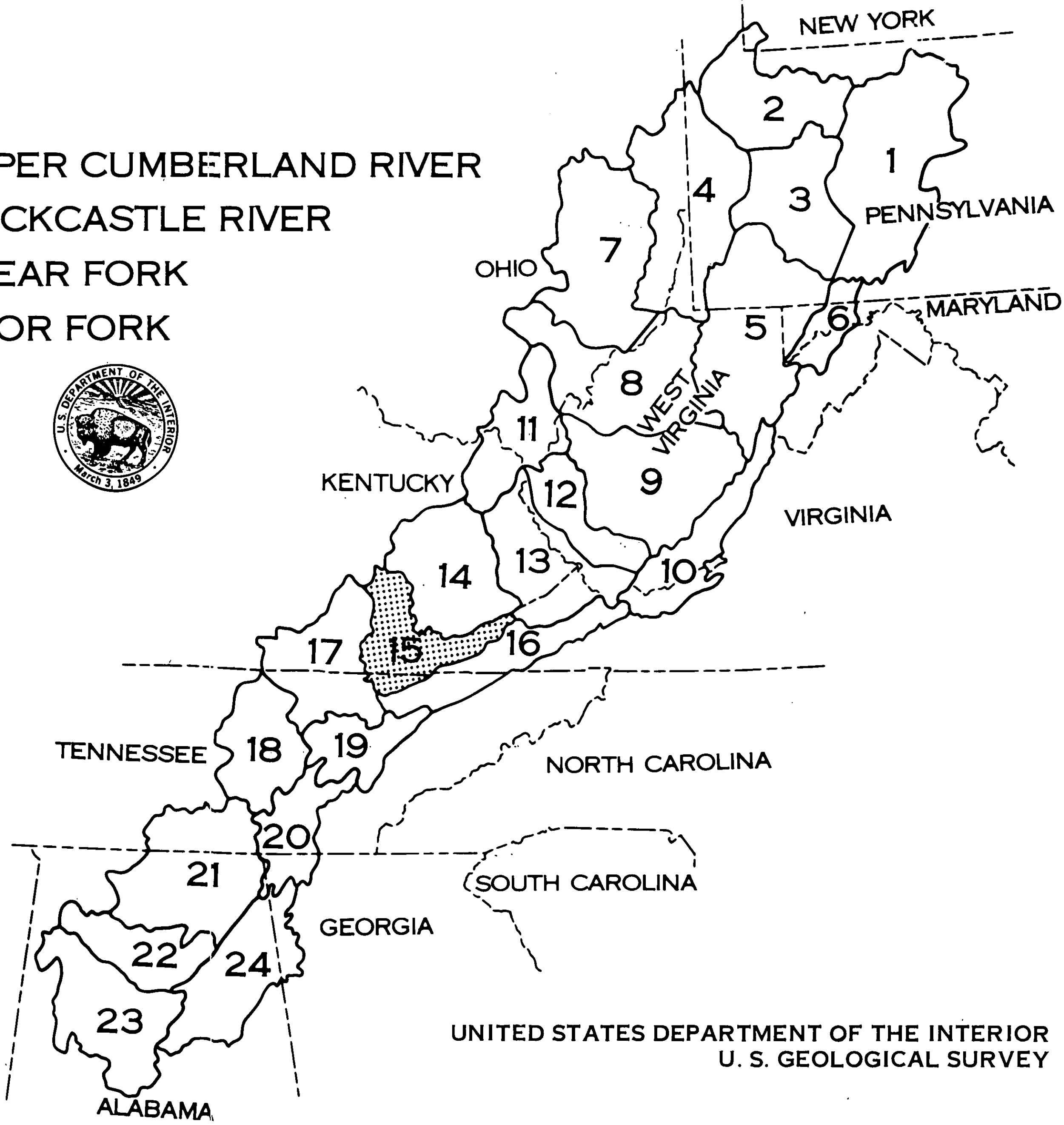
HYDROLOGY OF AREA 15, EASTERN COAL PROVINCE, KENTUCKY AND TENNESSEE

- UPPER CUMBERLAND RIVER
- ROCKCASTLE RIVER
- CLEAR FORK
- POOR FORK



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

WATER-RESOURCES INVESTIGATIONS
OPEN-FILE REPORT 81-809

HYDROLOGY OF AREA 15, EASTERN COAL PROVINCE, KENTUCKY AND TENNESSEE

BY
DAVID W. LEIST, FERDINAND QUINONES, DONALD S. MULL, AND MARY YOUNG

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LOUISVILLE, KENTUCKY
JANUARY 1982

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, *SECRETARY*

GEOLOGICAL SURVEY

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Room 572 Federal Building
Louisville, Kentucky 40202

CONTENTS

FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM OF UNITS (SI)

For the convenience of readers who may want to use International System of Units (SI), the data may be converted by using the following factors:

Multiply inch-pound units	By	To obtain SI units
inches (in)	25.4	millimeters (mm)
inches per hour (in/h)	25.4 2.54	millimeters per hour (mm/h) centimeters per hour (cm/h)
feet (ft)	0.3048	meters (m)
feet per mile (ft/mi)	0.1894	meters per kilometer (m/km)
miles (mi)	1.609	kilometers (km)
square miles (mi^2)	2.590	square kilometers (km^2)
acres	4047.	square meters (m^2)
acre-feet (acre-ft)	1233.	cubic meters (m^3)
gallons per minute (gal/min)	0.06309	liters per second (L/s)
million gallons per day (Mgal/d)	0.04381 3785.	cubic meters per second (m^3/s) cubic meters per day (m^3/d)
cubic feet per second (ft^3/s)	0.02832	cubic meters per second (m^3/s)
cubic feet per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meters per second per square kilometer [(m^3/s)/km^2]
pounds (lb)	453.6	grams (g)
tons	0.9072	metric tons
tons per square mile per year [(tons/mi^2)/yr]	0.3503	metric ton per square kilometer per year [(metric ton/km^2)/yr]

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Abstract

Area 15 is one of 24 hydrologic reporting areas in the Eastern Coal province. This area is in southeastern Kentucky and northeastern Tennessee, within the Appalachian Plateaus province. The Cumberland and it tributaries, the Laurel and Rockcastle Rivers drain the area of 3,095 square miles.

Rocks of Pennsylvanian and pre-Pennsylvanian age are exposed in Area 15. The Breathitt Formation of Pennsylvanian age crops out in about 75 percent of the area and contains most of the coal.

Forests cover about 80 percent of Area 15. The terrain is steep, with deep valleys and slopes ranging from 20 to 60 percent. The soils are mostly acidic, derived from sandstones, siltstones and shales, and have great erosion potential.

Coal production is concentrated in Harlan and Bell counties (Ky.), in the Cumberland River basin. Production in 1978 was about 22 million tons, with surface mines accounting for about 52 percent of the total.

Annual average precipitation ranges from 46 to 55 inches. The 10-year 24-hour rainfall frequency storm averages about 4.5 inches.

Water use in 1975 averaged about 12.9 million gallons per day. Surface water supplied about 80 percent of the water. Recreation and fishing are important water uses in the area.

Hydrologic data are available for 59 active and 27 inactive surface-water sites. Streamflow varies seasonally and geographically. Average annual runoff at sites in the Cumberland River basin (mined) is about 25.6 inches per square mile, whereas in the Rockcastle River basin (largely unmined), the average annual runoff is about 19.9 inches per square mile. Low flows in the area are poorly sustained, with a 7-day 10-year minimum flow of zero at many streams draining less than 100 square miles.

Floods are frequent and severe in the area. They vary with drainage area size, topography, and geology. Flood frequencies and magnitudes can be estimated from regression equations. Twenty-two maps delineating the limits of the 100-year and the maximum-known flood are available for areas in the basins of the Cumberland and Laurel Rivers.

Water-quality data are available from 38 active surface water sites in Area 15. Streamflow quality varies from near-natural conditions of less than 100 milligrams per liter of dissolved solids at sites in the largely unmined Rockcastle River basin, to as much as 1,040 milligrams per liter of dissolved solids at sites in the mined Cumberland River basin.

Acid-mine drainage generally is naturally neutralized near its source. Most of the water in streams in the area has near-neutral pH values in the 7 to 8 units range.

Dissolved sulfate is a significant water-quality parameter that can be related to mining activities in Area 15. In basins where mine-drainage is not significant, dissolved sulfate concentrations range from 4.5 to 74 milligrams per liter. In basins where surface coal-mining activities are significant, dissolved sulfate concentrations are as high as 998 milligrams per liter with median concentrations exceeding 50 milligrams per liter. Sulfate concentrations correlate well with specific conductance measurements at mined sites.

Most of the iron in streamflow is in suspension and is transported with the suspended-sediment load. The amount of iron in solution is relatively minor. Dissolved manganese constitutes more than half of the total recoverable manganese. Its concentration does not increase or decrease significantly with changes in flow. Iron and manganese concentrations are higher in waters of mined basins than in unmined basins.

Suspended-sediment data are inadequate to calculate sediment yields in most basins. Suspended-sediment yields are highest in basins affected by surface mining but vary seasonally. Most of the yearly suspended-sediment load can be produced by one flood.

In general, trace constituents do not occur in troublesome concentrations either in water or in bottom sediments of streams. However, dissolved mercury concentrations at some sites exceed maximum recommended limits for aquatic life.

Ground water in Area 15 occurs in multiple sandstone aquifers in the Breathitt and underlying Lee Formations. Precipitation provides most of the recharge to the area aquifers. Ground-water levels fluctuate seasonally and water levels range from above land surface to 300 feet below land surface. Yields to wells range from about 1 to 250 gallons per minute from Pennsylvanian rocks, but seldom exceed 50 gallons per minute from pre-Pennsylvanian formations.

Ground-water quality is highly variable but is generally suitable for most purposes. Waters range from soft to very hard and contain iron concentrations that range fron 0.003 to 25 milligrams per liter. Water with more than 1,000 milligrams per liter of dissolved solids commonly occurs at depths of 300 feet below valleys in the Breathitt and Lee Formations.

1.0 INTRODUCTION
1.1 Objective

Area 15 Report to Aid in Preparing and Appraising Mine Permit Applications

Existing hydrologic conditions are described and identification of sources of hydrologic information are presented.

A need for hydrologic information and analysis on a scale never before required nationally was initiated when the "Surface Mining Control and Reclamation Act of 1977" was signed into law as Public Law 95-87, August 3, 1977. This need is partially met by this report which broadly characterizes the hydrology of a large sub-basin in the eastern coal area of Kentucky and Tennessee(fig. 1.1-1). This report, which is for Area 15, is one of a series that covers the coal provinces nationwide. The report contains a brief text with an accompanying map, graph, or other illustration for each of a number of water-resources related topics. The summation of the topical discussions provides a description of the hydrology of the area.

The hydrologic information presented or available through sources identified in this report, may be used in describing the hydrology of the general area of any proposed mine. Furthermore, it is expected that this hydrologic information will be supplemented by the lease applicant's specific site data as well as data from other sources to provide a more detailed picture of the hydrology of the area in the vicinity of the mine and the anticipated hydrologic consequences of the mining operation.

The information contained herein should be useful to surface mine owners, operators, and consulting engineers in the preparation of permits, and to regulatory authorities in appraising the adequacy of permit applications.

Figure 1.1-1 Location of Area 15.

BASE FROM U. S. GEOLOGICAL SURVEY
U. S. BASE MAP, 1980

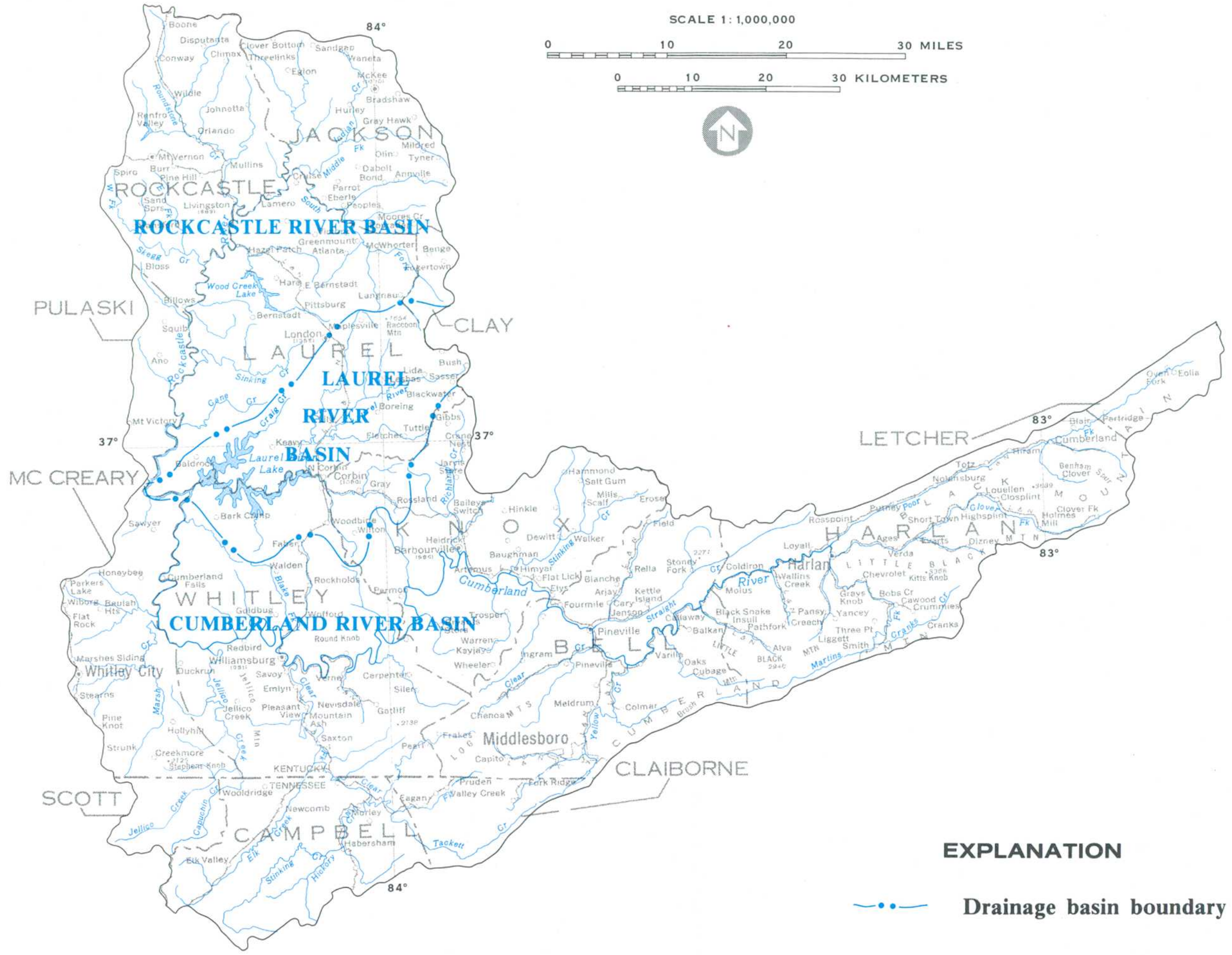
Area is in Central Part of Eastern Coal Province

Area 15 comprises 3,095 square miles of the Cumberland, Rockcastle, and Laurel River basins in southeastern Kentucky and northcentral Tennessee.

The Eastern Coal province has been divided into 24 hydrologic reporting areas (see cover). The divisions are based on drainage boundaries, location of basins, size, hydrology, and mining activities. Several drainage basins or parts of basins are combined to form one reporting area (fig.1.2-1). Area 15 is in the central part of the province.

The area is in southeastern Kentucky and northcentral Tennessee. It includes 3,095 mi^2 of the Cumberland, Rockcastle, and Laurel River basins. About 90 percent of the project area is in Kentucky and about 10 percent is in Tennessee. The area is within the Eastern Coal province and is part of Fenneman's (1938) Appalachian Plateaus physiographic province (fig. 1.2-2). It includes all or parts of Harlan, Bell, Knox, Whitley, McCreary, Laurel, Letcher, Rockcastle, and Jackson counties in Kentucky, and Claiborne, Campbell, and Scott counties in Tennessee.

The population of Area 15 is about 200,000 people. It is mostly rural, with about 30 percent of the total residing in Harlan and Bell counties where coal mining is the principal industry. The area's principal cities -- Middlesboro, Harlan, Cumberland, Barbourville, London, Corbin, and Williamsburg -- are in Kentucky.

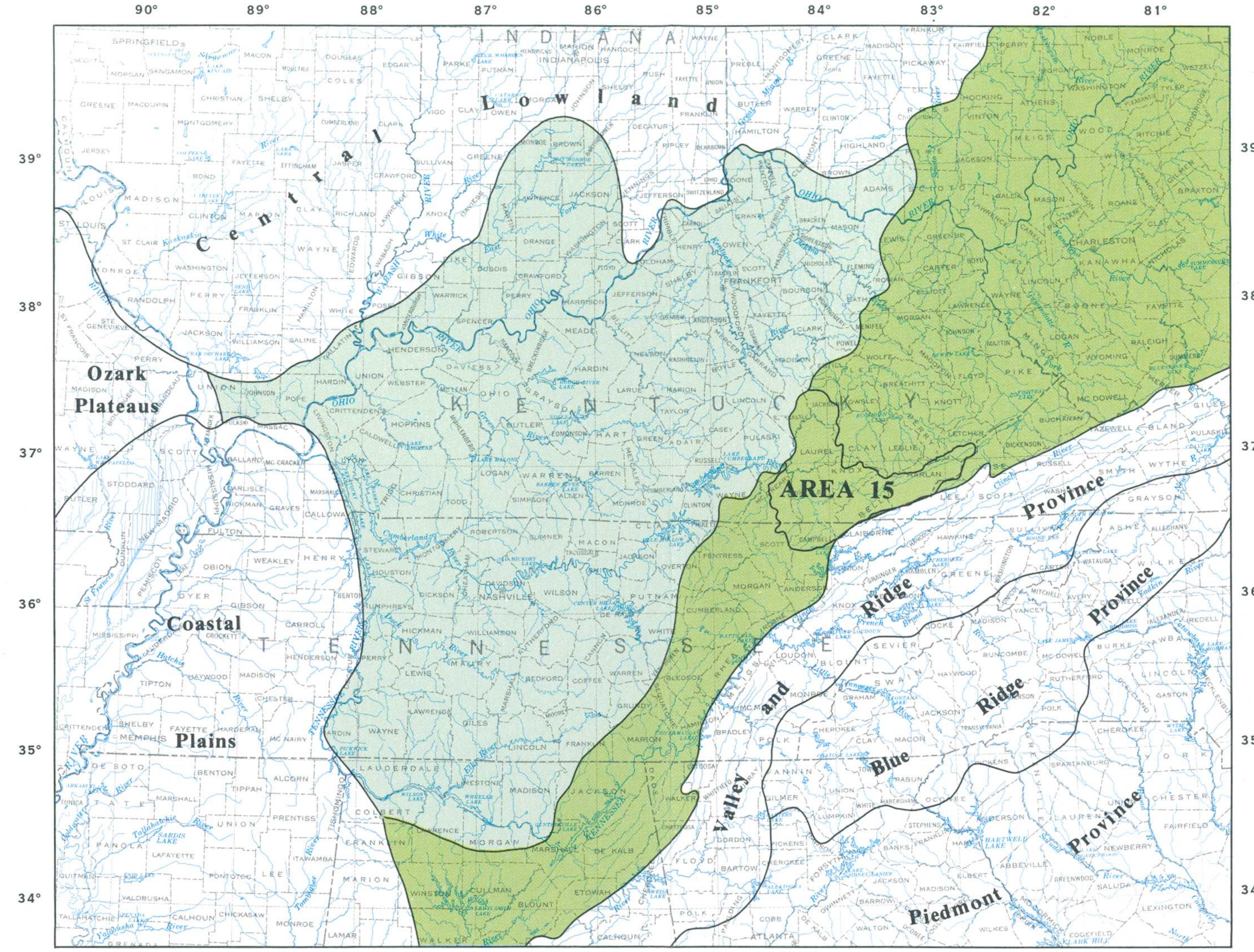


BASE FROM U. S. GEOLOGICAL SURVEY
STATE BASE MAP, 1973

EXPLANATION

Drainage basin boundary

Figure 1.2-1 Drainage basins.



BASE FROM U. S. GEOLOGICAL SURVEY
U. S. BASE MAP, 1980

Physiography from Fenneman (1946)

0 50 100 MILES

0 50 100 KILOMETERS

EXPLANATION

Physiographic provinces

Interior Low Plateaus

Appalachian Plateaus

Figure 1.2-2 Physiographic provinces.

Hydrologic Environment Can be Adversely Altered by Surface Coal Mining

Erosion, sedimentation, decline in water levels, and degradation of water quality are typical problems associated with surface coal mining.

Surface mining drastically alters the environment of undisturbed areas and may cause detrimental changes to the environment. Mining activities such as the removal of vegetation, excavation, and dumping of large volumes of unconsolidated spoil materials may create unstable areas of loose earth and rock. These generally erode easily and may contribute, if not controlled, additional sediment to surface streams, channels, and flood plains. If the mined area is reclaimed shortly after mining is completed, some of the detrimental environmental effects can be decreased or prevented.

Adverse effects associated with erosion and increased sedimentation include excessive sediment deposition in streams and reservoirs which in turn increases the cost of maintaining navigation channels and treating water for industrial and domestic uses. Other adverse effects include destruction of wild-life habitat, increased flooding due to filling of the stream channels and flood plains by sediment, and reduction of aesthetic value and recreation use.

Along with increased sedimentation, another common and troublesome water-quality problem is acid-mine drainage. After mining, accelerated weathering of iron-bearing minerals (pyrite and marcasite, for example) in spoil materials and coal beds produces sulfuric acid and accelerates the dissolution of minerals (fig. 1.3-1). Water draining such a mined area generally has low pH values (2.5-5.0 units), and increased sulfate and dissolved-solids concentrations. The acidic water reacts with other minerals, increasing concentrations of metals such as copper, lead, iron, manganese, and zinc. Adverse effects associated with acidic and highly mineralized mine drainage may include reduction of aquatic life, increased corrosiveness of water, limitations on the use of water for domestic and industrial purposes, and reduction of aesthetic value and recreational use.

The adverse effects are most apparent on and near the mine site. The receiving stream for surface and seepage drainage at the mine site usually is most affected. Problems caused by suspended sediment, increased metals content, and low pH values will usually diminish in severity downstream from the mine. This is due to settling out of the sediment, and the increased buffering and dilution capacity of the stream.

Decline of ground-water levels can occur in and near surface-mining areas when excavation extends below the water table causing some wells and springs to go dry (fig. 1.3-2). The quality of ground water can also be affected even though the effect may take much longer to detect at points remote from mining activities.

The magnitude of the effect of surface mining on the surrounding hydrologic environment depends on several physical and chemical factors. The more influential factors include mining and reclamation methods, topography, geology, climate, rate of water movement and volumes, the distance to the mine site, and the time elapsed since mining began.

Some generalized chemical and physical relations and trends that can result from surface coal mining are shown in figure 1.3-3.

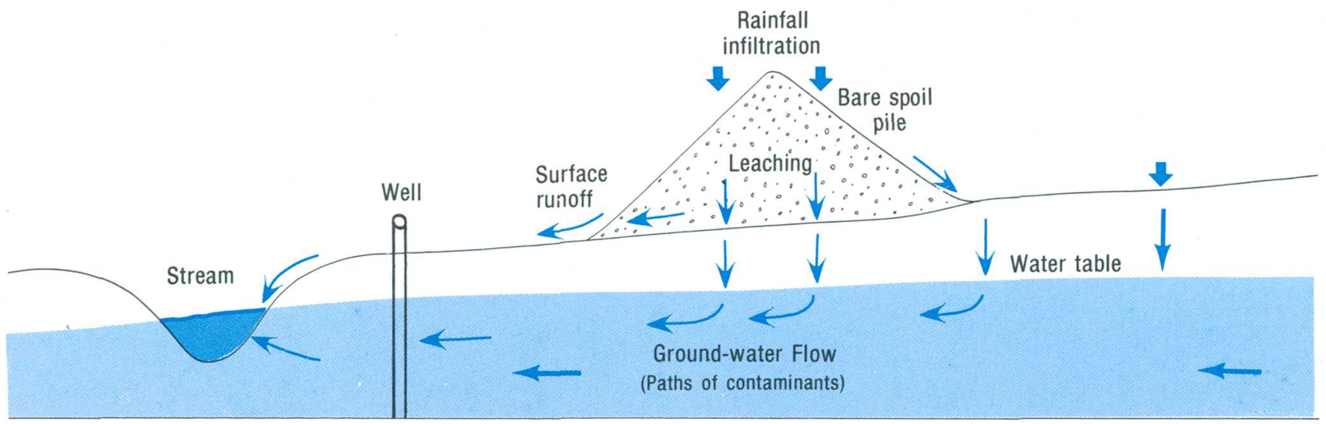


Diagram from Rickert and others, 1979

Figure 1.3-1 Leaching spoil material.

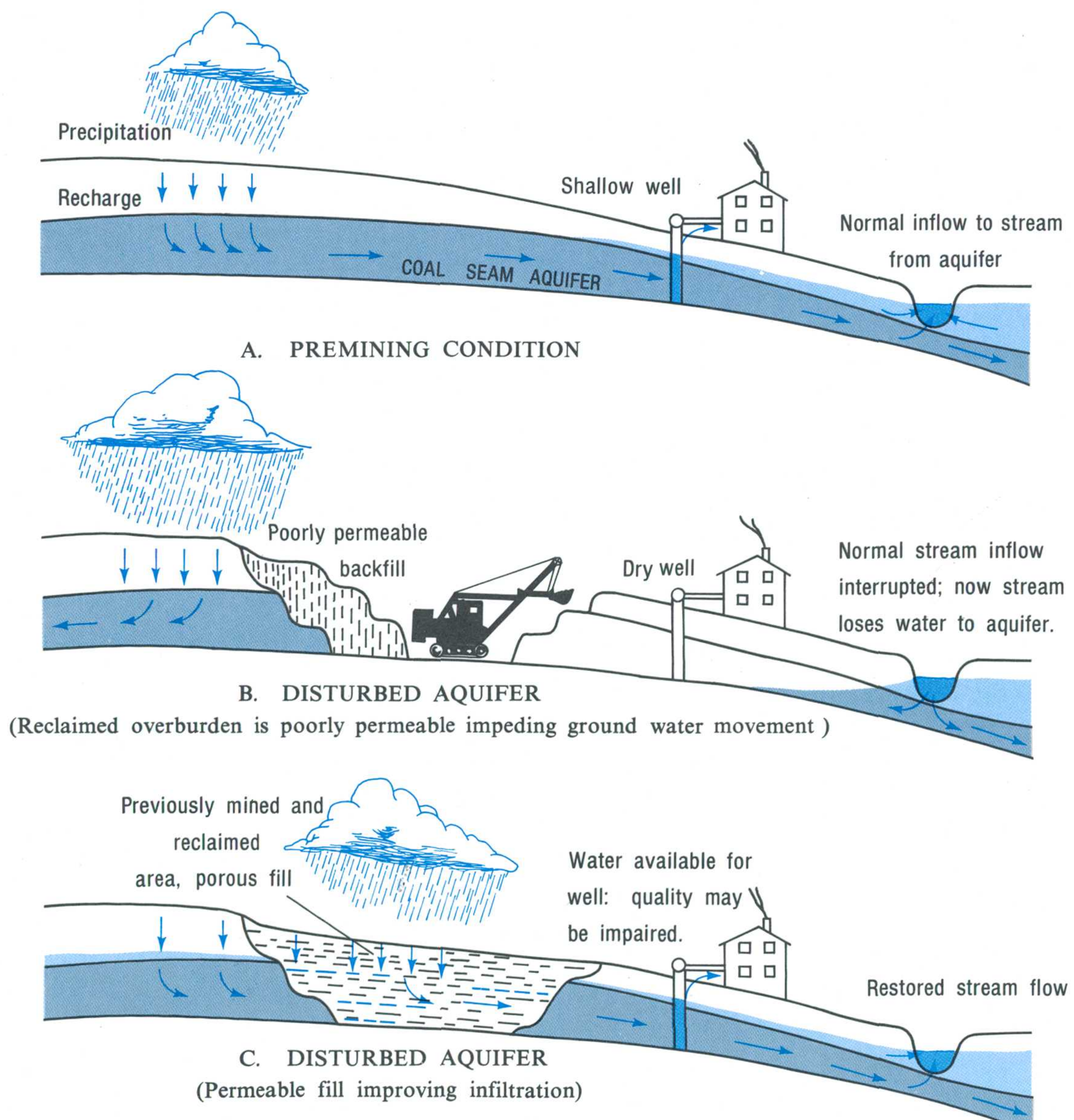
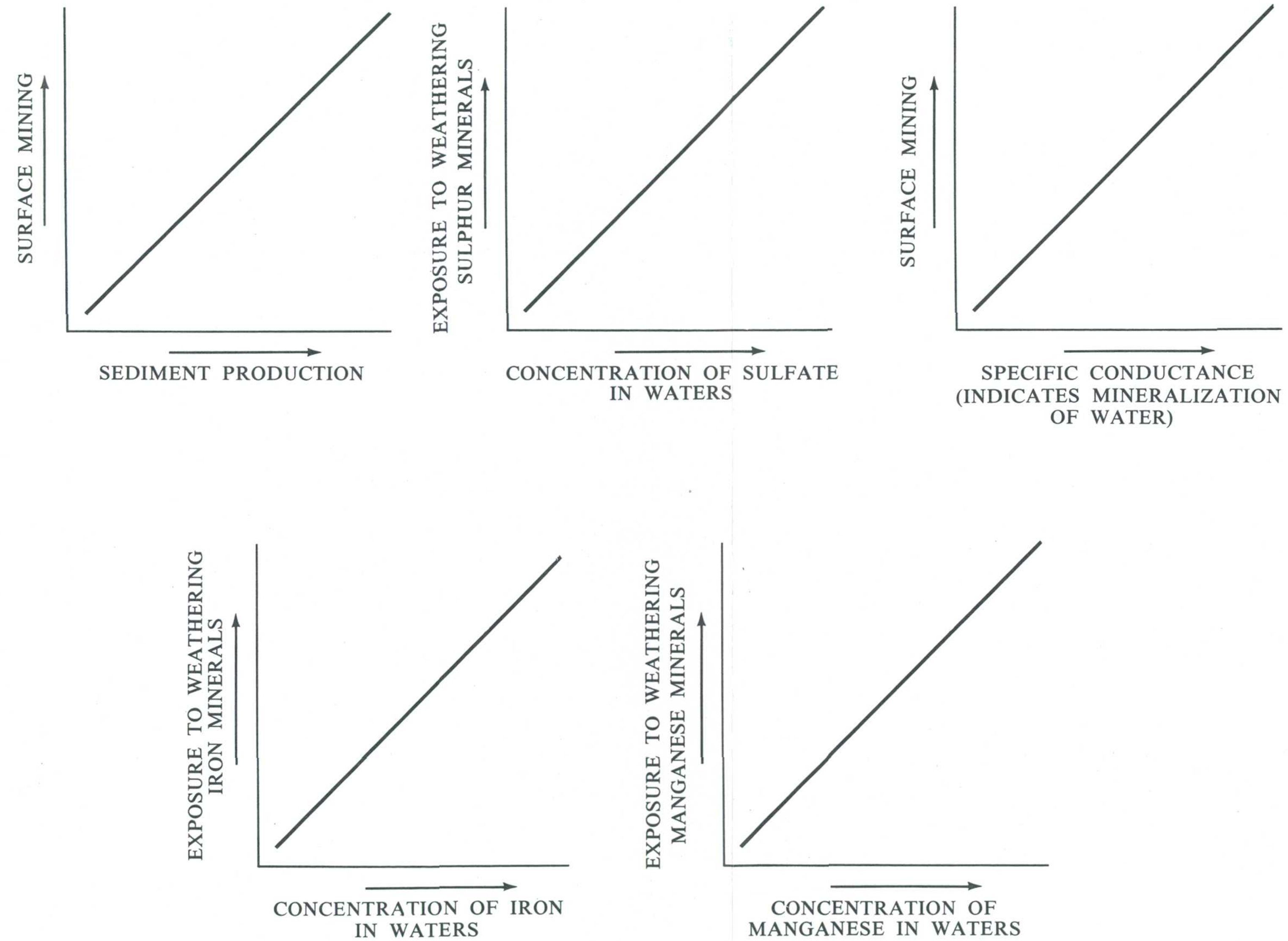


Diagram from Rickert and others, 1979

Figure 1.3-2 Possible impacts of mining aquifers.



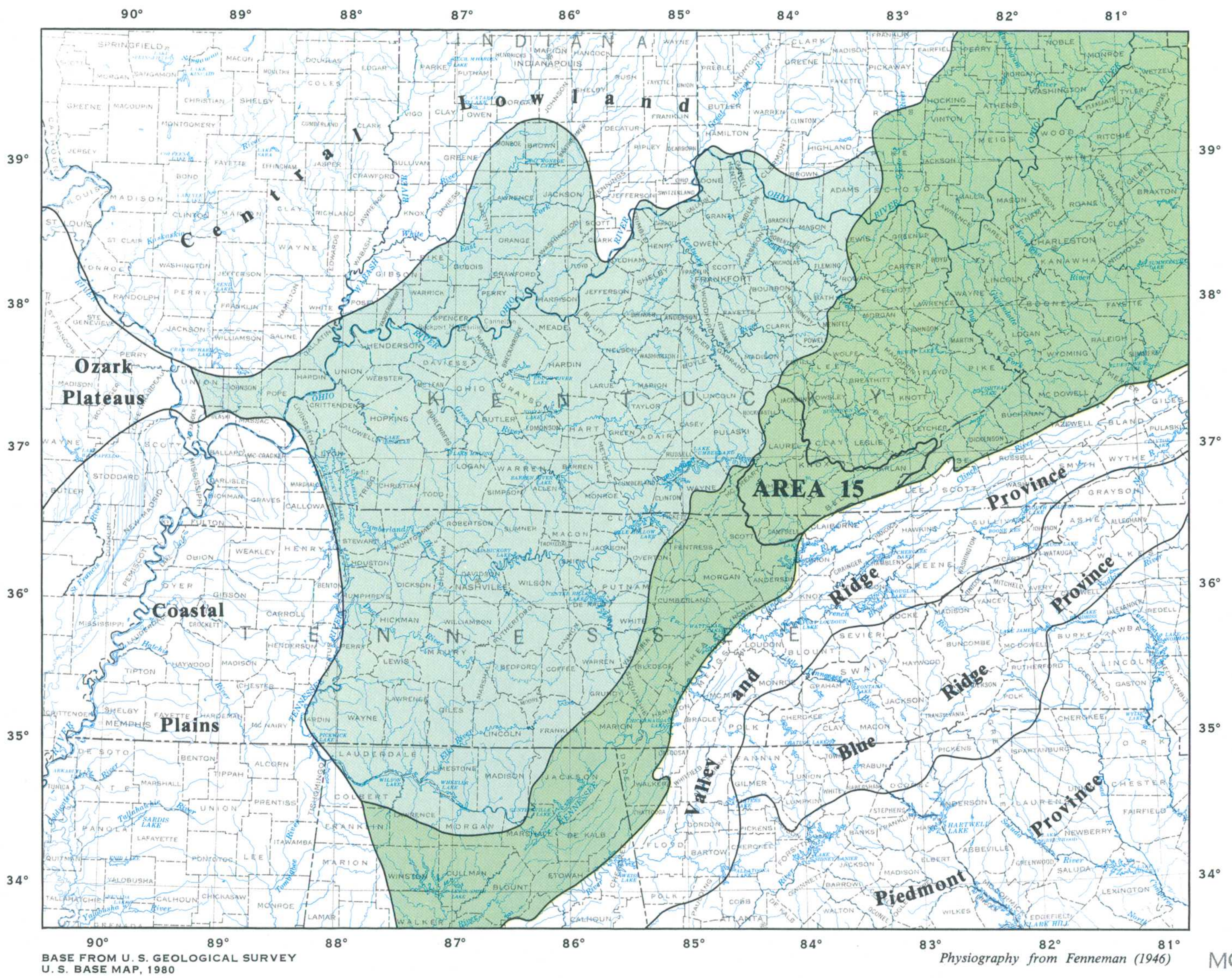
Relations and trends from May and others, 1981

Figure 1.3-3 Generalized relations and trends that can result from surface coal mining.

Area Within Three Physiographic Sections

The area is in the Cumberland Mountain, Cumberland Plateau, and Kanawha sections of the Appalachian Plateaus province.

Area 15 lies within the Appalachian Plateaus physiographic province (fig. 2.1-1; Fenneman 1938, 1946) which is subdivided into the Cumberland Mountain, Kanawha, and Cumberland Plateau sections (fig. 2.1-2). The Cumberland Mountain section consists of two parallel ridges; Pine Mountain and Cumberland Mountain, ranging from about 2,000 to 3,000 feet in altitude. Rugged hills lie between Pine and Cumberland mountains. The Kanawha section is a dissected plateau characterized by narrow, crooked valleys, and narrow, irregular steep-sided ridges. This section is underlain by sandstone, siltstone, and shale of Pennsylvanian age. The Cumberland Plateau section is a broad plateau of moderate relief. Along its western margin it is intricately dissected into very narrow ridges which are bordered by deep valleys having steep walls. The surface of the upland is shale and sandstone of Pennsylvanian age. In the northwest part of the area, the valleys and part of the ridges are shale and limestone of Mississippian age.



0 50 100 MILES
0 50 100 KILOMETERS

EXPLANATION

Physiographic provinces

- Interior Low Plateaus
- Appalachian Plateaus

Figure 2.1-1 Physiographic provinces.

EXPLANATION

Appalachian Plateaus province

- Cumberland Mountain section
- Kanawha section
- Cumberland Plateau section

SCALE 1:750,000

0 10 20 30 MILES
0 10 20 30 KILOMETERS

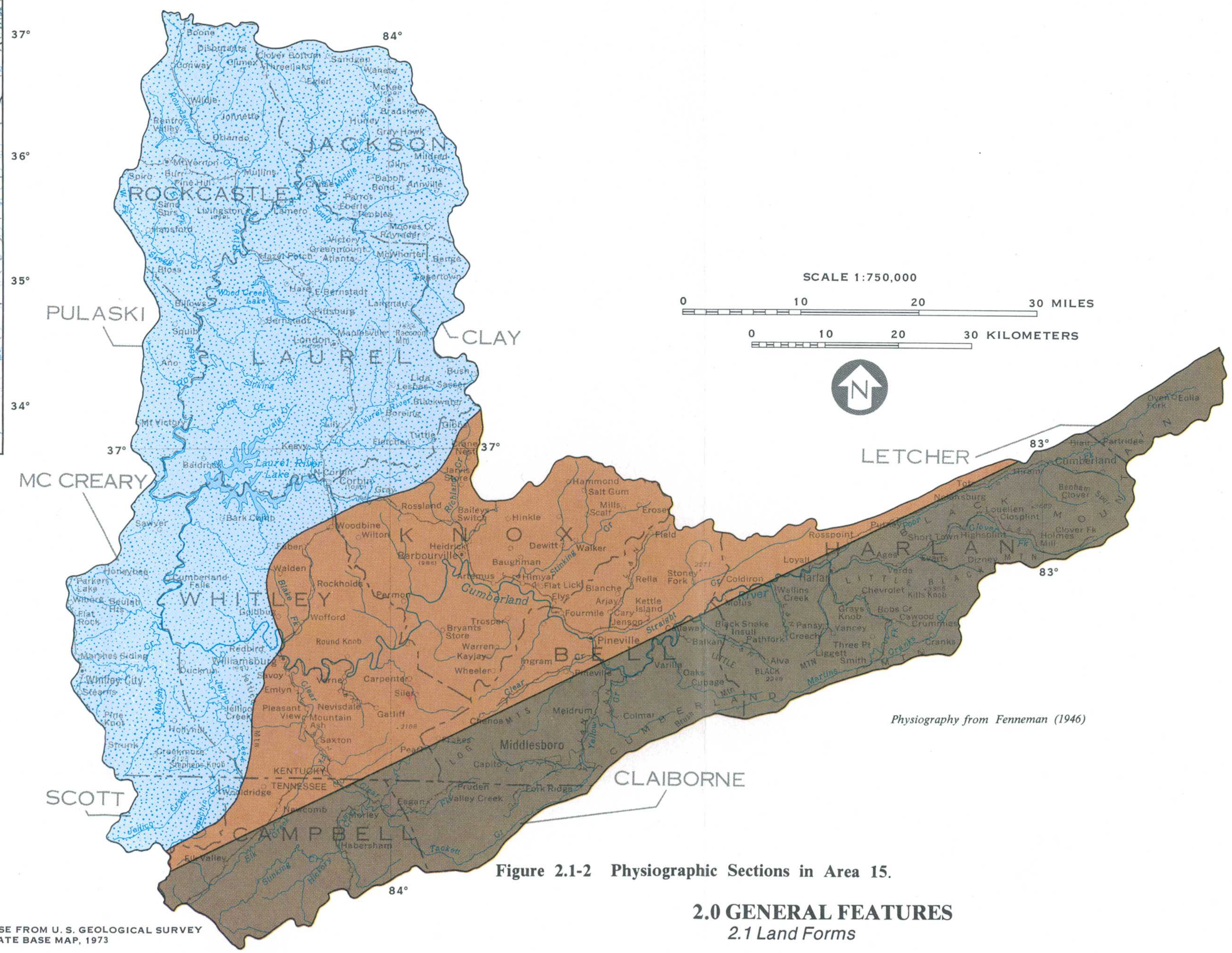


Figure 2.1-2 Physiographic Sections in Area 15.

Three Major Rock Types Underlie Area

Shale and sandstone of the Breathitt and Lee Formations of Pennsylvanian age and shale and limestone of Mississippian and Devonian age underlie the area. Coal occurs in the rocks of Pennsylvanian age.

Pennsylvanian age rocks in Area 15 are subdivided into the Breathitt and Lee Formations. Differences in geologic names east and west of Pine Mountain in Kentucky and usage of different names in Tennessee complicate the correlation of strata in the area. Therefore, for convenience in this report, all strata younger than the Lee Formation, as recognized in Kentucky, are grouped together into the Breathitt Formation.

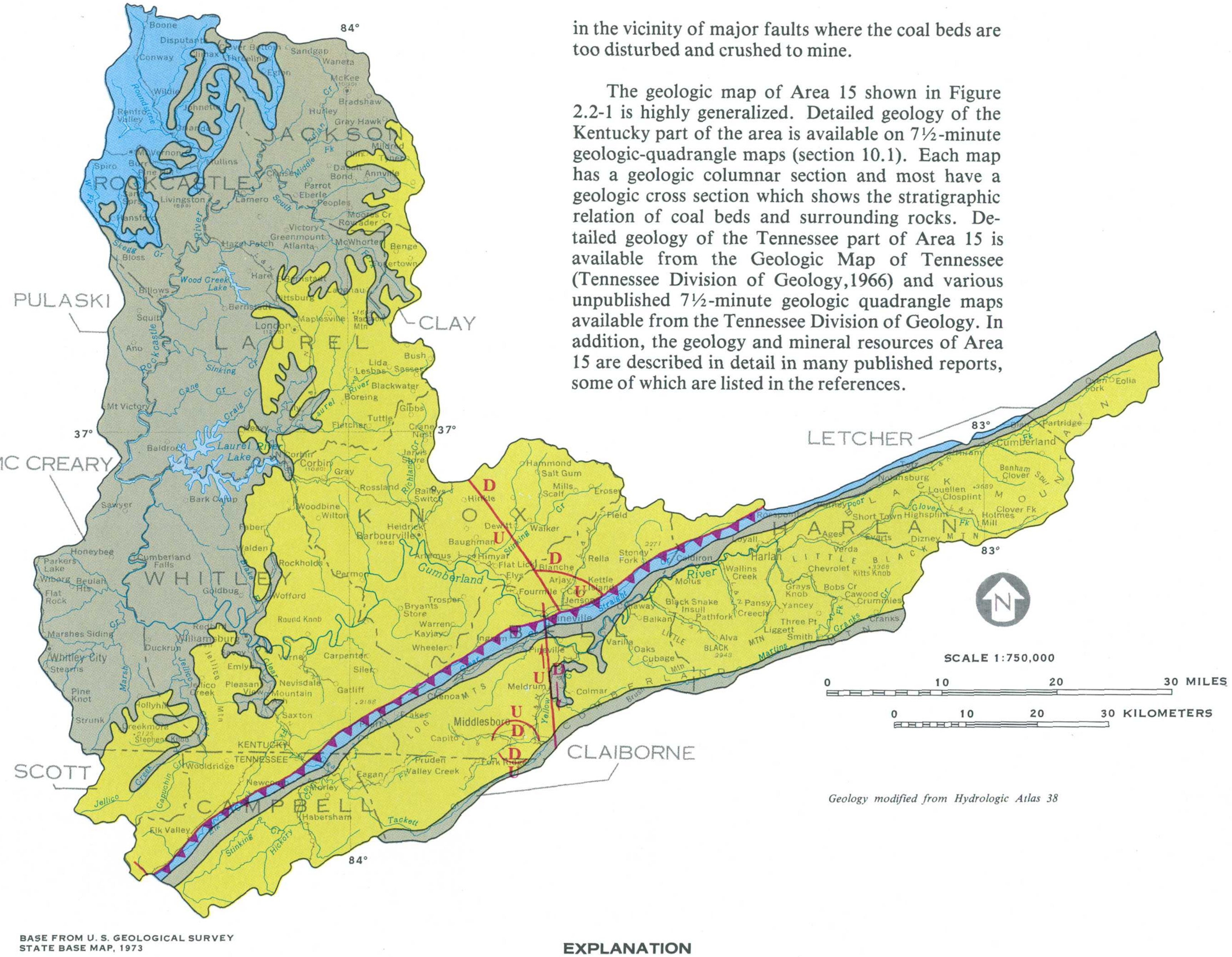
The Breathitt Formation, which crops out in about 75 percent of Area 15, contains most of the minable coal (fig. 2.2-1). It has a maximum thickness of about 2,500 feet and consists of sandstone, siltstone, shale, underclay, coal, ironstone, and very little limestone. Sandstone units (30 to 120 feet thick) commonly show frequent lateral lithologic changes and rarely form area-wide mappable units. Siltstone and shale intergrade, are commonly carbonaceous, and contain plant fragments. Ironstone occurs principally as siderite concretions in thin lenses or nodules in shale or siltstone (Rice and others, 1979). As many as 25 coal beds are present in the formation (fig. 2.2-2) and individual beds are as much as 64 inches thick. Intervals between the principal coal beds range from a few feet to nearly 400 feet (Huddle and others, 1963). Individual coal beds usually have a wide lateral extent, but may vary considerably in thickness within a given area or may be cut out by channel-fill sandstone. These characteristics, in combination with the many different names given to coal beds, make area-wide correlation of individual coal beds difficult.

Rocks of the Lee Formation are exposed in the western part of the area and near the crest of Pine and Cumberland Mountains. They underlie the Breathitt Formation throughout Area 15. In the central part of the area the Lee Formation is exposed only in the larger and more deeply eroded valleys and in some of the areas of structural highs. The formation consists of conglomerate, sandstone, siltstone, calcareous shale, underclay, and coal and is characterized by massive beds of orthoquartzite that locally contain conglomerate lenses. Sandstone makes up more than 80 percent of the formation which has in places been divided into six mappable members, the lower members in places intertongue with the underlying Mississippian rocks. Shale, siltstone, and coal are frequently interbedded and are more common in the upper part of the formation. As many as 15 coal beds are in the Lee Formation, but only three have been mined extensively. The coal beds are usually thin and markedly lenticular. The Lee Formation ranges in thickness from 350 feet in the north to 1,500 feet or more in the southeastern part of the area.

Pre-Pennsylvanian rocks of Mississippian and Devonian age are undifferentiated in this report. Mississippian age rocks are exposed in the deep valleys in the northern part of the area and Mississippian and Devonian rocks are exposed along the northern slope of Pine Mountain. The pre-Pennsylvanian age rocks consist of limestone, shale, siltstone, and sandstone and range in thickness from 400 to about 700 feet.

The strata in Area 15 have a regional dip of about 20 feet per mile to the southeast. Superimposed on this gentle regional dip are synclines, anticlines, and basins. The major structural features are the Pine Mountain fault (which is the northwest border of the Cumberland overthrust block), the Rocky Face fault, and the Middlesboro syncline. The Middlesboro syncline is bounded by Pine Mountain on the northwest and Cumberland Mountain on the southeast. Strata near the center of the syncline are relatively flat lying but the dips of strata on Pine and Cumberland Mountains range from 10 to 65 degrees. The strata dip into the basin and form a broad trough that trends from the southwest to the northeast along the southeastern border of the area. The Middlesboro syncline is broken by the Rocky Face fault, a transverse fault zone, which extends between Cumberland Gap and Pineville Gap. Geologic structure has little effect on mining except in the vicinity of major faults where the coal beds are too disturbed and crushed to mine.

The geologic map of Area 15 shown in Figure 2.2-1 is highly generalized. Detailed geology of the Kentucky part of the area is available on 7½-minute geologic-quadrangle maps (section 10.1). Each map has a geologic columnar section and most have a geologic cross section which shows the stratigraphic relation of coal beds and surrounding rocks. Detailed geology of the Tennessee part of Area 15 is available from the Geologic Map of Tennessee (Tennessee Division of Geology, 1966) and various unpublished 7½-minute geologic quadrangle maps available from the Tennessee Division of Geology. In addition, the geology and mineral resources of Area 15 are described in detail in many published reports, some of which are listed in the references.



EXPLANATION

Pennsylvanian

Breathitt Formation
Siltstone, sandstone, clay shale, coal underclay and some limestone

Lee Formation
Sandstone, conglomerate, shale, coal and underclay

Pre-Pennsylvanian

Shale, limestone, sandstone, and siltstone

Thrust Fault
Sawteeth on upper plate

Faults
Arrows indicate relative movement: U upthrown side; D downthrown side

Figure 2.2-1 Generalized geology

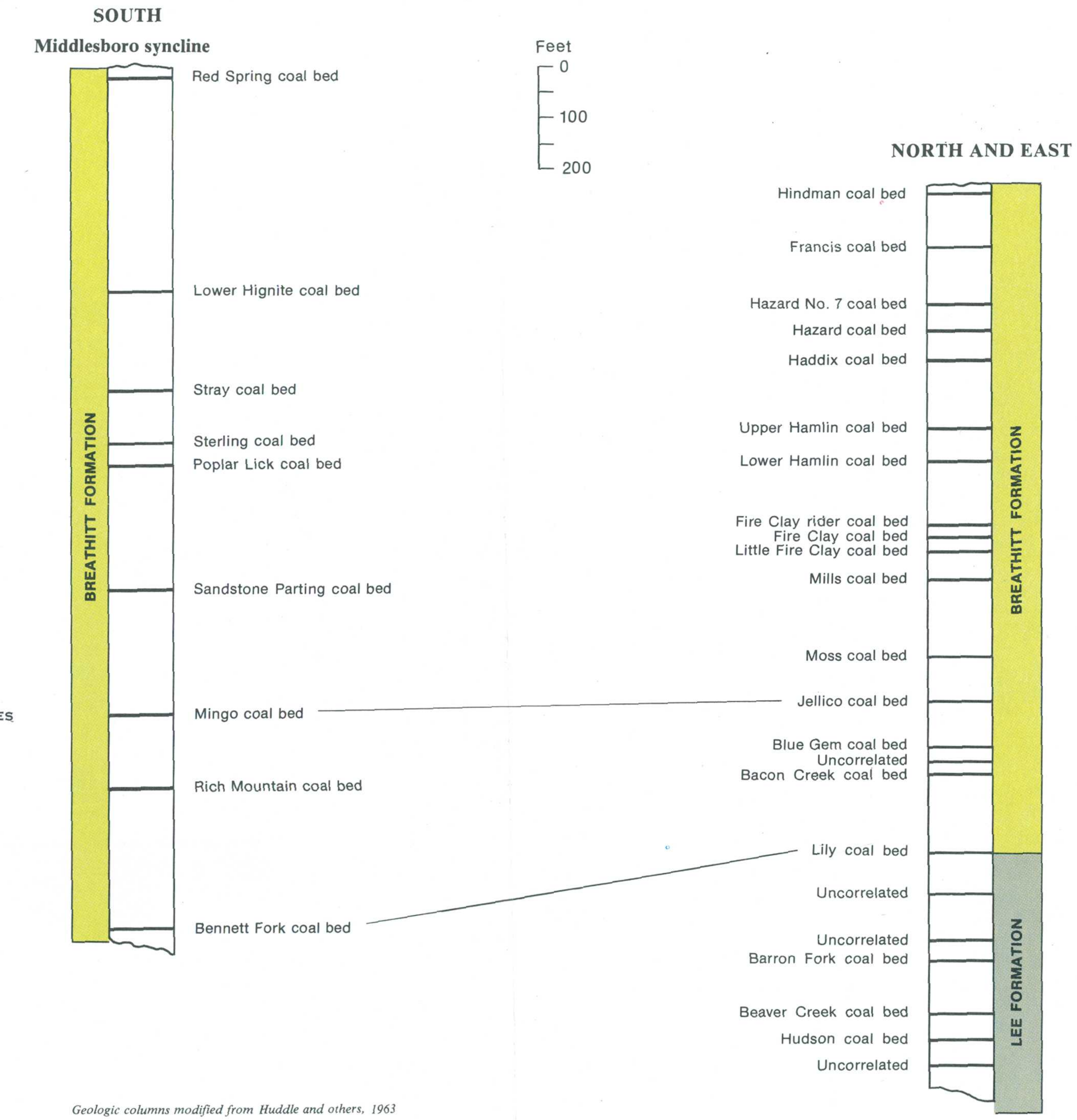


Figure 2.2-2 Generalized geologic columns in the Eastern Coal Field region.

Cumberland River Drains Area

The Rockcastle and Laurel Rivers are major tributaries to the Cumberland River within the area.

The Cumberland River is the principal stream in Area 15. It flows from the confluence of Poor and Clover Forks in Harlan County, along the edge of Cumberland Mountain, and drains heavily-mined and high-relief areas before flowing through the Daniel Boone National Forest (fig. 2.3-1). It enters Cumberland Lake, flows through a series of reservoirs in northern Tennesse, ending with Lake Barkley, and empties into the Ohio River at Smithland in western Kentucky. The confluence of the Cumberland River with the Laurel River and the Rockcastle River is in Area 15, near the western boundary, within the Daniel Boone National Forest. Other principal tributaries of the Cumberland River are Poor Fork, Clover Fork, Martins Fork, Clear Fork, and Jellico Creek.

Laurel River drains most of Laurel County before flowing into Laurel River Lake, which is also within the National Forest. From this lake, the Laurel River flows into the Cumberland River.

Rockcastle River drainage is primarily within the National Forest, in Rockcastle, Jackson, and Laurel counties. Its main tributaries are the South and Middle Forks, and Roundstone Creek. It flows into the Cumberland River downstream from Laurel River.

Drainage areas and average slopes of the major rivers and tributaries in Area 15 are:

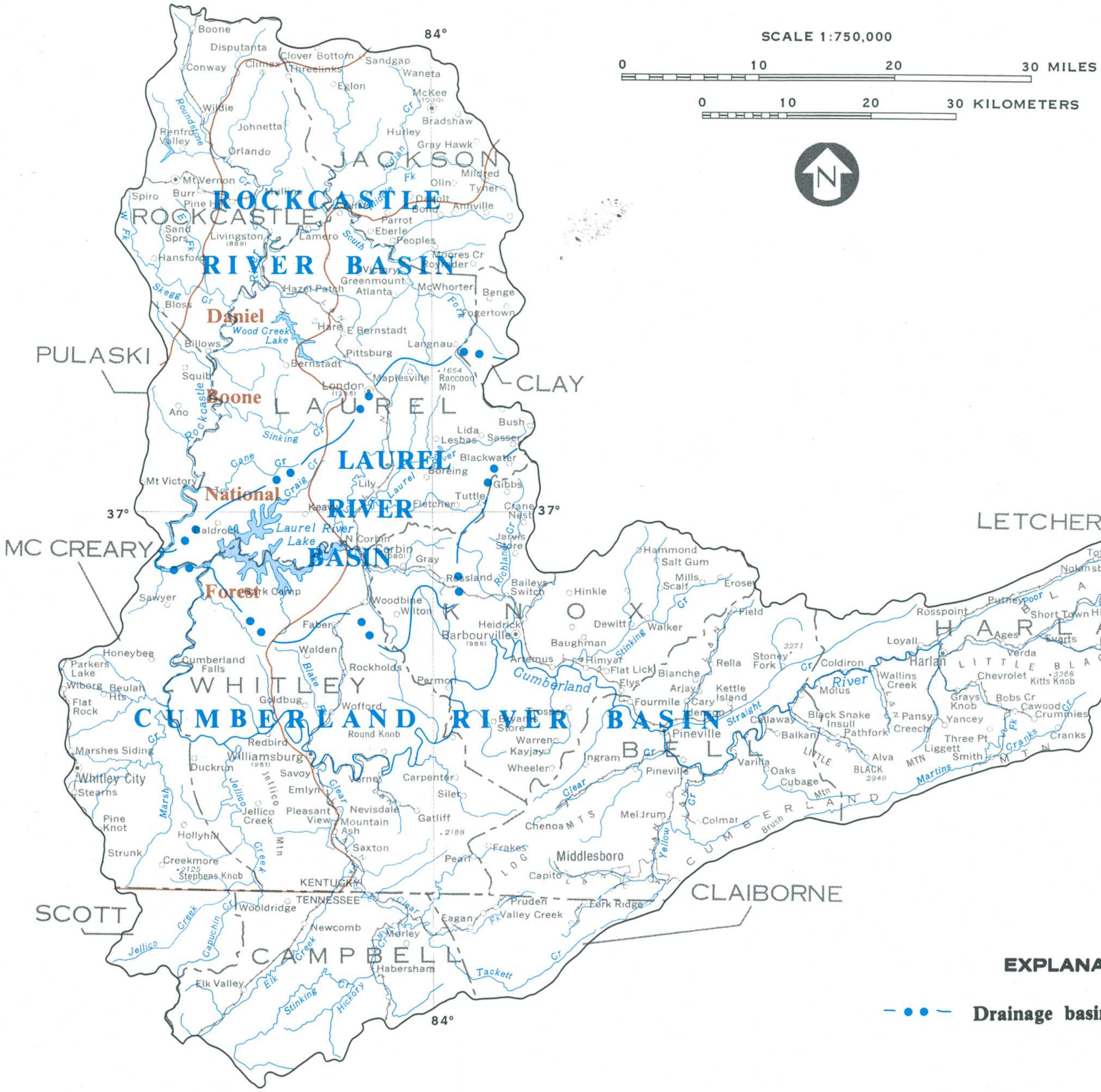
BASIN	DRAINAGE AREA (mi^2)	AVERAGE SLOPE (ft/mile)
Poor Fork	150	13.7
Clover Fork	222	12[1]
Clear Fork	370	2.3
Martins Fork	116	7.1[1]
Jellico Creek	131	4.6[1]
Cumberland River above Rockcastle River	2,332	7.0
Laurel River	289	7.3 (above lake)
Rockcastle River	763	4.2
Cumberland River (at Area 15 boundary)	3,095	7.0

[1] estimated from topographic maps

The major lakes and reservoirs in Area 15 are:

LOCATION	COUNTIES	SURFACE AREA (acres)	CAPACITY (acre-ft)
Cranks Creek	Harlan	219	6,400
Fern Lake	Bell	101	902
Wood Creek Lake	Laurel	672	23,270
Renfro Lake	Rockcastle	274	4,404
Corbin Reservoir	Laurel, Knox, and Whitley	139	2,500
Tyner Lake	Jackson	87	2,364
Cannon Creek Dam	Bell	243	11,300
Martins Fork	Harlan	340	21,120
Laurel River Lake	Laurel and Whitley	6,060	435,600

SOURCES: Kentucky Department for Natural Resources and Environmental Protection, Division of Water Quality; Kentucky Water Quality Report to Congress,1975.

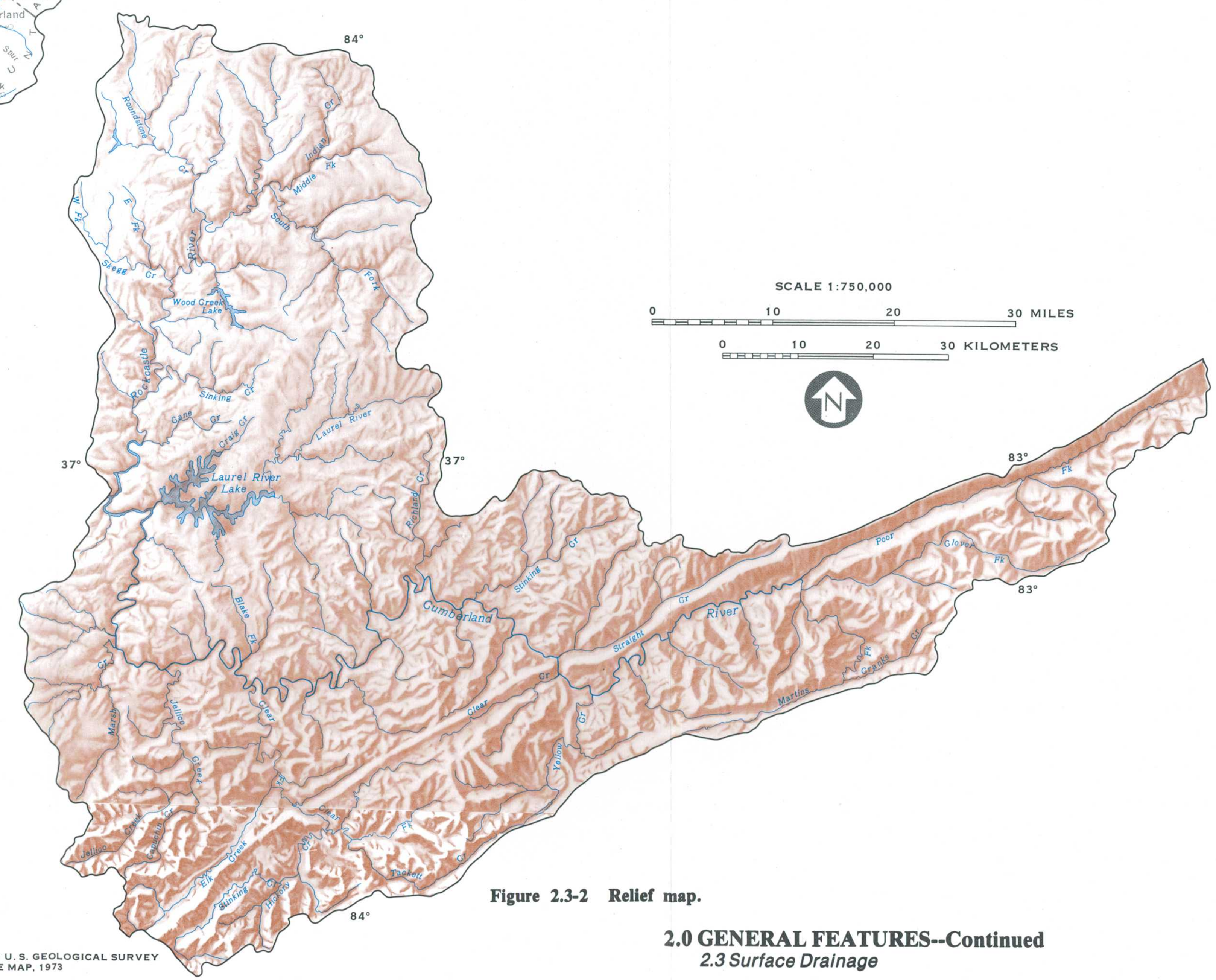


BASE FROM U. S. GEOLOGICAL SURVEY
STATE BASE MAP, 1973

EXPLANATION

— • • — **Drainage basin boundary**

Figure 2.3-1 Major drainage basins.



BASE FROM U. S. GEOLOGICAL SURVEY
STATE BASE MAP, 1973

Figure 2.3-2 Relief map.

2.0 GENERAL FEATURES--Continued

2.3 Surface Drainage

Forests Cover Most of the Area

Forests cover about 80 percent of Area 15, followed by cropland and pastures.

The principal land use in Area 15 is forest, covering about 79 percent of the area (fig. 2.4-1 and table 2.4-1). The steep, hilly landscapes of the area generally are not suited for agricultural, industrial, or urban development. About 16 percent of Area 15 is within the Daniel Boone National Forest.

Land suitable for agriculture in Area 15 occurs in relatively small areas in narrow valleys or on narrow ridgetops. These areas, about 8 percent of the total, generally are not suited for extensive cropping and the narrow valleys are often subjected to flash flooding. Pastures, mostly in Jackson, Rockcastle, and Whitley counties, comprise about 7 percent of the land use, often combined with other agricultural land.

The category for "other land" includes that used for farm roads, feed lots, rural and non-farm residences, strip mines and quarries and other minor uses. Land-use data are not available to differentiate between these uses, which account for about 3 percent of Area 15. Urban and built-up areas also account for about 3 percent of the area.

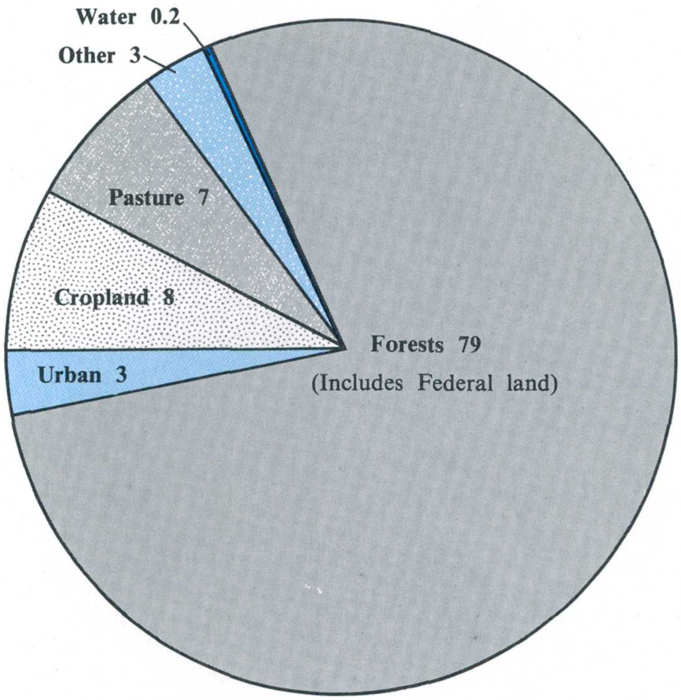


Figure 2.4-1 Percent of land uses.

Table 2.4-1 Land use in 1967.

COUNTY	TOTAL LAND AREA 1	CROP-LAND	PASTURE	FOREST	OTHER LAND 2	FEDERALLY OWNED NON-CROPLAND 3	URBAN AND BUILT-UP	SMALL WATER AREAS
	ACRES, IN THOUSANDS							
BELL	236	2.8	4.1	202	7.3	9.3	9.6	.7
HARLAN	300	4.6	2.6	261	19.1	1.4	10.7	1.2
JACKSON	216	20.1	27.6	109	1.2	52.4	4.3	.7
KNOX	239	28.3	14.3	178	11.8	0.0	6.0	.8
LAUREL	285	62.2	18.0	141	8.4	46.1	9.6	.2
MCCREARY	268	5.1	8.0	93	2.9	157.0	1.7	.1
ROCKCASTLE	199	27.4	30.1	63	1.9	11.4	6.2	.3
WHITLEY	294	19.6	31.9	197	4.4	32.5	9.4	.2
TOTALS 4	2037	169.1	136.6	1244	57.0	310.1	57.5	4.2

1 INCLUDES TOTAL AREA OF COUNTY. DOES NOT INCLUDE TENNESSEE OR LETCHER COUNTY, KENTUCKY.

2 NON-FEDERALLY OWNED RURAL LAND NOT CLASSIFIED AS CROPLAND, PASTURE, FOREST WOODLAND, OR URBAN AND BUILT-UP AREA.

3 LAND USE STATUS NOT GIVEN IN SOURCE; CONSIDERED BY AUTHORS TO BE FOREST LAND IN DANIEL BOONE NATIONAL FOREST.

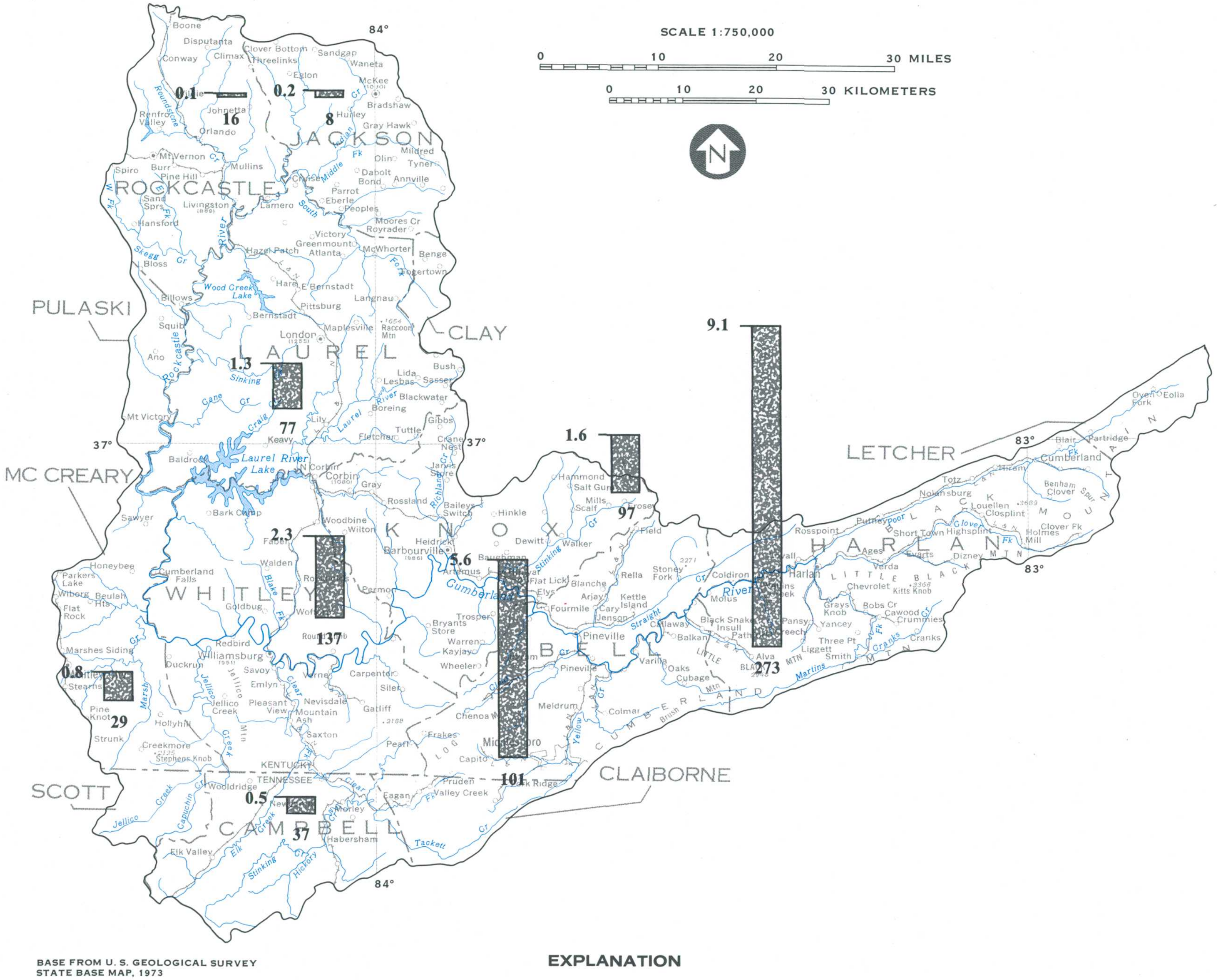
4 BECAUSE OF ROUNDING OFF, THE SUMS OF THE LAND USES DO NOT AGREE WITH THE TOTAL LAND AREA.

LAND USE DATA FROM STATE CONSERVATION NEEDS INVENTORY COMMITTEE (1970), EXCEPT AS OTHERWISE NOTED.

Coal Production in 1978 was about 22 Million Tons in Area 15

In 1978, the principal coal production was from Harlan and Bell Counties with a combined total of 14.7 million tons. Surface mining production was about 52 percent of the total.

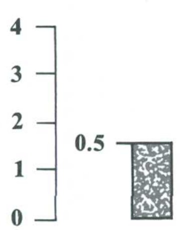
Coal production in Area 15 was about 22 million tons in 1978 of which about 52 percent was from surface mines. More than 67 percent of the production (14.7 million tons) was from mines in Harlan and Bell Counties in the upper Cumberland River basin (fig. 2.5-1). In Bell County, coal production data from 1950-78 show a steady increase in surface mining (fig. 2.5-2). However, in Harlan County, underground production is seven times surface mining production (fig. 2.5-3). This greater volume of under-ground mining is due in part to the topography of the upper Cumberland River basin which is more rugged in Harlan than in Bell County, and to deeper coal seams in the headwaters of the basin which make surface mining impractical or uneconomical.



EXPLANATION

Coal production, in million tons

Production figures show total tonnage for the indicated counties.



37 Number of surface and underground mines, undifferentiated

Figure 2.5-1 Coal production and number of mines in 1978.

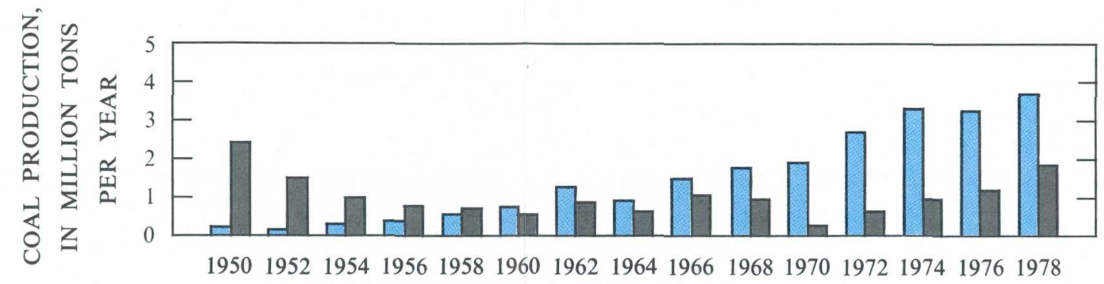
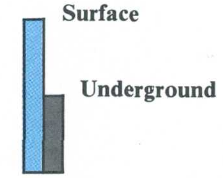


Figure 2.5-2 Coal production from underground and surface mines in Bell County, Kentucky, 1950-78.

EXPLANATION



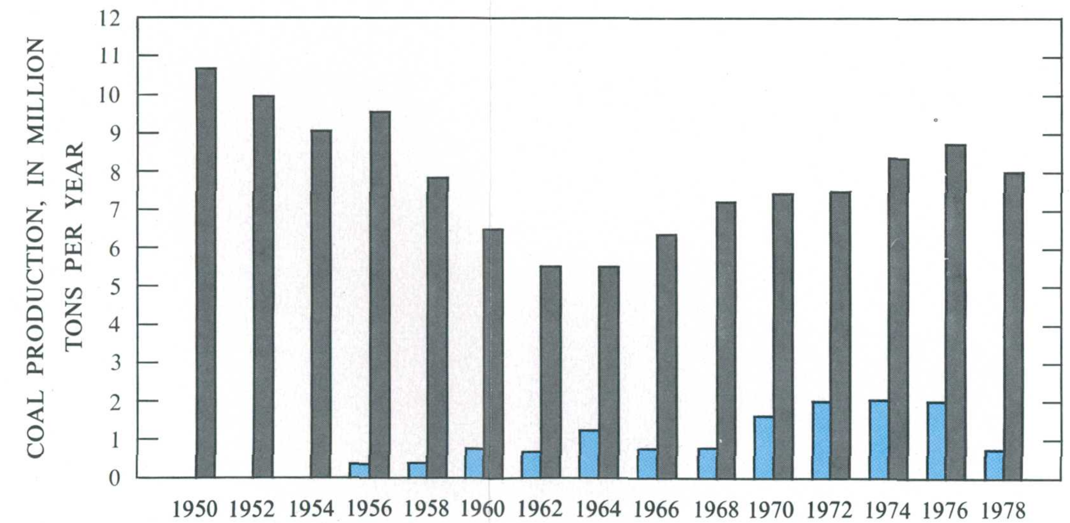


Figure 2.5-3 Coal production from underground and surface mines in Harlan County, Kentucky, 1950-78.

Soils Originate from Sandstone, Siltstone and Shale

The principal soil associations are groups of the Jefferson-Shelocta, Lathan-Shelocta, and Shelocta-Gilpin.

Most of the soils in Area 15 are deep, well-drained, acidic soils of the Jefferson-Shelocta, Lathan-Shelocta and Shelocta-Gilpin associations (fig. 2.6-1) (Soil Conservation Service, 1974 and 1978).

The predominant association in the Cumberland River basin is the Shelocta-Gilpin. These are moderately deep to deep, well-drained soils formed in loamy colluvium from acid siltstones, shales, and sandstones (table 2.6-1). They occupy the long-steep side slopes of the higher ridges of the Cumberland River basin in the Cumberland Mountains. Slopes range from 20 to 60 percent.

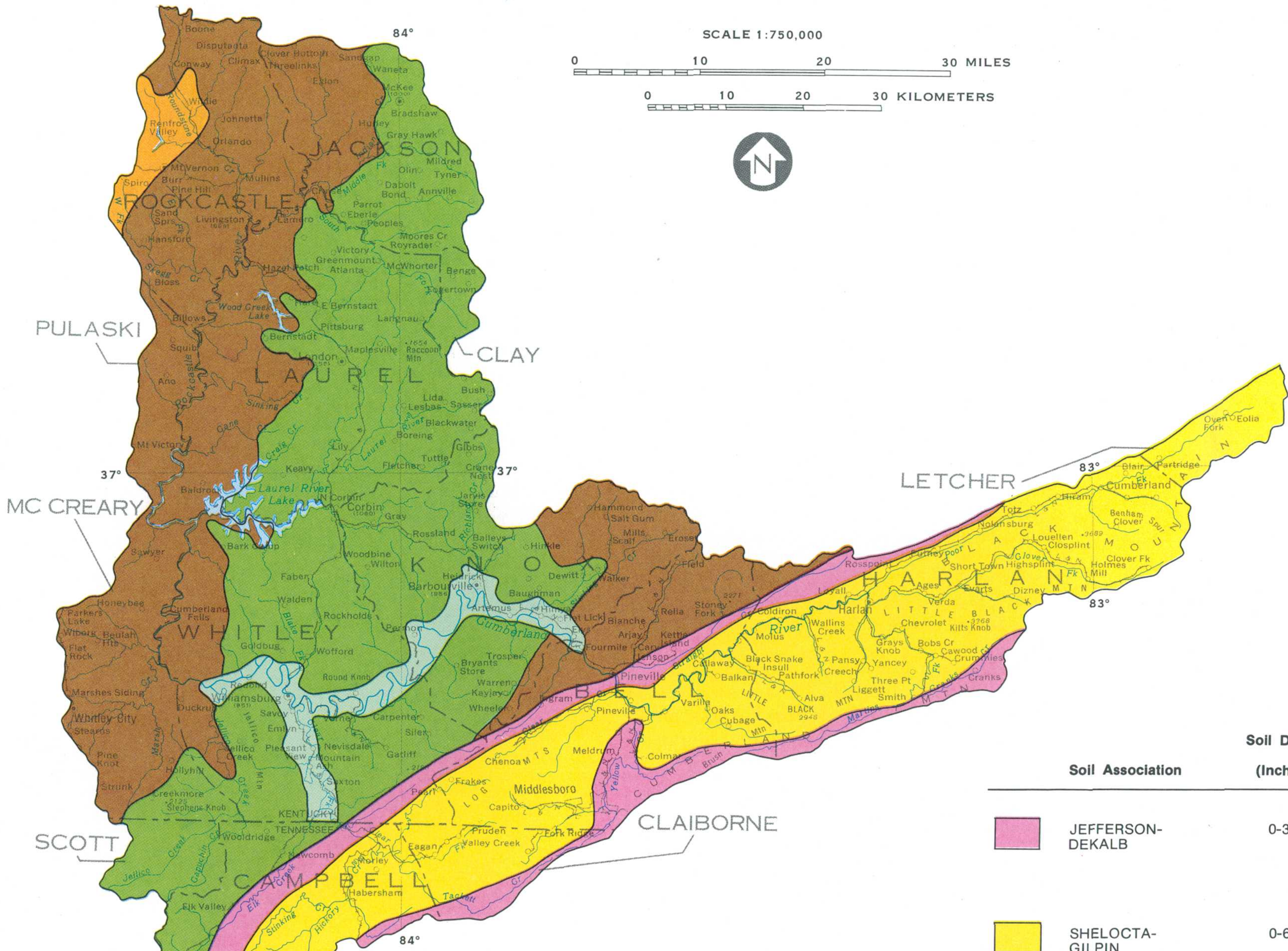
Soils along the northern edge of the Cumberland River basin in Bell and Knox counties, and in most of the Laurel River basin, are associations of the Lathan-Shelocta group. These are moderately deep to deep, well-drained soils formed in clayey residium of acid shales and loamy colluvium. The slopes range from 20 to 50 percent. The steepness of the mountainous terrain where these soils occur makes them unsuitable for most agricultural uses. These slopes are mostly woodland, with some pasture.

Most of the Rockcastle River basin includes the soils of the Jefferson-Shelocta association. A large band of these soils is also present in the northern Cumberland River basin, in Knox and Bell counties. These are also deep to moderately deep, well-drained soils. They are formed in loamy colluvium from shales, sandstones and siltstones. The area where these soils are found is covered with forest. Steep slopes (20 to 60 percent) also make these soils poorly suited for agriculture.

Toward the center of Area 15 there is a band of several mixed soils, mostly of alluvial origin. These are formed on terraces and floodplains along the lower Cumberland River in Knox and Whitley counties. These are the best agricultural soils but are subject to periodic flooding from the Cumberland River.

Two narrow bands of the Jefferson-Dekalb soils run from east to west along Pine and Cumberland Moutains. The soils are very similar to those in the Rockcastle River basin (Jefferson-Shelocta).

The soils in the Tennessee part of Area 15 are similar to the Shelocta-Gilpin and Lathan-Shelocta groups. Tennessee classifications list them as part of the Muskingum-Gilpin-Jefferson associations (Soil Conservation Service, 1978)(table 2.6-1).



Soil associations from Soil Conservation Service, 1974 and 1978

BASE FROM U. S. GEOLOGICAL SURVEY
STATE BASE MAP, 1973

Figure 2.6-1 Generalized soil associations.

CORRELATION OF SOIL ASSOCIATIONS

Kentucky		Tennessee
LATHAM-SHELOCTA SHELOCTA-GILPIN	------------	MUSKINGUM-GILPIN-JEFFERSON
JEFFERSON-DEKALB	------------	BOULDIN-ROCK OUTCROP-RAMSEY

Table 2.6-1 Soil association features

Soil Association	Soil Depth (Inches)	Depth to Bedrock (Feet)	pH (Units)	Permeability (Inches/Hour)	Available Water Capacity (Inches/In)	Slope (Percentage)	Description
JEFFERSON-DEKALB	0-30	1.5-8.0	4.5-5.5	0.2-6.3	0.06-0.18	20-60	Steep side slopes of higher mountains with narrow ridge tops and flood plains of Cumberland Mountains. Deep to moderately deep, well-drained soils formed in loamy colluvium from acid sandstone, siltstone, and shale.
SHELOCTA-GILPIN	0-60	1.5-10	3.6-5.5	0.6-2	0.06-0.2	20-60	Long steep side slopes of higher mountains with narrow ridge tops and plains in the Cumberland Mountains. Deep to moderately deep, well-drained soils formed in loamy colluvium from acid siltstone, shale and sandstone.
LATHAM-SHELOCTA	0-74	4-8	3.6-5.5	0.63-6	0.12-0.16	20-50	Steep side slopes with narrow ridge tops and flood plains in the Cumberland Mountains. Deep to moderately deep, well-drained soils, formed in clayey residium from acid shales.
JEFFERSON-SHELOCTA	0-38	5-8	4.5-6.5	0.63-6.3	0.1-0.18	20-60	Steep side slopes with narrow ridge tops and flood plains in the Cumberland Mountains. Deep to moderately deep, well-drained soils, formed in loamy colluvium from acid sandstone, siltstone and shale. Includes some Shelocta-Brookside and Colyer-Rockcastle associations in northern Rockcastle and Jackson Counties.
FREDRICK-MOUNTVIEW	0-108	>6	4.5-6.5	0.6-2	0.13-0.23	2-30	Rolling broad ridge tops dissected by small streams and karst areas. Deep well drained soils formed in loess or clayey limestone residuum.
OTHERS (MIXED ALLUVIALS)	0-74	3->6	4.5-7.3	0.6-6	0.07-0.24	0-20	Terraces and flood plains of major mountain streams. Deep, well to poorly drained soils formed in loamy alluvium on flood plains. Not mapped in Tennessee.

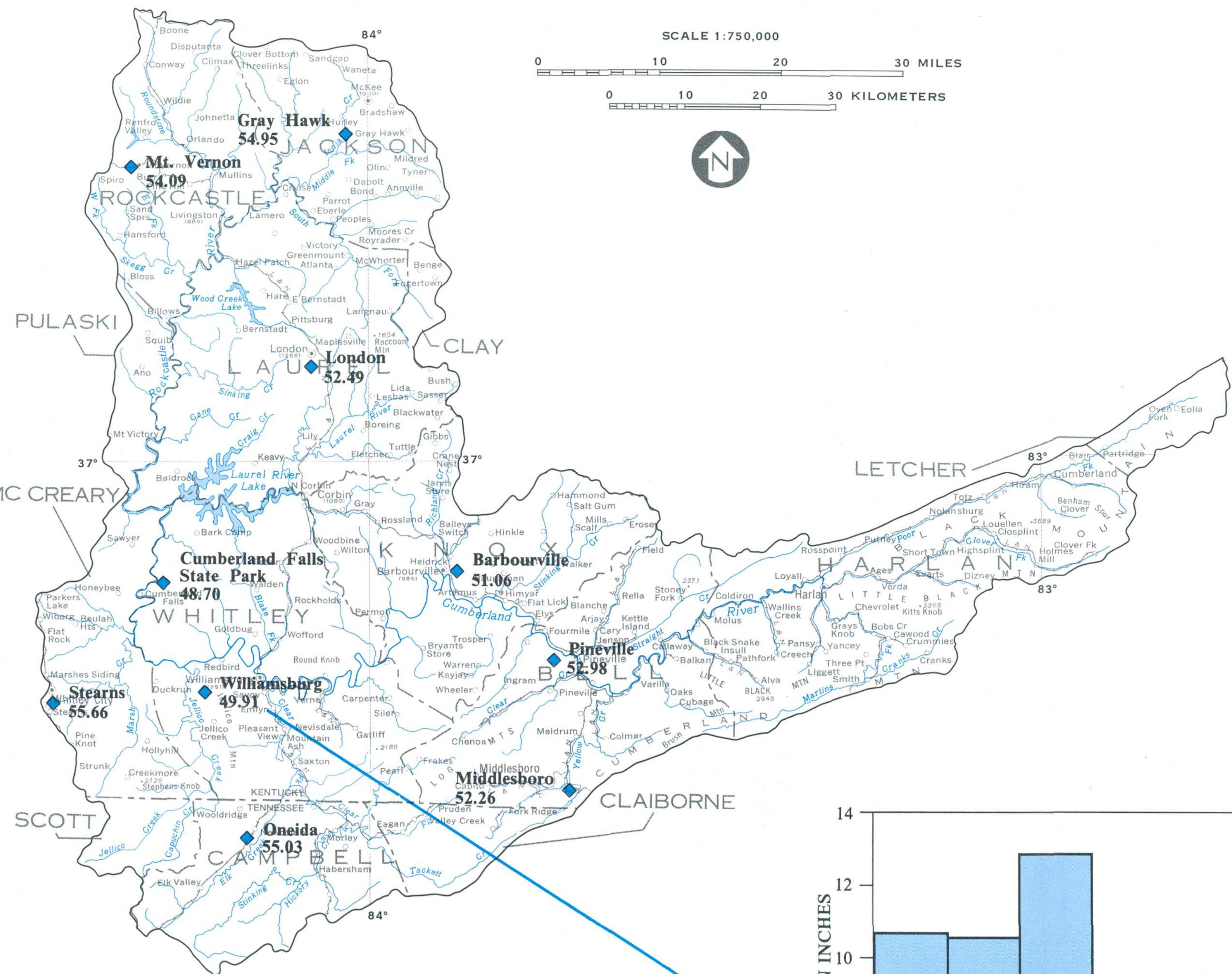
Precipitation Averages about 46 to 55 Inches and Occurs 110 to 130 Days Per Year

March and July average rainfall is greater than other months; September and October average rainfall is least.

The average precipitation from 1951 to 1978 at nine precipitation measuring stations in Area 15 ranges from about 46 to 55 inches per year (fig. 2.7-1). Length of station records range from 16 to 27 years. Measurable precipitation occurs 110 to 130 days per year. During an average year, most rainfall at Williamsburg, Ky. (Whitley County) occurs during March and July, while the least occurs in September and October (fig. 2.7-2).

Extreme storms with rainfall averaging about 4.5 inches in a 24-hour period have a recurrence interval of 10 years (fig. 2.7-3). The upper Cumberland River basin is subject to very intense local storms. The most recent intense storm was during 1978, with 24-hour rainfalls of as much as 4.4 inches, and a three day rainfall total of 6.0 inches. Rainfalls of this intensity generally cause flash floods, landslides, and heavy sediment runoff.

Snow and sleet are not a significant part of the precipitation. They average about 20 inches per year which is equal to about two inches of rainfall. However, during extreme years, snow totals of more than 50 inches can contribute significantly to the spring runoff.

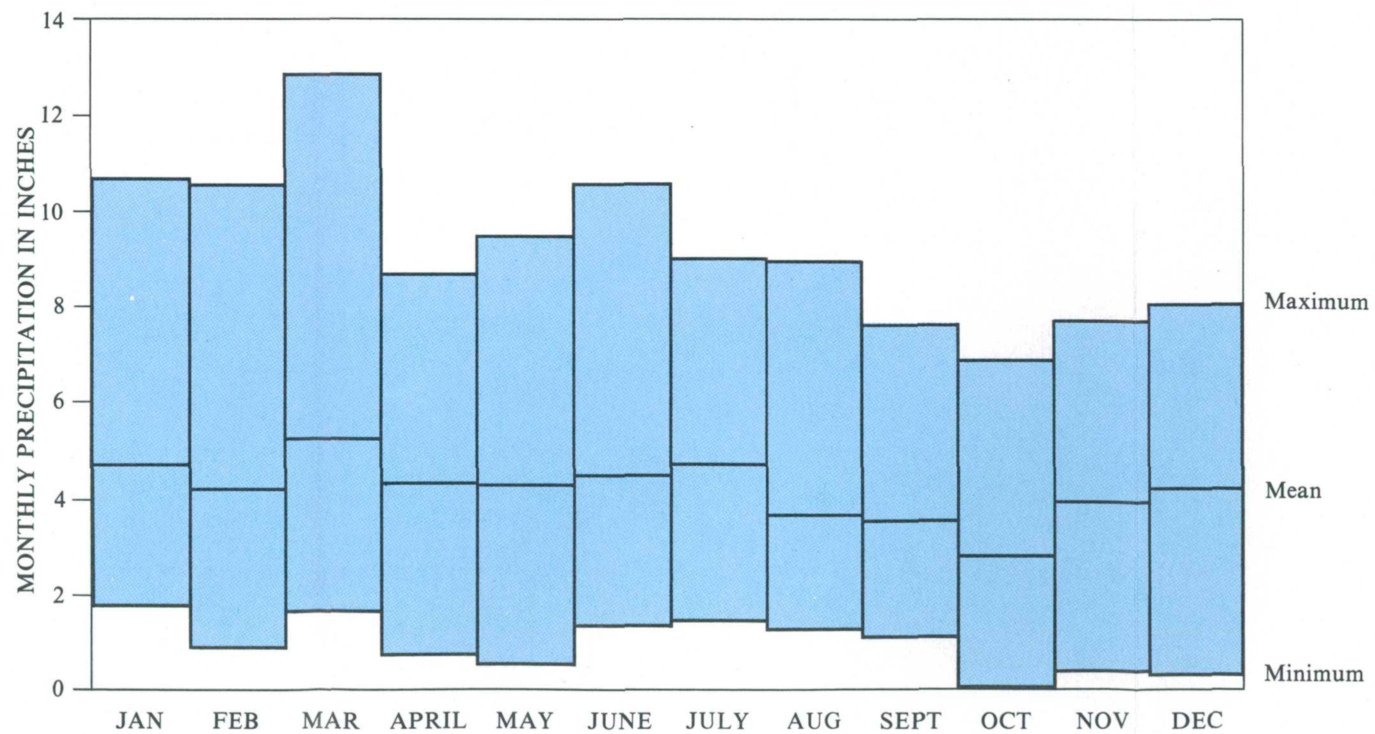


BASE FROM U. S. GEOLOGICAL SURVEY
STATE BASE MAP, 1973

EXPLANATION

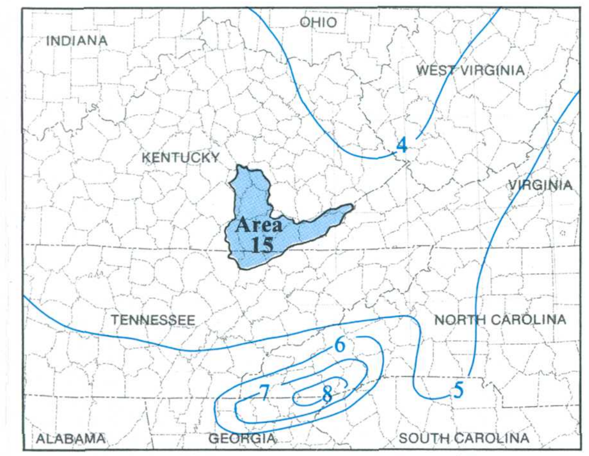
◆ Pineville 52.98 — **Precipitation station and name**
Number indicates average annual precipitation, in inches. Period of record: Kentucky, to 1979; Tennessee, to 1972

Figure 2.7-1 Precipitation stations.



Precipitation data by National Oceanic and Atmospheric Administration

Figure 2.7-2 Monthly normal precipitation at Williamsburg, Whitley County, Kentucky, 1941-70.



Rainfall frequency from U.S. Department of Commerce, 1961

EXPLANATION

—4— **10-year, 24-hour rainfall frequency, in inches**

Figure 2.7-3 Rainfall frequency.

Principal Water Use is for Domestic Supply

About 12.9 million gallons per day was withdrawn in 1975 for domestic, industrial, and agricultural uses. Water is also used extensively for recreation.

Water use in Area 15 during 1975 was about 12.9 Mgal/day. Water use data by county are presented in figure 3.0-1. About 84 percent of the water used (10.8 Mgal/d) was for public supply, mainly for domestic use (fig. 3.0-2). Surface water is the primary source of supplies, accounting for about 80 percent of the water withdrawn.

Recreation is an important water use in Area 15. The upper Cumberland River basin is considered one of the most important fishing areas in the state. About 1,040 miles of streams are considered of fishery importance (Carter and Jones, 1969). Many streams have a wide variety of game fish.

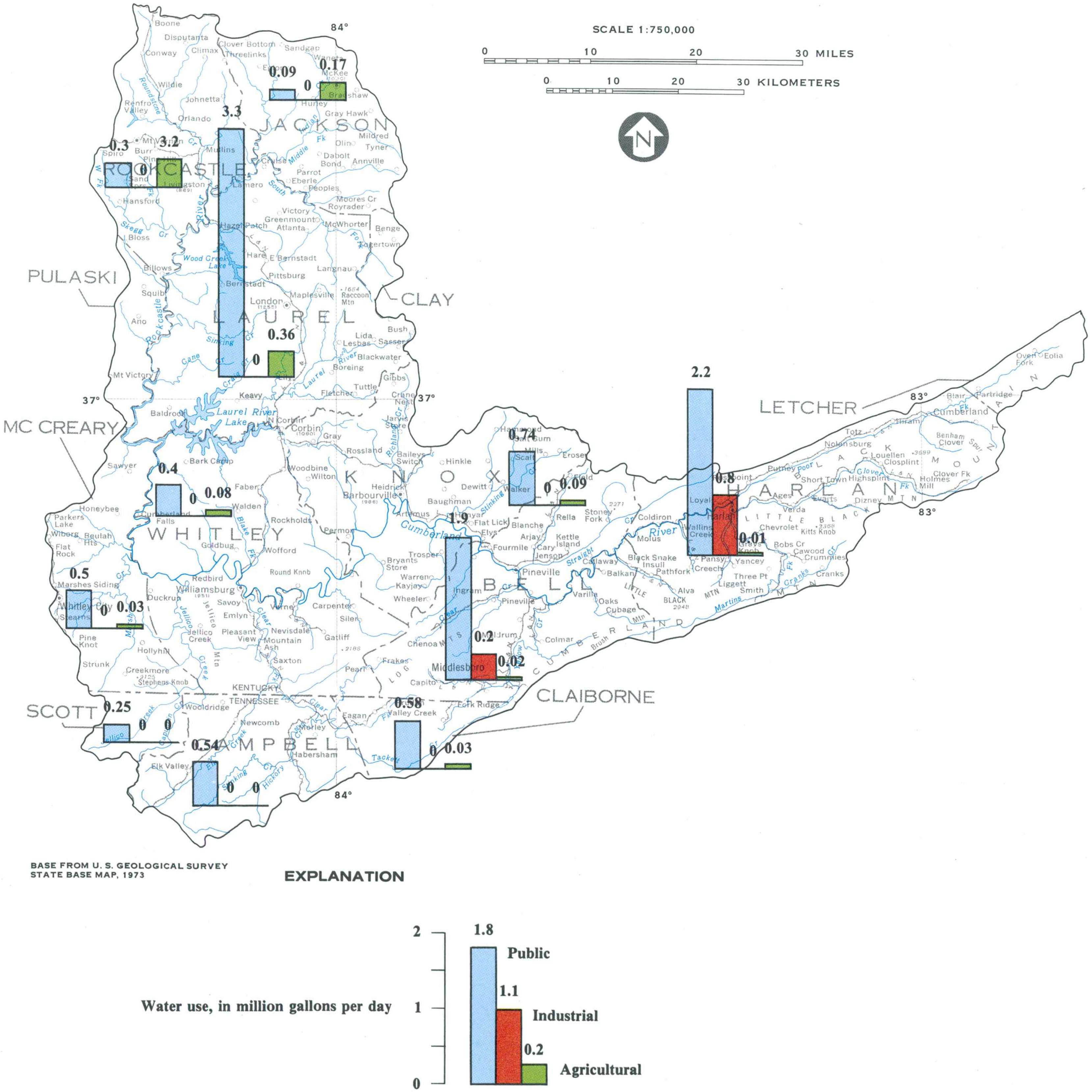


Figure 3.0-1 Water use in 1975, by county.

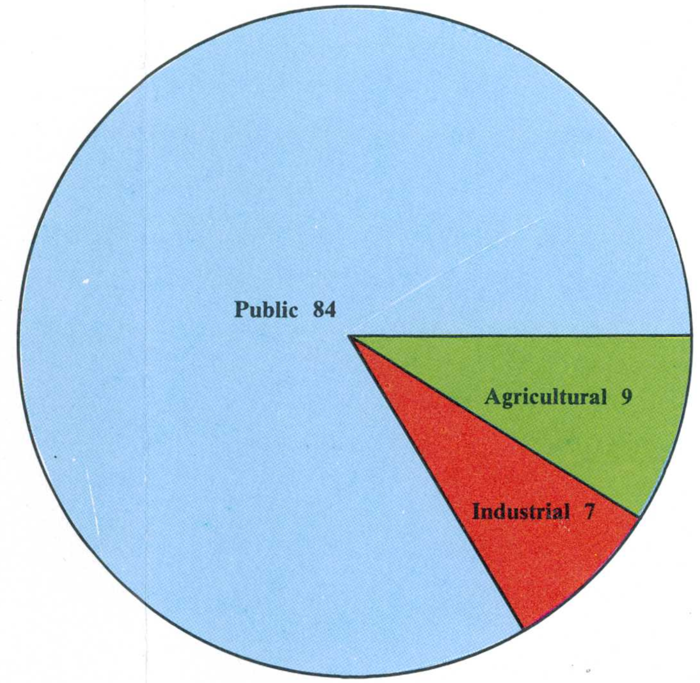


Figure 3.0-2 Percentage of total water use in Area 15.

Information on Surface Water Available for 86 Sites

Surface-water data-collection sites in Area 15 were expanded from 30 to 59 sites in 1979 by the U.S. Geological Survey in response to the Surface Mining Control and Reclamation Act. Data are also available for 27 inactive sites.

At the time of the passage of the Act there were 12 active continuously recording surface-water gaging stations and 18 non-recording sites on streams in Area 15. One continuosly-recording site and 28 non-recording sites were added in 1979. In addition, one non-recording site was started in 1979 but discontinued in the same year. The continuously-recording gaging stations record stream stage with time. These data can, in turn, be converted to stream discharge after each station is rated or calibrated. Thus continuous-recording stations, as shown on figure 4.1-1 and in section 10.2, are sites where a continuous record of stream stage and flow is recorded. The non-recording stations are on small streams where streamflow measurements are made several times annually (fig. 4.1-1 and section 10.2).

Records of stream stage and flow are valuable data used in analyzing the hydrology of basins and for planning structures and water uses of streams. Various data-analysis techniques, such as flow-duration curves, flood-frequency relations, and low-flow analyses (to be presented in subsequent sections) rely on a record of stage and discharge relation with time.

In addition to the active continuously recording sites, two discontinued recording sites and 25 discontinued non-recording sites are also shown (fig. 4.1-1 and section 10.2).

The historical data, as well as data on active sites, are published in the annual reports "Water Resources Data for Kentucky" and "Water Resources Data for Tennesee". The information is also readily available through the National Water Data Exchange (NAWDEX) as described in Section 9.0.

Surface-water quality data are valuable and needed along with flow data to assess existing conditions and changes that may result from mining and reclamation practices as well as other land uses.

Very little surface-water quality data were available area-wide prior to 1979 when the number of water-quality sites was expanded, as shown in section 10.2. This expansion of data-collection sites occured in two ways; collection on a regular six-week interval of water quality data at selected continuously recording sites, and collection of water-quality data at sites on streams where streamflow was not continuously recorded. At these latter sites, generally on smaller streams, streamflow was measured and water samples were collected for selected physical and chemical analysis at approximately three-month intervals in order to measure seasonal quality and quantity variations. All water quality sample collecting was done as simultaneously as possible to provide areawide water-quality data during a particular flow condition. Surface-water quality data are available from the previously mentioned "Water Resources Data" reports for Kentucky and Tennessee or from NAWDEX.

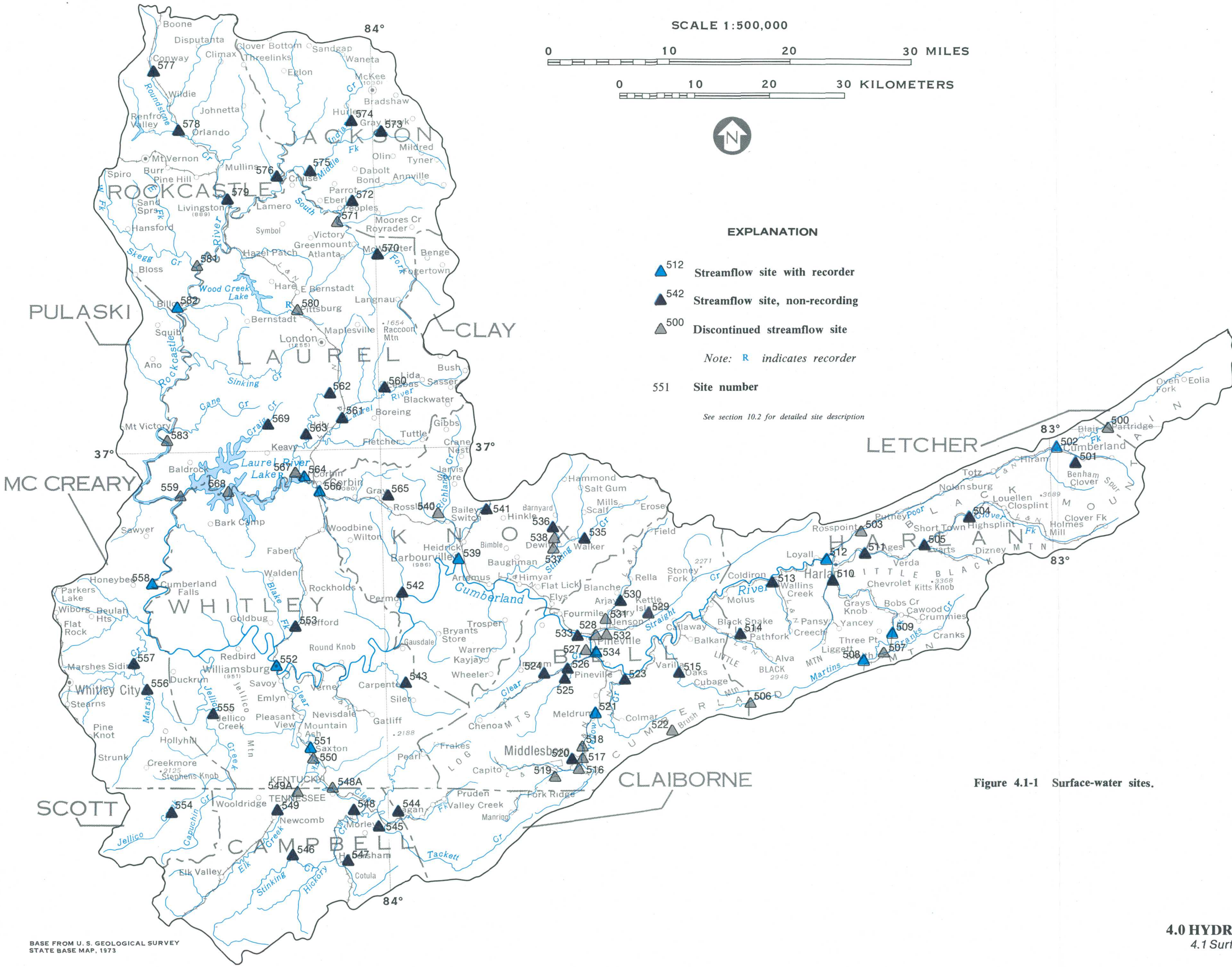


Figure 4.1-1 Surface-water sites.

Four Reports Describe Ground-Water Hydrology of the Area

Chemical analyses of ground water are available for most of Area 15. Three wells monitor ground-water levels and one well monitors ground-water quality.

Surface mining and other land disturbances can alter the quality and quantity of ground-water. Data on ground-water availability and quality have been published in reports that include all of Area 15 (fig. 4.2-1). The reports, all of a reconnaissance nature, show depth of wells, reported or measured water levels, yields of wells, reported or analyzed quality of ground water, data on chemical analysis of ground water, and contain a general discussion on the ground-water hydrology of the report area.

The locations of wells for which chemical analyses of water are available are shown on figure 4.2-2 and in section 10.3. Data from these analyses were used in the summary of ground-water quality in Section 8.0.

Long-term water-level information is currently available from 3 wells in the area (fig. 4.2-1). These wells provide information on the artesian and water-table aquifers . One well tapping the Lee Formation in Bell County has been sampled periodically for chemical and physical analyses since 1964; annual samples have been collected since 1969. Data on these wells are listed below.

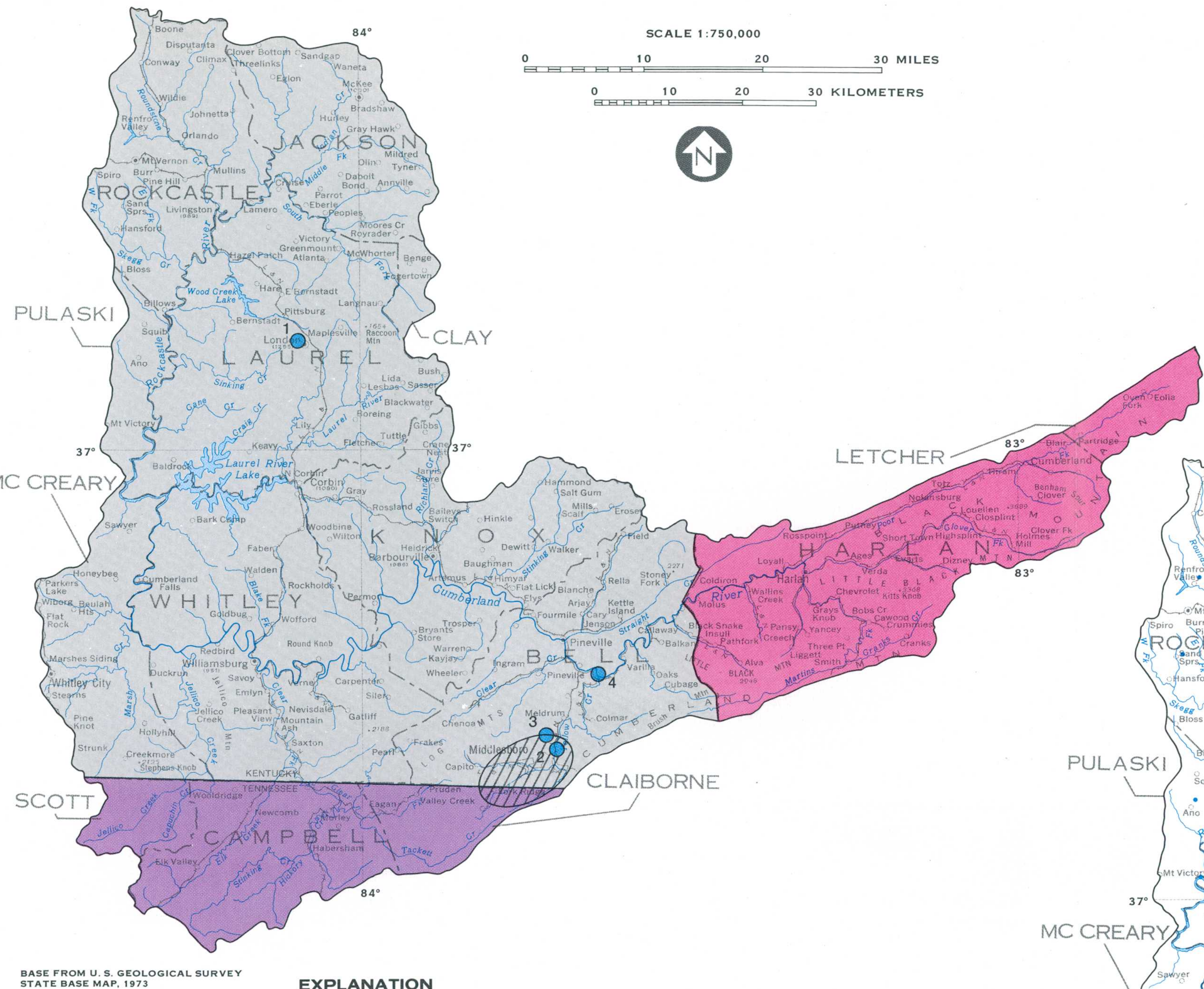
A comprehensive study of the hydrogeology of the Eastern Coal Field region in Kentucky was begun in 1980 by the Kentucky Geological Survey. The study, which includes Area 15, will gather additional data on the aquifers in the area, will develop a data base to supplement the present ground-water monitoring program, and will establish a network of observation wells.

The ground-water data collected during 1980, as well as historical data, are published in the annual report "Water Resources Data for Kentucky". The information is also readily available through the National Water Data Exchange (NAWDEX) as described in section 9.0.

Ground-water monitoring sites

Site number	Site identification number	Depth of well, in feet	Formation tapped	Period of record	Frequency of measurement[1]
1	370757084045001	370	Lee	1951-62 1965-	R
2	363730083423501	940	Lee	1964, 1966-67, 1969-	P, Q
3	363749083430701	39	Breathitt	1964-	R
4	364326083383101	92	Lee	1965-	R

[1] P - Periodic, R - Recorded, Q - Water quality



EXPLANATION

2 **Observation well and number**
See table on facing page for details

Available reports on ground water

- **Kilburn and others, 1962**
- **Price and others, 1962**
- **Mull and Pickering, 1968**
- **Newcome and Smith, 1958**
  See list of references for additional data

Figure 4.2-1 Areas of available reports on ground water and location of observation wells.

EXPLANATION

Well, chemical analysis of water available
See section 10.3 for additional data

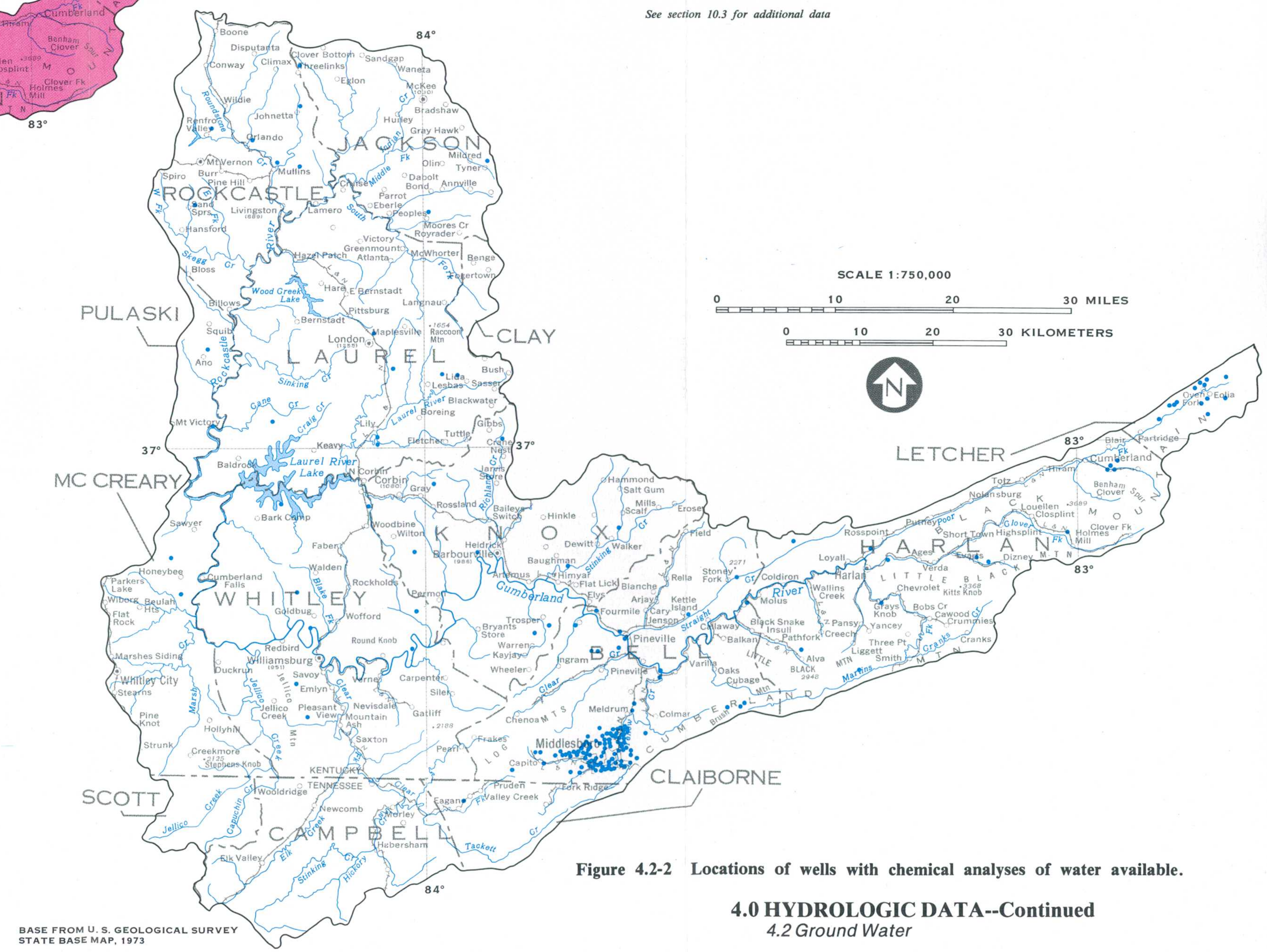


Figure 4.2-2 Locations of wells with chemical analyses of water available.

Streamflow Varies Seasonally and Geographically

Streamflow fluctuates seasonally with precipitation and evapotranspiration. Runoff at sites in the Cumberland River basin averages about 25.6 inches per year, while in the Rockcastle River basin, the average is about 19.4 inches per year.

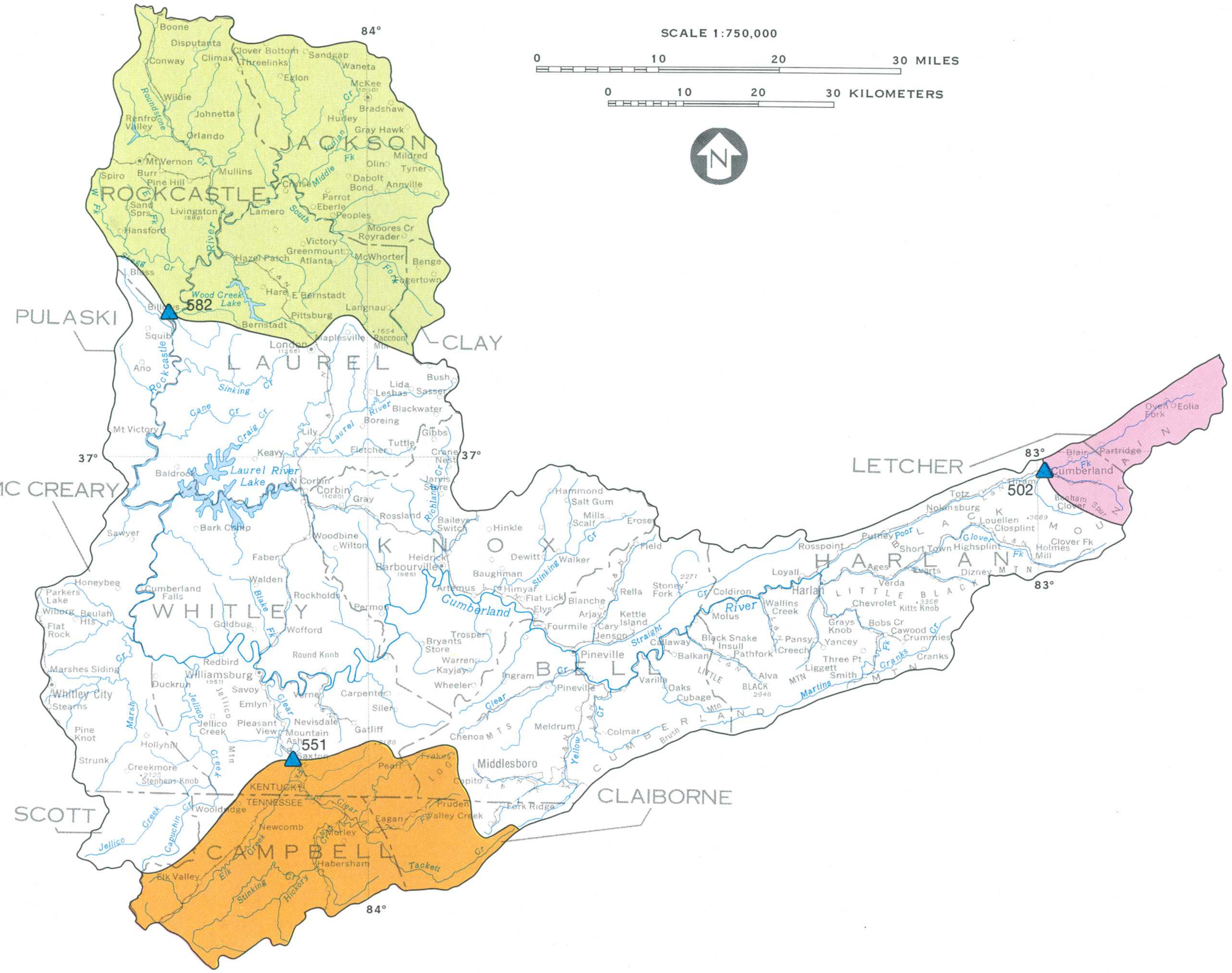
Streamflow throughout Area 15 varies seasonally with precipitation and evapotranspiration. The yearly cycle of streamflow is considered to begin in October, normally the month of least precipitation and lowest streamflows (fig. 5.1-1 to fig. 5.1-3). Streamflow at sites in the area generally increase during November as precipitation increases and evapotranspiration decreases. Increasing precipitation both as rain or snow augments flows through the winter months. Spring thunderstorms help to maintain a relatively high runoff through May. The low-flow season generally begins around June, as precipitation decreases and evapotranspiration increases, and extends through late October or early November. Summer thunderstorms temporarily reverse the trend of low streamflow during this season.

Average runoff at streamflow sites in the area ranges from 18.6 to 35.3 in/yr (Table 5.1-1, below). In general, runoff is several inches higher at sites in the Cumberland River basin (mined) than in the Rockcastle River basin (partially mined). Rainfall in Area 15 is fairly uniform, ranging from about 46 to 55 in/yr. At most of the sites in the Cumberland River basin, runoff of about 25.6 in/yr is about 50 percent of precipitation. In comparison, at the sites in the Rockcastle River basin, runoff of about 19.9 in/yr is about 40 percent of precipitation. Physiographic, cultural, and geologic differences probably account for part of the excess runoff at sites on the Cumberland River. The effect of surface-mining in the basin on average runoff is unknown.

Table 5.1-1 Average runoff.

SITE NUMBER	BASIN	YEARS OF RECORD	INCHES PER YEAR
502	CUMBERLAND	39	23.9
509	"	8	35.3
512	"	39	25.4
521	"	39	25.8
534	"	37	23.7
539	"	40	25.3
551	"	11	25.6
552	"	29	23.6
558	"	69	22.1
564	LAUREL	6	27.6
566	"	6	25.0
567	"	33	22.8
580	ROCKCASTLE	18	18.6
582	"	43	21.2

See section 10.2 for detailed site description



BASE FROM U. S. GEOLOGICAL SURVEY
STATE BASE MAP, 1973

EXPLANATION

551 Site location and number

Drainage basin of Rockcastle River at Billow (site 582)

Drainage basin of Clear Fork near Saxton (site 551)

Drainage basin of Poor Fork near Cumberland (site 502)

See section 10.2 for detailed site description

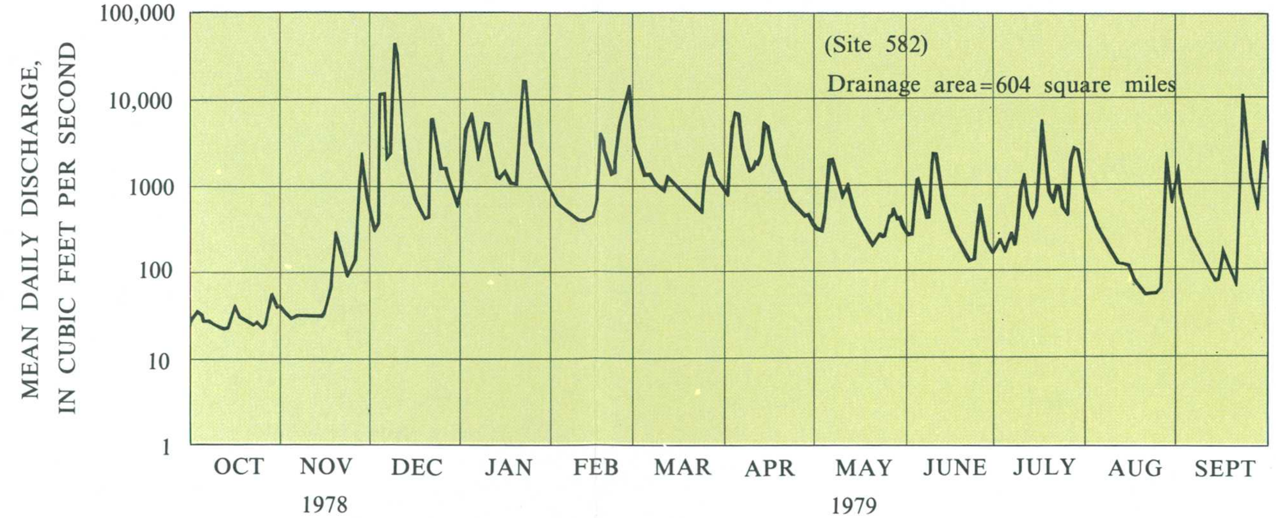


Figure 5.1-1 Mean daily discharge for Rockcastle River at Billows, Kentucky, 1979 water year.

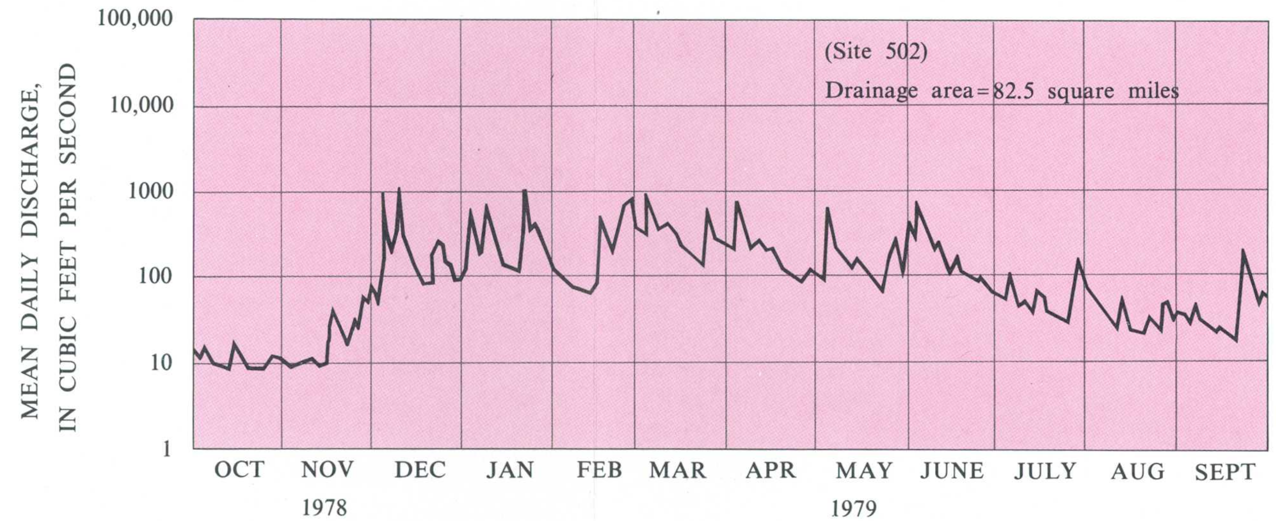


Figure 5.1-2 Mean daily discharge for Poor Fork near Cumberland, Kentucky, 1979 water year.

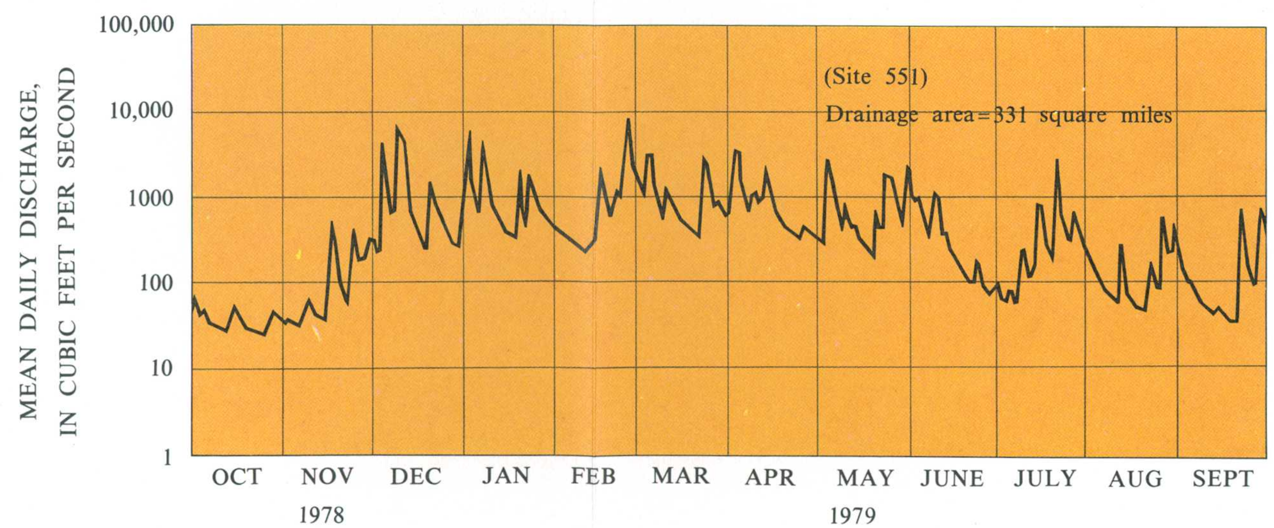


Figure 5.1-3 Mean daily discharge for Clear Fork at Saxton, Kentucky, 1979 water year.

5.0 SURFACE WATER

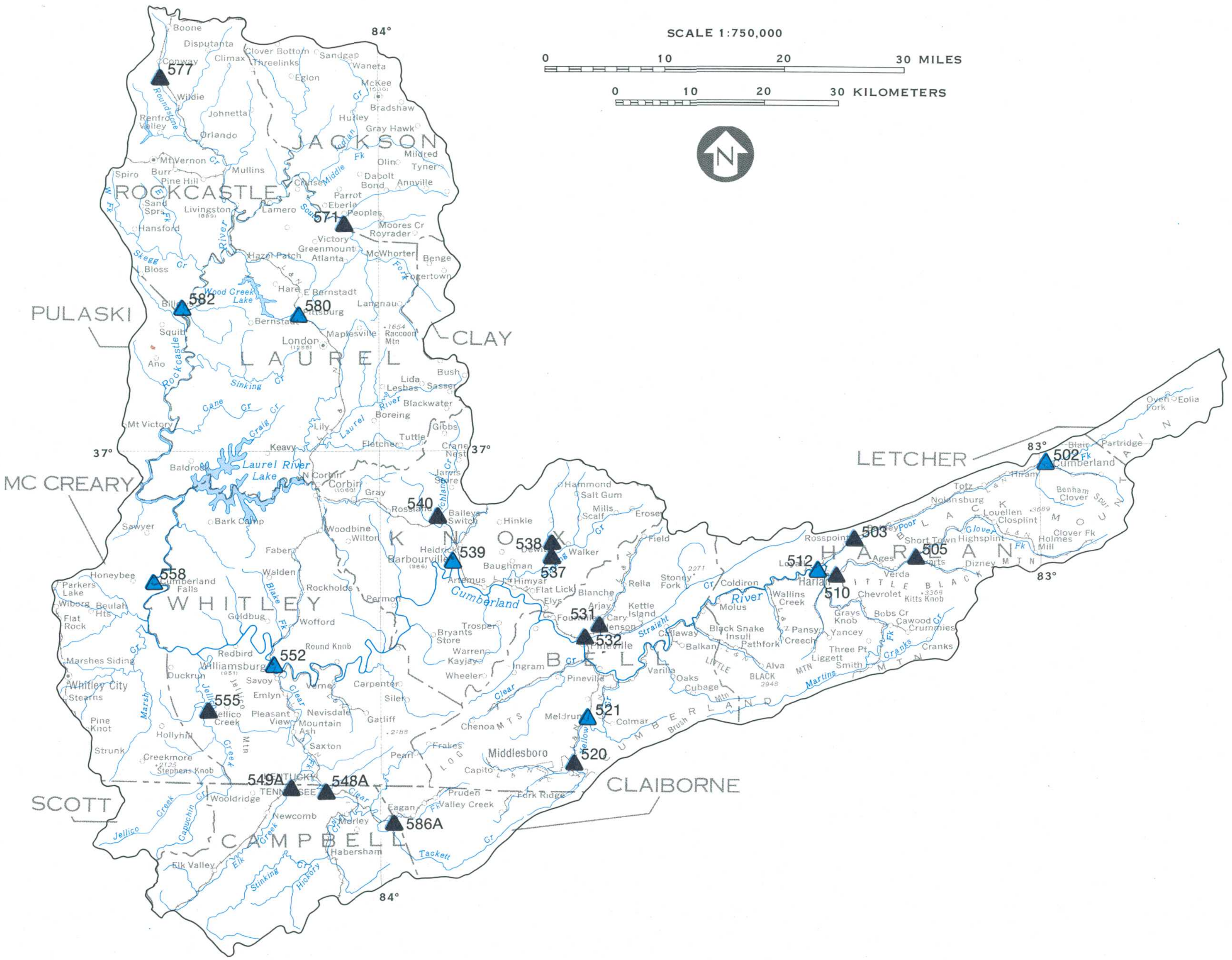
5.1 Streamflow Characteristics

Most Streams Draining Less Than 100 Square Miles Dry Up Occasionally

Many sites draining less than 100 square miles have 7 day-10 year minimum flows of zero.

The steep slopes of the area cause rapid surface runoff that coupled with the semi-impervious nature of the soils limits the infiltration of precipitation to aquifers. As a result, there is not sufficient ground water in storage to sustain sizable or prolonged base flows in streams. Therefore, during the low-flow season, from about July through August, many of the small streams draining less than 100 mi^2 become dry.

A network of low-flow sites has been operated throughout the area for many years. Data on low-flow measurements of streamflow at non-recording sites are compared with data from recording sites (index stations) to estimate low flow at the non-recording sites. Data from the low-flow sites in Area 15 are presented in figure 5.2-1 and table 5.2-1. Results of the frequency analyses and calibration of non-recording sites were published in 1974 and 1980 (Swisshelm, 1974 ; Sullavan, 1980). Data about additional sites may be obtained from the U.S. Geological Survey District Office in Louisville.



BASE FROM U. S. GEOLOGICAL SURVEY
STATE BASE MAP, 1973

EXPLANATION

▲ Recording streamflow (index) site

▲ Non-recording site

580 Site number

See section 10.2 for detailed site description

Figure 5.2-1 Streamflow sites with low-flow data.

Table 5.2-1 7-day, 2-year and 7-day, 10-year low flows.

SITE NUMBER	DRAINAGE AREA (mi²)	7-DAY 2-YEAR DISCHARGE (ft³/s)	7-DAY 10-YEAR DISCHARGE (ft³/s)
502	82.3	8.9	4.2
503	142	10.0	4.0
505	82.4	4.8	1.8
510	116	8.0	3.3
512	374	28.0	11.0
520	35.3	0.5	0.1
521	60.6	4.6	2.3
531	33.7	0.5	0.1
532	89.8	2.2	0.6
537	49.1	0.1	0.0
538	25.2	0.0	0.0
539	960	50.0	13.0
540	27.7	0.0	0.0
548A	240	1.5	0.4
549A	51.1	0.8	0.2
552	1607	74.0	18.0
555	103	0.1	0.0
558	1977	74.0	20.0
571	95.1	0.2	0.0
579	144	0.0	0.0
580	3.8	0.4	0.3
582	604	11.0	3.0

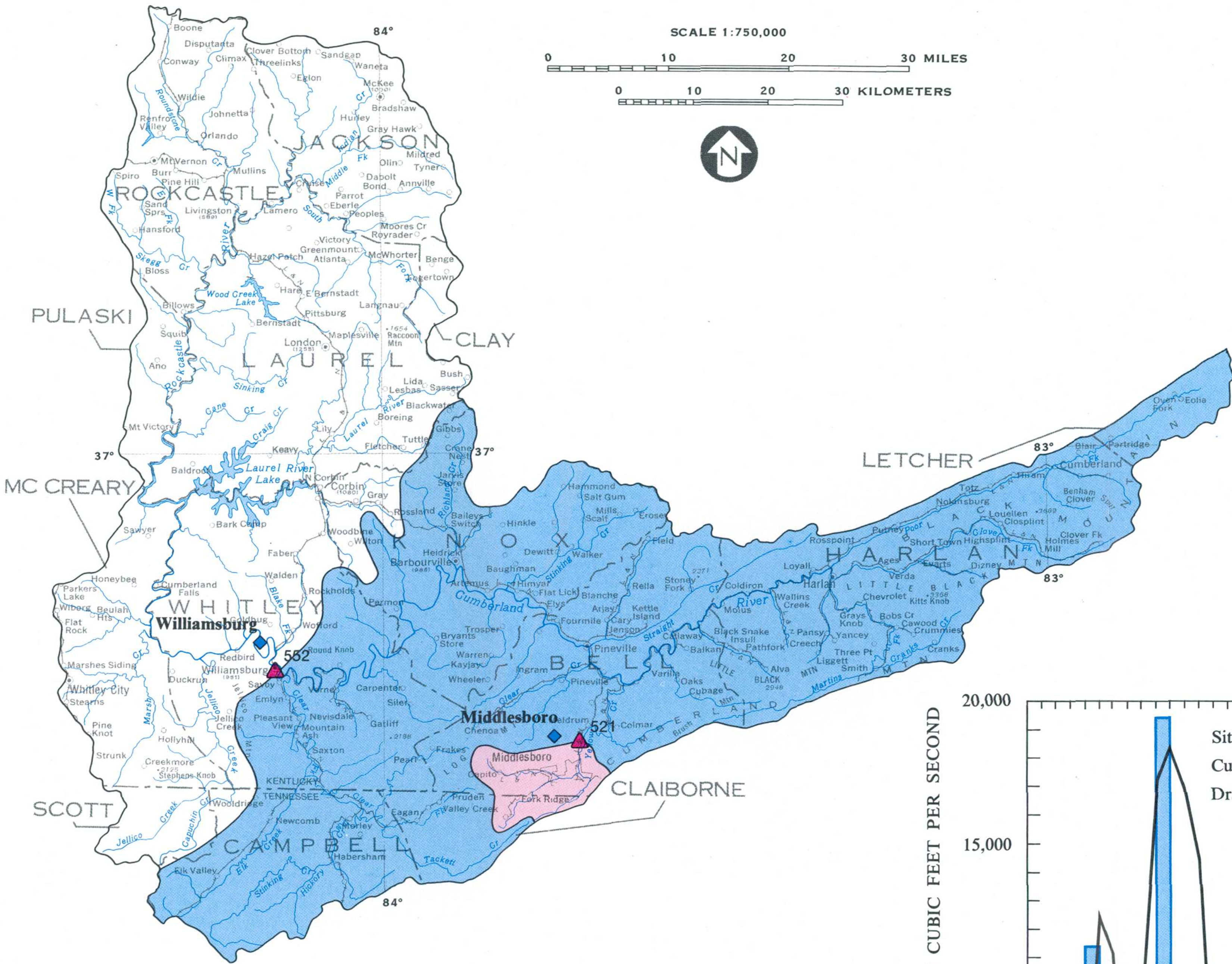
See section 10.2 for detailed site description

Flooding Severe in Area 15

Intense precipitation and topographic factors produce severe flooding throughout the area. Floods are usually of short duration.

Severe flooding occurs throughout Area 15 in response to intense precipitation and topographic factors. Intense storms, generated from moisture-laden low-pressure systems from the southwest, occur frequently. The area has steep slopes and short narrow basins, which causes a short runoff travel-time from the headwaters to the lower parts of the area. In most of the smaller basins, floods are of short duration but high magnitude, flash flooding commonly occurs.

Peak discharge and rainfall data have been collected at 12 sites in Area 15 over the last 50 years. Peak discharges at gaging stations range from 30 to 193 [$(ft^3/s)/mi^2$]. Runoff and precipitation comparisons at sites on streams with different drainage areas show that streamflows increase rapidly in response to precipitation (figures 5.3-1 and 5.3-2). Flood-data for the December 1978 flood shown in figures 5.3-1 and 5.3-2 represent flood discharges of less than two years recurrence interval. Typically the streams recede to their previous flow conditions within several days after the peak.



BASE FROM U. S. GEOLOGICAL SURVEY STATE BASE MAP, 1973

EXPLANATION

522 Site and number

Williamsburg — Precipitation station and name

Drainage basin of Cumberland River at Williamsburg (site 552)

Drainage basin of Yellow Creek near Middlesboro (site 521)

See section 10.2 for detailed site description

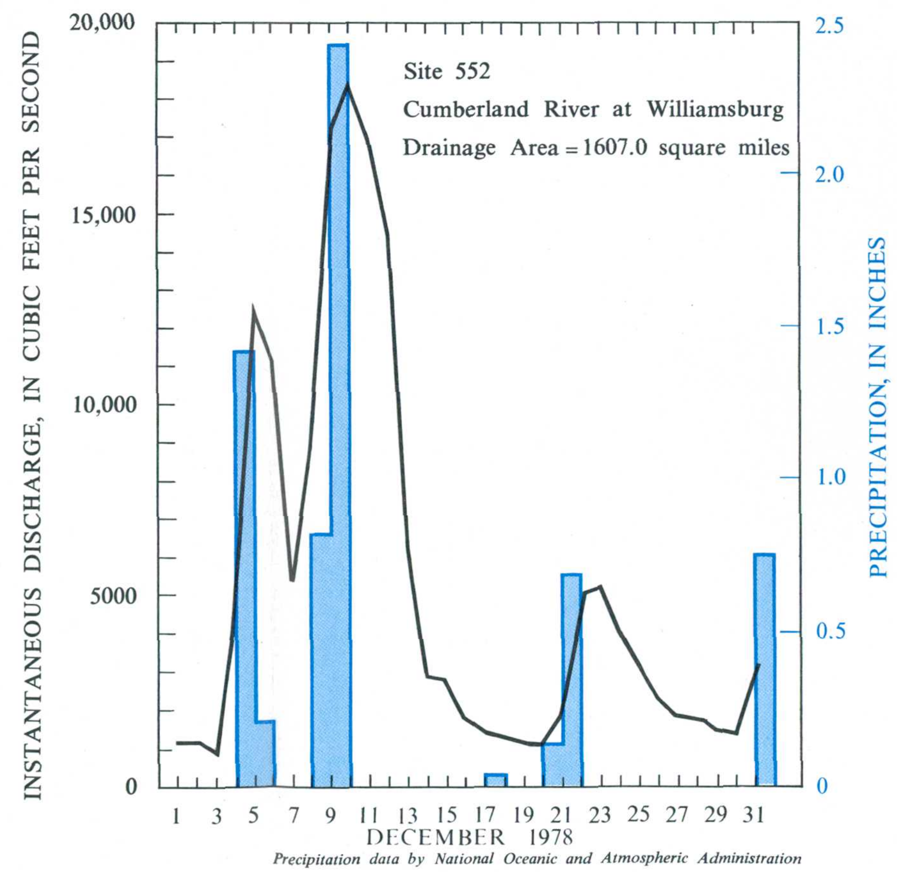


Figure 5.3-1 Flood hydrograph of Cumberland River and daily precipitation at Williamsburg, December 1978 flood.

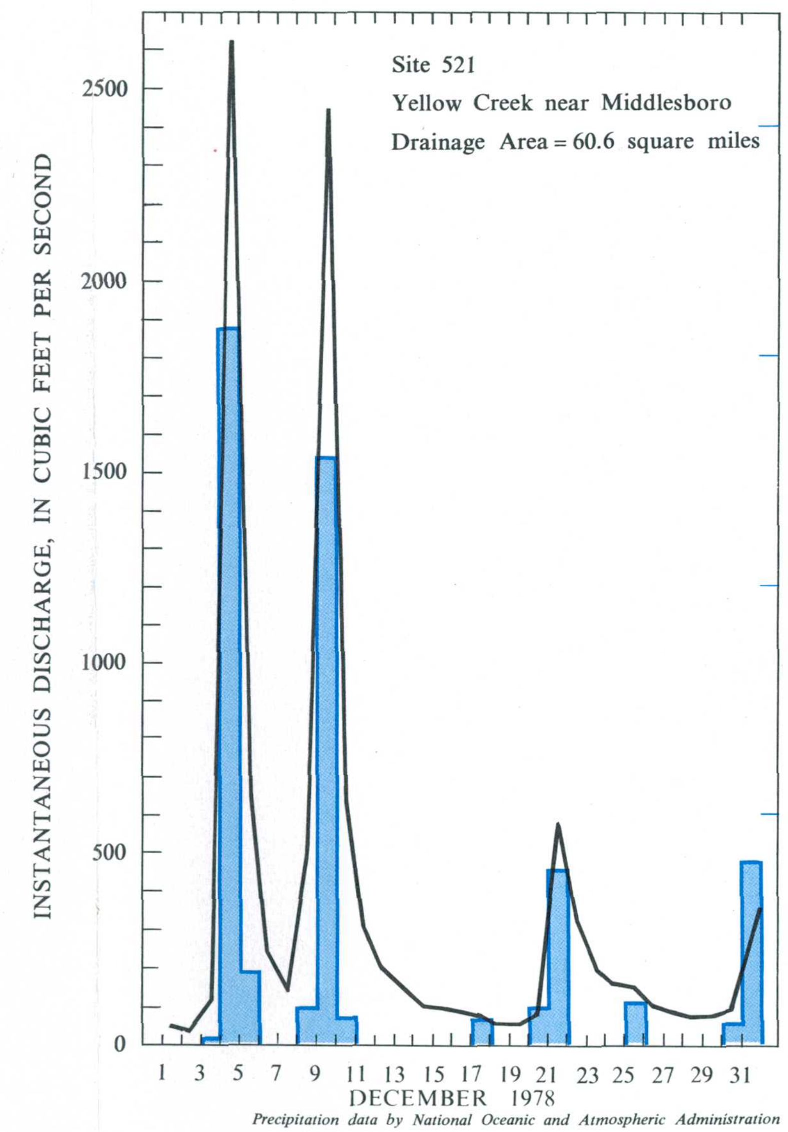


Figure 5.3-2 Flood hydrograph of Yellow Creek and daily precipitation at Middlesboro, December 1978 flood.

Floods Vary with Drainage Area, Topography and Geology

Differences in geography contribute to the magnitude and frequency of floods in Area 15. Several techniques are available to estimate the magnitude and frequency of floods.

Flood-frequency analysis is important for the design of structures in flood plains. The frequency of flooding is expressed as a probability of occurrence, or recurrence interval. For example, the 50-year flood (Q_{50}) could be expected, on the average, to occur once in 50 years. The 50-year recurrence-interval flood means that during any given year there is a 0.02 probability (two percent chance) that a flood of similar magnitude will be equalled or exceeded. Techniques for estimating magnitude and frequency of floods at gaged and ungaged sites throughout Kentucky have been developed by McCabe (1962) and Hannum (1976), and in Tennessee by Randolph and Gamble (1976).

Hannum developed generalized regression equations from which estimates at any site in Kentucky can be made. For the 50-year flood, the following equation applies:

$$Q_{50} = 638 \times A^{0.663} \times R^{1.040}$$

where:

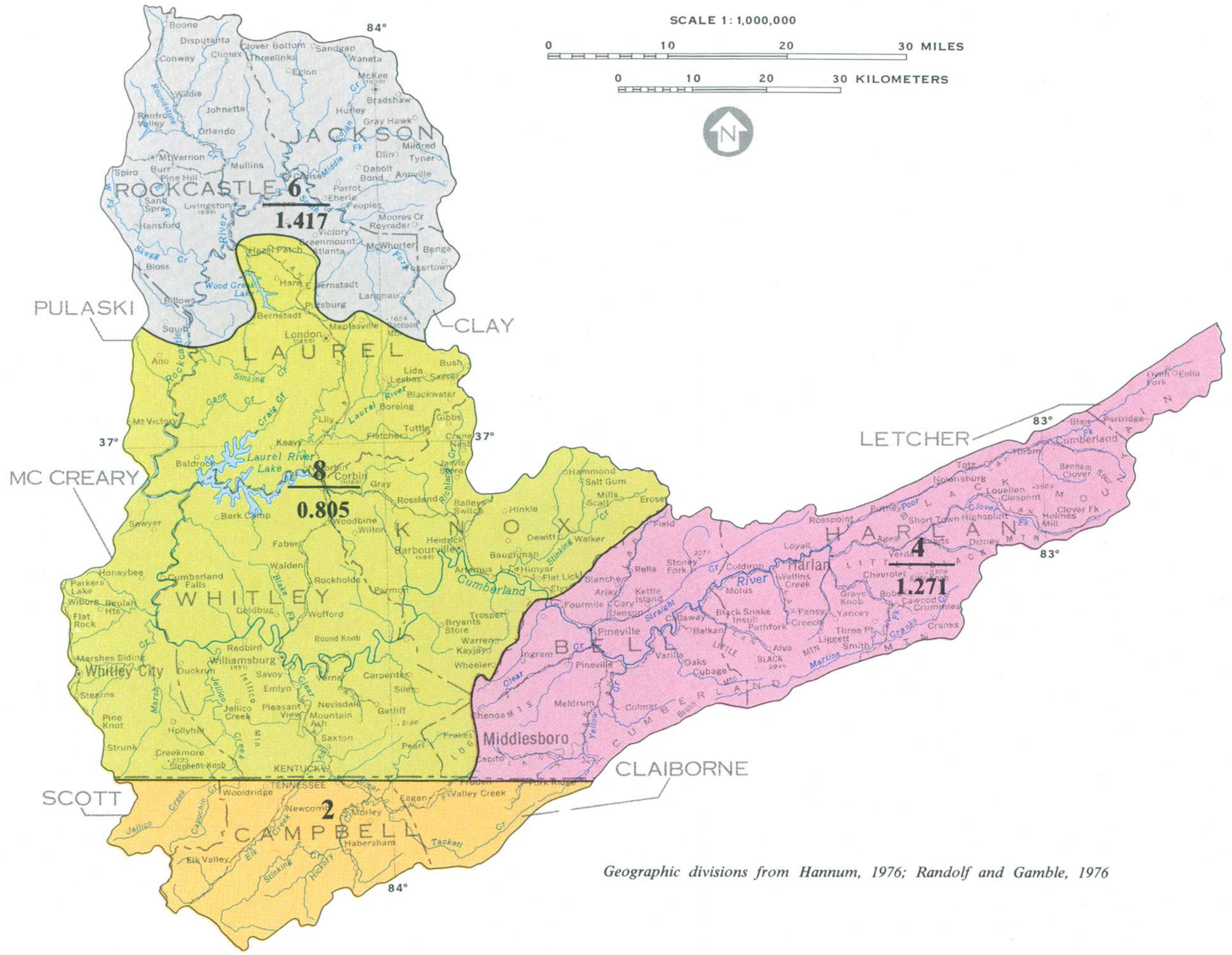
Q_{50} = discharge of 50-year flood in ft^3/s,

A = drainage area, in square miles

R is a geographical factor related to the geology and topography. R values for Area 15 are from 1.417 in the headwaters of the Rockcastle River, 1.271 in the headwaters of the Cumberland River, and 0.805 farther downstream.

Graphical solutions to the equations defining the three geographical divisions of Kentucky in Area 15 (fig. 5.4-1) are shown in figures 5.4-2 to 5.4-4. Equations defining other flood frequencies are described by Hannum (1976).

Tennessee has been divided into four hydrographic areas by Randolph and Gamble (1976). Area 15 is in hydrographic Area 2. Graphic solutions to the equations for the hydrographic Area 2 of Tennessee are shown in figure 5.4-5. They developed generalized regression equations similar to Hannum (1976) that do not use a geographical factor.



Geographic divisions from Hannum, 1976; Randolf and Gamble, 1976

BASE FROM U. S. GEOLOGICAL SURVEY
STATE BASE MAP, 1973

EXPLANATION

4	Geographic area
1.417	Geographical factor (R) in regression equation

Figure 5.4-1 Geographic divisions for estimating magnitude and frequency of floods.

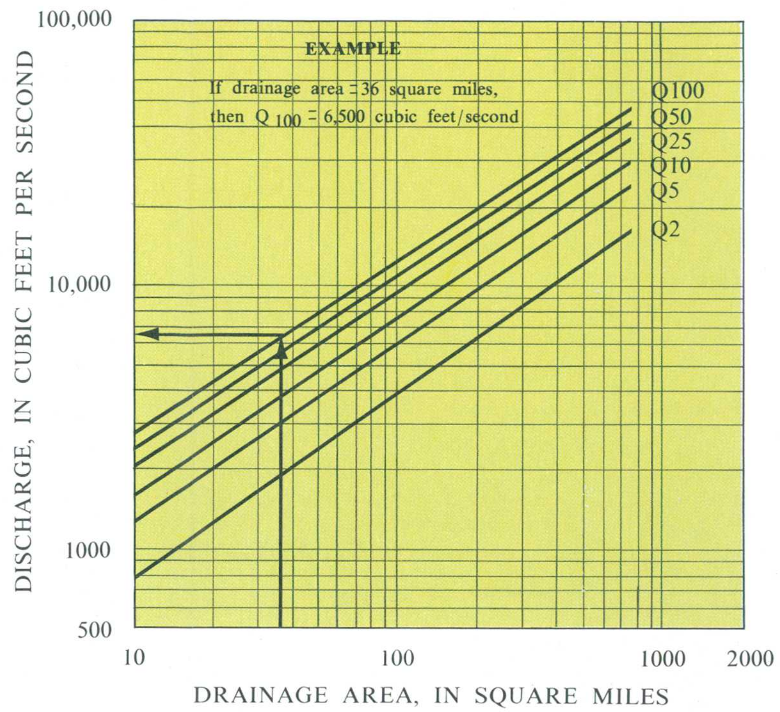


Figure 5.4-2 Graphical solutions for estimating flood frequencies of geographical area 8.

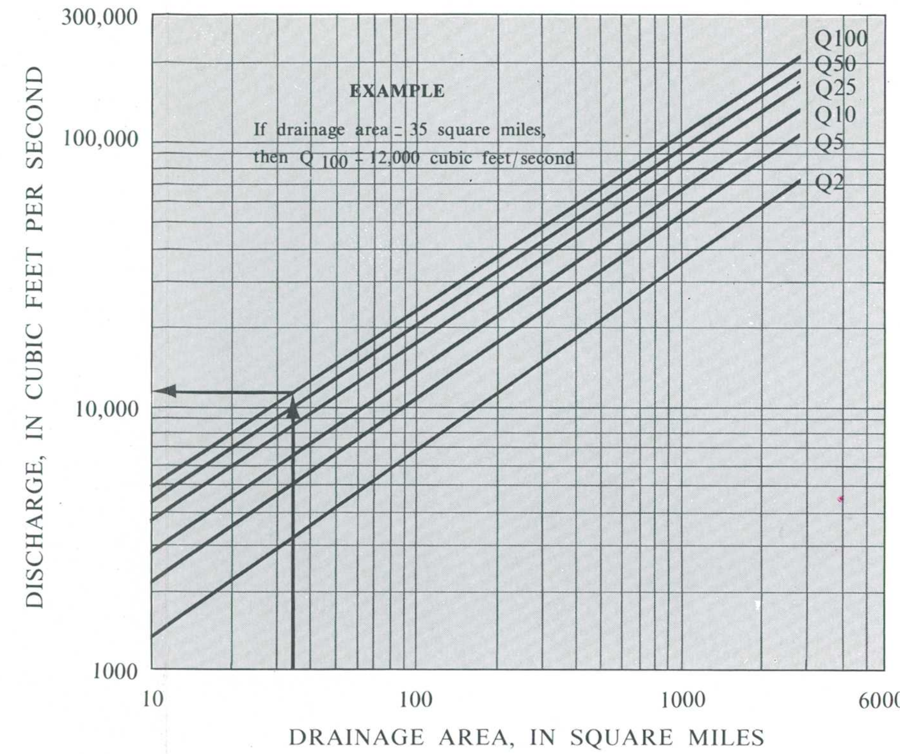


Figure 5.4-3 Graphical solutions of the discharge equation for geographical area 6.

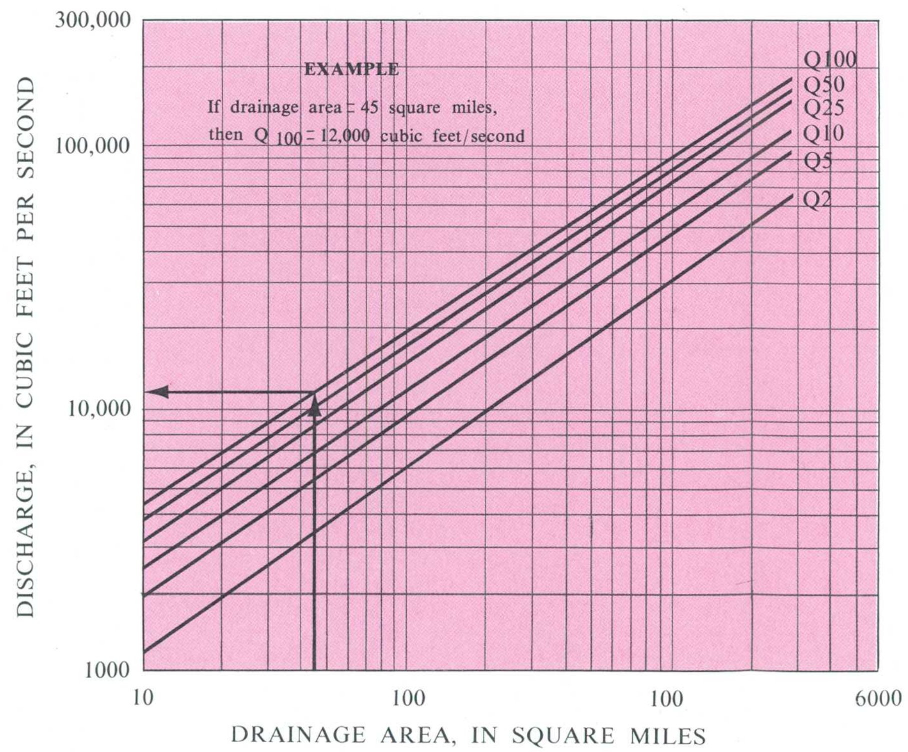


Figure 5.4-4 Graphical solution of the discharge equation for geographical area 4.

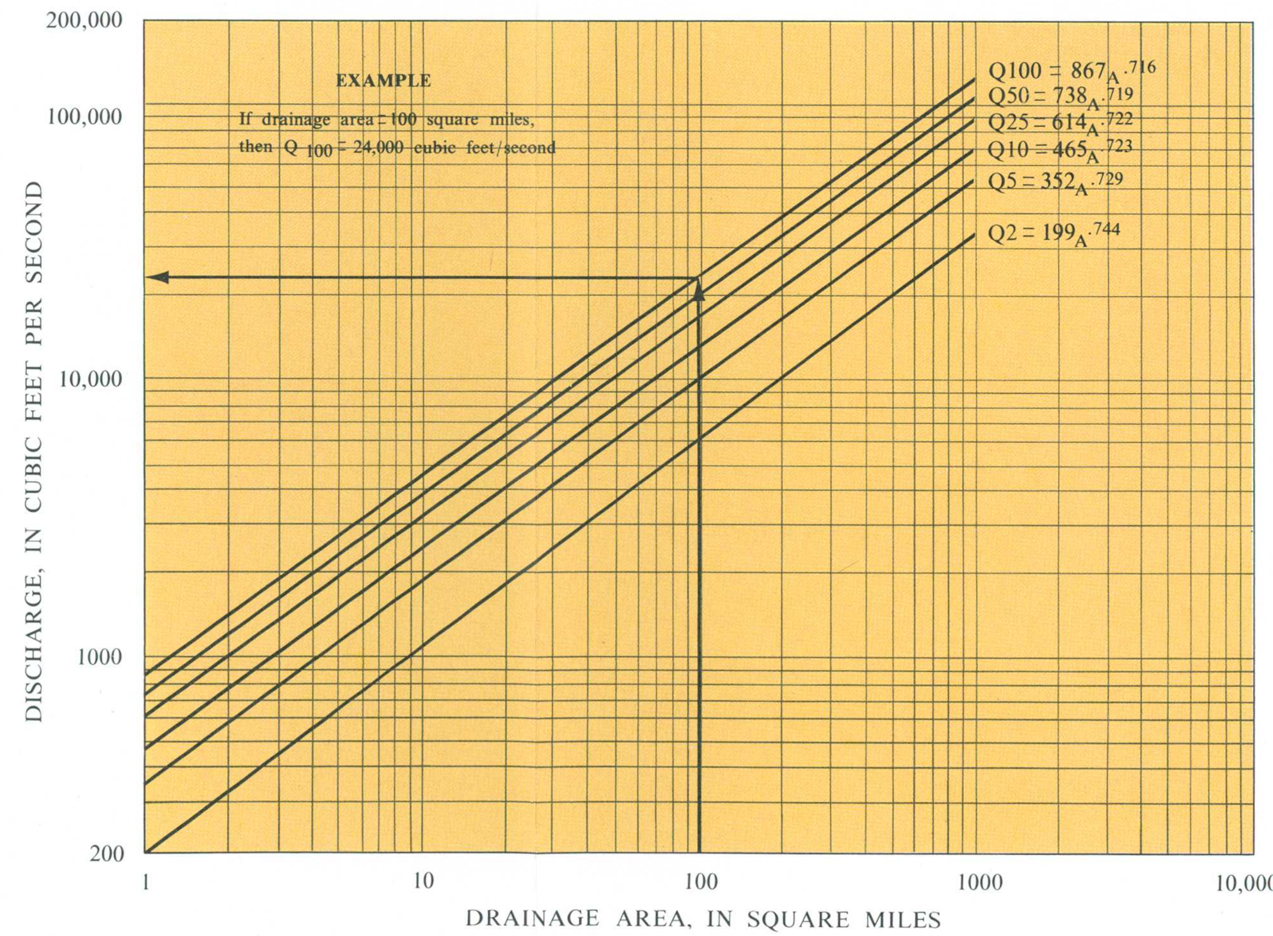


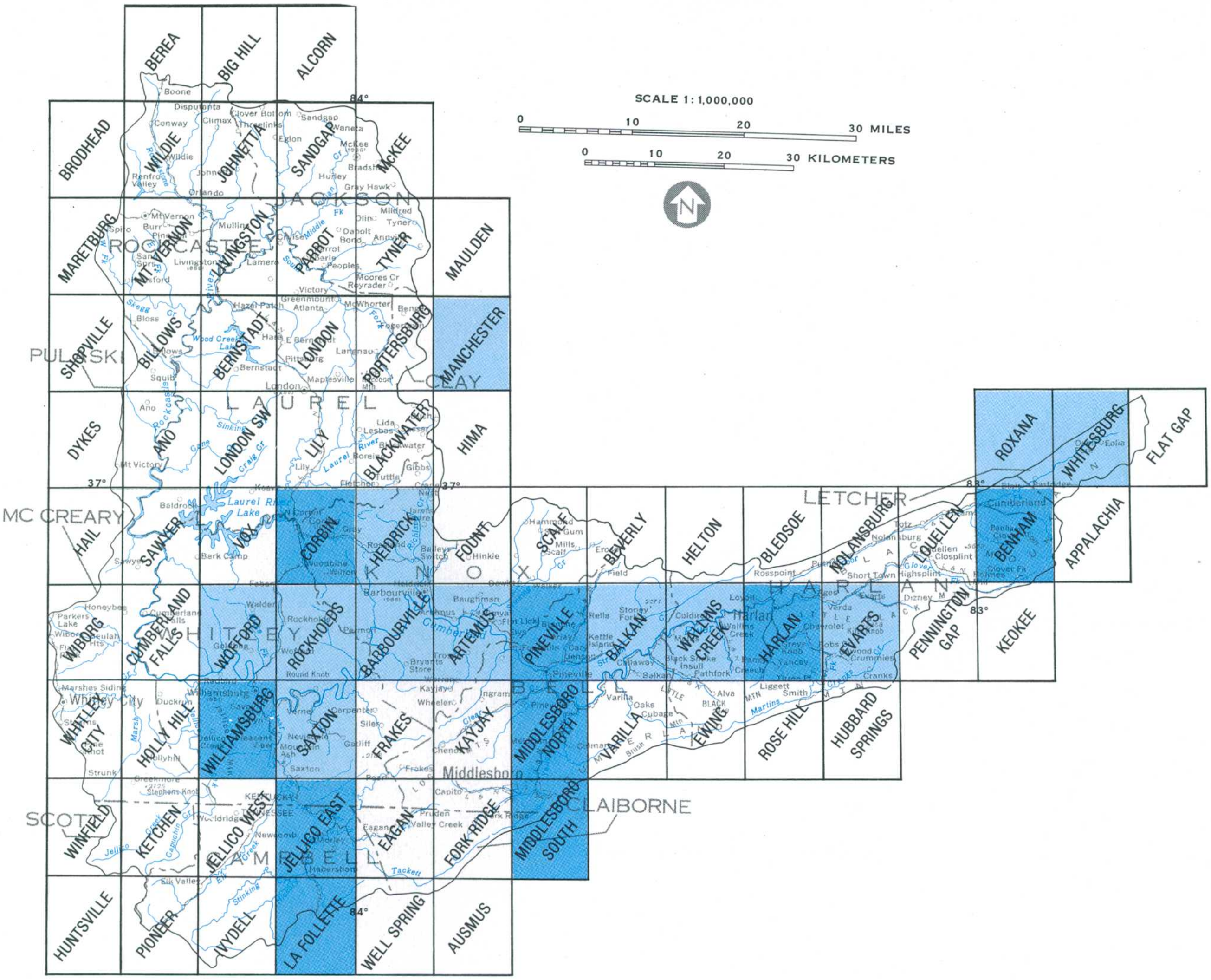
Figure 5.4-5 Graphical solution of the discharge equation for geographical area 2.

Maps Delineating Flood-Prone Areas Available

The limits of the 100-year recurrence-interval flood or the maximum-known flood are shown on 21 maps for parts of Area 15.

The National Flood Insurance Act of 1968, and the Flood Disaster Protection Act of 1973, established programs for investigating the severity and extent of flooding in urban areas and rural communities. In 1968, the U.S. Geological Survey began a program to delineate flood-prone areas and maximum-known floods for selected areas in Kentucky and Tennessee. The objective of the program was to define the 100-year flood in areas identified as subject to flooding. Areas were selected where enough information was available to estimate the altitude of the 100-year flood. A map delineating the maximum-known flood, regardless of the recurrence interval, was prepared for areas where information was not available to define a flood-frequency relation.

Twenty-one flood-prone area maps are available for areas within Area 15 (fig. 5.5-1). These include 12 maps where the 100-year flood has been defined and 9 maps where the maximum-known flood has been delineated. Most of the maximum-flood maps available are along the Cumberland River in the southern part of the area. Areas that may be subject to flooding are delineated on 7½-minute quadrangle topographic bases at a scale of 1:24,000.



BASE FROM U. S. GEOLOGICAL SURVEY
STATE BASE MAP, 1973

EXPLANATION

Flood-prone area maps

EVARTS — Flood with 100-year frequency

HARLAN — Highest known flood regardless of frequency

Figure 5.5-1 Index of flood-prone area maps.

Flow of Streams is Poorly Sustained

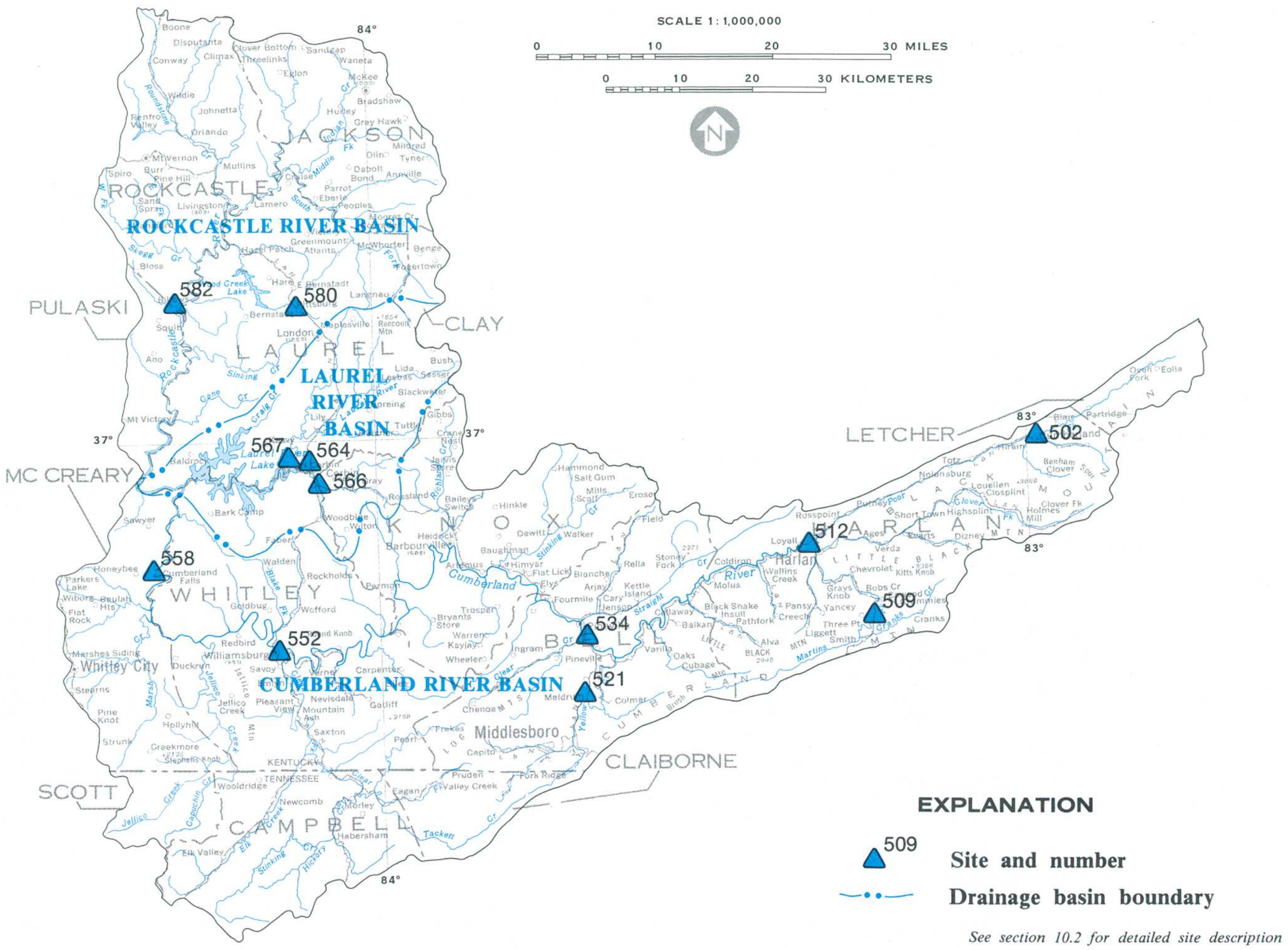
Flow-duration data are available for 12 stations. Streamflow in Area 15 is highly variable and low flows decrease rapidly during the dry season.

The streamflow at a given point is an integration of the partial effects of climate, topography, and geology, providing a distribution of runoff in time and magnitude. The flow duration curve is a cumulative frequency curve that shows the percent of time that a discharge was equalled or exceeded. Mean daily discharges are particularly suitable for flow-duration analysis and are available from continuous recording stations. Flow-duration data provide a convenient method of comparing flow characteristics of streams and estimating the percent of time that a given amount of flow was exceeded. Searcy (1959) describes how flow duration data at ungaged sites may be estimated if several streamflow measurements made during low flow are available.

The slope of the flow-duration curve for a stream is a measure of the variability of flow. A steep slope indicates highly variable flow whereas a flat slope indicates more uniform flow which can be caused by surface or ground-water storage contributions.

Flow-duration data are available for 12 stations in Area 15 (fig. 5.6-1 and table 5.6-1). Data are available from 10 sites in mined basins and 2 sites in the Rockcastle River basin, which is only partially mined.

The flow-duration curves from sites in Area 15 are typical of basins with steep slopes, high surface runoff rates, and minor contributions to streamflow from ground water (fig. 5.6-2). The curves are for different periods of record but are presented in unit discharges (flow per square mile) to provide a more direct comparison between the sites. Poor recharge and ground-water storage conditions result in low yields during dry periods. In the basins where coal is mined, although unit base flows are low, discharges appear to be better sustained than in unmined areas. Some of the increase in base flows could be due to increased infiltration of surface runoff in mined areas. Changes in the relief and permeability of the mined area may reduce the slope of the terrain and increase groundwater recharge and subsequently base flow. Similar conditions were observed by Dyer and Curtis (1977) in several small basins in Breathitt County.



BASE FROM U. S. GEOLOGICAL SURVEY
STATE BASE MAP, 1973

Figure 5.6-1 Streamflow sites with flow-duration data.

Table 5.6-1 Flow-duration data.

STATION NAME	SITE NUMBER	PERIOD OF RECORD	DRAINAGE AREA MI^2	PERCENTAGE OF THE TIME INDICATED DISCHARGE (CUBIC FEET PER SECOND) WAS EQUALLED OR EXECEEDED (FOR THE PERIOD OF RECORD INDICATED)								
				1	5	10	25	50	70	75	90	95
Poor Fork at Cumberland, Ky.	502	1940-78	82	1100	480	330	170	70	30	25	12	8.8
Martins Fork near Harlan, Ky.	509	1971-78	56	1100	500	320	160	70	31	24	10	4.9
Cumberland River near Smith, Ky.	512	1940-78	374	5900	2450	1580	770	310	130	110	47	29
Yellow Creek near Middlesboro,Ky.	521	1940-78	61	1200	420	250	120	44	18	14	6.6	4.7
Cumberland River near Pineville, Ky.	534	1938-75	809	13000	5100	3100	1600	610	220	170	71	45
Cumberland River at Williamsburg, Ky.	552	1950-78	1610	23200	12200	6820	3010	1150	440	350	140	86
Cumberland River at Cumberland Falls, Ky.	558	1915-78	1980	26000	13600	8000	3600	1360	540	400	140	71
Laurel River at Municipal Dam near Corbin, Ky.	564	1974-78	140	2600	980	650	250	100	35	26	5.8	0.2
Lynn Camp Creek at Corbin, Ky.	566	1974-78	54	1000	380	220	95	42	16	12	3.5	2.1
Laurel River at Corbin, Ky.	567	1923-73	200	3200	1520	800	350	100	21	14	2.6	1.8
Wood Creek near London, Ky.	580	1953-71	3.9	48	20	13	5.8	2.3	0.9	0.8	0.7	0.4
Rockcastle River at Billows, Ky.	582	1936-78	604	10100	3570	2140	990	320	102	73	23	13

REMARKS: SITE 509 REGULATED BY MARTINS FORK DAM SINCE JAN. 1979.
SITE 521 OCCASSIONALLY REGULATED BY FERN LAKE.
SITE 534 LOW FLOW REGULATED BY POWER PLANT 1.9 MILES UPSTREAM.

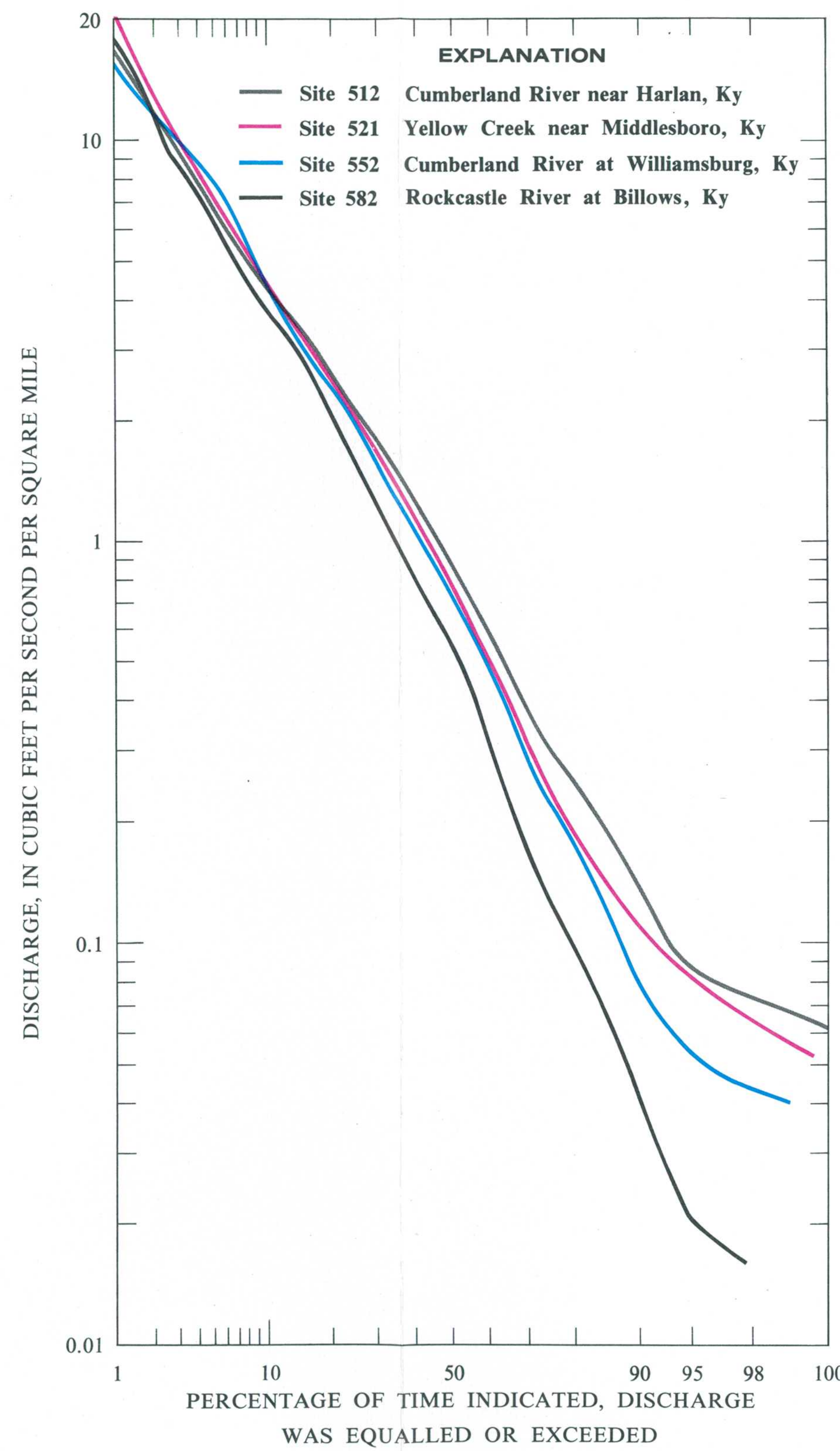


Figure 5.6-2 Flow duration at selected sites.

Water Quality Data Collected at 38 Active Sites

Surface water samples taken in 1979-80, as well as prior samples, provide a general view of seasonal variation of water quality in Area 15.

Some of the effects of surface coal-mining activities on the hydrologic environment can be evaluated from water-quality data. The Surface Mining Control and Reclamation Act established a series of permissible ranges and maximum-permissible limits for a number of water-quality characteristics in effluents draining mined areas. These are:

•pH range from 6.0 to 9.0 units.

•Total manganese concentration of 4,000 $\mu g/L$ (micrograms per liter)

•Total iron concentration of 7,000 $\mu g/L$.

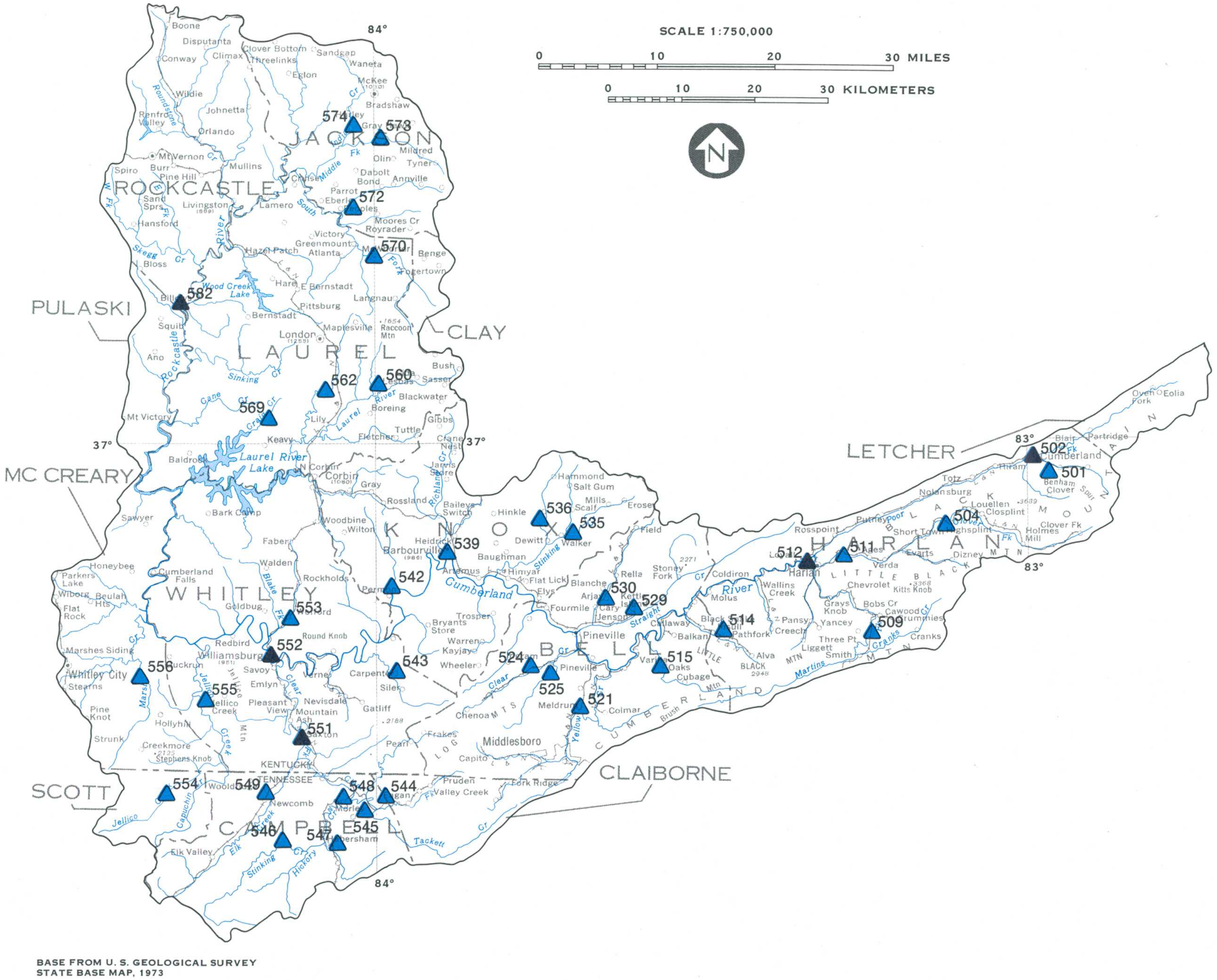
•Total suspended-solids concentration of 70 mg/L (milligrams per liter).

Sufficient data to define seasonal water-quality changes are also required by several sections of the Act.

Water-quality data are collected at 38 active sites in Area 15 (fig. 6.1-1 and section 10.2). Determination of pH, specific conductance, alkalinity, temperature, iron and manganese concentrations (total recoverable and dissolved), sulfate, dissolved solids and suspended-sediment concentrations are made in order to define the seasonal water-quality variations. Additional constituents not specified by the Act were determined from samples collected during low-flow. They include concentrations of the most common dissolved constituents (calcium, magnesium, sodium, potassium, chloride, and fluoride), selected trace constituents (barium, cadmium, chromium, copper, lead, silver, zinc, cyanide, arsenic, mercury, and selenium), and percent of coal in bottom sediments.

In addition to data collected at the 38 active sites, limited water-quality data have been collected in the past at numerous streams in the basin. Many of these sites were re-activated in the present study (section 10.2). Analyses of the historical data, plus the data collected in 1979 and 1980, are presented in the following sections of this report.

Samples were collected in 1979-80 during the spring, summer, and fall seasons in an effort to determine surface water quality during several flow regimes (low, medium, and high flow conditions). The data represent water-quality conditions during extreme low, medium, and some high flows; extreme high-flow conditions were not encountered. Several streams in July and September, 1980, were dry. The data collected provide an instantaneous or synoptic view of water quality during a particular flow condition.



EXPLANATION

Site and number

512 — **Water samples collected every 6 to 8 weeks; suspended-sediment samples collected 2 to 5 times per week and during storms; continuous record of streamflow**

560 — **Water and suspended-sediment samples collected at 3-month intervals; streamflow measurement made at time of sampling**

See section 10.2 for detailed site description

Figure 6.1-1 Water-quality sampling sites.

Specific Conductance can be Used to Estimate Dissolved Solids

Specific conductance values throughout Area 15 range from 41 to 1,750 micromhos per centimeter, while dissolved solids range from 24 to 1,040 milligrams per liter.

The specific conductance of water, expressed in units of micromhos per centimeter at 25°C (μmhos/cm), is a general indicator of the amount of dissolved solids (Hem, 1970). The simple and inexpensive procedure for the field determination of specific conductance makes it one of the most valuable tools for estimating dissolved-solids concentrations. Dissolved solids at most sites in the area can be estimated by multiplying the specific conductance by a factor of approximately 0.6; many of the ions dissolved in water correlate with the specific conductance. For these reasons, specific conductance is routinely determined at all sites where streamflow measurements are made or water samples are collected.

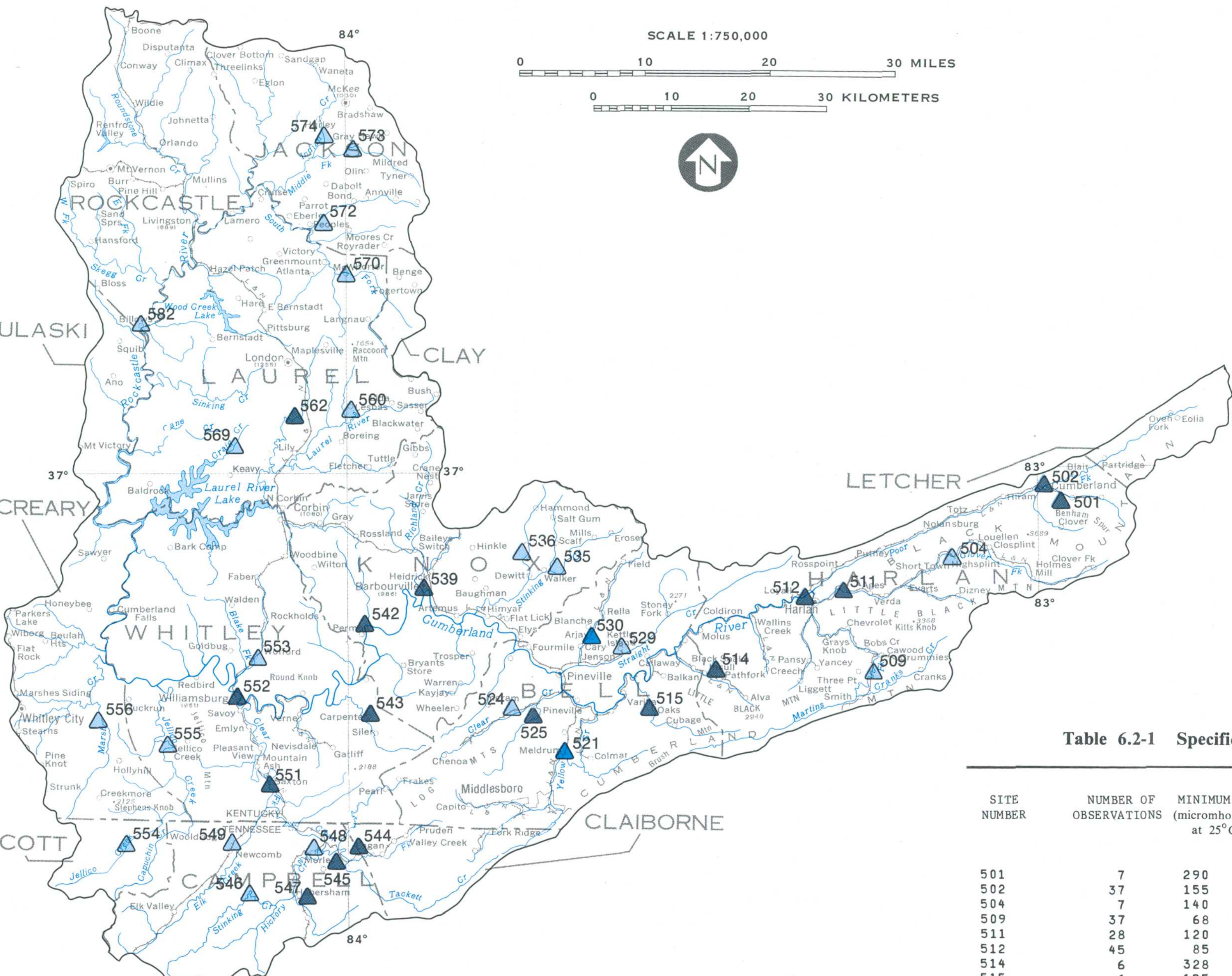
The specific conductance values and the dissolved solids concentrations are affected by the amount of streamflow. The data in table 6.2-1 show that the specific conductance values are higher during low-flow periods (usually in late summer). Dilution of the dissolved constituents occurs during periods of higher flow. During periods of either low or high flows, specific conductance and dissolved-solids values are higher at sites affected by mining than at sites in unmined basins.

Specific conductance values throughout Area 15 range from 41 to 1,750 μmhos/cm (fig. 6.2-1 and table 6.2-1). Minimum instantaneous values range from 41 to 380 μmhos/cm; maximum instantaneous values range from 110 to 1,750 μmhos/cm.

Dissolved-solids concentrations in the area range from 24 to 1,040 mg/L (fig.6.2-1 and table 6.2-2). Minimum values range from 24 to 243 mg/L; maximum values range from 60 to 1,040 mg/L. The highest dissolved solids and specific conductance values occur in samples collected in the headwaters of the Cumberland River basin, in Harlan and Knox counties, where mining is most intense.

Correlation analyses between specific conductance and dissolved solids are highly significant at both mined and unmined sites in Area 15 (fig. 6.2-2). Dissolved solids and specific conductance values are shown for 1979-80; data used in the regression analysis were 1979-80 and selected historical data. Regression models of Yellow Creek near Middlesboro (site 521, mined and draining Pennsylvanian rocks) and Rockcastle River at Billows (site 582, largely unmined and draining a large area including Mississippian rocks), are highly significant at the 95 percent confidence level. Similar relations exist at most of the sites in Area 15, with correlation coefficients (r) usually higher than 0.9; however, at very low specific conductance values (about 50 μmhos/cm and less), this relation becomes poorly defined.

There is no significant difference in the ratios between specific conductance and dissolved solids in water from the two sites shown in figure 6.2-1. However, the range of the values at the Yellow Creek site is about one order of magnitude greater than at the Rockcastle River site. This is probably due to the higher loads of dissolved constituents generated in the basin with mine drainage. Comparison of other sites throughout Area 15 shows similar relations.



EXPLANATION

Site location and number	Maximum specific-conductance value, in micromhos per centimeter at 25° C
△504	0-500
▲511	501-1,000
▲521	Greater than 1,000

Figure 6.2-1 Specific-conductance sampling sites.

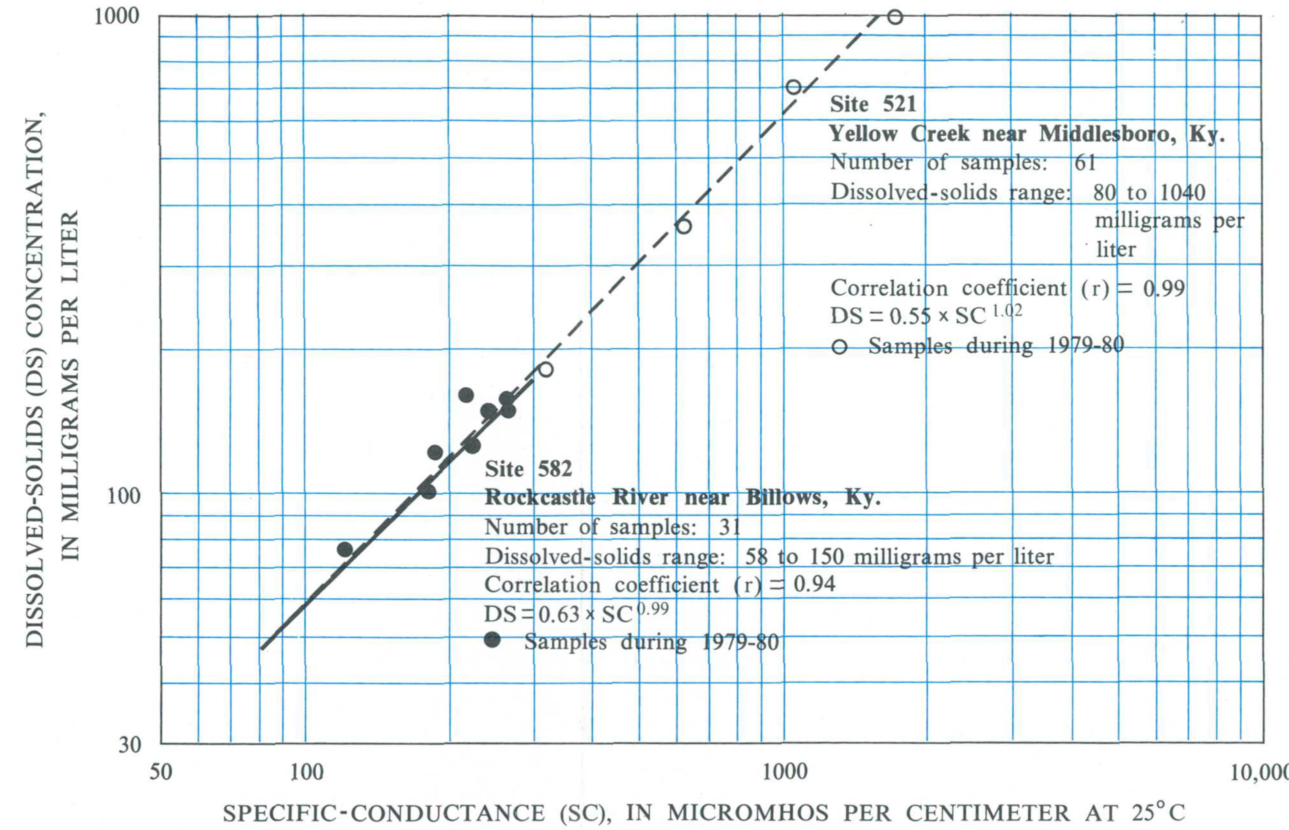


Figure 6.2-2 Relation of dissolved-solids concentration and specific-conductance at sites 521 and 582.

Table 6.2-1 Specific-conductance values and corresponding discharge.

SITE NUMBER	NUMBER OF OBSERVATIONS	MINIMUM (micromhos/cm at 25°C)	DISCHARGE (ft^3/s)	MAXIMUM (micromhos/cm at 25°C)	DISCHARGE (ft^3/s)	MEAN (micromhos/cm at 25°C)	MEDIAN (micromhos/cm at 25°C)
501	7	290	162	960	11.5	653	640
502	37	155	762	880	9.1	423	410
504	7	140	312	450	35.0	316	385
509	37	68	5.0	270	0.70	144	135
511	28	120	4950	560	22.5	311	318
512	45	85	7440	660	430	322	325
514	6	328	49.6	880	1.50	525	477
515	6	195	81.0	750	1.0	386	345
521	114	150	1730	1750	4.17	507	430
524	6	50	57.4	110	2.2	79	80
525	6	230	55.6	560	0.29	390	380
529	6	190	56.0	415	1.51	271	246
530	6	258	66.1	1300	4.2	699	648
535	5	51	29.7	195	0.18	105	84
536	4	75	40.0	500	0.13	186	84
539	39	130	6430	615	103	293	310
542	6	380	61.8	600	0.50	503	520
543	6	220	30.7	560	0.40	369	350
544	4	321	56.5	530	5.9	455	485
545	4	191	64.4	570	6.3	369	358
546	4	112	48.0	270	10.0	189	186
547	4	229	20.0	670	1.84	392	335
548	4	202	211	420	25.0	303	295
549	4	182	63.0	295	5.3	243	248
551	28	150	5390	555	299	299	288
552	340	87	---	663	422	227	190
553	5	280	12.0	480	0.71	362	360
554	4	155	44.0	240	1.9	215	232
555	9	41	---	320	66	163	155
556	6	161	71.6	300	0.49	220	205
560	4	88	93.2	145	5.2	108	100
562	6	117	58.0	580	1.8	288	280
569	6	42	16.0	205	0.03	111	90
570	5	115	41.0	360	0.03	202	180
572	5	53	56.8	158	-	101	85
573	5	64	41.1	158	0.14	97	80
574	3	86	87.6	175	6.9	130	---
582	51	90	2900	280	26.0	170	164

See section 10.2 for detailed site description

Table 6.2-2 Summary of dissolved-solids data.

SITE NUMBER	NUMBER OF OBSERVATIONS	DISSOLVED SOLIDS (milligrams per liter) MINIMUM	MAXIMUM	MEAN	MEDIAN
501	4	243	679	424	386
502	16	79	500	283	248
504	4	106	253	187	195
509	12	39	152	97	94
511	4	128	258	202	211
512	23	53	363	198	189
514	4	182	542	343	324
515	4	118	564	304	268
521	62	80	1040	334	285
524	4	37	102	64	58
525	4	141	370	255	254
529	4	120	242	182	183
530	4	159	803	504	527
535	3	42	105	65	---
536	2	50	60	55	---
539	9	132	366	219	219
542	4	239	364	319	336
543	4	150	336	246	248
551	14	127	410	233	213
552	291	55	409	137	116
553	3	175	313	240	---
555	5	24	166	99	92
556	4	98	223	151	142
560	2	70	84	77	---
562	4	79	361	193	166
569	4	36	116	79	82
570	3	71	214	129	---
572	3	42	101	62	---
573	3	50	106	69	---
574	2	64	101	82	---
582	31	58	150	100	104

See section 10.2 for detailed site description

pH of Streamflow is Near Neutral at Most Sites

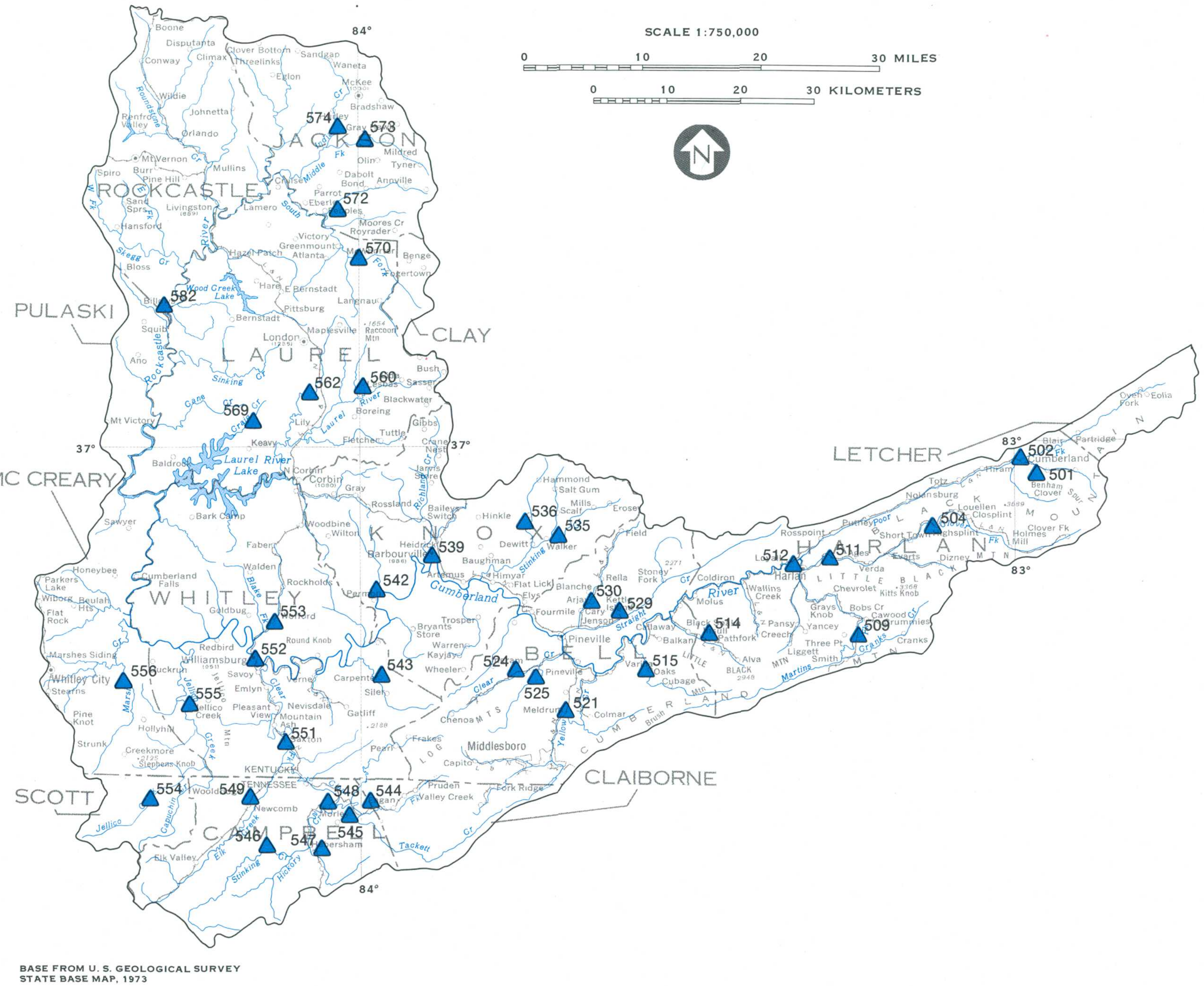
The pH of streams in Area 15 ranges from 5.9 to 8.8 units, but at most sites it is in the 6 to 8 units near-neutral range.

The acidity or alkalinity of water is generally expressed in pH units. A pH value of 7.0 represents neutral water, while values less than 7.0 represent acidic water and greater than 7.0 represent alkaline water. Natural acidity usually is caused by the presence of dissolved carbon dioxide or hydrolysis of salts of weak acids and strong bases. Sources of these substances include rainfall, weathered rocks, and organic matter in soils.

The pH of waters draining areas affected by surface-coal mining may be altered by chemical reactions with minerals in mining spoils. In some areas, weathering of pyrite and other sulfur-bearing minerals results in the production of sulfuric acid. The Surface Mining Control and Reclamation Act of 1977 established a permissible range of pH from 6.0 to 9.0 units for effluents draining mined areas. Acid-mine drainage may have low pH values in the range from about 2.5 to 5.0 units. Unless the acid is neutralized, the pH of streams receiving mine drainage may be lowered below natural levels. In Area 15, rocks contain calcareous minerals, such as calcium carbonate, and acid-mine drainage is quickly neutralized; the pH of some streams actually increases to alkaline levels (pH greater than 7.0) as a result of coal mining activities.

pH data are available from 38 sites throughout Area 15 (fig. 6.3-1). Long-term data are available from only three sites (512, 521, and 552) while at most of the other sites data collection began in 1979. All of the data available represent instantaneous measurements of pH.

The pH at stream-sites in Area 15 ranges from 5.9 to 8.8 units (table 6.3-1). Median values range from 7.0 to 8.4 units, but most are in the 7.0 to 7.5 units range. During 1979-80, there were no samples with pH values less than 6.5 units.



EXPLANATION

501 Site location and number

See section 10.2 for detailed site description

Figure 6.3-1 pH sampling sites.

Table 6.3-1 pH data for active sites.

SITE NUMBER	NUMBER OF OBSERVATIONS	MINIMUM (UNITS)	MAXIMUM (UNITS)	MEDIAN
501	7	7.8	8.5	8.4
502	18	7.6	8.8	8.0
504	7	7.2	8.1	7.6
509	10	6.5	7.5	7.1
511	6	7.4	8.6	7.8
512	26	6.7	8.2	7.8
514	6	7.6	8.4	8.2
515	6	7.4	8.0	7.8
521	65	6.4	8.3	7.0
524	6	7.1	7.4	7.2
525	6	7.8	8.4	8.0
529	6	7.2	7.8	7.4
530	6	7.2	7.8	7.6
535	5	7.0	7.4	7.2
536	4	6.8	7.2	7.0
539	12	7.4	8.0	7.7
542	6	7.4	7.7	7.4
543	6	7.3	7.9	7.6
544	4	7.5	8.1	7.6
545	4	7.7	8.1	7.9
546	4	6.9	8.2	7.4
547	4	7.6	8.5	8.0
548	4	6.9	7.9	7.5
549	4	7.3	7.5	7.4
551	17	7.0	8.0	7.4
552	219	5.9	8.1	7.1
553	5	7.4	7.6	7.6
554	4	6.9	7.6	7.0
555	6	7.0	7.3	7.2
556	4	6.9	7.6	7.0
560	4	6.8	7.2	7.0
562	6	6.6	7.4	7.0
569	6	6.8	7.6	7.2
570	5	6.8	7.6	7.1
572	5	7.2	7.6	7.4
573	5	7.2	7.5	7.2
574	3	7.2	7.8	---
582	8	7.6	8.2	7.8

See section 10.2 for detailed site description

Sulfate Concentrations are Highest at Sites in the Cumberland River Basin

At most sites in the headwaters of the Cumberland River Basin, median sulfate concentrations exceed 50 mg/L and are as high as 180 mg/L.

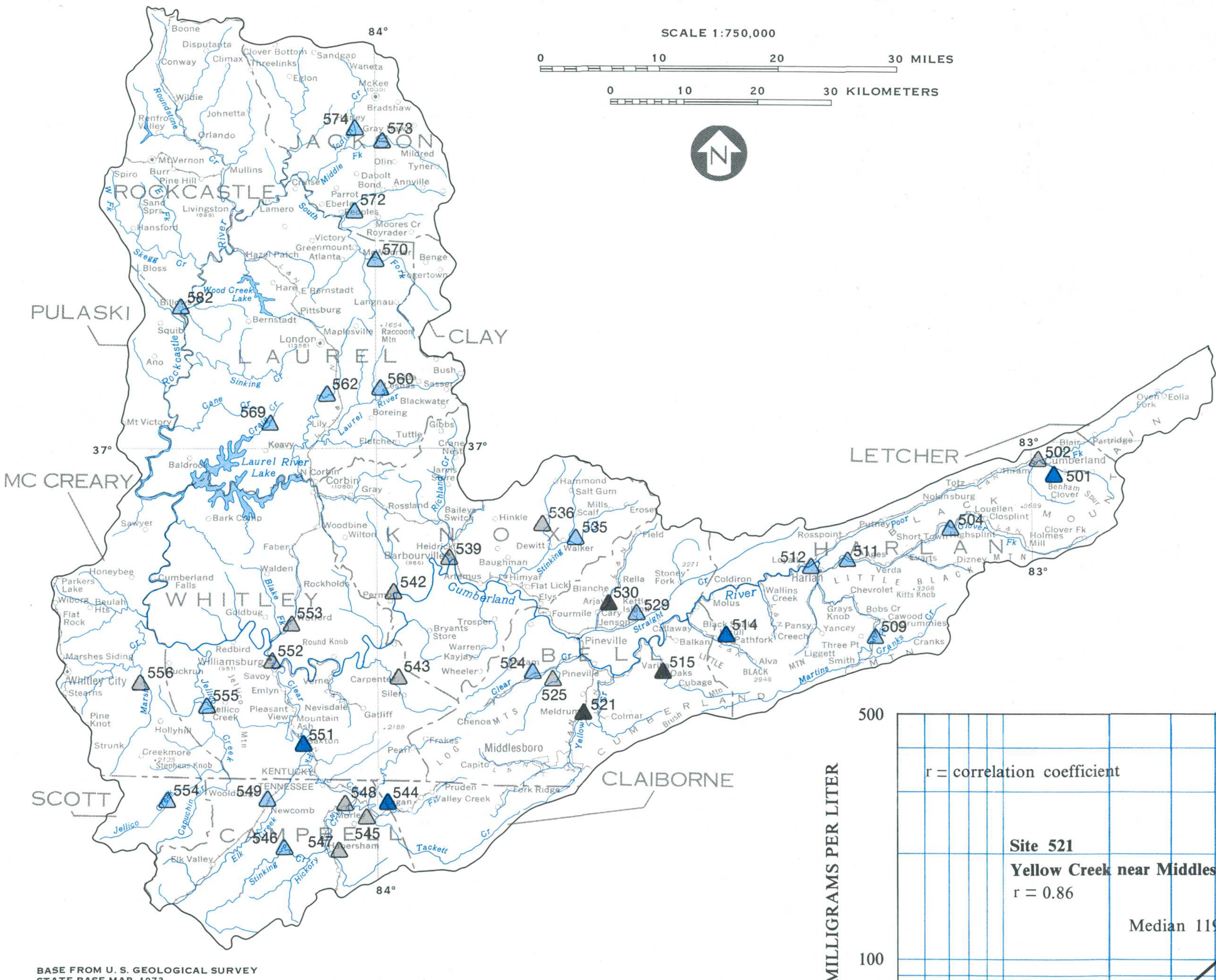
Surface mining exposes soils and rocks to weathering and oxidation. Sulfuric acid is produced when minerals containing sulfur are oxidized. Dissolved sulfate and large amounts of dissolved solids are in effluents from coal-mining operations. Sulfate concentrations are commonly used as an indicator of mine drainage. Concentrations in streams draining relatively unmined basins generally are low (1 to 20 mg/L), while concentrations from mined areas are highly variable and may be very high (20 to 200 mg/L) (Dyer and Curtis, 1977).

The variability of sulfate concentrations in streams draining mined areas is primarily due to the presence of reactive minerals in spoil material, the length of time of exposure of these materials to weathering, the length of time water is in contact with the spoils, and the quantity of water leaving the mined areas. Sulfate concentrations are highest during low flow, when contact time with spoil has been fairly long, and water draining from spoil material may constitute a significant part of the flow. Sulfate Concentrations are lower during high flow when contact time is short and dilution occurs.

Sulfate-concentration data are available from 38 active sites in Area 15 (fig. 6.4-1). The data show that sulfate concentrations range from 4.5 to 998 mg/L (table 6.4-1). At 24 of the sites, median sulfate concentrations exceed 50 mg/L, indicating mine-drainage effects. The highest sulfate concentrations are at sites in the Cumberland River basin, where most of the mining occurs in Area 15. In the headwaters of the basin, in Bell and Harlan Counties, sulfate concentrations range from 6.4 to 998 mg/L. In comparison, the lowest concentrations ranged from 7.6 to 74 mg/L at sites in the Rockcastle River basin, in Jackson and Laurel Counties. Most of the Rockcastle River basin is in the Daniel Boone National Forest, where no significant surface mining occurs. In addition, the Rockcastle River drains an area of Mississippian limestone and shale that contain relatively small amounts of sulfurous minerals.

Significant correlation exists between sulfate concentration and specific conductance at sites affected by mine drainage (fig. 6.4-2). At the site in the Rockcastle River basin (site 582), where no significant mining occurs, the correlation is poor.

Comparison of sulfate concentrations and streamflow at the three sites (table 6.4-2) shows an inverse correlation (sulfate concentration decreases as discharge increases) at sites draining mined areas and poor correlation exist at unmined sites. At the Rockcastle River site (582), a significant reduction in the sulfate concentration did not occur until the flow increased to 1,710 ft^3/s (table 6.4-2). The same trend prevails at other sites in the basin, with even lower sulfate concentrations.



BASE FROM U. S. GEOLOGICAL SURVEY
STATE BASE MAP, 1973

EXPLANATION

Site and number	Maximum dissolved sulfate concentration, in milligrams per liter
546	0-99
525	100-199
544	200-299
530	Greater than 300

See section 10.2 for detailed site description

Figure 6.4-1 Sulfate sampling sites.

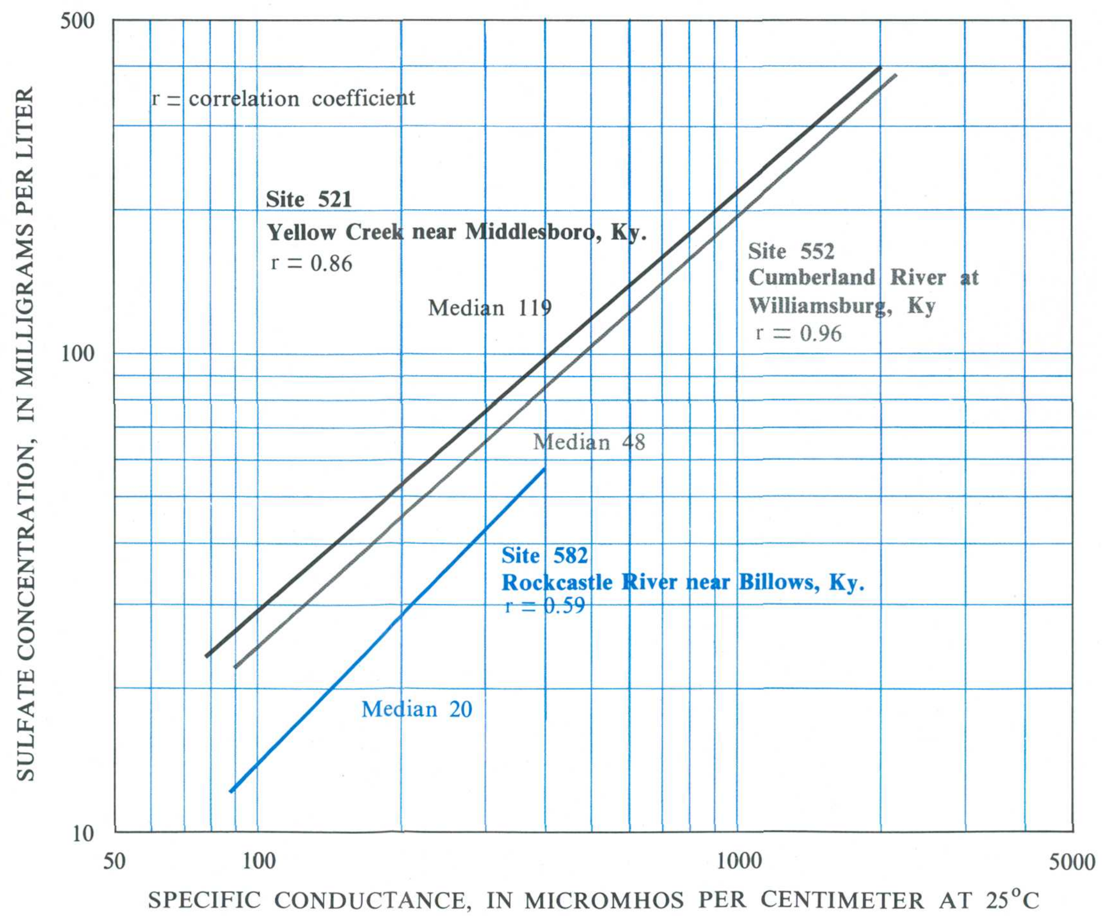


Figure 6.4-2 Relation of sulfate concentrations to specific conductance at sites 521, 552, and 582.

Table 6.4-1 Sulfate data for active sites.

SITE NUMBER	NUMBER OF OBSERVATIONS	MINIMUM	MAXIMUM	MEAN	MEDIAN
		(Milligrams per liter)			
501	6	63	200	115	110
502	18	30	120	73	70
504	6	32	78	56	58
509	14	15	75	41	38
511	6	40	78	65	74
512	24	18	96	60	59
514	6	85	240	149	140
515	6	60	300	137	116
521	65	39	998	131	119
524	6	6.4	13	8.9	8.3
525	6	56	180	112	101
529	6	53	93	74	74
530	6	81	410	218	180
535	5	9.4	12	10	9.7
536	4	17	130	47	20
539	12	41	110	74	80
542	6	130	180	160	165
543	6	69	140	102	98
544	4	110	220	168	170
545	4	53	160	102	98
546	4	34	87	60	60
547	4	64	190	110	93
548	4	68	140	105	106
549	4	42	69	57	59
551	16	52	200	108	92
552	214	19	159	54	48
553	5	88	160	114	110
554	4	53	94	82	92
555	9	7.6	83	45	48
556	6	50	110	78	70
560	4	15	29	21	20
562	6	18	42	28	23
569	6	4.5	7.0	5.5	5.2
570	5	23	74	45	38
572	5	7.6	8.8	8.2	8.4
573	5	7.8	11	9.6	9.4
574	3	29	40	33	--
582	32	14	51	24	20

Table 6.4-2 Relation of sulfate concentration to streamflow at sites 521, 552, and 582.

SITE NUMBER	STREAMFLOW FT^3/S	SULFATE MG/L
552	62	120
	178	84
	314	94
	877	69
	2620	50
	4480	67
	6170	41
521	4.2	250
	8.9	190
	34	130
	92	69
	261	72
582	8.0	43
	32	44
	181	29
	272	31
	464	39
	900	34
	1710	19

See section 10.2 for detailed site description

Iron Concentrations Vary with Location and Discharge

The total recoverable iron concentration in streams in Area 15 increases with flow and is generally higher at sites draining mined areas. The dissolved fraction is relatively minor; most of the iron is suspended.

Iron is common in rocks and in soils rich in organic material. Surface mining exposes rocks and soils to weathering, accelerating the oxidation and dissolution of iron compounds. In addition to dissolved iron, large amounts of iron compounds are transported in suspension.

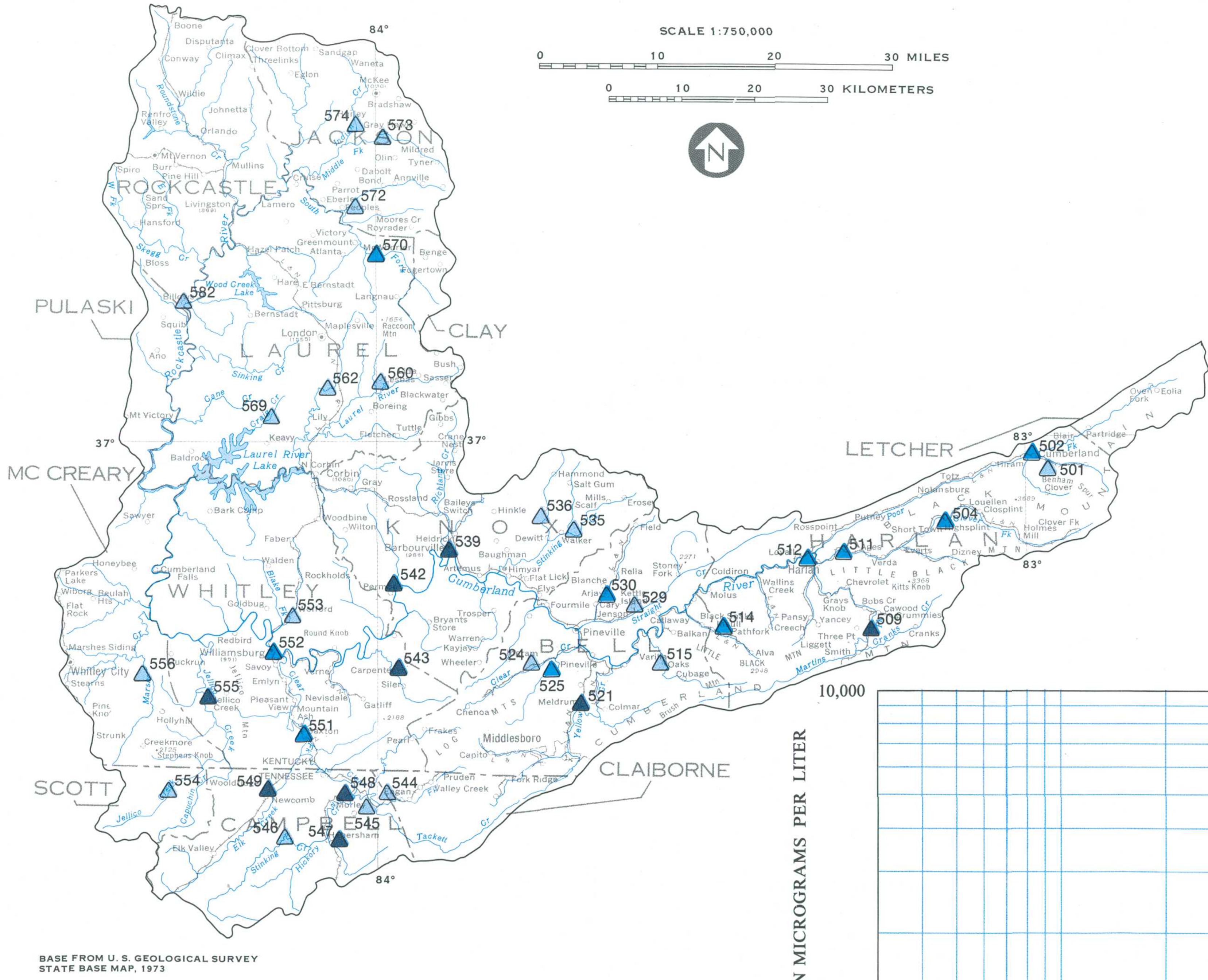
Dissolved and total recoverable iron concentrations (suspended plus dissolved) are important water-quality parameters that affect the suitability of water for domestic and industrial uses. Dissolved-iron concentrations in excess of 300 μg/L cause staining, impart an undesirable taste to water, and require treatment for most uses (U.S. Environmental Protection Agency, 1976). In streams, dissolved iron may precipitate, producing "yellow boy" (ferrous hydroxide, ochre-yellow precipitate), which flocculates and settles on river beds adversely affecting bottom aquatic life. The Act established a permissible limit of 7,000 μg/L of iron for effluents from mined areas.

Determinations of iron concentrations are available from 38 active sites in Area 15 (fig. 6.5-1). Total recoverable iron concentrations in streams in Area 15 range from 10 to 46,000 μg/L (table 6.5-1). However, in most streams, mean concentrations exceed 1,000 μg/L, but are less than 2,000 μg/L. Maximum recommended concentrations for aquatic life of 1,000 μg/L and for drinking water of 300 μg/L (U.S. Environmental Protection Agency, 1976) are frequently exceeded at many sites in both mined and unmined basins.

The highest total recoverable iron concentrations occur at sites in the headwaters of the Cumberland River basin, where coal mining is most intense. The lowest concentrations usually occur at sites in the largely unmined Rockcastle River basin.

Most of the iron in streamflow in Area 15 is suspended, with only a small fraction in the dissolved phase (table 6.5-2). At most sites in mined and unmined basins, the dissolved iron is usually less than 10 percent of the total recoverable iron. Large increases in flow generally do not result in substantial changes in dissolved-iron concentrations. An increase in suspended iron; however, generally occurs with increasing streamflow at most of the sites.

The transport of iron at selected sites in Area 15 correlates significantly with the suspended-sediment concentration (fig. 6.5-2) increasing with increasing-suspended sediment concentration. Definition of the suspended-sediment yields at a site are essential for estimating iron yields from mined and unmined basins. Since runoff from one storm may transport most of the annual sediment load at a site (see section 6.7), sediment and iron transport processes cannot be defined from random and intermittent sampling. Frequent sampling during the full range of flow is necessary to determine iron yields from a basin.



EXPLANATION

Site and number	Maximum total-recoverable-iron concentration, in micrograms per liter
515	0-3,000
539	3,001-7,000
514	Greater than 7,000

See section 10.2 for detailed site description

Figure 6.5-1 Iron sampling sites.

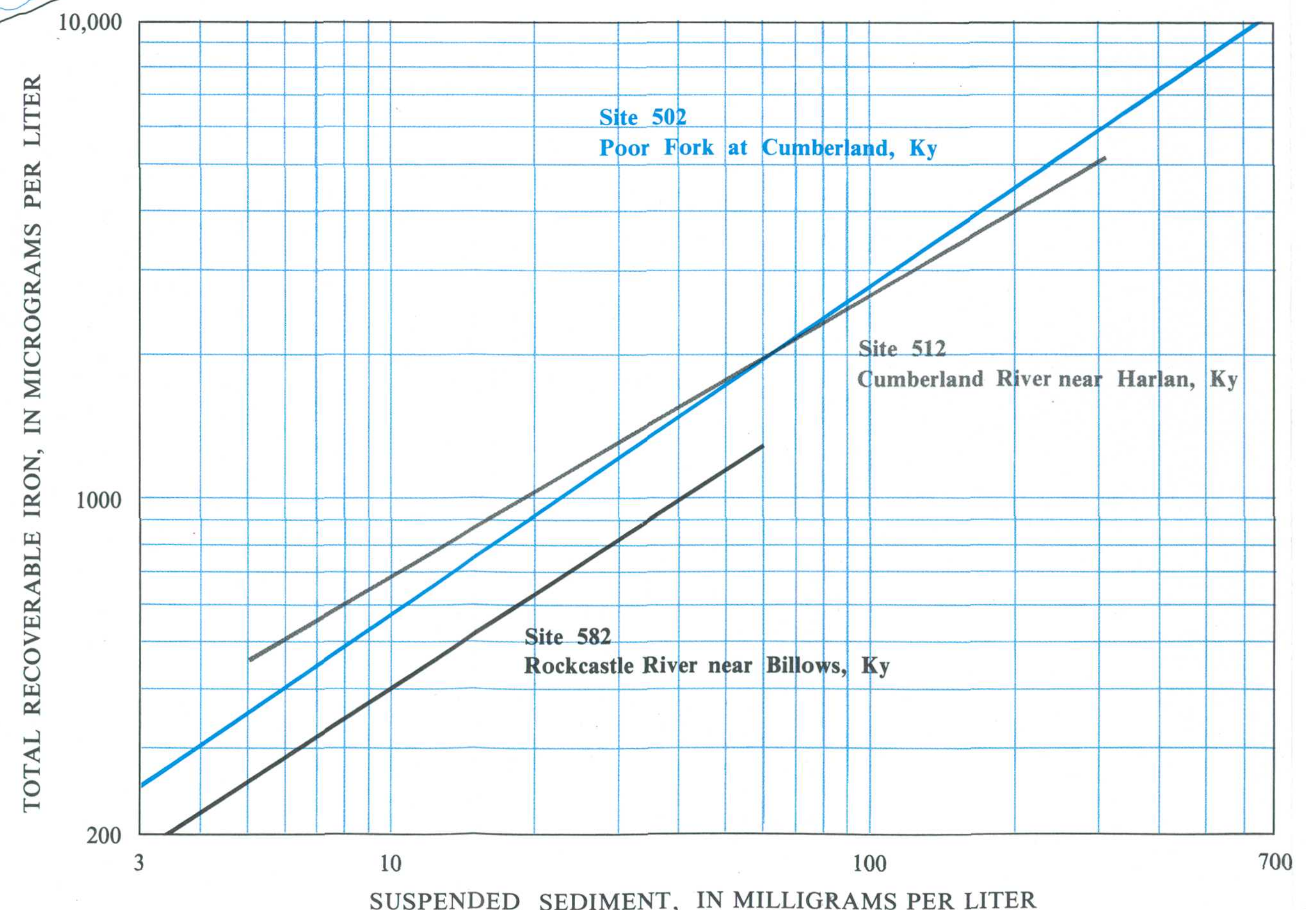


Figure 6.5-2 Relation of total-iron concentrations to suspended-sediment values at sites 502, 512, and 582.

Table 6.5-1 Total-recoverable-iron data for active sites.

MAP NUMBER	NUMBER OF SAMPLES	MINIMUM (micrograms per liter)	MAXIMUM	MEAN	MEDIAN
501	6	310	2600	1500	1300
502	11	320	10000	2700	1100
504	6	300	7000	2190	1550
509	7	390	6600	2200	1300
511	6	470	29000	8360	3400
512	23	10	7800	1300	710
514	6	150	8500	2100	720
515	6	380	1700	880	680
521	7	140	3400	1800	1800
524	6	570	1200	810	725
525	6	450	46000	8800	790
529	6	380	2100	915	750
530	6	570	12000	2800	940
535	5	830	2700	1600	1700
536	4	740	1200	980	990
539	10	690	4600	2000	1300
542	6	600	4300	1800	1600
543	6	650	3900	1500	1150
544	4	710	1600	1100	1100
545	4	410	750	530	480
546	4	290	1700	850	710
547	4	390	3100	1200	600
548	4	1300	4600	2700	2400
549	4	1100	3800	2600	2800
551	11	410	24000	3900	1500
552	142	10	12000	308	40
553	5	640	1000	800	710
554	4	680	1100	930	980
555	7	190	6800	1500	680
556	6	330	610	510	540
560	4	1300	2100	1600	1500
562	6	750	1600	1200	1400
569	6	510	2700	1000	760
570	5	630	12000	3100	940
572	5	370	750	550	520
573	5	270	740	520	440
574	3	430	480	460	---
582	19	10	1000	215	130

See section 10.2 for detailed site description

Table 6.5-2 Relation of dissolved and total-recoverable-iron concentrations to streamflow at sites 521, 552, and 582.

SITE NUMBER	DISCHARGE FT^3/S	DISSOLVED IRON (micrograms per liter)	TOTAL RECOVERABLE IRON
521	4.2	160	1800
	8.9	90	3400
	34	440	860
	92	50	960
	261	110	3100
552	62	50	380
	167	30	670
	330	20	890
	877	140	540
	2620	30	1300
	4480	20	12000
	5060	30	4500
582	8.0	40	250
	24	30	170
	69	120	610
	181	80	320
	464	20	340
	900	100	830
	1710	60	1000

Manganese Concentrations are Highest in Streams Draining Mined Basins

Manganese concentrations at stream sites in the headwaters of the Cumberland River basin, where coal mining is most intense, are higher than at unmined sites in Area 15. The concentration of manganese does not increase significantly with increasing flow.

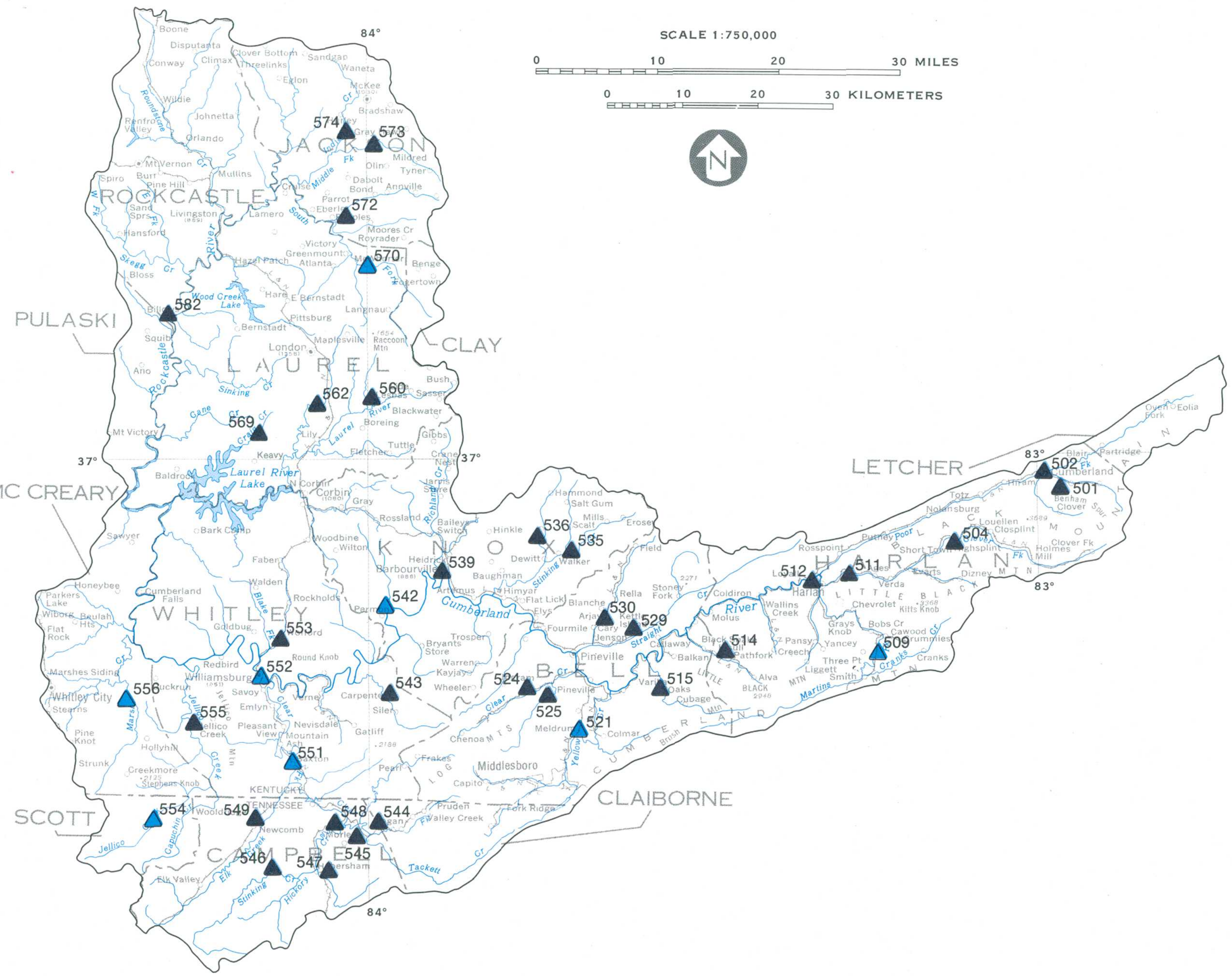
Manganese is one of the most common elements in soils and rocks. Soils rich in organic matter are one of the main sources of manganese in natural waters. Although dissolved manganese is an essential element for plant and animal metabolism, concentrations in excess of 150 $\mu g/L$ impart objectionable taste to water and staining of fabrics (U.S. Environmental Protection Agency, 1976).

Most water-supply criteria (U.S. Environmental Protection Agency, 1976) contain maximum limits for dissolved manganese (50 $\mu g/L$). The Act specifies 4,000 $\mu g/L$ as the maximum permissible concentration of total manganese in effluents from mined areas.

Dissolved and total recoverable manganese data are available for 38 sites in Area 15 (fig. 6.6-1 and table 6.6-1). Prior to 1979, data were available for only 6 sites. All of the data available represent intermittent samples with insufficient information to define seasonal flow relations.

Total recoverable manganese concentrations in streams throughout Area 15 range from 20 to 3,800 $\mu g/L$. In general, the highest manganese concentrations occur in streams in the Cumberland River basin, where mining is most intense. The lowest values occur at stream sites in the Rockcastle River basin, in Jackson County.

Dissolved manganese constitutes more than half, and in some analyses all, of the total recoverable manganese at most of the sites in Area 15 (table 6.6-2). The data show that the amount of manganese, dissolved and/or suspended, does not change substantially with the amount of streamflow. Determination of manganese loads can only be achieved by frequent sampling. The lack of any significant correlation between manganese and other water-quality parameters, such as specific conductance, indicates that load estimates in streams cannot be obtained except by frequent and intense sampling throughout the full range of streamflows.



BASE FROM U. S. GEOLOGICAL SURVEY
STATE BASE MAP, 1973

EXPLANATION

Site location and number	Maximum-total-recoverable-manganese concentrations, in micrograms per liter
▲ 535	0-999
▲ 570	Greater than 1,000

See section 10.2 for detailed site description

Figure 6.6-1 Total-recoverable manganese.

Table 6.6-1 Total-recoverable-manganese data for active sites.

SITE NUMBER	NUMBER OF OBSERVATIONS	MINIMUM (micrograms per liter)	MAXIMUM (micrograms per liter)	MEDIAN (micrograms per liter)	MEAN (micrograms per liter)
501	6	70	240	130	145
502	11	50	370	90	124
504	6	40	180	60	75
509	7	50	1400	180	338
511	6	50	710	115	240
512	13	70	220	110	128
514	6	30	190	50	77
515	6	150	300	250	233
521	37	70	3800	405	487
524	6	30	110	60	67
525	6	40	790	50	183
529	5	390	800	530	570
530	6	130	450	250	273
535	5	70	500	180	226
536	4	80	470	-	-
539	12	70	260	125	120
542	6	520	1300	625	758
543	6	260	570	460	433
544	3	210	460	-	-
545	3	120	250	-	-
546	4	170	650	-	-
547	3	30	430	-	-
548	4	330	930	-	-
549	4	290	580	-	-
551	13	270	1000	430	467
552	20	60	1400	140	245
553	5	100	230	180	172
554	4	510	1600	-	-
555	7	130	700	310	318
556	6	260	1300	785	755
560	4	150	250	-	-
562	6	200	920	580	525
569	6	30	430	90	187
570	5	160	1100	290	430
572	5	30	270	50	96
573	5	20	520	50	138
574	3	160	270	-	-
582	10	40	170	85	95

See section 10.2 for detailed site description

Table 6.6-2 Relation of dissolved and total-recoverable-manganese concentrations to streamflow at sites 521, 552, and 582.

MAP NUMBER	DISCHARGE (ft(3)/s)	DISSOLVED MANGANESE (micrograms per liter)	TOTAL RECOVERABLE MANGANESE (micrograms per liter)
521	4.2	300	330
	8.9	440	490
	34	240	240
	92	140	140
	261	150	210
552	62	70	90
	167	60	110
	330	80	110
	877	50	60
	2620	100	140
	4480	110	540
	5060	110	240
582	8.0	70	150
	24	70	90
	69	40	40
	181	20	60
	464	10	80
	900	20	80
	1710	80	110

Suspended-Sediment Data Limited

Suspended-sediment data are collected two to five times per week and during storms at six sites, and at three-month intervals at 32 sites in Area 15.

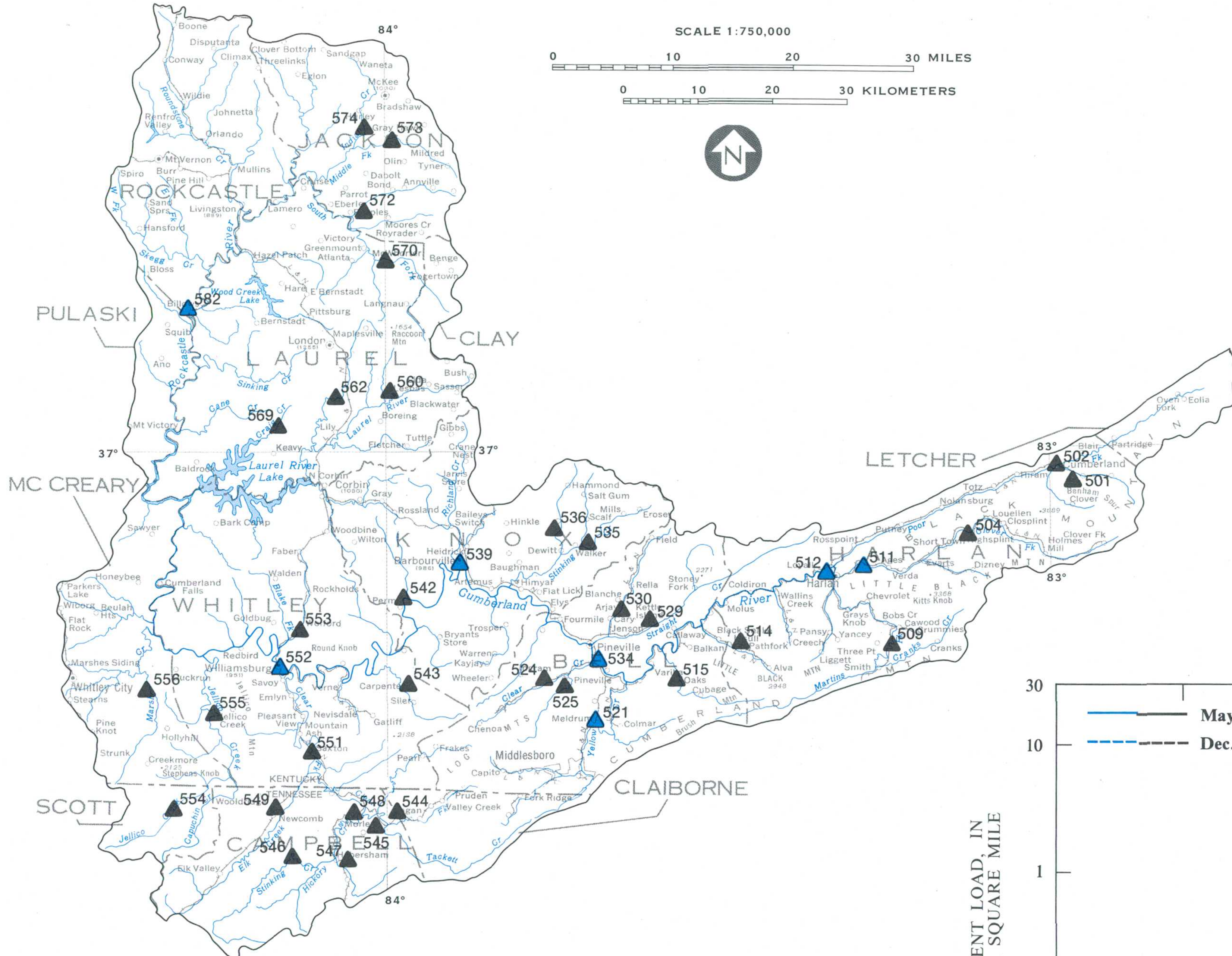
Frequent sampling during the full range of flow is necessary to determine suspended-sediment yield from a basin. Sediment transport processes cannot be defined from random and intermittent sampling, since one storm may transport most of the annual sediment load at a site. Only limited sediment data were collected in Area 15 prior to 1979, although suspended-sediment samples were occasionally collected at streamflow sites during storm-discharge measurements.

In response to the Act, the collection of suspended-sediment data was expanded in 1979 to 38 sites (fig. 6.7-1). At six sites, samples are collected two to five times each week and during storms. Data from these sites will be used to compute daily and annual suspended-sediment loads. At 32 sites, samples are collected at three-month intervals, during various flow conditions, in order to define a preliminary suspended-sediment transport curve to estimate sediment loads.

The data collected during 1979-80 show that the transport of suspended sediment in Area 15 is affected by seasonal precipitation and intensity of mining. Comparison of suspended-sediment transport curves for sites 512 and 552 in the Cumberland River basin (fig. 6.7-2) shows that the suspended-sediment yields are about 10 times higher during May to November than during December to April. More frequent and intense storms occur in the basin during the summer-fall months than during the winter months. Similar seasonal patterns in the transport of suspended sediment have been observed in other coal basins in eastern Kentucky (Quinones and others, 1981).

The effects of surface mining on the suspended-sediment transport are evident from a comparison of the transport curves between several sites in Area 15 (fig. 6.7-3). Suspended-sediment yields in the heavily mined Yellow Creek basin (site 521) are from five to ten times higher than in the Rockcastle River basin (site 582), which is largely forested and undisturbed. Yields in the Clover Fork basin (site 511) are affected by water impoundments that cover about 20 percent of the drainage area.

The transport of most of the annual suspended-sediment load at sites in Area 15 can occur during one intense storm (fig. 6.7-4). The suspended-sediment load transported during the March 20-21 storm at Yellow Creek near Middlesboro (site 521) accounted for about 60 percent of the annual suspended-sediment load during 1980.



BASE FROM U. S. GEOLOGICAL SURVEY
STATE BASE MAP, 1973

EXPLANATION

Site and number	
▲ 534 (blue)	Samples collected 2 to 5 times weekly and during storms
▲ 556 (black)	Samples collected at 3-month intervals

See section 10.2 for detailed site description

Figure 6.7-1 Suspended-sediment sampling sites.

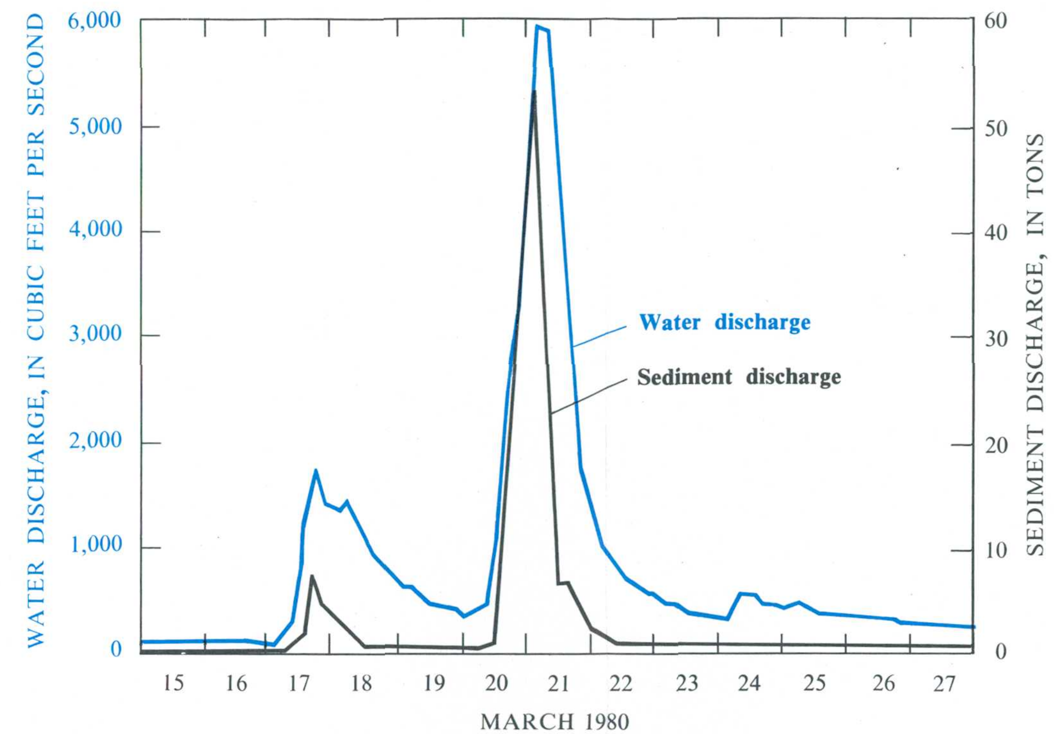


Figure 6.7-4 Relation between suspended-sediment discharge and streamflow at Yellow Creek near Middlesboro (site 521).

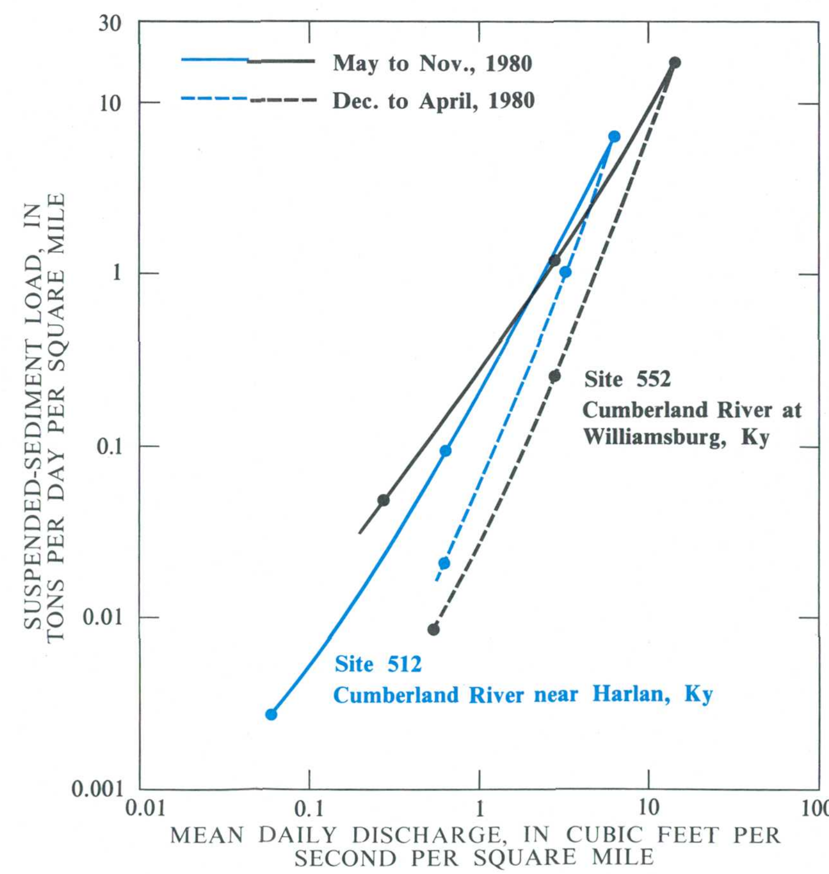


Figure 6.7-2 Seasonal effects on the suspended-sediment transport.

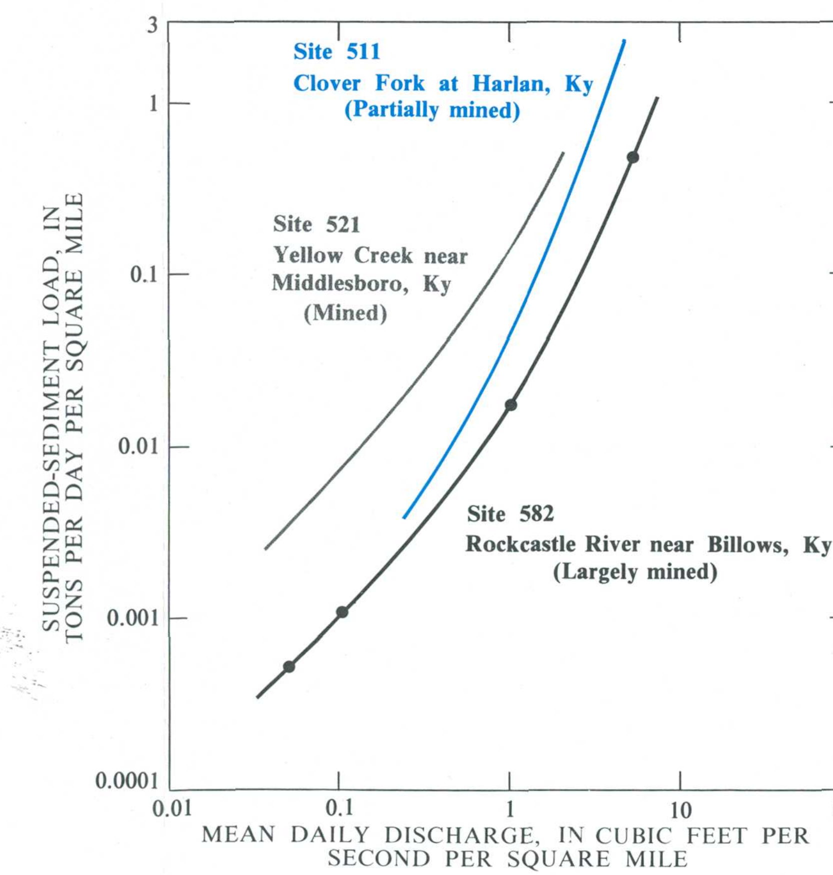


Figure 6.7-3 Relation between instantaneous water discharge and suspended-sediment loads at partially mined and unmined sites.

Most Concentrations of Trace Constituents in Water and Bottom Material Were Low

Concentrations of dissolved mercury at selected sites in Area 15 exceed maximum recommended State and Federal limits for water for aquatic life. Low concentrations of trace constituents were found in streams and in stream bottom material in Area 15. Data available are not adequate to define transport of trace constituents.

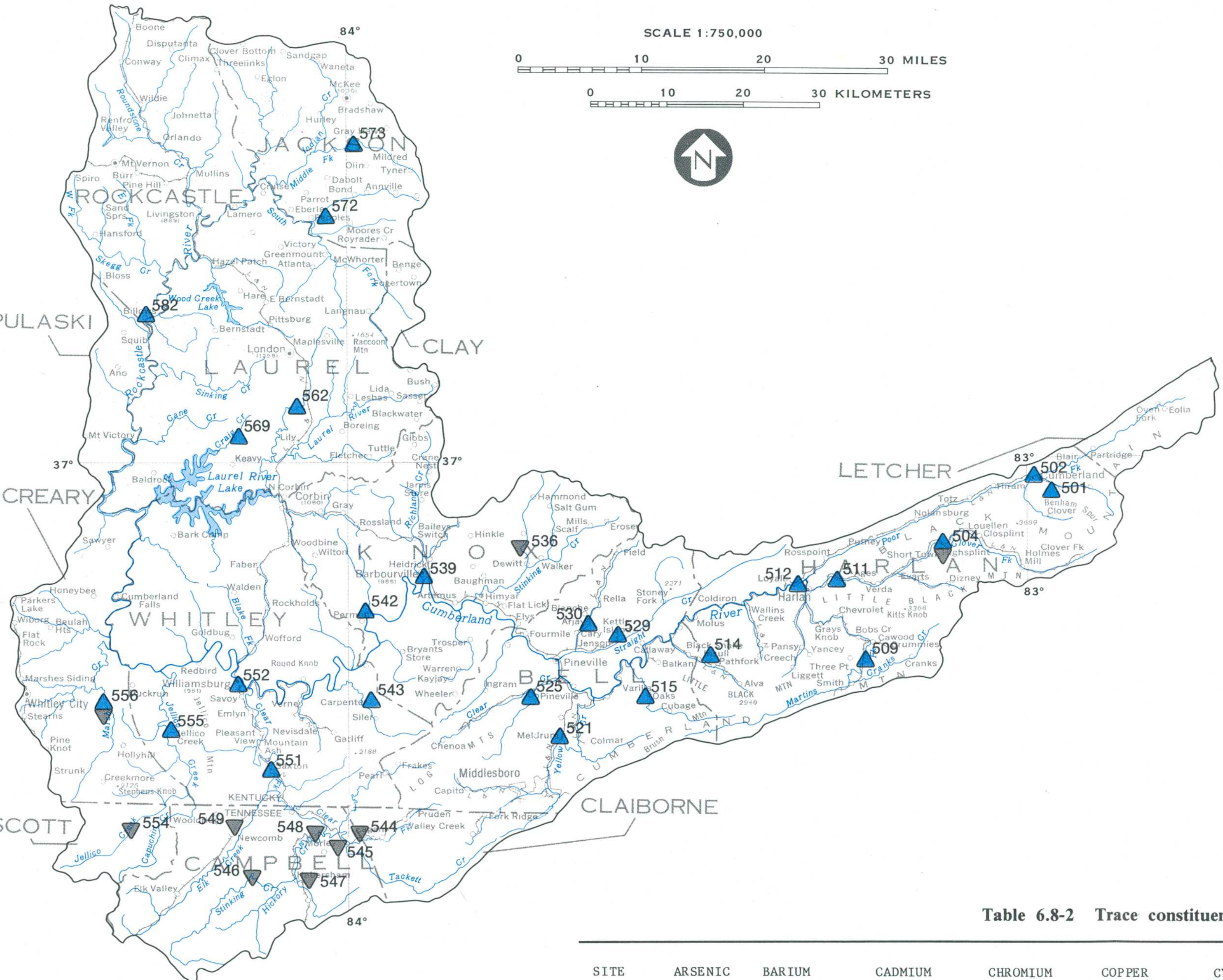
Trace constituents are predominantly metals of low solubility. They normally occur in low concentrations in natural water. In low concentrations most of the constituents are essential to life. However, in high concentrations some are toxic to plants and animals. Trace constituents are present in soils and rocks and under normal weathering conditions slowly leach into natural waters. High concentrations of trace metals in water are usually associated with industrial-waste discharges and acid-mine drainage.

The oxidation of minerals containing sulfur in mining spoils produces sulfuric acid. The acid accelerates the leaching of minerals and dissolution of salts. These processes may increase the dissolved-solids and the trace-constituents concentration in water. Mine drainage, particularly when acidic, usually contains concentrations of trace constituents that exceed background levels. When mine-drainage is neutralized, trace constituents may precipitate and concentrate in stream-bottom deposits.

Concentrations of selected constituents in water and stream-bottom sediments at sites in Area 15 (fig. 6.8-1) are shown in tables 6.8-1 and 6.8-2. The samples were collected during low-flow periods during 1979-80.

The available data show that trace constituents are not present in significant concentrations in water, or in the stream-bottom sediments at the sampled sites. Dissolved mercury concentrations at some sites exceed State and Federal maximum-recommended concentrations of 0.05 μg/L for aquatic life (U.S. Environmental Protection Agency, 1976). None of the streams contained more than 2.0 μg/L of mercury, which is the maximum recommended concentration for domestic water supply. Iron and manganese concentrations in bottom sediments of streams draining mined areas are higher than those at other sites in Kentucky where no mining occurs (U.S. Geological Survey, 1980).

The transport of trace constituents in areas affected by mining is generally associated with the transport of suspended sediment. The data in Area 15, however, are not adequate to define these relations. An intensive program involving time and stage sampling is required to define these processes.



BASE FROM U. S. GEOLOGICAL SURVEY
STATE BASE MAP, 1973

EXPLANATION

Site location and number

511 **Trace constituents in water**

536 **Trace constituents in bottom sediments**

See section 10.2 for detailed site description

Figure 6.8-1 Trace-constituents sampling sites.

Table 6.8-1 Trace constituents, in bottom sediments.

SITE NUMBER	DATE	ARSENIC TOTAL	CADMIUM RECOVERABLE	CHROMIUM RECOVERABLE	COBALT RECOVERABLE	COPPER RECOVERABLE	IRON RECOVERABLE	LEAD RECOVERABLE
		MICROGRAMS PER GRAM						
504	8-15-79	0	<10	<10	10	20	9800	10
536	8-25-79	0	<10	20	<10	40	8600	50
544	9-04-79	0	<10	10	20	20	24000	20
	7-16-80	0	<10	20	40	20	56000	20
545	9-04-79	0	<10	10	20	20	21000	20
	7-16-80	0	<10	<10	20	<10	18000	<10
546	9-05-79	0	<10	10	10	10	22000	10
	7-16-80	0	<10	10	10	10	30000	10
547	9-05-79	0	<10	20	20	10	25000	<10
	7-16-80	0	<10	30	40	20	76000	20
548	9-04-79	0	<10	<10	20	<10	9000	20
	7-16-80	0	<10	10	20	10	22000	<10
549	9-05-79	0	<10	30	<10	20	20000	30
	7-16-80	0	<10	20	10	10	43000	10
554	9-05-79	0	<10	50	40	30	93000	10
	7-16-80	0	<10	20	20	<10	19000	<10
556	8-23-79	0	<10	<10	10	<10	4600	30

SITE NUMBER	DATE	MANGANESE TOTAL	MERCURY RECOVERABLE	SELENIUM TOTAL	ZINC RECOVERABLE
		MICROGRAMS PER GRAM			
536	8-23-79	220	0	0	20
	8-25-79	50	0	0	320
504	8-15-79	250	0	0	50
544	9-04-79	830	0	0	<10
	7-16-80	1700	0	0	130
545	9-04-79	970	0	0	80
	7-16-80	740	0	0	44
547	9-05-79	1200	0	0	78
	7-16-80	1200	0	0	90
546	9-05-79	800	0	0	70
	7-16-80	690	0	0	65
548	9-04-79	380	0	0	20
	7-16-80	1200	0	0	78
549	9-05-79	740	0	0	80
	7-16-80	2100	0	0	60
554	9-05-79	1500	0	0	120
	7-16-80	700	0	0	58

Table 6.8-2 Trace constituents in water.

SITE NUMBER	ARSENIC	BARIUM	CADMIUM	CHROMIUM	COPPER	CYANIDE	LEAD	MERCURY	SILVER	ZINC
	MICROGRAMS PER LITER									
501	1	100	0	20	4	0	6	<0.1	0	20
502	1	100	2	10	12	0	20	<0.1	0	30
504	1	100	0	10	3	0	10	<0.1	0	20
509	0	100	0	<10	2	0	9	<0.1	0	50
511	1	100	1	10	7	0	15	0.1	0	60
512	1	100	2	10	6	0	29	0.1	0	30
514	1	100	0	10	2	0	11	<0.1	0	20
515	0	100	3	20	9	0	17	0.1	0	50
521	2	100	2	20	4	0	21	0.1	0	30
525	0	100	0	10	2	0	6	<0.1	0	10
529	1	100	1	20	3	0	7	<0.1	0	20
530	0	200	0	10	2	0	2	<0.1	0	10
539	0	100	0	10	3	0	7	0.2	0	60
542	1	100	0	20	5	0	8	<0.1	0	20
543	0	100	0	10	3	0	2	<0.1	0	40
551	0	<50	0	10	3	0	8	<0.1	0	10
552	0	100	2	10	25	0	10	0.5	0	170
555	1	100	1	10	3	0	7	<0.1	0	10
556	0	100	0	10	3	0	9	<0.1	0	20
562	3	100	0	10	4	0	4	0.2	0	20
569	0	<50	0	<10	4	0	7	0.1	0	20
572	0	200	0	10	7	0	3	0.1	0	140
573	0	100	0	10	5	0	3	0.1	0	90
582	1	<50	0	20	6	0	2	0.1	0	40

Note: All samples taken during July, 1980.

Aquifers Recharged by Precipitation

Multiple sandstone aquifers are present in the Breathitt and Lee Formations in Area 15. They are recharged by precipitation and discharge to springs and streams.

Almost all ground water in Area 15 originates as precipitation that percolates downward to the zone of saturation, the upper surface of which is called the water table. The water table generally follows the shape of the land surface but is not as deep under valleys as under hilltops. Multiple aquifers can underlie the same area and each aquifer can have its own potentiometric surface or artesian head (fig. 7.1-1).

An artesian (confined) aquifer can occur between less permeable beds (shale and underclay). The water level in a well tapping an artesian aquifer rises above the top of the aquifer. Nearly all ground water in Area 15 is under artesian pressure.

A perched aquifer may be separated from the main water table by less permeable rocks that interrupt percolation and cause water to accumulate in an upper stratum. These occurences are in the hilly terrain underlain by alternating beds of permeable sandstone and less permeable rocks (fig. 7.1-1). Perched aquifers are easily altered by earth-moving operations such as strip mining or road construction.

Ground water is stored in and moves through intergranular and fracture openings in rocks. Most of the ground water in Area 15 comes from fracture openings that have developed in sandstone aquifers in the Breathitt and Lee formations. In the northwest part of the area, and along the northern slope of Pine Mountain, solutionally enlarged fracture openings in limestones of pre-Pennsylvanian age permit relatively free movement of large quantities of ground water to wells and springs.

Regionally, little is known about the direction of ground-water movement. Movement of water is from areas of high to areas of low pressure and is generally downdip along bedding planes. In the Middlesboro Syncline water moves to the center of the basin from Pine Mountain and Cumberland Mountain. Locally water may move in different directions because of influences of topography, impermeable beds, and the orientation of fracture systems. The rate of movement depends on the size and interconnection of water bearing openings and the hydraulic gradient.

Direct infiltration of precipitation is the major source of recharge to upper aquifers (fig. 7.1-1). Lower aquifers are recharged by leakage from overlying aquifers and to a lesser extent by direct infiltration of precipitation. Some water is contributed by streams that flow over the outcrop of the aquifer, provided the water table is below stream level. Recharge from streams can be large where the streams cross an aquifer that has been extensively fractured.

All ground water is in motion from areas of recharge to areas of discharge. Water discharges downward from areas of recharge and laterally to the outcrop as seeps or springs on hillsides (fig. 7.1-1). Water from lower aquifers moves downward, laterally, or upward to become streamflow. Pumping wells can alter the water levels in nearby wells or streams.

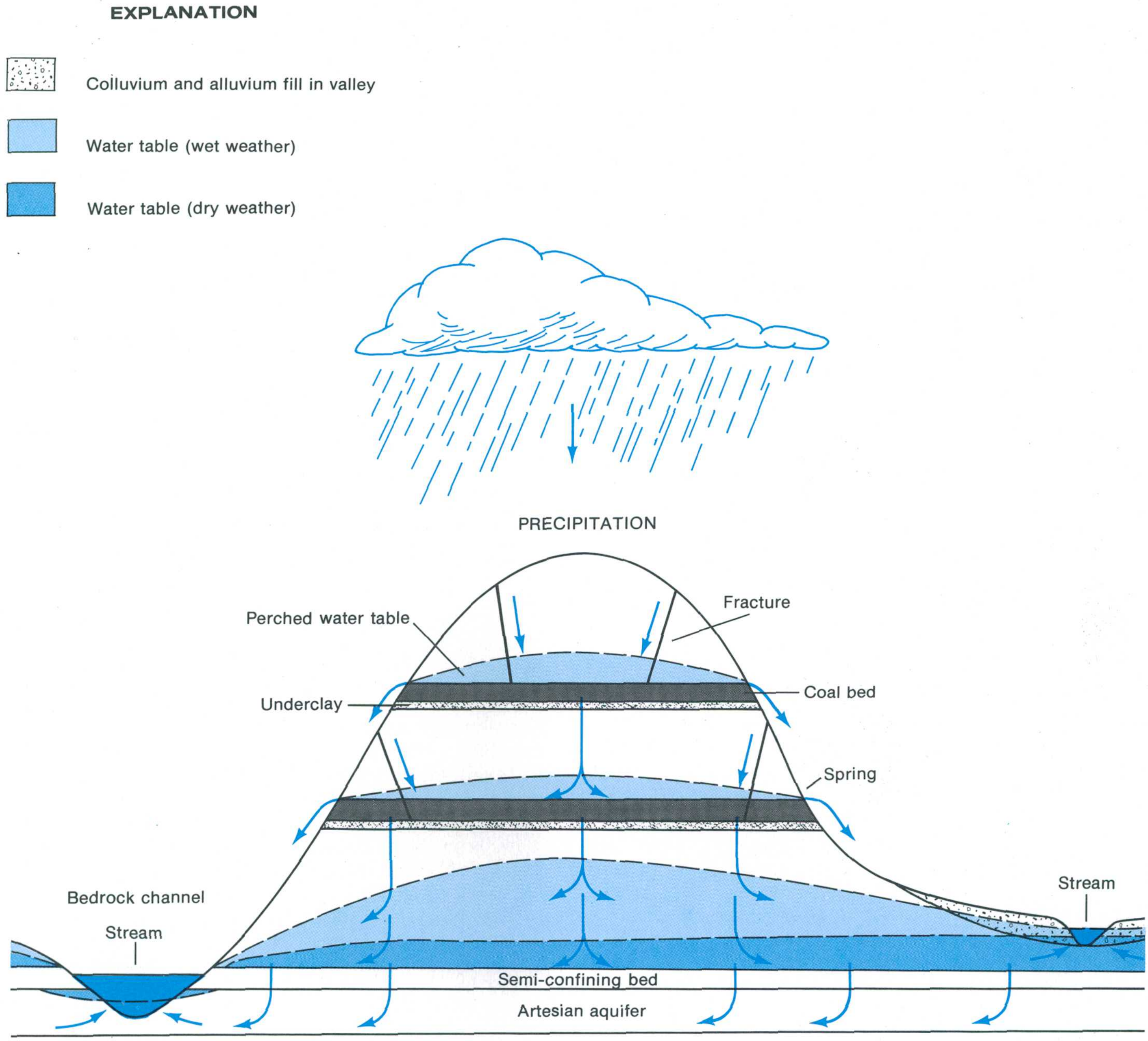


Figure 7.1-1 Generalized storage and movement of ground water.

Water Levels Fluctuate Seasonally

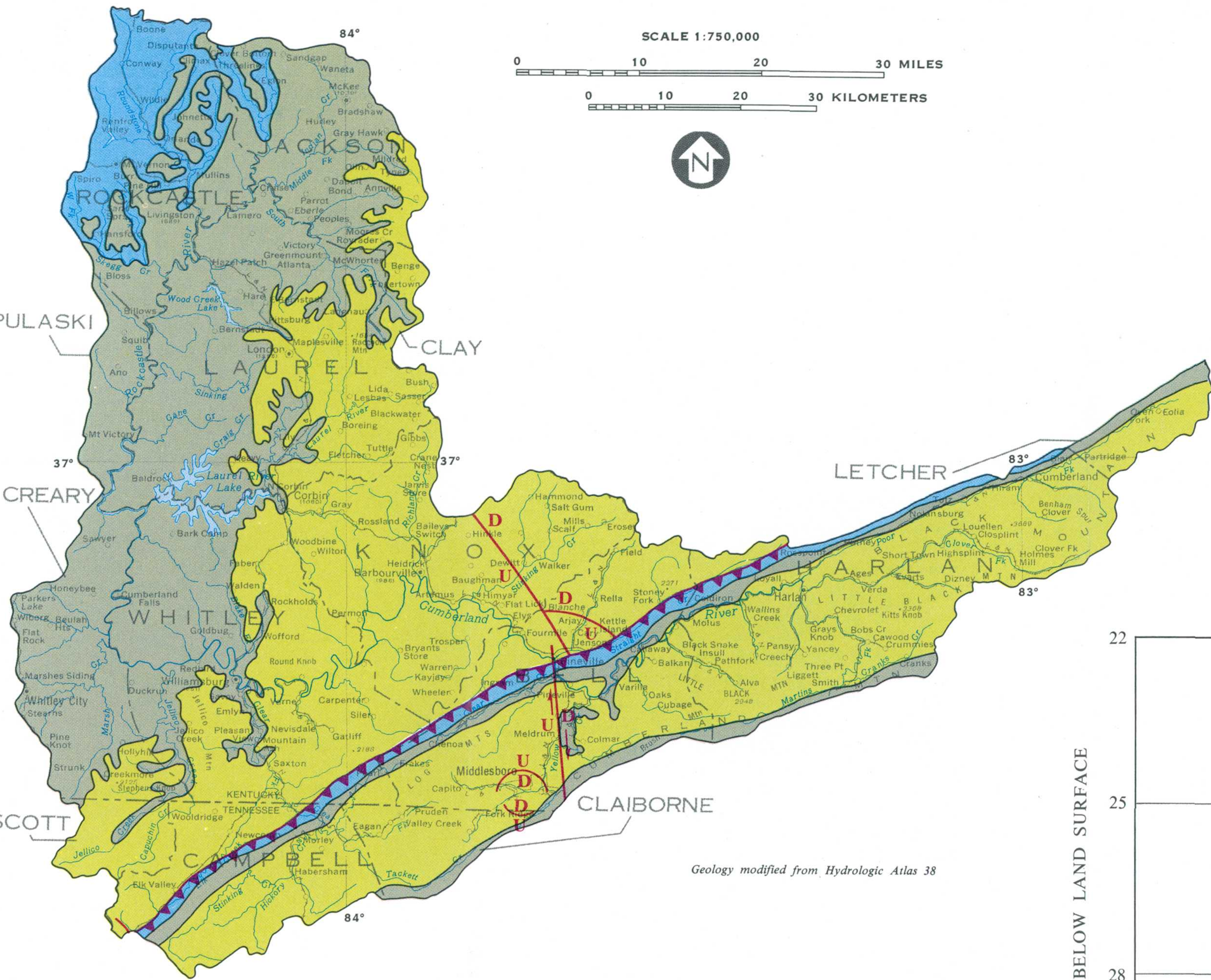
Water-level fluctuations reflect seasonal variations in the rate of recharge to, and discharge from aquifers in Area 15. Water levels range from above land surface to as much as 300 feet or more below land surface.

Water levels in Area 15 fluctuate in response to recharge and discharge of ground water. The principal factors affecting water levels are precipitation, evapotranspiration, natural discharge, and pumping from wells. During the growing season plants intercept water before it can enter the zone of saturation. Evapotranspiration causes a decline in water levels during the growing season as discharge continues to be greater than recharge. The lowest water levels occur in the fall prior to the first killing frost. During the winter months evapotranspiration decreases and water levels rise as recharge exceeds discharge. The highest water levels usually occur in the spring prior to the onset of the growing season.

Long-term ground-water level data are available from four wells in Area 15. Water levels for a 5-year period for one of the wells, tapping Pennsylvanian rocks, are shown in the hydrograph, figure 7.2-1. Based on this hydrograph, there are no long-term rising or falling water level trends. The hydrograph for the 1979 water year shows typical ground-water level response to seasonal variations in recharge and precipitation at a nearby station. The peaks in the ground water record are caused when recharge from precipitation exceeds discharge from the aquifers with individual peaks caused by isolated periods of precipitation. The range in water-level fluctuations for the period of record is about 13 feet. The fluctuation can vary from place to place and may be considerably different in other parts of the area. Water-level fluctuations greater than 13 feet are typical in the limestone rocks of pre-Pennsylvanian age in Area 15. Water levels are more variable in these limestone rocks due to faster recharge and discharge through solution openings.

The depth to water is generally less than 50 feet under valleys and may be as much as 300 feet under ridges. However, the depth to water may be considerably less where perched water zones occur under ridges. Flowing wells are fairly common in the Middlesboro Syncline.

Continous water-level records for observations wells in Area 15 may be obtained from the U.S. Geological Survey at Louisville or from the series of annual reports "Water Resources Data for Kentucky", published by the U.S. Geological Survey. Hydrographs of water levels in observation wells through 1976 are published in Whitesides and others (1978).



EXPLANATION

Pennsylvanian

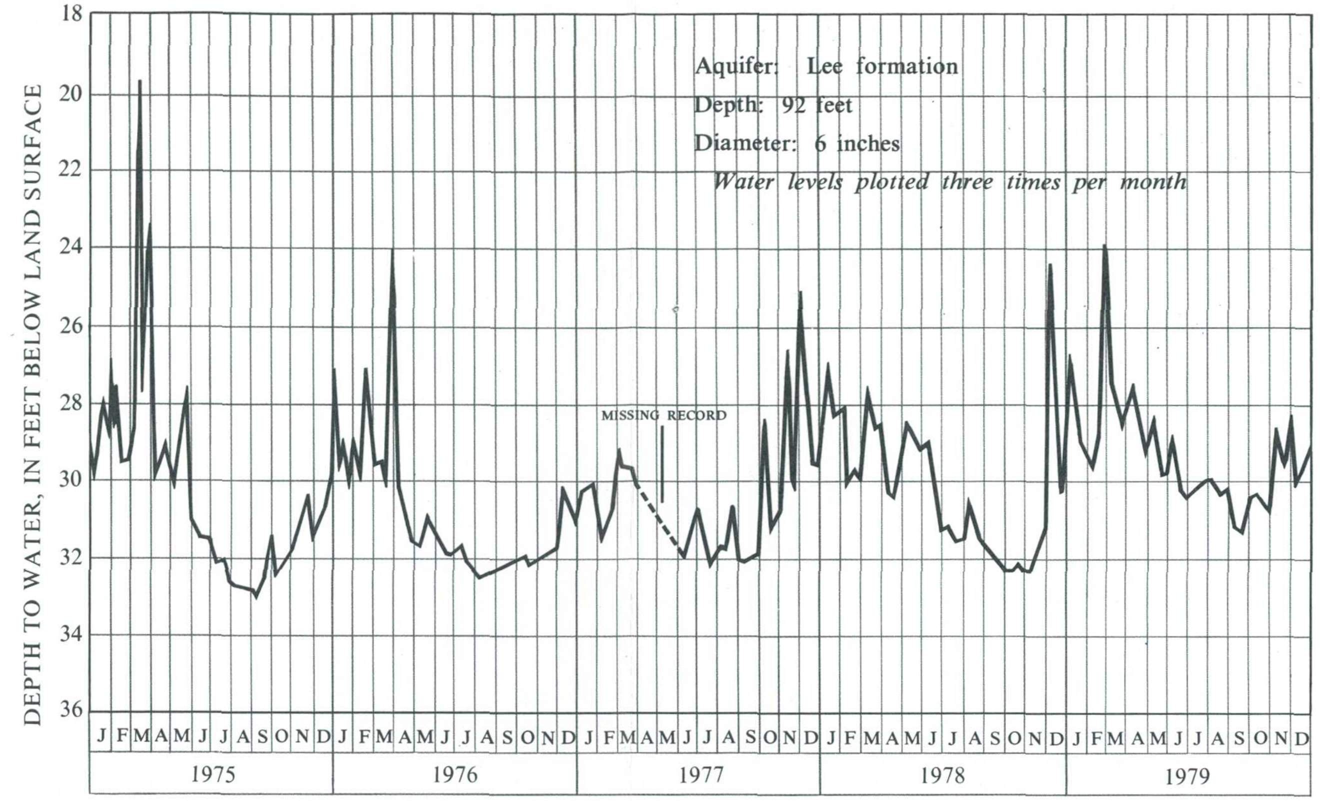
Breathitt Formation
Siltstone, sandstone, clay shale, coal underclay and some limestone

Lee Formation
Sandstone, conglomerate, shale, coal and underclay

Pre-Pennsylvanian
Shale, limestone, sandstone, and siltstone

Thrust Fault
Sawteeth on upper plate

Faults
Arrows indicate relative movement: U upthrown side; D downthrown side



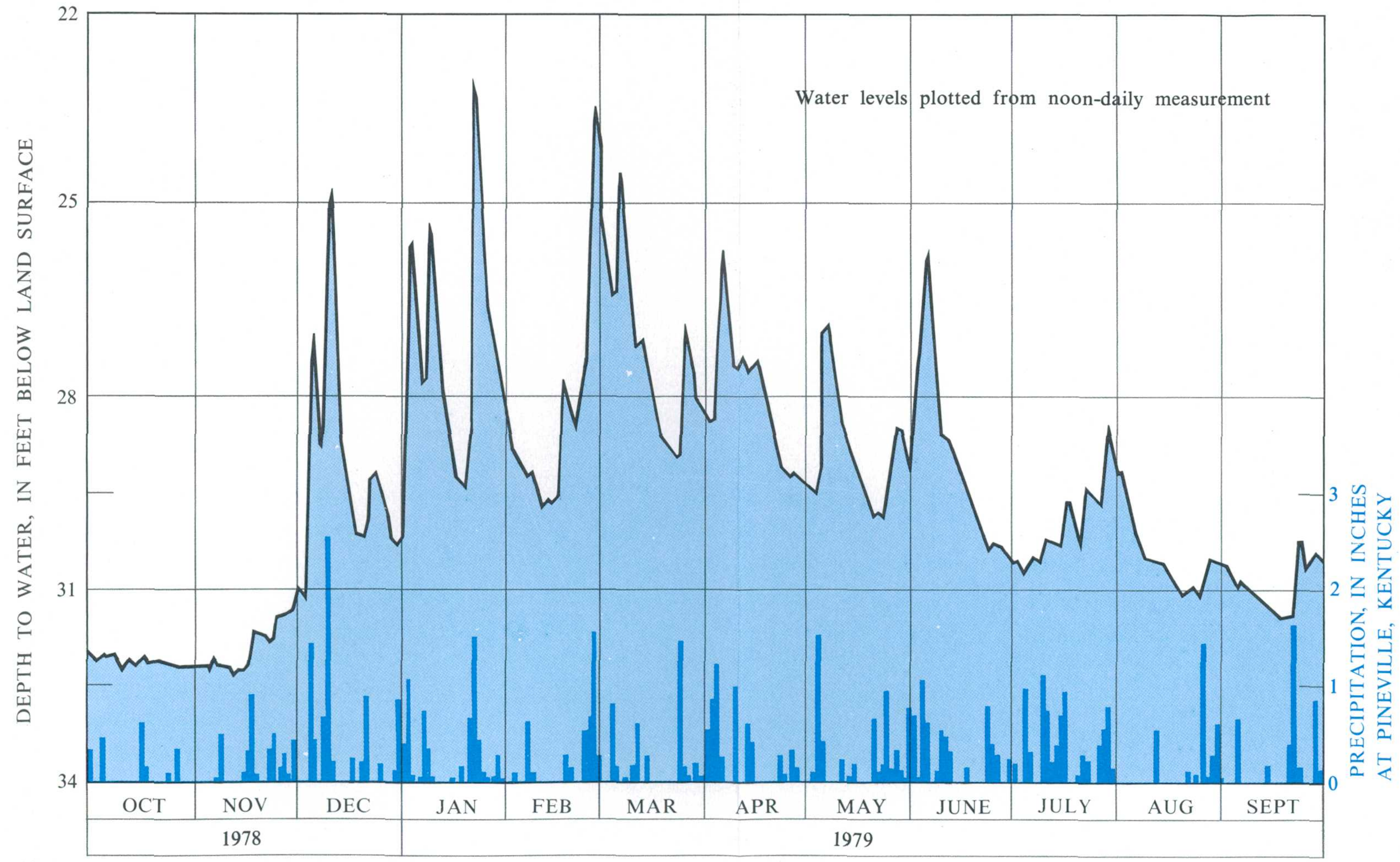


Figure 7.2-1 Water-level fluctuations.

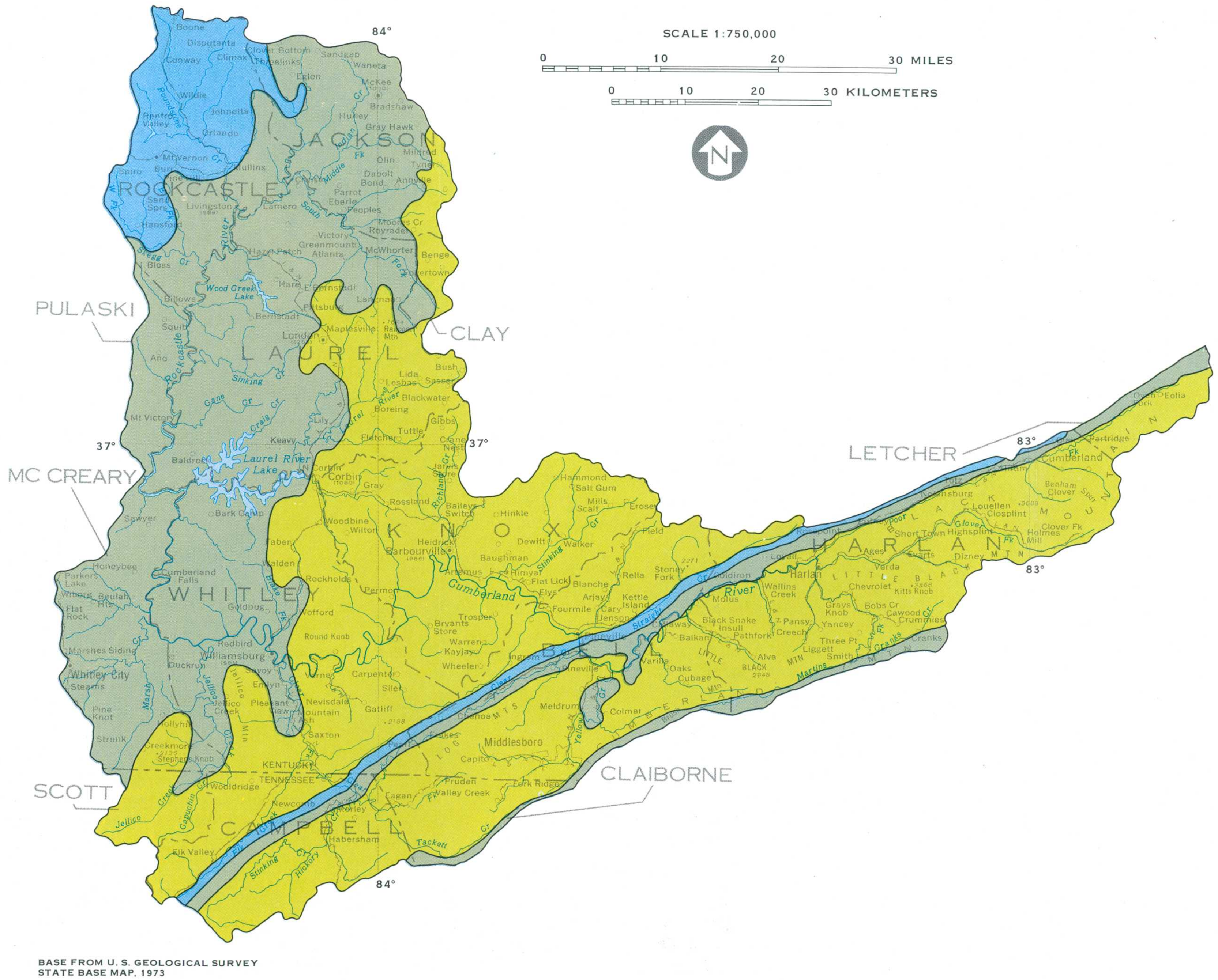
Measured Yields to Wells Range from 1 to 250 Gallons Per Minute

Pennsylvanian rocks yield from 1 to 250 gallons per minute to wells depending on location and well depth. Pre-Pennsylvanian rocks generally yield less than 50 gallons per minute to wells.

The principal factors governing well yields are well depth, location, lithology of the rocks tapped, and fractures. In general, deeper wells have greater yields. However, fractures are generally fewer in number and smaller at greater depths. Hence, greater depths may not necessarily produce a corresponding increase in yield.

The main sources of ground water in Area 15 are the Breathitt and Lee Formations of Pennsylvanian age (fig. 7.3-1). Sandstone is the principal aquifer but shale and coal deposits also yield water to wells. Yields usually range from less than 1 to 25 gal/min from wells 200 feet or less in depth. Yields as much as 250 gal/min are known from fractured sandstones of the Lee Formation near the Pine Mountain Fault in Harlan County. Similar yields may be obtained in the vicinity of other major faults because fractures tend to be larger and more numerous near fault zones. Yields as much as 250 gal/min are known from wells tapping sandstone of the Lee Formation 600 feet below the valleys of perennial streams. Deep wells (about 1,000 feet) tapping the Lee Formation in the Middlesboro Syncline flow as much as 15 gal/min (Mull and Pickering, 1969). Possibly the yields from depths greater than 300 feet are from intergranular pore spaces where sandstone particles are poorly cemented (Price and others, 1962).

The availability of ground water in pre-Pennsylvanian rocks is related to well depth, topography, rock type, and the character of the overlying Pennsylvanian rocks. The major aquifers are limestone rocks that may yield more than 50 gal/min from interconnected, solution openings. Springs may flow more than 20 gal/min from similar openings. Yields generally range from less than 1 to more than 50 gal/min, but typically are less than 1 gal/min where limestone above stream level is overlain by shale or siltstone of Pennsylvanian age.



EXPLANATION

Yield to wells
(in gallons per minute)

Breathitt formation
less than 1 to 25

Lee formation
less than 1 to 250

Pre-Pennsylvanian rocks
less than 1 to more than 50

Figure 7.3-1 Yield to wells.

Chemical Quality of Ground Water is Highly Variable

Ground water in Area 15 is generally suitable for most uses, although treatment is required for some uses. High iron concentrations in water are common and hardness ranges from soft to very hard.

The quality of ground water in Area 15 is highly variable, but is generally acceptable for most uses with proper treatment. There are not enough chemical analyses available to adequately define the chemical characteristics of ground water in Pennsylvanian aquifers throughout Area 15 and there are no chemical analyses from pre-Pennsylvanian aquifers.

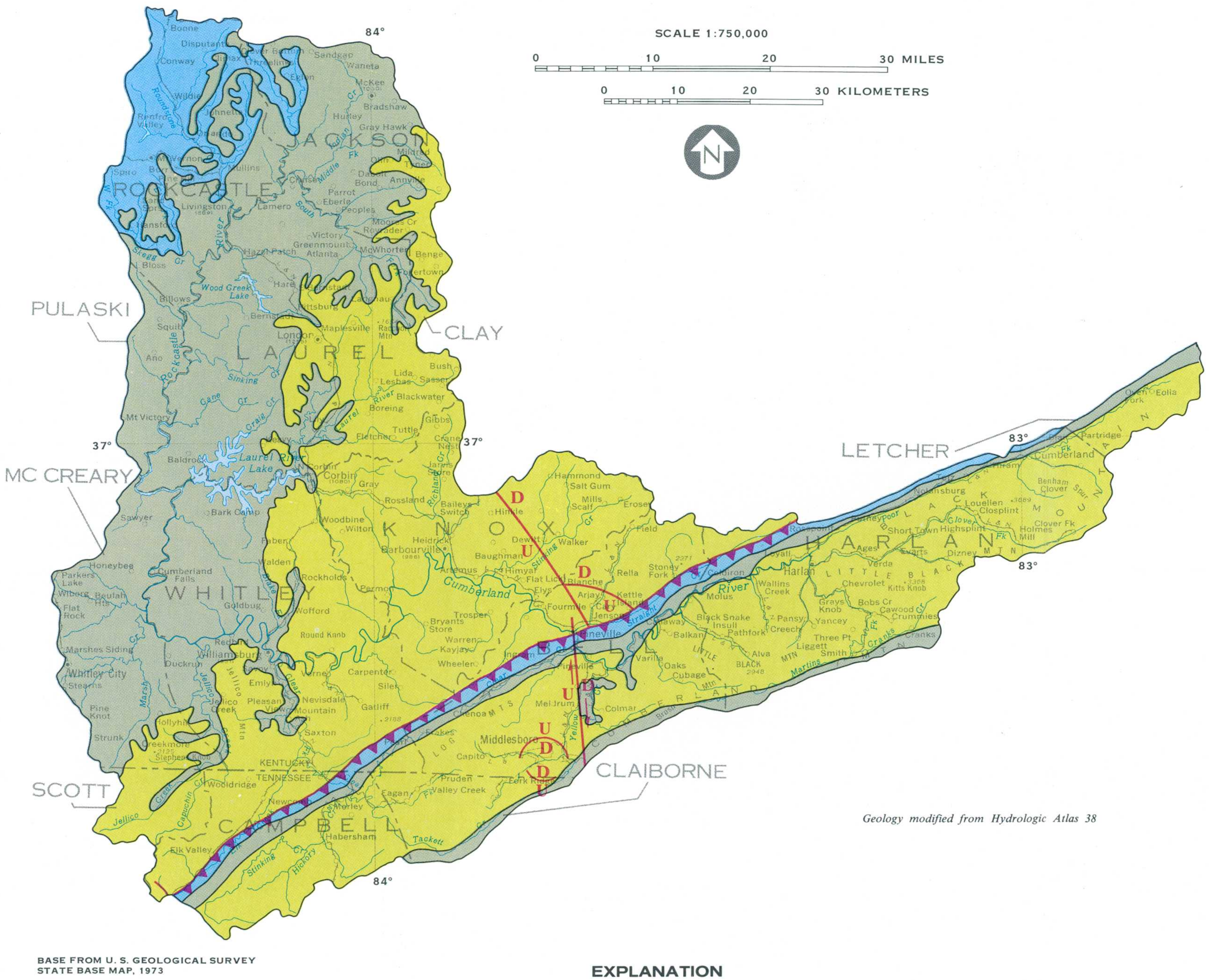
Available minimum, median, and maximum values for the concentration of common chemical constituents in the Breathitt and Lee formations are shown in figure 8.0-1. Most water analyses from the Breathitt Formation are from Bell County. Median values are shown because they are more representative than average or extreme values, especially in the Lee Formation where brines and brackish water occur. Waters with specific conductance values greater than 10,000 μmhos/cm were considered to be unsuitable for domestic use and were not used in compiling the water-quality table in figure 8.0-1. Ground-water quality data for Kentucky have been compiled by Faust and others (1980).

Water having more than 1,000 mg/L dissolved solids,(Hopkins, 1966) in Area 15 is found at depths more than about 300 feet below valleys except in areas adjacent to major faults and in the Middlesboro Syncline. For example, Hopkins (1966) reported only 2 mg/L of chloride in water from two wells that were reported to be 1,500 feet deep near a fault area in Bell County. Fresh water at such depth probably occurs in fractures related to the Pine Mountain overthrust fault. Saline water occurs at depths less than 100 feet below the level of the deeper valleys in non-faulted areas, such as in Knox, Laurel, and Whitley Counties. It is common in the vicinity of oil and gas fields because saline water can migrate upward through improperly plugged or abandoned oil, gas, or test wells. In general, the concentration of dissolved solids increases with depth, and water classified as brines (more than 35,000 mg/L dissolved solids) can be found at depths greater than 1,000 ft in any part of the area. Sodium and chloride are the main constituents of the saline water.

Iron is generally the second most common constituent found in ground water which may limit its use in Area 15. The dissolved-iron concentrations range from 0.003 to 25 mg/L. Water from coal mines or water that has drained through beds of black shale is most likely to have high concentrations of iron (Price and others, 1962). Locally, water from all formations in the area may contain concentrations of iron in excess of the 0.3 mg/L recommended limit for water for domestic use (U.S. Environmental Protection Agency, 1977).

Hardness is also frequently troublesome in ground water from Area 15. Hardness in water from rocks of Pennsylvanian age ranges from 5 to 790 mg/L. Hardness shows little relation to depth or location of wells.

Most waters from rocks of Pennsylvanian age in Area 15 can be classified as calcium magnesium bicarbonate, sodium bicarbonate or sodium sulfate types. None of these types is unique to either the Breathitt or Lee Formation. All types occur in each formation. The principal factors that govern the chemical quality of ground water are rock type and the amount of time water has been in contact with the rocks. Water from deep wells tends to be more highly mineralized than water from shallow wells or springs, because of the greater time the water has been in contact with rocks. Water from wells near hilltops is usually less mineralized than water from wells in valleys. In places where coal and black shale are relatively close to the surface, water in these rocks tends to have pH values less than 7.0 units.



EXPLANATION

Pennsylvanian

- **Breathitt Formation** — Siltstone, sandstone, clay shale, coal underclay and some limestone
- **Lee Formation** — Sandstone, conglomerate, shale, coal and underclay

Pre-Pennsylvanian

- Shale, limestone, sandstone, and siltstone

Thrust Fault — Sawteeth on upper plate

Faults — Arrows indicate relative movement: U upthrown side; D downthrown side

Figure 8.0-1 Generalized geology

Table 8.0-1 Summary of analyses of ground water in Area 15.

Breathitt Formation

Constituent	Range	Median	Number of samples
Iron(Fe)	0.02 - 25	1.0	98
Calcium(Ca)	2.3 - 86	26	15
Manganese(Mg)	0.5 - 38	6.4	15
Sodium(Na)	1.2 - 312	22	15
Potassium(K)	0.3 - 6.4	2.2	14
Bicarbonate(HCO_3)	0 - 455	127	99
Sulfate(SO_4)	0 - 237	9.7	98
Chloride(C1)	0.5 - 220	4	120
Specific Conductance (micromhos per centimeter at 25° C)	17 - 1,410	215	98
Hardness as calcium carbonate ($CaCO_3$)	5 - 540	82	99
pH (Units)	3.8 - 9.7	6.9	95
Dissolved solids	16 - 798	199	11

Lee Formation

Constituent	Range	Median	Number of samples
Iron(Fe)	0.003 - 9.7	0.79	49
Calcium(Ca)	1 - 201	13	36
Manganese(Mg)	0.30 - 70	2.5	41
Sodium(Na)	0.4 - 1,520	1.8	38
Potassium(K)	0.5 - 19	4.6	38
Bicarbonate(HCO_3)	5 - 315	61	61
Sulfate(SO_4)	0 - 240	6.5	64
Chloride (Cl)	0 - 2,630	3	89
Specific Conductance (micromhos per centimeter at 25° C)	15 - 8,240	137	63
Hardness as calcium carbonate ($CaCO_3$)	5 - 790	44	63
pH (Units)	5.7 - 8.4	6.8	59
Dissolved solids	19 - 4,860	77	36

NAWDEX, WATSTORE, and OWDC Information

Water data are collected in coal areas by large number of organizations in response to a wide variety of missions and needs.

Within the U.S. Geological Survey there are three activities that help to identify and improve access to the vast amount of existing water data. These activities are:

(1) The National Water Data Exchange (NAWDEX), which indexes the water data available from over 400 organizations and serves as a central focal point to help those in need of water data to determine what information is available.

(2) The National Water Data Storage and Retrieval System (WATSTORE), which serves as the central repository of water data collected by the U. S. Geological Survey and which contains large volumes of data on the quantity and quality of both surface and ground waters.

(3) The Office of Water Data Coordination (OWDC), which coordinates Federal water-data acquisition activities and maintains a "Catalog of Information on Water Data." To assist in identifying available water-data activities in coal provinces of the United States, special indexes to the Catalog are being printed and made available to the public.

A more detailed explanation of these three activities are given in sections 9.2, 9.3, and 9.4.

NAWDEX Simplifies Access to Water Data

The National Water-Data Exchange (NAWDEX) is a nationwide program managed by the U.S. Geological Survey to assist users of water data or water-related data in identifying, locating, and acquiring needed data.

NAWDEX is a national confederation of water-oriented organizations working together to make their data more readily accessible and to facilitate a more efficient exchange of water data.

Services are available through a Program Office located at the U.S. Geological Survey's National Center in Reston, Virginia, and a nationwide network of Assistance Centers located in 45 states and Puerto Rico, which provide local and convenient access to NAWDEX facilities (fig. 9.2-1). A directory is available on request that provides names of organizations and persons to contact, addresses, telephone numbers, and office hours for each of these locations [Directory of Assistance Centers of the National Water Data Exchange (NAWDEX), U.S. Geological Survey Open-File Report 79-423 (revised)].

NAWDEX can assist any organization or individual in identifying and locating needed water data and referring the requester to the organization that retains the data required. To accomplish this service, NAWDEX maintains a computerized Master Water Data Index (fig. 9.2-2), which identifies sites for which water data are available, the type of data available for each site, and the organization retaining the data. A water Data Sources Directory (fig. 9.2-3) also is maintained that identifies organizations that are sources of water data and the locations within these organizations from which data may be obtained. In addition NAWDEX has direct access to some large water-data bases of its members and has reciprocal agreements for the exchange of services with others.

Charges for NAWDEX services are assessed at the option of the organization providing the requested data or data service. Search assistance services are provided free by NAWDEX to the greatest extent possible. Charges are assessed, however, for those requests requiring computer cost, extensive personnel time, duplicating services, or other costs encountered by NAWDEX in the course of providing services. In all cases, charges assessed by NAWDEX Assistance Centers will not exceed the direct costs incurred in responding to the data request. Estimates of cost are provided by NAWDEX upon request and in all cases where costs are anticipated to be substantial.

For additional information concerning the NAWDEX program or its services contact:

Program Office
National Water Data Exchange (NAWDEX)
U.S. Geological Survey
421 National Center
12201 Sunrise Valley Drive
Reston, VA 22092

Telephone: (703) 860-6031
FTS 928-6031

Hours: 7:45 - 4:15 Eastern Time

or

NAWDEX ASSISTANCE CENTER
KENTUCKY
U.S. Geological Survey
Water Resources Division
Room 572 - Federal Building
600 Federal Place
Louisville, KY 40202

Telephone: (502) 582-5241
FTS 352-5241

Hours: 8:00 - 4:45 Eastern Time

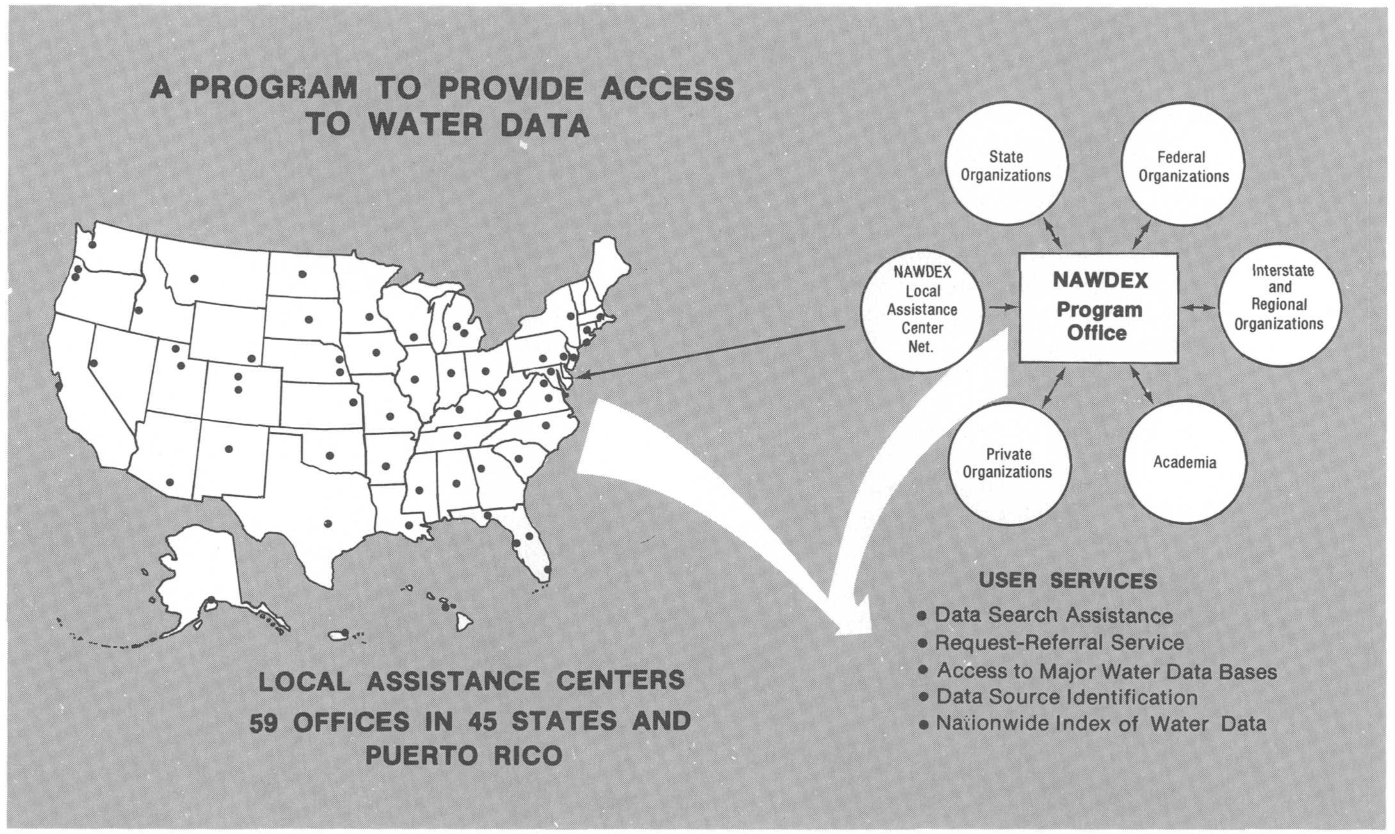


Figure 9.2-1 Access to water data.

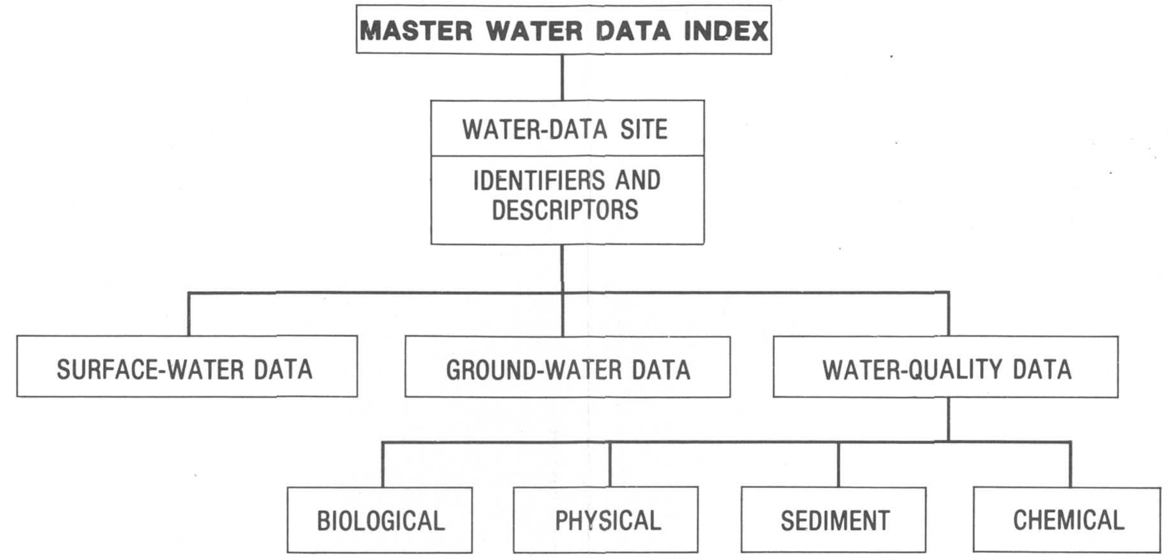


Figure 9.2-2 Master water-data index.

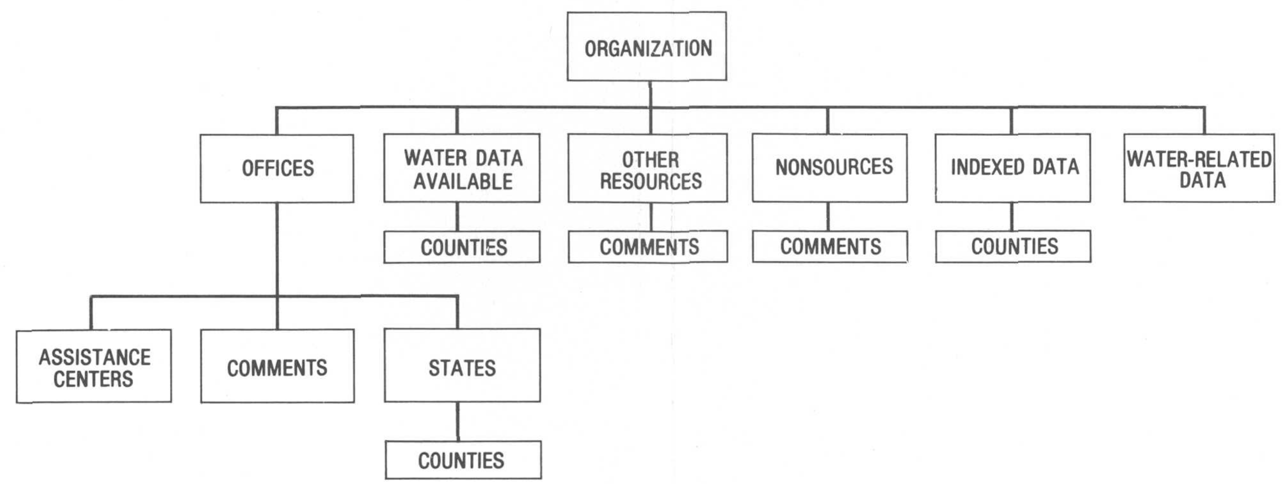


Figure 9.2-3 Water-data sources directory.

WATSTORE Automated Data System

The National Water Data Storage and Retrieval System (WATSTORE) of the U.S. Geological Survey provides computerized procedures and techniques for processing water data and provides effective and efficient management of data-releasing activities.

The National Water Data Storage and Retrieval System (WATSTORE) was established in November 1971 to computerize the U.S. Geological Survey's existing water-data system and to provide for more effective and efficient management of its data-releasing activities. The system is operated and maintained on the central computer facilities of the Survey at its National Center in Reston, Virginia. Data may be obtained from WATSTORE through the Water Resources Division's 46 district offices. General inquiries about WATSTORE may be directed to:

Chief Hydrologist
U.S. Geological Survey
437 National Center
Reston, VA 22092

or

U.S. Geological Survey
Water Resources Division
Room 572 - Federal Building
600 Federal Place
Louisville, KY 40202

The Geological Survey currently (1980) collects data at approximately 16,000 streamgaging stations, 1,000 lakes and reservoirs, 5,200 surface-water quality stations, 1,020 sediment stations, 30,000 water-level observation wells, and 12,500 ground-water quality wells. Each year many water-data collection sites are added and others are discontinued; thus, large amounts of diversified data, both current and historical, are amassed by the Survey's data-collection activities.

The WATSTORE system consists of several files in which data are grouped and stored by common characteristics and data-collection frequencies. The system is also designed to allow for the inclusion of additional data files as needed. Currently, files are maintained for the storage of: (1) surface-water, quality-of-water, and ground-water data measured on a daily or continuous basis; (2) annual peak values for streamflow stations; (3) chemical analyses for surface- and ground-water sites; (4) water parameters measured more frequently than daily; and (5) geologic and inventory data for ground-water sites. In addition, an index file of sites for which data are stored in the system is also maintained (fig. 9.3-1). A brief description of each file is as follows:

Station Header File: All sites for which data are stored in the Daily Values, Peak Flow, Water-Quality, and Unit Values files of WATSTORE are indexed in this file. It contains information pertinent to the identification, location, and physical description of nearly 220,000 sites.

Daily Values File: All water-data parameters measured or observed either on a daily or on a continuous basis and numerically reduced to daily values are stored in this file. Instantaneous measurements at fixed-time intervals, daily mean values, and statistics such as daily maximum and minimum values also may be stored. This file currently contains over 200 million daily values including data on streamflow, river stages, reservoir contents, water temperatures, specific-conductance, sediment concentrations, sediment discharges, and ground-water levels.

Peak Flow File: Annual maximum (peak) streamflow (discharge) and gage height (stage) values at surface-water sites comprise this file, which currently contains over 400,000 peak observations.

Water-Quality File: Results of over 1.4 million analyses of water samples that describe the chemical, physical, biological, and radiochemical characteristics of both surface and ground waters are contained in this file. These analyses contain data for 185 different constituents.

Unit Values File: Water parameters measured on a schedule more frequent than daily are stored in this file. Rainfall, stream discharge, and temperature data are examples of the types of data stored in the Unit Values File.

Ground-Water Site-Inventory File: This file is discussed above, but it is cross-referenced to the Water-Quality File and the Daily Values File. It contains inventory data about wells, springs, and other sources of ground water. The data included are site location and identification, geohydrologic characteristics, well-construction history, and one-time field measurements such as water temperature. The file is designed to accommodate 255 data elements and currently contains data for nearly 70,000 sites.

All data files of the WATSTORE system are maintained and managed on the central computer facilities of the Geological Survey at its National Center. However, data may be entered into or retrieved from WATSTORE at a number of locations that are part of a nationwide telecommunication network.

Remote Job Entry Sites: Almost all of the Water Resources Division's district offices are equipped with high-speed computer terminals for remote access to the WATSTORE system. These terminals allow each site to put data into or retrieve data from the system within several minutes to overnight, depending upon the priority placed on the request. The number of remote job entry sites is increased as the need arises.

Digital Transmission Sites: Digital recorders are used at many field locations to record values for parameters such as river stages, conductivity, water temperature, turbidity, wind direction, and chlorides. Data are recorded on 16-channel paper tape, which is removed from the recorder and transmitted over telephone lines to the receiver at Reston, Virginia. The data are recorded on magnetic tape for use on the central computer. Extensive testing of satellite data collection platforms indicates their feasibility for collecting real-time hydrologic data on a national scale. Battery-operated radios are used as the communication link to the satellite. About 200 data relay stations are being operated currently (1980).

Central Laboratory System: The Water Resources Division's two water-quality laboratories, located in Denver, Colorado, and Atlanta, Georgia, analyze more than 150,000 water samples per year. These laboratories are equipped to automatically perform chemical analyses ranging from determinations of simple inorganic compounds, such as chlorides, to complex organic compounds, such as pesticides. As each analysis is completed, the results are verified by laboratory personnel and transmitted via a computer terminal to the central computer facilities to be stored in the Water-Quality File of WATSTORE.

Water data are used in many ways by decision-makers for the management, development, and monitoring of our water resources. In addition to its data processing, storage, and retrieval capabilities, WATSTORE can provide a variety of useful products ranging from simple data tables to complex statistical analyses. A minimal fee, plus the actual computer cost incurred in producing a desired product, is charged to the requester.

Computer-Printed Tables: Users most often request data from WATSTORE in the form of tables printed by the computer. These tables may contain lists of actual data or condensed indexes that indicate the availability of data stored in the files. A variety of formats is available to display the many types of data.

Computer-Printed Graphs: Computer-printed graphs for the rapid analysis or display of data are another capability of WATSTORE. Computer programs are available to produce bar graphs (histograms), line graphs, frequency distribution curves, X-Y point plots, site-location map plots, and other similar items by means of line printers.

Statistical Analyses: WATSTORE interfaces with a proprietary statistical package (SAS) to provide extensive analyses of data such as regression analyses, the analysis of variance, transformations, and correlations.

Digital Plotting: WATSTORE also makes use of software systems that prepare data for digital plotting on peripheral offline plotters available at the central computer site. Plots that can be obtained include hydrographs, frequency distribution curves, X-Y point plots, contour plots, and three-dimensional plots.

Data in Machine-Readable Form: Data stored in WATSTORE can be obtained in machine-readable form for use on other computers or for use as input to user-written computer programs. These data are available in the standard storage format of the WATSTORE system or in the form of punched cards or card images on magnetic tape.

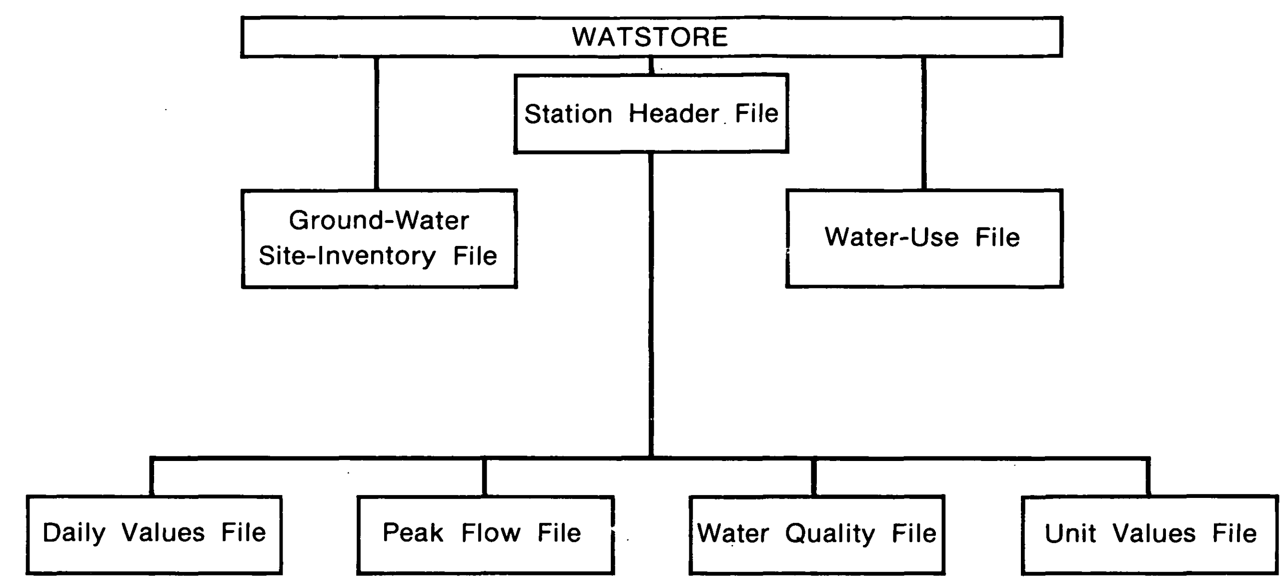


Figure 9.3-1 Index file stored data.

Water Data Indexed for Coal Provinces

A special index, "Index to Water-Data Activities in Coal Provinces of the United States," has been published by the U.S. Geological Survey's Office of Water Data Coordination (OWDC).

The "Index to Water-Data Activities in Coal Provinces of the United States" was prepared to assist those involved in developing, managing, and regulating the Nation's coal resources by providing information on the availability of water-resources data in the major coal provinces of the United States. It is derived from the "Catalog of Information on Water Data," which is a computerized information file about water-data acquisition activities in the United States, and its territories and possessions, with some international activities included.

This special index consists of five volumes (fig. 9.4-1): volume I, Eastern Coal province; volume II, Interior Coal province; volume III, Northern Great Plains and Rocky Mountain Coal provinces; volume IV, Gulf Coast Coal province; and volume V, Pacific Coast and Alaska Coal provinces. The information presented will aid the user in obtaining data for evaluating the effects of coal mining on water resources and in developing plans for meeting additional water-data needs. The report does not contain the actual data; rather, it provides information that will enable the user to determine if needed data are available.

Each volume of this special index consists of four parts: Part A, Streamflow and Stage Stations; Part B, Quality of Surface-Water Stations; Part C, Quality of Ground-Water Stations; and Part D, Areal Investigations and Miscellaneous Activities. Information given for each activity in Parts A-C includes: (1) the identification and location of the station, (2) the major types of data collected, (3) the frequency of data collection, (4) the form in which the data are stored, and (5) the agency or organization reporting the activity. Part D summarizes areal hydrologic investigations and water-data activities not included in the other parts of the index. The agencies that submitted the information, agency codes, and the number of activities reported by type are shown in a table.

Those who need additional information from the Catalog file or who need assistance in obtaining water data should contact the National Water Data Exchange (NAWDEX) (see section 9.2).

Further information on the index volumes and their availability may be obtained from:

U.S. Geological Survey
Water Resources Division
Room 572 - Federal Building
600 Federal Place
Louisville, KY 40202

Telephone: (502) 582-5241
FTS 352-5241

or

Office of Surface Mining
U.S. Department of the Interior
530 Gay St., Suite 500
Knoxville, TN 37902

Telephone: (615) 637-8060
FTS 852-0060

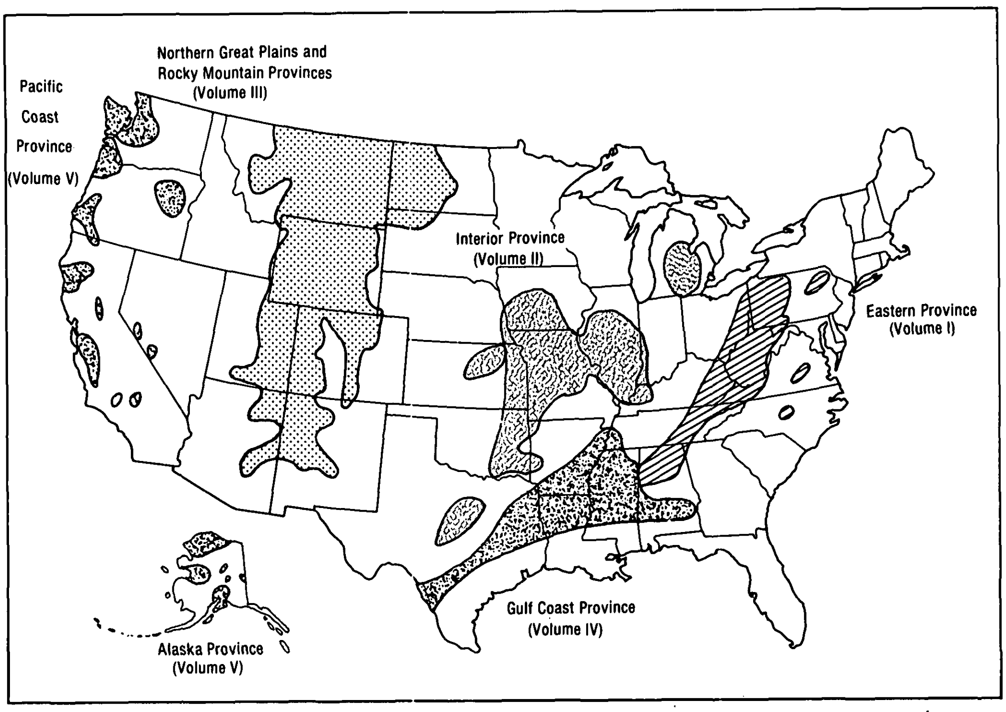


Figure 9.4-1 Index volumes and related provinces.

10.0 SUPPLEMENTAL INFORMATION FOR AREA 15

10.1 Index of Geologic Quadrangle Maps

BASE FROM U. S. GEOLOGICAL SURVEY
STATE BASE MAP, 1973

AGENTS FOR MAP SALES

Kentucky Geological Survey

311 Breckinridge Hall
University of Kentucky
Lexington, KY 40506

Kentucky Department of Commerce

Map Sales Office
133 Holmes Street
Frankfort, KY 40601

U.S. Geological Survey

Branch of Distribution
1200 South Eads Street
Arlington, VA 22202

SITE NO	STATION NUMBER	STATION NAME	DRAINAGE AREA mi^2	LAT	LONG	CON- TINUOUS RECORD	STREAM- FLOW BEGIN YEAR	STREAM- FLOW END YEAR	QUALITY BEGIN YEAR	QUALITY END YEAR	SUSPENDED SEDIMENT DATA COLLECTED
500	03400000	Poor Fork at Harlan Letcher City Line,Ky	51.7	370000	0825435	NO	1940	1943	-	-	NO
501	03400480	Looney Creek near Clutts, Ky	-	365817	0825806	NO	1979	-	1979	-	YES
502	03400500	Poor Fork at Cumberland,Ky	82.3	365826	0825935	YES	1940	-	1979	-	YES
503	03400585	Poor Fork at Rosspoint, Ky	142	365304	0831719	NO	1972	1977	-	-	NO
504	03400650	Clover Fork near Shields, Ky	-	365348	0830825	NO	1979	-	1979	-	YES
505	03400700	Clover Fork at Evarts,Ky	82.4	365156	0831137	NO	1954	-	1960	1972	NO
506	03400735	Martins Fork near Middlesboro,Ky	-	364050	0832753	NO	1979	1979	1979	1979	YES
507	03400796	Crane Creek near Smith, Ky	1.63	364451	0831550	NO	1976	1977	-	-	NO
508	03400798	Martins Fork Lake near Smith,Ky	55.7	364508	0831531	YES	1979	-	1979	-	NO
509	03400800	Martins Fork near Smith,Ky	55.8	364457	0831452	YES	1971	-	1970	-	YES
510	03400985	Martins Fork at Harlan,Ky	116	364957	0831936	NO	1960	1960	-	-	NO
511	03400990	Clover Fork at Harlan,Ky	222	365050	0831931	NO	1978	-	1978	-	YES
512	03401000	Cumberland River near Harlan,Ky	374	365048	0832121	YES	1940	-	1949	-	YES
513	03401040	Pearl Branch at Wallins Creek,Ky	1.4	365007	0832443	NO	1976	-	-	-	NO
514	03401250	Puckett Creek near Pathfork,Ky	-	364519	0832745	NO	1979	-	1979	-	YES
515	03401290	Brownice Creek near Oaks,Ky	-	364318	0833332	NO	1979	-	1979	-	YES
516	03401400	Left Yellow Creek at Middlesboro,Ky	10.8	363630	0834213	NO	1959	1966	1964	1965	NO
517	03401406	Yellow Creek at Middlesboro,Ky (upstream from sewage treatment plant)	-	363727	0834233	NO	-	-	1965	1965	NO
518	03401407	Yellow Creek at Middlesboro,Ky	-	363739	0834227	NO	-	-	1965	1965	NO
519	03401430	Bennetts Fork near Middlesboro,Ky	-	363624	0834447	NO	-	-	1964	1965	NO
520	03401500	Yellow Creek Bypass Middlesboro,Ky	35.3	363752	0834345	NO	1940	-	-	-	NO
521	03402000	Yellow Creek near Middlesboro,Ky	60.6	364005	0834119	YES	1940	-	1977	-	YES
522	03402010	Shilalah Creek near Middlesboro,Ky	-	363857	0833419	NO	1979	1979	1979	1979	YES
523	03402230	Yellow Creek near Ferndale,Ky	99.5	364235	0833840	NO	1972	-	-	-	NO
524	03402400	Clear Creek near Pineville,Ky	-	364342	0834429	NO	1979	-	1979	-	YES
525	03402450	Little Clear Creek near Pineville,Ky	-	364317	0834327	NO	1979	-	1979	-	YES
526	03402480	Clear Creek at Clear Creek Springs,Ky	-	364340	0834842	NO	1975	-	-	-	NO
527	03402490	Straight Creek at Pineville,Ky	-	364557	0834123	NO	1960	1965	1960	1965	NO
528	03402500	Cumberland River at Pineville,Ky	676	364448	0834134	NO	1929	1931	-	-	NO
529	03402800	Straight Creek near Kettle Island,Ky	-	364706	0833609	NO	1979	-	1979	-	YES
530	03402830	Left Fork Straight Creek near Cary,Ky	-	364754	0833936	NO	1979	-	1979	-	YES
531	03402850	Left Fork Straight Creek at Cary,Ky	33.7	364729	0833057	NO	1958	1976	-	-	NO
532	03402852	Straight Creek at Straight Creek,Ky	89.8	364624	0834012	NO	1953	1967	-	-	NO
533	03402990	Cumberland River below Pineville,Ky	806	364749	0834539	NO	1943	-	-	-	NO
534	03403000	Cumberland River near Pineville,Ky	809	364848	0834558	YES	1938	-	1979	-	YES
535	03403100	Middle Fork Stinking Creek near Walker,Ky		365314	0834225	NO	1979	-	1979	-	YES
536	03403150	Road Fork Creek near Barnyard,Ky	-	365402	0834441	NO	1979	-	1979	-	YES
537	03403180	Stinking Creek at Dewitt,Ky	49.1	365235	0834417	NO	1961	1975	-	-	NO
538	03403255	Road Fork at Dewitt,Ky	25.2	365238	0834417	NO	1961	1975	-	-	NO
539	03403500	Cumberland River at Barbourville,Ky	960	365145	0835313	YES	1922	-	1978	-	YES
540	03403530	Richland Creek near Barbourville,Ky	27.7	-	0835420	NO	1961	1976	-	-	NO
541	03403538	Little Richland Creek near Hinkle,Ky	11.6	365549	0834954	NO	1973	-	-	-	NO
542	03403550	Little Indian Creek near Permon,Ky	-	364940	0835821	NO	1979	-	1979	-	YES
543	03403590	Fourmile Branch near Bryants Store,Ky	-	364648	0835605	NO	1979	-	1979	-	YES
544	03403697	Clear Fork at Highway 90 at Anthras,Tn	-	363246	0835936	NO	1979	-	1979	-	YES
545	03403710	Tackett Creek at Anthras,Tn	-	363225	0840020	NO	1979	-	1979	-	YES
546	03403715	Stinking Creek near Newcomb,Tn	-	363026	0840836	NO	1979	-	1979	-	YES
547	03403720	Lick Creek at Haversham,Tn	-	363001	0840432	NO	1979	-	1979	-	YES
548	03403740	Hickory Creek at Morley,Tn	-	363300	0840242	NO	1979	-	1979	-	YES
548A	03403750	Clear Creek near Jellico,Tn	240	363513	0840516	NO	1934	1945	-	-	NO
549	03403770	Elm Creek at Newcomb,Tn	-	363310	0840953	NO	1979	-	1979	-	YES
549A	03403800	Elk Creek at Jellico,Tn	51.1	363459	0840821	NO	1940	1958	-	-	NO
550	03403900	Clear Fork at Sukey Siler Hollow, Saxton,Ky	-	363730	0840638	NO	-	-	1965	1965	NO
551	03403910	Clear Fork at Saxton,Ky	331	363802	0840642	YES	1968	-	1970	-	YES

SITE NO	STATION NUMBER	STATION NAME	DRAINAGE AREA mi^2	LAT	LONG	CON-TINUOUS RECORD	STREAM-FLOW BEGIN YEAR	STREAM-FLOW END YEAR	QUALITY BEGIN YEAR	QUALITY END YEAR	SUSPENDED SEDIMENT DATA COLLECTED
552	03404000	Cumberland River at Williamsburg,Ky	1607	364438	0840930	YES	1950	-	1948	-	YES
553	03404100	Watts Creek near Wofford,Ky	-	364708	0840807	NO	1979	-	1979	-	YES
554	03404150	Jellico Creek at Ketchen,Tn	-	363413	0841901	NO	1979	-	1979	-	YES
555	03404200	Jellico Creek near Williamsburg,Ky	103	364056	0841520	NO	1953	-	1979	-	YES
556	03404350	Marsh Creek near Duckrun,Ky	-	364255	0842118	NO	1979	-	1979	-	YES
557	03404390	Marsh Creek near Whitley City,Ky	-	364438	0842216	NO	1960	-	-	-	NO
558	03404500	Cumberland River at Cumberland Falls,Ky	1977	365014	0842036	YES	1907	-	1948	-	NO
559	03404600	Lake Cumberland at Bark Camp,Ky	2025	365640	0841744	NO	1965	1980	-	-	NO
560	03404650	Tributary to Laurel River near Lesbas,Ky	-	370334	0835956	NO	1979	-	1979	-	YES
561	03404688	Laurel River near Lily,Ky	52.3	370230	0840254	NO	1975	-	-	-	NO
562	03404800	Tributary to Laurel River near Pine-grove,Ky	-	370347	0840447	NO	1979	-	1979	-	YES
563	03404810	Little Laurel River near Lily,Ky	42.4	370103	0840641	NO	1975	-	-	-	NO
564	03404820	Laurel River at Municipal Dam near Corbin,Ky	140	365813	0870711	YES	1973	-	1976	-	NO
565	03404867	Gozey Hollow near Corbin,Ky	.31	365641	0835942	NO	1975	-	-	-	NO
566	03404900	Lynn Camp Creek at Corbin,Ky	53.8	365705	0840537	YES	1973	-	1972	-	NO
567	03405000	Laurel River at Corbin,Ky	201	365809	0840736	YES	1910	1973	1949	1973	NO
568	03405500	Laurel River near Vox,Ky	245	365705	0841330	NO	1929	1931	-	-	NO
569	03405550	Craig Creek near Hightop,Ky	-	370108	0841049	NO	1979	-	1979	-	YES
570	03405600	South Fork Rockcastle River near Crawford,Ky	-	371217	0835642	NO	1979	-	1979	-	YES
571	03405700	South Fork Rockcastle River near Peoples,Ky	95.1	371605	0840302	NO	1961	1972	1961	1972	NO

SITE NO	STATION NUMBER	STATION NAME	DRAINAGE AREA mi2	LAT	LONG	CON-TINUOUS RECORD	STREAM-FLOW BEGIN YEAR	STREAM-FLOW END YEAR	QUALITY BEGIN YEAR	QUALITY END YEAR	SUSPENDED SEDIMENT DATA COLLECTED
572	03405730	Pond Creek near Peoples,Ky	-	371708	0840313	NO	1979	-	1979	-	YES
573	03405780	Laurel Fork near McKee,Ky	-	372247	0835921	NO	1979	-	1979	-	YES
574	03405800	Indian Creek near Hurley,Ky	-	372445	0840215	NO	1979	-	1979	-	YES
575	03405818	Middle Fork Rockcastle River near Parrot,Ky	79.0	372036	0840446	NO	1975	-	-	-	NO
576	03405842	Horse Lick Creek near Lamero,Ky	61.7	371912	0840818	NO	1975	-	-	-	NO
577	03405854	Big Hurricane Branch at Conway,Ky	1.91	372751	0842008	NO	1975	-	-	-	NO
578	03405868	Roundstone Creek at Hummel,Ky	52.9	372318	0841739	NO	1975	-	-	-	NO
579	03405900	Roundstone Creek at Livingstone,Ky	144	371755	0841250	NO	1953	1976	1960	1972	NO
580	03406000	Wood Creek near London,Ky	3.89	370940	0840643	YES	1953	1971	-	-	NO
581	03406330	Skegg Creek near Billows,Ky	55.9	371348	0841637	NO	1975	-	-	-	NO
582	03406500	Rockcastle River at Billows,Ky	604	371016	0841746	YES	1936	-	1948	-	YES
583	03407000	Rockcastle River at Rockcastle Springs,Ky	745	370035	0841855	NO	1921	1931	-	-	NO

BELL COUNTY KENTUCKY

STATION NUMBER	LOCAL IDENTIFIER	SITE TYPE	GEOLOGIC UNIT	DEPTH OF WELL	NUMBER OF ANALYSIS	BEGINING YEAR	ENDING YEAR
363539083443301	HUBERT BARNWELL	SPRING	324BRTT	.	1	1964	1964
363543083455801	PREMIER SPR. AMER. ASSOC.	SPRING		.	1	1964	1964
363628083404701	MIDDLESBORO TANNERY CO.	SPRING	327LEE	.	2	1953	1958
363652083462001	WILLIAM W. HILL	SPRING		.	1	1964	1964
363715083420801	STELLA GOINS	SPRING	324BRTT	.	1	1965	1965
363729083431601	GRACE RAINES	SPRING	324BRTT	.	1	1964	1964
363734083441501	JACK RAINES	SPRING	324BRTT	.	1	1964	1964
363805083425501	LEE HATTFIELD	SPRING	324BRTT	.	1	1964	1964
363812083432001	J.W. OWEN	SPRING	324BRTT	.	1	1964	1964
363957083410901	AMERICAN ASSOC.	SPRING	324BRTT	.	1	1964	1964
364436083422501	COMMONWEALTH OF KY	SPRING	327LEE	.	1	1960	1960
364711083355301	ADVENTURE COAL CO.	SPRING		.	1	1953	1953
364941083313001	RITTER LUMBER CO.	SPRING		.	1	1958	1958
363527083460501	ROBERT CROWLEY & WILLS CAMP	WELL		74.00	1	1964	1964
363537083433801	SUDIE HARRIS	WELL	324BRTT	109.00	1	1964	1964
363537083521401	CLEAR FORK COAL CO.	WELL	324BRTT	600.00	1	1953	1953
363539083441201	LEONARD GORDON	WELL	324BRTT	10.00	1	1964	1964
363541083432301	E.H. SOWDERS	WELL	324BRTT	225.00	1	1964	1964
363542083443001	EVERETT STARETT	WELL	324BRTT	84.00	1	1964	1964
363543083431801	ERVIN BAKER	WELL	324BRTT	.	1	1964	1964
363543083432101	PARKER RD. WELL	WELL	324BRTT	.	1	1965	1965
363544083440701	O. POORE	WELL	324BRTT	74.01	1	1964	1964
363545083425501	MILTON W. REESE	WELL		16.00	1	1964	1964
363545083431401	ED NUNN	WELL		37.00	1	1965	1965
363547083415301	RILEP ROOP	WELL	324BRTT	98.00	1	1965	1965
363548083442201	R.C. TENNYSON	WELL	324BRTT	10.00	1	1964	1964
363552083442901	JAMES GARRETT	WELL	324BRTT	41.00	1	1964	1964
363552083444901	CLIFTON LEACH	WELL		72.00	1	1964	1964
363554083443601	J. GOOD	WELL	324BRTT	47.01	1	1964	1964
363554083443602	J. GOOD	WELL	324BRTT	90.01	1	1964	1964
363556083442201	ADA SMIDDY	WELL	324BRTT	23.00	1	1964	1964
363558083450301	JOE AYRES	WELL	327LEE	1500.00	1	1964	1964
363600083442101	BILL SHUMATE	WELL	324BRTT	92.00	1	1964	1964
363603083450201	JOHN SOUTHERN	WELL		250.00	1	1964	1964
363604083425001	DR. FRED B. WELLER	WELL	324BRTT	182.00	1	1965	1965
363604083444701	BOSS MONDAY	WELL	111AMOT	15.00	1	1964	1964
363604083452001	OTIS CHUMLEY	WELL		68.00	2	1964	1964
363607083421401	MATT WEBB	WELL		22.00	1	1964	1964
363608083412701	J.F. SCHNEIDER & SON, INC.	WELL	327LEE	1900.00	3	1952	1965
363608083430701	UNKNOWN	WELL	111ALVM	26.01	1	1965	1965
363609083421101	F. LANGFORD	WELL	324BRTT	18.01	1	1964	1964
363614083492801	MONARCH MINING CO.	WELL		.	1	1964	1964
363621083430001	E. BUSH	WELL	324BRTT	180.01	1	1966	1966
363622083443601	KATHERINE HEATH	WELL	111AMOT	12.00	1	1964	1964
363635083435201	MIDDLESBORO TANNERY CO.	WELL	111ALVM	20.01	1	1965	1965
363635083452301	RUFUS BARNETT	WELL		18.00	1	1964	1964

BELL COUNTY KENTUCKY

STATION NUMBER	LOCAL IDENTIFIER	SITE TYPE	GEOLOGIC UNIT	DEPTH OF WELL	NUMBER OF ANALYSIS	BEGINING YEAR	ENDING YEAR
363638083412301	V.R. JOHNSON	WELL	324BRTT	63.00	1	1965	1965
363638083481301	MIKE WARD	WELL		22.00	1	1964	1964
363639083424801	CITY OF MIDDLESBORO, KY	WELL		1600.00	1	1964	1964
363643083450801	EDGAR TAYLOR	WELL	111AMOT	14.00	1	1964	1964
363644083451701	GORDON TURNER	WELL		53.00	1	1964	1964
363645083452301	ROBERT SMITH	WELL	111AMOT	15.00	1	1964	1964
363646083435101	UNKNOWN	WELL	111ALVM	15.01	1	1965	1965
363646083465701	BELL COUNTY SCHOOLS	WELL	324BRTT	71.00	1	1964	1964
363646083470501	BUD SWANNICON	WELL		23.00	1	1964	1964
363646083472301	UNKNOWN	WELL		38.00	1	1964	1964
363649083461701	QUILL VANOVER	WELL		.	1	1964	1964
363649083495701	UNION SCHOOL	WELL	324BRTT	94.00	1	1965	1965
363650083453901	C.B. JOHNSON	WELL	111AMOT	11.00	1	1964	1964
363651083453701	LUTHER SULFREDGE	WELL		23.00	1	1964	1964
363651083495001	GARMEDA	WELL	324BRTT	125.00	1	1964	1964
363652083463901	J.M. HUBER CORP.	WELL		36.00	1	1964	1964
363654083474401	MARY BURTON	WELL		18.00	1	1964	1964
363655083412501	K. STEPHENSON	WELL	324BRTT	.	1	1964	1964
363658083422601	PERMA PIPE CO.	WELL	324BRTT	190.00	1	1961	1961
363702083452501	CLAIR HUNLEY	WELL		20.00	1	1964	1964
363708083414901	MYRTLE MASINGO	WELL	324BRTT	36.00	2	1964	1964
363714083435001	WALTER FARMER	WELL		55.00	1	1964	1964
363714083454201	CECIL FRY	WELL		44.00	1	1964	1964
363715083421301	MAYNARD GOINS	WELL	324BRTT	65.00	1	1965	1965
363718083421301	OSCAR B. MIRACLE	WELL	324BRTT	22.00	1	1965	1965
363719083451501	HUGH GORDON	WELL		41.00	1	1964	1964
363722083421301	OTTO GUILLEN	WELL	324BRTT	50.00	1	1965	1965
363724083453601	GILBERT MARTIN	WELL		14.00	1	1964	1964
363725083451101	EARL OVERTON	WELL		14.00	1	1964	1964
363726083434501	MIRL COLLINGSWORTH	WELL	324BRTT	60.00	1	1964	1964
363727083435101	ALEXANDER OSBORNE	WELL	324BRTT	230.00	1	1964	1964
363730083423501	MID. TANNERY	WELL	327LEE	940.00	16	1964	1980
363731083420501	BILL BROOKS	WELL		27.00	1	1965	1965
363734083431501	KENNETH ELLISON	WELL		134.00	1	1964	1964
363734083452401	JUNIOR GORDON	WELL		27.00	1	1964	1964
363735083440701	BOB PAVIS	WELL	324BRTT	58.00	1	1964	1964
363736083432001	MOSE GODSEY	WELL	324BRTT	68.00	1	1964	1964
363741083432401	EARNEST RAINES	WELL	324BRTT	42.00	1	1964	1964
363743083434801	ZANE RAINES	WELL	324BRTT	25.00	1	1964	1964
363752083421501	MS. BANGO	WELL	324BRTT	287.00	1	1964	1964
363753083435501	JIM HARVILLE	WELL	324BRTT	64.00	1	1964	1964
363755083435101	DEXTER DILLMAN	WELL	324BRTT	124.00	1	1964	1964
363800083421301	SHARPS COURT	WELL	324BRTT	133.00	1	1964	1964
363801083425401	SARAH RAMSEY	WELL	324BRTT	96.00	2	1964	1964
363802083424401	MINNIE L. JOHNSON	WELL		83.00	1	1964	1964
363803083451601	MS. RUTH MELTON	WELL		29.00	1	1964	1964
363804083422301	MS. J.B. VANBEUER	WELL	324BRTT	15.00	1	1964	1964
363808083421901	ROY JANEWAY	WELL	324BRTT	109.00	1	1964	1964
363809083433301	FRED MAXWELL	WELL	324BRTT	14.00	1	1964	1964
363810083401001	JOB CORPS	WELL	327LEE	450.00	1	1967	1967
363818083415801	HOWARD MC GEORGE	WELL	324BRTT	137.00	2	1964	1964
363818083424901	MCKINLEY SMITH	WELL	324BRTT	65.00	1	1964	1964
363819083422401	DAMON HELTON	WELL	324BRTT	39.00	1	1964	1964
363820083424201	FRANCIS HELTON	WELL	324BRTT	10.00	1	1964	1964
363824083424201	CAL SMITH	WELL	324BRTT	9.00	1	1964	1964
363825083421101	HIGHWAY OIL CO.	WELL	324BRTT	87.00	1	1964	1964
363829083420801	AUSTIN REDMAN	WELL	324BRTT	96.00	1	1964	1964
363830083421101	AUSTIN REDMAN	WELL	324BRTT	85.00	1	1964	1964
363831083420901	A.REDMAN	WELL	324BRTT	90.01	2	1964	1965
363832083420401	OTTO SAMS	WELL	324BRTT	.	1	1964	1964
363833083422001	MILLETT HARDWOOD, CO.	WELL	324BRTT	130.00	1	1964	1964
363840083420001	E.W. KOONTS	WELL	324BRTT	106.00	1	1964	1964
363840083442101	AMERICAN ASSOC.	WELL	327LEE	1500.00	1	1964	1964
364005083322501	HENSLEY FLATS TW NO.2	WELL		.	1	1974	1974
364010083311501	JOB CORPS	WELL	327LEE	450.00	5	1967	1975
364013083311001	HENSLEY FLATS TW NO.1	WELL		.	1	1974	1974
364024083410301	WARD CHAPELL SCHOOL	WELL	324BRTT	111.00	1	1964	1964
364234083383801	J.L. ROBINS	WELL	327LEE	46.00	1	1954	1954
364326083383101	TVA PINEVILLE, KY.	WELL	327LEE	92.00	1	1965	1965
364420083441901	COMMONWEALTH OF KY	WELL	327LEE	.	1	1960	1960
364425083445501	COMMONWEALTH OF KY	WELL	327LEE	.	1	1960	1960
364435083422701	COMMONWEALTH OF KY	WELL	327LEE	.	1	1960	1960
364523083413501	PINEVILLE WATER CO.	WELL	111AMOT	110.00	1	1958	1958
364546083422601	PINEVILLE HOSPITAL	WELL	324BRTT	204.00	1	1964	1964
364547083422601	PINEVILLE HOSPITAL	WELL	324BRTT	138.00	1	1964	1964
364619083461601	MS. ETHYLE TINSLEY	WELL	324BRTT	36.00	1	1954	1954
364723083443001	LONE JACK COMMUNITY	WELL		240.00	1	1964	1964
364725083443301	BELL CO. BD OF ED.	WELL	324BRTT	125.00	1	1964	1964
364804083303401	KY CARDINAL CO.	WELL	324BRTT	260.00	1	1953	1953

HARLAN COUNTY KENTUCKY

STATION NUMBER	LOCAL IDENTIFIER	SITE TYPE	GEOLOGIC UNIT	DEPTH OF WELL	NUMBER OF ANALYSIS	BEGINING YEAR	ENDI YEA
364419083254001	BLACK STAR COAL CORP.	WELL	324BRTT	250.00	1	1953	1953
364747083181801	W. SIMONTON	WELL	324BRTT	200.00	2	1953	1958
365047083083201	PEABODY COAL CO.	WELL	324BRTT	266.00	1	1953	1953
365100083173401	CLOVER FORK COAL CO.	WELL	320PSLV	.	2	1953	1958
365106083092201	PEABODY COAL CO.	WELL	324BRTT	229.00	1	1953	1953
365147083191501	CHAPPELL DAIRY	WELL	327LEE	500.00	2	1953	1958
365220083261201	JORDAN SAYLOR	WELL	324BRTT	43.00	1	1954	1954
365301083011301	O. SAYLOR	WELL	324BRTT	40.00	1	1954	1954
365733082564501	UNKNOWN	WELL	320PSLV	.	1	1951	1951
365738082565701	INTERNATIONAL HARVESTER	WELL	320PSLV	.	1	1953	1953
365740082565501	MAGGARD "B"	WELL		.	3	1976	1977
365742083034001	H. MORRIS	WELL	327LEE	56.00	1	1954	1954
365800082563501	WISC "B" 2	WELL		.	2	1976	1976

JACKSON COUNTY KENTUCKY

STATION NUMBER	LOCAL IDENTIFIER	SITE TYPE	GEOLOGIC UNIT	DEPTH OF WELL	NUMBER OF ANALYSIS	BEGINING YEAR	ENDI YEA
372043083541801	L. REYNOLDS	WELL	324BRTT	60.00	1	1954	1954

KNOX COUNTY KENTUCKY

STATION NUMBER	LOCAL IDENTIFIER	SITE TYPE	GEOLOGIC UNIT	DEPTH OF WELL	NUMBER OF ANALYSIS	BEGINING YEAR	ENDI YEAR
365137083552001	KY. DEPT. OF HIGHWAYS	SPRING	324BRTT	.	1	1954	1954
364551083500801	MS. A.B. CULTON	WELL	324BRTT	200.00	1	1964	1964
365048083470101	KENNETH PATERSON	WELL	327LEE	71.00	1	1954	1954
365152084010801	CLYDE MCGEE	WELL	327LEE	59.00	1	1954	1954
365337083422301	JOHN BINGHAM	WELL	111ALVM	18.00	1	1954	1954
365653083592101	S.A. PARKER	WELL	324BRTT	185.00	1	1954	1954
370014083525901	C.F. HELTON	WELL	324BRTT	60.00	1	1954	1954

LAUREL COUNTY KENTUCKY

STATION NUMBER	LOCAL IDENTIFIER	SITE TYPE	GEOLOGIC UNIT	DEPTH OF WELL	NUMBER OF ANALYSIS	BEGINING YEAR	ENDING YEAR
365947084042901	ROTHWELL HUFF	WELL	327LEE	224.00	1	1954	1954
370017084043101	C.C. ADAMS	WELL	327LEE	111.00	1	1954	1954
370131084141601	LOUIS MORGAN	WELL	327LEE	49.00	1	1954	1954
370455083571001	B.F. CREECH	WELL	324BRTT	58.00	1	1954	1954
370502083582701	HERSCHEL HENDRICKS	WELL	324BRTT	200.00	1	1954	1954
370530084030101	C. C. FELTNER	WELL	327LEE	150.00	1	1965	1965
370757084045001	J.R. HALE	WELL	327LEE	370.00	1	1965	1965

LETCHER COUNTY KENTUCKY

STATION NUMBER	LOCAL IDENTIFIER	SITE TYPE	GEOLOGIC UNIT	DEPTH OF WELL	NUMBER OF ANALYSIS	BEGINING YEAR	ENDING YEAR
370106082522101	M. WHITSON	WELL	324BRTT	93.00	1	1954	1954
370120082473301	A. MORGAN	WELL	324BRTT	18.00	1	1960	1960
370206082480901	C. COLLIER	WELL	111AMOT	12.00	1	1954	1954
370208082510401	H. BLAIR	WELL	324BRTT	120.00	1	1960	1960
370218082504701	C. SMITH	WELL	324BRTT	48.10	1	1960	1960
370222082504201	J. CRAIGER	WELL	324BRTT	16.50	1	1960	1960
370229082475401	B. BOGGS	WELL	324BRTT	51.00	2	1960	1962
370229082475402	B. BOGGS	WELL	111ALVM	12.00	1	1960	1960
370232082460401	C. CHURCH	WELL	111AMOT	10.00	1	1960	1960
370319082485201	N. SCOTT	WELL	324BRTT	32.50	1	1960	1960
370338082481601	G. ISON	WELL	327LEE	28.00	1	1960	1960
370339082480901	P. BOGGS	WELL	324BRTT	6.00	1	1960	1960
370350082475001	L. COLLINS	WELL	327LEE	96.00	1	1960	1960
370404082460401	J. MAGGARD	WELL	111AMOT	9.50	1	1960	1960
370421082483701	W. CRAFT	WELL	327LEE	50.40	1	1960	1960

MCCREARY COUNTY KENTUCKY

STATION NUMBER	LOCAL IDENTIFIER	SITE TYPE	GEOLOGIC UNIT	DEPTH OF WELL	NUMBER OF ANALYSIS	BEGINING YEAR	ENDING YEAR
365127084232401	J.E.PATRICK	WELL	327LEE	51.00	1	1954	1954

PULASKI COUNTY KENTUCKY

STATION NUMBER	LOCAL IDENTIFIER	SITE TYPE	GEOLOGIC UNIT	DEPTH OF WELL	NUMBER OF ANALYSIS	BEGINING YEAR	ENDING YEAR
370647084200801	W.H. WHITAKER	WELL	332CSTR	121.00	1	1955	1955

ROCKCASTLE COUNTY KENTUCKY

STATION NUMBER	LOCAL IDENTIFIER	SITE TYPE	GEOLOGIC UNIT	DEPTH OF WELL	NUMBER OF ANALYSIS	BEGINING YEAR	ENDING YEAR
371732084212001	J.E. CALHOUN	WELL	333SGVV	46.00	1	1954	1954
372028084114101	J.W. RUPPE	WELL	327LEE	71.00	1	1954	1954
372218084160401	GEORGE W. BAKER	WELL	338WVRL	48.00	1	1954	1954
372317084194601	RENFRO VALLEY ENT.	WELL	338WVRL	85.00	1	1954	1954
372454084113101	W.M. STEWARD	WELL	338OSGE	.	1	1954	1954
372756084113501	J.L. PHILLIPS	WELL	327LEE	50.00	1	1954	1954

WHITLEY COUNTY KENTUCKY

STATION NUMBER	LOCAL IDENTIFIER	SITE TYPE	GEOLOGIC UNIT	DEPTH OF WELL	NUMBER OF ANALYSIS	BEGINING YEAR	ENDING YEAR
364202084120101	LAJOK CORP-HARVARD UNIVERSITY	WELL	327LEE	.	1	1967	1967
364444084011501	G.C. LAWSON	WELL	327LEE	125.00	1	1954	1954
364617084104201	D. ROSS #3, O. WATSON	WELL	327LEE	.	1	1967	1967
364727084005801	J.W. HILL	WELL	324BRTT	35.00	1	1955	1955
364902084115201	W.M. FUSON	WELL	327LEE	101.00	1	1955	1955
365513084051901	CITIZEN ICE FUEL CO.	WELL	327LEE	158.00	2	1952	1958
365525084132001	L.S. HENSLEY	WELL	327LEE	79.00	1	1954	1954

11.0 LIST OF REFERENCES

Bower, David E., and Jackson, William H.,1981, Drainage areas of streams at selected locations in Kentucky: U.S. Geological Survey Open-file report 81-61, 118 p.

Carter, James P., and Jones, Albert R., 1969, Inventory and classification of streams in the upper Cumberland River drainage, Kentucky Fisheries Bulletin No. 52, 70 p.

Currens, J. C., and Smith, G. E., 1977, Coal production in Kentucky, 1790-1975: Kentucky Geological Survey Information Circular 23, 66 p.

Division of Water Resources, 1979, Rainfall frequency values for Kentucky: Commonwealth of Kentucky, Department of National Resources and Environmental Protection, Engineering Memorandum No. 2, 37 p.

Dyer, K. L., and Curtis, W.R., 1977. Effects of strip mining on water quality in small streams in eastern Kentucky, 1967-1975: U.S. Department of Agriculture, Forest Service research paper NE-372, 13 p.

Englund, K.J., and Roen, J.B., 1962, Origin of the Middlesboro Basin, Kentucky: U.S. Geological Survey Professional Paper 450-E, p. E20-E22.

Faust, R. J., Banfield, G. R., and Willinger, G. A., 1980, A Compilation of ground water quality data for Kentucky: U.S. Geological Survey Open-File Report 80-685, 963 p.

Fenneman, N.M., 1938, Physiography of the Eastern United States, New York, New York, Mcgraw-Hill, 714 p.

-----1946, Physical divisions of United States: U.S. Geological Survey (map), scale 1:7,000,000.

Hannum, C. H., 1976, Technique for estimation magnitude and frequency of floods in Kentucky: U.S. Geological Survey WRI 76-62, 70 p., + 1 plate.

Harvey, C. E., 1977, The economics of Kentucky coal: The University Press of Kentucky, Lexington, 173 p.

Hem, J. D., 1970, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 1473. 363 p.

Hendrickson, G. E., 1958, Summary of occurrence of ground water in Kentucky: U.S. Geological Survey Hydrologic Investigations Atlas HA-10, 1 sheet.

Hopkins, Herbert T., 1966, Fresh-saline water interface map of Kentucky: Kentucky Geological Survey Series 10.

Huddle, J.W., Lyons, E.J., Smith, H.L., Ferm, J.C., and others, 1963, Coal reserves of eastern Kentucky: U.S. Geological Survey Bulletin 1120, 247p.

Kentucky Department for Natural Resources and Environmental Protection, Division of Water (Quality), 1975, Kentucky water quality report to Congress: Frankfort, Ky., 225 p.

Kentucky Geological Survey, 1979, Generalized geologic map of Kentucky: University of Kentucky, Lexington, 1 plate, scale 1:1,000,000.

Kilburn, Chabot, Price, Jr., W.E., and Mull D.S., 1962, Availability of ground water in Bell, Clay, Jackson, Knox, Laurel, Leslie, McCreary, Owsley, Rockcastle, and Whitley Counties, Kentucky: U.S. Geological Survey Hydrologic Investigations, Atlas HA-38, 3 sheets.

Kirkpatrick, H. N., 1979, Annual Report Kentucky Department of Mines and Minerals, 1978: Commonwealth of Kentucky, Department of Mines and Minerals, 218 p.

Leamon, A.R., and Maher, S.W., 1974, Coal mining in Tennessee, State of Tennessee information circular 17, 29 p.

May, V. J., and others, 1981, Hydrology of Area 18, Eastern Coal Province, Tennessee: U. S. Geological Survey Water Resources Investigations 81-492, 73 p.

McCabe, J. A., 1962, Floods in Kentucky-Magnitude and frequency: U.S. Geological Survey Information Circular 9, 196 p. + 1 plate.

McFarlan, A. C., 1943, Geology of Kentucky: Lexington, Ky., University of Kentucky, 531 p. (Reprinted 1961, Kentucky Department Economic Development).

Mull, D.S., and Pickering, R.J., 1968, Water resources of the Middlesboro area, Kentucky: Kentucky Geological Survey series 10, Report of Investigations 9, 51 p.

Murray, C. R., and Reeves, E. B., 1977, Estimated use of water in the United States in 1975: U.S. Geological Survey Circular 765, 39 p.

National Oceanic and Atmospheric Administration, 1973, Monthly normals of temperature, precipitation, and heating and cooling degree days 1941-70: U.S. Department of Commerce Pub. No. 81 (KY), 7 p.

Newcome, R., and Smith O., 1958, Ground-water resources of the Cumberland Plateau in Tennessee: Water Policy Commission, Tennessee Division of Water Resources, 64 p.

Price, Jr., W.E., Mull, D.S., and Kilburn, Chabot, 1962, Reconnaissance of ground-water resources in the Eastern Coal Field region, Kentucky: U.S. Geological Survey Water Supply Paper 1607, 56 p.

Quinones, F., Kiesler, J., and Macy, J. A., 1980, Flow-duration at selected stream sites in Kentucky: U.S. Geological Survey Open-File Report 80-1221, 143 p.

Quinones, F., Mull, D.S., York, K.L., and Kendall, V., 1981, Hydrology of Area 14 Eastern Coal province, Kentucky, Water Resources Investigations 81-137, 145 p.

Randolph, W.J., and Gamble, C.R., 1976, Technique for estimating magnitude and frequency of floods in Tennessee: Tennessee Department of Transportation, 52 p.

Rice, Charles L., Sable, Edward G., Dever, Jr., Garland R., and Kehn, Thomas M., 1979, The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States-Kentucky: U.S. Geological Survey Professional Paper 1110-F, 32 p.

Rickert, D.A., Ulman, W.J., and Hampton, E.R., 1979, Synthetic fuels development, earth science considerations: U.S. Department of Interior / Geological Survey, 45 p.

Searcy, James K., 1959, Flow duration curves: U.S. Geological Survey Water supply Paper 1542-A, 33 p.

Soil Conservation Service, 1974, General soil map of Kentucky: Soil Conservation Service, 1 plate , scale 1:750,000.

-----,1978, General soil map Tennessee: Soil Conservation Service, 1 plate, scale 1:750,000.

State Conservation Needs Inventory Committee, 1970, Kentucky soil and water conservation needs inventory: Commonwealth of Kentucky, Division of Soil and Water Conservation Special Report, 256 p.

Sullavan, J. N., 1980, Low-flow characteristics of Kentucky streams: U.S. Geological Survey Open-File Report 80-1225, 1 plate.

Swisshelm, R. V., 1974, Low-flow characteristics of Kentucky streams: U.S. Geological Survey Open-File Report, 1 plate,

Tennessee Division of Geology, 1966, Geologic map of Tennessee, East-Central sheet, 1 plate.

U.S. Department of Commerce, 1961, Rainfall frequency atlas of the United States: Weather Bureau Technical Paper No. 40, 61 p.

U.S. Environmental Protection Agency, 1976, Quality criteria for water: Environmental Protection Agency Report, 256 p.

-----, 1977, National interim primary drinking water regulations: Environmental Protection Agency report 570/9-76-003, 159 p.

U.S. Geological Survey, 1980, Water resources data for Kentucky annual reports: U.S. Geological Survey, Louisville, Kentucky, 804 p.

Whitesides, D.V., Kernodle, J.M., and Leist, David W., 1978, Water levels in observation wells in Kentucky 1935 through 1976: U.S. Geological Survey Open-File Report 78-129, 156 p.

Zogorski, J. S., and Kiesler, J. L., 1976, Water temperatures of Kentucky: U.S. Geological Survey Water Resources Investigations 76-86, 1 plate.