U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared in cooperation with the
COLORADO DEPARTMENT OF NATURAL RESOURCES,
DIVISION OF WATER RESOURCES, and the
COLORADO WATER CONSERVATION BOARD

HYDROLOGIC INVESTIGATIONS ATLAS HA–746D
Thickness of unconsolidated sediments—SHEET 1 of 5
Robson, S.G., and others, 2000, Geohydrology of the shallow aquifers in the Boulder–Longmont area, Colorado

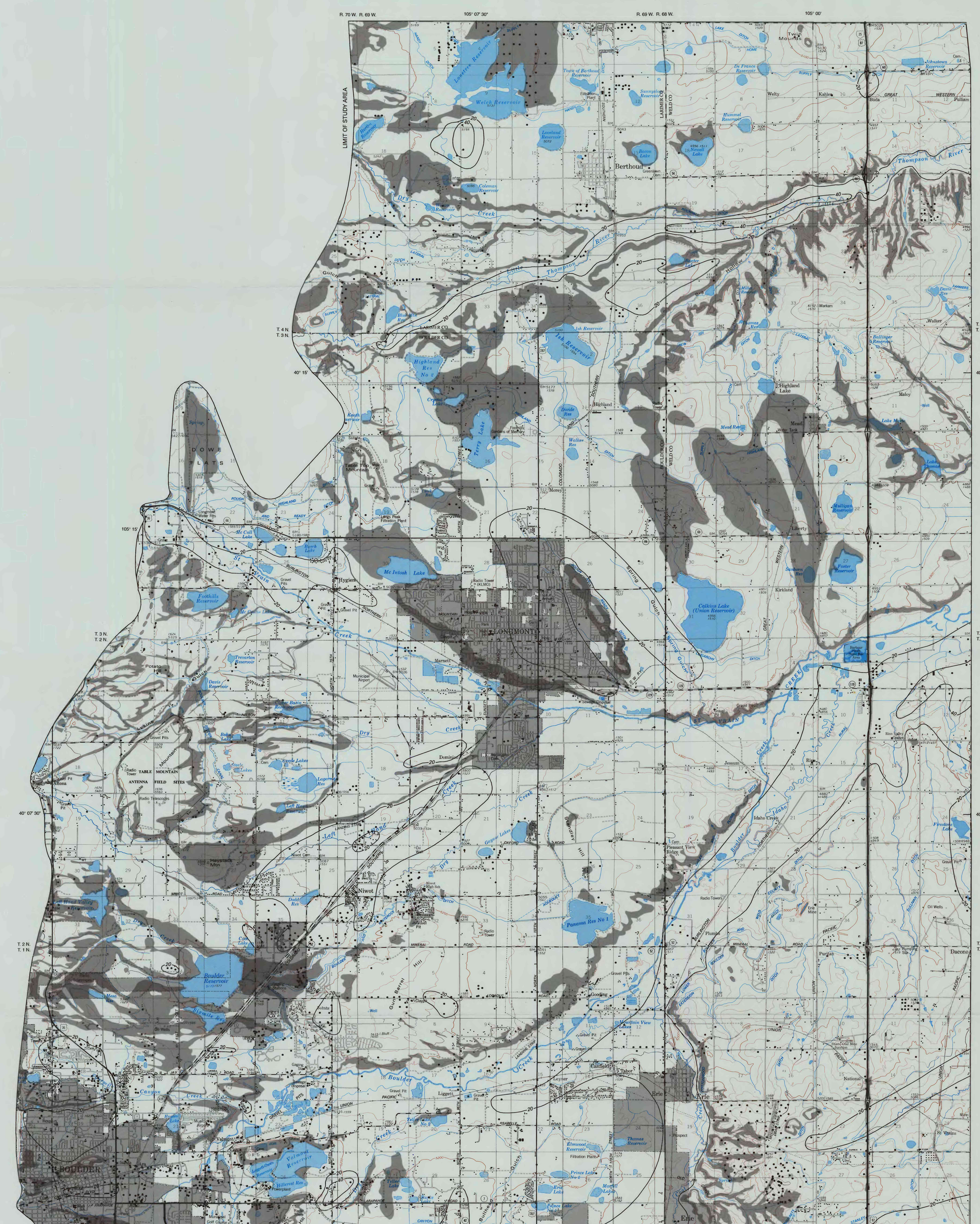

FIGURE 3—Thickness and extent of unconsolidated sediments.

EXPLANATION

Bedrock outcrop

—20— **Line of equal thickness of unconsolidated sediments**—Contour interval 20 feet. Hachures indicate enclosed thin interval

• **Location of well or test hole with lithologic log**

INTRODUCTION

Urban areas commonly rely on ground water for at least part of the municipal water supply, and as population increases, urban areas expand and require larger volumes of water. However, the expansion of an urban area can reduce ground-water availability. This may occur through processes of depletion (withdrawal of most of the available ground water), degradation (chemicals used in the urban area seep into the ground and contaminate the ground water), and preemption (cost or restrictions on pumping ground water from under extensively urbanized areas may be prohibitive). Thus, a vital natural resource needed to support the growth of an urban area and its infrastructure can become less available because of growth itself.

The diminished availability of natural resources caused by expansion of urban areas is not unique to water resources. For example, large volumes of aggregate (sand and gravel) are used in concrete and asphalt to build and maintain the infrastructure (buildings, roads, airports, and so forth) of an urban area. Yet, mining of aggregate commonly is preempted by urban expansion; for example, it cannot be mined from under a subdivision. Energy resources such as coal, oil, and natural gas likewise are critical to the growth and existence of an urban area but may become less available as an urban area expands and preempts mining and drilling.

In 1996, the U.S. Geological Survey began work on a national initiative designed to provide information on the availability of those natural resources (water, minerals, energy, and biota) that are critical to maintaining the Nation's infrastructure or that may become less available because of urban expansion. The initiative began with a 3-year demonstration project to develop procedures for assessing resources and methods for interpreting and publishing information in digital and traditional paper formats. The Front Range urban corridor of Colorado was chosen as the demonstration area (fig. 1), and the project was titled the Front Range Infrastructure Resources Project (FRIRP). This report and those of Robson (1996), Robson and others (1998), and Robson and others (2000a, 2000b, 2000c) (fig. 1) are the results of FRIRP water-resources investigations; reports pertaining to geology, minerals, energy, biota, and cartography of the FRIRP are published separately. The water-resources studies of the FRIRP were undertaken in cooperation with the Colorado Department of Natural Resources, Division of Water Resources, and the Colorado Water Conservation Board.

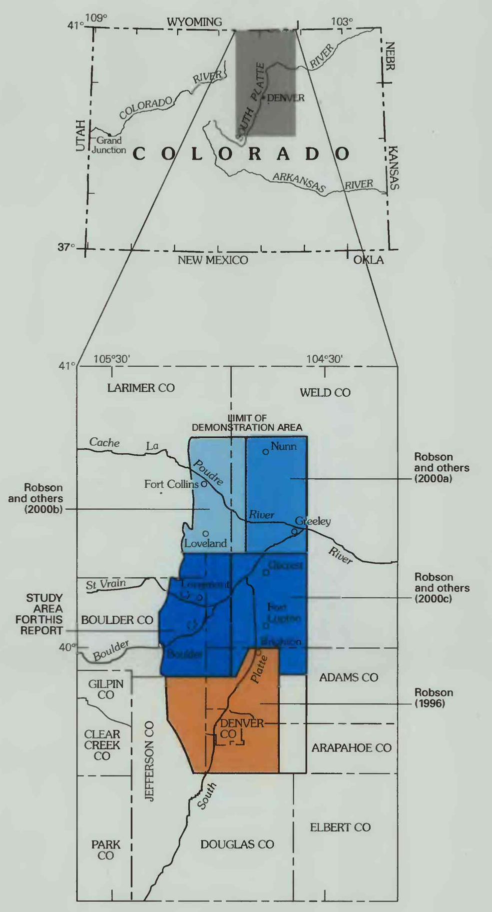

FIGURE 1—Location of demonstration area and study areas described in this and other U.S. Geological Survey reports.

The FRIRP demonstration area encompasses about 2,500 square miles and extends from the Arapahoe-Douglas County line on the south to the middle of Larimer and Weld Counties on the north, just north of the small town of Nunn (fig. 1). The western limit of the demonstration area is the approximate mountain front of the Front Range of the Rocky Mountains; the eastern limit is an arbitrary north-south line extending through a point about 4 miles east of Greeley.

This report presents the results of a systematic mapping of the extent, thickness, and water-table altitude of the shallow aquifers in the Boulder-Longmont study area, a 490-square-mile area in the west-central part of the demonstration area (fig. 1). The shallow aquifers described in this report are present within unconsolidated sediments that form a discontinuous mantle overlying bedrock in the study area. However, where bedrock occurs at or near the land surface, the potentiometric surface of bedrock aquifers have been mapped as part of the water table of these shallow aquifers because at these locations, the bedrock aquifers generally are unconfined and have water level conditions similar to these in the unconsolidated sediments. Figure 2 is a diagram showing the terms used to describe a shallow aquifer.

The five large maps in this report (figs. 3, 4, 7, 8, and 9) show (1) thickness and extent of the unconsolidated sediments that overlie bedrock formations in the area, (2) altitude and configuration of the bedrock surface, (3) altitude of the water table and direction of ground-water movement, (4) saturated thickness of the shallow aquifers, and (5) depth to the water table in the shallow aquifers. The maps primarily are intended to indicate the general altitude and thickness of the aquifers and are not intended to define conditions at specific sites.

The boundaries of the study area are the eastern edge of Range 68 West at Colorado Boulevard and Weld County Road 13 on the east, the southern edge of Township 1 South at 120th Avenue in Adams and Boulder Counties on the south, the mountain front of the Front Range on the west, and the northern edge of Township 4 North at Larimer County Road 14 and State Highway 60 on the north (fig. 3). Most of the study area is rural, although rapid urban growth is occurring in several parts of the area. Boulder is the largest city in the area and has about 15 square miles of urban area. Longmont, Louisville, Broomfield, and Lafayette are rapidly growing communities with 3 to 5 square miles of urban area each. Numerous small towns have less than 1 square mile of urban area.

The southern boundary of this study area coincides with the northern boundary of the study area shown in Robson (1996) (fig. 1). Some of the shallow aquifer mapping along the northern margin of the area mapped in Robson (1996) has been reexamined and revised as the result of the newer mapping to the north. The revised contours are shown in figure 3 and 7 as extensions beyond the southern boundary of the Boulder-Longmont study area. These revisions have been incorporated into the coverages available through the project website.

Data used in this study consist of water-level measurements in wells and lithologic logs of wells and test holes. These data were obtained from records of wells and test holes constructed between about 1945 and 1997. Principal sources of data include the Colorado Division of Water Resources, the U.S. Geological Survey, the Colorado Department of Labor and Employment, the Colorado Geological Survey, and the Colorado Department of Transportation. Several other governmental agencies and private companies also provided data. Principal sources of lithologic data in published literature include Barb (1946); Colton and Anderson (1977); Colton and Fitch (1974); Jenkins (1961); McConaghy and others (1964); Schneider (1983); and Trimble and Fitch (1974). Principal sources of water-level data in published literature include Brookman (1971); Code (1958); Hall and others (1979); Hillier and others (1979); Hurr and Luckey (1972, 1973); Jenkins (1961); Major and others (1983); McConaghy and others (1964); Meinzer (1937); Meinzer and Wenzel (1936, 1938, 1939, 1940, 1941, 1942, 1944, 1946); Sayre (1947); Schneider (1983); Schneider and Hillier (1978); Trimble and Fitch (1974); U.S. Geological Survey (issued annually); and Wilson (1965). About 3,000 data points were compiled for use in mapping the geohydrology of the shallow aquifer in this study area.

Geospatial data consisting of ArcInfo[1] coverages of the geohydrologic contours and linework shown in figures 3, 4, 7, 8, and 9 of this report are available from the U.S. Geological Survey Colorado District Office and from the Front Range Infrastructure Resources Project website at http://rockyweb.cr.usgs.gov/frontrange. ArcInfo procedures used in preparing the maps are defined in the website metadata for each coverage. Digital data for well and test-hole locations and depths to bedrock and the water table also are available on the website.

This work could not have been completed without the cooperation and assistance of numerous individuals in governmental agencies and businesses who allowed access to their well and lithologic log information and geotechnical data bases. In addition, Sharon A. Rafferty and Stephen J. Char assisted with much of the digital map preparation. Thomas D. McCarthy and Gregory S. Danziger collected and compiled well data. Alene J. Brogan, Sharon P. Clendening, Alan M. Duran, John M. Evans, Mary A. Kidd, Joy K. Monson, and Robert J. Olmstead aided in cartographic production, text editing, and manuscript preparation.

[1]The use of trade, product, industry, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

MAP ACCURACY AND RESOLUTION

The geohydrologic mapping for this report was produced from three sets of initial data: (1) thickness of unconsolidated sediments measured from lithologic logs, (2) altitude of the water table measured in wells, and (3) altitude of the land surface as defined by 7.5-minute topographic quadrangles or their equivalent digital elevation models. Maps of the thickness of the unconsolidated sediments (fig. 3) and the altitude of the water table were prepared at 1:24,000 scale by hand contouring data using 10- and 20-foot interval contours. These maps were produced directly from data and herein are considered to be first-order maps with a vertical accuracy of about 10 feet. These maps were digitized for use with an ArcInfo-based geographic information system. The geographic information system was used to plot the maps at 1:50,000 scale and 20-foot contour intervals for use in figures 3 and 7. Digital elevation models and the equivalent topographic quadrangle maps with 10- or 20-foot contour intervals also are considered here to be first-order maps with vertical accuracy of 5 or 10 feet.

The map of the altitude of the bedrock surface (fig. 4) was computed by the geographic information system as the difference between the maps of the altitude of the land surface and the thickness of the unconsolidated sediments. The map of the depth to the water table (fig. 9) was computed as the difference between the maps of the altitude of the land surface and the altitude of the water table. The altitude of the bedrock surface and depth to water table maps herein are considered to be second-order maps because they are computed from two first-order maps. The second-order maps likely have vertical accuracies between 10 and 15 feet.

The map of the saturated thickness of the aquifers (fig. 8) was computed by the geographic information system as the difference between the maps of the altitude of the water table (a first-order map) and the altitude of the bedrock surface (a second-order map). The map of the saturated thickness is a third-order map because it is computed from a first- and a second-order map. The vertical accuracy of this map likely is about 20 feet.

The resolution of a map pertains to the minimum size of features that can be distinguished on the map. Geohydrologic mapping in this report has a resolution of about 0.02 square mile. Thus, the smallest geohydrologic feature that can be resolved on these maps is about 750 feet on a side.

GEOLOGY

Most of the study area is underlain by bedrock of the Pierre Shale. However, the southeastern portion of the area is underlain by the Fox Hills Sandstone, Laramie Formation, Arapahoe Formation, and Denver Formation, and the western margin of the area contains subcrops and outcrops of the Benton Group and Niobrara Formation. The Pierre Shale consists of shale or mudstone with localized beds of sandstone. The upper part of the Pierre Shale is transitional with the Fox Hills Sandstone and grades upward from predominantly shale to shale interbedded with siltstone and sandstone. The Fox Hills Sandstone consists of poorly to moderately consolidated, fine-grained sandstone interbedded with shale. The Laramie Formation consists of interbedded sandstone, mudstone, and shale with localized beds of lignite and coal. The Arapahoe and Denver Formations are composed of sandstone and mudstone with layers of conglomerate. The Benton Group is comprised of Graneros Shale, Greenhorn Limestone, and Carlile Shale. The Niobrara Formation is comprised of Fort Hays Limestone and Smoky Hill Shale. The Benton and Niobrara both consist of shale or mudstone interlayered with limestone. All bedrock units in the area are of Cretaceous age except the Denver Formation, which is of Tertiary and Cretaceous age. Most of the bedrock outcrops are weathered and poorly consolidated, and the bedrock is extensively faulted in the southern one half of the area. The western extent of the Benton Group defines the approximate western limit of the study area. The Laramie-Fox Hills aquifer is a principal bedrock aquifer in eastern Colorado and primarily consists of water-yielding sandstones in the lower Laramie Formation and the Fox Hills Sandstone (Robson, 1987). The Laramie-Fox Hills aquifer directly underlies the alluvium along Boulder Creek valley east of Boulder (Robson and others, 1998); in such areas, ground water may flow from alluvial to bedrock aquifers or from bedrock to alluvial aquifers, depending on the relative water levels in the two aquifers.

Unconsolidated sediments overlie much of the bedrock in the study area. These sediments tend to be thin in upland areas between stream valleys, where bedrock outcrops are more prevalent, and thicker in the valleys and paleovalleys (ancient valleys) of the major streams. The unconsolidated sediments are of Quaternary age and are composed of alluvium, colluvium, and eolian deposits.

The oldest alluvium (Pleistocene age) in the study area comprises the pre-Rocky Flats Alluvium, Rocky Flats Alluvium, Verdos Alluvium, and Slocum Alluvium (Colton, 1978; Trimble and Machette, 1979). These deposits primarily consist of gravel and sand, contain boulders, cobbles, and caliche near the mountain front, and decrease in grain size to the east. The old alluvium is prevalent along the entire length of the mountain front in the study area. Younger alluvium (late Pleistocene age) consists of the Louviers Alluvium and Broadway Alluvium. These deposits are composed of well-stratified gravel, sand, and silt and are present on terraces along the margins of the major stream valleys. This alluvium also decreases in grain size to the east. The youngest alluvium (Holocene age) in the area consists of Piney Creek and post-Piney Creek Alluvium composed of gravel, sand, silt, and clay along the valleys and flood plains of the principal streams. This alluvium is highly variable in composition, contains organic matter, and generally decreases in grain size with increasing distance downstream. In general, all alluvium in the study area has moderate to large hydraulic conductivity and readily yields water to wells where it is saturated. The thickness and extent of the youngest alluvium make it a good source of ground water.

Colluvium consists of bouldery to pebbly, sandy silt and clay primarily deposited by gravity and sheetwash on slopes. Colluvium overlies the bedrock in many areas of steep topography, particularly along the steeper flanks of stream valleys. These deposits are Pleistocene to Holocene in age and commonly are derived from nearby or underlying bedrock. Hydraulic conductivity of the colluvium is small where it consists of clay derived from weathered shale and is moderate where it consists of coarser sediments derived from weathered sandstone. Because the colluvium is limited in both thickness and areal extent, it generally is not a good source of ground water.

Eolian deposits of sand, silt, and clay cover much of the land surface between principal stream valleys in the study area. These deposits are Pleistocene to Holocene in age and primarily take the form of loess deposited downwind from flood plains and weathered bedrock. The eolian deposits have moderate to large hydraulic conductivity and readily yield water to wells where saturated. However, because the saturated thickness of the deposits generally is small, the deposits provide only a limited supply of ground water.

The contact between bedrock and unconsolidated sediments is distinct and easily identified in lithologic logs of wells in many areas, but the contact is transitional and difficult to identify in logs in other areas. Along valleys and paleovalleys of principal streams, gravel and cobbles commonly are present at the base of the unconsolidated sediments, and the contact with underlying shale bedrock is distinct. In other parts of the study area, however, the contact is difficult to identify because the upper part of the bedrock is weathered to form a transitional zone, the upper part of which sometimes is nearly indistinguishable from overlying unconsolidated sediments. In such cases, differences in grain size, color, consolidation, rate of drill penetration, and degree of fracturing are used to estimate the position of the contact. Because of the indistinct contact, unconsolidated weathered bedrock likely has been mapped as part of the unconsolidated sediments.

Bedrock is present at or near land surface in many parts of the study area (fig. 3). The locations of the outcrops are based on geologic mapping of 1:24,000 scale in Braddock, Houston, Colton, and Cole (1988); Braddock, Nutalaya, and Colton (1988); Colton and Anderson (1977); Machette (1977); Malde (1955); Spencer (1961); Trimble (1975); Wells (1963); and Wrucke and Wilson (1964); at 1:100,000 scale in Colton (1978) and Trimble and Machette (1979); and at 1:250,000 scale in Braddock and Cole (1978). Minor revisions to the previously published shape of some outcrops were made based on new information from lithologic logs of wells and test holes in or near the outcrops.

Thickness and Extent of Unconsolidated Sediments

Thickness data from lithologic logs of wells and test holes and the zero thickness associated with mapped bedrock outcrops were used to define the thickness of the unconsolidated sediments in the study area. The map of the thickness and extent of the unconsolidated sediments (fig. 3) was prepared by a combination of hand contouring and plotting using the geographic information system. Hand contouring was used to better interpret the varied and inconsistent data values that sometimes resulted from local irregularities in the bedrock surface, the imprecise bedrock contact, mislocated data points, or conflicting data. Thickness contours generally were drawn using the preponderance of data in a local area and do not necessarily agree with each individual data value. Small topographic features and large earthen structures such as dams, gravel pits, and highway embankments generally were disregarded when constructing the contours. The general thickness and extent of the unconsolidated sediments in the study area are shown in figure 3.

The unconsolidated sediments in the study area range in thickness from zero in the numerous areas of bedrock outcrop in upland areas to as much as 40 feet in a few widely scattered small areas. Sediment thickness is consistently in excess of 20 feet only along some reaches of the larger stream valleys such as those of the Little Thompson River, Saint Vrain Creek, Boulder Creek, Coal Creek, Left Hand Creek, and Big Dry Creek. In most of the rest of the area, sediments generally are less than 20 feet thick; areas of greater thickness generally are small and widely scattered. There is little indication of linear trends in thickness that could be caused by paleovalleys beyond present stream valleys, even though such paleovalleys are common features in adjacent areas (Robson and others, 2000a, 2000b, 2000c; Robson, 1996).

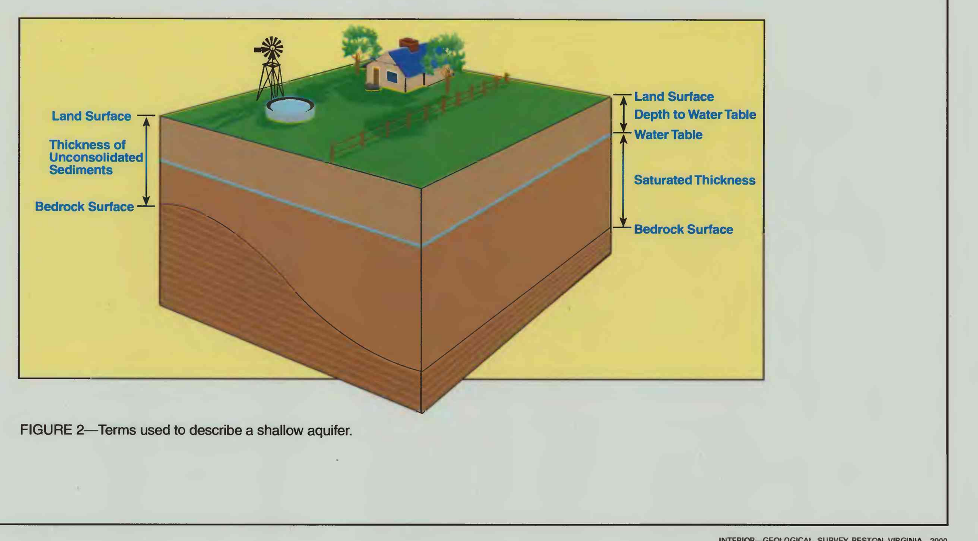

FIGURE 2—Terms used to describe a shallow aquifer.

Base from U.S. Geological Survey 1:50,000 Adams, Boulder, Larimer, and Weld Counties

SCALE 1:50,000

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

GEOHYDROLOGY OF THE SHALLOW AQUIFERS IN THE BOULDER–LONGMONT AREA, COLORADO

By
S.G. Robson, J.S. Heiny, and L.R. Arnold

2000