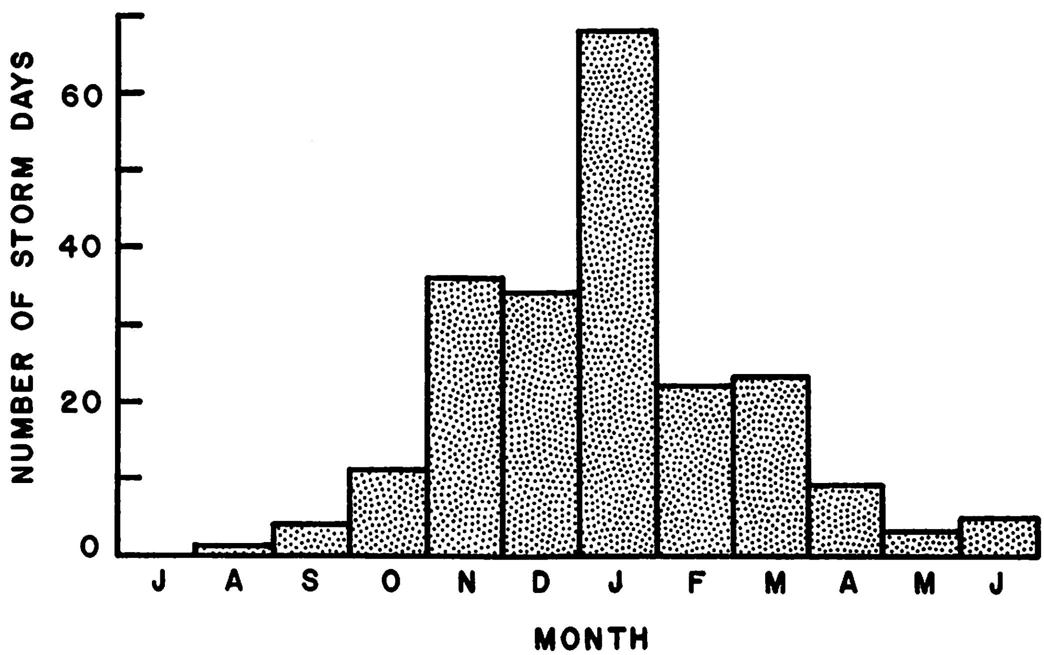

Figure 31. Monthly distribution of storm days at Boulder, Colorado, based on data reported in the local press, 1869 to 1973 (from Whiteman & Whiteman, 1973).

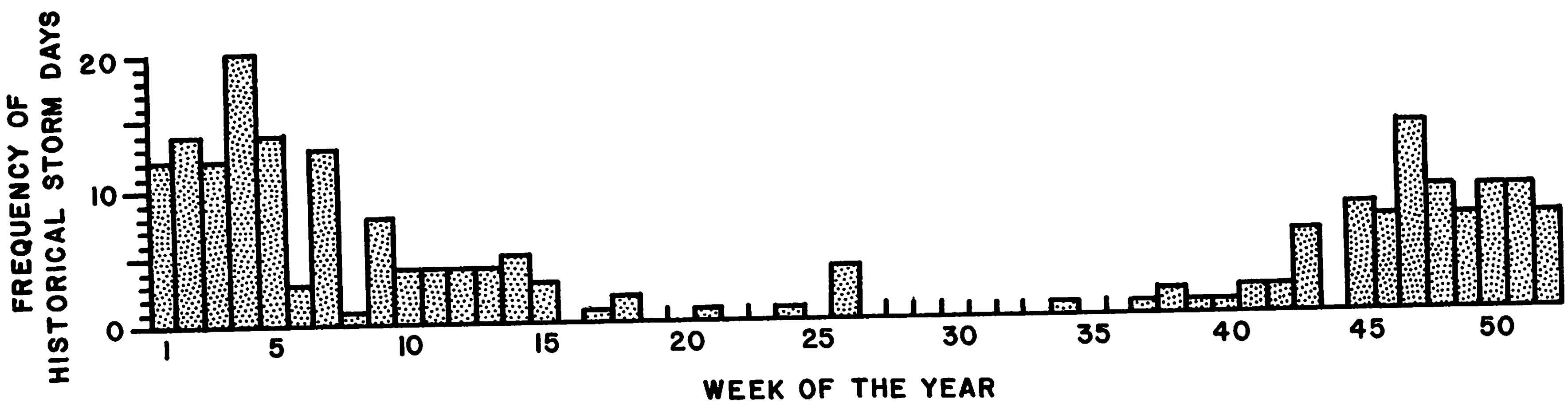

Figure 32. Number of damaging storm days at Boulder for each of the 52 weeks of the year as determined from data reported in the local press, 1869 to 1973 (from Whiteman & Whiteman, 1973).

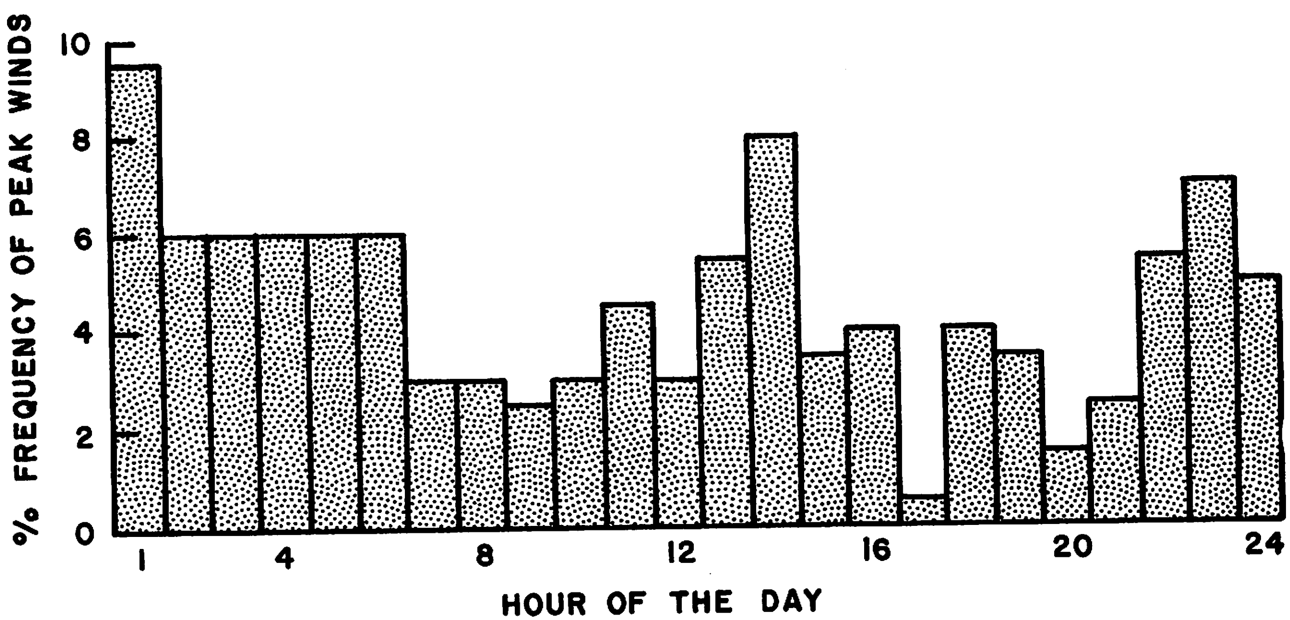

Figure 33. Relative frequency of occurrence of peak winds within 1-hour intervals of the day based on data reported in the local press, 1869 to 1973 (from Whiteman & Whiteman, 1973).

relationship to wind conditions in the mountains to the west.

Relatively few data are available on the spatial distribution of high winds in Boulder. Only in the last few years has a moderately good network of wind recording stations been available through NCAR (National Center for Atmospheric Research) and NOAA (National Oceanographic and Atmospheric Administration). Unfortunately, recent budget cutbacks may cause the NOAA network to be abandoned.

The well-documented storm of November 26, 1972, (Figure 34) was also characterized by very high winds south of the city and also toward the north. How typical this distribution is of Boulder windstorms is difficult to say. However, on the southern edge of the city, particularly Eldorado Canyon, Davidson Mesa, and Rocky Flats, high winds (70-80 mph.) are frequently observed when relatively calm conditions prevail in central Boulder (D. Whiteman, pers. comm., 1973). Because it is believed that data pertaining to hazardous winds is not yet abundant enough to construct a meaningful map of the entire Boulder area, no attempt is made to include this kind of information on Plate 6. Recently, Miller, Brinkmann, and Barry (in press) have summarized the physical characteristics of Boulder area windstorms, their effect on buildings, the damage caused by storms between 1969 and 1972, human perception and adjustment to the wind hazard, and hazard abatement measures. They note that the arrangement of buildings may significantly influence wind loads and stresses such that leeward (downwind) buildings may experience greater loads than windward or isolated buildings. Furthermore, they suggest that while maximum losses resulting from the severe windstorm of January 7, 1969, were in the southern part of the city, this pattern may not reflect a topographically determined characteristic of windstorms. Newspaper reports dating back to the turn of the century indicate damages elsewhere in Boulder and the county with the only common factor possibly being the absence of shelter.

The survey of wind damage made by the City Manager's Office (1970) following the severe storms of January 7 and 29, 1969, is not a study of where high speed winds occurred, but where damage resulted. Survey findings represent the net effect of high wind speeds, shelter by trees and other buildings, and building inadequacies. As noted above, the greatest damage during these two storms occurred at the northern and southern margins of the city, with less damage in the central section of town. This, of course, partly reflects the historical development of the town. In the zone of low damage, particularly in the western part, many large trees act as wind breaks or shields to housing. On the northern and southern margins of the city there are fewer wind breaks and more construction in progress and

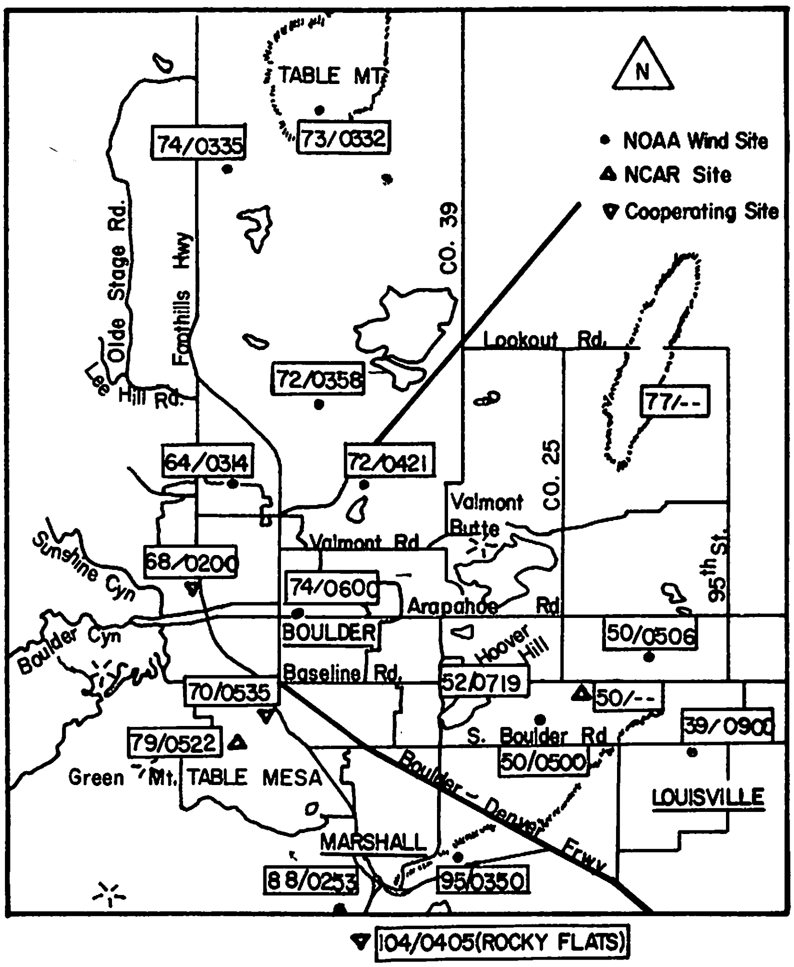

Figure 34. Boulder's windstorm, November 26, 1972. The first set of numbers given at each site is peak wind speed in mph and the second set is time of peak in LST (local standard time) after Whiteman & Whiteman (1973).

damage will thus tend to be greater even with equal wind speeds.

12.5 SUBSIDENCE

Although not of wholly natural causes, subsidence is a significant hazard in southeast Boulder County. The Laramie Formation which underlies the high mesas and hills south and east of Boulder contains several thin beds of coal. Three of these beds have been mined extensively throughout the 30 square miles encompassed by the Boulder-Weld County coal field and their removal has led to varying amounts of local subsidence.

The extent of the mined-out areas was mapped by Lowrie (1966) and updated by R. B. Colton of the U.S. Geological Survey, assisted by Harold R. Fitch, in 1972. Louis A. Gaz, Consulting Engineer, Lafayette, Colorado, also contributed to the updated map which was recently published by the U.S. Geological Survey (Colton and Lowrie, 1973). According to Colton and Gaz (1973), the thickness of coal removed ranges from 2 to 14 feet, but averages about 2.5 feet. Colton and Lowrie (1973) note that depth to mined coal ranges from 0 to 500 feet, generally increasing from west to east.

Colton and Gaz (1973) have documented collapse and subsidence over broad areas and damage to man-made structures including railroads, highways, irrigation ditches, and buildings. They recommend that test borings be made prior to any development near mined-out areas inasmuch as some of the mine surveys used in compiling their maps were discovered to be inaccurate. Also, it is important to note that the area of collapse may be broader than the mined-out area. Furthermore, to demonstrate that subsidence can occur long after mining has ceased, Gaz (pers. comm., 1973) cites a locality where mining was discontinued in 1926, but which subsided measurably in 1957.

Eastern Boulder County communities such as Lafayette and Louisville were formed as company towns, built on company-owned property, which generally means, over the mines. Other communities such as Erie, Marshall, and Superior were likewise linked to this industry and are either near or partially over mined-out areas. A mine near Marshall which caught fire several decades ago has been burning underground ever since. Collapse over the burned-out area and the threat of toxic fumes in the smoke issuing from it comprise a separate hazard. Colton and Lowrie (1973) note that the shafts and drifts shown on their map, which is incorporated into Plate 6, "are only approximately located, and some may not be shown."

12.6 FIRE

Fire hazard maps have been prepared for western Boulder County by the Colorado State Forest Service. Slope is a major component of these maps, the critical value being a grade of 30%. Fire spreads twice as fast on a slope of 30% as on level ground (Colorado State Forest Service). Hulbert (1972) illustrates the relationship between increased slope and the rate at which fire spreads by analogy with a match held in an inclined position with the lighted end down. Part of the problem is the convective flow of warm air which preheats the surface over which it moves. This self-perpetuating updraft becomes more serious where gullies and canyons are associated with steep slopes. The rising warm air tends to converge into them, producing an even more rapid funneling. The effect is analogous to opening the flue of a chimney over a fireplace. Hence, fire fighters refer to such gullies and canyons as "chimneys" or "flues."

Of course, building on steep slopes (e.g. 30% grades) involves factors other than fire. Slope stability, erosion potential, and road maintenance also must be considered. Geologically, some slopes are stable at values greater than 30% while others are unstable at values significantly less than 30%. Combining data derived from forestry and geology, we would recommend that 30% be the maximum slope upon which development be allowed without undertaking special fire precautions such as thinning trees and removing fuel supplies (Hulbert, 1972). Although a 30% grade is the recommended maximum, it is not the minimum. Consideration of slope stability may impose a much lower limit. Also, special precautions such as noted above should not be permitted if they upset slope stability or promote run-off and erosion.

Needless to say, road construction and maintenance is as much a part of the slope use question as is housing. There is a tendency for access routes to homes to be more of a problem than the housing itself. Roadcuts frequently induce landsliding because of loss of support and/or disruption of natural drainage. Furthermore, roads and driveways that are too steep can cause a significant amount of erosion and water pollution if the runoff and its sediment load has access to a nearby stream.

During the summer of 1970, the Colorado State Forest Service supported a group of researchers from Colorado State University in conducting a poll of mountain residents and subdivision developers in Boulder and Jefferson Counties concerning their reaction to the possibility of forest fires. The poll results as discussed by Hulbert (1972) show a low level of awareness of the fire hazard, the seriousness of which can be demonstrated by analogy with southern California where relatively high population densities in mountainous areas have existed for more than two decades. Unfortunately, loss of life and destruction of homes is too often repeated there. Although the summer drought is not usually as severe in Boulder County, the potential for fire during the summer season is generally high. Considering that a huge percentage of fires are man-made, the probability of a fire occurring must increase with a rise in population. Southern California also demonstrates the kinds of after effects of forest fire, such as massive erosion and slope instability.

According to Hulbert (1972), of the 300 residents and 20 subdivision developers polled,only 25% were seriously concerned about the fire hazard. Moreover, 80% of the developers polled were unaware of the relationship between slope and the rate at which fire spreads. Only 4% of those interviewed had considered the relationship between road grade, narrowness, sharpness of turns, and length of cul-de-sacs with respect to entrapment of fire-fighting equipment and blockage of access or escape routes to or from the fire.

The Colorado State Forest Service is making a film to inform the public of the fire hazard and the ways in which it can be combatted. Hulbert (1972) lists seven activities that can help reduce the threat. These include:

1. Thin dense stands of trees to lessen the chance of a crown fire and increase the growth of the residual trees.

2. Prune dead limbs and remove branches to a height of 8 to 10 feet to reduce chances of a fire reaching the tree crowns.

3. Remove trees close to homes and branches overlapping the rooftop, especially those near the chimney.

4. Clean up dead debris on the ground, especially along roadsides.

5. Don't burn trash or dead wood in outside incinerators. This is the principal source of man-caused forest fires.

6. Plan for emergencies, including familiarization with escape routes.

7. Work for adequate subdivision regulations.

12.7 AVALANCHES

12.71 General

Avalanche refers to a mass of snow set in motion when the strength of the snowpack can no longer support its own weight. They occur in mountainous areas where steep slopes receive heavy snowfall which persists long enough for certain meteorological conditions to develop an unstable snowpack. Velocities attained by large avalanches may exceed 200 mph, and impact forces can be on the order of hundreds or thousands of pounds per square foot. Buildings are easily obliterated by a direct hit.

Unlike several other rapidly developing mountain areas, Boulder County does not have a serious avalanche problem. As shown in Plate 6, some do occur in the vicinity of the high peaks along the Continental Divide. However, this region is well removed from localities where year-round residences are practical and is almost entirely on National Forest land. The great, steep slopes that sweep from altitudes of 11,000 feet down to altitudes of 8,000 feet, as at Vail, are generally lacking in Boulder County. Furthermore, the ferocious winds of the Front Range alpine area tend to blow the snow from the slopes where avalanching is most likely to occur onto the more gentle and timbered slopes below. Slopes sufficiently steep to produce avalanches are uncommon in that part of the region where most subdivisions are appearing. Likewise, the necessary quantity of snow and meteorological conditions are generally lacking.

Although avalanches do not pose a serious problem to Boulder County mountain residences, the same cannot be said for the growing number of residents engaged in offroad recreation. Once, big game hunting was the main source of such activity, but now a legion of cross-country skiers, snowmobilers, and winter campers have joined them. Unfortunately, these pursuits often lead people into highly hazardous areas. The death toll from such activities over the past few winters suggests that the number of fatalities and disruptive and costly search and rescue operations are likely to increase in the years ahead. For this reason, avalanche areas are delimited on Plate 6 and the following paragraphs are included as a "primer" on this subject.

12.72 Genesis and Classification of Avalanches

Instability is usually produced in a snowpack by phenomena associated with snow temperature. If temperatures are the same, or at least similar throughout the depth of the snowpack, a process known as equitemperature metamorphism can occur. This process, which is most rapid at 32° F, slows progressively with lower temperatures until below -40° F it virtually ceases. During equitemperature metamorphism, snow crystals change so that the ratio of surface area to volume approaches a minimum. What this means is that the individual ice particles in contact with one another tend to weld together in a process called sintering. Total surface area is reduced by the transfer of water vapor to the points of contact between particles. This transfer bonds the particles, strengthening the snowpack and increasing stability. Unfortunately, conditions other than sintering may occur which decrease snow strength and establish conditions favorable to avalanching. Low air temperatures can create a situation whereby snow at the top of the pack is colder than that near the bottom. If the temperature gradient is strong enough and the pack has a high permeability to air, a process referred to as temperature gradient metamorphism may occur. Because the equilibrium water vapor pressure in the interstitial spaces of adjacent snow layers is temperature dependent, the equilibrium point varies with the temperature gradient. Vapor then flows from regions of higher pressure (warmer snow) to areas with lower pressure (colder snow) causing a grain to grain transfer of matter. Vapor is deposited as ice on the cold surface of an adjacent grain, while opposite to this point of deposition, vapor is removed to be deposited as ice on the cold surface of the next grain. In short, the upper part of the snow pack gains material at the expense of the lower part of the pack. In addition, this process tends to produce cup-shaped crystals which possess little cohesion and undergo almost no sintering. This usually results in larger crystals with fewer ice bonds whose tensile strength, resistance to shearing, and load bearing capacity are greatly reduced. If the process is allowed to go to completion, the snow involved develops into a mass of crystals with little or no internal cohesion. This is called depth hoar and its occurrence in a snowpack on steep slopes can lead to dangerous avalanche conditions (LaChapelle, 1969).

12.73 Factors Responsible for Avalanching

Wind will redeposit snow on the lee side of ridges, thus loading these slopes with more snow than if there had been no wind. Winds greater than 15 mph will usually move snow. Wind can compact snow to form slab, which when fractured begins sliding as a unit. Wind slab also provides a surface upon which new snow can slide.

Rapid Accumulation will not allow the snow to settle. Generally sustained rates of 1 inch per hour of new snow produces hazardous conditions (U.S. Dept. of Agri., 1970).

Water. If the snowpack contains much water, its internal cohesion is reduced. This is the cause of slush avalanches in the spring.

Low Temperatures may lead to formation of depth hoar. If a temperature gradient exists, the sintering process and its stabilizing influence will be greatly slowed.

Deep Snow will cover surface irregularities which tend to anchor the pack. Once these irregularities are completely buried, new snow will have a smooth surface upon which to slide. The situation is worse if the hillside has no irregularities.

Convex Slopes are generally considered more dangerous than concave slopes in that tangential forces will be acting on the snow along the zone of curvature.

Snow Crystal Structure is important in that small needles and pellets result in more dangerous conditions than dendritic or star-shaped crystals.

Man. Many slopes reach a condition of instability, but require an external source to trigger an avalanche. In many cases, the source is a falling cornice, rockfall, another small slide, or all too often, the activities of humans (Gallagher, 1967).

12.74 Characteristics of Avalanche Hazard Areas

There are two main types of avalanche hazard areas, the well-defined avalanche track or gully and the steep barren slope which may "run" over a considerable area. A well-channeled avalanche track will usually lead from a bowl-shaped catchment basin at its head, termed the starting zone, and trend downslope to terminate at a fan-shaped deposit which is the central portion of the runout zone. When material in the catchment basin avalanches, it is funnelled into the gully where it is usually contained until reaching the valley floor below. The other type of hazard area consists of a steep hillside with little or no vegetation. In these areas, it is hard to define a catchment basin as the entire hillside may avalanche if slab conditions develop.

Avalanches can occur on essentially any slope of 25° to 60°, but are most common on slopes of 30° to 45°. Slopes less than 25° are not really steep enough to be hazardous except under rare and peculiar conditions, and those greater than 60° are so steep that snow tends not to accumulate on them.

Areas prone to avalanches can usually be recognized by associated plant communities and/or a general lack of vegetation. Tracks that avalanche every few years will be nearly devoid of trees. Those that run every several decades are characterized by bands of mature aspen trees trending through coniferous forest. In places, trimlines separating small trees from larger ones are evident on hillsides as are "stringer slides," slides whose locations are revealed by narrow lanes devoid of trees. Two important points to keep in mind are that any steep slope can "run" under proper conditions and even a small slide which travels only a hundred feet or so can kill (Fraser, 1967).

12.75 Avalanche Types

Two basic types of avalanches are recognized on the basis of differences in their starting zones. One type, loose snow avalanches, start at a point or in a small area and grow in size as they descend the slope. The snow particles in them have little internal cohesion. They tend to occur where fluffy snow accumulates on steep slopes during times of little or no wind. Metamorphism subsequently reduces internal cohesion and the snow gives way to seek stability at a lower angle of repose.

The slab avalanche comprises the second basic type. Wind is one of the dominant factors in its development. Unlike the loose snow avalanches, they possess much internal cohesion and tend, therefore, to begin sliding as a coherent slab. They characteristically leave a well-developed fracture line. Sliding takes place on an incompetent layer such as depth hoar or a buried sun crust.

Slab avalanches are classified as soft and hard, according to the condition of the snow coming to rest in the runout zone. Soft slab avalanches have the typical fracture line, but break up into incoherent, loose snow during movement. Hard slab avalanches, on the other hand, leave angular blocky debris in their run-out zones. Slab avalanches are responsible for the majority of property damage and deaths recorded in Colorado.

12.76 Avalanches and People

Death and destruction by avalanching is a problem in several sectors of the United States. During the heyday of mining activity in Colorado's mountains in the late 1800's and early 1900's many miners were lost to avalanches. Today when conditions for avalanching become dangerous along mountain highways, critical areas are shot with a cannon to release unstable snow at times when the flow of traffic is being restrained. Offroad winter activity obviously is not protected in a similar manner. A matter of growing concern is that as the number of people engaged in winter recreation approaches the number once involved in mining, the death toll due to avalanches may also become comparable.

Fortunately, avalanche hazards in Boulder County are minimal compared to many other areas in the state. They do occur, but are mainly confined to the cirques and valley heads along the Continental Divide, essentially uninhabited areas. Even here a well-developed avalanche chute or gully is seldom seen and only a few avalanche boulder tongues testify to the occurrence of avalanching. Nonetheless, those who ski, snowshoe, or snowmobile should be able to recognize avalanche areas and avoid them whenever there is the slightest doubt as to the stability of the snow. Furthermore, if an avalanche occurs, the survivor(s) should know what to do to maximize the victim's chance of being rescued.

12.8 ROCKFALL

Areas of rockfall are generally mapped on the basis of the resultant deposits of talus. Rockfall is a hazard only in limited areas, mainly at very high altitudes along valleys whose sides were oversteepened by glaciation and in the "narrows" of deep canyons carved by the major streams draining to the plains. These areas are too small and irregular to be shown on Plate 6. Most rockfall occurs on spring days warm enough to thaw the surfaces of very steep slopes having a southerly exposure or during and immediately after intense rains that occur mainly during late spring and summer.

Incidents of damage and injury due to rockfall have been relatively few thus far. One death by falling in the vicinity of Isabelle Glacier during the summer of 1972 may have been precipitated by sliding rock debris. Another accident, a bit more representative of this hazard, involved four people who were killed when a large boulder weighing several tons bounced onto their automobile in Clear Creek Canyon west of Denver on July 4, 1967. This event occurred after a rain storm which was but one that occurred with monotonous regularity during the early summer of that year.

Rockfall is a hazard mainly to highway traffic. However, housing is beginning to appear in a few rockfall prone places, along portions of Boulder Canyon, South St. Vrain Canyon, the Peak-to-Peak Highway, and Lee Hill Road where it parallels the Fountain Formation.

Cloudbursts and storms capable of producing the 20-, 50-, or 100-year floods are also capable of triggering large rockfall as well as dangerous earth and debris flows. During prolonged stormy periods, the hazard is serious enough to warrant regulating traffic in the same way it is controlled when avalanche danger is high or snow storms engulf mountain passes.

12.9 ROCK GLACIERS

Rock glaciers are masses of fragmental rock debris along valley walls and in valley heads above timerline. They are moving very slowly, average velocities being on the order of 5 to 10 cm per year in the Colorado Front Range (White, 1971) and 20 cm per year in the San Juan Mountains (Andrews and Carrara, 1973). They move because they either overlie a core of clear ice or contain a network of ice-filled voids (Outcalt and Benedict, 1965; Madole, 1972) which allows them to behave much like a true glacier. Construction on them of any kind, be it for a road, telephone poles, ski lift towers, powerlines, or buildings, will lead to failure. Exposure of the interstitial ice leads to melting, collapse, exposure of more ice, more melting, and then more collapse. Rock glaciers occur only at altitudes above 11,000 feet which is too high for housing. Nonetheless, construction on them of the other features listed has been attempted in various parts of western North America (Goolsby, 1972, Oral Presentation, Rocky Mountain Section, Geol. Soc. Amer.). Rock glaciers in Boulder County range from a few hundred to a few thousand feet in maximum dimension, which is too small to delimit on Plate 6. The location of most, however, is shown in Madole (1972).

SECTION 13

LAND USE AND TENURE

J. Nichol

13.1 INTRODUCTION

The highly diverse terrain of Boulder County is reflected in its wide range of land use types (see Plate 7). Most agricultural and residential areas are in the flatter eastern portion of the county while in the mountains which comprise approximately 60% of the county, agricultural pursuits are limited to low density grazing, and residential areas are few, widely scattered, and small except close to Boulder. All agricultural land of eastern Boulder County is privately owned. Also, 33.6% of the county is federally owned (see Table 10). Almost all of this is U.S. Forest Service land located in the mountains as shown in Plate 7.

The areas shown in Plate 7 were defined from air photographs, field surveys, and thematic maps. They are based on both physical and cultural features, inasmuch as cultural aspects are in large measure a response to physical factors such as soil, vegetation, geology, and slope. The areal extent of each land use type is shown in Table 11. The results of a random stratified sample of 17 sections (see Fig. 35) in the non-mountainous part of the county are summarized in Table 12.

13.2 LAND USE TYPES IN THE MOUNTAINS

13.21 Alpine Tundra

The tundra has a low use capacity and is used for low density recreational activities, for educational purposes in that it is a unique outdoor laboratory for certain environmental sciences, and by tourists and others who come to partake of its magnificent scenery. The extent to which the tundra and adjoining subalpine zone serve as a source of water to the plains is such that one of their most important uses is as watersheds.

TABLE 10

Land ownership in mountainous Boulder County

Owner	Approx. Sq. Miles
United States Forest Service	215
Private Land Unsubdivided (approx.)	170
Rocky Mountain National Park	40
Urbanized Area	20
Private Land, Subdivided	10.7
Colorado State Forest Service	3
Bureau of Land Management	2
	460*

*Boulder County encompasses approximately 760 square miles.

13.22 Subalpine Zone

This densely forested region is also typified by low intensity use for both concentrated and dispersed recreational activities which are, up to certain levels of use, compatible with both the region's aesthetic value and its water catchment function. Climatic restraints make this region unsuitable for residential uses.

13.23 Upper Montane Zone

This is the most intensively used zone in the mountain sector for residential purposes. It contains several concentrated settlements as at Nederland, Ward, and Allens Park, and scattered residential sites on some of the flatter ridge tops and gently sloping valley sides. Parts of both the Upper and Lower Montane zones are used for summer pasture for cattle.

13.24 Lower Montane Zone

The scarcity of flat land makes this zone less suitable for residential purposes and concentrated recreational activities. The main uses are grazing and low density recreational activities such as climbing and picnicking.

13.25 Foothills Zone

This zone is used mainly for low density grazing and scattered residential use, particularly along the north-south strike valleys just inside the mountain front. Stone is also quarried in this zone, especially near the town of Lyons.

13.3 LAND USE TYPES ON THE PLAINS

13.31 Piedmont Zone

This land is used mainly for medium density grazing purposes. Residential uses are extending onto this land type to the north and south of Boulder.

Section 6a. Of the two sample sections studied in this zone (Fig. 35), both have low land values at $30 and $50 an acre respectively. Also, land tenure is extremely stable in both. Section 6a(i) had been owned by the same family since 1860 and was being used for grazing, while Section 6a(ii) was bought from ranchers in 1956 by Beech Aircraft Corporation who are using the land as a test site for cryogenic research.

Table 11

Area of Each Land Use Type		(Square Miles)
Land Use Type		**Area**
Mountains		
1	Tundra	60
2	Subalpine	109
3	Upper Montane	122
4	Lower Montane	126
5	Foothills	29
Mountains Total		446
Plains		
6a	Dry Piedmont	30
6b	Dry Piedmont	13
6c	Dry Piedmont	9
	Total	52
7a	Dry Farmland	9
7b	Dry Farmland	6
7c	Dry Farmland	8
	Total	23
8a	Irrigated Pasture	18
8b	Irrigated Pasture	14
	Total	32
9a	Irrigated Cropland	15
9b	Irrigated Cropland	46
9c	Irrigated Cropland	13
9d	Irrigated Cropland	11
9e	Irrigated Cropland	24
	Total	122
10	Flood Plains	35

Table 11 (continued)

11 Urban and Industrial	44
Plains Total	280
Water Surfaces Mountains and Plains	9
Overall Total	734
Error	-24

Section 6b. Land use in Section 6b is similar to that in 6a, though grazing is at a lower density.

Section 6c. Section 6c is irrigated and used mainly for grazing, with a minimal amount of fodder crop cultivation. The land is more productive than 6a, a condition reflected by its higher grazing density and the small amount of hay grown here. The value of land in this section was $180 an acre. The northern half of the section is owned by Martin Marietta and used as an industrial site, while the southern half is used for grazing, growing a small amount of hay for winter fodder, and for storage of irrigation water in Foothills Reservoir. The owners, who live in Arizona, have rented the land to the same tenants since 1946. Apparently, there has been little pressure to sell the land for development.

13.32 Dry Farmland

Dry farming is done on uplands which are generally sloping and are too high above the level of the surrounding terrain to irrigate by gravity flow. Fields with roughly a 16 to 1 length to width ratio are alternately planted to wheat then left fallow for a year in order to restore suitable soil moisture. The fields are oriental north-south at right angles to the prevailing wind. Stubble is left on the fallow fields in order to reduce soil erosion and to trap drifting snow. Dry farmland has a relatively low productivity because of restriction to one crop every two years. Farm sizes tend to be large, approximately 360 acres, and land values lower than in areas amenable to irrigation.

Section 7a. The two sample sections in this area, 7a(i) and 7a(ii), (see Fig. 35) are in agricultural use, but 7a(i) shows signs of change. This section increased from $90 to $100 an acre between 1970 and 1972. Land transactions included the sale of two 5-acre lots in the northwest quarter of the section and 40 acres in the southwest quarter. Part of the northwest quarter is owned by a trust while 120 acres of the southwest quarter is owned by a development corporation. Sample section 7a(ii) is owned by the Union Pacific Railroad.

A characteristic of dry farmland is the scarcity of farmhouses and other types of settlement. However, residential encroachment is in progress on the southwest side of Gunbarrel Hill in Section 7a(i). This may be the beginning of a trend that is likely to continue.

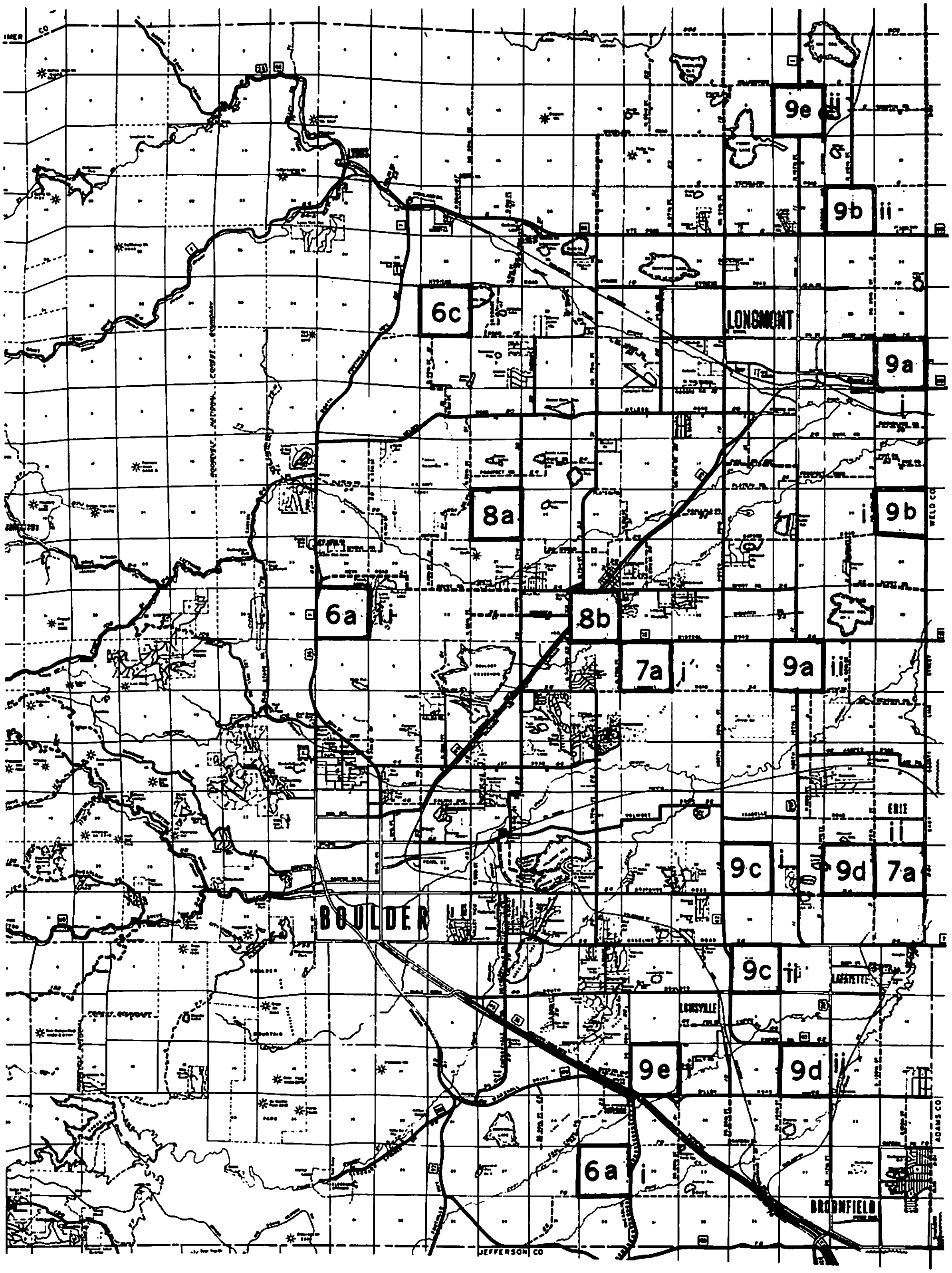

Figure 35. Land use types in a random stratified sample of 17 sections in eastern Boulder County.

Section 7b. In Section 7b, fields are wider, roughly a 6 to 1 length-width ratio. This section is also slightly more productive than in the 7a sections.

Section 7c. Section 7c is the poorest agriculturally of the dry farmland types. Otherwise, its field and farm size is similar to the 7a sections.

13.33 Irrigated Pasture Land

Section 8a. Land use in Section 8a is over 80% irrigated pasture. Field and farm sizes tend to be large, often comprising the majority of a section. The section sampled contained half of a 360 acre farm and 485 acres used for grazing.

Signs of change are evident as a parcel of 38 acres in the southwest quarter sold for $1,465 per acre in 1972 and a development corporation has acquired property in the northeast part of the section. It should be noted that the land which sold for $1,465 per acre had an agricultural value of $100 per acre. The farm which is partly in this section was inherited. Average yields on this acreage for alfalfa, hay, corn for sileage, and grass are above those for Boulder County as a whole. However, emphasis in this section is on dairy and beef cattle. Existing agricultural problems derive from difficulties in irrigating and tilling.

Section 8b. This land is moist, low lying, productive pastureland. The one farm in Section 8b had some acreage planted in wheat and alfalfa which is rotated with pasture. However, emphasis here as in Section 8a is on raising cattle. How long the current pattern of use will persist is questionable inasmuch as the whole of the northeast and southwest quarters are owned by a real estate company and building firm. Several 5-acre tracts have been sold to different owners. Areas within this land type have already been converted to residential use, notably in an area midway between Lyons and Longmont, at the IBM facility, and in scattered localities just to the north of IBM.

13.34 Irrigated Cropland

Section 9a. Section 9a has irrigated cropland with gentle slopes ranging from 0 to 5% grade. Cash and fodder crops are combined with feedlot livestock in roughly a three-year rotation. Corn is the principal crop, used for both grain and sileage. Smaller amounts of land are planted in alfalfa, grass, beans, and barley. Most farms and fields are large.

In both 9a(i) and 9a(ii), trends toward high intensity use were very evident. In Section 9a(i), all available farmland, namely two farms of 360 and 80 acres respectively, had been purchased in 1972 for development. Although the selling price could not be determined, the entire adjoining section sold in the same year for $2,800 per acre. Agricultural land values in Section 9a(i) were $350 per acre. Previously, the two farms had been tenant operated. The remaining 200 acres in the western part of the sample section are occupied by a golf course.

Land values in Section 9a(ii) slightly exceeded the $350 per acre base of Section 9a(ii), and land sales in the entire northwest quarter and half of the northeast were sold in 1972 to an investment corporation. In 1973, 80 acres of the southeast quarter were sold for development, the farmer-owner remaining as a tenant until the end of the year.

Section 9b. Sections 9b(i) and 9b(ii) are high quality agricultural land similar to those of the 9a sections, but are slightly flatter and topographically lower. Both have a high agricultural productivity, with five year crop rotation of beets, corn, alfalfa, barley, and beans. Livestock is not as important as in the 9a sections and farm and field size is generally smaller, ranging from 60 to 160 acres and 20 to 25 acres respectively. Farms are prosperous, well kept, and have a productivity higher than crop averages for the county as a whole.

Current land transactions are not as numerous as in the 9a sections. In Section 9b(i) 80 acres were sold in the northeast quarter in 1972 for $2,250 per acre to a local landowner. Other owners and operators interviewed had received numerous offers from developers, but were holding out for higher prices. In Section 9b(ii), 158 acres changed hands in 1971, but no other transactions occurred between 1970 and the present.

Section 9c. The main difference between Sections 9b and 9c is that the latter often experiences a shortage of water toward the end of the growing season in a dry year. This is characteristic of all cropland south of Boulder Creek. Consequently, there is more emphasis on feedlot livestock. The main crops which are grown mainly for fodder include grass, alfalfa, hay, beans, and corn for silage. Some land is in pasture and farm and field sizes are similar to those in the 9b sections. Both 9c(i) and 9c(ii) showed signs of impending higher intensity use, though both were still wholly agricultural. Most farms experience water shortages in dry years and there were surprisingly few crop rotations in this land type.

Table 12

Summary of the sample survey

Land Type	Value, $/Acre	Owners Interviewed	% Land in Farms	Farms per Section	Predominant Tenure	Land* Sales
6a(i)	30	1	-	-	Tenant	0
6a(ii)	50	1	-	0	-	0
6c	180	1	50	1	Tenant	0
7a(i)	100	0	100	2	-	2
7a(ii)	E	0	100	-	-	0
8a	100	1	40	1	-	2
8b	250	1	-	-	-	1
9a(i)	350	2	70	2	Tenant	2
9a(ii)	375	2	-	3	Tenant	2
9b(i)	350	2	100	7	Tenant	1
9b(ii)	325	2	100	6	Tenant	2
9c(i)	300	4	100	6	Owner	5
9c(ii)	250	1	-	4	Tenant	2
9d(i)	110	4	100	4	Tenant	2
9d(ii)	220	2	-	5	Tenant	1
9e(i)	150	5	95	4	Tenant	8
9e(ii)	200	1	-	-	Tenant	3

*No. of land transactions, not including 5-acre subdivisions.
E Tax exempt.

Of the six farms in Section 9c(i), five are owner operated. However, land ownership is changing rapidly as 110 acres in the northern half were sold to a land developer in 1971, 30 acres to a buyer in New Mexico in 1972, and more recently 20 acres in the southwest quarter were sold to a real estate company and two 5-acre tracts went to individuals. Moreover, a farmer sold 40 acres in the southwest quarter to a land developer while dividing another 20 acres into 5-acre tracts. The southeast quarter contained one 40-acre farm which was sold to a real estate company in 1972. Subdivision into 5-acre lots followed some of which were sold and re-sold. As in Section 9b, farmers have experienced continued pressure to sell, but most are waiting for more favorable offers. Sample Section 9c(ii) contains four farms and some publicly owned land. Property transactions included one farm and some 5-acre subdivisions sold in 1972 to a real estate company.

Section 9d. This cropland is on slightly elevated ground with slopes of 3 to 9% and is, therefore, difficult to irrigate. In addition, a shortage of water occurs in some years. Productivity is therefore limited, and the resulting emphasis, consequently, is on livestock and a greater amount of land is devoted to pasture and fodder crops relative to Section 9c. Farm and field sizes tend to be large and land values lower than in the cropland areas of Section 9a, 9b, and 9c.

Both 9d(i) and 9d(ii) consist mainly of large farms of 160 to 350 acres, although four 80-acre farms and some subdivisions also occur there. Emphasis in both sections is on livestock, with supplemental amounts of land devoted to wheat, barley, corn, alfalfa, and oats grown generally in 5-year rotations with pasture for cattle and horses.

Section 9d(i) contains four farms, three of which were tenant operated. The one owner-operated farm consisted of 330 acres in this and the adjoining section to the east. This farmer wishes to continue using the land for agriculture.

An 80-acre tract in the northeast quarter was sold in 1971 for conversion to a subdivision. On the whole, pressure for development was less in this section than in the other cropland sections and land tenure correspondingly more stable. However, the town of Erie has zoned the entire section to the west for a trailer park, provided a supply of water can be obtained, a requirement that may not be easily realized. All of Section 9d(ii) is in crops or is being used for grazing. Relative to the other sections in this category, a minor amount of land dealings have occurred. These include 15 acres annexed by Louisville for a sewage treatment plant and 160 acres sold in 1973 to a development corporation.

Section 9e. Farms and fields in Section 9e tend to be larger than in Section 9d and there is greater emphasis on livestock and a larger amount of pastureland. Some pasture is permanent and some is rotated with grass and alfalfa. The two sections sampled were characterized by low productivity, low land values, and a predominance of tenant farmers. Of the five farms interviewed, only one produced cash crops consisting of wheat, barley, and corn in a three-year rotation.

Eight land transactions of recent vintage had occurred in Section 9e(i). These transactions suggest a trend to smaller farm sizes in this area. A tract of 40 acres sold for housing in 1970 is still in pasture, hay, and oats. Two parcels of 40 acres each and three of 20 acres changed hands between 1970 and 1972. One farmer in this section expressed a desire to sell his 60 acre farm because of difficulties encountered in operating in the vicinity of urban developments. A transaction in 1972 netted the owner $1,250 per acre for an 18-acre tract.

Section 9e(ii) is predominantly tenant operated. The landowners involved generally live long distances from their properties. The only relatively recent land transaction in this section involved a 160-acre farm sold in 1972 to a buyer residing in Texas. The farm has continued in agricultural use for grazing, alfalfa, and hay under a tenant operator.

13.35 Floodplains

This land is not generally suitable for cropland because of poor drainage, stoniness, and related problems. Agricultural use is confined almost exclusively to pasture. Gravel mining is extensive in places and much of the floodplain in and around the city of Boulder is in residential uses.

13.36 Urban and Industrial Areas.

These include major cities and towns, and scattered communities such as the Gunbarrel Hill housing development. Many have been developed only recently and tend to be of a lower density than the older central portions of the urban areas. The two major urban centers, Boulder and Longmont, are expanding rapidly. Boulder is expanding to the north and south along the Piedmont and eastward along the flood plain. Although Longmont's expansion is outward in all directions, that to the north and south appears to be progressing more rapidly.

13.4 WATER SURFACES

This category includes the major lakes and reservoirs of the mountains and plains.

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GLOSSARY

alluvial fan. The land counterpart of a delta. An assemblage of sediments marking the place where a stream moves from a steep gradient to a flatter gradient and suddenly loses its transporting power. Typical of arid and semiarid climates, but not confined to them.

alluvium. A general term for unconsolidated sediments deposited from streams, including sediments laid down in river beds, flood plains, lakes, fans at the foot of mountain slopes, and estuaries.

alpine life zone. See "tundra".

aquiclude. A body of relatively impermeable rock that is capable of absorbing water slowly but functions as an upper or lower boundary of an aquifer and does not transmit ground water rapidly enough to supply a well or spring.

aquifer. A body of rock that contains sufficient saturated permeable material to conduct ground water and to yield economically significant quantities of ground water.

arenaceous. Said of a sedimentary rock consisting wholly or in part of sand size fragments, or having a sandy texture or appearance of sand; pertaining to sand of arenite.

arkose. A feldspar rich typically coarse-grained sandstone commonly pink or reddish to pale gray or buff, composed of angular to subangular grains that may be either poorly or moderately well sorted, usually derived from the rapid disintegration of granite or granitic rocks.

atmosphere. The mixture of gases that surround the earth: chiefly oxygen and nitrogen, with some argon and carbon dioxide and minute quantities of helium, krypton, neon and xenon.

Audubon stade. A portion of Neoglacial time characterized by climatic cooling and renewed glacial and periglacial activity in the Colorado Front Range between 100 A.D. to 1000 A.D. (initially described and named Arikaree by Benedict, 1968; renamed Audubon by Mahaney, 1972).

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*Denotes definitions taken from Glossary of Geology, American Geological Institute (1972). Most other terms are from Longwell, C. R., Flint, R. F., and Sanders, J. E., 1969, Physical Geology, 1st Edition, John Wiley and Sons, Inc. unless otherwise indicated.

avalanche. A large mass of snow, ice, soil, or rock, or mixtures of these materials, sliding or falling very rapidly under the force of gravity.

B-horizon. A mineral zone in the soil, below A-horizon, sometimes called "zone of accumulation".

base course. A layer of selected or processed aggregate material placed immediately below the pavement or wearing surface and above the subbase or subgrade.

base flow. Sustained or fair weather flow of a stream, whether or not affected by the works of man.*

base metal. (a) Any of the more common and more chemically active metals, e.g., lead, copper; (b) the principal metal of an alloy, e.g., the copper in brass.

bearing capacity. An estimate of soil strength when loaded with weight based on particle-size distribution, liquid limit, and plasticity.

bedrock. The more or less solid undisturbed rock in place either at the surface or beneath superficial deposits of gravel, sand, or soil.

bentonite. A soft, plastic, porous, light-colored rock consisting largely of colloidal silica and composed essentially of clay minerals. It commonly has great ability to absorb large quantities of water accompanied by an enormous increase in volume.

boulder. A rock volume greater than that of a sphere with a diameter of 256 mm.

Bull Lake Glaciation. Name given to two stades of glaciation that occurred between 130,000 and 40,000 years ago. The name derives from the Wind River Mountains, Wyoming (Blackwelder, 1915).

calcareous. Containing calcium carbonate: ($CaCO_3$).

caliche. A whitish accumulation of calcium carbonate developed in a soil profile. Also known as a calerete.

Cenozoic. Geologic time period extending from the present to about 65 million years before present.

cerite. A mineral $(Ca,Ce)_3S_{12}(O_1OH_1F)_9$

cirque. A steep-walled niche, shaped like a half bowl, in a mountain side, excavated mainly by ice plucking and frost action.

clastic rock. A general term for a sedimentary rock having clastic texture.

clastic texture. A texture of sediments and sedimentary rocks result- from physical transport and deposition of broken particles of older rocks, of older sediments, and of organic skeletal remains.

clay. Dimension of sedimentary particles having diameters less than 1/256mm.

claystone. A clastic rock consisting predominantly of clay-size particles.

clay loam. Soil material that is 27% to 40% clay and 20% to 45% sand.

climax vegetation. An exclusive plant community which terminates a succession and is in equilibrium with the prevailing environment; the highest form of vegetation the prevailing environment can support.

cobble size. Sediment particles having diameters greater than 64mm (about the size of a tennis bell) and less than 256mm (about the size of a volleyball).

cohesion. An electrostatic force of attraction among fine particles.

colluvium. A body of sediment that has been deposited by any process of mass-wasting or by overland flow.

color IR (infrared) imagery. A type of "photography" which utilizes a color film that is also sensitive to reflected light in the near-infrared wave lengths; accuracy of interpretation of image enhanced by ional features where vegetation appears in red shades.

columbite. A black mineral, $(Fe,Mn)(Nb,Ta)_2O_6$ occurring in granites and pegmatites.

confined aquifer. An aquifer in which flow of ground water in all directions, particularly upward, is prevented by impermeable material.

conglomerate. A clastic sedimentary rock containing numerous rounded pebbles or larger particles.

convection. A mechanism by which material moves because its density is different from that of surroundings material. The density differences are frequently brought about by heating.

copper. A ductile, malleable, reddish or salmon pink mineral occurring abundantly in large masses. The native element Cu.

creep. The imperceptibly slow downslope movement of regolith.

Cretaceous. Geologic time period extending from approximately 65 to 135 million years before present.

cross-bedding. An internal arrangement of minor layers in a stratified rock inclined more or less regularly in straight sloping or concave lines at various angles to the original bedding plane.

crystalline texture. A texture resulting from simultaneous growth of associated particles.

crystallization. The process of development of crystals by condensation of materials in a gaseous state,by precipitation of materials in a solution, or by solidification of materials in a melt.

cul-de-sac. A dead-ended local road with special provisions for turning around.

debris flows. The rapid downslope plastic flows of a mass of debris.

demography. The study concerned with the analysis of populations including births, deaths, age, etc.

denudation. The sum of the processes that result in the wearing away of the earth's surface.

depth hoar. New centers of crystallization caused by vertical diffusion of water vapor (constructive metamorphism). These crystals are of a different character than the original snow, and often are cup shaped and layered. Cohesion is very poor between crystals. A steep temperature gradient within the snow cover will induce such formations. Also known as cup crystals and sugar snow.

dike. A tabular igneous intrustion that cuts across the planar structures of the surrounding rock.

dip. The angle in degrees between a horizontal plane and an inclined plane, measured down from horizontal in a plane perpendicular to the strike. Dip is measured with a clinometer.

dipslope. A ground surface plain coincident in slope with the dip of the underlying resistant rock.

discharge. The quantity of water passing a given point in a given unit of time.

diurnal. Active in the day-time in contrast to nocturnal; occurring every day.

drainage basin. The total area that contributes water to a stream.

drift. Any material laid down directly by ice, or deposited in lakes, oceans, or streams, as a result of glacial activity. Unstratified glacial drift is called "till" and forms "moraines". Stratified glacial drift forms "outwash" plains, eskers, kames, and varves.

earth's crust. The outermost zone of the earth. Composed of solid rock 20 to 30 miles thick under continents.

ecology. The study of the relations between organisms and environment. Paleoecology is the same study applied to past conditions.

ecosystem. The major ecological unit having both structure and function where structure refers to the different species and environmental factors present and function relates to the flow of energy and the cycling of materials through the structural members.

effluent. Liquid discharged from a sewage treatment facility or storm sewer.

engineering geologic map. Map showing the relationships of geologic units to the location, planning, design, construction, operation and maintenance of engineering structures and ground water resources.

eolian. Pertaining to the wind and wind transported deposits.

equitemperature metamorphism. A process whereby rocks undergo physical or chemical change, within an environment in which the ambient temperature is equal to the temperature of the rocks, to achieve equilibrium with conditions other than those under which they were originally formed.

erosion. A general term that describes the physical breaking down, chemical solution, and movement of broken-down and dissolved rock materials from place to place on the earth's surface.

escarpment. A cliff or steep slope breaking the continuity of the land and separating two levels or gently sloping surfaces.

extrusive rock. A rock that has solidified from material poured or thrown out upon the earth's surface by volcanic activity.

fault. A fracture along which the opposite sides have been relatively displaced.

feldspar. A group of abundant rock-forming minerals of general formula: $MAS(Al_1Si)_3O_8$ where M=K,Na,Ca,Ba,Rb,Sr,Fe. Feldspars are the most widespread of any mineral group and constitute 60% of the earth's crust.*

fissile. Capable of being split along closely spaced planes.*

floodplain. That part of any stream valley which is inundated during floods.

flourspar. A transparent to translucent mineral: CaF_2. Usually occurs in veins in associations with lead, tin, and zinc ores.*

fluvial. Of or pertaining to a river or rivers.*

fly ash. Very fine-grained residue from combustion of coal. This and sulfur compounds are obstacles to the widespread use of coal as an energy source.

fold. A pronounced bend in layers of rock.

foliation. A parallel or nearly parallel structure in metamorphic rocks along which the rock tends to split into flakes or thin slabs.

formation. The basic or fundamental rock-stratigraphic unit in the local classification of rocks, consisting of a body of rock generally characterized by some degree of internal lithologic homogeneity or distinctive lithologic features (texture, fossils).*

fracture. (As applied to minerals). The capacity of a mineral to break along irregular surfaces.

Gannett Peak stade. Refers to the readvance of small glaciers and/or reactivation of periglacial features (rock glaciers, protalus ramparts) within the last 300 years.

geologic map. A map that shows the distribution, at the surface, of rocks of various kinds or of various ages.

geology. The science of the earth.

geomorphology. The study of physical and chemical processes that affect the origin and evolution of surface forms.

glacier. A body of ice, consisting mainly of recrystallized snow, flowing on a land surface.

gradient. Applied to a stream, it is the slope measured along the stream, on the water surface or on the bottom.

granite. A coarse-grained igneous rock consisting in major part of potassium feldspar, some sodic plagioclase (albite), and quartz, with minor amounts of ferromagnesian minerals.

granodiorite. A coarse-grained felsic igneous rock, with composition intermediate between granite and diorite, containing quartz and in which plagioclase is the chief feldspar.

gneiss. A coarse-grained foliate breaking along irregular surfaces and commonly containing prominently alternating layers of light-colored and dark-colored minerals.

gravel. Loose, or unconsolidated, coarse granular material larger than sand grains, resulting from erosion of rock by natural agencies. The lower size limit is usually set at 2 millimeters.

groundmass. The particles surrounding the phenocrysts of a porphyritic rock.

groundwater. The water, beneath the earth's solid surface, contained in pore spaces within regolith and bedrock.

group. A unit of stratigraphic classification. A local or provincial subdivision of a system based on lithologic features. A group is usually less than a standard series and contains two or more formations.

hogback. A sharp-crested ridge formed by differential erosion of a resistant bed of steeply dipping rock.

horizon, soil. A layer of soil or soil material approximately parallel to the land surface, and differeing from adjacent genetically related layers in physical, chemical, and biological properties or characteristics.

hydrocompaction. A densification and reduction of volume of a dryland soil causing differential settling when loaded. It is commonly caused by lawn watering or otherwise adding more moisture to a soil than the past climate provided.

hydrology. The science that deals with continental water, its properties, circulation and distribution, on and under the earth's surface and in the atmosphere.*

igneous rock. Rock formed by solidification of molten silicate materials.

impermeable. Rock or sediments having a texture that does not permit perceptible movement of water under the head differences ordinarily found in subsurface water.

impervious. The condition of a rock, sediment, or soil that renders it incapable of transmitting fluids under pressure.*

infiltration. The soaking into the ground of water on the surface.

intercalated. Layered material that exists or is introduced between layers of a different character.

interception. The process by which water from precipitation is caught and stored on plant surfaces and eventually returned to the atmosphere without having reached the ground.*

interfluve. The area between rivers or interstream area.*

intermediate regional flood. A flood having a one percent probability of occurrence in any given year -- the 100-year flood.

intrusive rock. A rock that has solidified from a mass of molten material within the earth's crust, but did not reach the surface.

inversion (meteorological). A reversal of the gradient of a meteorologic element (an increase rather than a decrease of temperature with increased altitude.*

Jurassic. The second period of the Mesozoic era, thought to have covered the span of time between 190 and 136 million years ago.*

kettle hole. A closed depression in drift, created by the melting out of a mass of underlying ice.

knob and kettle topography. An undulating morainal landscape in which a disordered assemblage of knolls, mounds, or ridges of glacial drift is interspersed with irregular depressions, pits, or kettles that are commonly undrained and may contain swamps or ponds.*

knot. A unit of speed of one nautical mile per hour (6,076.10 feet/hr.)

lag time. In development of a unit hydrograph, it is the time from the center of the storm to the maximum discharge produced by the storm.

landslide. A general term for relatively rapid mass movement, such as slump, rock slide, debris slide, mudflow and earthflow.

land tenure. Length of ownership of a given parcel of land; long time ownership.

lateral moraine. A ridge of till along the edge of a valley glacier. Composed largely of material that fell to the glacier from valley walls.

lava. Molten silicate materials reaching the earth's surface.

leach field. Subsurface disposal field receiving the liquid effluent from a septic system and disposing of it primarily by infiltration into the surrounding soils.

lead. A soft, heavy, malleable, and ductile mineral, the native metallic element Pb.

lichen. A plant consisting of two unrelated components (fungi and algae) living in close symbiotic association.

lichenometry. Measurement of the diameter of lichens growing on exposed rock surfaces as a method of dating geomorphic features.

limestone. A sedimentary rock consisting predominantly of calcium carbonate.

lithology. The study of stones or rocks, especially those of sedimentary origin. Also, the description of the total physical characteristics of specified samples or formations.

loam. A rich, permeable soil composed of a friable mixture of relatively equal and moderate proportions of clay, silt and sand particles, and usually containing organic matter.*

lobate rock glacier. A mass of rock rubble cemented by interstitial ice and capable of slow downhill flow. Usually occur in high mountainous areas.

lode. A mineral deposit consisting of a zone of veins.*

loess. Wind-deposited silt, usually accompanied by some clay and some fine sand.

loose snow avalanche. An avalanche involving layers of snow with little or no internal cohesion that start from a point or very small area, move as a formless mass, and do not leave a distinct line separating the snow that stayed in place from that which slide away (from Frutiger and Martinelli, 1966).

marl. A mixture of calcium carbonate and clay; a common lake deposit.

mass movement. Surface movement of earth materials induced by gravity.

member. A subdivision of a geologic formation that is identified by lithologic characteristics such as color, hardness, composition, and similar features and that has considerable geographic extent. Members may receive formal names.

mesa. A flat-topped landmass bounded by steep slopes.

Mesozoic. An era of geologic time, from the end of the Paleozoic to the beginning of the Cenozoic (225 to 65 million years ago).

metamorphic Rock. A rock formed within the earth's crust by the transformation of a pre-existing rock in the solid state without fusion and with or without addition of new material, as a result of high temperature, high pressure, or both.

micaceous. Consisting of, containing, or pertaining to mica.

micas. A group of silicate minerals characterized by perfect sheet or scale cleavage resulting from their atomic pattern, in which silicon-oxygen tetrahedra are linked in sheets. Biotite is the ferromagnesion black mica. Muscovite is the potassic white mica.

mineral belt. A term applied to a zone of mineralization related mainly to porphyritic intrusives of Tertiary age that trends across the Front Range from Breckenridge on the southwest to Boulder on the northeast.

montane life zone. An altitudinal zone of mid-mountain elevations approximately between 6,000 and 9,000 feet in Boulder County which is characterized by the dominant tree species, douglasfir and ponderosa pine.

monzonite. A group of plutonic rocks intermediate in composition between syenite and diorite, containing approximately equal amounts of orthoclase and plagoclase, little or no quartz and commonly augite as the main mafic mineral.*

moraine, terminal. A ridgelike accumulation of drift, deposited by a glacier along its front margin.

natural levee. A broad, low ridge of fine alluvium built along the side of a stream channel by water spreading out of the channel during floods.

Neoglaciation. Refers to glacial events which post-date the climatic optimum (approximately 4,000 BP to present).

nonclastic. A sedimentary rock texture showing no evidence that the sediment or rock was derived from a pre-existing rock or was deposited mechanically.*

non-metallic mineral. A mineral that does not have metallic properties.

orthoclase. The feldspar in which K+ is the diagnostic positive ion; $K(AlSi_3O_8)$.

outcrop area. The area, on a geologic map, shown as occupied by a particular rock unit.

outwash. Stratified drift deposited by streams of meltwater as they flow away from a glacier.

overburden. Rock material, usually unconsolidated, overlying a mineral deposit and which must be removed prior to mining.*

overland flow. That part of surface runoff flowing over land surfaces toward stream channels.*

oxidized. Having combined with oxygen.

Paleozoic. An era of time from the end of the Precambrian to the beginning of the Mesozoic (570 to 225 million years ago).

parent material. Mineral or organic material that is relatively little affected by soil-forming processes, and which somewhat resembles the material from which the soil is presumed to have been formed.

peak discharge. The maximum discharge or stage value of a flood.*

pediment. A sloping surface, cut across bedrock, adjacent to the base of a highland in an arid climate.

pedology. The science of soils, their origin, use and protection.

pegmatite. Exceptionally coarse-grained granite with individual particles and crystals ranging in length from 1 cm to many meters.

Pennsylvania age. A period of the Paleozoic era, thought to have covered the span of time between 320 and 280 million years ago.*

periglacial. Region beyond the margin of a glacier.

permeability. A measure of the capacity of a material to transmit fluids.

Permian. The last period of the Paleozoic, thought to have covered the span of time between 280 and 225 million years ago.*

phenocryst. A relatively large, conspicuous crystal in a porphyritic rock.

piedmont. Lying or formed at the base of a mountain or mountain range.*

Pinedale Glaciation. Last major glaciation tc affect the Rocky Mountain region. Although the time of beginning and end are not precisely known, this glaciation was in progress between 25,000 and 7,000 years ago. The name derives from the Wind River Mountains, Wyoming (Blackwelder, 1915).

Pleistocene. An epoch of the Quaternary Period, after the Pliocene Epoch of the Tertiary Period and before the Holocene Epoch.

porphyritic. A textural term for igneous rocks in which larger crystals, called phenocrysts are set in a finer groundmass. which may be crystalline or glassy, or both.

porphyry. An igneous rock of any composition that contains conspicuous phenocrysts in a fine-grained groundmass.*

porphyry belt. A term applied to a zone of porphyritic intrusives of Tertiary age to which most Front Range mineral deposits relate that reaches from Breckenridge on the southwest to Boulder on the northeast.

Precambrian. All geologic time and its corresponding rocks, before the beginning of the Paleozoic, it is equivalent to about 90% of geologic time (from approximately 4-5 to 0.57 billion years ago.

precipitation. The discharge of water, in the form of rain, snow, hail, sleet, fog, or dew, on a land or water surface. Also, the process of separating mineral constituents from a solution by evaporation (halite, anhydrite) or from magma to form igneous rocks.

prismatic structure. Parallel, prismatic columns, either hexagonal or pentagonal in cross section.*

protalus rampart. An arcuate ridge consisting of boulders and other coarse debris marking the downslope edge of an existing or melted snowbank.*

quartzite. A quartz-rich nonfoliated metamorphic rock.

quartz monzonite. Granitic rock in which quartz comprises 10-50% of the felsic constituents and in which the alkali feldspar/total feldspar ratio is between 35% and 65%.

Quaternary. The second period of the Cenozoic era, thought to cover the last two or three million years.

recharge. The addition of water to the groundwater zone of saturation.

remote sensing. The measurement or acquisition of information of some property of an object or phenomenon by a recording device that is not in physical or intimate contact with the object or phenomenon under study.*

representative fraction (R.F.) scale. The scale of a map, expressed in the form of a numerical fraction that relates linear distances on the map to the corresponding actual distances on the ground, measured in the same unit.

residual regolith. Unconsolidated weathered and partly weathered soil and soil parent material presumed to have developed in place by weathering of the solid bedrock upon which it lies.

residual surficial deposits. See residual regolith.

riparian. Pertaining to or situated on the bank of a body of water.*

riser. The vertical or steeply sloping surface of one of a series of natural step-like landform.*

rock fall (and debris fall). The rapid descent of a rock mass, vertically from a cliff or by leaps down a slope.

rock glaciers. A lobate, steep-fronted mass of coarse, angular regolith, extending from cliffs in a mountainous area. Downslope movement of the mass is aided by interstitial water and ice.

rock-stratigraphic unit. A stratigraphic unit having a substantial degree of lithologic homogeneity.*

rotor effect. Westerly winds blowing across the Front Range have been observed to include components with a rotary motion such that wind blows across the divide, descends on the east, and curls back westward to drift snow into the east slope cirques. (Lloyd, 1970).

rottenstone. Any highly decomposed but still coherent rock.*

runoff. Water that flows over the lands.

runout zone. The zone where avalanches naturally stop.

salinity. The proportion of dissolved salts in a solution.

sandstone. A clastic sedimentary rock consisting predominantly of sand-size particles.

sandy loam. A soil containing 43-85% sand, 0-50% silt and 0-20% clay or a soil containing at least 52% sand and no more than 20% clay and having the percentage of silt plus twice the percentage of clay exceeding 30, or a soil containing 43-52% sand, less than 50% silt and less than 7% clay.

schist. A well-foliated metamorphic rock in which the component flaky minerals are distinctly visible.

section. An exposed surface or cut, either natural or artificial through a part of the earth's crust.*

sedimentary rock. A rock formed by cementation of sediment or by other processes acting at ordinary temperatures at or close beneath the earth's surface.

sedimentation. The act or process of forming or accumulating sediment in layers, including such processes as the separation of rock particles from the material from which the sediment is derived, the transportation of these particles to the site of deposition, the actual deposition or settling of the particles, the chemical and other changes occurring in the sediment, and the ultimate consolidation of the sediment into solid rock.*

septic system. Small, usually private, sewage disposal system generally designed for a detention period of 24 hours plus sludge storage capacity.

shale. A fine-grained, fissile sedimentary rock composed of clay-size and silt-size particles of unspecified mineral composition.

shearing. A stress causing parts of a solid to slip past one another, like cards in a pack.

shrink-swell potential. An indication of the volume change to be expected of soil material with changes in moisture content (from Moreland and Moreland).

silica. The dioxides of silicon: SiO_2.

silicate. Minerals with crystal structures containing SiO_4 tetrahedra.

silt size. Scale of sediment particles having diameters larger than 4 microns and smaller than 1/16mm.

siltstone. A clastic sedimentary rock consisting predominantly of silt-size particles.

silt loam. A soil containing 50-88% silt, 0-27% clay, and 0-50% sand.*

sintering. The process by which ice and snow particles bond together at temperatures below the melting point. The process is in two stages: (1) the welding of snow particles in contact with one another, and (2) elimination of porosity.

slab avalanche. An avalanche involving layers of snow with decided internal cohesion that begin movement as a unit and leave a distinct fracture line demarcating the starting zone (modified from Frutiger and Martinelli, 1966).

slope wash. Soil and rock material that is being or has been moved down a slope predominantly by the action of gravity assisted by running water that is not concentrated into channels. The term applies to the process as well as the materials.

slush avalanches. A snow avalanche having a very high water content.

soil. A natural three-dimensional body on the earth's surface that supports plants and that has properties resulting from the integrated effect of climate, and living matter acting upon parent material, as conditioned by relief over periods of time.

soil association. Two or more soils in a given geographic area thatare distinguishable among themselves but that, on all but very detailed soil maps, are grouped together on the basis of their common characteristics, because of their intricate areal distribution.*

soil capability class. The broadest category of a classification that groups soils to show, in a general way, their suitability for various kinds of farming. It is based on their limitations, risk of damage if used in a particular way, and their response to treatment. Roman numerals are part of the class designation and an increase in number means greater limitations and/or narrower choice of land use options.

soil complex. See "soil association".

soil profile. The succession of distinctive horizons in a soil and the unchanged parent material beneath it.

soil series. The basic unit in soil classification and more specific than a soil family.*

soil structure. The combination or aggregation of primary soil particles into compound particles, or clusters of primary particles, which are separated from adjoining peds by surfaces of weakness. The principal forms are platy, columnar, blocky, granular and structureless.

solifluction. The imperceptibly slow downslope flow of water-saturated regolith.

solifluction lobe. An isolated, tongue-shaped feature, up to 25 meters wide and 150 meters long, formed by more rapid solifluction on certain sections of the slope showing vaiations in gradient. It commonly has a steep front (15-25%) and a relatively smooth upper surface.*

stade of glaciation. A substage of a glacial stage marked by a glacial readvance.*

standard project flood. The flood that may be expected from the most severe combination of meteorological and hydrological conditions considered characteristic of an area.

starting zone. The actual places within the catchment basin where avalanches start. It is nearly but not necessarily synonymous with the term accumulation zone which is the main collection area for snow at the head of an avalanche path.

stock. A pluton, roughly circular or elliptical in plan, with an exposed area of less than 40 square miles (100 km^2).

strata. Tabular or sheet-like masses, or distinct layers of homogeneous or gradational sedimentary material of any thickness visually separable from other layers above and below.*

stratification. The layered arrangement of the constituent particles of a rock body.

stratigraphic column. A composite diagram that shows in a single column the subdivisions of part or all of geologic time or the sequence of stratigraphic units of a given region.

stratigraphic section. Any sequence of rock units found in a given region either at the surface or below it.*

stratigraphy. The systematic study of stratified rocks.

strike. The compass direction of the horizontal line in an inclined plane.

strike - valley. A valley eroded in and developed parallel to the strike of underlying weak strata.*

structure. The general disposition, attitude, arrangement, or relative positions of the rock masses of a region or area.*

Subalpine. Of, pertaining to, or inhabiting cool upland slopes below the timber line, characterized by the dominance of evergreen trees.

subbase (subgrade). The bottom of a roadway excavation or top of fill finished to a smooth uniform surface upon which a layer of specified surfacing material is to be placed.

subbituminous coal. A black coal intermediate in rank between lignite and bituminous coals. It is distinguished from lignite by higher carbon and lower moisture contents.*

subsidence. A local mass movement that involves principally the gradual downward settling or sinking of the solid earth's surface with little or no horizontal motion and that does not occur along a free surface.

successional stand type. A generalized category (abstraction) of a plant community which is one of an orderly progression of communities that ends in the climax vegetation typical of a given environment and geographical area; a seral stage.

surface detention. The amount of water from precipitation existing as overland flow.*

surface water. All waters on the surface of the earth, including fresh and salt water, ice and snow.*

surficial geology. Geology of the unconsolidated, residual, alluvial, or glacial deposits lying on bedrock or occurring on or near the earth's surface.

suspended particulate matter. The part of the total load that is carried for a considerable period of time in suspension, free from contact with earth or solid structures on it.*

swelling soils. Soil that contains a large amount of clay and that advances (flows plastically) principally because of volume expansion when wetted.*

synoptic. Pertaining to simultaneously existing, meteorologic conditions that together give a description of the weather.*

talus. Rock fragments of any size or shape (usually coarse and angular) deriving from and lying at the base of a cliff or very steep, rocky slope.*

temperature gradient metamorphism. A process of modification of ice crystals in deposited snow, characterized by vapor transfer under strong vapor pressure and temperature gradients.*

Temple Lake stade. Refers to the readvance of small glaciers and/or reactivation of periglacial features (rock glaciers and protalus ramparts) post-dating the Climatic Optimum --thought to have occurred 2,800 to 2,300 years ago.*

tensile strength. A stress paralleling the direction in which a body subject to deforming tends to be elongated or pulled apart.

terminal moraine. The end moraine deposited by a glacier along the line of greatest advance.

terrace (geological). A relatively flat, elongated surface, bounded by a steeper ascending slope on one side and a steep descending slope on the other. Stream terraces which are seldom subject to flood are sometimes called second bottoms by farmers to distinguish them from floodplains.

Tertiary Age. The first period of the Cenozoic era, thought to have covered the span of time between 65 and three or two million years ago.*

texture. The sizes and shapes of the particles, in a rock or a sediment, and the mutual relationships among them.

thalli. Refers to the bodies of certain simple plants such as algae, seaweeds and liverworts, that are characterized by having relatively little cellular differentiation and no true roots, stems, or leaves.*

till. Nonsorted glacial drift.

timberline. The elevation or latitudinal limits at which tree growth stops.*

tongue-shaped rock glacier. A mass of rock rubble overlying an ice core and capable of slow downhill flow. Occur in high mountain basins.

topoclimate. The climate of a topographic location with a particular slope, aspect, vegetation, etc.

topography. The relief and form of a land surface.

transpiration. The passing of water vapor into the atmosphere from pores of plant tissues.

trend surface analysis. A statistical method for fitting and evaluating the degree of fit of a set of data to a calculated mathematical surface of linear, quadratic or higher degree.

Triassic. The first period of the Mesozoic era thought to have covered the span of time between 225 and 195-190 million years ago.*

tundra. A treeless, level or gently undulating plain characteristic of arctic and subarctic regions. It usually has a marshy surface which supports a growth of mosses, lichen and numerous low shrubs and is underlain by a dark, mucky soil and permafrost. Alpine tundra is similar in terms of vegetation.

tungsten. A term formerly applied to tungsten minerals such as scheelite and wolframite.*

U.S.G.S. United States Geological Survey.

unconfined aquifer. An aquifer having a water table; an aquifer containing unconfined groundwater.*

unconformity. A buried erosion surface separating two rock masses, the older of which was exposed to erosion for a long interval of time before deposition of the younger.

valley head. The upper part of a valley.

varigated. Sediment or sedimentary rock showing variations of color or tints in irregular spots, streaks, blotches, stripes or reticulate patterns.*

watershed. The region drained by, or contributing water to, a stream, lake or other body of water.*

water table. The upper surface of the zone of saturation.

water vapor. Water in the gaseous state.

weathered rind. An outer crust or layer on a pebble, boulder, or other rock fragment, formed by weathering.*

weathered zone. That layer of ground immediately below the surface that has been oxidized and otherwise affected by the processes of weathering.

weathering. The chemical alternation and mechanical breakdown of rock materials during exposure to air, moisture, and organic matter.

wet avalanche. The avalanche also called a spring avalanche because of the season when it becomes common, involves layers of wet snow with little cohesion, moves slowly, but has great destructive power because of its weight (after Frutiger & Martinelli, 1966).

Wisconsin. Pertaining to the fourth glacial stage of the Pleistocene Epoch in North America; it began about 85,000±15,000 years ago and ended about 7,000 years ago.*

zinc. A bluish-white mineral, the native metallic element Zn.*

APPENDIX A

"Boulder City and County Health Department Summary of Lab Results for Stream and Waste Water Samples - Stream Monitoring Reports " (1967-1972).

Of the parameters measured in this study, fecal colliform is the best for ascertaining degree of sewage induced pollution. State levels are placed at one-thousand fecal colliform bacteria per one-thousand milliters. Waters containing more than this limit are judged suitable only for agriculture. Note the reading from below the Peaceful Valley Lodge on the Middle St. Vrain Creek.

MONITORING STATION LOCATION		FECAL COLI/1000 ml.
1)	Middle Boulder Creek - Nederland inf.	2.8
2)	Middle Boulder Creek East Nederland	42.6
3)	N. Beaver Cr. Confl. Middle Boul. Cr.	3351.6
4)	Nederland STP	
	Influent	4500000
	Effluent	44.5
5)	Mid. Boul. Cr. at Hydro. Plant	72.3
6)	" " " at Hwy. 119	60.3
7)	" " " at Eben G. Fine Park	162.9
8)	" " " at E. Arapahoe Rd.	410.5
9)	" " " at 275 ft. above E. Pearl STP	449.8
10)	Boulder East Pearl STP	
	Influent	-----
	Effluent	862625
11)	Mid. Boul. Cr. at Valmont Bridge	123785
12)	" " " 50 ft. above San. Laz. STP	321.8
13)	San Lazaro Trailer Ct. STP	
	Influent	-----
	Effluent	744063
14)	100 ft. below San Laz. STP	95.8
15)	Mid. Boul. Cr. at 61st St.	3654.7
16)	Whiterock STP	
	Influent	-----
	Effluent	5960.5
17)	Mid. Boul. Cr. at 75th St.	16590.7
18)	" " " at 95th St.	11988.7
19)	" " " at Weld Cnty. Line	3465.1
20)	N. Beaver Cr. W. of Peak to Peak Hwy.	15.4

21)	S. Boul. Cr. Louisville - Lafayette inf.	6.5
22)	South Bldr. Cr. Below Eldorado Springs	27.5
23)	San Souci Trailer Court STP	
	Influent	-----
	Effluent	24794
24)	Price's Trailer Court STP	
	Influent	-----
	Effluent	50957
25)	South Bldr. at Valmont Bridge	175.8
26)	Coal Creek above Louisville STP	33563
27)	Louisville STP	
	Influent	-----
	Effluent	1020243
28)	Coal Cr. 200' below Louisville STP	21449.7
29)	" " 50' above Lafayette STP effluent	913.8
30)	Lafayette STP	
	Influent	-----
	Effluent	405086
31)	Coal Cr. 300' below Lafayette STP	9715.4
32)	Middle St. Vrain at Camp Dick	9.5
33)	" " " at Peaceful Valley Lodge	552302
34)	" " " below Raymond	82.4
35)	South St. Vrain at Peak to Peak Highway	7.5
36)	North St. Vrain 300' above Lyons STP	51.1
37)	Lyons STP	
	Influent	-----
	Effluent	9002711
38)	St. Vrain 300' below Lyons STP	179.4
39)	" " at Hwy. 7	3420.3
40)	" " at Hover Road	2646.9
41)	" " 150' above Longmont STP	6784.3
42)	Longmont STP	
	Influent	-----
	Effluent	3649781
43)	St. Vrain below Longmont STP	184058
44)	St. Vrain at Weld County Line	160214
45)	Lefthand Cr. below Ward	6.5
46)	" " at Hwy. 7	257.6
47)	Lefthand Cr. at Diagonal	3206
48)	James Cr. at Peak to Peak Hwy.	131.5
49)	" " above Jamestown	15.1
50)	" " below Jamestown	12.8
51)	Little Dry Cr. above Bldr. Reservoir	148.3
52)	Dry Cr. above Bldr. Res.	609.2

Occasional Papers

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Occasional Paper No. 1: The Taxir Primer, R. C. Brill, 1971.

Occasional Paper No. 2: Present and Paleo-Climatic Influences on the Glacierization and Deglacierization of Cumberland Peninsula, Baffin Island, J. T. Andrews and R. G. Barry, and others, 1972.

Occasional Paper No. 3: Climatic Environment of the East Slope of Colorado Front Range, R. G. Barry, 1972.

Occasional Paper No. 4: Short-Term Air-Sea Interactions and Surface Effects in the Baffin Bay - Davis Strait Region from Satellite Observations, J. D. Jacobs, R. G. Barry, B. Stankov and J. Williams, 1972.

Occasional Paper No. 5: Simulation of the Climate at the Last Glacial Maximum Using the NCAR Global Circulation Model, Jill Williams, R. G. Barry, and W. M. Washington, 1973.

Occasional Paper No. 6: Guide to the Mosses of Colorado, William A. Weber, 1973.

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