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

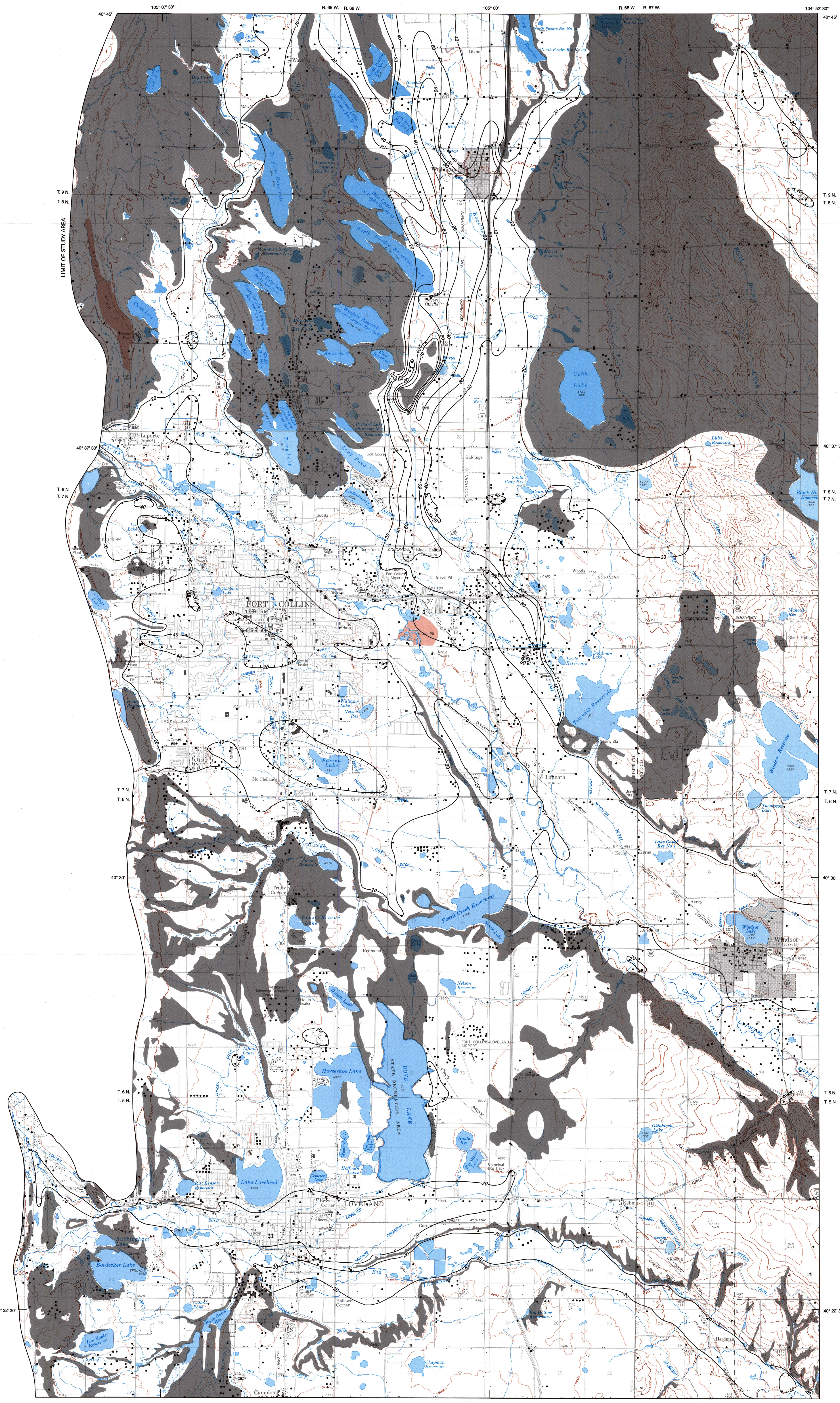

FIGURE 3—Thickness and extent of unconsolidated sediments.

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) 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.

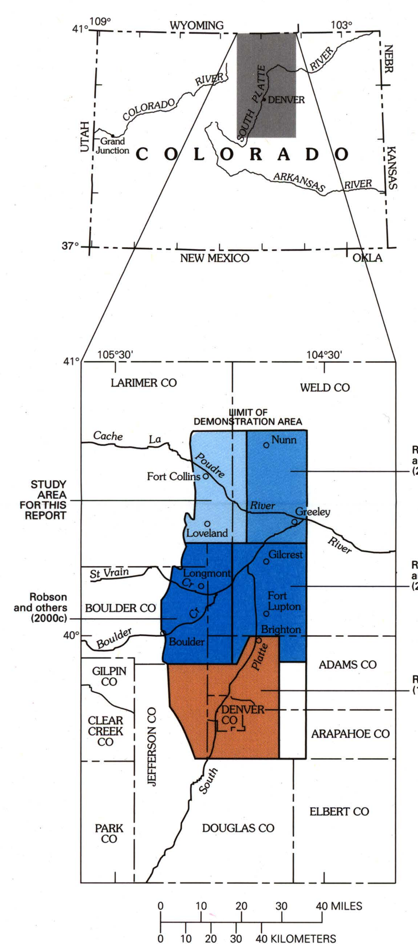

FIGURE 1—Location of demonstration area and study areas described in this and other U.S. Geological Survey reports.

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 Fort Collins-Loveland study area, a 400-square-mile area in the northwestern 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 has been mapped as part of the water table of the shallow aquifers because at these locations, the bedrock aquifers generally are unconfined and have water-level conditions similar to those 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 trends in altitude and thickness of the aquifers and are not intended to define conditions at specific sites.

The boundaries of the study area are 104°52'30" west longitude on the east, the southern edge of Township 5 North at Larimer County Road 14 and State Highway 60 on the south, the mountain front of the Front Range on the west, and 40°45' north latitude on the north (fig. 3). Most of the area is rural, although rapid urban growth is occurring in the western part of the area. Fort Collins is the largest city in the area and has about 15 square miles of urban area; Loveland has slightly less than 10 square miles of urban area. Several small towns have less than 1 square mile of urban area.

Data used in this study consist of lithologic logs for wells and test holes and water-level measurements in wells. 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 for lithologic data in published literature include Barb (1946), Ching (1972), Colton and Fitch (1974), Schneider (1983), Schneider and Hershey (1961), Shelton (1972), Stewart and others (1967), and Stollar (1969). Principal sources for water-level data in published literature include Brookman (1971), Code (1958), Hurr and Luckey (1972, 1973), Major, and others (1975), Meinzer and Wenzel (1936, 1938, 1939, 1940, 1941, 1942, 1944, 1946), Meinzer (1937), Sayre (1947), Schneider (1983), Schneider and Hershey (1961), Schneider and Hillier (1978), U.S. Geological Survey (issued annually), and Wilson (1965). About 2,800 data points were compiled for use in mapping the geohydrology of the shallow aquifers in this study area.

Geospatial data consisting of ArcInfo[1] coverages of the geohydrologic contours and linework shown on 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 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 (fig. 7) 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 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 the depth to the water table (fig. 9) was computed as the difference between 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 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

The study area is underlain by bedrock formations of Cretaceous age. Most of the study area is underlain by the Pierre Shale; however, along the eastern margin of the area, the Fox Hills Sandstone is present, and along the western margin of the area, subcrops and outcrops of the Benton Group and Niobrara Formation are present. 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 and forms the lower part of the Laramie-Fox Hills aquifer (Robson, 1987). The Benton Group, which comprises the Graneros Shale, Greenhorn Limestone, and Carlile Shale, and the Niobrara Formation, which comprises the Fort Hays Limestone and Smoky Hill Shale, consist of shale or mudstone interlayered with limestone. Most of the bedrock outcrops in the area are weathered and poorly consolidated. The western extent of the Benton Group defines the approximate western limit of the study area.

Unconsolidated sediments overlie much of the bedrock in the study area. These sediments tend to be thinner in upland areas between stream valleys, where bedrock outcrops are more prevalent, and thicker in the valleys and paleovalleys (ancient valleys) of 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 Verdos Alluvium and Slocum Alluvium (Colton, 1978; Shelton and Rogers, 1987). These deposits consist of gravel and sand containing boulders, cobbles, and caliche near the mountain front and decrease in grain size to the east. The alluvium is prevalent along the mountain front in the area between Fort Collins and Loveland. 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 Cache La Poudre River, Big Thompson River, and Boxelder Creek. The youngest alluvium (Holocene age) in the area consists of Piney Creek and post-Piney Creek Alluvium, which are composed of gravel, sand, silt, and clay along the valleys and flood plains of the principal streams. This alluvium is highly variable in composition and contains organic matter. In general, all alluvium in the study area decreases in grain size with increasing distance downstream, has moderate to large hydraulic conductivity, and readily yields water to wells where it is saturated. The thickness and extent of 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 neither thick nor extensive, it generally is not a good source of ground water.

Eolian deposits of sand, silt, and clay have covered 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 the land surface in extensive areas north of the Cache La Poudre River and in less extensive areas between the Cache La Poudre and Big Thompson Rivers (fig. 3). Locations of outcrops are based on geologic mapping at 1:24,000 scale in Braddock, Calvert, Gawarecki, and Nutalaya (1970), Braddock, Calvert, O'Conner, and Swann (1989), Braddock, Connor, Swann, and Wohlford (1988), and Braddock, Nutalaya, and Colton (1988), at 1:62,500 scale in Hershey and Schneider (1972), at 1:100,000 scale in Colton (1978), and at 1:250,000 scale in Braddock and Cole (1978). In the area north of the Cache La Poudre River, the previously published shape of the bedrock outcrop was modified on the basis of 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. Ancient stream channels (paleochannels) and larger ancient stream valleys (paleovalleys) are common features of the area. The general thickness and extent of the unconsolidated sediments in the study area are shown in figure 3.

Thickness of the unconsolidated sediments in the study area ranges from zero in the numerous areas of bedrock outcrop in upland areas to more than 80 feet in a paleovalley of Boxelder Creek near Wellington. This paleovalley extends about 11 miles from near Black Hollow Junction to the northern boundary of the study area and may have been cut into the bedrock surface by the ancestral Boxelder Creek during a time when the creek flowed about 1.5 miles west of its present location near Cobb Lake. Unconsolidated sediments in the paleovalley range in thickness from 20 to 90 feet. A small paleovalley of Dry Creek has 20- to 30-foot-thick sediments and extends from northwest of Fort Collins toward Waverly.

The Cache La Poudre and Big Thompson Rivers are the principal streams crossing the study area, yet sediment thickness near the streams is only about 20 feet in most areas. Sediments are about 30 feet thick 1 to 2 miles north of the Cache La Poudre River between Timnath and Windsor. Sediments 20 to 30 feet thick underlie much of Fort Collins.

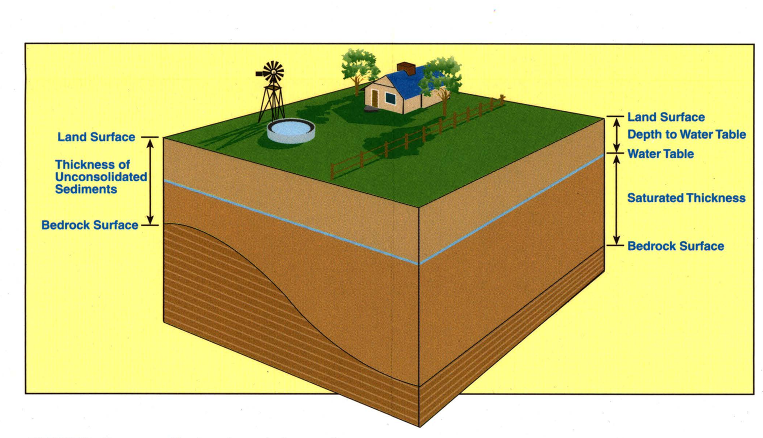

FIGURE 2—Terms used to describe a shallow aquifer.

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

SCALE 1:50,000
1 1/2 0 1 2 3 4 MILES
1 .5 0 1 2 3 4 5 KILOMETERS

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

GEOHYDROLOGY OF THE SHALLOW AQUIFERS IN THE FORT COLLINS–LOVELAND AREA, COLORADO

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

2000