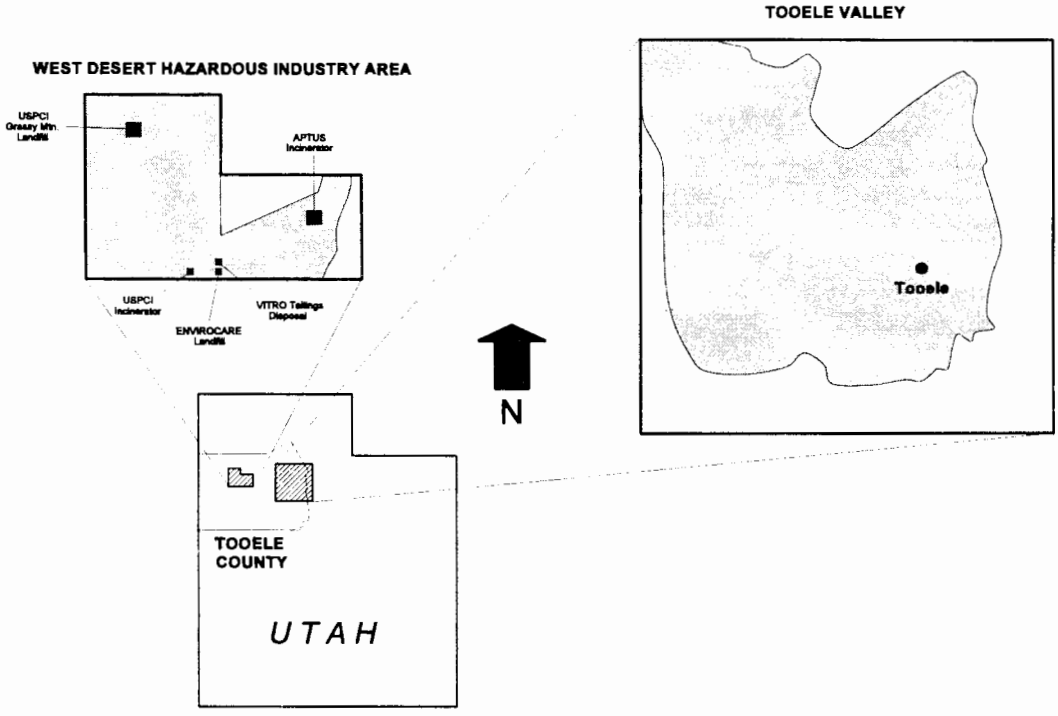
GEOLOGIC HAZARDS AND LAND-USE PLANNING FOR TOOELE VALLEY AND THE WEST DESERT HAZARDOUS INDUSTRY AREA, TOOELE COUNTY, UTAH

Barry J. Solomon and Bill D. Black, editors



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EXECUTIVE SUMMARY
AND
GUIDE TO GEOLOGIC HAZARDS IN LAND-USE PLANNING

by

Barry J. Solomon

Geologic hazards are naturally occurring geologic processes that present a risk to life and property, and are important factors to be considered prior to development. Under Chapter 12 of the Zoning Ordinance, Tooele County may require that special site-specific studies be performed to identify geologic hazards at sites proposed for development. Reports of study results, recommending measures for hazard reduction if necessary, should be submitted to the county for approval prior to construction. Cities have a similar authority to require special studies under zoning ordinances, subdivision ordinances, or development codes.

This report provides the basis for enforcing these land-use regulations. It identifies areas within Tooele Valley and the West Desert Hazardous Industries Area (WDHIA), Tooele County, where special studies should be performed because of the potential for geologic hazards. The report contains a text which discusses geologic hazards, and maps which show areas where hazards may exist.

The report text is divided into sections, each of which discusses individual geologic hazards or groups of closely related hazards. Each section is designed to stand alone and is organized as listed below. Hazard maps are provided with selected sections.

- INTRODUCTION - A brief overview of the basis for considering the hazard.
- CHARACTERISTICS - A definition of the hazard and why it occurs.
- EFFECTS - A description of the potential consequences of each hazard.
- HAZARD REDUCTION - A summary of techniques to reduce potential effects, or avoid the hazard.
- USE OF HAZARD MAPS - In selected sections, a description of information used to assess the hazard potential and recommendations on how planners may use the hazard maps.
- SITE INVESTIGATIONS - A summary of the scope of detailed site

investigations recommended in areas of potential hazards.

- REFERENCES - A list of references used to prepare each chapter.

Associated with selected sections are a set of maps (plates 1 through 5). These maps show areas of similar hazard potential or susceptibility, and are designed to indicate areas where site-specific investigations should be required by local governments prior to development. Table 1 gives our recommendations regarding requirements for these investigations, which should be conducted by qualified professionals, chiefly engineering geologists and geotechnical engineers. Maps have been prepared for the WDHIA at a scale of 1:50,000, and for Tooele Valley at a scale of 1:24,000 on U.S. Geological Survey topographic quadrangles, of hazards for which sufficient data exist. Maps included with this report are:

- SURFACE FAULT RUPTURE - During a large earthquake, fault rupture at depth causing the earthquake may propagate upward and displace the ground surface. This commonly results in formation of a main scarp and adjacent zone of deformation. The zone of deformation, which may be several hundred feet wide along the main fault trace, includes features such as ground cracks and tilted and downdropped blocks.

  The Oquirrh fault zone (OFZ) at the eastern margin of Tooele Valley is the only fault zone in either Tooele Valley or the WDHIA known to have ruptured the surface during Holocene time (the last 10,000 years). The most recent surface fault rupture occurred along the OFZ between 4,300 and 6,900 years ago, and a significant potential exists for it to recur. Several smaller faults in southeastern Tooele Valley and northern Rush Valley may have ruptured during the last 10,000 years, but conclusive evidence is lacking. Maps show main fault traces of the OFZ and smaller faults, and also show special study areas that are generally 1,000 feet (300 m) wide centered on the main fault scarps. These areas are where the potential for surface fault rupture and related deformation should be determined for certain land uses by special studies prior to development. Design of structures to withstand surface fault rupture is difficult, and we recommend certain facilities be set back a safe distance from active faults identified by site-specific studies.

- LIQUEFACTION SUSCEPTIBILITY - Liquefaction occurs when earthquake ground shaking causes certain soils to liquefy, lose their ability to support structures, and in some cases move downslope. Liquefaction susceptibility maps address ground-water conditions and soil properties conducive to liquefaction. Areas most susceptible to liquefaction are northern Tooele Valley and the western WDHIA.

Table 1. Recommended requirements for site-specific investigations for geologic hazards mapped in this study (modified from Lowe, 1990a, table A-1). Site-specific investigations (for all development types) are also recommended for other geologic hazards described in the text but not mapped because of insufficient regional information.

Hazard	Hazard Area Designation	Development Type			
		Essential facilities, lifelines, special- and high-occupancy buildings	Industrial and commercial buildings (other than high-occupancy)	Residential subdivisions	Residential single lots
Surface fault rupture *(plate 1)*	In (SFR)[1]	Yes	No[2]	No[2]	No[2]
	Out	Yes	No	No	No
Liquefaction *(plate 2)*	High and Moderate	Yes	Yes	No[2]	No[2]
	Low and Very Low	Yes	No	No	No
Landslides *(plate 1)*	High and Moderate	Yes	Yes	Yes	Yes
	Low and Very Low	Yes	No	No	No
Debris-slide/flow susceptibility *(plate 3)*	High and Moderate	Yes	Yes	Yes	Yes
	Low	Yes	No	No	No
Debris-flow/flood deposits and stream flooding *(plate 3)*	In (DFF)[1]	Yes	Yes[3]	Yes[3]	Yes[3]
	Out	Yes	No	No	No
Rock fall *(plate 4)*	In (RF)[1]	Yes	Yes	Yes	Yes
	Out	Yes	No	No	No
Lake flooding *(plate 1)*	Great Salt Lake: below 4,217 ft Rush Lake: below 4,979 ft	Yes	Yes	Yes	Yes
	Great Salt Lake: above 4,217 ft Rush Lake: above 4,979 ft	No	No	No	No
Ponding and sheet flooding *(plate 1)*	In (PSF)[1]	Yes	Yes	Yes	Yes
	Out	Yes	No	No	No
Shallow ground water *(plate 4)*	0-10 ft	Yes	Yes	Yes	Yes
	10-30 ft	Yes	Yes	Yes	Yes
	30-50 ft	Yes	No	No	No
	>50 ft	Yes	No	No	No
Expansive soil *(plate 5)*	In (Xclay)[1]	Yes	Yes	Yes	Yes
	Out	Yes	No	No	No
Gypsiferous soil *(plate 5)*	In (Gyp)[1]	Yes	Yes	Yes	Yes
	Out	Yes	No	No	No

[1]Recommended requirements are for site-specific geologic-hazards investigations in hazard areas designated by the symbols in parentheses.
[2]Appropriate disclosure should be required.
[3]Site-specific investigations are required in canyon bottoms and at canyon mouths along mountain fronts, where no debris basin or flood-control structure exists above the site. Elsewhere, site-specific investigations (or appropriate disclosure) are at the discretion of the Tooele County Department of Engineering.

Although the maps do not address the probability of earthquake ground shaking sufficient to cause liquefaction, other studies show a significant potential for liquefaction-induced ground failure sufficient to cause moderate to severe damage in areas of high susceptibility in Tooele Valley. Because of a lesser earthquake potential, the hazard is substantially lower in the WDHIA. Avoidance of areas susceptible to liquefaction is usually not necessary. Structural measures and site-modification techniques are available to reduce this hazard.

- LANDSLIDE HAZARD - Landslides are the downslope movements of blocks of rock or soil under the force of gravity. They are usually the result of changing moisture conditions in susceptible rock or soil (static conditions), but may be induced by earthquakes (dynamic conditions). Landslides may affect property, buildings, transportation routes, and utility lines, and may also produce flooding from damming of streams.

  Landslide maps show the location of existing deep-seated (greater than 10 feet [3 m] thick) landslides and the relative susceptibility of slopes to fail under static conditions. Only a few landslides exist in Tooele Valley; their scarcity is due to the competent rock. The landslide hazard is greatest in the Oquirrh and Stansbury Mountains at the south end of the valley, where the slide-prone Manning Canyon Shale is present in slopes. No landslides have been found within the WDHIA, where there is no significant landslide hazard. The landslide hazard under dynamic conditions was not evaluated, however areas most susceptible to static landsliding are generally most susceptible to earthquake-induced landsliding as well. Avoidance is the least expensive measure for landslide-hazard reduction, but engineering techniques are available to stabilize slopes and ensure that site grading and development do not destabilize slopes.

- DEBRIS-SLIDE, DEBRIS-FLOW, DEBRIS-FLOOD, AND STREAM-FLOODING HAZARDS - Debris slides, debris flows, debris floods, and stream floods form a continuum of sediment/water mixtures which originate in mountain canyons, but may cause damage over large areas beyond canyon mouths. Loss of life and property damage may result from drowning, high-velocity impact, erosion, or burial.

  Susceptibility maps show relative susceptibility to slope failure in areas where debris originates. In Tooele Valley, canyon slopes in the southern Oquirrh Mountains near Tooele are most susceptible, where over 90 debris slides and debris flows were identified; the WDHIA has a low susceptibility. Hazard maps show the location of existing debris-flow and debris-flood deposits and areas that may be impacted as debris and flood water travels downslope. The greatest hazards are in stream channels and gently sloping areas at channel mouths (alluvial fans) where streams issue

from mountain canyons. Such areas include alluvial fans along the Oquirrh and Stansbury Mountain fronts in Tooele Valley; the eastern portion of the WDHIA, which includes extensive alluvial fans deposited by streams from the Cedar Mountains; and small alluvial fans on the margin of the Grayback Hills in the WDHIA.

Avoidance of areas subject to these hazards is an effective means of hazard reduction, but is not always possible because active alluvial fans commonly exist within developed areas, including Tooele City. Hazard-reduction techniques include source-area stabilization, modification of the zone in which debris and flood water travel from source to destination, and engineered structures to control deposition. Flood warnings and floodproofing may also be effective to reduce the risk from stream flooding.

- ROCK-FALL HAZARD - Rock falls originate when erosion and gravity dislodge rocks from slopes. Rock falls commonly occur during storms and snowmelt, and may also be initiated by earthquakes. During a rock fall, dislodged material travels at high velocities and can pose a threat to structures and personal safety.

The hazard maps show areas potentially affected by rock falls. Rock-fall hazards are found in all mountain canyons, in Tooele Valley near the base of the Oquirrh and Stansbury Mountains and South Mountain, and in the WDHIA in the Grayback Hills. The best method of hazard reduction is avoidance, but modification or stabilization of the source area, construction of engineered barriers to stop or deflect rock-fall debris, and structural strengthening of facilities at risk are also possible.

- LAKE FLOODING, PONDING, AND SHEET FLOODING - Lake flooding refers to inundation of low-lying areas associated with rises in the level of Great Salt Lake. Temporary, localized flooding in low areas during storm runoff or snowmelt is termed ponding. Sheet flooding occurs when flood waters, often generated by intense storms, spread over an area and are not concentrated in a well-defined depression or channel. Lake flooding may be both seasonal and long-term and may produce significant property damage. Ponding and sheet flooding are generally seasonal or short-term phenomena, but they may repeatedly occur and cause significant local damage.

A lake-flood hazard may arise in northern Tooele Valley from an increase in the level of Great Salt Lake. The lake rose to an elevation of 4,217 feet (1285 m) in the 1600s, the record highstand in recent times, and may reasonably be expected to reach that elevation again in the future. A lake-flood hazard may also arise in northern Rush Valley from an increase in the level of Rush Lake. The highest measured elevation of Rush Lake was 4,979 feet (1,514 m) in the 1800s. Ponding and sheet flooding may

occur in the mudflats south of the Great Salt Lake shore in Tooele Valley, and in the mudflats of the Great Salt Lake Desert in the western WDHIA. Land use in the zone of lake flooding should be compatible with the hazard. Engineered flood-control measures are possible but often expensive and subject to events that exceed design criteria. Floodproofing measures are available for structures in areas subject to lake flooding, ponding, and sheet flooding.

- SHALLOW GROUND WATER - Ground water at depths of less than 30 feet (9 m) poses a hazard to basements, foundations, transportation routes, utility lines, and waste-disposal facilities. Shallow ground water also contributes to the potential of other geologic hazards, including liquefaction, surface flooding, expansive soils, and dissolution of soluble minerals. Shallow ground water is readily polluted by surface sources, and may ultimately contaminate deeper drinking-water supplies.

  Shallow ground water is present in northern Tooele Valley, and west of the Grayback Hills and in northern Ripple Valley in the WDHIA. Shallow ground water flooded basements in Erda in 1985 in response to several years of greater than average precipitation. Avoidance of below-ground facilities is the easiest solution to shallow ground-water problems, and is the recommended and often mandated solution when the proposed facility may result in environmental contamination. Foundation drains or pumps may be used to lower water tables, however both are expensive and unreliable long-term solutions.

- PROBLEM SOILS - Problem soils are surficial geologic materials susceptible to volumetric change, collapse, subsidence, dissolution, or other engineering problems. In the study areas, mapped problem soils are either expansive or gypsiferous.

  Expansive soils are clay-rich, and expand and contract with changes in moisture content. Such soils may crack foundations and road surfaces, and plug wastewater disposal systems. Expansive soils are a potential hazard in northern Tooele Valley, and from Ripple Valley westward in the WDHIA. The best method of hazard reduction is to control the amount of moisture available to the soil. Engineering techniques also exist to stabilize foundations and roads.

  Gypsum in soil may dissolve, resulting in settlement. Gypsiferous soils are also a weak material with low bearing strength, and weather to form sulfuric acid and sulfates which may react with cement and weaken foundations. Gypsiferous soils are found in mudflats of northern Tooele Valley south of the Great Salt Lake shore, and the Great Salt Lake Desert on the western edge of the WDHIA. Dissolution of gypsiferous soils may be avoided by reducing the amount of moisture available to the soil.

Sulfate-resistant concrete should also be used for foundations in areas with gypsiferous soils.

Maps indicate only where potential hazards may exist. We recommend that local government requirements for site-specific investigations, performed prior to issuance of building permits, be based on map hazard-area designations and development type as shown in table 1. The investigations may show that: (1) no hazards actually exist; (2) hazards exist, but recommended measures can reduce the hazards to acceptable levels or the hazard is already acceptably low ; or (3) hazards exist for which no hazard-reduction measures will suffice or are economically feasible, and the site is not suitable for the intended use. Once submitted to the local government, the report should be reviewed by qualified geologists and engineers and, if necessary, revised through additional investigations. Building permits should either be approved or denied only after submittal of complete investigation results. Once approved, it is important that report recommendations are followed during construction.

Additional geologic hazards are discussed in this report for which no hazard maps were prepared. As with other geologic hazards, these must also be considered in site-specific investigations:

- GROUND SHAKING - Ground shaking is the most widespread and frequent earthquake hazard, and is responsible for most earthquake-related damage. Tooele Valley and the WDHIA are susceptible to ground shaking from both nearby earthquakes and more distant earthquakes, such as those along the Wasatch fault zone. Ground shaking cannot be avoided, but can be reduced by adhering to seismic provisions in the Uniform Building Code (UBC) for all construction. Tooele Valley is in UBC seismic zone 3, and the WDHIA is in both zones 2B and 3.

- TECTONIC SUBSIDENCE - Tectonic subsidence is the warping, lowering, and tilting of a valley floor that may accompany large surface-faulting earthquakes. This hazard may cause inundation along lake and reservoir shores and ponding of water in areas with shallow ground water, and may adversely affect facilities that require gentle gradients or horizontal floors such as wastewater-treatment plants and sewer lines.

  Tectonic subsidence may be a hazard in northeastern Tooele Valley west of the OFZ associated with surface faulting on the fault, but is unlikely to occur in the WDHIA because no surface-faulting hazards have been identified there. Avoidance of this hazard is generally not practical because areas potentially affected may be large and difficult to define. Engineered flood-control measures are possible and floodproofing measures are available for structures in areas subject to flooding. Tilting may be considered in the design tolerance of structures that depend on gravity-induced flow, such as wastewater-treatment plants. Facilities which contain dangerous substances may incorporate safety features. Releveling of facilities may be required after large earthquakes.

- OTHER EARTHQUAKE HAZARDS - A variety of other hazards may accompany earthquakes. These include: (1) ground failure due to loss of strength in sensitive clays; (2) subsidence in granular materials from ground shaking, and (3) flooding caused by seiches in Great Salt Lake, surface drainage disruptions, and increased ground-water discharge. The extent of property damage and loss of life depends on the earthquake characteristics, duration of ground shaking, proximity to the earthquake epicenter, geologic and hydrologic conditions, nature of foundation materials, and building design.

  Tooele Valley and the WDHIA may be susceptible to these hazards from both local and distant earthquakes. The effects can be mitigated by special foundation designs or strengthening of structures subject to the hazard and, in the case of seiches, by the use of dikes and engineered breakwaters.

- DAM FAILURE - Dam failures generally occur with little or no warning. The severity of flooding depends on the size of the reservoir and the type of failure. The effects of dam failure may include loss of life and structural or other flood damage to buildings. In May of 1983 and 1984, stream inflow exceeded that which could be safely released from the Settlement Canyon Reservoir south of Tooele. Resultant floodwaters inundated Tooele streets, breached a dike, and damaged property.

  Dam-failure inundation studies are necessary to assess the likely extent of flooding caused by failure of dams in, and on the margin of, Tooele Valley. The WDHIA is not subject to dam-failure flooding because there are no dams in the vicinity. Land-use planning may restrict development in areas subject to dam-failure flooding, but a more common means of hazard reduction is a coordinated dam monitoring program and community emergency-response plan.

- PIPING AND MINE SUBSIDENCE - Piping is the subsurface erosion of fine-grained sediment by ground water. This erosion may create large underground voids which could collapse and cause surface subsidence. Fine-grained sediments deposited by Lake Bonneville, present in both Tooele Valley and the WDHIA, are susceptible to piping. The hazard potential may only be assessed with site-specific studies. Piping and related damage may be reduced by proper drainage.

  Subsidence can also be caused by collapse of underground mines. Mine subsidence is a potential hazard on mountain slopes adjacent to Tooele Valley. In areas above mines, the collapse potential should be assessed prior to development. The Utah Division of Oil, Gas, and Mining can provide information regarding mining activity and the potential for subsidence in these areas.

- INDOOR RADON - Radon is a naturally occurring radioactive gas that, when inhaled in sufficient concentrations, can cause lung cancer. High indoor-radon levels are more likely to occur in areas underlain by rock or soil with relatively high amounts of uranium, deep ground water, and high permeability. Indoor-radon levels also depend on weather, construction type, and occupant lifestyle. A detailed assessment of factors affecting indoor-radon levels has been conducted in Tooele Valley, but not in the WDHIA. The detailed study in Tooele Valley shows that the hazard potential is generally moderate; scattered areas of high hazard potential are found in the southern and western portions of the valley, whereas areas of low hazard potential are found in the northern portion. Regional data suggest that the radon-hazard potential is also generally moderate the WDHIA. The most effective means of determining indoor-radon levels is to conduct indoor tests. If excessive levels are found, the hazard can be reduced by a variety of construction modifications. Construction techniques may be applied to new buildings in areas of high hazard potential to reduce radon entry routes.

The geologic-hazard maps included with this report are generalized for planning purposes to show areas where site-specific studies are needed. The hazard potential of any specific area may differ from that shown on the maps. Moreover, hazards may exist that are not shown. The maps do, however, provide an indication of hazard potential that a prudent developer should consider prior to construction. Responsible local-government officials should consult the maps early during the planning and permitting process and use them to require the appropriate studies by developers. Utah Geological Survey staff are available to assist local governments in using these maps and reviewing final site-investigation reports.

SECTION A:
BACKGROUND

by

Barry J. Solomon

INTRODUCTION

Geologic studies have been conducted in Tooele County for more than a century. In the first study, an 1854 expedition across the Great Basin of the western U.S., Beckwith (1855) was inspired with the ancient shorelines of "Tuilla Valley" which "will perhaps afford....the means of determining the character of the sea by which they were formed...." Later, the great American geomorphologist G.K. Gilbert (1890) recognized that the landscape of the region had been shaped to a great extent by a large lake, rather than a "sea," and said of the Great Salt Lake Desert that "The area formerly covered by the main body of Lake Bonneville is now a plain, conspicuous for its flatness." He described the "'lost mountains' of Great Salt Lake Desert" as "circled by rocky and inhospitable coasts" during the Lake Bonneville highstand, but the "Cedar Range....bleak and barren as it now is, we may picture as then mantled with verdure (Gilbert, 1890)."

Today, geologic studies determine more than just the nature of ancient processes which formed the landscape. The study of geology provides information to evaluate geologic hazards that must be considered for safe and responsible development. To aid such development, the Utah Geological Survey (UGS) has undertaken a program of geologic hazards mapping throughout the state. Two areas were selected in Tooele County for assessment of geologic hazards (figure A-1): (1) Tooele Valley in east-central Tooele County, and (2) the West Desert Hazardous Industry Area (WDHIA) in north-central Tooele County. Tooele Valley contains most of the county's population, and is on the western margin of expanding metropolitan Wasatch Front communities. The WDHIA is an administrative unit established in 1987 by Tooele County to coordinate the development of hazardous-waste treatment, storage, and disposal facilities.

These areas have been severely impacted by geologic hazards in the last decade, and a variety of potential geologic hazards are present. Above-average precipitation in the early 1980s resulted in basement flooding in Erda from shallow ground water, surface flooding in Tooele City from rapid snowmelt and an uncontrolled release of water over the spillway from Settlement Canyon Dam, and landslides and debris flows in canyons in the Oquirrh Mountains on the east side of Tooele Valley. Potential geologic and related environmental hazards include contamination of ground water in basin-fill aquifers; rock falls, debris flows, and flash floods in canyons and along valley margins; and earthquake-related hazards. Adverse foundation conditions also occur. Silty and sandy sediments subject to liquefaction or hydrocompaction, clayey sediments and mudflats subject to shrinking or swelling, and gypsiferous dunes and mudflats subject to subsidence due to dissolution are all present in Tooele Valley and the WDHIA. A knowledge of these conditions and related hazard potential will

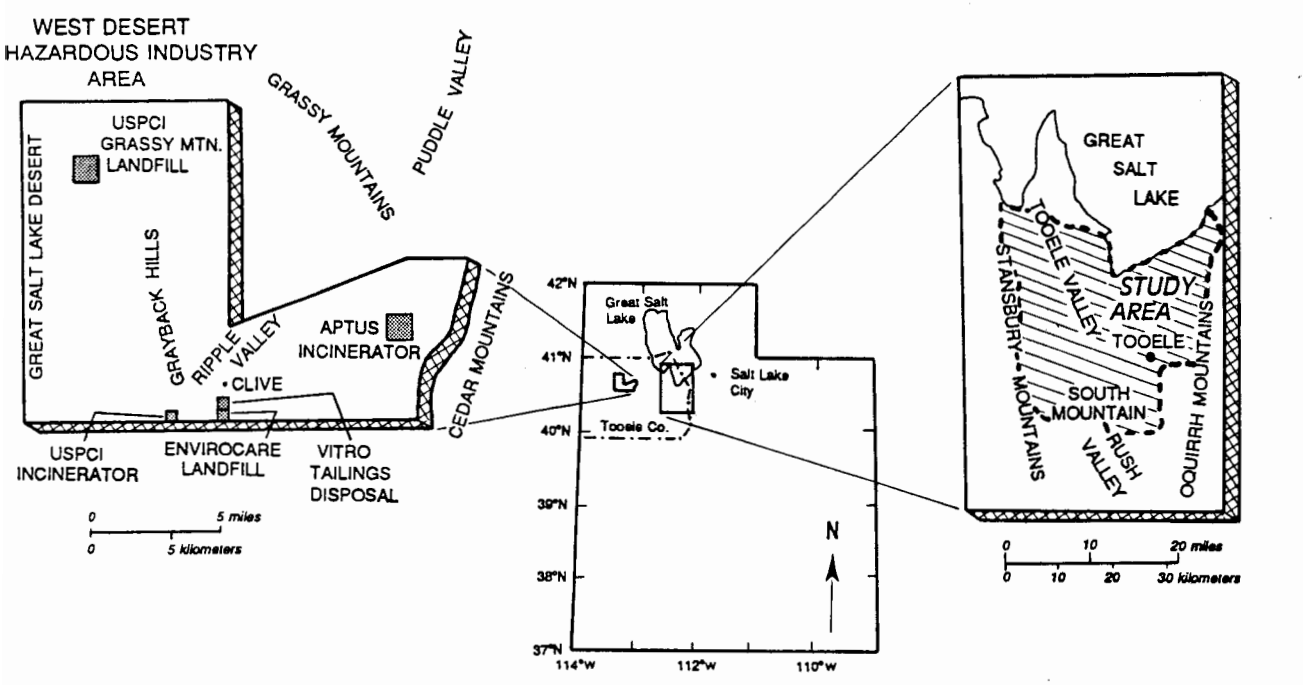

Figure A-1. Location map of Tooele Valley and the West Desert Hazardous Industry Area, Tooele County, Utah. The boundary of the Tooele Valley study area is shown by a dashed line.

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provide decision makers with valuable tools to undertake responsible action.

This report defines and describes the hazards, and delineates areas in which hazards are likely to occur. A summary of hazards and their distribution is shown on table A-1. Related reports previously published include a preliminary assessment of geologic hazards in the WDHIA (Solomon and Black, 1990), a description of landslides in the Oquirrh Mountains on the eastern margin of Tooele Valley (Harty, 1990), and a road log and summary of geologic hazards in Tooele Valley (Solomon and others, 1992).

PURPOSE AND METHODS

The purpose of this study is to provide a tool for early planning by compiling maps depicting pertinent basic geologic data and constructing derivative maps to delineate areas where adverse geologic conditions might occur. The report and maps are designed to be the basis for enforcing

land-use regulations, such as ordinances and development codes, regarding geologic hazards. Geologic criteria are important considerations for responsible development. Such criteria are best applied early in the planning process to minimize construction and maintenance costs and environmental contamination, and ensure safe siting of critical facilities.

The two study areas were selected after discussion with staff of the Tooele County Department of Engineering. A literature search was undertaken to determine geologic map coverage and the impact and extent of past geologic hazards in the study areas. Surficial geology of the study areas, the basic data from which many hazard interpretations have been derived, was first mapped on air photos. Accuracy of air-photo interpretation was checked with field investigations, and air-photo maps were then transferred to 7.5-minute topographic quadrangles at a scale of 1:24,000 (Solomon, 1993). Additional air-photo interpretation and field investigations inventoried existing geologic hazards and examined geologic materials to determine their potential for future impacts. Air-photo maps of geologic hazards, supported by field data, were then overlain on the geologic maps to construct derivative maps of hazard potential. Selected hazard interpretations were supplemented with computer modelling. The derivative maps, which delineate areas subject to geologic hazards, are compiled at the same scale as the geologic maps, and on the same base maps (figure A-2).

The maps are only to be used for planning purposes and to determine potential hazards that might be encountered. Once hazards at a site have been identified using these maps, the site suitability must be demonstrated by detailed site characterization. Our recommendations for studies and hazard reduction will reduce the likelihood of property damage or loss of life from geologic hazards. However, the level of risk acceptable to local governments could vary, and these recommendations for studies and hazard reduction should be tailored to fit individual needs. UGS staff are available to assist local governments in using these maps and reviewing final site-investigation reports.

SETTING

Tooele Valley is in east-central Tooele County (figure A-1), a rural county with a 1990 population density of about 3.8 persons per square mile (1.5 persons/km^2) and population of 26,601 (U.S. Census Bureau, 1990). The Oquirrh Mountains form the eastern border of Tooele Valley, and the Stansbury Mountains form the western border. Great Salt Lake lies to the north of Tooele Valley, which is separated from Rush Valley to the south by South Mountain. Drainage is north into Great Salt Lake.

The Tooele Valley study area is bounded by the Stansbury Mountain crest to the west, the county line between Tooele and Salt Lake Counties in the Oquirrh Mountains to the east, and the lake shore to the north, and includes the northernmost margin of Rush Valley to the south. The study area has a north-south dimension of about 17 miles (27 km), an east-west dimension of about 22 miles (35 km), and covers about 375 square miles (971 km^2). Elevations range from about 4,200 feet (1,280 m) at the Great Salt Lake shore to 11,030 feet (3,360 m) at Deseret Peak in the Stansbury

Table A-1. Hazard map summary.

		PLATE 1			PLATE 2	PLATE 3	PLATE 4		PLATE 5
		Surface Fault Rupture	Landslide Hazards	Lake Flooding, Ponding, Sheet Flooding	Liquefaction Susceptibility	Debris-slide, Debris-flow, Debris-flood, and Stream-Flooding Hazards	Rock Fall	Shallow Ground Water	Problem Soils
	TEXT SECTION	B	G	J	E	H	I	K	L
NO.	MAPPED AREA								
A	West Desert Hazardous Industry Area	-[1]	VL-L	X	VL-H	L-M[2]	X	A-D	Xclay, Gyp
B	Flux Quadrangle	-[1]	VL-M	X	VL-H	L-M[2]	X	A-D	Xclay, Gyp
C	Burmester Quadrangle	-[1]	VL[1]	X	M-H	L[2]	-[1]	A-B	Xclay, Gyp
D	Mills Junction Quadrangle	X	VL-M	X	VL-H	L-M[2]	X	A-D	Xclay, Gyp
E	Farnsworth Peak Quadrangle	X	VL-M	X	VL-H	L-M[2]	X	A-D	-[1]
F	North Willow Canyon Quadrangle	-[1]	VL-M	-[1]	VL-M	L-M[2]	X	B-D	-[1]
G	Grantsville Quadrangle	-[1]	VL-M	-[1]	VL-H	L[2]	-[1]	A-D	Xclay
H	Tooele Quadrangle	X	VL-M	-[1]	VL-H	L-M[2]	X	A-D	Xclay
I	Bingham Canyon Quadrangle	X	VL-L	-[1]	VL[1]	L-H[2]	X	D	-[1]
J	Deseret Peak East Quadrangle	-[1]	VL-M	-[1]	VL[1]	L-M[2]	X	D	-[1]
K	South Mountain Quadrangle	X	VL-M	X	VL-H	L-M[2]	X	A-D	Xclay
L	Stockton Quadrangle	X	VL-H	-[1]	VL-M	L-H[2]	X	B-D	-[1]
M	Lowe Peak Quadrangle	-[1]	L,H	-[1]	VL[1]	M-H	X	D	-[1]

X	Hazard occurs in the mapped area.	Xclay	Expansive clay.
-	Hazard does not occur in the mapped area.	Gyp	Gypsiferous soil.
VL-H	Hazard potential or range of potential: VL = Very Low L = Low M = Moderate H = High	A-D	Depth to shallow ground water or range of depth: A = 0-10 feet (0-3 m) B = 10-30 feet (3-9 m) C = 30-50 feet (9-15 m) D = >50 feet (15 m)

[1]No map is included because the hazard does not occur in the mapped area or the potential for the hazard is uniformly very low.

[2]Includes areas of sediment deposition and flooding from debris flows, debris floods, and stream flooding (DFF, table 1).

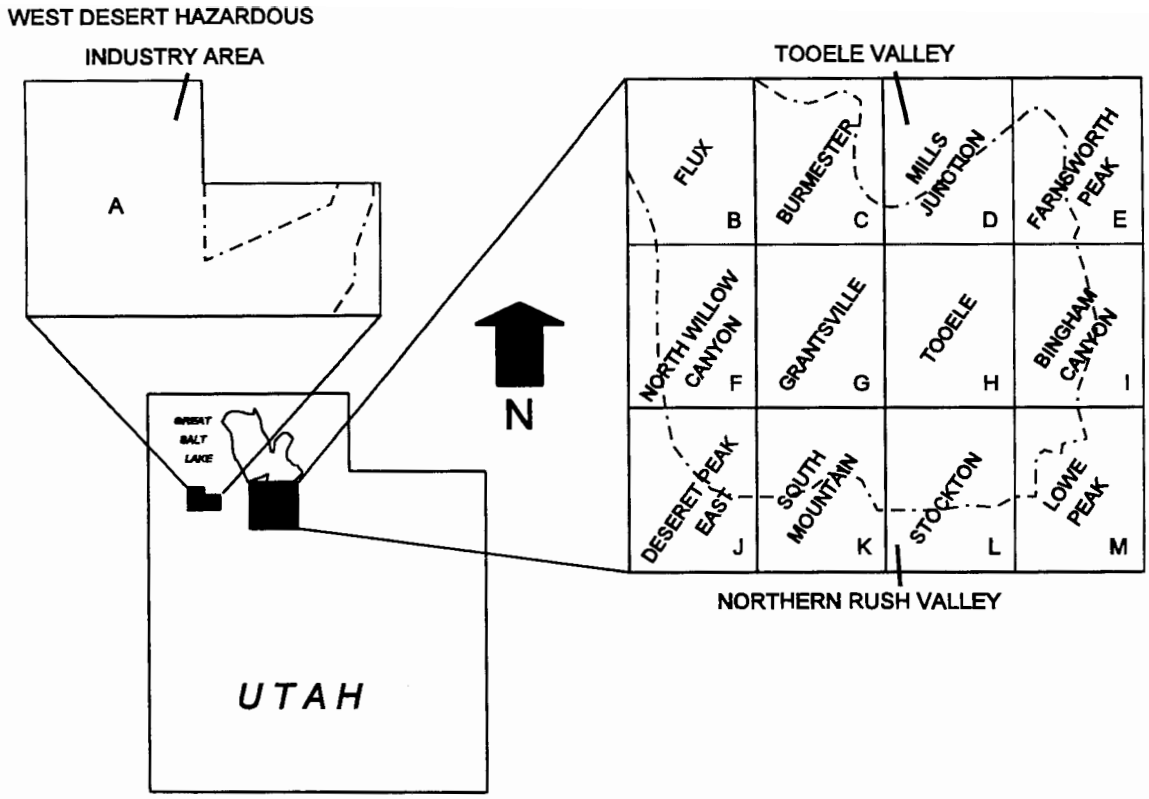

Figure A-2. Index map of Tooele Valley and the West Desert Hazardous Industry Area. Letters A through M are used in plate designations and table A-1. Study area boundaries are shown by dashed lines.

Mountains. The study area includes portions of twelve U.S. Geological Survey 7.5-minute topographic quadrangles (figure A-2).

Tooele City, in the southeastern corner of Tooele Valley, is about 30 miles (50 km) southwest of Salt Lake City. Tooele City is the county seat and largest community in the county, with a population of 13,887 in 1990 and more than 50 percent of the county total. Grantsville, in northwestern Tooele Valley, is the second largest community with an estimated population of 4,500 in 1990 (U.S. Census Bureau, 1990).

Tooele Valley has a semi-arid climate with wide seasonal and diurnal temperature variability typical of middle-latitude continental regions (National Oceanic and Atmospheric Administration, 1990). Tooele City has an approximate mean annual temperature of 50.7° F (10.4° C); mean monthly

temperatures are lowest in January (28.8° F [-1.8° C]) and highest in July (75.4° F [24.1° C]). Annual precipitation is 16.5 inches (42.0 cm).

The WDHIA, located in north-central Tooele County (figure A-1), is essentially uninhabited. The Great Salt Lake Desert bounds the WDHIA to the north, west, and south. The Grassy Mountains and Puddle Valley lie to the northeast, and the Cedar Mountains to the southeast. Ripple Valley is in the center of the WDHIA, and is separated from the Great Salt Lake Desert by the Grayback Hills. Drainage of the WDHIA is west into the Great Salt Lake Desert.

A zoning district established by the Tooele County Commissioners Board as "Hazardous Industrial District MG-H" defines the perimeter of the WDHIA. The district is about 20 miles (32 km) long, has a maximum width of about 15 miles (24 km), and covers about 140 square miles (363 km^2) (figure A-2). Elevations range from about 4,225 feet (1,288 m) in the western mudflats to 5,000 feet (1,524 m) in the foothills of the Cedar Mountains.

The WDHIA is about 65 miles (105 km) west of Salt Lake City. Four facilities operate in the area and one more is under construction (figure A-1). The first was established by U.S. Pollution Control, Inc. (USPCI) in 1981 when the Grassy Mountain hazardous-waste landfill opened. The site now contains several lined pits for the disposal of hazardous wastes, and equipment for the recycling and chemical destruction of other industrial by-products. In 1984, the Utah Department of Health opened a facility at Clive for the disposal of low-level radioactive mill tailings and associated contaminated residues and soil removed from the Vitro uranium mill in South Salt Lake City. The Vitro project encouraged Envirocare of Utah to open, in 1988, a landfill for low-level radioactive and mixed (low-level radioactive and hazardous) wastes adjacent to the Clive site. USPCI began operation in 1992 of industrial- and hazardous-waste transfer, storage, and incineration facilities, and similar facilities to be operated by Aptus are under construction. The incinerators are designed to thermally destruct both "hazardous" chemical waste materials, as defined under the Resource Conservation and Recovery Act, and "toxic" chemical waste materials, as defined under the Toxic Substance Control Act.

The WDHIA has an arid climate, unlike Tooele Valley, but both areas have in common wide seasonal and diurnal temperature variability. The WDHIA has an approximate mean annual temperature of 46.6° F (8.1° C); mean monthly temperatures are lowest in January (19.2° F [-7.1° C]) and highest in July (79.0° F [26.1° C]). Annual precipitation is 6.6 inches (16.8 cm).

ACKNOWLEDGEMENTS

Portions of the text dealing with descriptions of geologic hazards and hazard-reduction techniques were taken directly from previous UGS publications (Lowe, 1990a,b; Olig, 1991; Solomon and Sprinkel, 1991; Mulvey, 1992). Mike Lowe and Douglas A. Sprinkel (UGS), and William E. Mulvey and Susan Olig formerly with the UGS (as well as Robert M. Robison [former Utah County Geologist], Craig V. Nelson [former Salt Lake County Geologist], and Gary E. Christenson [UGS] in Lowe, 1990a,b) contributed to the creation of the original texts.

J. Raymond Johnson, P. Rodney Thompson, and Barry Formo, Tooele County Department of Engineering, provided valuable comments throughout the development of this project. This manuscript was reviewed by Gary E. Christenson, UGS, and we thank him for his critical comments and helpful suggestions.

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SECTION B:
SURFACE FAULT RUPTURE

by

Bill D. Black

INTRODUCTION

Movement along faults at depth generates earthquakes. During earthquakes larger than Richter magnitude 6.5, ruptures along normal faults in the intermountain region generally propagate to the surface (Smith and Arabasz, 1991) as one side of the fault is uplifted and the other side downdropped (figure B-1). The resulting fault scarp has a near-vertical slope. Faults that show evidence of recurrent movement during Quaternary time (last 1.6 million years) have a potential to generate earthquakes that could cause surface rupture; the potential is highest along those faults that show evidence of recurrent movement during the Holocene (last 10,000 years).

Surface fault rupture is a potential hazard in the Tooele Valley study area, but there are no known active faults (and therefore little potential for surface fault rupture) in the WDHIA. Tooele Valley is the result of millions of years of faulting, which has uplifted the Oquirrh and Stansbury Mountains on the east and west, and downdropped the basin between them (Everitt and Kaliser, 1980; Barnhard and Dodge, 1988). Although no surface ruptures have occurred in Tooele Valley in historical time, the Oquirrh fault zone (OFZ) along the base of the Oquirrh Mountains has had a large-magnitude earthquake accompanied by surface rupture within the last 7,000 years (Olig and others, 1994). Other faults in Tooele Valley and northern Rush Valley show evidence for activity during Quaternary time. A potential exists for surface rupture to recur along these faults, and structures which straddle them may be damaged or destroyed by surface fault rupture.

CHARACTERISTICS

Oquirrh Fault Zone

The OFZ is evident as a series of west-facing normal fault scarps 9.5 to 35.4 feet (2.9 - 10.8 m) high, which offset Quaternary alluvial deposits (Barnhard and Dodge, 1988). The scarps extend discontinuously 11 miles (17 km) north-south along the Oquirrh Mountains, from east of Lake Point to south of Middle Canyon (plates 1D, 1E, 1H, and 1I).

Studies have indicated evidence for active faulting on the OFZ. Paleoseismic data from trenches excavated across scarps near the mouths of Big Canyon (plate 1E) and Pole Canyon (plate 1D) suggest the most-recent surface-rupturing earthquake (MRE) occurred from 4,300 to 6,900 years

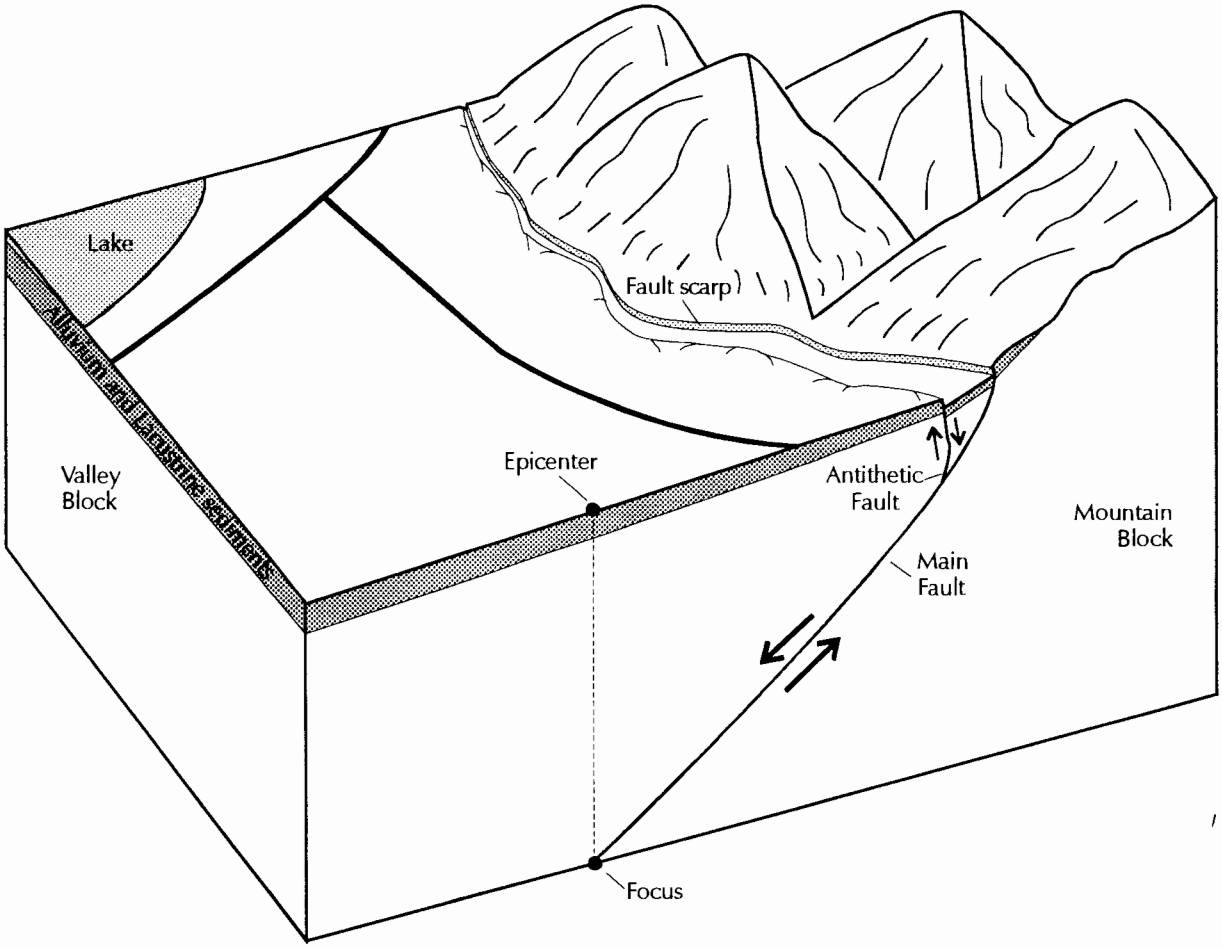

Figure B-1. Diagram of a normal fault showing relationship of the epicenter to the focus, and the trace of surface rupture (fault scarp). The fault plane likely dips 50-60 degrees toward the valley. Note the focus of the earthquake is beneath the valley (downdropped) block, not on the trace of surface rupture (modified from Robison, 1993).

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ago, with a penultimate event between 20,300 and 26,400 years ago and an antepenultimate event older than 32,800 years ago (Olig and others, 1994). Lund and others (1994) indicate the Bonneville shoreline was displaced 8 to 10 feet (2.5-3.0 m) during the MRE; a large amount considering the length (7.5 miles [12 km]) of surface rupture. There is also geomorphic evidence for recurrent faulting near the northern end of the OFZ, where the scarp of the MRE diverges from an older scarp (Barnhard and Dodge, 1988). The compound scarps, representing both the MRE and older surface-

faulting events, are up to twice as high as the single-event scarp and have surface displacements of up to 24 feet (7.3 m) (Barnhard and Dodge, 1988; Hecker, 1993).

Other Faults

Other faults in the Tooele Valley study area also have evidence for Quaternary movement. These include: (1) a discontinuous set of west-facing normal fault scarps south of Tooele (plates 1H and 1L), which offset late Pleistocene alluvial-fan deposits topographically above the Bonneville shoreline (Tooker and Roberts, 1992; Solomon, 1993); (2) a 0.2-mile (0.3-km) long west-facing normal fault scarp south of Stockton (plate 1L), which offsets Holocene to late-Pleistocene Lake Bonneville deposits (Tooker and Roberts, 1992; Solomon, 1993); and (3) a 0.8-mile (1.3-km) long east-facing normal fault scarp in northwestern Rush Valley near East Hickman Canyon (plate 1K), which offsets Pleistocene alluvial-fan deposits topographically above the Bonneville shoreline (Solomon, 1993). A Pleistocene-age fault not evident at the surface was also found in a gravel pit roughly 2 miles (3 km) northwest of Tooele (Utah Section of the Association of Engineering Geologists, 1994), and similar faults may occur elsewhere. No detailed investigations have been conducted on these faults and no paleoseismic data are available.

EFFECTS

During surface-faulting earthquakes, offset occurs on the main surface trace of the fault zone (Schwartz and Coppersmith, 1984). This offset forms a near-vertical scarp, commonly in unconsolidated surficial deposits, that begins to ravel and erode back to the material's angle of repose (33-35 degrees). Antithetic faults (faults with an opposite sense of movement from the main fault) on the downthrown side of the main trace may also form, generally exhibiting a lesser amount of offset, but sometimes as much as several feet (figure B-2). The zone between these two faults may be faulted and tilted in a complex manner. In some cases, a broad zone of flexure may form on the downthrown side of the main fault in which the surface is tilted downward toward the fault zone. Deformation associated with surface fault rupture can damage or destroy structures and sever lifelines.

HAZARD REDUCTION

It is difficult, both technically and economically, to design a structure to withstand several feet of offset through its foundation. Because surface fault rupture occurs without warning and is a life-threatening hazard, avoidance of the main trace of the fault is the principal hazard-reduction technique. However, in some areas adjacent to the main trace within the zone of deformation, avoidance may not be necessary. Less damaging (smaller) offsets and tilting may occur and structural measures may be taken to reduce damage and threat to life. However, structural damage

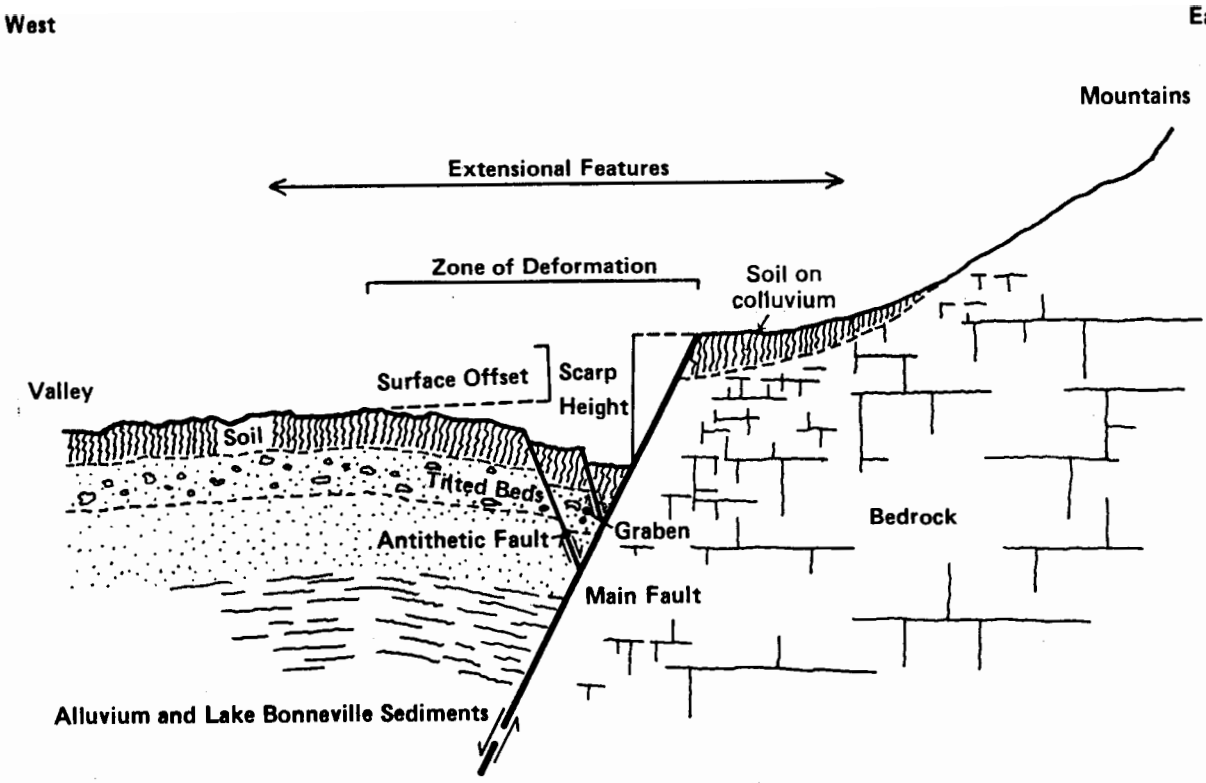

Figure B-2. Diagram of a normal-fault zone showing typical features near the ground surface. Although the sketch is not to scale, surface offset is usually 6-9 feet (2-3 m) (Robison, 1993).

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may still be great, and buildings in the zone of deformation may not be safe for occupants following a large earthquake.

USE OF HAZARD MAPS

Plate 1 shows main fault traces with the greatest potential for future movement in the Tooele Valley study area (figure B-3). These maps also indicate special study areas where surface-fault-rupture hazards need to be considered for certain land uses (table 1). The special study areas, which follow fault traces mapped by Solomon (1993), are about 500 feet (152 m) wide on both the upthrown and downthrown sides of the main fault scarp. Site-specific investigations addressing surface-fault-rupture hazards are needed in special study areas because the fault maps are not detailed enough to include all fault traces and delineate zones of deformation at a particular location.

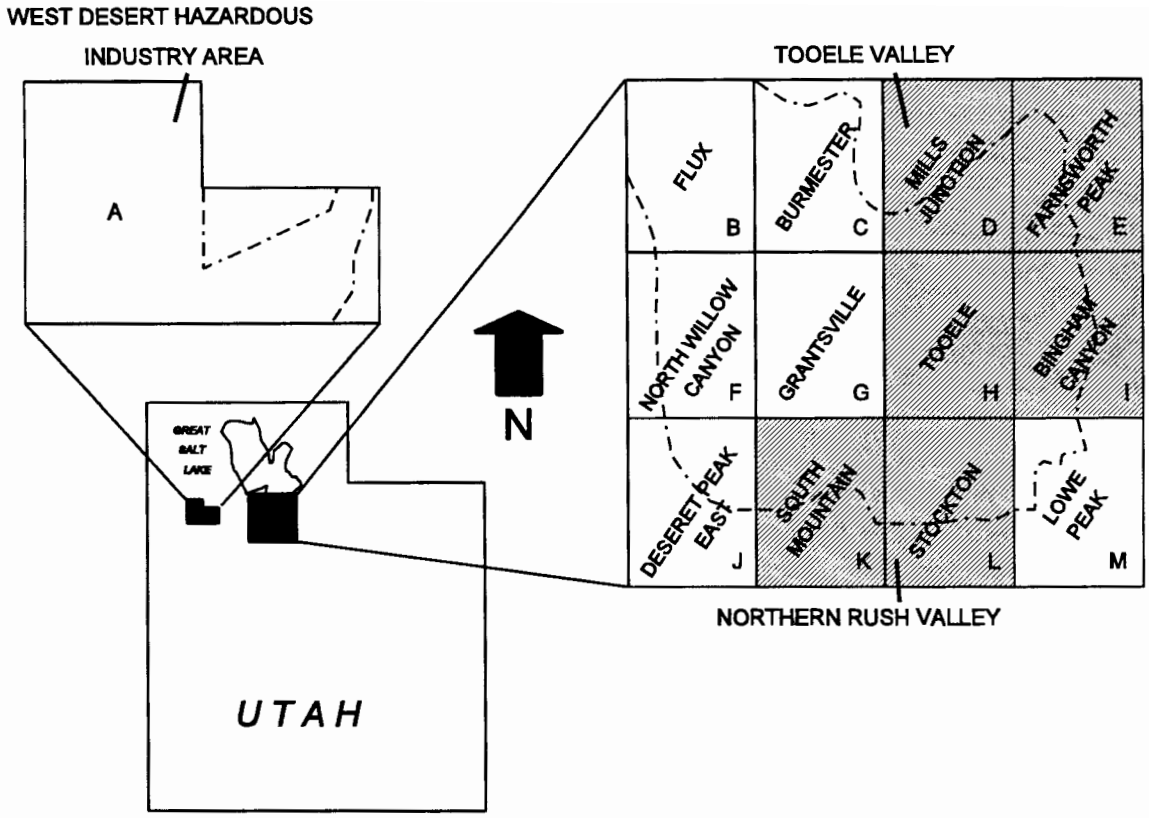

Figure B-3. Index map of areas (crosshatched) where surface-fault-rupture hazards are mapped on plate 1. Letters are used in plate designations. Study area boundaries are shown by dashed lines.

SITE INVESTIGATIONS

Site investigations for surface-fault-rupture hazards will vary depending on the proposed land use, nature of faulting, and amount of pre-existing disturbance of the surface. In general, investigations are needed to delineate the location of faults (if present), characterize offsets, and suggest setback distance. The Utah Section of the Association of Engineering Geologists (1987) has prepared guidelines for performing surface-fault-rupture investigations and preparing reports.

At undisturbed sites, the initial phase of a surface-faulting investigation should include mapping of all suspected faults and scarps. Mapping consists chiefly of identifying fault scarps or

field investigations. If fault scarps are found, topographic profiles (two-dimensional cross sections) can define slopes needed to determine standard fault setbacks. The likely location of the fault and minimum setback distances can be determined from scarp slopes. Faults are commonly located at the midpoint of their scarps (McCalpin, 1987); if the scarp slope is less than 30 percent, structures should be set back a minimum of 50 feet (15 m) from the scarp midpoint (figure B-4a). If the scarp slope is 30 percent or greater, then the setback should be taken from the 30 percent slope break at the top and bottom of the scarp (figure B-4b). If profiles indicate that backtilting, flexure, secondary faulting, or graben-bounding antithetic faults are present in a wide zone of deformation, the setback distance should be taken from the outermost faults or where the undeformed pre-fault surface slope is regained (figure B-4c). By following these recommendations, structures should avoid straddling the main, and potentially most dangerous, fault trace. However, the setbacks only reduce the risk from surface fault rupture and do not guarantee that damage won't occur.

If structures are to be placed within the 50-foot (15-m) setback zone, trenching studies are needed to demonstrate a lack of deformation within this zone. Trenching studies may also be needed to characterize faults which have not been adequately studied, such as those in northern Rush Valley. Based on trenching data, fault activity can be assessed and recommendations can be made for variances from minimum setback guidelines. In some cases, trenches should be offset (along the strike of the fault) from actual building foundations to avoid adversely affecting soil-foundation conditions with trench backfill.

In areas where surface deposits have been disturbed or regraded, or geologically young areas such as active stream flood plains and alluvial fans, surficial materials may post-date faulting and be sufficiently thick to conceal older faulted deposits and faults. These areas would require that site-specific studies contain recommendations for setback distances by projecting faults from adjacent property through the study area. If setback distances cannot be determined from projections, trenching may be done to a depth that encounters older disturbed material.

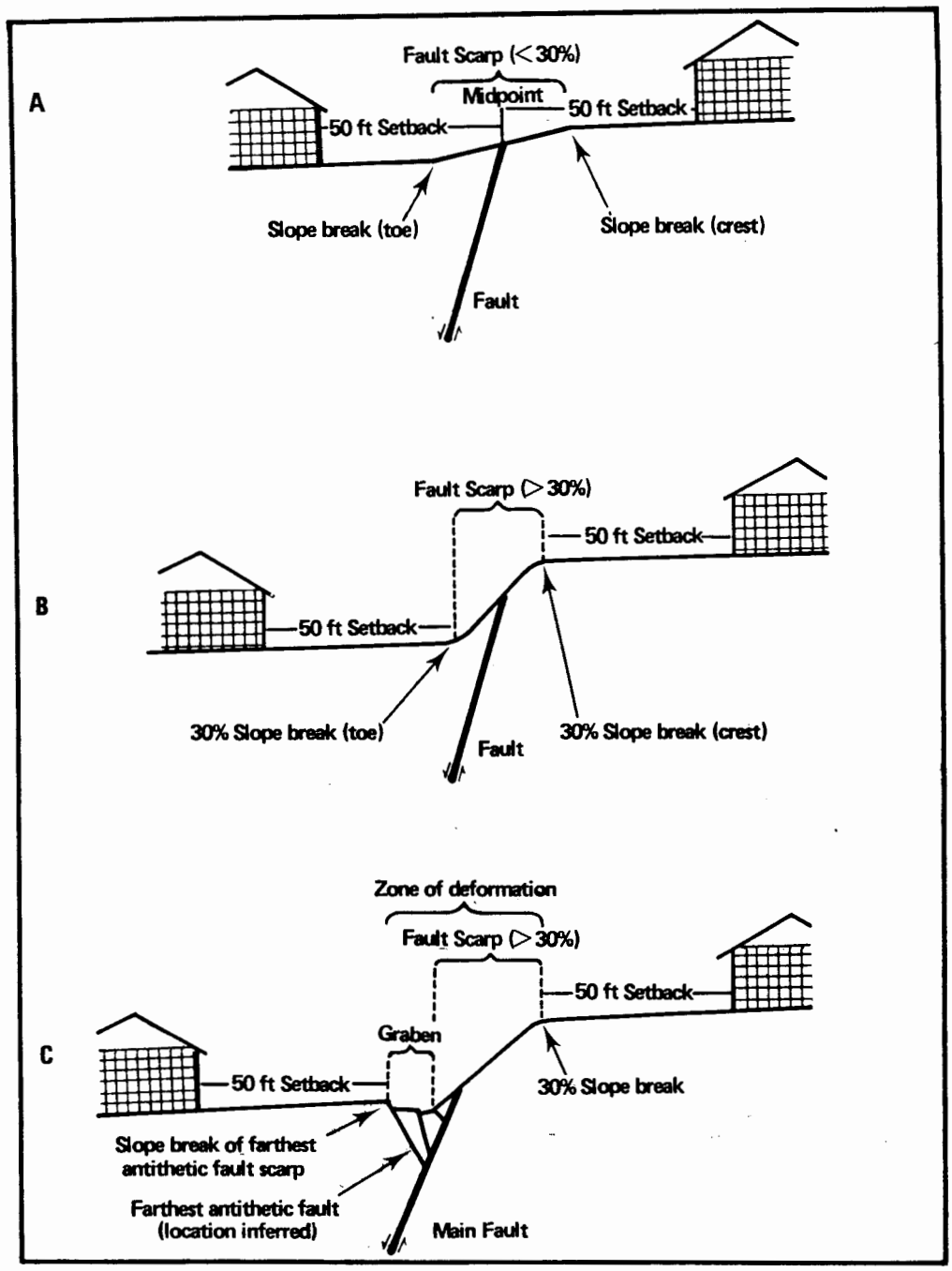

Figure B-4. Diagram of recommended minimum setback distances, relative to fault scarps, in areas where trenching studies are not performed. Recommended setback distances are: (A) 50 feet from the midpoint of a scarp that is less than a 30-degree slope, (B) 50 feet from the top and bottom slope break on a scarp that is greater than a 30-degree slope, and (C) 50 feet from the slope break (at the top of the scarp) and the farthest antithetic fault for scarps where a graben is present (Robison, 1993).

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SECTION C:
GROUND SHAKING

by

Bill D. Black

INTRODUCTION

Ground shaking is the most widespread and frequently occurring earthquake hazard. The Tooele Valley study area is located in the Intermountain seismic belt (ISB), a generally north-south trending zone of increased earthquake activity which bisects Utah (figure C-1). The WDHIA is west of the ISB. There are many active faults within this zone capable of producing earthquakes. Both Tooele Valley and the WDHIA could be susceptible to ground shaking from a surface-faulting earthquake centered on a nearby fault or distant fault. In addition, earthquakes large enough to cause damage, but which don't cause surface fault rupture (up to magnitude 6.5) and thus are not attributable to a mapped fault, may occur anywhere in the area (Smith and Arabasz, 1991).

Ground shaking is caused by seismic waves generated during an earthquake. The waves originate at the source of the earthquake (or focus) and radiate out in all directions (figure C-2). The extent of property damage and loss of life due to ground shaking depends on factors such as: (1) proximity and strength of seismic waves at the surface (horizontal accelerations are the most damaging); (2) amplitude, duration, and frequency of ground motions; (3) nature of foundation materials; and (4) building design (Costa and Baker, 1981).

A building need only withstand the force of gravity (1 g) to support its own weight. However, during an earthquake, a structure is also subjected to horizontal accelerations that may be greater than that of gravity. Accelerations are normally expressed in decimal fractions of the acceleration due to gravity (g) (32 feet/second^2 [9.8 m/s^2]). The threshold for damage to weak structures (buildings not specifically designed to resist earthquakes) is roughly 0.1 g (Richter, 1958).

CHARACTERISTICS

Large magnitude earthquakes typically cause more damage because they result in larger amplitudes of ground motion for longer periods of time. Because energy is dissipated as seismic waves travel through the earth, ground shaking generally decreases with increasing distance from the epicenter. Seismic waves can travel long distances, as shown in the September 19, 1985, magnitude 8.1 Michoacan, Mexico earthquake that devastated portions of Mexico City, 240 miles (386 km) from an epicenter off the Pacific coast of Mexico (Ghosh and Kluver, 1986).

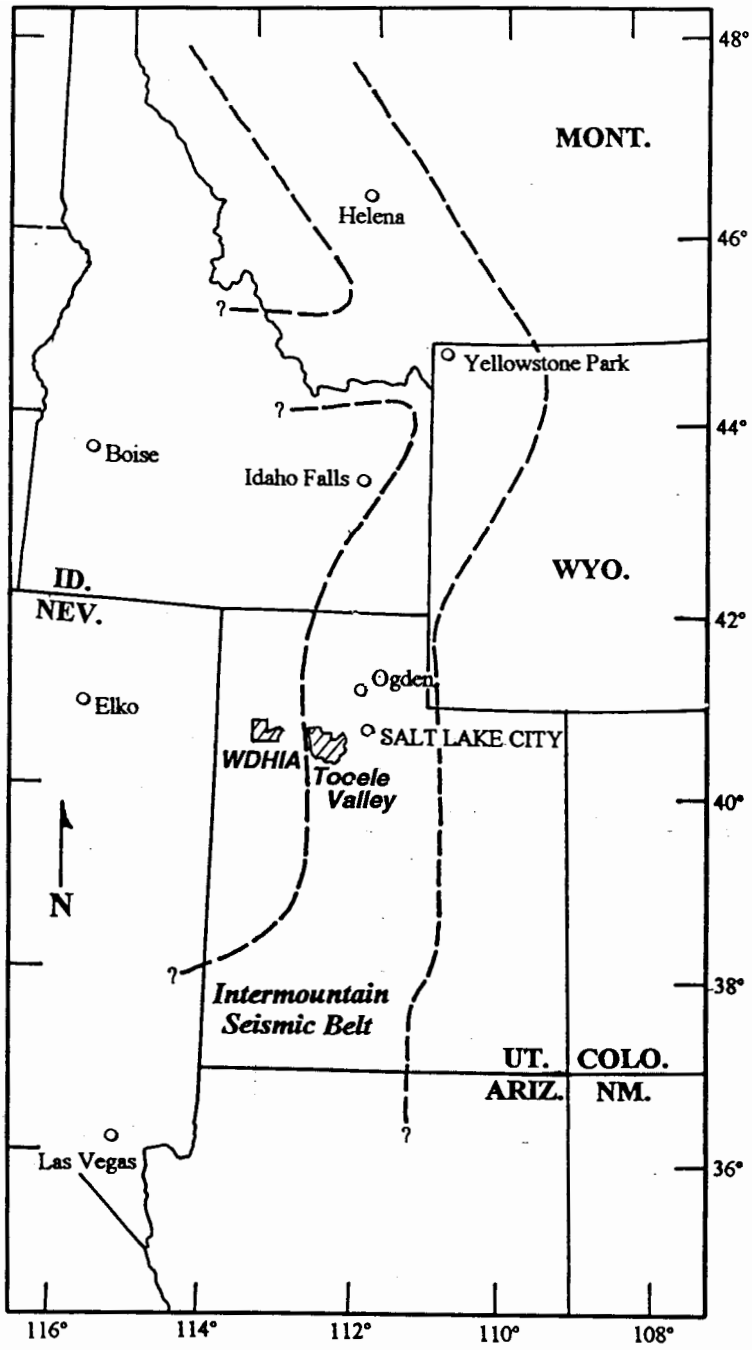

Figure C-1. Tooele Valley and the West Desert Hazardous Industry Area with respect to the Intermountain seismic belt (modified from Arabasz and Smith, 1981).

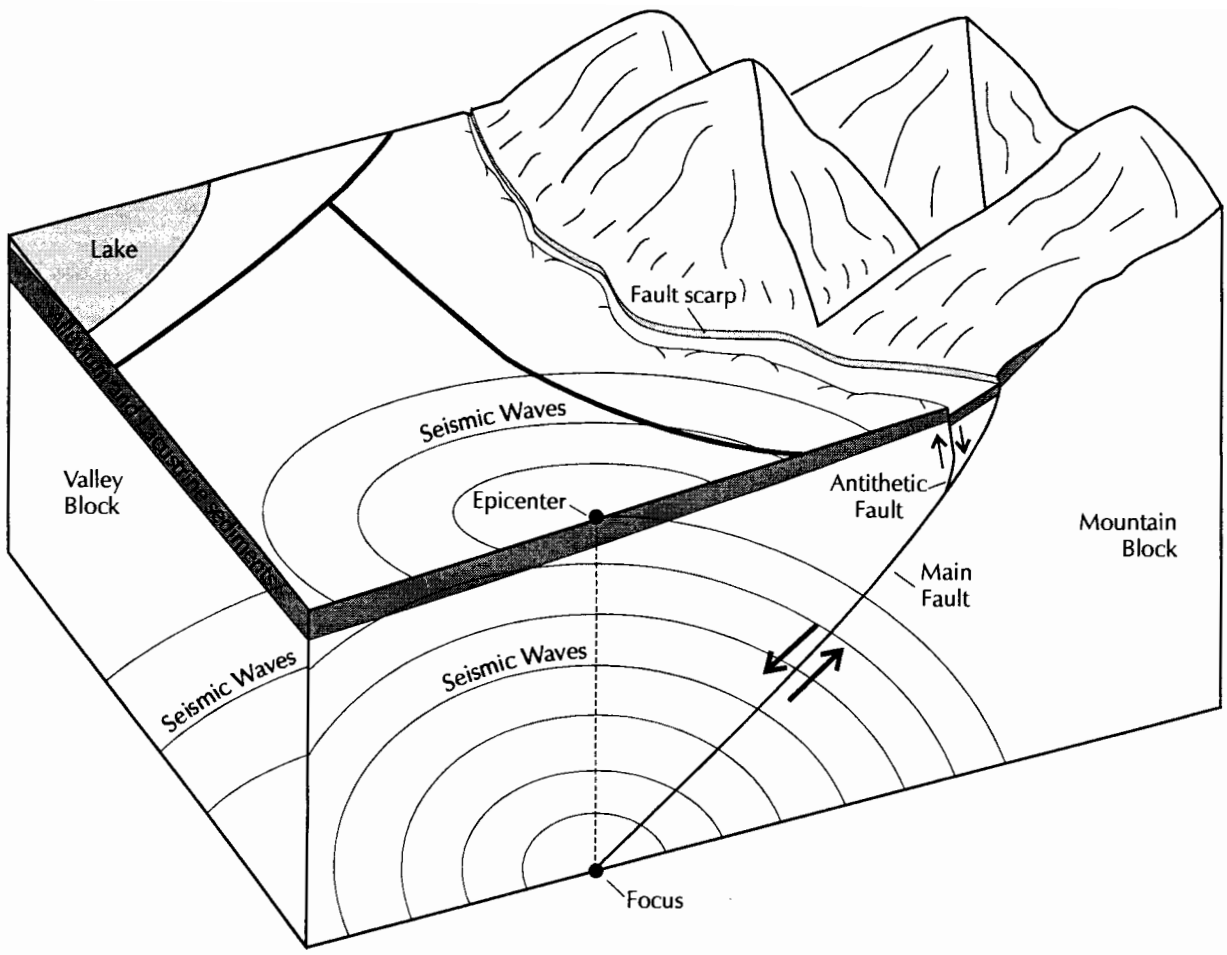

Figure C-2. Diagram showing factors affecting ground shaking, including: fault location, earthquake focus and epicenter, surficial deposits, and propagation of seismic waves (modified from Robison, 1993).

In certain cases, earthquake ground motions can be amplified and shaking duration prolonged by local site conditions (Hays and King, 1982). The degree of amplification depends on factors such as thickness of the sediments and their physical characteristics such as "stiffness" or "softness". "Soft" sediments are generally clays with low shear-wave velocities. Studies along the Wasatch Front of weak ground motions produced by distant explosions at the Nevada Test Site indicate that certain ground motions are amplified on soft-soil sites by as much as 10 to 13 times relative to rock sites (Hays and King, 1982). Studies of earthquakes worldwide have

demonstrated that near-surface "soft" sediments amplify ground motions (Gutenberg, 1957; Seed and others, 1987; Borcherdt and others, 1989; Jarpe and others, 1989). These "soft" sediments include fine-grained fluvial or lake deposits, which are extensive throughout Tooele Valley and the WDHIA. Recent theoretical studies by Adan and Rollins (1993) and Wong and Silva (1993) indicate that amplification may also occur in shallow stiff (sandy and gravelly) soils. These conditions may be found around the periphery of Tooele Valley along mountain fronts and around the Grayback Hills in the WDHIA.

Both Tooele Valley and the WDHIA are susceptible to ground shaking from an earthquake on a mapped fault, or from a "floating earthquake" on a fault not evident at the surface. Although the principal active fault mapped in Tooele Valley is the Oquirrh fault zone (OFZ) of Barnhard and Dodge (1988), there are several other potentially active faults within 30 miles (48 km) of Tooele Valley: (1) the Wasatch fault zone, at the base of the Wasatch Range east of Tooele Valley; (2) faults such as the Mercur, St. John Station, and Clover fault zones in Rush Valley to the south (Barnhard and Dodge, 1988), and other lesser-known faults in northern Rush Valley (Tooker and Roberts, 1992; Solomon, 1993); (3) the Stansbury fault zone, on the west side of the Stansbury Mountains west of Tooele Valley (Barnhard and Dodge, 1988; Hecker, 1993); and (4) the East Great Salt Lake fault zone, beneath Great Salt Lake west of Antelope Island (Arabasz and others, 1992; Hecker, 1993). There are no active faults mapped within the WDHIA, but there are two potentially active faults within 30 miles (48 km) of the WDHIA: (1) the Puddle Valley fault zone, on the west side of Puddle Valley to the northeast (Barnhard and Dodge, 1988); and (2) the Stansbury fault zone to the east.

EFFECTS

Failure of man-made structures from ground shaking is responsible for most earthquake losses. Proper building design can reduce damage. Older unreinforced-masonry buildings are at a higher risk than newer earthquake-resistant designs. Studies have cited the high risk from ground shaking for the large number of older buildings in Utah (Algermissen and others, 1988).

Horizontal motions are typically the most damaging type of ground shaking. In addition, different types of structures are affected by different frequencies of vibration. When the dominant frequency of ground shaking matches the natural frequency of vibration of a structure (a function of building height and construction type), resonance can occur that may result in severe damage or collapse. Proximity to the source of the earthquake also influences the damage caused by ground shaking. Ground motion maps prepared by Algermissen and others (1990) show the expected peak horizontal acceleration on bedrock with a 10% chance of being exceeded in time periods of 50 and 250 years (figure C-3). Horizontal accelerations on the 50-year map are typically used in building design. These accelerations range from 0.15 to 0.20 g in Tooele Valley and from 0.1 to 0.15 g in the WDHIA (figure C-3). As an example of damaging ground motions, accelerations of 0.26 and 0.29 g were recorded close to the I-880 freeway overpass that collapsed during the 1989 Loma Prieta earthquake in California (Shakal and others, 1989).

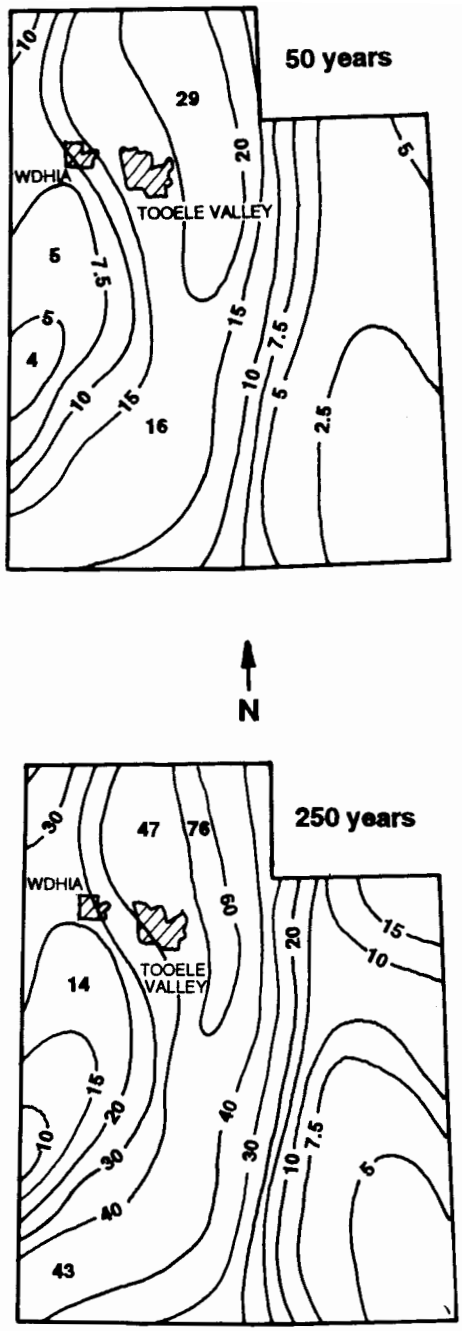

Figure C-3. Expected horizontal acceleration on bedrock in Utah with a 10% chance of being exceeded in 50 and 250 years (after Algermissen and others, 1990). Tooele Valley and the West Desert Hazardous Industry Area (WDHIA) are crosshatched.

Bolt (1988) relates peak horizontal acceleration (PHA) to the Modified Mercalli intensity scale. The Modified Mercalli intensity scale measures the effects of ground shaking through a ranking based on observed effects and damage (table C-1). A PHA of 0.12 g, equivalent to Modified Mercalli intensity VII, was recorded 25 km (16 mi) from the epicenter of the M_L 5.7 1962 Cache Valley earthquake (Smith and Lehman, 1979). Despite the relatively modest ground motions, this earthquake caused nearly $1 million of damage (1962 dollars; Lander and Cloud, 1964) and illustrates the power of even moderate-sized earthquakes to cause considerable damage. By comparison, estimated damage from the 1993 magnitude 5.6 Scotts Mills earthquake in Oregon is so far nearly $30 million (Madin and others, 1993).

Table C-1. Modified Mercalli intensity scale (modified from Bolt, 1988)

Intensity value and description		Peak horizontal acceleration
I.	Felt only 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.	
III.	Felt quite noticeably indoors, especially on upper floors of buildings. However, many do not recognize it as an earthquake. Standing automobiles may rock slightly. Vibration is like a passing truck. Duration estimated.	
IV.	Felt indoors by many during the day, outdoors by only a few. At night some people awakened. Dishes, windows, and doors disturbed; walls make creaking sounds. Sensation is like a heavy truck striking the building. Standing automobiles rocked noticeably.	0.015g-0.02g
V.	Felt by nearly everyone; many people awakened at night. Some dishes and windows broken; cracked plaster in a few places; unstable objects overturned. Disturbance of trees, poles, and other tall objects is sometimes noticed. Pendulum clocks may stop.	0.03g-0.04g
VI.	Felt by all, many frightened and run outdoors. Some heavy furniture is moved; a few instances of fallen plaster and damaged chimneys. Damage is slight.	0.06g-0.07g
VII.	Everybody runs outdoors. Damage is: (1) negligible in buildings of good design and construction; (2) slight to moderate in well-built ordinary structures; and (3) considerable in poorly-built or badly-designed structures. Some chimneys are broken. Noticed by people driving cars.	0.10g-0.15g
VIII.	Damage is: (1) slight in specially-designed structures; (2) considerable in ordinary buildings, with partial collapse; and (3) great in poorly-built structures. Panel walls thrown out of frame structures. Chimneys, factory stacks, columns, monuments, and walls fall down. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. People driving cars disturbed.	0.25g-0.30g
IX.	Damage is considerable in specially-designed structures; well-designed frame structures thrown out of plumb. Damage is great in ordinary buildings, with partial collapse. Buildings shifted off of foundations. Ground conspicuously cracked.	0.50g-0.55g
X.	Some well-built wooden structures destroyed; most masonry and frame structures with foundations destroyed; ground is badly cracked. Rails bent. Numerous landslides from river banks and steep slopes. Sand and mud shifted. Water splashed and slopped over river banks.	....More than 0.60g
XI.	Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in the ground. Underground pipelines completely out of service. Earth slumps in soft ground. Rails bent greatly.	
XII.	Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into the air.	

HAZARD REDUCTION

Ground shaking cannot be avoided because it is so widespread, and the best alternative to reduce the potential effects of the hazard is to strengthen structures. Because failure of man-made structures is the cause of most earthquake losses, engineers, building officials, and architects play a key role in reducing losses by implementing improved design and construction practices.

The Uniform Building Code (UBC), which was adopted statewide in 1987, specifies requirements for earthquake-resistant design and construction to minimize structural damage and loss of life from earthquakes (International Conference of Building Officials, 1991). It applies to all new building construction, including schools, hospitals, commercial and residential buildings, fire and police stations, and power plants. The "Earthquake Regulations" in the code were extensively revised for the 1988 edition, but the basic philosophy to reduce potential structural damage and protect lives during earthquakes remained the same. In any case, the regulations do not ensure that the structure or its contents will not be damaged during an earthquake, a painful lesson learned by many building owners since adoption of the first earthquake-resistant design provisions in 1961.

Two factors, Z and S, are defined in the UBC to quantify the minimum level of ground shaking that structures must be designed to withstand without collapse. The seismic zone factor (Z) attempts to quantify ground motions on rock, whereas the site coefficient (S) attempts to quantify the effects of near-surface sediments on the ground motions. Specifically, Z is tied to accelerations on rock with a 10% chance of being exceeded in 50 years. Site coefficients range from 1.0 to 2.0, depending on the type and thickness of sediments underlying a site; larger site coefficients attempt to account for larger amplifications of ground motions by near-surface "soft" sediments.

SITE INVESTIGATIONS

Although no large-scale maps have been prepared showing the actual ground-shaking hazard for Tooele Valley or the WDHIA, the UBC seismic zone map is sufficient to determine minimum design levels for buildings (figure C-4). Krinitzsky (1989) studied ground motions for an engineering site in the south area of the Tooele Army Depot in Rush Valley, but no other specific studies on ground-shaking hazards have been made in the area. Maps showing site coefficients are not available, and site-specific studies are generally needed to determine S factors.

The UBC requires that buildings be designed to withstand a minimum amount of lateral motion, usually expressed in terms of peak horizontal acceleration (Olig, 1991). Many cities and counties in Utah independently adopted some version of the UBC, which first included earthquake-resistant design provisions in the 1961 edition. Prior to 1961, the only requirements for buildings to resist horizontal forces in Utah were those determined by wind loads (Rogers and

others, 1976). Until recently, requirements were left to the discretion of local jurisdictions. However, in 1987 the Utah State Legislature adopted the 1985 UBC statewide for the first time. This edition was later superseded by the 1988 UBC, adopted statewide in 1989 as part of the Uniform Building Standards Act. This act also established the UBC Commission to oversee statewide implementation of the code. The UBC was most recently revised in 1994 (International Conference of Building Officials, 1994).

Seismic zones range from 0 to 4, with only zones 1, 2B, and 3 being present in Utah (figure C-4). New construction in Tooele Valley and the WDHIA should conform to the guidelines set forth in the UBC. Tooele Valley lies within zone 3, whereas the WDHIA straddles zones 2B and 3 but lies mostly within zone 2B. Although accurate determination of seismic zones and site coefficients is important, the UBC is ineffectual without adequate implementation and enforcement of the earthquake regulations in the code.

Site-specific evaluations of ground-shaking hazards involve accurate determination of Z (expected peak horizontal accelerations) and S (site coefficients) factors. The Z factor can be taken directly from the seismic zone map, but site coefficients (table C-2) are determined either by drilling or estimation based on geologic conditions and existing geotechnical data. Site-specific probabilistic estimates of earthquake ground motions are generally only performed for certain high-cost, high-occupancy, or environmentally-sensitive critical facilities. Details of methods used to perform such studies are beyond the scope of this report, but are available in Reiter (1990) and Krinitsky and others (1993). Adequate plan checks by qualified building officials are recommended prior to issuance of building permits to ensure proper enforcement of seismic building code provisions.

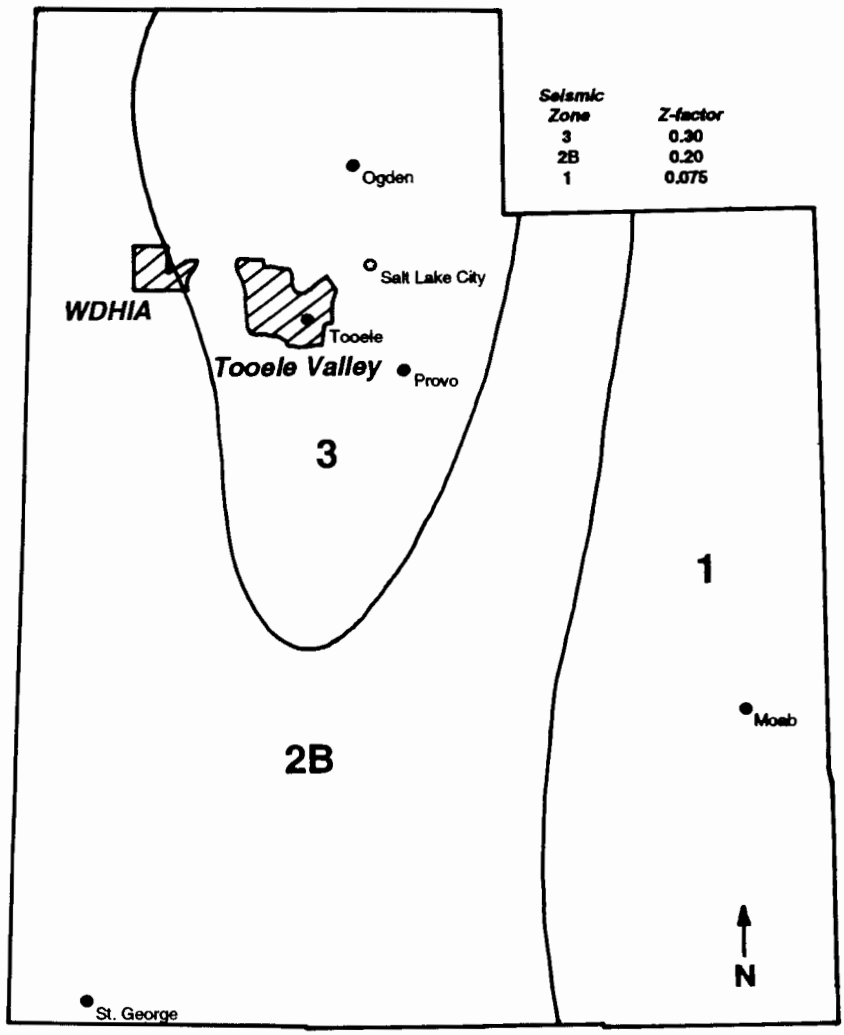

Figure C-4. The UBC seismic zone map of Utah. Tooele Valley and the West Desert Hazardous Industry Area (WDHIA) are crosshatched (from International Conference of Building Officials, 1994).

Table C-2. Site coefficients from soil-profile types (based on geotechnical data). In locations where soil properties are not known in sufficient detail to determine the soil profile type, use soil profile S_3 (modified from International Conference of Building Officials, 1991).

TYPE	DESCRIPTION	S FACTOR
S_1	A soil profile with either: (a) A rock-like material characterized by a shear-wave velocity greater than 2,500 feet per second (762 m/sec) or by other suitable means of classification, or (b) Stiff or dense soil conditions where the soil depth is less than 200 feet (61 m).	1.0
S_2	A soil profile with stiff or dense soil conditions where the soil depth exceeds 200 feet (61 m).	1.2
S_3	A soil profile 70 feet (21 m) or more in depth and containing more than 20 feet (6 m) of soft to medium stiff clay, but not more than 40 feet (12 m) of soft clay.	1.5
S_4	A soil profile containing more than 40 feet (12 m) of soft clay characterized by a shear-wave velocity less than 500 feet per second (152 m/sec).	2.0

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SECTION D:
TECTONIC SUBSIDENCE

by

Bill D. Black

INTRODUCTION

Tectonic subsidence is the warping, lowering, and tilting of a valley floor that accompanies surface-faulting earthquakes on normal (dip-slip) faults, such as the OFZ. Subsidence occurred during the 1959 Hebgen Lake earthquake in Montana and 1983 Borah Peak earthquake in Idaho, and geologic evidence indicates that there has also been tectonic subsidence during prehistoric earthquakes along the Wasatch Front (Keaton, 1987). Inundation along lake and reservoir shores, and ponding of water in areas with a shallow water table, may be caused by tectonic subsidence. Also, tectonic subsidence may adversely affect certain structures which require gentle gradients or horizontal floors, particularly wastewater-treatment facilities and sewer lines (Keaton, 1987).

Tectonic subsidence could be a hazard in Tooele Valley, along known faults with evidence of surface faulting, particularly during the last 10,000 years. However, there have been no specific studies of the potential for tectonic subsidence for Tooele Valley. In the WDHIA there are no active faults, and thus the hazard from tectonic subsidence is very low.

Tectonic subsidence from an earthquake on the OFZ will be greatest in the eastern part of Tooele Valley on the western (downdropped) side of the fault, where the maximum amount of potential subsidence may occur. Flooding related to tectonic subsidence on the OFZ, as well as ponding of water and disruption of buried facilities, will be greatest in the northeastern part of the valley due to shallow ground-water levels and the proximity to the shore of Great Salt Lake.

CHARACTERISTICS AND EFFECTS

Tectonic subsidence, also termed seismic tilting, occurs during surface-faulting earthquakes (greater than magnitude 6.5) along normal faults. The extent of seismic tilting is controlled chiefly by the amount and length of surface displacement. Subsidence typically extends only a short distance beyond the ends of the fault rupture. The maximum amount of subsidence should occur at the fault and decrease gradually away on the downdropped valley block.

The probability of tectonic subsidence accompanying an earthquake on a specific fault is the same as that for a surface-faulting earthquake, although the extent of subsidence varies. Because no detailed studies have been made on the OFZ, subsidence characteristics are not known. However, the 1983 Borah Peak earthquake in Idaho may provide a model for subsidence associated with the

OFZ. Up to 4.3 feet (1.3 m) of subsidence at the fault was observed following this earthquake, with subsidence extending up to 9.3 miles (15 km) from the fault on the downdropped side (Keaton, 1987).

The two major types of hazards associated with tectonic subsidence are tilting of the ground surface and flooding from lakes, reservoirs, or shallow ground water (figure D-1) (Smith and Richins, 1984). Tilting of the ground surface may compromise gravity-flow structures such as wastewater-treatment plants and sewer lines, and thus prevent them from working properly. Flooding from lakes and reservoirs may damage structures along shorelines and result in injury or loss of life. Subsidence may also cause ground-water levels to rise, causing water to pond and flooding basements and buried facilities.

HAZARD REDUCTION AND SITE INVESTIGATIONS

Because subsidence may occur over a large area, it is generally not practical to avoid, except in low-lying lake shoreline areas. However, some structures may have to be releveled after tectonic subsidence occurs. Therefore, tolerance to slight changes in gradient should be considered for gravity-flow structures, such as wastewater-treatment plants, in areas of potential subsidence.

Flooding problems along the Great Salt Lake shoreline from tectonic subsidence depend on lake levels at the time of the event. The greatest effects would result from high lake levels. At the present lake level of 4,200 feet (1,280 m), flooding due to subsidence is likely within the zone of normal lake flooding, which is discussed in Section J. If it is determined that probability of an earthquake occurring on the OFZ when lake levels are high is sufficient to merit hazard reduction, methods such as raising structures above expected flood levels or building dikes should be considered to reduce flooding effects.

The effects of subsidence-induced flooding due to rising ground-water levels can be minimized using methods discussed in Section K. However, shallow ground-water conditions are also conducive to earthquake-induced liquefaction (Section E), which may compound hazard-reduction problems.

The magnitude and extent of tectonic subsidence along the OFZ is unclear, and a study similar to Keaton (1987) is required to better define the amount and extent of potential subsidence. Without such a study, estimates of the amount of subsidence can be made based on the amount of fault offset per earthquake event (from paleoseismic data) and the extent of subsidence from similar historical events. Site investigations may determine the depth to ground water and surface elevation, which can then be compared to the amount of subsidence to define areas of potential lake-margin flooding and ponded shallow ground water. Vulnerable essential facilities such as wastewater-treatment plants and hazardous-waste facilities should also consider potential tilting.

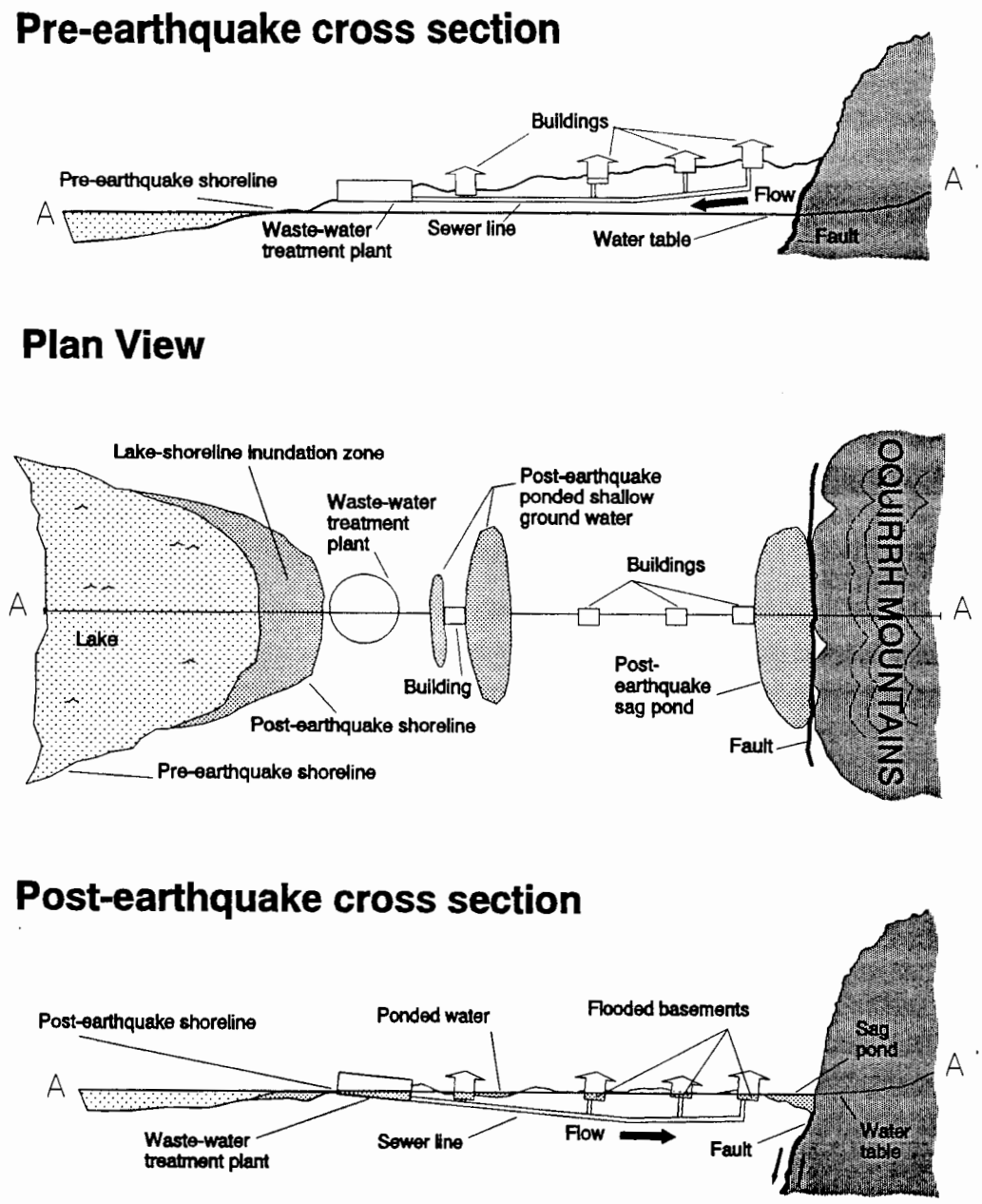

Figure D-1. Hypothetical plan view and cross sections showing tectonic subsidence accompanying a surface-faulting earthquake. Top cross section shows the lake shoreline and structures on the plan view (below) in their pre-earthquake position. Bottom cross section shows the possible effects of tectonic subsidence and their extent on the plan view (above), including inundation along the lake shoreline (lake shoreline inundation zone); post-earthquake flooding, ponded water, and sag ponds (produced by backtilting) due to the rising water table; and changes in gradient from backtilting causing a reversal of flow in sewer lines (modified from Robison, 1993).

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SECTION E:
LIQUEFACTION

by

Bill D. Black

INTRODUCTION

Earthquake ground shaking causes a variety of phenomena which can damage structures and threaten lives. One of these phenonema is liquefaction. Liquefaction occurs when ground shaking increases the pressure in the pore water between soil grains, which decreases the stresses between the grains. The loss of intergranular stress can cause the strength of some soils to decrease to nearly zero. When this happens, the soil behaves like a liquid, and therefore is said to have liquefied. Liquefaction of a soil can have four major adverse effects: (1) foundations may crack; (2) buildings may tip; (3) buoyant buried structures, such as septic tanks and storage tanks, may rise; and (4) gentle slopes may fail as liquefied soils and overlying materials move downslope.

Liquefaction potential depends on soil and ground-water conditions and the severity and duration of ground-shaking. Liquefaction most commonly occurs in areas of shallow ground water (less than 30 feet [9 m]) and loose sandy soils. In general, an earthquake of Richter magnitude 5 or greater is necessary to induce liquefaction (Kuribayashi and Tatsuoka, 1975, 1977; Youd, 1977). For larger earthquakes, liquefaction has a greater likelihood of occurrence and will be found at greater distances from the epicenter (the point on the earth's surface directly above the focus of the earthquake). Liquefaction has been documented up to 170 miles (274 km) from the epicenter of an earthquake (1977 Romanian earthquake, magnitude 7.2) (Youd and Perkins, 1987).

Liquefaction is a hazard that can affect Tooele Valley and the WDHIA. Soil and ground-water conditions are conducive to liquefaction in both areas, although the likelihood of sufficient ground shaking is greater in Tooele Valley.

CHARACTERISTICS

Liquefaction itself does not necessarily cause damage, but may induce damaging ground failures. Four types of ground failure commonly result from liquefaction: (1) loss of bearing strength, (2) ground oscillation, (3) lateral-spread landslides, and (4) flow landslides (Youd, 1978a, 1978b; Tinsley and others, 1985). Youd (1978a) relates these types of ground failure to the slope of the ground surface (table E-1).

Loss of bearing strength and resulting deformation of a soil mass beneath a structure are the principal effects of liquefaction in areas where slopes are generally less than about 0.1 percent

(Youd, 1978a, 1984; Bartlett and Youd, 1992). Liquefaction reduces shear strength of the soil which provides foundation support, allowing structures to settle and tilt (Youd, 1984; National Research Council, 1985; figure E-1).

Table E-1. Ground slope and expected failure mode resulting from liquefaction (modified from Youd, 1978a; Anderson and others, 1982; Bartlett and Youd, 1992).

GROUND SURFACE SLOPE	FAILURE MODE
Less than 0.1 percent	Bearing capacity
Less than 0.1 percent, liquefaction at depth	Ground oscillation
0.1 to 5.0 percent	Lateral-spread landslides
Greater than 5.0 percent	Flow landslides

Ground oscillation takes place when liquefaction occurs beneath the ground surface, below soil layers that do not liquefy, and where slopes are too gentle for lateral displacement to occur (Tinsley and others, 1985). Under these conditions, liquefaction at depth commonly causes overlying soil blocks to detach from each other and jostle back and forth on the liquefied layer during an earthquake (National Research Council, 1985; figure E-2). The detached soil blocks vibrate differently from the underlying and surrounding firm ground, causing fissures to form and impacts to occur between oscillating blocks and adjacent firm ground (National Research Council, 1985; Tinsley and others, 1985).

Where the ground-surface slope ranges between 0.1 and 5.0 percent, failure by lateral spreading may occur (Anderson and others, 1982; Bartlett and Youd, 1992). Lateral spreads are characterized by surficial blocks of sediment which are displaced laterally downslope as a result of liquefaction in a subsurface layer (National Research Council, 1985; figure E-3). The surface layer commonly breaks up into blocks, bounded by fissures, which may tilt and settle differentially (National Research Council, 1985). The amount of lateral displacement depends on soil and ground-water conditions, slope, and the strength and duration of ground shaking (Tinsley and others, 1985).

Where ground-surface slopes are steeper than about 5.0 percent, slope failure may occur in the form of flow landslides (Anderson and others, 1982; figure E-4). They are comprised chiefly of liquefied soil or blocks of intact material riding on a liquefied layer (National Research Council, 1985). Flow landslides can cause soil masses to be displaced several miles (Tinsley and others, 1985).

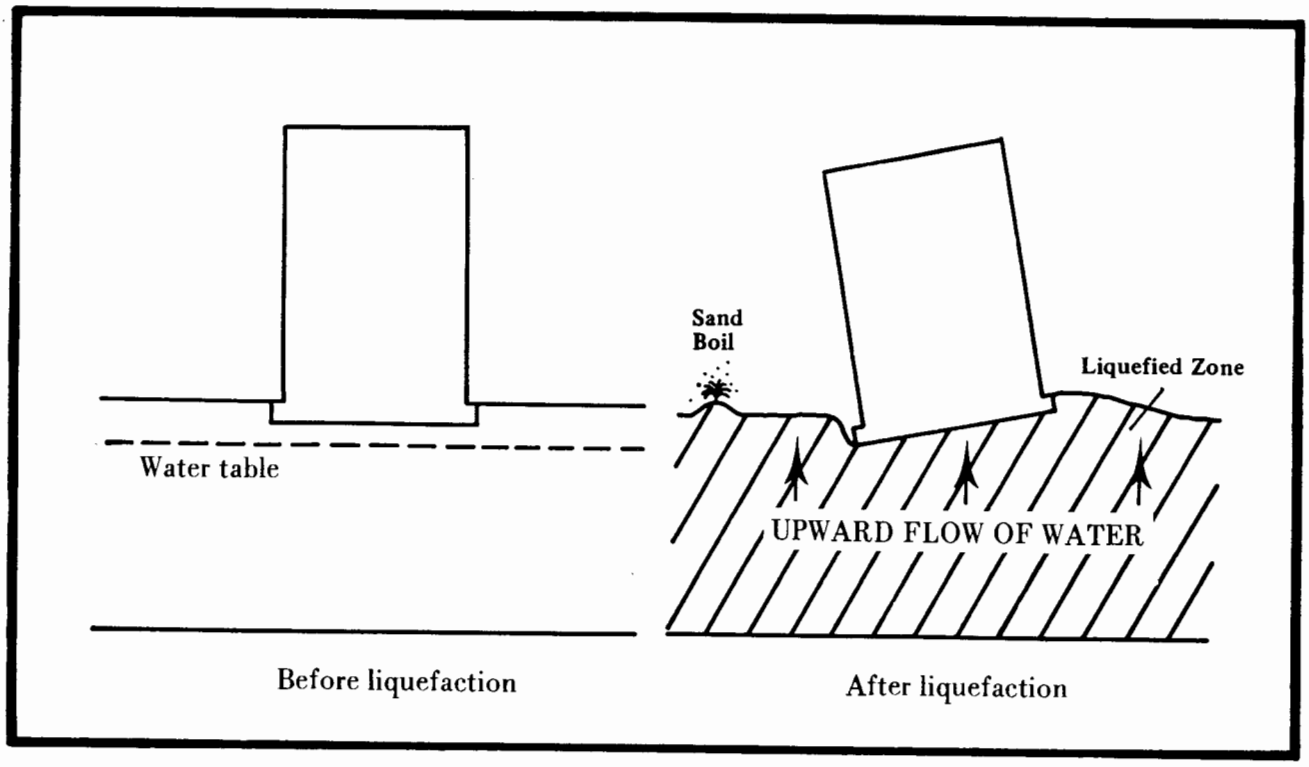

Figure E-1. Tilting of a building due to liquefaction and loss of bearing strength in the underlying soil, allowing the building to settle and tilt (Youd, 1984, in National Research Council, 1985).

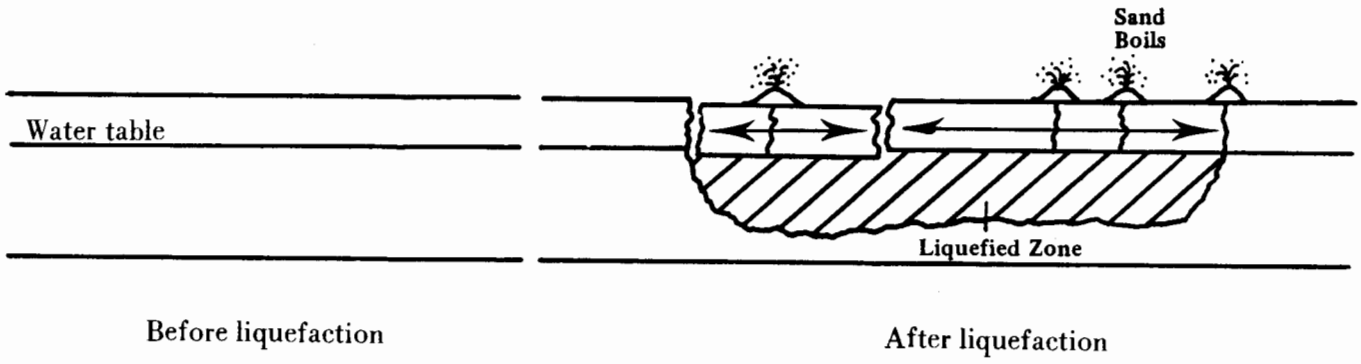

Figure E-2. Diagram of liquefaction-induced ground oscillation. Liquefaction occurs in the cross-hatched zone and causes ground settlement, opening and closing of fissures, and sand boils as the surface layer detaches from the surrounding firm ground (Youd, 1984, in National Research Council, 1985).

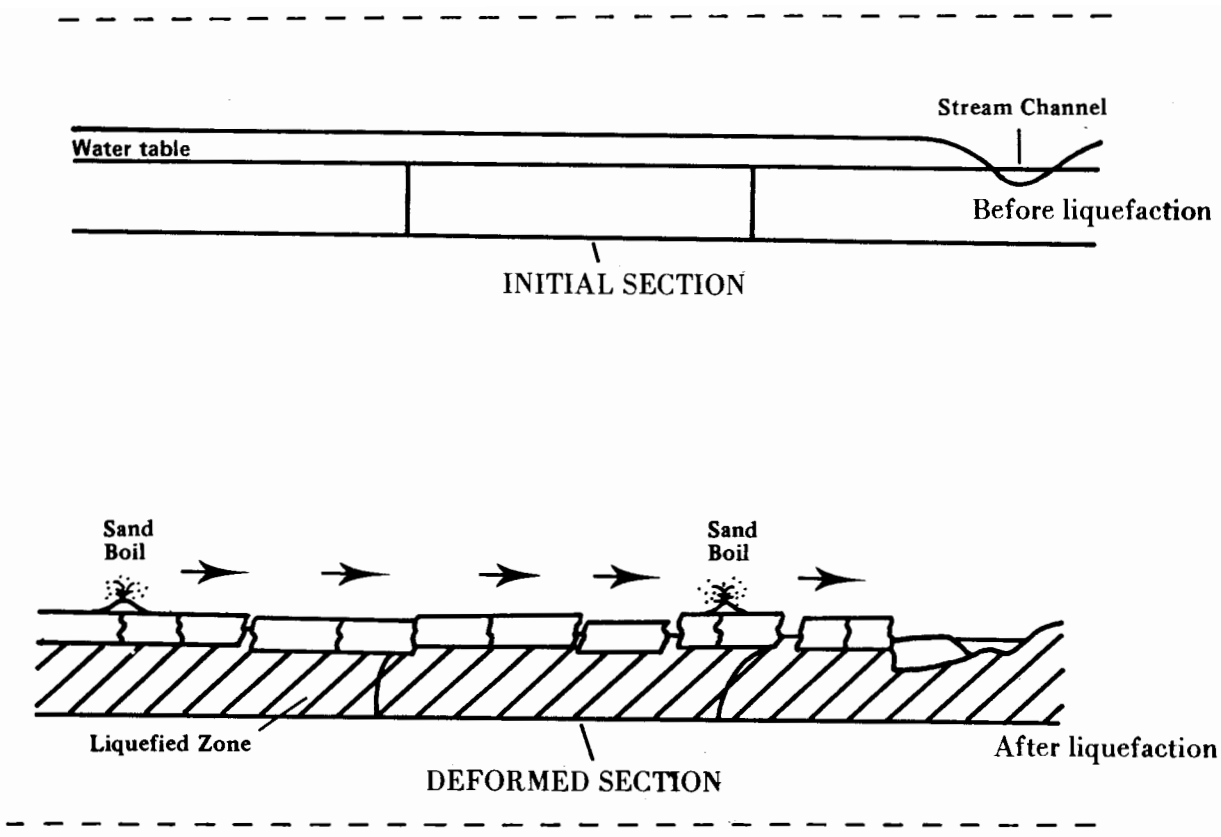

Figure E-3. Diagram of a lateral spread. Liquefaction occurs in the cross-hatched zone, causing the surface layer to detach from surrounding firm ground and move downslope (Youd, 1984, in National Research Council, 1985).

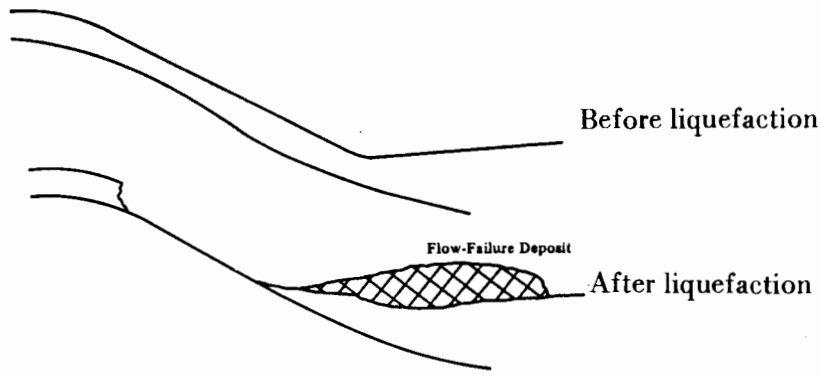

Figure E-4. Diagram of a flow failure. Liquefaction beneath the ground surface causes a loss of shear strength, allowing the soil mass to flow down the steep slope (Youd, 1984, in National Research Council, 1985).

EFFECTS

Earthquake-induced liquefaction and ground failures have the potential to cause damage to most types of structures. Structures that are particularly sensitive to liquefaction-induced ground failure include: buildings with shallow foundations, railway lines, highways and bridges, buried structures, dams, canals, retaining walls, shoreline structures, utility poles, and towers (National Research Council, 1985).

Loss of bearing strength in foundation soils causes structures to settle and/or tilt. Buoyant buried structures, such as gasoline storage or septic tanks, may also float upward in liquefied soils (Tinsley and others, 1985). Among the more spectacular examples of a bearing-capacity failure was the tilting of four 4-story buildings, some as much as 60 degrees, in the 1964 magnitude 7.3 earthquake in Niigata, Japan (National Research Council, 1985). Buried septic tanks rose by as much as three feet (1 m) during the same earthquake (Tinsley and others, 1985).

Ground oscillation can also cause damage to structures and buried facilities. Damage is caused by differential settlement, opening and closing of fissures, and formation of sand boils which commonly accompany the oscillations (Tinsley and others, 1985).

Lateral-spread landsliding can cause significant damage to structures (table E-2) and may be especially destructive to pipelines, utilities, bridge piers, and structures with shallow foundations (Tinsley and others, 1985). Lateral-spread landslides with ground displacements of only a few feet caused every major pipeline break in San Francisco during the 1906 earthquake (Youd, 1978a), and thus were indirectly responsible for the inability to control the fires that damaged the city (Tinsley and others, 1985).

Table E-2. Relationship between ground displacement and damage to structures (modified from Youd, 1980).

GROUND DISPLACEMENT	LEVEL OF EXPECTED DAMAGE
Less than 4 inches (0.1 m)	Little damage, repairable
4 inches (0.1 m) to 1 foot (0.3 m	Severe damage, repairable
1 foot (0.3 m) to 2 feet (0.6 m)	Severe damage, non-repairable
More than 2 feet (0.6 m)	Collapse, non-repairable

Flow landslides are the most catastrophic mode of liquefaction-induced ground failure

(Tinsley and others, 1985). Extensive damage due to flow landslides occurred in the cities of Seward and Valdez, Alaska, during the 1964 Alaska Earthquake (Tinsley and others, 1985). A flow landslide near the Mount Olivet Cemetery during the 1906 San Francisco earthquake knocked a power house off its foundation (Youd, 1973).

HAZARD REDUCTION

The National Research Council (1985) identifies several alternative approaches for existing structures threatened by earthquake-induced liquefaction. The choices include: (1) structure and/or site retrofitting to reduce the potential for liquefaction-induced damage; (2) abandoning the structure if the retrofit costs exceed potential benefits derived from maintaining the structure; or (3) accepting the risk.

Areas of moderate to high liquefaction susceptibility need not be avoided; structural measures and site modification techniques are available to reduce hazards. The cost of reducing liquefaction hazards is commonly excessive for single-family dwellings, and liquefaction is generally not a life-threatening hazard in such structures. However, hazard reduction may be recommended for existing larger structures (Anderson and others, 1987).

Possible actions which may be taken if a liquefaction hazard exists at the site for a proposed structure include: (1) improving site conditions to lower the liquefaction potential; (2) designing the structure to withstand liquefaction effects; (3) avoiding the risk by moving the proposed development to a less hazardous site; (4) insuring the development so that if liquefaction-induced damage occurs, funds will be available to repair the damage; or (5) accepting the risk if the liquefaction potential and consequences are clearly understood.

Structural solutions to reduce the effects of liquefaction can take several forms. For buildings, foundation-support problems in liquefiable soils may be avoided by using end-bearing piles, caissons, or fully-compensated mat foundations, designed for the predicted liquefaction phenomena at the site (National Research Council, 1985). Methods of improving liquefiable soil-foundation conditions are: (1) densification of soils through vibration or compaction, (2) grouting, (3) dewatering with drains or wells, and (4) loading or buttressing to increase confining pressures (National Research Council, 1985). Costs of site improvement techniques range from less than \$0.50 to more than \$500.00 per cubic yard (0.76 m^3) of soil-foundation material treated (National Research Council, 1985).

USE OF HAZARD MAPS

As originally proposed by Youd and Perkins (1978), a liquefaction potential map is derived by superimposing a liquefaction susceptibility map and liquefaction opportunity map. Liquefaction susceptibility represents properties of near-surface earth materials, whereas liquefaction opportunity represents the seismic potential of a region. Liquefaction susceptibility maps (plate 2) have been

prepared for quadrangles in Tooele Valley and the WDHIA where liquefaction hazards are likely (figure E-5). Although the probability of earthquake ground shaking sufficient to cause liquefaction was not included in this assessment, there is a significant potential for liquefaction-induced ground failure to cause severe damage in areas of high susceptibility in Tooele Valley (Mabey and Youd, 1989). Because of a lesser earthquake potential, the hazard is substantially lower in the WDHIA.

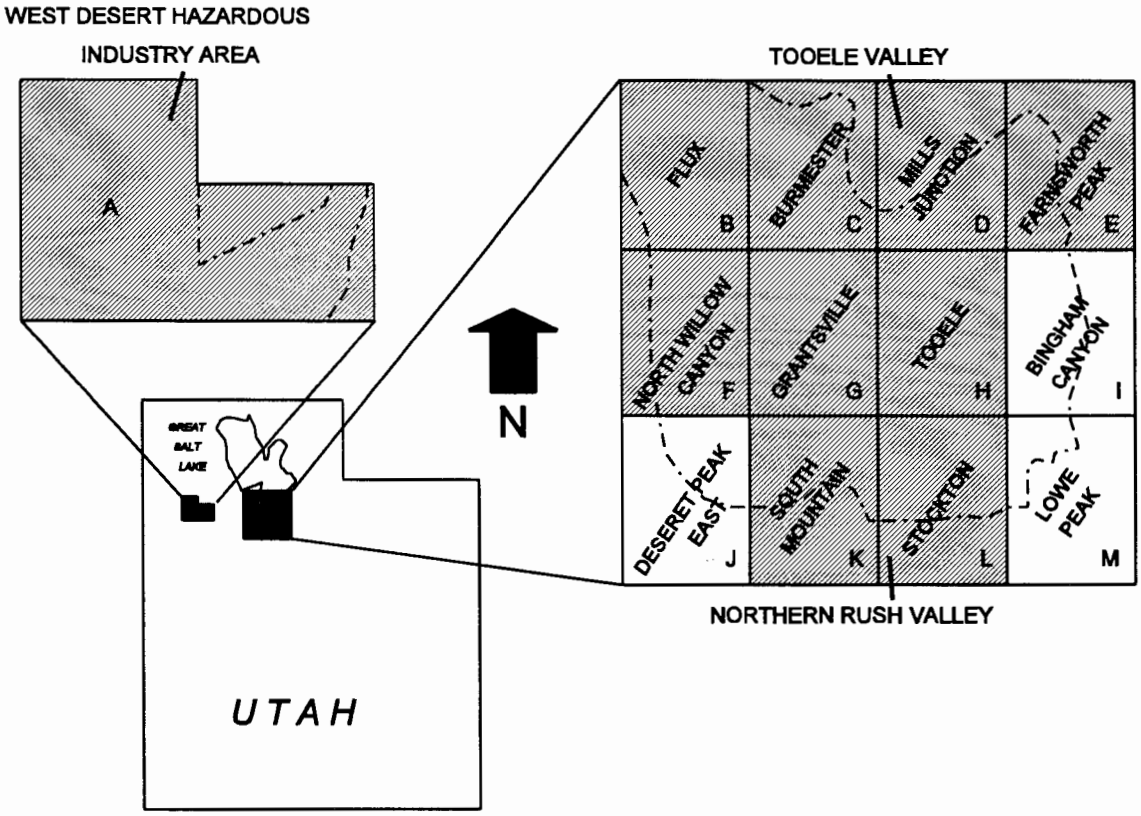

Figure E-5. Index map of areas (crosshatched) where liquefaction susceptibility is mapped on plate 2. Letters are used in plate designations. Study area boundaries are shown by dashed lines.

Liquefaction susceptibility was determined primarily from geologic and ground-water data. In areas that may have sediments susceptible to liquefaction where the depth to ground water is less than 50 feet (15 m), susceptibility was mapped as: (1) high, if the depth to ground water is less than 10 feet (3 m); (2) moderate, if the depth to ground water is from 10 to 30 feet (3-9 m); or (3) low, if the depth to ground water was from 30 to 50 feet (9-15 m). Areas with a very low liquefaction susceptibility do not have susceptible sediments, or have ground-water depths greater than 50 feet

(15 m). Seasonal and long-term fluctuations in ground water levels can affect the susceptibility at a given site.

The expected mode of ground failure for liquefaction at a given site may be evaluated by determining the approximate ground surface slope at the site and referring to table E-1. To differentiate between bearing capacity and ground oscillation failure modes in areas of less than 0.1 percent slope, the depth to the liquefiable layer(s) at the site must be known. Ground oscillation is likely if the liquefiable layer(s) are deep.

The liquefaction susceptibility maps are at a regional scale and, although they can be used to gain an understanding of the susceptibility of a given area for liquefaction-induced ground failure, they are not designed to replace site-specific evaluations. Mapped areas classified with a particular liquefaction susceptibility may contain isolated areas with other classifications, and site-specific geotechnical studies are still required. Site-specific evaluations for liquefaction hazards should be conducted for all essential facilities regardless of mapped liquefaction susceptibility, and for industrial and commercial buildings in areas with a high and moderate susceptibility (table 1). However, for other types of structures in high susceptibility areas such as single-family dwellings, liquefaction hazards need only be disclosed.

SITE INVESTIGATIONS

A liquefaction potential evaluation should be part of a standard soil-foundation investigation. Liquefaction susceptibility evaluations are based on ground-water depth and soil characteristics, including soil density determined from standard penetration tests and/or cone penetration tests. To evaluate liquefaction potential, the probability for ground-shaking levels sufficient to induce liquefaction (liquefaction opportunity) must be determined from a probabilistic ground-shaking evaluation (Section C).

A site-specific liquefaction potential report should include accurate maps of the area showing any proposed development, the location of bore holes and/or test pits, and the site geology. Logs of bore holes and test pits should be included in the report and any ground water encountered should be noted on the logs. The location of and depth to liquefiable soils should be noted, and the probability of ground-shaking levels needed to induce liquefaction in these soils determined. Recommendations for hazard-reduction techniques should also be included.

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SECTION F:
OTHER EARTHQUAKE HAZARDS

by

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and
Barry J. Solomon

INTRODUCTION

A variety of phenonema that can damage property and/or threaten lives may accompany earthquakes. The principal hazards are addressed in other sections of this report, covering surface fault rupture, ground shaking, liquefaction, tectonic subsidence, landslide, and rock-fall hazards. Other potentially damaging but less understood phenonema associated with earthquakes include: (1) ground failure due to loss of strength in sensitive clays, (2) subsidence in granular materials due to ground shaking, (3) flooding caused by seiches in Great Salt Lake, (4) flooding caused by surface drainage disruptions, and (5) flooding caused by increased ground-water discharge.

GROUND FAILURE DUE TO LOSS OF STRENGTH IN SENSITIVE CLAYS

Characteristics and Effects

Most clays lose strength when disturbed; sensitive clays experience a particularly large loss of strength. Sensitive clays are wet clays whose undisturbed shear strength is lost abruptly following a shock or disturbance (Parry, 1974). The sensitivity of clays is defined as the ratio of shear strength in an undisturbed condition to shear strength after being severely disturbed (Costa and Baker, 1981). Rosenqvist (1953, 1966) proposes that these clays originate as platy clay particles deposited in an edge-to-edge "house of cards" (flocculated) structure in saline environments, in which sodium and other cations in water provide bonding strength. Later, when this saline water is leached out by fresh ground water, the clays are left in an unstable arrangement subject to collapse or liquefaction when disturbed or shaken. One triggering mechanism for ground failure is ground shaking generated by earthquakes. During and after disturbance, the clays may revert from a flocculated soil structure in which ground water fills the interstitial pore spaces, to a dispersed soil structure in which the interstitial water is expelled, liquefying the clay (Costa and Baker, 1981).

The potential for ground failure in sensitive clays is related to the intensity and duration of ground shaking, and sensitivity of the clays. Clays with high sensitivities (ratio of undisturbed shear strength to disturbed shear strength of 10 or more) may be prone to failure during

earthquake-induced ground shaking (Earthquake Engineering Research Institute, 1986). The existence of such clays and intensity and duration of ground shaking needed to induce failure have not been investigated in Tooele Valley and the WDHIA. Therefore, the probability of this type of failure has not been determined. However, sensitive clay horizons have been identified within lake sediment sequences along the central Wasatch Front (Parry, 1974).

The principal effect of disturbance of sensitive clays is ground failure. The kinds of ground failure associated with sensitive clays are similar to those accompanying liquefaction, including flow failures, slump-type landslides, and lateral-spread or translational landslides (Chapter E; Costa and Baker, 1981; Earthquake Engineering Research Institute, 1986). Liquefied sensitive clays may flow downhill on slopes as low as 2 percent or less (Costa and Baker, 1981). The most devastating damage resulting from the 1964 Alaska earthquake (magnitude 8.6) was due to translational landslides partly from failure of sensitive clays. The largest of these landslides damaged 75 homes in the Turnagain Heights residential area in Anchorage (Hansen, 1966).

Hazard Reduction and Site Investigations

Ground failure due to sensitive clays has the potential to cause damage to most types of structures. Possible actions which may be taken if sensitive clays are present include: (1) improving site conditions by converting the clays from a flocculated soil structure to a dispersed structure using preconstruction vibration techniques, and/or dewatering the site; and (2) designing the structure to withstand the potential effects of ground failure using structural solutions such as end-bearing piles placed below the sensitive clays, caissons, or fully-compensated mat foundations designed for the anticipated failure type.

The distribution and extent of sensitive clays in Tooele Valley and the WDHIA is unknown, and maps have not been produced which show their extent. Fine-grained lake sediments underlie much of both areas, deposited by lakes occupying the Great Salt Lake Basin during the last 15 million years (Currey and others, 1984). Many of these lake sediments are silicate clays, some of which have been classified as sensitive in the Wasatch Front area (Parry, 1974). Assessment of this hazard should be undertaken at the site-specific level, as part of a standard geotechnical investigation, in areas where the depth to shallow ground water is less than 30 feet (9 m).

Site investigations for sensitive clays require sampling and testing of foundation sediments. Testing involves applying axial loads to unconfined cylindrical samples first in an undisturbed state and then in a disturbed state (Spangler and Handy, 1973) to determine the soil sensitivity. Additional study is then needed to determine the levels of ground shaking necessary to cause ground failure in sensitive clays. Sensitive clays should be considered in site-specific studies for all major construction in clayey soils, particularly critical facilities.

SUBSIDENCE IN GRANULAR MATERIALS CAUSED BY GROUND SHAKING

Characteristics and Effects

Loose granular materials such as sand and gravel may be prone to subsidence when shaken. Earthquake ground shaking can effectively compact these materials as individual particles move closer together. This rearrangement decreases the volume of the material, causing subsidence. During the 1964 Alaska earthquake, ground shaking caused as much as 5.9 feet (1.8 m) of subsidence at some locations (Costa and Baker, 1981).

Differential settlement can occur in deposits that are susceptible to vibratory subsidence. This may result in building damage or foundation cracking as one part of a foundation settles more than another (Costa and Baker, 1981). Structural failure of building members may also be caused by excessive settlement (Dunn and others, 1980). Even minor differential settlement can cause extensive damage to earthen-fill structures such as railway embankments, highway foundations, bridge abutments, and dikes and levees. Buried utility lines and connections may also be severed by settlement. Rate of subsidence is an important factor that must be considered in evaluating the potential for damage (Dunn and others, 1980). Subsidence due to earthquake ground shaking would be virtually instantaneous.

Hazard Reduction and Site Investigations

Structural methods to reduce settlement damage include supporting structures on piles, piers, caissons, or walls founded below the susceptible material (U.S. Bureau of Reclamation, 1985). Where structural measures to reduce settlement in granular soils are not possible, other actions to reduce the hazard include: (1) improving site conditions by removing or compacting in-place granular materials prior to construction, and (2) properly engineering and compacting fill materials.

Maps delineating areas susceptible to vibratory subsidence in granular soils have not been prepared for Tooele Valley and the WDHIA, and the extent of soils subject to subsidence is unknown. However, areas of Tooele Valley and the WDHIA are underlain by deposits that may be prone to vibratory subsidence, such as clean sand and gravel deposited in Pleistocene Lake Bonneville. If not adequately compacted during placement, artificial fill may also be susceptible to vibratory subsidence (Schmidt, 1986).

Levels of ground shaking necessary for subsidence vary with conditions, and assessment of this hazard must be undertaken on a site-specific basis as part of geotechnical investigations. Standard penetration and cone penetrometer tests are commonly used to evaluate the potential for subsidence (Dunn and others, 1980). The potential for subsidence should be considered during soil-foundation investigations for all major construction, especially for critical facilities.

FLOODING CAUSED BY SEICHES IN GREAT SALT LAKE

Characteristics and Effects

Oscillations in the surface of a landlocked body of water can produce unusually large waves, or seiches, similar to oscillations produced by sloshing water in a bowl when shaken or jarred (Nichols and Buchanan-Banks, 1974). Seiches may be generated by wind, landslides, and/or earthquake effects such as ground shaking or surface fault rupture. The magnitude of seiches caused by landslides or surface fault rupture depends on the amount of water and ground displacement. For wind- and ground-shaking-induced seiches, the magnitude is determined by the degree of resonance between the water body and the periodic driving force. The magnitude is greatest when this driving force is oscillating at the same frequency at which the body of water naturally oscillates (Costa and Baker, 1981). A lake's natural oscillation period is determined by parameters such as water depth, lake size and shape, and shoreline configuration, much as the natural frequency of a pendulum is determined by its physical characteristics (Lin and Wang, 1978).

Studies of wind seiches in Great Salt Lake conclude that the maximum wave amplitude is expected to be about 2 feet (0.6 m) (Lin and Wang, 1978); no systematic or theoretical studies of landslide or earthquake-induced seiches have been made. However, seiches were reported along the southern shoreline of Great Salt Lake at Saltair and the Lucin trestle during the 1909 Hansel Valley earthquake (magnitude 6) (Williams and Tapper, 1953). The elevation of the lake was 4202.0 feet (1280.7 m) at this time (U.S. Geological Survey lake elevation records). The seiche generated by this earthquake overtopped the Lucin cutoff railroad trestle at an elevation of 4214.85 feet (1284.69 m) (Southern Pacific Transportation Company records). Assuming lake and trestle elevation records and reports of the seiche are accurate, the seiche was more than 12 feet (3.7 m) high (Lowe, 1993).

Studies from other areas have shown that seiches may raise or lower a water surface from a few inches to several yards (Blair and Spangle, 1979). Seiches may cause damage from flooding and erosion in areas around the margins of lakes, and are a hazard to shoreline development, dams, and in-lake structures. The principal area at risk in Tooele County is along the shore of Great Salt Lake.

Hazard Reduction and Site Investigations

Dikes protected against erosion on the lakeward side and engineered breakwaters can be used to protect development or dissipate wave energy. Shoreline buildings can also be floodproofed, elevated, and constructed or reinforced to withstand the lateral forces of seiches (Costa and Baker, 1981).

Landslide and earthquake-generated seiches are a hazard to shoreline development and in-lake construction. They should be taken into consideration when planning development in Great Salt Lake and within the proposed Great Salt Lake Beneficial Development Area (Utah

Division of Comprehensive Emergency Management, 1985). Accounts of the seiche generated by the 1909 Hansel Valley earthquake suggest that maximum wave amplitudes generated by earthquakes may far exceed those associated with wind, and that areas above 4,217 feet (1,285 m) (Section J) may be affected by seiches during high lake levels.

Because no comprehensive studies have been completed for Great Salt Lake, maps have not been produced that show the likely area to be affected by seiches in Tooele Valley. Site investigations and recommendations for proposed development in lake-flooding areas are discussed in Section J. However, because they may far exceed normal flood elevations, it is recommended seiches be considered for any development at elevations less than 4,220 feet (1,286 m).

FLOODING DUE TO SURFACE-DRAINAGE DISRUPTIONS

During earthquakes, ground shaking, surface fault rupture, ground tilting, and landsliding can cause flooding if water tanks, reservoirs, pipelines, or aqueducts are ruptured, or if stream courses are blocked or diverted. Areas where such flooding may occur can be predicted to some extent by defining known active faults, active landslides, and potentially unstable slopes. Damming of streams by landslides can cause upstream inundation and, if the dam subsequently fails, cause catastrophic downstream flooding (Schuster, 1987). Maps delineating active faults and landslides are available with this report (plate 1; figures B-3 and G-2).

Site-specific studies which address earthquake and slope-failure hazards should be completed prior to construction for all major water-retention structures or conveyance systems so that hazard-reduction measures can be recommended. To prepare for water-system breaks, shut-off valves and emergency response/repair plans should be in place. For existing facilities, studies can evaluate the possible locations and extent of flooding and recommend drainage modifications to prevent floods or divert flood waters. Potential flooding from diversion of stream courses is more difficult to evaluate, but should be considered in hazards evaluations for critical facilities.

INCREASED GROUND-WATER DISCHARGE

The effects of earthquakes on ground-water systems have not been extensively studied and, consequently, are not well understood. Increases in spring flow and expulsion of water from shallow bedrock aquifers caused surface flooding during the 1983 Borah Peak, Idaho, earthquake. Stream flow increased by more than 100 percent following the earthquake, and flow remained high for 2 weeks before declining to near original levels (Whitehead, 1985). Although this earthquake appeared to cause a more profound effect on ground water than other earthquakes, similar effects may occur during large-magnitude earthquakes in Tooele Valley. Flooding from increased spring flow in mountain drainages will be confined to stream channels, and adherence to Federal Emergency Management Agency flood-plain regulations should effectively reduce the risk. However, increased spring flow on valley floors could result in

ponded water and basement flooding.

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SECTION G:
LANDSLIDES

by

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and
Bill D. Black

INTRODUCTION

Landslides are downslope movements of rock or soil under the influence of gravity, including both deep-seated and shallow slope failures. Deep-seated slope failures have failure planes generally greater than 10-feet (3-m) deep, and include rotational and translational slides and associated earth flows (Varnes, 1978). This section addresses the landslide hazard posed by deep-seated slope failures. Rock falls and earth movements of shallow origin (failure plane generally less than 10 feet [3.0 m] deep), such as debris flows, are addressed in sections I and H of this report.

Landslides may be caused by oversteepening of slopes, loss of lateral support, weighting of the head, and increased pore pressure (static conditions). In addition, landslides may also be induced by earthquakes (dynamic conditions). Older landslides may reactivate due to conditions in the landslide such as increased permeability and established failure planes. Landslides can damage buildings, transportation routes, and utility lines by displacement of the ground, and cause flooding due to discharge of springs and damming of streams.

Because of the predominance of relatively slide-resistant rock, deep-seated landsliding historically has caused little damage in Tooele Valley. The landslide hazard is greatest in the Oquirrh and Stansbury Mountains at the southern end of Tooele Valley, where the slide-prone Mississippian-age Manning Canyon Shale crops out or lies just below the ground surface. There is no significant landslide hazard in the WDHIA. The areas most susceptible to dynamic landsliding are generally those areas most susceptible to static (non-earthquake) landsliding.

CHARACTERISTICS

Two types of landslides are common. Rotational slides generally have a curved failure plane and are called slumps. The head of a slump is back-tilted compared to the original slope. Many slumps include an earth flow at the toe where material moves onto the land surface below the slump (figure G-1). Translational slides generally have a more planar failure surface, and may be broken into discrete blocks. Slumps and translational slides may move slowly and progressively over periods of years, or rapidly in a matter of a few seconds.

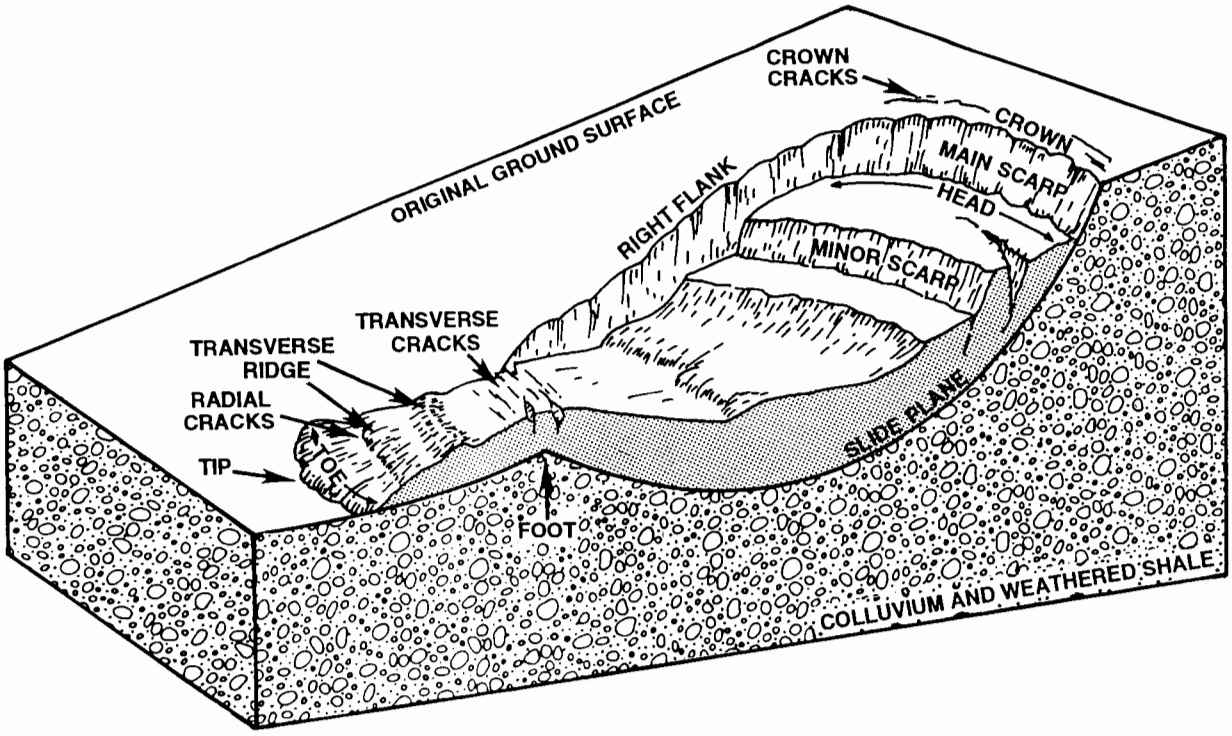

Figure G-1. Block diagram of a rotational landslide (slump) and earth flow (modified from Varnes, 1978).

Landslides may occur in Tooele Valley in a moderate to strong earthquake. Slopes considered unstable under static conditions will be even less stable during an earthquake, and some slopes that are stable under static conditions may also fail as a result of earthquake ground shaking, particularly if wet. Most landslides caused by earthquakes are new slope failures, not reactivated older landslides (Keefer, 1984). Deep-seated slumps and translational slides commonly accompany earthquakes with Richter magnitudes greater than 4.5 (Keefer, 1984). In Utah, slope failures (predominantly rock falls or rock slides) have been noted in earthquakes (magnitudes 4.3 to 6.6) from 1850 to 1986 (Keaton and others, 1987). The September 2, 1992 magnitude 5.8 St. George earthquake caused a large, destructive translational landslide near Springdale, Utah, 27 miles (44 km) from the epicenter (Black, 1994). Earthquakes of magnitude 7.0 could cause deep-seated slope failures as far as 100 miles (161 km) from the epicenter (Keefer, 1984).

Landslides are also likely in years of above-average precipitation, such as during the wet cycle of the 1980s (1982-1986). However, few deep-seated landslides occurred during this time in Tooele Valley because most rock and sediment in the valley and surrounding mountains is not susceptible to landsliding.

Factors such as slope steepness, precipitation, ground-water regime, and bedrock structure are important in determining landslide susceptibility, but the most important factor is rock type. Rock units containing low-strength, moisture-sensitive shale or clay are usually the most susceptible to landsliding. Landslides are not numerous in the mountains in the WDHIA or those surrounding Tooele Valley, and only one geologic unit, the Mississippian-age, clay-rich Manning Canyon Shale, is particularly susceptible to landsliding. The general lack of landslides in the northern Stansbury and Oquirrh Mountains, and in the Cedar Mountains, is due mainly to a lack of susceptible geologic units (Harty, 1990).

The Manning Canyon Shale has been involved in many damaging landslides in northern Utah, particularly in the foothill slopes of the Wasatch Range in and east of Provo (Harty, 1991). In the Stansbury Mountains, the Manning Canyon Shale mainly crops out south of South Willow Canyon (Sorenson, 1982), and from Magpie Canyon north to about Miners Canyon (Rigby, 1958; Sorenson, 1982). In 1983, a large landslide in Manning Canyon Shale occurred at the confluence of Morgan and East Hickman Canyons about 2.5 miles (4.0 km) south of the study area boundary. The slide took out the East Hickman Canyon road, and only since 1990 has the road been restored (Paul Dart, Range Technician, U.S. Forest Service, verbal communication, December, 1990). In the Oquirrh Mountains, the Manning Canyon Shale crops out in the southeastern part of the study area, in Soldier Canyon. Here, it was likely involved in the large, middle-to-early Holocene-age Soldier Canyon landslide about 3.5 miles (5.6 km) up the canyon on its southern flank.

Landslides may also occur in the unconsolidated sediments of Pleistocene Lake Bonneville. Many landslides along the Wasatch Front have occurred in Lake Bonneville sediments, especially in the highest shoreline and delta deposits that typically form steep slopes. However, there are no landslides mapped in unconsolidated sediments in Tooele Valley and the WDHIA.

EFFECTS

Landslide movement may be preceded by cracks at the landslide head and a bulge at the toe (figure G-1). Damage from a landslide can occur either on or adjacent to the slide mass. The top of most landslides is characterized by an arcuate downslope-facing scarp (main scarp) created by downward displacement (figure G-1). A building that straddles the main scarp loses foundation support and may collapse. Structures upslope from the landslide head are at risk because the newly formed main scarp is commonly unstable and may progressively fail, forming new scarps upslope. Buildings within the central mass of the landslide may experience differential displacement on minor scarps and movement in both vertical and horizontal directions. The toe of a landslide will normally move horizontally and upward and may proceed downslope causing extensive damage. Table E-2 shows the relationship between ground displacement and expected levels of damage to structures.

Landslides have damaged numerous structures, including roads, railroads, and utility lines. Rupture of canals, aqueducts, sewers, and water lines can cause flooding and add water to the slide plane and promote further movement. Floods may occur during landslides due to damming of streams causing upstream flooding as water is ponded, and downstream flooding if the impounded water overtops and breaches the landslide dam.

HAZARD REDUCTION

Many methods have been developed for reducing landslide hazards. Proper planning or avoidance are made possible if slide-prone areas are identified early in the planning process. Where avoidance is not feasible, various engineering techniques are available to stabilize slopes. Care in site grading, with proper compaction of fills and engineering of cut slopes, is necessary for hillside development. De-watering (draining) can stabilize slopes and existing landslides. Retaining structures built at the toe of a landslide may help stabilize the slide and reduce the possibility of smaller landslides. In some cases, piles may be driven through the landslide mass into stable material beneath the slide. If the dimensions of the landslide are known, and the landslide is not excessively large, removing the landslide may be effective. Diversion of drainage away from a slide reduces the destabilizing effects of infiltrating ground water. Other techniques used to reduce landslide hazards include bridging, weighting, or buttressing slopes with compacted earth fills. A more complete list of landslide-hazard-reduction techniques can be found in Costa and Baker (1981), and Kockelman (1986). Chapter 70 of the Uniform Building Code (UBC) (International Conference of Building Officials, 1994) includes specifications for site grading and slope design.

USE OF HAZARD MAPS

Plate 1 shows the slope stability of natural slopes under static (non-earthquake) conditions for Tooele Valley and the WDHIA (figure G-2). Slope stability was estimated from geologic maps, slope steepness, and the presence of existing landslides. Four categories were used: high, moderate, low, and very low.

Included on plate 1 are existing landslides in Tooele Valley determined from geologic maps and aerial photographs; there are no existing landslides in the WDHIA. The Soldier Canyon landslide, originally mapped by Tooker and Roberts (1988), is the only major slump-type failure identified in Tooele Valley. The Bear Trap Flat area in Settlement Canyon was mapped as a possible landslide by Colton (1988), however, subdued topography and heavy forest cover make it difficult to confirm. Several bedrock blocks are also mapped as landslides in and north of Black Rock Canyon at the northern end of the Oquirrh Mountains. These rocks, including the locally well-known "Black Rock" on the shore of Great Salt Lake, are believed to have been dislodged by ancient Lake Bonneville wave erosion (Tooker and Roberts, 1971) and are not considered a hazard. Two large rock slides in upper Settlement Canyon are shown on both the landslide and debris-slide/flow maps (plate 3) because the slopes on which they occurred may be subject to different types of failure.

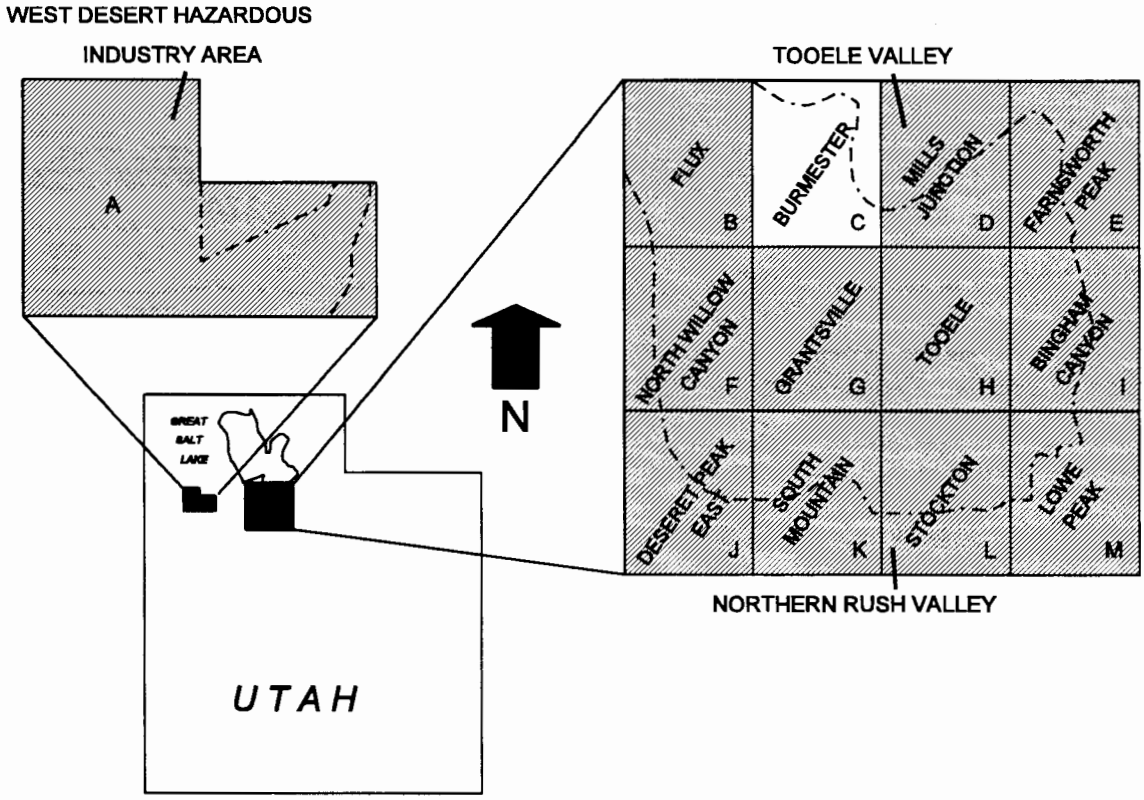

Figure G-2. Index map of areas (crosshatched) where landslide hazards are mapped on plate 1. Letters are used in plate designations. Study area boundaries are shown by dashed lines.

Slopes included in the high-hazard category are slopes on or adjacent to existing landslides. Existing landslides pose a particular problem for development because of their tendency to reactivate. The only areas where a high hazard was assigned is in the vicinity of the Soldier Canyon landslide and on the rock-slide slopes in Settlement Canyon.

The moderate-hazard category includes slopes greater than 15 percent (9 degrees) that also meet one of the following criteria: (1) slopes underlain by slide-prone material; (2) slopes composed of unconsolidated Lake Bonneville sediments; or (3) slopes that show evidence of sloughing, such as those along some stream-channel banks. All of the moderate-hazard areas in the Stansbury Mountains are areas where the Manning Canyon Shale crops out. In eastern Tooele Valley, most of the moderate designations are slopes in Lake Bonneville deposits.

Low-hazard areas include slopes that are equal to or greater than 15 percent, and underlain

by slide-resistant material. Most slopes in the Oquirrh and Stansbury Mountains, and in the Grayback Hills, are in this hazard class. Unlike debris slides and flows (Section H), which commonly occur on steep slopes, deep-seated landslides such as slumps usually occur on moderate slopes; many deep-seated landslides in Utah have initiated on slopes of about 15 percent. A statewide survey shows that the lower limits of slope for rotational slumps range from 7 to 18 degrees (12-32.5 percent), and earth flows range from 4 to 20 degrees (7-36 percent) (Sidle and others, 1985). The lower limit of 15 percent (9 degrees) is a conservative choice for the hazard maps. Landslide susceptibility is designated "very low" where slopes are less than 15 percent. Most of Tooele Valley and the WDHIA is in this hazard category.

In areas where potentially unstable slopes are bounded by flat, stable surfaces, landslide-hazard boundaries extend beyond the base and top of the unstable slope. This happens along the stream banks of Settlement and Middle Canyons, and at the Stockton bar, where potential instability in the steep portion of the slope may affect areas both above and below. The width of the landslide-hazard zones in these areas depends on the height, steepness, ground-water conditions, and strength of the material underlying the slope. In these areas, a conservative stable slope angle through the center of the steep slope was taken to determine the area potentially affected. Rollins, Brown, and Gunnel (1977) recommend that this conservative slope angle should be 2 horizontal to 1 vertical (2:1; 50 percent) for dry granular soils, and 2.5:1 (40 percent) for moist fine-grained material.

Tooele County has a zoning ordinance provision whereby a conditional-use permit approved by the planning committee must be obtained before building on slopes greater than 15 percent (9 degrees) (Barry Formo, Tooele County Engineering Department, verbal communication, May 28, 1991). Obtaining the conditional-use permit generally requires that an engineering study of the site be performed, with report reviews by the Tooele County Engineering Department before approval is granted or denied. The criteria used for the landslide-hazard maps fit with the existing 15-percent slope-ordinance provision.

The landslide-hazard maps are intended for planners to identify areas where site-specific investigations addressing slope stability should be performed prior to development. Site investigations are recommended on all slopes mapped as high and moderate hazard. Slope-failure potential should be determined and, if necessary, hazard-reduction measures recommended in site-specific engineering-geologic reports as outlined in table 1.

The landslide-hazard maps provide a general indication of where the hazards may exist, and serve as a means for determining the need for site-specific studies. These maps are at a regional scale and, although they can be used to gain an understanding of the potential for landslides occurring in a given area, they are not designed to replace site-specific evaluations. Mapped areas rated as having high or moderate landslide hazards may contain areas that are not prone to landsliding, even during earthquake ground shaking, and areas in the low or very low hazard category may contain areas that are susceptible to landsliding.

SITE INVESTIGATIONS

Site investigations for landslides and potentially unstable slopes, including earthquake-induced landslides, should be performed prior to construction of any structure for human occupancy in high and moderate hazard areas on the maps. Investigation reports should include maps showing the proposed development, existing landslides, moderate to steep slopes, and the site geology. An assessment of present slope stability, and effects on slope stability due to development or slope modifications, should be included. Where necessary, a factor-of-safety analysis can be computed by a geotechnical engineer or engineering geologist to determine the stability of natural or proposed cut slopes. Slope-stability analyses should include an assessment of the potential for movement under static, development-induced, and earthquake-induced conditions as well as likely ground-water conditions. Site grading, including design of cuts and fills, should comply with Chapter 2 and 70 of the most current edition of the Uniform Building Code. A useful guide for preparing site-investigation reports is found in Utah Geological Survey Miscellaneous Publication M, "Guidelines for Preparing Engineering Geological Reports in Utah," by the Utah Section of the Association of Engineering Geologists (1986).

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SECTION H:
DEBRIS SLIDES, FLOWS, AND FLOODS, AND STREAM AND DAM-FAILURE FLOODS

by

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and
Bill D. Black

INTRODUCTION

Debris slides, debris flows, and debris floods consist of mixtures of soil, rock, water, and organic material that move downslope and can present a hazard to life and property. Debris slides are generally shallow slope failures, with slide planes less than about 10-feet (3-m) deep. They form on steep slopes and usually lack sufficient water (less than 10-30 percent) to travel far from their source areas. Debris slides thus present a hazard primarily on and adjacent to steep slopes, usually in mountainous areas. Debris flows are a muddy slurry (70-90 percent solids by weight; Costa, 1984) much like wet concrete, that flow downslope usually in surges or pulses. They generally are confined to slopes and stream channels in mountains, but may deposit debris over large areas on alluvial fans at and beyond canyon mouths. Debris floods, also called hyperconcentrated floods, are mixtures of soil, organic material, and rock debris that are transported by fast-moving flood waters (Wieczorek and others, 1983). Solids account for 40 to 70 percent of the material by weight (Costa, 1984). Like debris flows, debris floods can transport material great distances from their source areas. Stream floods occur when the stage or height of water exceeds some given datum such as the banks of the normal stream channel (Costa and Baker, 1981). In normal stream flow, solids account for less than 40 percent of the water/sediment mixture by weight (Costa, 1984). Dam-failure floods consist of an unintentional release of impounded water.

Tooele Valley is susceptible to debris flows, debris floods, and stream flooding from the steep mountains that border the valley. Debris slides are typically only a hazard in the mountains because they rarely make it to the valley. Susceptibility to these hazards is lower in the WDHIA because of subdued topography. Debris flows, debris floods, and stream flooding have occurred in Tooele Valley during historical time and have caused significant damage to engineered structures and property. Early accounts usually did not distinguish debris flows or debris floods from clear-water stream flooding, making it difficult to separate these events. From 1878 to 1969, 13 cloudburst floods affecting the city of Tooele were reported in local newspapers (Woolley, 1946; Butler and Marsell, 1972). At least five of these events deposited debris on roads, or in ditches and houses. Of the six cloudburst storms reported to have affected Grantsville during this period, three deposited debris. In late July, 1887, a severe rainstorm in the Stansbury Mountains generated a debris flow that covered 0.5 acres (0.2 ha) of cropland in

Grantsville to a depth of 2.5 feet (0.8 m) (Deseret News, July 28, 1887, in Woolley, 1946).

Stream flooding in Tooele Valley and the WDHIA occurs as the result of spring snowmelt in the mountains and summer cloudburst rainstorms. These events may also contribute to dam-failure flooding. Floods occurring in Tooele Valley and the WDHIA between 1970 and 1982 are not comprehensively documented. However, the Federal Emergency Management Agency (FEMA) (1989a) and the local newspaper (Tooele Transcript-Bulletin, June 14, 1983) report that major flooding occurred in Tooele City during the spring of 1973, when snowmelt runoff from an above-average snowpack rapidly filled the Settlement Canyon Reservoir, causing an uncontrolled release of water over the spillway from early May until the latter part of July.

Snowmelt flooding caused about $4.5 million in damage in Tooele County during the abnormally high precipitation years of 1983 and 1984 (FEMA, in Transcript-Bulletin, July 24, 1984). Most of the major canyons in the Oquirrh and Stansbury Mountains, including Middle, Settlement, Soldier, North Willow, and South Willow Canyons carried floodwaters onto farm and grazing land, and into populated areas. In 1983, stream inflow exceeded that which could be safely released from the Settlement Canyon Reservoir, and on May 30th, the overflow outlet began releasing floodwaters into Tooele Valley. In May 1984, Settlement Canyon Reservoir again released floodwaters. During both events, floodwaters inundated streets in Tooele City, and house and property damage occurred when floodwaters breached a dike (Tooele Transcript-Bulletin, May 31, 1983; May 15, 1984). Major damage caused by the flooding included road destruction in Middle, Settlement, and Soldier Canyons; rupture of the main culinary water line in Middle Canyon; deposition of sediment on farmland; and inundation of roads, farm and grazing land, residential property, and houses in Stockton, Erda, Grantsville, Tooele, and surrounding areas.

Many debris slides occurred in the Oquirrh Mountains during the spring and summer of 1983 and 1984. Although most of the damage sustained in Tooele Valley during these years was related to stream flooding, a number of debris flows and debris floods also caused damage. A rainstorm on July 31, 1983 generated a debris flow about 7 miles (11.3 km) up Settlement Canyon that buried a large part of the canyon road (Tooele Transcript-Bulletin, August 2 and 9, 1983). Kaliser (1989) reports that a debris flow or debris flood that occurred sometime between July 31 and August 19, 1983 destroyed four sections of a main culinary water line in Soldier Canyon. On May 14, 1984, a series of debris flows and floods from an unnamed tributary channel in Settlement Canyon trapped three men in the canyon for seven hours. A truck parked in the canyon washed away during these events (Tooele Transcript-Bulletin, May 15, 1984). Debris flows and floods flowed into Settlement Canyon Reservoir and covered an irrigation intake pipe 60 feet (18.3 m) below the water level with about 6 to 7 feet (1.8 to 2.1 m) of sediment (Tooele Transcript-Bulletin, May 22, June 12, 1984). Also, on May 14, 1984, a debris flow from Baltimore Gulch near the head of Pine Canyon in the Oquirrh Mountains struck and killed a man operating a bulldozer at the Carr Fork mine.

CHARACTERISTICS

Debris Slides, Flows, and Floods

Debris slides, flows, and floods, and normal stream flow form a continuum of sediment/water mixtures that grade into each other with changes in the relative proportion of sediment to water, and stream gradient (Pierson and Costa, 1987). Debris flows and debris floods present a greater hazard to valley areas than debris slides. Deposition of sediment transported by debris flows and debris floods may take place on alluvial fans at and beyond canyon mouths. Deposition on alluvial fans is caused by the decrease in channel gradient and increase in channel width, resulting in a decrease in depth and velocity of flow and an increase in internal friction of the flowing debris as the stream leaves its constricted channel and enters the main valley floor (Jochim, 1986).

Debris flows can form in at least two different ways. In the Oquirrh and Stansbury Mountains, where cloudburst rainstorms are common, overland flow and flood waters can scour materials from the ground surface and stream channels, thereby increasing the proportion of soil materials to water until the mixture becomes a debris flow (Wieczorek and others, 1983). The size and frequency of debris flows generated by rainfall are dependent upon several factors including the amount of loose material available for transport, the magnitude and frequency of the storms, the density and type of vegetative cover, and the moisture content of the soil (Campbell, 1975; Pack, 1985; Wieczorek, 1987). Debris flows can also mobilize directly from debris slides once the slide reaches a stream, or when the water content in the slide increases by some other means until sufficient to permit flow. Many debris slides occurred in the Oquirrh Mountains during the 1983-84 wet years.

As the relative proportion of water to sediment increases with either the addition of water or removal of sediment by deposition, debris flows become debris floods. Debris floods can also originate through progressive incorporation of materials into flood waters (Waitt and others, 1983; Wieczorek and others, 1983).

Many of the debris slides and flows that occurred in the Oquirrh Mountains in 1983-1984 were generated by rapid melting of an unusually thick snowpack. Of the 102 debris slides and flows identified, over 70 percent occurred on south-facing slopes. The high percentage on south-facing slopes was due in part to weather conditions. During the winters of 1983 and 1984, the greater-than-average snowpack was preserved by cool early-spring temperatures (Wieczorek and others, 1989). The more intense solar radiation received by south-facing slopes, combined with sudden, sustained high temperatures in late spring, caused rapid melting of the snowpack. Kaliser and Slosson (1988) report that landslides occurring in 1983 generally followed the melting snowline, generating debris slides and flows at progressively higher elevations. Infiltration of meltwater into porous colluvium on steep mountain slopes probably exceeded the rate of drainage into the underlying bedrock, causing a rapid rise in pore-water pressure in the colluvium, resulting in loss of frictional resistance and sudden failure of the shallow colluvial layer.

Pore-water pressure in colluvium may increase with draining of bedrock aquifers into the colluvium. Mathewson and others (1990) found evidence of this in Davis County by observing sustained spring flow from debris-slide scars. We are uncertain whether such flow occurred following debris slides in the Oquirrh Mountains. However, because south-facing slopes in the Oquirrh Mountains produced more than twice the number of shallow failures than north-facing slopes, accelerated snowmelt on southern slopes was likely the dominant process creating debris slides.

Stream Floods

Stream floods may be caused by direct precipitation, melting snow, or a combination of both. In Tooele Valley, floods are most common in April through June during spring snowmelt. High flows are sustained from a few days to several weeks (Federal Emergency Management Agency, 1989a). Snowmelt floods are somewhat predictable because flood levels depend on the volume of snow in the mountains and the rate of temperature increase. Localized cloudburst storms centered over the mountains are also effective in causing floods. These storms typically last from a few minutes to several hours, and generally occur between mid-April and September. The flooding potential of cloudburst rainstorms is dependent upon many factors including: (1) the rate of rainfall, (2) the duration of rainfall, (3) the distribution of rainfall and direction of storm movement, (4) soil characteristics, (5) antecedent soil-moisture conditions, (6) vegetation conditions, (7) topography, and (8) drainage pattern. Because many of these conditions are generally not known until rain is actually falling on critical areas, the magnitude of flooding from a given cloudburst storm is difficult to predict. Summer cloudburst floods account for localized but often very destructive flooding and can occur with little warning. Tooele Valley communities have experienced many cloudburst floods in historical times; those occurring between 1850 and 1969 are shown in table H-1.

Table H-1. Historic cloudburst floods, Tooele Valley, Utah, 1850-1969 (Woolley, 1946; Butler and Marsell, 1972).

CITY	YEAR
Grantsville	1881, 1887, 1913, 1930 (2), 1955, 1961
Erda	1957
Lake Point	1927
Tooele	1881, 1934 (2), 1954 (2), 1957, 1961, 1963, 1965, 1967, 1968, 1969
Stockton	1936

Dam-Failure Floods

Flooding can result from the failure of dams, and may occur with little warning. The severity of flooding depends on the size of the reservoir and the extent of failure. The term dam failure includes all unintentional releases of water from the dam, including complete failure and release of all impounded water (Harty and Christenson, 1988). Only eight of 33 dam failures documented in Utah prior to 1984 were complete failures; most were due to overtopping and/or erosion around spillways and outlets during flood events (Harty and Christenson, 1988). Although dam failures have many causes, the most common cause is structural and foundation failures resulting from piping (Dewsnup, 1987). Uncontrolled release of water over the spillway was the cause of repeated flooding from the Settlement Canyon Reservoir in the Oquirrh Mountains.

Most historical dam failures in Utah have been small dams in rural areas; larger dams are less prone to failure because of more rigorous design, construction, and inspection practices (Harty and Christenson, 1988). Earthquake-induced ground shaking, liquefaction, landslides, and seiches (flood waves) may occur in Tooele Valley and could cause dam failures.

EFFECTS

Loss of life during debris slides, flows, and floods may result from drowning, high-velocity impact, or burial. Damage associated with debris flows has been described by Campbell (1975), and is summarized here. Damage to residential structures ranges from simple inundation to complete destruction by high-velocity impact. The velocity of a debris flow is an important consideration in determining the level of damage to structures. Many debris flows move with speeds on the order of 40 feet/second (12.2 m/sec), but others move as slowly as 1 foot/second (0.3 m/sec) as they flow down relatively gentle slopes. Debris flows of sufficient volume and momentum have destroyed residential structures and removed the remains from their foundations. Debris flows of relatively small volume but high momentum have broken through walls and passed completely through structures. Low-velocity debris flows may enter dwellings through doors and windows. Debris flows and floods may fill basements with mud, water, and debris, or pile debris around structures. Debris may also bury yards, streets, parks, driveways, parking lots, and other ground-level structures. In the distal parts of alluvial fans, damage is usually comparatively minor, consisting primarily of mud and water damage to outer walls of buildings, basements, and yards.

Loss of life during stream and dam-failure floods may occur by drowning where floodwaters are deep or flowing swiftly. Water damage depends largely on depth of inundation, and damage potential increases dramatically with increases in floodwater velocity (Federal Emergency Management Agency, 1985). High-velocity floodwaters can cause structures to collapse due to pressures applied by fast-moving water. Flowing water can also induce erosion and undermine structures. Areas subject to rapid inundation by flash floods pose special threats to life and property because there is insufficient time for evacuation, emergency floodproofing, or

other protective measures (Federal Emergency Management Agency, 1985).

HAZARD REDUCTION

Debris Slides, Flows, And Floods

Methods for reducing debris-related hazards include: (1) avoidance, (2) source-area stabilization, (3) transportation-zone modification, and (4) defensive measures in the depositional zone (Hungr and others, 1987). Different methods or combinations of methods may be appropriate for different drainages or types of development.

Debris-flow hazards may be reduced by avoiding, either permanently or at the time of imminent danger, areas at risk (source areas, transportation zone, and depositional zones). Permanent avoidance is not possible in all areas because some Tooele Valley communities are on active alluvial fans (potential depositional zones) where damage from debris flows may occur. Reduction of debris-flow hazards could be required for proposed new development through creation and enforcement of foothill (zoning) ordinances that prohibit or regulate development in deposition zones.

Warning systems may be used to avoid life threats from debris flows at the time of imminent danger, generally through evacuation of threatened areas. Hungr and others (1987) identify three categories of debris-flow warning systems: pre-event, event, and post-event. Pre-event warning systems identify when climatic conditions have increased the potential for debris-flow occurrence. Event warning systems provide an alarm when a debris-flow event is occurring (Hungr and others, 1987). Post-event warning systems, such as slide-warning fences, are usually designed to warn of disruption of transportation routes (Hungr and others, 1987).

Source-area stabilization reduces the amount of hillside material available for incorporation into debris slides, flows, or floods. Improving drainage-basin vegetation is one method of source-area stabilization. Prevention of wildfires, overlogging, and overgrazing will protect existing vegetation. Terracing of mountain slopes, such as that done in the 1930s in Davis County by the Civilian Conservation Corps (Bailey and Croft, 1937), may be useful in preventing debris flows caused by erosion during cloudburst storms. Additional hazard-reduction techniques used near the source area include: (1) control of subsurface drainage, (2) diversion of surface drainage, (3) grading of source areas to a uniform slope, (4) riprap repair of source areas, and (5) retaining walls (Baldwin and others, 1987).

Transportation-zone modifications are generally designed to reduce incorporation of channel material into debris flows and floods, and to improve the ability of the channel to pass debris downstream. The transportation zone consists of the debris-flow track between the source and deposition zone. Scour of material in stream beds and undercutting of unstable stream banks are two of the most important processes contributing to the growth of debris flows (Hungr and others, 1987). Check dams (small debris-retention structures placed in unstable channels) are

used to arrest or retard debris flows, and prevent incorporation of channel material (Hungr and others, 1987). Stream-bed stabilization is also achieved by lining the channel. The ability of channels to pass debris surges downstream may be improved through: (1) removal of channel irregularities, (2) enlargement of culverts with upstream removable grates to prevent blockage, and (3) flumes, baffles, deflection walls, and dikes (Jochim, 1986; Baldwin and others, 1987). Structures crossing potential debris-flow channels may be protected by: (1) bridging the channels to allow debris to pass under structures, (2) constructing debris sheds designed to allow debris flows to pass over structures, and (3) designing structures to withstand debris-flow impact, burial, and re-excavation (Hungr and others, 1987).

Defensive measures in debris-flow deposition zones are designed to control the extent of deposition and prevent damage to structures (Hungr and others, 1987). Defensive measures include deflection devices, impact walls, and debris basins. Deflection devices are used to control the direction and reduce the velocity of debris flows (Baldwin and others, 1987). Deflection devices include: (1) pier-supported deflection walls, (2) debris fences (a series of steel bars or cables placed horizontally at increasing elevations above the stream channel), (3) berms, (4) splitting-wedge walls (reinforced concrete walls in the shape of a "V" with the point facing uphill), and (5) gravity structures like gabions (hollow wire baskets filled with rocks) (Jochim, 1986; Baldwin and others, 1987).

Impact walls and debris basins are methods commonly used to reduce debris-flow hazards. Impact walls are designed to sustain the instantaneous force of impact from debris flows while containing the soil and vegetation debris until it can be removed (Baldwin and others, 1987). Impact walls include concrete, soldier pile, and soil and/or rock gravity walls (including gabions) (Baldwin and others, 1987). Two types of debris basins, open and closed, are used to constrain the area of debris deposition. Open debris basins have a basin-overflow spillway designed to direct excess material either to an insensitive area or back into the stream channel. Closed debris basins generally have a straining outlet to pass water, and a spillway to handle emergency debris overflow (Hungr and others, 1987). Both types of debris basins require access for removal of entrapped debris and maintenance.

Stream Floods

Methods for reducing stream-flood hazards and risk include: (1) avoidance, (2) drainage-basin improvement, (3) flow modification and detention, (4) flood warning and evacuation, and (5) floodproofing. Avoidance is not possible in a few areas in Tooele Valley because some structures are on active alluvial fans which are subject to periodic flooding. Flood hazards in many undeveloped areas in Tooele Valley and the WDHIA may be avoided by discouraging development on alluvial fans and flood plains of streams, or by regulating uses vulnerable to flood losses. Methods for discouraging new development and removal or conversion of existing development on flood plains are described in detail in Kockelman (1977) and later in this section.

Drainage-basin improvement consists primarily of measures to increase infiltration and decrease runoff. Improving drainage-basin vegetation is one method of decreasing runoff. The

prevention of wildfires and forest fires combined with protection against overgrazing will protect existing vegetation. Slope terraces may be useful in decreasing runoff during rainstorms and spring snowmelt.

Flow modification and detention can effectively lower flood hazards. Flood losses often lead to demands for public-works programs to provide protection such as dams, ditches, canals, sluices, holding basins, and detention reservoirs; channel deepening, straightening, widening, and paving; bypass or diversion channels, dikes, revetments, floodwalls, levees, and underground drainage facilities; or combinations of several of these (Kockelman, 1977). Construction of flood-control works can, however, create problems and unrealistic expectations. As urban development of flood plains continues, population and property values in areas subject to flooding tend to increase at rates greater than that at which protection can be provided (Kockelman, 1977). Most flood-control works are expensive and require periodic maintenance. During dry cycles the public becomes complacent and is unwilling to see tax dollars spent on maintaining structures it deems unneeded. The presence of flood-control structures may lead the public to believe that flood hazards have been eliminated rather than simply lowered. Flood-control structures may not prevent losses from great and infrequent floods that exceed design criteria, often with catastrophic results. Unfortunately, after such catastrophes, the public commonly assumes that flooding occurred because flood-control structures were inadequately designed.

Flood warning and evacuation may be the best means of reducing life loss due to floods where flood-control structures are inadequate or non-existent. Reliable and timely flood warnings permit temporary evacuation of people and some personal property from flood-hazard areas.

Floodproofing may be the most effective way of lowering flood damage in areas where floods are of short duration and have low stages and velocities. Floodproofing measures include using special cements for flooring; providing adequate electric fuse protection; anchoring buoyant tanks; sealing the outside walls of basements; installing automatic sump pumps, sewer-check valves, seal-tight windows and doors, and door and window flood shields; and using wire-reinforced glass (Kockelman, 1977). Structural modifications may be necessary, including reinforcing basement walls and floor underpinnings to withstand increased hydrostatic pressures, permanently sealing exterior openings to basements, erecting low floodwalls, and elevating the lowest floor and access roads to at least 2 feet (0.61 m) above the 100-year flood elevation.

Requiring flood insurance in areas of frequent flooding is another means of dealing with flood hazards. In Tooele Valley, Flood Insurance Rate Maps are only available for major drainages in Tooele City (Federal Emergency Management Agency, 1989b); there are no such maps for the WDHIA. These maps are designed to be used in conjunction with the Federal Insurance Administration's National Flood Insurance Program, which permits construction of new structures in floodways only if accompanying increases in flood heights are less than 1.0 foot (0.30 m) and hazardous velocities are not produced (Federal Emergency Management Agency, 1989a). The program requires new development in and around floodways to be elevated

above the level of the 100-year flood, and flood insurance be purchased if property is within the boundary of the 100-year flood. The Utah Division of Comprehensive Emergency Management may be contacted for information regarding the National Flood Insurance Program. County and city planning offices can provide information regarding zonation on the FEMA Flood Insurance Rate Maps.

Dam-Failure Floods

Little can practically be done through land-use planning to reduce hazards from dam-failure floods. Methods used to reduce hazards from stream flooding, such as proper land use along flood plains, will help decrease damage due to dam-failure flooding to some extent. Emergency evacuation based on dam-failure-inundation maps is the principal means of reducing hazards due to dam-failure flooding. The Utah Division of Water Rights, Dam Safety Section, is the agency regulating dam safety in Tooele County.

USE OF HAZARD MAPS

Debris-slide, debris-flow, debris flood, and stream-flood hazards are shown on plate 3 (figure H-1). The plates show locations of debris slides and debris flows, and give a relative rating of slope-failure susceptibility to indicate slopes expected to generate debris slides and debris flows. They also show areas that may experience flooding and deposition of sediment from debris flows, debris floods, or stream floods. To date, no dam-failure inundation studies have been performed on dams in Tooele County, thus no inundation maps are available.

Mapped on plate 3 are 104 debris slides and flows in the Oquirrh Mountains, most of which occurred during 1983 and 1984. They were identified using 1:40,000-scale air photos and field reconnaissance. Where identifiable, the travel paths and deposits of these failures are also shown. No debris slides or debris flows were identified in the Stansbury Mountains or the WDHIA. There are two probable pre-historic debris flows which originated near Stockton. Debris slides and flows in the Oquirrh Mountains occurred only in the southern half of the study area, between Soldier Canyon on the south and Flood Canyon on the north. All but a few are in Settlement, Middle, Pass, and Flood Canyons. No debris flows and only four debris floods deposited material beyond canyon mouths during 1983 or 1984, when debris floods in Pass and Swensons Canyons in the Oquirrh Mountains deposited sand and gravel on alluvial fans east of the town of Lincoln up to 1.5 miles (2.4 km) from the base of the mountains. Two small, unnamed canyons in the northern Stansbury Mountains northwest of Timpie Valley also yielded debris floods that deposited material on alluvial fans beyond the canyon mouths.

Slope-failure susceptibility in debris-flow source areas (source-area susceptibility on plate 3) provides a relative rating of susceptibility to failure, but does not estimate probability or likelihood of failure for a given time period. The frequency of occurrence (recurrence) of debris-slide and debris-flow events in a drainage basin depends upon climatic factors as well as the availability of debris. The map ratings are based mainly on the presence of pre-existing slope

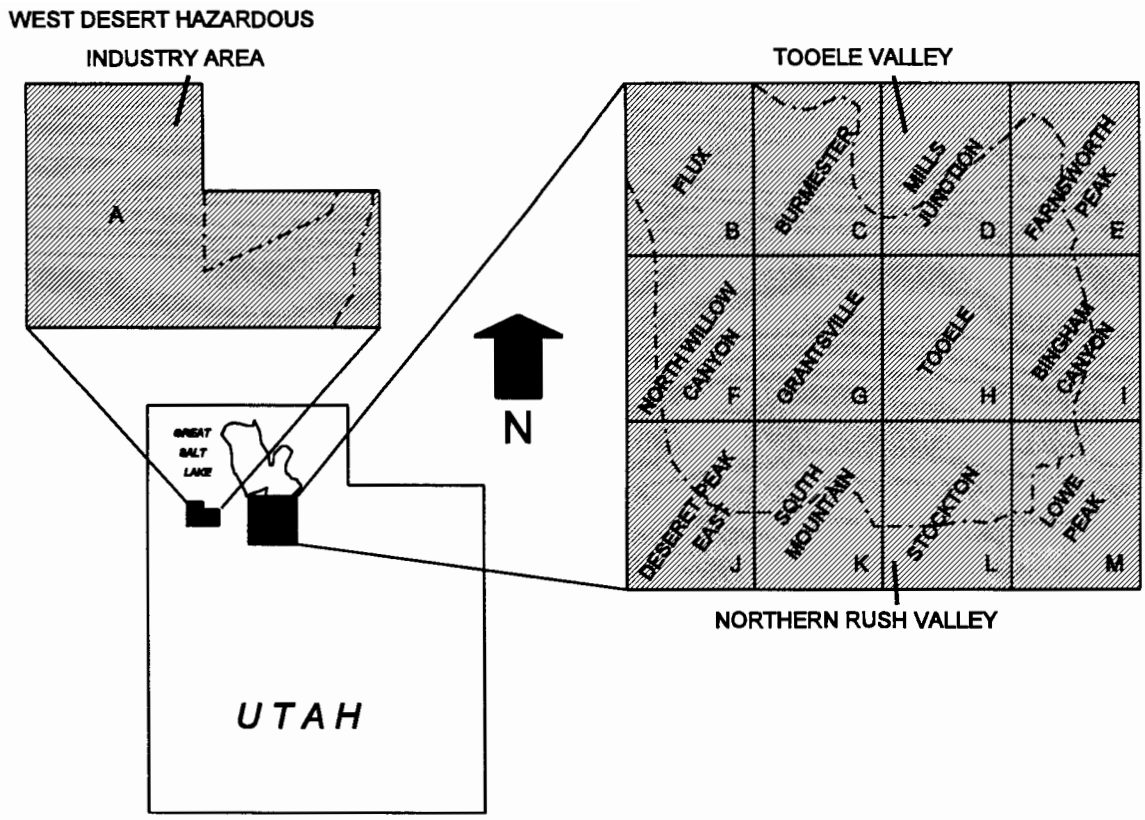

Figure H-1. Index map of areas (crosshatched) where debris-slide, debris-flow, debris-flood, and stream-flood hazards are mapped on plate 3. Letters are used in plate designations. Study area boundaries are shown by dashed lines.

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failures and slope angle. Other factors considered included vegetation type and density, rock and soil type, geologic structure, slope aspect, and elevation.

With a few exceptions, areas with a "high" susceptibility rating are generally slopes that produced debris slides and flows during 1983 and 1984. These slopes mainly include the upper reaches of Flood and Pass Canyons, the south-facing slope of Clipper Ridge in Middle Canyon, and the Kelsey Canyon area of Settlement Canyon. Although only one debris flow was identified in the Shingle Gulch area of Middle Canyon, adjacent slopes are included in the "high" susceptibility category because geologic and topographic conditions mirror those on the Clipper Ridge slopes. Slopes in the Left Hand Fork area of Settlement Canyon are included in the "high" category because conditions there are similar to those in the Kelsey Canyon area. Slopes

surrounding rock slides at the head of Settlement Canyon are also included in the "high" susceptibility category because bedrock in this area dips downslope and is prone to bedding-plane failures. If the rock slides in this area are not considered, the susceptibility would instead be "moderate".

The "moderate" susceptibility category includes slopes that are steeper than 30 percent (17 degrees) that did not experience debris slides or flows during the wet years. All areas with slopes greater than 30 percent are considered potential debris-flow sources. The "low" susceptibility category includes slopes less than 30 percent. Few debris slides or flows occur on slopes less than 30 percent, and no such slope failures have occurred on these slopes in the WDHIA or Tooele Valley study area.

A number of Wasatch Front communities have hillslope building ordinances that require studies or restrict development in areas of 30 percent slope and greater. Virtually all mountain slopes not in the high susceptibility group are in the moderate category; most valley areas and much of the WDHIA are in the low category. Site investigations addressing slope stability should be performed in all areas of high and moderate susceptibility.

Plate 3 also shows areas of potential debris deposition and flooding (DFF) where site-specific studies are recommended. Hazard areas were defined from surficial geologic mapping by Solomon (1993), and show active (and potentially active) alluvial fans and stream channels where debris-flow, debris-flood, and stream-flood hazards may occur. Debris flows that reach canyon mouths generally deposit sediment on the heads of alluvial fans at canyon mouths close to mountain fronts. Therefore, hazard areas along the fronts of the Oquirrh, Stansbury, and Cedar Mountains, and the Grayback Hills, have the greatest debris-flow hazard. Site investigations addressing the potential for sediment deposition and flooding from debris flows should be performed in DFF areas in canyon bottoms and at canyon mouths along mountain fronts, where no debris basin or other flood control structure exists above the site. However, debris floods and stream floods can affect areas farther away from mountain fronts than debris flows. Therefore, site investigations addressing these hazards (or disclosure of the hazards) may also be required for DFF areas in the valley, as deemed neccesary by the local government. Because of the scale of the maps, some small hazard areas are not shown. In addition, boundaries of DFF areas could change depending on activities such as road construction and residential development (which can change drainage patterns). Therefore, studies are recommended for critical facilities even outside of the mapped hazard areas.

The adequacy of existing dams, debris basins, or structures built to divert debris flows or minimize flooding was not considered during preparation of the hazard maps. Such structures, where properly placed and of sufficient size, may limit the extent of deposition and flooding and reduce the potential hazard. Estimates of flooding and potential sediment yields from large events are necessary in evaluating the adequacy of these structures.

In addition to active alluvial fans and stream channels, the hazard maps also show areas in Tooele City expected to be inundated by floods with 100- and 500-year recurrence intervals

(plate 3H; Federal Emergency Management Agency, 1989b). Although these flooding events have only a 1.0 and 0.2 percent chance, respectively, of being equaled or exceeded during any year (Federal Emergency Management Agency, 1989a), most of these areas were flooded in 1983-84. Although these recurrence intervals represent the "long-term average" period between floods of a specific magnitude, rare floods could occur at shorter intervals or even within the same year (Federal Emergency Management Agency, 1989a). Methods used to produce the flood maps are outlined in more detail in Federal Emergency Management Agency (1989a).

For areas of Tooele City contained within flood zones outlined by Federal Emergency Management Agency (1989b) (plate 3H), no new development is permitted in the 100-year flood plain unless: (1) detailed engineering studies show that the proposed development will not increase the flood hazard to other property in the area; (2) the proposed development is elevated above the 100-year flood base elevation; and (3) for federally-insured loans, flood insurance is purchased from a company participating with the Federal Insurance Administration or a private carrier. Areas outside the 100-year flood zone are not restricted, but could experience flooding if high peak flows overtop man-made waterways or if flood problems are aggravated by debris deposits or flood plain development (Federal Emergency Management Agency, 1989a).

SITE INVESTIGATIONS

Site-specific investigations for debris-flow, debris-slide, and debris-flood hazards should include an assessment of: (1) the potential for an area to produce debris flows and floods based on the presence of debris slides and colluvium-filled slope concavities, the amount of debris available for scour from the channel, and an estimate of the largest probable volumes likely to be produced during a single event; (2) stream-channel conditions to determine if the channel will supply additional debris, impede flow, or contain debris in the area of the proposed development; and (3) engineered structures upstream that may contain, divert, or deflect debris flows and debris floods. In addition, the report should include recommendations concerning necessary channel improvements, flow-modification and catchment structures, direct-protection structures, or floodproofing measures to help protect the proposed development.

The storage capacity of reservoirs or debris basins upstream from the site of critical facilities within hazard areas must be evaluated, and quality of debris-basin maintenance should be addressed. Wieczorek and others (1983), Pack (1985), and Keaton and others (1988) identify factors to be considered when evaluating debris-flow hazards, and should be consulted when conducting site investigations.

Tooele City is a member of the National Flood Insurance Program and, therefore, development is required by FEMA to comply with National Flood Insurance Program standards along drainages for which Flood Insurance Rate Maps are available. FEMA has established guidelines for amending Flood Insurance Rate Maps for areas where the mapping is inaccurate or conditions have changed, such as areas where debris basins or retention ponds have been established after the maps were completed. In addition, not all areas subject to flooding were

mapped, particularly those that are undeveloped or adjacent to small local drainages (Federal Emergency Management Agency, 1989b). Flood hazard studies should determine elevation of the structure with respect to the 100-year flood plain, and recommend floodproofing or other hazard-reduction techniques if needed. No special site investigations are required for development in dam-failure inundation zones, except where they coincide with stream-flood-hazard areas.

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SECTION I:
ROCK FALL

by

Kimm M. Harty
and
Bill D. Black

INTRODUCTION

Rock fall is a natural erosional process in mountainous areas of Tooele Valley and the WDHIA. As urban development advances towards the mountains, the risk from falling rocks increases. Rock falls can damage structures, roadways, and vehicles and may pose a significant safety hazard. The potential for rock-fall hazards is greatest along the Oquirrh Mountains in eastern Tooele Valley; however, a lesser rock-fall hazard also exists along the Stansbury Mountains and South Mountain in Tooele Valley, and along the Grayback Hills in the WDHIA.

Rock falls originate when weathering and erosion of supporting rock and sediment destabilize and eventually dislodge rocks from slopes. The most susceptible slopes are those with outcrops broken by bedding surfaces, joints, or other discontinuities into abundant loose individual rock fragments called clasts. Shoreline benches eroded by Lake Bonneville and alluvium or glacial till also contain clasts that may dislodge and fall. When the clast falls or rolls from the slope, it may travel great distances by sliding, rolling, and bouncing.

CHARACTERISTICS AND EFFECTS

A primary mechanism responsible for triggering rock falls is water in outcrop discontinuities. In Norway, for example, 60 percent of all rock falls occur in April and May during maximum snowmelt and October and November during periods of heavy rainfall (Costa and Baker, 1981). In addition, rock falls are also the most common type of slope instability initiated by earthquakes. Case (1987a) estimates that a major Wasatch Front earthquake (magnitude 7-7.5) could produce thousands of rock falls along the Wasatch Front, including Tooele Valley. Keefer (1984) indicates that rock falls may occur in earthquakes as small as magnitude 4.0. In August 1988, the San Raphael Swell earthquake (magnitude 5.3) in central Utah produced hundreds of rock falls, temporarily obscuring the surrounding cliffs in clouds of dust (Case, 1988a). The September 1992, M_L 5.8 St. George earthquake caused numerous rock falls that caused minor damage (Black and Christenson, 1993).

Rock falls are hazardous because a large rock mass traveling at high speed can damage structures and increase risk to personal safety. Rock falls that occur in remote or uninhabited

regions often go unnoticed. A 1987 rock fall near Dead Horse Point, Utah, was large enough to register on seismographs as far away as Blanding (Case, 1987b). Along the Wasatch Front, rock falls have historically caused problems along canyon roads by damaging paved surfaces, blocking traffic, or striking vehicles. The structures most often affected by rock falls in canyons are roads and above-ground aqueducts. Water service in both Big Cottonwood and Provo Canyons has been suspended due to aqueduct damage by impact and puncture from falling rocks. Homes built along the mountain front are also subject to rock falls.

HAZARD REDUCTION

Techniques for reducing rock-fall hazards include rock stabilization or modification of exposed structures or facilities. Rock-stabilization techniques such as bolting, cable lashing, burying, and grouting discontinuities; and removal or break-up of potential rock clasts are all physical methods of reducing the hazard. Deflection berms, slope benches, and rock-catch fences may stop or at least retard falling rocks. Strengthening a structure to withstand impact is an example of modifying structures at risk. Twenty-seven techniques for reducing landslide hazards, including rock falls, are described by Kockelman (1986). Hazard-reduction problems can arise when rock-fall source areas are located on land not owned by those in the rock-fall runout zone.

In areas where the rock-fall hazard is present but is determined through site-specific investigation to be low, disclosure of potential hazards to land owners and residents may be an acceptable alternative to avoidance or mitigation, at least for single-family residences. Disclosure ensures that buyers are informed of the hazard, acknowledge the risks, and willingly accept them.

USE OF HAZARD MAPS

Plate 4 shows areas that may be susceptible to a rock-fall hazard in Tooele Valley and the WDHIA (figure I-1). The primary factor in determining these areas is the presence of a source for rock-fall clasts. If there are no rocks on a slope, the rock-fall hazard is low. Case (1987c, 1988b) identified some of the range-front slopes, called spurs, along the Oquirrh Mountains in Tooele Valley on which a rock-fall source was found. Additional source areas along the Oquirrh, Stansbury, and Cedar Mountains, South Mountain, and the Grayback Hills, were identified during this study.

The hazard area for each susceptible spur was determined using a computer model called the Colorado Rock-fall Simulation Program (CRSP) (Pfeiffer and Higgins, 1988). This program was primarily designed to predict rock bounce heights, but was used here to simulate maximum travel distances of rock clasts. The program incorporates factors such as velocity, rock size and shape, roughness of the travel surface, and topography of the slope. Rock-fall events were simulated using the highest and steepest potential rock-fall source areas. Rocks were started with

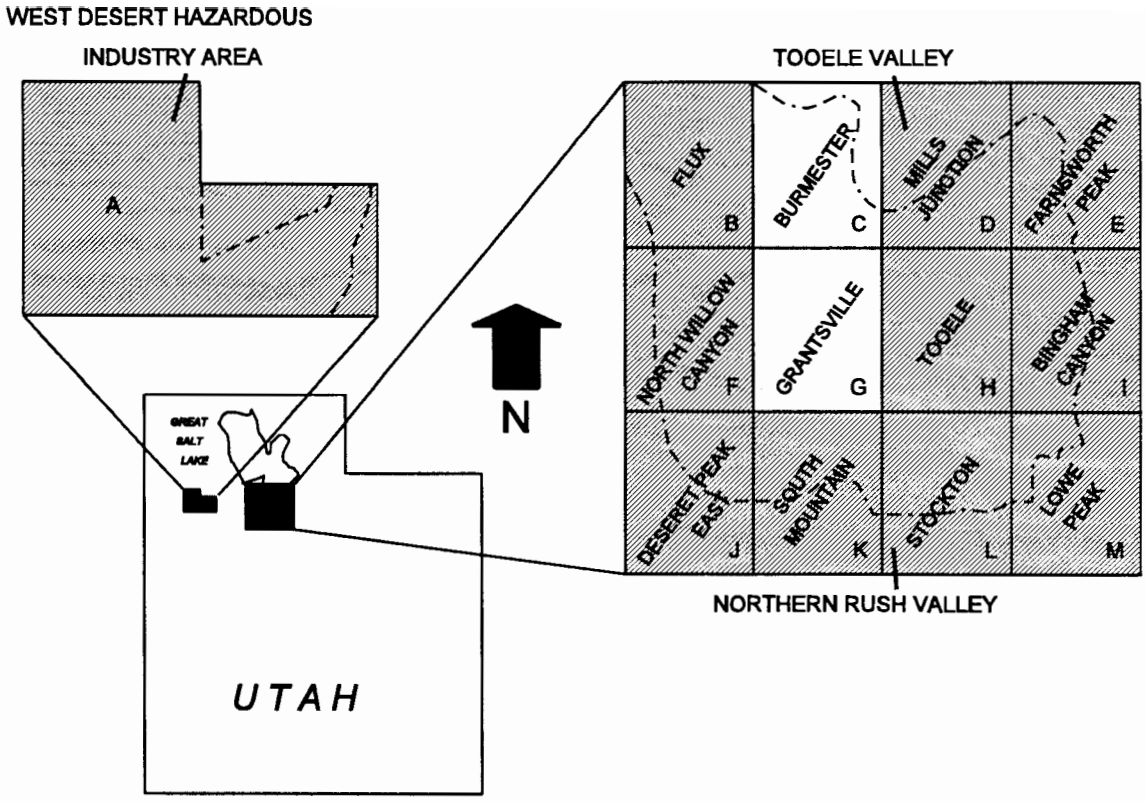

Figure I-1. Index map of areas (crosshatched) where rock-fall hazards are mapped on plate 4. Letters are used in plate designations. Study area boundaries are shown by dashed lines.

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an initial velocity (throw) of 1 foot/second (0.30 m/sec). The size of rock-fall clasts used in the simulation was based on the largest clast observed on the slopes below the rock-fall source area. The program simulates 100 rock falls for each source area; the clast traveling the longest distance from its source was used to delineate rock-fall-hazard areas. Possible decceleration of rock clasts by existing structures, such as roads, railroad tracks, and fences, was not used in the analysis. Thus, the hazard areas represent conservative, worst-case rock-fall events.

Rock-fall simulations were run only on susceptible slopes along mountain-front areas; mountain interiors generally contain numerous rock-fall source areas and all canyons were included in the hazard areas. Using a conservative approach, mountain-front slopes greater than 30 percent were also generally included in the hazard areas. Exceptions to this rule were mainly steeper areas where the rock-fall hazard is lessened by the presence of a dense vegetation cover, such as in the southwestern South Mountain area, and in the Stansbury Mountain foothills

between Box Elder and North Willow Canyons. Rock-fall hazard was not evaluated in the Flux vicinity due to active quarry operations that continuously alter the natural slopes.

Rock-fall hazard areas are numerous along the base of the Oquirrh Mountains in Tooele Valley due to steep slopes created by active mountain uplift and valley down-drop along the Oquirrh fault zone, and by erosion along the Lake Bonneville shoreline bench. In contrast, slopes along the eastern base of the Stansbury Mountains are generally gradual and more heavily vegetated than those along the Oquirrhs. Thus, the rock-fall hazard is lower along the Stansbury Mountains. Rounded basalt boulders and short, steep slopes contribute to the rock-fall hazard along the Grayback Hills in the WDHIA.

SITE INVESTIGATIONS

Prior to development, site-specific rock-fall evaluations may be appropriate in the hazard areas. Hazard potential should be assessed in site-specific engineering-geologic reports, including, if necessary, recommendations for hazard-reduction measures or dislosure.

Site investigations should define rock-fall sources and estimate runout paths and distances from each source. Rock-fall sources may be outcrops or individual clasts on a slope. Size, shape, depth of burial, and slope geometry are all factors to be considered in defining sources as well as runout paths and distances. Computer models are available to simulate runout, but physical evidence such as extent of clast accumulations below sources, topographic configuration, damaged vegetation, and natural barriers are also important considerations.

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SECTION J:
LAKE FLOODING, PONDING, AND SHEET FLOODING

by

Bill D. Black

INTRODUCTION

A flood is the stage or height of water above some given datum, such as a commonly occupied lake shoreline. Floods are recurrent natural events which become a hazard to residents of a flood plain or shoreline whenever water rises to the extent that life and property are threatened. Tooele Valley is subject to flooding from rises in Great Salt Lake, and both Tooele Valley and the WDHIA are subject to local ponding and sheet flooding.

CHARACTERISTICS AND EFFECTS

Although fluctuating water levels are a problem in lakes, they are especially acute on lakes which, like Great Salt Lake, have no outlet. Natural factors causing fluctuations include precipitation, evaporation, runoff, ground water, ice, aquatic growth, and wind; human factors include dredging, diversions, consumptive use, and regulation by engineered works (Federal Emergency Management Agency, 1985). Lake-level fluctuations may be grouped into three categories: (1) long term, (2) seasonal, and (3) short term. Fluctuations of Great Salt Lake have occurred in prehistoric and historic time, and flooding due to rising water levels is a hazard in Tooele Valley.

Long-term fluctuations are the result of persistent low or high water-supply conditions for more than one year. Figure J-1 shows the effects of long-term excess precipitation during the 1980s on Great Salt Lake elevation. Long-term climatic trends play a major role in determining lake levels, as do diversions of water sources by man. The intervals between periods of high and low lake levels, as well as the length of such periods during long-term fluctuations, vary widely and erratically (Federal Emergency Management Agency, 1985). Extreme lake levels are likely to persist even after the factors which caused them have changed.

Seasonal fluctuations reflect the annual hydrologic cycle. Lake levels are lowest in winter and generally rise in the spring due to melting snow, heavier rains, and cooler temperatures, until the lake peaks in early summer (Federal Emergency Management Agency, 1985). During the summer, more persistent winds, drier air, and warmer temperatures intensify evaporation; runoff and ground-water flow to the lake decrease significantly. As the amount of water supplied to the lake becomes less than that removed by evaporation, the water level drops to winter minima

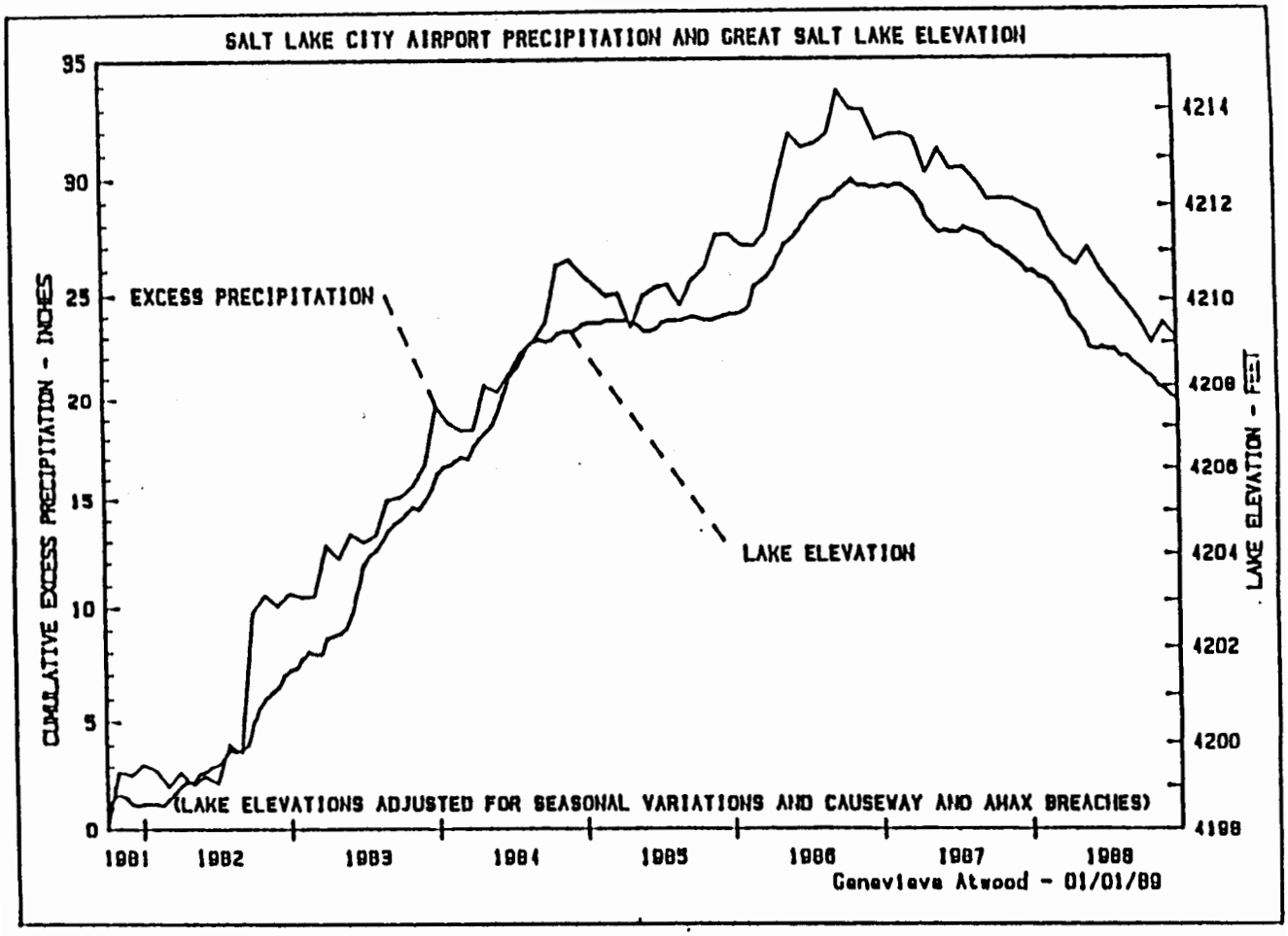

Figure J-1. Graph showing the effect of cumulative excess precipitation on Great Salt Lake elevation. Lake elevations have been adjusted to remove seasonal water-level variations and the effects of the Great Salt Lake causeway and Amax dike breaches (Atwood and Mabey, written communication, 1989).

(Federal Emergency Management Agency, 1985). Great Salt Lake elevations fluctuate approximately two feet (0.6 m) between winter low and summer high lake levels.

Short-term fluctuations are caused by strong winds and sharp differences in barometric pressure (Federal Emergency Management Agency, 1985). These fluctuations usually last less than one day and do not represent any changes in the amount of water in the lake.

In prehistoric time, water levels in lakes occupying the Great Salt Lake basin, such as Lake Bonneville, fluctuated with great elevation differences between high and low stands (figure J-2). Geologic evidence indicates that Great Salt Lake reached a post-Lake Bonneville high of approximately 4,221 feet (1286 m) about 2,000 years before present (Murchison, 1989).

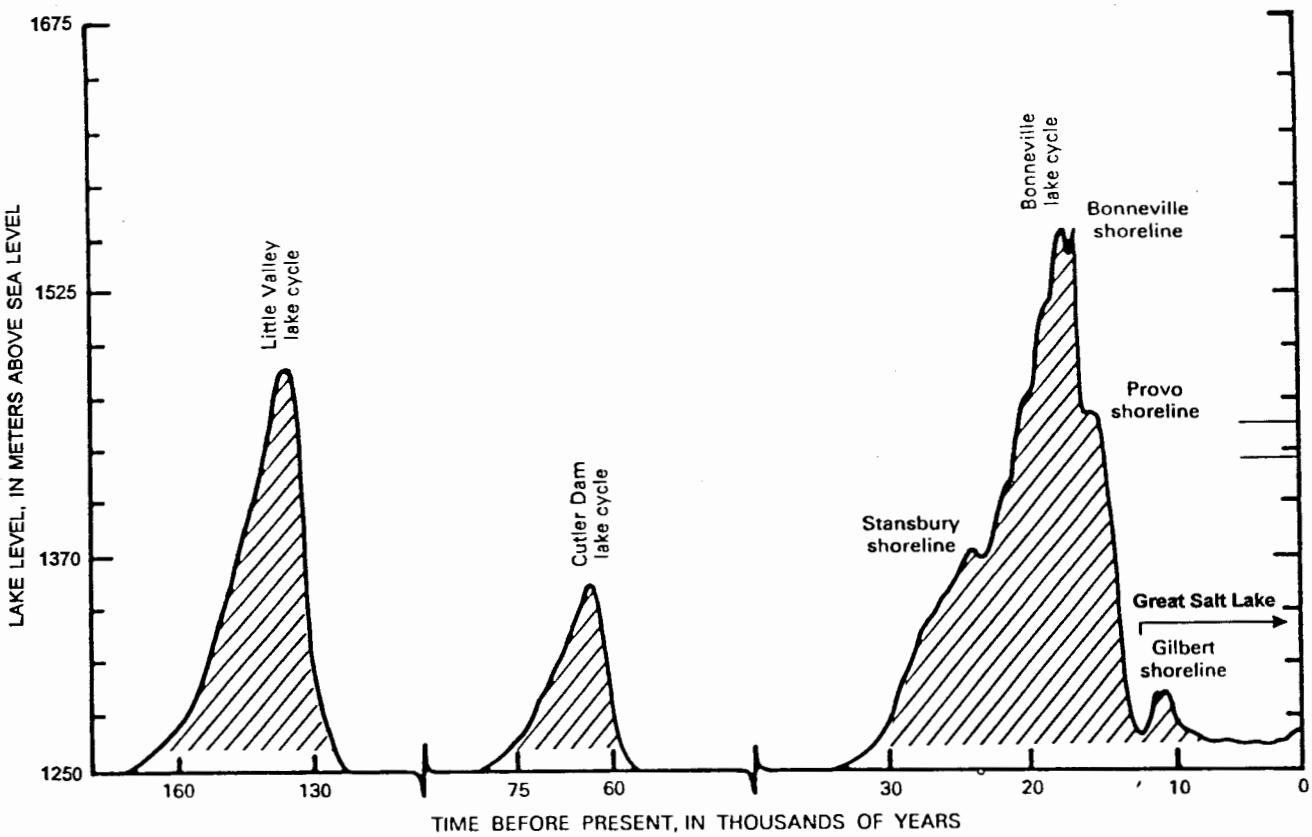

Figure J-2. Diagram showing a hydrograph of probable lake levels in the Lake Bonneville (Great Salt Lake) basin for the past 150,000 years (modified from Currey and Oviatt, 1985; and Machette and others, 1987).

Archaeological evidence indicates that the most recent high stand of Great Salt Lake was at 4,217 feet (1285 m) sometime during the 1600s (Utah Division of Comprehensive Emergency Management, 1985; Murchison, 1989).

Water levels in Great Salt Lake have also fluctuated in historical time. Until mid-1986, the historic high of Great Salt Lake was about 4,211.5 feet (1283.6 m) (Arnow and Stephens, 1990). This level was reached in the early 1870s and is based on a relative elevation estimate of water depth over the Stansbury bar (Gilbert, 1890). Direct measurements of the lake's elevation began in 1875 (Currey and others, 1984). The lake dropped slowly from its high in the 1870s, reaching an historic low of 4,191.35 feet (1277.46 m) in 1963. Above-average precipitation in the 1980s caused Great Salt Lake to attain a new historical high of 4,211.85 feet (1283.71 m) in June, 1986 (Arnow and Stephens, 1990) and April, 1987 (U. S. Geological Survey records). This rise in lake level caused damage to structures and property along the shoreline and within the lake (power lines, causeways, dikes, buildings, and refuse dumps). Figure J-3 summarizes

historical levels of Great Salt Lake and illustrates that significant lake fluctuations can occur within a relatively short time.

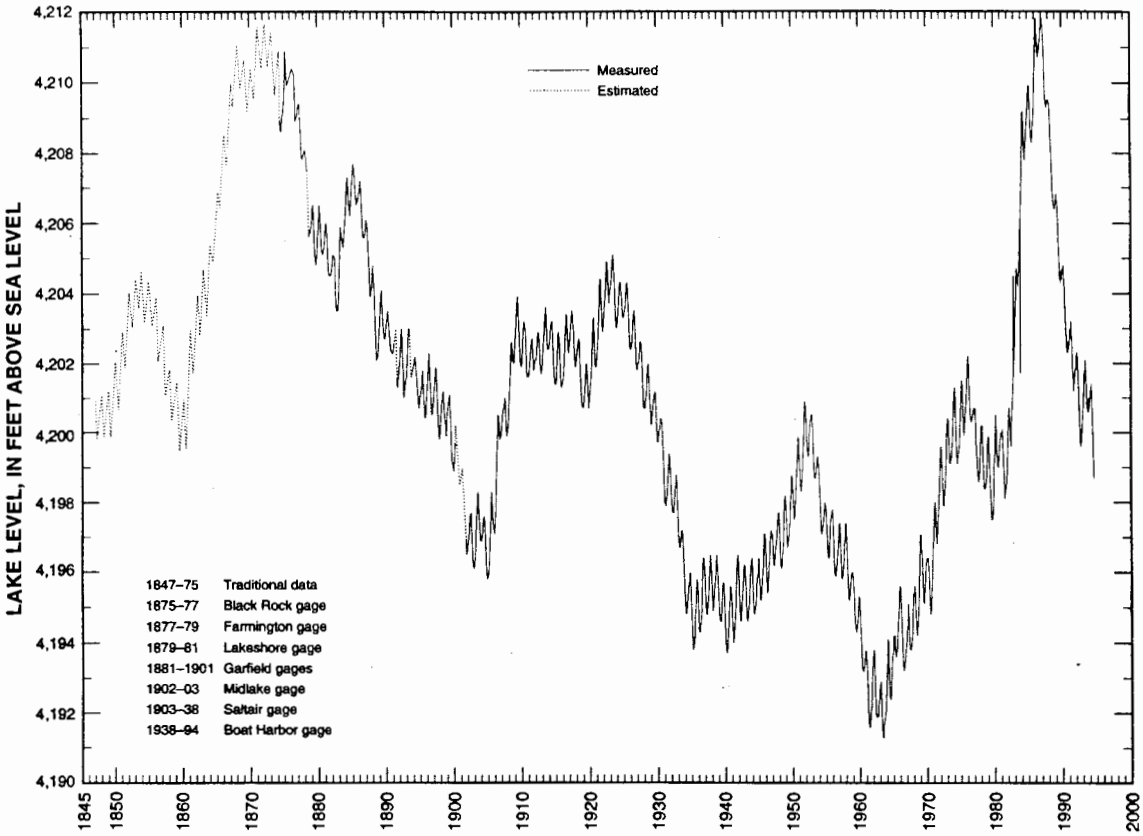

Figure J-3. Historical Great Salt Lake hydrograph.

Rush Lake has fluctuated from the size of a "small pond" in the early 1860s (Gilbert, 1890) to marsh-like and dry in the late 1950s to mid-1970s (Harty and Christenson, 1988). The lake was at or near 4,979 feet (1,518 m) when measured in 1872 (Gilbert, 1890), and reached it's highest elevation in 1876 or 1877, although no measurements were made at that time (Harty and Christenson, 1988). Like Great Salt Lake, water levels in Rush Lake also rose in the 1980s; between 1983 and 1985 Rush Lake rose nearly 10 feet (3 m), damaging powerlines and croplands surrounding the lake (Harty and Christenson, 1988).

Ponding and sheet flooding are flood hazards that could occur in mudflats of the western WDHIA and in northern Tooele Valley, usually resulting from periods of intense, cloudburst rainfall, or rapid melting of snow. Any runoff or precipitation that reaches the mudflats usually

evaporates, but ponding often occurs in the winter and early spring. Localized, high-intensity, cloudburst rainstorms, which last from a few minutes to a few hours, are unpredictable and likely cause most of the ponding and sheet flooding. These rainstorms are characterized by high peak, high velocity, short duration, and small volume runoff. Snow melt floods may also cause ponding and sheet flooding. These floods are generally predictable, and are characterized by large volume runoff, moderately high peak flows, and marked diurnal fluctuation in flow.

Water damage accompanies flooding and ponding, and the amount of damage largely depends upon depth of inundation and duration. Along the shore of Great Salt Lake, the problems associated with water damage are also compounded by the presence of salt in the water. In areas where flooding is deep and of long duration, such as along the shoreline of Great Salt Lake, water damage to structures is especially serious. Although this flooding generally is not life-threatening, it will likely cause permanent property loss or damage.

HAZARD REDUCTION

Hazard-reduction methods for lake flooding include avoidance, diking, diverting inflow to the lake, and increasing outflow and/or evaporation through pumping (Utah Division of Water Resources, 1977). Avoidance, floodproofing, and site grading can reduce ponding and sheet-flooding hazards. Different methods or combination of methods may be appropriate for different types of flooding or development.

Using the best available historical and scientific data on Great Salt Lake, government policy makers and lake experts have recommended that a beneficial development strategy should exist for lake-shore areas up to 4,217 feet (1,285 m) in elevation (Utah Division of Comprehensive Emergency Management, 1985). This strategy establishes a "Beneficial Development Area" along the shore of Great Salt Lake between 4,191.4 feet (1,277.5 m) (historic low stand, 1963) and 4,217 feet (1,285 m). Within this area, it is recommended that development take place in a manner that will encourage the maximum use of the land for the people of Utah, while avoiding unnecessary disaster losses (Utah Division of Comprehensive Emergency Management, 1985). The most effective way to reduce hazards would be to adopt this beneficial development strategy and ensure that development within this area is either compatible with or protected from the flood hazard.

Recent shoreline flooding around Great Salt Lake has been locally controlled by dikes. However, this is not a long-term solution. Stabilization of the water level may be accomplished in several ways, including pumping to adjacent basins to increase evaporation, and diversion of inflow.

Flooding around the margins of Great Salt Lake has been controlled by increasing evaporation through pumping. Lake water was pumped into the west desert to increase surface area subject to evaporation. Although these pumps are effective in controlling lake levels during wetter-than-normal years, it is possible for precipitation during a very wet period to exceed the

capabilities of pumping and evaporation.

Shoreline flooding around Great Salt Lake could also be controlled by diverting water from rivers which flow into the lake. This option has been most frequently discussed with regard to the Bear River. To be effective, the water must be diverted completely out of the Great Salt Lake basin. Bear River water could be discharged into the Snake River drainage.

Avoidance is one method of dealing with ponding and sheet flooding, although it may not be possible where population centers are on relatively flat valley floors. Floodproofing is also an effective way of reducing flood damage in areas where floods are of short duration and have low stages and velocity. Floodproofing measures include the use of special cements for flooring, adequate electrical fuse protection, anchors for buoyant tanks, sealed outside walls and basements, wire-reinforced glass, automatic sump pumps, sewer-check valves, sealed windows and doors, and window and door flood shields (Kockelman, 1977). Modifications of site grade, such as elevating structures and access roads, may also be needed.

USE OF HAZARD MAPS AND SITE INVESTIGATIONS

Plate 1 depicts areas that may be subject to ponding and sheet flooding, and lake flooding (figure J-4). Areas subject to ponding and sheet flooding are restricted to mudflats in the western WDHIA, northern Tooele Valley, and Rush Lake. Areas in Tooele Valley along the southern shoreline of Great Salt Lake, where the proposed lake flooding beneficial development strategy is recommended, include all areas below an elevation of 4,217 feet (1,285 m). The location of the 4,217-foot (1,285-m) contour has been interpolated from 1:24,000 scale U. S. Geological Survey topographic quadrangle maps. Areas in northern Rush Valley include areas below an elevation of 4,979 feet (1,518 m), which were defined as the potential flood boundary for Rush Lake in Harty and Christenson (1988). However, these lines are only approximate and accurate field surveys should be performed prior to development.

Site investigations for proposed development in lake-flooding areas near Great Salt Lake need only indicate site elevation, whereas ponding and sheet-flooding hazards need to be addressed in a hydrologic report for the site. Development proposals in areas with elevations less than 4,217 feet (1,285 m) for Great Salt Lake, or 4,979 feet (1,518 m) for Rush Lake, should be reviewed by the county planning department with respect to lake-flooding potential and compatibility of proposed use. Hydrologic reports for ponding and sheet flooding should consider factors such as precipitation, drainage area, and soil permeability, and should also contain recommendations for design of floodproofing or other hazard-reduction strategies.

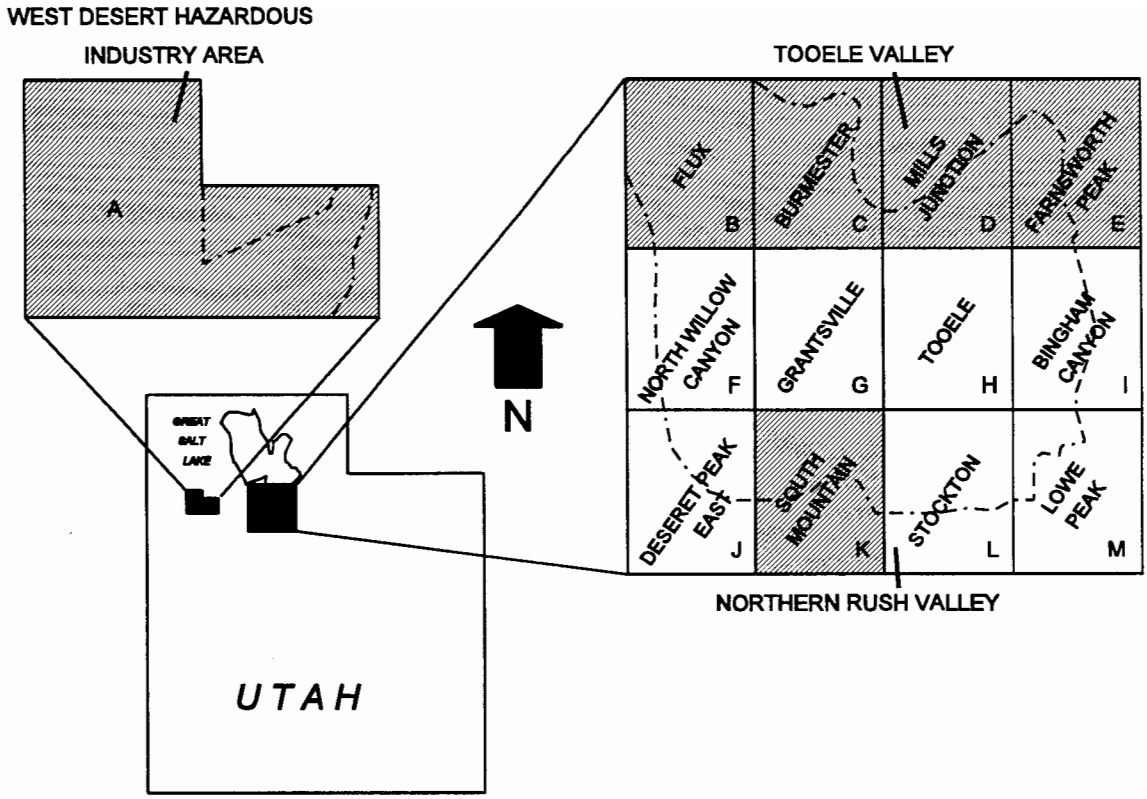

Figure J-4. Index map of areas (crosshatched) where lake-flooding, ponding, and sheet-flooding hazards are mapped on plate 1. Letters are used in plate designations. Study area boundaries are shown by dashed lines.

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SECTION K:
SHALLOW GROUND WATER

by

Bill D. Black

INTRODUCTION

Ground water is water in saturated zones beneath the land surface in various materials at various depths. Ground water fills fractures and pore spaces in rocks and voids between grains in unconsolidated deposits (clay, silt, sand, and gravel). Ground water is considered shallow when the water table is within 30 feet (9 m) of the ground surface (Hecker and others, 1988).

Shallow ground water in rock is not considered here because it poses a relatively insignificant geotechnical hazard. Foundations and conventional waste-water disposal systems in rock are uncommon, and foundation stability is not appreciably reduced by saturated conditions (Hecker and others, 1988).

However, most construction takes place in areas of unconsolidated sediments subject to various hazards associated with shallow ground water. Such hazards include flooding of subsurface facilities such as basements and buried facilities, destabilization of foundations or excavations, surface flooding, and liquefaction of soils during earthquakes. Shallow ground water is found in northern Tooele Valley and in much of the WDHIA, and must be taken into consideration when siting waste-disposal facilities and septic-tank soil-absorption systems.

Flooding due to shallow ground water in basements, foundations, and excavations is generally only a hazard when the saturated zone is within the depth to which most building foundations are excavated, usually about 10 feet (3 m) or less. Surface flooding due to shallow ground water can occur anytime ground water rises to the surface. Liquefaction during earthquakes, and potential ground failure, may occur in saturated sandy soils where the depth to ground water is less than 30 feet (9 m) (Youd and others, 1978) (Section E). Earthquakes may also cause rises in water tables and increased ground-water discharge (Section F).

CHARACTERISTICS

Ground water in unconsolidated deposits, chiefly stream alluvium, alluvial-fan, and lacustrine sediments, occurs under unconfined and confined conditions in geologic units known as aquifers. These units are permeable enough to yield water in usable quantities to wells and springs (Heath, 1983).

An unconfined aquifer is generally not saturated throughout its entire thickness; the top of the saturated zone in unconsolidated sediments is termed the water table (figure K-1). Localized occurrences of unconfined ground water above the water table are called "perched zones" (figure K-1). Perched ground water commonly occurs above localized layers of low-permeability sediments, such as clay.

Where ground water saturates the entire thickness of an aquifer below an areally extensive low-permeability layer, termed a confining bed, the aquifer is said to be under confined conditions. Ground water under confined conditions (artesian water) is usually under hydrostatic pressure exerted by higher water levels in recharge areas. Water in wells which penetrate a confined aquifer usually rises above the top of the aquifer to the potentiometric surface (well B, figure K-1), which is determined by hydrostatic pressure in the aquifer. However, confining beds in unconsolidated deposits are generally semi-permeable and may allow water to leak upward and help maintain the water table above the confined aquifer (Hely and others, 1971; Razem and Steiger, 1981) (figure K-1).

Shallow ground water is replenished by infiltration from streams, lakes, precipitation, lateral subsurface flow from adjacent higher ground-water areas, and upward leakage from underlying confined aquifers (Heath, 1983). The shallowest water tables are generally found in the central parts of valleys, where leakage from underlying artesian aquifers is greatest and potentiometric surfaces are commonly above the ground surface (figure K-1). Man influences local water levels through irrigation, pumping from wells, and surface-drainage diversions and reservoirs (Hecker and others, 1988).

The shallow water table is dynamic and fluctuates in response to a variety of conditions. Ground-water levels may rise and fall with seasonal variations in precipitation, long-term climatic changes, or changes in rates of irrigation or pumping. A series of years with greater-than-average precipitation beginning in the late 1960s, but particularly between 1982 and 1986, increased ground-water recharge to basins and elevated ground-water levels statewide. Drought conditions in the late 1980s caused a general decline.

EFFECTS

The most significant hazards associated with shallow ground water are flooding of subsurface facilities (such as basements) and damage to underground utility lines; inundation of landfills and waste dumps and effects on septic-tank soil-absorption fields; and possible damage to foundations, roads, and airport runways from soils affected by moisture. Structures extending below the water table may experience water damage to their foundations and/or contents; underground utilities may also experience water damage. Landfills and waste dumps may become inundated and contaminate aquifers, and septic-tank soil-absorption fields can become flooded and cause ground-water contamination as well as system failure. In addition, certain foundation soils can settle or expand when wet, causing damage to foundations and structures (Section L). Roads and airport runways may buckle or settle as bearing strength of foundation

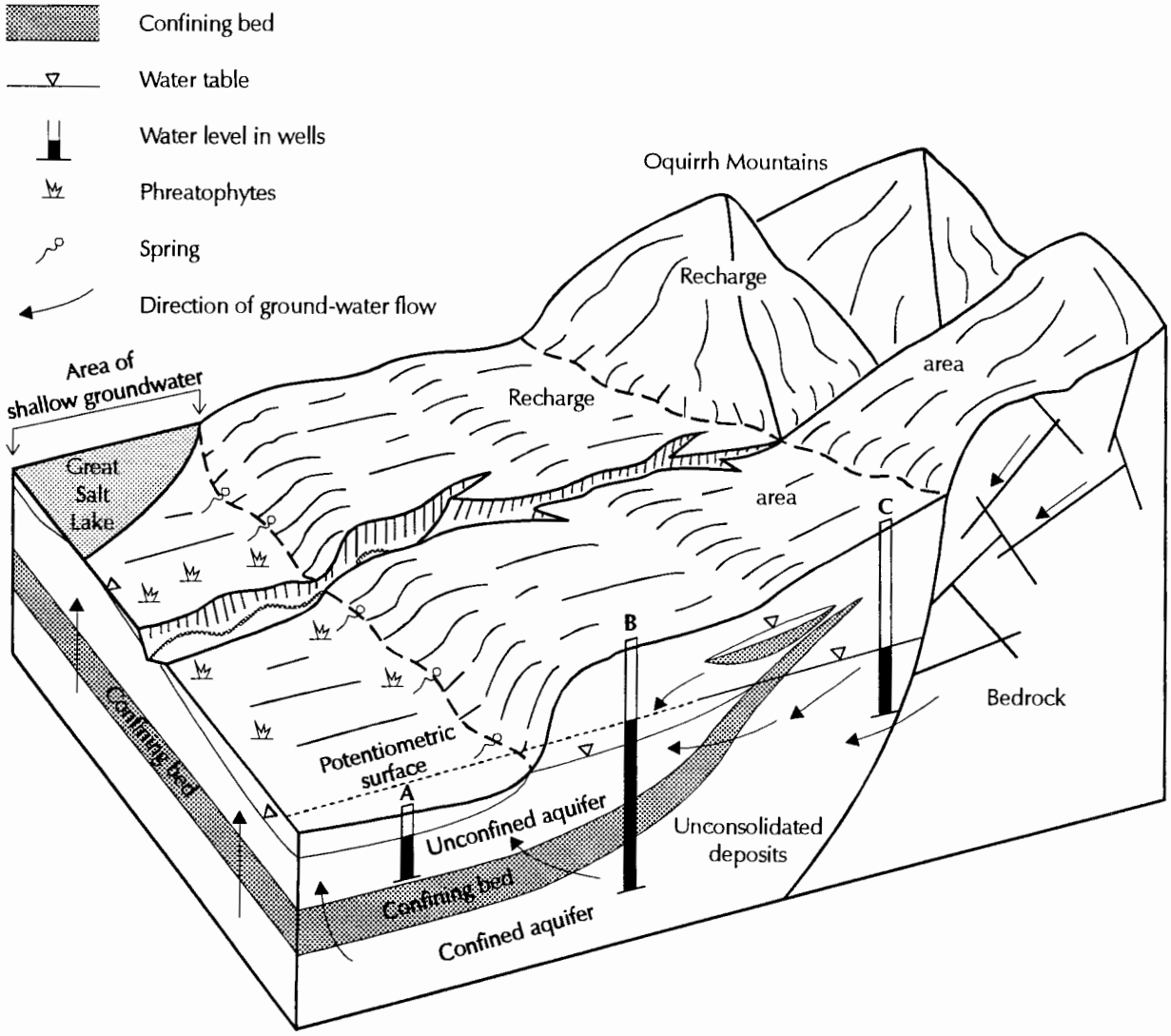

Figure K-1. Diagram of ground water in Tooele Valley showing: unconfined and confined aquifer, confining bed, perched water, water table, potentiometric surface, recharge area, and area of shallow ground water. Note level of water in well B rises above water table due to artesian (confined) conditions (modified from Hely and others, 1971).

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soils is reduced by saturation.

Shallow ground water may also erode and dissolve subsurface materials, resulting in soil piping and settlement (Section L). Water flowing through bedrock fissures in limestone or

gypsiferous rocks can dissolve the rock and create holes which may also collapse.

Contaminants are easily introduced into shallow ground water because it is readily accessible from the surface. Pollutants will flow with the ground water and may enter deeper aquifers or seep into wells. About 85 percent of Utah's wells are located within basin-fill aquifers; some are becoming increasingly contaminated (Waddell and Maxell, 1987).

HAZARD REDUCTION

Avoidance, although not always possible, is one method of reducing shallow ground-water problems. Construction techniques may be employed which reduce or eliminate the adverse effects of ground-water flooding. Water-proofing of subsurface structures may be the most common technique, and may include drainage systems around basements. Water-proofing requirements are given in the Uniform Building Code (International Conference of Building Officials, 1994). Slab-on-grade buildings, which have no basement, are common in areas with a shallow water table. Pile foundations may also be used to increase foundation stability. Occasionally it is necessary to add fill to raise building elevation.

Pumping to lower the water table is also possible, but is typically used only during the construction phase. Pumping is an expensive and unreliable technique for permanently lowering a water table. Basement sump pumps are usually effective for individual homes.

Septic-tank soil-absorption fields do not function properly if inundated by shallow ground water. Utah State Health Department regulations therefore require that the base of the drain lines be at least two feet (0.6 m) above the highest seasonal ground-water table. Wisconsin mound septic-tank soil-absorption systems are currently experimental in Utah, but may be an alternative system that could be used in shallow ground-water areas. The drain lines in this type of system are buried in a mound above the natural ground surface to increase evaporation and the soil thickness above the water table.

USE OF HAZARD MAPS AND SITE INVESTIGATIONS

Plate 4 shows areas where a shallow ground-water hazard may be found in the WDHIA and Tooele Valley (figure K-2). In areas for which no maps were prepared, depth to ground water is generally greater than 50 feet (15 m). Ground-water depths are grouped into four zones on the maps: (1) less than 10 feet (3 m), (2) 10 to 30 feet (3 to 9 m), (3) 30 to 50 feet (9 to 15 m), and (4) greater than 50 feet (15 m). Information on Tooele and Rush Valley is from Razem and Steiger (1981), Hood and others (1969), and well-log data from the Utah Division of Water Rights. Information on the WDHIA is from Dames & Moore and others (1987), Stephens (1974), and U.S. Department of Energy (1983). Springs and phreatophytes (plants whose roots

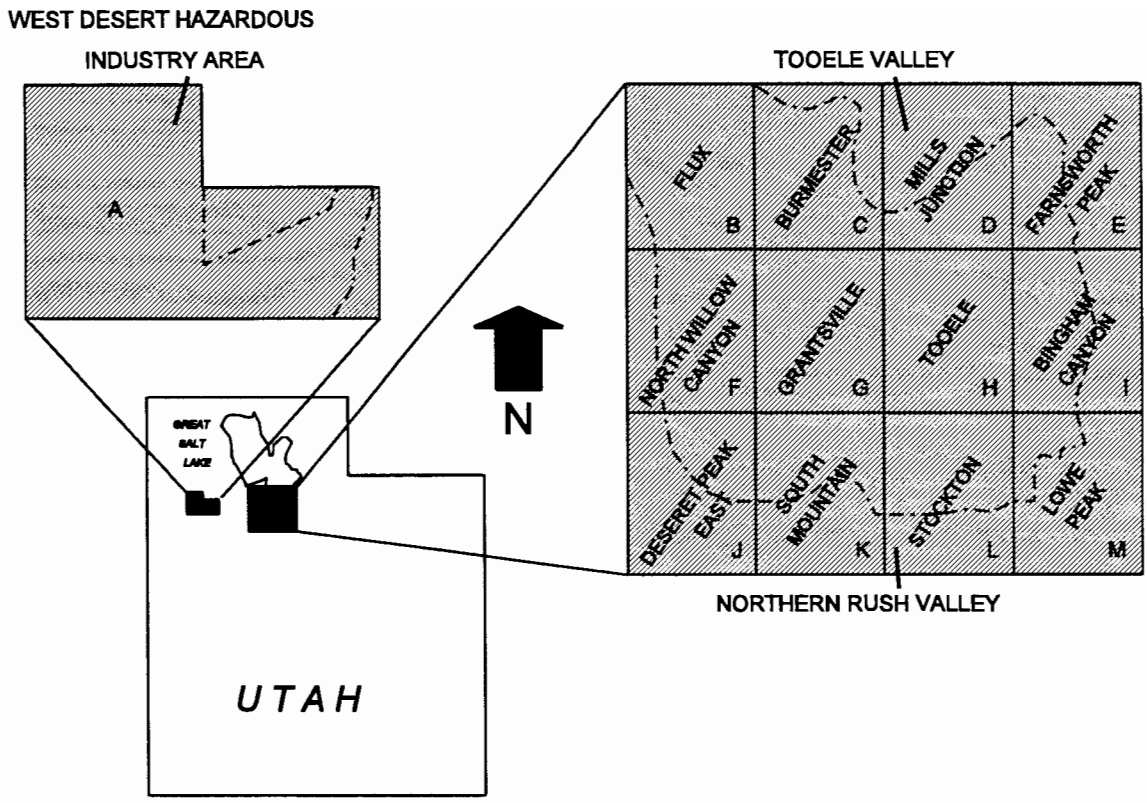

Figure K-2. Index map of areas where the depth to shallow ground water is mapped on plate 4. Letters are used in plate designations. Study area boundaries are shown by dashed lines.

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intersect the water table) also provided information regarding the presence of shallow ground water.

Most problems associated with shallow ground water occur when the water table is within about 10 feet (3 m) of the ground surface. Ground water at this depth is found in both the WDHIA and Tooele Valley. Site-specific shallow ground-water studies are recommended for all types of construction with subsurface facilities in areas where the water table is likely to be within 10 feet (3 m) of the ground surface. All proposed construction in these areas (particularly of buildings with basements or using septic-tank soil-absorption fields) should address shallow ground-water hazards in site-specific investigations.

Site-specific studies should identify the highest ground-water level recorded or visible in sediments, as well as the present and highest expected water table. To do this, it may be

necessary to use additional information about long-term water-level fluctuations from measurements in wells over time to define a range of seasonal and annual fluctuation. Water-table measurements during known wet periods, such as 1982-1986, can also be used to approximate highest levels. Shallow ground-water hazards can be addressed in a soil-foundation report for the site or in testing for soil-absorption systems. If a hazard is found and construction is still planned, the report should include recommendations for stabilizing or lowering the water table and any floodproofing designs or other hazard-reduction strategies deemed necessary. Such studies must also address soil conditions and the potential for collapse, piping, dissolution, or swelling of saturated soils.

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SECTION L:
PROBLEM SOILS AND SUBSIDENCE

by

Bill D. Black

INTRODUCTION

Problem soil is a broad category of geologic hazards which result from unconsolidated surficial geologic materials with characteristics that make them susceptible to volumetric changes, collapse, subsidence, or other engineering-geologic problems. These hazards include expansive soil, gypsiferous soil, piping, and mine subsidence. Expansive soil is a hazard in both Tooele Valley and the WDHIA; deposits susceptible to piping may also occur in these areas. Gypsiferous soil may be found in mudflats of northern Tooele Valley and western portions of the WDHIA, whereas mine subsidence is generally only a hazard in the Oquirrh Mountains east of Tooele Valley.

Geology is the main factor influencing the extent of problem soil, and the geologic parent material largely determines the type of problem present. For example, expansive soil is most often associated with clay and shale, whereas dissolution features commonly form in limestone and gypsiferous material. Climate is an additional factor for soils subject to dissolution and collapse. However, one subsidence problem is not soil related; mine subsidence is due to the collapse of underground mines and is related solely to the activities of man.

CHARACTERISTICS

Expansive Soil

Expansive soil is clay rich. Clay minerals cause the soil to expand and contract with changes in moisture content. All clay minerals expand to some degree, but some varieties such as montmorillonite (the most common variety of clay in Utah) can swell to 2,000 times their original dry volume (Tourtelot, 1974). Expansive soil may be found in fine-grained lake deposits in northern Tooele Valley and the western half of the WDHIA.

Clays may swell in two ways when wetted, either by absorption of water between clay particles or by absorption of water into the crystal lattice that makes up individual particles (figure L-1). In both processes, the absorbed water causes the clay to expand. Montmorillonite commonly swells by absorption of water between individual crystals. As the material dries, the loss of water causes it to shrink. The processes of wetting, drying, freezing, and thawing churn and disturb the surface of expansive deposits, giving some of them a characteristic "popcorn"

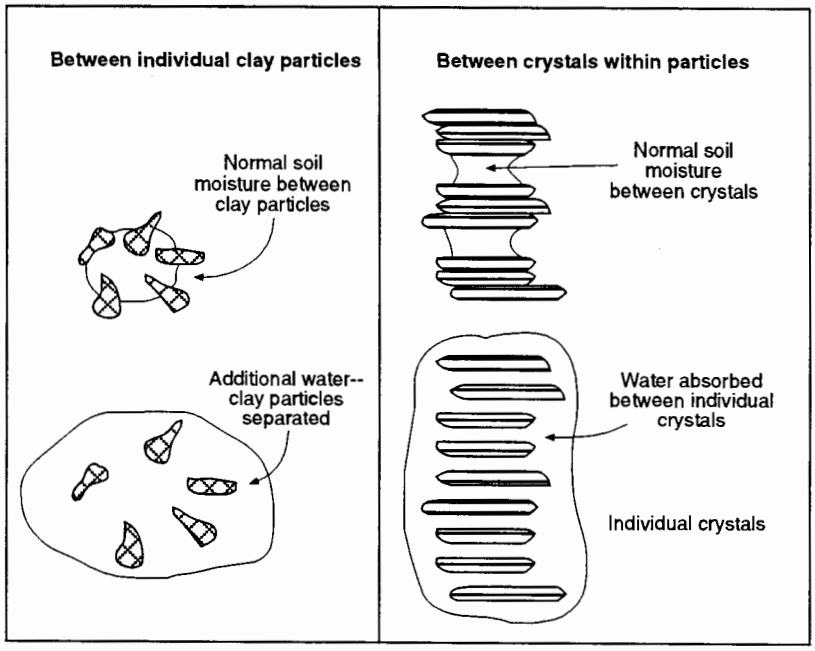

Figure L-1. Diagram of water-absorption processes in clay minerals (modified from Mulvey, 1992).

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texture. This texture is a good indicator of the presence of expansive soil.

Gypsiferous Soil

Gypsum is soluble, and gypsiferous soil may be subject to dissolution. Settlement may occur due to loss of internal structure and volume from dissolution. Gypsum-rich soil may be formed as a secondary mineral leached from surficial layers and concentrated lower in the soil profile, or may be transported by wind or water from outside sources. The most common sources for airborne gypsum are playas, on which crusts of gypsum salts are formed as the wetted playa surface dries during warmer months. These gypsum crusts are easily eroded and transported by wind. Gypsiferous soil may occur in wind-blown deposits in the western half of the WDHIA.

Piping and Mine Subsidence

Piping is a common process in arid climates where fine-grained, uncemented, unconsolidated deposits are incised by streams. Piping occurs when ground water, moving along permeable, noncohesive layers in unconsolidated materials and exiting at a free face that

intersects the layer, causes subsurface erosion (Cooke and Warren, 1973; Costa and Baker, 1981). Removal of fine-grained particles (silt and clay) by this process creates voids that act as minute channels which direct the movement of water (figure L-2). As channels enlarge, water moving through the conduit increases velocity and removes more material, forming a "pipe." The "pipe" becomes a preferred avenue for ground-water flow, growing in size as larger volumes of water are intercepted. Increasing the pipe size removes support for its walls and roof, causing eventual collapse. Collapse features form on the surface above the pipes, directing even more surface water into them. Eventually, total collapse forms a gully that concentrates erosion along a line of interconnected collapse features.

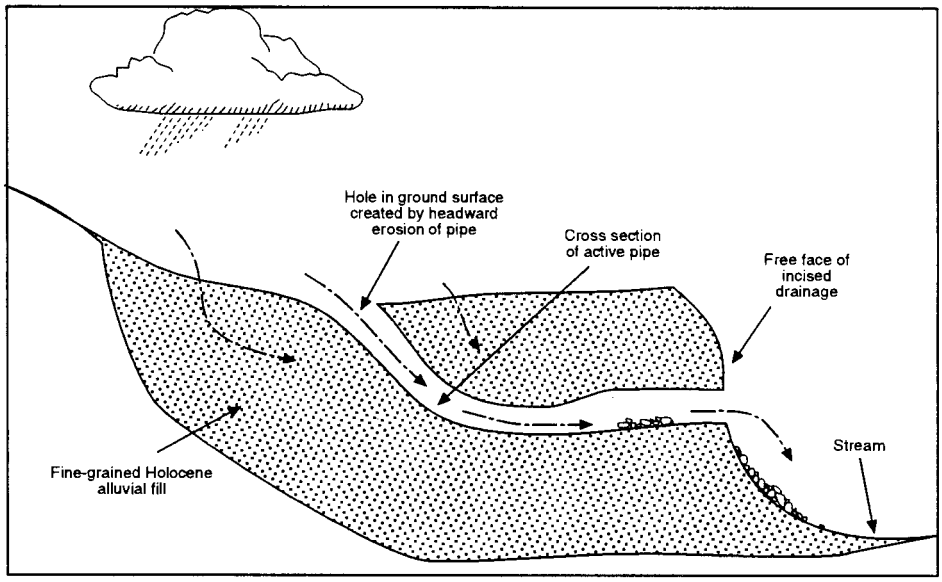

Figure L-2. Cross section of a pipe in Holocene alluvium (modified from Mulvey, 1992).

Deposits susceptible to piping in Tooele County include fine-grained marl and silt deposited by Lake Bonneville (Mulvey, 1992). Several conditions are necessary for piping. Water must be present in volumes large enough to soak into the subsurface and reach layers or zones (animal burrows, decayed plant roots) which conduct the water to a free face. The local surface topography must also have enough relief to create a hydraulic head, and move water

through the subsurface. Deposits susceptible to piping must be fine grained and uncemented, but permeable enough to allow subsurface movement of water. Finally, a free face or cliff is necessary for water and sediment to exit the deposit (Costa and Baker, 1981).

Mine subsidence occurs above both active and abandoned mines. The removal of rock from the subsurface can cause subsidence of the land surface above, as the void left by mining is filled by collapse of overlying material (figure L-3). The long history of mining in Utah has created many areas with surface subsidence or sinkholes. Companies removing rock from the subsurface are now required by law to devise a mining method that reduces the potential for surface subsidence, monitor subsidence, and file a report with the Utah Division of Oil Gas and Mining (DOGM) each year. The subsidence investigations are based on surveyed grids laid out over mining areas. If subsidence occurs, the mine is required to alter their mining methods to prevent further subsidence (A.C. Keith, Utah Geological and Mineral Survey, personal communication, January, 1990). The Bingham mining district, in the Oquirrh Mountains on the western edge Tooele Valley, may be subject to this hazard, although there are no documented occurrences of mine subsidence.

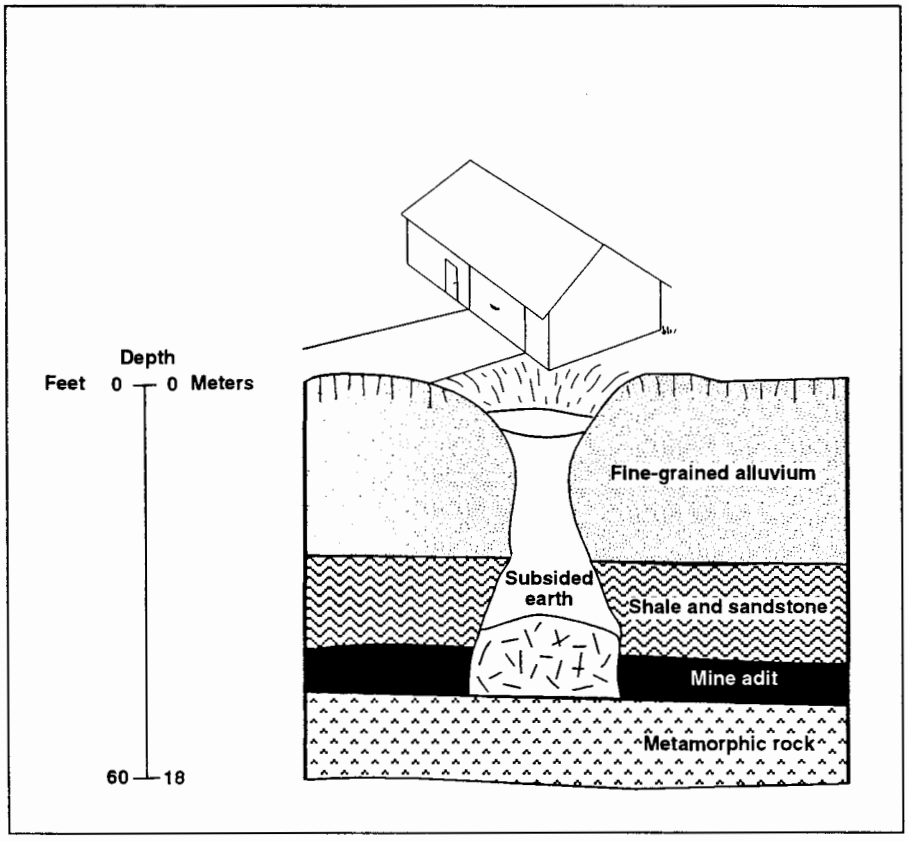

Figure L-3. Cross section of a subsidence pit, under a house, in an area of thick soil cover (modified from Turney, 1985).

EFFECTS

Expansive Soil

Problems commonly associated with expansive soil are cracked foundations (figure L-4), heaving and cracking of road surfaces, and failure due to plugging of septic-tank wastewater soil-absorption systems. Single family homes are particularly susceptible to expansive soil because foundation loads (1,500 to 2,500 lbs/ft^2) [7,323 to 12,205 kg/m^2] may be less than the expansive pressures (3,000 to 11,200 lbs/ft^2) [14,646 to 54,678 kg/m^2] caused by the swelling material, making them subject to heave (Costa and Baker, 1981). Larger, heavier buildings are better able to withstand the expansive pressure, and are less susceptible. Sidewalks, roads, buried utilities, and slabs-on-grade are also susceptible to cracking and damage due to differential expansion and contraction of underlying material.

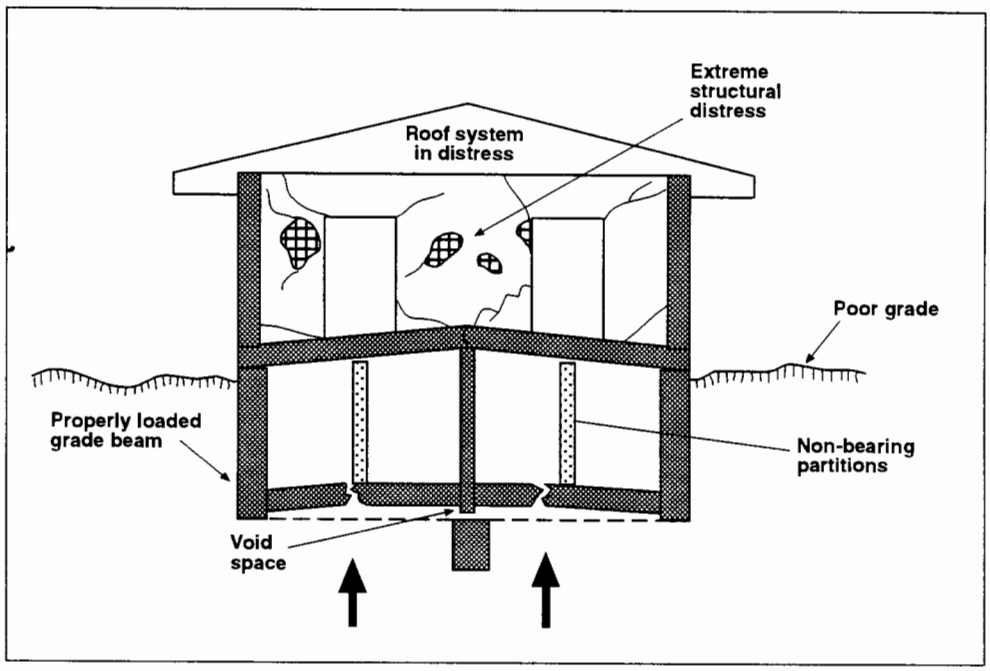

Figure L-4. Typical major house damage from expansive soils (from Holtz and Hart, 1978).

Wastewater disposal systems using soil-absorption fields can also be effected by expansive soil. Clay-rich deposits develop cracks when dry, leaving voids which allow large volumes of water to infiltrate initially. Once saturated, the clay minerals swell, closing the voids. Soil-absorption systems installed in expansive soil work until the soil becomes saturated and swells. The soil quickly becomes impermeable and the systems clog and fail, causing wastewater to flow to the surface creating a health hazard.

Gypsiferous Soil

Gypsiferous soil has the potential to cause damage to foundations and/or cause land subsidence and sinkholes. When wetted by irrigation for crops or landscaping, or by water from wastewater disposal systems, gypsiferous soil may subside due to dissolution. In some cases large underground solution cavities may form and then collapse. Gypsum is also a weak material with low bearing strength. When gypsum weathers it forms sulfuric acid and sulphate (Bell, 1983). These compounds may react with certain types of cement, weakening foundations by damaging the exterior surface.

Piping and Mine Subsidence

Piping and mine subsidence can cause damage to any overlying structure. Earthfill structures such as dams may be susceptible to piping, and piping of fine-grained embankment materials at the base of the Quail Creek dike, near St. George, contributed to its failure in 1989 (James and others, 1989). In the Uinta Basin, irrigation of cropland adjacent to incised drainages has caused extensive piping. In areas where piping is common, roads are most frequently damaged because they commonly parallel stream drainages and cross-cut numerous pipes. In addition, their construction commonly disturbs natural runoff, concentrating it near the roads. Collapse of underground mine adits may damage overlying structures and alter local surface topography. Mine subsidence is affected by factors such as depth of the mine, size and orientation of adits, and subsurface geology. Unlike other problem soil hazards, mine subsidence is man-related and is only a hazard in areas of underground mining.

HAZARD REDUCTION

Expansive Soil

The best method to reduce the hazard from expansive soil is to restrict changes in water content. Drainage conditions affecting soil moisture are important in areas of expansive soil. When water from sprinkler systems or runoff from roofs and roads reaches deposits beneath the structure, damage may occur as the material expands.

To reduce damage from expansive soil, several techniques can be used. For structures, these include: (1) using gutters and downspouts to direct water at least 10 feet (3m) away from foundation slabs; (2) avoiding vegetation that concentrates or draws large amounts of water from

the soil near foundations; (3) insulating floors or walls near heating or cooling units, which prevents evaporation and local changes in soil moisture; (4) strengthening house foundations by reinforcing concrete with steel bars; and (5) driving pilings into the soil to a depth below the active zone to support walls (Costa and Baker, 1981). Wide shoulders and good drainage along highways can prevent road damage. In highway foundations, a combination of hydrated lime, cement, and organic compounds can be added to road subgrade materials to stabilize the underlying soil (Costa and Baker, 1981). For wastewater-disposal systems, a 24-hour "presoak" of the material (prior to determining percolation rates) may yield a more reliable percolation rate on which to base system design and approval.

Gypsiferous Soil

Damage to structures from gypsiferous soil can be limited by several methods. The outer walls of structures can be coated with impermeable membranes or bituminous coatings to protect them from deterioration. Special sulfate-resistant concrete can also be used. Because gypsum is dissolved by contact with water, runoff from roofs and gutters should be directed away from the structure. Landscaping close to the house should not include plants which require regular watering.

Piping and Mine Subsidence

Damage caused by piping can be reduced by controlling drainage in susceptible soil. Runoff concentrated or ponded along paved surfaces allows greater infiltration and encourages piping. Culverts to collect runoff, and closed conduits to carry the water away from the road, will prevent damage. Concrete-lined drainage ditches, and concrete or asphalt around culvert inlets and outlets, can also limit damage. Damage to cropland can be reduced by limiting the amount of irrigation along incised stream drainages. Avoidance is the easiest and most cost-effective hazard-reduction technique for mine subsidence. In areas above mines, assessment of the potential for collapse should be made prior to development.

USE OF HAZARD MAPS

Plate 5 shows the likely extent of expansive and gypsiferous soils, based on surficial geology, in the WDHIA and Tooele Valley (figure L-5). The map is designed to highlight areas where these soils may be present and should be evaluated in standard soil-foundation investigations prior to development. In hazard areas, improperly designed roads and structures can be susceptible to damage. The maps are generalized and other localized areas may occur outside of mapped problem-soil areas. Areas where piping or mine subsidence may be found were not mapped.

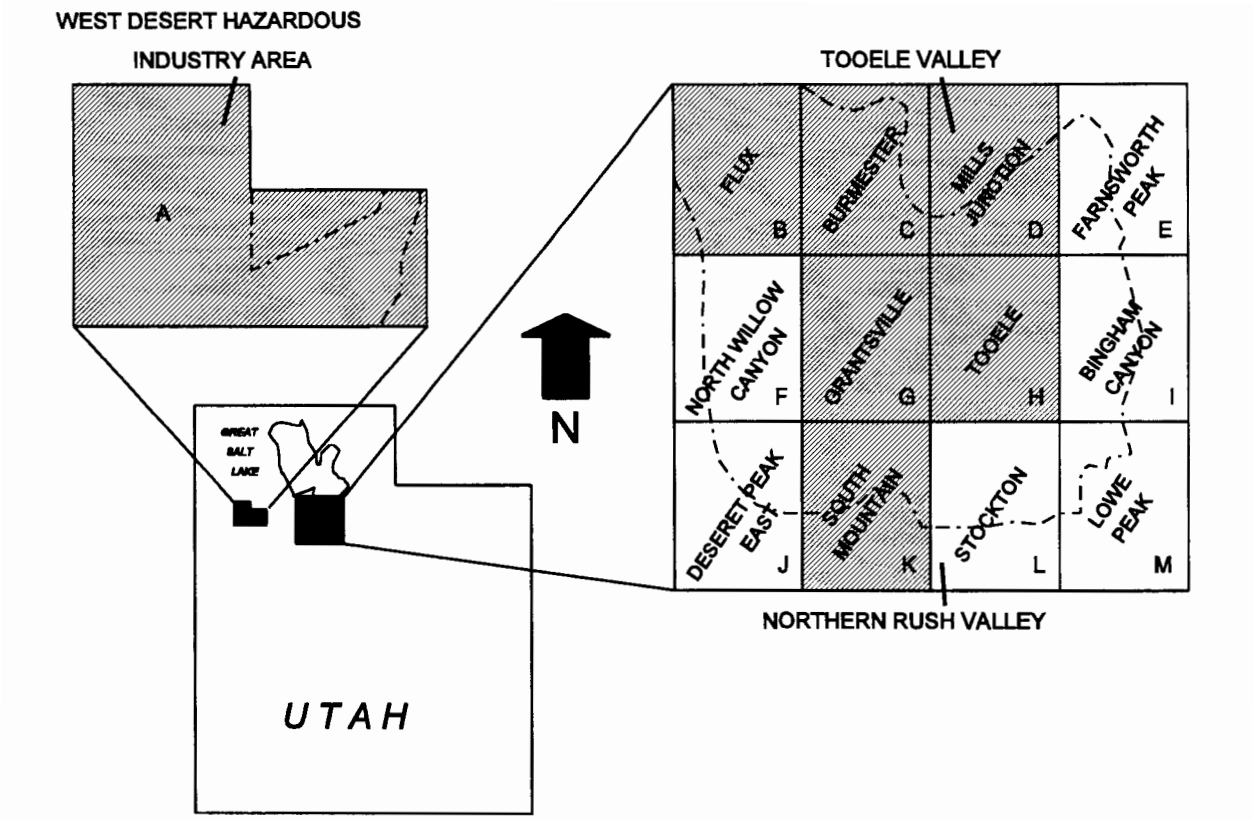

Figure L-5. Index map of areas (crosshatched) where problem soils are mapped on plate 5. Letters are used in plate designations. Study area boundaries are shown by dashed lines.

SITE INVESTIGATIONS

Most hazards created by problem soil can be reduced or avoided once they are identified. A standard soil-foundation investigation can indicate the presence of problem soil, and such investigations are recommended to provide information for foundation design even for areas that lie outside of the mapped problem-soil areas. Investigations should determine if clay is present and, if present, the type of clay and it's expansive qualities. Studies must also identify if gypsum is present, and in what quantity. If problem soils are found, the report should recommend appropriate hazard reduction strategies. The potential for piping should also be addressed.

The potential for mine subsidence should be considered for all development in areas of historic mining activity, such as the Bingham Mining District. The Utah Division of Oil Gas and

Mining (DOGM) can provide information regarding mining activity and the potential for subsidence in these areas.

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SECTION M:
INDOOR RADON

by

Bill D. Black
and
Barry J. Solomon

INTRODUCTION

Most geologic hazards are natural, dynamic, earth processes that alter the landscape and adversely affect the works of society. The occurrence of high radon concentrations in buildings, although not a process of landscape alteration like most geologic hazards, is recognized as a geologic hazard.

Radon is a naturally occurring gas derived from geologic materials. When inhaled, radon can be a significant cause of lung cancer. Whereas high levels of radon gas in uranium mines have long been recognized as a health hazard to miners, the hazard from indoor radon at lower levels has only recently been recognized. Radon has been found in many buildings throughout the United States in sufficient concentrations to represent a health hazard to building occupants. Concern for the health consequences associated with long-term indoor-radon exposure has prompted scientists and health officials, at both the national and state levels, to assess the radon hazard and determine the extent of the problem.

CHARACTERISTICS

Radon is an odorless, tasteless, and colorless radioactive gas which forms as a product of radioactive decay. The most common source of radon is decay of uranium (^{238}U) to stable lead (^{206}Pb) (figure M-1). During this decay sequence, new isotopes form which emit radiation. One such isotope, radon (^{222}Rn), forms directly from decay of radium (^{226}Ra). Two other isotopes of radon (^{219}Rn and ^{220}Rn) also occur in nature and may contribute to the indoor-radon problem. However, ^{222}Rn is the most abundant of the radioactive radon isotopes, has the longest half-life at 3.825 days, and is considered to be the most significant contributor to the indoor-radon hazard. Subsequent references to radon imply ^{222}Rn derived from the ^{238}U decay chain.

In nature, radon is found in small concentrations in nearly all rocks and soils. The exposure to the hazard, in most cases, depends on factors such as geology, foundation condition, building ventilation, construction material, and occupant lifestyle. Tanner (1986) suggests four prerequisites for elevated indoor-radon concentrations. The home must: (1) be built on ground that contains a radon source material, (2) have underlying soils that promote easy movement of radon, (3) have

porous building materials or openings below grade, and (4) have a lower atmospheric pressure inside than outside.

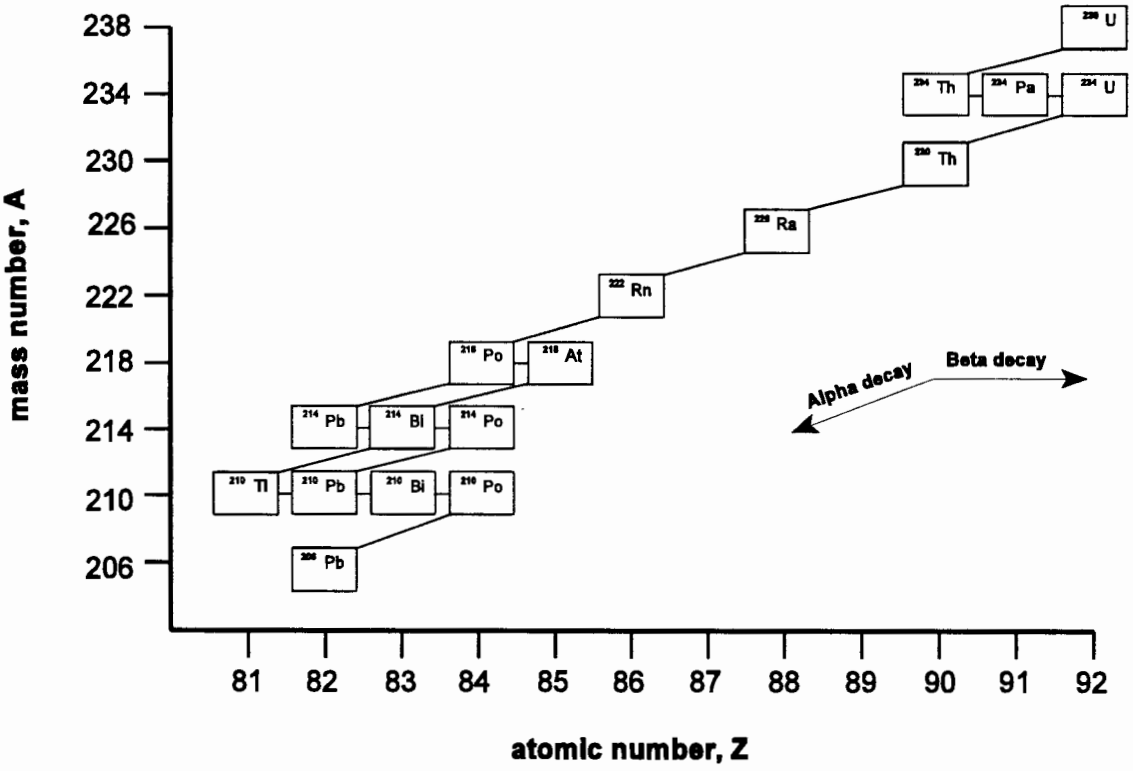

Figure M-1. Uranium (^{238}U) decay series. Radon (^{222}Rn) is derived from radium (^{226}Ra) and is the only isotope in the series that is a gas. Because it is inert, radon also has the ability to move with air or water without participating in chemical reactions (modified from Durrance, 1986).

There are several geologic factors which affect the radon hazard. The first is the distribution of uranium-enriched rock and soil. Granite, metamorphic rocks, some volcanic rocks, and black, organic-rich shales are generally associated with indoor-radon hazards. Once uranium is present in a rock or soil, other factors can enhance or impede radon production and movement, including permeability and water saturation (Tanner, 1964, 1980; Barretto, 1975). A high permeability enhances radon movement by allowing the gas to diffuse through the rock or soil. Water saturation inhibits radon migration by filling pore spaces and restricting the flow of soil gas (Tanner, 1980).

Although radon may move with the water, the flow of water through geologic materials is usually much slower. However, water does provide an effective means to carry radon from its rock source (Tanner, 1980). Where domestic water sources contain high levels of radon, they may contribute to indoor-radon levels (Vitz, 1989).

Radon is highly mobile and can find its way into buildings through small basement cracks or other foundation penetrations such as utility pipes (figure M-2). Although outdoor radon concentrations never reach dangerous levels because air movement dissipates the gas, people can be subject to a radon hazard in buildings that have poor air circulation. Maximum radon concentrations are often found in basements or low crawl spaces (Fleischer and others, 1982), which are in contact with the ground and usually poorly ventilated.

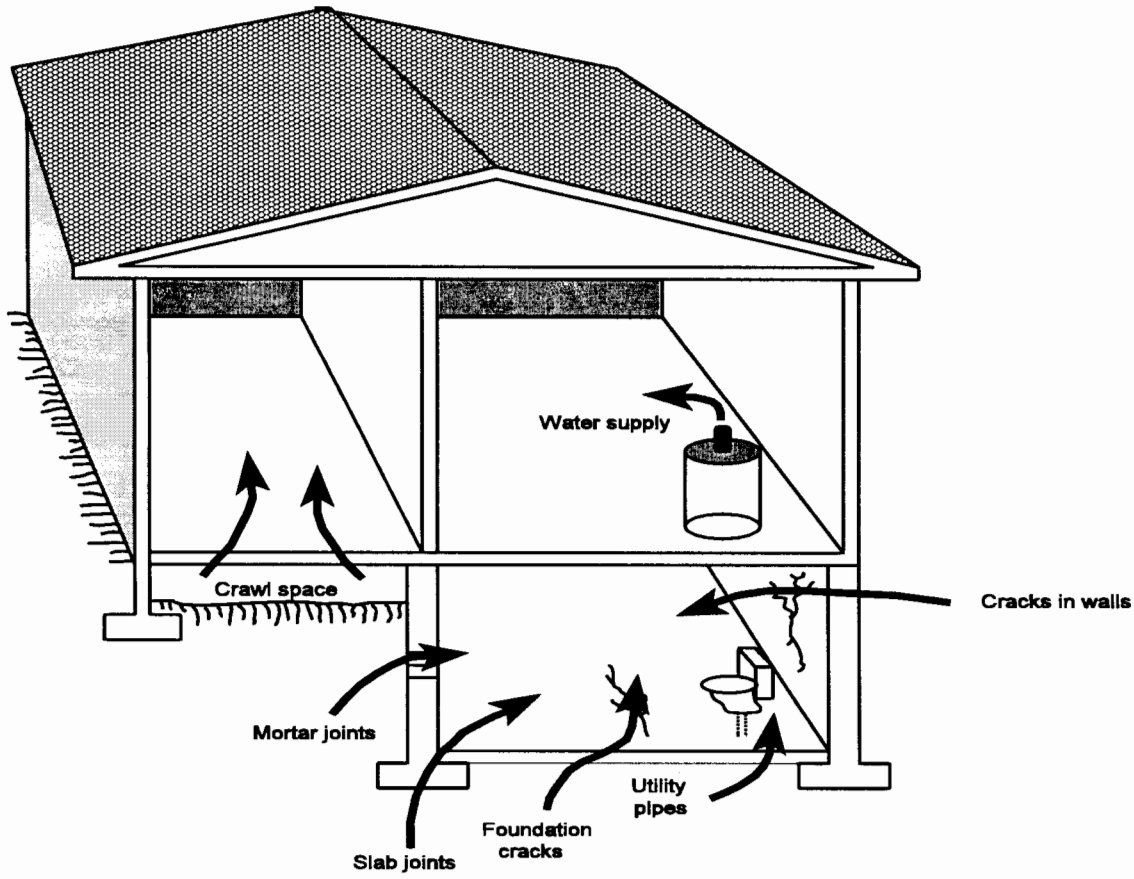

Figure M-2. Various pathways for radon to enter a home. Most of the entry routes are in the basement, because that is the part of the house with the greatest surface area exposed to the surrounding soil (modified from U.S. Environmental Protection Agency, 1992).

Radon concentration is measured in picocuries per liter of air (pCi/L), which represents a decay of 2 radon atoms per minute per liter of air. Most buildings throughout the United States usually have concentrations less than 3 pCi/L (Nero and others, 1986). The U.S. Environmental Protection Agency (U.S. EPA, 1992) recommends that action be taken to reduce indoor levels when they exceed 4 pCi/L.

Changes in building practices over the past 15 years have contributed to the radon problem. Since the 1973 oil embargo, conservation of non-renewable energy resources has been a national goal through energy-efficient practices. Although the building industry has made structures more energy efficient, they have not improved ventilation systems to accommodate restricted natural air flow. Buildings constructed before 1973, including single-family homes, often did not use energy-efficient measures and allowed indoor air to escape through above-grade joints and uninsulated walls and attics. Energy-efficient homes and buildings prevent the loss of indoor air to the outside. Studies have shown that newer, energy-efficient buildings with under-designed ventilation systems generally have higher indoor-radon levels compared with older, conventional buildings (Fleischer and others, 1982; Nero and others, 1982).

EFFECTS

Radon and other sources of natural radiation are widespread in low levels, but most natural background radiation is not a health threat. Most buildings throughout the United States contain some radon, but concentrations are usually less than 3 pCi/L. Long-term exposure to these levels is generally considered a small health risk. However, health officials believe breathing elevated levels of radon over time increases a person's risk of lung cancer because of internal radiation damage to the lungs from decaying radon and radon progeny (Jacobi and Eisfeld, 1982; National Council on Radiation Protection and Measurements, 1984a, 1984b; Samet, 1989; figure M-3).

The greater your exposure to radon, the greater your risk of developing lung cancer. The EPA estimates that from 8,000 to 40,000 Americans will die each year from lung cancer caused by long-term radon inhalation (Schmidt and others, 1990). If you regularly drink household water containing radon, it is not considered a health risk. Waterborne radon is a problem only when the radon is released from the water and enters the household air. Estimates of the contribution of radon in water to airborne radon range from 1 to 2.5 pCi/L in air for every 10,000 pCi/L in water.

Inhalation of radon is not thought to be the primary source of internal radiation because radon atoms are inert and do not attach themselves to the lining of the lungs. In addition, most radon atoms are exhaled before they can decay and emit dangerous alpha particles to lung tissue. The radioactive isotopes formed from radon decay are of more concern because they are not inert and readily attach themselves to the first charged surface they come in contact with (typically dust or smoke in the air). People who smoke place the occupants of a building at greater risk because the smoke increases the number of airborne particles, to which radon progeny then become attached and are inhaled into the lungs. Once dust or smoke particles with attached radon progeny become lodged in the lungs, these particles allow tissue to be directly bombarded and damaged by energetic alpha particles as

radioactive decay occurs.

RADON RISK IF YOU SMOKE*			
Radon level	*If 1,000 people who smoked were exposed to this level over a lifetime...*	*The risk of cancer from radon exposure compares to...*	*WHAT TO DO: Stop smoking and...*
20 pCi/L	About 135 people could get lung cancer	⬅100 times the risk of drowning	Fix your home
10 pCi/L	About 71 people could get lung cancer	⬅100 times the risk of dying in a home fire	Fix your home
8 pCi/L	About 57 people could get lung cancer		Fix your home
4 pCi/L	About 29 people could get lung cancer	⬅100 times the risk of dying in an airplane crash	Fix your home
2 pCi/L	About 15 people could get lung cancer	⬅2 times the risk of dying in a car crash	Consider fixing your home between 2 and 4 pCi/L
1.3 pCi/L	About 9 people could get lung cancer	(Average indoor radon level)	(Reducing radon levels below 2 pCi/L is difficult)
0.4 pCi/L	About 3 people could get lung cancer	(Average outdoor radon level)	
*If you are a former smoker, your risk may be lower.			

RADON RISK IF YOU DON'T SMOKE*			
Radon level	*If 1,000 people who smoked were exposed to this level over a lifetime...*	*The risk of cancer from radon exposure compares to...*	*WHAT TO DO: Stop smoking and...*
20 pCi/L	About 8 people could get lung cancer	⬅The risk of being killed in a violent crime	Fix your home
10 pCi/L	About 4 people could get lung cancer		Fix your home
8 pCi/L	About 3 people could get lung cancer	⬅10 times the risk of dying in an airplane crash	Fix your home
4 pCi/L	About 2 people could get lung cancer	⬅The risk of drowning	Fix your home
2 pCi/L	About 1 person could get lung cancer	⬅The risk of dying in a home fire	Consider fixing your home between 2 and 4 pCi/L
1.3 pCi/L	Less than 1 person could get lung cancer	(Average indoor radon level)	(Reducing radon levels below 2 pCi/L is difficult)
0.4 pCi/L	Less than 1 person could get lung cancer	(Average outdoor radon level)	
*If you are a former smoker, your risk may be higher.			

Figure M-3. Radon risk evaluation chart. The U.S. Environmental Protection Agency (1992) has developed this chart to provide comparable risks for people to evaluate their personal risk from radon.

HAZARD REDUCTION

If elevated indoor-radon levels are discovered in a home, a number of methods can be considered for reducing levels. These methods fall into two categories: (1) preventing radon from entering the house, and (2) removing radon (or decay products) after entry. The specific method chosen will depend upon the initial radon concentration, house design, and construction.

Some actions may be taken immediately, and can be done quickly with a minimum of expense. Discourage smoking inside a home; this not only reduces the risk from radon exposure but also the overall chance of developing lung cancer. Radon collects in the basement and low areas of a home; spending less time in these areas of higher radon concentrations will reduce the risk. Ventilation can be improved by opening windows and turning on fans, but is not always possible during cold winter months.

Although immediate actions are effective, they are not long-term solutions. The selection of permanent radon-reduction methods requires identification of radon-entry routes and driving forces, and diagnostic testing to aid in the selection of the most effective method. Professional assistance is often required. There are five classes of permanent methods: (1) increased ventilation through natural means (such as opening windows) or ventilators; (2) sealing to restrict movement of radon from soil into the house and gas flow through entry routes (known as "closure"); (3) soil ventilation to withdraw radon-contaminated soil gas and divert it outdoors; (4) house pressure adjustments to restrict flow of soil gas into the house by altering pressure differentials between the house and soil; and (5) air cleaning to remove radon decay products (which are solid particles) from the air after radon entry (U.S. EPA, 1989). Once appropriate radon-reduction methods are chosen and implemented, diagnostic tests should also be conducted to ensure that radon levels have been reduced.

An effective method of hazard reduction is to prevent radon from entering the structure. Prevention is advisable in new construction, particularly in high hazard areas. New design and construction may incorporate methods to restrict radon entry by minimizing: (1) soil gas entry pathways; and (2) indoor-outdoor pressure differences, because these differences are the driving force for soil gas to enter a home (Osborne, 1988). Features can also be incorporated during construction that facilitate radon removal. Although these features are technical in nature and not discussed here, the information is available from the EPA.

If there is no measured problem with airborne radon in a home, there is generally no need to test household water for radon. If indoor levels are high, low-cost water test kits are available from commercial laboratories. Testing of water from municipal water supplies is generally not necessary; radon contamination usually only occurs in well water and is not common.

If a water test indicates radon problems, the radon may either be removed from the air after it has left the water or from the water before it reaches indoor air (U.S. EPA, 1987). Good ventilation of bathrooms, laundry rooms, and kitchens, particularly during periods of water use, may be adequate to remove radon from indoor air. Methods to remove radon from water include: (1)

storing water for several days to allow radon time to decay, which may require large storage tanks; (2) home aeration systems that spray water through an air-filled chamber and use fans to remove the contaminated air; and (3) devices which use granular activated charcoal to remove radon from water. Activated charcoal devices are presently the least costly alternative for homes using their own wells and, to date, the most extensively tested and used method.

USE OF HAZARD MAPS AND SITE INVESTIGATIONS

Hazard Potential Maps

Detailed maps have been prepared that show the extent of radon hazards in Tooele Valley, but not the WDHIA. However, site investigations addressing radon hazards are not required. The maps are included for information purposes to prioritize testing and show areas where radon-resistant construction should be considered. The UGS has prepared a statewide radon-hazard potential map, and the portion covering Tooele County is shown in figure M-4. Figure M-5 shows the results of a more detailed study in Tooele Valley (Black and Solomon, in preparation). Hazard potential on these maps was determined from geologic factors such as uranium concentration, soil permeability, and depth to shallow ground water (Black, 1993). Three categories of hazard potential are mapped: (1) high, areas where all geologic factors contribute to elevated indoor-radon levels; (2) moderate, areas where some geologic factors contribute to elevated indoor-radon levels; and (3) low, areas where no geologic factors contribute to elevated indoor-radon levels (Black, 1993; Black and Solomon, in preparation). It is important to note that these maps are generalized and show only the relative geologic potential for radon hazards. Actual indoor-radon levels may vary, and the map should not be used to predict indoor-radon levels. Indoor testing is the only reliable way to determine if a radon hazard exists, and is recommended in all areas regardless of radon-hazard potential. New construction in high hazard-potential areas may also wish to incorporate radon-reduction techniques.

The radon-hazard potential of the WDHIA is mostly moderate (figure M-4). Isolated areas of high hazard potential are found in the Cedar Mountains, on the eastern edge of the WDHIA, and in the Grayback Hills. Deep ground water and highly permeable soils with moderate-to-high uranium levels are found in these areas. The hazard potential is low in the Great Salt Lake Desert, on the western edge of the WDHIA, where shallow ground water and impermeable, clay-rich soils are found. No indoor-radon concentrations have been measured in the WDHIA. Although radon emanation from low-level nuclear waste repositories such as Vitro and Envirocare is unknown, high on-site levels have been found at similar facilities (Tomczak and others, 1993).

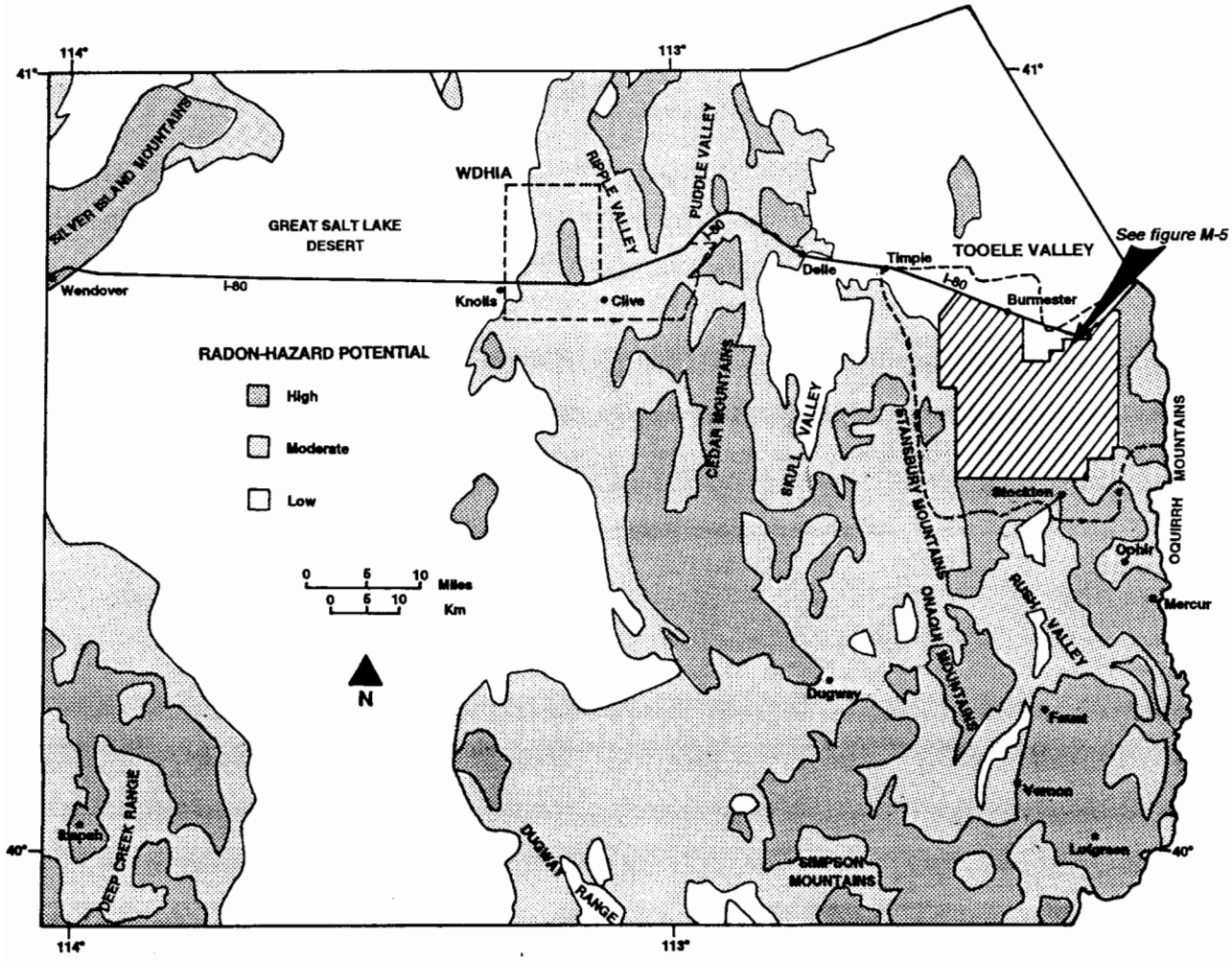

Figure M-4. Radon hazard potential of Tooele County from geologic factors (modified from Black, 1993).

Detailed studies by the UGS show the radon-hazard potential of Tooele Valley is also mostly moderate (figure M-5). Scattered areas of high hazard potential occur where deep ground water and highly-permeable soils with moderate-to-high uranium levels are found. Areas of low hazard potential occur in the northern part of the valley in low-lying areas surrounding Great Salt

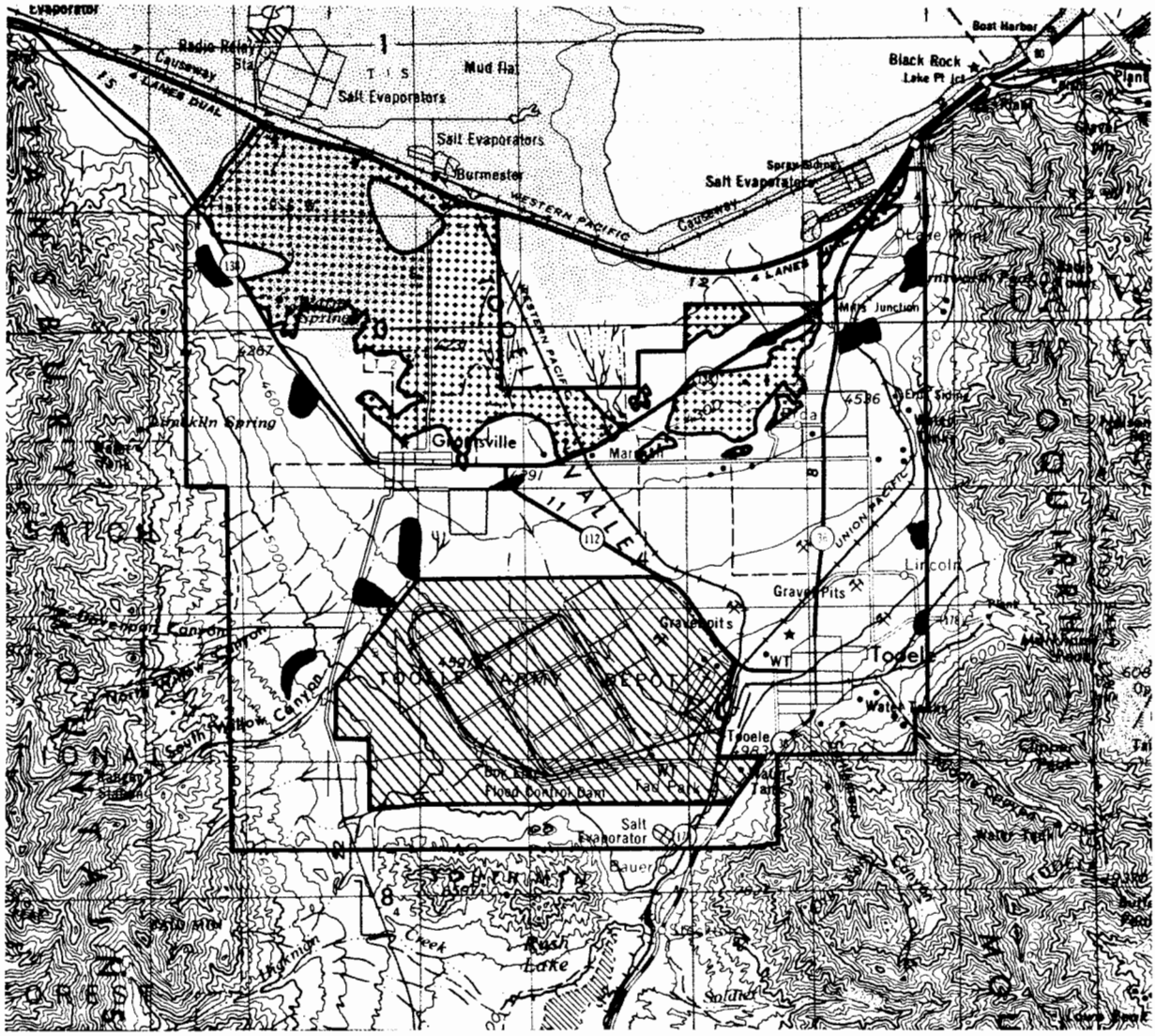

Figure M-5. Radon hazard potential of Tooele Valley based on geologic factors (modified from Black and Solomon, in preparation).

Lake, where there is shallow ground water and impermeable, clay-rich soils. The Utah Division of Radiation Control (UDRC) measured indoor-radon concentrations in 70 homes in Tooele Valley, most of which were in moderate-hazard areas (Black and Solomon, in preparation). Mean concentration of these measurements was 2.2 pCi/L (81 Bq/m^3) (Black and Solomon, in preparation). The highest measured indoor-radon concentration in Tooele Valley was 8.0 pCi/L (296 Bq/m^3), with 18.6 percent of the measurements greater than or equal to 4 pCi/L (148 Bq/m^3) (Black and Solomon, in preparation).

Indoor Testing

Radon can be measured with both short-term and long-term passive detectors and electronic instruments. Some detectors can be placed by homeowners, whereas others require professional installation. Because most people want information quickly, they often select short-term monitoring methods. A short-term measurement is one conducted for a period less than three months. However, long-term monitoring, typically for a twelve-month period, provides more realistic information.

Measurements taken over a few days or on a single day provide only a snapshot of indoor-radon levels for that particular time. Radon emissions from the ground, and resultant indoor-radon levels, can fluctuate daily, weekly, and monthly because of atmospheric changes. In addition, concentrations fluctuate seasonally because building ventilation is less in winter than summer, and indoor heating and air conditioning affect concentrations. A longer period of monitoring is recommended to smooth out short-term fluctuations. This provides a realistic picture of the yearly average concentration. The UDRC provides information on types of radon detectors available, their advantages and disadvantages, and comparative cost.

Radon measurement protocols suggested by the EPA (U.S. Environmental Protection Agency, 1992) attempt to assure accuracy and consistency of data. The protocols were developed to balance the need for quick results with measurements that best reflect long-term indoor-radon levels. To accurately determine indoor-radon levels throughout a home, long-term monitoring is needed on each floor. However, short-term screening measurement which follows EPA protocol (closed-house conditions) may be conducted in the lowest living area to determine if additional testing is required. Charcoal canisters are commonly used for short-term measurements; alpha-track detectors are commonly used for long-term measurements.

EPA protocols emphasize immediate follow-up testing in homes with screening measurements exceeding 4 pCi/L (U.S. Environmental Protection Agency, 1992). Occupants of homes with radon levels exceeding 4 pCi/L should take action to reduce radon concentrations. Additional testing is not needed if a short-term screening measurement is less than 4 pCi/L and, although a small health risk is present, remediation is unnecessary. If a result is greater than 4 pCi/L and less than 20 pCi/L, a 12-month follow-up measurement is recommended. If retesting confirms screening measurements, remediation should be done within the next few years. If a screening measurement is from 20 to 200 pCi/L, a 3-month follow-up measurement is recommended. If the measurement is confirmed, remediation should take place within a few

months. If a screening measurement exceeds 200 pCi/L, retest immediately. If confirmed, remediation should take place within weeks.

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Landslide, and ponding and sheet-flooding hazards, West Desert Hazardous Industry Area, Tooele County, Utah.

COMPILED BY BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 1A
1995

N

Scale 1:50,000

0 1 2 3 4 5 KILOMETERS

0 1 2 3 MILES

NATIONAL GEODETIC VERTICAL DATUM OF 1929
CONTOUR INTERVAL 5 AND 20 METERS

EXPLANATION

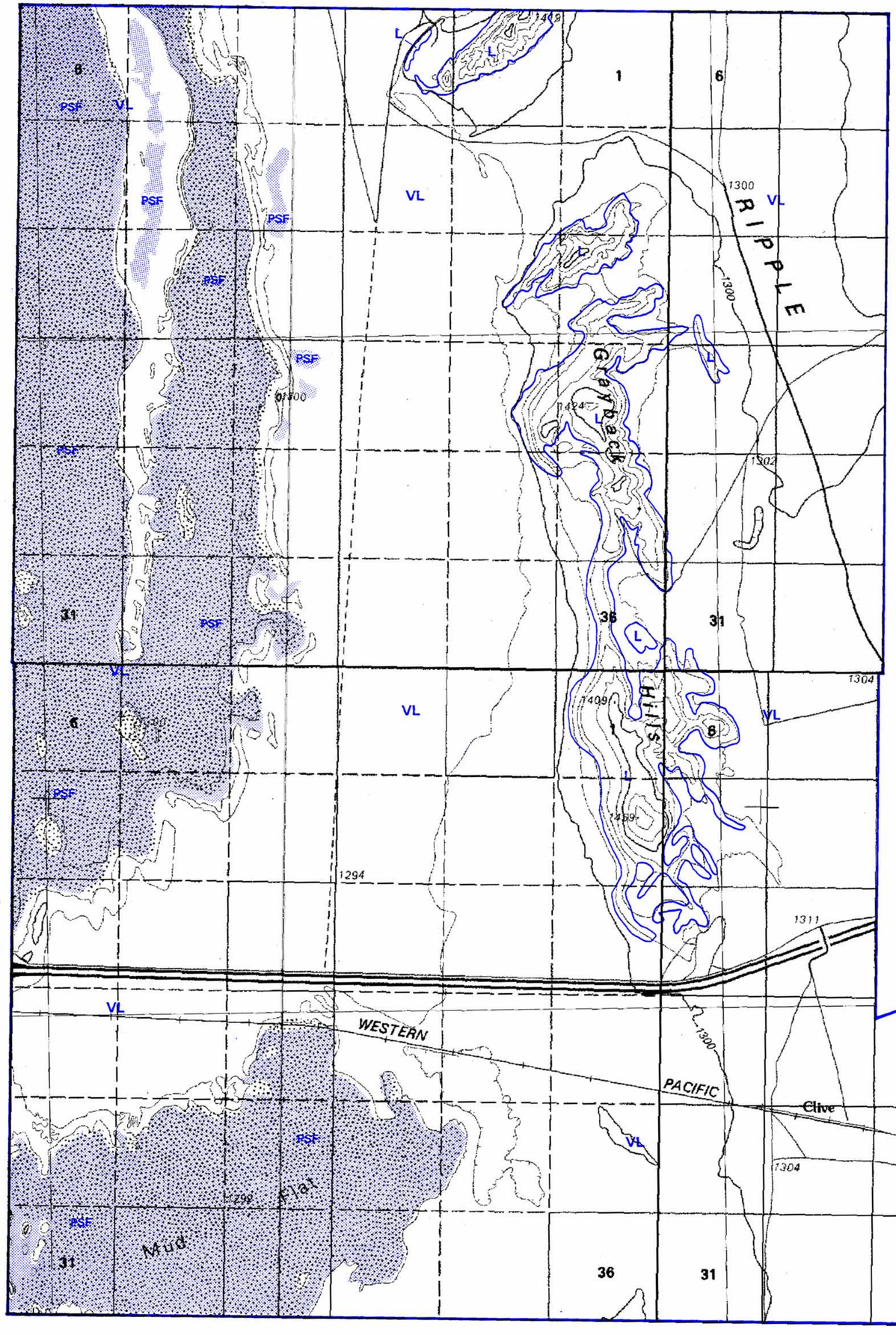
Landslide susceptibility

H*	High; includes existing landslides (crosshatched).
M*	Moderate.
L	Low.
VL	Very low.

Ponding and sheet flooding

PSF *	Subject to ponding and sheet flooding.

* Special studies are recommended for certain land uses in areas of high and moderate landslide susceptibility, and in areas subject to ponding and sheet flooding (see table 1).



Base map from BONNEVILLE SALT FLATS and TOOELE, U.S.G.S. 30x60 minute topographic map series.

Landslide, lake-flooding, and ponding and sheet-flooding hazards, Flux quadrangle, Tooele County, Utah.

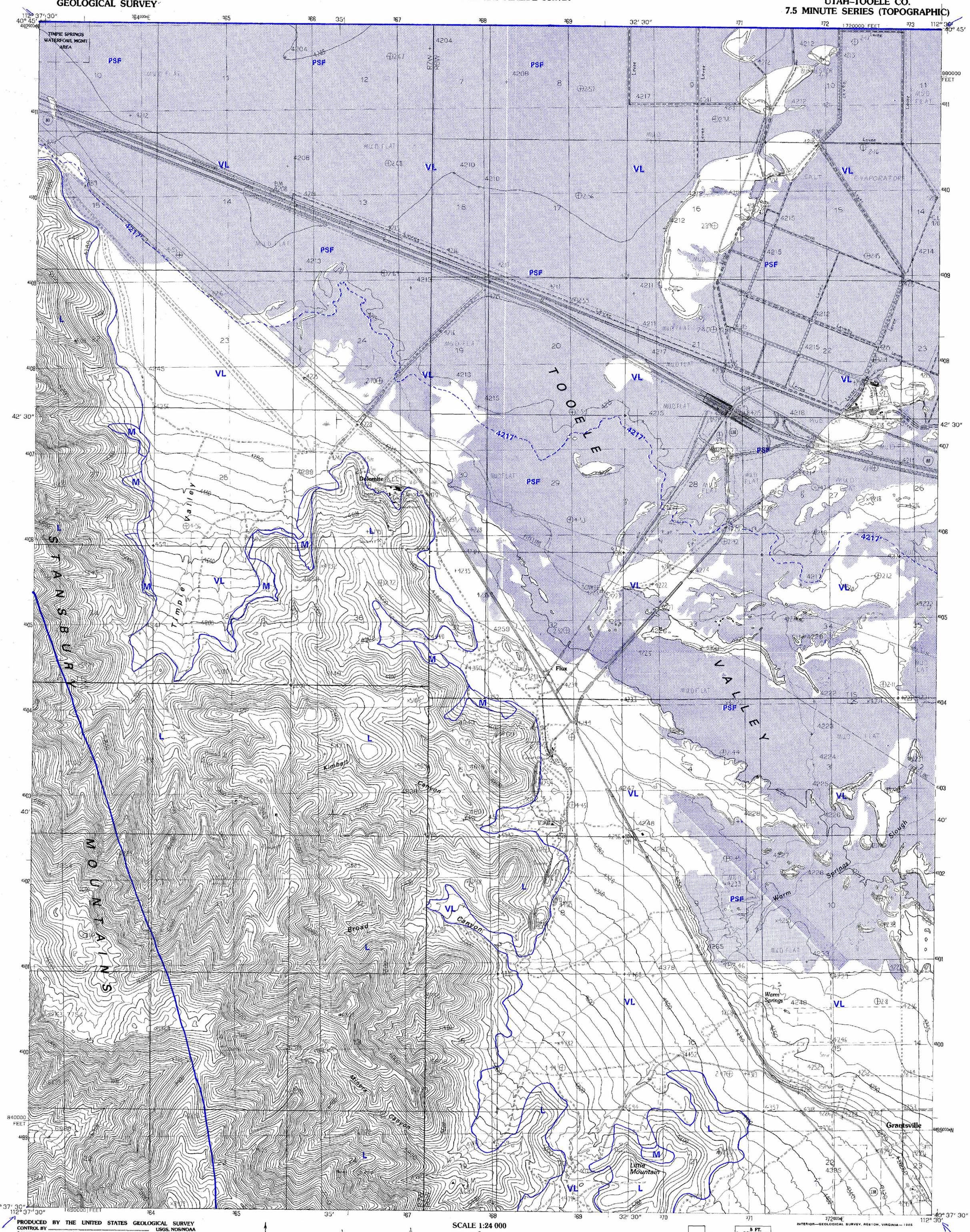
MAPPED AND COMPILED BY KIMM M. HARTY AND BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 1B
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATE OF UTAH
UTAH GEOLOGICAL AND MINERAL SURVEY

FLUX QUADRANGLE
UTAH–TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)



PRODUCED BY THE UNITED STATES GEOLOGICAL SURVEY
CONTROL BY ..... USGS, NOS/NOAA
COMPILED FROM AERIAL PHOTOGRAPHS TAKEN 1980
FIELD CHECKED ..... 1981 MAP EDITED 1985
PROJECTION ..... LAMBERT CONFORMAL CONIC
GRID: 1000-METER UNIVERSAL TRANSVERSE MERCATOR ..... ZONE 12
10,000-FOOT STATE GRID TICKS ..... UTAH, CENTRAL ZONE
UTM GRID DECLINATION ..... 1°01' WEST
1985 MAGNETIC NORTH DECLINATION ..... 15° EAST
VERTICAL DATUM ..... NATIONAL GEODETIC VERTICAL DATUM OF 1929
HORIZONTAL DATUM ..... 1927 NORTH AMERICAN DATUM

To place on the predicted North American Datum of 1983, move the projection lines as shown by dashed corner ticks (10 meters north and 67 meters east)

There may be private inholdings within the boundaries of any Federal and State Reservations shown on this map

SCALE 1:24 000

1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 KILOMETER

CONTOUR INTERVAL 5 AND 40 FEET

NORTH

UTAH
QUADRANGLE LOCATION

5 FT. CONTOURS
40 FT. CONTOURS

ROAD LEGEND

Improved Road
Unimproved Road
Trail
Interstate Route U.S. Route State Route

PROVISIONAL MAP
Produced from original manuscript drawings. Information shown as of date of field check. 2

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U.S. GEOLOGICAL SURVEY, DENVER, COLORADO, 80225
OR RESTON, VIRGINIA 22092

1	2	3	1 Poverty Point 2 Corral Canyon 3 Plug Peak 4 Timpie 5 Burmester 6 Salt Mountain 7 North Willow Canyon 8 Grantsville
4		5	
6	7	8	

ADJOINING 7.5 QUADRANGLE NAMES

FLUX, UTAH
PROVISIONAL EDITION 1985
40112-F5-TF-024

EXPLANATION

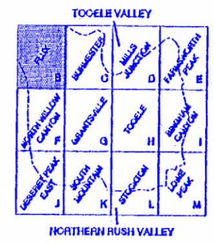
Landslide susceptibility

H*	High; includes existing landslides (crosshatched).
M*	Moderate.
L	Low.
VL	Very low.

Lake flooding, and ponding and sheet flooding

--4217'--	Boundary of the "Beneficial Development Area" (4217-foot [1285-m] contour). Areas below this elevation are subject to lake flooding and land use must be compatible with potential flood hazards.
PSF *	Subject to ponding and sheet flooding.

* Special studies are recommended for certain land uses in areas of high and moderate landslide susceptibility, and in areas subject to ponding and sheet flooding (see table 1).



Landslide, lake-flooding, and ponding and sheet-flooding hazards, Burmester quadrangle, Tooele County, Utah.

MAPPED AND COMPILED BY KIMM M. HARTY AND BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 1C
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

BURMESTER QUADRANGLE
UTAH—TOOELE CO.
7.5 MINUTE SERIES ORTHOPHOTOMAP (TOPOGRAPHIC)

Study Area Boundary

ALKALI OR MUD

PSF

VL

GREAT SALT LAKE

ELEVATION 4200
1953

Burmester

Coyote Knolls

Willow Fields

Blue Lakes

Warm Springs

Stouts Creek

Coolers Creek

Flowing Well

Flowing Wells

Borrow Pit

Borrow Pits

Well

Spring

Creek

WESTERN PACIFIC

PIPELINE

ROAD

BURMESTER

TOOELE VALLEY

SALT EVAPORATORS

(CORRAL CANYON)

(PLUG PEAK)

(PLUG PEAK SE)

(TIMPIE 1:62 500)

(MILLS JUNCTION)

(GRANTSVILLE)

(TOOELE)

6 MI. TO UTAH 36
SALT LAKE CITY 28 MI.

Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Planimetry by photogrammetric methods from aerial photographs taken 1953. Topography by planetable surveys 1923 and 1955
Revision and orthophotomosaic from aerial photographs taken 1971
Field checked 1972

Underwater contours by photogrammetric methods from aerial photographs taken 1966, 1969, and 1971–72

Projection and 10,000-foot grid ticks: Utah coordinate system, central zone (Lambert conformal conic)
1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue. 1927 North American datum

UTM GRID AND 1972 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 5 FEET
DATUM IS MEAN SEA LEVEL

ROAD CLASSIFICATION

Primary highway, hard surface
Secondary highway, hard surface
Light-duty road, hard or improved surface
Unimproved road
Interstate Route
U. S. Route
State Route

UTAH
QUADRANGLE LOCATION

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR WASHINGTON, D. C. 20242
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

BURMESTER, UTAH
N4037.5—W11222.5/7.5

1972

AMS 3565 III NW—SERIES V8970

EXPLANATION

Landslide susceptibility

H*	High; includes existing landslides (crosshatched).
M*	Moderate.
L	Low.
VL	Very low.

Lake flooding, and ponding and sheet flooding

--4217'--	Boundary of the "Beneficial Development Area" (4217-foot [1285-m] contour). Areas below this elevation are subject to lake flooding and land use must be compatible with potential flood hazards.
PSF *	Subject to ponding and sheet flooding.

* Special studies are recommended for certain land uses in areas of high and moderate landslide susceptibility, and in areas subject to ponding and sheet flooding (see table 1).

TOOELE VALLEY
NORTHERN RUSH VALLEY

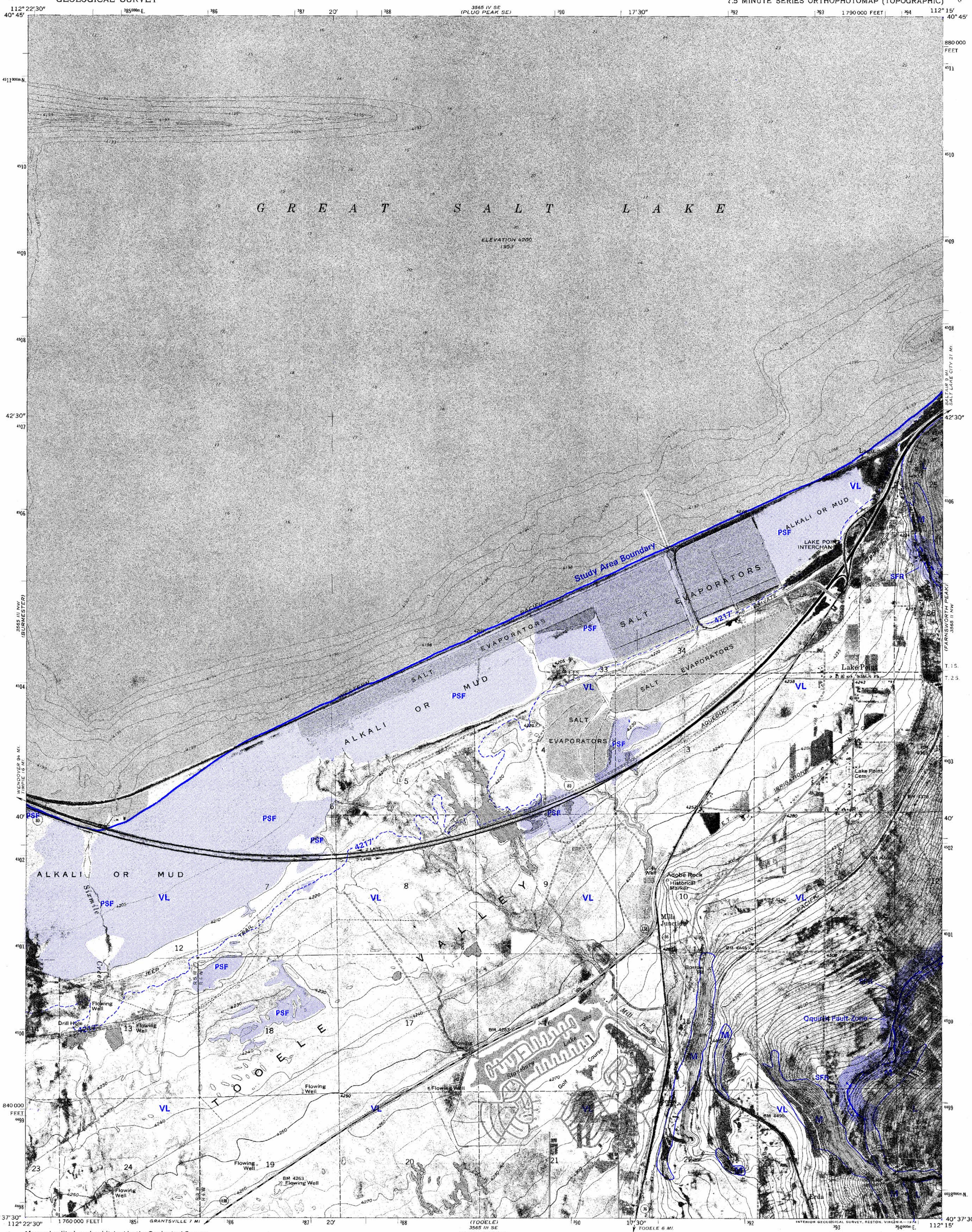
Landslide, surface-fault-rupture, lake-flooding, and ponding and sheet-flooding hazards, Mills Junction quadrangle, Tooele County, Utah.

MAPPED AND COMPILED BY KIMM M. HARTY AND BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 1D
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

MILLS JUNCTION QUADRANGLE
UTAH—TOOELE CO.
7.5 MINUTE SERIES ORTHOPHOTOMAP (TOPOGRAPHIC)



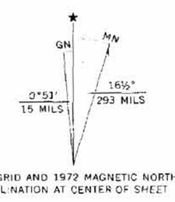
Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Topography by photogrammetric methods from aerial photographs taken 1953 and by planetable surveys 1923–24 and 1955
Revision and orthophotomosaic from aerial photographs taken 1971
Field checked 1972

Underwater contours by photogrammetric methods from aerial photographs taken 1966, 1969, and 1971–72. Soundings compiled from chart furnished by U.S. Naval Reserve

Projection and 10,000-foot grid ticks: Utah coordinate system, central zone (Lambert conformal conic)
1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue. 1927 North American datum



UTM GRID AND 1972 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

1 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER

CONTOUR INTERVAL 10 FEET
DOTTED LINES REPRESENT 5-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL
SOUNDINGS IN FEET—DATUM IS LAKE ELEVATION 4200 FEET

QUADRANGLE LOCATION

ROAD CLASSIFICATION

Primary highway, hard surface
Secondary highway, hard surface
Light-duty road, hard or improved surface
Unimproved road
Interstate Route
U. S. Route
State Route

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY
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A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

MILLS JUNCTION, UTAH
N4037.5—W11215/7.5

1972

AMS 3565 III NE SERIES V8970

EXPLANATION

Landslide susceptibility

H*	High; includes existing landslides (crosshatched).
M*	Moderate.
L	Low.
VL	Very low.

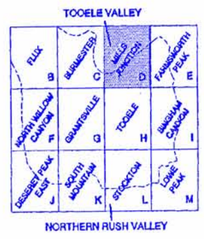
Surface fault rupture

———	Main trace of active faults with evidence of possible Quaternary movement (within the past 1.6 million years). Dashed where inferred, bar and ball on downthrown side.
SFR *	Possible surface fault rupture.

Lake flooding, and ponding and sheet flooding

– –4217′– –	Boundary of the "Beneficial Development Area" (4217-foot [1285-m] contour). Areas below this elevation are subject to lake flooding and land use must be compatible with potential flood hazards.
PSF *	Subject to ponding and sheet flooding.

* Special studies are recommended for certain land uses in areas of (1) high and moderate landslide susceptibility, (2) ponding and sheet flooding, and (3) possible surface fault rupture (see table 1).



ISBN 0-7017-0494-2

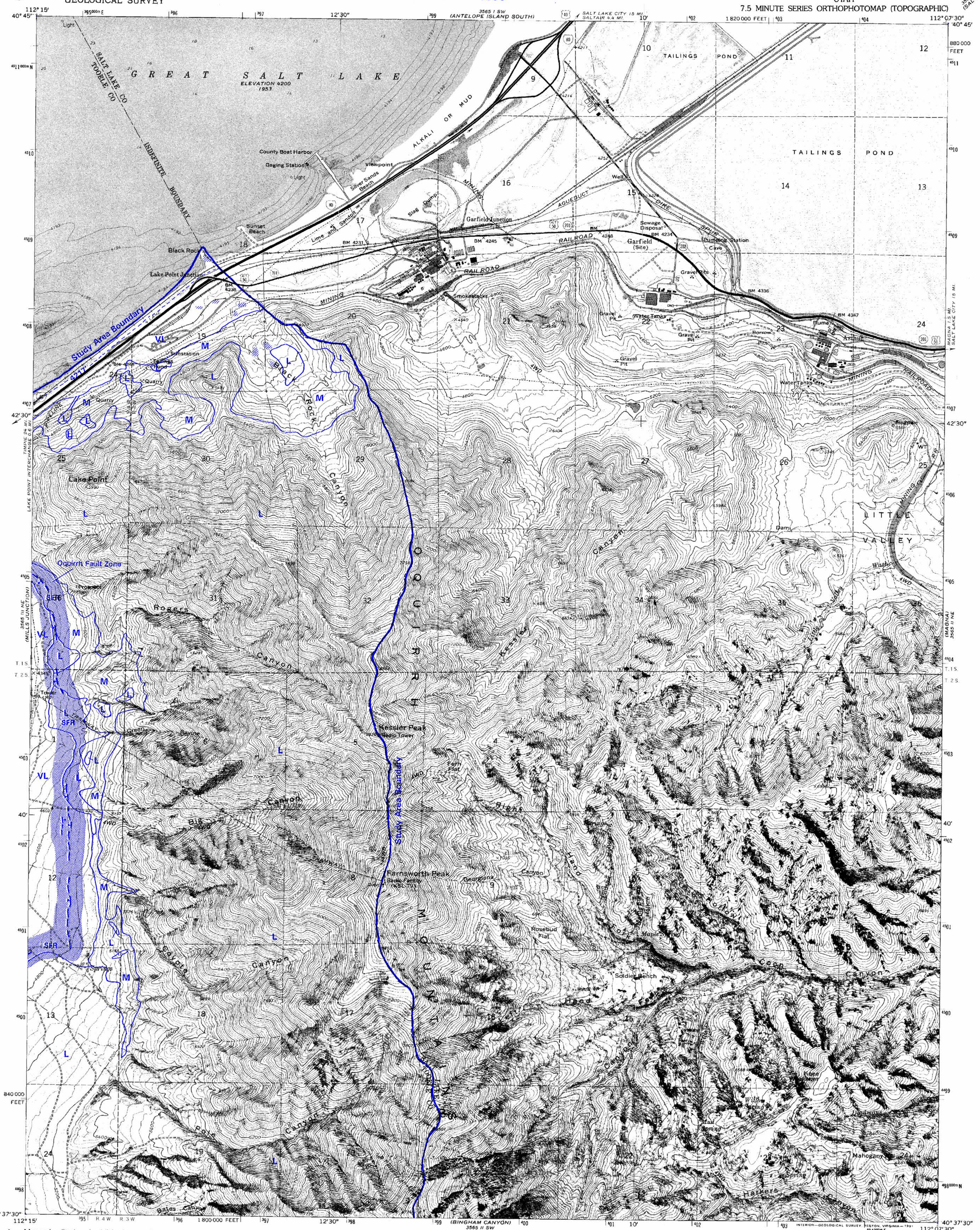
Landslide, surface-fault-rupture, and lake-flooding hazards, Farnsworth Peak quadrangle, Tooele County, Utah.

MAPPED AND COMPILED BY KIMM M. HARTY AND BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 1E
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

FARNSWORTH PEAK QUADRANGLE
UTAH
7.5 MINUTE SERIES ORTHOPHOTOMAP (TOPOGRAPHIC)



Mapped, edited, and published by the Geological Survey

Control by USGS and NOS/NOAA

Topography by photogrammetric methods from aerial photographs taken 1950. Field checked 1952. Revision and orthophotomosaic from aerial photographs taken 1971. Field checked 1972

Underwater contours by photogrammetric methods from aerial photographs taken 1966, 1969 and 1971-72
Soundings compiled from chart furnished by U.S. Naval Reserve

Projection and 10,000-foot grid ticks: Utah coordinate system, central zone (Lambert conformal conic)
1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue
The difference between 1927 North American Datum and North American Datum of 1983 (NAD 83) for 7.5 minute intersections is given in USGS Bulletin 1875. The NAD 83 is shown by dashed corner ticks

UTM GRID AND 1972 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 10-FOOT CONTOURS
NATIONAL GEODETIC VERTICAL DATUM OF 1929
SOUNDINGS IN FEET-DATUM IS LAKE ELEVATION 4200 FEET

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U.S. GEOLOGICAL SURVEY
DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

QUADRANGLE LOCATION

ROAD CLASSIFICATION
Primary highway, hard surface
Secondary highway, hard surface
Light-duty road, hard or improved surface
Unimproved road
Interstate Route U. S. Route State Route

FARNSWORTH PEAK, UTAH
40112-F2-OM-024
1972
DMA 3565 II NW-SERIES V897

EXPLANATION

Landslide susceptibility

- **H*** — High; includes existing landslides (crosshatched).
- **M*** — Moderate.
- **L** — Low.
- **VL** — Very low.

Surface fault rupture

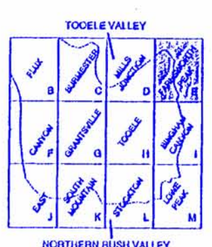
Main trace of active faults with evidence of possible Quaternary movement (within the past 1.6 million years). Dashed where inferred, bar and ball on downthrown side.

SFR * — Possible surface fault rupture.

Lake flooding

--4217'-- Boundary of the "Beneficial Development Area" (4217-foot [1285-m] contour). Areas below this elevation are subject to lake flooding and land use must be compatible with potential flood hazard.

* Special studies are recommended for certain land uses in areas of (1) high and moderate landslide susceptibility, and (2) possible surface fault rupture (see table 1).



Landslide hazards, North Willow Canyon quadrangle, Tooele County, Utah.

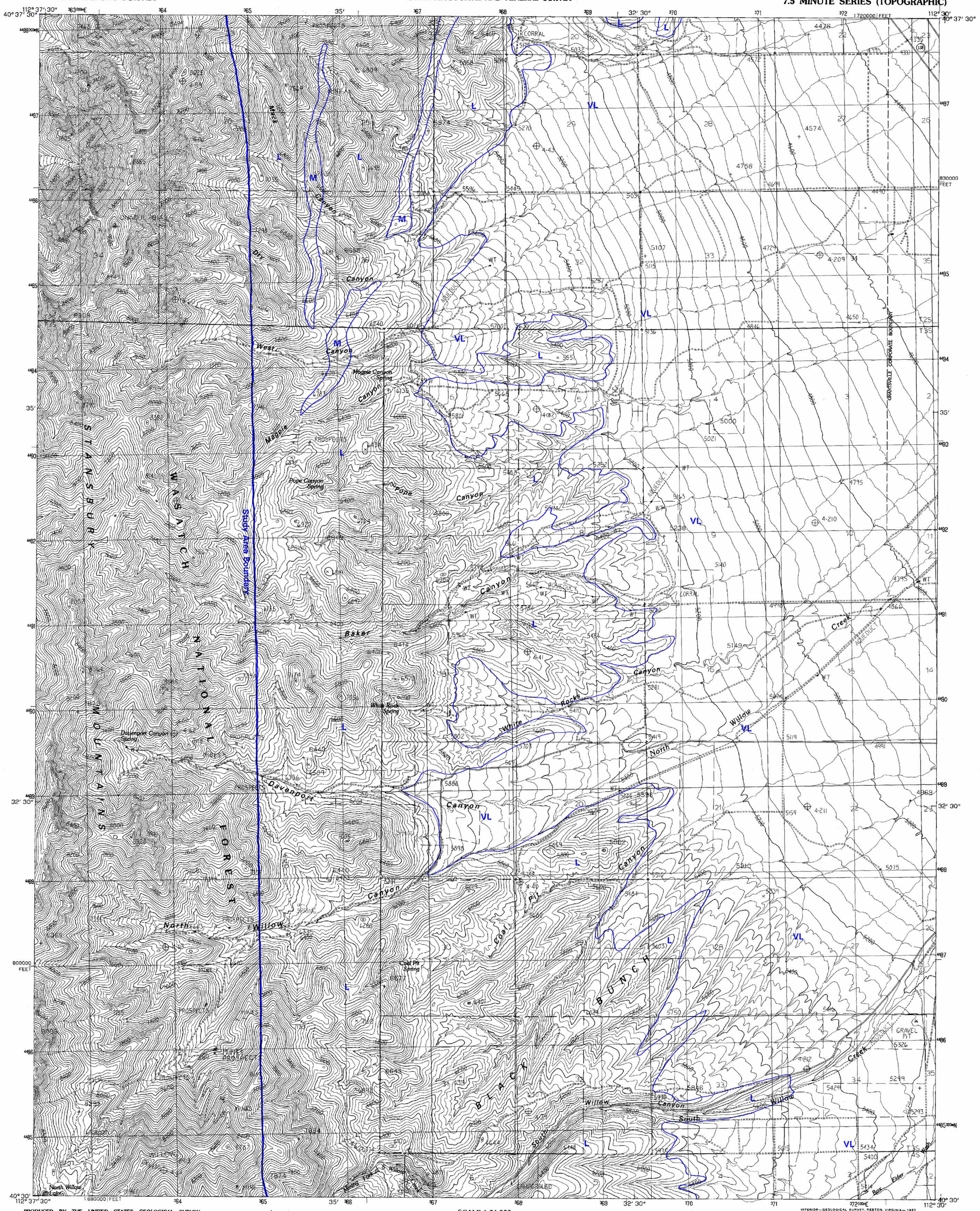
MAPPED BY KIMM M. HARTY
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 1F
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATE OF UTAH
UTAH GEOLOGICAL AND MINERAL SURVEY

NORTH WILLOW CANYON QUADRANGLE
UTAH–TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)



PRODUCED BY THE UNITED STATES GEOLOGICAL SURVEY
CONTROL BY ..... USGS, NOS/NOAA
COMPILED FROM AERIAL PHOTOGRAPHS TAKEN 1980
FIELD CHECKED ..... 1981 MAP EDITED 1985
PROJECTION ..... LAMBERT CONFORMAL CONIC
GRID: 1000-METER UNIVERSAL TRANSVERSE MERCATOR ..... ZONE 12
10,000-FOOT STATE GRID TICKS ..... UTAH, CENTRAL ZONE
UTM GRID DECLINATION ..... 1°01′ WEST
1985 MAGNETIC NORTH DECLINATION ..... 15° EAST
VERTICAL DATUM ..... NATIONAL GEODETIC VERTICAL DATUM OF 1929
HORIZONTAL DATUM ..... 1927 NORTH AMERICAN DATUM

To place on the predicted North American Datum of 1983, move the projection lines as shown by dashed corner ticks (10 meters north and 67 meters east)

There may be private inholdings within the boundaries of any Federal and State Reservations shown on this map

Where omitted, land lines have not been established

PROVISIONAL MAP
Produced from original manuscript drawings. Information shown as of date of field check. 2

NORTH

SCALE 1:24 000

1 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER

CONTOUR INTERVAL 40 FEET

UTAH

QUADRANGLE LOCATION

1	2	3	1 Timpie 2 Flux 3 Burmester 4 Salt Mountain 5 Grantsville 6 Deseret Peak West 7 Deseret Peak East 8 South Mountain
4		5	
6	7	8	

ADJOINING 7.5 QUADRANGLE NAMES

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U.S. GEOLOGICAL SURVEY, DENVER, COLORADO. 80225
OR RESTON, VIRGINIA 22092

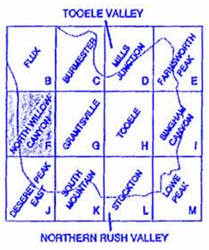
EXPLANATION

Landslide susceptibility

H*	High; includes existing landslides (crosshatched).
M*	Moderate.
L	Low.
VL	Very low.

* Special studies are recommended for certain land uses in areas of high and moderate landslide susceptibility (see table 1).

TOOELE VALLEY



NORTHERN RUSH VALLEY

ROAD LEGEND

Improved Road .....
Unimproved Road .....
Trail .....

Interstate Route U.S. Route State Route

NORTH WILLOW CANYON, UTAH

PROVISIONAL EDITION 1985

40112-E5-TF-024

Landslide hazards, Grantsville quadrangle, Tooele County, Utah.

MAPPED BY KIMM M. HARTY
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 1G
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

GRANTSVILLE QUADRANGLE
UTAH—TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)

Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Topography from planetable surveys 1923 and by Kelsh plotter from aerial photographs taken 1953. Field check 1955

Polyconic projection. 1927 North American datum
10,000-foot grid based on Utah coordinate system, central zone

1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue

Dashed land lines indicate approximate locations

APPROXIMATE MEAN DECLINATION, 1955

SCALE 1:24000

CONTOUR INTERVAL 10 FEET
DASHED LINES REPRESENT 5-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

ROAD CLASSIFICATION
Heavy-duty — Light-duty
Medium-duty — Unimproved dirt
U. S. Route — State Route

QUADRANGLE LOCATION

GRANTSVILLE, UTAH
N4030—W11222.5/7.5
1955

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

EXPLANATION

Landslide susceptibility

H*	High; includes existing landslides (crosshatched).
M*	Moderate.
L	Low.
VL	Very low.

* Special studies are recommended for certain land uses in areas of high and moderate landslide susceptibility (see table 1).

TOOELE VALLEY
NORTHERN RUSH VALLEY

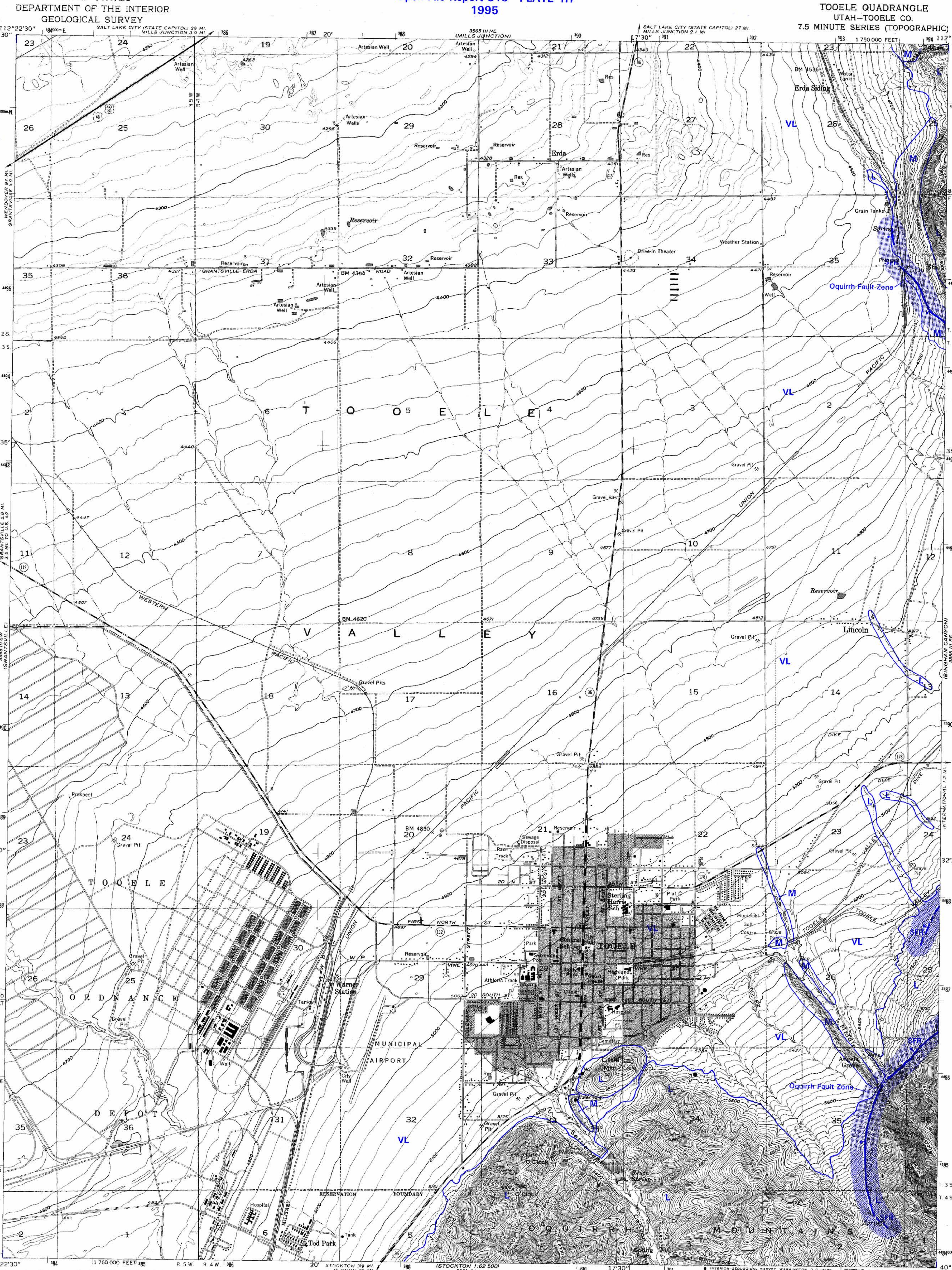
Landslide and surface-fault-rupture hazards, Tooele quadrangle, Tooele County, Utah.

MAPPED AND COMPILED BY KIMM M. HARTY AND BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 1H
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

TOOELE QUADRANGLE
UTAH—TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)



Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Culture and drainage compiled from aerial photographs taken 1953
Topography by planetable surveys 1923–24 and by photogrammetric methods
Contour revision and field check 1955

Polyconic projection. 1927 North American datum
10,000-foot grid based on Utah coordinate system, central zone

1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue

Red tint indicates areas in which only landmark buildings are shown

Dashed land lines indicate approximate locations

Revisions shown in purple compiled from aerial photographs taken 1969. This information not field checked

Purple tint indicates extension of urban areas

UTM GRID AND 1969 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

GN MN 0°51' 15 MILS 17° 302 MILS

SCALE 1:24 000

CONTOUR INTERVAL 20 FEET
DASHED LINES REPRESENT 5-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

QUADRANGLE LOCATION

ROAD CLASSIFICATION

Heavy-duty — Light-duty
Medium-duty — Unimproved dirt
U. S. Route — State Route

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

TOOELE, UTAH
N4030—W11215/7.5

1955
PHOTOREVISED 1969

AMS 3565 III SE—SERIES V897

EXPLANATION

Landslide susceptibility

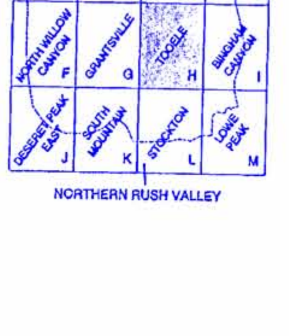
H*	High; includes existing landslides (crosshatched).
M*	Moderate.
L	Low.
VL	Very low.

Surface fault rupture

Main trace of active faults with evidence of possible Quaternary movement (within the past 1.6 million years). Dashed where inferred, bar and ball on downthrown side.

SFR * Possible surface fault rupture.

* Special studies are recommended for certain land uses in areas of (1) high and moderate landslide susceptibility, and (2) possible surface fault rupture (see table 1).



Landslide and surface-fault-rupture hazards, Bingham Canyon quadrangle, Tooele County, Utah.

MAPPED AND COMPILED BY KIMM M. HARTY AND BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 1I
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

BINGHAM CANYON QUADRANGLE
UTAH
7.5 MINUTE SERIES (TOPOGRAPHIC)

Mapped, edited, and published by the Geological Survey

Control by USGS and NOS/NOAA

Topography from aerial photographs by photogrammetric methods
Aerial photographs taken 1950. Field check 1952, except contour and track detail in open pit mine which is subject to frequent change

Polyconic projection. 1927 North American datum
10,000-foot grid based on Utah coordinate system, central zone

Dashed land lines indicate approximate locations

Unchecked elevations are shown in brown

1000-meter Universal Transverse Mercator grid ticks, zone 12, shown *in* blue

Revisions shown in purple compiled from aerial photographs taken 1969 and 1975. This information not field checked

UTM GRID AND 1975 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24000

CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

UTAH
QUADRANGLE LOCATION

ROAD CLASSIFICATION
Medium-duty — Light-duty
Unimproved dirt
State Route

BINGHAM CANYON, UTAH
N4030—W11207 5/7.5

1952
PHOTOREVISED 1969 AND 1975
AMS 3565 II SW—SERIES V897

TOOELE VALLEY

FLUX B	SUMMESTER C	MILLS JUNCTION D	FARNSWORTH PEAK E
NORTH WILLOW CANYON F	GRANTSVILLE G	TOOELE H	BINGHAM CANYON I
DESERET PEAK EAST J	SOUTH MOUNTAIN K	STOCKTON L	LONE PEAK M

NORTHERN RUSH VALLEY

EXPLANATION

Landslide susceptibility

H*	High; includes existing landslides (crosshatched).
M*	Moderate.
L	Low.
VL	Very low.

Surface fault rupture

Main trace of active faults with evidence of possible Quaternary movement (within the past 1.6 million years). Dashed where inferred, bar and ball on downthrown side.

SFR * Possible surface fault rupture.

* Special studies are recommended for certain land uses in areas of (1) high and moderate landslide susceptibility, and (2) possible surface fault rupture (see table 1).

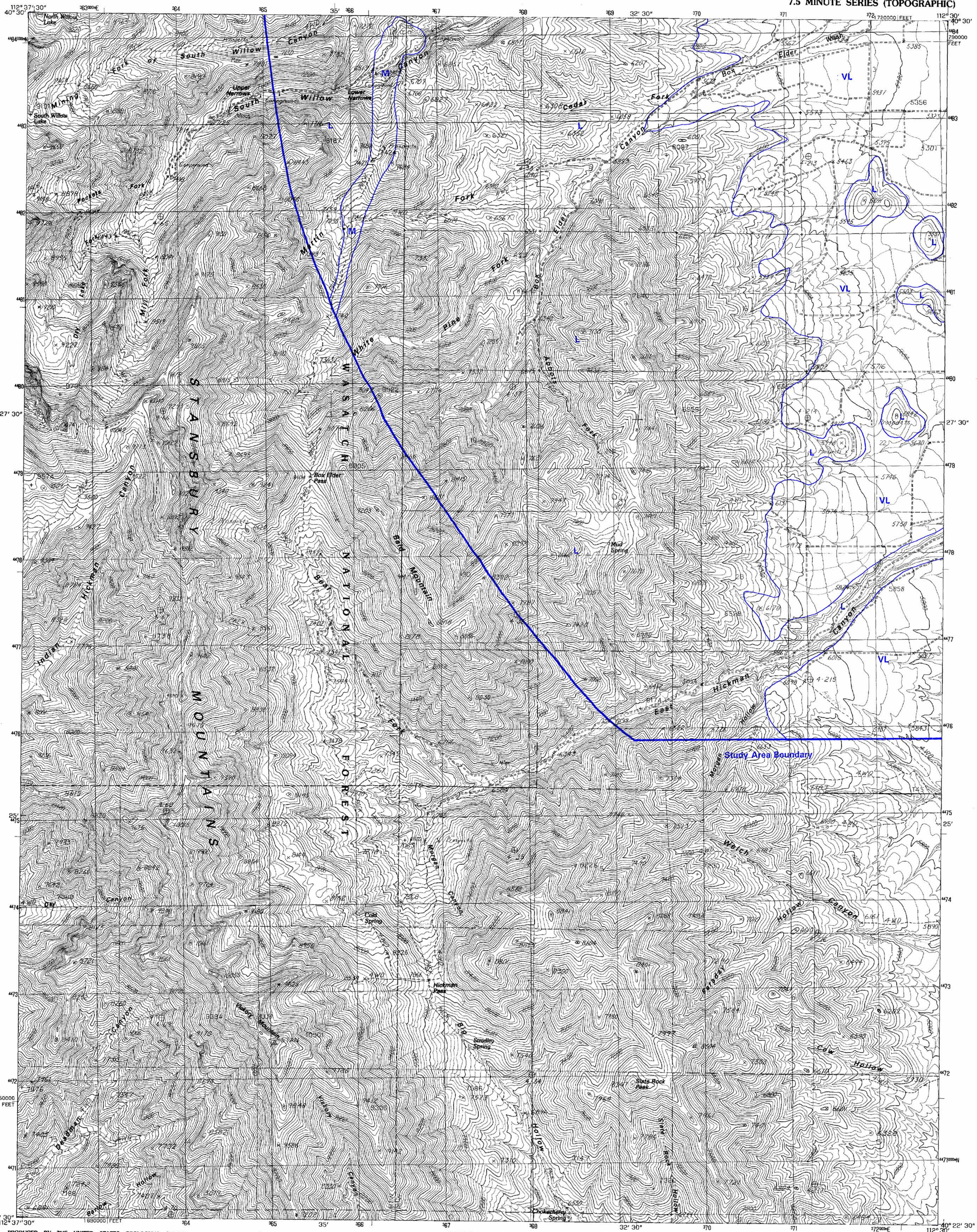
Landslide hazards, Deseret Peak East quadrangle, Tooele County, Utah.

MAPPED BY KIMM M. HARTY
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 1J
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

DESERET PEAK EAST QUADRANGLE
UTAH–TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)



PRODUCED BY THE UNITED STATES GEOLOGICAL SURVEY
CONTROL BY ..... USGS, NOS/NOAA
COMPILED FROM AERIAL PHOTOGRAPHS TAKEN 1980
FIELD CHECKED ..... 1981 MAP EDITED 1985
PROJECTION ..... LAMBERT CONFORMAL CONIC
GRID: 1000-METER UNIVERSAL TRANSVERSE MERCATOR ..... ZONE 12
10,000-FOOT STATE GRID TICKS ..... UTAH, CENTRAL ZONE
UTM GRID DECLINATION ..... 1°01' WEST
1985 MAGNETIC NORTH DECLINATION ..... 15° EAST
VERTICAL DATUM ..... NATIONAL GEODETIC VERTICAL DATUM OF 1929
HORIZONTAL DATUM ..... 1927 NORTH AMERICAN DATUM
To place on the predicted North American Datum of 1983, move the projection lines as shown by dashed corner ticks (10 meters north and 67 meters east)
There may be private inholdings within the boundaries of any Federal and State Reservations shown on this map
Where omitted, land lines have not been established

PROVISIONAL MAP
Produced from original manuscript drawings. Information shown as of date of field check. 2

SCALE 1:24 000

1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 KILOMETER

NORTH

CONTOUR INTERVAL 40 FEET

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U.S. GEOLOGICAL SURVEY, DENVER, COLORADO. 80225
OR RESTON, VIRGINIA 22092

UTAH
QUADRANGLE LOCATION

1	2	3	1 Salt Mountain 2 North Willow Canyon 3 Grantsville 4 Deseret Peak West 5 South Mountain 6 Terra 7 Johnson Pass 8 Saint John
4		5	
6	7	8	

ADJOINING 7.5 QUADRANGLE NAMES

EXPLANATION

Landslide susceptibility

H*	High; includes existing landslides (crosshatched).
M*	Moderate.
L	Low.
VL	Very low.

* Special studies are recommended for certain land uses in areas of high and moderate landslide susceptibility (see table 1).

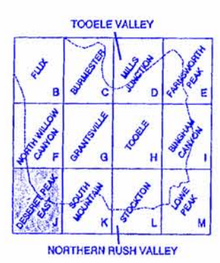
ROAD LEGEND

Improved Road .....
Unimproved Road .....
Trail .....
Interstate Route U.S. Route State Route

DESERET PEAK EAST, UTAH

PROVISIONAL EDITION 1985

40112-D5-TF-024



Landslide, surface-fault-rupture, lake-flooding, and ponding and sheet-flooding hazards, South Mountain quadrangle, Tooele County, Utah.

MAPPED AND COMPILED BY KIMM M. HARTY AND BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 1K
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

SOUTH MOUNTAIN QUADRANGLE
UTAH–TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)

3465 II SE (NORTH WILLOW CANYON)
3565 III SW (GRANTSVILLE)
3565 III SE (TOOELE)
3464 I NE (DESERET PEAK EAST)
3464 I SW (JOHNSON PASS)
3564 IV NW
3564 IV SW (SAINT JOHN)
3564 IV NE (STOCKTON)
3564 IV SE (OPHIR)

112°30' 112°22'30" 40°30' 27'30" 25' 40°22'30"
1 750 000 FEET 750 000 FEET
R 6 W R 5 W
T 4 S T 5 S

VL
L
M
SFR
PSF
4979'
Study Area Boundary
unnamed fault (offsets Pleistocene-age alluvial fans)

TOOELE ARMY DEPOT
SOUTH MOUNTAIN
TOOELE VALLEY
RUSH VALLEY
Lake Bonneville
Hickman Canyon
Hickman Creek
Watch Canyon
Cow Hollow
Bowery Creek
Elder Creek
Indian Hill
Gravel Pits
Gravel Pit
Spring
Well
Prospect
BM 4974
BM 4977
BM 5014
South 4901
6597 △ South
4997 △ Bill
Stockton
Lake
PSF
4WD
SAINT JOHN STA. 1.1 MI.
VERNON 21 MI.
FAIRFIELD 21 MI.
STOCKTON 1.5 MI.
BOUNDARY
CORPORATE
LANDING STRIP

Produced by the United States Geological Survey
Control by USGS and NOS/NOAA

Compiled from aerial photographs taken 1974. Revised from aerial photographs taken 1987 and other sources. Field checked 1988 Map edited 1993

1927 North American Datum (NAD 27). Projection and 10000-foot ticks: Utah Coordinate System, central zone (Lambert Conformal Conic)
Blue 1000-meter Universal Transverse Mercator ticks, zone 12

North American Datum of 1983 (NAD 83) is shown by dashed corner ticks. The values of the shift between NAD 27 and NAD 83 for 7.5-minute intersections are given in USGS Bulletin 1875

There may be private inholdings within the boundaries of the National or State reservations shown on this map

Fine red dashed lines indicate selected fence and field lines where generally visible on aerial photographs

GN MN 0°55' 16 MILS 14° 249 MILS
UTM GRID AND 1993 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000
1 MILE
7000 FEET
1 KILOMETER
CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 20-FOOT CONTOURS
NATIONAL GEODETIC VERTICAL DATUM OF 1929

UTAH
QUADRANGLE LOCATION

ROAD CLASSIFICATION
Primary highway, hard surface
Secondary highway, hard surface
Light-duty road, hard or improved surface
Unimproved road
Interstate Route U. S. Route State Route

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

SOUTH MOUNTAIN, UTAH
40112-D4-TF-024
1993
DMA 3564 IV NW–SERIES V897

TOOELE VALLEY
FLUX B | BURMESTER C | MILLS JUNCTION D | FARNSWORTH PEAK E
NORTH WILLOW CANYON F | GRANTSVILLE G | TOOELE H | SIMKINS CANYON I
DESERET PEAK EAST J | SOUTH MOUNTAIN K | STOCKTON L | LONE PEAK M
NORTHERN RUSH VALLEY

EXPLANATION

Landslide susceptibility

- H* — High; includes existing landslides (crosshatched).
- M* — Moderate.
- L — Low.
- VL — Very low.

Surface fault rupture

- Main trace of active faults with evidence of possible Quaternary movement (within the past 1.6 million years). Dashed where inferred, bar and ball on downthrown side.
- SFR * — Possible surface fault rupture.

Lake flooding, and ponding and sheet flooding

- ––4979'–– Measured historic high of Rush Lake (4,979-foot [1,518-m] contour). Areas below this elevation are subject to lake flooding and land use must be compatible with potential flood hazards.
- PSF * — Subject to ponding and sheet flooding.

* Special studies are recommended for certain land uses in areas of (1) high and moderate landslide susceptibility, (2) ponding and sheet flooding, and (3) possible surface fault rupture (see table 1).

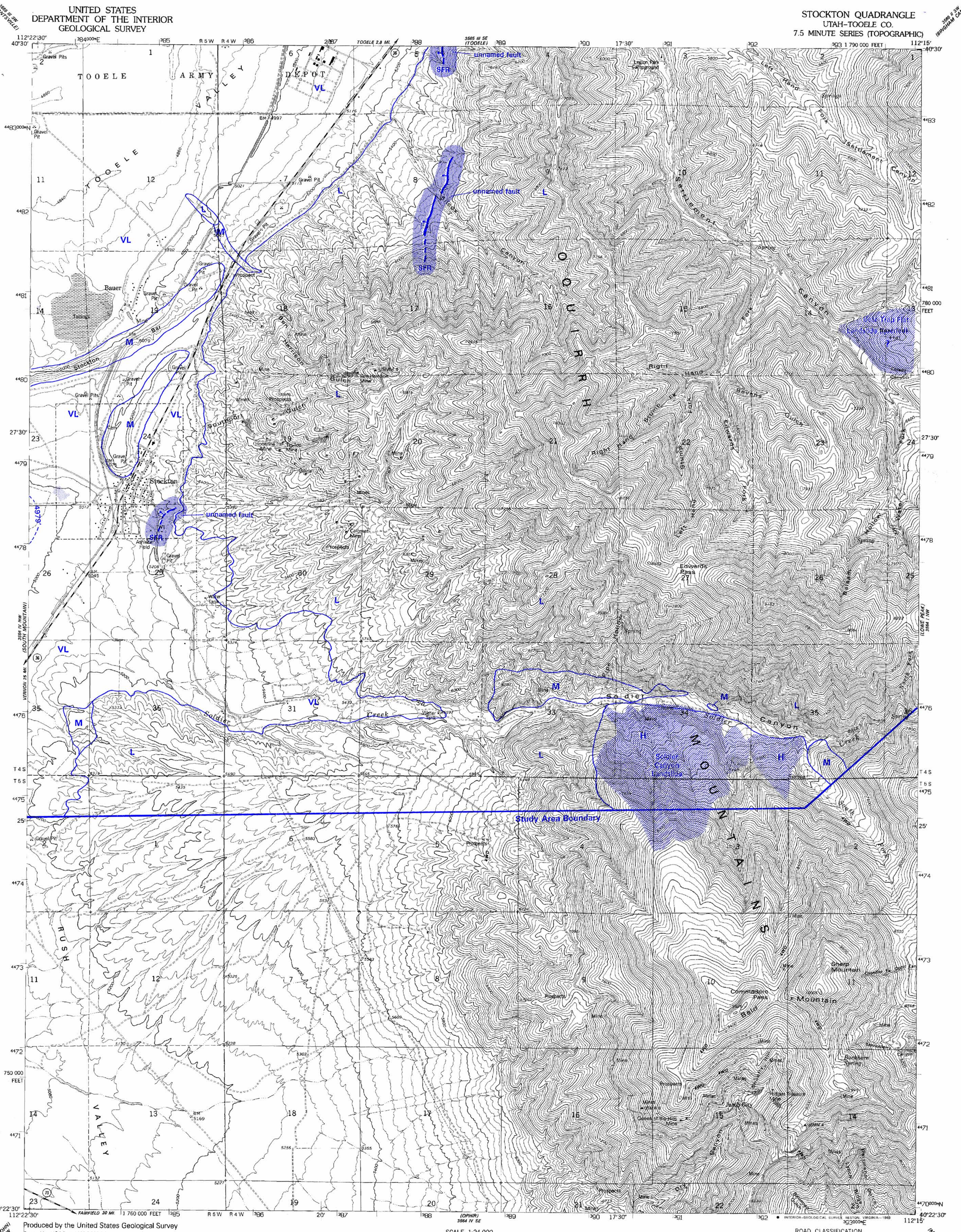
Landslide, surface-fault-rupture, and lake-flooding hazards, Stockton quadrangle, Tooele County, Utah.

MAPPED AND COMPILED BY KIMM M. HARTY AND BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 1L
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STOCKTON QUADRANGLE
UTAH–TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)



Produced by the United States Geological Survey
Control by USGS and NOS/NOAA

Compiled from aerial photographs taken 1974. Revised from aerial photographs taken 1987 and other sources. Field checked 1989
Map edited 1993

1927 North American Datum (NAD 27). Projection and 10 000-foot ticks: Utah Coordinate System, central zone (Lambert Conformal Conic)
Blue 1000-meter Universal Transverse Mercator ticks, zone 12

North American Datum of 1983 (NAD 83) is shown by dashed corner ticks. The values of the shift between NAD 27 and NAD 83 for 7.5-minute intersections are given in USGS Bulletin 1875

There may be private inholdings within the boundaries of the National or State reservations shown on this map

Fine red dashed lines indicate selected fence and field lines where generally visible on aerial photographs. This information is unchecked

UTM GRID AND 1993 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET
SUPPLEMENTARY CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

UTAH
QUADRANGLE LOCATION

ROAD CLASSIFICATION

Primary highway, hard surface
Secondary highway, hard surface
Light-duty road, hard or improved surface
Unimproved road
Interstate Route
U. S. Route
State Route

STOCKTON, UTAH
40112-D3-TF-024

1993

DMA 3564 IV NE–SERIES V897

TOOELE VALLEY

NORTHERN RUSH VALLEY

EXPLANATION

Landslide susceptibility

H*	High; includes existing landslides (crosshatched).
M*	Moderate.
L	Low.
VL	Very low.

Surface fault rupture

	Main trace of active faults with evidence of possible Quaternary movement (within the past 1.6 million years). Dashed where inferred, bar and ball on downthrown side.
SFR *	Possible surface fault rupture.

Lake flooding, and ponding and sheet flooding

--4979'--	Measured historic high of Rush Lake (4,979-foot [1,518-m] contour). Areas below this elevation are subject to lake flooding and land use must be compatible with potential flood hazards.

* Special studies are recommended for certain land uses in areas of (1) high and moderate landslide susceptibility, and (2) possible surface fault rupture (see table 1).

Landslide hazards, Lowe Peak quadrangle, Tooele County, Utah.

MAPPED BY KIMM M. HARTY
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 1M
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

LOWE PEAK QUADRANGLE
UTAH
7.5 MINUTE SERIES (TOPOGRAPHIC)

Study Area Boundary

Produced by the United States Geological Survey
Control by USGS and NOS/NOAA

Compiled from aerial photographs taken 1966. Revised from aerial photographs taken 1987. Field checked 1989. Map edited 1993

North American Datum of 1927 (NAD 27). Projection and 10 000-foot grid ticks: Utah Coordinate System, central zone (Lambert Conformal Conic). 1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue
The difference between NAD 27 and North American Datum of 1983 (NAD 83) for 7.5 minute intersections is given *in* USGS Bulletin 1875. The NAD 83 is shown by dashed corner ticks

UTM GRID AND 1993 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

ROAD CLASSIFICATION

Primary highway, hard surface
Secondary highway, hard surface
Light-duty road, hard or improved surface
Unimproved road
Interstate Route
U. S. Route
State Route

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U.S. GEOLOGICAL SURVEY
DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

QUADRANGLE LOCATION

LOWE PEAK, UTAH
40112-D2-TF-024
1993
DMA 3564 I NW–SERIES V897

EXPLANATION

Landslide susceptibility

H*	High; includes existing landslides (crosshatched).
M*	Moderate.
L	Low.
VL	Very low.
	Landslide scarps.

* Special studies are recommended for certain land uses in areas of high and moderate landslide susceptibility (see table 1).

Liquefaction susceptibility, West Desert Hazardous Industry Area, Tooele County, Utah.

COMPILED BY BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 2A
1995

N

Scale 1:50,000

0 1 2 3 4 5 KILOMETERS

0 1 2 3 MILES

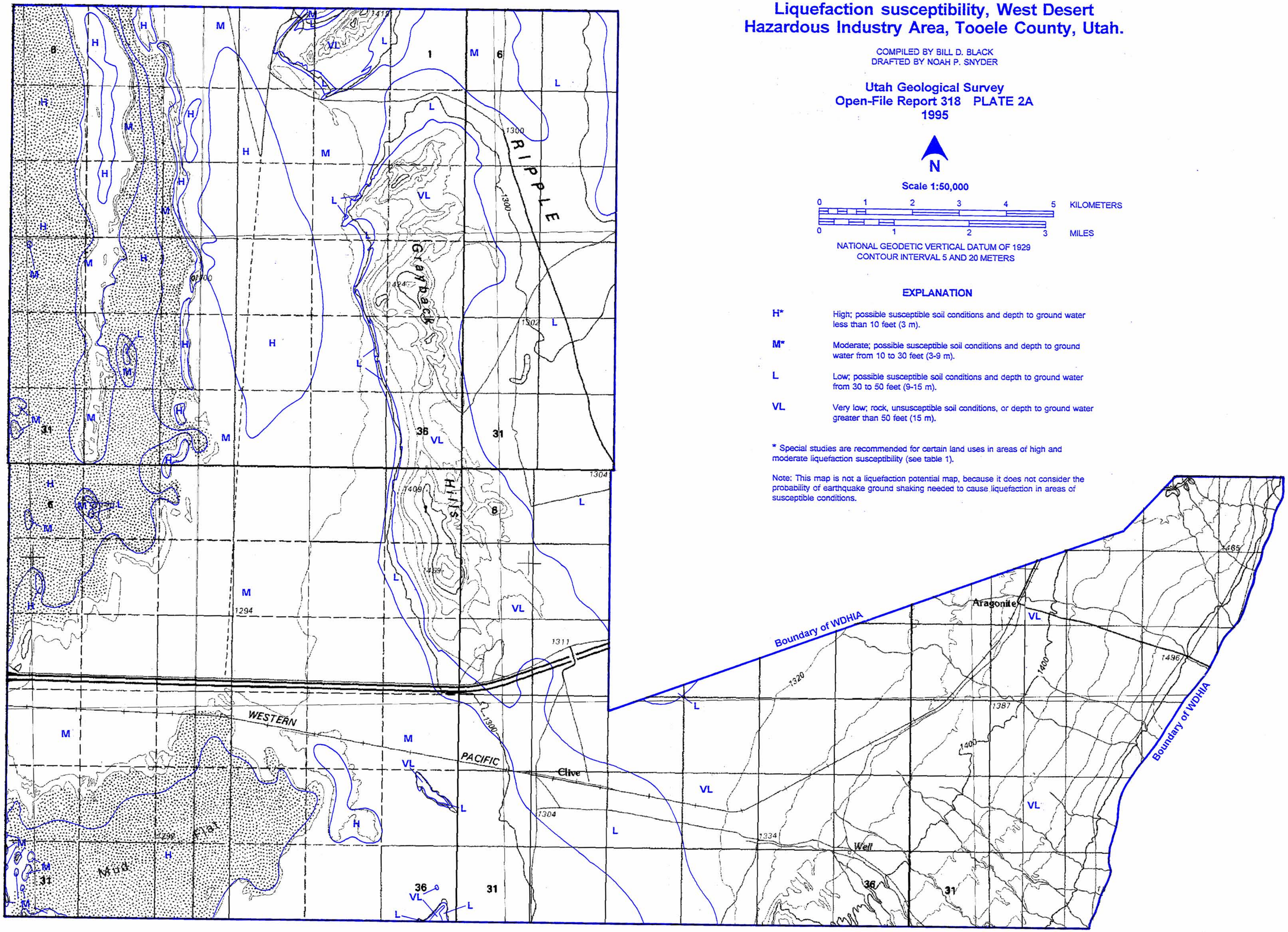
NATIONAL GEODETIC VERTICAL DATUM OF 1929
CONTOUR INTERVAL 5 AND 20 METERS

EXPLANATION

H*	High; possible susceptible soil conditions and depth to ground water less than 10 feet (3 m).
M*	Moderate; possible susceptible soil conditions and depth to ground water from 10 to 30 feet (3-9 m).
L	Low; possible susceptible soil conditions and depth to ground water from 30 to 50 feet (9-15 m).
VL	Very low; rock, unsusceptible soil conditions, or depth to ground water greater than 50 feet (15 m).

* Special studies are recommended for certain land uses in areas of high and moderate liquefaction susceptibility (see table 1).

Note: This map is not a liquefaction potential map, because it does not consider the probability of earthquake ground shaking needed to cause liquefaction in areas of susceptible conditions.



Base map from **BONNEVILLE SALT FLATS** and **TOOELE**, U.S.G.S. 30x60 minute topographic map series.

Liquefaction susceptibility, Flux quadrangle, Tooele County, Utah.

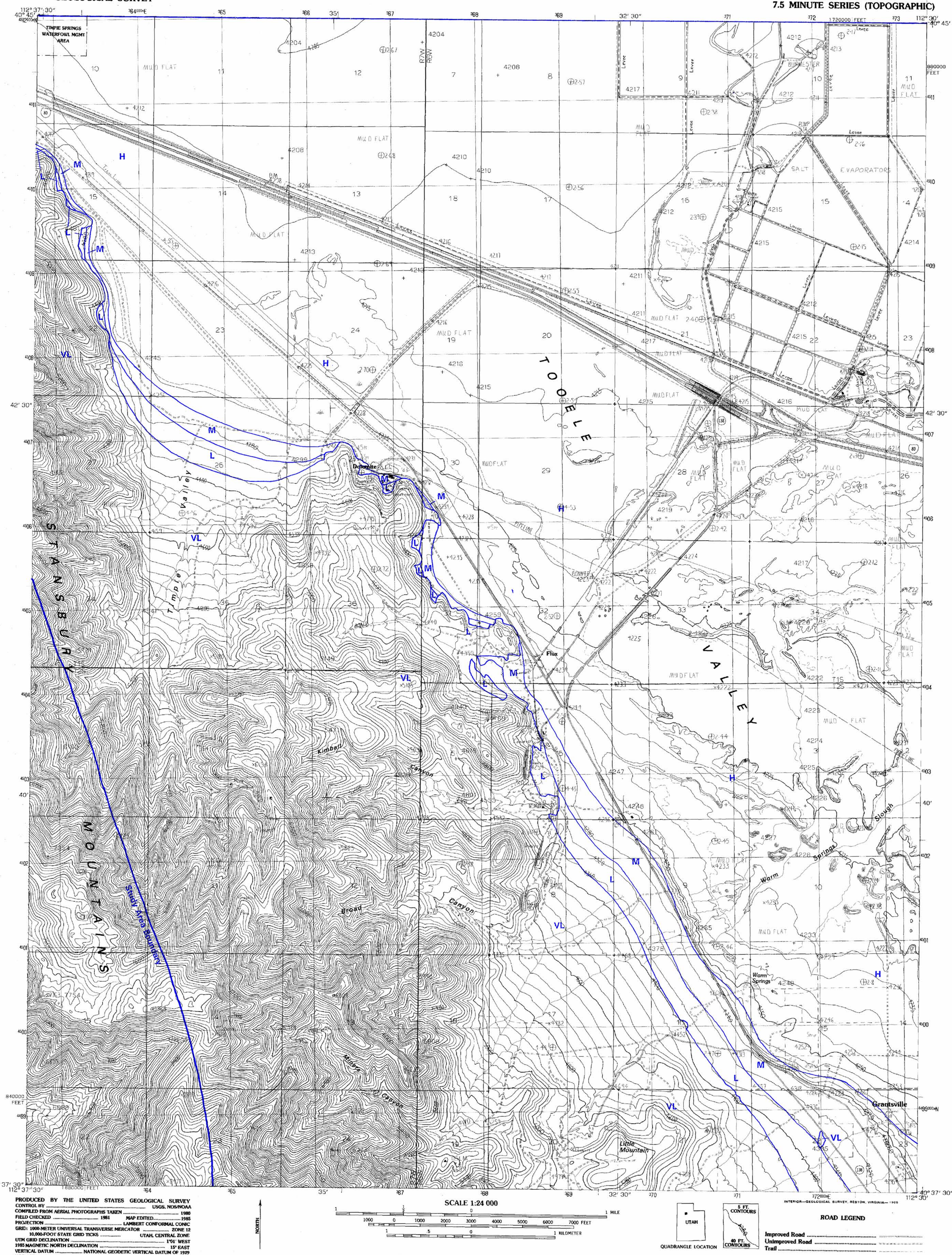
COMPILED BY BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 2B
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATE OF UTAH
UTAH GEOLOGICAL AND MINERAL SURVEY

FLUX QUADRANGLE
UTAH–TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)



PRODUCED BY THE UNITED STATES GEOLOGICAL SURVEY

CONTROL BY	USGS, NOS/NOAA
COMPILED FROM AERIAL PHOTOGRAPHS TAKEN	1980
FIELD CHECKED 1981	MAP EDITED 1985
PROJECTION	LAMBERT CONFORMAL CONIC
GRID: 1000-METER UNIVERSAL TRANSVERSE MERCATOR	ZONE 12
10,000-FOOT STATE GRID TICKS	UTAH, CENTRAL ZONE
UTM GRID DECLINATION	1°01' WEST
1985 MAGNETIC NORTH DECLINATION	15° EAST
VERTICAL DATUM	NATIONAL GEODETIC VERTICAL DATUM OF 1929
HORIZONTAL DATUM	1927 NORTH AMERICAN DATUM

To place on the predicted North American Datum of 1983, move the projection lines as shown by dashed corner ticks (10 meters north and 67 meters east)

There may be private inholdings within the boundaries of any Federal and State Reservations shown on this map

PROVISIONAL MAP
Produced from original manuscript drawings. Information shown as of date of field check. 2

SCALE 1:24 000

1 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER

NORTH

CONTOUR INTERVAL 5 AND 40 FEET

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U.S. GEOLOGICAL SURVEY, DENVER, COLORADO, 80225
OR RESTON, VIRGINIA 22092

UTAH
QUADRANGLE LOCATION

5 FT. CONTOURS
40 FT. CONTOURS

1	2	3	1 Poverty Point 2 Corral Canyon 3 Plug Peak 4 Timpie 5 Burmester 6 Salt Mountain 7 North Willow Canyon 8 Grantsville
4		5	
6	7	8	

ADJOINING 7.5 QUADRANGLE NAMES

ROAD LEGEND

Improved Road
Unimproved Road
Trail

Interstate Route U.S. Route State Route

EXPLANATION

H* High; possible susceptible soil conditions and depth to ground water less than 10 feet (3 m).

M* Moderate; possible susceptible soil conditions and depth to ground water from 10 to 30 feet (3-9 m).

L Low; possible susceptible soil conditions and depth to ground water from 30 to 50 feet (9-15 m).

VL Very low; rock, unsusceptible soil conditions, or depth to ground water greater than 50 feet (15 m).

* Special studies are recommended for certain land uses in areas of high and moderate liquefaction susceptibility (see table 1).

Note: This map is not a liquefaction potential map, because it does not consider the probability of earthquake ground shaking needed to cause liquefaction in areas of susceptible conditions.

FLUX, UTAH

PROVISIONAL EDITION 1985

40112-F5-TF-024

INTERIOR—GEOLOGICAL SURVEY, RESTON, VIRGINIA—1985

Liquefaction susceptibility, Burmester quadrangle, Tooele County, Utah.

COMPILED BY BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 2C
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

BURMESTER QUADRANGLE
UTAH—TOOELE CO.
7.5 MINUTE SERIES ORTHOPHOTOMAP (TOPOGRAPHIC)

Study Area Boundary

ALKALI OR MUD

GREAT SALT LAKE
ELEVATION 4200
1953

Burmester

Borrow Pits

Slough

Springs

Warm

Coyote Knolls

Willow Fields

Cooley's Slough

Blue Lakes

TOOELE VALLEY

WESTERN PACIFIC

BURMESTER

PIPELINE

ROAD

Flowing Well

Flowing Wells

Well

BM 4221

BM 4226

BM 4223

BM 4217

Creek

EVAPORATORS

SALT

(CORRAL CANYON) 3565 I SE

(PLUG PEAK SE) 3565 IV SE

(TIMPIE 1:62 500) 3465 II

(MILLS JUNCTION) 3565 III NE

(GRANTSVILLE) 3565 III SW

(TOOELE) 3565 III SE

WENDOVER 87 MI.
TIMPIE 9 MI.

6 MI. TO UTAH 36
SALT LAKE CITY 28 MI.

Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Planimetry by photogrammetric methods from aerial photographs taken 1953. Topography by planetable surveys 1923 and 1955
Revision and orthophotomosaic from aerial photographs taken 1971
Field checked 1972

Underwater contours by photogrammetric methods from aerial photographs taken 1966, 1969, and 1971–72

Projection and 10,000-foot grid ticks: Utah coordinate system, central zone (Lambert conformal conic)
1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue. 1927 North American datum

UTM GRID AND 1972 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 5 FEET
DATUM IS MEAN SEA LEVEL

ROAD CLASSIFICATION

Primary highway, hard surface
Secondary highway, hard surface
Light-duty road, hard or improved surface
Unimproved road
Interstate Route
U. S. Route
State Route

UTAH
QUADRANGLE LOCATION

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR WASHINGTON, D. C. 20242
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

BURMESTER, UTAH
N4037.5—W11222.5/7.5

1972

AMS 3565 III NW—SERIES V8970

EXPLANATION

H* High; possible susceptible soil conditions and depth to ground water less than 10 feet (3 m).

M* Moderate; possible susceptible soil conditions and depth to ground water from 10 to 30 feet (3-9 m).

L Low; possible susceptible soil conditions and depth to ground water from 30 to 50 feet (9-15 m).

VL Very low; rock, unsusceptible soil conditions, or depth to ground water greater than 50 feet (15 m).

* Special studies are recommended for certain land uses in areas of high and moderate liquefaction susceptibility (see table 1).

Note: This map is not a liquefaction potential map, because it does not consider the probability of earthquake ground shaking needed to cause liquefaction in areas of susceptible conditions.

TOOELE VALLEY

NORTHERN RUSH VALLEY

Liquefaction susceptibility, Mills Junction quadrangle, Tooele County, Utah.

COMPILED BY BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 2D
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

MILLS JUNCTION QUADRANGLE
UTAH—TOOELE CO.
7.5 MINUTE SERIES ORTHOPHOTOMAP (TOPOGRAPHIC)

3565 IV SW (PLUG PEAK) — 3565 IV SE (PLUG PEAK SE) — 3565 I SW (ANTELOPE ISLAND SOUTH)

112° 22′30″ — 385 000m E. — 386 — 387 — 20′ — 388 — 390 — 17′30″ — 392 — 393 — 1 790 000 FEET — 394 — 112° 15′
40° 45′ — 4511 000m N. — 880 000 FEET — 4511

G R E A T S A L T L A K E

ELEVATION 4200
1953

Study Area Boundary

ALKALI OR MUD
SALT EVAPORATORS
WESTERN PACIFIC
ALKALI OR MUD
SALT EVAPORATORS
SALT EVAPORATORS
ALKALI OR MUD
ALKALI OR MUD
T O O E L E V A L L E Y

H
M
L
VL

Lago
Lake Point
Lake Point Cem.
Adobe Rock Historical Marker
Mills Junction
Stansbury Lake
Golf Course
Mill Pond
Flowing Well
Drill Hole
Promise Well
Sixmile Creek
JEEP TRAIL
2 LANE
AQUEDUCT
IRRIGATION
PIPELINE
UNION PACIFIC
BM 4263
BM 4445
BM 4496
BM 4378
Borrow Pit

SALTAIR 9 MI. SALT LAKE CITY 21 MI.
WENDOVER 94 MI. TIMPIE 16 MI.
(BURMESTER) 3565 III NW
(FARNSWORTH PEAK) 3565 II NW
(BINGHAM CANYON) 3565 II SW
(GRANTSVILLE) 3565 III SW

T. 1 S.
T. 2 S.
R. 5 W.
R. 4 W.

4511 — 4510 — 4509 — 4508 — 42′30″ — 4507 — 4506 — 4505 — 4504 — 40′ — 4502 — 4501 — 4500 — 840 000 FEET — 4499 — 4498 — 40° 37′30″

112° 22′30″ — 1 760 000 FEET — 385 — GRANTSVILLE 7 MI — 386 — 387 — 20′ — 388 — (TOOELE) 3565 III SE — 390 — 17′30″ — TOOELE 6 MI. — 392 — 393 — 394 000m E. — 112° 15′

INTERIOR-GEOLOGICAL SURVEY, RESTON, VIRGINIA—1974

Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Topography by photogrammetric methods from aerial photographs taken 1953 and by planetable surveys 1923–24 and 1955
Revision and orthophotomosaic from aerial photographs taken 1971
Field checked 1972

Underwater contours by photogrammetric methods from aerial photographs taken 1966, 1969, and 1971–72. Soundings compiled from chart furnished by U.S. Naval Reserve

Projection and 10,000-foot grid ticks: Utah coordinate system, central zone (Lambert conformal ic)
1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue. 1927 North American datum

GN — MN — 0°51′ 15 MILS — 16½° 293 MILS
UTM GRID AND 1972 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000
1 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER

CONTOUR INTERVAL 10 FEET
DOTTED LINES REPRESENT 5-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL
SOUNDINGS IN FEET—DATUM IS LAKE ELEVATION 4200 FEET

UTAH
QUADRANGLE LOCATION

ROAD CLASSIFICATION
Primary highway, hard surface
Secondary highway, hard surface
Light-duty road, hard or improved surface
Unimproved road
Interstate Route — U. S. Route — State Route

MILLS JUNCTION, UTAH
N4037.5—W11215/7.5

1972

AMS 3565 III NE SERIES V8970

TOOELE VALLEY
FLUX B — BURMESTER C — MILLS JUNCTION D — FARNSWORTH PEAK E
MEADOW-REDDISH CANYON F — GRANTSVILLE G — TOOELE H — BINGHAM CANYON I
DROWNED PEAK EAST J — SOUTH MOUNTAIN K — STOCKTON L — LOOKE PEAK M
NORTHERN RUSH VALLEY

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY
DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

EXPLANATION

H* — High; possible susceptible soil conditions and depth to ground water less than 10 feet (3 m).

M* — Moderate; possible susceptible soil conditions and depth to ground water from 10 to 30 feet (3-9 m).

L — Low; possible susceptible soil conditions and depth to ground water from 30 to 50 feet (9-15 m).

VL — Very low; rock, unsusceptible soil conditions, or depth to ground water greater than 50 feet (15 m).

* Special studies are recommended for certain land uses in areas of high and moderate liquefaction susceptibility (see table 1).

Note: This map is not a liquefaction potential map, because it does not consider the probability of earthquake ground shaking needed to cause liquefaction in areas of susceptible conditions.

ISBN 0-7044-0407-2

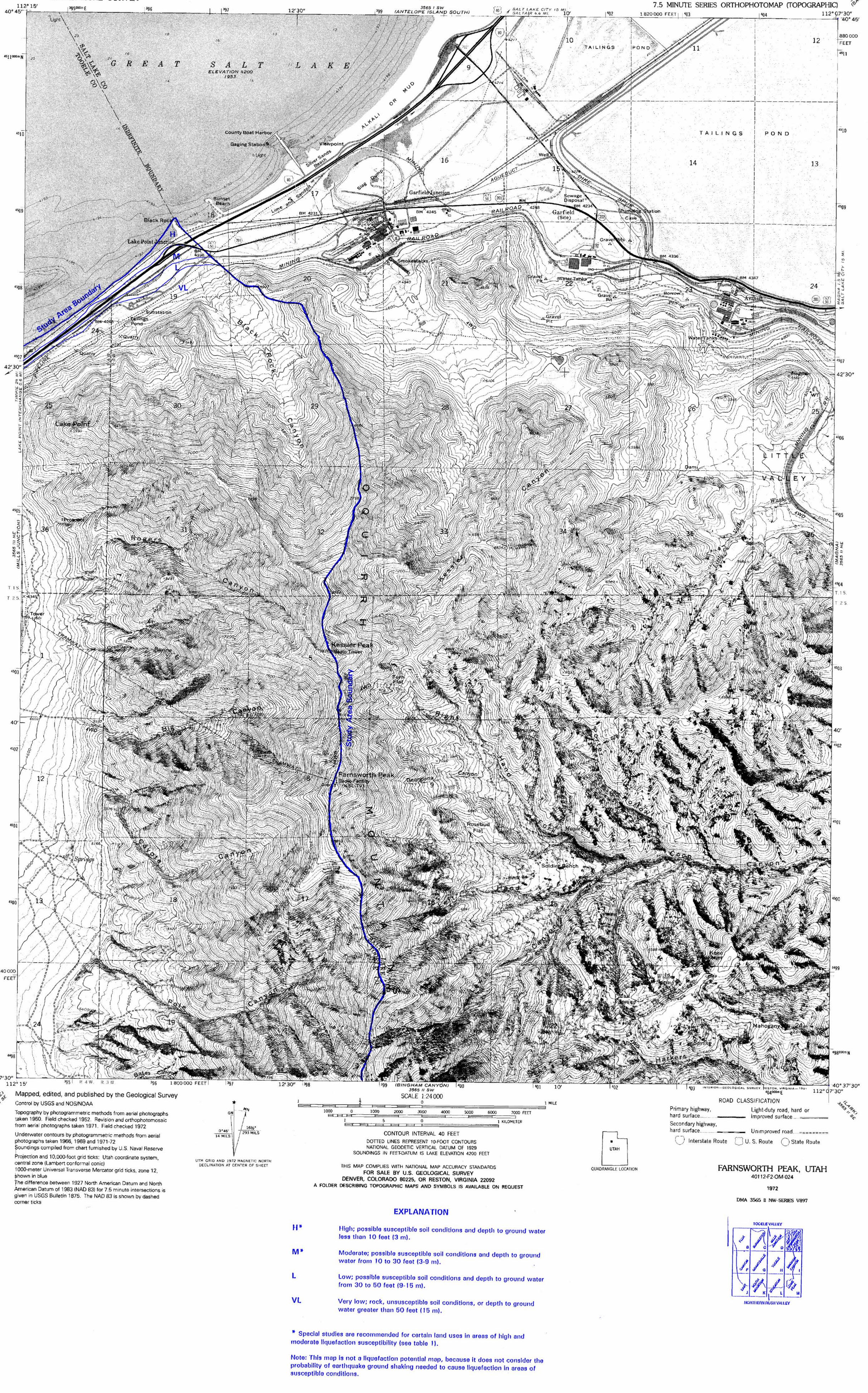
Liquefaction susceptibility, Farnsworth Peak quadrangle, Tooele County, Utah.

COMPILED BY BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 2E
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

FARNSWORTH PEAK QUADRANGLE
UTAH
7.5 MINUTE SERIES ORTHOPHOTOMAP (TOPOGRAPHIC)



Mapped, edited, and published by the Geological Survey

Control by USGS and NOS/NOAA

Topography by photogrammetric methods from aerial photographs taken 1950. Field checked 1952. Revision and orthophotomosaic from aerial photographs taken 1971. Field checked 1972

Underwater contours by photogrammetric methods from aerial photographs taken 1966, 1969 and 1971-72
Soundings compiled from chart furnished by U.S. Naval Reserve

Projection and 10,000-foot grid ticks: Utah coordinate system, central zone (Lambert conformal conic)
1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue
The difference between 1927 North American Datum and North American Datum of 1983 (NAD 83) for 7.5 minute intersections is given in USGS Bulletin 1875. The NAD 83 is shown by dashed corner ticks

UTM GRID AND 1972 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 KILOMETER

CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 10-FOOT CONTOURS
NATIONAL GEODETIC VERTICAL DATUM OF 1929
SOUNDINGS IN FEET-DATUM IS LAKE ELEVATION 4200 FEET

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U.S. GEOLOGICAL SURVEY
DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

QUADRANGLE LOCATION

ROAD CLASSIFICATION

Primary highway, hard surface
Secondary highway, hard surface
Light-duty road, hard or improved surface
Unimproved road
Interstate Route
U. S. Route
State Route

FARNSWORTH PEAK, UTAH
40112-F2-OM-024

1972

DMA 3565 II NW-SERIES V897

EXPLANATION

H* — High; possible susceptible soil conditions and depth to ground water less than 10 feet (3 m).

M* — Moderate; possible susceptible soil conditions and depth to ground water from 10 to 30 feet (3-9 m).

L — Low; possible susceptible soil conditions and depth to ground water from 30 to 50 feet (9-15 m).

VL — Very low; rock, unsusceptible soil conditions, or depth to ground water greater than 50 feet (15 m).

* Special studies are recommended for certain land uses in areas of high and moderate liquefaction susceptibility (see table 1).

Note: This map is not a liquefaction potential map, because it does not consider the probability of earthquake ground shaking needed to cause liquefaction in areas of susceptible conditions.

Liquefaction susceptibility, North Willow Canyon quadrangle, Tooele County, Utah.

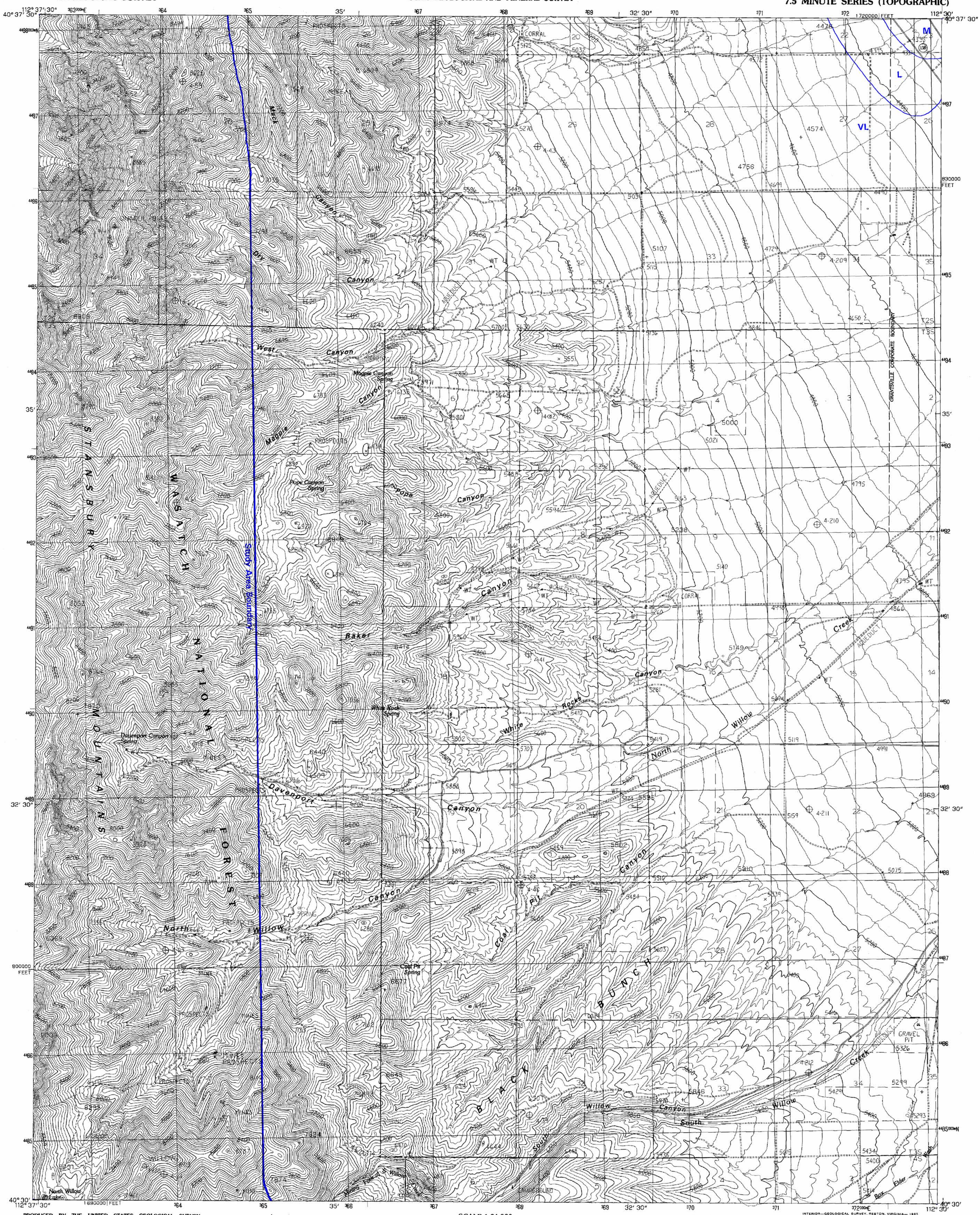
COMPILED BY BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 2F
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATE OF UTAH
UTAH GEOLOGICAL AND MINERAL SURVEY

NORTH WILLOW CANYON QUADRANGLE
UTAH–TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)



PRODUCED BY THE UNITED STATES GEOLOGICAL SURVEY
CONTROL BY ..... USGS, NOS/NOAA
COMPILED FROM AERIAL PHOTOGRAPHS TAKEN 1980
FIELD CHECKED ..... 1981 MAP EDITED 1985
PROJECTION ..... LAMBERT CONFORMAL CONIC
GRID: 1000-METER UNIVERSAL TRANSVERSE MERCATOR ..... ZONE 12
10,000-FOOT STATE GRID TICKS ..... UTAH, CENTRAL ZONE
UTM GRID DECLINATION ..... 1°01' WEST
1985 MAGNETIC NORTH DECLINATION ..... 15° EAST
VERTICAL DATUM ..... NATIONAL GEODETIC VERTICAL DATUM OF 1929
HORIZONTAL DATUM ..... 1927 NORTH AMERICAN DATUM

To place on the predicted North American Datum of 1983, move the projection lines as shown by dashed corner ticks (10 meters north and 67 meters east)

There may be private inholdings within the boundaries of any Federal and State Reservations shown on this map

Where omitted, land lines have not been established

NORTH

PROVISIONAL MAP
Produced from original manuscript drawings. Information shown as of date of field check. 2

SCALE 1:24 000

1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 KILOMETER

CONTOUR INTERVAL 40 FEET

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U.S. GEOLOGICAL SURVEY, DENVER, COLORADO. 80225
OR RESTON, VIRGINIA 22092

EXPLANATION

H* High; possible susceptible soil conditions and depth to ground water less than 10 feet (3 m).

M* Moderate; possible susceptible soil conditions and depth to ground water from 10 to 30 feet (3-9 m).

L Low; possible susceptible soil conditions and depth to ground water from 30 to 50 feet (9-15 m).

VL Very low; rock, unsusceptible soil conditions, or depth to ground water greater than 50 feet (15 m).

* Special studies are recommended for certain land uses in areas of high and moderate liquefaction susceptibility (see table 1).

Note: This map is not a liquefaction potential map, because it does not consider the probability of earthquake ground shaking needed to cause liquefaction in areas of susceptible conditions.

QUADRANGLE LOCATION

1	2	3	1 Timple 2 Flux 3 Burmester 4 Salt Mountain 5 Grantsville 6 Deseret Peak West 7 Deseret Peak East 8 South Mountain
4		5	
6	7	8	

ADJOINING 7.5 QUADRANGLE NAMES

INTERIOR—GEOLOGICAL SURVEY, RESTON, VIRGINIA— 1985

ROAD LEGEND

Improved Road .....
Unimproved Road .....
Trail .....

Interstate Route U.S. Route State Route

NORTH WILLOW CANYON, UTAH

PROVISIONAL EDITION 1985

40112-E5-TF-024

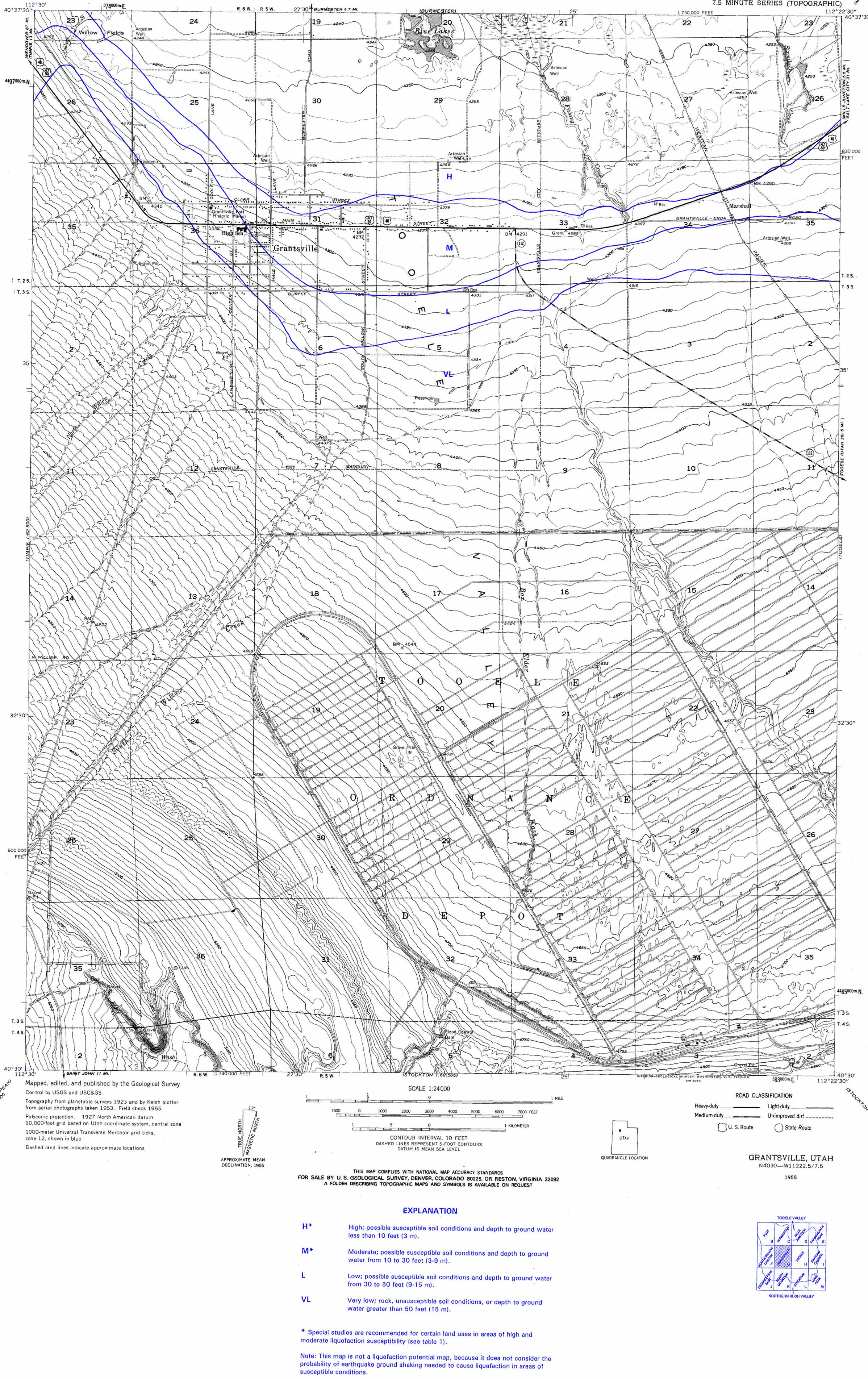
Liquefaction susceptibility, Grantsville quadrangle, Tooele County, Utah.

COMPILED BY BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 2G
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

GRANTSVILLE QUADRANGLE
UTAH—TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)



Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Topography from planetable surveys 1923 and by Kelsh plotter from aerial photographs taken 1953. Field check 1955

Polyconic projection. 1927 North American datum
10,000-foot grid based on Utah coordinate system, central zone

1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue

Dashed land lines indicate approximate locations

APPROXIMATE MEAN DECLINATION, 1955

SCALE 1:24000

CONTOUR INTERVAL 10 FEET
DASHED LINES REPRESENT 5-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

ROAD CLASSIFICATION

Heavy-duty — Light-duty
Medium-duty — Unimproved dirt
U. S. Route — State Route

QUADRANGLE LOCATION

GRANTSVILLE, UTAH
N4030—W11222.5/7.5

1955

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

EXPLANATION

H*	High; possible susceptible soil conditions and depth to ground water less than 10 feet (3 m).
M*	Moderate; possible susceptible soil conditions and depth to ground water from 10 to 30 feet (3-9 m).
L	Low; possible susceptible soil conditions and depth to ground water from 30 to 50 feet (9-15 m).
VL	Very low; rock, unsusceptible soil conditions, or depth to ground water greater than 50 feet (15 m).

* Special studies are recommended for certain land uses in areas of high and moderate liquefaction susceptibility (see table 1).

Note: This map is not a liquefaction potential map, because it does not consider the probability of earthquake ground shaking needed to cause liquefaction in areas of susceptible conditions.

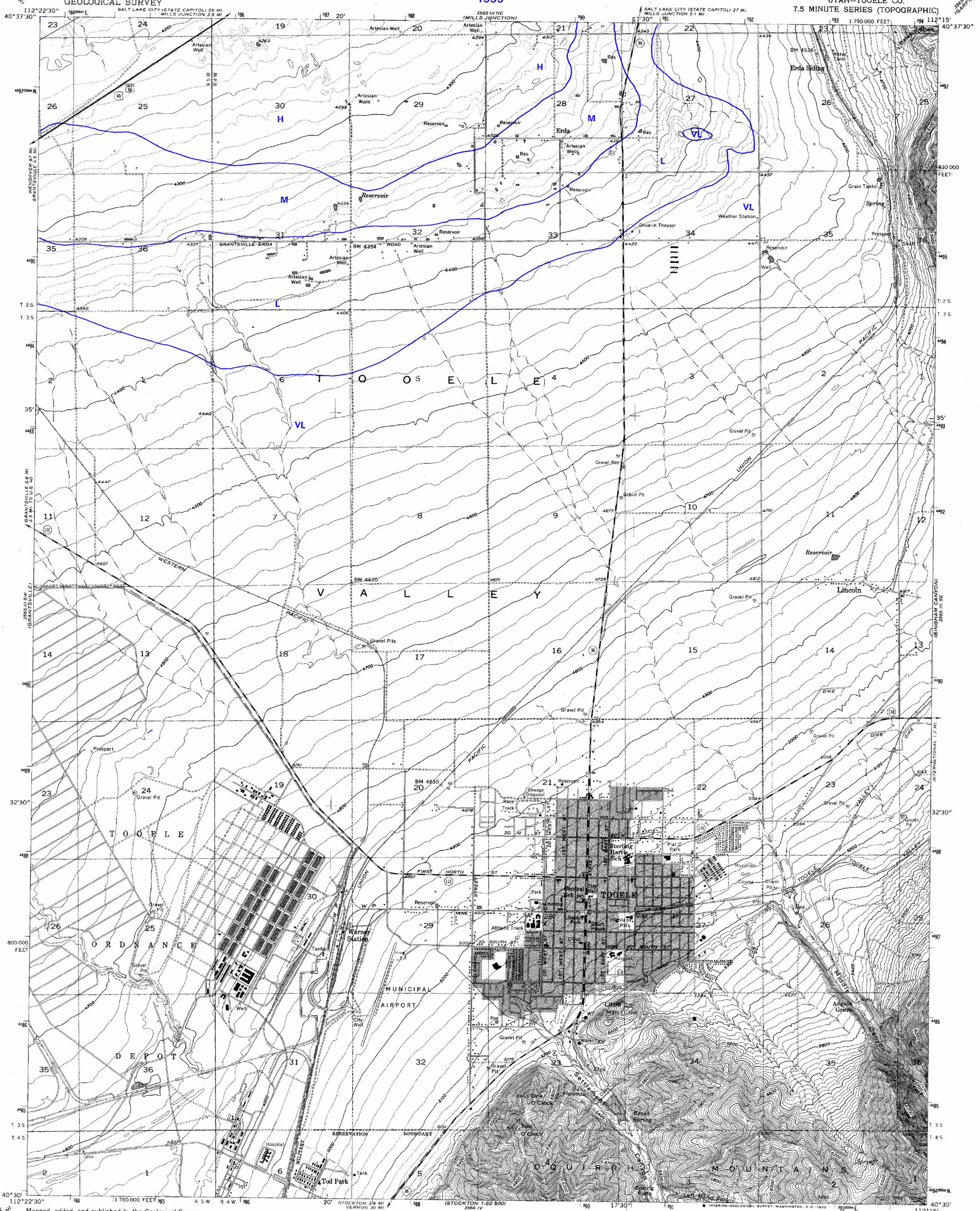
Liquefaction susceptibility, Tooele quadrangle, Tooele County, Utah.

COMPILED BY BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 2H
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

TOOELE QUADRANGLE
UTAH—TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)



Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Culture and drainage compiled from aerial photographs taken 1953
Topography by planetable surveys 1923–24 and by photogrammetric methods
Contour revision and field check 1955

Polyconic projection. 1927 North American datum
10,000-foot grid based on Utah coordinate system, central zone

1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue

Red tint indicates areas in which only landmark buildings are shown

Dashed land lines indicate approximate locations

Revisions shown in purple compiled from aerial photographs taken 1969. This information not field checked

Purple tint indicates extension of urban areas

GN MN 0°51' 15 MILS 17° 302 MILS
UTM GRID AND 1969 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24000

1 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET
DASHED LINES REPRESENT 5-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

ROAD CLASSIFICATION

Heavy-duty	Light-duty
Medium-duty	Unimproved dirt
U. S. Route	State Route

UTAH
QUADRANGLE LOCATION

TOOELE, UTAH
N4030—W11215/7.5

1955
PHOTOREVISED 1969

AMS 3565 III SE—SERIES V897

TOOELE VALLEY
FLUX · BURMESTER · MILLS JUNCTION · FARNSWORTH PEAK
NORTH WILLOW CANYON · GRANTSVILLE · TOOELE · BINGHAM CANYON
DESERET PEAK EAST · SOUTH MOUNTAIN · STOCKTON · LOWE PEAK
NORTHERN RUSH VALLEY

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

EXPLANATION

H* — High; possible susceptible soil conditions and depth to ground water less than 10 feet (3 m).

M* — Moderate; possible susceptible soil conditions and depth to ground water from 10 to 30 feet (3-9 m).

L — Low; possible susceptible soil conditions and depth to ground water from 30 to 50 feet (9-15 m).

VL — Very low; rock, unsusceptible soil conditions, or depth to ground water greater than 50 feet (15 m).

* Special studies are recommended for certain land uses in areas of high and moderate liquefaction susceptibility (see table 1).

Note: This map is not a liquefaction potential map, because it does not consider the probability of earthquake ground shaking needed to cause liquefaction in areas of susceptible conditions.

Liquefaction susceptibility, South Mountain quadrangle, Tooele County, Utah.

COMPILED BY BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 2K
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

SOUTH MOUNTAIN QUADRANGLE
UTAH–TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)

Study Area Boundary

VL
L
M
H
M
F
VL

Produced by the United States Geological Survey
Control by USGS and NOS/NOAA

Compiled from aerial photographs taken 1974. Revised from aerial photographs taken 1987 and other sources. Field checked 1988
Map edited 1993

1927 North American Datum (NAD 27). Projection and 10000-foot ticks: Utah Coordinate System, central zone (Lambert Conformal Conic)
Blue 1000-meter Universal Transverse Mercator ticks, zone 12

North American Datum of 1983 (NAD 83) is shown by dashed corner ticks. The values of the shift between NAD 27 and NAD 83 for 7.5-minute intersections are given in USGS Bulletin 1875

There may be private inholdings within the boundaries of the National or State reservations shown on this map

Fine red dashed lines indicate selected fence and field lines where generally visible on aerial photographs

UTM GRID AND 1993 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 20-FOOT CONTOURS
NATIONAL GEODETIC VERTICAL DATUM OF 1929

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

UTAH
QUADRANGLE LOCATION

ROAD CLASSIFICATION

Primary highway, hard surface
Secondary highway, hard surface
Light-duty road, hard or improved surface
Unimproved road
Interstate Route
U. S. Route
State Route

EXPLANATION

H* — High; possible susceptible soil conditions and depth to ground water less than 10 feet (3 m).

M* — Moderate; possible susceptible soil conditions and depth to ground water from 10 to 30 feet (3-9 m).

L — Low; possible susceptible soil conditions and depth to ground water from 30 to 50 feet (9-15 m).

VL — Very low; rock, unsusceptible soil conditions, or depth to ground water greater than 50 feet (15 m).

* Special studies are recommended for certain land uses in areas of high and moderate liquefaction susceptibility (see table 1).

Note: This map is not a liquefaction potential map, because it does not consider the probability of earthquake ground shaking needed to cause liquefaction in areas of susceptible conditions.

SOUTH MOUNTAIN, UTAH
40112-D4-TF-024

1993

DMA 3564 IV NW–SERIES V897

TOOELE VALLEY

FLUX B | BURMESTER C | MILLS JUNCTION D | FARNSWORTH PEAK E
NORTH WILLOW CANYON F | GRANTSVILLE G | TOOELE H | BINGHAM CANYON I
DESERET PEAK EAST J | SOUTH MOUNTAIN K | STOCKTON L | LONE PEAK M

NORTHERN RUSH VALLEY

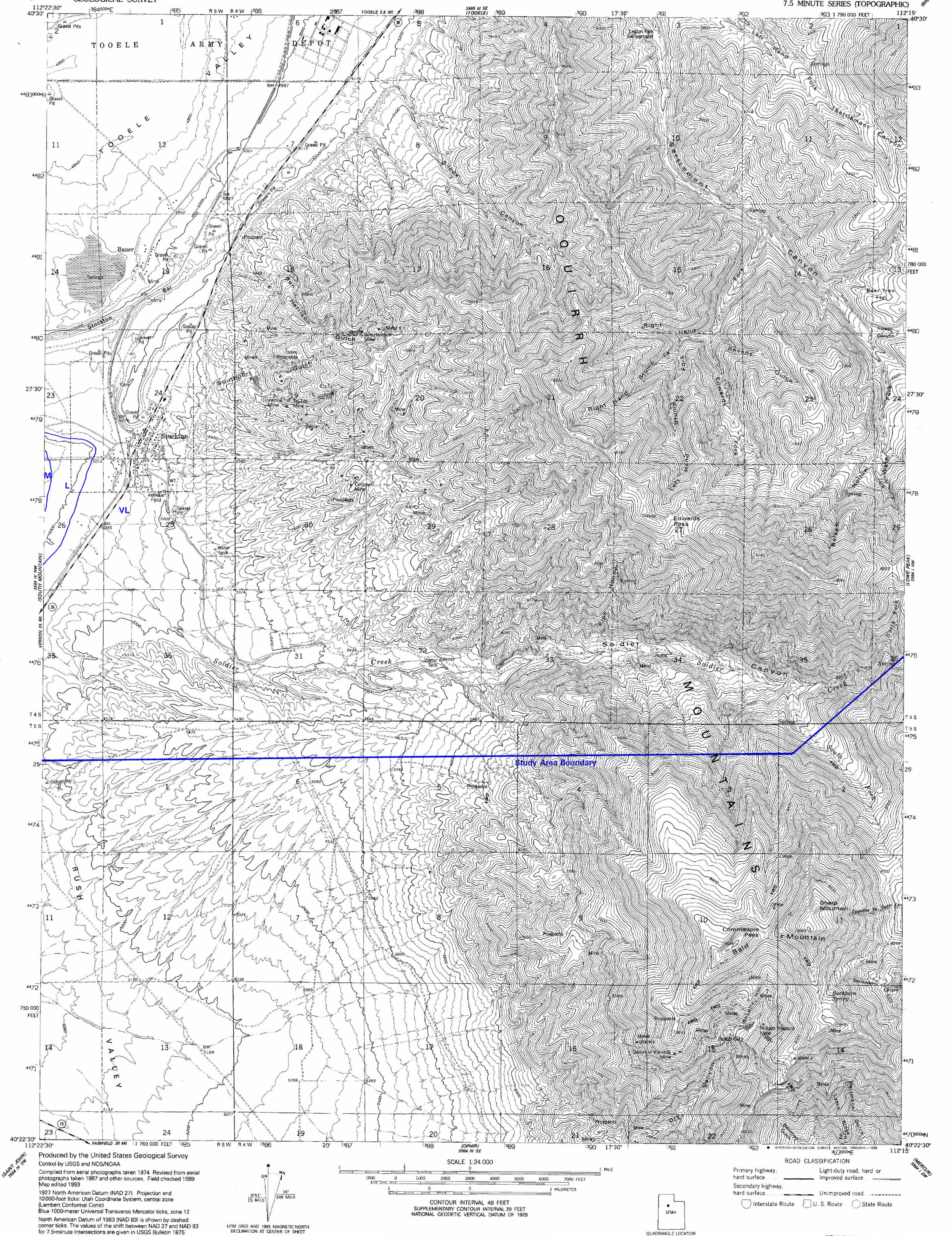
Liquefaction susceptibility, Stockton quadrangle, Tooele County, Utah.

COMPILED BY BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 2L
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STOCKTON QUADRANGLE
UTAH–TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)



Produced by the United States Geological Survey

Control by USGS and NOS/NOAA

Compiled from aerial photographs taken 1974. Revised from aerial photographs taken 1987 and other sources. Field checked 1989. Map edited 1993

1927 North American Datum (NAD 27). Projection and 10 000-foot ticks: Utah Coordinate System, central zone (Lambert Conformal Conic)
Blue 1000-meter Universal Transverse Mercator ticks, zone 12

North American Datum of 1983 (NAD 83) is shown by dashed corner ticks. The values of the shift between NAD 27 and NAD 83 for 7.5-minute intersections are given in USGS Bulletin 1875

There may be private inholdings within the boundaries of the National or State reservations shown on this map

Fine red dashed lines indicate selected fence and field lines where generally visible on aerial photographs. This information is unchecked

UTM GRID AND 1993 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

1 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 5 0 1 KILOMETER

CONTOUR INTERVAL 40 FEET
SUPPLEMENTARY CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

QUADRANGLE LOCATION

ROAD CLASSIFICATION

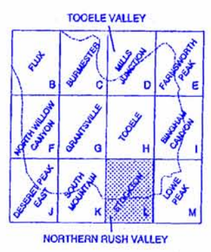
Primary highway, hard surface
Secondary highway, hard surface
Light-duty road, hard or improved surface
Unimproved road
Interstate Route
U. S. Route
State Route

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

STOCKTON, UTAH
40112-D3-TF-024

1993

DMA 3564 IV NE–SERIES V897



EXPLANATION

H* — High; possible susceptible soil conditions and depth to ground water less than 10 feet (3 m).

M* — Moderate; possible susceptible soil conditions and depth to ground water from 10 to 30 feet (3-9 m).

L — Low; possible susceptible soil conditions and depth to ground water from 30 to 50 feet (9-15 m).

VL — Very low; rock, unsusceptible soil conditions, or depth to ground water greater than 50 feet (15 m).

* Special studies are recommended for certain land uses in areas of high and moderate liquefaction susceptibility (see table 1).

Note: This map is not a liquefaction potential map, because it does not consider the probability of earthquake ground shaking needed to cause liquefaction in areas of susceptible conditions.

Debris-slide, debris-flow, debris-flood, and stream-flood hazards, West Desert Hazardous Industry Area, Tooele County, Utah.

COMPILED BY BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 3A
1995

N

Scale 1:50,000

0 1 2 3 4 5 KILOMETERS
0 1 2 3 MILES

NATIONAL GEODETIC VERTICAL DATUM OF 1929
CONTOUR INTERVAL 5 AND 20 METERS

EXPLANATION

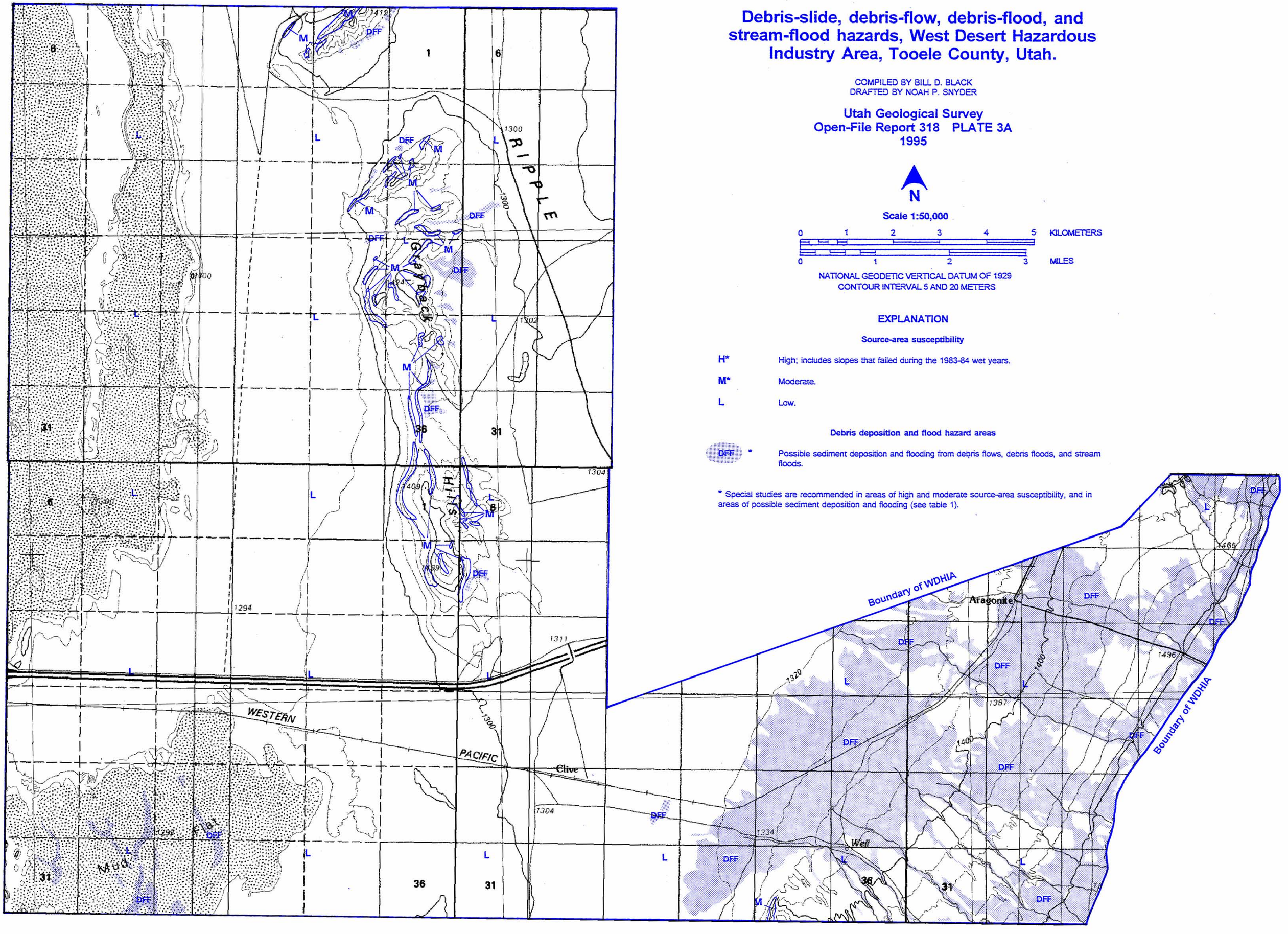
Source-area susceptibility

H*	High; includes slopes that failed during the 1983-84 wet years.
M*	Moderate.
L	Low.

Debris deposition and flood hazard areas

DFF *	Possible sediment deposition and flooding from debris flows, debris floods, and stream floods.

* Special studies are recommended in areas of high and moderate source-area susceptibility, and in areas of possible sediment deposition and flooding (see table 1).



Base map from **BONNEVILLE SALT FLATS** and **TOOELE**, U.S.G.S. 30x60 minute topographic map series.

Debris-slide, debris-flow, debris-flood, and stream-flood hazards, Flux quadrangle, Tooele County, Utah.

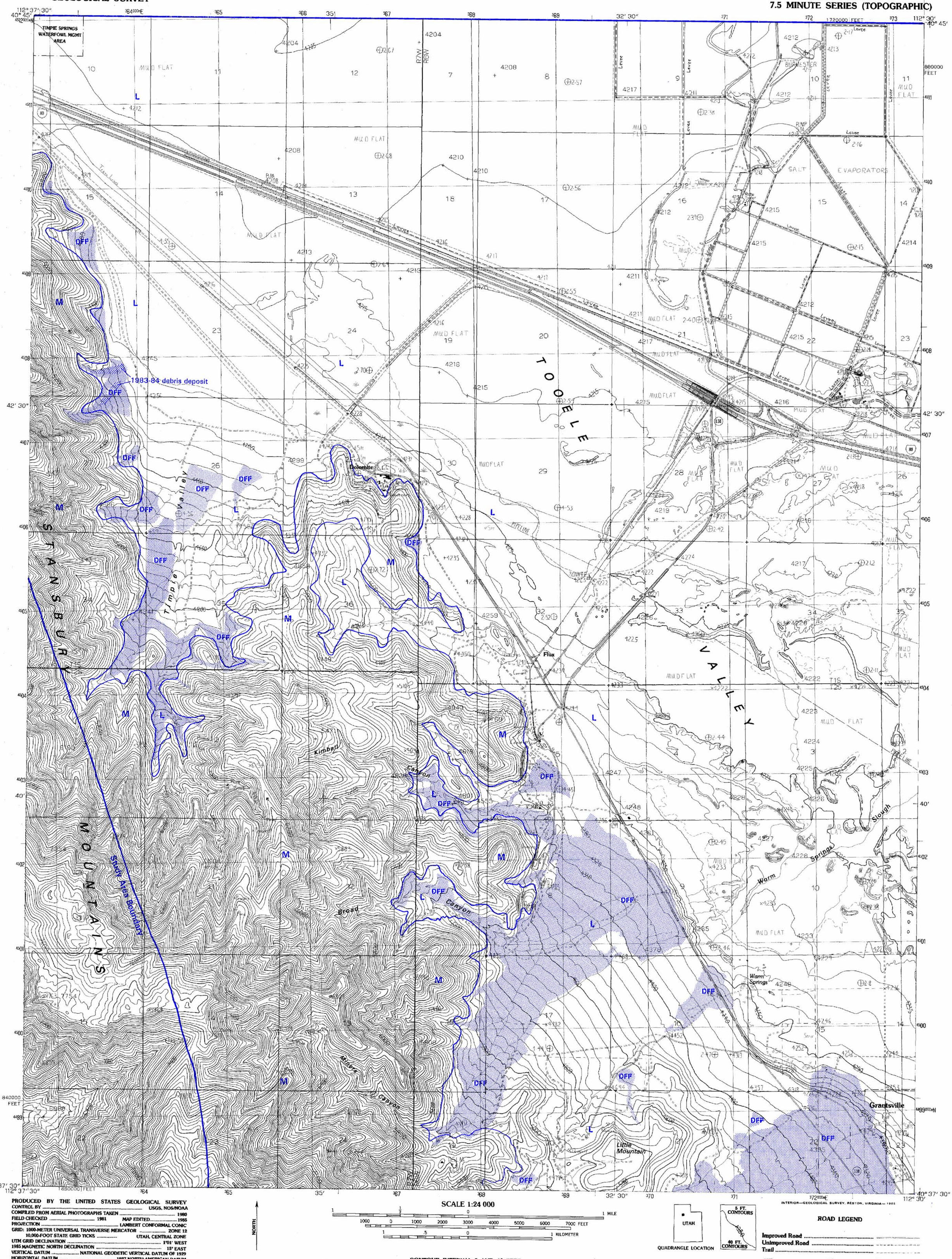
MAPPED AND COMPILED BY KIMM M. HARTY
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 3B
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATE OF UTAH
UTAH GEOLOGICAL AND MINERAL SURVEY

FLUX QUADRANGLE
UTAH–TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)



PRODUCED BY THE UNITED STATES GEOLOGICAL SURVEY
CONTROL BY ..... USGS, NOS/NOAA
COMPILED FROM AERIAL PHOTOGRAPHS TAKEN 1980
FIELD CHECKED ..... 1981 MAP EDITED 1985
PROJECTION ..... LAMBERT CONFORMAL CONIC
GRID: 1000-METER UNIVERSAL TRANSVERSE MERCATOR ..... ZONE 12
10,000-FOOT STATE GRID TICKS ..... UTAH, CENTRAL ZONE
UTM GRID DECLINATION ..... 1°01' WEST
1985 MAGNETIC NORTH DECLINATION ..... 15° EAST
VERTICAL DATUM ..... NATIONAL GEODETIC VERTICAL DATUM OF 1929
HORIZONTAL DATUM ..... 1927 NORTH AMERICAN DATUM
To place on the predicted North American Datum of 1983, move the projection lines as shown by dashed corner ticks (10 meters north and 67 meters east)
There may be private inholdings within the boundaries of any Federal and State Reservations shown on this map

PROVISIONAL MAP
Produced from original manuscript drawings. Information shown as of date of field check.

SCALE 1:24 000

CONTOUR INTERVAL 5 AND 40 FEET

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U.S. GEOLOGICAL SURVEY, DENVER, COLORADO, 80225
OR RESTON, VIRGINIA 22092

1	2	3	1 Poverty Point 2 Corral Canyon 3 Flag Peak 4 Timpie 5 Burmester 6 Salt Mountain 7 North Willow Canyon 8 Grantsville
4		5	
6	7	8	

ADJOINING 7.5 QUADRANGLE NAMES

UTAH
QUADRANGLE LOCATION

5 FT. CONTOURS
40 FT. CONTOURS

ROAD LEGEND
Improved Road
Unimproved Road
Trail
Interstate Route U.S. Route State Route

EXPLANATION

Source-area susceptibility

H*	High; includes slopes that failed during the 1983-84 wet years.
M*	Moderate.
L	Low.

Debris deposition and flood hazard

DFF *	Possible sediment deposition and flooding from debris flows, debris floods, and stream floods; includes 1983-84 debris deposits (crosshatched).

* Special studies are recommended in areas of high and moderate source-area susceptibility, and in areas of possible sediment deposition and flooding (see table 1).

FLUX, UTAH

PROVISIONAL EDITION 1985

40112-F5-TF-024

Debris-slide, debris-flow, debris-flood, and stream-flood hazards, Burmester quadrangle, Tooele County, Utah.

MAPPED AND COMPILED BY KIMM M. HARTY
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 3C
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

BURMESTER QUADRANGLE
UTAH—TOOELE CO.
7.5 MINUTE SERIES ORTHOPHOTOMAP (TOPOGRAPHIC)

Study Area Boundary

ALKALI OR MUD

GREAT SALT LAKE
ELEVATION 4200
1953

Borrow Pit
Borrow Pits
Burmester
Run
Slough
Springs
Warm
Coyote Knolls
Flowing Well
Flowing Wells
Well
Willow Fields
Cooleys
Blue Lakes

WESTERN PACIFIC
PIPELINE
ROAD
BURMESTER
TOOELE VALLEY

Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Planimetry by photogrammetric methods from aerial photographs taken 1953. Topography by planetable surveys 1923 and 1955
Revision and orthophotomosaic from aerial photographs taken 1971
Field checked 1972

Underwater contours by photogrammetric methods from aerial photographs taken 1966, 1969, and 1971–72

Projection and 10,000-foot grid ticks: Utah coordinate system, central zone (Lambert conformal conic)
1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue. 1927 North American datum

UTM GRID AND 1972 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 5 FEET
DATUM IS MEAN SEA LEVEL

ROAD CLASSIFICATION

Primary highway, hard surface
Secondary highway, hard surface
Light-duty road, hard or improved surface
Unimproved road
Interstate Route
U. S. Route
State Route

UTAH
QUADRANGLE LOCATION

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR WASHINGTON, D. C. 20242
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

BURMESTER, UTAH
N4037.5—W11222.5/7.5

1972

AMS 3565 III NW—SERIES V8970

TOOELE VALLEY
NORTHERN RUSH VALLEY

EXPLANATION

Source-area susceptibility

H* High; includes slopes that failed during the 1983-84 wet years.

M* Moderate.

L Low.

Debris deposition and flood hazard

DFF * Possible sediment deposition and flooding from debris flows, debris floods, and stream floods; includes 1983-84 debris deposits (crosshatched).

* Special studies are recommended in areas of high and moderate source-area susceptibility, and in areas of possible sediment deposition and flooding (see table 1).

Debris-slide, debris-flow, debris-flood, and stream-flood hazards, Mills Junction quadrangle, Tooele County, Utah.

MAPPED AND COMPILED BY KIMM M. HARTY
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 3D
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

MILLS JUNCTION QUADRANGLE
UTAH—TOOELE CO.
7.5 MINUTE SERIES ORTHOPHOTOMAP (TOPOGRAPHIC)

Study Area Boundary

Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Topography by photogrammetric methods from aerial photographs taken 1953 and by planetable surveys 1923–24 and 1955
Revision and orthophotomosaic from aerial photographs taken 1971
Field checked 1972

Underwater contours by photogrammetric methods from aerial photographs taken 1966, 1969, and 1971–72. Soundings compiled from chart furnished by U.S. Naval Reserve

Projection and 10,000-foot grid ticks: Utah coordinate system, central zone (Lambert conformal conic)
1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue. 1927 North American datum

UTM GRID AND 1972 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 10 FEET
DOTTED LINES REPRESENT 5-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL
SOUNDINGS IN FEET—DATUM IS LAKE ELEVATION 4200 FEET

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY
DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

UTAH
QUADRANGLE LOCATION

ROAD CLASSIFICATION
Primary highway, hard surface
Light-duty road, hard or improved surface
Secondary highway, hard surface
Unimproved road
Interstate Route U. S. Route State Route

MILLS JUNCTION, UTAH
N4037.5—W11215/7.5
1972
AMS 3565 III NE SERIES V8970

TOOELE VALLEY
FLUX B | ARAGONITE C | MILLS JUNCTION D | FARNSWORTH PEAK E
MEADOW-HILLSDALE CANYON F | GRANTSVILLE G | TOOELE H | BINGHAM CANYON I
GRANTSVILLE PEAK EAST J | KELTON MOUNTAIN K | STOCKTON L | LONE PEAK M
NORTHERN RUSH VALLEY

EXPLANATION

Source-area susceptibility

H* High; includes slopes that failed during the 1983-84 wet years.

M* Moderate.

L Low.

Debris deposition and flood hazard

DFF * Possible sediment deposition and flooding from debris flows, debris floods, and stream floods; includes 1983-84 debris deposits (crosshatched).

* Special studies are recommended in areas of high and moderate source-area susceptibility, and in areas of possible sediment deposition and flooding (see table 1).

ISBN 0-7607-5985-2

Debris-slide, debris-flow, debris-flood, and stream-flood hazards, Farnsworth Peak quadrangle, Tooele County, Utah.

MAPPED AND COMPILED BY KIMM M. HARTY
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 3E
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

FARNSWORTH PEAK QUADRANGLE
UTAH
7.5 MINUTE SERIES ORTHOPHOTOMAP (TOPOGRAPHIC)

Study Area Boundary

DFF

L

M

Mapped, edited, and published by the Geological Survey

Control by USGS and NOS/NOAA

Topography by photogrammetric methods from aerial photographs taken 1950. Field checked 1952. Revision and orthophotomosaic from aerial photographs taken 1971. Field checked 1972

Underwater contours by photogrammetric methods from aerial photographs taken 1966, 1969 and 1971-72
Soundings compiled from chart furnished by U.S. Naval Reserve

Projection and 10,000-foot grid ticks: Utah coordinate system, central zone (Lambert conformal conic)
1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue
The difference between 1927 North American Datum and North American Datum of 1983 (NAD 83) for 7.5 minute intersections is given in USGS Bulletin 1875. The NAD 83 is shown by dashed corner ticks

UTM GRID AND 1972 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET

DOTTED LINES REPRESENT 10-FOOT CONTOURS
NATIONAL GEODETIC VERTICAL DATUM OF 1929
SOUNDINGS IN FEET-DATUM IS LAKE ELEVATION 4200 FEET

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U.S. GEOLOGICAL SURVEY
DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

QUADRANGLE LOCATION

ROAD CLASSIFICATION

Primary highway, hard surface
Secondary highway, hard surface
Light-duty road, hard or improved surface
Unimproved road
Interstate Route
U. S. Route
State Route

INTERIOR—GEOLOGICAL SURVEY, RESTON, VIRGINIA—1991

EXPLANATION

Source-area susceptibility

H* High; includes slopes that failed during the 1983-84 wet years.

M* Moderate.

L Low.

Debris deposition and flood hazard

DFF* Possible sediment deposition and flooding from debris flows, debris floods, and stream floods; includes 1983-84 debris deposits (crosshatched).

* Special studies are recommended in areas of high and moderate source-area susceptibility, and in areas of possible sediment deposition and flooding (see table 1).

FARNSWORTH PEAK, UTAH
40112-F2-OM-024

1972

DMA 3565 II NW-SERIES V897

Debris-slide, debris-flow, debris-flood, and stream-flood hazards, North Willow Canyon quadrangle, Tooele County, Utah.

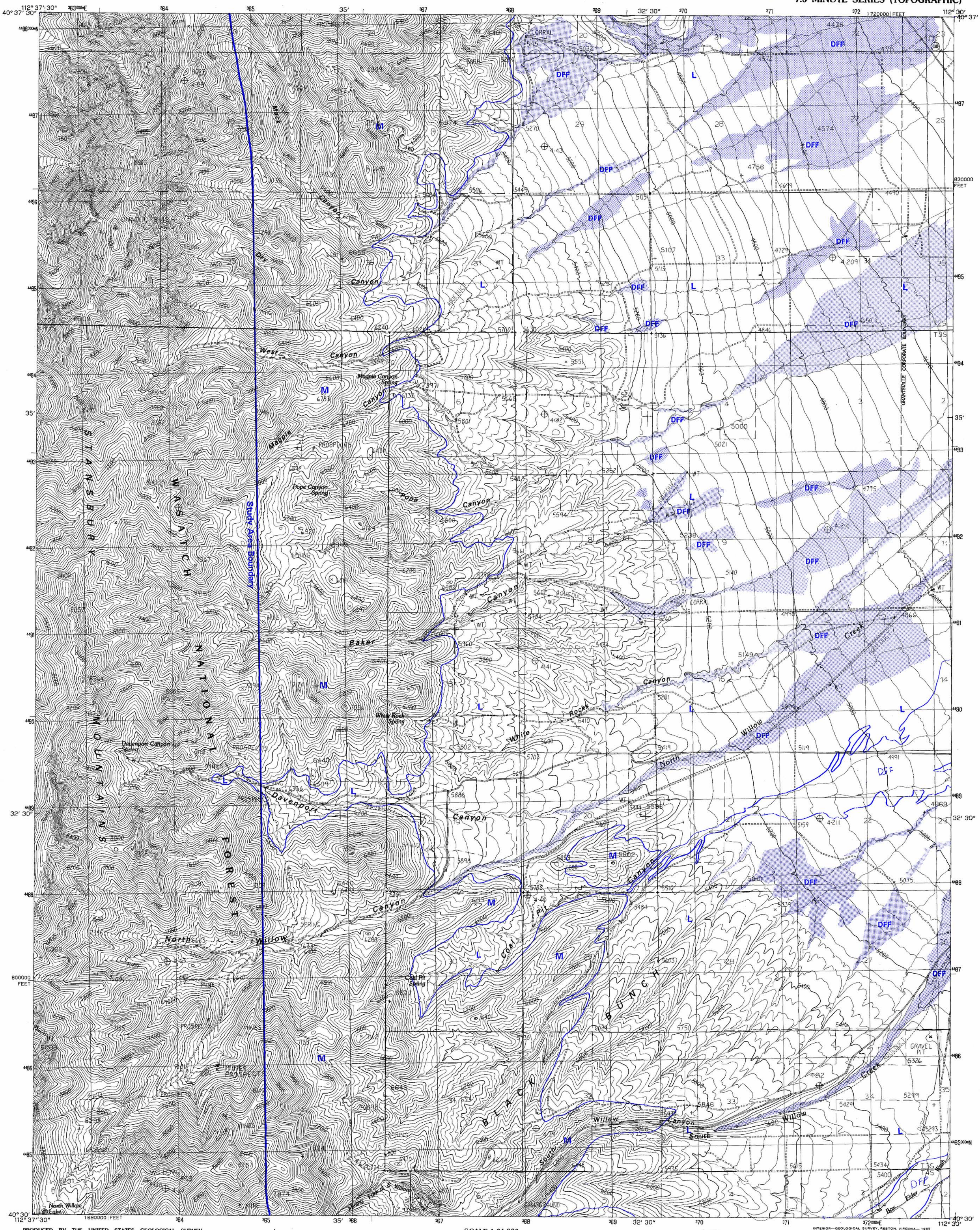
MAPPED AND COMPILED BY KIMM M. HARTY
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 3F
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATE OF UTAH
UTAH GEOLOGICAL AND MINERAL SURVEY

NORTH WILLOW CANYON QUADRANGLE
UTAH–TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)



SCALE 1:24 000

NORTH

CONTOUR INTERVAL 40 FEET

PRODUCED BY THE UNITED STATES GEOLOGICAL SURVEY
CONTROL BY ..... USGS, NOS/NOAA
COMPILED FROM AERIAL PHOTOGRAPHS TAKEN 1980
FIELD CHECKED ..... 1981 MAP EDITED 1985
PROJECTION ..... LAMBERT CONFORMAL CONIC
GRID: 1000-METER UNIVERSAL TRANSVERSE MERCATOR ..... ZONE 12
10,000-FOOT STATE GRID TICKS ..... UTAH, CENTRAL ZONE
UTM GRID DECLINATION ..... 1°01' WEST
1985 MAGNETIC NORTH DECLINATION ..... 15° EAST
VERTICAL DATUM ..... NATIONAL GEODETIC VERTICAL DATUM OF 1929
HORIZONTAL DATUM ..... 1927 NORTH AMERICAN DATUM

To place on the predicted North American Datum of 1983, move the projection lines as shown by dashed corner ticks (10 meters north and 67 meters east)

There may be private inholdings within the boundaries of any Federal and State Reservations shown on this map

Where omitted, land lines have not been established

PROVISIONAL MAP
Produced from original manuscript drawings. Information shown as of date of field check. 2

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
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OR RESTON, VIRGINIA 22092

QUADRANGLE LOCATION

1	2	3	1 Timpie 2 Flux 3 Burmester 4 Salt Mountain 5 Grantsville 6 Deseret Peak West 7 Deseret Peak East 8 South Mountain
4		5	
6	7	8	

ADJOINING 7.5 QUADRANGLE NAMES

EXPLANATION

Source-area susceptibility

H*	High; includes slopes that failed during the 1983-84 wet years.
M*	Moderate.
L	Low.

Debris deposition and flood hazard

DFF *	Possible sediment deposition and flooding from debris flows, debris floods, and stream floods; includes 1983-84 debris deposits (crosshatched).

* Special studies are recommended in areas of high and moderate source-area susceptibility, and in areas of possible sediment deposition and flooding (see table 1).

ROAD LEGEND

Improved Road .....
Unimproved Road .....
Trail .....

Interstate Route U.S. Route State Route

NORTH WILLOW CANYON, UTAH

PROVISIONAL EDITION 1985

40112-E5-TF-024

Debris-slide, debris-flow, debris-flood, and stream-flood hazards, Grantsville quadrangle, Tooele County, Utah.

MAPPED AND COMPILED BY KIMM M. HARTY
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 3G
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

GRANTSVILLE QUADRANGLE
UTAH—TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)

Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Topography from planetable surveys 1923 and by Kelsh plotter from aerial photographs taken 1953. Field check 1955

Polyconic projection. 1927 North American datum
10,000-foot grid based on Utah coordinate system, central zone

1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue

Dashed land lines indicate approximate locations

APPROXIMATE MEAN DECLINATION, 1955

SCALE 1:24000

CONTOUR INTERVAL 10 FEET
DASHED LINES REPRESENT 5-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

ROAD CLASSIFICATION

Heavy-duty ——— Light-duty ———
Medium-duty ——— Unimproved dirt - - - - -
U. S. Route State Route

QUADRANGLE LOCATION

GRANTSVILLE, UTAH
N4030—W11222.5/7.5

1955

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

EXPLANATION

Source-area susceptibility

H*	High; includes slopes that failed during the 1983-84 wet years.
M*	Moderate.
L	Low.

Debris deposition and flood hazard

DFF	*	Possible sediment deposition and flooding from debris flows, debris floods, and stream floods; includes 1983-84 debris deposits (crosshatched).

* Special studies are recommended in areas of high and moderate source-area susceptibility, and in areas of possible sediment deposition and flooding (see table 1).

TOOELE VALLEY
FLUX B | BURMESTER C | MILLS JUNCTION D | FARNSWORTH PEAK E
NORTH WILLOW CANYON F | GRANTSVILLE G | TOOELE H | BIGHAM CANYON I
DESERET PEAK EAST J | SOUTH MOUNTAIN K | STOCKTON L | LONE PEAK M
NORTHERN RUSH VALLEY

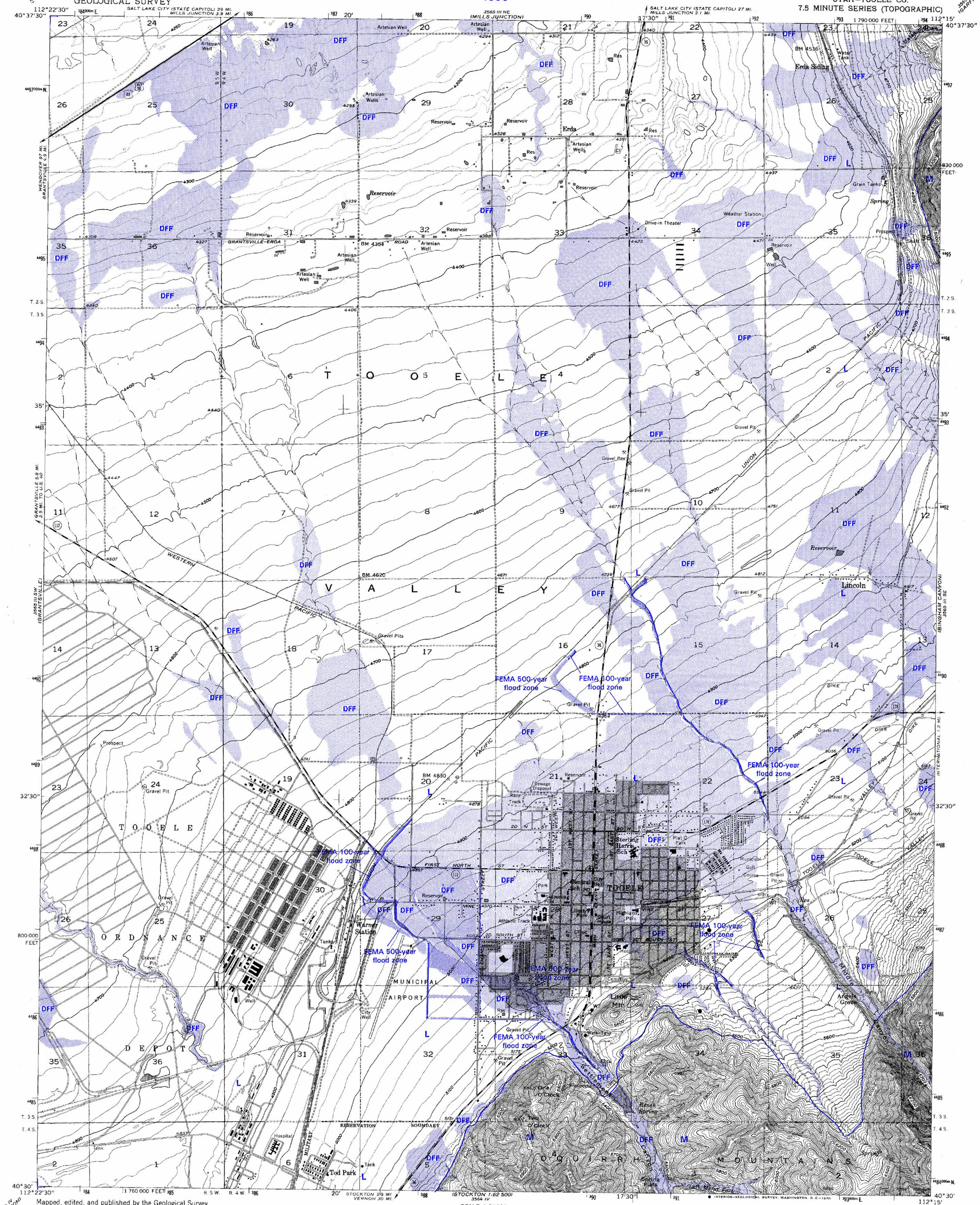
Debris-slide, debris-flow, debris-flood, and stream-flood hazards, Tooele quadrangle, Tooele County, Utah.

MAPPED AND COMPILED BY KIMM M. HARTY AND BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 3H
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

TOOELE QUADRANGLE
UTAH—TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)



Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Culture and drainage compiled from aerial photographs taken 1953
Topography by planetable surveys 1923–24 and by photogrammetric methods
Contour revision and field check 1955

Polyconic projection. 1927 North American datum
10,000-foot grid based on Utah coordinate system, central zone

1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue

Red tint indicates areas in which only landmark buildings are shown

Dashed land lines indicate approximate locations

Revisions shown in purple compiled from aerial photographs taken 1969. This information not field checked

Purple tint indicates extension of urban areas

GN MN 0°51' 15 MILS 17° 302 MILS
UTM GRID AND 1969 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24000

1 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 5 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET
DASHED LINES REPRESENT 5-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

UTAH
QUADRANGLE LOCATION

ROAD CLASSIFICATION
Heavy-duty
Medium-duty
Light-duty
Unimproved dirt
U.S. Route
State Route

TOOELE, UTAH
N4030—W11215/7.5

1955
PHOTOREVISED 1969

AMS 3565 III SE–SERIES.V897

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

EXPLANATION

Source-area susceptibility

H*	High; includes slopes that failed during the 1983-84 wet years.
M*	Moderate.
L	Low.

Debris deposition and flood hazard

DFF *	Possible sediment deposition and flooding from debris flows, debris floods, and stream floods; includes 1983-84 debris deposits (crosshatched).
	FEMA 100-year flood zone.
	FEMA 500-year flood zone.

* Special studies are recommended in areas of high and moderate source-area susceptibility, and in areas of possible sediment deposition and flooding (see table 1).

TOOELE VALLEY

FLUX B	BURMESTER C	KILLS JUNCTION D	FARNSWORTH PEAK E	
NORTH MILLER CANYON F	GRANTSVILLE G	TOOELE H	BINGHAM CANYON I	
CLEDGET PEAK EAST J	SOUTH MOUNTAIN K	STOCKTON L	LOWE PEAK M	

NORTHERN RUSH VALLEY

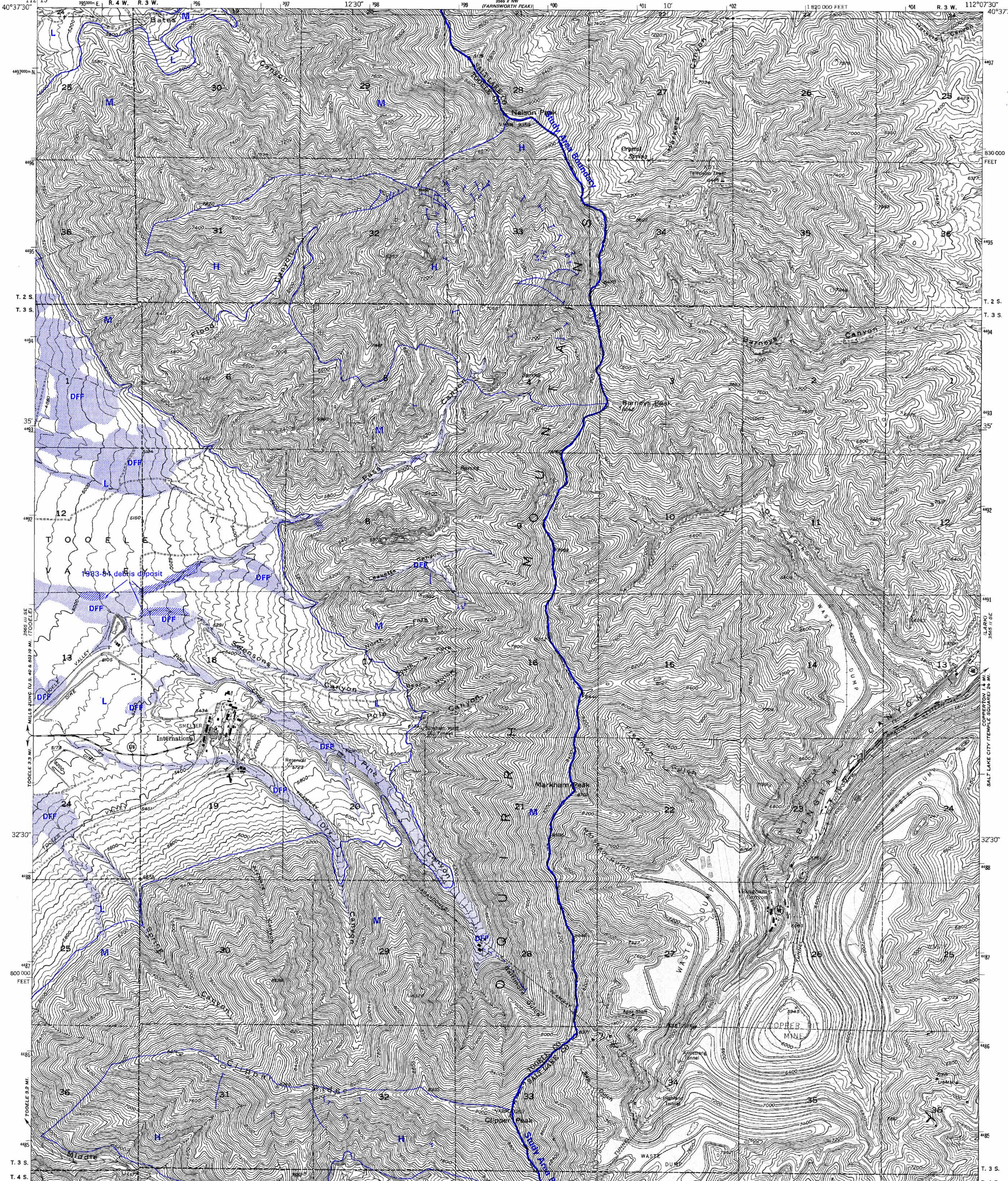
Debris-slide, debris-flow, debris-flood, and stream-flood hazards, Bingham Canyon quadrangle, Tooele County, Utah.

MAPPED AND COMPILED BY KIMM M. HARTY
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 3I
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

BINGHAM CANYON QUADRANGLE
UTAH
7.5 MINUTE SERIES (TOPOGRAPHIC)



Mapped, edited, and published by the Geological Survey

Control by USGS and NOS/NOAA

Topography from aerial photographs by photogrammetric methods
Aerial photographs taken 1950. Field check 1952, except contour and track detail in open pit mine which is subject to frequent change

Polyconic projection. 1927 North American datum
10,000-foot grid based on Utah coordinate system, central zone

Dashed land lines indicate approximate locations

Unchecked elevations are shown in brown

1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue

Revisions shown in purple compiled from aerial photographs taken 1969 and 1975. This information not field checked

(STOCKTON 1:62 500) 3564 IV

UTM GRID AND 1975 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET
0°46' 14 MILS
15½° 276 MILS

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

QUADRANGLE LOCATION

ROAD CLASSIFICATION
Medium-duty — Light-duty
Unimproved dirt
State Route

(TICKVILLE SPRING) 3564 I NE

BINGHAM CANYON, UTAH
N4030—W11207 5/7.5
1952
PHOTOREVISED 1969 AND 1975
AMS 3565 II SW—SERIES V897

EXPLANATION

Source scar / Travel path — Debris slide or debris flow.

Source-area susceptibility

H* — High; includes slopes that failed during the 1983-84 wet years.

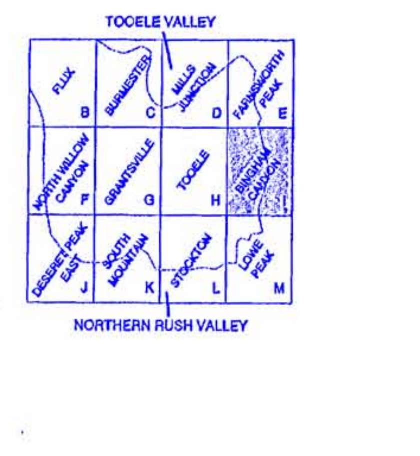
M* — Moderate.

L — Low.

Debris deposition and flood hazard

DFF * — Possible sediment deposition and flooding from debris flows, debris floods, and stream floods; includes 1983-84 debris deposits (crosshatched).

* Special studies are recommended in areas of high and moderate source-area susceptibility, and in areas of possible sediment deposition and flooding (see table 1).



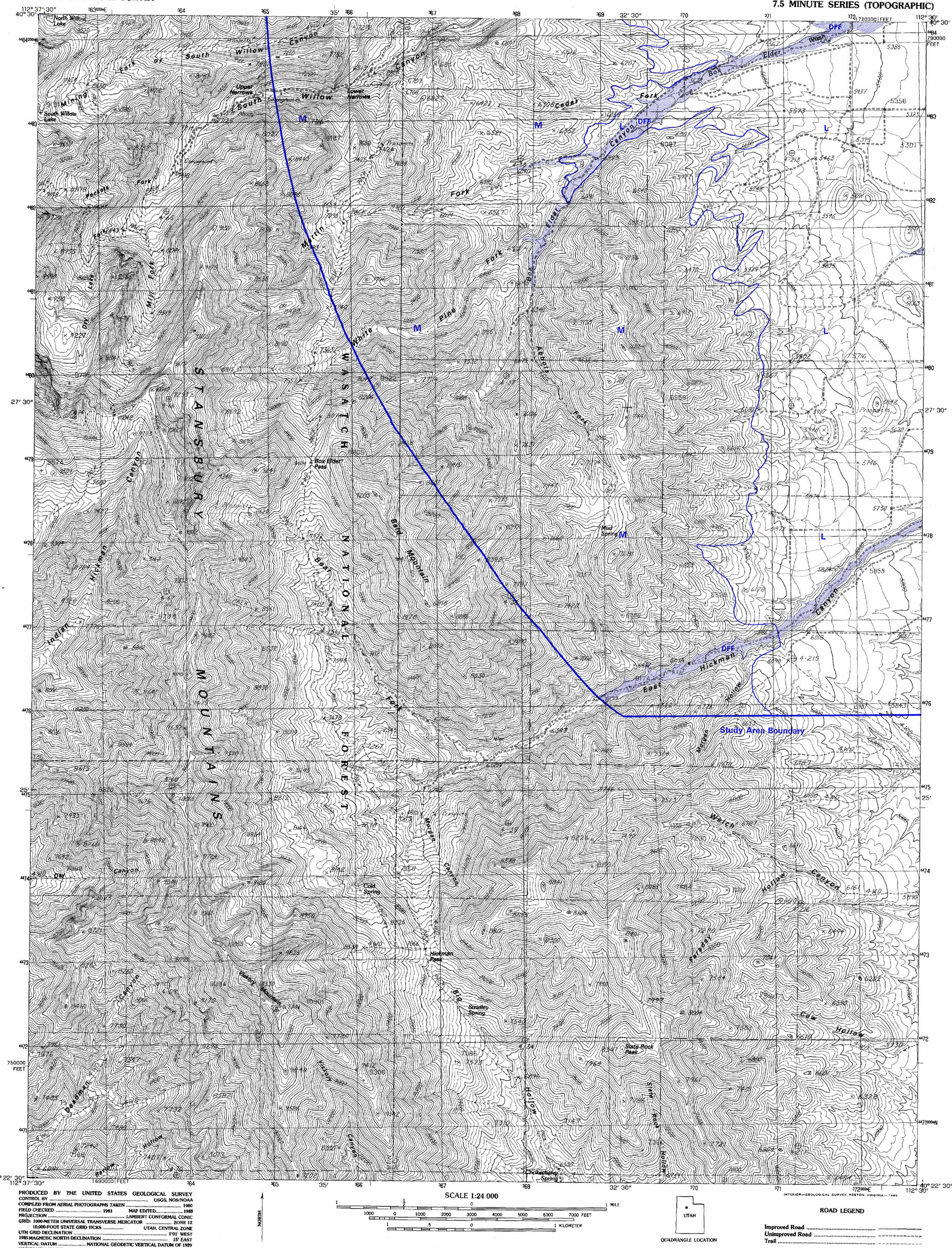
Debris-slide, debris-flow, debris-flood, and stream-flood hazards, Deseret Peak East quadrangle, Tooele County, Utah.

MAPPED AND COMPILED BY KIMM M. HARTY
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 3J
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

DESERET PEAK EAST QUADRANGLE
UTAH–TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)



PRODUCED BY THE UNITED STATES GEOLOGICAL SURVEY
CONTROL BY ..... USGS, NOS/NOAA
COMPILED FROM AERIAL PHOTOGRAPHS TAKEN 1980
FIELD CHECKED ..... 1981 MAP EDITED 1985
PROJECTION ..... LAMBERT CONFORMAL CONIC
GRID: 1000-METER UNIVERSAL TRANSVERSE MERCATOR ..... ZONE 12
10,000-FOOT STATE GRID TICKS ..... UTAH, CENTRAL ZONE
UTM GRID DECLINATION ..... 1°01' WEST
1985 MAGNETIC NORTH DECLINATION ..... 15° EAST
VERTICAL DATUM ..... NATIONAL GEODETIC VERTICAL DATUM OF 1929
HORIZONTAL DATUM ..... 1927 NORTH AMERICAN DATUM
To place on the predicted North American Datum of 1983, move the projection lines as shown by dashed corner ticks (10 meters north and 67 meters east)
There may be private inholdings within the boundaries of any Federal and State Reservations shown on this map
Where omitted, land lines have not been established

PROVISIONAL MAP
Produced from original manuscript drawings. Information shown as of date of field check. 2

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U.S. GEOLOGICAL SURVEY, DENVER, COLORADO. 80225
OR RESTON, VIRGINIA 22092

UTAH
QUADRANGLE LOCATION

1	2	3	1 Salt Mountain 2 North Willow Canyon 3 Grantsville 4 Deseret Peak West 5 South Mountain 6 Terra 7 Johnson Pass 8 Saint John
4		5	
6	7	8	

ADJOINING 7.5 QUADRANGLE NAMES

ROAD LEGEND

Improved Road .....
Unimproved Road .....
Trail .....
Interstate Route U.S. Route State Route

EXPLANATION

Source-area susceptibility

H* High; includes slopes that failed during the 1983-84 wet years.

M* Moderate.

L Low.

Debris deposition and flood hazard

DFF * Possible sediment deposition and flooding from debris flows, debris floods, and stream floods; includes 1983-84 debris deposits (crosshatched).

* Special studies are recommended in areas of high and moderate source-area susceptibility, and in areas of possible sediment deposition and flooding (see table 1).

DESERET PEAK EAST, UTAH

PROVISIONAL EDITION 1985

40112-D5-TF-024

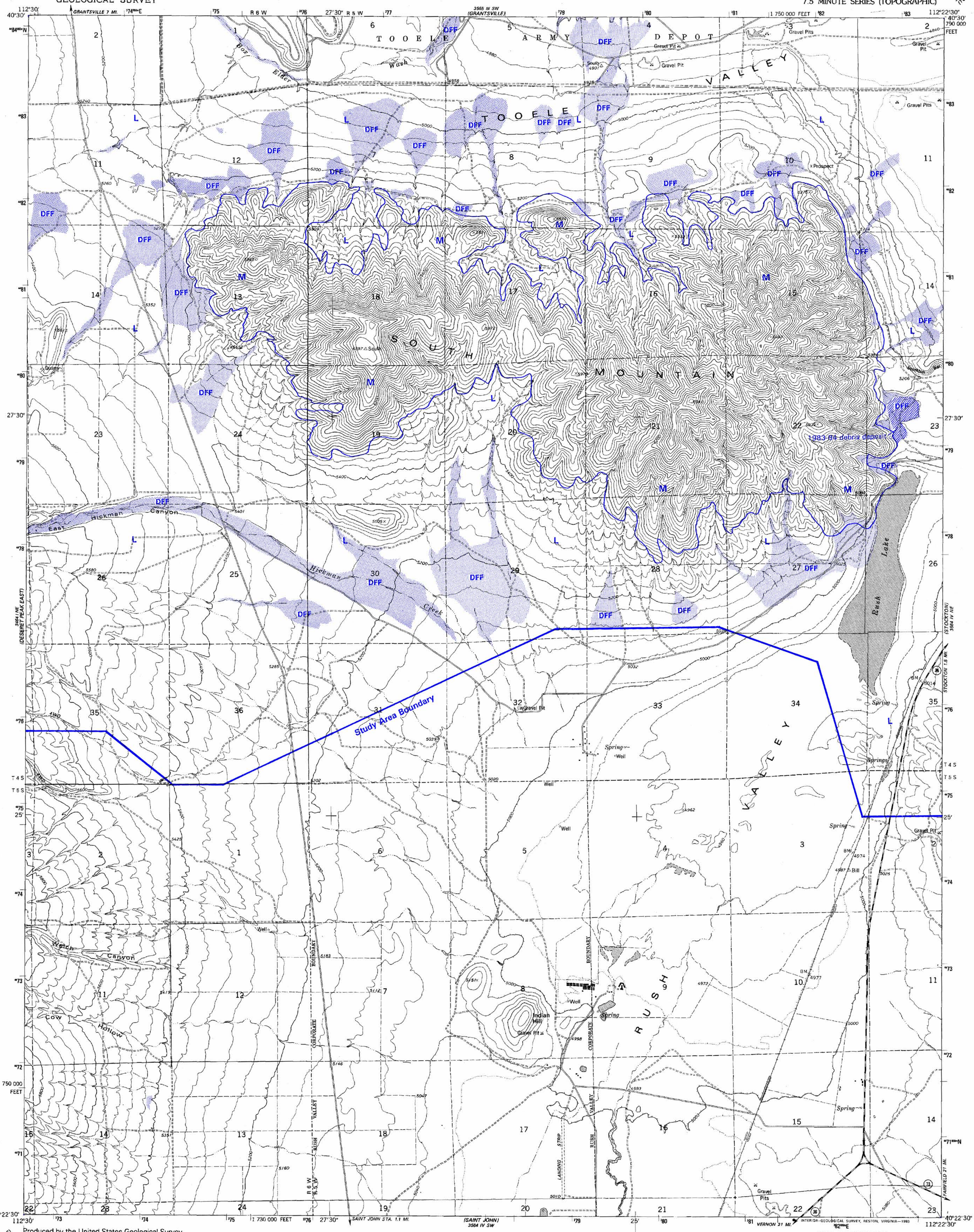
Debris-slide, debris-flow, debris-flood, and stream-flood hazards, South Mountain quadrangle, Tooele County, Utah.

MAPPED AND COMPILED BY KIMM M. HARTY
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 3K
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

SOUTH MOUNTAIN QUADRANGLE
UTAH-TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)



Produced by the United States Geological Survey
Control by USGS and NOS/NOAA

Compiled from aerial photographs taken 1974. Revised from aerial photographs taken 1987 and other sources. Field checked 1988
Map edited 1993

1927 North American Datum (NAD 27). Projection and 10 000-foot ticks: Utah Coordinate System, central zone (Lambert Conformal Conic)
Blue 1000-meter Universal Transverse Mercator ticks, zone 12

North American Datum of 1983 (NAD 83) is shown by dashed corner ticks. The values of the shift between NAD 27 and NAD 83 for 7.5-minute intersections are given in USGS Bulletin 1875

There may be private inholdings within the boundaries of the National or State reservations shown on this map

Fine red dashed lines indicate selected fence and field lines where generally visible on aerial photographs

UTM GRID AND 1993 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 20-FOOT CONTOURS
NATIONAL GEODETIC VERTICAL DATUM OF 1929

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

UTAH
QUADRANGLE LOCATION

ROAD CLASSIFICATION
Primary highway, hard surface
Secondary highway, hard surface
Light-duty road, hard or improved surface
Unimproved road
Interstate Route U. S. Route State Route

SOUTH MOUNTAIN, UTAH
40112-D4-TF-024
1993
DMA 3564 IV NW-SERIES V897

TOCELE VALLEY
FLUX B | BURMESTER C | MILLS JUNCTION D | FARNSWORTH PEAK E
NORTH WILLOW CANYON F | GRANTSVILLE G | TOOELE H | BIRDSEYE CANYON I
DESERET PEAK EAST J | SOUTH MOUNTAIN K | STOCKTON L | LAKE POINT M
NORTHERN RUSH VALLEY

EXPLANATION

Source-area susceptibility

H* High; includes slopes that failed during the 1983-84 wet years.

M* Moderate.

L Low.

Debris deposition and flood hazard

DFF * Possible sediment deposition and flooding from debris flows, debris floods, and stream floods; includes 1983-84 debris deposits (crosshatched).

* Special studies are recommended in areas of high and moderate source-area susceptibility, and in areas of possible sediment deposition and flooding (see table 1).

Debris-slide, debris-flow, debris-flood, and stream-flood hazards, Stockton quadrangle, Tooele County, Utah.

MAPPED AND COMPILED BY KIMM M. HARTY
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 3L
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STOCKTON QUADRANGLE
UTAH–TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)

1983-84 debris deposit

Study Area Boundary

Produced by the United States Geological Survey
Control by USGS and NOS/NOAA

Compiled from aerial photographs taken 1974. Revised from aerial photographs taken 1987 and other sources. Field checked 1989
Map edited 1993

1927 North American Datum (NAD 27). Projection and 10000-foot ticks: Utah Coordinate System, central zone (Lambert Conformal Conic)
Blue 1000-meter Universal Transverse Mercator ticks, zone 12

North American Datum of 1983 (NAD 83) is shown by dashed corner ticks. The values of the shift between NAD 27 and NAD 83 for 7.5-minute intersections are given in USGS Bulletin 1875

There may be private inholdings within the boundaries of the National or State reservations shown on this map

Fine red dashed lines indicate selected fence and field lines where generally visible on aerial photographs. This information is unchecked

UTM GRID AND 1993 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET
SUPPLEMENTARY CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

UTAH
QUADRANGLE LOCATION

ROAD CLASSIFICATION

Primary highway, hard surface
Secondary highway, hard surface
Light-duty road, hard or improved surface
Unimproved road
Interstate Route
U. S. Route
State Route

STOCKTON, UTAH
40112-D3-TF-024

1993

DMA 3564 IV NE–SERIES V897

TOOELE VALLEY

FLUX B | BURMESTER C | MILLS JUNCTION D | FARNSWORTH PEAK E
NORTH WILLOW CANYON F | GRANTSVILLE G | TOOELE H | RUSHVALE CANYON I
DESERET PEAK EAST J | SOUTH MOUNTAIN K | STOCKTON L | LOVE PEAK M

NORTHERN RUSH VALLEY

EXPLANATION

Source-area susceptibility

H* — High; includes slopes that failed during the 1983-84 wet years.

M* — Moderate.

L — Low.

Debris deposition and flood hazard

DFF* — Possible sediment deposition and flooding from debris flows, debris floods, and stream floods; includes 1983-84 debris deposits (crosshatched).

* Special studies are recommended in areas of high and moderate source-area susceptibility, and in areas of possible sediment deposition and flooding (see table 1).

Debris-slide, debris-flow, debris-flood, and stream-flood hazards, Lowe Peak quadrangle, Tooele County, Utah.

MAPPED AND COMPILED BY KIMM M. HARTY
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 3M
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

LOWE PEAK QUADRANGLE
UTAH
7.5 MINUTE SERIES (TOPOGRAPHIC)

Study Area Boundary

Produced by the United States Geological Survey
Control by USGS and NOS/NOAA

Compiled from aerial photographs taken 1966. Revised from aerial photographs taken 1987. Field checked 1989. Map edited 1993

North American Datum of 1927 (NAD 27). Projection and 10 000-foot grid ticks: Utah Coordinate System, central zone (Lambert Conformal Conic). 1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue
The difference between NAD 27 and North American Datum of 1983 (NAD 83) for 7.5 minute intersections is given in USGS Bulletin 1875. The NAD 83 is shown by dashed corner ticks

UTM GRID AND 1993 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
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QUADRANGLE LOCATION

ROAD CLASSIFICATION

Primary highway, hard surface
Secondary highway, hard surface
Light-duty road, hard or improved surface
Unimproved road
Interstate Route U. S. Route State Route

EXPLANATION

Source scar
Travel path
Debris slide or debris flow.

Source-area susceptibility

H* High; includes slopes that failed during the 1983-84 wet years.

M* Moderate.

L Low.

* Special studies are recommended in areas of high and moderate source-area susceptibility (see table 1).

LOWE PEAK, UTAH
40112-D2-TF-024
1993
DMA 3564 I NW-SERIES V897

TOOELE VALLEY
NORTHERN RUSH VALLEY

Rock-fall hazard and depth to ground water, West Desert Hazardous Industry Area, Tooele County, Utah.

COMPILED BY BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 4A
1995

N

Scale 1:50,000

0 1 2 3 4 5 KILOMETERS
0 1 2 3 MILES

NATIONAL GEODETIC VERTICAL DATUM OF 1929
CONTOUR INTERVAL 5 AND 20 METERS

EXPLANATION

Rock fall

RF * Potentially subject to impact by rock fall.

Depth to ground water

A* Less than 10 feet (3 m).

B 10 to 30 feet (3-9 m).

C 30 to 50 feet (9-15 m).

D Greater than 50 feet (15 m).

* Special studies are recommended in areas subject to rock fall and where the depth to ground water is less than 10 feet (3 m) (see table 1).

Boundary of WDHIA

Base map from BONNEVILLE SALT FLATS and TOOELE, U.S.G.S. 30x60 minute topographic map series.

Rock-fall hazard and depth to ground water, Flux quadrangle, Tooele County, Utah.

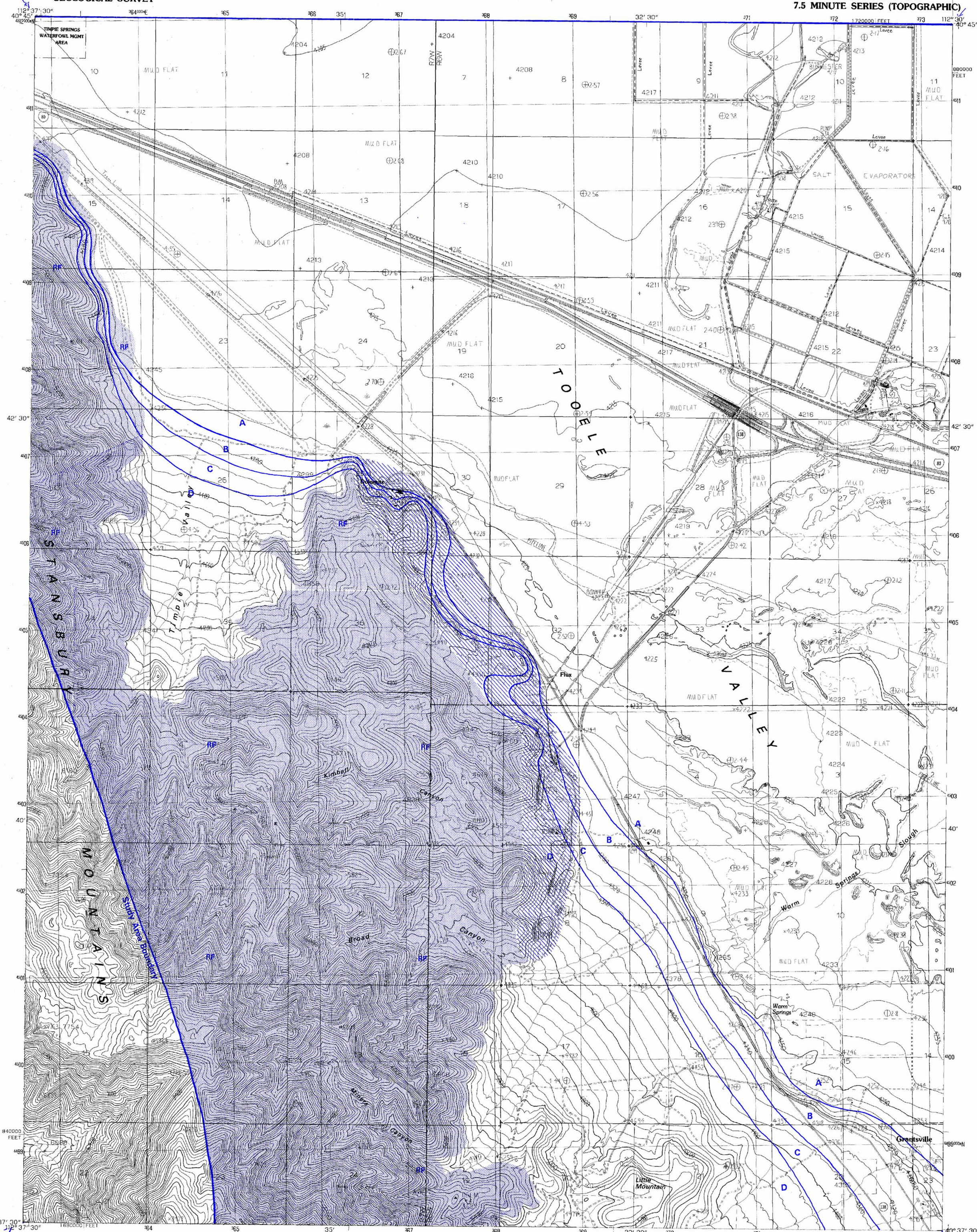
MAPPED BY KIMM M. HARTY AND BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 4B
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATE OF UTAH
UTAH GEOLOGICAL AND MINERAL SURVEY

FLUX QUADRANGLE
UTAH–TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)



PRODUCED BY THE UNITED STATES GEOLOGICAL SURVEY
CONTROL BY ..... USGS, NOS/NOAA
COMPILED FROM AERIAL PHOTOGRAPHS TAKEN 1980
FIELD CHECKED ..... 1981 MAP EDITED 1985
PROJECTION ..... LAMBERT CONFORMAL CONIC
GRID: 1000-METER UNIVERSAL TRANSVERSE MERCATOR ..... ZONE 12
10,000-FOOT STATE GRID TICKS ..... UTAH, CENTRAL ZONE
UTM GRID DECLINATION ..... 1°01' WEST
1985 MAGNETIC NORTH DECLINATION ..... 15° EAST
VERTICAL DATUM ..... NATIONAL GEODETIC VERTICAL DATUM OF 1929
HORIZONTAL DATUM ..... 1927 NORTH AMERICAN DATUM
To place on the predicted North American Datum of 1983, move the projection lines as shown by dashed corner ticks (10 meters north and 67 meters east)
There may be private inholdings within the boundaries of any Federal and State Reservations shown on this map

PROVISIONAL MAP
Produced from original manuscript drawings. Information shown as of date of field check.

SCALE 1:24 000

CONTOUR INTERVAL 5 AND 40 FEET

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U.S. GEOLOGICAL SURVEY, DENVER, COLORADO, 80225
OR RESTON, VIRGINIA 22092

QUADRANGLE LOCATION

1	2	3	1 Poverty Point 2 Corral Canyon 3 Flag Peak 4 Timpie 5 Burmester 6 Salt Mountain 7 North Willow Canyon 8 Grantsville
4		5	
6	7	8	

ADJOINING 7.5 QUADRANGLE NAMES

EXPLANATION

Rock fall

RF * Potentially subject to impact by rock fall (crosshatched area not studied).

Depth to ground water

A* Less than 10 feet (3 m).

B 10 to 30 feet (3-9 m).

C 30 to 50 feet (9-15 m).

D Greater than 50 feet (15 m).

* Special studies are recommended in areas subject to rock fall and where the depth to ground water is less than 10 feet (3 m) (see table 1).

ROAD LEGEND

Improved Road .....
Unimproved Road .....
Trail .....
Interstate Route U.S. Route State Route

FLUX, UTAH

PROVISIONAL EDITION 1985

40112-F5-TF-024

TOOELE VALLEY
NORTHERN RUSH VALLEY

Depth to ground water, Burmester quadrangle, Tooele County, Utah.

COMPILED BY BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 4C
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

BURMESTER QUADRANGLE
UTAH—TOOELE CO.
7.5 MINUTE SERIES ORTHOPHOTOMAP (TOPOGRAPHIC)

Study Area Boundary

Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Planimetry by photogrammetric methods from aerial photographs taken 1953. Topography by planetable surveys 1923 and 1955
Revision and orthophotomosaic from aerial photographs taken 1971
Field checked 1972

Underwater contours by photogrammetric methods from aerial photographs taken 1966, 1969, and 1971–72

Projection and 10,000-foot grid ticks: Utah coordinate system, central zone (Lambert conformal conic)
1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue. 1927 North American datum

UTM GRID AND 1972 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 5 FEET
DATUM IS MEAN SEA LEVEL

ROAD CLASSIFICATION

Primary highway, hard surface
Secondary highway, hard surface
Light-duty road, hard or improved surface
Unimproved road
Interstate Route U. S. Route State Route

UTAH
QUADRANGLE LOCATION

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A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

BURMESTER, UTAH
N4037.5—W11222.5/7.5

1972

AMS 3565 III NW—SERIES V8970

EXPLANATION

Depth to ground water

A*	Less than 10 feet (3 m).
B	10 to 30 feet (3-9 m).
C	30 to 60 feet (9-15 m).
D	Greater than 60 feet (15 m).

* Special studies are recommended in areas where the depth to ground water is less than 10 feet (3 m) (see table 1).

TOOELE VALLEY
NORTHERN RUSH VALLEY

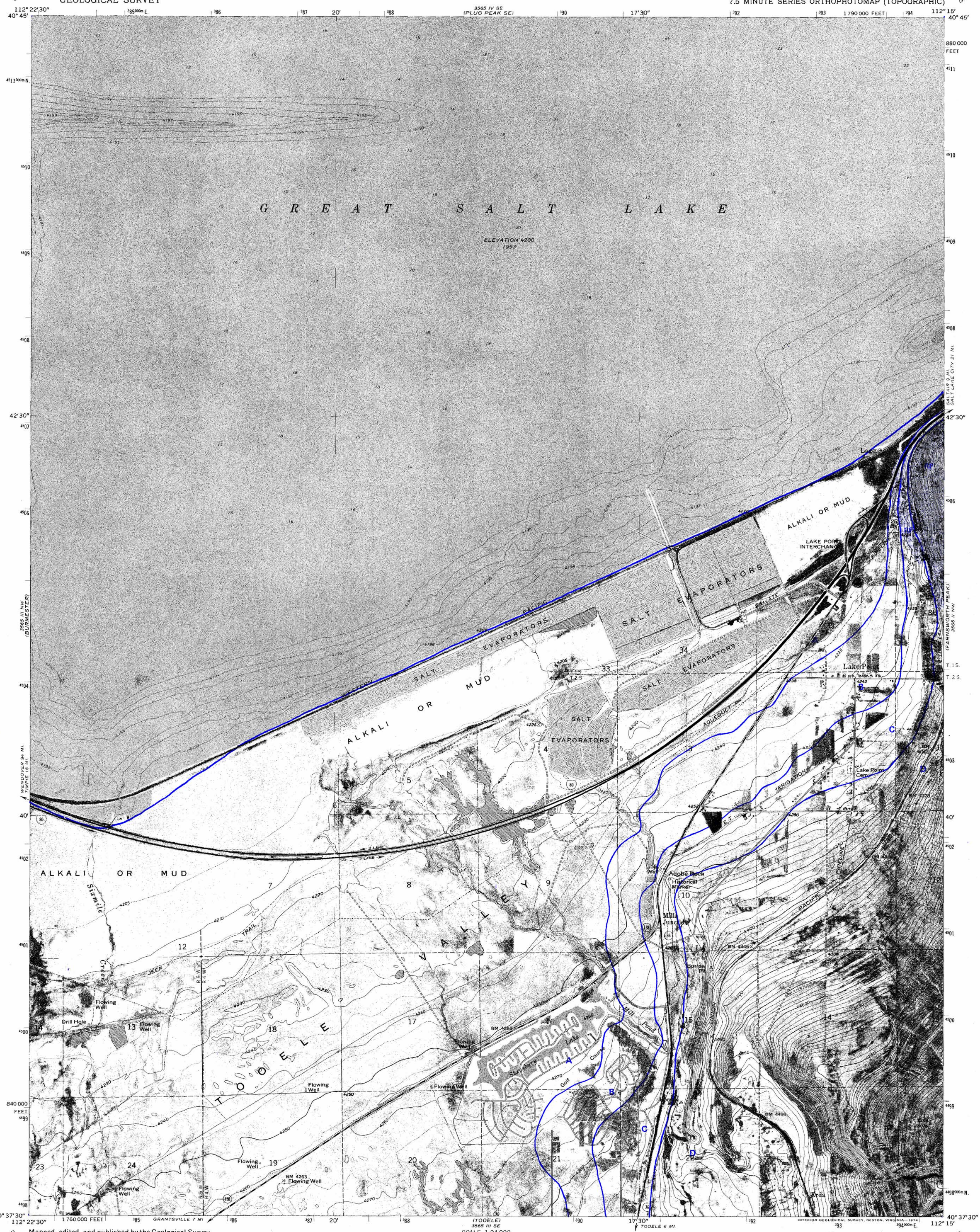
Rock-fall hazard and depth to ground water, Mills Junction quadrangle, Tooele County, Utah.

MAPPED BY KIMM M. HARTY AND BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 4D
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

MILLS JUNCTION QUADRANGLE
UTAH—TOOELE CO.
7.5 MINUTE SERIES ORTHOPHOTOMAP (TOPOGRAPHIC)



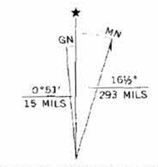
Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Topography by photogrammetric methods from aerial photographs taken 1953 and by planetable surveys 1923–24 and 1955
Revision and orthophotomosaic from aerial photographs taken 1971
Field checked 1972

Underwater contours by photogrammetric methods from aerial photographs taken 1966, 1969, and 1971–72. Soundings compiled from chart furnished by U.S. Naval Reserve

Projection and 10,000-foot grid ticks: Utah coordinate system, central zone (Lambert conformal conic)
1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue. 1927 North American datum



UTM GRID AND 1972 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

1 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER

CONTOUR INTERVAL 10 FEET
DOTTED LINES REPRESENT 5-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL
SOUNDINGS IN FEET—DATUM IS LAKE ELEVATION 4200 FEET

QUADRANGLE LOCATION

ROAD CLASSIFICATION

Primary highway, hard surface
Secondary highway, hard surface
Light-duty road, hard or improved surface
Unimproved road
Interstate Route U. S. Route State Route

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
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DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

EXPLANATION

Rock fall

rf * Potentially subject to impact by rock fall.

Depth to ground water

A* Less than 10 feet (3 m).

B 10 to 30 feet (3-9 m).

C 30 to 50 feet (9-15 m).

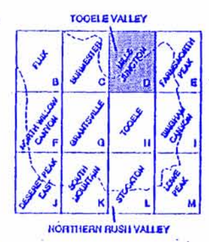
D Greater than 50 feet (15 m).

* Special studies are recommended in areas subject to rock fall and where the depth to ground water is less than 10 feet (3 m) (see table 1).

MILLS JUNCTION, UTAH
N4037.5—W11215/7.5

1972

AMS 3565 III NE SERIES V8970



ISBN 0-607-54709-2

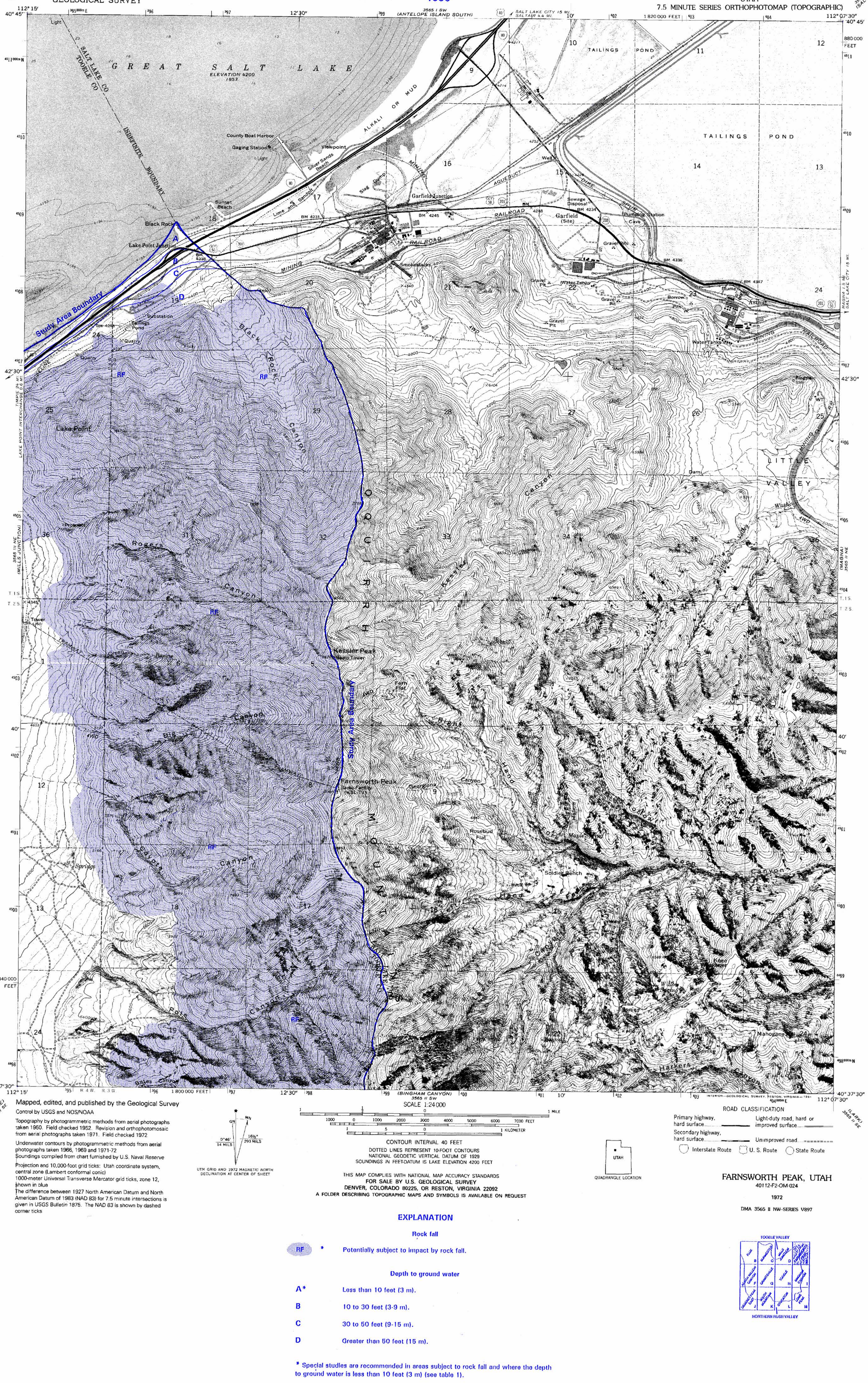
Rock-fall hazard and depth to ground water, Farnsworth Peak quadrangle, Tooele County, Utah.

MAPPED BY KIMM M. HARTY AND BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 4E
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

FARNSWORTH PEAK QUADRANGLE
UTAH
7.5 MINUTE SERIES ORTHOPHOTOMAP (TOPOGRAPHIC)



Mapped, edited, and published by the Geological Survey

Control by USGS and NOS/NOAA

Topography by photogrammetric methods from aerial photographs taken 1950. Field checked 1952. Revision and orthophotomosaic from aerial photographs taken 1971. Field checked 1972

Underwater contours by photogrammetric methods from aerial photographs taken 1966, 1969 and 1971-72
Soundings compiled from chart furnished by U.S. Naval Reserve

Projection and 10,000-foot grid ticks: Utah coordinate system, central zone (Lambert conformal conic)
1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue
The difference between 1927 North American Datum and North American Datum of 1983 (NAD 83) for 7.5 minute intersections is given in USGS Bulletin 1875. The NAD 83 is shown by dashed corner ticks

UTM GRID AND 1972 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24000

CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 10-FOOT CONTOURS
NATIONAL GEODETIC VERTICAL DATUM OF 1929
SOUNDINGS IN FEET-DATUM IS LAKE ELEVATION 4200 FEET

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
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A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

QUADRANGLE LOCATION

ROAD CLASSIFICATION
Primary highway, hard surface
Secondary highway, hard surface
Light-duty road, hard or improved surface
Unimproved road
Interstate Route U. S. Route State Route

FARNSWORTH PEAK, UTAH
40112-F2-OM-024
1972
DMA 3565 II NW-SERIES V897

TOOELE VALLEY
NORTHERN RUSH VALLEY

EXPLANATION

Rock fall

RF * Potentially subject to impact by rock fall.

Depth to ground water

A* Less than 10 feet (3 m).

B 10 to 30 feet (3-9 m).

C 30 to 50 feet (9-15 m).

D Greater than 50 feet (15 m).

* Special studies are recommended in areas subject to rock fall and where the depth to ground water is less than 10 feet (3 m) (see table 1).

Rock-fall hazard and depth to ground water, North Willow Canyon quadrangle, Tooele County, Utah.

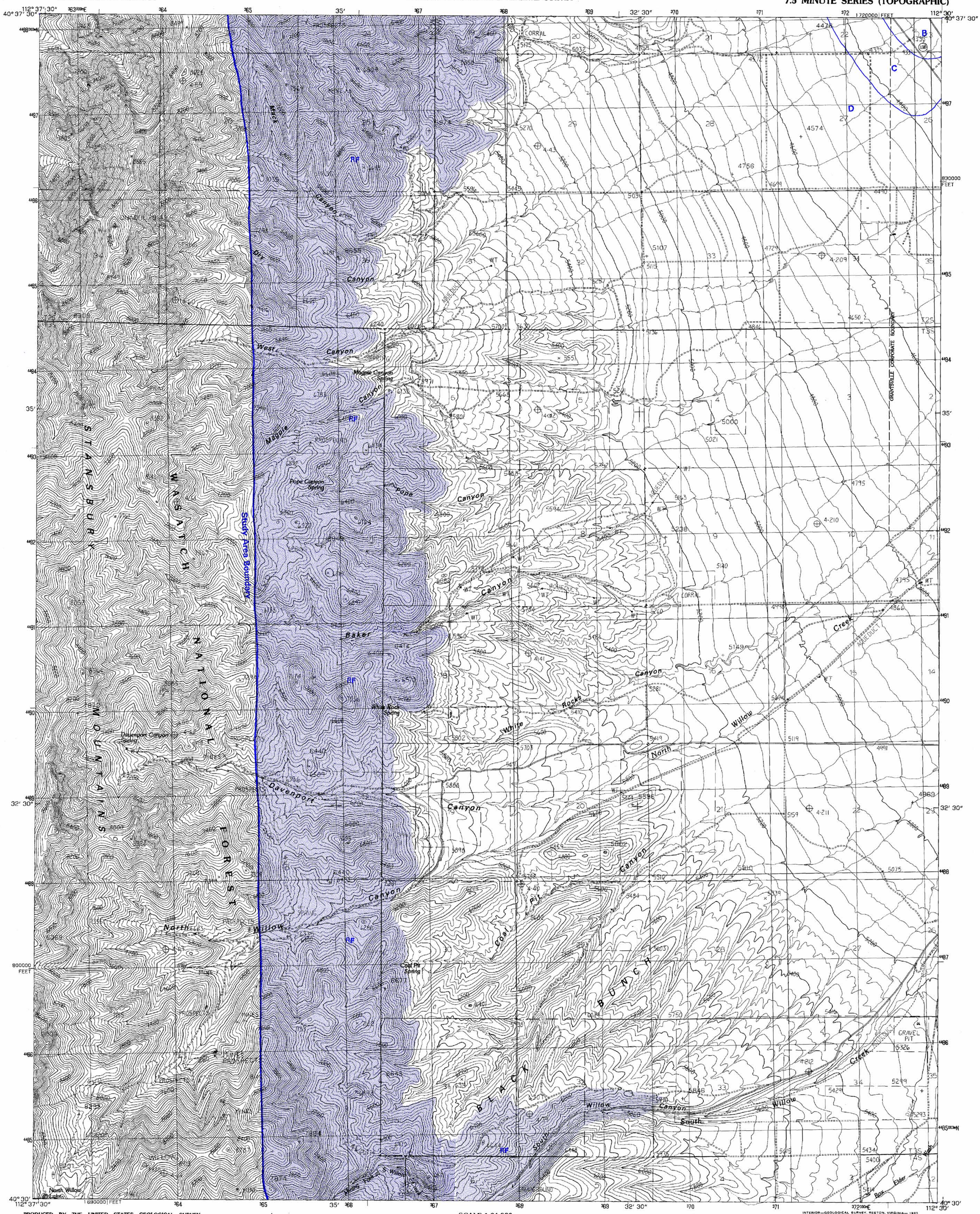
MAPPED BY KIMM M. HARTY AND BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 4F
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATE OF UTAH
UTAH GEOLOGICAL AND MINERAL SURVEY

NORTH WILLOW CANYON QUADRANGLE
UTAH–TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)



SCALE 1:24 000

NORTH

CONTOUR INTERVAL 40 FEET

PRODUCED BY THE UNITED STATES GEOLOGICAL SURVEY
CONTROL BY ..... USGS, NOS/NOAA
COMPILED FROM AERIAL PHOTOGRAPHS TAKEN 1980
FIELD CHECKED ..... 1981 MAP EDITED 1985
PROJECTION ..... LAMBERT CONFORMAL CONIC
GRID: 1000-METER UNIVERSAL TRANSVERSE MERCATOR ..... ZONE 12
10,000-FOOT STATE GRID TICKS ..... UTAH, CENTRAL ZONE
UTM GRID DECLINATION ..... 1°01' WEST
1985 MAGNETIC NORTH DECLINATION ..... 15° EAST
VERTICAL DATUM ..... NATIONAL GEODETIC VERTICAL DATUM OF 1929
HORIZONTAL DATUM ..... 1927 NORTH AMERICAN DATUM

To place on the predicted North American Datum of 1983, move the projection lines as shown by dashed corner ticks (10 meters north and 67 meters east)

There may be private inholdings within the boundaries of any Federal and State Reservations shown on this map

Where omitted, land lines have not been established

PROVISIONAL MAP
Produced from original manuscript drawings. Information shown as of date of field check. 2

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U.S. GEOLOGICAL SURVEY, DENVER, COLORADO. 80225
OR RESTON, VIRGINIA 22092

UTAH

QUADRANGLE LOCATION

1	2	3	1 Timpie 2 Flux 3 Burmester 4 Salt Mountain 5 Grantsville 6 Deseret Peak West 7 Deseret Peak East 8 South Mountain
4		5	
6	7	8	

ADJOINING 7.5 QUADRANGLE NAMES

TOOELE VALLEY

NORTHERN RUSH VALLEY

EXPLANATION

Rock fall

RF * Potentially subject to impact by rock fall.

Depth to ground water

A* Less than 10 feet (3 m).

B 10 to 30 feet (3-9 m).

C 30 to 50 feet (9-15 m).

D Greater than 50 feet (15 m).

* Special studies are recommended in areas subject to rock fall and where the depth to ground water is less than 10 feet (3 m) (see table 1).

ROAD LEGEND

Improved Road .....
Unimproved Road .....
Trail .....

Interstate Route U.S. Route State Route

NORTH WILLOW CANYON, UTAH

PROVISIONAL EDITION 1985

40112-E5-TF-024

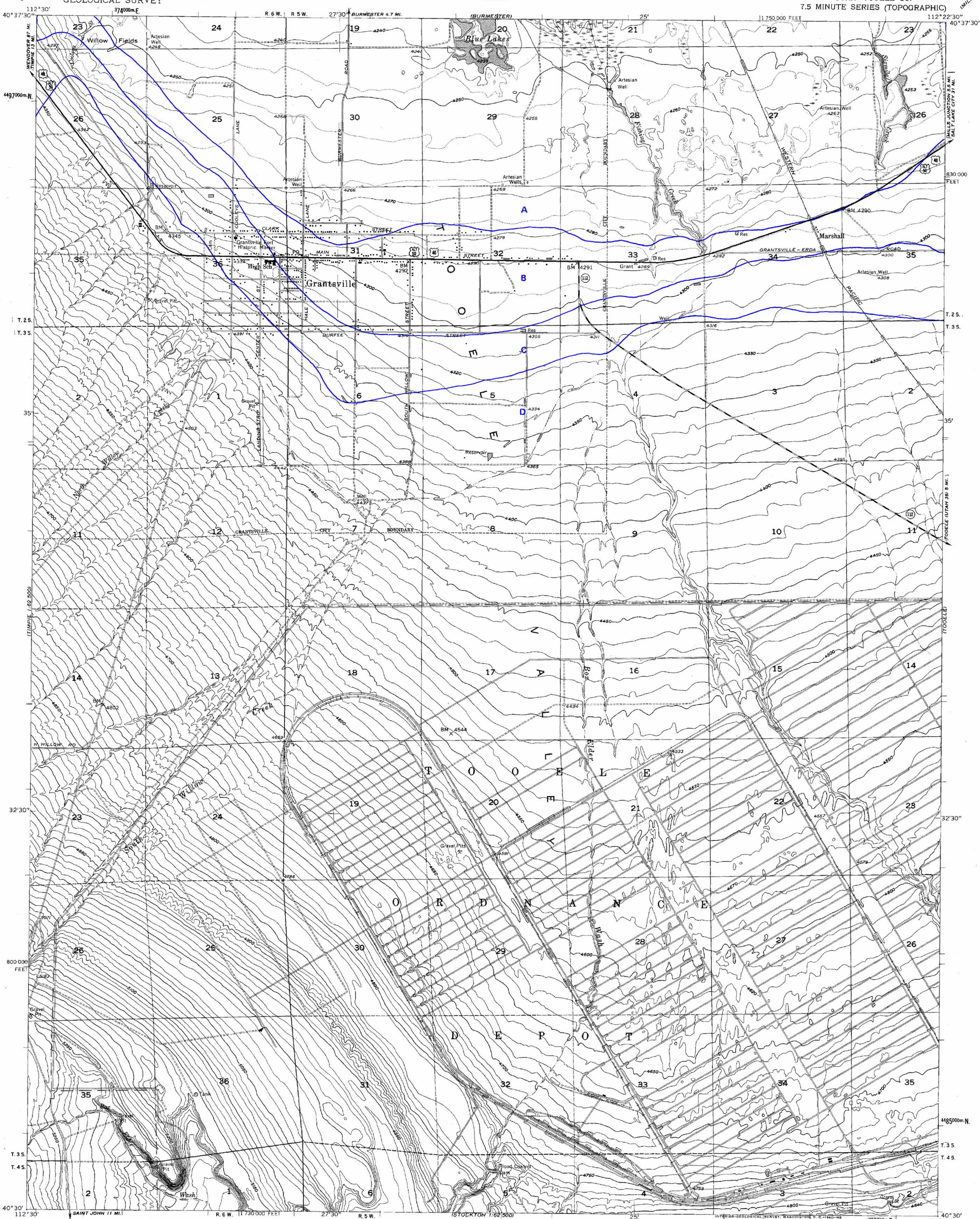
Depth to ground water, Grantsville quadrangle, Tooele County, Utah.

MAPPED BY BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 4G
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

GRANTSVILLE QUADRANGLE
UTAH—TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)



Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Topography from planetable surveys 1923 and by Kelsh plotter from aerial photographs taken 1953. Field check 1955

Polyconic projection. 1927 North American datum
10,000-foot grid based on Utah coordinate system, central zone

1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue

Dashed land lines indicate approximate locations

17° TRUE NORTH MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 1955

SCALE 1:24000

1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 KILOMETER

CONTOUR INTERVAL 10 FEET
DASHED LINES REPRESENT 5-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

ROAD CLASSIFICATION

Heavy-duty ——— Light-duty ———
Medium-duty ——— Unimproved dirt - - - - -
U. S. Route State Route

UTAH
QUADRANGLE LOCATION

GRANTSVILLE, UTAH
N4030—W11222.5/7.5

1955

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
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A FOLDEH DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

EXPLANATION

Depth to ground water

A*	Less than 10 feet (3 m).
B	10 to 30 feet (3-9 m).
C	30 to 50 feet (9-15 m).
D	Greater than 50 feet (15 m).

* Special studies are recommended in areas where the depth to ground water is less than 10 feet (3 m) (see table 1).

TOOELE VALLEY
FLUX · BURMESTER · MILLS JUNCTION · FARNSWORTH PEAK
NORTH WILLOW CANYON · GRANTSVILLE · TOOELE · SIMPSON SUMMIT
DESERET PEAK EAST · SOUTH MOUNTAIN · STOCKTON · LOOKE PEAK
NORTHERN RUSH VALLEY

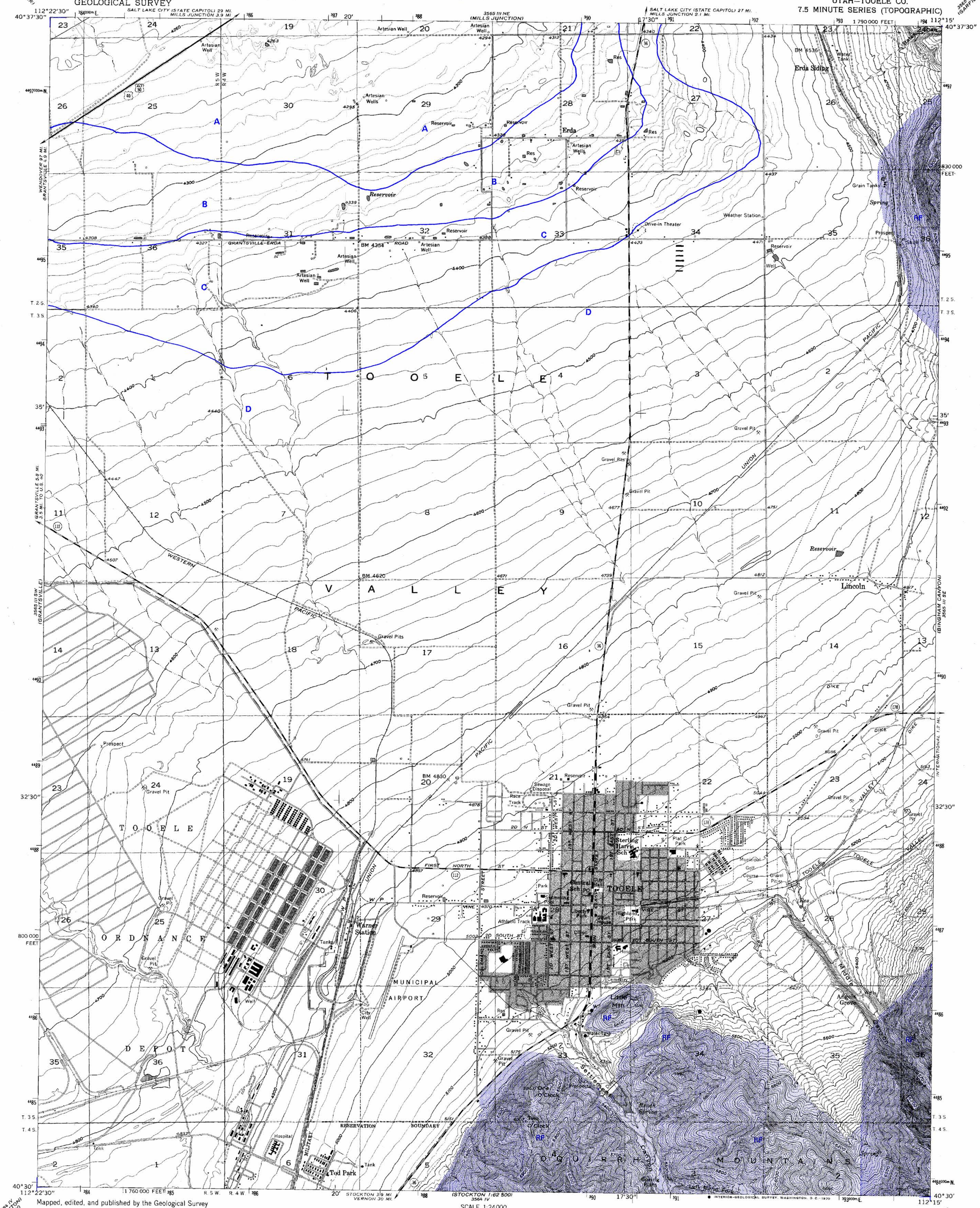
Rock-fall hazard and depth to ground water, Tooele quadrangle, Tooele County, Utah.

MAPPED BY KIMM M. HARTY AND BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 4H
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

TOOELE QUADRANGLE
UTAH—TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)



Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Culture and drainage compiled from aerial photographs taken 1953
Topography by planetable surveys 1923–24 and by photogrammetric methods
Contour revision and field check 1955

Polyconic projection. 1927 North American datum
10,000-foot grid based on Utah coordinate system, central zone

1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue

Red tint indicates areas in which only landmark buildings are shown

Dashed land lines indicate approximate locations

Revisions shown in purple compiled from aerial photographs taken 1969. This information not field checked

Purple tint indicates extension of urban areas

UTM GRID AND 1969 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24000

1 MILE
7000 FEET
1 KILOMETER

CONTOUR INTERVAL 20 FEET
DASHED LINES REPRESENT 5-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

ROAD CLASSIFICATION

Heavy-duty
Medium-duty
Light-duty
Unimproved dirt
U. S. Route
State Route

UTAH
QUADRANGLE LOCATION

TOOELE, UTAH
N4030—W11215/7.5

1955
PHOTOREVISED 1969

AMS 3565 III SE—SERIES V897

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
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A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

EXPLANATION

Rock fall

RF * Potentially subject to impact by rock fall.

Depth to ground water

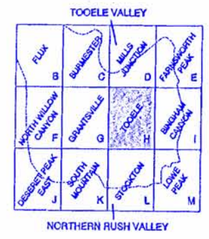
A* Less than 10 feet (3 m).

B 10 to 30 feet (3-9 m).

C 30 to 50 feet (9-15 m).

D Greater than 50 feet (15 m).

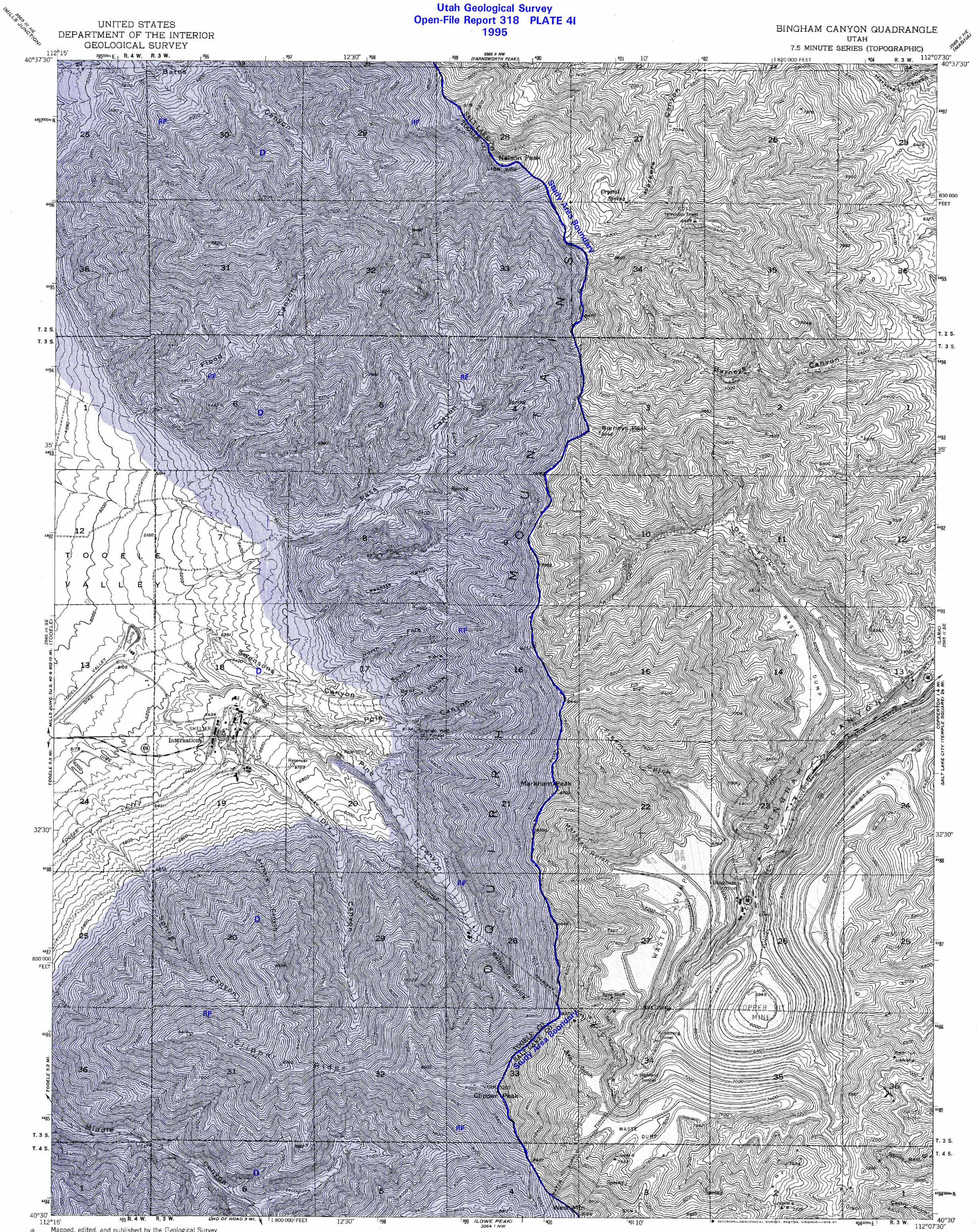
* Special studies are recommended in areas subject to rock fall and where the depth to ground water is less than 10 feet (3 m) (see table 1).



Rock-fall hazard and depth to ground water, Bingham Canyon quadrangle, Tooele County, Utah.

MAPPED BY KIMM M. HARTY
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 4I
1995



Mapped, edited, and published by the Geological Survey

Control by USGS and NOS/NOAA

Topography from aerial photographs by photogrammetric methods
Aerial photographs taken 1950. Field check 1952, except contour and track detail in open pit mine which is subject to frequent change

Polyconic projection. 1927 North American datum
10,000-foot grid based on Utah coordinate system, central zone

Dashed land lines indicate approximate locations

Unchecked elevations are shown in brown

1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue

Revisions shown in purple compiled from aerial photographs taken 1969 and 1975. This information not field checked

UTM GRID AND 1975 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

ROAD CLASSIFICATION

Medium-duty ——— Light-duty ———

Unimproved dirt - - - - - -

State Route

UTAH

QUADRANGLE LOCATION

BINGHAM CANYON, UTAH
N4030—W11207 5/7.5

1952
PHOTOREVISED 1969 AND 1975
AMS 3565 II SW—SERIES V897

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

TOOELE VALLEY
FLUX B · BURMESTER C · MILLS JUNCTION D · FARNSWORTH PEAK E
MOUTH WILLOW CANYON F · GRANTSVILLE G · TOOELE H · BINGHAM CANYON I
DESERET PEAK EAST J · SOUTH MOUNTAIN K · STOCKTON L · LONE PEAK M
NORTHERN RUSH VALLEY

EXPLANATION

Rock fall

RF * Potentially subject to impact by rock fall.

Depth to ground water

A* Less than 10 feet (3 m).

B 10 to 30 feet (3-9 m).

C 30 to 50 feet (9-15 m).

D Greater than 50 feet (15 m).

* Special studies are recommended in areas subject to rock fall and where the depth to ground water is less than 10 feet (3 m) (see table 1).

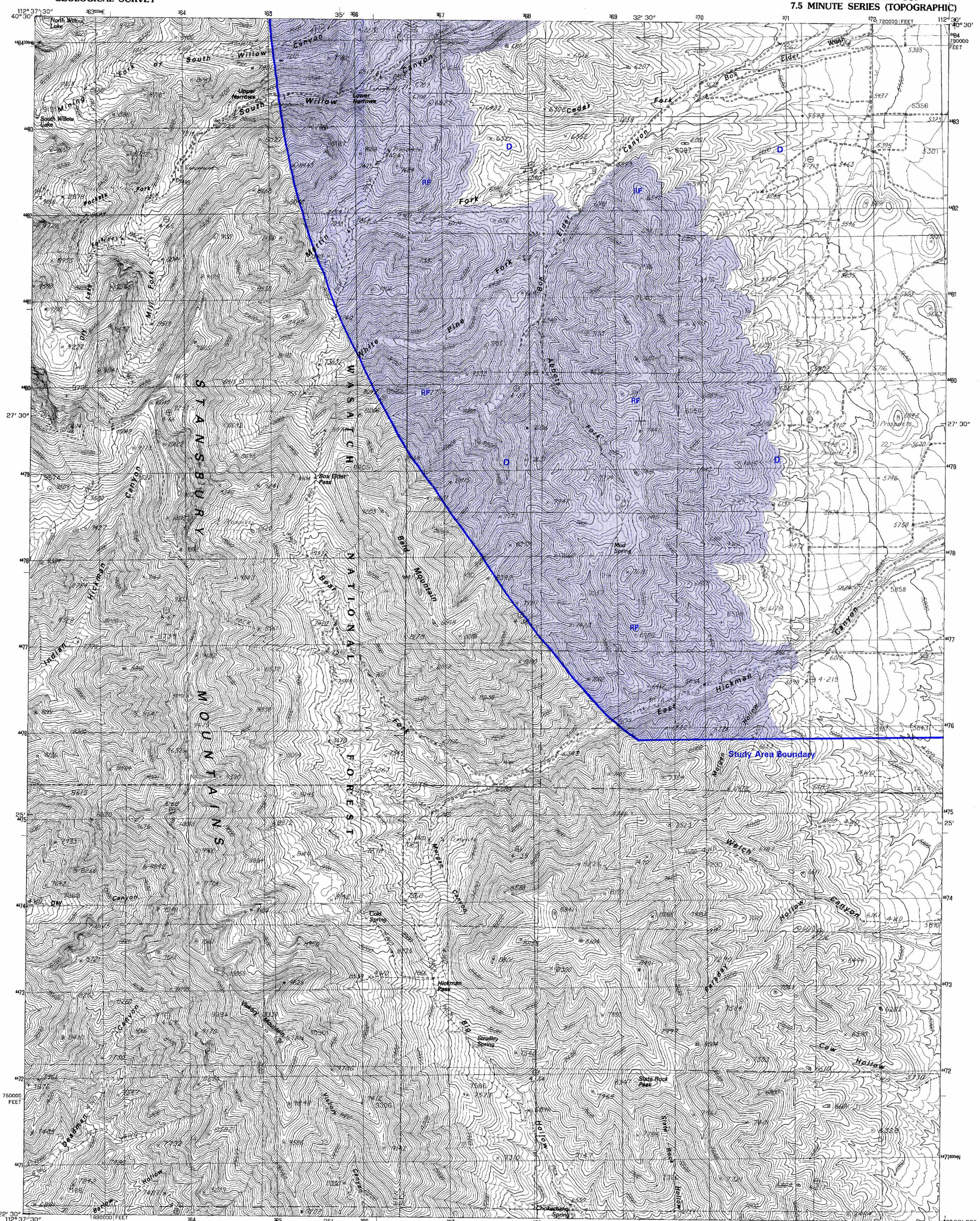
Rock-fall hazard and depth to ground water, Deseret Peak East quadrangle, Tooele County, Utah.

MAPPED BY KIMM M. HARTY
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 4J
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

DESERET PEAK EAST QUADRANGLE
UTAH–TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)



PRODUCED BY THE UNITED STATES GEOLOGICAL SURVEY
CONTROL BY .... USGS, NOS/NOAA
COMPILED FROM AERIAL PHOTOGRAPHS TAKEN 1980
FIELD CHECKED .... 1981 MAP EDITED 1985
PROJECTION .... LAMBERT CONFORMAL CONIC
GRID: 1000-METER UNIVERSAL TRANSVERSE MERCATOR .... ZONE 12
10,000-FOOT STATE GRID TICKS .... UTAH, CENTRAL ZONE
UTM GRID DECLINATION .... 1°01' WEST
1985 MAGNETIC NORTH DECLINATION .... 15° EAST
VERTICAL DATUM .... NATIONAL GEODETIC VERTICAL DATUM OF 1929
HORIZONTAL DATUM .... 1927 NORTH AMERICAN DATUM
To place on the predicted North American Datum of 1983, move the projection lines as shown by dashed corner ticks (10 meters north and 67 meters east)
There may be private inholdings within the boundaries of any Federal and State Reservations shown on this map
Where omitted, land lines have not been established

NORTH

PROVISIONAL MAP
Produced from original manuscript drawings. Information shown as of date of field check. 2

SCALE 1:24 000
1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 KILOMETER

CONTOUR INTERVAL 40 FEET

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U.S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225
OR RESTON, VIRGINIA 22092

UTAH
QUADRANGLE LOCATION

1	2	3	1 Salt Mountain 2 North Willow Canyon 3 Grantsville 4 Deseret Peak West 5 South Mountain 6 Terra 7 Johnson Pass 8 Saint John
4		5	
6	7	8	

ADJOINING 7.5 QUADRANGLE NAMES

INTERIOR—GEOLOGICAL SURVEY, RESTON, VIRGINIA—1985

ROAD LEGEND
Improved Road
Unimproved Road
Trail
Interstate Route U.S. Route State Route

DESERET PEAK EAST, UTAH
PROVISIONAL EDITION 1985
40112-D5-TF-024

EXPLANATION

Rock fall

RF * Potentially subject to impact by rock fall.

Depth to ground water

A* Less than 10 feet (3 m).
B 10 to 30 feet (3-9 m).
C 30 to 50 feet (9-15 m).
D Greater than 50 feet (15 m).

* Special studies are recommended in areas subject to rock fall and where the depth to ground water is less than 10 feet (3 m) (see table 1).

Rock-fall hazard and depth to ground water, South Mountain quadrangle, Tooele County, Utah.

MAPPED BY KIMM M. HARTY AND BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 4K
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

SOUTH MOUNTAIN QUADRANGLE
UTAH-TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)

3565 III SE (NORTH WILLOW CANYON)
3565 III SW (GRANTSVILLE)
3565 III SE (TOOELE)
3564 I NE (DESERET PEAK EAST)
3564 IV NW (STOCKTON)
3564 IV SW (SAINT JOHN)
3564 I SW (JOHNSON PASS)
3564 IV SE (OPHIR)

Study Area Boundary

RF — Potentially subject to impact by rock fall.

Depth to ground water

A*	Less than 10 feet (3 m).
B	10 to 30 feet (3-9 m).
C	30 to 50 feet (9-15 m).
D	Greater than 50 feet (15 m).

* Special studies are recommended in areas subject to rock fall and where the depth to ground water is less than 10 feet (3 m) (see table 1).

Produced by the United States Geological Survey
Control by USGS and NOS/NOAA

Compiled from aerial photographs taken 1974. Revised from aerial photographs taken 1987 and other sources. Field checked 1988
Map edited 1993

1927 North American Datum (NAD 27). Projection and 10 000-foot ticks: Utah Coordinate System, central zone (Lambert Conformal Conic)
Blue 1000-meter Universal Transverse Mercator ticks, zone 12

North American Datum of 1983 (NAD 83) is shown by dashed corner ticks. The values of the shift between NAD 27 and NAD 83 for 7.5-minute intersections are given in USGS Bulletin 1875

There may be private inholdings within the boundaries of the National or State reservations shown on this map

Fine red dashed lines indicate selected fence and field lines where generally visible on aerial photographs

UTM GRID AND 1993 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 20-FOOT CONTOURS
NATIONAL GEODETIC VERTICAL DATUM OF 1929

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

QUADRANGLE LOCATION

ROAD CLASSIFICATION

Primary highway, hard surface
Secondary highway, hard surface
Light-duty road, hard or improved surface
Unimproved road
Interstate Route U. S. Route State Route

SOUTH MOUNTAIN, UTAH
40112-D4-TF-024

1993

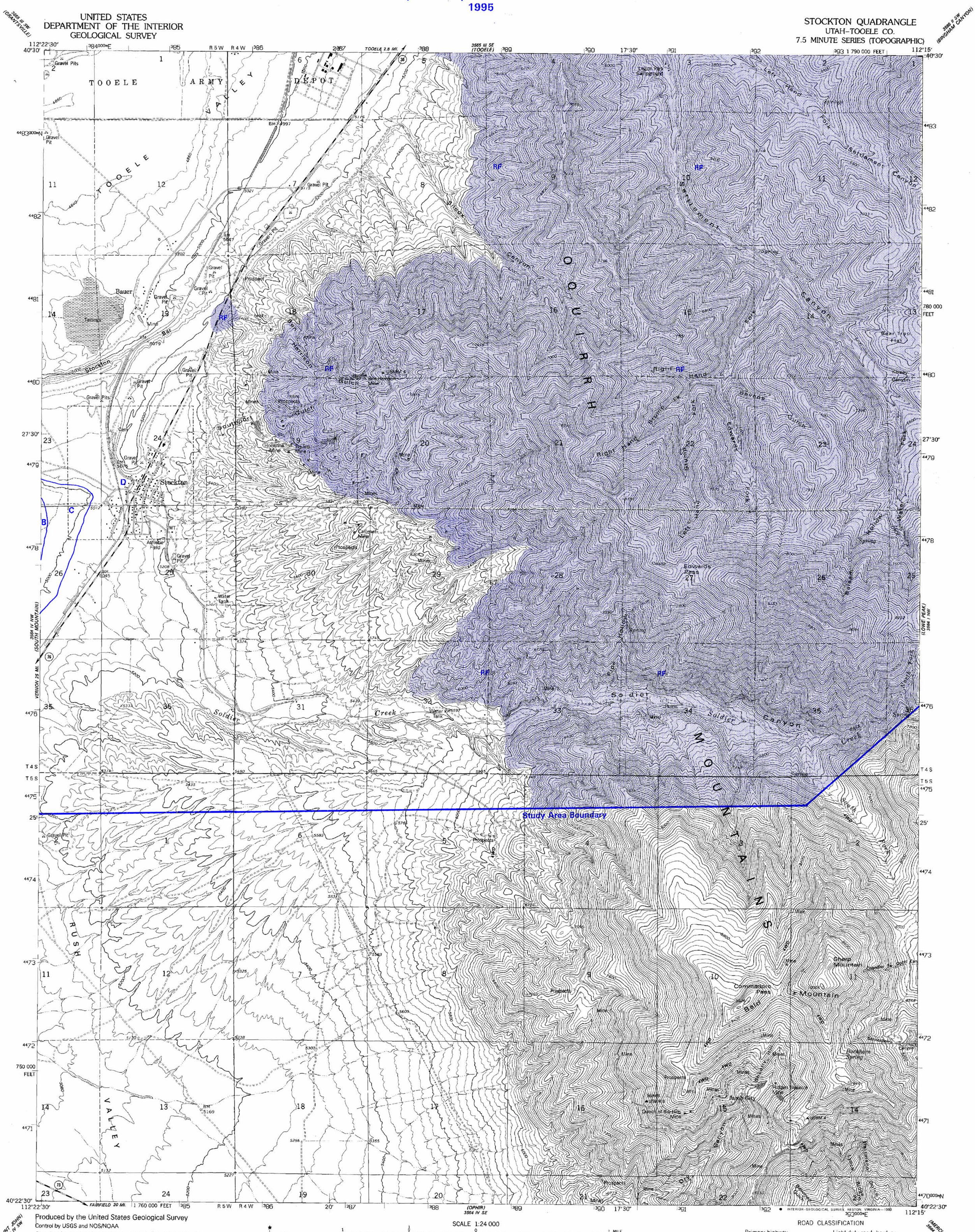
DMA 3564 IV NW-SERIES V897

TOOELE VALLEY
NORTHERN RUSH VALLEY

Rock-fall hazard and depth to ground water, Stockton quadrangle, Tooele County, Utah.

MAPPED BY KIMM M. HARTY AND BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 4L
1995



Produced by the United States Geological Survey
Control by USGS and NOS/NOAA

Compiled from aerial photographs taken 1974. Revised from aerial photographs taken 1987 and other sources. Field checked 1989
Map edited 1993

1927 North American Datum (NAD 27). Projection and 10000-foot ticks: Utah Coordinate System, central zone (Lambert Conformal Conic)
Blue 1000-meter Universal Transverse Mercator ticks, zone 12

North American Datum of 1983 (NAD 83) is shown by dashed corner ticks. The values of the shift between NAD 27 and NAD 83 for 7.5-minute intersections are given in USGS Bulletin 1875

There may be private inholdings within the boundaries of the National or State reservations shown on this map

Fine red dashed lines indicate selected fence and field lines where generally visible on aerial photographs. This information is unchecked

UTM GRID AND 1993 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

1 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER

CONTOUR INTERVAL 40 FEET
SUPPLEMENTARY CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

QUADRANGLE LOCATION

ROAD CLASSIFICATION

Primary highway, hard surface
Secondary highway, hard surface
Light-duty road, hard or improved surface
Unimproved road
Interstate Route
U. S. Route
State Route

EXPLANATION

Rock fall

RF * Potentially subject to impact by rock fall.

Depth to ground water

A* Less than 10 feet (3 m).

B 10 to 30 feet (3-9 m).

C 30 to 50 feet (9-15 m).

D Greater than 50 feet (15 m).

* Special studies are recommended in areas subject to rock fall and where the depth to ground water is less than 10 feet (3 m) (see table 1).

STOCKTON, UTAH
40112-D3-TF-024

1993

DMA 3564 IV NE–SERIES V897

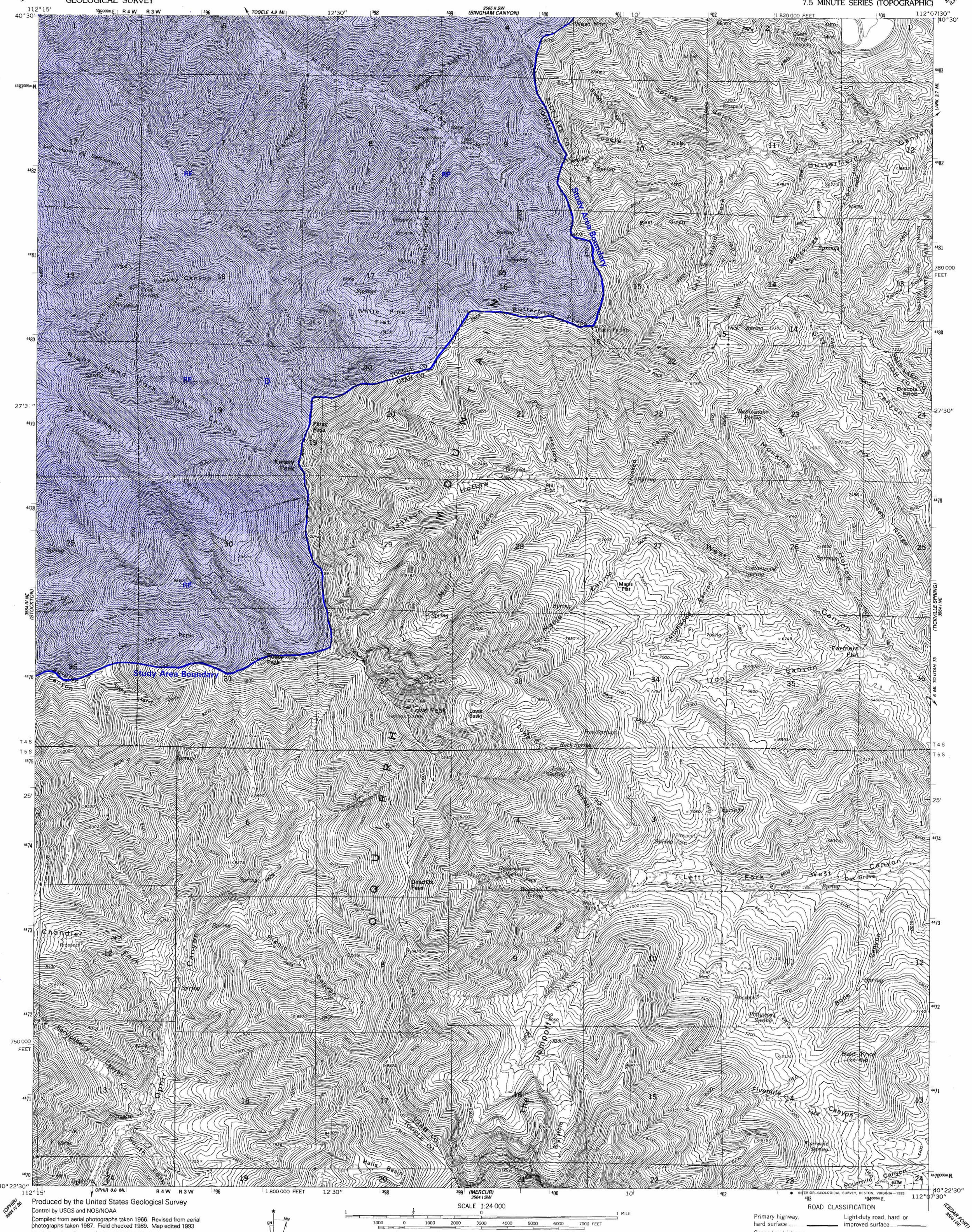
Rock-fall hazard and depth to ground water, Lowe Peak quadrangle, Tooele County, Utah.

MAPPED BY KIMM M. HARTY
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 4M
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

LOWE PEAK QUADRANGLE
UTAH
7.5 MINUTE SERIES (TOPOGRAPHIC)



Produced by the United States Geological Survey
Control by USGS and NOS/NOAA

Compiled from aerial photographs taken 1966. Revised from aerial photographs taken 1987. Field checked 1989. Map edited 1993

North American Datum of 1927 (NAD 27). Projection and 10 000-foot grid ticks: Utah Coordinate System, central zone (Lambert Conformal Conic). 1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue
The difference between NAD 27 and North American Datum of 1983 (NAD 83) for 7.5 minute intersections is given in USGS Bulletin 1875. The NAD 83 is shown by dashed corner ticks

UTM GRID AND 1993 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
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A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

ROAD CLASSIFICATION

Primary highway, hard surface
Secondary highway, hard surface
Light-duty road, hard or improved surface
Unimproved road
Interstate Route
U. S. Route
State Route

QUADRANGLE LOCATION

EXPLANATION

Rock fall

RF * Potentially subject to impact by rock fall.

Depth to ground water

A* Less than 10 feet (3 m).

B 10 to 30 feet (3-9 m).

C 30 to 60 feet (9-15 m).

D Greater than 60 feet (15 m).

* Special studies are recommended in areas subject to rock fall and where the depth to ground water is less than 10 feet (3 m) (see table 1).

LOWE PEAK, UTAH
40112-D2-TF-024

1993

DMA 3564 I NW-SERIES V897

Problem soils, West Desert Hazardous Industry Area, Tooele County, Utah.

COMPILED BY BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 5A
1995

N

Scale 1:50,000

0 1 2 3 4 5 KILOMETERS
0 1 2 3 MILES

NATIONAL GEODETIC VERTICAL DATUM OF 1929
CONTOUR INTERVAL 5 AND 20 METERS

EXPLANATION

XCLAY	Possible expansive soil.
GYP	Possible gypsiferous soil.
GYP/XCLAY	Both possible gypsiferous and expansive soils.

Note: A standard soil investigation is recommended in all areas, including those where expansive and gypsiferous soils are not present (see table 1).

Base map from **BONNEVILLE SALT FLATS** and **TOOELE**, U.S.G.S. 30x60 minute topographic map series.

Problem soils, Flux quadrangle, Tooele County, Utah.

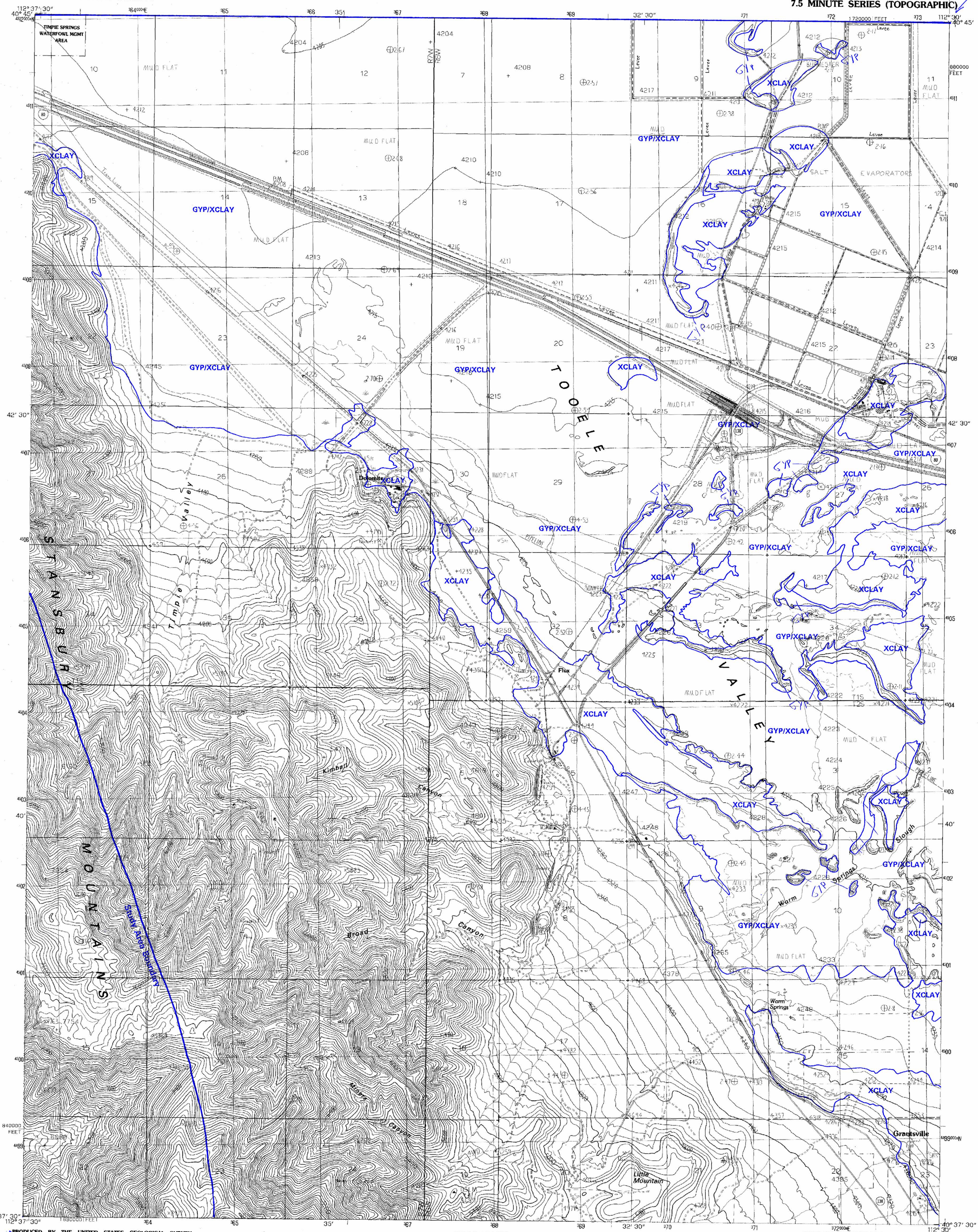
COMPILED BY BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 5B
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATE OF UTAH
UTAH GEOLOGICAL AND MINERAL SURVEY

FLUX QUADRANGLE
UTAH–TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)



PRODUCED BY THE UNITED STATES GEOLOGICAL SURVEY
CONTROL BY ..... USGS, NOS/NOAA
COMPILED FROM AERIAL PHOTOGRAPHS TAKEN 1980
FIELD CHECKED ..... 1981 MAP EDITED 1985
PROJECTION ..... LAMBERT CONFORMAL CONIC
GRID: 1000-METER UNIVERSAL TRANSVERSE MERCATOR ..... ZONE 12
10,000-FOOT STATE GRID TICKS ..... UTAH, CENTRAL ZONE
UTM GRID DECLINATION ..... 1°01' WEST
1985 MAGNETIC NORTH DECLINATION ..... 15° EAST
VERTICAL DATUM ..... NATIONAL GEODETIC VERTICAL DATUM OF 1929
HORIZONTAL DATUM ..... 1927 NORTH AMERICAN DATUM

To place on the predicted North American Datum of 1983, move the projection lines as shown by dashed corner ticks (10 meters north and 67 meters east)

There may be private inholdings within the boundaries of any Federal and State Reservations shown on this map

NORTH

PROVISIONAL MAP
Produced from original manuscript drawings. Information shown as of date of field check.

SCALE 1:24 000

1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 KILOMETER

CONTOUR INTERVAL 5 AND 40 FEET

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U.S. GEOLOGICAL SURVEY, DENVER, COLORADO, 80225
OR RESTON, VIRGINIA 22092

UTAH
QUADRANGLE LOCATION

5 FT. CONTOURS
40 FT. CONTOURS

1	2	3	1 Poverty Point 2 Corral Canyon 3 Plug Peak 4 Timpie 5 Burmester 6 Salt Mountain 7 North Willow Canyon 8 Grantsville
4		5	
6	7	8	

ADJOINING 7.5 QUADRANGLE NAMES

ROAD LEGEND
Improved Road .....
Unimproved Road .....
Trail .....
Interstate Route U.S. Route State Route

INTERIOR—GEOLOGICAL SURVEY, RESTON, VIRGINIA—1985

FLUX, UTAH

PROVISIONAL EDITION 1985

40112-F5-TF-024

EXPLANATION

XCLAY	Possible expansive soil.
GYP	Possible gypsiferous soil.
GYP/XCLAY	Both possible gypsiferous and expansive soils.

Note: A standard soil investigation is recommended in all areas, including those where expansive and gypsiferous soils are not present (see table 1).

Problem soils, Burmester quadrangle, Tooele County, Utah.

COMPILED BY BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 5C
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

BURMESTER QUADRANGLE
UTAH—TOOELE CO.
7.5 MINUTE SERIES ORTHOPHOTOMAP (TOPOGRAPHIC)

Study Area Boundary

GYP/XCLAY

XCLAY

ALKALI OR MUD

GREAT SALT LAKE
ELEVATION 4200
1953

Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Planimetry by photogrammetric methods from aerial photographs taken 1953. Topography by planetable surveys 1923 and 1955
Revision and orthophotomosaic from aerial photographs taken 1971
Field checked 1972

Underwater contours by photogrammetric methods from aerial photographs taken 1966, 1969, and 1971–72

Projection and 10,000-foot grid ticks: Utah coordinate system, central zone (Lambert conformal conic)
1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue. 1927 North American datum

UTM GRID AND 1972 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 5 FEET
DATUM IS MEAN SEA LEVEL

ROAD CLASSIFICATION

Primary highway, hard surface
Secondary highway, hard surface
Light-duty road, hard or improved surface
Unimproved road
Interstate Route U. S. Route State Route

UTAH
QUADRANGLE LOCATION

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR WASHINGTON, D. C. 20242
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

EXPLANATION

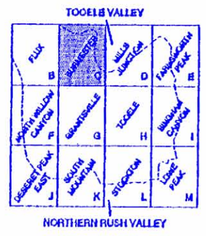
XCLAY	Possible expansive soil.
GYP	Possible gypsiferous soil.
GYP/XCLAY	Both possible gypsiferous and expansive soils.

Note: A standard soil investigation is recommended in all areas, including those where expansive and gypsiferous soils are not present (see table 1).

BURMESTER, UTAH
N4037.5—W11222.5/7.5

1972

AMS 3565 III NW—SERIES V8970



Problem soils, Mills Junction quadrangle, Tooele County, Utah.

COMPILED BY BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 5D
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

MILLS JUNCTION QUADRANGLE
UTAH—TOOELE CO.
7.5 MINUTE SERIES ORTHOPHOTOMAP (TOPOGRAPHIC)

GREAT SALT LAKE

ELEVATION 4200
1953

Study Area Boundary

GYP/XCLAY

XCLAY

ALKALI OR MUD

SALT EVAPORATORS

PACIFIC

WESTERN

TOOELE VALLEY

Lake Point

Lake Point Cem

Adobe Rock
Historical Marker

Mills Junction

Flowing Well

Drill Hole

Stansbury Lake Golf Course

Mill Pond

Erda

2 LANE

JEEP TRAIL

AQUEDUCT

IRRIGATION

R5W R4W

T.1S. T.2S

SALT LAKE CITY 21 MI.

WENDOVER 94 MI.
TIMPIE 16 MI.

GRANTSVILLE 7 MI

TOOELE 6 MI.

(GRANTSVILLE) 3565 III SW

(BINGHAM CANYON) 3565 II SW

3565 IV SW (PLUG PEAK)

3565 IV SE (PLUG PEAK SE)

3565 I SW (ANTELOPE ISLAND SOUTH)

3565 III NW (BURMESTER)

3565 II NW (FARNSWORTH PEAK)

(TOOELE) 3565 III SE

112° 22′ 30″ — 112° 15′ — 40° 45′ — 40° 37′ 30″ — 42′ 30″ — 20′ — 17′ 30″

385 000m E. — 386 — 387 — 388 — 390 — 392 — 393 — 1 790 000 FEET — 394 — 394 000m E.

4511 000m N. — 4511 — 4510 — 4509 — 4508 — 4507 — 4506 — 4505 — 4504 — 4503 — 4502 — 4501 — 4500 — 4499 — 4498 000m N. — 840 000 FEET — 880 000 FEET

Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Topography by photogrammetric methods from aerial photographs taken 1953 and by planetable surveys 1923–24 and 1955
Revision and orthophotomosaic from aerial photographs taken 1971
Field checked 1972

Underwater contours by photogrammetric methods from aerial photographs taken 1966, 1969, and 1971–72. Soundings compiled from chart furnished by U.S. Naval Reserve

Projection and 10,000-foot grid ticks: Utah coordinate system, central zone (Lambert conformal conic)
1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue. 1927 North American datum

GN — MN — 0°51′ 15 MILS — 16½° 293 MILS

UTM GRID AND 1972 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

1 MILE — 1000 0 1000 2000 3000 4000 5000 6000 7000 FEET — 1 KILOMETER

CONTOUR INTERVAL 10 FEET
DOTTED LINES REPRESENT 5-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL
SOUNDINGS IN FEET—DATUM IS LAKE ELEVATION 4200 FEET

UTAH
QUADRANGLE LOCATION

ROAD CLASSIFICATION

Primary highway, hard surface
Secondary highway, hard surface
Light-duty road, hard or improved surface
Unimproved road
Interstate Route — U. S. Route — State Route

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY
DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

EXPLANATION

XCLAY	Possible expansive soil.
GYP	Possible gypsiferous soil.
GYP/XCLAY	Both possible gypsiferous and expansive soils.

Note: A standard soil investigation is recommended in all areas, including those where expansive and gypsiferous soils are not present (see table 1).

MILLS JUNCTION, UTAH
N4037.5—W11215/7.5

1972

AMS 3565 III NE SERIES V8970

TOOELE VALLEY
FLUX (B) — BURMESTER (C) — MILLS JUNCTION (D) — FARNSWORTH PEAK (E)
NORTH MILLCREEK CANYON (F) — GRANTSVILLE (G) — TOOELE (H) — MIDDLE CANYON (I)
DESERET PEAK EAST (J) — SOUTH ACCLAIM (K) — STOCKTON (L) — LAKE PEAK (M)
NORTHERN RUSH VALLEY

ISBN 0-607-54909-2

Problem soils, Grantsville quadrangle, Tooele County, Utah.

COMPILED BY BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 5G
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

GRANTSVILLE QUADRANGLE
UTAH—TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)

(TIMPIE 1:62 500) (MILLS JUNCTION)

112°30′ 40°37′30″ 374000m.E. R. 6 W. R 5 W. 27′30″ 25′ 1 750 000 FEET 112°22′30″ 40°37′30″

4497000m.N. 830 000 FEET

T. 2 S. T. 3 S. 35′ 32′30″ 800 000 FEET 4485000m.N.

40°30′ 112°30′ 40°30′ 112°22′30″

(DESERET PEAK) 1:62 500 (STOCKTON 1:62 500)

SAINT JOHN 11 MI. 1 730 000 FEET (STOCKTON 1:62 500) 383000m.E.

XCLAY

GYP

GYP/XCLAY

Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Topography from planetable surveys 1923 and by Kelsh plotter from aerial photographs taken 1953. Field check 1955

Polyconic projection. 1927 North American datum
10,000-foot grid based on Utah coordinate system, central zone

1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue

Dashed land lines indicate approximate locations

17°
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 1955

SCALE 1:24000

1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 KILOMETER

CONTOUR INTERVAL 10 FEET
DASHED LINES REPRESENT 5-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

UTAH
QUADRANGLE LOCATION

ROAD CLASSIFICATION

Heavy-duty ——— Light-duty ———
Medium-duty ——— Unimproved dirt - - - - -
U. S. Route State Route

INTERIOR-GEOLOGICAL SURVEY, WASHINGTON, D. C.—1960—NS
MR 2059

GRANTSVILLE, UTAH
N4030—W11222.5/7.5

1955

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING *TOPOGRAPHIC MAPS AND SYMBOLS* IS AVAILABLE ON REQUEST

EXPLANATION

XCLAY	Possible expansive soil.
GYP	Possible gypsiferous soil.
GYP/XCLAY	Both possible gypsiferous and expansive soils.

Note: A standard soil investigation is recommended in all areas, including those where expansive and gypsiferous soils are not present (see table 1).

TOOELE VALLEY

FLUX B	BURMESTER C	MILLS JUNCTION D	FARNSWORTH PEAK E	
NORTH WILLOW CANYON F	GRANTSVILLE G	TOOELE H	ERDA I	
DESERET PEAK EAST J	SOUTH MOUNTAIN K	STOCKTON L	LOOP PEAK M	

NORTHERN RUSH VALLEY

Problem soils, Tooele quadrangle, Tooele County, Utah.

COMPILED BY BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 5H
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

TOOELE QUADRANGLE
UTAH—TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)

Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Culture and drainage compiled from aerial photographs taken 1953
Topography by planetable surveys 1923–24 and by photogrammetric methods
Contour revision and field check 1955

Polyconic projection. 1927 North American datum
10,000-foot grid based on Utah coordinate system, central zone

1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue

Red tint indicates areas in which only landmark buildings are shown

Dashed land lines indicate approximate locations

Revisions shown in purple compiled from aerial photographs taken 1969. This information not field checked

Purple tint indicates extension of urban areas

UTM GRID AND 1969 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24000

CONTOUR INTERVAL 20 FEET
DASHED LINES REPRESENT 5-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

ROAD CLASSIFICATION

Heavy-duty ——— Light-duty ———
Medium-duty ——— Unimproved dirt - - - -
U. S. Route State Route

UTAH
QUADRANGLE LOCATION

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

TOOELE, UTAH
N4030—W11215/7.5

1955
PHOTOREVISED 1969

AMS 3565 III SE–SERIES V897

EXPLANATION

XCLAY	Possible expansive soil.
GYP	Possible gypsiferous soil.
GYP/XCLAY	Both possible gypsiferous and expansive soils.

Note: A standard soil investigation is recommended in all areas, including those where expansive and gypsiferous soils are not present (see table 1).

TOOELE VALLEY
NORTHERN RUSH VALLEY

Problem soils, South Mountain quadrangle, Tooele County, Utah.

COMPILED BY BILL D. BLACK
DRAFTED BY NOAH P. SNYDER

Utah Geological Survey
Open-File Report 318 PLATE 5K
1995

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

SOUTH MOUNTAIN QUADRANGLE
UTAH-TOOELE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)

XCLAY

XCLAY

XCLAY

Study Area Boundary

Produced by the United States Geological Survey
Control by USGS and NOS/NOAA

Compiled from aerial photographs taken 1974. Revised from aerial photographs taken 1987 and other sources. Field checked 1988
Map edited 1993

1927 North American Datum (NAD 27). Projection and 10000-foot ticks: Utah Coordinate System, central zone (Lambert Conformal Conic)
Blue 1000-meter Universal Transverse Mercator ticks, zone 12

North American Datum of 1983 (NAD 83) is shown by dashed corner ticks. The values of the shift between NAD 27 and NAD 83 for 7.5-minute intersections are given in USGS Bulletin 1875

There may be private inholdings within the boundaries of the National or State reservations shown on this map

Fine red dashed lines indicate selected fence and field lines where generally visible on aerial photographs

UTM GRID AND 1993 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 20-FOOT CONTOURS
NATIONAL GEODETIC VERTICAL DATUM OF 1929

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

ROAD CLASSIFICATION

Primary highway, hard surface
Secondary highway, hard surface
Light-duty road, hard or improved surface
Unimproved road
Interstate Route
U. S. Route
State Route

QUADRANGLE LOCATION

SOUTH MOUNTAIN, UTAH
40112-D4-TF-024

1993

DMA 3564 IV NW-SERIES V897

EXPLANATION

XCLAY	Possible expansive soil.
GYP	Possible gypsiferous soil.
GYP/XCLAY	Both possible gypsiferous and expansive soils.

Note: A standard soil investigation is recommended in all areas, including those where expansive and gypsiferous soils are not present (see table 1).

TOOELE VALLEY
NORTHERN RUSH VALLEY