Environmental geology of the southeast margin of the Gallatin Valley, Gallatin County, Montana
by Earl Francis Griffith

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Earth Science
Montana State University

Abstract:

Bozeman's attraction as an outdoor recreation area and community with a high quality of life has resulted in significant development of former agricultural land. Most of the area studied is privately owned and within the boundary of the Bozeman City-County Planning area.

This corner of the Gallatin Valley is part of a downdropped block bounded on the south by the Gallatin Range and on the northeast by the Story Hills and the south end of the Bridger- range. Tertiary (Bozeman Group)' rocks comprise the major portion of rocks in the area. Various thicknesses of Quaternary colluvial material and fan deposits veneer the Tertiary near the mountain fronts.' More recent Quaternary alluvium dominates the alluvial valleys. Two major faults border the study area; the northwest trending Bridger Creek-Bear Canyon fault along the eastern edge, and1 the Gallatin Range front fault along the southern edge.

Frequently encountered hazards are rockfall, rock-slides , small local landslides, seismic hazards of ground shaking and potential fault displacement and flooding along all major streams. Geologic constraints include unstable and potentially unstable slopes, creep, solifluction, very steep slopes over 30%, north aspect slopes greater than 15%, problematic soils and high ground water.

Overturned and thrust-faulted Paleozoic and. Mesozoic rocks in Bridger Canyon are very susceptible to rock-fall and rockslides. Active landslides have developed on overturned Cretaceous rocks east of the Bridger Creek-Bear Canyon fault in the Story Hills. These rocks are characterized by bentonite clays, low permeability, low shear strength and a dip slope attitude. Flooding along the major streams is a frequent problem, especially in the East Gallatin drainage north of Interstate 90 and along Bozeman (Sourdough) Creek where existing conduits cannot handle peak flood flows.

STATEMENT OF PERMISSION TO COPY

In presenting this thesis in partial fulfillment of the requirements for an advanced degree at Montana State University, I agree that the Library shall make it freely available for inspection. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by my major professor, or, in his absence, by the Director of Libraries. It is understood that any copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Signature Earl P. Griffith

Date 28 April 1982

ENVIRONMENTAL GEOLOGY OF THE SOUTHEAST MARGIN OF THE GALLATIN VALLEY, GALLATIN COUNTY, MONTANA

by

EARL FRANCIS GRIFFITH

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Earth Science

Approved:

John Montagne

Chairperson, Graduate Committee

Witt

Head, Major Department

Michael Malone

Graduate Dean

MONTANA STATE UNIVERSITY
Bozeman, Montana
April 1982

ACKNOWLEDGMENTS

Valuable comments on needed information came from Paul Bolton, City-County Planner; Ray Center, P.E., of Survco, Inc., and John W. Rold, Director, Colorado Geological Survey. Insights into identifying and mitigating geologic constraints were given by my committee chairman, Dr. John Montagne, and committee member, Dr. Stephan Custer. Professor Robert L. Taylor provided invaluable lessons in dealing with bureaucracy.

Funding was provided, in part, by Gallatin County through the Subdivision Review Board with the aid and approval of County Commissioners Joy Nash, George Sager and John Buttelman. Additional funding came from the Planning Board and from consulting opportunities provided by Mr. Rick Mayfield of Mayfield and Associates, and Mr. Ron Burgess, owner of Survco Inc.

TABLE OF CONTENTS

TABLE OF CONTENTS (Con't)

TABLE OF CONTENTS (Con't)

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Bozeman's attraction as an outdoor recreation area and community with a high quality of life has resulted in significant development of former agricultural land. Most of the area studied is privately owned and within the boundary of the Bozeman City-County Planning area.

This corner of the Gallatin Valley is part of a downdropped block bounded on the south by the Gallatin Range and on the northeast by the Story Hills and the south end of the Bridger range. Tertiary (Bozeman Group) rocks comprise the major portion of rocks in the area. Various thicknesses of Quaternary colluvial material and fan deposits veneer the Tertiary near the mountain fronts. More recent Quaternary alluvium dominates the alluvial valleys. Two major faults border the study area; the northwest trending Bridger Creek-Bear Canyon fault along the eastern edge, and the Gallatin Range front fault along the southern edge.

Frequently encountered hazards are rockfall, rockslides, small local landslides, seismic hazards of ground shaking and potential fault displacement and flooding along all major streams. Geologic constraints include unstable and potentially unstable slopes, creep, solifluction, very steep slopes over 30%, north aspect slopes greater than 15%, problematic soils and high ground water.

Overturned and thrust-faulted Paleozoic and Mesozoic rocks in Bridger Canyon are very susceptible to rockfall and rockslides. Active landslides have developed on overturned Cretaceous rocks east of the Bridger Creek-Bear Canyon fault in the Story Hills. These rocks are characterized by bentonite clays, low permeability, low shear strength and a dip slope attitude. Flooding along the major streams is a frequent problem, especially in the East Gallatin drainage north of Interstate 90 and along Bozeman (Sourdough) Creek where existing conduits cannot handle peak flood flows.

CHAPTER I

INTRODUCTION

Purpose

Land use planning within Bozeman's City-county planning area requires a physical constraint assessment to make rational land use decisions. This thesis, with the accompanying maps, should be the first in a series of efforts to describe to planners, land developers, contractors, and prospective home buyers the geologic constraints in the planning area. The need for this kind of information is underscored by the present effort to update the Bozeman Area Master Plan.

Legislated guidelines regarding land use planning in Colorado (Shelton, 1979), and legal trends toward emphasizing comprehensive plans as a tool in land planning in Oregon (Bela, 1979), are two examples where states now are mandating a physical data base prior to land development.

Document Use

General

The map and thesis information is a compilation of existing data and field reconnaissance, subject to change as additional information becomes available. The maps represent average conditions as they existed at the time of investigation, and in no way preclude the need for more specific on-site investigations. The information base and resulting recommendations are intended as an aid to the decision-making process.

The thesis text is structured around the maps where possible. Major thesis headings usually correlate with specific maps to help the reader find data. A glossary and appendixes are provided to clarify technical language and supply additional information to the reader.

Site Evaluation

The maps and text provide constraint information which can be compared with a project's site requirements to assess compatibility and viability. A map scale of 1:24,000 or approximately 1 inch to 2000 feet is used on all the accompanying plates. Major projects may require more specific on-site surveys at a scale of 1 inch to 200 feet.

Land Capability

Land capability maps can be derived from the six available maps and thesis information using the overlay method if desired. This has been partially addressed on the Construction Constraints map. All the maps, thesis data, and recommendations are based on the premise that future development will be primarily residential or light industrial/commercial, in keeping with past growth patterns and projected future development.

Policy Determination

Comprehensive planning requires at the outset a physical data inventory to augment sound decision making. Not only does sound planning provide a direction to decision makers, it makes the prospective land buyer/developer aware of the constraints present on a given site and protects the well-being and safety of the general public (Bela, 1979).

Map Scale and Detail

Numerous geologic, hydrologic and soil maps have been prepared for portions of the study area, but not at a common scale. I have attempted to include all pertinent map data whenever possible. Some of the map data required a scale change to accommodate the 1:24,000 base scale.

The only area where more detailed maps were used was in the Story Hills. Mayfield and Associates provided the maps for the site-specific study of Subdivision 3 in June 1980 and Survco, Inc. furnished the maps for a preliminary site assessment of Story Hills Subdivisions 2 and 3 in June 1979.

CHAPTER II

GEOGRAPHY

Location and Extent

Rapid residential development has taken place and is expected to continue in the 36 square mile study area. Boundaries were established by natural topographical barriers and within simple political borders which included those areas of rapid development. (Figure 1 -- Location Map). The six base maps were generated from four 1:24,000 scale Upper Missouri River Basin Survey Maps numbered 87, 88, 97, and 98.

Topography

Figure 1 shows the physiographic regions of the study area. Land divisions are based on present form, modifying processes and materials. The four major land forms discussed include alluvial stream valleys, alluvial fans, remnant surfaces and mountainous uplands.

The alluvial stream valleys of Bridger Creek, the East Gallatin River and Bozeman Creek overlie thick deposits of Tertiary sedimentary rocks (Hackett, 1960). Flood plain slopes range from 0-2% except on the upper reaches of Bozeman Creek.

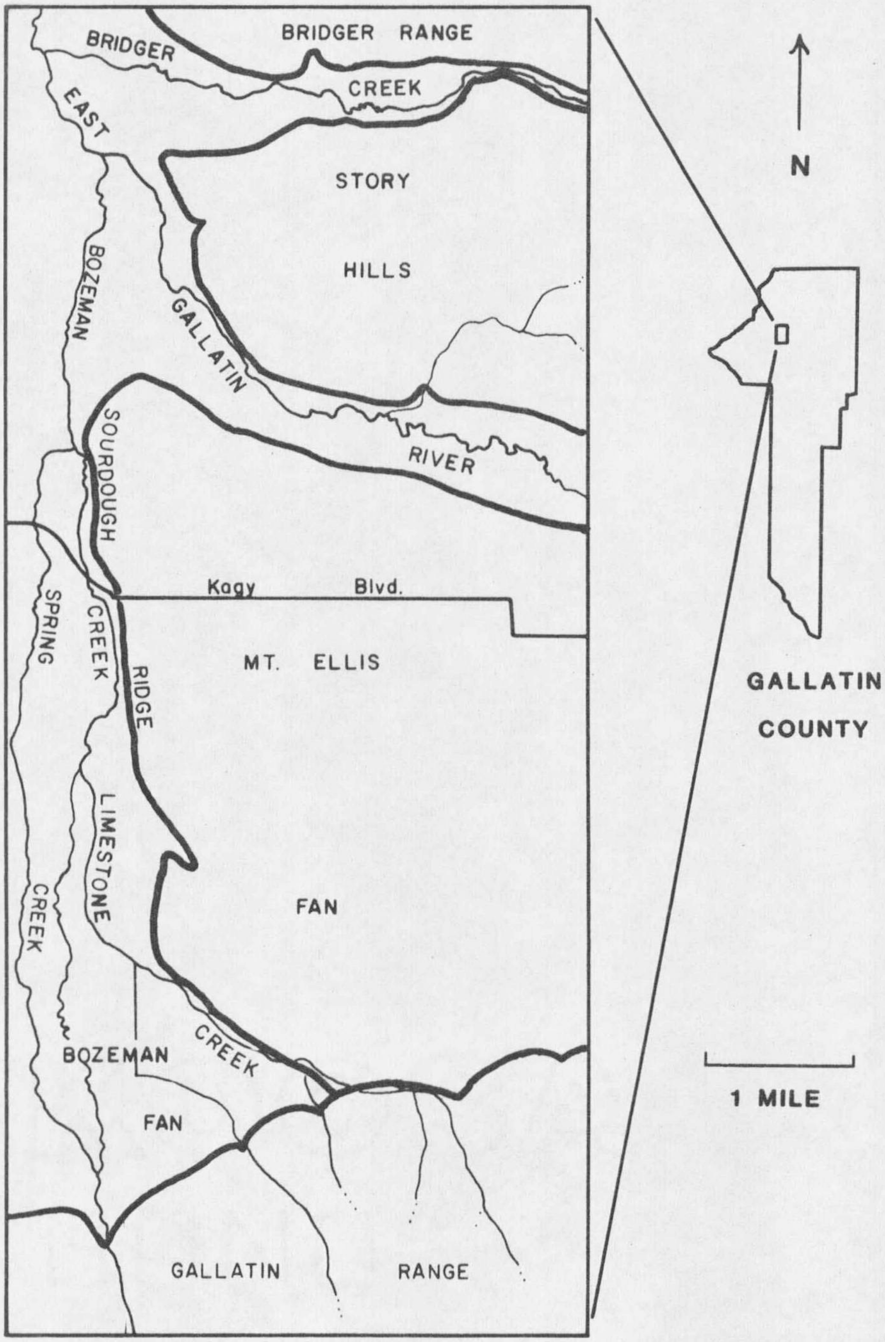

Figure 1. Study area location map.

The Bozeman and Mount Ellis alluvial fans dominate the south-central portion of the study area. Quaternary slope-wash and alluvial sediments 'thin' rapidly away from the Gallatin Range front to an east-west line just south of Kagy Boulevard on the Mount Ellis fan. Fan materials of a later depositional period comprise the dissected Bozeman fan in the study area (Hackett, 1960). The western edge of the Mount Ellis fan is established by Sourdough Ridge. Thick deposits of silt loam soils overlie the entire Mount Ellis fan area from Sourdough Ridge to the edge of the study area and from the mountainous uplands to the East Gallatin River alluvial valley. Slopes generally range from 0-10% except along Sourdough Ridge and in established drainageways where slopes range from 15-30%.

Between the East Gallatin River and Bridger Creek an erosion remnant of Tertiary sedimentary rocks, down-faulted against overturned Devonian through Cretaceous units, comprises the bulk of the Story Hills. Slopes range from 5% to well over 30% in the drainageways and on slopes adjacent to major streams. Aspect ranges from south to north, with much of the developable land facing west-southwesterly.

The steep mountainous areas of the south end of the

Bridger Range and the north flank of the Gallatin Range are generally under public stewardship. Very steep slopes dominate both areas and the Gallatin Range front has the additional problem of a north aspect.

Population and Land Use

Regional recreational amenities and efforts to attract light industry are expected to maintain the present rapid population growth through the 80's. Increasing energy and transportation costs will encourage development closer to Bozeman. The flood plains of Bozeman Creek, the East Gallatin River, and Bridger Creek, the western portion of the Story Hills, Sourdough Ridge and the Mount Ellis alluvial fan areas will receive moderate development pressures.

Problems associated with this expected change in land use are greatest on the surface drainage systems. For instance, urban growth reduces available infiltration areas and speeds up surface runoff to existing channels (Dunne and Leopold, 1978). Downstream flooding will increase, soil erosion will increase, and the 100-year flood plain will expand over time.

CHAPTER III

GEOLOGY

Structural Setting

The Gallatin Valley is part of the Three Forks structural basin, a high intermontane basin, characteristic of the northern Rocky Mountain Physiographic Province (Hackett, 1960).

Formation of the Three Forks structural basin in pre-Oligocene (Eocene?) time was probably due to a late phase of Laramide compression which obstructed the eastward drainage system and promoted aggradation in the closed basin (Robinson, 1961). The advent of tensional faulting (post-Oligocene?) caused recurrent eastward tilting of the basin and shifted the depositional center, accounting for the Miocene and Pliocene sediments in the basin's eastern half (Glancy, 1964). Subsequent uplift to the south caused the Tertiary beds to develop a northwesterly slope, consequently the master drainage changed from an east flowing system to a west and north flowing one (Robinson, 1961).

Major Tectonic elements in the area include the overturned and thrust-faulted Paleozoic and Mesozoic rocks at the south end of the Bridgers; the northwest-trending Bridger Creek-Bear Canyon normal fault (McMannis, 1955; Overturf, 1974); and the east-northeast-trending normal fault along the Gallatin Range front as indicated by aeromagnetic data (Davis, and others, 1965). East-trending normal faults in Tertiary deposits are found along South Church Avenue (Hackett, 1960) and are suspected in both the Story Hills and Bridger Canyon from gravity, structural, and geomorphological data (Plate 1).

Geomorphic Setting

Alteration of the master drainage from an east to a west and north flowing system set the stage for all depositional and erosional activity since the late Pliocene or early Pleistocene. Erosion dominated this period but some deposition took place adjacent to the Bridger and Gallatin Ranges (Hackett, 1960). The net result of all these processes is clearly indicated by the valley landforms. Quaternary deposits become thinner away from the mountain front on Sourdough Ridge, the Mount Ellis and Bozeman fans, and the small fans on the west side of the Bridgers. Remnants of Tertiary (Miocene-Pliocene) sedimentary rocks are present in the Story Hills and the northern portion of the Mount Ellis Fan (Plate 1).

The youngest natural geologic materials are the

Quaternary clay, silt, sand, and gravel in the flood plains of all the creeks of the study area. Erosion in both the Bozeman Creek and Limestone Creek drainages has obliterated any of the alluvial fan form most writers believe was present prior to a change in water and/or material balance.

Loess from both the Madison and Gallatin River flood plains deposited during interglacial periods of the Quaternary is the final overprint to the area's land forms (Bourne, 1960). The resulting Bozeman and Bridger silt loam soils are dominant on the relatively flat surfaces of the Mount Ellis Fan. The soils are discussed further in the section entitled Geologic Hazards and Constraints. Flood-plain soils are delineated and explained on Plate 4.

Surficial Geologic Units

The complex history of Tertiary and Quaternary erosion and sedimentation has resulted in an abundance of surficial geologic units consisting of unconsolidated and semiconsolidated deposits of gravel, sand, silt, and clay of varying extent and thickness. Man's contribution to surficial geology is noted along the flood plain and channel reaches of the East Gallatin River and Bozeman Creek and at various other locations. These units are described in the text below.

Holocene-Manmade Deposits (Hm). These unconsolidated and uncompacted deposits consist of excavation material, construction waste, and demolition rubble; and in older (pre 1940?) sites, variable thicknesses of solid waste. The deposits are located along the channels and flood plains of the East Gallatin River and Bozeman Creek in low-lying areas zoned commercial/industrial and at other sites as noted on Plate 4. Thickness varies from 2 feet to well over 25 feet.

Holocene-Landslides (Hls). These geomorphic features have resulted from slope failure within the last 15 years. The small landslides are located in the eastern portion of the Story Hills and consist of unconsolidated surficial soil materials, Tertiary sedimentary rocks and the underlying fractured Cretaceous bedrock (Plates 4 and 5). A prominent headscarp, dip-slope attitude, large amount of available groundwater, hummocky topography and a lobate terminus characterize these small slides (Figures 3 and 4). Thickness is probably less than 25 feet.

Holocene Rockslide (Hrs). The Bridger Canyon rockslide consists of various sized blocks derived from Big Snowy-Amsden siltstone, dolomite and limestone and possibly some overlying Madison Limestone to the west. The slope angle exceeds 50% and the entire north slope area is unstable and undergoing continuous downslope movement (Plates 4 and 5).

Quaternary Young Alluvium (Qya). According to Roberts (1964), the material consists of unconsolidated, interbedded clay, silt, sand, and gravel along stream channels and on flood plains (Plate 1). The alluvium varies in thickness and generally overlies older Quaternary and Tertiary deposits. Relief is from 0 to 2% along the major drainages and may increase to 10%(+) along streams near the mountains. The materials are characterized by a high groundwater table and are regularly subject to flooding and bank erosion (Plates 3 and 6).

Quaternary Fan Deposits (Qf). Fan deposits consist of a heterogeneous mixture of coarse- and fine-grained sediments deposited by Pleistocene streams which cut higher older (Qac) deposits (Hackett, 1960). The unit is found in the Bozeman Creek drainage near the mountain front and along the eastern margin of the study area as a remnant of the Bozeman alluvial fan.

Quaternary Alluvium-Colluvium (Qac). Unconsolidated slope wash and alluvial fan deposits of mixed silt, sand, pebbles, cobbles and boulders characterize the Qac (Roberts, 1964). The unit is located adjacent to and thins rapidly away from the Gallatin and Bridger ranges.

Quaternary Landslide (Qls). A major feature on the north slope of the Story Hills is a large (1.5 miles E-W by 0.6 miles N-S) ancient landslide (Plate 1). It is an unconsolidated, unstratified, heterogeneous mixture of soil and Tertiary (Bozeman Group) materials, which slid off the highlands of the Story Hills to the north and west during the Pleistocene. Hummocky terrain, north slope, steep variable slope angle, soil creep, and springs on the north slope distinguish this feature (Plate 5). The combination of constraints supports classifying the approximate slide area as an unstable slope (See Chapter III, Mass Movement-Constraints).

Tertiary-Bozeman Group (Tb). The Bozeman Group is comprised of poorly stratified, variously consolidated tuffaceous siltstone, sandstone, claystone, and conglomerate (Roberts, 1964). Most of the Story Hills presently considered for development and the northern portion of the Mount Ellis Fan consist of these materials (Plate 1).

Bedrock Geologic Units

Bedrock exposures are limited to the Bridger Canyon area and the Gallatin Range front portion of the study area. The rocks in the Bridger Canyon area have been severely thrusted and the more resistant rocks show complex jointing. The more resistant rocks maintain steep slopes whereas the shale and silty units become covered topographic swales. Gneiss, schist and granite dominate bedrock exposures along the Gallatin Range front except in sections 3 and 10, T.3 S., R.6 E., where Paleozoic and Mesozoic limestone, sandstone, and shale rest on the Precambrian rocks.

Because geologic constraints are closely related to rock unit competency and erodibility, the brief discussion which follows is in two parts: resistant and non-resistant units. A more detailed description of all rock units is listed on Plate 1.

Resistant Units

Resistant units are generally the limestone, dolomite, cemented sandstone, and gneiss, schist, and granitic rocks which maintain steep slopes and are relatively resistant to erosion. Geologic constraints in resistant rocks usually involve the steep slopes. The overturned and fractured rocks in the Bridger Canyon area are inherently unstable and the hazards from rockslides and rockfall are very severe (See Chapter 4 -- Mass Movement-Hazards and Plate 5).

Non-Resistant Units

Nearly all the non-resistant rocks are mixtures of interbedded shale, siltstone, sandstone, and limestone. These easily erodible units are almost always concealed. Serious mass movement constraints are encountered on these units in the Story Hills east of the Bridger Creek-Bear Canyon Fault (Plates 1 and 4). Here, the dip slope attitude and impermeable shale layers of the Colorado Group rocks are the controlling elements of slope failure.

Structural Elements

Faults

The geologic maps accompanying this text show the major known or suspected faults in the study area (Plate 1). Location is as precise as field evidence or gravity data allow, and any fault location on the maps should be viewed as approximate. Any reader wishing a more detailed discussion of the valley structure is referred to McMannis (1955), Robinson (1961, 1963), Glancy (1964), and Tysdal (1966).

Bridger Creek-Bear Canyon Fault

The Bridger Creek-Bear Canyon fault is the major and most critical fault in the study area. Tertiary rocks on the west side of the fault have been dropped relative to the Paleozoic-Mesozoic rocks on the east side. Displacement of the fault east of Belgrade is about 2,500 feet, but is unknown in the study area (Davis and others, 1965).

The fault is identified and located by: (1) two deep coulees along the fault trace; (2) well data which indicates a definite change in rock types at depth; (3) recent roadcut exposures of Cretaceous bedrock; and (4) the existence of springs along the fault trace.

A fault trace is normally a weak zone and erosion will exploit this weakness. The existence of the deep coulees infers the presence of the faults. A number of wells were drilled in 1974 in the Story Hills in an attempt to locate an adequate water supply. Well logs from two of these wells indicate the presence of a major fault in the area. One well, located 1300 feet southwest of the center of section 3, T.2 S., R.6 E., penetrated 318 feet through Tertiary rocks. From 318 to 400 feet, clay and "blue" shale were encountered. This thickness of clay and shale is very unlikely in the Tertiary fluvial rocks and probably marks the fault plane of the Bridger Creek-Bear Canyon fault (Overturf, 1974). The second well, located ¼ mile south of the northwest corner of section 3 penetrated 440 feet of gravel and conglomerate. A comparison of the well log data indicates a west dipping fault plane with a surface expression very likely at or near the deep coulees. Road excavations at the topographic saddle between the two coulees exposed a sandstone unit. Slightly east of this location, another road cut exposes a lignite unit and a bentonite clay layer. Tertiary rocks are present on the surface east of the deep coulees and rest on the sandstone, lignite and clay units. The sandstone, lignite and clay units are not found in shallow excavations or well holes west of the deep coulees. This evidence supports post-Pliocene faulting along the Bridger Creek-Bear Canyon fault. Finally, faults often act as ground-water barriers by disrupting ground-water flow along the fault plane. Springs at the surface are indicators of such a fault barrier. Both coulees have springs originating in their upper reaches which may indicate a fault contact.

Gallatin Range Front Fault

Field evidence for the Gallatin Range front fault is locally rather general. The linear contact between the mountain front and valley fill implies faulting of some sort. The best evidence is based on a gravity study conducted by Davis and others (1965, p. 3).

> An analysis of the gradients and of a gravity profile crossing the center of the southernmost negative anomaly indicates that a bedrock trough occurs beneath the southeastern margin of the basin. Near South Cottonwood Creek the bottom of the trough is computed to be about 2 miles wide and approximately 6,000 feet beneath the surface. Northeastward the trough broadens slightly, then narrows, and becomes shallower southeast of Bozeman. The subsidiary low in the eastern part of the anomaly coincides with a large alluvial fan and may be caused in part by the low density of the fan material. The high southeastern gradient of the main anomaly probably is the expression of a concealed steep fault zone that lies along the base of the Gallatin Range. The fault zone is inferred to extend northeastward from the mouth of Gallatin River canyon to Bear Creek and to have at least 4,000 feet of throw beneath South Cottonwood Creek.

In addition to this gravity data, Tysdal (1966, p. 79) listed numerous lines of evidence for the fault's existence in the Hyalite (Middle) Creek, South Cottonwood Creek and Big Bear Creek drainages. The data include: (1) the linear expression of the mountain front; (2) concentration of landslide debris at the mountain front; (3) absence of pre-Tertiary outcrops in the basin proper; (4) a steep contact plane locally where Tertiary strata abut the mountain front; (5) pre-Tertiary strata dip toward the proposed fault near the range front (sections 32, 35, and 36, T.3 S., R.4 E.); (6) horizontal offset of the Squaw Creek-Cherry

Creek fault along the range front trends (McMannis and Chadwick, 1964); and (7) shearing of metamorphic rocks in sections 14, 15, and 22, T.3 S., R.5 E. The estimated minimum length of the fault is 23 miles (Tysdal, 1966, p. 80). Tertiary rocks in the SE¼, sec 21, T.3 S., R.5 E., are disturbed where they abut the Precambrian metamorphic rocks, but a Quaternary alluvial fan has not been disturbed. This evidence dates the latest fault activity as post Miocene-Pliocene (Tysdal, 1966, p. 81).

Bridger Creek -- Story Hills E-W Linear Faults

Structural control along east-west linear axes in Bridger Canyon and the Story Hills is inferred from geomorphic, stratigraphic and gravity data. Offset of the two Story Hills erosion surfaces (Plate 1, contour map) suggests a post-Pliocene adjustment along an east-trending fault coincident with the main coulee through the hills (Overturf, 1974). The south surface appears structurally lower than the north and topographically higher surface. Vertical displacement is estimated at 150 to 200 feet, assuming equivalent erosion rates for both surfaces. Addtional evidence for faulting is implied by the deep linear coulee separating the erosion surfaces. The linear character suggests exploitation of an underlying weakness by a tributary stream in the Story Hills. Finally, gravity data show a trough trending east-northeasterly through the Story Hills at this point, possibly indicating a fault at depth (Davis and others, 1965).

The Bridger Creek east-west fault is a more complex and difficult problem. A preliminary structural assessment of the area at a scale of 1:8,000 conducted by the author and Adrienne Bonnet in 1976 disclosed sufficient stratigraphic offset and structural discrepancies from one side to the other to imply offset along a fault plane (Plate 1).

The following inferences suggest a fault with an east-west trend through Bridger Canyon in Section 34, T.1 S., R.6 E.: (1) strata north of Bridger Creek are overturned, have a general northeast strike and dip northwestward, while strata south of Bridger Creek are also overturned but strike northwest and dip southwestward; and (2) a lack of stratigraphic continuity across the narrow canyon implies some kind of structural control which offsets the units along an east-west fault plane.

More pronounced thrusting on the south side of Bridger Canyon (Plate 1) supports McMannis' (1955) suggestion that a second phase of Paleocene compression occurred in the canyon area. This evidence and the structural and stratigraphic inferences noted above support the existence of a tear-fault coincident with Bridger Creek resulting from the second phase of Paleocene thrust faulting.

CHAPTER IV

GEOLOGIC HAZARDS AND CONSTRAINTS

General

The limits which natural processes and conditions impose on any given land use are called geologic constraints (e.g. creep, steep slopes). When these conditions and processes conflict with human activity, they become known as geologic hazards (Hansen and others, 1975). Human interaction with geologic constraints dates from the earliest civilization (Hansen and others, 1975). The costs to society of this confrontation have increased markedly with the advent of technology. Not all costs are measured in dollars however, as the quality of living is reduced as a result of the conflict (Hansen and others, 1975). The special place accorded Geology in the planning process comes from the unique guidelines and insights it provides the scientist to better evaluate and predict the consequences of the interaction of human land use and natural processes (Hansen and others, 1975).

Constraints addressed in this report include mass movement phenomena and the associated factors of slope steepness and aspect, creep, solifluction and unstable and potentially unstable slopes (Plate 5). Hydrologic constraints include high groundwater limitations, water supply, groundwater pollution potential, and the partial variable source area (Plates 3 and 6). A general review of soil constraints is given in the text and a detailed delineation and explanation of flood plain soil is provided on Plate 4.

Earthquake hazards, especially those associated with seismic shaking are examined in detail in the text. The effects of seismic shaking on existing natural conditions and processes is critical in steep slope zones, along faults, in areas of active mass movement and in areas where soil strength may be adversely affected, such as flood plains.

Flood hazard is a recurring and potentially destructive problem as the statewide floods of May 1981 so graphically illustrated. The 100-year flood plain and areas where flood control has been attempted are delineated and explained on Plate 3.

The following two themes are essential to a discussion of constraints: (1) proper respect for geologic constraints will reduce the possibility of creating a geologic hazard; and (2) the severity of a hazard is directly related to the intensity of human activity.

Earthquakes

General

Energy release and the related earth shaking which accompanies slippage along an active fault is called an earthquake (Bela, 1979). Earthquake activity in southwest Montana is such that the U.S. Coast and Geodetic Survey has given this area a Zone 3 probability rating; the worst rating possible. Seismic events of 1925, 1947 and the Hebgen earthquake of August 17, 1959 had epicenters ranging from 58 to 120 miles from Bozeman. In 1959, minor damage was incurred by Bozeman's two old Main Street hotels, the Baxter and the Bozeman, and considerable shaking was felt throughout the valley. Thus, the possibility of a moderate seismic event in the region demands adherence to strict building codes and application of special engineering for any major structure.

Fault Hazard

Actual fault displacement is not the primary damaging mechanism in a seismic event; ground shaking does most of the damage (Seed, 1981). In this paper, faults are classified as active or inactive rather than young or old to better define their hazard potential. An active fault is one that has moved in recent geologic time. Bela (1979) used 10,000 years as the time frame while Witkind (1980) said post Miocene movement is "active" in the Rocky Mountains. I prefer to follow Witkind's lead for these reasons: (1) The Bridger Creek-Bear Canyon fault and Gallatin Range Front fault have incurred post-Pliocene movement in keeping with other Rocky Mountain "active" faults; (2) Pardee (1927) noted recent fault activity north of Sixteen Mile Creek in the Bridger Range fault zone; and (3) the study area is part of a very active seismic region.

Faults that are covered by alluvial or colluvial material present special problems for planners because fault displacement is masked by the overlying material (Nichols, 1974). Because of this problem, land use regulations regarding known or suspected faults should include:

1. A minimum 100' setback from the fault line;
2. when feasible, prescribe an alterative use such as open space or parks; and
3. if avoidance is not feasible, enforce engineered design and earthquake-resistant construction to mitigate the hazard and increase personal safety.

Development along the covered portions of the Bridger Creek-Bear Canyon fault, the Gallatin Range Front fault and the

Story Hills linear fault should adhere to the above guidelines to avoid potential damage from fault displacement.

Mercalli Scale -- Intensity

Intensity is the measure of the size of an earthquake at a particular place by its effect on persons, structures and earth materials (Bela, 1979). With limited observations, the scale is imprecise, but it enjoys widespread acceptance and has universal application because it requires no equipment. Effects of the Mercalli Scale are described in Table I, a general comparison between the Mercalli intensity and Richter magnitude scales.

Richter Scale -- Magnitude

The Richter Scale is a measure of earthquake energy based on records from seismometers (Bela, 1979). The system utilizes a logarithmic scale to indicate magnitude. Each unit increase denotes a ten-fold increase in the amplitude of the seismic wave and about a 30-fold increase in the amount of energy released (Bela, 1979). For example, an earthquake of magnitude 6 releases about thirty times more energy than a magnitude 5 quake. A magnitude 7 quake, however, releases approximately 900 times more energy than a magnitude 5 event, or 30 x 30 = 900. An earthquake event

Table I. Scale of Earthquake Intensities and Magnitudes

Mercalli Intensity	Description of Effects	Equiv. Richter Magnitude
I	Not felt except by a very few under especially favorable circumstances.	
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.	3.5 to
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.	4.2
IV	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building; standing motor cars rock noticeably.	4.3 to
V	Felt by nearly everyone; many awakened. Some dishes, windows broken. A few instances of cracked plaster; unstable objects overturned. Some disturbance of trees, poles, and other tall objects noticed. Pendulum clocks may stop.	4.8
VI	Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.	4.9 to 5.4
VII	Everyone runs outdoors. Damage negligible in buildings of good design and construction, slight to moderate in well-built ordinary structures, considerable in poorly built or badly designed struc-	5.5 to 6.1

Table I. Scale of Earthquake Intensities and Magnitudes (Con't)

	tures; some chimneys broken. Noticed by persons driving motor cars.	
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motor cars disturbed.	6.2 to
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.	6.9
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.	7.0 to 7.3
XI	Few if any (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.	7.4 to 8.1
XII	Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.	Max. recorded 8.9

has only one magnitude but may have various intensities depending on distance, geology, duration and building construction (Bela, 1979).

Earthquake Hazards

The most damaging hazard of any seismic event is ground shaking. Secondary hazards include landslides, soil liquifaction, differential ground movement, rockfalls, floods from dam and levee failures, and fire (Bela, 1979). The seismic history and the geologic constraints combine to impose a high seismic hazard classification for Bozeman and the surrounding area.

Other Seismic Factors

Duration. Soil strength studies show that the duration of the seismic event is very important in soil response (Bela, 1979). The longer the shaking, the greater the damage (Seed, 1981). With time, the shaking builds cyclic stresses in soil and increases pore water pressure, which can ultimately lead to soil failure.

Fault length. Studies show that the longer the fault, the greater the earthquake magnitude (Seed, 1981). Short faults release much less stored energy than longer ones because crustal deformation is much less. Thus, the

San Andreas fault stores a tremendous amount of elastic strain energy from crustal deformation with time compared to the much shorter "Red Canyon" or Hebgen faults, the faults involved in Montana's 1959 Hebgen earthquake. Idealized values of magnitude versus length are given in Table II (Housner, 1970). For comparison, displacement of the

Table II

Idealized earthquake length versus magnitude

Length (miles)	Magnitude
1600	8.8
530	8.5
190	8.0
70	7.5
25	7.0
9	6.5
5	6.0
3.4	5.5
2.1	5.0
1.3	4.5
0.83	4.0
0.33	3.0

23 mile long Gallatin Range Front fault could result in a magnitude 6.8 earthquake, while the Bridger Creek-Bear Canyon fault (estimated length 6+ miles) could generate quake magnitudes of 6.0 or better.

Effect of distance. Seismic wave energy dissipates as it moves through the earth's crust because of dispersion, bedrock structure, friction, depth and other factors (Bela, 1979). If a fault moves during a seismic event, the most important distance to measure is that from the fault or line of slippage rather than from the epicenter (Seed, 1981). See Figure 2.

Geology. The local geology of the Gallatin Valley is especially sensitive to seismic events for two reasons: (1) the valley is filled with unconsolidated to semi-consolidated alluvial material ("soil" in an engineering sense) and (2) the valley is bordered and bisected by major faults. In addition, a major secondary hazard from landsliding in susceptible areas (Story Hills) is possible from ground shaking.

Soil response. Historic data has shown that maximum earthquake intensities are generally limited to areas of firm or unstable ground rather than solid bedrock (Evernden and others, 1973). Increased duration of the seismic

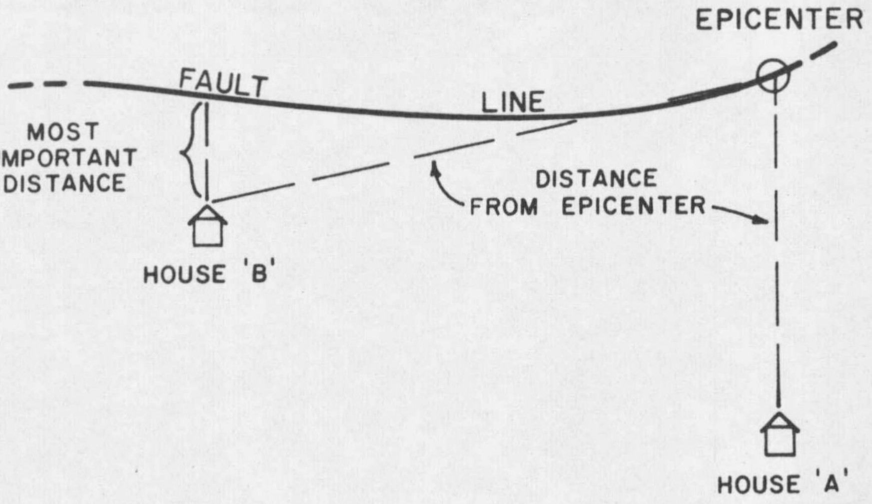

Figure 2. Map diagram showing distance from source of energy release along fault line versus distance from epicenter. House A is closer to the epicenter than House B, but House B would be more severely damaged because it is closer to the fault.

event weakens the bonds between soil grains, greatly increasing the possibility of soil shear. Pore pressure increases as shear stresses build, inducing the phenomenon of soil liquifaction. Soil factors influencing soil liquifaction include soil structure, soil density or relative density, degree of saturation, and the length of time the soil has had to settle. Thus, man-made fills of mixed, end-dumped, and often unsuitable materials will undergo differential compaction and possibly fail in a seismic event

(Legget, 1973).

Natural problematic materials in the valley include deep profiles of the Bridger and Bozeman silty clay loam soils, some sandy soils, and the saturated silty clay soils of the flood plains. As a general rule, the more water a soil contains, the greater its potential for failure when subjected to quake induced stresses.

Foundation difficulties inherent with placement of large structures on problematic soils can be addressed by: (1) driving foundation piles into a soil layer (gravel, for example), which will not contract or undergo liquifaction if disturbed by seismic shaking (Zaruba, 1976); and (2) using spread footings or a mat foundation to better distribute the building load over the soil materials (Pool, 1977).

Potential building damage. Serious building damage can occur from a soil-structure response called the "double resonance phenomenon" (Seed, 1981). This occurs when the building and the underlying rock or soil have similar natural periods of vibration. The resonance or oscillation of maximum amplitude induced in the building by seismic shaking can double and the potential for building damage can increase 100% (Seed, 1981). Because ground motion intensities are greater on alluvial materials, tall buildings suffer more serious damage than one- and two-story wooden frame structures. For example, tall structures built on deep valley fill suffered major damage during an earthquake in Caracas, Venezula (Seed, 1981). A rule of thumb for the Bozeman area would be to build one- and two-story residential structures on deep soils and restrict very tall buildings (hotels and dormitories) to bedrock or shallow soils (Seed, 1981). If tall structures cannot be located on shallow soils, they should be designed for the maximum predictable event (Seed, 1981). Specific questions concerned with seismic engineering problems should be addressed to the appropriate engineer or team of scientists. Average residential buildings which meet the Zone 3 earthquake codes and engineering guidelines can usually withstand a moderate event with minimal damage because of inherent flexibility.

Mass Movement

General

Mass Movement is the downslope movement of rock and soil materials in response to the force of gravity and effects of water (Bela, 1979). Several types of mass movement are present in the area including landslides, solifluction, creep, and rockfall and rockslide hazards.

Large areas of potential mass movement have been identified in the study area. These unstable and potentially unstable slopes are affected by factors including steep slopes, natural soil materials which have failed nearby, dip slope bedrock control, north aspect, and the possibility of seismic shaking.

Causes

Slope movement occurs when the downslope gravity force exceeds the shear resistance of the slope material (Bela, 1979). Factors which control downslope forces and shear strength of the soil or rock material are described in detail in Table III (Dunne and Leopold, 1978).

An important point which the control parameters in Table III make clear is the influence man exerts on hillslope stability. On one hand, man can destroy slope stability by slope undercutting or loading and by reducing shear resistance through improper water management. In other instances, man may not have any control over an unstable situation influenced by the nature of the bedrock geology, slope aspect, fault displacement or seismic shaking.

Table III*

Controls of Hillslope Stability

Controls of the Downslope Force

Hillslope gradient

Steepening of the slope by tectonic tilting

Undercutting of the slope by geomorphic processes or human interference

Loading of the upper end of the slope

Short-term downslope stresses generated by earthquakes

Control of the Shear Strength

Nature of the geologic materials: rock type and structure (joints, faults, angle of dip); nature of weathering products;

Water-pressure changes due to fluctuations in rainfall and snowmelt; diversion of storm water; submergence; fluctuation of reservoir levels; leakage from canals, irrigated fields, septic tanks, sewerage lines, and water pipes; reduction of evapotranspiration following change of vegetation. Concentration of groundwater flow by geologic structures, such as joints, or by the sequence of geologic materials;

Earthquake vibrations, which can reduce the strength of weakly cemented sands or silts;

Tree roots, which can increase the cohesion of soils; this cohesion is lost when the roots decay after logging or burning.

---

*From Dunne and Leopold, 1978, p. 561.

Hazards

Any geologic condition or process which directly conflicts with human activity is considered a hazard. Mass movement hazards in the study area are generally confined to the Bridger Canyon area and that portion of the Story Hills east of the Bridger Creek-Bear Canyon Fault (Plates 4 and 5).

Story Hills landslides. Two small landslide features in the Story Hills appear to be controlled in part by dip-slope failure in overturned Cretaceous bedrock. Both occurred within the last 10 years, as verified from air photo analysis.

A small two-acre slide approximately 300 feet east of the intersection of Big Gulch Drive and Carney Road in sec. 3, T.1 S., R.6 E. is a shallow soil failure on an overturned Cretaceous dip slope. Directly north of and adjacent to the slide, water is discharging from a small spring. This slope failure occurred in spite of the fact it has a southwest (climatically dry) aspect and an 18% slope (Figure 3).

The small landslide located from 400 feet to 900 feet south of the N¼ corner, sec. 3, T.1 S., R.6 E. is characterized by a northwest aspect, possible dip slope control,

Figure 3. Small landslide on the dip slope of overturned Cretaceous bedrock in the Story Hills.

moderate to steep (23%) topographic slope, moderate to high available soil water and Cretaceous bedrock. All the characteristic indicators of slope failure are present including a well-defined north trending head scarp (4 feet to 6 feet in height), very irregular hummocky ground surface and a bulging toe at the downslope terminus. The slide showed evidence of slight downslope movement in June, 1981 where the head-scarp bisects the road (Figure 4). The movement was probably due to saturated ground conditions resulting from the rains in late May, 1981.

These two small landslide features should serve as indicators of potential hazards in this part of the study area and in other areas of similar lithology and topographic character.

Bridger Canyon rockslide. Many geologic controls contribute to the Bridger Canyon rockslide. The rock mass has been overturned and severely thrusted (McMannis, 1955), is proximal to the Bridger Creek-Bear Canyon normal fault, had its slope oversteepened by the natural downcutting of Bridger Creek, and appears to have Madison Limestone thrust over weaker Big Snowy-Amsden silty and shaly limestone and dolomites. The severe thrusting fractured the overturned beds along E-W trending, north dipping shear planes.

Figure 4. Headscarp displacement across existing roadway on reactivated landslide in the Story Hills. Rock hammer for scale.

In 1962, a large reverse rotation slide block moved downslope, presumably on one of the many shear planes (Montagne, J., 1981, personal communication). Successive slope failures were called retrogressive slumps, a situation in which slope failure will march upslope in large blocks as the downslope blocks lose support at the toe. These shear planes may be a blessing in disguise, however, for they allow small portions of the hillslope to calve off periodically, and thus prevent the development of large landslides. Prior to the road realignment in the 1960's, the slide area had been a limestone quarry. Once the delicate and unstable geologic balance was upset, the rockslide was inevitable.

The seriousness of the rockslide hazard should not be underestimated. Recurrent slides capable of moving large boulders (3 feet - 5 feet on a side) will probably continue until the natural angle of the repose is established or the toe is artificially stabilized by deep fill in the canyon. Downslope movements increase during the spring runoff season. A slide of major proportions, possibly covering both roads and damming the creek is not unlikely in this seismically active area. Because of these inherent hazards, the need to observe recommendations developed by Montagne still apply (Montagne, J., 1981 personal communication).

1. Carefully survey and monitor the slide, noting rates of movement and periods of increased downslope failure activity.
2. Increase observations as the rate of movement increases.
3. Install signs in the area warning the public of the hazard, and prohibit parking on the south roadway.
4. Carefully consider road closure during periods of increased seismic activity.

A plan for an alternate route was presented by the State Highway Department in 1977 (Armstrong, 1977). The project involved stabilizing the toe of the slide by filling the narrow canyon area and putting a straighter road segment on the north side of the canyon.

Bridger Canyon rockfall area. Directly across from the Bridger Canyon rockslide are cliffs of Madison Limestone (Plate 5). These jointed and fractured rocks present a very localized rockfall hazard. The competency of the limestones and their shallow dip away from the road preclude a large scale slide onto the roadway. However, the stresses of mechanical weathering and continued loss of support material in combination with the very steep slope allows rocks of varying sizes to roll downslope onto the highway.

The hazard involved came to the public's attention in late 1976 by the threat an overhanging block of jointed limestone presented to drivers. After some weeks of periodic road closures and discussions of removal procedures, the rock mass (called Maiden Rock) was finally blasted down on September 16, 1976 (Wills, 1976).

This situation was special because the rockslide across the creek had closed that portion of the highway while the rockfall threatened the detour. The public should be aware of rockfall hazard in areas of steep often unvegetated slopes or bare bedrock cliffs. Rockfalls occur without warning and are very rapid events, and thus present a special hazard to human safety.

Constraints

Constraints of mass movement are geologic conditions or processes which contribute to, or are indications of, mass movement, and which do not conflict with human activity. They tend to be less well defined topographically and geologically than hazards, and have an uncertain history of failure or potential for failure. Development in areas with mass movement constraints should not proceed without an assessment of these contraints, and an evaluation of the risk of slope failure. Often, avoidance is the most cost effective remedy, but in other less constrained areas, mitigation procedures may contribute to slope stability over time.

Slope aspects. The orientation of a slope face relative to compass bearing is called its aspect. For example, in this paper, south aspect slopes are synonymous with south slopes. Slope aspect for critical areas is indicated on Plate 6. Slope aspect influences the microclimate of an area to such a degree that some north slopes in the Story Hills are potentially unstable and exhibit surficial creep while geologically equivalent but steeper south slopes are stable. Predominantly north facing slopes retain snow longer than south slopes, have more available soil moisture and thus have a different vegetative assemblage (dense conifers, aspens, shrubs and forbes) than south slopes (range grasses and sagebrush). North slopes also maintain a lower average temperature and retain more water than south slopes. Difficulty of access and concurrent road maintenance costs due to snow accumulation are probably greater on north slopes than south slopes.

Slope angle. Slopes greater than 15% (Plate 2) are limiting to utility line construction and house siting because: (1) earth moving costs are greater than on lesser slopes, (2) more extensive preliminary surveys and cut and fill plans are needed, (3) more care and time must be taken to insure equipment and personnel safety, and (4) the probability of initiating slope failure increases with increasing slope angle. Septic drainfields on slopes greater than 15% run the risk of initiating slope failure by slope loading and reducing shear strength in the soil materials. Increasing slope angle increases the magnitude of the downslope gravity force relative to the resisting shear forces. Many north aspect slopes exceeding 15% exhibit active soil creep. The very steep slopes of Bridger Canyon are conducive to rockfall hazard, while the less steep slopes of the Gallatin Range tend to be more stable.

* *Soil creep*. Soil creep is the slow downhill movement of soil debris from wetting or drying or slow deformation under the soils' own weight (Dunne and Leopold, 1978). Nearly all hillslopes undergo creep to some degree. In forested regions, creep contributes considerable material to stream channels, though movement is very slow (Dunne and Leopold, 1978). Creep may disrupt fences or bend tree trunks but is not normally a serious natural problem unless construction takes place on slopes exhibiting active creep.

North slopes in the study area exhibit much more creep than south slopes (Plate 4). Creep occurs on the relatively steep north slopes and drainageways of the Story Hills, and on the steep north slopes of the Gallatin Range. Development potential on the Gallatin Range Front is limited for a number of other reasons including slope angle, aspect, and access. Figure 5 shows a "pistol butted" fir tree in the Story Hills, caused by active creep.

* _Solifluction_. Solifluction is a form of slope movement caused by thawing, saturation, and flow of surficial soil materials on a frozen subsurface. Meltwater, prevented from draining through the frozen soil, saturates the thawed soil and flow results. Areas of solifluction in the study area are characterized by terraces on steeper (greater than 15%) hillslopes. The process appears restricted to the south, west and east slopes of the Story Hills (Plate 4). Long-term overgrazing (Ryerson, D., 1979) by cattle seems to have accentuated the terraces by compaction from use as grazing trails. Solifluction is not evident on the heavily grassed but ungrazed drainageway sideslopes of the Sourdough Ridge-Mount Ellis fan area or on the north aspect slopes where other processes dominate.

* _Unstable slopes_. Unstable slopes display all the

Figure 5. "Pistol butted" fir trees at the head of a coulee on a north slope in the Story Hills.

physiographic characteristics of landslides, but signs of *recent* movement are nonexistent or uncertain (Soule, 1976). The large ancient landslide located in the S½, S½ sec. 32 and SW¼ sec. 33 T.1 S., R.6 E., and the N½ sec. 4 and the N½, NW¼ sec. 3, T.2 S., R.6 E. of the Story Hills is considered the only unstable slope in the study area (Plate 5). Movement occurred following the Pliocene and many have been triggered by slope undercutting action of Bridger Creek. Steep slopes, hummocky topography, creep, a north aspect, high water use vegetation, and springs characterize the slide.

Some flat areas of the slide are suitable for low or medium density housing, but available sites are limited by steep slopes and drainageways. Access road construction to suitable building sites on the north slope could initiate slope failure. Any potential hazard associated with this slope is less certain than on an active landslide. A precise determination of the degree of possible failure is directly related to the particular land use proposed.

✱ *Potentially unstable slopes*. "Potentially unstable slopes are ones with all the attributes of unstable slopes, but where evidence of past or present slope failure is not apparent" (Soule, 1976, p. 16). Attributes appropriate in the study area include proximity to areas of present or past failure, steep slope gradient, north aspect, historically weak bedrock units and active creep. These slopes offer no obvious evidence of failure and are less predictable than active or unstable slopes. For this reason, human activity can pose a greater hazard on these areas than on active or unstable slopes.

All of the area east of the Bridger Creek-Bear Canyon fault not considered as active landslides is considered potentially unstable (Plate 5). This includes the areas controlled by dip slopes in overturned Cretaceous units and the very steep side slopes of the Bridger Canyon exclusive of the rockslide areas. The high mountainous slopes of the Gallatin Range have thin soil profiles and exhibit active creep throughout. The additional effects of increased precipitation and north aspect further supports a classification as potentially unstable.

Other areas so classified include the steep west slope along Sourdough Ridge, steep drainageway sideslopes throughout the study area and the steep east and west slopes of the Story Hills. Potential development activity in these areas combined with the physical characteristics are the reasons for the potentially unstable classification.

Impacts and Recommendations

Mass movement constraints can impose serious limitations on development, even to the extent of becoming hazards. The key to addressing constraints is recognition and an understanding of limiting elements. Often, constraints are not a limiting factor singularly, but become problematic through interaction (Hansen, 1975). Questions about constraints which can be applied to decision making include (Hansen, 1975):

1. How does the land use affect the hydrogeologic system?
2. What impact will land uses have on natural processes?
3. What hazards might ensue?
4. What sequential land uses are most compatible with the needs of the community and the processes of nature?
5. How can open space help mitigate geologic constraints?

In addressing these questions, the following approaches to evaluating mass movement problems are recommended.

1. Evaluate the degree of hazard by comparing the

intended use to the slope constraint for a given area.

2. Assemble a complete list of impacts expected from the planned land use and the effect each has on the natural environment.
3. Delineate areas with the most serious constraints and hazards and consider these for use as open space when possible.
4. Encourage access road design and structure siting which optimizes available building sites, but which does not interfere with the natural surface drainage system or conflict with known hazards or constraints.
5. Always avoid, when possible, areas of known active slope failure and unstable or potentially unstable slopes to avoid costly remedial measures which may become necessary in the future.

Problems of communication and information availability have allowed some lots in Story Hills Subdivision, number 3 to be put on the market and sold despite the fact these lots have serious constraints to development. A procedure needs to be established to ensure that the seller provides the buyer with a list of site limitations even if it requires a site-specific geologic and engineering assessment prior to the sale. Active landslides on former $400/ acre grazing land should not be allowed on the market as exclusive country homesites for $2000/acre unless the buyer is informed of the constraints and is prepared to pay the price to satisfactorily mitigate them. Developers, planners, and the buying public must understand and adequately address constraints and use flexibility in zoning procedures, building requirements and engineering design methods to meet this end. In some instances, addressing constraints through engineered design may be impossible or too costly and the best solution to the problem is total avoidance.

Soils

Purpose

The study of soils and the application of soils data are not directly the concern of this investigation. However, because soils are related to bedrock geology, surficial geologic processes and geologic constraints, their relation to general geologic and topography parameters is described. For more detailed information about the valley soils the reader is referred to the "Soil Survey of the Gallatin Valley Area, Montana" (1931) by William DeYoung. Flood plain soils are delineated and discussed on Plate 4.

General

The term, soils, as used in this chapter and on Plate 4, refers to the biochemically altered part of the regolith approximately equivalent to the root zone. This zone is generally from 3 to 6 feet in depth and distinguished from underlying layers by: (1) higher organic matter, (2) abundance of plants and organisms, (3) characteristic horizontal layers (horizons), and (4) more intense weathering.

Weathering processes which physically disintegrate minerals, leach constituents and control chemical breakdown reactions and recombination processes are influenced by topography (Bela, 1979). North slopes generally have more available water and thus more organic matter in the upper horizons than do south slopes (Birkeland, 1974). Soils on steep slopes are shallower and less well developed than soils on flatter surfaces (Birkeland, 1974). Lower slopes and valley bottoms will have thicker soils and a greater accumulation of clay sized particles (Birkeland, 1974). The high clay content of these soils is restrictive to septic drainfields and foundation siting, while the topographic expression very often contributes to high ground water and thus shrink-swell, frost heaving and, the potential for liquifaction if saturated and vibrated.

Parent material of soils in the study area plays an important role in soil genesis. The Bozeman Silt Loam, for example, is derived from wind blown silt (loess) carried into the area from the flood plains of the Gallatin and Madison Rivers during interglacial periods (Bourne, 1960). These silty soils cover the Mount Ellis Fan area south of the East Gallatin River and east of Sourdough Ridge. These silty and silty clay loam soils are easily erodible, have a high water holding capacity, and will undergo shrunk-swell and frost heaving under appropriate soil moisture conditions. Flood-plain soils vary in basic constituents and almost all are limited by a high ground-water table. Septic systems and buildings with basements are a serious problem on all flood-plain soils.

Soil Distribution

Flood-plain soils. These soils as described in the East Gallatin River Flood Hazard Analysis report (1972) have a fluctuating water table between 30 and 60 inches below the ground surface. Most of these soils are used for tame hay and pasture with some small grain cropping (SCS, 1972). The soils tend to be somewhat poorly drained, range in thickness from 20 to 40 inches and overlie sands and gravels (SCS, 1972). Limitations to development are severe where the water table reaches to within 30 inches of the surface. These soils are subject to occasional flooding, have a low bearing capacity and a high potential for frost action. If the water table is below 30 inches, the limitations are less severe. In all flood-plain soils, septic limitations are severe.

Soils adjacent to the 100-year flood plain are from 20 to 40 inches thick, are well drained, overlie sands and gravels, and are mainly loams and silt loams. They are used for pasture or small grain production and are steadily being developed. Flooding is rare and limitations to development include low bearing capacity and high frost potential. Where permeability is slow, or very rapid, septic drainfields may be restricted.

Story Hills. Soils west of the Bridger Creek-Bear Canyon fault are underlain by Tertiary alluvium and limitations are minimal except for steep slopes and areas with a north aspect. Permeability tests by Survco indicate adequate percolation for septic systems in sec. 3 and 4, T.2 S., R.6 E. of the Story Hills. Field observations during the late stages of a moderate three-day rain in May, 1980 and again in May, 1981 did not show any significant amount of surface runoff in the area, even in the large east-west master drainage.

Soils east of the fault vary, depending on the extent of Tertiary material overlap and the nature of underlying Cretaceous bedrock. Scattered clay lenses in the gravels were noted in the north slope pits about 100 yards east of the fault, an indication that Tertiary material overlapped the fault and covered areas of Cretaceous bedrock. A pit on lot 24 of the subdivision number 3 about 200 feet southeast of the intersection of Alder Gulch Way and Big Gulch

Drive near the center of sec. 3, T.2 S., R.6 E. revealed a parent material of fine sandstone (Colorado Group rocks ?) overlain by 18 inches of clay loam soil. Just 100 feet west of this pit in the shallow swale adjacent to Alder Gulch Way another pit revealed a saturated soil with 40% clay and traces of gypsum. This pit was located in order to verify suspicions that high clay soils unsuitable for construction and severely limiting to septic systems would be found and to compare this data to the soils data in the original report by Overturf, Strand and Associates (1974). Soils data in the original 1974 Story Hills report were severely limited by a lack of exposure and soil pits. The report's classification 5 (soils underlain by Colorado shales), for example, should not extend west of the Bridger Creek-Bear Canyon fault. Use of these data should be tempered by more recent information from percolation test holes, deep soil excavations, water line trenches, and road excavations.

<u>Sourdough Ridge-Mount Ellis Fan</u>. Soils in this area are dominated by the relatively well drained silt loams and silty clay loams of the Bozeman and Bridger Series. These loess-derived soils vary in thickness and tend to thicken eastward as though Sourdough Ridge acted as a barrier, causing the silt to fall out of suspension. An exposure at Kagy

and Highland Boulevards shows a thin (less than 2') soil over Tertiary gravels, whereas a road cut exposure on Kagy three-quarters of a mile east of Highland showed no less than 10 feet of loess and soil. Good drainage and resistance to drought make these loess-derived soils excellent agricultural soils. These same characteristics make the soils suitable for development (Nielsen, G., 1981, personal communication). As long as the soils are well drained, the problem of frost heaving is avoided.

Mountain soils. The mountainous soils of publicly owned land in the Gallatin and Bridger Ranges are generally thin, well drained, and overlie bedrock ranging from Precambrian gneiss to Madison Limestone and Cretaceous marine sediments. Logging in the National Forest lands of the Gallatin Range portion of the area has created some erosion problems on the steeper slopes and road cuts and will likely continue until stabilized by understory vegetation.

Man-made soils. Man-made fill soils composed of excavated soils, construction rubble and occasionally trash are prevalent on the East Gallatin flood plain from Bohart Lane to Griffin Drive, the Bozeman Creek flood plain from Lamme to Griffin and at former gravel pit sites in the industrial/commercial areas north of Durston (Plates 1 and 4).

The materials may contribute to particulate and chemical pollution, and reduce channel cross section when used in or near streams, not to mention reducing the aesthetics of the channel reach. Off-stream dump sites and fills of exhausted gravel pits very often pollute shallow groundwater, and can cause problems for future construction projects. End dumping of mixed rubble and excavated material contributes to differential settlement over time (Legget, 1973). Few problems would be encountered if fill materials were properly placed in horizontal layers and compacted.

It is doubtful that construction debris and excavated soil placement in fills will change significantly in the future. The potential problems these areas present in future land use can be addressed by: (1) mapping all known historic dump sites and present fill areas as precisely as possible, (2) describing the nature of the fill materials, and (3) maintaining strict controls on the fill material to prohibit indiscriminate dumping.

Soil Erosion

Farming practices, change in land use from agriculture to urban residential and inadequate erosion control at construction sites are major factors contributing to soil erosion. Rapid spring runoff from small grain fields south of Kagy Boulevard frequently produces large sediment loads and on occasion has washed out the roadway. Housing developments reduce ground area available to store precipitation and runoff. This increases runoff from a given area, and as a consequence erosion increases (Dunne and Leopold, 1978). Construction site soil erosion is the nemesis of building contractors who start construction early in the spring. Too often the site is completely cleared of vegetation, excavated soil is left bare, and access roads are not designed and built to minimize soil erosion.

Impacts and Recommendations

Soil erosion throughout most of the study area is not a serious problem, except along the East Gallatin River (Shouse, 1978). Increased development will increase erosion potential, consequently sediment pollution can be expected to increase unless measures are taken to control or reduce it. Principles for minimizing erosion and sediment movement from urban construction sites require: "(1) a minimum size of construction area, (2) quick re-establishment of permanent vegetation, (3) use of temporary vegetation and mulches on exposed soil, (4) use of as short a length of steep slopes as possible, (5) reduction of volume and velocity of water that crosses disturbed areas by means of planned engineering works, and (6) better use of hardened or established channels for transporting increased runoff, whether sediment-loaded or not" (Coates, 1976, p. 23). These methods will not stop erosion, but rather reduce sediment movement. Care must be taken to use an appropriate method or build an adequate structure to fit the needs of the area and the project. Whenever possible, natural vegetative controls should be used to minimize sediment production (Coates, 1976).

CHAPTER V

HYDROLOGY

Purpose

A complete hydrological assessment of the study area is beyond the scope of this paper. This section stresses the hydrologic limitations to development, present and future problems, and suggestions for addressing them. For a more complete assessment of flood plain/flooding problems, groundwater supply and flood control measures, the reader is directed to the following publications:

1. Dunn, D. E., 1978, Ground Water Levels and Ground Water Chemistry: Prepared for the Blue Ribbons of the Big Sky Country 208 Report.
2. Shouse, J. E., Project Director, 1978, Blue Ribbons of the Big Sky Country; Areawide Planning Organization: Final Report 158p.
3. Soil Conservation Service, 1972, East Gallatin River and Upper Tributaries; Flood Hazard Analyses, Gallatin County, Montana; United States Department of Agriculture, Soil Conservation Service, 112p.
4. Soil Conservation Service, 1980, Preliminary Investigation Report; Bozeman Creek Watershed, Gallatin County, Montana: United States Department of Agriculture,

Soil Conservation Service, 31p.

5. Soil Conservation Service, 1980, Floodway-Flood Boundary and Floodway Map; City of Bozeman, Montana, Gallatin County, Montana: Preliminary Report, United States Department of Agriculture, Soil Conservation Service.

The following is an overview of surface water and the associated problems in the study area.

Surface Water

General

Three major streams flow through the study area (Plate 3). Bozeman (Sourdough) Creek flows almost due north and presents the most serious problems. The Creek has dissected the east border of the so-called Bozeman fan complex and flows in a narrow ribbonlike floodway without natural diking, a situation common to geomorphically young stream valleys (Wells, 1977). The East Gallatin River flows westward along the south flank of the Story Hills and joins Bozeman Creek just north of Griffin Drive east of Rouse Avenue. The East Gallatin meanders through a flood plain restricted on the south by the Burlington Northern Railroad embankment and Interstate 90. Bridger Creek flows westward through the steep-walled Bridger Canyon and joins the East

Gallatin River in sec. 31, T.1 S., R.6. E. The Creek is contained within a well-defined channel in an area devoted primarily to hay cropping.

Flood Plain Delineation

All three tributary flood plains have been evaluated twice since 1970. The peak 100-year frequency flows were determined for an unobstructed floodway; history indicates no blockages by trees or debris have been recorded (Hamilton, S., 1981, personal communication). This is not to say that such an occurrence won't happen in the future, however. Map boundaries for the 100-year flood plain are based on 1972 data. The intense 1980 study differs only slightly from the first report in 1972, because of a channel improvement in the East Overflow (Mill Ditch Diversion) channel. Downtown flooding should now be restricted to the streets and not seriously affect basements (Plate 3). Both studies scrutinize the Bozeman drainage more carefully because of its higher flood risk and potential for property loss.

Present Flooding Problems

Major flooding occurs in May and June when snowmelt and rains combine to produce peak flows (SCS, 1972). Continued urbanization on areas adjacent to the flood plains will increase downstream flooding to some extent. Numerous studies have shown that urbanization increases peak flow and reduces the lag time of the flood wave in an urbanized watershed (Dunne and Leopold, 1978). Figure 6 shows the effects of urbanization on a one-square mile drainage basin. As development increases, impervious areas increase, resulting in higher average peak flows occurring more often. Figure 7 shows the effect of urbanization on the lag time between the rainfall event and flood occurrence, and the effect on peak flow. Urbanization reduces the lag time and increases the peak flood flow.

The response of the three tributary streams to development may not be clear cut. All three originate in mountainous terrain and have a high percentage of watershed area in this upland portion. Water from urbanized areas would be shunted out of the system prior to peak flooding from the mountains (Hamilton, S., 1981, personal communication). A worst possible case would involve a deep snow pack, relatively warm rain and high relative humidity (Yaw, R., 1981, personal communication). This would contribute maximum runoff in the shortest time.

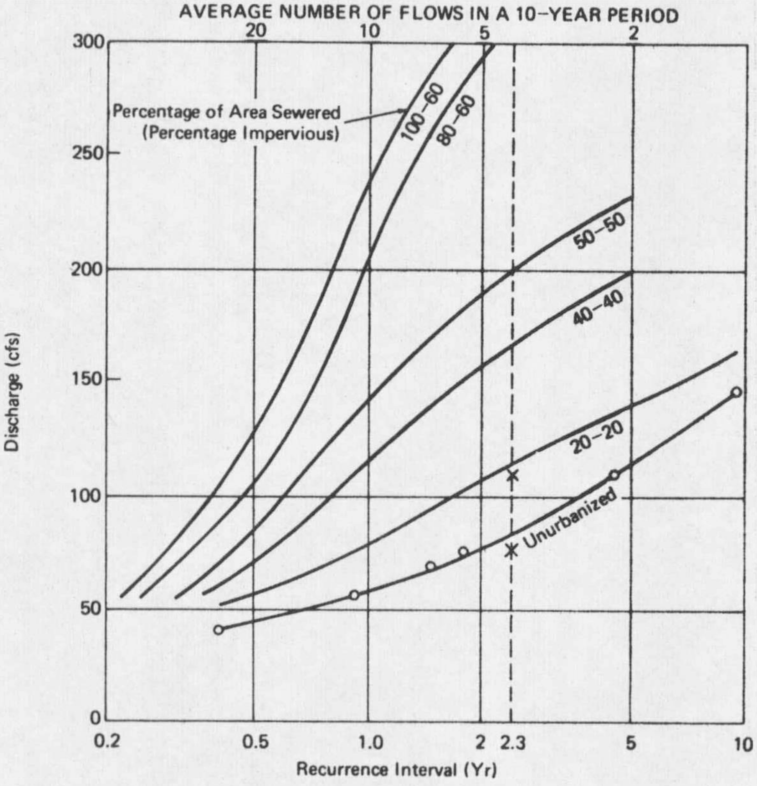

Figure 6. Flood frequency curve for a one-square mile basin in various stages of urbanization. (L. B. Leopold, U.S. Geological Survey Circular 559, 1968; from Keller, 1976, p. 88).

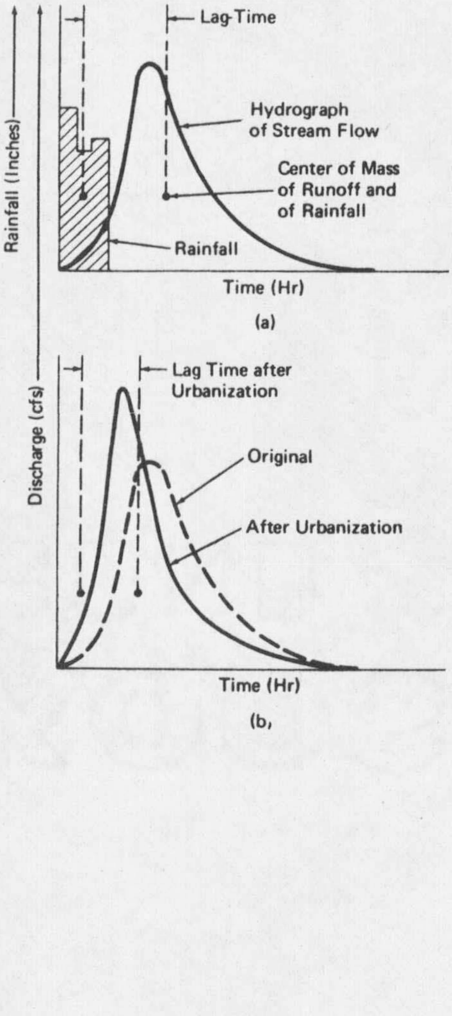

Figure 7. Generalized hydrographs. (L. B. Leopold, U.S. Geological Survey Circular 559, 1968; from Keller, 1976, p. 88).

Channel Constraints

Bozeman Creek has been steadily channelized since before 1900. Severe restrictions from bridges, culverts, conduits under structures, and channel cross-section reduction by riprap is continuous from south of Story Street to the culverts at Interstate 90. Some flooding pressure was relieved by improvements of the East Overflow (Mill Ditch Diversion) Channel (Hamilton, S., 1981, personal communication). North of Interstate 90, a more natural channel exists. Despite some use as a fill area, the channel is relatively well vegetated, shows few places where erosion is serious and experiences little overbank flooding. Encroachment by industrial/commercial development on the vegetated channel area could increase downstream flooding problems.

A major channel alteration to accommodate Interstate 90 steepened the gradient of the East Gallatin for nearly 1000 feet along Bohart Lane (Plate 3). Accelerated erosion of meander bends downstream is creating some problems for present landowners. Dynamic adjustment to the increased upstream gradient as well as easily erodible banks due to overgrazing appear to be the major problems affecting this reach of the channel as evidenced by the May 1981 flood.

Upstream from this area the river is entrenched in a well vegetated channel. Downstream from "L" Street, a short northwest flowing reach is relatively entrenched along Story Mill Road as a result of previous channel excavation and rip-rap work. The last west-flowing reach from the stockyards to the Bozeman Creek confluence has been seriously altered. Overgrazing has removed vegetation on both banks; debris, including car bodies and miscellaneous trash line the banks; riprap is improperly placed; and an easily erodible berm of gravel has ostensibly been installed along the north bank to limit flooding. Flooding is a common occurrence along this portion of the East Gallatin channel and affects the low-lying industrial and commercial businesses in the area. The results of such practices are increased bank erosion and more frequent flooding.

Bridger Creek is confined to a well vegetated, relatively well entrenched natural channel from Bridger Canyon to Story Mill Road. Some backwater flooding from the bridge across Story Mill Road and minor downstream flooding is not unusual. The 100-year flood utilizes not only the flood plain but also the area along the old Milwaukee right-of-way near the confluence in sec. 31, T.1 S., R.6 E. Damage is minimal because the adjacent land is in pasture or small grains (SCS, 1972).

Urbanization

In addition to increasing peak flows and reducing the lag time of the flood peak, urbanization causes severe channel changes over time. Elimination of small subtle swales and ephemeral channels either by design or ignorance reduces the number of available surface channels for a given area. Runoff is thus confined to fewer channels incapable of handling the increased flows and erosion is initiated. The ultimate result is an enlarged channel.

The steps leading up to the enlarged channel warrant some attention. First, the channel cross-section decreases by deposition within the channel. As expected, the frequency of discharges which exceed bankful increase markedly. These changes, however, lag urbanization by 10 to 15 years (Dunne and Leopold, 1978). Secondly, the initiation of higher peak flows due to decrease in surface channels and infiltration area starts a progressive enlargement of the channel. Stability is ultimately achieved in the form of an enlarged channel (Dunne and Leopold, 1978). The result of upstream development along Bozeman Creek, for example, could very well be increased erosion and higher peak flows from Kagy Boulevard downstream.

The partial-variable source area phenomenon of surface flow generation is extremely important to developers, especially in areas of shallow slopes near flowing streams (Gregory, 1973). Runoff comes from many places in a drainage basin. For example, in areas of low permeability or zones of saturated soil, rainwater cannot infiltrate and the water ponds on the ground surface. If enough water collects, downslope flow is initiated. In areas near the drainageway the water table is commonly close to the ground surface. As a result, saturation is easily achieved and runoff is very common from this part of the drainage basin (Dunne and Leopold, 1978). The size of the saturated area will vary depending on ground water flow, soil characteristics, and the intensity and duration of the storm event.

Partial-variable source areas are an integral part of drainage basin's hydrologic system and can affect construction practices in a variety of ways. Excavation removes vegetation and the soil binding influence of roots resulting in accelerated soil erosion from higher runoff. The areas have a naturally high water table which precludes septic drainfield siting and houses with basements, and influences the foundation bearing capacity of the soil. Localized flooding potential is high in the partial-variable source areas from sheet flow and occasional overbank flooding. Finally, plants in these areas act as filters which protect streams from sediment and chemical pollution. The areas may be identified by noting the existence of a swale or small drainageway, saturated soil in the spring, water-loving grasses and shrubs and the presence of green grasses late in the summer.

Because many low gradient swales along major flowing streams are potential partial-variable source areas, they are not specifically identified on Plates 3 or 6 in the interest of map simplicity.

Future Problems and Recommendations

Bridger Creek. Development along Bridger Creek seems unlikely, given its past history of limited development. Factors which may limit the area to development are the needs of the bordering landowners, its inherent natural character, present agricultural use, the high ground water table, and designation as a flood plain. If development is proposed, every effort should be made to preserve the natural state of the stream and flood plain to minimize flooding and erosion problems.

East Gallatin River. Potential problems seem most probable from the East Overflow Channel inlet culvert on the East Gallatin to the confluence with Bozeman Creek. A mixture of residential, industrial and commercial developments are planned along the stream, or near the 100-year flood plain. All of these developments will contribute to runoff and reduce offstream flood storage. Large roof areas and large expanses of impervious parking and storage surfaces may generate some localized flooding. Pollution from sediment and chemical wastes from parking lots may increase unless control measures are implemented.

Channel degradation from Bohart Lane northwest to "L" Street will continue under the present use conditions. Overgrazing should be stopped and, if necessary, banks revegetated to slow bank erosion. Future uses should allow the meander curve migration to continue as part of the natural system. The same recommendations apply to the segment from the stockyards to the confluence of the East Gallatin River with Bozeman Creek. An effort to remove debris (car bodies, etc.) would increase channel cross-section, encourage natural vegetation to stabilize banks and improve channel appearance.

Bozeman Creek. In addition to the extensive recommendations outlined in the 1980 Bozeman Creek Watershed Preliminary Report the following basic suggestions are offered:

1. Dwellings should be sited on minimally altered lots in a manner which best preserves and maintains the natural drainage system to limit local flooding.
2. Construction activities should be staged so that ground disturbance is minimal or non-existent during periods of high surface runoff to reduce erosion.
3. Provide sediment control at the site through catch basins, minimal vegetation removal, and immediate revegetation of disturbed areas to further reduce erosion.
4. Build detention basins in natural drainageways to attentuate runoff and collect sediment from high density developments. These basins are not infiltration ponds, but rather storage structures with a known outflow designed to fit a given storm hydrograph for the affected watershed, and would be water filled only during periods of peak runoff.
5. Designate and use stream flood plains as linear parks, open space, golf courses, etc. wherever possible. This allows the areas to be used by

the public with minimal risk to life and property during floods. Imaginative and flexible funding or land trade arrangements with developers and present landowners should be pursued to this end.

6. Use bridges of adequate span to minimize channel constriction.

The local streams, especially Bozeman Creek, have to varying degrees been altered by human activity, and structural controls may become a necessary part of the management program. Sound planning procedures and good communication between community officials and developers in the future will help to avoid escalating the existing flood hazard situation.

Ground Water

General

Ground water quality and quantity has apparently not changed a great deal since the time of the Hackett (1960) study (Dunn, D., 1981, personal communication). Wells throughout the valley showed varied depths in 1978 both higher and lower than well depths recorded in the early 1950's. Some old shallow wells proximal to the Gallatin Range have been deepened in recent years; the cause of the apparent loss of aquifer yield is not yet clear. Study area well data are found in Appendix B and on Plate 3.

Ground water supply from the stream valleys and alluvial fans near the mountains appears sufficient for residential development. Some areas such as the east portion of the Story Hills or mountainous areas with shallow soils and underlying bedrock will probably have limited available groundwater because of poor water bearing strata and/or questionable quality.

Distribution

Story Hills. The Tertiary alluvium of the Story Hills has not proven to be a high yielding aquifer (Plate 3). This may be due to the limited recharge area, its isolation from the valley alluvium, or limited transmissibility of the Tertiary alluvium. Appendix A gives a complete ground water history of the area.

The vertical and horizontal discontinuity of the alluvium makes well drilling success rather uncertain. The alluvium dips east-northeasterly at a low angle, making the north slopes of the Story Hills the most attractive for potential ground water.

Wells drilled near the bottom of the large east-west oriented coulee yield ample water for single family dwellings (Plate 3). The proximity of the wells to the deep coulee is probably the major controlling hydrologic factor on yields.

Stream valleys. The stream valleys offer the best potential for ground water because of recharge by surface streams and high inherent transmissivity (Hackett, 1960). Advantages of a ground water source and limited available surface rights may force developers and the city to seriously consider moderately high yield wells for domestic water. Excessive drawdown from such systems is not expected because of the high transmissivity (Hackett, 1960).

Sourdough Ridge-Mount Ellis Fan. Recharge of this area is from surface stream seepage into the fans and Tertiary alluvium (Hackett, 1960). The Tertiary rocks in this area have yielded more than 70 gpm over a short pumping period (Appendix B, well 2-6-20C and Plate 3). Present housing density has not affected the ground water; and it is unlikely that higher density projects with a central water system would affect present water supply levels provided wells are adequately spaced and drilled deep enough.

Mountain areas. Well yields are generally much lower and wells much more shallow in mountainous areas unless a fault zone or joint system is encountered in the underlying limestone, sandstone or granitic bedrock. For example, the city water source from Lyman Creek is a spring located at the intersection of two faults in the Madison Limestone (McMannis, 1955).

Constraints

Ground-water table. People who live on or plan to build on the flood plain should be prepared for problems associated with high ground. To meet sanitary requirements, the measured minimum depth to ground water for a septic drainfield is six (6) feet, with the test conducted during the period of highest ground water in May or June. The most common cause of wet basements is high ground water resulting from inadequate landscaping close to dwellings and the uncompacted nature of backfill materials near the foundation (Wells, 1977). Additional problems from a high water table include reduced runoff storage and foundation-bearing capacity limitations and frost heaving in soils with a high clay or silt content.

Pollution. Research conducted for the Blue Ribbons of the Big Sky Country 208 Water Study (1978), showed no obvious areas of ground water pollution within the valley. A possible increase in dissolved solids was detected, and if valid, is primarily attributed to a change in land use from natural prairie to farming (Dunn, D., 1978, personal communication). No significant changes in water quality are expected given the historical data (Dunn, D., 1978, personal communication).

Supply. Recent (1978) well data indicates that no downward trend in the ground water level is occurring in the valley area (Dunn, D., 1981, personal communication). There is no indication that the ground-water supply for the immediate study area is declining or will decline with future demand. Only one area, the high elevation, east portion of the Story Hills has notable supply problems for the projected population (Plate 3 and Appendix A). Numerous alternatives are available to address the supply problem, if and when, development levels demand it. (See Appendix A).

CHAPTER VI

CONSTRUCTION CONSTRAINTS

General

For the purpose of this study, Construction Constraints are defined as any existing natural or man-caused condition or process which imposes limitations on construction in the area. These constraints include: (1) geologic limitations from unstable slopes, incompetent and failure-prone geologic strata and fault areas; (2) hydrologic parameters of high ground water, flooding, erosion and the partial-variable source area problem; (3) soil conditions such as man-made soils in dumps and fills, saturated and frost-prone soils in flood-plain areas, and easily erodible soils; (4) topographic limitations of slope angle and aspect; (5) seismic shaking hazards; and (6) mass movement hazards.

Plate 6, titled Construction Constraints, is a composite of the constraint information from other sources. This does <u>not</u> mean that all areas on the map with constraints are precluded from development; it is simply a means of showing the existing limitations which need to be recognized. The manner in which these limitations are addressed is dependent on the extent of human activity, the relative risk(s) inherent in the constraint(s), and in some cases the money available to mitigate the problem.

Problems and Recommendations

Geological Problems

Landslide areas, rockslides, unstable and potentially unstable slopes and fault areas are geologic conditions which are often best dealt with through avoidance. The remedial costs to correct the problems of man's interference often exceeds the value of the land and property involved. Unstable and potentially unstable slopes deserve special attention because of their inherent risk for failure. Utilities, roads, and dwelling should be carefully engineered if the constraint cannot be avoided. Areas displaying very recent landsliding or rockslide activity should be avoided when possible. The instability of such areas is obvious, often documented and sometimes avoidable. If use of such areas is unavoidable, the proposed remedy should be carefully engineered by qualified engineers and/or geologists.

Structures located near identified faults should have a minimum setback of one hundred (100) feet. Larger public buildings require greater setbacks. Where faults are presumed or covered by alluvium and building is allowed, the builder should follow strict building procedures and adhere to the Uniform Building Code requirements for Zone 3 earthquake areas. Lending institutions would do well to monitor loans for construction in such areas to protect their investment.

Hydrologic Problems

Chapter V discusses in more detail the hydrologic constraints of the study area, so the following is a brief overview of construction-related problems. Flooding problems are important to everyone and flood-prone areas have been relatively well defined. Septic limitations in the study area due to high water table problems are best addressed by the county sanitarian, the Soil Conservation Service, or other qualified professional. High clay soils and a high groundwater table are generally associated with stream channels, flood plains and surface drainageways. Because partial-variable source areas are part of the surface and groundwater systems their elimination or disruption can cause many problems for the contractor, homeowner, or developer. Building to fit the natural topography of a given site would be a major step in dealing with this problem.

Soils

Erosion can be reduced by the basic procedures outlined in Chapter IV, Geologic Constraints - Soils. Seasonal timing of construction projects to avoid high runoff-rainfall periods (a long-time Forest Service practice regarding logging activities) would help reduce erosion and improve site conditions for the contractor.

Identifying and mapping man-made soils would help protect future excavators and builders from needless surprises, not unlike those encountered by the highway contractor who unknowingly unearthed a buried landfill directly in the path of a connecting link to the Northwest Bypass in Great Falls. These kinds of soils are not easily compactable because of the mixed materials, and have a tendency for differential compaction over time. Such soils may pollute shallow groundwater or surface water with both sediment and chemical constituents. These soils should be avoided in areas where heavy structures are to be built or where high volumes of heavy traffic are anticipated. The best solution is to know the location of such materials so that site developers can avoid them or at least know what confronts them.

Topography

Slope angle not only limits access to a builder, but restricts septic drainfield alternatives and increases the potential for slope failure (Dunne and Leopold, 1978). Most steep slopes are found in the public lands of the Gallatin and Bridger mountain ranges and along the drainageways of the Story Hills and Sourdough Ridge-Mount Ellis fan areas. Occasionally, a steep slope problem can be solved through careful engineering by a qualified individual. the costs and risks of such activities must be borne by the landowner, who too often is not cognizant of the hazard(s) involved.

Increasing energy costs and a marked upturn of available solar devices and technology will very likely encourage more homebuilders to seek out south slopes. In fact, two solar-heated houses have already been built in the Story Hills.

Seismic Shaking

Regardless of the building site location, adherence to the Uniform Building Code is recommended for all of Southwest Montana. "From the 1976 Edition of the Uniform Building Code, sections of note include 2312 (earthquake regulations), 2130 (wall anchorage), 3704 (anchorage of chimneys), and 1807K (anchorage of mechanical and electrical equipment in highrise structures)" (Bela, 1979). Present codes do not address ground response or resonance amplification between buildings and underlying soils. This information will soon be available in the Applied Technology Council (A.T.C. 111) Code (Bela, 1979).

Conclusion

Construction constraints are the composite synthesis of this paper. Plate 6 is an attempt to visually integrate the natural limitations of a complex geologic environment. Areas displaying multiple constraint and/or hazard conditions warrant careful scrutiny and a cautious approach to planned development. Areas displaying few constraint or hazard conditions are those best suited to development.

REFERENCES CITED

Armstrong, J. C., 1977, Public Hearing for Bridger Canyon Road Plan: Montana State Highway Department and Gallatin County, Bozeman, Mont., March 17, 1977.

Bela, J. L., 1979, Geologic Hazards of Eastern Benton County, Oregon: Oregon Department of Geology and Mineral Industries, Bulletin 98, 122 p.

Birkeland, P. W., 1974, Pedology, Weathering, and Geomorphological Research: Oxford University Press, New York, 285 p.

Bourne, W. C., 1960, A Study of the Morphology and Pedogenesis of a Medial Chernozem Developed in Loess: Michigan State University, Ph.D. Thesis, 126 p.

Coates, D. R., ed., 1976, Urban Geomorphology: Geological Society of America, Special Paper 174, 166 p.

Davis, W. E., Kinoshita, W. T., and Robinson, G. D., 1965, Bouguer Gravity, Aeromagnetic, and Generalized Geologic Map of the Eastern Part of the Three Forks Basin, Broadwater, Madison and Gallatin Counties, Montana: United States Geological Survey Map GP 498, 5 p.

De Young, William, and Smith, L. H., 1936, Soil Survey of the Gallatin Valley Area, Montana: United States Department of Agriculture, Bureau of Chemistry and Soils Bulletin 16, Series 1931.

Dunne, T., and Leopold, L. B., 1978, Water in Environmental Planning: W. H. Freeman and Company, San Francisco, 818 p.

Evernden, J. F., Hibbard, R. R., and Schneider, J. F., 1973, Interpretation of Seismic Intensity Data: Seismological Society of America Bulletin, Vol. 63, No. 2, p. 399-422.

Gary, M., McAfee, R., Jr., Wolf, C. L., eds., 1974, Glossary of Geology: American Geological Institute, Washington, D. C., 805 p., bibliography.

Glancy, P. A., 1964, Cenozoic Geology of the Southeastern Part of the Gallatin Valley, Montana: Unpublished Masters Thesis, Montana State University, Bozeman, 66 p.

Gregory, K. J., and Walling, D. E., 1973, Drainage Basin Form and Process: John Wiley and Sons, New York, 458 p.

Hackett, O. M., Visher, F. N., McMurtrey, R. G., and Steinhilber, W. L., 1960, Geology and Groundwater Resources of the Gallatin Valley, Gallatin County, Montana: United States Geological Survey Water-Supply Paper 1482, 282 p.

Hansen, W. R., Chairman, 1975, Geologic Constraints in the Urban Environment: Report of the Committee on Environment and Public Policy, a panel convened by the Geological Society of America on February 27 and 28, Boulder, Colorado., Geological Society of America Depository No. 76-19, 12 p.

Housner, G. W., 1970, Strong Ground Motion in Wiegel, R. L., ed., Earthquake Engineering: Prentice-Hall, Englewood Cliffs, N. J., p. 77.

Keller, E. A., 1976, Environmental Geology: Charles E. Merrill Publishing Company, Columbus, Ohio, 488 p.

Legget, R. F., 1973, Cities and Geology: McGraw-Hill Book Company, New York, 624 p.

McMannis, W. J., 1955, Geology of the Bridger Range, Montana: Geological Society of America Bulletin, Vol. 66, pp. 1385-1430.

McMannis, W. J. and Chadwick, R. A., 1964, Geology of the Garnet Mountain Quadrangle, Gallatin County, Montana: Montana Bureau of Mines and Geology Bulletin 43, 47 p.

Nichols, D. R., and Buchanan-Banks, J. M., 1974, Seismic Hazards and Land Use Planning: United States Geological Survey Circular 690, 33 p.

Overturf, T. A., and Strand, R. C., 1974, Story Hills, A Planned Unit Development Concept for Bozeman, Montana: Overturf, Strand and Associates, Architects, Land Planners and Developers, Billings, Montana, 39 p., appendix.

Pardee, J. T., 1927, The Montana Earthquake of June 27, 1925: United States Geological Survey Professional Paper 147, p. 7-23.

Pool, J., 1977, Report of Foundation Investigation, Proposed Life of Montana Building, Bozeman, Montana: Prepared by Northern Testing Laboratories, Inc., Consulting Geotechnical Engineers, Billings, Montana.

Roberts, A. E. 1964, Geologic Map of the Fort Ellis Quadrangle, Montana: United States Geological Society, Miscellaneous Geological Investigations, Map I-397.

Roberts, A. E., 1964, Geologic Map of the Mystic Lake Quadrangle, Montana: United States Geological Survey, Miscellaneous Geological Investigations, Map I-398.

Robinson, G. D., 1961, Origin and Development of the Three Forks Basin, Montana: Geological Society of America Bulletin Vol. 72, No. 7, p. 1003-1014.

Robinson, G. D., 1963, Geology of the Three Forks Quadrangle, Montana: United States Geological Survey Professional Paper 370, 143 p.

Seed, H. B., 1981, Fundamental Seismology: Northern Testing Laboratory, Joint Technical Seminar, Great Falls, Montana, February 12, 1981.

Shelton, J. C., and Prouty, D., 1979, Nature's Building Codes, Geology and Construction in Colorado: Colorado Geological Survey Special Publication 12, 72 p.

Shouse, J. E., Project Director, 1978, Blue Ribbons of the Big Sky Country; Areawide Planning Organization: Final Report, 158 p.

Soil Conservation Service, 1972, Report of East Gallatin River and Upper Tributaries Flood Hazard Analysis Gallatin County, Montana: United States Department of Agriculture, Soil Conservation Service, Bozeman, Montana, 112 p.

Soil Conservation Service, 1980, Preliminary Investigation Report, Bozeman Creek Watershed, Gallatin County, Montana: United States Department of Agriculture, Soil

Conservation Service, Bozeman, Montana, 31 p.

Soule, J. M., 1975, Geologic Hazards in the Crested Butte-Gunnison Area, Gunnison County, Colorado: Information Series 5, Colorado Geological Survey, Denver, 33 p.

Tysdal, R. G., 1966, Geology of a Part of the North End of the Gallatin Range, Gallatin County, Montana: Unpublished Masters Thesis, Montana State University, Bozeman, 95 p.

Wells, W. C., 1977, Hydrologic Problems in Land Development Planning in Shelton, D. C., ed., Geologic Factors in Land-Use Planning: Colorado Geological Survey, Special Publication 8, p. 53-58.

Wills, L., 1976, Bridger Canyon Road May Be Open This Weekend: Bozeman Daily Chronicle, September 26, 1976, p. 1.

Witkind, I. J., 1980, The Concept of Active Faults as Applied to Urbanization and Mining: Geological Society of America, Rocky Mountain Section, 33rd Annual Meeting, Ogden, Utah, May 16-17, 1980.

Zaruba, W., and Mencl, V., 1977, Engineering Geology: Developments in Geo-technical Engineering, Vol. 10, Elsevier Scientific Publishing Company, Amsterdam, 504 p.

GLOSSARY

Aggradation -- the upbuilding by a stream of bed materials to establish or maintain uniformity of grade or slope; or upbuilding due to more bed load than the stream has energy to transport.

Alluvial channels -- a channel whose bed is composed entirely of alluvial materials.

Alluvial fan -- a low, outspread relatively flat to gently sloping mass of loose rock material, shaped like an open fan or cone segment; deposited by a stream at the place where it issues from a narrow mountain valley upon a broad plain or valley floor.

Alluvium -- the general term for clay, silt, sand, gravel or other unconsolidated detritus deposited during recent geologic time by a stream or other body of running water.

Aquifer -- the general term for the rock or soil material containing a good supply of groundwater; with the notable chracteristics of large volume, high drainable porosity and ease of water movement to a well.

Basin -- a topographically depressed area with no surface outlet; or in reference to water, a physiographic feature that is capable of collecting, storing, and discharging water by reason of its shape and nature of its confining materials.

Bearing capacity -- the load per unit of area which the ground can safely support without excessive yield.

Bentonite -- a montorillonite-type clay formed by the decomposition of volcanic ash. It is greasy to the touch and can swell to about 8 to 10 times when wetted and thus cause foundation problems.

Calcareous -- said of a substance that contains calcium carbonate.

Capture -- the natural diversion of the headwaters of one stream into the channel of another stream having greater erosional activity and flowing at another level.

Cement -- a chemically precipitated mineral material that occurs in the spaces among the individual grains of a consolidated sedimentary rock, binding the grains together to form a rigid coherent mass.

Clay -- an earthy, extremely fine grained material (particle diameter less than 0.005 mm). Clays become plastic when wet and hard upon drying.

Claystone -- A compacted, hardened clay having the texture and composition, but lacking the fine lamination or fissility of shale.

Colluvial deposit -- (gravity deposit) -- deposit formed by material moving or falling from an unstable position to a more stable one. Common types of colluvial deposits include landslides, mudflows, rockfalls, and talus.

Confluence -- a place of meeting of two or more streams, the place where the tributary joins the main stem.

Conglomerate -- a coarse-grained clastic sedimentary rock composed of rounded (to subangular) fragments, larger than 2 mm in diameter set in a fine-grained matrix of sand, silt, clay or any of the other common natural cementing materials (such as iron oxide, calcium carbonate, silica, or hardened clay).

Contact -- a plane or irregular surface between two different types or ages of rock.

Creep -- the slow, gradual, more or less, continuous, nonrecoverable (permanent) deformation sustained by ice, soil and rock materials under gravitational body stresses.

Cretaceous -- the final period of the Mesozoic Era, thought to have covered the span of time between 136 and 65 million years ago; also the corresponding system of rocks.

Depression (geomorph) -- any hollow in or relatively sunken part of the Earth's surface; especially a low-lying area completely surrounded by higher ground and having no natural outlet for surface drainage.

Detritus -- a collective term for loose rock and mineral material that is worn off or removed directly by mechanical means, as by abrasion or disintegration; especially fragmental material, such as sand, silt and clay derived from older rocks and moved from its place of origin.

Degradation (stream) -- the vertical erosion or downcutting performed by a stream in order to maintain or establish uniformity of grade or slope.

Dip -- the angle at which a bedded rock formation is tilted from the horizontal.

Dip slope -- a slope on the surface of the land that has approximately the same angle as the underlying formation.

Environmental geology -- the study of geology as it relates to man's activities and their impact on the environment.

Eocene -- an epoch of the lower Tertiary period after the Paleocene and before the Oligocene; also the corresponding series of rocks.

Ephemeral stream -- a stream or reach of a stream that flows briefly only in direct response to precipitation in the immediate locality and whose channel is at all times above the water table.

Epicenter -- the point on the Earth's surface which is directly above the focus of an earthquake.

Erosion surface -- a land surface shaped and subdued by the action of erosion, especially running water. The term is generally applied to a level or nearly level surface.

Fault -- a surface or zone of rock fracture along which there has been displacement, from a few centimeters to a few kilometers in scale.

Fault line -- the trace of a fault plane with the surface or with a horizontal plane.

Flood plain -- any flat or nearly flat, usually dry lowland that borders a stream and that may be covered by its waters at flood stages.

Fluvial deposit -- a sedimentary deposit consisting of material transported by, suspended in, or laid down by a river system.

Focus -- the point within the earth which is the center of an earthquake and the origin of its elastic waves.

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 homogeniety.

Frost potential -- the possible changes in soil volume and bearing capacity of fine-grained soils resulting from the effects of freeze-thaw action.

Geologic constraint -- the limits which natural processes or conditions impose on any given land use.

Geologic hazard -- a condition of land use when geologic constraints conflict with man's activity.

Ground motion -- a general term for all seismic motion, including ground acceleration, displacement, stress and strain.

Ground water -- that part of the subsurface water that is the zone of saturation, including underground streams.

Ground-water table -- that surface of a body of unconfined ground water at which the pressure is equal to that of the atmosphere.

Group -- a major rock-stratigraphic unit next higher in rank than formation, consisting wholly of two or more contiguous or associated formations having significant lithologic features in common.

Headcut -- a vertical face or drop on the bed of a stream channel, occurring at a knick point.

Holocene -- an epoch of the Quaternary period, from the end of the Pleistocene to the present time; also the corresponding rocks and deposits.

Igneous -- a rock formed by the cooling and solidification of a molten mass. This may occur within the earth or on the surface.

Impermeability -- the condition of a rock, soil, or sediment that renders it incapable of transmitting fluids under pressure.

Intensity (seismic) -- a measure of the effects of an earthquake at a particular place on humans and/or structures. The intensity at a point depends on earthquake strength, distance of the earthquake from the epicenter and local geology at the point.

Interbedded -- said of beds laid between or alternating with others of different character.

Joint -- a term for a planar fracture in solid rock along which little or no movement has taken place.

Landslide -- a general term covering a wide variety of mass movement landforms and processes involving the moderately rapid to rapid downslope transport of soil and rock material.

Lignite -- a brownish-black coal that is intermediate in coalification between peat and subbituminous coal.

Limestone -- a sedimentary rock comprised mainly of calcium carbonate ($CaCO_3$) formed in water by the gradual settling of calcium carbonate particles. Limestone is usually a hard, resistant rock especially in the arid West.

Meander -- one of a series of somewhat regular, sharp, freely developing, and sinuous curves, bends, loops, turns, or windings in the course of a stream. It is produced by a mature stream swinging from side to side as it flows across its flood plain.

Miocene -- an epoch of the Tertiary period, after the Oligocene and before the Pliocene; also the corresponding series of rocks.

Normal fault -- a fault in which the hanging wall appears to have moved downward relative to the footwall. The angle of the fault is usually between 45 - 90°.

Overturned -- said of a fold, or limb of a fold, that has tilted beyond the perpendicular. Sequence of strata that appears to be reversed.

Paleocene -- an epoch of the lower Tertiary period, after the Cretaceous period and before the Eocene epoch; the corresponding series of rocks.

Partial source area -- the concept of ground-water/surface water flow in which the ground-water surface in swales, coulees and small depressions rises more quickly than surrounding areas and surface water flow will occur in these areas first.

Permeability -- the property or capacity of a porous rock, sediment or soil for transmitting a fluid without impairment.

Pliocene -- an epoch of the Tertiary period, after the Miocene epoch and before the Pleistocene; also, the corresponding series of rocks.

Precambrian -- all geologic time, and its corresponding rocks, before the beginning of the Paleozoic; it is equivalent to about 90 percent of geologic time.

Quarternary -- the most recent geologic period extending from about 2½ million years ago to the present.

Rockfall -- an area subject to very rapid, intermittent and usually unpredictable rolling, sliding, bounding or free falling of rocks and debris or individual rock blocks.

Rockslide -- an area of active downslope movement of large masses of fractured bedrock and debris.

Sandstone -- a rock comprised mainly of sand-sized particles that have been compacted or cemented.

Sedimentary -- a term describing rocks formed by the accumulation or deposition of particles. These are commonly laid down by water, but can also be deposited by wind.

Shale -- a rock comprised of clay size particles which have been compacted or cemented. Shale is usually well stratified and in some cases, is weak and crumbly.

Siltstone -- a rock comprised mainly of silt size particles which have been compacted or cemented.

Solifluction -- the soil creep of a material saturated with water and/or ice; initiated by frost action and augmented by meltwater from alternate freezing and thawing of snow and ground ice.

Tear fault -- a very steep to vertical fault associated with a low-angle overthrust fault and occurring in the hanging wall. It strikes perpendicular to the strike of the overthrust; displacement may be horizontal and there may be a scissor effect.

Terrace (geomorph) -- a step like feature located on a slope; the terrace itself is flat or gently sloping and bounded above and below by steeper slopes. Terraces are considered to consist of alluvium and flank each side of a river valley.

Tertiary -- the first period of the Cenozoic era, thought to have covered the span between 65 million years ago to about 2½ million years ago.

Thrust fault -- a fault with a dip of 45° or less in which the hanging wall appears to have moved upward relatively to the footwall. Horizontal compression rather than vertical displacement is its characteristic feature.

APPENDICES

APPENDIX A

Story Hills Subdivision #3

Water Supply

History

Three wells were drilled during the initial development period of the Story Hills in 1974. The purpose was two fold: to establish a geologic framework in the area of a suspected fault and to locate a water supply sufficient to meet the needs of the development. The following well data begins with the non-producing wells (1 and 3) and ends with a discussion of producing well #2. Generally all 3 wells were drilled into Tertiary sediments collectively known as the Bozeman Group. These materials are laterally and/or vertically inconsistent sand, silt, clay and gravel with varying amounts of calcium carbonate cement.

Well #1

Location: ¼ mile south of the center of sec. 4, a few feet from the bottom of the deep E-W trending coulee which separates two distinct erosion surfaces.

Elevation: 5250 feet at the surface.

Depth: 541 feet. Bottom elevation 4709 feet. SWL (static water level) 480 feet or elevation 4770 feet. Perforation extent unknown. Cemented Cgl. at bottom.

Yield: 2 gpm.

Even though the well penetrates to a depth well below (100-150 feet) that of the East Gallatin River, insufficient water for a single family dwelling was obtained.

Some possible reasons for this limited flow are:

1. Penetration into a highly cemented portion of the sediments (gravel conglomerate).

2. Insufficient perforations in less confined (less cemented) section of the sediment pile.

Well #3

Location: 1300 feet SW of the center of sec. 3 on a possible slump in Tertiary sediments.

Elevation: 5285 feet at the surface.

Depth: 400 feet. Bottom elevation 4885 feet.

Material: 0 to 318 feet. Tertiary sediments.
318 to 400 feet. Cretaceous clays and shales (Mowry-Thermpolis ?)

Yield: Dry hole.

The change from gravels to clay at 318 feet infers the presence of the NW trending fault between the Tertiary sediments to the west and the overturned Cretaceous units to the east.

Well #2

Location: Approximately ¼ mile south of the NW corner of sec. 3. The well is about 250 feet east of the intersection of the existing road and the recently built Plutchack Way.

Elevation: 5425 minus 6 feet due to recent landscaping

Depth: 410 feet. Bottom elevation 5015 feet. Bottom is cemented conglomerate lying 40 feet lower than that of Well #1.

Material: 0-235 feet. Low permeability mixed silts and clays with zones of clayey gravels. 235-304. Clean sand and gravel with zones of very fine poorly graded sand. SWL 304-410. Mixed sands, gravels, silts and low permeability clay zones, bottoming on a cemented gravel conglomerate.

Yield: Originally estimated at 400 gpm, but tested at a maximum of 50 gpm.

Probable Water Source:

Preliminary assessments of the geological-groundwater relationship need review in light of more recent work. The original hypothesis included the following: "Location of the production well site was selected to take advantage of the major fault in the area which has created increased permeability of the materials." In the paragraph which follows: "From the information available and knowledge of the geologic profile of the area, the recharge area has been determined to be located generally east of Well #2. (Overturf, Strand, 1974, p. 5)."

The reasons for change are as follows:

1. 2000 feet east of Well #2, overturned lower Cretaceous (Colorado Group) rocks abut the Tertiary sediments along a NW trending fault.
2. The fault is topographically expressed by two deeply incised water courses. One trends north in the E½, E½, NW¼, sec. 3, and the other trends SE

in the SE¼, sec. 3. These water courses would act as a sink for water originating from the east.

3. Colorado Group materials behave as plastic masses under stress, and thus do not generate permeability enhancing joint systems. If anything, permeability is probably reduced.
4. Well #2 is located at the north central edge of a large ancient landslide. Any rearrangement of these Tertiary sediments due to landsliding would serve to close pore spaces and reduce permeability.

For these reasons, I suggest that the source of water for the present production well is derived from south and west in the Tertiary sediments.

NEW WELLS -- Location and Yield

Given the track record of wells in the Story Hills, it was unfortunate that a fourth major well was attempted in the summer of 1980. This rotary drilled well penetrated approximately 500 feet into the Tertiary sediments and was located about 1000 feet south of the beacon in the SW¼ of sec. 4. The well was dry and subsequently abandoned.

Location may not have been the only reason for the dry hole; rotary drilling, under pressure in these mixed sediments could very possibly have plugged any water bearing strata as the drilling progressed.

Though city sewer and water is planned for the western portion of the Story Hills, this doesn't solve the water supply problems for the E½, sec. 4 and developable areas of sec. 3. The 50 gpm capacity (estimated) of Well #2, even with storage, simply isn't adequate for the planned low density housing. To address these problems, I suggest that the alluvial valleys of Bridger Creek or the East Gallatin River be developed to provide higher volume wells at much lower capital costs. The problems of site access, land ownership and/or easements, and pipeline to storage facility easements should be assessed before commitments to develop the eastern portion of the Story Hills proceeds.

The following is a letter addressing one possible solution to the water supply problem of the Story Hills.

26 March 1981

Mr. John Schunke
Morrison-Maierle, Inc.
202 East Kagy Blvd.
Bozeman, Montana 59715

RE: Story Hills Water Supply Problem

Dear John:

Our discussion on March 20, 1981, about the somewhat confused data presented in the zoning meeting over water yields, etc. prompts this letter which I hope will ease the conflict and benefit all parties concerned.

The water supply difficulty was recognized early in 1974 after Potts Drilling managed only limited yields from 3 wells. Hillman's dry hole on the south flank of "Beacon Hill" in 1980 only served to reinforce conclusions that I, and others have reached, about water availability in the Story Hills proper.

I support the approach suggested by Tom Strand in 1974 for developing the western segment of the Hills property and which we discussed on March 20, 1981. The cost effectiveness of shallow high yield wells in the alluvial valley of the East Gallatin with booster pumps, pipeline and storage facilities certainly seems to outweigh any further investment in the Hills proper. To meet the needs of the zoning commission and to adequately address the water supply question, I suggest the developer(s) do the following:

1. Contract to have a well drilled in tract 1 close to available power with pump and pipeline siting in mind to minimize future costs.

2. Conduct a pump test of 24 hours or until the water level stabilizes to obtain the best possible yield and drawdown information.

3. Carefully monitor the effect of this pump test on nearby wells to insure that wells already in use will not be adversely affected by the test well drawdown.

4. Determine the best well spacing interval suited to the needs of the developer which would not interfere with established wells.

Without the benefit of city water for the west sector development, the most economic and efficient solution to the problem starts with a test well proximal to the west side of the Story Hills.

Sincerely,

Earl F. Griffith

Earl F. Griffith
Geologist-Hydrologist

EFG/cef

cc: Rick Mayfield
Paul Bolton
Ed Juvan
Art Van't Hull
Walt Anderson

APPENDIX B

WELL DATA

The table which follows is a partial listing of well data for the study area. The list is not complete because many logs weren't available or were not sufficiently documented as to yield, specific location, depth etc. to be used.

Location and general data symbols and terminology are as follows:

e.g. Well 2-6-4Ad

2 -- Township 2 South

6 -- Range 6 East

4 -- Sec. 4

A -- NE¼ sec 4 (B=NW¼, C=SW¼, D=SE¼)

d -- SE¼, NE¼ and so on

Additional symbols and terminology

Tert -- Geologic source material (Quaternary or Tertiary)

D -- Domestic Use

SWL -- Static water level (feet)

80-T -- Capacity (GPM) and method of test (T--Turbine, A--Air)

TABLE IV

STUDY AREA WELL DATA

Location	Geologic Source	Use	Depth	SWL (in feet)	Capacity and Test GPM	Casing Size	Driller and Method	Date Drilled
1-6-34Bc	Fault Zone Cambrian (?)	D	200	4'7"	19	12"	Liberty Churn Drill	1960
1-6-33Ca	Tert-Quat (?)	D	95	60	5	6	Haggerty Cable Tool	1980
1-6-32Cd	Quat (?)	D	49	12	12	6	Jones Churn Drill	1960
2-6-3Ca	Tert-Cret Contact (?)	D	400	--	dry	6	Potts Cable Tool	March 1974
2-6-4Ad	Tert	D	440	330	50-A	6	Potts Cable Tool	March 1974
Redrill 2-6-4Ad	Tert	D	410	297	50-A	8	Potts Cable Tool	March 1979
2-6-4Db	Tert	D	500	--	dry	6	Hillman Rotary	1980
2-6-4Cd	Tert	D	541	480	2	6	Potts Cable Tool	March 1974
2-6-5Ac	Tert	D	138	50?	3-3	6	Haggerty Cable Tool	1980
2-6-5Ca	Tert	D	133	18	80-T	6	Potts Cable Tool	1978
2-6-8Ac	Tert	D	125	80	25(?)	6	Hillman Rotary	1980
2-6-16Dc	Tert	D	125	85	12	6	--	1962
2-6-18Dc	Quat-Tert	D	66½	37	15	6	VanDyken Cable Tool	1958
2-6-20C?	Tert	D	150	132	6	6	Hulbert Cable Tool	1974
2-6-20C	Tert	D	262	183	90-T	6	Potts Cable Tool	1977
	5 hours @ 90 GPM -- SWL 200'							
2-6-22D	Tert	I	18	--	40 ?	6	--	1955
2-6-22A	Tert	I(?)	25	--	9	6	--	1955
2-6-30C	Quat	I(?)	45	14	60	6	--	1955
2-6-30D	Quat Tert	D	121	42	10	6	VanDyken Cable Tool	1967
2-6-29C	Tert	D	142	107	15	6	VanDyken Cable Tool	1976